U.S. Environmental Protection Agency

Watershed Academy Web

Distance Learning Modules on Watershed Management

http://www.epa.gov/watertrain

Watershed Ecological Risk Assessment

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Introduction

Ecological risk assessment is a process to collect, organize, analyze and present scientific information to improve decision making. When applied in a watershed context, risk assessment methods can help bring scientific data into environmental decisions.

This module introduces watershed ecological risk assessment and cites examples of its use. By following the principles described in two EPA guidance documents (USEPA 1992, USEPA 1998) and experiences from several watershed assessments, the module provides information on how to develop a risk assessment and present results to decision makers and stakeholders. The module also links to other websites that provide the details about several watershed risk case studies. The content of this module is appropriate for scientific/technical audiences. Although some watershed organizations may not have the scientific resources to conduct detailed watershed risk assessments, they may still benefit from using parts of the risk assessment processes described in this module.

The aims of this module are:

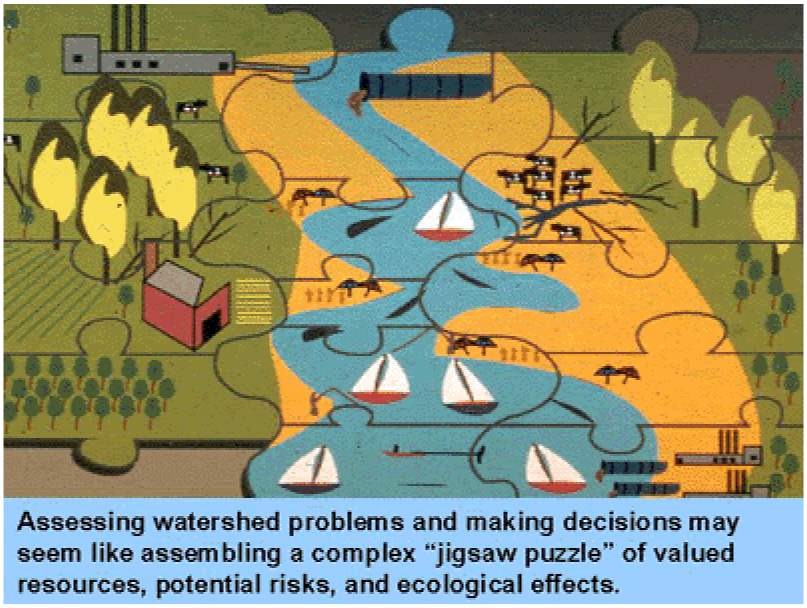
- to introduce a sound science-based assessment method to people working in watersheds;
- to point out how using the methodology makes environmental assessment data more useful to managers;
- to provide links to real watershed risk case studies for further study.

Throughout the module, **underlined terms in bold** are in the glossary on page 30.

The Challenge: Watershed Assessment

The watershed, a hydrologically-bounded ecosystem, is a logical unit for environmental management. A watershed management approach helps environmental managers focus on the highest priority problems affecting ground water and surface waters as well as issues of ecosystem health and community well-being. Watershed approaches are organized around the guiding principles of partnerships, geographic focus, and well-organized management, ideally based on sound science and data.

Incorporating science consistently in watershed management decisions, however, is challenging. Tradeoffs among environmental, political, economic and social factors based on subjective value judgements may occur as part of the decision process (Figure 1). It is often difficult to reconcile the desire to take scientifically supportable actions with the complexity of how local watershed decisions are often reached. As a result, scientific information is often underutilized when it is not clear how to incorporate it with other considerations.



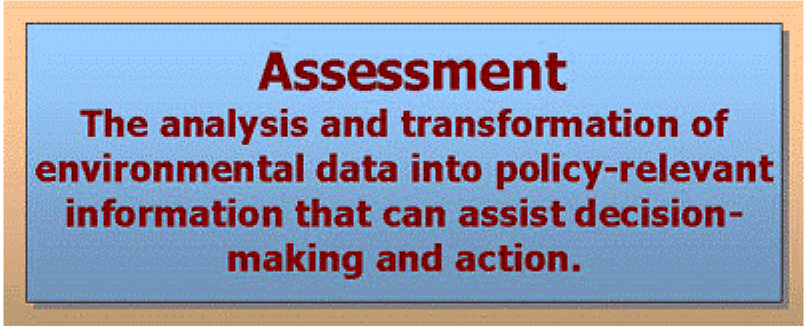
Assessing watershed problems and making decisions may seem like assembling a complex “jigsaw puzzle” of valued resources, potential risks, and ecological effects.

Figure 1

The science underlying watershed assessment is also complex and difficult, which further complicates science-based decision making in watersheds. Multiple, interrelated sources of watershed problems result in numerous adverse effects. Information gaps are common.

Assessment (Figure 2) is one of the most critically important parts of watershed management because it attempts to transform scientific data into policy-relevant information that can support decision-making and action. Many other definitions and methods of environmental assessment are in use, but none has been widely adopted for incorporating science into watershed management. Ecological risk assessment may be particularly useful in watersheds as a scientific method that includes steps for integration with planning, priority-setting, and decision-making.

More definitions of assessment are included in Table 1.



Assessment

The analysis and transformation of environmental data into policy-relevant information that can assist decision-making and action.

Figure 2

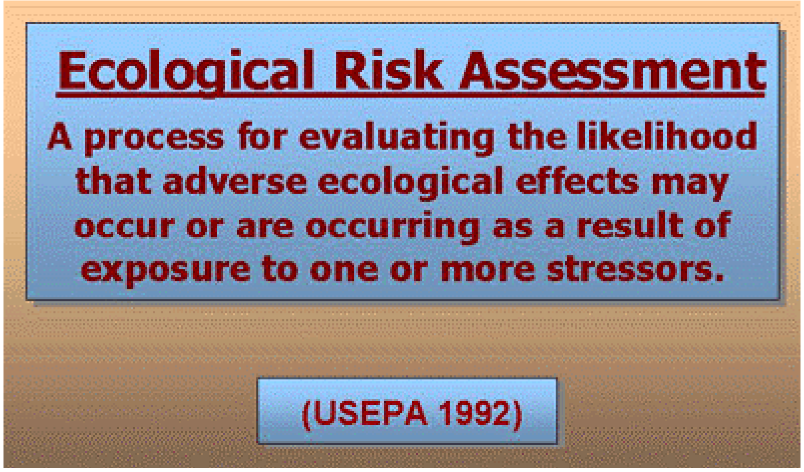
More Definitions of Assessment	
Cowling (1992)	Process by which scientific and technological evidence is marshaled for the purposes of predicting the outcomes of alternative courses of action
EPA Environmental Monitoring and Assessment Program (1994)	Interpretation and evaluation of monitoring results to answer policy-relevant questions about ecological resources
National Environmental Policy Act (1969)	Evaluation of action consequences, short and long-term .... for the purposes of avoiding ... undesirable consequences for the environment.
National Acid Precipitation Assessment Program (1991)	Interdisciplinary activity wherein findings from diverse disciplines are coordinated to produce a better understanding of the cumulative impacts of a stressor (e.g., acidic deposition)
Suter (1993)	Combination of analysis with policy-related activities such as identification of issues and comparison of risks and benefits.

Table 1

Using Ecological Risk Assessment in Watershed Management

Watershed managers need a process for determining which ecological features in the watershed are at risk and choosing the best actions to protect them. Ecological risk assessment (Figure 3) is a process to collect, organize, analyze and present scientific information to optimize its use in decision making. This is accomplished by evaluating the likelihood that **adverse ecological effects** may occur or are occurring as a result of exposure to one or more stressors. The process also brings together scientists and decision-makers so that scientists can better focus on needs of the decision-makers while helping them better understand the ecological implications of their actions. Risk assessment provides a basis for comparing, ranking and prioritizing risks, and estimating ecological effects as a function of exposure to stress in the watershed.

Comments from a review of five pilot watershed risk assessments (Eastern Research Group 1998) indicated that, although watershed risk assessment was a new application of ecorisk methods, the following points appear promising:



Ecological Risk Assessment

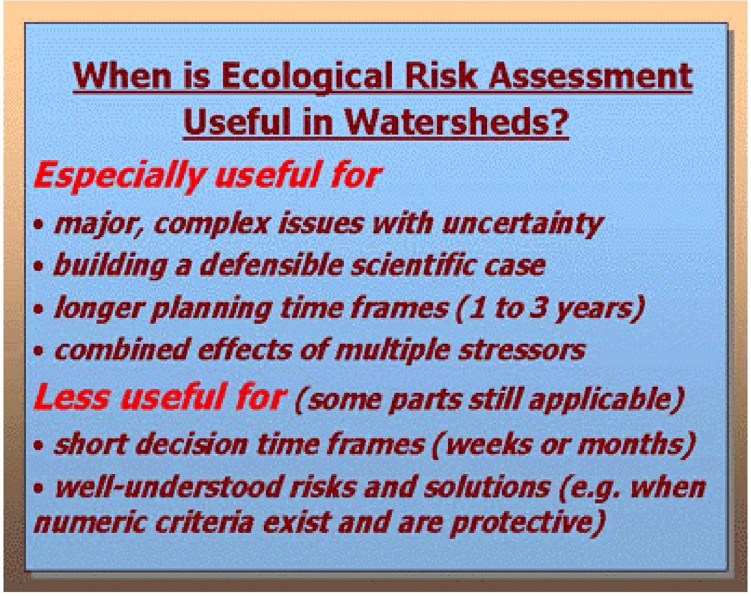
A process for evaluating the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

(USEPA 1992)

Figure 3

- watershed management can benefit from the use of the formal, scientifically defensible methods of risk assessment (Figure 4);
- the ecological risk assessment process helps people to carefully examine what led them to their conclusions and document their findings; and
- the risk assessment framework can add value to watershed-based management programs, particularly when addressing problems caused by multiple and non-chemical stressors.

Ecological risk assessment methods can be particularly useful in evaluating whether uses are threatened when a stressor of concern is not expressed as a numeric criterion in Water Quality Standards. For instance, is a fish population at risk due to increasing sediment load, although Standards may not address this? The methods are also very useful for evaluating the relative importance of multiple potential stressors. This may help determine if it is primarily the sediment load, increased temperature, degraded channel conditions, or a combination of all three that is impairing the fishery.



When is Ecological Risk Assessment Useful in Watersheds?

Especially useful for

- ***major, complex issues with uncertainty***
- ***building a defensible scientific case***
- ***longer planning time frames (1 to 3 years)***
- ***combined effects of multiple stressors***

Less useful for (some parts still applicable)

- ***short decision time frames (weeks or months)***
- ***well-understood risks and solutions (e.g. when numeric criteria exist and are protective)***

Figure 4

A sound scientific approach is not without cost, however, and the methods of risk assessment are not for all situations. Many communities do not have the financial resources, technical expertise or necessary data to conduct a comprehensive watershed risk assessment. Yet, they can still follow risk assessment principles for better insights on what monitoring data to collect, or how to organize or present their data. In complex systems such as watersheds, and when funds and time are limited, completing the risk assessment planning and problem formulation may yield an effective stand-alone product without continuing further.

