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Introduction

Historically, the term *risk assessment* has been applied to the examination of potential risk to human health as a result of exposure to some introduced environmental toxicant. As an intellectual discipline, risk assessment is in its infancy. Within the past couple of decades, considerable research has been done in the fields of toxicology, industrial hygiene, environmental impact assessment, engineering, and epidemiology. The vast majority of the accessible literature deals with such risk events as radiation exposure as a result of an industrial accident, impact of hazardous material on human health, impact of pesticides on human health, and oil spills. In recent years, a branch of risk analysis has formed that deals primarily with risks posed to the environment as a result of human activity; this type of analysis is generally referred to as "ecological risk analysis." This paper summarizes the approaches associated with the traditional methods of risk analysis and with ecological risk analysis.

Traditional Risk Analysis

Traditional risk analysis focuses on the potential impacts to a human population due to the presence of an introduced substance or event, for example the presence of pesticides in a body of water used for human consumption, or an oil spill. A broad variety of techniques are used to evaluate risk in these situations. Risk analysis typically involves four steps: hazard identification, risk assessment, determining the significance of the risks, and risk communication. Traditional risk analysis does not typically attempt to address any social or political aspects that are associated with most risk decisions. Risk analysis is often used in such activities as hazardous waste disposal, use of various risk agents, and selection of sites for potentially hazardous facilities. It should be noted that while most risk analyses follow similar methodologies, there is no single protocol for determining risk; the required techniques will vary according to the type of activity in question. For this reason, it is unwise to apply the results of one risk assessment to another situation.

Hazard Identification

The first step in any risk assessment is the determination of the existence of a hazard. This process is not as straightforward as it might appear. Adverse health effects such as toxicity, carcinogenicity, mutagenicity, and teratogenicity require sophisticated laboratory techniques for detection. The results of such analyses are frequently less than clear. Four types of analytical tools are typically used in hazard determination: epidemiological studies (Lilienfeld and Lilienfeld, 1980), *in vivo* animal bioassays, short-term *in vitro* cell and tissue culture tests, and structure-activity relationship analyses.

Epidemiological studies are statistical examinations of the patterns of human disease and the factors that influence those patterns. Epidemiology is most useful in situations where, for example, exposure to risk agents is high, adverse health effects are distinctive, or when environmental levels of the risk agent are relatively high (Cohrssen and Covello, 1989).

Frequently, epidemiological data are unavailable. Laboratory studies performed on live animals can provide information useful to decision makers. Animal bioassay procedures typically fall into one of three categories: acute exposure tests, subchronic exposure tests, and long-term chronic exposure tests (Cohrssen and Covello, 1989). A large number of researchers are involved in this particular area of hazard *identification.* For more information on specific laboratory methodologies of *in vivo* animal bioassays, see Tennant, *et al,* 1987.

Cell and tissue culture is used in determination of substances that may be human mutagens and carcinogens. However, application of *in vitro* genetic toxicity tests to *in vivo* carcinogenicity is apparently quite controversial (Cohrssen and Covello, 1989).

Structure-Activity Relationship (SAR) Analysis involves comparing the molecular structures and properties of chemicals with unknown hazards to similar chemicals with known toxicity. According to Cohrssen and Covello, 1989, SAR Analysis has the most potential for wide application and use in the field of chemical hazard identification.

Risk Assessment

Risk assessment attempts to establish the probability and severity of harm to human health and/or the environment resulting from exposure to a risk agent. Numerous procedures are used to effect risk assessment. Some of these are source/release assessment, exposure assessment, dose-response assessment, and risk characterization.

Source/release assessment is most often engineering related, as it attempts to determine the likelihood of the accidental release of some toxin from an engineered facility, for example a nuclear power plant. Other examples of situations which would suit this type of assessment include stormwater runoff, leakage from a hazardous waste landfill, and the release of pathogenic microorganisms from a hospital or research facility. Source/release assessment can be quite quantitative, involving statistical analyses or modeling.

Exposure assessments attempt to estimate or measure the quantities of risk agents received by a particular population or environment (Davis and Gusman, 1982). Exposure assessments are quite difficult to carry out; humans and other organisms engage in behaviors that make it difficult to quantify the duration and/or location of exposure to the risk agents.

