Remediation Strategy for Soil and Groundwater Pollution - RemS - A Decision Support Tool

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Abstract: Danish environmental authorities undertake investigations, risk assessments and soil and groundwater remediation projects on a large number of sites. These projects are publicly funded and often involve several stakeholders. Therefore requirements are high in terms of cost effectiveness, environmental friendly solutions and decisions that are both transparent and well documented.

The Capital Region of Denmark, Information Centre on Contaminated Sites - DANISH REGIONS and the Danish EPA have - in collaboration with NIRAS and DTU Environment – developed a decision support tool (RemS) to assist in the planning and projecting phase when remedial techniques and strategies are decided on a specific site.

RemS combine the most important decision parameters:

- Remediation efficiency and local secondary effects (positive and negative)
- Environmental impact from the remediation activities (LCA screening)
- Economic costs
- Time

Basic results from the site investigations comprising geological stratigraphy, aquifers and a characterisation of the pollution (constituents, affected areas, layers, aquifers, mean and max concentrations and free phase product) are entered in a simple model. Potential remediation strategies are defined by combining techniques or treatment trains that are assumed to be applicable to meet the remediation goals in the source zone and the plume area.

RemS return a proposed inventory of the construction and operation activities in terms of site specific default values of used energy and material resources during the remediation process. A life cycle screening is performed automatically using LCA unit processes that convert the inventory into an overview of the consumption of resources and environmental impacts in a life cycle perspective. Environmental impacts consist of emissions to air, potential toxic effects and waste production. Results are also returned as the total energy consumption (MJ) and the carbon footprint (kg $CO_{2\text{-eq}}$).

The same inventory is also input for a site specific estimate of costs for the alternative remediation strategies. The default inventory can – with a quick review of key input parameters - be used for screening estimates or – if the user has better knowledge – a more detailed inventory to perform more precise LCA and cost assessments.

The cost estimates uses net present values to discount future costs. This allows a comparison of alternative strategies with different payment profiles over time (relevant for long term operation). The discount rate can be altered in order to make sensitivity analysis.

A time saving methodology called Successive Calculation use an input data set, which comprises the most optimistic, the most likely and the most pessimistic input values. The Successive Calculation returns results as mean values with a standard deviation and an overview of the most important uncertain unit costs and time of operation.

The availability of default input data for LCA and economic estimates combined with the possibility for user adjustments makes the RemS tool seamless in detail levels and easy to use resulting in tailored decision support. Finally all decision parameters are summarized in a score system for an easy identification of the best remediation strategy. The score system can be adjusted according to the users needs by weighting each of the decision parameters.

INTRODUCTION

Several Danish Regions have included cost-effectiveness assessments into decision making of major remediation projects or even included cost-effectiveness assessments as a part of an obligatory decision making process in the project planning phase. Cost-effective analyses are used to find the remedial solution that can meet success criteria at lowest "price". Positive and negative side effects from the projects are described and if needed quantified in technical or monetary units applicable for the assessment process.

The actual project "Remediation Strategy for Soil and Groundwater Pollution – RemS" is based on experiences from cost-effectiveness analysis /2, 4/ and the EU LIFE project (2000) /5/ which was aimed to development a holistic decision making methodology comprising a lifecycle screening. The project focus was on the environmental balancing between the environmental impact from remediation activities compared to the environmental benefits that was the purpose of the remediation project.

Experiences from the earlier projects and from the use of cost-effectiveness paradigms show that e.g. life cycle assessment is difficult for those who are not familiar with LCA methodologies. The aim for the new RemS methodology is to create a tool that is more easy to use and limited in the needs for data input.

Purpose and target group
RemS is used to visualize and put important decision parameters together in the assessment of the sustainability of remediation techniques, strategies (e.g. treatment trains) and compare alternative strategies. RemS is intended to be used in the planning phase for soil and groundwater remediation projects on the site specific level. An additional use is to optimize what kind of energy and materials that are the most suitable to minimize the environmental impact from the planned processes.

