United States Environmental Protection Agency

Office of Solid Waste and Emergency Response

Publication 9345.0-05I
December 1991

ECO Update

Office of Emergency and Remedial Response
Hazardous Site Evaluation Division (OS-230)

Intermittent Bulletin
Volume 1, Number 2

Ecological Assessment of Superfund Sites: An Overview

This document is the second issue of the *ECO Update* series of intermittent bulletins, published by the Toxics Integration Branch, Hazardous Site Evaluation Division, Office of Emergency and Remedial Response. Practical experience with the process of ecological assessment at Superfund sites has pointed to the need for information and guidance concerning both the scientific and management aspects of ecological assessment. The *ECO Update* series is intended to fill this need.

Ecological Assessment of Superfund Sites: An Overview is an updated framework for ecological assessment in the Superfund program. As such, it offers a description of ecological assessment components and a discussion of how they fit into the Remedial Investigation and Feasibility Study (RI/FS) process. Ecological assessment in the removal process will be addressed in a future *ECO Update.*

The *ECO Update* Series

ECO Updates are a series of Intermittent Bulletins intended to facilitate ecological assessment of Superfund sites. Each Bulletin focuses on one aspect of ecological studies or ecological assessment in the remedial process. Individual Bulletins may discuss either technical methods or the management of ecological assessments.

Limiting each Bulletin to a specific topic allows flexibility for the user to select only those Bulletins that are applicable to the site in question or the user's needs. For example, some sites do not require toxicity tests, so investigators would not need to consult Bulletins specific to testing. A user who needs only general information on Natural Resource Trustees can refer to a specific Bulletin on that topic and not have to look through a larger document containing other, less relevant information.

The Bulletin series is written for both general and technical audiences, which includes EPA site managers and staff, contractors, State personnel, and anyone else involved in the performance, supervision, or evaluation of ecological assessments in Superfund.

Ecological assessment involves considerable professional judgement. The *ECO Updates* assume that readers will confer with qualified scientists for site-specific advice. These Bulletins are not step-by-step guides on how to accomplish an assessment. The series supplements the advisory process involving Regional Biological Technical Assistance Groups (BTAGs). EPA staff should consult their BTAG coordinator for more detailed information on ecological assessment in their Region.

Background

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, requires EPA to remediate uncontrolled hazardous waste sites in ways that will protect both human health and the environment. To fulfill this mandate, the National Oil and Hazardous Materials Contingency Plan (NCP) requires that

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the baseline risk assessment, which is conducted during the Remedial Investigation and Feasibility Study (RI/FS), "characterize the current and potential threats to human health and the environment."[1] The NCP also specifies that "[e]nvironmental evaluations shall be performed to assess threats to the environment, especially sensitive habitats and critical habitats of species protected under the Endangered Species Act."[2]

In December 1988, the Office of Emergency and Remedial Response (OERR) and the Office of Waste Programs Enforcement issued a joint memorandum to Regional Division responsible for Superfund, directing that "thorough and consistent" ecological assessments be performed at all Superfund sites in both the removal and remedial programs. In particular, the directive called on the Regions to incorporate ecological assessments into the RI/FS stage during development of the work plan, and to discuss the ecological assessment in the Proposed Plan for site remediation.

To assist the Regions in implementing this policy, OERR issued the Superfund Environmental Evaluation Manual [3] in March 1989 to provide site managers with a general framework for understanding the ecological assessment process. The manual is predicated on the understanding that ecological assessment combines careful observation, data collection, testing, and professional judgement. Hence, the manual's principal goal is to introduce the subject to site managers and encourage them to seek the advice and assistance of the Regional BTAG.[4]

What is an Ecological Assessment?

The Environmental Evaluation Manual defines ecological assessment as:

…a qualitative and/or quantitative appraisal of the actual or potential effects of a hazardous waste site on plants and animals other than people or domesticated species.