An Overview of Ecological Risk Assessment

The ecological risk assessment process (Figure 5) consists of three main phases, seen in the accompanying flow chart: **problem formulation**, **risk analysis**, and **risk characterization**. Three additional compartments appear in the flow chart: planning, risk communication/management, and iterative monitoring/data acquisition.

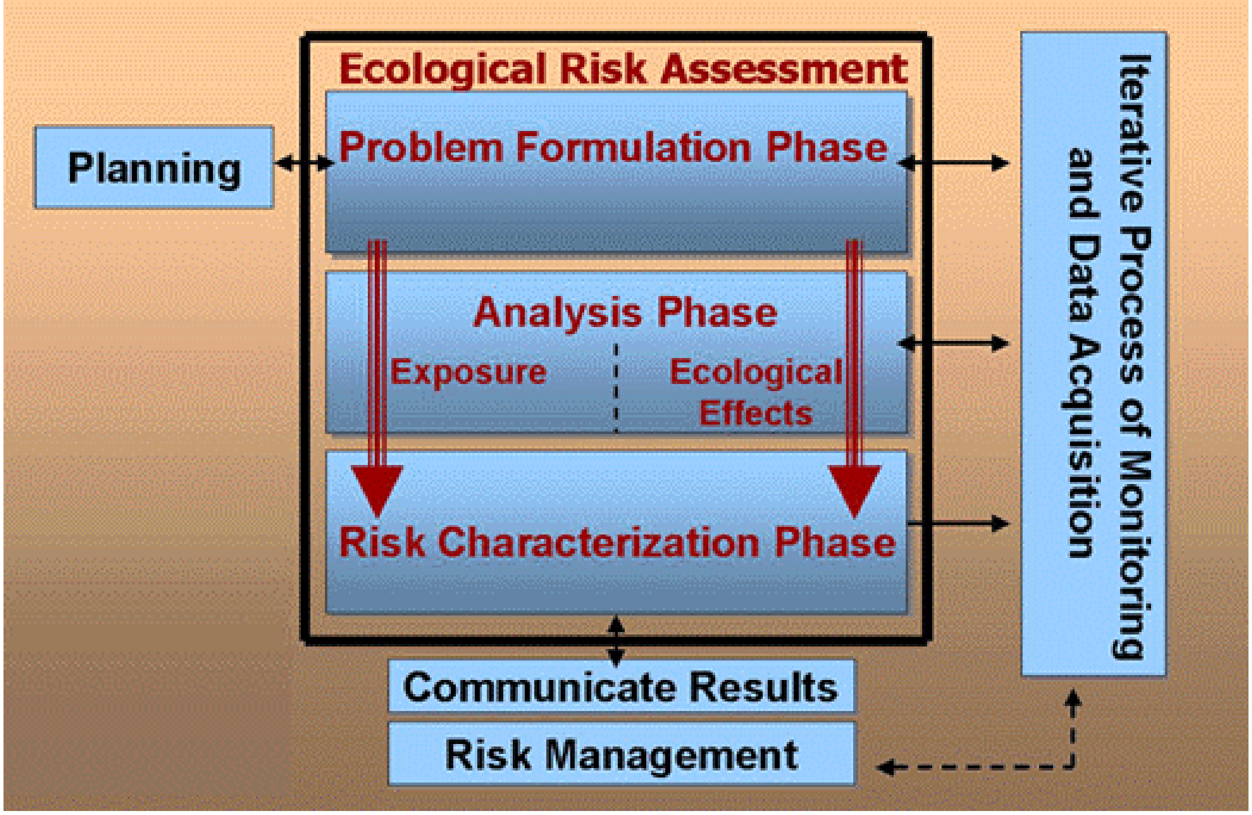


Figure 5

During planning, scientists and managers with input from stakeholders seek agreement on the focus, scope and complexity of an assessment. Then the formal risk assessment process commences with problem formulation during which key questions, conceptual models and an analysis plan are developed. The analysis phase evaluates the exposure of valued ecological resources to stressors and the relationship between stressor levels and ecological effects. During risk characterization, the risks are described and if possible estimated quantitatively, forming the basis for the assessment’s conclusions and a report. Monitoring and new data acquisition may occur in support of any of these phases, wherever needed. After completion, the risk assessment’s findings are communicated to the managers, who determine a course of action.

Planning a Watershed Risk Assessment

Managers, stakeholders and scientists begin their discussion of the focus, scope and complexity of the risk assessment during planning. They may also discuss the assessment's expected output and the technical and financial resources that are available or needed.

Before beginning a watershed ecological risk assessment, the planning process should bring together people from diverse backgrounds and interests to identify the watershed management goals and objectives that drive the assessment.

Figure 6

Scientists, managers and stakeholders all play a role in watershed risk assessment (Figure 6). Although others may be involved, the primary assessors are the scientists, and watershed managers are their primary clients for the assessment results. Managers (here meant to include watershed council leaders, local government staff or officials, water resources program leaders, public lands managers, etc.) need to describe why the risk assessment is needed and what they expect to do with the information they will receive. In turn, scientists need to communicate what they can realistically provide to the managers, where problems are likely and where uncertainty may arise. The quality of communication that occurs during this initial planning process heavily influences the success of the risk assessment.

Local watershed management efforts often involve many stakeholders (*Table 2*), such as federal and state regulatory/trustee agencies, local governments and tribes, the regulated community (industry, land development, etc.), academia, environmental organizations, private corporations, landowners, citizens' groups and others. Planning may involve stakeholders in the dialogue to help ensure that the risk assessment is relevant to social concerns and that all

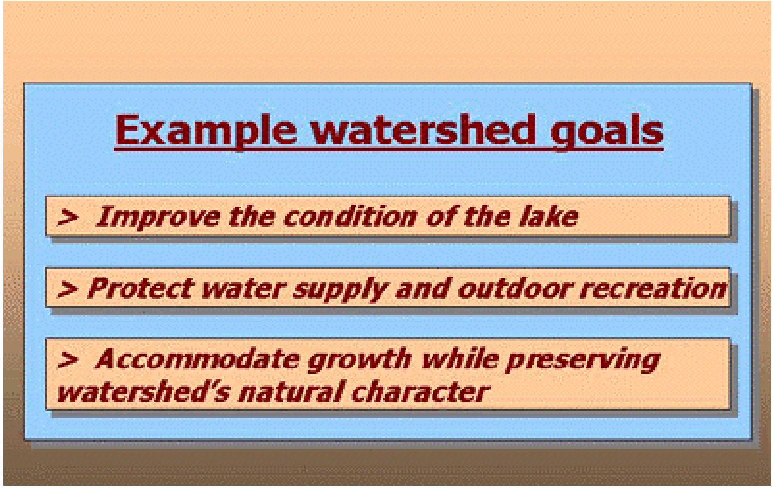
Example Watershed Stakeholders
Landowners
Land management organizations
Town or County officials
Farm organizations
Citizens' groups, civic associations
Grassroots environmental groups
Sport or recreation groups
Water treatment plants or agencies
Local corporations, industries
Financial institutions
Researchers, science organizations
Environmental education centers
Teachers and students
Soil and water districts
Indian tribes
Local, state, federal agencies

Table 2

the ecological resources of concern to stakeholders and others have been identified (*Figure 7*). Watershed risk assessment planning can be especially complex when there are multiple jurisdictional boundaries as well as many differing stakeholder interests. Stakeholder involvement needs to be initiated in the planning step and reestablished periodically during the assessment.

Stakeholders identified valued ecological resources for the middle Platte River risk assessment, including Whooping Cranes (left), a half-million Sandhill Cranes (right) and several million ducks and geese that migrate through the area.

Figure 7



Example watershed goals

> Improve the condition of the lake

> Protect water supply and outdoor recreation

> Accommodate growth while preserving watershed's natural character

Figure 8

Before beginning the actual assessment, managers should agree on management goals for the watershed (*Figure 8)*. Elements of existing goal statements from watershed councils, neighborhood conservation plans, or local growth planning strategies should be incorporated where appropriate. Significant effort may be needed to generate clearly worded management goals for the watershed. Public meetings, constituency group meetings and evaluation of resource management organization charters, are some methods to develop shared management goals. Although this essential step may delay the assessment, reaching agreement on watershed goals among diverse interests is valuable for interactions far beyond the assessment.

The goal should be supported by a set of more tangible management objectives (*Figure 9*), which a subgroup of the planning team may develop. The team members assigned to this task should understand ecological processes and the characteristics of the watershed being studied. Their important role is to translate the goal -- which may be very general, abstract and impossible to measure -- into management objectives that relate closely to the goal and can be verified when met. If site-specific water quality objectives are in place, they should be considered and may even be used as the management objectives if they are relevant to the valued ecological resources. The watershed goals and their objectives set the foundation for the risk assessment.

Management objectives related to goals

- Improve the condition of the lake
  - > Stop the yearly algae blooms
  - > Double the lake's gamefish populations
- Protect water quality and outdoor recreation
  - > Restore vegetation stabilizing all banks
  - > Accommodate 20% increase in camping

Figure 9

When watershed risk assessment planning is completed, participants should have:

- an idea of what issues the watershed managers want to address
- awareness of the stakeholders and their interests
- awareness of valued ecological resources that may be at risk
- overall ecological goal(s) and objectives for the watershed
- clear expectations for the assessment scope and products

Problem Formulation Phase

Problem formulation provides the organizing framework upon which the entire risk assessment depends (Figure 10). In this phase, the assessors use available information on ecological resources potentially at risk, stressors, and observed or anticipated ecological effects, to describe the nature of the problem and identify measurable traits of the ecological resources that can be used as **indicators** (**note:** due to the ambiguous use of this common term, risk assessment guidelines recommend using the more specific terms **measure of effect**, **measure of exposure**, and **assessment endpoint**, as appropriate). The problem formulation phase then produces a **conceptual model** of interrelationships among resources, stressors, and effects, and focuses the forthcoming analysis phase on answering one or more questions. When problem formulation is complete, the risk assessors should have a clear focus for the assessment and a plan for the analysis phase. Even if the remaining assessment phases are not carried out, the problem formulation alone is extremely valuable to watershed management because it summarizes often complex environmental risks, impacts and relationships in an organized manner.

