“TIME” AND “LAND-USE” AS INTERPRETATION KEYS FOR THE EVALUATION OF DIFFERENT REMEDIAL SCENARIOS

Carmelo Di Mauro, Tom van Teunenbroek, Anja Sinke

TNO - Institute of Environmental Sciences, Energy Research and Process Innovation - Department of Environmental Quality
P.O. Box 342, 7300 AH Apeldoorn, The Netherlands

Key words: chlorinated hydrocarbons, cost-benefit analysis, decision support, exposure model, human health risk, risk assessment, risk management

Summary

In the regulated community there is often concern as to whether mass removal at a contaminated site actually reduces risk, or whether the small risk reductions achieved warrant the large costs incurred. Decision-makers have to select feasible solutions based on the required risk reduction, costs of the remediation and environmental impact. Thus, a correct risk evaluation has to assess exposure according the required time frame and the characteristics of the process.

In order to assess more accurately the affects of time and space in risk assessment, a new framework for quantifying short/long-term risk reduction was developed. In particular the research study highlights the following two innovative aspects:

1. A new approach for risk assessment, related to long-term in-situ remediation activities, and according to the land use and future land planning.
2. An analysis and evaluation of the overall costs related to remediation activities and redesign of the land use.

The paper reports a study case of a site contaminated by chlorinated solvents. Different intervention scenarios were investigated in terms of technological control of the plume, potential risk, land-use redesign and costs.

1 Introduction

Soil remediation policies aim to reduce human-health and ecological risks. Currently, they are not effective in recovering contaminated land because remediation strategies do not address economic and social interests. Also, decision processes are affected by a high degree of uncertainty due to the weak interpretation of both technical remediation aspects and economical ones.

In this paper, a case study is presented in which several scenarios were compared in order to design and support remediation strategies. The evaluations were based on expected risk reduction, likelihood of success, and cost of remediation scenarios.

2 Multi-objective decision approach

The first step of the decision process is to clearly define the objective. Normally, the objective of any soil remediation policy is to reduce the concentration of the chemical of concern under a certain safety level (Ferguson and Kasamas 1999). It may be argued that risk management and corrective action decisions are generally complex processes that involve a variety of technical, political, and socio-economic considerations. Under this approach, a risk management policy is intended to meet only the minimum attainable safety levels. Therefore, it is considered as quite limited. On the other hand, the decision process is a multi-objectives problem in which many actors involved in decision process seek to achieve their own objectives.

3 Methodology

A finite set of alternative remediation scenario's represents the possible intervention choices, so the alternatives are the potential solutions to the decision problem. Each alternative is described by two attributes:

- *Technology:* the effectiveness of each technology is evaluated according to the capability of removing and controlling the spread out of pollutants in the environment. Hence, the performance of each technology is evaluated in time and space.
- *Land Use:* a spatial pattern that characterises and summarises the potential exposure of people to substances released into the environment.

In order to compare the several different alternatives, a set of decision criteria were defined (di Mauro et al. in prep.). The decision criteria included: 1) risk level considered in time and space, 2) costs and benefits (remediation costs,

costs of conversion of land use, beneficial or lost use of land), and 3) availability of land in time.

The scenarios were ranked by a normalised index (risk index, cost-benefit index, and unavailable land index). These indices express results in terms of preferences. Consequently, the decision process aims to minimise all three indices even if each actor has a different preference. Therefore, the results of the analysis (i.e. multi-objectives decision methodology) are expressed in terms of "Efficient Frontier" curves which provide judgement values.

3.1 Definition of Risk Index

In many risk assessments, a "reasonable maximum exposure" level is used. It is based on the 90th percentile of the estimated worst-case exposure [1]. Instead, the developed methodology assesses exposures only for that period of time in which the chemical will be present at the site. Hence, the risk level depends mainly on the trend of the contaminant concentrations. As already mentioned above, land-use patterns can be considered as proxy for exposure scenarios. If we consider that a contaminated site can be recovered by changing the socio-economic functionality, the exposure changes have to be properly taken into account. For example, remediation of an industrial site may intend to convert the area to another beneficial use after a certain amount of years (e.g., residential area, park area). Thus, a dynamic approach has to be applied in order to assess risk level in time and space.

3.2 Cost-Benefit Index

The decision to remediate a contaminated site should be examined in an economic context. For each remediation alternative, the Cost-Benefit Index represents the economic aspects. The calculation of this index was performed analogous to the REC tool that has been developed by Beinat and co-authors (Beinat 1998). In order to define a clear method suitable for the comparison of alternatives, all costs and benefits of each scenario have to be considered according common criteria. Obviously, investments, operational costs, and benefits related to each alternative might be different in terms of investment but also in terms cash flow over time. Thus, each economic evaluation is performed as a function of time value of investment.

