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# MODELLING TOOLS FOR THE SELECTION AND OPTIMISATION OF CONTAMINATED LAND MANAGEMENT STRATEGIES

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## INTRODUCTION

In Germany, Italy and other European countries, contaminated land and groundwater is a widespread problem that may severely impact human health, the environment and the economy. Efficient and sustainable management strategies are urgently required as existing problems evolve into even more severe problems that become harder and harder to solve. For the design of such strategies, decision makers need appropriate planning tools assisting them in the assessment, selection and optimisation of possible alternatives. A lack of decision-support tools exists particularly for large sites (so-called megasites) in urban environments (e.g. SCHWARZE *et alii*, 2005). Due to the large scale and complex nature of these sites, a special focus must be put on the development of tiered decision-making procedures where investigation methods and data, as well as planning and optimisation tools are consistently and efficiently combined (e.g. RÜGNER *et alii*, 2006). In this paper, we wish to (i) put forward some fundamental ideas that should be followed in the development of tools for the selection and optimisation of contaminated land management strategies, and (ii) provide a brief overview about our current activities in this field.

## DATA, TOOLS AND INSTRUMENTS

Contaminated land management is a regulatory-driven process of several steps including (i) the identification and (ii) investigation of sites, (iii) the assessment for potential risks to human or ecological environments, and, based on the findings of these activities, (iv) the review, selection and planning of possible management strategies, (v) the operation of clean-up or pollution control measures and finally (vi) the closure of these measures. For each of the steps of the process, appropriate decisions are required. These decisions are largely based on information and data collected from the site. Therefore, quality and quantity of information rules the quality, i.e. appropriateness, of decisions. Pervasive uncertainty is also a major issue with respect to contaminated land and groundwater management, particularly when dealing with large-scale sites where achievable density of collected data is usually lower than for smaller sites characterized, e.g. by only a single hot-spot. It is simply technically impossible to arrive at a complete picture of what is going on in the subsurface at a contaminated site, since every piece of information gained is subject to uncertainty to some extent and may also change over time. At any level of the planning process uncertainty in any of the parameters, data or information relevant to one or more decision criteria may lead to wrong or inappropriate decisions, i.e. decisions that would not have been made if the uncertainty either did not exist or had been previously identified. Consequently, managing uncertainty is a key factor for the development of cost-efficient site restoration or re-use programs. Managing uncertainty also poses particular challenges to the development of a decision-making framework:

- the incorporation of quantitative approaches/models for the evaluation of decision criteria wherever and whenever possible (quantification as a premise to assess the significance of uncertainty to the decision);
- procedures to analyse the sensitivity of decision criteria to the uncertainty of particular parameters (identification of 'major uncertainties');
- the evaluation of efforts/expenditures required to resolve or to lower existing 'uncertainties' and of expected benefits from these efforts;
- a probabilistic assessment of possible decision options and consequences;
- procedures to decide if uncertainties are acceptable or whether activities need to be undertaken to narrow the range of assessment results.

The first prominent push towards the explicit incorporation of uncertainty in decision-making was U.S. EPA's Triad approach (e.g. U.S. EPA, 2001; ITRC, 2003) suggesting (i) a systematic project planning, (ii) a dynamic work strategy, and (iii) the use of innovative field investigation technologies with real-time measurements as key elements to arrive at an improved management approach. Further, it can be concluded that there is a strong need for a number of decision-specific well-balanced packages of investigation methods, computer based decision support and modelling tools that are suitable to facilitate the multitude of decisions to be taken over the duration of a project (Fig. 1).

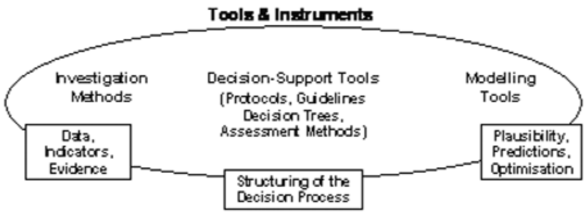


Fig.1 - Type and role of tools and instruments to support contaminated land management

## TIERED APPROACH FOR SELECTION AND OPTIMISATION OF MANAGEMENT STRATEGIES

With increasing scale and complexity of the contaminated site, more and more management options are to be considered and assessed for their technical and economic feasibility. A detailed investigation of the multitude of individual technologies, technology combinations and schedules, however, is not economically feasible. Hence, streamlining the planning and decision process is a mandatory requirement. Ultimately, decisions should be made as early as possible in order to reduce expenditures on site investigation. A tiered decision-making procedure is required, including (i) an identification and prioritization of focal areas (origin) of risks, (ii) a feasibility screening of remediation targets, as well as of available remediation technologies to narrow the range of possible options, (iii) a preliminary cost-efficiency assessment of possible management options for (iv) subsequent detailed investigations of only a few preferable options. When taken together, these steps comprise an in-depth design optimisation of the site-specific selected measure or combination of measures. For each of these elements tailored decision and investigation concepts are required. These concepts and employed methods should be specifically adapted to the type, scale, and information basis of the particular decision to be taken – more target-oriented and cost-efficient investigation programmes, as well as model-based assessment methods are needed.

