ECOLOGICAL RISK ASSESSMENT

Ecological risk assessment (ERA) is a very effective tool for determining the potential ecological harm a proposed project or activity, such as our hypothetical KL pulp and paper mill expansion, may have on a receiving environment. Risk assessments are often conducted as part of an overall environmental impact assessment (EIA).

ERA is the process that estimates the likelihood and size of adverse ecological effects due to exposure to environmental stressors. ERA represents an important tool for environmental decision making as it can help identify environmental problems, establish priorities, and provide a scientific basis for action. ERA can be used in a variety of situations, including:

- Evaluating ecological risks posed by existing environmental conditions
- Predicting ecological risks posed by a planned development
- Comparing risks posed by alternative development actions
- Evaluating effectiveness of alternative remediation options
- Ranking risks posed bydifferent stressors in order to prioritize mitigation actions
- Developing site-specific criteria for remediation.

Major terminology involved in ERA are summarized in Table 1. The four components of ERA are detailed in the following sections.

PROBLEM FORMULATION

Problem formulation is the first and probably most important component of an ERA, as it defines the scope and focus for how the assessment will be conducted. In this respect, problem formulation provides the foundation for the entire ERA process.

A well-conducted problem formulation benefits the overall risk assessment because it:

- Provides an opportunity for communication between risk assessors and environmental managers and ensures the risk assessment supports management decisions
- Focuses the risk assessment on relevant contaminants, exposure pathways and receptors
- Allows for public involvement
- Provides clear decision criteria for various management options
- Reduces the overall cost of an environmental assessment.

A number of steps must be followed in order to complete the problem formulation, including an integration of available information, site characterization, identification of stressors and receptors, receptor characterization, and preparation of a conceptual model. Throughout the completion of the problem formulation it is important to maintain effective communication between the risk assessor and environmental managers to ensure that the risk assessment supports the decision-making process. Before implementing the ERA, the

Table 1 Terminology of risk assessment

ASSESSMENT ENDPOINTS	Ecological components which require protection. Assessment endpoints are statements or goals concerning an ecological characteristic (such as reproductive effects on aquatic organisms) that is to be evaluated or protected within the ecosystem. For example, in the Mekong River the assessment endpoint could be protection of a particular fishery.
CONCEPTUAL MODEL	A series of hypotheses of how the stressor might affect the ecological components – often presented as visual representations that use flow diagrams with boxes and arrows to illustrate relationships. The conceptual model describes the ecosystem potentially at risk, the relationship between the assessment and measurement endpoints, and potential exposure pathways.
CO-OCCURRENCE	A stressor that indirectly effects the ecological component. For example, some bird species rest on sandbars in rivers during migration and prefer to have a clear view of their surrounding environment. If a bridge is constructed that obstructs the view, they avoid these areas. Thus, a bridge near a stretch of river where bird species normally rest would keep them away, and act as a stressor even though it does not contact the animals themselves.
EXPOSURE	Co-occurrence or contact between a stressor and a receptor. Exposure is related to the size and type of stressor and the presence of the receptor.
MEASUREMENT ENDPOINTS	A measurable ecological characteristic that is related to the valued ecological component (assessment endpoint). For example, if protection of the carp fishery is the assessment endpoint, the measurement endpoint may be the survival or reproduction of local carp populations.
RECEPTOR	An ecological component (e.g., individual, population, community, or ecosystem) that might be adversely affected by exposure to a stressor.
RISK	Probability of an undesirable effect on ecological components.
STRESSOR	Any physical, chemical or biological entity that can an adversely effect an ecological component (e.g., individuals, populations, communities, or ecosystems).

environmental manager and risk assessor must agree on the overall goals, scope and timing of the risk assessment.

Integration of Available Information

The foundation for problem formulation is based on how well available information on stressor sources (e.g., such as our hypothetical KL pulp and paper mill), characteristics, and exposure opportunities characterizes the ecosystem potentially at risk. An initial evaluation of existing information often provides the basis for generating a preliminary conceptual model or identifying assessment endpoints. In this case, the more we know about the type and quantity of effluent discharged and the biology of the aquatic biota exposed to the effluent, the better we will be at determining potential exposure pathways and relationships. If there is little existing information, environmental managers might insist on extensive baseline monitoring prior to initiation of the risk assessment.

Site Characterization

This is an important component of the problem formulation and provides the risk assessor with an opportunity to learn more about the site. This component can include a number of different studies that may assist in defining the scope of the ERA. For example, an assessment of previous site use can be used to determine historical contamination. Additionally, characterization of the surrounding land usage can be used to determine whether other sites are contributing any additional stressors to the ecosystem.

Identification of Stressors

Identifying stressors is the next component of the problem formulation. Stressors are any physical (e.g., extremes in natural conditions or habitat loss), chemical (e.g., inorganic or organic substances), or biological entity that can cause an adverse effect on an ecological component. Most ERAs are concerned with chemical stressors, and for the remainder of this lesson, we will consider stressors to be of a chemical nature. Identifying stressors and documenting their environmental characteristics helps to choose the ecosystem component that might be at risk, the ecological effects that might result, and the medium of concern (e.g., air, soil, surface or groundwater, animal tissue).

