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EPA

Risk Assessment Guidance for Superfund Volume II Environmental Evaluation Manual

Interim Final

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The policies and procedures set forth here are intended as guidance to Agency and other government employees. They do not constitute rulemaking by the Agency, and may not be relied on to create a substantive or procedural right enforceable by any other person. The Government may take action that is at variance with the policies and procedures in this manual.

Preface

This document is part of a two-manual set entitled *Risk Assessment Guidance for Super fund. One* manual, the *Environmental Evaluation Manual,* provides guidance for ecological assessment at Superfund sites; the other, the *Human Health Evaluation Manual*, provides guidance for health risk assessment at these sites. Guidance in both areas is needed so that EPA can meet the requirements of sections 121 (b) (l) and (d) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), namely, that selected remedial actions be protective of human health and the environment. This risk assessment guidance also can assist EPA in complying with other CERCLA directives. For example, Section 121(c) requires future reviews to ensure that human health and the environment continue to be protected at sites where contaminants remain after remedial actions were completed.

The *Risk Assessment Guidance for Superfund* manuals were developed to be used during the Removal and Remedial Investigation/Feasibility Study (RI/FS) processes at Superfund sites. The analytical framework and specific methods described in the manuals, however, may also be applicable to evaluations of hazardous wastes and hazardous materials for other purposes. For the RI/FS process, these manuals are companion documents to EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (October 1988), and users should be familiar with that guidance. The two Superfund risk assessment manuals were developed with extensive input from EPA workgroups composed of both Regional and Headquarters staff. These manuals are interim final guidance; final guidance will be issued after the revisions to the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), proposed in December 1988, become final.

Although environmental evaluation and human health evaluation are different processes, they share certain information needs and generally will use some of the same chemical and other data for a site. Planning for both evaluations should begin during the scoping stage of the RI/FS, and site sampling and other data collection activities to support the two evaluations should be coordinated. An example of this type of coordination is the sampling and analysis of fish or other aquatic organisms; if such sampling is done properly, data can be used in assessing human health risks from ingestion of fish and shellfish and in assessing impacts to, and potential effects on, the aquatic ecosystem.

The two manuals in this set have somewhat different target audiences. The *Environmental Evaluation Manual* primarily addresses Remedial Project Managers (RPMs) and On-Scene Coordinators (OSCs), who are responsible for ensuring a thorough evaluation of potential environmental effects at sites. The *Environmental Evaluation Manual* is not a detailed "how-to" type of guidance, and it does not provide "cookbook" approaches for evaluation. Instead, it identifies the kinds of help that RPMs or OSCs are likely to need and where to find that help. Then it describes an overall framework for considering environmental effects. A detailed discussion of environmental evaluation methods may be found in *Ecological Assessments of Hazardous Waste Sites: A Field and Laboratory Reference Documnet (EPA/600/3-89/013),* published by EPA's Office of Research and Development. The *Human Health Evaluation Manual,* available in 1989, provides a basic framework for health risk assessment at Superfund sites. The health evaluation manual is addressed primarily to the individuals actually conducting health risk assessments for sites and who are frequently contractors to EPA, States, or potentially responsible parties. It is also targeted to EPA staff, including those responsible for ensuring a thorough evaluation of human health risks (i.e., RPMs). The *Human Health Evaluation Manual* replaces a previous EPA guidance document, *The Superfund Public Health Evaluation Manual,* or SPHEM (October 1986), which should be used until the Interim *Final Human Health Evaluation Manual* is available. The new manual incorporates lessons learned from application of the earlier manual and addresses a number of issues raised since publication of the SPHEM.

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Acknowledgments

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This manual is the product of an extensive planning and review process within EPA. The EPA Work Group, which also included representatives from the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Fish and Wildlife Service (USFWS), conferred several times to discuss the organization, content, and policy implications of the document. The Work Group members reviewed and provided extensive comments on each of several drafts of the manual. In the early stages of the project, members of the Region 111 Bioassessment Work Group - Dr. David Charters (EPA Environmental Response Team), Dr. Alyce Fritz (NOAA, Region III), and Ronald Preston (Environmental Services Division, EPA Region III) - provided invaluable planning assistance.

The authors were privileged to have as a reference a draft version of a manual prepared by the Ecological Risk Assessment Subcommittee of the EPA Region I Risk Assessment Work Group. The document, entitled *Guidance for Ecological Risk Assessments*, was issued as a Draft Final in February 1989. Concepts and some wording of the Region I document were adapted for use in several parts of this manual. We gratefully acknowledge the Subcommittee's cooperation (in particular, Susan Norton of the Office of Health and Environmental Assessment) in making their draft available to us.

Chapter 1
Introduction

This manual is intended to help Remedial Project Managers (RPMs) and On Scene Coordinators (OSCs) manage environmental evaluation of Superfund sites. Environmental evaluation is an important part of the Remedial and Removal processes. Since RPMs and OSCs have primary responsibility for managing these processes, it is important for them to understand basic ecological concepts and how they relate to hazardous waste remediation.

Environmental evaluation at Superfund sites should provide decision makers with information on threats to the natural environment associated with contaminants or with actions designed to remediate the site. Decisions such as those made on Superfund sites are necessarily made with varying degrees of uncertainty. The environmental evaluation is intended to reduce the inevitable uncertainty associated with understanding the environmental effects of a site and its remediation, and to give specfic boundaries to that uncertainty. However, it is important to recognize that **environmental evaluations are not research projects they are not intended to provide absolute proof of damage, nor are they designed to answer long-term research needs.** Not all sites will require environmental evaluations. Indeed, many are in industrial areas with little if any wildlife. For those sites that do need to be evaluated, the RPM or OSC is responsible for determining the level of effort appropriate to the decisions required for each site.

The purpose of this document is to provide a scientific framework for designing studies, at the appropriate level of effort, that will evaluate pertinent ecological aspects of a site for the Remedial and Removal processes. These ecological aspects include:

- Living resources at or near the site requiring protection,
- Effects of the site's contaminants on those resources, and
- Effects of remedial actions.

This manual does not offer detailed descriptions of specific field or laboratory methods; these are discussed in a companion publication prepared by EPA's Office of Research and Development, ***Ecological Assessments of Hazardous Waste Sites: A Field and Laboratory Reference Document.*** The ***Superfund Exposure Assessment Manual*** describes methods for estimating and modeling the fate and transport of contaminants in the environment. Other information that should be used to supplement this manual may be found in these and the other publications listed in Table 1.1.

The manual is based on the assumption that RPMs and OSCs will obtain assistance from technical specialists as early as possible in the assessment process, and is designed to facilitate communication between the RPM or OSC and these specialists. Support for designing and evaluating ecological assessments is available from technical assistance groups in those EPA Regions that have formed them. In other Regions, ecologists may be found on the staffs of other EPA offices and contractors, or on the staffs of other Federal agencies. The role of these specialists is discussed in greater detail in Chapter 4.

1.1 What is Ecological Assessment?

Although "environmental evaluation" has been a commonly used term for this process, ecological assessment is a more precise description of the activity, and will be used throughout this manual.

Ecological assessment, as discussed in this manual, is **a qualitative and/or quantitative appraisal of the actual or potential effects of a hazardous waste site on plants and animals other than people and domesticated species.** It is important to emphasize, however, that the health of people and domesticated species is inextricably linked to the quality of the environment shared with other species. Information from ecological studies may point to new or unexpected exposure pathways for human populations, and health assessments may help to identify environmental threats.

Table 1.1 Additional EPA Documents to be Consulted

Title	Source	Reference No.
Superfund Exposure Assessment Manual (1988)	Office of Solid Waste and Emergency Response	EPA/540/1-88/001
Ecological Assessments of Hazardous Waste Sites A Field and Laboratory Reference Document (1989)	Office of Research and Development - Corvallis Environmental Research Laboratory	EPA/600/3-89/013
Ecological Information Resources Directory (1989)	Office of Information Resource Management	In Preparation
User's Guide to the Contract Laboratory Program (1989)	Office of Emergency and Remedial Response	OSWER Dir. 9240.0-1
Estimating Toxicity of Industrial Chemicals to Aquatic Organisms Using Structure Activity Relationships (1988)	Office of Toxic Substances	EPA/560/6-88/001
CERCLA Compliance with Other Laws Manual (1988)	Office of Solid Waste and Emergency Response	EPA/540/6-89/006
Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (Interim Final, 1988)	Office of Solid Waste and Emergency Response	EPA/540/6-89/004

1.2 *Ecological Assessment in the Superfund Process*

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), calls upon EPA to protect human health and the environment with respect to releases or potential releases of contaminants from abandoned hazardous waste sites. The proposed revision of the National Contingency Plan (NCP) calls for identification and mitigation of the environmental impacts of these sites and the selection of remedial actions that are "protective of environmental organisms and ecosystems." In addition, numerous Federal and State laws and regulations concerning environmental protection are potentially "applicable or relevant and appropriate requirements" (ARARs). Compliance with these laws and regulations may require evaluation of a site's ecological effects and the measures needed to mitigate those effects. The specific legislative and other mandates for ecological assessment are discussed in Chapter 2 of this manual.

Ecological assessment may take place before, during and after removal and remedial actions. Removal actions, directed by the OSC, are generally taken in response to an immediate hazard. When an emergency response is under consideration, the ecological assessment associated with removal actions must be performed quickly. Existing information, augmented by any field data that can be collected in a short period of time, will be used to:

- Decide if removal is necessary based on ecological considerations,
- Predict the ecological effects of removal actions, and
- Provide preliminary information to support a Remedial Investigation if one is needed.

Ecological data should also be gathered before and during remedial action, under the direction of the RPM. These data will be used to:

- Determine the appropriate level of detail for the ecological assessment,
- Decide if remedial action is necessary based on ecological considerations,
- Evaluate the potential ecological effects of the remedial action itself,
- Provide information necessary for mitigation of the threat, and
- Design monitoring strategies for assessing the progress and effectiveness of remediation.

A detailed assessment may be required to determine whether or not the potential ecological effects of the contaminants at a site warrant remedial action. Although human health is frequently the major concern, the ecological assessment may serve to expand the scope of the investigation, enlarging the area under consideration, or redefining remediation criteria, or both. Therefore, when appropriate, the Scope of Work for the Remedial Investigation /Feasibility Study (RI/FS) should be written to incorporate ecological investigations as early as possible in the process.

The RPM also evaluates the alternatives outlined in the RI/FS to determine whether the proposed remedial action itself will have any deleterious environmental effects. For example, if dredging is included as part of a remedial alternative, the effects of the dredging on aquatic organisms living on or in the sediments will very likely need to be considered. If a remediation plan proposes channeling a stream into a new drainage area, the downstream effects on wetlands may require investigation.

Finally, ecological assessment may suggest strategies for monitoring the progress and effectiveness of remediation at or near a site. For example, toxicity tests of soils, sediments, and water have been used to supplement chemical residue data in establishing cleanup criteria. On-site toxicity tests may be more sensitive to low levels of contaminants than other monitoring methods, and may indicate toxicity of mixtures of contaminants more readily than single-chemical criteria.

Environmental evaluation and human health evaluation are parallel activities in the evaluation of hazardous waste sites. As Figure 1.1 illustrates, much of the data and analyses relating to the nature, fate, and transport of a site's contaminants will be used for both evaluations. At each point of these common stages, however, analysts should be sensitive to the possibility that certain contaminants and exposure pathways may be more important for the environmental evaluation than for the health evaluation, or vice versa. It is also important to recognize that each of the two evaluations can sometimes make use of the other's information. For example, the potential of a contaminant to bioaccumulate may be estimated for a health evaluation but be useful for the environmental evaluation. Similarly, measurement of contaminant levels in sport and commercial species for an environmental evaluation may yield useful information for the health evaluation.

1.3 Who Should Read this Manual?

This manual is designed for use by Remedial Project Managers and On Scene Coordinators. The following may also find the manual useful for understanding the ecological assessment process as it relates to Superfund sites:

- EPA Regional Office managers of RPMs or OSCs,
- State hazardous waste officials who wish to undertake ecological assessments of their own,
- EPA contractors and others who may perform ecological assessments,
- Ecologists who have no past experience with Superfund ecological assessments, and
- Potentially responsible parties (if they are performing the work at the site).

1.4 Organization of the Manual

This manual is intended to address the following questions:

- How does ecological assessment help EPA meet its statutory responsibilities?
- What is the underlying scientific basis for ecological assessment?
- How should the RPM or OSC use technical specialists in managing ecological assessments?
- What kinds of data are necessary for ecological assessments?

The chapters following this introduction are

- Chapter 2: Statutory and Regulatorv Basis of Ecological Assessment,
- Chapter 3: Basic Concepts for Ecological Assessment,
- Chapter 4: The Role of Technical Specialists in Ecological Assessment,
- Chapter 5: Planning an Ecological Assessment, and
- Chapter 6: Organization and Presentation of an Ecological Assessment

As Figure 1.2 illustrates, Chapters 2 through 4 provide introductions to different aspects of the ecological assessment process. Chapters 5 and 6 then provide more specific guidance on the information needed in an ecological assessment.

Chapter 2 describes the authority provided by CERCLA (as amended by SARA), requirements contained in the National Contingency Plan, and references to ecological assessment in the RI/FS and Removal Guidances. The chapter also discusses Federal standards, requirements, criteria, or limitations that are potential ARARs.

Chapter 3 describes the basic scientific concepts underlying ecological assessment. It is intended to assist the RPM or OSC in working with the ecologists who will provide technical advice or perform the studies, by describing the conceptual framework within which these specialists make their judgments. This chapter defines numerous terms that are used later in the manual. Readers who are familiar with the concepts and terminology of ecology and environmental chemistry may choose to skim this chapter or skip it entirely.

Chapter 4 details the role of technical specialists in ecological assessment. Their primary function is to assist the RPM and the OSC in directing the collection and evaluation of information on ecological effects. They may serve as advisers or may actually

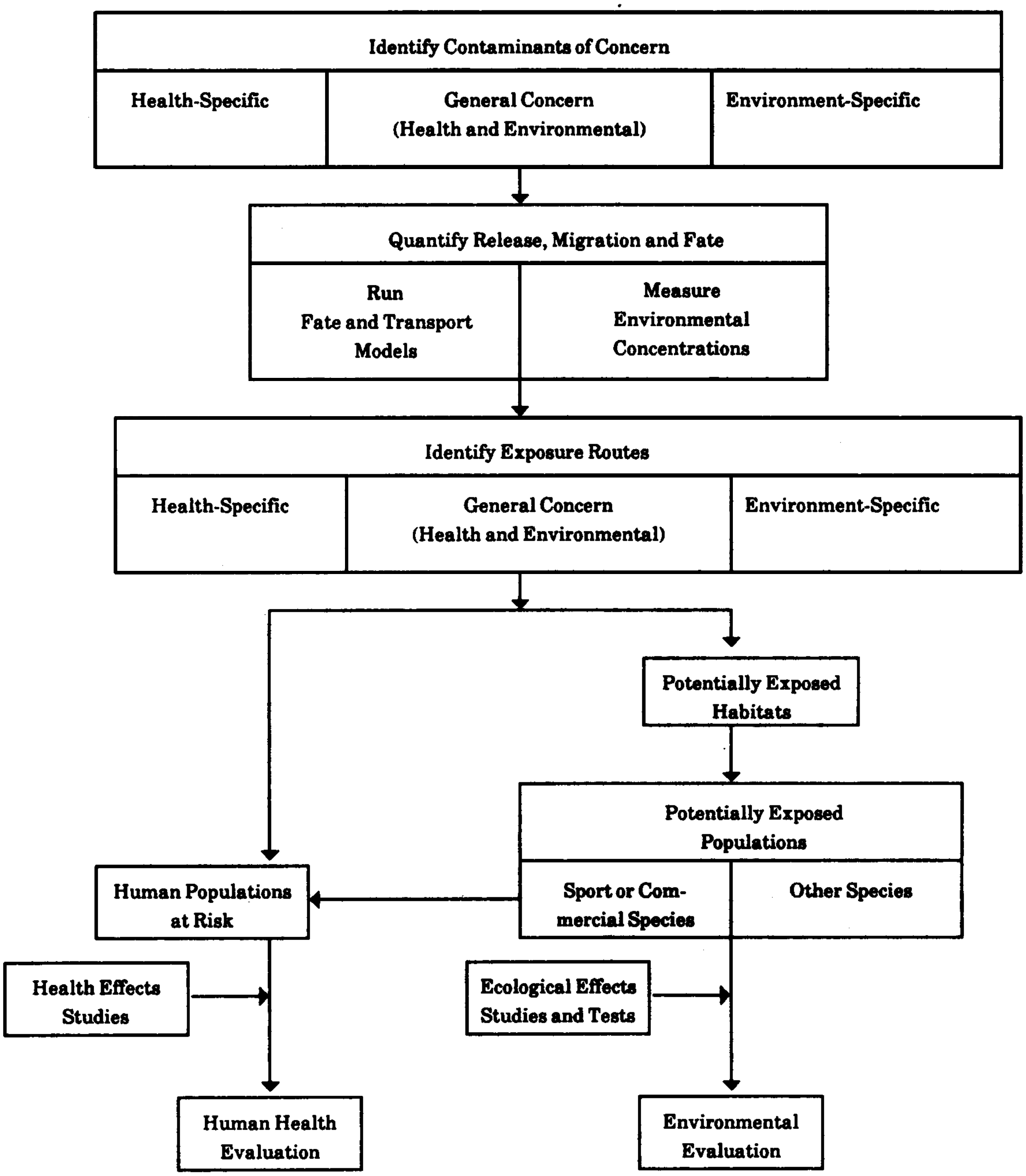

Figure 1.1 **Relationship between health and environmental evaluations.**

perform the ecological assessment under the direction of the RPM or the OSC.

Chapter 5 discusses the process of developing an appropriate study design for assessment of a site, including evaluation of contaminants of concern, site characteristics, and ecological assessment endpoints. In addition to specifying study objectives, this phase must also address quality assurance and quality control (QA/QC) issues associated with the assessment.

Chapter 6 describes a basic outline for an assessment. Although each site's assessment will differ according to the details of the contaminants, exposure routes, potentially affected habitats, and species, this chapter provides a checklist of items for the RPM or OSC to expect when overseeing the preparation of an assessment. For any individual site, expansion of the topics here maybe needed, with appropriate explanations.

This manual is an introduction to a complex subject. Assessment of an actual site requires a detailed knowledge of the habitats and species that are potentially exposed, the activity and movement of contaminants in the environment, and the sampling and analytical methods needed to make scientifically defensible judgments. Use of this manual will provide a basis for the successful management of such assessments.

