CIVE 3331 - ENVIRONMENTAL ENGINEERING
Spring 2003

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Environmental Risk Assessment

Risk assessment is a tool in engineering used to determine the probability of a loss (adverse outcome) from an engineered system or device.

Fundamental Question

The essence of risk assessment are methods to try to answer the following question: What is the probability (chance) that an undesirable consequence will occur as a result of exposure to some engineered (or natural) situation?

Essential ideas

The essential risk calculation/assessment ideas are:

Exposure

Consequence

Chance

Example : The Texas Lottery

Exposure – You have to buy a ticket to win (unless you are the contractor/operator, but that's another story)

Consequence – Huge Jackpot (we call the level of money in the jackpot an SFL amount – Set For Life)

Chance – Quite small (almost nil – take the number 1 and divide it by ~18 x 10^6, that's the chance of any single ticket winning a jackpot)

In the jargon of risk, your individual risk (probability) of winning the jackpot is quite small. In the case of money we can quantify the expected payoff as the product of the probability of occurrence and the magnitude of the consequence.

In the present example that value (using the fixed jackpot) is $\$4.0 \times 10^6 / (18.0 \times 10^6) = \$0.22$ Thus even if you are an incredibly lucky person your "average" or "expected" net winnings over the long term are about $0.22 (twenty two cents).

In engineering we play the lottery differently – if a system fails then we get sued, fined, and/or jailed. If we can estimate the probability of failure, the money people can make a good guess of the fine, lawsuit, or cost to rebuild. The product of the probability and cost is the "expected net loss" and is used to determine insurance premiums.

Example: Zero-Sum Game
2 players.

Public and Corporation.

Each player places a dollar into a "reward" pot. Once the money is placed the player cannot withdrawl.

Flip a coin once – heads, the public wins, tails the corporation wins.

Expected gain for each player is 0.5 * $2.00 = $1.00.

Realized loss (before the toss) is $1.00

Net Expected Benefit is $1.00 - $1.00 = $0.00 (this is called a zero sum game)

Now suppose the coin comes up heads, then the corporation ends up paying the public $1.00. Half the time the corporation plays it expects to lose, so its expected loss is 0.5 * $1.00 = $0.50. This amount of money is the "risk" of being in business (assuming the corporation must play).

Now corporations have some choices at this point –

Lobby for rule changes so they don't have to pay as much to play.

Purchase insurance to cover the expected loss (key is to have better information than the insurance company).

Change their business practices to decrease their odds of losing (make the coin "unfair").

Each approach in the abstract is a legitimate business model to reduce risk to the corporation – if the particular game is truly zero-sum, then the public bears more risk, but in environmental engineering not all the games are zero-sum.

Example: Simultaneous Trials

Now lets change the example one more time

Corporations produce products to make life better, an unavoidable by-product is pollution. Everyone plays a game when they eat, drink, breathe the pollution. Each unit of pollution can be thought of as one coin. If you eat 4 units, you flip 4 coins at once. Suppose the game is such that if any coin comes up heads, then you will go to the doctor and spend one dollar to get well. Now figure the probabilities of getting sick:

One coin = 50% ; Risk = 50%*$1.00 = $0.50

4 coins , probability that at least one will come up heads is 15/16; Risk = (15/16)*$1.00 = $0.94

Now lets examine these games in terms of the original concepts:

Exposure – You must play the game.

Chance – The more times you play (or more coins you toss at once) the greater chance of loss. In chemical and pathogen exposure, the "Dose" impacts the chance as well as the degree of the consequence.

Consequence – The loss itself, either the fine, jail time, doctor bill etc.

Risk Management

- Techniques employed to make the loss bearable (insurance, changing the rules, etc.)
- Techniques employed to make the chance (dose) smaller (pollution treatment, discharge limits, change in business behavior, etc.)
- Techniques employed to reduce exposure (limited access, cyclone fencing, armed guards, vector control, substitute materials, etc.