In practical terms, ecological assessment comprises four interrelated activities:

- **Problem Formulation—**qualitative evaluation of contaminant release, migration, and fate; identification of contaminants of concern, receptors, exposure pathways, and known ecological effects of the contaminants; and selection of endpoints[5] for further study.
- **Exposure Assessment**—quantification of contaminant release, migration, and fate; characterization of exposure pathways and receptors; and measurement or estimation of exposure point concentrations.
- **Ecological Effects Assessment**—literature reviews, field studies, and toxicity tests, linking contaminant concentrations to effects on ecological receptors.
- **Risk Characterization—**measurement or estimation of both current and future adverse effects.

These components of ecological assessment are illustrated in Figure 1. As the diagram indicates, each element in the process can affect others. In reality, investigators frequently find that the components do not always follow one another in a stepwise manner, and may actually find themselves working on aspects of all four components at the same time.

Problem Formulation

Problem Formulation defines the objectives and scope of the ecological assessment. This component of an ecological assessment primarily involves a review of existing data (including previous studies of the site, such as the Preliminary Assessment, Site Inspection, RI Field Investigation, and other sources). Its end product is a conceptual model that identifies the environmental values to be protected, the data needed, and the analyses to be used.

The problem formulation component may be difficult to distinguish from exposure assessment or ecological effects assessment. This situation arises from elements (e.g., effects and receptors) shared among these three components. Problem formulation differs from the other two components in the level of detail and quantification. The difference lies in the distinction between **identification** (i.e., naming and listing) of these common elements and **characterization** (i.e., description and quantification). In problem formulation, investigators:

- Focus on collecting preliminary information necessary to design the exposure and ecological effects assessment, and
- Identify data needed to complete those assessments.

Qualitative Evaluation of Contaminant Release, Migration, and Fate

This portion of problem formulation describes what is known about contaminated media, contaminant movement, and the geographical extent of current and future contamination. Ecological considerations for contaminant release, migration, and fate include:

[1] 40 CFR Part 300.430 (d)(4).

[2] 40 CFR Part 300.430(e)(2)(i)(G).

[3] U.S. Environmental Protection Agency, *Risk Assessment Guidance for Superfund, Volume II: Environmental Evaluation Manual* (EPA/540-1-89/001), 1989.

[4] These groups are sometimes known by different names, depending on the Region, and not all Regions have established BTAGs. Readers should check with the appropriate Superfund manager for the name of the BTAG coordinator or other sources of technical assistance in their Region.

[5] An **endpoint** is an expected or anticipated effect of a contaminant on an ecological receptor. Endpoints are discussed at greater length in the section on Problem Identification.

- Ground water discharge to surface water and wetlands,
- Transport of contaminated sediment,
- Runoff from and erosion of contaminated soils, and
- Bioaccumulation and bioconcentration.

Identification of Contaminants of Concern

Not all contaminants warrant equal attention with regard to risk. Further, not all contaminants that pose human health risks are important with respect to ecological risk—and vice versa. Factors to consider in identifying a contaminant of ecological concern include its:

- **Environmental concentration** in media (soils, surface water, ground water, sediments, air, and biota) representing ecological exposure pathways;
- **Frequency of occurrence,** defining the prevalence of the contaminant in site media;
- **Background levels,** indicating the concentrations that cannot be attributed to the site;
- **Bioavailability,** or presence in a form that can affect organisms;
- **Physical-chemical properties,** such as volatility and solubility;
- **Potential for bioaccumulation or bioconcentration,** based on its physical-chemical properties and its tendency to occur in biota at higher concentrations than the surrounding environment;
- **Potency,** or the amount of toxicant capable of producing adverse effects; and
- **Effects,** such as acute lethality or sublethal responses (e.g., reproductive impairment).

Identification of Exposure Pathways

Based on the analysis of contaminant release, migration, and fate, investigators identify potential exposure pathways for ecological receptors. An exposure pathway is the link between a contaminant source and a receptor. In evaluating exposure pathways, the analyst should consider all media (groundwater, surface water, sediments, soils, air, and biota) that are or could be contaminated. For example, exposure may be the result of direct contact with contaminated media (e.g., dermal, uptake through gills, ingestion) or exposure through the food chain. Investigators should consider all potential receptors when identifying exposure pathways.