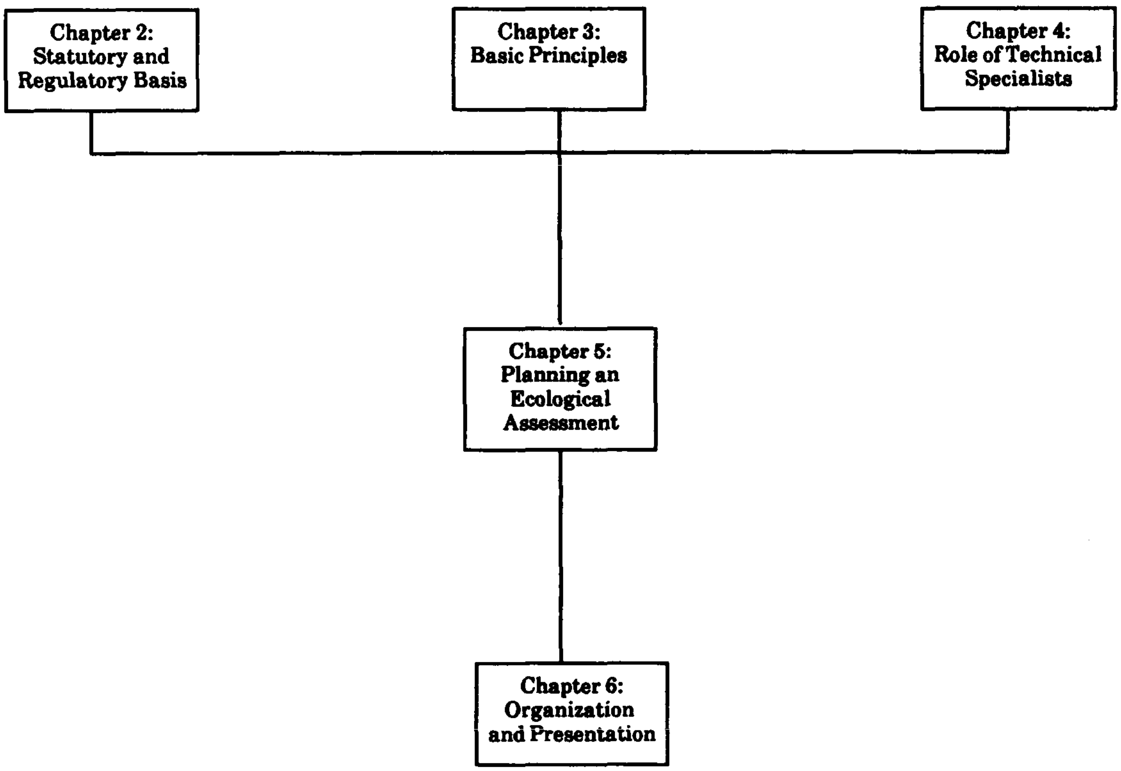

Figure 1.2 Logical Organization of this manual.

Chapter 2

Statutory and Regulatory Basis of Ecological Assessment

Ecological assessment of hazardous waste sites is an essential element in determining overall risk and protecting public health, welfare, and the environment. The Agency considers ecological factors in assessing hazards and in reviewing alternative remedial actions because:

- Through the authority found in CERCLA (as amended by SARA) and other statutes, the Agency seeks to protect wildlife, fisheries, endangered and threatened species, and valued habitats.

- From a scientific viewpoint, the Agency needs to examine ecological effects and routes of exposure so that (a) important impacts and transport pathways are not overlooked, and (b) reasonable estimates are made of health and environmental effects.

This chapter describes the statutory and regulatory framework underlying ecological assessment. Certain provisions of CERCLA and SARA are especially important in this regard:

- The statutes require that remedial actions selected for a site be sufficient to protect human health *and the environment.*

- Compliance with applicable or relevant and appropriate requirements (ARARs) entails consideration of numerous Federal and State laws and regulations concerning natural resource preservation and protection when evaluating possible response actions.

- SARA calls upon EPA to notify Federal natural resource trustees of negotiations with potentially responsible parties and to encourage trustees' participation in the negotiations if a release or threatened release may result in damages to protected natural resources.

The chapter begins with a discussion of the authority provided in the amended CERCLA for conducting ecological assessments. Section 2.2 describes the implementation of CERCLA as outlined in the proposed revisions to the National Contingency Plan. Guidance documents for removal actions and the RI/FS process are discussed in Sections 2.3 and 2.4, respectively. A wide array of potential ARARs is the subject of Section 2.5. It is important to note, however, that this section is not intended to be an exhaustive survey of potential ARARs; the RPM or OSC will need to ascertain the specific Federal and State requirements that apply to each site, depending on the contaminants of concern and the characteristics of the site.

2.1 CERCLA/SARA Authorities

The Comprehensive Environmental Response, Compensation and Liability Act, as amended by the Superfund Amendments and Reauthorization Act of 1986, requires EPA to ensure the protection of the environment in (1) selection of remedial alternatives and (2) assessment of the degree of cleanup necessary. Several sections of CERCLA make reference to protection of health and the environment as parts of a whole. Section 105(a)(2) calls for methods to evaluate and remedy "any releases or threats of releases. . . which pose substantial danger to the public health or the environment." Section 121(b)(l) requires selection of remedial actions that are "protective of human health and the environment. " Section 121(c) calls for "assurance that human health and the environment continue to be protected." And Section 121(d) directs EPA to attain a degree of cleanup "which assures protection of human health and the environment."

CERCLA Section 104(b)(2) calls upon EPA to notify the appropriate Federal and State natural resource trustees promptly about potential dangers to protected resources. The Federal natural resource trustees include:

- The U.S. Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Bureau of Land Management (BLM) of the Department of the Interior;

- The National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce; and

- The U.S. Department of Agriculture Forest Service.

State agencies and Indian tribes are also designated trustees for natural resources under their jurisdiction. Section 122(j) of the amended CERCLA requires the Agency to notify the Federal natural resource trustees of any negotiations regarding the release of hazardous substances that may have resulted in natural resource damage. Section 122 (j)(l) also calls upon EPA to encourage Federal natural resource trustees to participate in negotiations with potentially responsible parties (PRPs). If EPA seeks to settle with a PRP by signing a covenant not to sue, the Federal natural resource trustee must agree to this covenant in writing. Section 122(j) (2) states that:

> The Federal natural resource trustee may agree to such a covenant if the potentially responsible party agrees to undertake appropriate actions necessary to protect and restore the natural resources damaged by such release or threatened release of hazardous substances.

The ecological assessment directed by the OSC or RPM should not be confused with the **Preliminary Natural Resource Survey (PNRS) or the Natural Resource Damage Assessment (NRDA),** which are performed by natural resource trustees. PNRSs are simple screening studies, based on readily available information, that may be conducted by trustees to determine whether or not (a) trustee resources may have been affected, and (b) further attention to trustee resources is warranted at a particular site. The NRDA may be conducted by one or more trustees if a response action will not sufficiently restore or protect natural resources damaged by a release. The purpose of the NRDA is to determine the appropriate level of compensation from a responsible party. Data collected in an ecological assessment may prove helpful to the trustees in carrying out their responsibilities. It is important to encourage the natural resource trustee to participate in the Superfund process at the earliest possible stage. In this way, the trustee can be assured that any potential environmental concerns are addressed, and conclusion of actions may be expedited.

2.2 The National Contingency Plan

As required by SARA Section 105, EPA has revised the National Contingency Plan (NCP)[1], which provides for effective response to discharges of oil and releases of hazardous substances. Section 300.120 of the proposed NCP charges the site-specific OSC or RPM with (1) identifying potential impacts on public health, welfare, and the environment, and (2) setting priorities for this protection.

Like CERCLA, the proposed NCP refers throughout to health and environment as aspects of the evaluation and remediation processes. For example, in discussing the baseline risk assessment in a Remedial Investigation, the purpose is defined as determining "whether the site poses a current or potential risk to human health and the environment in the absence of any remedial action." The exposure assessment in the RI "is conducted to identify the magnitude of actual or potential human or environmental exposures . . ." The toxicity assessment "considers. . . the types of adverse health or environmental effects associated with chemical exposures." In addition, the proposed NCP states that "Superfund remedies will . . . be protective of environmental organisms and ecosystems."

Sections 300.175 and 300.180 of the proposed NCP direct the RPM or OSC to coordinate with other Federal and State agencies. USFWS and NOAA are specifically cited with respect to endangered or threatened species. Under Section 300.430, the RPM or OSC is to notify affected land management agencies and natural resource trustees regarding any release or discharge that affects natural resources under their jurisdiction. According to the proposed NCP, "when trustees are notified of or discover possible damage to natural resources, they may conduct a preliminary survey of the area to determine if natural resources under their trust are affected." The document adds an important proviso:

> Although a trustee may be responsible for certain natural resources affected or potentially affected by a release, it is important that only one person (i.e., the lead agency OSC or RPM) manage activities at the site of a release or potential release. The OSC or RPM shall coordinate responsibilities for CERCLA section 104 assessments, investigations, and planning, including Federal trustees' participation in negotiations with PRPs as provided in CERCLA section 122(j)(l). Close communication and coordination between OSCs/RPMs and trustees is essential.

If, after the remedial action is completed, any hazardous substances remain on a site "above levels that allow for unlimited use and unrestricted exposure for human and environmental receptors," the proposed NCP would require the lead Agency to review the remedial action every five years to ensure that the environment continues to be protected.

1 USEPA, National Oil and Hazardous Substances Pollution Contingency Plan 40 CFR Part 300. EPA Proposed Revisions to the NCP at 53 Fed. Reg. 51395 (Proposed Rule, December 21, 1988). All references to the "proposed NCP" in this manual are to this proposed rule. Quotations from the NCP used in this section are from the Preamble.

2.3 Removal Action Guidance

The Guidance covering removal actions calls upon the OSC to consider threats to the environment in addition to public health when preparing the Action Memorandum required for all removals.[2] For example, in discussing the role of the National Response Team (NRT), the Guidance states that the NRT "should be activated as an emergency response team if [al release . . . [i]nvolves significant population threat or national policy issues . . . or substantial threats to natural resources. "[3] In the section on determining the need for and urgency of a removal, the manual specifies:

> At any release, regardless of whether the site is on the NPL, where the OSC determines that there is a threat to public health, welfare or the environment, . . . the OSC may take any appropriate action to abate, minimize, stabilize, mitigate or eliminate the actual or potential release and the resulting threat.[4]

For those incidents not categorized as "classic emergencies," the Guidance indicates that "the OSC should conduct more extensive data collection and analysis to document more completely the actual or potential health and environmental threat." As an example, the manual calls on the OSC to "make a concerted effort to use existing environmental and health standards as triggers for initiating response and as guidelines in determining response actions."[5]

In describing the contents of the preliminary assessment, the Guidance points out that "the OSC must incorporate any special procedures or technical criteria EPA has established for a variety of special, complex cases," which include floodplains and wetlands.[6] Among the determinations that need to be made at the conclusion of the preliminary assessment, the Guidance includes the following

> If the OSC determines that natural resources have been or are likely to be damaged, the OSC should ensure that the trustees of the affected natural resources are notified in order that they may initiate appropriate actions[7]. . . .

The Guidance devotes a section to removal actions in floodplains and wetlands, pointing out that such actions "should be consistent to the extent practicable with Federal policy and procedures for the protection of floodplains and wetlands." Descriptions and references for the specific regulations are given in Section 2.5, below. Under the policy established by the Office of Emergency and Remedial Response, specific actions are required of the OSC:

- "[As] part of the preliminary assessment, . . . determine whether the release is in, near or affecting a floodplain or wetland."
- If "the release is in proximity to or has the potential to affect a floodplain or wetland," evaluate
  - "Possible impact of proposed response actions on the floodplain/wetland,"
  - "Alternate response actions. ..," and
  - "Measures to minimize potential adverse impacts."
- "[D]ocument the results of this evaluation in the Action Memorandum."
- "[E]nsure that the implementation of approved response actions minimizes adverse impacts on the floodplain/wetland."[8]

The Guidance also makes specific reference to environmental threats in the Appendices describing the Action Memorandum. For example, demonstration of actual or potential "catastrophic environmental damage" may be cited as the reason for activating an OSC's $50,000 authority in a time-critical removal. In describing the characteristics of an incident, the OSC is asked to demonstrate "that the incident already has posed or imminently will pose an imminent and significant danger to the public or to the environment." One way of demonstrating this is to show "proximity to . . . significant natural resources." The Guidance goes on to ask several key questions whose answers will help determine if the incident is time-critical:

> Are there confirmed reports of injuries to natural resources or injuries to or deaths of flora and fauna? Are more anticipated? How sensitive critical are these resources (e.g., protected wildlife refuge)? Is there catastrophic environmental damage?

Even if the incident does not appear to be time-critical, the Guidance cautions the OSC that "[s]ome environmental threats are not urgent, but nevertheless are significant. " To aid in demonstrating that failure to respond "will create an

[2] *Superfund Removal Process* (OSWER Directive 9360.O-03B). EPA Office of Emergency and Remedial Response, February 1988.

[3] Ibid., p. III-10.

[4] Ibid., p. 111-14.

[5] Ibid., p. Ill-15.

[6] Ibid., p. Ill-11.

[7] Ibid., p. 111-12.

[8] Ibid., pp. IV-12 and IV-13

unacceptable impact on natural resources and the environment," the Guidance poses these questions:

- "What additional information (beyond that requested in the time-critical screen) documents the threat to the environment (e.g., monitoring or other data verifying injury to or destruction of natural resources, critical habitats)?"

- "What are the known short- and long-term effects that are likely if there is no response or response is delayed? When is that threat likely to manifest itself?"[9]

For removals that will take less than 12 months and cost less than $2 million, Appendix 6 of the Guidance provides a model Action Memorandum to assist the OSC in meeting the requirements of CERCLA and the proposed NCP. Under the heading "Site Description," the model reminds the OSC to describe "areas adjacent to the incident or site in terms of vulnerable or sensitive populations, habitats and natural resources. " The section goes on to cite sensitive areas such as wetlands, floodplains, "sensitive ecosystems," or wild and scenic rivers. Under the heading "Threats to the Environment," the model calls upon the OSC to:

> List all the current and potential threats. . . that adversely affect the environment (e.g., damage to ecosystem, animals, ground water). Identify any natural resource or environmental damage that already has occurred and the extent of exposure (e.g., acute or chronic). Indicate whether there have been reports of deaths of flora or fauna (e.g., fish kills). . . . Discuss potential damage to the environment and indicate a time frame within which damage will occur if response actions are not taken.
>
> Discuss all actual or potential impacts on the affected area. Describe any anticipated exposure and whether it is imminent. Indicate whether the release threatens endangered species, critical wetlands, or other resources protected under law. State whether natural resources trustees have been notified. [10]

2.4 *Remedial Investigation and Feasibility Study (RI/FS) Guidance*

Remedial Project Managers are responsible for all phases of the remedial process, including but not limited to the RI/FS. Ecological assessment of appropriate detail may be conducted at any of these phases. The nature, extent, and level of detail of the ecological assessment will be determined according to the phase of the remedial process, the specific study objectives, and the characteristics of the site and its contaminants. These decisions should be made in close consultation with technical advisers, as discussed in Chapter 4.

This Section focuses on ecological components of the RI/FS process as outlined in EPA's RI/FS Guidance.11 In the scoping phase, the RPM develops a project plan to define the problem and identify solutions. Among the activities at this stage are

> collecting and analyzing existing data to develop a conceptual model that can be used to assess both the nature and the extent of contamination and to identify potential exposure pathways and potential human health and/or environmental receptors.[12]

As part of the collection and analysis of existing data, the Guidance specifically mentions "evidence of . . . biotic contamination," identification of "biotic migration pathways," information on ecology of the area, and data on "environmental receptors." The Guidance further states:

> Existing information describing the common flora and fauna of the site and surrounding areas should be collected. The location of any threatened, endangered, or rare species, sensitive environmental areas, or critical habitats on or near the site should be identified.[13]

A limited field investigation may be undertaken in this phase of the RI/FS process. The Guidance includes a preliminary "ecological reconnaissance" in the list of possible components of this field investigation.

The project planning stage is also the time for the RPM to begin preliminary identification of ARARs and To Be Considered (TBC) information. The Guidance points out that some requirements "may set restrictions on activities within specific locations such as floodplains or wetlands."[14]

Characterized as the most important part of the scoping process, the identification of data needs includes determining the information required to "define source areas of contamination, the potential pathways of migration, and the potential receptors and associated exposure pathways." The objective is

9 Ibid., Appendix 5, pp. *3-5.*

10 Ibid., Appendix 6, pp. 6-7.

11 Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (Interim Final}. OSWER Directive 9355.3-01. EPA Office of Emergency and Remedial Response. October 1988.

12 Ibid., p. 2-2.

13 Ibid., p. 2-7.

14 Ibid., p. 2-13.

to determine "whether, or to what extent, a threat to human health or the environment exists."[15]

The culmination of the project planning stage is the preparation of the Work Plan and the Sampling and Analysis Plan (SAP). The Work Plan includes a preliminary evaluation of (a) potential pathways of contaminant migration and (b) public health and environmental impacts. The SAP is a key step in the assessment process, because it defines what data are to be sought, why the data are needed, where and how the data will be collected, and how the data will be analyzed and interpreted. Equally important, the SAP specifies the data quality objectives and quality assurance plan for the study, indicating the levels of precision and accuracy that are expected in data collection and analysis, and describing how the expected precision and accuracy will be maintained.

It is at this stage that data collection for ecological assessment should be planned, including field surveys, toxicity testing, bioaccumulation studies, and sampling to determine the extent of contamination.[16] As with other aspects of the SAP, the planning process for ecological assessment may be iterative: that is, analysis of early data may indicate that the sampling and analysis need revision. This may entail expanding the area to be sampled or planning new toxicity tests. It may also point to a reduction in effort if anticipated results fail to materialize.

In describing the baseline risk assessment for the RI, the RI/FS Guidance makes frequent reference to the ecological side of the assessment. The baseline risk assessment is intended to "provide an evaluation of the potential threat to human health and the environment in the absence of any remedial action. " The process includes among its tasks the identification and characterization of (a) levels of contamination in relevant media, including biota, and (b) "potential human and environmental receptors." The toxicity assessment component "considers . . . the types of adverse health or environmental effects associated with individual and multiple chemical exposure s." The risk characterization component entails estimating "carcinogenic risks, noncarcinogenic risks, and environmental risks."[17] The Guidance specifies further:

> Characterization of the environmental risks involves identifying the potential exposures to the surrounding ecological receptors and evaluating the potential effects associated with such exposure(s). Important factors to consider include disruptive effects to populations (both plant and animal) and the extent of perturbations to the ecological community.[18]

The Feasibility Study involves screening of remediation alternatives for their effectiveness, including their "potential impacts to human health and the environment during the construction and implementation phase."[19] Alternatives are expected to be evaluated during the screening process "to ensure that they protect human health and the environment from each potential pathway of concern."[20]

2.5 CERCLA Compliance with other Environmental Statutes (ARARs)

Section 121(d)(2)(A) of CERCLA requires that the Superfund remedial action meet Federal and State standards, requirements, criteria, or limitations that are "applicable or relevant and appropriate requirements" (ARARs). The OSC or RPM is responsible for identifying potential ARARs for each site.