Chemicals in the environment

Hazardous chemicals

-- Properties that cause a consequence

Ingitability

Corrosivity

Reactivity

Toxicity

-- Effects (the consequence)

Acute – immediate

Chronic – long term; delayed

Transport from source to receptor

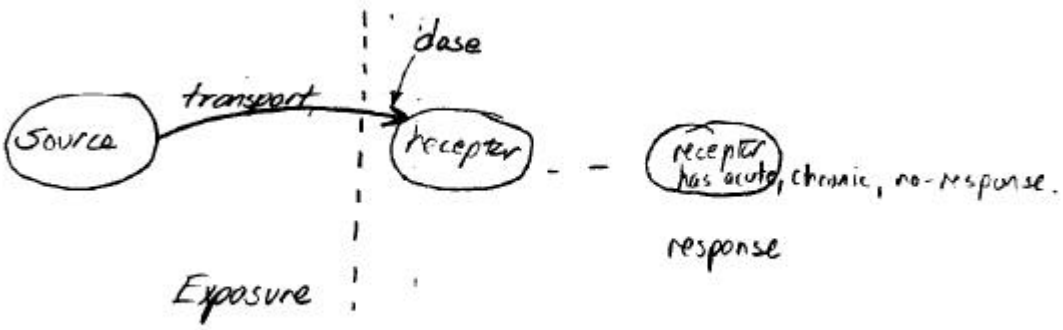


Figure 1. Source to Receptor Transport

Sources of materials

-- biological cycles

-- domestic wastes

-- industrial wastes

-- nonpoint sources

What is the risk associated with the assimilation of a particular compound ant a certain concentration over a short (acute) and long (chronic) exposure?

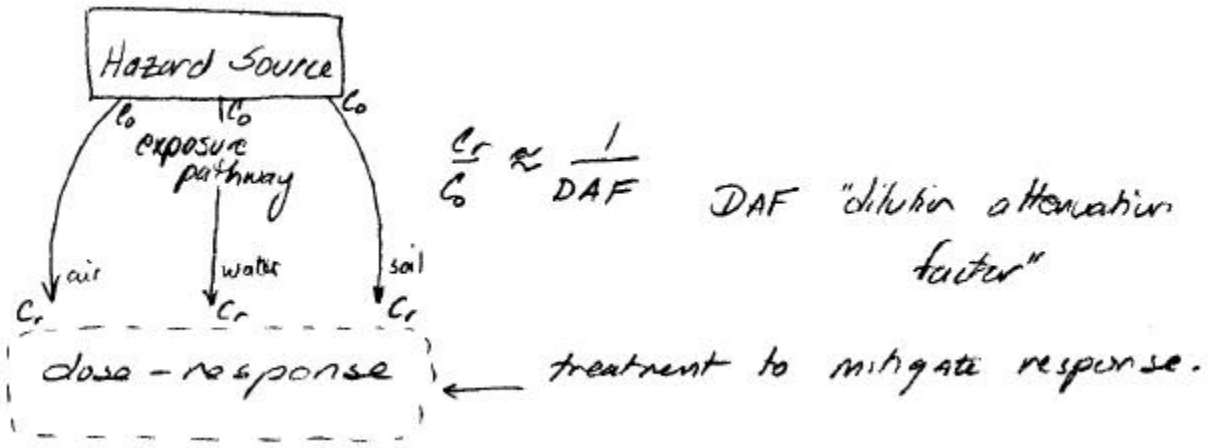


Figure 2. Source - Dose Relationship

Ratio of receptor to source concentration is called the DAF – dilution attenuation factor.

Exposure Concentration

--source

--production rates

-- release rates

--transformation during transport

--Estimate population at risk

--occupation

--medical surveillance

--socioeconimic use habits

Dose-Response

For a response the material must cause a consequence and the receptor must be exposed.

Very toxic, no exposure – no hazard

Slightly toxic, high exposure – could be a significant hazard

Environmental toxicology assumes:

Toxicity is proportional to concentration

Longer contact time, greater probability of toxic effects

Amount of toxicant absorbed is decreases by metabolic activity if exposure is terminated.