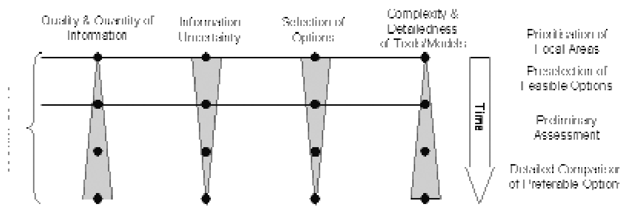


Fig. 2 - Type and role of tools and instruments to support contaminated land management

## PRELIMINARY COST-EFFICIENCY ASSESSMENT OF MANAGEMENT STRATEGIES

There is a plenitude of commercial and research tools available that are intended to support the assessment and selection of soil or groundwater remediation technologies. Tools are available for the technical feasibility screening of technologies (e.g., U.S. EPA, 1995; FRTR, 2002; BRADY *et alii*, 1998), detailed cost calculation (e.g., EARTHTEC, 2005), and risk assessment (e.g., STRENGE & CHAMBERLAIN, 1995). In addition, there exists a large number of mathematical models available that can be used for the prediction of remedial effects. However, a gap has existed with respect to preliminary assessment methodologies at an interim assessment level (see Fig. 2) where possible management options are evaluated in order to provide a first overview about current and future risks, as well as of effects and costs of remediation strategies consisting of various individual measures that may be scheduled for different time periods within the time horizon of the site management.

Typical questions that can be answered at an interim assessments scale are:

What is the time scale of risks to be expected for the given problem of contamination?

What performance/efficiency of a particular technology "X" would be required in order to (a) be a useful component of a remediation strategy?, (b) achieve a given objective?

How will individual technologies perform as a combination?

For the purpose of a preliminary assessment, the decision support tool CARO (SERAPIGLIA *et alii*, 2005) has been developed, which is currently being extended to CARO-Plus (MCKNIGHT *et alii*, 2006), to enable a fast and effective "screening" of management options. These scenarios can include both source treatment in soil and groundwater (e.g., air sparging, surfactant flushing), as well as plume management options (e.g. pump-and-treat, permeable reactive barrier). Since the amount of available data usually does not allow for a detailed description of large-scale sites, a relatively high abstraction level was chosen specifically serving the purpose of a preliminary assessment. Moreover, simplified approaches (analytical models) are used to simulate contaminant transport in soil and groundwater, and to predict future risk to the receptor. CARO-Plus utilizes a source-pathway-receptor concept, based on a conceptual site model developed from existing site data, to identify the relevant sources of contamination, propagation pathways and potentially affected receptors, as shown in Figure 3. The effects of

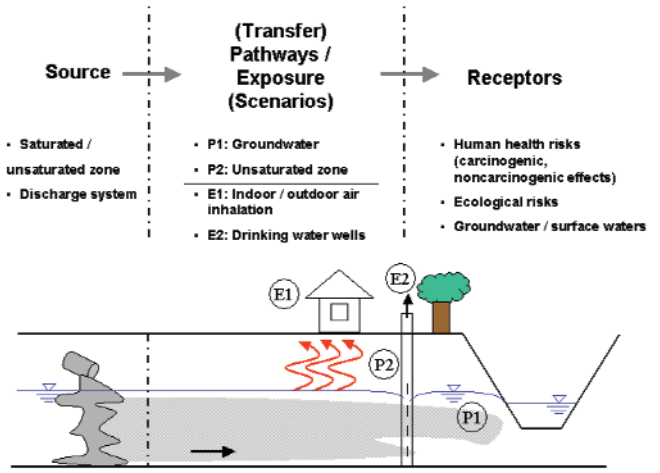


Fig. 3 - Schematic illustration of the source-pathway-receptor concept implemented in the program system CARO-Plus

remediation options are analysed on the basis of contaminant mass flux, concentrations, and risk indices (carcinogenic/non-carcinogenic). Costs are calculated in terms of net present values.

## OPTIMISATION FRAMEWORK

Optimisation or parameter estimation tools are a very important means when searching for optimal management strategies (Figure 4). Any of the available technological options that may be part of a management strategy typically comprises an endless number of variants or layouts, respectively (e.g. pumping well settings as specified by number and location of wells and pumping rates). Trying to identify the most cost-effective or cost-efficient variant cannot be done without the help of appropriate algorithms and tools. Meanwhile, combining of computational and algorithmic efficiency allows solving even very complex problems. Modern single- or multi-objective search techniques, which so far have only existed in theoretical applications are of increasing practical relevance (BAYER & FINKEL 2004, 2006; BAYER *et alii*, 2006; BÜRGER *et alii*, 2006, FINKEL *et alii*, 2006). Though still being far from routine application, demonstration projects of formal optimisation procedures to real sites revealed enormous potential for saving money compared to common trial and error approaches when selecting an appropriate land or groundwater management option (MINSKER *et alii*, 2004)

Although the best suitable optimisation routine depends on the individual problem characteristics, for practical applications, the objective is to find a robust and reliable routine, which can be easily adapted to a broad range of problems. In view of the high complexity and diversity of optimisation problems in the field of contaminated land management, particularly heuristic methods are coming to the fore, such as evolutionary algorithms. They are appealing due to their flexibility and applicability without in-depth knowledge of the specific problem. Therefore it is possible to solve both small-scale and multi-dimensional, large scale problems involving multiple technical design variants or combinations and multiple objectives. As such, algorithmic optimisation is not a smart additive to ideal contaminated land and groundwater planning, it rather evolves as an essential element at each decision level.

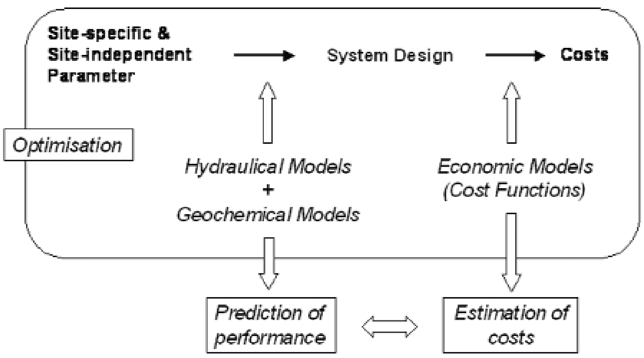


Fig. 4 - Framework for model-based optimisation of remediation strategies

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