The RPM or OSC should use the EPA ARARs Manual[21] to assist in identifying potential ARARs on a case-by-case basis. Some of the Federal environmental statutes and regulations that may be ARARs for a particular site include:

- *The Resource Conservation and Recovery Act of 1976, as Amended.* RCRA requirements for ground-water protection, surface impoundments, waste piles, underground storage tanks, and surface treatment are all considered to be potentially applicable for both human health and protection of the environment at sites that contain RCRA-listed or characteristic wastes and where waste management activities took place after the effective date of the relevant RCRA Subtitle. The RPM or OSC should consult with the appropriate Regional RCRA staff to make this determination.

- *The Federal Water Pollution Control Act, as Amended.* This law, also known as the Clean Water Act, includes numerous sections that may pertain to remediation of Superfund sites. The OSC or RPM should consult the ARARs Manual for a detailed discussion of relevant sections.

[15] Ibid., p. 2-14.

[16] See EPA/ORD, *Ecological Assessments of Hazardous Waste Sites: A Field and Laboratory Reference Document* (EPA/600/3-89/013) for specific information on field and laboratory methods.

[17] Ibid., pp. 3-35 through 3-43.

[18] Ibid., p. 3-43.

[19] Ibid., p. 4-24.

[20] Ibid., p. 4-30.

[21] CERCLA Compliance With Other Laws Manual, (OSWER Directive 9234.1-01) EPA Office of Emergency and Remedial Response. Draft , August 8, 1988.

Section 404, which requires protection of wetlands, is of special importance for environmental evaluation of Superfund sites.

- *The Clean Air Act of 1970, as Amended.* Under the CAA, EPA has established National Ambient Air Quality Standards for key pollutants. In the development of these standards, the Agency prepares Air Quality Criteria documents that investigate various effects of exposure to the subject pollutants, including those that occur on vegetation. These criteria documents and the standards developed from them may help establish remediation criteria where airborne exposure is possible. In addition, EPA has established limitations for numerous chemicals in its National Emission Standards for Hazardous Air Pollutants and the New Source Performance Standards. The OSC or RPM may wish to determine the utility of these standards for the protection of natural resources from airborne exposure to contaminants.

- *The Toxic Substances Control Act of 1976.* Section 2601 (b) of the Toxic Substances Control Act states the policy of the United States that ". . . adequate data should be developed with respect to the effect of chemical substances and mixtures on health and the environment . . . ." Data collected under TSCA concerning ecological effects may prove useful in determining protective levels of contaminants. The OSC or RPM should refer to the ARARs Manual for other information on applicability of TSCA.

- *The Federal Insecticide, Fungicide and Rodenticide Act of 1947, as Amended.* FIFRA requires that all pesticides be registered with EPA. To obtain registration, manufacturers must supply EPA with certain data concerning environmental fate and transport, health effects, and ecological effects. EPA's Office of Pesticide Programs (OPP) has issued Registration Standards, which summarize the Agency's assessment of many pesticide active ingredients, some of which are found at Superfund sites. The analyses contained in these documents may assist in the evaluation of hazards and in determining protective levels of contaminants. OPP's regulatory positions on the continued registration of individual pesticides may also provide guidance on controlling environmental hazards.

- *Endangered Species Act of 1973, as Reauthorized in 1988.* Section 7 of the Act requires Federal agencies to ensure that their actions will not jeopardize the continued existence of any endangered or threatened species. The U.S. Fish and Wildlife Service and the National Marine Fisheries Service have primary responsibility for this Act.

- *Fish and Wildlife Conservation Act of 1980.* Section 2903 requires States to identify significant habitats and develop conservation plans for these areas. Although it is unlikely that a Superfund site would be located in one of these significant habitats, the RPM should cofirm this with the responsible State agency.

- *Marine Protection, Research and Sanctuaries Act of 1972.* Section 1401 declares the U.S. policy of regulating dumping to ". . . prevent or strictly limit the dumping into ocean waters of any material which would adversely affect human health, welfare, or amenities or the marine environment, ecological systems, or economic potentialities." This legislation may be relevant for cleanup and removal actions at or near the ocean.

- *Coastal Zone Management Act of 1972.* This legislation is designed to (a) encourage States to develop management plans to protect and preserve the coastal zone, and (b) ensure that Federal actions are consistent with these management plans. The RPM or OSC would need to obtain these management plans if remedial or removal actions will take place in the coastal zone.

- *Wild and Scenic Rivers Act of 1972.* Section 2171 declares that certain rivers ". . . possess outstanding remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar value" and should be preserved. [f remedial or removal action is taking place at or near a river, the RPM or OSC should determine whether it has been designated as "wild and scenic," and whether there are any action-specific ARARs regarding the site or its contaminants. The National Park Service has primary responsibility for this Act.

- *Fish and Wildlife Coordination Act, as Amended in 1965.* Section 662(a) states that the Fish and Wildlife Service must be consulted when bodies of water are diverted or modified by another Federal Agency. The facility is to be constructed "with a view to the conservation of wildlife resources by prevention of loss, or damage to such resources as well as providing for the development and improvement thereof. . . ." The RPM should consult with USFWS or NOAA if remedial action entails altering streams or wetlands.

- *The Migratory Bird Treaty Act of 1972* implements many treaties involving migratory birds. This statute protects almost all species of native birds in the U.S. from unregulated "take," which can include poisoning at hazardous waste sites. The Act is a primary tool of the U.S. Fish and Wildlife Service and other Federal agencies in managing migratory birds.

- *The Marine Mammal Protection Act of 1972.* This law protects all marine mammals, some but not all of which are endangered species. The National Oceanic and Atmospheric Administration has primary responsibility for this Act. The Fish and Wildlife Service also has responsibility for some species.

Under the authority of the Clean Water Act, EPA develops Federal Water Quality Criteria (FWQCs), including criteria for protection of aquatic life. In 1987, EPA's Office of Water Regulations and Standards revised and published its *Quality Criteria for Water, 1986.* For each of more than 120 inorganic and organic compounds, this publication contains numerical Ambient Water Quality Criteria for the protection of fresh and salt water plants and animals and their habitats, covering both acute and chronic exposure. The proposed NCP describes the FWQCs as:

> . . . nonenforceable guidelines used by the States to set Water Quality Standards (WQS) for surface water. . . . States designate the use of a given water body based on its current and potential use and apply the FWQC to set pollutant levels that are protective of that use. . . . If a State has promulgated a numerical WQS that applies to the contaminant and the designated use of the surface water at a site, the WQS will generally be applicable or relevant and appropriate for determining cleanup levels, rather than a FWQC.

The proposed NCP discusses the difference between use of a FWQC when the water will be used for drinking and when the principal human exposure is expected through consumption of fish. Separate FWQC exist for protection of aquatic life. According to the proposed NCP:

> A FWQC for protection of aquatic life may be relevant and appropriate for a remedy involving surface waters (or ground-water discharges to surface water) when the designated use requires protection of aquatic life or when environmental concerns exist at the site. If protection of human health and aquatic life are both a concern, the more stringent standard should generally be applied.

The proposed NCP sets several criteria for determining the relevance and appropriateness of a FWQC. The FWQC should be "intended to protect the uses designated for the water body at the site, or . . . the exposures for which the FWQC are protective are likely to occur." The FWQC "must also reflect current scientific information." Finally, the relevance and appropriateness "depends on the availability of standards, such as an MCL [Maximum Contaminant Level] or WQS, specific for the constituent and use."

It is important to stress that the above list of statutes is not intended to be exhaustive. In particular, the preceding discussion focused only on potentially applicable Federal laws and regulations. State, local, and other Federal requirements may also be applicable or relevant and appropriate. For a specific site, specific requirements will apply, depending on the contaminants of concern, the location of the site, and the potentially exposed receptors. Some, all, or none of the potential ARARs discussed in this Section may apply. The RPM or OSC should confer with appropriate State regulatory authorities, officials in other EPA programs, and representatives of other Federal agencies in the event of uncertainty on possible ARARs.

Chapter 3

Basic Concepts for Ecological Assessment

This chapter has three purposes. First, the chapter introduces and defines ideas and terms commonly used in ecology. Our intent is to make the RPM or OSC aware of the general meaning of these concepts, so as to facilitate discussion with the technical specialists providing consultation on ecological assessment. Second, the chapter discusses the nature of contaminants' ecological effects. Although a contaminant may cause illness or death to individual organisms, its effects on the structure and function of ecological assemblages may be measured in terms quite different from those used to describe individual effects. Third, the chapter describes some of the biological, chemical, and environmental factors that influence the ecological effects of contaminants.

Readers who are familiar with these topics may wish to skim this chapter. Those who are well versed in ecology and environmental chemistry may want to skip it entirely.

3.1 Objects of Study in Ecology

Ecologists generally study three levels of organization: populations, communities, and ecosystems. (See Figure 3.1.) Each level has its characteristic measures of extent, structure, and change.

A **population** is a group of organisms of the same species, generally occupying a contiguous area, and capable of interbreeding. The size and extent of populations are most often described in terms of density, the number of organisms per unit area. Such terms as standing crop or standing stock may be used to indicate population size at a particular time interval, with the unit area specified or implied. The structure of populations is often expressed in terms of the numbers of organisms in different age classes, such as eggs, juveniles, and adults. Population growth and decline are determined by characteristic rates of birth, death, immigration, and emigration, all of which are subject to change with environmental conditions, including interaction with populations of other organisms.

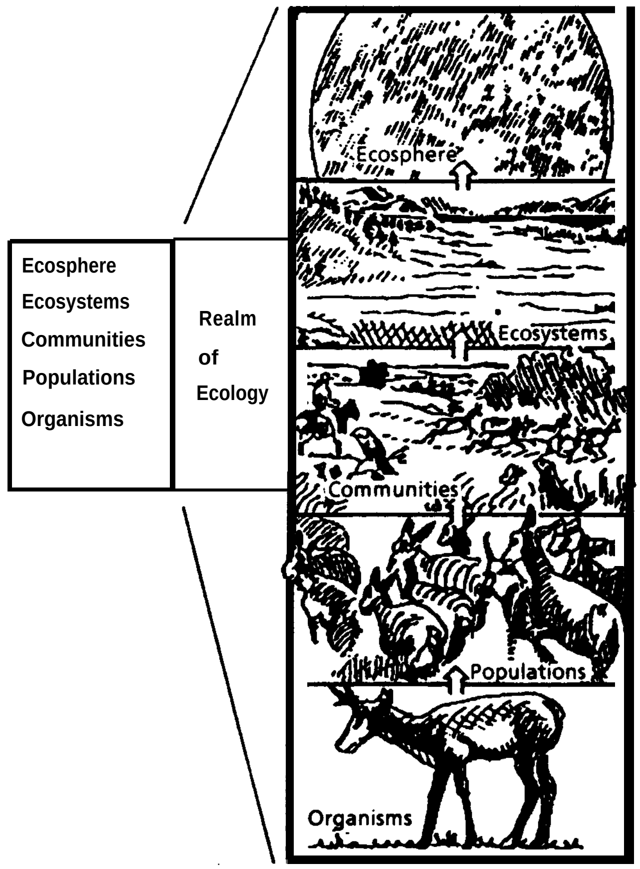

Figure 3.1. Levels of organization of matter.
Source: *Living in the Environment, 3/E,* by G. Tyler Miller, Jr. Copyright (C) 1982 by Wadsworth, Inc. Reprinted by permission of the publisher.

No species in nature exists in isolation from all others. Populations of different species live together in complex associations called **communities.** The interactions among populations and the chemical and physical constraints of the environment together determine a community's structure and geographical extent. The structure of a community is defined by what species are present, in what numbers, and in what proportion to each other. It is also described by the **food web,** or **trophic structure:** that is, which species eat which other species, or who produces and consumes how much.

Most communities change seasonally or over longer cycles as some species increase or decrease in abundance in response to environmental changes such as temperature or rainfall cycles. Communities also can evolve over longer periods of time in a process known as **succession.** In successional change, some species are displaced by others and new environmental conditions are created that support more species. For example, when a meadow "grows" into a forest, annual plants are gradually replaced by perennials, shrubs, and trees. Each plant type modifies the environment in ways that tend to favor the succeeding type. Eventually, tree canopies shade much of the area that was once exposed to sunlight, and a leaf-litter layer covers soil that was once bare. Species **diversity** - expressed as the number of species or the relative abundance of the various species in a given area - is often used to characterize and compare the structure and evolutionary "maturity" of communities. Communities are in constant" flux as organisms are born, eat and get eaten, immigrate and emigrate, die and decompose. These fluxes are described as energy and nutrient flows through food webs, and are determined by rates of primary production (photosynthesis) by plants and rates of consumption by herbivores, carnivores, and decomposers.

Just as populations exist only in association with others in communities, so too do communities interact continuously with the nonliving components of the environment in an **ecosystem:** "A functional system of complementary relationships, and transfer and circulation of energy and matter. "[1] The ecosystem comprises all the living organisms, their remains, and the minerals, chemicals, water, and atmosphere on which they depend for sustenance and shelter. Living and nonliving components are closely linked, each affecting the other. For example:

- Soil composition and structure are often highly influenced by the organisms that inhabit it, and by the decomposition products of organisms after they die.

- Orological formations such as coral reefs and chalk cliffs are the result of calcium deposition by plants and animals over eons; they in turn affect the flow of wind and water, and provide habitat for countless other organisms.

Ecosystems are characterized by many of the same measures as communities: species composition and diversity, nutrient and energy flows, and rates of production, consumption, and decomposition. Unlike community measures, however, ecosystem structure and function includes nonliving stores of materials and energy along with the animals, plants, and microbes that make up the biotic portion of the environment. Because it encompasses all of the relevant physical and biological relationships governing organisms, populations, and communities, the ecosystem is generally considered the fundamental unit of ecology.

[1] Eugene P. Odum, *Fundamentals of Ecology,* Third Edition (Philadelphia W.B. Saunders Company, 1971).

Energy and matter flow through ecosystems by means of complex systems known as **food chains** and **food webs.** (See Figures 3.2a and 3.2b.) A food chain describes the transfer of material and energy from one organism to another organism as one eats or decomposes the other. **Food chains** are hierarchically arranged into trophic levels:

- **Primary producers** - green plants (including algae and microscopic aquatic plants called phytoplankton) - capture solar. energy through photosynthesis which converts carbon dioxide and water into carbohydrates, a form of energy storage suitable for use by other organisms;

- **Primary consumers (herbivores)** eat plants;

- **Secondary consumers (carnivores)** eat herbivores;

- **Tertiary consumers (top carnivores)** feed on other carnivores; and

- **Decomposers** - including certain fungi, and bacteria - feed on dead and decaying organisms, liberating simple organic chemicals and mineral nutrients for recycling in the ecosystem.

Food webs are interconnecting food chains. These more realistically describe the complex system of pathways by which the flow of matter and energy takes place in nature. Such pathways do not always follow a strict progression of producer to herbivore to carnivore. Some plants die and are decomposed without first being eaten by herbivores. Many species have mixed diets of plant and animal material; others change their feeding habits seasonally or have different food requirements at different life stages. For example, many bird species that feed primarily on seeds during most of the year switch to insects and other invertebrates when raising young, because the higher protein content of the animal prey increases the likelihood that the young birds will survive.

3.2 Types of Ecosystems

The types of ecosystems vary with climatic, topographical, geological, chemical, and biotic factors. On land, they range from Arctic tundras to tropical rain forests, sand dunes to mountain tops,

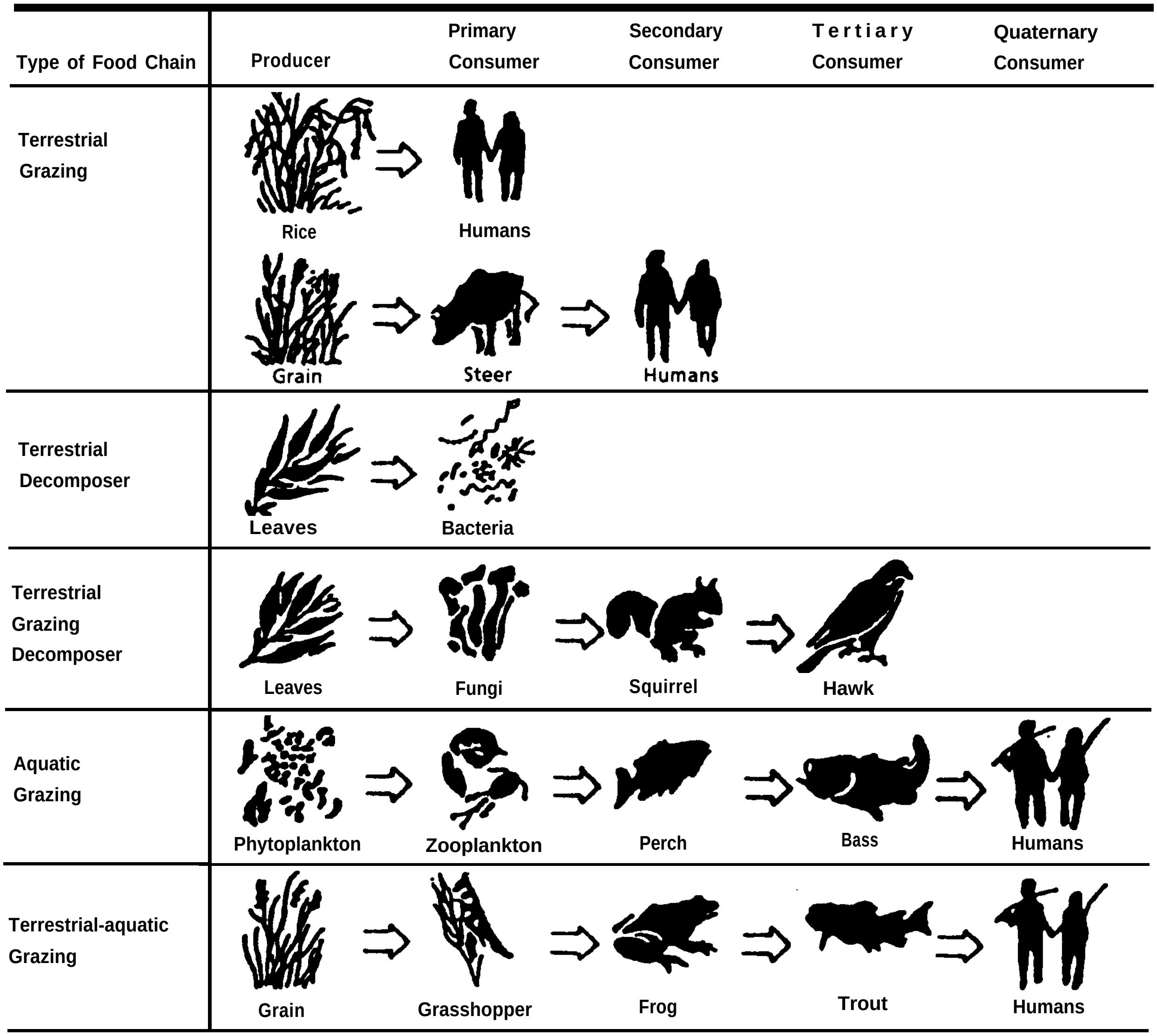

Figure 3.2a. Example of Typical Food Chains
Source: *Living in the Environmental,* 3/E, by G. Tyler Miller, Jr. Copyright (C) 1982 by Wadsworth, Inc. Reprinted by permission of the publisher.

deserts to forests, pure stands of evergreens to mixed stands of hardwoods. Freshwater ecosystems include ponds, lakes, streams and rivers. In the transition zones between land and water, wetlands include fresh-water and salt marshes, wet meadows, bogs, and swamps. Marine ecosystems range from estuaries and intertidal zones to the open sea and deep ocean trenches. Each ecosystem type has unique combinations of physical, chemical, and biological characteristics, and thus may respond to contamination in its own unique way. Not only does the environment influence the activities of organisms, but organisms also influence the environment.