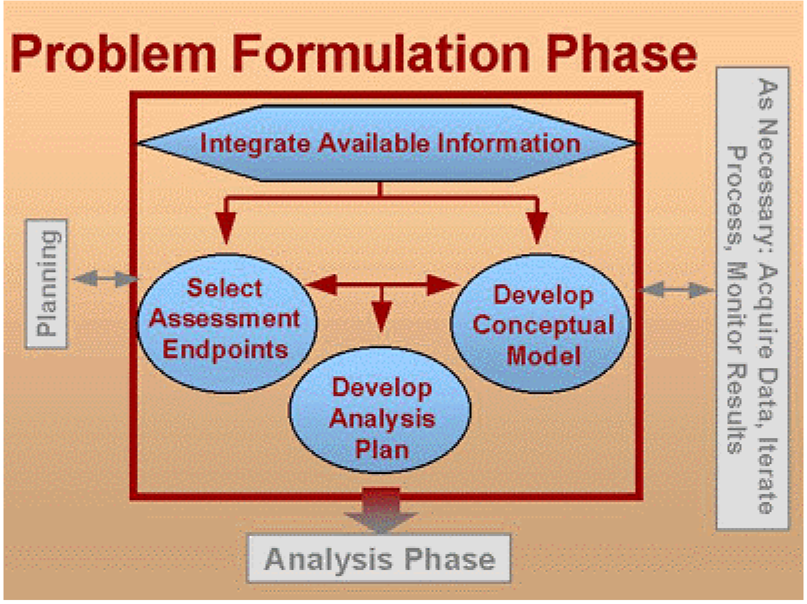


Figure 10

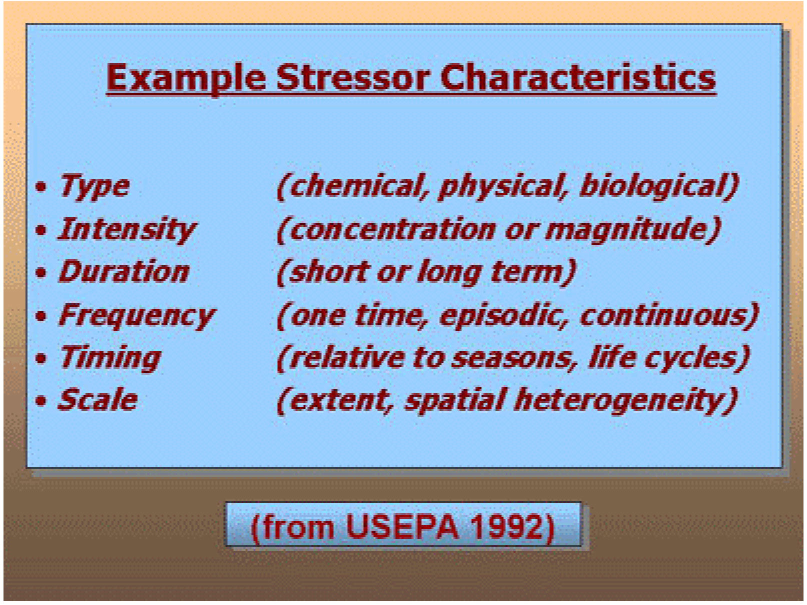
Gathering available information about the watershed, its ecological resources potentially at risk, stressors and **exposure** opportunities, and ecological effects is a practical starting point. The type, quantity and quality of existing information determine whether problem formulation is easily completed, or if time must be spent filling key information gaps. In this phase, enough information must be available to define or conceptualize the watershed problems and risks, but not yet to analyze or quantify them. Existing information does need to be evaluated for data validity and information gaps, to guide further data collection. Evaluating available information will also help the assessors identify known and unknown relationships among stressors, **exposure scenarios**, and effects; much of the assessment will focus on improving the understanding of these relationships.

Valued ecological resources: During problem formulation, the description of valued resources becomes more scientific. In Waquoit Bay, MA, concerns about fewer fish and lost habitat were refocused in the assessment on declining eelgrass beds.

Figure 11

Ecological resources potentially at risk. In the planning process, stakeholders identified (possibly in non-scientific terms) the watershed's valued ecological resources of concern (Figure 11). These valued resources are an important focus of the problem formulation phase. Describing the basic characteristics of the watershed ecosystem is now necessary, as it provides a backdrop for evaluating the stakeholders' concerns and then determining which of the valued watershed resources may be at risk. Important watershed properties to consider include the abiotic environment, biotic community structure, and ecosystem processes. After characterizing the watershed, assessors can restate the stakeholders' concerns in scientific terms, including how and where in the watershed adverse effects might occur. Assessors should also begin to focus on specific watershed traits that are measurable and might indicate changes in the condition of valued ecological resources.

Stressor (and source) characteristics. **Stressors** are defined as any physical, chemical, or biological entity that can cause an adverse effect (Figure 12). Typically a wide range of stressors affects a watershed, and these may originate from **stressor sources** including a wide variety of human activities and natural processes. Here, too, it is important to note stressor characteristics that are measurable and potentially useful in developing measures of exposure. The stressor evaluation process should be made through the collective best professional judgement of an interdisciplinary team. Occasionally, a large number of stressors may be identified; the team may then focus on the ones most likely responsible for adverse effects on the watershed.



Example Stressor Characteristics

• *Type*	*(chemical, physical, biological)*
• *Intensity*	*(concentration or magnitude)*
• *Duration*	*(short or long term)*
• *Frequency*	*(one time, episodic, continuous)*
• *Timing*	*(relative to seasons, life cycles)*
• *Scale*	*(extent, spatial heterogeneity)*

(from USEPA 1992)

Figure 12

Ecological effects. In some cases ecological effects (Figure 13) (e.g., fish kills, declining biodiversity) may already have been observed in the watershed. Other situations may involve expected effects, based on experiences elsewhere or on knowledge of the watershed and its ongoing changes. In any case, information on ecological effects is essential for the analysis of how stressors pose specific risks to the watershed.

Once the available information on ecological resources, stressors and effects has been gathered, it is used to:

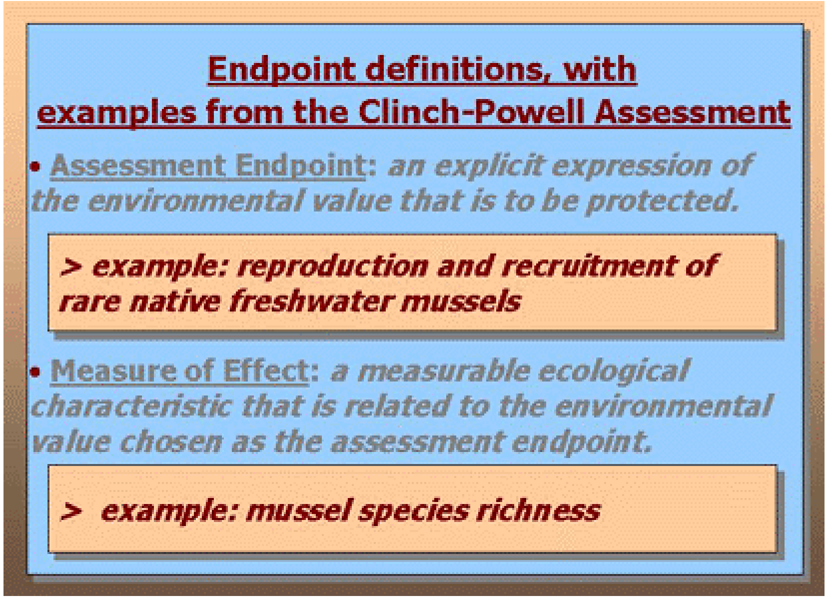
- Identify and select the specific subjects of the assessment (the **assessment endpoints**);
- produce a conceptual model and associated questions that the assessment may address; and
- define a plan of action for the analysis phase and measurements that are needed.

Ecological effects. A fish kill observed but not yet explained in stressor-response terms. The risk assessment will seek information on the stressors responsible and the pathways of exposure that led to fish mortality.

Figure 13

Endpoint selection. Assessment endpoints (Figure 14) are selected which provide a link between what can be measured (e.g., mussel species richness, used for the Clinch Valley assessment) and one or more management objectives (e.g., protecting threatened and endangered mussel species). Assessment endpoints are related to the management objectives and the valued ecological resources identified during planning, but they are more specific, and focus on a key characteristic of the valued ecological resource to be assessed. Three criteria for assessment endpoints are:

- relevancy to important traits of the ecological resource at risk;
- relationship to policy goals and resources valued by the community; and
- susceptibility to the stressor.



Endpoint definitions, with examples from the Clinch-Powell Assessment

- **Assessment Endpoint:** *an explicit expression of the environmental value that is to be protected.*

> example: reproduction and recruitment of rare native freshwater mussels

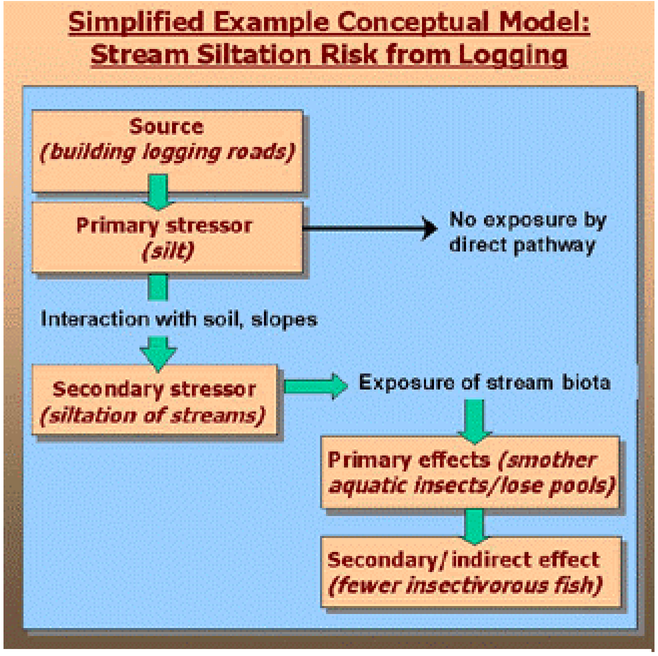
- **Measure of Effect:** *a measurable ecological characteristic that is related to the environmental value chosen as the assessment endpoint.*

> example: mussel species richness

Figure 14

Several assessment endpoints may be used in one assessment to cover the range of management objectives and valued ecological resources, and also to help build stakeholder and manager acceptance. Assessment endpoints are often not easily measured. When direct measurement is not possible, the next step is to select **measures of effect**, formerly called **measurement endpoints**, which are measurable responses to a stressor. They are selected for their suitability in detecting changes to the broader assessment endpoint, singly or in groups (e.g. as an index), as well as for their ability to be measured accurately, consistently and economically. See the accompanying figure for examples of how objectives, valued resources, assessment endpoints, and measures of effect all interrelate.

Endpoint selection is of particular importance because this step translates abstract management goals to scientific measurements -- this is often a challenge in watershed management. Documenting the reasoning behind this linkage is also crucial when explaining scientific results at the end of the assessment.