3.3 Unavailable land index

Remediation technologies and strategies are normally applied to recover land for some beneficial use. However, the complete process application may last several decades. According to such long time frame, it is very important to assess what the decreasing trend of unavailable area, (i.e., area characterised by an unacceptable risk level). Evaluating the technology/strategy according to this criteria, it may be useful in designing and supporting land use planning.

4 A study case: a site contaminated by chlorinated solvents

We report the results of an application of this risk assessment methodology which show how the three indices contribute to supporting the decision process. A site contaminated by chlorinated solvents has been investigated in order to assess which could be the most feasible approach in terms of risk control, cost optimisation and land-use planning. Six alternative scenarios have been investigated and compared (Tab. 1). The overall evaluation (i.e., risk, costs, land unavailability) has been performed according to the following time series: after 1 year, 2 years, 3 years, 5 years, 10 years, 20 years.

Tab. 1. Technology considered for each scenario

Scenario	1	2	3	4	5	6
Removal of Source		x		x	x	x
Pump &Treat					x	x
Natural Attenuation	x	x			x	
Enhanced Natural Attenuation			x	x		

4.1 Site characteristics

The surface of the area is 80 ha. The first aquifer has only a few meters of thickness and it is characterised by an average transmissivity of 2250 m^2/d. The top of the aquifer is at 4 - 5 m below ground level. The second aquifer is separate by a layer of clay which range around 10 meters. The contamination source is a leakage of Tetrachloroethylene (PCE). The spill rate at the source has been assumed equal to 2.25 kg PCE/yr and the resulting groundwater concentration at the source is about 10 mg PCE/l. According to sequential degradation process of chlorinated solvents, four different plumes have been generated. The plumes are in equilibrium, i.e. the occurring degradation processes keep in balance contaminant transport effects. The fate and transport of pollutants have been simulated by running a hydrological model (MODFLOW) and a sequential degradation model for chlorinated solvents (RT3D) (di Mauro et al. in prep). Some technical references are reported in Tab. 2.

Tab. 2. Some technical aspects related to the degradation of contaminants

Area [ha]	80			
Groundwater velocity [m/yr]	100			
	PCE	**TCE**	**DCE**	**VC**
Degradation rate [1/day]	0.0036	0.0080	0.0012	0.0060
Retardation Factor	3.65	1.66	1.66	1.03

4.2 Exposure pattern and dose effect

The exposure levels have been assessed using the CSOIL model (Beinat 1998). The model was developed for the derivation of the Dutch Intervention Values for soil and groundwater. The model calculates the exposure dose according to the potential characteristics of contaminants and human habits. In particular three different land uses have been considered: Residential Area, Working Area, and Green Area. The results reported in Fig. 1 and Fig. 2 show the difference between risk evaluations for each scenario according to land use planning. The assumed slope factor values are: PCE = 2.1E-2 $(mg/kg\text{-}d)^{-1}$; TCE = 1.0E-2 $(mg/kg\text{-}d)^{-1}$, DCE = 1.75E-1 $(mg/kg\text{-}d)^{-1}$; VC = 2.7E-1 $(mg/kg\text{-}d)^{-1}$