The user target group comprise technical administrative units and consultants who are planning and projecting remedial projects.

Decision support parameters
RemS combine the most important decision parameters; remediation efficiency and local secondary effects (positive and negative), environmental impact from the remediation activities (LCA screening), economic costs and time.

The most important facilities in the tool are briefly described below.

User interface, language and LCA sources
RemS is developed in Danish in a Microsoft Excel 2003 Workbook with 9 spreadsheets visible for the user. A version with an English user interface will be available primo 2010.

The lifecycle screening is based on process data from the Ecoinvent Life Cycle Inventory (LCI) database version v2.1. The LCA software SimaPro 7.1.8 was used to model a number of combined processes and to calculate environmental impacts using the impact assessment methods EDIP97 and Cumulative Energy Demand. The characterised results were normalised using the updated EDIP normalisation references from Stranddorf et al. 2005 /6/ and weighting was done using the updated weighting factors from 2005 /7/.

Use of sand and gravel was included in the life cycle inventory of finite resources with default normalisation and weighting factors adopted from Danish National Railway Agency and the Danish State Railways (2000). DTU Environment assisted in the review and selection of inventory data and the modelling in SimaPro.

INPUT DATA

Conceptual model

The major input activity is to build up a conceptual site model that describe the geological conditions and gives a characterization of the pollution in the source zone and in the plume area, e.g. as illustrated in figure 1.

Figure 1 Example of a "real life" pollution with chlorinated solvents

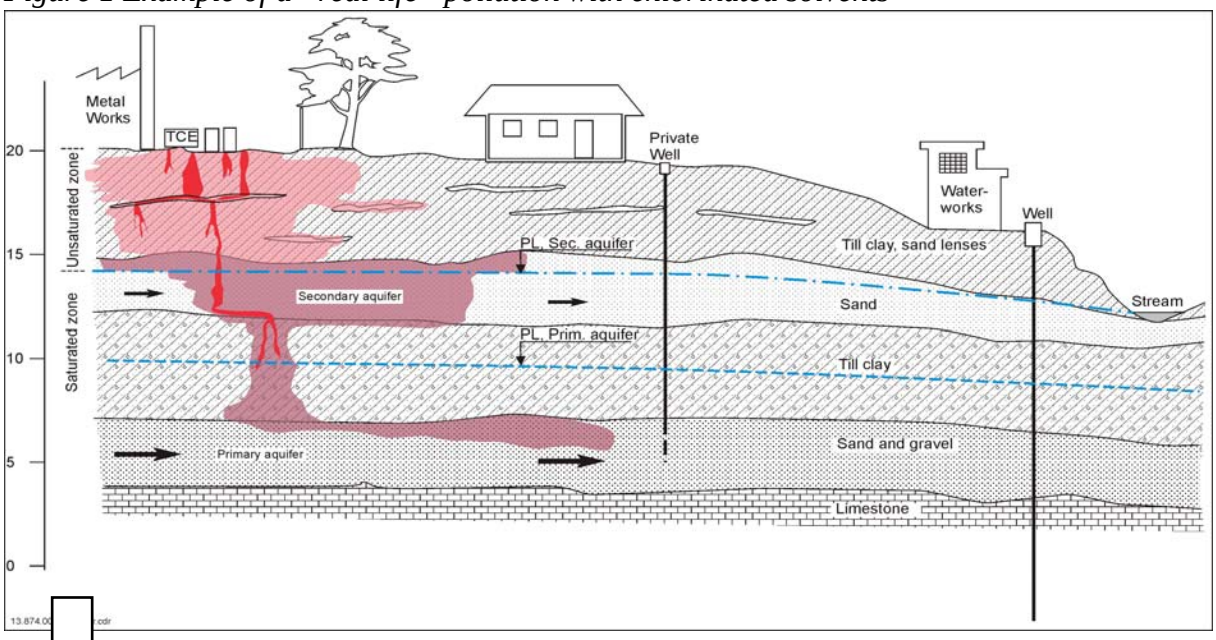


Table 1 Data input format for the conceptual model

Sub environment	Source zone pollution	Plume pollution
Indoor/outdoor climate	Air/Ambient air	Air/Ambient air
Topsoil	Soil	Soil
Unsaturated zone – sub soil 1	Soil	Soil gas
Secondary aquifer	Water	Water
Saturated zone – sub soil 2	Soil	Soil
Primary aquifer	Water	Water