The physical and chemical structure of an ecosystem may determine how contaminants affect its resident species, and the biological interactions may determine where and how the contaminants move in the environment and which species are exposed to particular concentrations. For example, contaminants in a forested area may be subject to less degradation due to sunlight than the same chemicals in grassland soils. Chemicals adhering to soil particles are less likely to be washed into streams if the soil is well covered with vegetation or decomposing leaf litter than if the area is sparsely vegetated or bare.

Terrestrial ecosystems are generally categorized according to the vegetation types that dominate the plant community. These are the species upon which the rest of the community's structure is based - the herbivores which feed on the vegetation, the

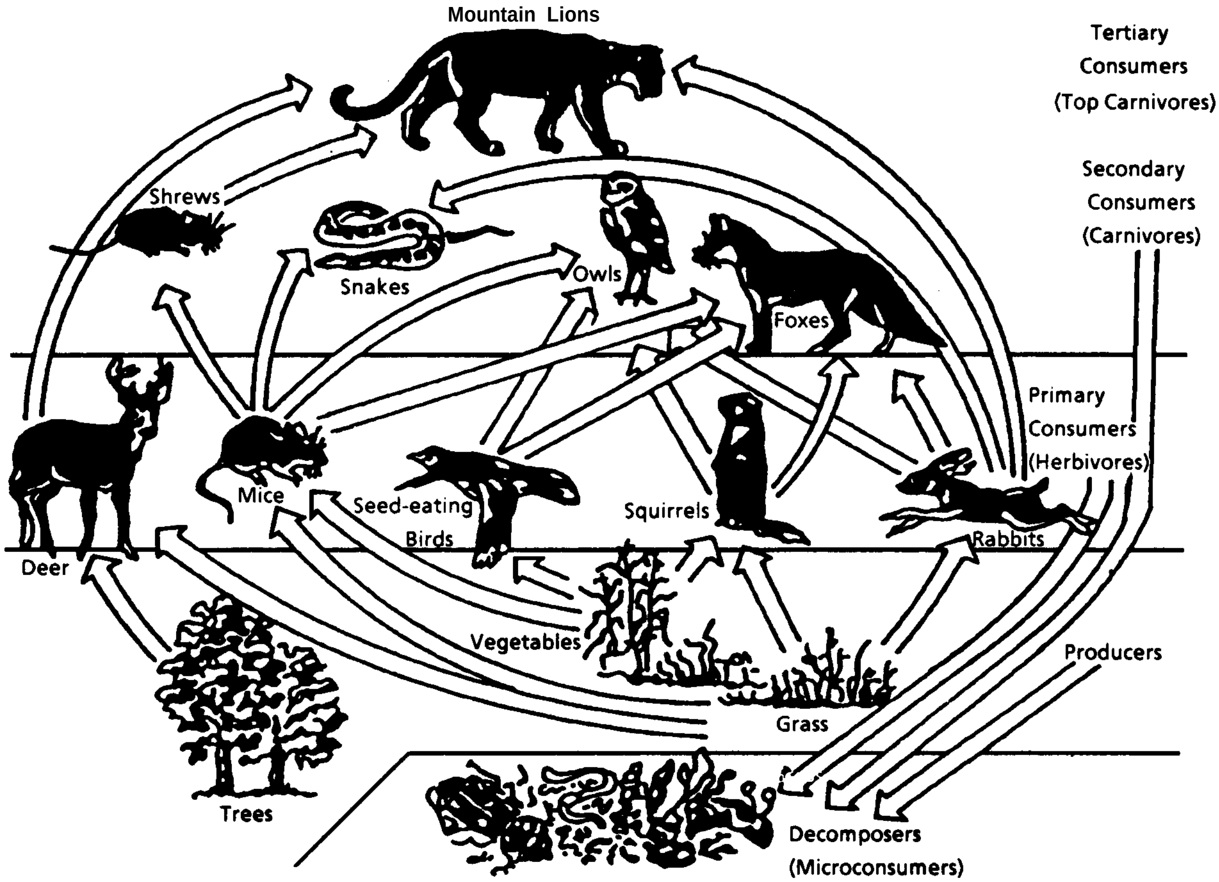

Figure 3.2b. A greatly simplified terrestrial food web.
Source: *Living in the Environment,* 3/E, by G. Tyler Miller, Jr. Copyright (C) 1982 by Wadsworth, Inc. Reprinted by permission of the publisher.

carnivores which feed on the herbivores and on each other, and the decomposers which feed on the dead plant and animal material and return mineral nutrients to the soil for recycling through the food web. The vegetation found at a particular site is determined by a wide variety of factors, including climate, soil type, altitude and slope of the land, and current and former uses of the land by people. Two very common ecosystem types in the temperate zone are deciduous forests and grasslands.

Temperate deciduous (leaf-shedding) forests are found in eastern North America. They have plentiful, evenly dispersed rainfall, moderate temperatures, and contrasting seasons. The annual leaf fall provides habitat for large numbers of insects and fungi that feed on the leaf litter, eventually breaking it down into organic materials and minerals that build up the soil.

Temperate grasslands cover the interior of North America and Eurasia, southern South America, and Australia. They receive moderate amounts of rainfall. Tall grasses tend to grow in soil having a high moisture content, while shorter grasses occur in more arid areas. Numerous grass species have developed adaptations to take advantage of seasonal variations in climate. One group grows in the cooler temperatures of the spring and fall, while another group thrives in the warmer temperatures of summer. These seasonal shifts in species' growth results in a high annual productivity in grasslands, as the growing season for the community as a whole is effectively extended to three seasons. This productivity has allowed grasslands to support large herds of grazing animals, such as bison, but the comparatively simple vegetation structure tends to support fewer animal species than a forest of similar size. The high volume of plant material available for decomposition in grasslands creates very different soil compositions from those created by forest leaf litter. Occasional fires contribute to the stability of grasslands, as they hinder the growth of competitive woody plants.

Wetlands are areas in which topography and hydrology create a zone of transition between terrestrial and aquatic environments. The combined characteristics of each create conditions of great productivity and biological diversity. Because of these unique conditions, both fresh-water and marine wetlands perform several important ecological functions and provide benefits that can be adversely affected by contamination. These include:

- Hydrologic benefits such as flood attenuation and ground-water recharge;

- Water-quality benefits such as (a) removal and cycling of sediments, organic materials, and nutrients, and (b) stabilization of banks and shorelines and control of erosion; and

- Wildlife benefits such as providing habitat and food sources for fish, shellfish, waterfowl and other birds, mammals and other wildlife.[2]

Contamination may adversely affect wetland functions in many ways, depending on the wetland type, geographic location, location within a watershed, and other factors. For example, **a** contaminated wetland may occur close to a National or State park or wildlife management area, or may be of a type and in an area that contains endangered species. (According to the U.S. Fish and Wildlife Service, most endangered species in the United States are dependent on wetlands.) Ecological impacts to wetlands may be either direct, where a contaminant has been deposited into a wetland, or indirect, where a wetland is in close proximity to a contaminant source.

The type of wetland may by itself be important in determining the ecological effects of contamination. For example, heavy-metal contaminants are more likely to impair ecological functions when released into an acidic bog than a similar release into the relatively well buffered waters of a salt marsh. Hence, the classification of wetlands can be used as a starting point for the evaluation of ecological impacts.[3] General wetland types include freshwater deciduous wetlands (dominated by red maple in the Northeastern U.S.), wet meadows (transitional stage to terrestrial systems), bogs (acidic peat rich soils prevalent in the Northeastern U.S.), bottomland hardwood wetlands (dominant in the Southeastern U.S.), and coastal salt marshes.

[2] For more information, see U.S. Fish and Wildlife Service, An Overview of Major Wetfand Functions and Values (FWS/OBS-84/18), September 1984.

[3] For a more complete reference on classification of wetland types, see Cowardin, Carter, Golet and LaRoe, Classification of Wetlands and Deepwater Habitats of the United States, (FWS/OBS-79/31) U.S. Fish and Wildlife Service, December 1979.

Fresh-water ecosystems, though comparatively smaller in area than marine and terrestrial habitats, are of great significance because they are:

- A major component in the hydrological cycle (rivers and streams drain a large percentage of the earth's land surface),

- A breeding and rearing habit for wildlife species of value to people,

- A readily accessible and low-cost source of water for domestic and industrial use, and

- A valued recreational and aesthetic resource.

In fresh-water environments, the dynamics of water temperature and movement can significantly affect the availability and toxicity of contaminants.

The waters in lakes and ponds have relatively long **residence times.** For example, consider the Niagara River as it flows into Lake Ontario. The Niagara's strong currents move a given molecule of water along the 37-mile length of the river in about one day. However, the same molecule will remain in the lake for several years before it flows into the St. Lawrence River. A similar molecule will remain in Lake Michigan for nearly a century, while another one would remain in Lake Superior for 191 years.

In addition, temperate lake ecosystems exhibit strong seasonal cycles. In summer, surface waters warm up and become **thermally stratified** - that is, they do not mix with the colder bottom waters. (See Figure 3.3.) As a result, nutrients released through decomposition of animal and plant material tend to accumulate in the bottom waters. In the fall and spring, when these temperature differentials disappear, the waters in the lake are able to mix, allowing circulation of accumulated nutrients. As nutrients are brought up into water that receives sunlight, they become available to aquatic plants, which can use the nutrients to support photosynthesis. These plants provide energy that sustains growth of most other organisms in the lake system. At each of these seasonal shifts, the biotic communities in the upper waters exhibit clear successional changes in their planktonic communities. **(Plankton** are small plants and animals that float passively, or can swim weakly, in the water column.) These annual cycles can also greatly influence the availability of contaminants that may reside in the lake sediments for part of the year and be dissolved or suspended in the water column at other times. Such contaminants may become available to upper-water organisms during periods of mixing.

Rivers and streams are substantially different from lakes and ponds not only in their obvious physical

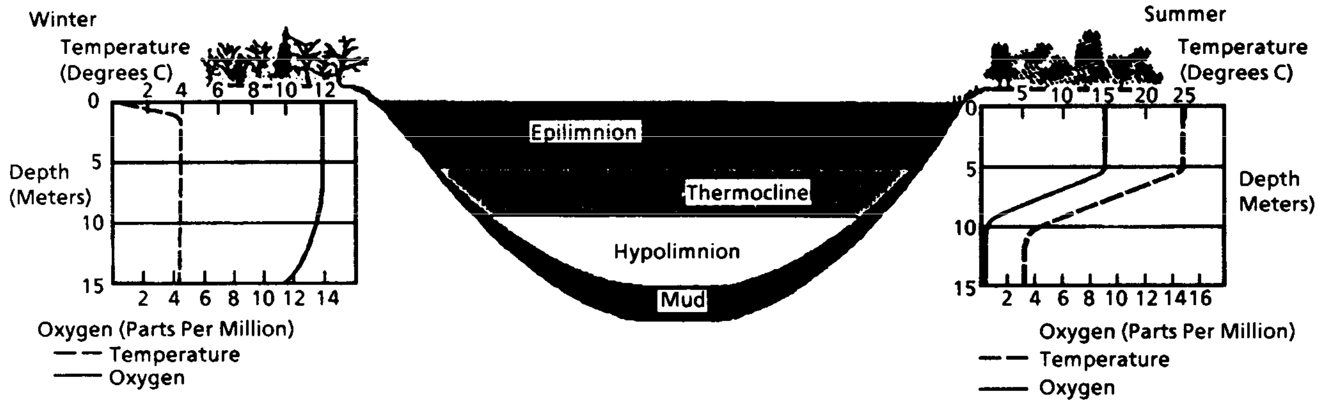

Figure 3.3 **Thermel stratification of a north temperate lake.**
Summer conditions are shown on the right, winter conditions on the left. Note that in summer a warm oxygen-rich circulating layer of water, the epilimnion, is separated from the cold oxygen-poor hypolimnion waters by a broad zone, called the thermocline, which is characterized by a rapid change in temperature and oxygen with increasing depth.

Source Figure 11-9 from *Fundamentals of Eco/ogy,* Third Edition, by E.P. Odum. Copyright (C) 1971 W.B. Saunders Company, A Division of Harcourt, Brace, Jovanovich, Inc. Reprinted by permission of the publishers.

conditions (e.g., moving vs. standing water, low vs. high degree of thermal stratification) but also in the types of organisms that they can support, especially in the numbers of smaller organisms and in the types of larger plants and animals. For example, a racing brook will have low numbers of plankton (regardless of the concentrations of nutrients present) because the current rapidly moves them down-stream. In the same brook, large plants must be firmly attached to rocks or rooted in the sediment, and fish must be strong swimmers. In contrast, a lake or pond can accumulate high densities of plankton, and lily pads and slow-swimming fish can thrive. As a broad generality, food chains and food webs in flowing waters will have fewer links or trophic levels than those in still waters.

Marine ecosystems are of primary importance because of their vast size and critical ecological functions, which maintain much of the global environment's capacity to sustain life. The sea accounts for some 70 percent of the earth's surface and supports a wide variety of life forms at all depths, especially in the areas bordering continents and islands. Oceans are constantly in motion and always circulating, which is critical for replenishing nutrients and dissolved oxygen vital for marine life. The world's oceans have pH values around 8 and average salinity of about 35 parts per 1,000. (Fresh water averages less than 0.005 parts per 1,000.)

The continental shelf comprises the submerged margins of the land mass. The high concentration and diversity of marine life found here is due to a high level of nutrients deriving from both land and sea bottom. Most of the world's marine fishing grounds are on the continental shelf. The characteristics of different types of ecosystems in this area can affect the nature and magnitude of the ecological risk associated with contaminants. **Intertidal** environments, with their continuous cycles of exposure and re-immersion, provide unique physical conditions for resident organisms and for flow and availability of contaminants. For instance, a volatile compound introduced into a rocky intertidal zone with considerable wave and tidal action will volatilize into the air much more rapidly than the same chemical released into a marsh with few waves and little tidal action. As another example, crude oil spilled onto the rocky, wave-swept coast of France in the early 1970s is now difficult if not impossible to detect; similar oil spilled about the same time along a marsh in Buzzards Bay, Massachusetts, is still detectable. Hence, tidal and subtidal ecosystems may range from relatively sheltered estuaries, where sediment deposition is the major physical condition, to open coasts, where wind and wave exposure are the dominant forces governing the fate of chemicals.

Estuaries are partly open bodies of water closely associated with the sea in coastal zones, including river mouths, bays, tidal marshes, or waters behind barrier beaches. The mechanics of estuarine systems are unique since they are strongly influenced by the salt water of tides and the drainage of fresh water from land. Tides play an important role in removing wastes and providing food. With a continual flow of nutrients from upstream and from nearby marine environments, estuaries support a multitude of diverse communities, and are more productive than their marine or freshwater sources. They are also especially important as breeding grounds for numerous fish, shellfish, and species of birds.

3.3 Effects of Contaminants on Ecosystems

The introduction of contaminants into an ecosystem can cause direct harm to organisms, or may indirectly affect their ability to survive and reproduce. The results of contamination may be immediately apparent or may become noticeable only after considerable delay. The effects of contaminants on ecosystems are due in part to the physical and chemical properties of the chemicals themselves, but are also mediated by the unique combination of physical, chemical, and biological processes occurring in each ecosystem. In addition, populations of exposed organisms can differ in their response to contaminants depending on their natural tolerance to the chemical, their behavioral and life-history characteristics, the dose to which they are exposed, and the exposure time. Furthermore, responses may be transient (and therefore reversible) or permanent (irreversible).

Ecological assessment seeks to determine the nature, magnitude, and transience or permanence of observed or expected effects. This must be accomplished in an environment that is itself changing and causing change in the organisms and systems under study. Hence, one critical goal of ecological assessment is to reduce the uncertainty associated with predicting and measuring adverse effects of a site's contaminants.

3.3.1 Reduction in Population Size

Populations change in size through births, deaths, immigration, and emigration. Contaminants can cause reductions in populations of organisms through numerous mechanisms affecting one or more of these four processes. Most obvious are increases in mortality due to the exposure of some organisms to lethal doses, or decreases in birth rates caused by sublethal doses. Mortality may also increase because a food source (e. g., a key prey species) has been depleted, perhaps by exposure to the contaminant, or because the contaminant allows tolerant organisms to outcompete other species for scarce resources. Birth rates can decline not only due to toxic effects but also through reduction of suitable breeding habitat or changes in the availability of high-quality food for breeding females. Populations may also be reduced through increased emigration or decreased immigration if organisms can sense and avoid contaminants in the environment, or if the contaminants' sublethal effects cause a change in migratory behavior.

3.3.2 Changes in Community Structure

Many communities are constantly changing. Populations may increase and decrease with the seasons or over longer periods. Predation and competition among species may bring about changes in the relative abundance of various species. Chance events, such as severe storms, may cause sudden increases in mortality of some species and open up habitat for others to colonize. Underlying all of this change, however, is a certain range of possibilities that help to define a given community. In the absence of a major disruption, species composition and relative abundance in a community can be expected to vary within definable boundaries, perhaps cyclically or perhaps randomly.

Contaminants introduced into such systems create new boundaries, changing the range of possibilities in ways that are not always predictable. Because most contaminants of concern exhibit toxic effects, they often reduce the number and kinds of species that can survive in the habitat. This may result in a community dominated by large numbers of a few species that are tolerant of the contaminant, or a community in which no species predominate but most of the component populations contain fewer organisms. A contaminant need not be directly toxic to affect community structure. If, for example, a change occurs in the salinity or dissolved oxygen content of an aquatic system, the new environmental conditions may eliminate some species and favor others, creating an entirely new species mix and food web. For example, salinity changes in Lake Michigan are changing the species composition of the primary producer component of the lake community from one dominated by green algae and diatoms to one composed principally of blue-green algae. Because many fish species currently in the lake are unable to feed on the blue-green algae, this species change portends significant shifts in other segments of the lake community.

Contaminants may cause or induce changes in the composition and structure of a biotic community as a secondary effect of the changes in the size of particular populations. These species may be a major source of food or shelter for the rest of the community, such as the large marine plants that give their name to California's kelp forests. Others may be crucial in maintaining a balance of species in a habitat. If, for example, a key predatory species is reduced or eliminated, the relative abundance of prey species may change significantly. In studies where predatory starfish were removed from an intertidal community, the number of species of prey animals (barnacles and shellfish) dropped from fifteen to eight. The starfish was preventing some species from outcompeting others because it preyed on whatever species was most abundant. In agricultural insect pest control, the phenomena of pest resurgence and secondary pest outbreaks are well known. When an insecticide kills off predatory insects along with the target pest, the pest population sometimes rebounds to much higher numbers than before because few predators remain to keep it in check. Destruction of the predators may also allow populations of other plant-feeding insects to increase beyond the limits imposed by the predators, thus creating new pest problems.