Identification of Receptors

Receptors are individual organisms, populations, or communities that can be exposed to a contaminant. Identification of receptors arises from a review of the fate, migration, and potential release of contaminants. Ecologists begin by identifying potentially exposed habitats on or near the site using a wide variety of methods, including field reconnaissance, aerial photography, satellite imagery, and a review of previous studies to accomplish this task. As they identify potentially exposed habitats, ecologists develop lists of species known or likely to occur in each habitat. Identification of receptors should include:

- Species considered essential to, or indicative of, the healthy functioning of the habitat (e.g., stream invertebrates);
- Rare endangered or threatened species on or near the site; and
- Species protected under Federal or State law (e.g., Migratory Bird Treaty Act, Marine Mammal Protection Act).

Identification of Known Effects

Many sources, including databases and publications, contain information on ecological effects of contaminants. For example, EPA's Ambient Water Quality Criteria (AWQC) Documents and AQUatic Toxicity Information REtrieval (AQUIRE) database contain peer-reviewed data describing effects of contaminants on aquatic (freshwater and marine) organisms. Data on terrestrial effects and aquatic information not included in the AWQC documents or AQUIRE are available in the published literature. Where appropriate, data on chemicals similar but not identical to site contaminants can help characterize likely effects. Modeling techniques, such as Quantitative Structure Activity Relationships (QSAR), sometimes help in identifying surrogate chemicals for data collection. These methods require specialized expertise to ensure proper selection of surrogates and interpretation of results.

Site managers should obtain information from other investigations conducted on or near the site, to help target the ecological assessment toward the most relevant questions. Examples of such information include:

- Field or laboratory studies from previous investigations of the site;
- Corroborated reports of unusual events such as fish kills, other animal mortality, highly stressed vegetation, or absence of species that experts would expect in the habitat; and
- Fish or wildlife consumption advisories issued by State or local government agencies.