Representative data from investigations or estimated data can be used as input data in the simple 6 layer model (here named sub environments). The structure of the conceptual model is limited to the fixed sub environments as shown together with the data input format in table 1.

The data input needed to characterize the air, soil, soil gas and groundwater pollution in the sub environments shown in table 1 comprise the specified parameters shown in table 2. The further use of these data is also specified in table 2.

Table 2 Specific data input parameters in the conceptual site model for each sub environment and further use

		Data use			
Input data type	(reference) [unit]	Alert, threshold limit	Mass estimate	Cost estimate	Environmental LCA screening
Conceptual model					
Constituents of pollution	(list)	**x**	**x**	**x**	**x**
Soil type	(list)		**x**		
Area	[m^2]		**x**		**x**
Depth interval	[m]		**x**		**x**
Concentration, maximum	[mg/m^3, mg/kg, µg/l]	**x**			
Concentration, average	[mg/m^3, mg/kg, µg/l]		**x**		
Free phase (source zone only)	[kg]	**x**	**x**		
Ranking of dimensioning constituent	[-]			**x**	**x**

Remediation strategies

The information of the constituent's presence, their maximum concentrations or maybe presence of free phase product gives an alert if threshold limits (Danish) in the respective sub environments are exceeded. This facility is intended to notice the user of which sub environments should be remediated.

The user shall identify the possible alternative remediation strategies (a remediation strategy can be one or more techniques or a treatment train). The user needs to have a competent knowledge of which techniques or combinations of techniques that can be used under the actual geological and geochemical conditions and for what extend and the likelihood that they are able to meet success criteria.

Techniques are selected from a list of available techniques comprising:

- Excavation and off site treatment (light oils)
- Sheet piling (trapeze wall and H profiles)
- Pumping - P
- Treatment – T (water and air, GAC)
- Dual Phase Extraction - DPE
- In Situ Chemical Oxidation - ISCO (potassium permanganate)

- Natural Attenuation - NA
- Stimulated Reductive Declorination – SRD (EOS, lactate, KB1)
- In Situ Thermal Desorption – ISTD (conductive heating)
- Soil Vapor Extraction - SVE
- Passive Soil Vapor Extraction – PSVE
- Soil mixing with zero valent iron - ZVI (planned)
- Thermal - Steam (planned)

The user gives each strategy an assessment of the expected remediation efficiency (mandatory score 0 – 3) and an assessment of possible secondary effects (optional score 0 – 3) on the following parameters:

- Positive or negative effects:
  - Esthetic value of area/landscape
  - Terrestic or aquatic changes of ecosystem
  - Geochemical changes (fixation or mobilization of constituents)
  - Geotechnical changes (foundation conditions)

- Neighbour annoyances during construction and remediation:
  - Noise and vibrations
  - Dust and smell
  - Traffic (accidental risk)

LCA inventory and economic costs

RemS combine the conceptual model and the information's about the selected techniques in each remediation strategy. Information of depth and area of the pollution in auto selected sub environments are used to up or down scale a "normal size" remediation to the site specific size of the remediation. Estimates of LCA input data sets (LCA inventory of main activities and resources used) on technique level and cost estimates (DKK) on phase level (planning, construction, operation, dismantling) are generated automatically as a proposal to the user.

