RISKS OF RISK ASSESSMENT

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ABSTRACT

The significance of risk assessment is due to the fact that the financial resources allocated for remediation and environmental services depend on the magnitude—real or perceived—of the environmental risk. This attitude is very important in the middle European countries where privatization of former state companies has been underway for about five years. Before privatization can occur it is necessary to remediate damages caused during the former so called "state care" period. Damages have occurred due to improper storage and handling of fuels, improper storage of industrial chemicals, and improper waste disposal practices. In this situation, a knowledge of risk assessment procedures has become an integral part of hydrogeological consulting practice. However, there are many cases where the damage assessments appear to be in error due to problems associated with the choice of the risk assessment criteria, both environmental and economic. The need to introduce additional criteria in the risk assessment procedures is stressed.

KEY WORDS

risk assessment, economics, pollution

INTRODUCTION

Risk assessment has become accepted practice in developed countries. Activities ranging from construction of power plants to remediation of contaminated sites require risk analysis. It is generally assumed that a risk analysis will make it possible to use financial resources more rationally and, thus, risk analysis has become an important tool in regulatory decision making. The increased interest in risk analysis has brought with it a concurrent increase in the number of risk experts. In the Czech Republic, with only 10 million inhabitants, there are almost 1,000 registered risk analysts, or 1 for every 100,000 inhabitants!

This paper attempts to generalize some experience with the hydroenvironmental aspects of risk analysis and calls attention to some conceptual problems.

SHORT HISTORY

Interest in risk analysis increased following passage of the "Superfund Act" [1] in the U.S. Cleanup of CERCLA sites is detailed in the National Contingency Plan which requires ground water cleanup goals to meet chemical-specific applicable or relevant and appropriate requirements (ARARS). If no standard exists for a particular chemical, then a site-specific risk assessment is the basis for cleanup. Cleanup goals are based on a risk level of 10^{-4} to 10^{-6} for carcinogens and a hazardous index of less than one for noncarcinogens.

Risk analysis has become a visible and often controversial part of environmental decision making. However, risk analysis is also used as a decision making tool in other areas where the benefit is a life saved, e.g. in highway safety [2].

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Vesilind [2] lists the analysis methods used in engineering decision making as: technical analysis, cost effectiveness analysis, benefit/cost analysis, risk analysis, environmental impact analysis and ethical analysis. In this sense, risk analysis is only one of the tools available for decision analyzing alternatives.

PARADIGM

In determining risk, a set of terms, definitions, aims, goals, equations and methodologies are applied. The elements have not yet been fully unified or agreed upon. As for the terms, the current paradigm uses expressions such as risk, cumulative risk, individual risk, hazard, hazard assessment, risk assessment, risk management, risk communication, risk perception and so on. Risk assessment is a process of defining and describing unfavorable effects caused by certain factors (herein called "impulses") in a given situation. It includes a description of the system, factors influencing it, and their expected individual, cumulative or subsequent influences at all levels.

Generally, the paradigm proceeds from beliefs that:

- the entire environmental system (hereafter the system), including all its elements, can be fully defined at all scales (e.g. micro, mezo and macro),
- all influences of the anthropogenic activity (building construction, introduction of new technologies affecting the system, hereafter anthropogenic impulses) can be defined and quantified in advance. At the same time, it is assumed that these influences can be purposefully controlled so as to minimize any negative influence on the environment,
- all effects of increasing the anthropogenic impulses in the environmental system (hereafter reactions) are known beforehand, and can be mathematically, or otherwise, adequately defined,
- the level of knowledge of the system, impulses, and reactions is sufficient to determine the extent and quantity of the necessary information,
- the technology for obtaining this information, its evaluation and subsequent utilization for prognostic calculations is available,
- the risk analysis methodology is able to quantify with sufficient accuracy all elements of the system, affecting impulses, and the expected reactions and to define appropriate direct and indirect positive or negative consequences,
- simple, sufficiently representative and reproducible criteria (standard functions) exist so that consequences can be expressed in a standardized way,
- on the basis of the risk analysis it is possible to select at least one optimal solution from many possible no-action solutions which will not damage the environment.

Risk expresses the probability of occurrence of a certain action harmful to humans. Risk may be defined as the probability that an injury, illness or death will result from a specific condition. It may also be defined as the probability that, under certain conditions, a specified change in a system will or will not occur; for example, a liner or monitoring system may fail.