Simplified Example Conceptual Model: Stream Siltation Risk from Logging

Source *(building logging roads)*

Primary stressor *(silt)*

No exposure by direct pathway

Interaction with soil, slopes

Secondary stressor *(siltation of streams)*

Exposure of stream biota

Primary effects *(smother aquatic insects/lose pools)*

Secondary/indirect effect *(fewer insectivorous fish)*

Figure 15

Conceptual model development. The conceptual model (Figure 15) consolidates all of the above and describes, in narrative and graphical form, relationships among human activities, stressors, and the effects on valued ecological resources. At this point in the assessment these relationships are based on best professional judgement, but usually not yet quantified; yet the framework for analysis and assessment is clearly described therein. This analysis plan then documents the exposure/effects relationships that will be quantified in the analysis phase, the data needed and measures to be used, and how risks will be described.

Developing the conceptual model provides a forum for discussion, a framework for understanding and explaining the problem's details, and a structure for the forthcoming analyses. Conceptual models may evolve as a better understanding of sources, stressors and pathways is acquired. Developing them also provides decision makers with a record of the opinions of the local and scientific experts and the references upon which the opinion is based. This record of supporting information later makes decision making more credible. Table 3 lists other positive contributions of conceptual model development observed in watershed ecorisk case studies.

When problem formulation is completed, the assessors should have:

- a conceptual model describing relationships among stressors, ecological resources, and effects;
- a set of questions that will be addressed in the assessment;
- assessment endpoints that identify what properties of the valued ecological resources will be assessed;
- identified measurements that will be needed to quantify risks or impacts;
- an analysis plan to guide the next phase of the assessment.

Role of Conceptual Model Development in Four Watershed Risk Case Studies	
Waquoit Bay, MA	provided a way for stakeholders, scientists and managers to agree on the most significant concern
Clinch River, VA	helped the group understand the interrelationships between the components of the assessment
Snake River, ID	provided a basis for coordinating multiple agencies' concerns
Big Darby Creek, OH	valuable for risk communication and facilitating stakeholder buy-in

Table 3

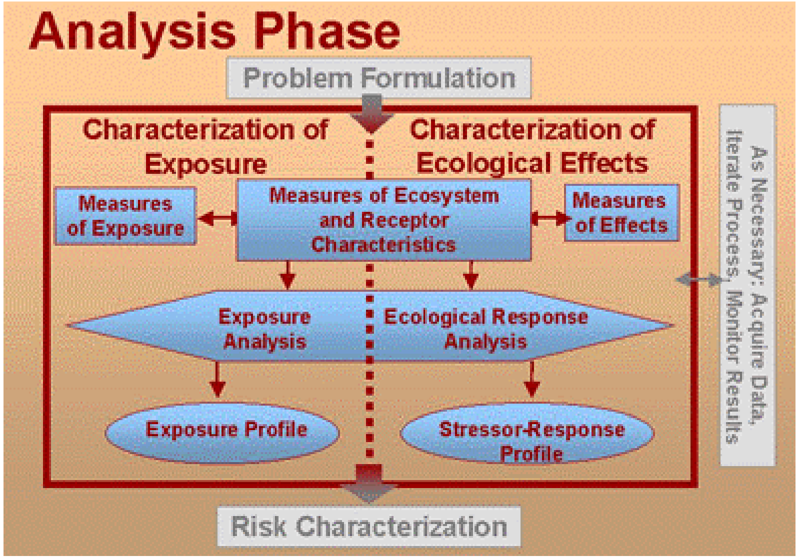


Figure 16

Analysis Phase

The **risk analysis phase** implements the analysis plan developed in problem formulation (Figure 16). This phase focuses on the most important stressors, their exposure pathways, and the resulting ecological effects.

The analysis phase includes **characterization of exposure** – the manner in which an ecological resource contacts or co-occurs with a stressor – and **characterization of effects** – the ecological response that occurs from exposure. The steps in this phase are significantly more technical and quantitative than the problem formulation phase, and may involve taking measurements of existing conditions, modeling, or extrapolation from field or laboratory data. In short, the analysis phase develops estimates of environmental exposure and the effects of the stressors on the ecosystem.

Analysis provides more details about the relationships between stressors and effects, first summarized in the problem formulation's conceptual model. As the analysis proceeds, interim findings should be presented to managers to ensure that the assessment is targeting the appropriate problems.

A quantitative approach is often not possible for every environmental exposure or effects setting, but this problem is not fatal to the assessment. Most quantitative risk assessments have targeted single species or chemicals, which represent simpler scenarios than highly complex watershed ecosystems affected by multiple stressors and facing a high likelihood of incomplete information. Best professional judgment and a "weight of scientific evidence" approach may be called upon to address informational gaps by estimating exposure or effects, but the amount of uncertainty related to this approach should be noted. A pilot analysis on a subwatershed may be a useful way to explore analytical approaches (MacDonald 1994).

The scope of the risk analysis may:

- *focus on the major stressor of concern* (Figure 17)
- *seek associations between numerous stressors and impacts* (Figure 18)

The Waquoit Bay, MA risk assessment focused its analysis on the major stressor of concern, nitrogen. Models were developed to clarify the pathways by which nitrogen reached the Bay, and to assess the ecological impacts of nitrogen once it reached the Bay.

Figure 17

The Big Darby Creek risk assessment sought associations between many stressors and impacts, and relied on current and past land use practices and biological measurements taken at specific sites to draw conclusions. Researchers used the Index of Community Integrity for stream invertebrates and the Index of Biotic Integrity for fish to represent ecological status within stream segments in the watershed. Multivariate statistical analyses were used to determine relationships between index results, instream stressors, and land use patterns in the watershed. Finally, the analysis identified components of the community that were associated with specific types of stress.

Figure 18

Multiple exposure pathways: The Clinch River Watershed Risk Assessment noted that a source of chemical pollution was acid mine drainage (left), and some agricultural practices (right) contributed to sedimentation and habitat disruption.

Figure 19

Characterizing exposure. Exposure is commonly estimated by measuring or modeling a stressor and describing the exposure pathways *(Figure 19) t*hrough which co-occurrence or contact between stressors and ecological resources may occur. The magnitude of exposure and the distribution in time and space of both the ecological resource of concern and the stressor are considered in identifying exposure pathways and developing a quantitative **exposure profile**.

Ecological Exposure is analyzed by linking stressors with their sources, describing the temporal and spatial distribution of stressors in the environment, and the degree to which stressors actually contact or co-occur with ecological resources. These three components analysis can be analyzed in any order, depending on the availability of information, the importance of different pathways (as described in the conceptual model developed during problem formulation), and the focus of potential management alternatives. A combination of monitoring and modeling is usually used for all three components; for example, fate and transport models can be used to predict environmental chemical concentrations downstream of a point source. For stressors that act through the deprivation of a resource, (e.g., reproductive habitat loss), exposure analyses often focus on documenting that the resource was indeed unavailable when it was needed. Exposure to biological stressors such as invasive non-native species may be particularly complex to characterize because of factors such as the species' population dynamics, interactions with other species, and variable invasion patterns. Important questions when characterizing any stressor and its exposure include:

What are the sources of the stressor?

Example: sources of stressors

Low stream pH is a stressor of primary concern to the managers of a northeastern US watershed. Research has concluded that acid precipitation is an important contributor to the stream acidity and as further traced it back to coal-fired power plant emissions from an industrial region. Atmospheric models are able to quantify the potential for acid precipitation related to emissions from the power plants.

How is the stressor distributed in time and space? How might this change?

Example: stressor distribution and change in time and space

Acid precipitation is a stressor of primary concern to the managers of a northeastern US watershed. Prevailing weather patterns vary in the transport of acid precipitation from its source several hundred miles away, so exposure is intermittent and variable in magnitude. Localized differences in amount of rainfall and snowfall occur in the watershed due to differences in elevation, and this affects distribution of the stressor in upper vs. lower parts of the stream. New air pollution regulations (reducing acid-causing emissions) and unusual climatic shifts (increasing heavy rainfall events) further complicate the patterns of this stressor's occurrence in the watershed. Relevant time scales include changes in the watershed's capacity to buffer acids over centuries; changes in emissions due to regulatory changes, over decades; and changes in intensity of acidification that may vary seasonally or even daily.

Are there additional, secondary stressors associated with the original stressor?

Example: secondary stressors

Acid precipitation has been identified as a primary stressor due to its direct aquatic effects (altering pH) observed in a given lake and its tributary streams. Secondary stressors occur through the effect of acidity on increasing the availability of metals toxic to stream invertebrates and fish. They also occur through the influence on forest species in the watershed, whose mortality increases due to reduced resistance to disease caused by the acid precipitation effects on foliage. Tree death near the stream destabilizes the streambanks and adds excess sediment to the streams and lake, which increases the adverse impacts on fish egg and fry survival rates.

What is the timing and location of the stressor's interaction with ecological resources of concern?

Example: interaction between stressor and ecosystem

Acid precipitation from an industrial region intermittently affects a stream several hundred miles away. Occurrence of pH below a given threshold affects fish survival, with some life stages more strongly affected than others. Improved air pollution controls have made low pH in the stream a very uncommon event, but the fish populations are not recovering as expected. Stressor characterization reveals that heavy snow melt and winter rainstorms significantly lower the pH at a very vulnerable time for eggs and fry, keeping fish populations from rebounding despite improved pH throughout most of the year.

Important Note: It is nearly impossible (and undesirable) to characterize stressors without reference to the ecosystems they influence. Both stressor characterization and effects characterization rely on sound information about the characteristics of the watershed ecosystem in which all these interactions take place. It is often necessary in the analysis phase to obtain better data on the watershed's ecological structure and processes than the qualitative data that were sufficient for the problem formulation phase.

Ecological exposure characterization at its best may be able to produce an **exposure profile**, which quantifies the patterns of stressor occurrence in space and time, and the resulting exposure of ecological resources that leads to adverse effects. Quantitative exposure profiles may be feasible in narrowly-defined assessments concerning single stressors or effects that are well documented. In watershed assessments, however, the interactions among multiple stressors and effects often make individual exposure profiles impractical to quantify. Furthermore, the optimal suite of data is typically not available and too costly to acquire. Using data from numerous sources is helpful and consistent with the watershed approach of using partnerships. By necessity, a watershed assessment usually focuses more on the relationship of a group of stressors (or their sources) to a group of ecological effects, rather than expending considerable effort to quantify each stressor's exposure and relationship to each adverse effect individually.