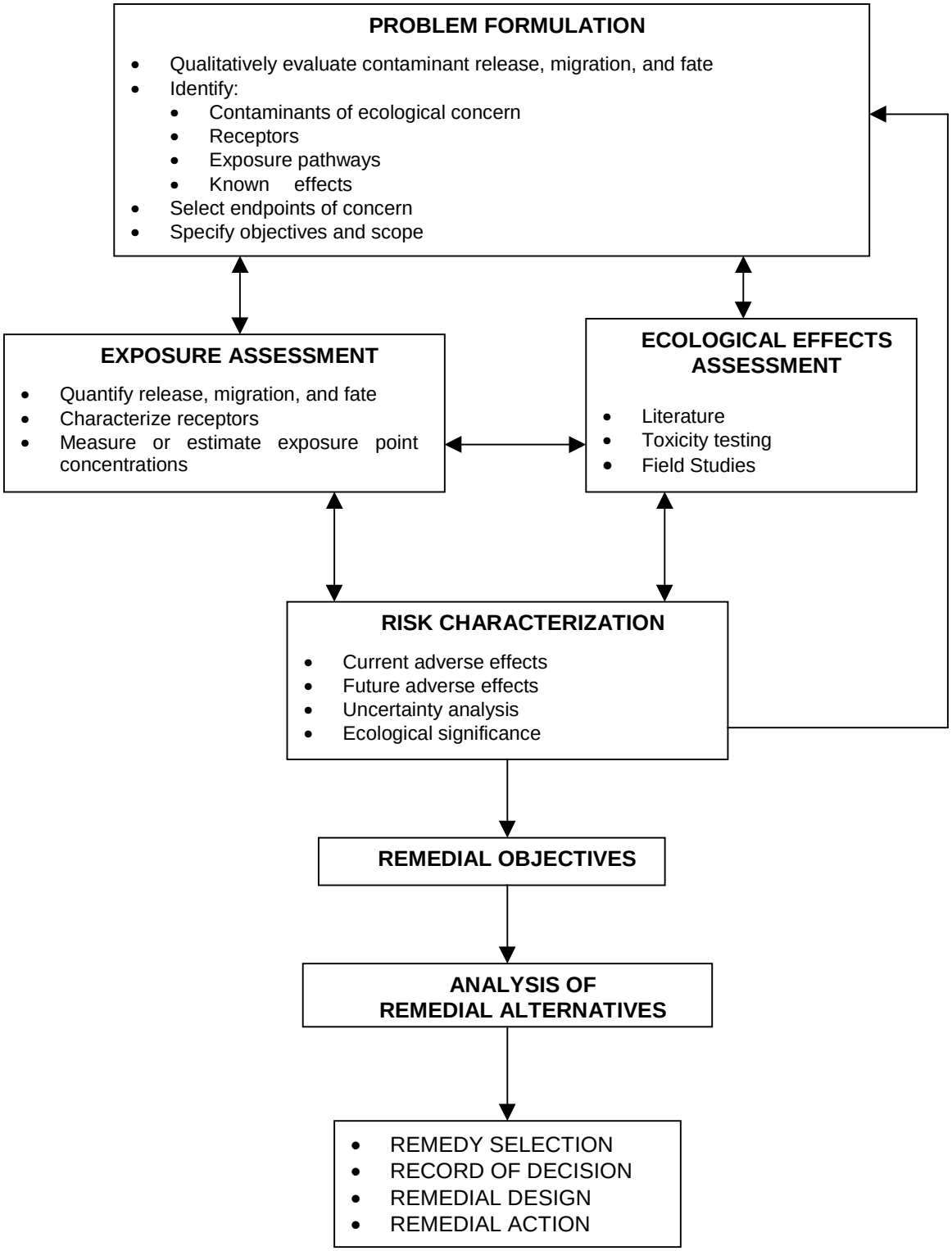
Selection of Endpoints

Investigators next identify effects requiring further study. These are known as **endpoints**. Risk assessors distinguish between two types of endpoints. An **assessment endpoint** describes the effects that drive decision making, such as reduction of key populations or disruption of community structure. **Measurement endpoints** approximate, represent, or lead to the assessment endpoint, using field or laboratory methods.[6] An assessment endpoint often has more than one

[6] Glenn W. Suter II, "Ecological Endpoints," Chapter 2 in USEPA, *Ecological Assessment of Hazardous Waste Sites: A Field and Laboratory Reference* (EPA/600/3-89/013).

Ecological Assessment of Superfund Sites: Overview

Figure 1



measurement endpoint associated with it. Most studies have more than one set of assessment and measurement endpoints.

The critical step in selecting endpoints is deciding what effects are important to remedial decision making. The assessment endpoint should reflect a potentially significant ecological impact. Primary criteria for selecting measurement endpoints are based on their usefulness in linking field or laboratory data to the assessment endpoint.

For example, the assessment endpoint for a particular site might be the probability of a significant reduction of a fish population. The measurement endpoint used to arrive at such a probability might be the chemical concentration shown to cause a reduction in survival, growth, or reproduction in a standard laboratory toxicity test.

Ecologists often select more definitive site-specific measurement and assessment endpoints during the exposure assessment component. Information on contaminant migration, fate and other factors, discussed below under "Exposure Assessment," influences the choice of appropriate endpoints.

Specifying Objectives and Scope

The purpose of the activities described above is to identify the preliminary objectives and scope of the ecological assessment and additional data needed to complete the assessment. This is critical to the assessment process. It ensures that data collection, field studies, laboratory tests, and the overall assessment can answer the questions relevant to making remedial decisions.

Ecological assessment is an iterative process. As such, investigators often must revise the objectives and scope of the ecological assessment as they collect and analyze site data. Using such information, they can identify a need for more study, different studies, or fewer studies.

Exposure Assessment

Exposure assessment quantifies the magnitude and type of actual and/or potential exposures of ecological receptors to site contaminants. The key elements in exposure assessment are:

- Quantification of contaminant release, migration, and fate;
- Characterization of receptors; and
- Measurement or estimation of exposure point concentrations.

Exposure assessment often involves considerable effort and technical expertise to complete. Site managers should consult with their Regional BTAG to identify specific approaches for evaluating ecological exposure.