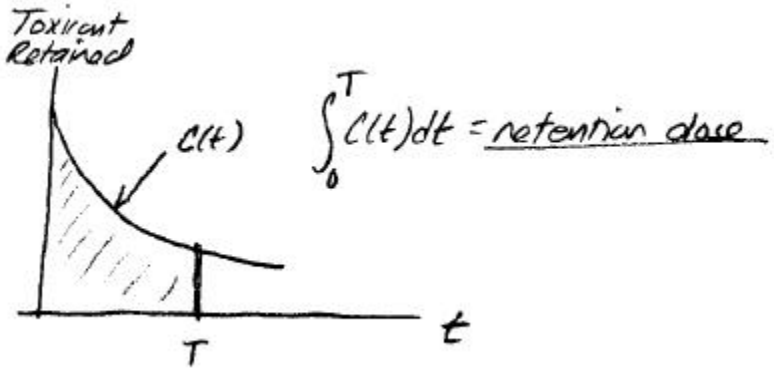


Figure 3. Retention Dose

Retention Dose

Lifetime (70 years) is called the dose commitment.

Typical formula is R = C U D

C = concentration

U = uptake rate

D = retention dose factor

Threshold

In drug therapy threshold doses (mg/Kg) where response changes. Usually two thresholds. Lower threshold beneath which there is no theraputic effect of the medication. Upper threshold, where the theraputic effect is replaced by systemic damage to the patient. Toxicants are also thought to have thresholds. Current practice (1998) is to use 1% of animal model threshold dose as an acceptable human exposure.

Latency (lag) – period between exposure and response. It is thought to increase as dose decreases.

Typical formula: $t = (K/D)^n$

Typical Risk Assessment Approach

1. Hazard identification
2. Exposure assessment
3. Dose-response assessment
4. Risk characterization -- determine the probability that the target population exposed to the hazard by a particular pathway will experience a specific response to a specific dose.
5. Risk management – If the probability above is too large, implement methods to reduce the probability. That is make the loss more bearable (better medicines); make the dose smaller (better waste treatment); make the exposure smaller (substitute materials).

Dose-Response

Dose-response depends on the compound and route of entry into the body. Also depends on the target organs. Many organs can withstand/repair for the dose is small.

Acute toxicity:

Lethal dose – amount of compound required to kill the organism. Usually expressed as an LD_{50}; the amount required to kill ½ of the target population in a bioassay. Shape of the LD_{50} data curve matters.

LD_{50} by experiment is not performed on humans (at least not intentionally).

Mutagenic materials

Causes a mutation in cell DNA, may lead to cancer (carcinogen) or offspring birth defect (tetragen).

Testing

Acute toxicity is determined using animal models.

Mutagenic testing is determined using bacteria models.

Chronic carcinogenic assay is done using bith animal and bacteria models.

Human studies
Usually by epidemology.

Occasionally as a result of drug testing/distribution

Examples: consider two valuable but dangerous medications:

Celebrex – for osteoarthritis treatment. Works well in 12-wwek clinical studies. But marketed as long-term OA therapy (to be taken for years). Post-clinical trials have demonstrated that sudden intestinal bleeding can occur. Obviously, the longer the exposure the greater the chance of this adverse outcome.

Prevacid – for heartburn (really severe heartburn). USFDA recommends use for only 120 days. It is liver metabolized, and over a long time can damage the liver. Yet many patients are given the medication as if it were just a better form of TUMS. Again the adverse effects were discovered after the clinical trials.

Point is even useful materials can be hazardous, and the short term studies do not always identify the consequences. Don't ignore your MD's advice, just be cautious and read the packaging when you take medicine!

Simple epidemologic screening tools

Matrix rate comparison

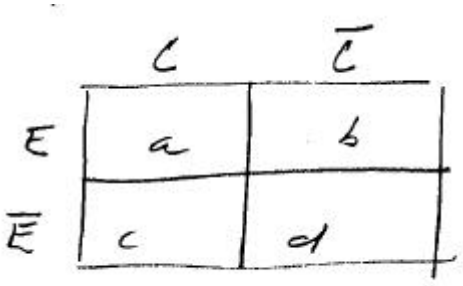


Figure 4. Matrix Comparison

1. Divide population into exposed and not exposed groups
2. Divide groups into consequence and no consequence
3. Calculate “relative risk”, “attributable risk”, and “odds ratio”

Relative risk

$$\text{RR}=\frac{a}{a+b}\bullet\frac{c+d}{c}$$

Is the probability of consequence higher in the exposed group? If RR>1 then exposure MAY be a causal agent.

