APPLICATION AND CRITERIA OF USING RISK ASSESSMENT IN THE CONTAMINATED SITE REMEDIATION PROCEDURE

Summary and Theses of PhD dissertation

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Introduction and summary of the dissertation topic

The dissertation discusses a special application of Human Health Risk Assessment in remediation goal setting of contaminated site clean up processes. The first chapter gives a brief methodological and historical overview of the risk assessment process.

The second chapter covers the **uncertainties** related to risk assessment and their effect on the contaminated land remediation decisions. Uncertainties from several sources contribute to the efficiency of the method. They come from uncertainties in site investigation, contaminant transport modeling, toxicological analysis and conceptual model formulation. Multiplication of these uncertainties leads to unrealistic risk values and poor remediation decisions by unnecessary overprotection.

Although uncertainties are inevitable, there are methods to handle them. In the risk assessment procedure some methods handle uncertainties by refining those parameters involved to the analysis, while others substitute them with extreme values (conservative assumptions, worst case scenarios, toxicological default assumptions). I have concluded that only the former ones support the process of remediation goal setting by refining the calculated risk values. The later ones by over estimating the real risk values can not support the selection of the cost efficient remediation alternative in remediation goal setting.

I also introduce those **toxicological default assumptions** that influence the reliability of risk based evaluation. The more toxicological default assumptions applied in the toxicity assessment, the less chance the assessor have to obtain realistic risk values, which decreases the chance of cost-efficient remediation. The same statement applies to the conservative assumptions.

In contrary the application of iterative approach and the stochastic method support the remediation goal setting by refining the actual risk parameters.

I stated that in complex polluted sites no-threshold chemicals have a leading role in remediation goal setting in almost every case. They set the most stringent remediation targets which are often caused by the Linear Multi Stage model applied as a toxic default assumption. Unnecessary application of the LMS model might lead to wasting of remediation resources

In chapter three I state that the human health risk assessment is a **necessary but not always efficient** procedure in remediation goal setting by not always providing sufficient protection of groundwater resources. For this reason other aspects of protection has to be incorporated, which are introduced in chapter 4 and 5.

In the **critical evaluation** of the risk based procedure I have stated its remarkable benefits too: the risk based evaluation of contaminated sites enables the assessor to compare:

- **environmental threats posed via different media, or**

- **environmental threats posed by different toxic substances.**

These features are used during the priority setting process of remediation programs.

I have defined and introduced through a case study the **method of net risk reduction**, which is to support remediation decisions based on the risk balance of an intervention by comparing the status before and after the clean up process. The method is capable to incorporate the risk of the actual remediation workers into the decision process.

In chapter 4 I have highlighted those factors that influence the value of the chemical specific remediation goal. I stated that some domestic practices do not consider financial and technical feasibility of the remediation when setting clean up target values. The five criteria that the remediation goal value has to comply with are:

- **human health risk protection;**
- **environmental media status conservation;**
- **ecological risks aspect;**
- **financial feasibility;**
- **technical feasibility.**

The appropriateness of a remediation can be evaluated by predefined compliance points. I have worked out a net of compliance points using two types of compliance schemes:
1. Risk based compliance points: The risk based protection of three specific receptor groups has to be guaranteed by each remediation action.
2. Concentration based compliance points: In order to guarantee the protection of the environmental media four types of concentration based compliance points were introduced.

The **qualitative evaluation matrix** of remediation actions was also introduced in this chapter. Based on the above mentioned two aspects all remediation actions can be classified into one of four categories: remediation accomplished, good or acceptable remediation, temporarily acceptable remediation, not acceptable remediation. The evaluating matrix qualifies as: not acceptable solutions those that can result only risk based compliance or cause unnecessary transfer of risk.

In chapter 5 I introduce an evaluation method to compare the efficiency of remediation alternatives. This **risk-based performance assessment** is a tool that supports the selection of optimal remediation alternative, in terms of remediation goal. The method applies three easily quantifiable indicators to evaluate the concurrent options:

1. Number of avoided events (NAE)
2. Remediation target value in media (D)
3. Total cost of remediation (C)

These three indicators quantify the most important factors of efficient clean up.

Utility theory that is widely used in economics and decision support was applied to the remediation decision process. Utility functions were defined for each indicator to assign single preference value for each of their alternatives. By applying predefined weights and algorithm, V_i utility values can be calculated to characterize each remediation options. The maximum V_{imax} utility value determines the most beneficial remediation option in a certain decision system. The method can also delineate a range of tolerable options, where the deviation from the most rational alternative still does not cause significant decrease in overall utility.