Quantification of Release, Migration, and Fate

In the Exposure Assessment phase, investigators develop estimates of current and future contaminant levels in affected media, including all relevant spatial and temporal characteristics of the contamination. These estimates can then be used to determine exposure point concentrations (discussed below).

Direct sampling of media yields information on the current location and concentration of contaminants. Fate-and-transport models predict the movement of contaminants from the source and between media. Site managers should consult their BTAGs and other Regional specialists about sampling design, sample placement and timing, and the availability and selection of models applicable to their sites.

Characterization of Receptors

Most sites requiring ecological assessments contain a large number of species, populations, and communities—from microbes to mammals, from algae to trees. Evaluating risks for each and every species present is impossible. To develop a reasonable and practicable evaluation, the investigator focuses on a limited number of receptors for the assessment. Ecologists select these receptors based on the endpoints of concern and specific characteristics of the site under study.

In characterizing receptors, investigators collect information (primary from published literature) on the species' feeding habits, life histories, habitat preferences, and other attributes that could affect their exposure or sensitivity to contaminants.

Exposure Point Concentrations

After identifying receptors, and selecting a subset of those receptors, investigators estimate the concentration of contaminant(s) in the media to which the receptors are exposed. This is known as the **exposure point concentration**, which investigators measure in the environmental medium or estimate using assumptions and/or fate-and-transport modeling.

The amount of contaminant a receptor takes in depends on such factors as:

- The properties of the contaminant,
- The way the organism assimilates it (e.g., direct absorption, ingestion),
- The nature of the receptors (e.g., behavior, life history), and
- The physical/chemical properties of the media (e.g., pH, hardness, organic carbon content).

If a contaminant is known or expected to bioconcentrate or bioaccumulate, investigators collect and analyze samples from biota at two or more trophic levels (e.g., plant, herbivore, carnivore) along with surrounding media. Risk assessors use this information in two ways:

- Directly, as exposure point concentrations for dietary exposure pathways for ecological receptors; or
- Indirectly, for calculating site-specific bioconcentration factors (BCFs) or bioaccumulation factors (BAFs) to predict the food-chain transfer of contaminants to organisms at higher trophic levels.

Ecological Effects Assessment

This component concerns quantitatively linking concentrations of contaminants to adverse effects in receptors. Literature reviews, field studies, and/or toxicity testing provide this "dose-response" information: that is, *how much* toxicant is associated with *how much* of an adverse effect.

Literature Reviews

Organisms differ widely in their ability to tolerate toxicants, depending on several factors, including environmental conditions, the nature of the chemical, the age and reproductive status of the organism, and inherent differences among species. Literature reviews can provide specific dose-response information for the species under study.

Dose-response information is useful in risk characterization (discussed below) or as the basis for further ecological effects studies. By comparing measured concentrations of contaminants in site media with literature values for adverse effects, investigation can decide whether they need to proceed with site-specific investigations such as field studies or toxicity tests.

Field Studies

Ecological field studies offer direct or corroborative evidence of a link between contamination and ecological effects. Such evidence could include:

- Reduction in population sizes of species,
- Absence of species normally occurring in the habitat,
- Presence of species associated primarily with stressed habitats,
- Changes in community diversity or trophic structure, and
- Incidence of lesions, tumors, or other pathologies.

Ecologists usually compare data on observed adverse effects to information obtained from a reference area not affected by contamination from the site. For instance, for a stream contaminated by a waste site, the reference site might be an area upstream from the source of contamination, or a nearby-uncontaminated stream with similar physical characteristics.

Investigators must collect chemical and biological data simultaneously. This allows them to determine if a correlation exists between contaminant concentrations and ecological effects.

Toxicity Testing

Toxicity tests evaluate the effects of contaminated media on the survival, growth, reproduction, and metabolism of test organisms. When ecologists review test results along with data on chemical concentrations and biological observations from field studies, they often find convincing evidence that observed or predicted effects are attributable to the presence of hazardous substances. Investigators also use toxicity tests to demonstrate the spatial extent of contamination and identify areas of high contaminant concentrations.