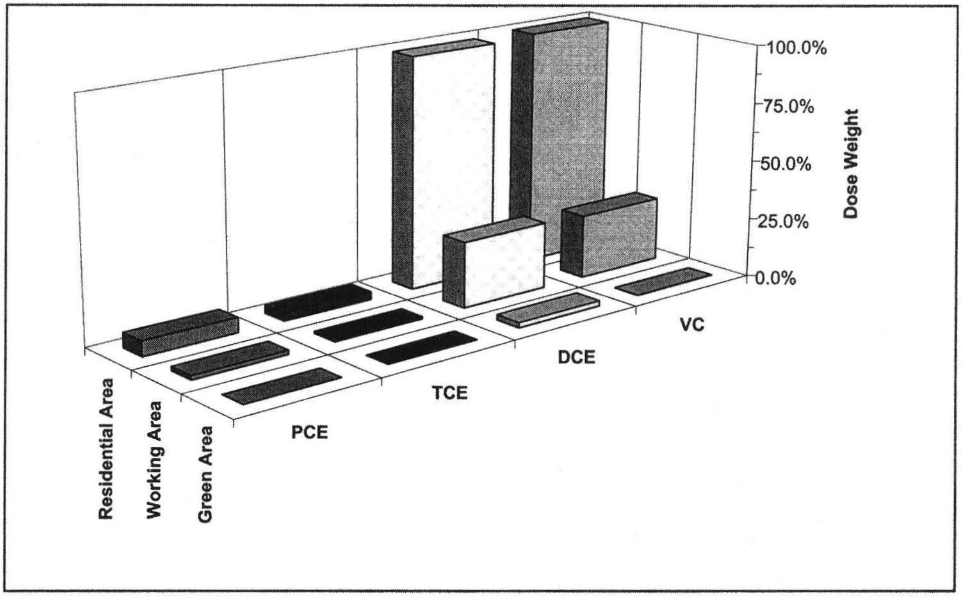

Fig.1. Total dose for three different exposure scenarios calculated by CSOIL

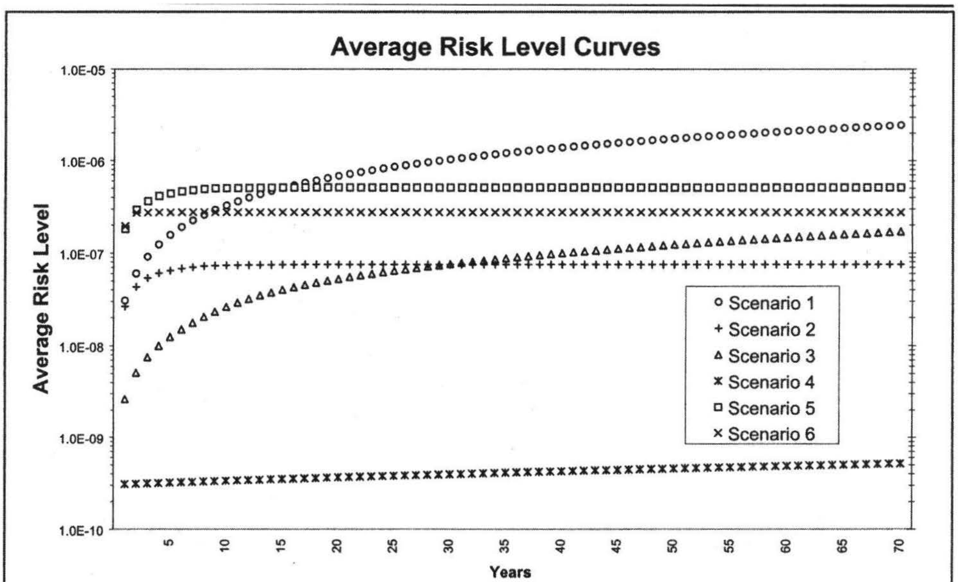

Fig. 2. Cumulative average risk curves related to "Residential Land-use"; Similar figures have been found for the other land-use patterns

4.3. Cost-Benefit Index

The costs of each technology have been analysed, and according to a common assumption for the evaluation of benefits, the Cost-Benefit Indices have been calculated. (Tab. 3) The evaluation of remedial costs shows that *Scenario 4* is the more expensive. Instead the costs of *Scenario* 2 is just 50 % of *Scenario 4*. The costs of the remaining scenarios are ranging between 12 % and 13 % of *Scenario 4*.

Tab. 3. Cost-Benefit Index for each scenario

Scenario	**1**	**2**	**3**	**4**	**5**	**6**
Cost-benefit Index	0.13	0.12	0.48	1.00	0.12	0.12

4.4 Unavailable land Index

According to the degradation process, the technology efficiency and plume behaviours, the land converted again to beneficial use can be assessed. The remediation strategies can take several years, thus "unavailable land index" reports the efficiency in time and space of reclaim the site. According to this criteria, the most efficient strategy is *Scenario 4*. The others are reported on the Tab. 4.

Tab. 4. Unavailable Land index for each scenario

Scenario	**1**	**2**	**3**	**4**	**5**	**6**
Unav. Land Index	0.98	0.76	0.25	0.06	0.58	1.00

4.5 Results and comments

Fig. 3 summarises the performance of the six scenarios according to the three decision-making criteria. It is clear that *Scenario 1* ranks as the worst because it characterised by a high risk level. Also, *Scenario 2* is preferred over *Scenario 1* in terms of risk. Comparison of the remaining alternatives does not permit ranking. For instance, *Scenario 5* outranks *Scenario 3* and *Scenario 4* in terms of cost performance, but is not preferable according to the other evaluation criteria. Instead, *Scenario 4* is more desirable in terms of risk and availability of land, but is characterised by a high cost index.