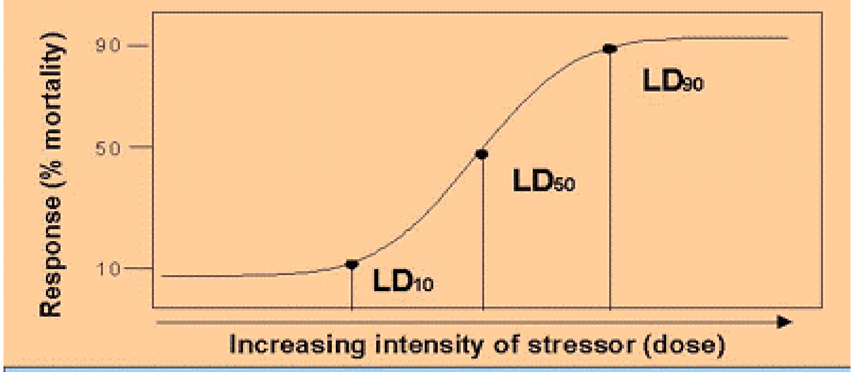
Characterizing effects. Ecological Effects are analyzed by describing stressor-response relationships, evaluating evidence for causality, and, when necessary, linking the effects that can be measured back to the effects of greatest interest (identified in problem formulation) (Figure 20). These three components can be developed in any order, and the emphasis may be different depending on whether the objective of the assessment is to predict the effects associated with future change, or retrospectively analyze the causal factors influencing current state of ecological resources.

Characterizing adverse effects: In the Mid-Snake River Risk Assessment, nutrient enrichment and changes in flow led to the growth of aquatic nuisance plants (like the thick mass of algae above) and related declines in fish and invertebrates.

Figure 20

Evaluating relevant effects data is more reliant upon professional judgement than other analysis steps, because of the need for choices among many data sources or decisions concerning data gaps. Relevance of available data is determined by its connection to the indicators selected in problem formulation, as well as data quality. Relevant data may be used in a number of ways. Literature synthesis may play an important role. Statistical techniques or mathematical models may be used to quantify and summarize the relationship of the stressor to the measured ecological resource. Extrapolations may be required such as between taxa (e.g., bluegill sunfish mortality to largemouth bass mortality); from laboratory to field (e.g., mortality of bluegills in laboratory tests to mortality of bluegills exposed to the same stressor under field conditions); and from field to field (e.g., from the results of a pond mesocosm test to a lake in a different area).

Characterizing the stressor-response relationship is where the quantitative analysis takes place. Common statistical tools used in effects analysis may include multivariate analysis, modeling, multiple regression analysis, principle components analysis, discriminant analysis and nonmetric clustering and association analysis, visualization techniques and simulation modeling (Foran and Ferenc, 1999).



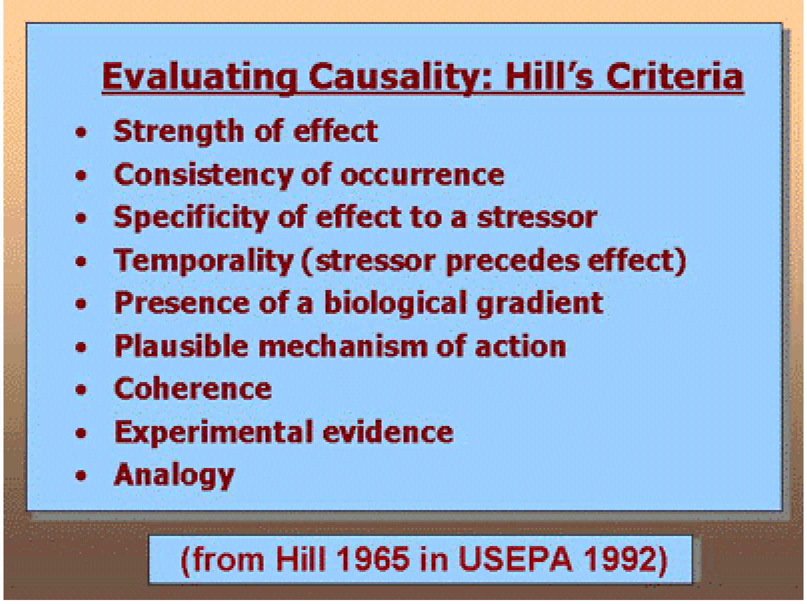
A simple stressor-response relationship (dose / % mortality). The curve shows a range of responses to varying stressor intensity; the points are commonly used levels of effect estimating lethal dose (LD) fatal to a given percent of organisms in a population. Relationships much more complex than this example are typical of ecological risk assessments, with multiple stressors and cumulative ecological effects.

Figure 21

Stressor-response profile development should try to relate the magnitude of the effect to the magnitude, duration, frequency, and timing of exposure. For narrowly defined assessments of a single stressor and effect, the calculated relationship may be expressed as a **stressor-response curve** (Figure 21), or summarized as a single reference value (a point on the curve), depending on the scenario being described and the best approach for its presentation to others. A typical watershed assessment, however, encounters much more complex interrelationships than the simplified example shown. As in other steps, documentation of uncertainty and assumptions made should be part of the analysis.

An analysis of the cause and effect relationship can be an important component of a watershed risk assessment when it is uncertain whether a stressor can cause the effects of concern (e.g., can more extreme flow events cause reductions in mussel abundance?). More often, causal evaluation is used to identify factors that are responsible for observed effects and can be manipulated to improve environmental conditions (e.g., did the increased flow conditions at point A cause the observed decline in mussel abundance at point B?). The development of methods useful for evaluating causality is an area of active research, but most methods build upon criteria similar to those developed by Hill in 1965 (Figure 22).

Response analysis should also evaluate the strength of the association between the stressors and the assessment endpoints and indicators; in the best case there is evidence of a cause-and-effect relationship, but the complexity of watersheds and limited data often preclude this. Ideally, the stressor-response relationship will relate the magnitude, duration, frequency, and timing of exposure in the watershed to the biological effects, but documenting just the general associations between sources or stressors and their effects may be more realistically achievable in multiple stressor assessments of watersheds.



Evaluating Causality: Hill's Criteria

- Strength of effect
- Consistency of occurrence
- Specificity of effect to a stressor
- Temporality (stressor precedes effect)
- Presence of a biological gradient
- Plausible mechanism of action
- Coherence
- Experimental evidence
- Analogy

(from Hill 1965 in USEPA 1992)

Figure 22

Given the above limitations, it may be most useful to first examine relationships between land use and biological data. Exposure stemming from different land uses may be inferred from available data in the watershed and exposure-effects information from the literature. For instance, in the Clinch Valley assessment the fish community was consistently poor when the surrounding sub-watershed included all four main sources of stress (mining, urbanization, major roads, and pasture areas in the riparian zone). The strong association of adverse effects on fish with the presence of these nearby land uses was meaningful even in the absence of more specific, quantitative profiles of exposure and effects. Yet, attempts to directly relate physical habitat quality measures to fish community condition resulted in much poorer associations, indicating that either the habitat measures were not accurately describing habitat stress in this watershed or that other unmeasured attributes of exposure (e.g., water quality stressors) accounted for the variability in condition. Nevertheless, more detailed information on specific stressors may be useful to guide management actions. It may be useful to know, for example, whether the pasture caused effects through livestock directly trampling stream organisms, because riparian vegetation was lost and bank erosion increased, or through increased temperature resulting from the streams becoming shallower and wider.

When the analysis phase is completed, the assessors should have:

- exposure characterizations that describe patterns of stressor occurrence in the watershed;
- ecological response analyses, that describe effects on the valued ecological resources identified earlier;
- stressor-response characterizations that are quantitative, where possible;
- documented assumptions and uncertainty levels for all of the above.

Risk Characterization Phase

In this final phase of assessment, the likelihood and significance of adverse effects due to exposure to stressors are evaluated. Good **risk characterization** uses this evaluation to help build answers for decision-relevant questions. The phase includes two major steps: risk estimation and risk description (Figure 23). The final product of this phase is the risk assessment report, prepared for managers to support science-based decision making based on defensible assessment conclusions.

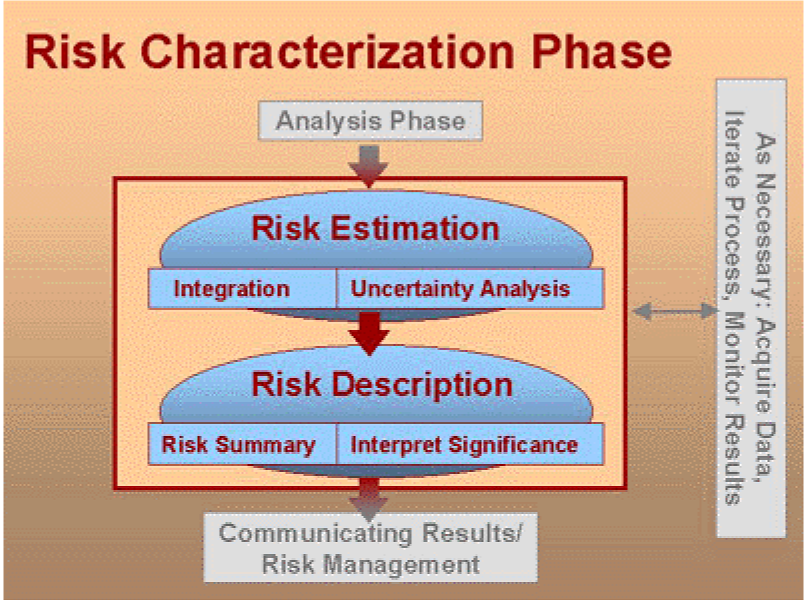
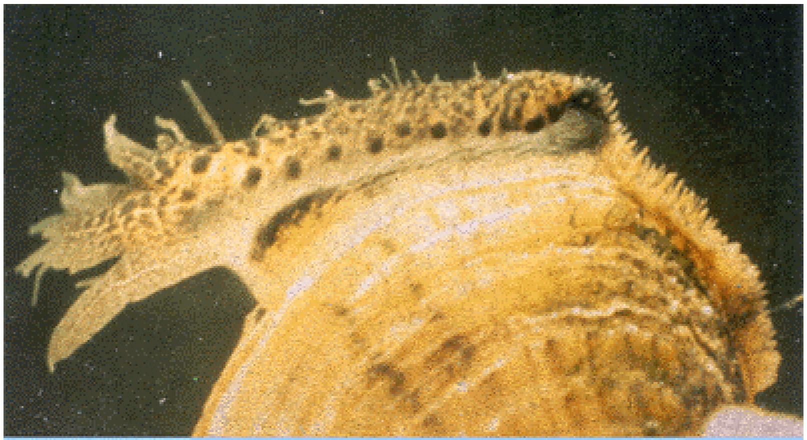


Figure 23

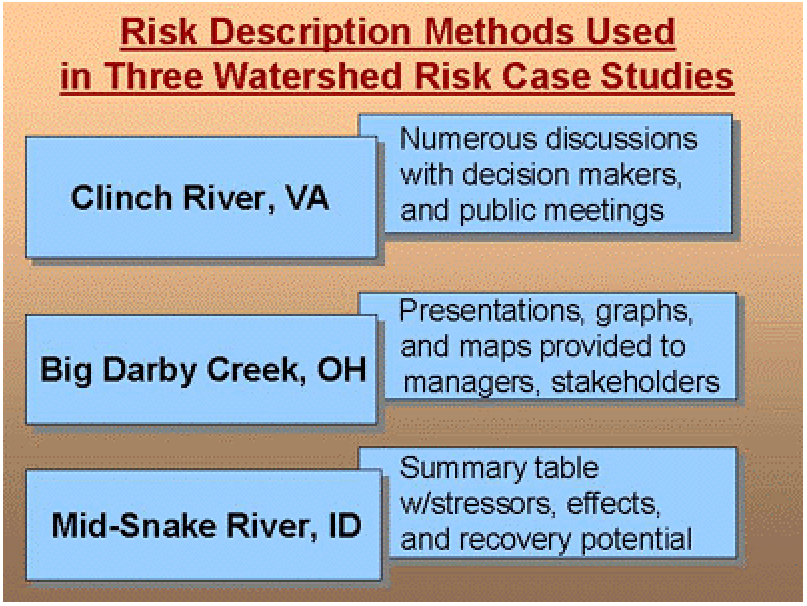


The Clinch River Risk Assessment focused on some of the world's most unusual fish and freshwater mussel species, including the Wavy-Rayed Mussel (above). Estimating risks involved assessing multiple stressors (sediment, habitat alteration, chemicals) with direct and indirect effects.