The degree of risk is usually described by qualitative, quantitative or semi-quantitative scales. A qualitative evaluation uses terms such as high, medium, low and extremely low risk. A quantitative evaluation describes the degree of risk as a probability that—under previously defined conditions—a certain event may or may not occur. The probability is expressed as a dimensionless quantity varying from 0 to 1 where 1 means that the event will certainly occur, and 0 that it will not occur. Risk is assessed in many ways [3]. For example, the probability (p) or risk of a cancer occurring due to consumption of a carcinogenic substance over a lifetime can be calculated as [4]

$$p = CDI \times SF \qquad (1)$$

where CDI is the daily intake (mg/kg/day) of the substance for an individual over 70 years old and SF is the carcinogenic slope factor $(mg/kg/day)^{-1}$. This equation is valid only at low risk levels.

Risk is also assessed by means of various semi-quantitative scales. For example, NATO uses a procedure [5] where the assessment is calculated by scaling various "investigation forms." The semi-quantitative approach is favored by many for its simplicity. Its main disadvantage is that the "investigation forms" may be at variance with actual physical conditions. For example, when estimating the risk of ground water pollution, the existence of a thick impermeable clay layer (scaling 0 = zero risk) at a certain location may be "outweighed" by the possible existence of ground water observed at the same location (scaling 5 = very high risk). In contrast, in the case of a permeable zone of aeration (scaling 5 = very high risk), where ground water is not observed (scaling 0 = zero risk) due to a long or short term decline in the ground water level, the risk may be incorrectly estimated as negligible.

Risk analysis based on probability criteria alone cannot be used for comparing alternate solutions. To compare solutions, not only the probability of the event occurring but also its consequences are needed. In such cases, it is convenient to use a measure such as the Total Risk Value (TRV) which can be expressed as

$$TRV = p * N \qquad (2)$$

where p is the probability of occurrence of a certain response to the tested activity, and N (expressed in any currency) are the damages (losses) or positive changes (contributions, returns) due to the reaction.

These and similar paradigms have serious shortcomings and often lead to contradictory and even paradoxical conclusions.

POSSIBILITIES OF THE CURRENT PARADIGM

Description of environmental system

Experience with hydroenvironmental risk analysis makes it clear that it is currently not possible to fully define systems in which the changes and relevant processes occur at all scales. A primary reason is the stochastic nature of these processes. Transition from the small scale in a process to a larger scale is complicated because it is not possible to estimate, in advance, the interactions of all the geometric, material and energetic hydrogeoenvironmental fields. The interaction of ground water flow and transport fields is a good example.

Description of anthropogenic effects

The majority of the real or assumed effects ("impulses") of an anthropogenic activity can be defined and quantified beforehand. For example, we are able to determine, in advance, quantities of ground water to be pumped, ground water levels in remediation systems, and—with some limitations—quantities of pollution emissions from waste dumps, and so on. However, problems can arise since many of the site conditions can change regularly or incidentally with time.

Theoretical basis for spreading of "impulses"

To perform a risk assessment it is necessary to perform a series of calculations using mathematical models. In fact, in the course of a hydroenvironmental risk assessment, a complex of working hypotheses is assessed with the aim of answering certain questions (Table 1).

Based on model calculations, a series of questions must be answered. For example, what is the probability that:

- a harmful material emanating from a potential pollution source will pollute soil, ground water or air?
- a pollution plume will spread to a certain locality and what will be the concentrations?
- a harmful material from a polluted zone will contact living organisms?
- the level of a harmful constituent in ground water will exceed regulatory standards at certain localities for certain times?

As for the remediation activities, it is necessary to answer questions such as:

- Is it necessary to perform any remediation?
- What will be the most effective, cheapest, quickest, technically feasible and practical technology?
- What will be the final result, or how great will be the reduction in potential environmental damages, including monitoring and remediation work, penalties and risk?

The theoretical basis for analyzing hydrogeoenvironmental fields makes it possible to model, mathematically or otherwise, the spreading of anthropogenic "impulses" in

Element	Variables	Assessed hypothesis
A: source of pollution	• pollutant • concentration • boundary conditions (BC) • time • spatial characteristics • finances • technology	• a pollution source exists? • is it a pollutant? • BC can be changed? • concentration is dangerous? • financial means and technologies are available? • pollution may be prevented?
B: transport	• geometric characteristics of the zone • hydrogeophysical fields • time • finances • technology	• what is or could be the extent of a pollution plume? • can it be limited or eliminated? • are there the financial means and technologies to do it?
C: receptor	• type of receptors • number of receptors • sensitiveness of receptors • concentration (dose)	• can they be impacted? • can they be moved? • can protective measures be provided? • can control conditions be established? • are the financial means and technologies available?

Table 1. Working hypotheses.

an environmental "system" only for very simplified conditions. So far, modeling is limited to simple subsystems; for example, certain groups of hydrogeoenvironmental fields—ground water, unsaturated zone and so on.

Acquisition of information

A hydrogeoenvironmental risk analysis requires a certain minimum amount of information on (modified from [6]):

- the environmental space (e.g. rock media, ground water, surface water, air, living organisms) where the "impulses" are spreading,
- the impulses (initial and boundary conditions) and any changes in time and space,
- the receptors and their locations in the environmental space.