Identification and Characterization of Receptors

After the stressors have been identified, the expected receptors are characterized. A receptor is an ecological component (e.g., individuals, populations, communities, or ecosystems) that may be affected by a stressor. Receptors are typically native populations of plants and animals. Receptors should be chosen based on:

- Spatial and temporal overlap with stressors of concern
- Potential sensitivity to stressors
- Status as endangered or threatened species
- Migratory birds or fish where populations are concentrated
- Ecological importance
- Aesthetic or cultural value to local communities
- Recreational or commercial importance
- Valuable or sensitive habitats.

Once the receptors are chosen, it is possible to select the assessment and measurement endpoints. The assessment endpoint is a specific ecological component or receptor that requires protection. For example, the assessment endpoint could be the viability of a commercially-important fish species in the Mekong River. Assessment endpoints may be identified at any level of organization (species, population, community, ecosystem). However, unless an ecological receptor is listed as a protected or endangered species, assessment endpoints are generally selected that are relevant to the population-level or higher. In many cases, community-level responses are of greatest concern. For example, changes in the benthic community structure serve as potential indicators of potential contaminant effects on the aquatic ecosystem as a whole.

Measurement endpoints are the critical link between the existing on-site conditions and the management goals established by the assessment endpoints. Measurement endpoints enable the quantitative measurement of assessment endpoints. They are used to determine the biological responses to a stressor and can be related back to the valued environmental component or characteristic identified in the assessment endpoint. Measurement endpoints can be directly investigated in field or laboratory studies and can include measures of effect (e.g., mortality, reproductive abnormalities) or exposure (e.g., concentration of contaminants in tissue). Using the commercially-important fish species as an example, one measurement endpoint may be the reproductive success of this species.

Conceptual Model

The conceptual model generally is a written description and visual representation of predicted relationships between ecological components and the stressors to which they may be exposed. A schematic diagram can be prepared to develop hypotheses about how a stressor might affect a receptor. The model includes descriptions of the ecosystem potentially at risk and the relationship between assessment and measurement endpoints.

EXPOSURE ASSESSMENT

Exposure assessment is the second step of an ERA and is a critical component – without exposure there is no risk, as illustrated in Figure 1. Exposure is the co-occurrence or contact between a stressor and a receptor. Exposure assessment describes the characteristics of the stressors and examines factors such as the source, size, frequency, duration and route of exposure. Key elements of exposure assessment include:

- Contaminant source and release – consider the source characteristics. For example, is contaminant release continuous, intermittent or no longer occurring?
- Contaminant transport and fate – consider the transport mechanisms for contaminants, fate processes (e.g., what happens to the contaminant once it is introduced to the environment – transformation, volatilization, adsorption, and dissolution).

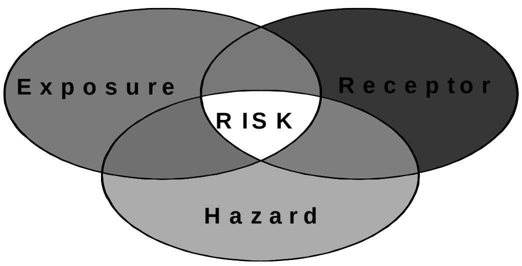

Figure 1 Conditions for ecological risk

- Exposure pathways – identify the possible exposure routes for each stressor and receptor. Four elements must be present for an exposure pathway to be complete: (i.e., source or release of the stressor, transport to a point of contact, contact, and absorption by the receptor).
- Amount of exposure – quantify exposure to receptors. This is usually expressed as a dose (e.g., mg /kg/day) for receptors such as mammals and birds and as a concentration (e.g., mg/kg for sediments and mg/L for water) for aquatic receptors such as fish and benthic invertebrates.

The end product of the exposure assessment is an estimation of the environmental concentration or distribution of concentrations of each contaminant in the medium to each receptor of concern exposed.

EFFECTS ASSESSMENT

Effects assessment is the third step of an ERA. This step describes the relationship between a stressor and a receptor and is used to link a contaminant to a biological response. Essentially, characterizing effects involves describing the effects elicited by the stressor, linking effects to the assessment endpoint and evaluating how effects change with varying stressor levels. This link is usually made through literature searches for toxicity data or by conducting site-specific toxicity testing experiments, but other approaches are also possible.

The end product of the effects assessment is the highest exposure concentration or the distribution of highest exposure concentrations for each contaminant that does not result in unacceptable ecological effects to each receptor.