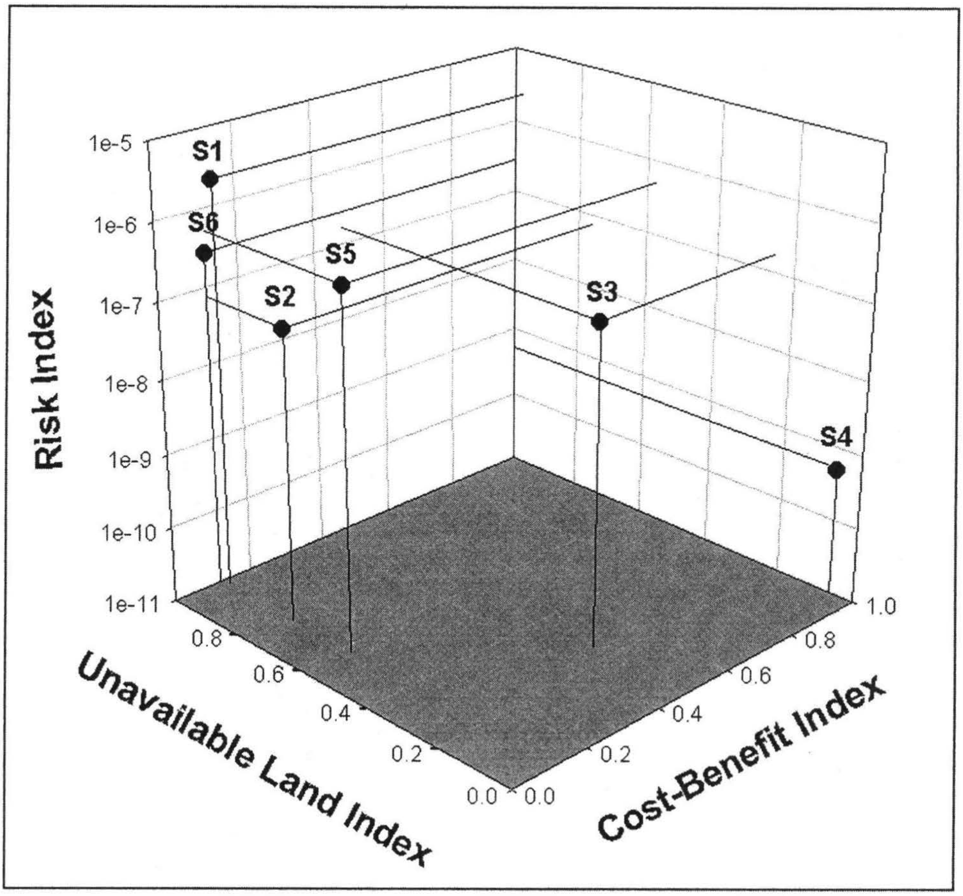

Fig. 3. Comparison of scenarios

The final decision will, then, depend on the importance of each index. In other words, the identification of the best strategies becomes the definition of index weights. Hence, the weights will represents the judgement value of actors involved and the constraints of the decision-making process.

5 Conclusions

The study shows how it is possible to improve risk assessment methodologies taking into account the environmental behaviour of contaminants over time and space. Therefore, it is possible to improve the approach of many protocols that are based on upper bound assumptions. Moreover, the evaluation of the risk in space and in time helps decision-makers in screening remediation strategies. Further research and experimentation will be required in order define a more sound decision-making tool that will define prioritisation criteria. However, it must be kept in mind that in the prioritisation an important role is played by the parties involved in the decision-making process and their judgement values.

Acknowledgement
This study was carried out with a grant from European Community n ENV4 - CT98 - 5098 (EC - Marie Curie Research Training Grants Program). The authors wish to express their gratitude to Victoria van Cappellen for her assistance during preparation of this manuscript.

References

Beinat (1998) The REC decsion support system for comparing soil remediation alternatives, NOBIS report 95-10-3, Gouda NL

Berg, R.v.d (1995)- CSOIL versie 8.0 (december 1997) geautomatiseerde versie van het csoil-formularium Bilthoven, RIVM, rapportnummer 725201006

Clement, T.P. (1997) RT3D: A modular Computer Code for Simulating Multispecies Transport in 3-Dimensional Groundwater Acquifers, Pacific Northwest National Laboratory, U.S.A

Di Mauro, C., Teunenbroek, T., Sinke, A.J. (in prep.) A multicriteria decision support tool to evaluate the role of "time", "land-use" and "costs" of different remedial scenarios at contaminated sites

Ferguson, C., Kasamas, H. (Eds.) (1999) Risk Assessment for Contaminated Sites in Europe - Volume 2 Policy Frameworks, LQM Press, Nottingham (UK)