Risk Characterization

The science of risk assessment in ecology has not evolved to the point where scientists can make standard risk calculations for common risk scenarios, as they often do in human health evaluations at Superfund sites. Risk characterization in ecological assessment is a process of applying professional judgement to determine whether adverse effects are occurring or will occur as a result of contamination associated with a site.

Risk characterization is primarily a process of comparing the results of the exposure assessment with the results of the ecological effects assessment. Available methods (either quantitative or qualitative) seek to answer the following questions:

- Are ecological receptors currently exposed to site contaminants at levels capable of causing harm, or is future exposure likely?
- If adverse ecological effects are observed or predicted, what are the types, extent, and severity of the effects?
- What are the uncertainties associated with the risk characterization?

The risk characterization concludes with a risk description, which (1) includes a summary of the risks and uncertainties, and (2) interprets the ecological significance of the observed or predicted effects. The risk description is a key step in communicating ecological risks to site managers and decision makers. When ecologists interpret and communicate ecological significance for the risk description, they should consider such factors as the nature and magnitude of the effects, the spatial and temporal distribution of the effects, and the potential for recovery.

Ecological Assessment in the RI/FS Process

Because the RI/FS supports risk-management decision making, assessment of ecological risk plays an essential role. Figure 2 shows where ecological information is necessary in the RI/FS and post-RI/FS activities.

Scoping of the RI/FS

Scoping of the ecological assessment should begin with, and be included as part of, the overall RI/FS scoping process to :

- Help identify the kinds of remedial decisions that site managers need to make,
- Determine the types of ecological data investigators need to support decision making, and

- Design field and/or laboratory studies for collecting those data.

Ecologists should participate in developing a conceptual model of the site. The ecological portion of this model is developed during the Problem Formulation phase of the ecological assessment.

Ecological assessment can be complex undertaking. For this reason, site mangers need to consult with their BTAGs while preparing work scopes. For most sites, Remedial Project Managers should develop a phased approach to the ecological assessment with expert review at each phase. In this way, investigators can use data or observations from one phase to determine the most appropriate studies for the next phase.

RI/FS Site Characterization

The Site Characterization phase of the RI/FS requires a baseline risk assessment, which includes an ecological assessment. The purposes of this ecological assessment are to:

- Describe the observed or potential magnitude of adverse ecological effects at the site and the primary cause of the effects, and
- Characterize the ecological consequences of the "no further action" remedial alternative.

Site managers should ensure that ecological studies for the baseline risk assessment are completed during the field investigation phase of site characterization.