Since the reliability of the risk assessment depends first of all on the reliability of the information and the prognostic methods used, we can differentiate as follows:

- qualified risk estimation (QRE) based only on judgment and background information (analogy, experience, site visit) on hydrogeoenvironmental conditions for pollutant transport. At the same time, the so-called zero hypothesis is defined, i.e., the conditions under which the expected event could not occur,
- orientation risk calculation (ORC) based on evaluation of archive materials, orientation soil gas and geophysical measurements, rapid hydrodynamic and transport tests, and limited water and or soil sampling. Subsequent calculations are performed using analytical models. Procedures based on scaling and testing extreme conditions by mathematical modeling are used to test the "sensitivity of a solution"; e.g. estimation of errors and economic losses expected under an assumption of insufficient information availability,
- expert risk calculation (ERC) based on a good knowledge of the assessed locality obtained by long-term monitoring and detailed hydrogeological and geophysical measurements where the information on the processes is at the mezo- and macrolevels.

From the theory of information acquisition it can be concluded that for normal hydrogeoenvironmental surveys it is possible to fully define systems at the smaller scales, but not at the larger scale due to the effect of system non-additivity. For this reason, information obtained at that small scale can only be extrapolated to the large scale under very limited conditions. In addition, extrapolation may be impeded by factors such as instrumental, financial, organizational, personal, social, psychological and other barriers to obtaining representative and reproducible information.

Generally, it is true that:

- the more reliable the survey information required, the longer and more expensive the survey must be,
- the more testing that is done, the greater the risk that an aquifer might be accidentally interconnected or pollution spreading intensified, resulting in a subsequent remediation activity that is more expensive.

Under normal hydrogeoenvironmental conditions, it is not possible to determine in advance the nature and extent of the necessary information nor the locations where such information should be collected. As a rule, the amount of data collected is determined by the amount a client or owner is willing or able to pay. Unfortunately, whether the data are useful or not is usually not known until the risk analysis is completed.

Technology of information collection

Some information on hydrogeoenvironmental fields cannot be determined at all due to the effect of "the Schrödinger cat." This means that the more something is investigated, the more the parameters are influenced by the measurements and, as a result, false results are obtained. In such cases, nondestructive or geophysical methods seem to be the only solution.

Definitions of effects

In complicated cases, it may not be possible to determine complete relationships for all the direct and indirect effects in individual system elements and even for the system as a whole. Those effects may include cumulative and multiplicative effects, or effects where apparently positive effects have negative consequences, or where harmful daughter products are produced from decay of harmless chemicals. Experience with production and migration of harmful chemicals in the environment indicates only limited possibilities for prognostic methods. This is in estimating health risks, which is presently the most developed area of risk analysis.

As a result of the health focus of current risk procedures, standards (limit values) apply primarily to humans and domestic livestock. For example, allowable levels of pesticides in soil for wildlife are not fixed. Concepts such as toxicity, mutagenity and carcinogenicity are only employed to estimate an effect of a pollutant on lower organisms as an indicator of a possible human health effect.

Toxicity

The criterion for estimating acute toxicity of a chemical or mixture of chemicals in a medium (water, foodstuff, air) is either the dying out or—on the contrary—the resistance of a certain homogeneous group of a living organisms exposed to the effects of the concentration of the chemical for a fixed time interval. These effects have a statistical character due to a certain unremovable inhomogeneity of the tested population.

Lethal dose

The lethal dose (LD_{50}) corresponds to the concentration of a chemical where 50% of the exposed organisms from the tested population die within a certain time interval—typically 4 hours. The dose is in fact a so-called average limiting concentration (TL_m).

Safe concentration

A number of relations can be used for determining the safe concentration (C_B). For example, the relation

$$C_B = 0.3\ A_{24}/(A_{24}/A_{48})n \qquad (3)$$

(where A_{24} and A_{48} are the values TL_m at 24 and 48 hours and n is a safety factor varying from 2 to 3) has been used. Other analogous relations, which can be regarded as empirical, are available. They differ from the above according to the conditions for which they were derived.

Standardized functions

To make it possible to compare several variants, to develop working hypotheses, to classify objects according to their importance, to estimate the advantage and usefulness of the tested anthropogenic activities, it is necessary to express risk analysis results in the form of so-called standardized functions. The most frequent way of standardization is to use an expression incorporating cost. Sometimes such an expression is not applicable, e.g., if we compare the value of a human life with the value of other elements in the ecosystem. Use of cost, a monetary criterion, is problematic in cases where the value of wildlife or wetland losses must be assessed.