Sensitivity analysis was completed for four weighting schemes. Weights in the range of 1-3 and 1-5 provided acceptable flexibility to the system and the appointed acceptable remediation options are realistic. I propose the range of acceptable deviation from the maximum utility alternative. The sensitivity analysis also proved the applicability of the utility functions assigned to the indicators.

Summary of scientific results

Thesis 1: When setting (D) remediation target values human health risk assessment (HHRA) is a necessary but not satisfactory procedure. HHRA provides appropriate level of protection to human receptors and only indirect protection to environmental media. In order to achieve appropriate level of protection other control points need to be set.

During my risk assessment activities it was an important recognition that the routinely used human or ecological risk assessment does not necessarily serve the protection of the subsurface environmental media. Figure T-1 compares the traditional remediation practice (guideline value-based) with the risk based remediation protocol. The figure locates the decision mechanism into he conceptual model of a pollution scenario. The traditional approach compares bases the level of protection of the environmental concentration data, while the risk based approach shifts the place of decision making from the environmental medium to the receptor. And the decision is made on risk basis.

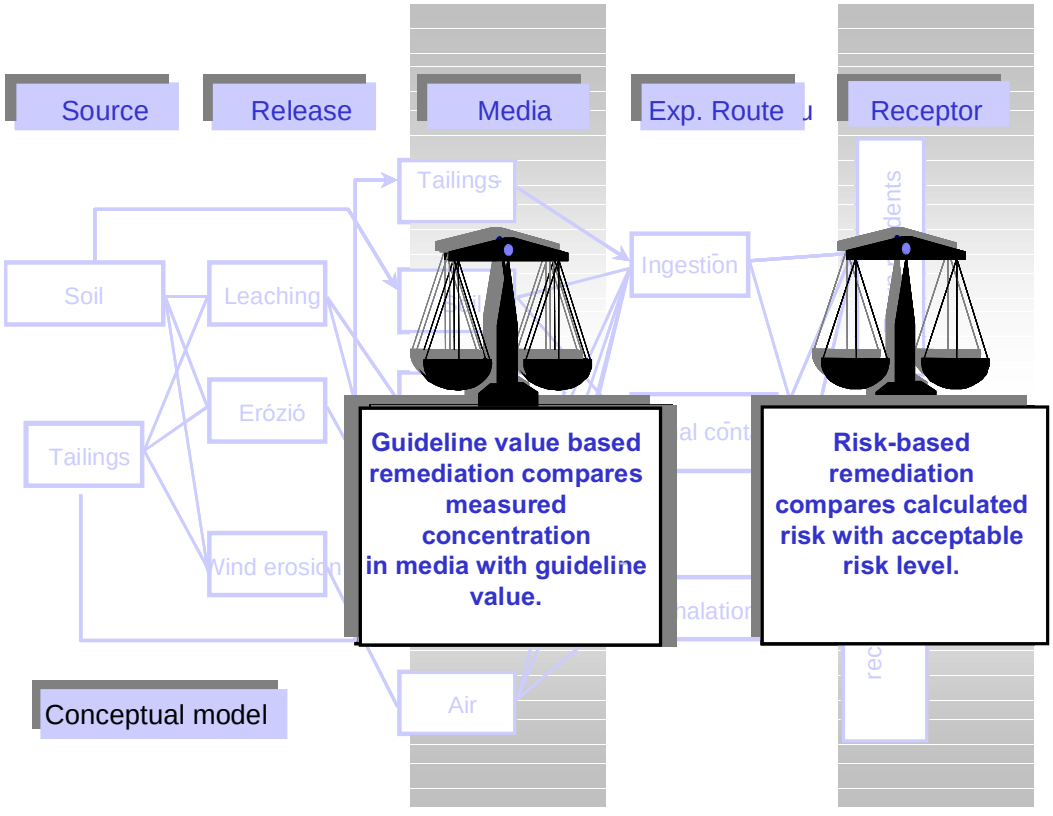

Figure T-1: The place and basis of decision making traditional and risk based remediation procedures [Madarász, 2000]

Using the Human Health Risk Assessment one can guarantee the protection of human receptors, but not in every case the protection of groundwater resources.

