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ENVIRONMENTAL RESTORATION: WHAT IS TO BE GAINED FROM QUANTITATIVE ESTIMATES OF RISK UNCERTAINTY?

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ABSTRACT

Quantitative risk predictions are uncertain because of incomplete information and knowledge about models and parameter values. Uncertainty in risk estimates due to these factors may be assessed by conducting uncertainty and sensitivity analyses using Monte Carlo simulations. However, the cost of such analyses may be considerably larger than for less comprehensive assessments of risk uncertainty that are largely qualitative rather than quantitative. This article considers the questions "How does the decision maker benefit by having available a quantitative estimate of risk uncertainty?," and "Is the additional information gained from a quantitative risk uncertainty analysis worth the added cost?"

INTRODUCTION

This article focuses on the issue of making environmental restoration (ER) decisions in the face of uncertainties about risk estimates. Risk information is used in ER activities to help make decisions with regard to determining, e.g., 1) the allowable levels of chemicals and radionulcides in environmental media, 2) the need for remedial action, 3) which remedial action technologies are most effective at reducing risk to acceptable levels, and 4) which sites should be remediated first? Estimates of risks are typically highly uncertain. Clearly, the amount of uncertainty should be assessed to help interpret the risk estimates and use them to make decisions. Oftentimes, qualitative rather than quantitative statements about the uncertainty of risk estimates are made. Indeed, the U.S. Environmental Protection Agency[1] (EPA) indicates that formal quantitative uncertainty assessments are usually not practical or necessary for Superfund risk assessments. However, the National Research Council (NRC), in a report[2] mandated by the 1990 amendments to the Clean Air Act, states that EPA "should conduct formal uncertainty analyses, which show where research might resolve major uncertainties and where it might not." Another recommendation in the report (among others) is that EPA should develop uncertainty analysis guidelines, both general and specific, for each step in the risk assessment process.

This article provides a brief discussion of some benefits of conducting formal uncertainty analyses to quantify the uncertainty of risk estimates. An underlying goal of this article is to encourage effective collaboration and teamwork among environmental statisticians and ER stakeholders so that the advantages and disadvantages of quantitative uncertainty and sensitivity analyses are clearly articulated and appropriate decisions are made regarding them.

Several publications provide information about how to conduct quantitative uncertainty and sensitivity analyses.[3,4,5,6] The ideas expressed here are from those publications.

WHEN IS A QUANTITATIVE ESTIMATE OF RISK UNCERTAINTY BENEFICIAL TO THE DECISION MAKER?

Serious consideration should be given to conducting probabilistic risk assessments (using uncertainty/sensitivity analyses) when:

- prima facie calculations show that uncertainty can impact the decision
- costs of reducing risk are high and risk estimates are near limits
- costs and consequences of making wrong decisions are significant
- there is a need to know how much weight to give a risk assessment when making risk management decisions
- there is a need to know the degree of conservatism in point risk estimates
- there is a need to decide whether to get more information to reduce uncertainties
- taking uncertainties into account may change the "best estimate"
- uncertainties are used to guide model refinement
- decision makers feel an ethical responsibility to be clear about limitations of their analyses.

Two of these potential benefits are now briefly discussed. First, it may help the decision maker to know the degree of conservatism in point estimates of risk that have been obtained using parameter values that are very conservative. Typically, when formal quantitative risk assessments are not conducted, a conservative (upper bound) point estimate of risk is obtained by using parameter values in the risk model that are themselves known to be upper bounds. In contrast, a formal uncertainty analysis conducted with Monte Carlo simulations will yield multiple, say n, estimates of risk. These multiple estimates provide information about the probability that the true (unknown) risk being estimated could fall between various values, conditional of course on the risk models, assumptions, and parameter values used in the simulations. Furthermore, the models, assumptions and parameter values can be varied within their bounds of uncertainty to determine the sensitivity of the risk estimates to these uncertainties and to alternative models.

This strategy generally leads to unrealistically conservative results

For a given risk model equation, the n estimates of risk are obtained from Monte Carlo simulations by first specifying a probability density function (pdf) of specified type, range, and shape, to characterize the uncertainty in each model parameter. This pdf may be obtained from actual measurements of the parameter, from the scientific literature, or by eliciting judgments about the parameter's uncertainty or variability from one or more experts using defendable elicitation methods.[7,8,9] With each iteration of the Monte Carlo code, a new value of each uncertain parameter is drawn from its respective pdf, and the risk is recomputed using the model equation. In this way, n estimates of risk are obtained.

These estimates can be displayed graphically in various ways to help the analyst or user understand and interpret the results. Histograms or boxplots may be used[10] to summarize and communicate the uncertainty about the value of the true risk. At this point one can compare the usual conservative estimate of risk (obtained by using conservative parameter values in the model) with the histogram or boxplot of risk estimates to assess the degree of conservatism in the point estimate. Such comparisons may help one decide whether the conservative estimate is "too conservative" for the decisions to be made.

A second important benefit to the decision maker is the ability to use the formal uncertainty and sensitivity analysis results as the basis for a comprehensive assessment of what research should be conducted to reduce risk and decision uncertainties to acceptable levels. As indicated above, the computer simulations can be repeated using different inputs to evaluate the sensitivity of the risk pdf to changes in the model or parameter pdfs. Also, multiple linear regression and correlation analyses[11] can be conducted on the multiple sets of inputs and risk estimates to determine which parameters contribute the most uncertainty to the overall risk uncertainty. This information is helpful in determining where research dollars should be focused to have the greatest impact on reducing uncertainty about the risks. Several methods of conducting sensitivity analyses are available.[4]

ARE THE BENEFITS OF QUANTITATIVE RISK UNCERTAINTIES WORTH THE COST?

The cost of conducting formal uncertainty and sensitivity analyses using Monte Carlo simulations can be large, particularly if the risk model is complex with many parameters and an extensive effort is required to develop defendable pdfs for model parameters by eliciting information from experts. Additional costs are incurred if unique software code must be developed to do the Monte Carlo simulations, as was required for the Hanford Environmental Dose Reconstruction (HEDR) Project.[10] That project estimated doses to potentially exposed individuals over a large geographical area for various time periods. For situations where a unique code is not required, user-friendly software is available (e.g.)[12,13,14] Among these codes, Ref. 12 is recommended if correlations among parameters are a concern.

CONCLUDING REMARKS

In practice, an evaluation must be made regarding the potential benefits of probabilistic risk assessments relative to projected costs. The benefits listed in this article should be carefully considered. This evaluation will require discussions with scientists, including statisticians, who have experience and knowledge of formal uncertainty/sensitivity analyses obtained from past experience. A better appreciation of how to judge what constitutes a defendable uncertainty/sensitivity analysis will be gained if EPA accepts the challenge of the National Research Council[2] to develop step-by-step guidance on how to conduct these analyses. Not until decision makers and stakeholders understand this step-by-step process will they feel confident in interpreting and using the results of such analyses.

delete e.g.

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