3.3.3 Changes In Ecosystem Structure and Function

As contaminants modify the species composition and relative abundance of populations in a community, the often complex patterns of matter and energy flow within the ecosystem may also change. If certain key species are reduced or eliminated, this may interrupt the flow of energy and nutrients to other species not directly experiencing a toxic effect. If plant life is adversely affected by a contaminant, the ecosystem as a whole may capture less solar energy and thus support less animal life. If microbial or invertebrate populations are disrupted, decomposition of dead plants and animals may not occur rapidly enough to supply sufficient mineral nutrients to sustain the plant community.

3.4 Factors Influencing the Ecological Effects of Contaminants

A contaminant entering the environment will cause adverse effects if:

- It exists in a form and concentration sufficient to cause harm,
- It comes in contact with organisms or environmental media with which it can interact, and
- The interaction that takes place is detrimental to life functions.

Adverse effects may also occur if a contaminant interacts with other chemicals already present such as to raise the overall toxicity of the contaminated environment. The likelihood of harm is thus a combined function of chemical, physical, and biological factors, depending both on the nature of the contaminant and the nature of the environment into which it is released.

3.4.1 Nature of Contamination

Classification of Chemicals

Chemical contaminants typically found at hazardous waste sites are classified into groups based on the analytical methods used to analyze for the chemicals in question. The CLP User's Guide[4] divides the contaminants commonly found at Superfund sites into two major classifications: inorganic and organic compounds (substances containing the element carbon).

The CLP routine inorganic analytical group is subdivided into two categories: heavy metals (lead, mercury, etc.) and cyanide. For the metal analysis, the OSC or RPM will need to determine whether they need "total" metal analysis (sample as collected in the field) or "dissolved" metal analysis (sample filtered to remove particulate matter).[5] A large amount of particulates in the sample matrix can produce large differences in the analytical results between the two analyses. The choice of analytical method also may depend on the expected route of exposure and the biotic species of concern at a particular site.

The routine organic analyses are subdivided into three categories: volatiles (benzene, vinyl chloride, etc.), semivolatiles (phenol, naphthalene, etc.), and pesticides (DDT, arochlors, etc.). For compounds not routinely analyzed for, or for unusual matrices, special analytical methods may be requested from the CLP. The OSC or RPM should consult the CLP User's Guide regarding the availability of special services. New procedures are also being developed in response to special requirements at some sites.

When requesting analytical services, the OSC or RPM should take note of any special conditions on the site that may make results of routine analyses insufficient for assessment needs. For example, it may not be possible to detect very low concentrations of certain contaminants in a sample matrix that contains (a) high concentrations of other contaminants or (b) chemicals (interferents) that coextract with the contaminants of concern.

Physical and Chemical Properties

Measurement of key physical/chemical properties of contaminants is useful in ecological assessment for two main reasons. First, these properties generally govern the transport and fate of chemicals in a particular environment. Second, for chemicals about which little is known, these characteristics can help the analyst identify chemical analogues among other commonly observed compounds that may serve as initial predictors of the novel compound's transport and fate.

The *Superfund Exposure Assessment Manual* (EPA, 1988), or SEAM, provides a comprehensive discussion of the environmental fate of contaminants by medium. Chapter 3 of the SEAM, "Contaminant Fate Analysis," includes both screening criteria and quantitative methods. Intermedia transfers and transformation are included in sections covering

[4] *User's Guide to the Contract Laboratory Program,* EPA Office of [ADD] (1988).

[5] "Filtered" is operationally defined as that which passes through a 0.45 μm filter.

atmospheric, surface-water, and ground-water fate, as well as biotic exposure pathways. In addition, the *Ecological Information Resources Directory* (EPA, 1989) will contain updated references for some parameters, such as bioconcentration factors.

Frequency of Release

The ecological effects of a single or occasional release are likely to be considerably different from those associated with a continuous release. Frequent release of a nonpersistent compound may have a long-term effect equivalent to a single release of a very persistent chemical. Occasional release may temporarily depress an invertebrate population, but continuous release may trigger drastic shifts in the species composition of an ecosystem. These effects should be carefully considered when performing quantitative exposure analyses as described in the SEAM.

Toxic chemicals may enter the environment, or move among compartments of the environment, on several possible time scales. For example, toxic discharges from a Superfund site to a waterway may occur:

- Only once (e.g., from an accidental spill),
- Intermittently (e.g., from storms causing nonpoint-source runoff of contaminated soils),
- Seasonally (e.g., from snowmelt in the spring),
- Regularly (e.g., from daily activities at the site), or
- Continuously (e. g., from ground-water discharge to the waterway).

Some or all of these types of release may happen at a particular site, and each type of release may cause a different concentration and mass to enter the waterway.

Different species of plants and animals may have different abilities to withstand or resist intermittent or continuous releases of toxic chemicals, so it is important to characterize the sources in terms of the kind of release that is occurring. For example, adults of a species may withstand a short-term discharge that kills all the juveniles, but be severely affected by a regular or continuous release. If such a differential effect were suspected, knowing the nature of the discharge might lead to monitoring strategies that emphasize one life stage or the other. Similarly, chronic discharges that allow bioaccumulation of certain toxicants may cause more lasting damage to certain species than to others. Such releases might be especially harmful to relatively immobile species.

Toxicity

Exogenous chemicals in an ecosystem can greatly increase the mortality rate of component populations, or can change the organisms' ability to survive and reproduce in less direct ways, such as:

- Altering developmental rates, metabolic processes, physiologic function, or behavior patterns;
- Increasing susceptibility to disease, parasitism, or predation;
- Disrupting reproductive functions; and
- Causing mutations or otherwise reducing the viability of offspring.

In assessing toxicity, the analyst is concerned about two aspects. The **hazard** posed by a contaminant is the effect (or **endpoint),** such as those mentioned above, that the chemical (or mixture of chemicals) can cause in the organism. The **dose-response** relationship describes the amount of chemical necessary to produce the observed effect. A broad array of toxicity tests are available for evaluating the effects of contaminants and their dose-response relationships. These are summarized in the companion volume to this manual and related references.[6]

The toxicity of a substance is generally described by the duration of exposure or the reactions it elicits.

Acute toxicity causes death or extreme physiological disorders to organisms immediately or shortly following exposure to the contaminant.

Chronic toxicity involves long-term effects of small doses of a contaminant and their cumulative effects over time. These effects may lead to death of the organism or disruption of such vital functions as reproduction.

Acute or chronic exposure can have lethal or sublethal effects.

- **Lethal** doses cause death directly through disruption of key physiological function. Population levels are affected by the

[6] *Ecological Assessments of Hazardous Waste Sites: A Reference Document* (EPA/600/3-89/013). EPA Office of Research and Development 1969.

contaminant if the overall mortality rate is increased.

- **Sublethal** toxicity entails symptoms other than death or severe disorder, but may have long-term effects on a population. For example, some toxicants at low concentrations cause a change in the behavior of migratory fish, interrupting their natural habit of returning to freshwater streams to spawn.

Evaluating the toxicity of a particular substance requires careful specification of the endpoints of concern, which entails describing

- The organism tested or observed,
- The nature of the effect,
- The concentration or dose needed to produce the effect,
- The duration of exposure needed to produce the effect, and
- The environmental conditions under which the effects were observed.

Ecologists will often use professional judgment to select a particular organism as an "indicator species," that is, a species thought to be representative of the well-being and reproductive success of other species in a particular habitat. The indicator species may also be chosen because it is known to be particularly sensitive to pollutants or other environmental changes. In addition, ecologists will often study some life stage of interest in the indicator species, such as:

- Reproductive success as measured by the survival of gametes, larvae, or embryos;
- Survival of juveniles or molts;
- Longevity of adults; or
- Incidence of disease, including physiological and behavioral abnormalities.

In studies of toxicity, certain measures are commonly used:

- **LD_{50}** or **LC_{50}** - the administered dose or environmental concentration at which 50 percent of the experimental organisms die in a spectified period of exposure time (often 96 hours).
- **ED_{50}** or **EC_{50}** - the dose or concentration at which 50 percent of the experimental organisms exhibit a certain nonlethal physiological or behavioral response in a specified time period (often 96 hours).
- **No Observed Effects Level (NOEL) or No Observed Adverse Effects Level (NOAEL)** - these measures, which are not time-dependent, describe the threshold below which predefined effects are not observed. When this threshold has not been determined, the **Lowest Observed Effects Level (LOEL) or Lowest Observed Adverse Effects Level (LOAEL)** describe the lowest recorded dosage at which effects were observed.

3.4.2 Physical/Chemical Characteristics of the Environment

A wide variety of environmental variables can influence both the nature and extent of effects of a contaminant on living systems. These factors - interacting with each other, with contaminants, and with organisms - can affect the outcome of a contamination by:

- Chemically changing the contaminant to make it more or less toxic,
- Making the contaminant more or less available in the environment, or
- Making the organisms more or less tolerant of the chemical.

Among the many factors that can affect the outcome of contamination in the environment are temperature, pH, salinity, water hardness, and soil composition.

Temperature affects the chemical activity of contaminants and biological activities of organisms in the environment. Low temperatures may be advantageous in certain contamination episodes, since both chemical and biological activity may be low. For example, low winter temperatures can reduce the toxicity of mining effluent to macroinvertebrates found in streams. But the same low temperatures can be detrimental in other circumstances. In a study of susceptibility of seabirds to oil contamination, researchers found that an amount of oil on the feathers too low to cause death under normal environmental conditions was much more stressful at colder temperatures.

The **pH** of the environmental medium may affect a contaminant's chemical form, solubility, and toxicity. This is especially true in the case of toxic metals. A one-unit decrease in pH can cause a more than twofold increase in lead concentrations in the blood of exposed rainbow trout. Studies have also shown that, in general, as environmental pH decreases, the toxicity of contaminants tends to increase.

Salinity, the amount of dissolved salts in a volume of water, is an environmental variable to which many marine and estuarine species are very sensitive. Some contaminants reduce these organisms' tolerance of normal changes in salinity, decreasing their ability to adjust to salinity fluctuations. For instance, one species of yearling salmon demonstrated reduced tolerance of increases in salinity after long-term exposure to copper.

Hardness, the amount of calcium, magnesium, and ferric carbonate in fresh water, can affect the toxicity of inorganic contaminants. Several Federal and State water quality criteria and standards are dependent on specific hardness ranges.

Soil composition can greatly affect the nature and extent of movement and toxicity of contaminants. Soils with a high clay-humus colloid content can absorb high levels of certain ions and neutral organics. The organic content of some wetland soils can bind large amounts of heavy metals, rendering them unavailable to the biota. Some water-insoluble pesticides are known to adsorb to soil particles that can then transport the chemical to surface water when erosion occurs. Light, sandy soils readily permit percolation of chemicals to ground water, which may in turn contaminate surface waters.

3.4.3 Biological Factors

Susceptibility of Species

Species differ in the ways that they take in, accumulate, metabolize, distribute, and expel contaminants. Taken together, these traits result in marked differences among species in their sensitivity to contamination. For example, over 400 species of insects and mites have developed resistance to pesticides used to control them, while hundreds of other species exposed to the same chemicals remain susceptible.

Usually, the major consideration as to how species will react to a potential toxicant is the dose. Generally speaking, the higher the dose, the greater is the likelihood that biological effects will occur. However, response to a particular dose may also depend on the duration of exposure. Some organisms can take in higher doses of a toxic material if exposure is spread out over time in smaller doses. For example, in one experiment, hens were fed leptophos (an organophosphate insecticide) in a single high dose or a series of lower doses. At the lower but multiple doses, the hens developed ataxia (paralysis of the legs) later than with the single high dose, but the total dosage over time was greater in the multiple feeding than the single amount that caused immediate ataxia.

Susceptibility of an organism varies with the mechanism through which contaminants are taken up from the environment. A given environmental concentration may result in different actual dosages for different species. For instance, some fish not only take in certain chemicals through their gills as they breathe, but can also absorb the chemicals through their skin. Species also differ in the way in which their bodies metabolize, accumulate, and/or store contaminants. For example, an organism that commonly holds energy in reserve in the form of body fat may experience little effect from the accumulation of fat-soluble chlorinated hydrocarbons such as DDT. However, in a time of scarce food supplies, the animal might then metabolize large amounts of fat, receiving a high dose of chemical as it does so.

In general, the susceptibility of a species to a particular contaminant will depend primarily on:

- The rapidity with which the contaminant is absorbed from the environment,
- The resultant dosage actually incurred at the physiological site where toxic effects occur within the organism (the "site of action"),
- The sensitivity of the site of action to the dosage incurred,
- The relationship between the site of action and the expression of symptoms of toxic injury, and
- The rapidity of repair or accommodation to the toxic injury.

Characteristics Governing Population Abundance and Distribution

For a given set of environmental conditions, species have characteristic attributes such as birth rates, age and sex distributions, migration patterns, and mortality rates. The species' habitat preferences, food preferences, and other behavioral characteristics (e.g., nesting, foraging, rearing young) also may determine population size and distribution in an area, and may also significantly affect the potential for exposure.

Differences in responses to contamination due to such characteristics may be manifest immediately. For instance, a species with a high proportion of juveniles in its age distribution might suffer a more precipitous decline after a release than another species that has a higher proportion of adults, simply because adults of a species can often sustain higher doses of a toxicant before succumbing than can juveniles.

Alternatively, the effects of species attributes governing population abundance and distribution may become apparent only when the stress is removed from the environment. Some species are very successful at colonizing new habitats. They typically have high rates of reproduction and short generation times, and are able to disperse widely in search of suitable habitat. For example, annual weeds, often the first plants to occupy disturbed environments, usually produce large numbers of seeds that are easily dispersed by wind or other means. In well established, more stable habitats, such "pioneer" species are often poor competitors against other species for limited resources. The species thriving in stable environments use the resources efficiently in the areas where they become established, and typically have low reproductive rates, long generation times, and often, longer life spans. They also tend to be better competitors in the territories they occupy. These are the species that are more likely to recolonize a disturbed habitat only after some considerable delay.

Species often combine characteristics of both of these idealized types. They may exhibit high reproductive rates and dispersal capability, along with other traits that allow them - under the right conditions - to outcompete later invaders. For example, in the southern United States, the imported fire ant has become a serious nuisance due in part to its ability to recolonize areas where insecticides were applied to control it. If the chemicals kill off other ant species, the fire ant is better able than its competitors to immigrate quickly and become entrenched in the newly opened habitat.

Temporal Variability in Communities

The effects of a contaminant discharge into a particular habitat may vary with seasonal or longer cycles governing community structure and function. Effects may be apparent immediately at one point of the cycle (e.g., in spring), whereas at another point the effects would be delayed. Contaminants may also elicit different effects at different stages of a community's development.

Seasonal changes entail relatively predictable, ordered changes associated with organisms' life histories, and are driven principally by cyclical changes in weather and other physical influences. Examples include:

- The spring blooms of plankton in estuaries and lakes,
- The change throughout the summer in the relative abundance of species of stream insects,
- The appearance of successive species of annual plants from spring to fall, and
- The concentration and dispersal of various animal species for breeding, nesting, and foraging.

When conducting an ecological assessment at a Superfund site, the analyst must consider these kinds of temporal variations when determining the probability of exposure. Depending on the time of year or the point in some longer cycle, a potentially exposed species may or may not be present or in a vulnerable life stage at the time of a chemical release.

Successional time scales are less regular and hence less predictable. Biological interactions or physical changes mediated by biological activity are usually important in the evolution of communities. The classic example of succession is the gradual change of a meadow to a forest. This series of events is measured in scores of years in undisturbed environments, and is not likely to be important in assessment of Superfund sites. Other successional change may be brought about by natural disturbance or human intervention and occur more rapidly. For example, intensive herbicide use in agricultural production sometimes results in preferential survival of weed species that are naturally tolerant to the chemicals used on the site. As the herbicides continue to kill off sensitive species, the herbicide-tolerant weeds come to dominate the non-crop plant community, and may in turn determine which species of insects, small mammals, and birds inhabit the area.

Movement of Chemicals in Food Chains

Food-chain transfer of contaminants represents a potential exposure route that should be addressed in assessing the ecological effects of a site. The processes involved in accumulation and transfer of chemicals via food webs are complex. Nonetheless, an understanding of a few basic aspects may be helpful in evaluating the importance of this phenomenon at a given site:

- Elevated concentrations of contaminants in organisms compared to environmental concentrations may not always signal food-chain transfer. Animals and plants canaccumulate chemicals directly from the medium in which they live. **Bioac - cumulation**[7] of chemicals in this manner is especially important for aquatic organisms and for terrestrial plants and animals (e.g., earthworms) in direct contact with soils. Elevated levels of a chemical found in most fresh-water fish and aquatic and soil invertebrates occur by direct concentration of the contaminant from the water, soil, or sediment rather than through the food chain.

- Certain species are more likely to be exposed due to food-chain transfer of bioaccumulating chemicals than others. Predators and other species near the tops of food chains are among the most vulnerable. Long-lived, fattier, and larger species have a greater opportunity to accumulate compounds in their tissues. Species that are more sensitive to the chemicals than the animals on which they are preying may be at particular risk of exposure (e.g., osprey feeding on contaminated fish).

- Certain chemicals are more likely to be transferred via food webs than others. Organochlorines and other persistent organic compounds (either parent materials or metabolizes resistant to further degradation) are more likely to be transferred than are non-chlorinated hydrocarbons and metals. Organic compounds with higher molecular weights are more likely to be transferred than those with lower molecular weights. Compounds with high **Log P**[8] values are most likely to be accumulated.

- Plants may take up chemicals with low Log P values by way of their roots, but cannot transport significant amounts of compounds with high molecular weights and high Log P values in the same manner. However, foliage can become contaminated from soil or water by sorption of volatilized chemical on the leaves or by deposits of dust, aerosols, and vapors.

- Longer food chains increase the time needed to reach equilibrium levels of contaminants in the predators at the top of the chain. The maximum value of bioaccumulation in the top species is also lower in longer food chains, but there is a greater certainty that a toxic chemical will have time to exert its effects on the population. Table 3.1 illustrates this for DDT applied to forest foliage. The table also shows the shift from DDT at the low end of the food chain to the more stable and toxic metabolite, DDE, at the high end.

- Bioaccumulation may be less than predicted for a variety of reasons. For example, organisms may avoid the chemical or prey that have consumed it, or exposure time may be insufficient to achieve equilibrium in living tissues. Furthermore, not all food chain transfers lead to **biomagnification**[9]**.** Field monitoring should be used wherever possible to determine actual tissue concentrations.

- For terrestrial species, **bioconcentration factors (BCFs)**[10] of as little as 0.03 can be signficant if the residue is toxic. For aquatic species, BCFs greater than 300 are generally considered significant.