Attributable Risk

$$\text{AR} = \frac{a}{a+b}-\frac{c}{c+d}$$

If AR>0 then exposure MAY be a causal agent.

Odds ratio

$$\text{OR}=\frac{ad}{bc}$$

Once this type of screening identifies a relationship, then much more rigorous statistical hypotheses testing is indicated.

Currently the US EPA uses “weight-of-evidence” approach. It is intentionally conservative.

Dose-response extrapolation – controversial, various methods

Lowest-observed-effect level (LOEL)

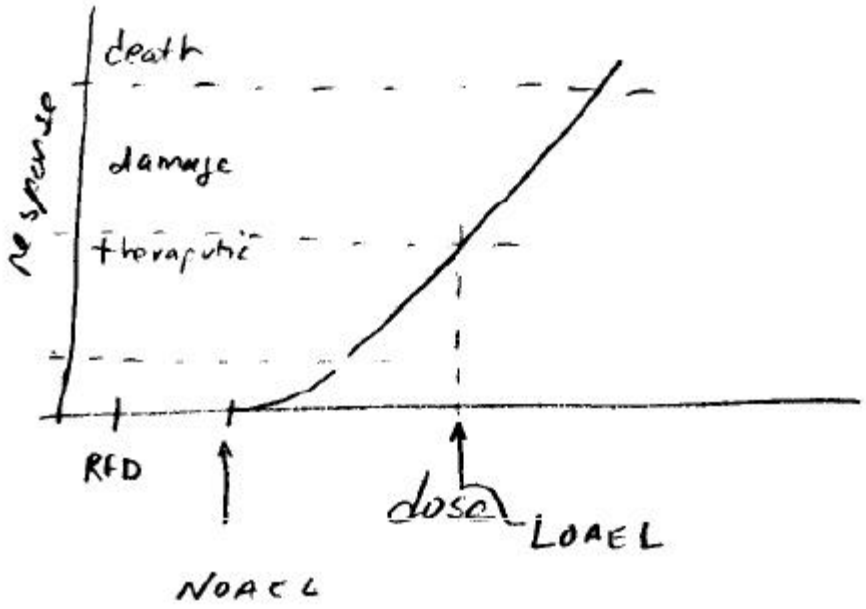


Figure 5. LOEL Concept

Various methods – TNRCC website, RBCA document

Comparative risk – likelihood equivalent

For risk you need three things:

Exposure

Chance (Dose)

Consequence (Response)

Break any one of these “legs” and the risk “stool” falls down – that is you have reduced actual risk.

Ecological risk assessment –

Extension of above concepts. Read material from SETAC (www.setac.org) Attached.

Society of Environmental Toxicology and Chemistry

Technical Issue Paper

Purpose: SETAC is a professional society with worldwide membership from academia, government, business, and nongovernmental organizations. TIPs provide a credible and balanced scientific discussion of important environmental issues.

Ecological Risk Assessment

In recent years, ecological risk assessment (ERA) has emerged as an important part of environmental protection programs. The following discussion provides a brief overview of ERA issues.

What is ecological risk assessment?

> *Ecological risk assessment is the practice of determining the nature and likelihood of effects of our actions on animals, plants, and the environment.*

Ecological risk assessments deal with human-caused changes that alter important features of ecological systems such as lakes, streams, forests, or watersheds. When we introduce a new chemical (such as a pesticide to a wheat field), accidentally import a new species (such as a foreign insect), or change a landscape (such as draining or filling a wetland), scientists often assess how much damage those actions may have on the plants or animals in the area. Ecological risks may be local—a hazardous waste site. The risks may be regional—the Chesapeake Bay, the Black Forest, or the Great Barrier Reef. The risks may be global—atmospheric transport of chemicals or global warming. Ecological risks may involve a specific type of plant or animal (a bass), a community of organisms (the fish in a lake), or an ecosystem (all of the biological and physical components of the lake).

What is ERA used for?

> *Industry, government agencies, policy makers, citizens, and legislators use ERA to support environmental management decisions.*

Ecological risk assessment helps organize information and contributes to informed decisions. It is a useful risk management tool that

- highlights the greatest risks, which is helpful for allocating limited resources;
- allows decision makers to ask "what if" questions regarding the consequences of various

potential management actions;
- facilitates explicit identification of environmental values of concern; and
- identifies critical knowledge gaps, thereby helping to prioritize future research.