Irrespective of Schopenhauer's statement that "money is a materialized common good," it is recognized that there are cases where another measure should be used for quantifying risk. The criteria should be based on an understanding that continuous changes in individual elements of an environmental system can lead to uncontrolled changes in relations between these elements which upset the environmental balance. Ultimately, this can lead to a condition where the system seeks a new equilibrium between the new or remaining environmental elements at a lower level. In such cases, either the instability of the relations between the elements of a system at a higher level, or the newly introduced stability of the system at a lower level, can lead to a significant reduction in human activities in the frame of these elements. In any case, economic considerations should not eliminate certain elements of an environmental system. However, it may be found that protection of some elements in an environmental system could be groundless.

Currently human health considerations are the sole basis for most risk analyses; that is, the measure of most, if not all, environmental values is man. This approach seems to embody what we can call the paradox of anthropocentrism where human health or economic interests are much more valued than the loss of any element in the ecosystem irrespective of the possibility that such a loss could—secondarily—jeopardize many more humans at a future time.

Non-zero solutions

Non-zero solutions in risk analysis assume that the anthropogenic activities analyzed will be realized. Due to the uncritical principle of anthropocentrism, it is assumed that Nature must serve humans and that an extensive transformation of nature is progress. Our experience suggests that risk analysis should also consider elements of the environment irrespective of whether the tested events are or are not directly related to humans. Anthropocentrism leads to the use of risk analysis to justify human activities, mainly economic. There appear to be few, if any, cases where a risk analysis admits that a human risk is higher than the risk to other animal species. Many economic analyses are based effectively on exhaustion of natural resources. In such cases the risk analysis can not include the zero solution since the activity would then not be realized. Instead, the least impact variant is selected from all bad ones! Efforts toward sustainable development assume some reduction in negative environmental effects but not their complete elimination.

Except for revitalization, remediation, sanitative and protective measures, all anthropogenic activity in its primary or secondary consequences has and will have some negative influence on the environment. However, it is not known what effects are at least "safe" for the general population.

Significance of risk analysis

In practice, decisions are made and actions are taken regardless of risk analysis results. The most important factors in making these decisions are typically political and social. This is why actions can be agreed upon even when such actions are not supported by the risk analysis. A risk analysis may be necessary, but it is not sufficient for acceptance of certain environmental decisions.

Engineers and scientists may view risk analysis as potentially the most objective decision-making tool. However, as Jasanoff [7] explains, there are in fact "two cultures of risk analysis." Realistically, risk analysis is not the ultimate decision making tool but only another tool. In particular, in adversarial settings, the opinions of experts may not be convincing.

Analysis of the environmental impacts of a project is typically a component of an economic analysis. Therefore, an environmental risk analyses (ERA) should always be done to define:

- risks and economic consequences if, e.g., a certain project will not be realized (its influence on taxes, unemployment and so on), or if a non-environmental activity will be canceled,
- risks and environmental consequences of the environmental impact.

In the United States this may be done as a benefit/cost analysis, an environmental impact analysis or as a risk/benefit/cost analysis.

ETHICAL ASPECTS

Decision making is criticized when it is perceived to ignore social and environmental values. In ethics, traditional benefit/cost analysis is essentially a utilitarian concept based primarily on money [8], whereas risk analysis is based primarily on health impacts and environmental impact analysis on long-term effects on the environment [3].

The ethical systems that guide current engineering and hydrogeological practice are anthropocentric. Whether the system considered in ethical decisions should be expanded to include "the land," as advocated by Leopold [9], is a topic for debate but is not seriously being considered, at least not in the United States.

RISKS OF THE RISK ANALYSIS

We conclude that at each stage of a risk analysis, an estimate of the uncertainty of the approach should be included. If the risk of financial failure due to an erroneous risk analysis exists, then it should be included as an uncertainty of the risk analysis. Therefore, every risk analysis should include at least a qualitative expression of the reliability of the conclusions and perhaps even an estimate of the losses which could occur due to an incorrect risk analysis. It would be ideal to calculate a cost for the risk dispersion of the risk analysis, i.e., the dispersion of the possible negative consequences if the recommended action is followed.

CONCLUSIONS

Environmental concerns lead to the conclusion that it would be desirable to modify the basic paradigm for risk analysis. This is so because it is not possible to quantify all influences in an environmental system, or even in its subsystems, in an analysis. Many of the processes are transient and will continue even when their causes are eliminated. Even the cumulative effects of small scattered (diffuse) sources which we are able to reliably analyze at the micro- and mezoscales, are not analyzable at the macroscale, e.g., at the global scale and for long times. If the expected changes at a global scale are already occurring, then normal protective, revitalization and remediation measures become inappropriate from a short-term point of view. Therefore, we argue that a new paradigm for risk analysis is needed which is based on the entire ecosystem. In any case, risk analysis results should not be a substitute for good common sense!

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