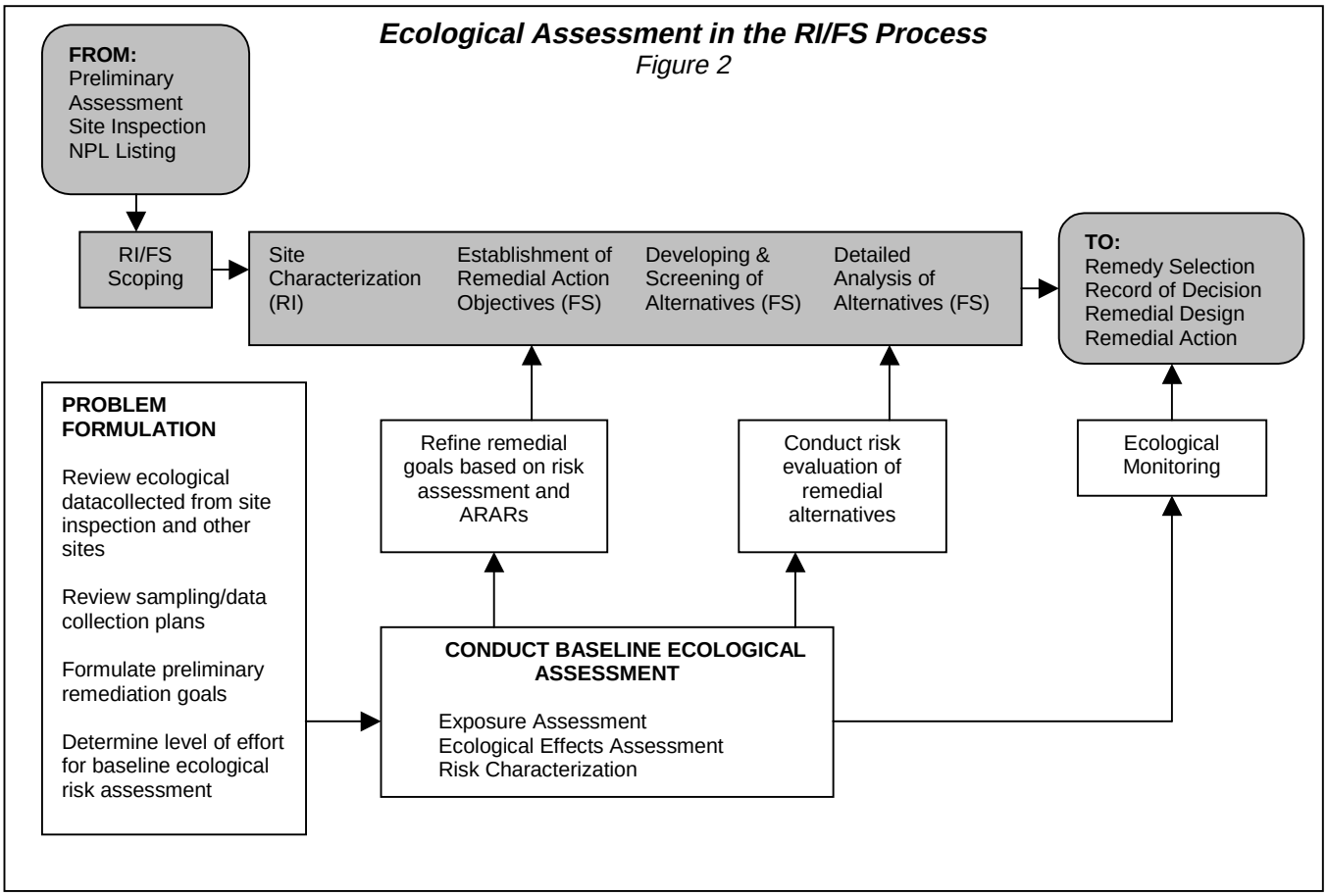
Feasibility Study

Ecological information contributes to the Feasibility Study (FS) process by assisting decision makers in the assessment and selection of remedial alternatives. In developing preliminary remediation goals (PRGs), investigators must address the results of the ecological assessment and other ecological issues specified in criteria, guidance, and applicable or relevant and appropriate requirements (ARARs).

Most FSs examine numerous remedial alternatives. In such cases, site managers must screen the alternatives to narrow the list that will be evaluated in detail. The ecological assessment helps this detailed analysis of alternatives by identifying risks or benefits of each with respect to ecological receptors. The analyses and conclusions of the ecological assessment can provide information on:

- The effectiveness of the alternative in reducing ecological risks associated with contamination, and
- The ecological effects that may result from the remedial action (e.g., habitat destruction).

The ecological assessment can provide information for ecological monitoring during remedial and post-remedial activities. For detailed advice on applying ecological information to the FS process, site managers should consult their Regional BTAGs.


Ecological Assessment in the RI/FS Process
Figure 2
FROM:
Preliminary Assessment
Site Inspection
NPL Listing
RI/FS Scoping
Site Characterization (RI)
Establishment of Remedial Action Objectives (FS)
Developing & Screening of Alternatives (FS)
Detailed Analysis of Alternatives (FS)
TO:
Remedy Selection
Record of Decision
Remedial Design
Remedial Action
PROBLEM FORMULATION
Review ecological datacollected from site inspection and other sites
Review sampling/data collection plans
Formulate preliminary remediation goals
Determine level of effort for baseline ecological risk assessment
Refine remedial goals based on risk assessment and ARARs
Conduct risk evaluation of remedial alternatives
Ecological Monitoring
CONDUCT BASELINE ECOLOGICAL ASSESSMENT
Exposure Assessment
Ecological Effects Assessment
Risk Characterization