Ecological risk assessment can be used to evaluate relative benefits of different clean-up options at hazardous waste sites, screen new chemicals prior to their commercial production, evaluate the risks that imported agricultural products may introduce exotic agricultural pests, or determine the threats to valued ecological resources in a watershed.

What are ERA's basic concepts?

Ecological risks are 1) estimated from the relationship between exposure and effects, and 2) made with varying degrees of uncertainty.

Ecological risk assessments evaluate two basic elements:

1. **Exposure** is the interaction of stressors with receptors. Measures of exposure can include concentrations of contaminants or physical changes in habitat.
2. The analysis of **effects** evaluates changes in the nature and magnitude of effects as exposure change.

Integrating exposure and effects information leads to an estimation of **risk**, the likelihood that adverse effects will result from exposure.
Approaches for evaluating exposure and effects include, for example, measuring chemical releases, predicting with models the environmental fate and effects of chemicals even before they are manufactured, and testing effects of these chemicals in a laboratory. Exposure and effects must be considered together because they are both important in estimating risk. When the potential for exposure and effects are low, the risk will be low. When both are high, the risk will be high. Whatever the approach, the goal is to use all available information to characterize exposure and effects and to integrate them into an understanding of ecological risks.

Because of the complexity of nature, risk assessment will include some degree of uncertainty. Although we can reduce some components of uncertainty by gathering additional data, we can only estimate other components due to their inherent variability (such as rainfall and temperature variations). While it is important for risk managers to understand the impact of natural variability and uncertainty on the conclusions of the risk assessment, making a risk management decision does not require the absence of uncertainty. In fact, an attempt is made to quantify and communicate uncertainty when conducting and reporting ERAs so that the best decisions can be made with our current state of knowledge.

How is ERA done?

Ecological risk assessments include

1.) Problem formulation: clearly defining the problem

2. *) Analysis: characterizing potential or existing exposure to stressors and their effects*
3. *) Risk characterization: integrating and evaluating exposure and effects information*

Planning the assessment with the risk manager and communicating the risks to decision-makers are important parts of the process.

The diagram below, from the USEPA's Proposed Guidelines for Ecological Risk Assessment, illustrates one of ERA's strengths: a generally accepted standard framework.

How does ERA relate to decision-making?

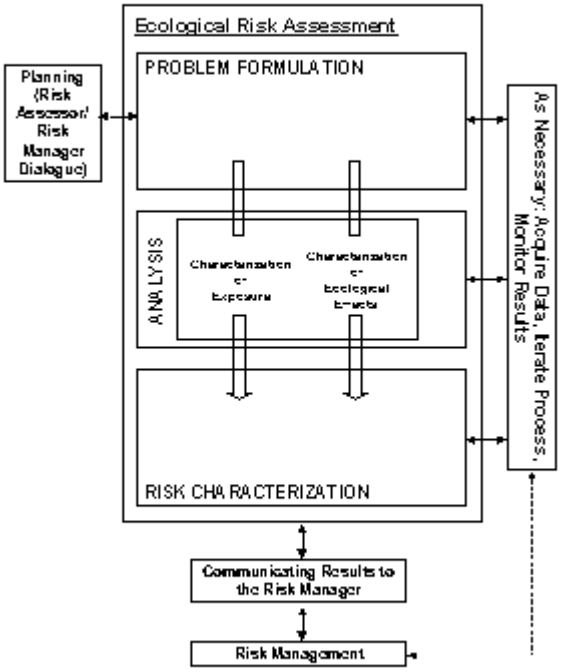
> *Ecological risk assessment is one input to environmental management decisions. Other inputs include stakeholder concerns, availability of technical solutions, benefits, equity, costs, legal mandates, and political issues.*

For example, a course of action that has the least ecological risk may be too expensive or not technologically feasible. Thus, while an ERA provides critical information to risk managers, it is only one part of the whole environmental decision-making process.

What are ERAs designed to protect?