Tabla 3.1. Forest Food Chain for DDT

Receptor	Chemical	Years to Maximum Cone
Foliage	DDT	0
Forest litter	DDT/DDE	1
Litter invertebrates	DDT/DDE	2
Ground-feeding birds	DDE	4-5
Canopy-feeding birds	DDE	5-7
Bird-eating hawks and owls	DDE	7-10

Source: James W. Gillett, Cornell University

[7] The process that results in increased concentrations of contaminants in organisms with increasing trophic levels in the food chain.

[8] The logarithm of the octanol-water coefficient (K_{ow}). Predictor of bioaccumulation in the oils of fish end the fat of animals.

[9] Higher concentration in the consumer than in the contaminated source.

[10] The BCF is the ratio of the concentration of a contaminant in the organism to the concentration in the immediate environment (soil, water, and sediments).

Chapter 4

The Role of Technical Specialists in Ecological Assessment

"Every site is unique."

This is probably the most common generalization on which ecologists who have worked on hazardous waste sites will agree. It is also only partly true.

What makes every site unique is its particular combination of characteristics - the contaminants of concern, the topography of the site, the presence or absence of surface water, the vegetation, other species present, soil types, proximity to other important habitats, etc. Taken together, these factors present an almost infinite array of potential ecological risk scenarios - the populations at risk, the nature of the contaminants, their toxicity to different species, routes and probabilities of exposure, environmental factors contributing to or inhibiting toxicity, short- and long-term shifts in the structure of biotic communities, and the effects of remediation on the habitats at or near the site.

Nonetheless, ecologists are able to find common elements in their study of populations, communities, and ecosystems, some of which were discussed in Chapter 3. These common elements form the basis for designing a strategy for characterizing any individual site and defining its specific properties. Thus, although every site is unique, the methods for assessing each site are not. Deciding which factors are important, and which methods to use to assess those factors, is a complex task requiring the expertise of ecologists who are familiar with the organisms, ecological processes, and environmental parameters that characterize a site. This chapter outlines how such specialists can help the RPM or OSC specify, obtain, and evaluate information needed to assess ecological effects at Superfund sites.

This guidance manual presumes that the RPM or OSC will obtain the assistance of ecologists and other environmental specialists. In some Regions, informal or formally constituted technical assistance groups already exist. In other Regions, advice may be obtained from various sources, including:

- EPA Regional Environmental Services Divisions;
- The EPA Environmental Response Team;
- EPA Regional NEPA coordinators;
- Ecosystem-specific EPA programs, such as the Great Lakes National Program Office in Chicago, or the Chesapeake Bay Program Office in Annapolis, Maryland;
- Laboratories of EPA's Office of Research and Development; and
- Regional and field offices of the U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration (especially NOAA's Coastal Resource Coordinators), and other Federal and State environmental and resource-management agencies.

Generally, technical specialists serve an advisory role. Their function is to assist the RPM or OSC with information collection and evaluation, and to help ensure that ecological effects are properly considered in investigations and decisions. In specific cases, it may be possible to make arrangements (such as interagency agreements in the case of non-EPA staff) for them to be involved directly in conducting the work.

In the following sections, we describe how ecological specialists can contribute to the RI/FS and Removal processes. We have divided the discussion into five major aspects:

- Site characterization,
- Site screening and identification of information gaps,
- Work plan development,
- Data review and interpretation, and
- Enforcement.

These divisions are made for convenience of discussion only. Not all sites will require all five types of activity, and some activities may proceed in parallel rather than sequentially.

4.1 Site Characterization

RPMs and OSCs are encouraged to consult with ecologists as early as possible to obtain their help in conducting an effective ecological assessment. This assessment should begin with an ecological characterization of the site. In the RI/FS process, this stage corresponds with the early phases of developing a site management strategy.

An initial site description will be necessary to orient the technical specialists. This description should be assembled by the RPM or OSC from existing sources of information, without conducting formal field studies. Its primary purpose is to allow the specialists to:

- Identify issues that should be addressed in the ecological assessment to follow, and
- Develop data-collection strategies.

The description should include information on the location of the site, its history, likely contaminants of concern, and the environmental setting of the proposed actions. Although primary responsibility for preparing the site description lies with the RPM or OSC, the technical specialists should provide guidance, when requested, on what information they need in the initial site description to allow them to understand the scope of the problem. Much of the information needed at this stage is commonly used material, available from published sources or from previous assessments of the site. For example, studies in support of a removal action may be useful in planning for a Remedial Investigation.

Site location. The technical specialists should be provided with maps and descriptions of the site, indicating, where possible:

- The geographical area (town, county, quadrant, or other appropriate unit) around the site;
- The locations of streams or other surface waters on or near the site;
- Locations of other ecological habitats such as forested areas, grasslands, floodplains, and wetlands on or near the site;
- Locations of soil types and current or projected uses; and
- Locations of contaminant sources at or near the site.

Topographical maps published by the U.S. Geological Survey should be provided. For areas that are predominantly privately owned, floodplains are delineated on the Flood Insurance Rate Maps and the Flood Hazard Boundary Maps published by the Federal Emergency Management Agency. For areas that are predominantly owned by States or the Federal government, the controlling agency can usually provide floodplain information.

Documentation of the fact that a site exists in or near wetlands is an important first step in the ecological assessment. Several sources of information are available to RPMs and OSCs to determine if a contaminated area is in or near a wetland. Maps of wetlands are available from a variety of sources, including the U.S. Fish and Wildlife Service, local and State planning agencies, and the Section 404 staffs in the EPA Regions. The National Wetlands Inventory maps (NWI) developed by the Fish and Wildlife Service, or other more specific information at the State level should be consulted as early as possible. If more exact locations and/or boundaries are required, the *Federal Manual for Identifying and Delineating Jurisdictional Wetlands* (March 1989) should be consulted. This manual was developed to identify jurisdictional wetlands subject to Section 404 of the Clean Water Act and the “Swampbusters” provision in the Food Securities Act, as well as to identify vegetated wetlands for the NWI.

The OSC or RPM should contact the State Geographical Information System, Information Management Office, and Land Management Offices for additional maps of environmental resources. Aerial and satellite photographs that include the site and its surroundings should also be sought out and provided to the specialists if appropriate.

Site history and contaminants of concern. The initial site description should include a history of the site drawn from existing sources. Topics that should be addressed include available information on chemical-handling activities, storage locations, and known or potential contaminants. If a health effects assessment has already been performed on the site, standard information on contaminants - chemical composition, amounts, and locations - will also be useful for ecological assessment. Where available, the descriptions of chemicals should also include information on:

- Decomposition rates and products,
- Bioaccumulation potential,
- Known toxic effects, and
- Fate and transport.

Environmental setting. The initial site description should include any available information on geology, hydrogeology, and ecological habitats at or adjacent to the site. Geological information may be obtainable from existing publications of the U.S. Geological Survey or similar sources. Precipitation records for nearby weather stations (often located at the nearest airport) can be obtained from the National Weather Service. Previous environmental analyses may be available for some sites, which could help identify important habitats or species for the assessment to consider. These might include, for example, an Environmental Impact Statement for a nearby facility (e.g., highway, power plant), a State Remedial Action Plan for a designated Area of Concern, or a National Pollutant Discharge Elimination System permit for wastewater discharge into a nearby waterway.

Obtaining information about local ecological resources may require consultations with local experts on the subject, including State pollution-control officials, State or Federal fisheries and wildlife-management specialists, State or Federal foresters, agricultural extension agents or Soil Conservation Service officials, and others familiar with the terrain and biology of the region. These individuals may also provide important details regarding past, present, and likely future uses of land and water resources in the area. The RPM or OSC may want to consult the technical assistance group or individual specialists for help in identifying people to contact for this information. These contacts may also provide assistance in identifying potential ARARs for the site.

Using this information, the technical specialists should be able to begin identifying the habitats potentially affected by contaminants at the site. Key to this activity will be a preliminary definition of the likely pathways for exposure to the contaminants. Once these habitats are identified, the relevant Federal and State natural resource trustees should be notified and invited to participate in planning the ecological assessment, if they are not already serving as technical specialists.

If possible, one or more technical specialists should accompany the RPM or OSC to the site for an initial field reconnaissance. This visit can help clarify for the assistance group the kinds and amounts of data that may be needed to characterize the site and its contaminants, keeping in mind that seasonal changes may alter the nature and quantity of releases or affected organisms.

4.2 Site Screening and Identification of Information Gaps

Following collection of existing data, the technical assistance group should be in a position to determine the nature and extent of ecological assessment that will be necessary for the site. If no ecological exposure pathways have been revealed in this initial review, little or no additional work may be needed. Alternatively, certain exposure pathways might be eliminated from further study while others might require more data. For instance, if there is no surface water on the site and no opportunity for contaminants to reach surface waters off the site, further data on aquatic effects would very likely be pointless, even though concern about exposure to terrestrial organisms might warrant extensive sampling and testing.

Examination of preliminary data could point up important gaps in the information concerning characterization of the site. Site visits, aerial or satellite photographs, or information from local experts may reveal habitats subject to exposure that were not part of the original data-gathering effort. For instance, careful examination of the site might result in the discovery of a previously unreported stream running through the property that could raise questions about contaminants reaching an off-site wetland.

Review of the data from initial studies may also indicate that potential exposure pathways or receptors were either overlooked or previously unknown to the site investigators. For example, evidence might be found that small mammals are burrowing and foraging near storage facilities. This information would probably raise concern about direct exposure of these animals to contamination. Depending on the persistence and bioaccumulation potential of the contaminants, the observation of these mammals might also suggest additional risk to predatory birds and mammals both on and off the site through the food chain. These concerns might then lead to a new study plan to trap some of the mammals and test their tissues for contaminants.

The technical specialists might also conclude from information developed during the early stages that the contaminants identified at the site are causing unexpected toxic effects. For instance, biotic surveys might show an absence of certain fish species that occur in otherwise similar, but uncontaminated, streams. If there is reason to suspect that the absence of these fish may be caused by toxic effects, field or laboratory toxicity tests might be appropriate to determine the toxicological potential of the contaminants.

4.3 Advice on Work Plans

Where applicable, ecological assessment is an integral part of the RI/FS Work Plan. Technical specialists should be consulted as early as possible in the development of the Work Plan and the Sampling and Analysis Plan, to ensure that the plans for ecological assessment are well designed and capable of answering the necessary questions about the ecological effects of the contaminants at a site.

Effective ecological assessment will require a design that is tailored to each site's specific characteristics and the specific concerns to be addressed. Choosing which of the many possible variables to investigate in the study will depend on the nature of the site, the types of habitats present, and the objectives of the study. The technical specialists should therefore assist the RPM in specifying technical objectives for the investigation. Such objectives might include:

- Determination of the extent or likelihood of impact,
- Interim mitigation strategies and tactics,
- Development of remedies, or
- Remediation criteria.

The technical specialists can then help the RPM develop data quality objectives to support these technical objectives.

Although each assessment is in some way unique, it is possible to outline the general types of data that may be required. For terrestrial habitats, the technical specialists may specify such data needs as:

- Survey information on soil types, vegetation cover, and resident and migratory wildlife;
- Chemical analyses to be conducted in addition to any previous work done as part of a Preliminary Assessment or Site Investigation; and
- Site-specific toxicity assessments to be conducted.

For fresh-water and marine habitats, the information needed will most likely include:

- Survey data on kinds, distribution, and abundance of populations of plants (phytoplankton, algae, and higher plant forms) and animals (fish, macro- and micro-invertebrates) living in the water column and in or on the bottom;
- Chemical analyses of samples of water, sediments, leachates, and biological tissue;
- Sediment composition and quality, grain sizes, and total organic carbon; and
- Toxicity tests designed to detect and measure the effects of contaminated environmental media on indicator species, or on a representative sample of species, such as water fleas (Daphnia or Ceriodaphnia), amphipods, chironomid midge larvae, tubificiid worms, mysid shrimp, and fathead minnows.

Where specialists have reason to believe that contaminants may move from one type of habitat to another, such as chemicals washing into a stream in runoff water, data from each potentially exposed habitat will be needed. The *Superfund Exposure Assessment Manual* contains much valuable information on predicting movement of contaminants from one medium to another.

The technical specialists should also provide guidance on such quality assurance and quality control (QA/QC) issues as:

- The area to be covered in biotic and chemical sampling programs,
- The number and distribution of samples and replicates to be drawn from each habitat,
- The preferred biological analysis techniques to be used,
- Adherence to the assumptions of predictive models used in the analysis,
- The physical and chemical measurements (e.g., dissolved oxygen in a water sample, pH of water or soil, ambient temperature) to be taken at the time of the survey, and
- Any special handling, preservation methods, or other precautions to be applied to the samples.

Technical specialists may make specific recommendations on sampling and analytical methods, or they may review plans and offer comments or suggestions for improvement of the assessment methodology. Ideally, the sampling and assessment process should be a phased approach, where preliminary results are reviewed by technical specialists, who may find reason to suggest changes in the scope of the project or in the methods used during subsequent stages of the study.

4.4 Data Review and Interpretation

The technical assistance group should also be called upon to review data and provide comments on the interpretation of data. In most situations, extensive and long-term ecological studies are unlikely to be undertaken, and informed professional judgment will be required to determine if the weight of evidence supports a particular decision regarding the site.

Specialists should be closely involved in reviewing interim and draft assessments as these documents are completed. The appropriate specialists should be consulted to ensure that the assessments:

- Address all important habitats and contaminants of concern,
- Identify all significant receptor populations,
- Portray all relevant routes of exposure,
- Characterize all significant ecological threats, and
- Describe uncertainties in the assessment process.

The specialists may also provide advice on how to present the results to decision makers who are not trained in environmental science.

4.5 Advice on Remedial Alternatives

Remediation measures can also pose environmental threats. For instance, channeling a stream may deprive a wetland of its primary water source; earthmoving and construction operations may increase siltation of nearby streams due to increased soil runoff. In such situations, compliance with appropriate laws and regulations may require that the remediation plan include provisions for minimizing environmental damage. Ecologists should therefore be involved as early as possible in the selection and review of remedial alternatives so that ecological as well as public health concerns are addressed in the Feasibility Study.

Technical specialists should also be involved in designing monitoring programs to evaluate the success of a removal or remedial project. Biological monitoring plans should be developed to evaluate the effects of remedial actions on local populations of various forms of wildlife. In addition, toxicity tests can be used as sensitive indicators of the presence or absence of contaminants following remediation. Such tests may be useful in defining cleanup levels.

4.6 Enforcement Considerations

If ecological effects of contaminants area factor in enforcement actions, technical specialists may be a valuable resource both in crafting the decision documents and in providing support for the decision. Proposed decisions that incorporate ecological criteria for cleanup or remedial action should be reviewed by appropriate ecological experts to ensure that the criteria (1) are accurately described and (2) can be effectively implemented. Technical specialists may serve as expert witnesses in court or administrative hearings in support of enforcement actions. Finally, as discussed above, ecologists may be consulted on the design and implementation of monitoring programs to help ensure that remedial actions achieve their objectives.

Chapter 5

Planning an Ecological Assessment

Because ecological assessments will vary widely from site to site, no standard design is appropriate. The scope, level of detail, and design of the assessment should be determined in close consultation with ecologists who understand both the technical issues involved and the requirements of the Superfund program. Some of the factors that should enter into the planning stage are:

- The objectives of the assessment, as determined by the management decisions required at the site;
- The programmatic goals, mandated schedules, and budgetary restrictions associated with the site's remediation;
- The kinds, forms, and quantities of contaminants at the site;
- The means of potential or actual release of contaminants into the environment;
- The topography, hydrology, and other physical and spatial features of the site;
- The habitats potentially affected by the site;
- The populations potentially exposed to contaminants;
- The exposure pathways to potentially sensitive populations; and
- The possible or actual ecological effects of the contaminants or of remediaractions.

This phase of the assessment process is concerned with determining what information should be collected for an ecological assessment. It consists primarily of identifying characteristics of the contaminants and the potentially affected environments, to:

- Determine if enough evidence exists to warrant further investigation of ecological effects at the site;
- Establish the scope of the ecological assessment (if one is judged necessary) in terms of spatial and temporal extent, tests to be conducted, time and resources needed, and level of detail required; and
- Define study goals and data quality objectives if collection of new data is deemed necessary.

If new data are collected, it is essential that data quality objectives reflect specific programmatic goals and management objectives, to ensure that time and funds spent to gather and analyze data are used efficiently and effectively.

This chapter discusses the principal components of defining the scope and design:

- Determination of the objectives and level of effort appropriate to the site and its contaminants,
- Evaluation of site characteristics,
- Evaluation of the contaminants of concern,
- Identification of exposure pathways, and
- Selection of assessment endpoints.

These are logically distinct activities, but they are not necessarily undertaken sequentially. All may be underway simultaneously, or one activity may await the outcome of data from other activities. The outcome of this process is the Sampling and Analysis Plan (SAP), which specifies the methods for data collection and analysis, and the procedures for quality assurance and control (QA/QC).

5.1 Determination of Need, Objectives, and Level of Effort for Ecological Assessment

Defining the scope and design of an assessment is initially based on available information and data from previous studies. Using this material, the RPM or OSC should consult with technical specialists, who can be expected to use good professional judgment to provide advice on how to evaluate a specific site. The outcome of this phase should be an assessment design that will ensure scientific defensibility of data and decisions based on those data, while remaining cognizant of the CERCLA-mandated schedules and budget constraints faced by decision makers.

An ecological assessment may be conducted to:

- Document actual or potential threat of damage to the environment, in support of a proposed removal action;
- Define the extent of contamination;
- Determine the actual or potential effects of contaminants on protected wildlife species, habitats, or special environments;
- Document actual or potential adverse ecological effects of contaminants, as part of a Remedial Investigation;
- Develop remediation criteria; and
- Evaluate the ecological effects of remedial alternatives, as part of a Feasibility Study.

A given assessment may entail one or more of these objectives as the primary reason(s) for the study. Specification of assessment objectives should in turn allow clear definition of the ecological endpoints of concern, the study methods to be employed, and the data quality objectives for the study.

The RPM or OSC should confer with technical specialists to determine appropriate levels of detail for ecological assessment of a site based on available information. This should be undertaken as an iterative process. Data from the field may warrant further investigation and greater detail. Conversely, such data may indicate that little or no additional work is necessary to characterize ecological effects. The definition phase should be used to identify the criteria needed to make these judgments.

Each assessment will vary in the extent to which resources, exposure concentrations, effects, and other variables are identified and quantified. The more serious effects found may not relate absolutely to the amount of detail required in the assessment. The need for detailed, quantitative information will be driven by the difficulty in adequately characterizing the parameters that comprise the assessment. For instance, a fish kill might be readily traced to a high concentration of a contaminant from a point source. On the other hand, considerable effort might be needed to evaluate the causes of unusually low populations of fish in a stream that contains low levels of diverse and dispersed contaminants.

5.2 Evaluation of Site Characteristics

5.2.1 Nature and Extent of Contaminated Area

In defining the scope and design for an ecological assessment, it is important to determine the full spatial extent of the contamination through sampling and measurement. The sampling plan should be designed with a broad enough radius to find the "edge of the plume," the farthest extent of the contamination in soils or other environmental media.