Dose-response assessment involves determination of the exact dose of the risk agent received by the exposed populations and the relationship between the dosage level and the magnitude of the adverse effects. This necessarily requires an involved statistical description of the risk agent and its effects. Dose-response methodologies are quite quantitative in nature, and are described in excruciating detail in almost every article published in the journal *Risk Analysis.*

Risk characterization is usually the final step in a risk assessment. It is most often a summarizing of the data generated in the previous steps with speculation on potential adverse effects that were not included in the risk assessment (also with an explanation of why they were excluded).

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Commonwealth's Declared Policy: "to preserve the wetlands and to prevent their despoliation and destruction..."

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Examples of some of the numerical risk measures one might find in a risk characterization are individual lifetime risk, population or societal risk, relative risk, and loss of life expectancy.

Determination of Significance of Risk

Risk analysis attempts to describe potential risk associated with a particular activity. Elimination of all risk is, of course, impossible. There are trade-offs associated with all risky activities; the risk associated with a particular activity is balanced by potential benefits of the activity. At some level, decisions must be made regarding what is considered "acceptable risk." Numerous analytical tools are used to determine and describe acceptable risk (Travis and Hattermer-Frey, 1988). Some of these methods are cost-benefit analysis, cost-effectiveness analysis, and decision analysis (Von Winterfeldt and Edwards, 1986). Recently, some researchers have described the concept of *de minimis* risk: a specified level below which a risk estimate is so small that it can be ignored (Whipple, 1987). None of these approaches is free from criticism, however. In recent years, acceptable-risk methodologies have been increasingly vilified as being inappropriate (Cohrssen and Covello, 1989). Acceptable-risk decisions appear particularly vulnerable to criticism when high consequence activities are involved (e.g., placement of hazardous waste facilities).

Risk Communication

There are many problems related to the communication of risk probabilities. According to Covello, *et al,* 1987, these problems include:

Message problems:

- deficiencies in scientific understanding, data, models, and methods resulting in large uncertainties in risk estimates
- highly technical risk analyses that are often unintelligible to laypersons

Source problems:

- lack of trust in responsible authorities
- disagreements among scientific experts

Channel problems:

- selective and biased media reporting that emphasizes drama, wrongdoing, disagreements, and conflict
- premature disclosures of scientific information
- oversimplifications, distortions, and inaccuracies in interpreting technical risk information

Receiver problems:

- inaccurate perceptions of levels of risk
- strong beliefs and opinions that are resistant to change
- desire and demand for scientific certainty
- reluctance to make trade-offs among different types of risks or among risks, costs, and benefits

In 1988, the EPA published a set of guidelines for effective risk communication (Covello and Allen, 1988). The EPA pointed out that there is no simple method for ensuring effective communication; they also noted that while the guidelines seem obvious, they are in fact violated frequently in practice.

Rule 1: Accept and involve the public as a legitimate partner.

Rule 2: Plan carefully and evaluate performance.

Rule 3: Listen to your audience.

Rule 4: Be honest, frank, and open.

Rule 5: Coordinate and collaborate with other credible sources.

Rule 6: Meet the needs of the media.

Rule 7: Speak clearly and with compassion.

Ecological Risk Assessment

The paradigm of traditional risk analysis (single stress—single endpoint) has limited applicability in the field of ecology. Situations which involve release of a toxin or pollutant into the environment might be well-suited to traditional approaches; however many environmental prob-

Table 1. Summary of ecological risk rankings[a]

Environmental Stress	Extent of stress: Biosphere	Regional	Ecosystem	Medium: Air	Water	Terrestrial	Recovery time: Short	Medium	Long
1. Global climate	HHH	HHH	HHH	HHH					X
Habitat alteration	HH	HHH	HHH		HHH	HHH		X	X
Stratospheric ozone	HHH	HHH	HHH	HHH					X
Biological depletion		HH	HHH		HH	HH			X
2. Herbicides/pesticides		M	HH	HH	HH			X	
3. Toxics in surface waters		M	HH		HH			X	
Acid deposition		H	H	H				X	
Airborne toxics	M	HH	HH	HH				X	
4. Nutrients			H		H		X		
BOD			M		M		X		
Turbidity			M		M		X		
5. Oil		L	M		M	L	X		
Groundwater		L	L		L				X
6. Radionuclides			L	L	L			X	
Acid inputs to surface waters			H		H			X	
Thermal pollution			L		L				

[a] From Harwell, *et al,* 1992

lems involve multiple stresses that affect many components of an ecosystem. For example, an oil spill poses readily quantifiable risks to human populations, but the problem is more complex with respect to the risks face by the affected ecosystem. The task of hazard identification takes on a whole new meaning when dealing with global climate change; an increase in average global temperature might favor some species, but adversely affect others.