These automatic generated first estimates of the LCA inventory input data and costs estimates have to be reviewed carefully by the user to ensure that results can be used the way they are intended. Corrections by the user are easy, transparent and back tracking of changes in input data is possible.

RESULTS

Remediation efficiency and local secondary effects

The assessment of remediation efficiency and local secondary effects (positive and negative) is already performed when the alternative remediation strategies were defined as described above.

Environmental impact from the remediation activities (LCA screening)

RemS generate an assessment of the potential impact on the environment expressed in 13 resource parameters and 11 parameters for the potential environmental effects, see table 3. Results are in absolute units.

Table 3 LCA screening parameters divided into resource consumption and potential environmental effects

Resource consumption			**Potential environmental effects**	
Global energy resources			Emissions to air	
• Crude oil	kg		• Global warming - PGW	kg $CO_{2\ -eq}$
• Natural gas	kg		• Acidification	kg $SO_{2\ -eq}$
• Uranium	kg		• Photochemical smog	kg $C_2H_{4\ -eq}$
• Black coal	kg		• Eutrophication	kg $NO_{3\ -eq}$
• Brown coal	kg		Toxicity	
Global raw materials			• Persistent toxicity $_{agg}$ [1)]	m^3
• Aluminium	kg		• Eco toxicity $_{water,\ acute}$	m^3
• Iron	kg		• Human toxicity $_{air}$	m^3
• Chromium	kg		Waste	
• Nickel	kg		• Bulk waste	kg
• Copper	kg		• Hazardous waste	kg
• Manganese	kg		• Radioactive waste	kg
• Molybdenum	kg		• Slags/ashes	kg
Local resources				
• Sand and gravel	kg			

[1)] Aggregated toxicity comprising eco toxicity$_{,\ cronical}$ and human toxicity. Both to soil and water.

The energy base for production of electricity varies from region to region. Even in the Nordic countries the energy bases vary a lot between black coal, oil, nuclear power and with a varying part of renewable energy mainly from water power and wind power. This is an important issue for electricity dense remedial solutions in terms of estimating the consumption of energy resources, the global warming potential and other environmental effects. RemS can switch energy base between electricity produced in Denmark (with/without allocation to heat), Sweden, Norway, the Nordic Countries, EU (EU27) and European electricity (UCTE). Electricity production based on black coal or natural gas can be selected as marginal electricity production.

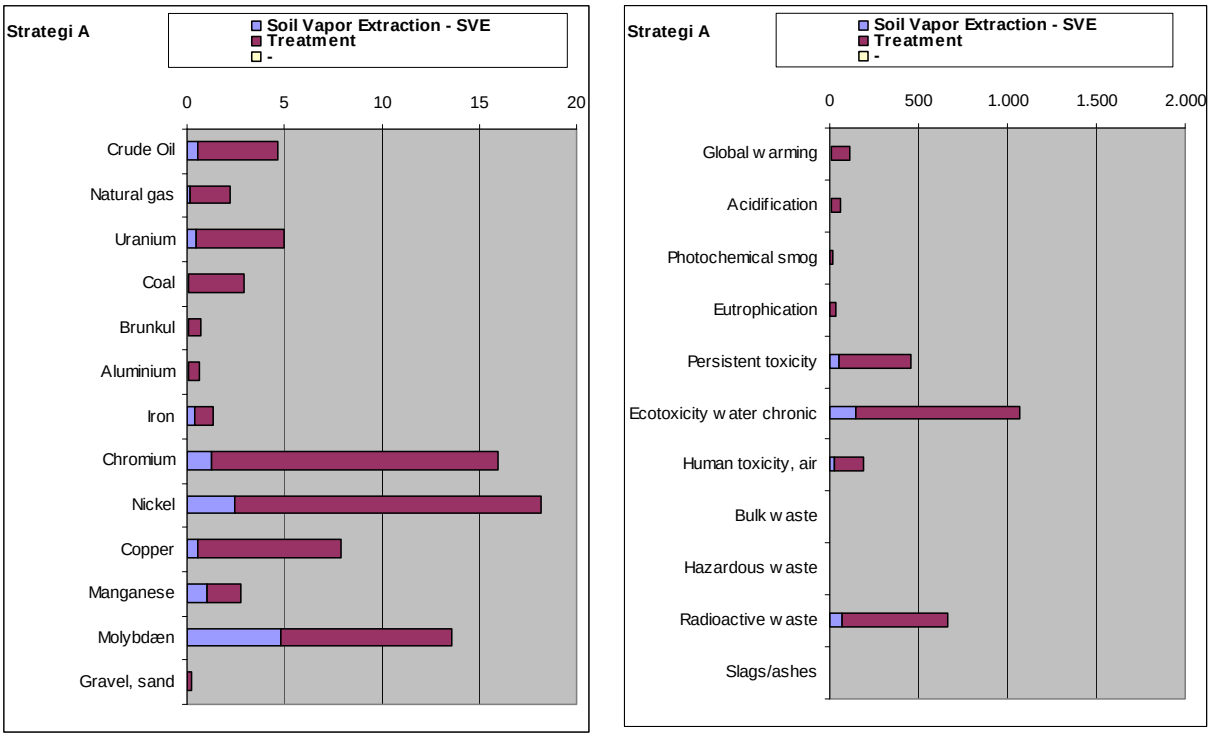
It is rather complicated to overview calculation results from all accounted parameters listed in table 3. Normal practice in LCA is also to show calculation results as normalized values and weighted values. An example of the weighted reporting is shown in figure 2.