When setting remediation target values only on the basis of HHRA one must be aware that the applied procedure does not consider the environmental media as a mean for protection rather as an exposure route

Thesis 2: The risk based remediation approach provides a tool to compare different pollution cases that would not be comparable by other means. It can compare different pollutants and/or different media in risk terms thus making the evaluator capable to prioritize environmental problems. Net Risk Reduction is a method to assess such cases.

Besides the critical evaluation articulated in he first thesis one must be aware of the unique benefits of the risk based remediation approach. The risk based evaluation of contaminated sites enables the assessor to compare:

- environmental threats posed via different media, or
- environmental threats posed by different toxic substances.

These features are used during the priority setting process of remediation programs.

I have defined and introduced through a case study the **method of net risk reduction**, which is to support remediation decisions based on the risk balance of an intervention by comparing the status before and after the clean up process. The method is capable to incorporate the risk of the actual remediation workers into the decision process.

Thesis 3: There are two groups of methods routinely applied in the risk assessment procedures. One of the methods decreases uncertainty by refining the input parameter, while the other group of tools only provides the most unfavorable value of the parameter (e.g. worst case assumptions) in most risk assessment applications both tool serves the purpose of the assessor, however when setting risk based remediation target value only those tools serve the cost effective remediation that are capable to refine the input parameter values.

Contaminated land related risk estimations are burdened with uncertainties from several areas, such as: complexity of geological setting, limitations of site investigation, limitations of contaminants investigation, limitations of contaminant transport and exposure modeling, toxicological parameter uncertainties. Uncertainties are multiplied during the assessment steps thus shifting risk calculations to the safe side, however when using their result as input to the risk based remediation goal setting they weaken the quality of decisions.

When using risk assessment in the remediation goal setting process only those uncertainty handling methods serve the cost effective remediation that are able to refine input parameters and not those that give an upper estimate.

Toxicological default assumptions are one major source of uncertainties in the RA procedure. In the dissertation I mention 8 toxicological default assumptions that are routinely used in the RA methodology. The more toxicological default assumptions are incorporated into the assessment the less chance the remediator has to obtain reasonable remediation goals. Similar statement is true for the conservative assumptions.

In contrary the iterative approach and stochastic risk assessment applications support the cost effective remediation goal setting.

Thesis 4: When complex (multiple) contaminants have been detected in the subsurface environment in almost every case the carcinogen (non-threshold) chemicals will lead the remediation goal setting. This is caused by the routinely used LMS model application during the dose-response relationship setting of the carcinogens. Inappropriate application of the LMS model has undesirable effect on the remediation target values.

The dose-response relationship of carcinogens runs to zero in linear way. Most of the carcinogen risk assessment protocols use this Linear Multistage Model [USEPA, 1986] in there evaluation framework. The method aims to extrapolate high dose range of animal test results to lower environmental doses.

According to our present understanding of carcinogen mechanism the LMS assumption is true for only some carcinogens (e.g. genotoxic carcinogens) in other cases it highly overestimates risks [CARACAS, 1998].

The application of preferred LMS model shift risk estimations to the safe side, however cause the raise of remediation costs to unreasonably high cost range.

The use of LMS and Slope factor in risk assessment has significant effect on the remediation decision making when we make decision using human health disk data. When complex contamination is observed on the site in almost every cases the carcinogen chemicals will lead the remediation decision making procedure. Obviously that chemical shall play leading role in the decision making process that even at infinite small quantities pose risk to humans, having no zero risk range [Madarász, 2002]. When the no threshold assumption is valid than the stringent remediation decision is appropriate, in contrary cases however the decision will cause inappropriate allocation of resources through unreasonably stringent remediation target values.

Thesis 5: The legal and really achievable range of remediation target values (D) is not necessarily coinciding.

In my dissertation I have collected those significant factors that influence the remediation target values.

The remediation target value must comply with the following aspects

1. Protection of environmental media
2. Minimizing human risks
3. Minimizing ecological risks
4. Technical feasibility
5. Financial feasibility

The above limiting factors all set limit to the potential legal barriers of the remediation target value. Criteria 1, 2 and 3 pose upper boundary, while 4 and 5 are lower boundaries of the potential range. Figure **T-5.** illustrate the effect of these factors on the potential concentration range of the "D" value.

In the domestic practice the criteria of technical feasibility and financial feasibility are hardly considered when setting environmental remediation standard, although they can significantly limit the real value range.