> *Ecological risk assessments may address any of a variety of environmental properties ranging from the survival of individual members of an endangered species to the productivity of the community in a stream or the biological diversity of an entire region.*

Although the risk assessment process is scientifically based, deciding what environmental properties we are concerned about requires input from stakeholders and includes considerations of ecological values as well as ecosystem-based science. In an initial planning process (problem formulation), risk managers and stakeholders may identify ecological concerns that have significant economic, social, or recreational value. The endpoints for the ERA should reflect these concerns while being ecologically relevant to the ecosystem they represent and being susceptible to the stressors of concern.



From U.S. EPA, 1996. Proposed Guidelines for Ecological Risk Assessment.

Won't protection of humans also result in protection of the environment?

> *Ecological receptors can receive more exposure to contaminants in the environment and can be more sensitive than humans.*

Protecting against risks to human health will not necessarily protect the environment. People do not interact with their environment in identical ways to those of other organisms, so separate human health and ecological assessments generally are necessary. As an example, consider a hazardous chemical found in a wetland. A fence surrounding the wetland may be perfectly adequate to prevent human access. However, birds, fish, and mammals using the wetland as a habitat and food resource receive much more exposure and may suffer toxic effects as a result. Finally, organisms differ in their susceptibilities to chemicals and other stressors, and protection of a single species does not ensure protection of other species.

How are ERA predictions useful?

> *Although there are various sources of uncertainty in ERA, we can predict many effects with confidence. Even when uncertainties are high, risk assessments with proper scientific review and consensus provide the best summary of the state of*

knowledge.

Ecological risk assessment results are most useful when risk managers clearly communicate the risks and decisions to the public. An ERA should

- summarize results so that the public can understand them,
- distinguish scientific conclusions from policy judgments,
- describe major differences of opinion on scientific issues or alternative conclusions that readers can draw from the data, and
- explain major assumptions and uncertainties.

How complex are ERAs?

Ecological risk assessments may involve the effects of multiple stressors on ecosystems containing numerous species that are interlinked and dependent on a range of processes.

Because of the complexity and variability of nature, the initial scoping phase of an ERA (problem formulation) is critical to providing a focus for the assessment. However, ERAs need not be complex or lengthy, they only need to define the risks with the degree of certainty required to support a risk management decision.

What is the future of ERA?

Anticipated improvements in ERA will include development of standard tools and approaches and more effective links to risk management. Increasingly, ERA will address issues concerning its application in the management of land and natural resources.

Some challenges facing ERA include the following:

- Integrating the concerns of stakeholders and risk managers with the scientific knowledge of risk assessors,
- Conducting risk assessments that encompass large areas and involve multiple stressors,
- Moving beyond effects on individual organisms and species to predicting changes in populations and ecosystems, and
- Communicating ecological risks to stakeholders.

While improving the science behind ERA will always be desirable, ERA is now and will continue to be a valuable tool supporting scientifically sound environmental decision-making.

Where is there more information about ERA?

While there are many excellent sources for ERA information, the following resources will help in further understanding the issue.

- U.S. Environmental Protection Agency. 1996. Proposed Guidelines for Ecological Risk

Assessment. Federal Register 61:47552-47631. This document can also be found at: http://www.epa.gov/ ORD/WebPubs/ecorisk.
- U.S. Environmental Protection Agency. 1992. Framework for Ecological Risk Assessment. EPA/630/R-92/001. Risk Assessment Forum, Washington, DC.
- Suter II GW. 1993. Ecological Risk Assessment. Boca Raton FL: Lewis. 550 p.

Society of Environmental Toxicology and Chemistry: E-mail setac@setac.org or Telephone 850 469 1500.

Ecological risk assessment terms

Endpoint: A characteristic of the environment that is evaluated or measured in an assessment.

Receptor: A plant, animal, community of organisms, or ecosystem that is exposed to stressors in the environment.

Risk Assessor: An individual or team with the appropriate training and range of expertise necessary to conduct a risk assessment.

Risk Management: The process of determining appropriate actions in response to an identified risk.

Risk Manager: An individual, team, or organization with responsibility for or authority to take action in response to an identified risk.

Stakeholder: Any individual, team or organization interested in or affected by the outcome of a risk assessment.

Stressor: Any physical, chemical, or biological entity that can induce an adverse response.

Uncertainty: A lack of confidence in the prediction of a risk assessment that may result from natural variability in natural processes, imperfect or in complete knowledge, or errors in conducting an assessment.

About this document

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