Maps and aerial photographs should be used whenever possible to define the general habitats at or adjacent to the site. Small wetlands, intermittent streams, and other potentially important areas that might have been missed during a preliminary site visit may be seen from aerial photographs or maps. Significant off-site information may also be derived from good maps and photographs (e.g., discharges from surrounding areas that may affect the site). This type of information may provide significant insight into the conduct of the site investigation. Ground verification of all habitat locations should be conducted before developing any sampling plans.

At this stage, it is also important to determine which transport processes are likely to be at work with respect to each contaminant. From this information, analysts should be able to discern likely off-site exposure routes and the habitats threatened or potentially threatened by that exposure. The RPM or OSC should consult the *Superfund Exposure Assessment Manual* (SEAM) for detailed information on predicting chemical fate and transport in the environment.

In characterizing a site and determining how contaminants may move through the environment associated with the site, the RPM or OSC should examine trend data such as variations in climatic conditions that may affect population levels of resident species. These data may indicate conditions, such as periods of high rainfall or drought, that place additional stress on local ecosystems and may affect the fate and effects of contaminants.

Based on all of this information, and in close consultation with technical specialists, the RPM or OSC should set site-specific objectives for investigation of each potentially contaminated habitat, including

- Environmental media to be sampled and analyzed for contaminant levels,
- Detection limits for contaminants,

- Toxicity tests to be performed and species to be tested, and

- Ecological (population, community, or ecosystem) effects to be measured or predicted.

Data quality objectives arising from these study objectives should then be developed to determine what level of effort will be necessary to obtain scientifically defensible answers. It is important to emphasize that the extent of delineation of exposed habitats should be determined by the potential for exposure, not by arbitrary distances or boundaries that lack a biological justification.

5.2.2 Sensitive Environments

For a particular site, the project team should prepare a list of habitats requiring special attention in the assessment. Although ecological judgment is necessary to define some priorities, State and Federal laws and regulations designate certain types of environments, such as wetlands, as requiring special consideration or protection. Critical habitats for species listed as threatened or endangered also may require protection. Consultation with natural resource trustees and other technical specialists will be invaluable in ensuring identification of these key areas.

In addition to identifying habitats that meet specific State or Federal criteria, the project team should also consider if any other habitats on the site are:

- Unique or unusual, or

- Necessary for continued propagation of key species (e. g., rare or endangered species, essential food sources or nesting sites for other species, spawning and rearing habitats, etc.).

The importance of habitats on or near a hazardous waste site will vary from area to area, depending on such factors as:

- The species native to the area and their significance (e.g., regionally important sport fish),

- The availability and quality of substitute habitats,

- The land use and management patterns in the area, and

- The value (economic, recreational, aesthetic, etc.) placed on such habitats by local residents and others.

The project team should define and identify sensitive environments based on a site- and area-specific analysis, keeping in mind the ecological connections between the site and nearby habitats.

5.3 Contaminant Evaluation

5.3.1 Identification and Characterization

Along with site characterization, a parallel prime objective in defining the scope and design of an assessment is to characterize the contaminants of concern (and their transformation products) in terms of their known or suspected potential to cause ecological harm. Besides identifying and classifying the contaminants of concern, the RPM or OSC should make sure that characteristics of the chemicals are measured that will help to determine the site's likely ecological effects. Based on measured or calculated physical/chemical properties and other published data, the contaminants' likely persistence in the environment should be estimated. The RPM or OSC should also obtain information to describe the frequency, intensity, and route(s) of chemical release to the environment.

Preliminary information on the physical/chemical properties, bioaccumulation potential, and other characteristics of contaminants can be used to define the parameters of studies to be conducted for an ecological assessment. For example:

- If chemicals are known or suspected to be water-soluble, analysts should be prepared to investigate potential exposure routes to aquatic habitats. Water-soluble compounds may also be expected to move readily within the aqueous phase of some soils, increasing the likelihood of exposure for soil-inhabiting organisms.

- For chemicals with low volubility in water, the RPM or OSC should investigate the potential for the compound to adsorb to soil particles. Should this occur, the chemical could be transported through erosive soil runoff to surface waters or other terrestrial environments near the site. Contaminated soil particles may also be ingested by organisms living on or in the ground.

- If a contaminant is judged to be persistent, or if environmental release is frequent or continuous, the ecological assessment may (where time permits) include chronic as well as acute toxicity tests on potentially exposed organisms. The RPM or OSC may also need to consider studies and/or use of appropriate predictive models to assess long-term population effects.

- If compounds are known or suspected to bioaccumulate, studies may be needed to determine the extent of bioaccumulation in potentially exposed organisms. This will probably entail a close look at transport and exposure pathways and collecting data on contaminant concentrations in tissues of likely bioaccumulators such as fish.

5.3.2 Biological and Environmental Concentrations

Based on the preliminary information about the nature the contaminants, a sampling and analysis plan can be devised to determine contaminant concentrations in all relevant media. As in all other assessments, the best measures are those that are accurate, precise, and representative of the situation in space and time. The best way to achieve this is to plan sampling programs with ecological assessment as a clearly specified objective. As a general principle, sampling, monitoring, and measurement should be designed by taking account of exposure pathways to habitats and organisms on or near the site.

A brief field reconnaissance of the site, combined with accurate maps or aerial photographs, should be sufficient to identify important habitats that may require sampling. Consultation with ecologists familiar with the area will probably indicate the kinds of organisms to be expected on the site and the probable exposure pathways that should be investigated. This in turn should lead to study designs for measuring contaminants in media appropriate to those exposure pathways. For instance, if a compound is known or suspected to be volatile, air sampling in potentially exposed habitats may be appropriate. If the chemicals are believed to have reached surface waters, stream sediments and biota may need to be analyzed to determine the full extent of contamination. If biological transport of the contaminants is considered possible, the sampling plan may need to include testing for the presence or effects of low levels of chemical at some distance from the source.

If contaminants are suspected of bioaccumulation or are considered fairly persistent, the RPM or OSC may need to require studies to determine if the chemicals are being transferred from organism to organism through the food web. Food-chain linkages can be evaluated using information on the trophic relationships of the species at a site. Direct measurements of chemical residues in animal tissues provide the most direct approach for assessing the extent to which food chain transfer of chemicals may be occurring. If such biological transfer of contaminants is suspected, the RPM or OSC should consult with technical specialists on the proper design of studies to evaluate the extent and effects of the phenomenon.

Estimating chemical fate and transport is a key first step in quantifying exposure. Having identified the exposure pathways, the analyst should plan on sampling pertinent media to determine the concentrations of the contaminants of concern. As discussed in detail in the SEAM, predictive models can help in estimating fate and transport of contaminants. For Superfund sites, the analyst should consult the SEAM and specialists to determine the applicability of any particular model to the specific site. Among the considerations will be the assumptions underlying the model, the quantity and quality of input data needed, and the degree of confidence in the model's results. The decision on what model(s) to use may determine sampling and analytical design, including analyses required, sample sizes, sampling method, and sampling frequency.

5.3.3 Toxicity of Contaminants

A key objective of the definition phase of the assessment process is to develop a sampling and analysis plan to assess the toxicity of site contaminants to potentially exposed populations of plants and animals. Evaluating the toxicity of a substance at a particular site requires careful specification of the effects of concern, such as mortality or reproductive failure, and the duration of exposure (i.e., acute or chronic). At the planning stage, literature reviews are the most likely sources of information on the toxicity of contaminants. Literature searches can help guide an investigation, especially in identifying the likely mechanisms of toxicity. However, the user of a literature review must fully understand the restricted character of the information. Its value in characterizing actual or probable hazards at a specific site is extremely limited, for several reasons:

- Toxicologists generally study a population of one species because the effects on a community or ecosystem are too difficult for standard practice. If the species chosen for the study is not a good indicator species for habitats found at the site, the study's findings may be a poor predictor of the site's actual hazards.

- Toxicologists generally study the effects of a single toxicant at a time. This practice is rarely representative of field conditions where organisms may be stressed simultaneously by several toxic ants, fluctuations in the availability and quality of nutrients, and variations in weather and climate. When organisms are exposed to two toxicants at the same time, the effects may be directly additive, more than additive (synergistic), or less than additive (antagonistic), depending on the toxicants in question, the organisms exposed, and the environmental conditions.

- Published research may use death or a subacute effect, such as behavioral change, as the endpoint. Incorporating statistics into their analyses, scientists may select the median (50 percent) response of a population, or they may choose some other percentile of response as appropriate, perhaps the 10 percent or the 90 percent response. Unless the measures used in the research correspond well to the objectives of the ecological assessment, the results may be difficult to apply to the specific site or contaminants at issue.

- Researchers usually report a fixed time for an experiment. For example, for aquatic tests, toxicologists often study the response over 48 or 96 hours, depending on the species and the toxicant. Occasionally, researchers will study a complete generation of organisms or a complete cycle of reproduction and recruitment, but rarely do they have the resources or time to study several generations.

A wide array of experimental protocols and results exists in the literature, in which every variation from study to study can be found different organisms, toxicants, laboratory conditions, endpoints, concentrations, statistical summaries, and durations. Although all of these studies may be informative for some purposes, they are difficult to compare and contrast, and judging the validity of extrapolation to a specific site and its contaminants should be left to qualified specialists.

Despite the wide diversity of experimental designs, ecologists have settled on a few widely recognized organisms and protocols for study. For example:

- To study effects on terrestrial invertebrates, researchers commonly use one or more species of earthworms to represent soil organisms, generally using two- or four-week test protocols.

- Toxicology studies of birds often use bobwhite quail, ring-necked pheasants, or mallard ducks.

- Because of their widespread use for human health assessment, there exists a large data base of toxicity studies on laboratory rats, mice, and rabbits. Therefore, these are also commonly used as surrogate species for estimation of toxicity to other mammals.

- For equivalent studies of aquatic organisms, scientists have long used species of *Daphnia* or *Ceriodaphnia* (water fleas) to represent freshwater invertebrates in 48- or 96-hour test protocols, while freshwater fish have been represented by the fathead minnow, rainbow trout, and bluegill.

- The Microtox® test, dissolved oxygen depletion test, or reazurin reduction test are sometimes used to indicate toxic effects on microbial populations.

- Commonly studied marine and estuarine species include mysid shrimp, Dungeness and blue crabs, oysters, mussels, and sheepshead minnows.

- For studies of effects on plants, domesticated species are often used, such as lettuce seeds in germination tests.

It is often possible to select one or more of these commonly tested species as surrogates for species found at a site if toxicity testing is warranted. To develop a proper understanding of conditions at the site, data on surrogate species need to be interpreted by wildlife/fishery toxicologists and ecologists experienced in evaluating contaminants. Differences in physiology between closely related species or apparently minor differences in physical or biological conditions at the site can often complicate such interpretations.

Literature surveys can help identify possible targets for investigation if toxic effects are reported, but they are unlikely to eliminate chemicals from further consideration if negative results are reported. Positive findings in a laboratory research study of toxic effects may indicate the mode of action of the chemical. They may also help the investigator determine the endpoint for toxicity tests conducted with materials from the site. Laboratory tests indicating low toxicity may or may not mean low toxicity in the field, since even the best laboratory simulation cannot mirror field conditions.

Generally speaking, field data, monitoring information, and toxicity testing of contaminated media are more useful and reliable than literature estimates. Wherever possible, the assessment should be based on data collected from the field.

In those circumstances where exposure appears likely, toxicity testing will be needed to determine the effects of contaminants in the concentrations found or expected at the site on potentially exposed plant and animal populations. Results from published studies can serve as a useful guide for deciding:

- What toxicity tests (e.g., acute, chronic) should be conducted with field-collected samples,
- What kinds of organisms should be tested,
- What effects should be anticipated, and
- How the tests should be interpreted.

From these decisions, a specific set of data quality objectives should be formulated, including:

- The number and type of tests to be run,
- The environmental conditions to be monitored,
- The detection limits for contaminants,
- The number of samples to be taken, and
- The acceptable margin of error in analyzing results.

Site-specific information on sensitivity to contaminants should be gathered wherever necessary and feasible. Studies to collect such data should be designed carefully, in close consultation with technical specialists. The general categories of studies that might be conducted include the following:

- *In-situ* (in-field) toxicity tests. Methods for *in-situ* studies are available for aquatic toxicology and, to a more limited extent, terrestrial toxicology. Such methods usually involve exposing animals in the field to existing aquatic or soil conditions. Generally, these methods involve the use of enclosures to hold the animals at a specific location for the designated exposure period (e.g., caged fish studies).
- Field observations. Correlation of the abundance and distribution of animals and plants with measurements of chemical concentrations may not prove the existence of toxic effects, but may offer some insights as to likely sensitivities and add to the "weight of evidence" concerning the site.
- Toxicity tests of contaminated water, soil, sediments, or elutriates in the laboratory. These can be used to evaluate the lethal or sublethal effects of chemicals as they occur in environmental media. They can also be used to test for toxicity of mixtures as they actually occur in the environment. Some methods for these tests have been published by EPA.[1]

5.3.4 Potential ARARs and Criteria

Once the contaminants at a site have been identified, the RPM or OSC should identify those for which criteria have been established, and determine whether any such criteria apply as potential ARARs at the site in question. (See Chapter 2.) If usable and applicable criteria exist, the assessment should include sampling and monitoring plans to determine the extent to which those criteria are exceeded by environmental concentrations at the site. If criteria do not exist for the contaminants in question, analysis of known toxic effects and possible threshold levels may be used to develop site-specific criteria against which to compare field data. The RPM or OSC may also wish to consult with technical specialists to determine if any chemicals for which criteria have been established might be appropriate analogues for the contaminants of concern at the site. EPA's Office of Toxic Substances has published a volume describing the use of analogues for estimating toxicity to aquatic organisms.[2]

5.4 Potential for Exposure

Before the effects of a contaminant on an organism can be evaluated, it is necessary to know how much of the chemical is actually or potentially reaching the point of exposure (the location where effects can occur). This depends on characteristics of the contaminant, the organism, and the environment. Exposure assessment seeks to answer the following questions:

- What organisms are actually or potentially exposed to contaminants from the site?
- What are the significant routes of exposure?
- To what amounts of each contaminant are organisms actually or potentially exposed?
- How long is each exposure?
- How often does or will exposure take place?

[1] *Ecological Assessments of Hazardous Waste Sites: A Field and Laboratory Reference Document* (EPA/600/389/013), EPA Office of Research and Development, 1989; J.C. Greene, S.A. Peterson, C.L. Bartels, and W.E. Miller, *Bioassay Protocols for Assessing Acute and Chronic Toxicity at Hazardous Waste Sites,* EPA Office of Research and Development, January 1988.

[2] *Estimating Toxicity of industrial Chemicals to Aquatic Organisms Using Structure Activity Relationships,* Office of Toxic Substances (EPA/560/688/001), July 1988.

- What seasonal and climatic variations in conditions are likely to affect exposure?

- What are the site-specific geophysical, physical, and chemical conditions affecting exposure?

Analysis of contaminant concentrations in tissues of exposed organisms can help provide a link between environmental concentrations and the amount of contaminant likely to reach the site of action. For many contaminants and organisms, time delays may need to be considered when attempting to correlate environmental and biotic concentrations. This will allow for the time that may elapse before a chemical is taken up into living tissue. Some of the factors that may influence uptake include:

- The **environmental concentration** of the contaminant in the media to which the organism is most often exposed;

- The **metabolic rate** of the organism, which in turn may be a function of such environmental parameters as temperature, availability of sunlight, water, nutrients, oxygen, etc.;

- Species-specific **metabolic processes,** such as food absorption rates and the ability to degrade, accumulate, store, and/or excrete the contaminant;

- **Behavioral characteristics** such as food preferences and feeding rates (both of which may vary with the time of year and the age of the organism), and the ability to detect and avoid contaminated media or food;

- **Other characteristics of the organism,** such as gill surface area, lipid content, and metabolic ability to liberate a “bound” residue; and

- The **bioavailability** of the contaminant, i.e., its tendency to partition into a form conducive to uptake; this will vary among chemicals and organisms. Bioavailability will be influenced by such environmental factors as temperature, salinity, pH, redox potential, particle size distribution, and organic carbon concentrations.

Because individuals and species accumulate contaminants differentially in their tissues, environmental concentrations and uptake rates will not necessarily predict biotic concentrations. Pharmacokinetic distribution following bioaccumulation determines the concentration of contaminant that actually reaches the physiological site of action within an organism, and thus the likelihood of adverse effects. Whether or not bioaccumulation is suspected, analysts should try to determine contaminant concentrations in environmental media and biotic tissues simultaneously. Based on these data, site-specific bioconcentration factors (BCFs) can be estimated. One must make sure, however, that the measured environmental concentrations are relatively stable and not short-term aberrations. If site-specific BCFs cannot be derived from monitoring data, the analyst may need to use published BCF values or predicted BCFs.

To be meaningful, chemical analyses of biota should use sample sizes large enough to obtain variance estimates. Extrapolating contaminant concentrations from a sample of organisms to an average for the population may be a complex process. Such factors as the time of year of the sample, the life stage or age of the organisms, and the spatial distribution of the population may need to be considered. For highly mobile animals, estimates of exposure may need to be adjusted to account for the likelihood that not all of the animal’s food will be obtained from the affected area. In one study, for example, the analysts calculated exposures for mink and mallard ducks based on the assumption that the contaminated area represented ten percent of their home ranges. When such adjustments are made, the analyst should clearly state the justification for the assumptions and estimates used.

The SEAM provides detailed guidance on estimating or predicting environmental concentrations in media and intermedia transfers of contaminants. In addition, it offers a brief discussion on evaluating biotic exposure pathways to human populations. However, the SEAM is specifically intended for estimation of human exposure. Since human and environmental receptors do not share all exposure routes, the analyst will need to go beyond the decision models provided in the SEAM to consider exposure of environmental receptors. For example, in the exposure assessment for contaminated soil, the analyst will need to determine if the soil is sterile or if it is inhabited by plants and animals. If the soil is inhabited, the analyst will need to determine if organisms are contaminated and, if so, what the potential is for off-site movement of animals or food chain transfer of contaminants.

5.5 Selection of Assessment and Measurement Endpoints

Based on the available information concerning the site, the contaminants, and the likely exposure pathways, the analyst should identify and select appropriate endpoints for the assessment. The companion volume to this manual discusses in detail the distinction between **assessment** and

measurement endpoints.[3] Assessment endpoints are those describing the effects that drive decision making, such as reduction of key populations or disruption of community structure. Measurement endpoints are those used in the field to approximate, represent, or lead to the assessment endpoint. If new data are to be collected to evaluate these endpoints, EPA's guidance on data quality objectives should be followed (see Section 5.6).