Figure 24

Risk estimation, the first step, integrates the exposure profiles and the stressor-response profiles developed in the analysis phase while also addressing uncertainties that arose throughout the assessment *(Figure 24)*. The integration approaches can include comparing single values of effect and exposure; comparing statistical distributions of exposure and effect values; or conducting simulation modeling. In watershed assessments, the spatial distribution of exposure and effects is important to consider -– GIS overlays of the two types of information can be a useful tool. In assessments where timing of events is critical (e.g., as in the acid precipitation example described previously, or in the assessment of episodic events), graphs that show the timing and distribution of excursions over an effects threshold may be a better way to integrate the information.

Also during this step, uncertainties originating in all three assessment phases and in external data should be summarized in an **uncertainty analysis**. Sources of uncertainty may include measurement data (inappropriate, imprecise or too few measurements), conditions of observation (such as extrapolating from laboratory tests to field predictions), or limitations of models (e.g., oversimplifying complex ecological processes). When exposure and effects data are limited or are not easily expressed in quantitative terms, qualitative evaluation techniques may be used to rank risks using best professional judgment and categories such as low, medium and high.



Risk Description Methods Used in Three Watershed Risk Case Studies

Clinch River, VA	Numerous discussions with decision makers, and public meetings
Big Darby Creek, OH	Presentations, graphs, and maps provided to managers, stakeholders
Mid-Snake River, ID	Summary table w/stressors, effects, and recovery potential

Figure 25

Risk description (Figure 25) concludes the characterization phase with the preparation of an ecological risk summary and the interpretation of ecological significance. Summarizing risk involves making a bottom-line estimate of risk, usually in the form of a quantitative statement (e.g., there is an 80% chance of 50% forest mortality in the watershed due to air pollution). It is crucial to include a discussion of the weight of evidence supporting this conclusion, which may cover the quality of the data, corroborating information, and evidence of causality. Agreement among multiple lines of evidence increases the confidence in the conclusions, however any differences in findings need to be discussed. Useful additional analyses that could improve the assessment's certainty may also be identified.

Interpreting ecological significance (Figure 26) translates possible risk estimates into a discussion of their consequences for the watershed. This step may address the nature and magnitude of effects, spatial and temporal patterns of effects, and the potential for ecosystem recovery. The significance of predicted effects may vary considerably in their consequences for different types of ecological systems. For example, the effect of a herbicide may be quite different in a stream that derives most of its organic carbon energy from plants as compared to a stream that utilizes predominantly detrital-based organic carbon. The loss of a small wetland area may be highly significant if it represents the only habitat available in an area for migratory waterfowl, but negligible if it occurs among thousands of other pothole-type wetlands.

Interpreting ecological significance: It is crucial not only to report on ecological risks, but to interpret their significance. For example, loss of alligators from an ecosystem isn't just about alligators, but involves declines or losses of many more species that utilize gator wallows as habitat in dry periods.

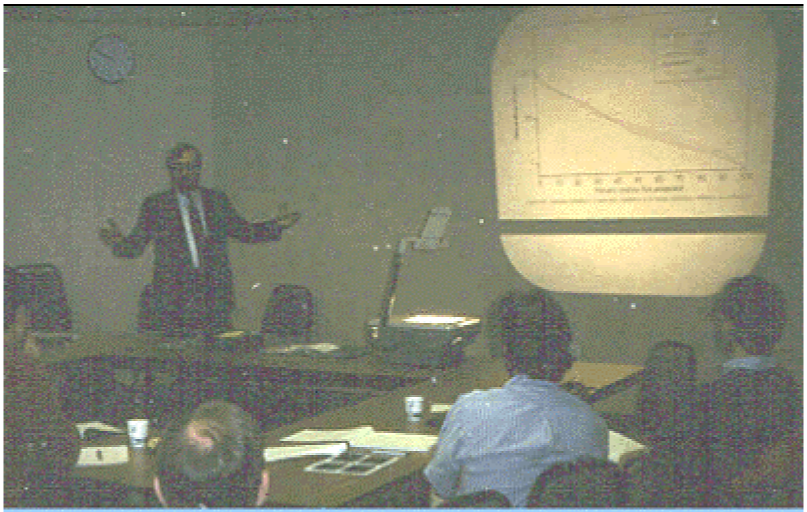
Figure 26

After risk characterization, assessors should have a better understanding of the risks at hand and a scientifically defensible report that provides:

- A description of risk assessor/risk manager planning results
- A review of the conceptual model and the assessment endpoints
- A discussion of the major data sources and analytical procedures used
- A review of the stressor-response and exposure profiles
- A description of risks to the assessment endpoints, including risk estimates and adversity evaluations
- A summary of major areas of uncertainty and the approaches used to address them
- Documentation of science policy judgments or default assumptions used to bridge information gaps, and the basis for these assumptions.

Risk Communication/Risk Management

The risk assessment final report is a technical, scientific product, but very often decision-makers are not scientifically trained. One final step addresses the critical issue of communicating assessment results to managers, and providing a complete understanding of the assessment's conclusions, assumptions, and limitations (Figure 27).

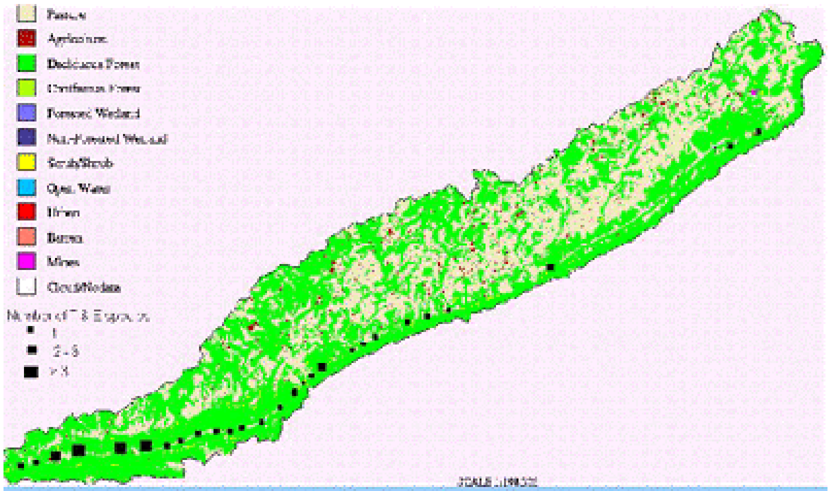


Communicating the risks: Different products can be developed for different audiences, but live presentation is often critical to any audience's full comprehension of the assessment results.

Figure 27

Presenting the Results. After the risk assessment is completed, its findings are presented in whatever manner can be best tailored to key audiences. Meetings between the risk assessor and watershed managers at the end of the risk assessment are important to present findings and ensure that the managers have a full and complete understanding of the assessment. The risk characterization should clearly communicate to the risk manager the major risks, the ecological significance of the findings, and the level of uncertainty. Maps, simplified scoring systems, clearly defined evaluative criteria and limiting the numbers of stressors and effects addressed all help to communicate effectively. A plain-English report or presentation that summarizes various risk estimates associated with a range of present or expected stressor levels can be especially useful for a manager who may need to choose among complicated management options.

Scientific information should be displayed in the manner most appropriate for addressing the major concerns. For instance if spatial distribution of a stressor is more important than its magnitude, that should be displayed using a map (Figure 28). Comparisons of before and after scenarios, and computer-based or clear map overlays representing different risk levels, are examples of the many effective techniques for risk communication.

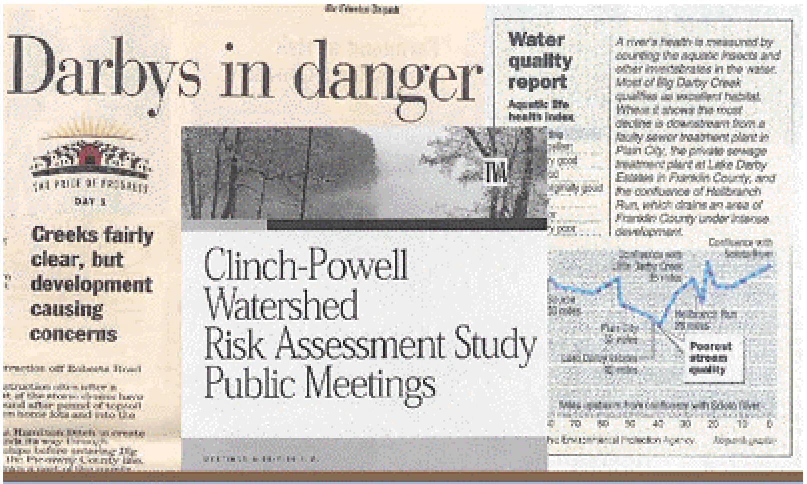


Communicating risk with maps: the Clinch assessment plotted occurrence of rare aquatic species (larger squares = more spp.) on a backdrop of watershed land uses that pose varying levels of threat. Green areas are forest, tan is pasture, red is urban.

Figure 28

Ecological dose-response curves can be used to show the effects of human activities within a watershed. Graphs are one of the best analytical tools for deciphering relationships between biological attributes and human influences. Summary tables are an effective approach to display the most meaningful information in one condensed exhibit.

Past experience suggests that scientists should communicate early, often, and in a straightforward manner. Regular and recurring interactions, beginning early in the process, are key to the success of an assessment. Communicating progress is a critical part of watershed work that can be done through meetings, websites, periodic reports, or news releases (Figure 29). By the time the assessment is completed, the manager should fully understand the assessment.


Darbys in danger

THE PRICE OF PROGRESS

DAY 1

Creeks fairly clear, but development causing concerns

Clinch-Powell Watershed Risk Assessment Study Public Meetings

Water quality report

Aquatic life health index

A river's health is measured by counting the aquatic insects and other invertebrates in the water. Most of Big Darby Creek qualifies as excellent habitat. Where it shows the most decline is downstream from a faulty sewer treatment plant in Plain City, the private sewage treatment plant at Lake Darby Estates in Franklin County, and the confluence of Hellbranch Run, which drains an area of Franklin County under intense development.