Normalized values indicate the environmental impact for the remedy related to the average environmental impact from one person per year, also named person equivalent – PE.

Weighted resource consumptions are the normalized values divided by the supply horizon for the economically assessable reserve. Weighted resource values are so to speak weighted with scarcity of the reserve. Figure 2a show e.g. a consumption of crude oil corresponding to approx. 5 times the crude oil reserve per worldperson and his/her descendants.

Weighted environmental effects are the normalized values weighted by politically targeted reduction goals. Figure 2b show e.g. a global warming potential corresponding to approx. 100 person equivalents weighted with a factor 1,12. RemS use international agreed reduction goals to set weighting factors. An additional option is to multiply with local defined weighting factors.

Figure 2 Example of the report of the weighted resource consumption and the potential environmental effects for a remediation strategy with soil vapour extraction combined with air treatment.



(a) (b)

An example of use of local weighting factors could be if VOC's are released to air in a dense populated area. Then it would be relevant to increase the weighting factors for human toxicity and photochemical smog (ozone formed during degradation of VOC's. Ozone poses a risk of respiratory problems to humans and is harmful to flora and fauna as well).

Carbon Footprint

A Carbon Footprint profile is reported as an alternative to the full LCA screening. The Carbon Footprint profile is targeted toward the major global impacts; the use of energy resources and the global warming potential - GWP.

The total use of energy is quantified in renewable and non-renewabel energy [MJ]. The GWP is quantified in CO_2 equivalents [kg $CO_{2\text{-eq}}$]. The results are shown in figures for an easy comparison between the remediation strategies.

Economic Costs

Alternative strategies often have different payment profiles over time. Some techniques are finished within weeks or months, while other have longer periods of operation and monitoring. RemS use Net Present Value – NPV calculations to discount future costs. This allows a comparison of projects with difference payment profiles. A discounting rate of 3 % is used as default according to recommendations to welfare economic analysis on environmental projects /1/. The discount rate can be altered by the user in order to make sensitivity analysis.

Remediation projects are by nature projects with uncertainties on cost estimates – especially in the planning phase. RemS has an option to use a methodology called Successive Calculation /3/ to locate and quantify the most dominant uncertainties on the cost estimates. The user need to estimate the most optimistic, the most likely and the most pessimistic costs on remedial phase level (planning, construction, operation and dismantling) on each technique. The Successive Calculation return results as mean values with a standard deviation on costs and time of operation. This result can be used to perform a focused break down budgeting in order to minimize the uncertainties.