RISK CHARACTERIZATION

Risk characterization is the final phase of the ERA and allows risk assessors to clarify the relationships between stressors, effects and ecological entities. Conclusions can be reached regarding the occurrence of exposure and the adversity of anticipated effects. Risk characterization combines the results of the exposure assessment and the effects assessment to evaluate the likelihood that adverse effects will occur as a result of exposure to the stressor and the magnitude of effects. Risk characterization involves three steps:

1. Calculation of risk estimate
2. Uncertainty analysis
3. Interpretation of the ecological significance.

Risk Estimate

Risk estimate can be calculated using a number of approaches and techniques. One technique is the quotient method, which is frequently used for single contaminants and exposure pathways with an individual receptor. This method can be used to identify the presence of a potential risk, but not its magnitude or probability. The quotient method involves dividing the expected environmental concentration (EEC), or exposure concentration, of the chemical by a benchmark effects concentration (BC) to obtain a value. The resulting value is known as a hazard quotient (HQ) or risk quotient and is shown below:

$$HQ = \frac{EEC}{BC}$$

EECs can be measured directly or predicted from environmental fate models. Benchmarks are threshold contaminant concentrations in an environmental medium, such as surface water or fish tissue, that are considered 'safe', below which adverse effects are not expected. Site-specific benchmarks may be determined in the effects assessment, or generic environmental protection benchmarks may be established by government agencies and applied to all projects or activities with similar adverse impacts. Acceptable effect levels should be selected in consultation with environmental managers during the problem formulation. In general, if the HQ is less than one, the site can be categorized as 'low risk' and there is no need to proceed further. If the HQ is greater than one, this indicates the presence of risk, and further analysis should be conducted.

Uncertainty Analysis

Analysis of uncertainty is a second key element of risk characterization. Uncertainty analysis identifies and quantifies uncertainty in problem formulation, exposure and effects assessment, and risk characterization and provides the environmental manager with an insight into the strengths and weaknesses of the ERA. Significant knowledge gaps can result in acceptable benchmark criteria being set so low that ecological components are not protected. Conversely, in the absence of adequate data, benchmarks can be set so conservatively high that the effluent treatment required is prohibitively expensive. The output of the uncertainty analysis is an evaluation of the impact of the uncertainties on the ERA and a description of the ways in which uncertainty could be reduced. Major sources of uncertainty are summarized in Table 2.

Ecological Significance

Interpreting the ecological significance of risk estimates relies heavily on professional judgement and provides an important link between the estimation of risks and the communication of assessment results. It should consider the nature and magnitude of the effects, the spatial and temporal patterns of the effects, and the potential for recovery once a stressor is removed. Interpretation of ecological significance should include a discussion of the following questions:

- Which species are most likely to be at risk?
- What part of a year is risk likely to occur?
- Is the risk even over the entire area or are there 'hot spots' of high risk?
- How do the pollutants move from the release site to the receptors (e.g., surface water run-off, groundwater movement, foodchain uptake from soil)?
- What is known about the ecology, biology, or behaviour of a species that appears to be at risk that may affect (i.e., mitigate or increase) this risk?
- Are some of the life stages of the organism at more risk than others?
- Should some of the species be of more concern because they create habitat or are a food source for a critical species of concern?

Table 2 Major sources of uncertainty

AREAS OF UNCERTAINTY	ELEMENT OF UNCERTAINTY
CONCEPTUAL MODEL FORMULATION	Product of problem formulation. Incorrect assumptions most difficult to identify, quantify and reduce.
INFORMATION AND DATA	Use of incomplete data or information. Reliance on professional judgement and assumptions.
STOCHASTICITY (NATURAL VARIABILITY)	Basic characteristics of stressors and receptors. Can be acknowledged and described, but not reduced. Subject to quantitative analysis.
ERROR	Introduced by experimental design, measurement, sampling procedures, or during simulation model development. Reduced by good laboratory practices, established protocols, sensitivity analysis, model calibration and comparison, and field validation.

- What knowledge and data gaps are barriers for making an adequate risk estimation?

RISK MANAGEMENT

When the ERA is complete, environmental managers and government agency decision makers need to make decisions about ecological risks. Decisions must be made on the ecological components at risk, their value, and the costs (i.e., both monetary and other benefits) of protecting or failing to protect the resources. When making their conclusions, environmental managers need to consider not only the risk assessment results, but also social, economic, and political issues. To facilitate decision making the following information should be provided:

- Goal of the ERA.
- Connection between the measurement and assessment endpoints.
- Magnitude and extent of the effect, which is a common key area of conflict in resource management and environmental management. Valuable ecological information is provided in a form that can be used by including spatial and temporal considerations and, if possible, recovery potential.
- Assumptions used and the uncertainties encountered during the risk assessment.
- Summary profile of the degrees of risk as well as a weight-of-evidence analysis.
- Potential incremental or additive risk from stressors other than those already under consideration (if possible).

Applied correctly, ERA can be a powerful tool for use in integrated environmental management and EIA. It provides a standardized approach and framework for analyzing ecological concerns. It also addresses uncertainty. Outputs from an ERA are valuable for decision makers as they make the difficult choice of how much of a resource's health to give up in exchange for anticipated social and economic benefits in assessing a proposed project or activity.