Communication and outreach to managers and citizens should clearly explain the assessment's purpose, progress, and results.

Figure 29

In the Clinch Valley assessment, frequent discussions with the decision makers and the public kept them informed, enhanced their understanding of the nature of the problem and involved them in developing remediation or work plans. Preliminary findings from the Big Darby assessment provided through graphs, maps, and discussion have stimulated some stakeholders to take voluntary actions, including removal of lowhead dams (with subsequent improvement in fish communities) and reducing erosion.

The risk assessment report may be repackaged into less technical forms for different audiences, such as a shorter and more general version for the general public. While all the relevant technical detail is required and needs to be scientifically peer reviewed to make the risk assessment report scientifically credible, its key information may be reformatted to help any target audience to focus on the results and consider alternate **risk management** options while avoiding the use of technical terms.

Risk Management

Risk management fills the crucial role of integrating the science-based assessment with the economic, social, legal, and political factors affecting management decisions and actions in the watershed. Since risk management can vary so much from case to case and is considered outside the immediate process of risk assessment, it is not discussed in detail here. Generally, watershed ecological risk assessment provides tools and information that may be used in managing risks within, for example, the following common water resources program actions:

- State nutrient management plans
- Setting and reviewing TMDLs
- NPDES permits
- Watershed protection plans
- Threatened and endangered species recovery plans
- Local land use decisions
- Future analyses from the data sets that get developed

Monitoring and Data Acquisition

This box of the flow chart (highlighted in Figure 30) does not follow the general sequence of phases and steps seen elsewhere, because it is iterative throughout all phases of the risk assessment process.

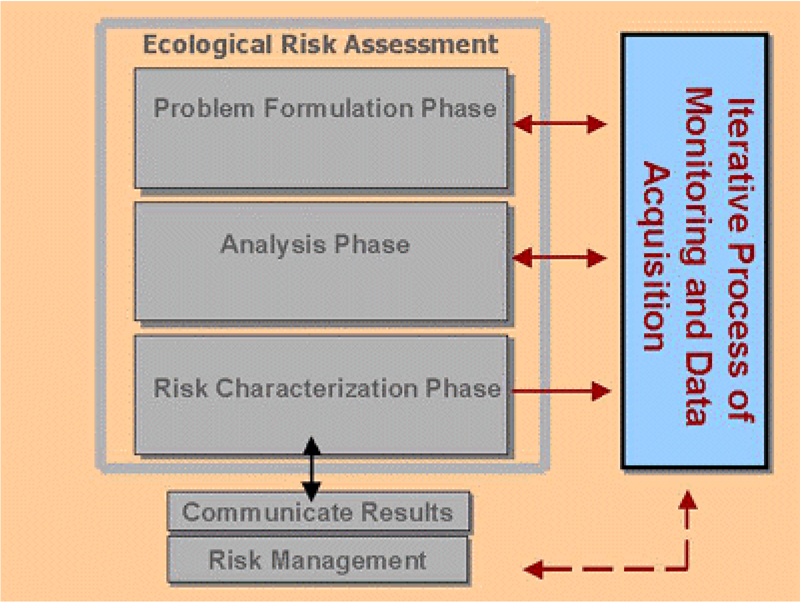


Figure 30

Although the ecological risk assessment flow chart appears to be linear, in reality it is an iterative process in more ways than one. All phases include both a regularly occurring dialogue between the scientists and the managers. Stakeholder and manager involvement needs to be initiated in the planning step, and recurring discussions are necessary throughout the process to keep data acquisition on the right track and make the assessment findings most useful.

In all assessment phases, new information is also obtained through iterative loops that may repeatedly access literature review, field data, peer review, or new analyses. This process is intended to incorporate new scientific information and changing risk management needs into the developing risk assessment.

Monitoring can play a major role in all phases. Verification monitoring can include validation of the ecological risk assessment process at any phase, as well as confirming predictions made during an assessment. The need for additional data acquisition also can occur at any phase in support of the assessment. Monitoring may provide data needed to develop exposure profiles or stressor-response profiles, track patterns and changes in stressors, and determine whether predicted effects in fact do occur over time. Continued monitoring also provides a key feedback loop with risk management, in that detection of continued adverse effects after risk management actions are in place indicates the need for more effective action.

Watershed Risk Assessment Case Studies

Five watershed risk assessments were cosponsored by EPA and others to demonstrate use of the ecological risk assessment method for resolving real world environmental problems. Visit the Web sites about each assessment by opening the links to each in a web browser.

Five Watershed Ecological Risk Assessment Case Studies

1) Big Darby Creek, OH
http://www.epa.gov/ncea/bigdarby.htm

2) id-Snake River, ID
http://www.epa.gov/ncea/midsnake.htm

3) Clinch River, VA-TN
http://www.epa.gov/ncea/clinch.htm

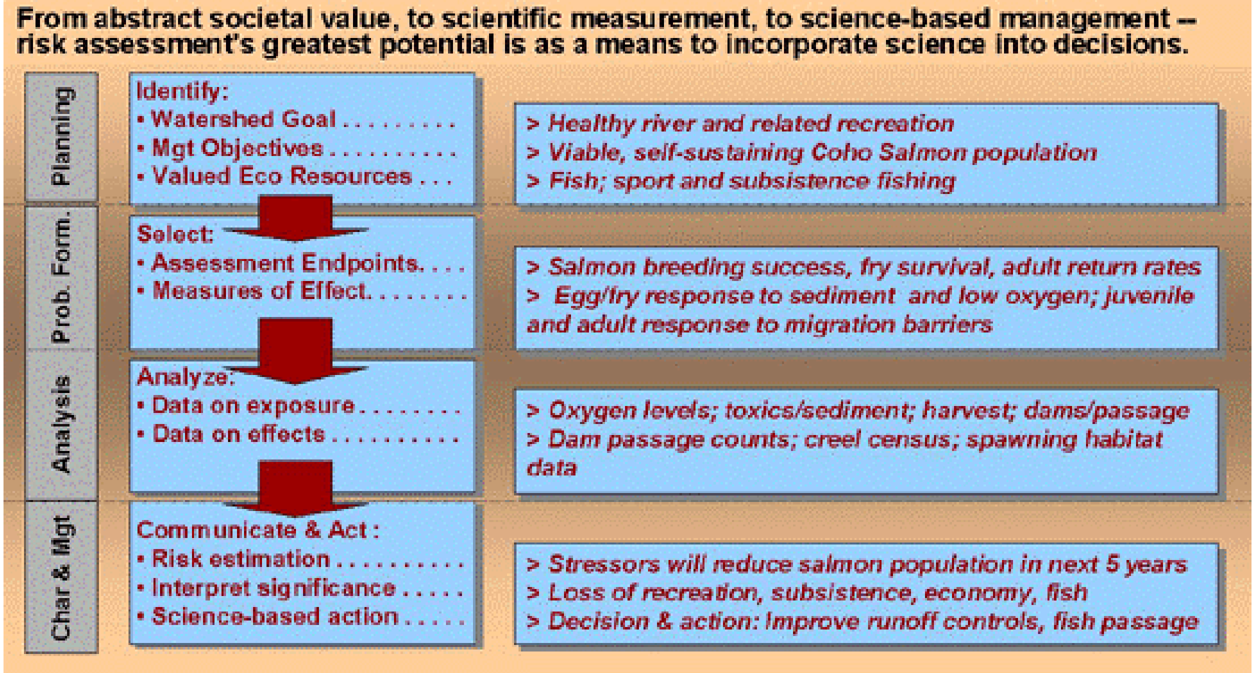
4) Waquoit Bay, MA
http://www.epa.gov/ncea/waquoit.htm

5) Middle Platte River, NE
http://www.epa.gov/ncea/midplatt.htm

Final Thoughts

Making good watershed management decisions requires science-based information that can be evaluated and priority-ranked in terms of the risks to the watershed. Ecological risk assessment facilitates this approach first by providing a logical method for estimating risks, but moreover, by providing clear links from this method to activities that typically occur in watershed management. This is extremely valuable to risk managers who must make complex decisions and may not see a clear path for how to incorporate science.

Figure 31 reviews the steps by which ecorisk enables something of abstract value about the watershed to be translated into scientifically measurable quantities, assessed, and translated back into the information needed to support management decisions.



From abstract societal value, to scientific measurement, to science-based management -- risk assessment's greatest potential is as a means to incorporate science into decisions.

Planning

Identify:
- Watershed Goal . . . .
- Mgt Objectives . . . .
- Valued Eco Resources . . .

> Healthy river and related recreation
> Viable, self-sustaining Coho Salmon population
> Fish; sport and subsistence fishing

Prob. Form.

Select:
- Assessment Endpoints. . . .
- Measures of Effect. . . . .

> Salmon breeding success, fry survival, adult return rates
> Egg/fry response to sediment and low oxygen; juvenile and adult response to migration barriers

Analysis

Analyze:
- Data on exposure . . . .
- Data on effects . . . .

> Oxygen levels; toxics/sediment; harvest; dams/passage
> Dam passage counts; creel census; spawning habitat data

Char & Mgt

Communicate & Act:
- Risk estimation . . . .
- Interpret significance . . . . .
- Science-based action . . . . .

> Stressors will reduce salmon population in next 5 years
> Loss of recreation, subsistence, economy, fish
> Decision & action: Improve runoff controls, fish passage

Figure 31

Using ecorisk is not an all-or-none proposition; parts of the process can be extremely useful in watershed management. Complexity, controversy, or pressure to proceed too quickly can sometimes leave watershed management efforts with a lack of clear goals and substantial uncertainty about the problems faced. At these times, problem formulation may be useful even without continuing into the other phases because it is such an effective process for organizing the key information needed for science-based decisions. Other aspects of risk assessment that are useful on their own include:

- identifying measurable indicators to represent broader, more abstract values;
- focusing on the likelihood of adverse affects as a basic philosophy for making environmental decisions; and
- joint planning among risk assessors, managers, and stakeholders.

Other benefits of using ecorisk in watershed assessment are also evident. The improvements in the communication and coordination associated with the planning and risk communication steps can bring priority issues into focus and reduce duplication of effort, and the increased awareness about watershed problems and their relative priority can prompt other independent actions to improve water quality. The risk assessor and risk manager should have a common understanding of the goals and scope at the beginning of the process and a clear view of the significance of the findings and the major uncertainties when the assessment is completed. Managers and stakeholders also can better understand cumulative impacts and more cost-effectively provide resources to address problems.