Time

RemS include a simple standard time schedule for the alternative strategies and techniques. The user shall indicate the latest finished technique on each strategy.

Summary

Finally all remediation strategies are summarized in a matrix versus all decision parameters. See table 4. Key figures for all strategies and techniques are included to give an overview. A score system is included to give an easy overview of the relative difference between decision parameters and between remediation strategies.

Table 4 Summary matrix (principle). Remediation strategies versus decision parameters. Weighting and scoring system.

	Total Score	**Remediation Efficiency**	**Secondary Effects**	**Environmental Impact - LCA**	**Carbon-Footprint**	**Eco Costs**	**Time**
		RE	SE	EI	CF	EC	T
Weight (w) [%]		40 %	15 %	20 %	-	20 %	5 %
Strategy A	**1,62**	Score	Score	Ranking score	-	Ranking score	Ranking score
ISTD				[PR, PET]	[MJ, kg CO_2]	[DKK]	[months]
SVE				[PR, PET]	[MJ, kg CO_2]	[DKK]	[months]
Strategy B	**1,86**	Score	Score	Ranking score	-	Ranking score	Ranking score
Excavation				[PR, PET]	[MJ, kg CO_2]	[DKK]	[months]
ISCO				[PR, PET]	[MJ, kg CO_2]	[DKK]	[months]
Strategy C	**0,93**	Score	Score	Ranking score	-	Ranking score	Ranking score
etc…….				[PR, PET]	[MJ, kg CO_2]	[DKK]	[months]

The summary matrix shows results for each technique and scores for each remediation strategy. Notice that "Remediation Efficiency" and "Secondary Effects" are only assessed on strategy level (the combination of techniques as a whole) with an individual score (0.0 – 3.0) as a result. Results for "Environmental Impact", "Carbon Footprint", "Economic Costs" and "Time" are summarized on technique level as totals and grand totals in respective units. Grand totals are then compared between the alternative remediation strategies and the best performing strategy is given the maximum ranking score 3.0 and the remaining strategies a relative lower score.

It is mandatory, that the remediation efficiency is high. The remediation efficiency score is thus multiplied with the sum of all other decision parameters. A default weight of each decision parameter can be adjusted by the user.

$$\text{Total score} = w_{RE}RE * (w_{SE}SE+w_{EI}EI+w_{CF}CF+w_{EC}EC+w_{T}T)$$

The score system is optional for an easy identification of the best remediation strategy. However any score system should be used with sound criticism. If it is not appropriate on a certain site then assessments can be performed without the scoring process.

CONCLUSIONS AND PERSPECTIVES

Sound decision making is often a multidisciplinary task. Your competences have to cover all areas that are important to choose the best decision. And you must be able to overlook all of them. Some areas can be difficult to assess – e.g. the environmental impact from the remediation activities themselves in a life cycle perspective.

RemS support the decision making process by systemizing and documenting the workflow and supports a quantification of the most important decision parameters. It helps the user to maintain an overview of the decision parameters through the project planning process.

The availability of default input data for LCA and economic estimates combined with possibility for user adjustments makes the RemS tool relatively easy to use and flexible in detail level.

The use of net present value cost estimates make alternatives comparable. An option to vary the discounting rate and the Successive Calculation methodology allow sensibility and uncertainty analysis to be performed on the cost estimates.

All remediation strategies are summarized in a matrix versus all decision parameters for an easy overview. A score system is included to give an easy overview of the relative difference between decision parameters and between remediation strategies. A user score based ranking of the remediation strategies is possible.

RemS strengthen the decision making process and make the process more transparent for co-operators and customers. Finally the reporting facilities ease communication to politicians and other stakeholders.

An English version of RemS is expected to be available primo 2010. Further information kwe@niras.dk .

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