Chemosphere 63 (2006) 751–761

CHEMOSPHERE

www.elsevier.com/locate/chemosphere

Model comparison for risk assessment: A case study of contaminated groundwater

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Received 7 October 2004; received in revised form 25 July 2005; accepted 9 August 2005
Available online 6 October 2005

Abstract

Many environmental multimedia risk assessment models have been developed and widely used along with increasing sophistication of the risk assessment method. Despite of the considerable improvement, uncertainty remains a primary threat to the credibility of and users' confidence in the model-based risk assessments. In particular, it has been indicated that scenario and model uncertainty may affect significantly the assessment outcome. Furthermore, the uncertainty resulting from choosing different models has been shown more important than that caused by parameter uncertainty. Based on the relationship between exposure pathways and estimated risk results, this study develops a screening procedure to compare the relative suitability between potential multimedia models, which would facilitate the reduction of uncertainty due to model selection. MEPAS, MMSOILS, and CalTOX models, combined with Monte Carlo simulation, are applied to a realistic groundwater-contaminated site to demonstrate the process. It is also shown that the identification of important parameters and exposure pathways, and implicitly, the subsequent design of uncertainty reduction and risk management measures, would be better-formed.

Keywords: Uncertainty; Model uncertainty; Sensitivity; Multimedia models; Monte Carlo; Conceptual model

1. Introduction

In many countries, more and more sites with contaminated groundwater caused by improper handling or disposal of hazardous materials or wastes have been found. These sites may cause adverse effects on the environment and human health, and thus need to be evaluated as to whether and what remediation scheme should be applied. Health risk assessment is deemed as the most important tool for quantifying human health impact associated with pollutant-releasing activities and hence has become widely used as an aid in environmental decision-making processes (Maxwell and Kastenberg, 1999; Ma, 2002).

Health risk assessment involves identifying the potential of a risk source to introduce risk agents into the environment, estimating the amount of risk agents that come into contact with the human–environment boundaries, and quantifying the health consequence of exposure. Since the risk assessment paradigm was established in 1983 (NRC, 1983), the methodology of risk assessment has become more sophisticated. Compared to traditional generic, single-medium, and deterministic risk assessment methods, site-specific, multimedia, and stochastic risk assessment has become common practice. However,

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0045-6535/$ - see front matter
doi:10.1016/j.chemosphere.2005.08.011

despite of the considerable improvement of the method, uncertainty remains a primary threat to the credibility of and hence users' confidence in the model-based risk assessments. Recent research on risk assessment has focused on uncertainty, because the uncertainty associated with parameter inaccuracy or variation, model simplification and inadequacy, and unsuited scenario designation often perplexes the users and decision makers in the process of risk assessment and management. Nevertheless, except research related to parameter uncertainty, the analysis of model and scenario uncertainty in the recent literature is still rare. Although the contribution of scenario and model uncertainty to overall uncertainty is usually assumed negligible or ignored, both types of uncertainty may affect significantly the outcome of risk assessment (Moschandreas and Karuchit, 2002). Some researches tried to quantify scenario and model uncertainty, and the outcome revealed that the total uncertainty including scenario, model and parameter uncertainty is three times greater than that considering only parameter uncertainty (Moschandreas and Karuchit, 2002). Although it has been indicated that scenario and model uncertainty are the important contributors to the total uncertainty, there are no practical measures as to how model and scenario uncertainty could be reduced.

Currently, many multimedia risk assessment models for implementing site-specific risk assessment have been developed, including MEPAS (Buck et al., 1995), MMSOILS (USEPA, 1996), CalTOX (Mckone, 1993a,b,c), 3MRA (USEPA, 2003), and TRIM (USEPA, 2002a,b), etc. One of these or related models will be adopted based on characteristics of different contaminated sites and scenario assumptions. But it is a difficult task for an inexperienced modelers to choose from so many environmental multimedia models (Del Re and Trevisan, 1995; Garen et al., 1999). Quite a few researches have performed model comparison to study the relationship between model differences and estimated results recently. Although model developers have tried hard to avoid uncertainty existing in the process of model construction, the differences in model design, environmental mechanism, mathematical formulations, and assumptions can result in difference of risk predictions by orders of magnitude (Laniak et al., 1997; Mills et al., 1997; Regens et al., 2002). Moreover, the uncertainty resulting from choosing different models has been shown more important than that caused by parameter uncertainty (Pollock et al., 2002). However, the finding that the results produced from different models may vary significantly does not provide suggestion as to which model is the best, except underlining the importance of understanding the limitations and assumptions of these multimedia models, and the compatibility between conceptual model and multimedia models to avoid the large errors introduced through use of improper models (Mills et al., 1997; Whelan et al., 1999; Regens et al., 2002).

Although model selection will cause considerable model uncertainty, very few studies explored the quantification and reduction of model uncertainty. Hertwich et al. (2000) even concluded that scenario and model uncertainty could be only exploratory and difficult to analyze quantitatively. At present the quantification of model uncertainty is generally conducted by way of calculating the range of outputs of different models (Moschandreas and Karuchit, 2002). Therefore, developing a screening procedure to compare the relative suitability between potential multimedia models would facilitate the reduction of uncertainty due to model selection by excluding unsuitable model. In other words, this study attempts to find out the relation between exposure pathways and estimated risk results and use this information to select the proper model through comparison of environmental multimedia models. A realistic groundwater contamination site is used as the case study.

2. Materials and methods

2.1. The contaminated-groundwater problem and conceptual model development

The important first step to implement risk assessment for a contaminated site is to develop the conceptual model of the site (Regens et al., 2002). The conceptual model is a descriptive model which uses available information to define all sources, types, and concentrations of contaminants, potentially contaminated media, potential exposure pathways, and final receptors (USEPA, 1989, 1991). According to the developed conceptual model, the exposure pathways in each multimedia model can be selected to correspond to the practical scenario.

The case study considered in this research is about a site, located in northern Taiwan, where it was discovered that the soil and groundwater was contaminated by chlorinated hydrocarbons, primarily trichloroethylene (TCE) and tetrachloroethylene (PCE). These chemicals were used as degreasing solvents by a local factory but improper handling and disposal of wasted solvents led to leakage and subsequent contamination of soil and groundwater.

Extensive resources and efforts have been spent in cleaning up the site. The soil cleanup has been considered complete, but little success has been reached for groundwater, due to dense-non-aqueous-phase-liquid's distinct physical characteristics that increase the difficulty of its identification and removal. At this point, the government needs to determine an appropriate course of management of groundwater contamination and subsequent feasibility of land use and development.