Key Risk Assessment References

The "Framework for Ecological Risk Assessment" (US EPA 1992) presented a good overview of the process and provided a good foundation for conducting ecological risk assessments for individual chemical or physical stressors and single endpoints. The "Guidelines for Ecological Risk Assessment" (http://www.epa.gov/ncea/ecorsk.htm, US EPA 1998) provides more detailed guidance for all types of ecological risk assessments (single stressor/endpoint as well as multiple stressors/endpoints). More specific information on how to characterize risks to multiple resources from multiple stressors in watersheds can be found in "Workshop Report on Characterizing Ecological Risk at the Watershed Scale" (http://www.epa.gov/ncea/ecorisk.htm, US EPA 2000). Readers may also want to visit the "Watershed ecological risk assessment" web site (http://www.epa.gov/ncea/placebas.htm).

Selected References about Ecological Risk Assessment and Watersheds

Andreasen, James A and S.B. Norton. 1997. Ecological risk assessment. Proceedings of the risk-based decision making in water resources VIII conference, October 12-17, 1997, Santa Barbara, CA.

Armitage, Derek. 1995. An integrative methodological framework for sustainable environmental planning and management. Environmental Management, Vol. 19, No. 4. Pp. 469-479. Springer-Verlag New York Inc.

Cook, R.B., G.W Suter II, and E.R. Sain. 1999. Ecological risk assessment in a large river-reservoir: 1. Introduction and background. Environmental Toxicology and Chemistry, Vol 18, No 4, pp. 581-588, 1999.

DeFur, P.L. 1997. The Chesapeake Bay program: An example of ecological risk assessment. American Zoologist; Chicago; December 1997.

Diamond, J. and B. Jessup. 1998. Sustaining Threatened and Endangered Species Using a Watershed Ecological risk assessment framework in Watershed Management: Moving from Theory to implementation. Proceedings of the 1998 Watershed Management Specialty Conference, May 3-6 1998, Denver, CO. Water Environment Federation report #CP3804, Alexandria, VA.

Diamond, J. and, V.B. Serveiss. 2000. The Clinch Valley ecological risk assessment. (Draft)

Eastern Research Group (ERG). 1998. Problem Formulation Synthesis Report: Lessons Learned from Five Watershed Case Studies. Work Assignment # 97-09 under contract #68-D5-0028. Lexington, MA.

Foran, J.A. and S. A. Ferenc. 1999. Multiple stressors in ecological risk and impact assessment. SETAC Pellston workshop on multiple stressors in ecological risk and impact assessment; 13-18 September 1997; Pellston, Michigan. Published by the Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, Florida, USA. 100p.

Harris, H.J., R.B. Wegner, V.A. Harris and D.S. Devault. 1994. A method for assessing environmental risk: A case study of Green Bay, Lake Michigan, USA. Environmental Management, Vol. 18, No.2, pp. 295-306. Springer-Verlag, New York Inc.

Karr, J.R and E.W. Chu. 1997. Biological monitoring: Essential foundation for ecological risk assessment. Human and Ecological Risk Assessment: Vol. 3, No. 6, pp. 993-1004.

National Research Council. 1993. Issues in Risk Assessment. National Academy Press. Washington, DC.

National Research Council. 1996. Understanding risk: Informing decisions in a democratic society. National Academy Press. Washington, DC.

DeMoss, Tom. 1999. Presentation on Mid-Atlantic Integrated Assessment at workshop on Applying the Problem Formulation Process to large spatial scales, August 24-26 1999, Washington, DC 20460.

Perhac, R.M. Jr. 1998. Comparative risk assessment: Where does the public fit in? Science Technology and Human Values; Cambridge; Spring 1998.

Presidential/Congressional Commission on Risk Assessment and Risk Management. 1997. Risk Assessment and Risk Management in regulatory decision-making. Final report, volume 2, 1997.

Reckhow, K.H. 1994. A decision analytic framework for environmental analysis and simulation modeling. Environmental Toxicology and Chemistry, Vol 13, No 12, pp. 1901-1906, 1994.

Stout, D.J. and R.A. Streeter. 1992. Ecological risk assessment: Its role in risk management. The Environmental Professional, Vol. 14, pp. 197-203.

Suter, G.W. II. 1990. Endpoints for regional ecological risk assessments. Environmental Management. Vol. 14, pp. 19-23.

Suter, G. W.II. 1993. Ecological Risk Assessment. Lewis Publishers.

Tennessee Valley Authority. 1999. Report on the watershed ecological risk characterization workshop. Prepared for the Office of Research and Development through interagency agreement with EPA no. DW64866901, Washington, DC.

Tetra Tech. 1997. Watershed level aquatic ecosystem protection: Value added of ecological risk assessment approach. Prepared by Tetra Tech for the Water Environment Research Federation (Alexandria, VA) under EPA cooperative agreement No. CR818249, Project No. 93-IRM-4(a).

US EPA. 1992. A Framework for Ecological Risk Assessment. Office of Research and Development, Risk Assessment Forum, Washington, DC. EPA/630/R-92/001. February 1992.

US EPA. 1996a. Middle Snake River Watershed Ecological Risk Assessment Planning and Problem Formulation. Office of Research and Development, Risk Assessment Forum, Washington, DC 20460. EPA/630-R-96-008a (draft). June 1996.

US EPA. 1996b. Big Darby Creek Watershed Ecological Risk Assessment Planning and Problem Formulation. Office of Research and Development, Risk Assessment Forum, Washington, DC 20460. EPA/630-R-96-006a (draft). June 1996.

US EPA. 1996c. Waquoit Bay Watershed Ecological Risk Assessment Planning and Problem Formulation. Office of Research and Development, Risk Assessment Forum, Washington, DC 20460. EPA/630-R-96-004a (draft). June 1996.

US EPA. 1996d. Clinch Valley Watershed Ecological Risk Assessment Planning and Problem Formulation. Office of Research and Development, Risk Assessment Forum, Washington, DC 20460. EPA/630-R-96-005a (draft). June 1996.

US EPA. 1996e. Middle Platte River Floodplain Watershed Ecological Risk Assessment Planning and Problem Formulation. Office of Research and Development, Risk Assessment Forum, Washington, DC 20460. EPA/630-R-96-007a (draft). June 1996.

US EPA. 1997a. People, Places and Partnerships: A progress report on community-Based Environmental Protection. Office of the Administrator. Washington, DC 20460. EPA 100-R-97-003.

US EPA. 1997c. An ecological assessment of the United States Mid-Atlantic Region. Office of Research and Development. Washington, DC 20460. EPA 600-R-97-130. November 1997.

US EPA. 1998. Guidelines for Ecological Risk Assessment. Office of Research and Development, Risk Assessment Forum, Washington, DC. EPA/630/R-95/002f. May 1998.

US EPA. 2000. Workshop Report on Characterization Ecological Risk at the Watershed Scale. Office of Research and Development. Washington, DC 20460. EPA 600-R-99-111. February 2000.

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Glossary for Watershed Ecological Risk Assessment Module

adverse ecological effects: Changes that are considered undesirable because they alter valued structural or functional characteristics of ecosystems or their components. An evaluation of adversity may consider the type, intensity, and scale of the effect as well as the potential for recovery.

assessment: The analysis and transformation of environmental data into policy-relevant information that can assist decision-making and action.

assessment endpoint: An explicit expression of the environmental value that is to be protected, operationally defined by an ecological entity and its attributes. For example, salmon are valued ecological entities; reproduction and age class structure are some of their important attributes. Together "salmon reproduction and age class structure" form an assessment endpoint.

characterization of ecological effects: A portion of the analysis phase of ecological risk assessment that evaluates the ability of a stressor(s) to cause adverse effects under a particular set of circumstances.

characterization of exposure: A portion of the analysis phase of ecological risk assessment that evaluates the interaction of the stressor with one or more ecological entities. Exposure can be expressed as co-occurrence or contact, depending on the stressor and ecological component involved.

conceptual model: A conceptual model in problem formulation is a written description and visual representation of predicted relationships between ecological entities and the stressors to which they may be exposed.

ecological risk assessment: An ecological risk assessment evaluates the potential adverse effects that human activities have on the plants and animals that make up ecosystems. The risk assessment process provides a way to develop, organize and present scientific information so that it is relevant to environmental decisions. When conducted for a particular place such as a watershed, the ecological risk assessment process can be used to identify vulnerable and valued resources, prioritize data collection activity, and link human activities with their potential effects.

exposure: The contact or co-occurrence of a stressor with a receptor.

exposure scenario: A set of assumptions concerning how an exposure may take place, including assumptions about the exposure setting, stressor characteristics, and activities that may lead to exposure.

exposure profile: The product of characterization of exposure in the analysis phase of ecological risk assessment. The exposure profile summarizes the magnitude and spatial and temporal patterns of exposure for the scenarios described in the conceptual model.

indicator: A measurement that can be used to assess the condition, status or trends of an ecological resource. The term is widely used in water resources management programs, but has many different interpretations. It is preferable in risk assessment to avoid using the term indicator and instead use the more specific terms measure of effect, measure of exposure, and assessment endpoint, as appropriate.

measure of effect (measurement endpoint): A change in an attribute of an assessment endpoint or its surrogate in response to a stressor to which it is exposed.

measure of exposure: A measure of stressor existence and movement in the environment and its contact or co-occurrence with the assessment endpoint.

measurement endpoint: See "measure of effect."

problem formulation: The first phase of ecological risk assessment, which includes a preliminary description of exposure and ecological effects, scientific data and data needs, key factors to be considered, and the scope and objectives of the assessment. This phase produces the risk hypotheses, conceptual model and analysis plan, around which the rest of the assessment develops.

risk analysis phase: A phase of ecological risk assessment consisting of two main parts: 1) characterization of ecological effects— evaluating the ability of a stressor(s) to cause adverse effects under a particular set of circumstances, and 2) characterization of exposure— evaluating the interaction of the stressor with one or more ecological entities.

risk characterization phase: A phase of ecological risk assessment that integrates the exposure and stressor response profiles to evaluate the likelihood of adverse ecological effects associated with exposure to a stressor. Lines of evidence and the adversity of effects are discussed.

risk estimation: Ideally, the conclusions of the risk characterization phase expressed as some type of quantitative statement (e.g., there is a 20% chance of 50% mortality under the circumstances assessed), but often expressed as a qualitative statement (e.g., there is a high likelihood of mortality occurring).

risk management: The process of evaluating and selecting action alternatives in response to risk assessment findings.

stressor: Any physical, chemical, or biological entity that can induce an adverse response (synonymous with agent).

stressor-response curve: A graphic, quantitative representation of the relationship between a stressor (such as a pesticide concentration in the water column) and an ecological effect (such as mortality of a given fish species if exposed to different concentrations of the pesticide).

stressor-response profile: The product of characterization of ecological effects in the analysis phase of ecological risk assessment. The stressor-response profile summarizes the data on the effects of a stressor and the relationship of the data to the assessment endpoint.

stressor source: An entity or action that releases to the environment or imposes on the environment a chemical, physical, or biological stressor or stressors.

uncertainty analysis: Part of the risk assessment process that describes, either quantitatively or qualitatively, the relative magnitude of uncertainties and their implications for the assessment.