I also stated that the criteria of ecological risks is in most cases can be complied by the compliance of the firs to above mentioned criteria.

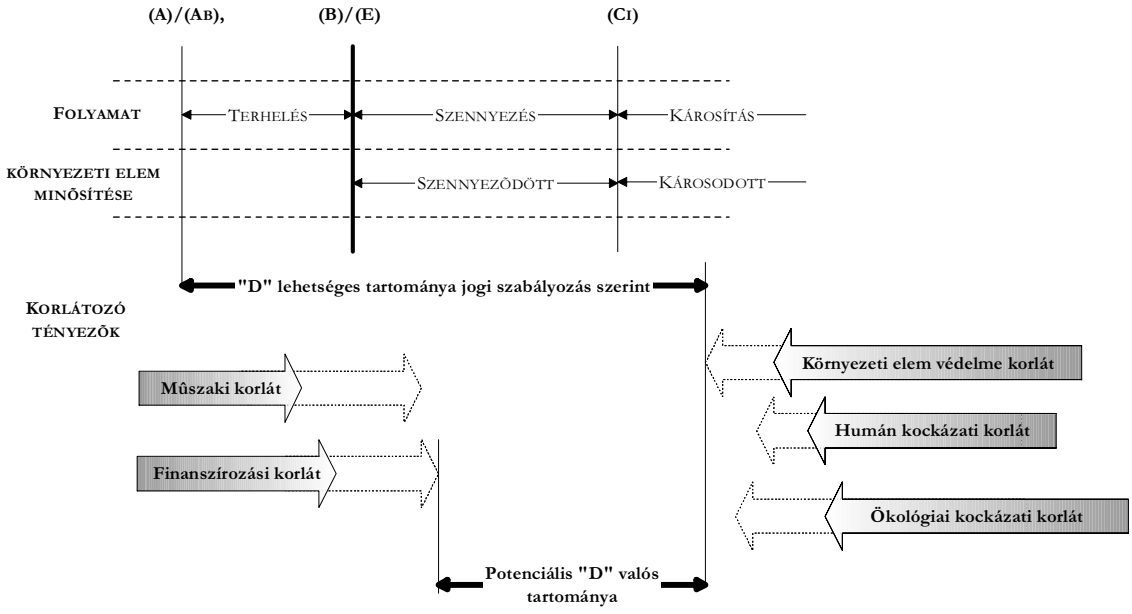

Figure T-5: Legal and realistic boundaries of D remediation target values [Naturaqua, (2000), modified]

Thesis 6: When setting remediation target values besides the risk based acceptability criteria other traditional concentration based criteria are also need to be set.

The appropriate level of remediation can be checked by compliance points. According to the known Hungarian recommendation (Gondi, et al. 2004) and partly modifying that I have set two groups of compliance points. **(Figure T-6.)**.

1. Risk based compliance points: the protection of three receptor groups must be guaranteed in every cases.

- On-site receptor
- Off-site receptor
- Water consumer as receptor

According to the Hungarian recommendation [Gondi et al., 2004] at the fence line of the contaminated property the "B" contamination limit must be reached. In my recommendation I state that in some cases this criteria can not always be met and the "E" risk based contamination limit is more appropriate for these cases

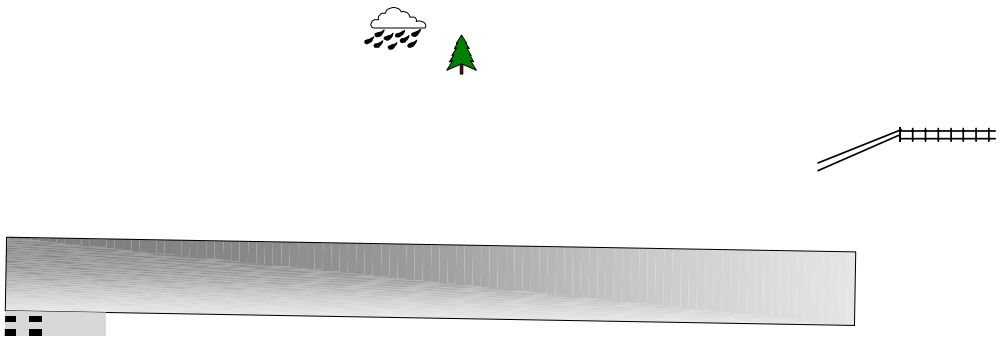

Figure T-6: Compliance points when setting remediation target values