Only the most general of paradigms is available for those interested in quantifying ecological risk. Harwell, *et al,* 1992, described this paradigm as a three-step approach: 1) characterization of the stress regime experienced by various components of the ecosystem; 2) characterization of how ecosystems respond to stresses; and 3) characterization of how ecosystems recover from or adapt to stress.

Stress in this sense includes traditional definitions of exposure, but also include such factors as occurrence of nonchemical stress, spatial extent, frequency, intensity, and duration of the stress event, differential intensities of the stress within the ecosystem, occurrence of other simultaneous anthropogenic stresses, and the background natural stresses. Harwell, *et al,* 1992, listed factors which limit researchers' ability to predict ecosystem response to stress events. These include:

- diversity of ecosystem type
- diversity of disturbance type
- differential response of ecosystems to stresses
- diversity in response according to scale
- lack of baseline information on ecosystem function
- fundamental limitations in ecological theory
- environmental variability and stochasticity

One method of dealing with ecological risk is a prioritization methodology described by Harwell, *et al,* 1992, and in two EPA publications (1987a and 1987b). The authors started with a list of environmental risks found in the EPA publications cited. The EPA list was expanded and modified to include a broad range of environmental

Table 2. Ecological risk priorities vs. public perception of environmental risks[b]

Highest ecological risks
- global climate change
- habitat alteration
- stratospheric ozone depletion
- biological depletion

Higher ecological risks
- herbicides and pesticides

High ecological risks
- toxics in surface waters
- acid deposition
- airborne toxics

Medium ecological risks
- nutrients
- BOD
- turbidity

Low ecological risks
- oil and petroleum products
- groundwater contamination
- radionuclides
- acid inputs to surface waters
- solid wastes
- thermal pollution

Public perception of environmental risks
- active hazardous waste sites
- abandoned hazardous waste sites
- water pollution from industrial sources
- oil spills
- stratospheric ozone depletion
- radiation from nuclear power plant accidents
- chemicals from industrial accidents
- radionuclides in nuclear waste
- industrial air pollution
- groundwater contamination from leaking tanks
- coastal pollution
- solid waste
- water pollution from agricultural runoff
- water pollution from sewage plants
- vehicular air pollution
- global climate change
- wetland habitat alteration
- acid deposition
- water pollution from urban runoff
- nonhazardous waste sites
- releases of genetically engineered organisms

[b]From Harwell. *et al,* 1992.

risks; the original list suffered from a bias toward human health risk. The authors created a matrix of environmental stresses and fundamental ecosystem types. This matrix was intended to include projections of recovery potential and magnitude of ecological effects for each ecosystem as a function of stress type. A second matrix distinguished among risks differentiated by scale (global, regional, or local) and risks differentiated by transport mechanism (air, water, or terrestrial). A third matrix related environmental stresses to recovery time frames. The ultimate result of all this was an "ecological risk prioritization matrix" (see Table 1). The authors noted with irony that their output matrix did not match well with public perception of environmental risks, or even the EPA's own points of emphasis (see Table 2).

Conclusion

Traditional risk analysis deals primarily with the human health concerns of various anthropogenic activities. Numerous protocols exist for estimating the human health risk associated with various environmental toxins. In contrast, ecological risk analysis attempts to resolve risks to the environment as a result of human activity. It is a much newer field, with few (if any) standard methodologies. Most of the ecological risk analyses performed place emphasis on activities that have broad scale consequences (e.g., global climate change) as opposed to those activities which introduce an environmental contaminant into a relatively limited area. These conclusions are often in direct conflict with public perception of environmental risk and with the focus of the federal government's own agencies. It seems likely that ecological risk analysis will become a key element in the future development of environmental policy at all levels of government.

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