5.5.1 Ecological Endpoints

Toxicity of contaminants to individual organisms can have consequences for populations, communities, and ecosystems. As discussed in Chapter 3, changes in rates of mortality, birth, immigration, and emigration can cause population sizes in an affected area to increase or decrease. These changes can also lead to shifts in the spatial distribution of populations in the environment. Such population-level effects may in turn determine the nature of changes in community structure and function, such as reduction in species diversity, simplification of food webs, and shifts in competitive advantages among species sharing a limited resource. Finally, ecosystem functions may be affected by contaminants, which can cause changes in productivity or disruption of key processes. For example, at a Superfund site contaminated with creosote and related compounds, the analysts noted:

> The presence of beds of detritus in the stream and layers of contaminated undecomposed leaves in the soil indicates that litter degradation is not occurring, at least not at a natural rate.

Contaminants can disturb ecosystems in ways other than direct toxicity. For example, a chemical that decreases available oxygen in aquatic systems can have catastrophic effects, whether or not it is toxic to the organisms there. Contamination leading to destruction of terrestrial vegetation can result in increased sedimentation of streams, which can adversely affect benthic populations that never come in contact with the chemical, Remedial actions that reduce water flow to a wetland or that replace indigenous vegetation with introduced plant species can remove an essential resource for one or more species in the community. In assessing the ecological effects of a site or its remediation, the analyst should consider use of appropriate measures of community and ecosystem function to determine if the weight of evidence indicates that effects other than toxicity are significant.

To characterize the effects of contaminants on populations, communities, and ecosystems, the analyst may choose one or more measures depending on the objectives of the study.

Use of these measures will usually require comparison of the site to a carefully selected reference area. To allow proper comparison, it is important that reference areas be chosen that:

- Are in close proximity to the contaminated area(s);
- Closely resemble the area(s) of concern in terms of topography, soil composition, water chemistry, etc.; and
- Have no apparent exposure pathways from the site in question or from other sources of contamination.

The RPM or OSC should consult closely with technical specialists on specific criteria for selecting an appropriate reference area.

The following are examples of measures that might be used to compare contaminated and reference areas:

- **Population abundance** - the number of individuals of a species in a given area, usually measured over a period of time or at a specified time;
- **Age structure** - the number of individuals in the population in each of several age classes or life history stages, which can be an indicator as to whether the population is increasing, decreasing, or stable;
- **Reproductive potential and fecundity** - expressed as the proportion of females of reproductive age, the number of gravid females, the number of eggs or viable offspring per female, or the percentage of females surviving to reproductive age;
- **Species diversity** - the number of species in an area (species richness), the distribution of abundance among species (evenness), or an index combining the two;
- **Food web or trophic diversity** - calculated in the same way as species diversity, but classifying organisms according to their place in the food web;
- **Nutrient retention** or **loss** - the amount of undecomposed litter or, conversely, the amounts of nutrients lost to ground or surface waters;

[3] *Ecological Assessments of Hazardous Waste Sites: A Reference Document.* EPA Office of Research and Development, 1989.

- **Standing crop** or **standing stock** - total biomass in an area; and

- **Productivity** - sometimes determined indirectly by measuring oxygen production by the plant community per unit time; ecologists also sometimes gauge **respiration** rates by measuring carbon dioxide output per unit time, and calculate the ratio of production to respiration **(P/R ratio)** as a measure of the efficiency of the ecosystem.

From measures such as these, specific assessment endpoints can be established, such as "reduction in population abundance" or "reduced fecundity." These would then be quantified to develop site-specific measurement endpoints, such as "significant difference between contaminated and reference areas with respect to numbers of organisms or numbers of young per female."

The analyst should use these measures with a great deal of caution. If differences appear in the above measures between contaminated and uncontaminated areas, it is a complex task to demonstrate that the effect observed is the result of contamination rather than some other factor.

In planning an ecological assessment, the OSC or RPM will be concerned with potentially affected habitats and, through them, potentially affected populations. Within each of these categories, a set of characteristic endpoints will need to be considered, and special types will elicit particular attention.

5.5.2 Evaluation of Potentially Affected Habitats

Habitats in the vicinity of a Superfund site can be affected by:

- Direct or indirect exposure to the site's contaminants due to transport from the source;

- Physical disruption of the habitat due to the site's design or operation;

- Chemical disruption of ecosystem processes due to the contaminants' interference with natural biochemical, physiological, and behavioral processes;

- Physical or chemical disturbance or destruction due to cleanup or remedial activities; and/or

- Other stresses not related to the site or its contaminants, such as extreme weather conditions or air pollution.

Each of these types of effects will be manifested differently in different ecosystems, depending on the magnitude of the disturbance and the nature of the habitat receiving the disturbance. The various types of terrestrial, aquatic, and marine ecosystems each have their own particular structures, dynamics, energy flows, and transport mechanisms that determine how they are affected by chemical or physical insult such as might occur at a Superfund site.

Structure and Dynamics

Planning an ecological assessment should consider collection of qualitative and (where feasible) quantitative information about the structure and dynamics of biotic communities that are potentially threatened, with sufficient detail to:

- Decide whether a detailed ecological assessment is necessary,

- Develop a defensible professional judgment as to the likelihood of contamination and adverse effects, and

- Define study goals and data quality objectives for an ecological assessment if it is justified by the preliminary evidence.

When considering study objectives for an ecological assessment, the RPM or OSC may wish to specify that data be collected to support calculation of certain measures of community structure and function. These include determining species diversity and community productivity. It is important to recognize that such measures were not designed for the purpose of estimating or demonstrating environmental harm, and they may be inappropriate for many sites. When these measures are used, they should not be relied upon to the exclusion of other information; rather, they may add to the weight of evidence supporting a particular conclusion about a site and its contaminants. Used properly, in close consultation with technical specialists, these measures may help to:

- Delineate the extent of contamination at a site, and/or

- Document the ecological effects of contamination.

Measures of biotic diversity have often been used to aid in characterizing community structure. The use of these measures in the context of hazardous waste sites rests on the premise that a disturbed or stressed area will exhibit changes in the composition and relative abundance of species as compared to a reference area that appears not to be contaminated. When using diversity indices or measures of community structure, the analyst should choose for study those segments of the ecosystem that are likely to:

- Be exposed to the contaminants of concern, and/or
- Contain organisms suspected of being vulnerable or sensitive to those contaminants or the effects of remediation.

Thus, for example, if the chemicals are present in surface soils, it would probably be useful to apply diversity comparisons to the soil or leaf litter organisms at a potentially affected site and a reference area.

The Office of Research and Development volume, *Ecological Assessments of Hazardous Waste Sites: A Reference Document*, contains detailed discussions of assessment and measurement endpoints for evaluating community and ecosystem level effects.

Significance and Uniqueness

The significance or uniqueness of an environment is often a subjective judgment, that may be determined by social, aesthetic, or economic considerations. Some environments, such as critical habitats for endangered species, are defined by law. To the extent that these concerns can be spelled out in the definition phase, they should be articulated with regard to any such habitats. Generally speaking, environments may be considered significant because, in the professional opinion of technical specialists, they:

- Are unusually large or small,
- Contain an unusually large number of species,
- Are extremely productive (such as an important fishery),
- Contain species considered rare in the area, or
- Are especially sensitive to disturbance.

In defining the scope of an ecological assessment, consideration of such environments should be similar to that given to rare and endangered species (see below). These areas may have unusual underlying physical and chemical characteristics that may affect removal and remediation decisions. The existence, location, and sensitivity of such environments should be noted, and study objectives may need to be developed to reflect the potential exposure of these special areas to contamination.

5.5.3 Evaluation of Potentially Affected Populations

Productivity and Abundance

Ecologists use the word "productivity" to mean the rate at which new biomass is produced per unit time. Plant stress may be a useful indicator of reduced productivity in an affected area. Visual inspection of the site during an initial visit may be sufficient to identify probable stress on terrestrial vegetation (such as yellowing, leaf drop, or other symptoms), but it is important to bear in mind that the cause could be something other than toxic effects of the contaminants. Reduction in the growth of plants in terrestrial or aquatic habitats will not be as easily observed and may require a detailed botanical survey in comparison to a reference area to be verified. Bioassays may need to be conducted to determine if the productivity of the plant community is being affected, and whether or not contaminants from the site are implicated. Toxic effects may be determined in tests using algae or easily grown terrestrial plants as test species. Seed germination, root elongation and morphology, and plant growth assays can be used to evaluate contaminated soils' effects on plant development.

Toxic chemicals may exhibit a wide range of effects that can ultimately influence productivity and abundance of animals. Effects of contaminants on animal productivity can be assessed through the use of field ecological studies, on-site toxicity tests, and laboratory tests. Study designs and data quality objectives for field and laboratory studies should be developed to determine exposure concentrations and their likely relation to observed or suspected effects.

The RPM or OSC should seek out trend data such as population fluctuations of key species over time. Such information may be available from State and Federal fish and game personnel, or from previous environmental analyses (such as an Environmental Impact Statement) conducted in the vicinity of the site. These data can assist analysts in distinguishing between normal fluctuations and changes that may be attributable to the effects of contamination.

Rare, Threatened, and Endangered Species

By definition, endangered and threatened species are already at risk of extinction: the loss of only a few individuals from the population may have significant consequences for the continued existence of the species. In the definition phase of the assessment process, the presence of threatened or endangered species, and/or habitats critical to their survival, should be documented. If information is available on these or related species' sensitivity to contaminants of concern, this should also be indicated. The RPM or OSC should consult with Federal and State natural resource trustees or other specialists to determine the location of such species and their potential for exposure to the contaminants.

Rare species may present a more difficult problem for ecological assessment. A species may be rare in a given locale because:

- The area is at the edge of the species' principal geographical range,
- The natural habitats available in the area are only marginally able to support the species,
- The species may be prevented from attaining high numbers by competition from other species or by predation, or
- The species depends upon rare habitats or food sources for its continued existence.

If a species is rare, but not legally designated as either threatened or endangered, the RPM or OSC will have to depend on consultation with local ecologists and other experts to determine the importance of the species in the context of the site.

The major sources of information on rare, threatened, and endangered species are field offices of the Fish and Wildlife Service (U.S. Department of Interior) and the National Oceanic and Atmospheric Administration (U.S. Department of Commerce), officials of State fish and game departments and natural heritage programs, and local conservation officials and private organizations.

Potentially Affected Sport or Commercial Species

In planning an ecological assessment, the analyst should note potential effects on species that are of recreational and commercial importance. In addition, species such as food sources that directly support these important species, and habitats essential for their reproduction and survival, should be considered in the planning and assessment process.

Information on which species are of recreational or commercial importance in an area can be gathered from State environmental or fish and wildlife agencies, Federal agencies such as NOAA and the U.S. Fish and Wildlife Service, and local conservation and fish and game personnel. Commercial fishermen's and trappers' associations may also be valuable sources of data.

Most States maintain fish stocking programs for sport or commercial fisheries. The agencies running these programs can provide information on where fish are stocked and released, and the areas to which they migrate. Many States also gather creel survey data for stream reaches or other bodies of water, and collect harvest data for management of deer, game birds, and other animals.

5.6 Sampling and Analysis Plan

The planning stage of the ecological assessment process culminates in the Sampling and Analysis Plan (SAP), which consists of a Field Sampling Plan and a Quality Assurance Project Plan (QAPP). In directing the preparation of the SAP, the OSC or RPM should be satisfied that the following questions are answered:

- What are the specific objectives of the sampling
- How will the proposed data collection meet those objectives?
- Will the sampling plan (types, number, distribution, and timing of samples) provide sufficient information to meet the objectives?
- Does the sampling plan address all important exposure pathways and environmental receptors?
- Does the sampling plan make the best use of preexisting data and sampling locations?
- Is the sampling of the various media associated with the site coordinated to allow maximum integration of the data (e.g., to measure or predict intermedia transfer of contaminants)?

5.6.1 Field Sampling Plan

To address all of these issues effectively, a Sampling and Analysis Plan should be developed that takes account of:

- Actual or potential sources of contaminant release,
- The media to which contaminants can be or are being released,
- The organisms that can come into contact with the contaminants, and
- The environmental conditions under which transport and/or exposure may be taking place.

Identification of exposure routes and media should lead in turn to a selection of the most appropriate plant and animal species to be sampled for analysis of contaminant concentration, toxicity testing, or other measures of potential effects. If food-chain transfer of contaminants is suspected, information on the trophic structures of affected ecosystems will be needed to determine which species should be examined for chemical residues.

Biological data to be collected in conjunction with these analyses may include such parameters as dry weight of tissues or organisms, percent moisture, lipid content, and the size and age or life stage of the organism. Contaminant concentrations may need to be expressed relative to the whole-body weight (sometimes minus the intestines) or weight of the edible portion (for input to human health studies).

Depending on the media to be sampled, the contaminants of concern, and the organisms under study, the sampling plan will also require collection of data on environmental conditions at the time of the study. For aquatic systems, these include:

- **Water quality parameters** such as hardness, pH, dissolved oxygen, salinity (for marine ecosystems), temperature, presence or absence of thermocline, color, dissolved organic carbon, conductivity, and total suspended solids;

- **Hydrologic characteristics** such as flow rate, ground-water discharge/recharge rates, aquifer thickness and hydraulic conductivity, depth, velocity and direction of current, tidal cycle and heights, and surface water inputs and outflows; and

- **Sediment parameters** such as grain size distribution, permeability and porosity, bulk density, organic carbon content, pH, color, general mineral composition, benthic oxygen conditions, and water content.

For studies of potentially contaminated soil, information will be needed on such parameters as particle size, permeability and porosity, fraction and total organic carbon, pH, redox potential, water content, color, and soil type.

The OSC or RPM should consult the SEAM and technical specialists to determine the specific set of environmental parameters that should be measured to permit effective analysis of contaminant fate, transport, exposure, and effects.

5.6.2 Quality Assurance

EPA policy requires that all Regional Offices, program offices, laboratories, and States participate in a centrally managed quality assurance (QA) program. This requirement applies to all environmental sampling, monitoring, and measurement efforts mandated or supported by EPA through regulations, grants, contracts, or other formal means. Each program office or laboratory that generates data must implement minimum procedures to ensure that the precision, accuracy, completeness, and representativeness of the data are known and documented.

To ensure that these responsibilities are met uniformly across the Agency, each EPA program office or laboratory must have a written Quality Assurance Project Plan (QAPP) covering each monitoring or measurement activity within its purview. These Quality Assurance and Quality Control (QA/QC) requirements apply for all monitoring at all Superfund sites or at any location where toxic substances have been released to the environment.

QAPPs are written documents for all planned sampling or monitoring at a named location, including ecological assessments of Superfund sites. The program office, Regional Office, contractor, grantee, State, or other organization must prepare and receive written approval for the QAPP for the specific sampling and measurement program before the field or laboratory work can begin.

The QAPP presents, in specific terms, the policies, organization, objectives, functional activities, and specific QA/QC activities designed to achieve the data quality goals for single or continuing activities. The QAPP must cover all environmentally related measurements, including but not limited to:

- The measurement of physical, chemical, or biological variables in air, water, soil, or other environmental media;

- The determination of the presence or absence of pollutants or contaminants in waste streams or site media;

- The assessment of ecological effects studies;

- The study of laboratory simulation of environmental events; and

- The study or measurement of pollutant transport and fate, including diffusion (i.e., dispersion and transport) models.

The QAPP serves two important functions. First, it seeks to ensure that as much as possible is done at the beginning of a study to achieve the QA objectives for the data. Second, it allows for analysis of the study to determine what improvements can be made if QA objectives are not met. The plan cannot guarantee results, but it requires the analyst to justify a particular approach before proceeding.

For each major measurement variable, the QAPP must state specific data quality objectives. This is usually accomplished by preparing a table listing the variable, the sampling method, the measurement method, the experimental conditions, the target precision (measured in relative standard deviation), the target accuracy (measured in acceptable relative deviation from the true value), and the completeness (measured in terms of percent coverage). The RPM or OSC should also require project analysts to specify clearly:

- What tests are to be performed,
- What measurements are to be taken, and
- How the results will be used (e.g., estimate exposure, correlate diversity or abundance with a chemical gradient, predict population response to ambient contaminant levels).

Consultation with a technical assistance group to define data needs and study goals is essential for the successful specification of data quality objectives. The ecological assessment is not a research project and thus should not be expected to entail long-term field studies. With the guidance of technical specialists who understand both the scientific questions at issue and the exigencies of the Superfund program, it is possible to define carefully delineated studies to collect the data needed for making reasoned judgments on Superfund sites.

Chapter 6

Organization and Presentation of an Ecological Assessment

This chapter provides a checklist of the basic questions that should be asked in an ecological assessment. It is intended to ensure completeness and consistency in the reporting of assessment results. The amount of detail required in a given report will depend upon the scope of the study, as determined in the iterative planning process discussed in Chapter 5, and the amount of data collected in the investigation. Regardless of the level of detail, the assessment report should be clear and concise, to ensure that the results are readily understood and properly interpreted.

To aid Agency review of assessments, metric units should be used throughout. These include specification of appropriate units in chemical quantification such as µg/1, µg/g, etc., instead of mixing ratios such as ppb or ppm.

Some information, such as characterization of the site or the contaminants of concern, may have been *given* in other sections of a report such as an RI or Action Memorandum. If so, the information can be referenced; however, the analyst may wish to summarize such information in the ecological assessment section.

6.1 Specify the Objectives of the Assessment

As discussed in Section 5.1, an ecological assessment may be undertaken for a variety of reasons, from evaluating the threat posed by a site to examining the effects of remedial alternatives. For example, for two sites evaluated by EPA's Environmental Response Team, the assessment objectives were stated as follows:

> The main objective of this. . . investigation was to generate data that could be utilized for the determination of site cleanup criteria for the creosote contaminated soils and sediments in the floodplain of the ________________ Creek.

> The objective of this study was to determine if the arsenic compounds. present in the water and sediments of the _____________ River watershed are resulting in an adverse ecological impact. The data collected [were] utilized in conjunction with existing data to determine the bioavailability and toxicity of arsenic contamination to the resident aquatic biological communities, and [to] quantitatively assess impacts.

6.2 Define the Scope of the Investigation

This section of the report should describe the kind and amount of information that was collected in the study. The analyst should describe the data in terms of the physical, biological, and chemical parameters measured, estimated, or calculated in the assessment. It is also important to specify the time frame of the study:

- Over what time period(s) and in what season(s) were the data collected?

- At what time intervals were samples taken?

- Were the data used to assess current effects or past damage, or to predict future scenarios?

The discussion gives the reader a clear indication of the nature, depth, and boundaries of the investigation. Was the assessment, or the data used in the assessment, based on long-term studies of the site and its surroundings or do the data provide a "snapshot" of the site in a restricted time period? Was the sampling extensive or limited to specific areas? Are the analyses reasonably straightforward or are considerable inferences and professional judgments involved?

6.3 Describe the Site and Study Area

In this section, the analyst should provide a physical description of the site at a level of detail appropriate to the scope of the assessment. The study area for an ecological assessment may extend well beyond the boundaries of the area in which hazardous wastes have been stored or released. For example, depending on the available pathways for exposure and the habitats potentially exposed to contamination, the area under investigation might include portions of several tributaries of a potentially affected river, a wetland downhill or downstream from a release source, or a wildlife refuge within the same drainage basin as a waste site.

The description should include the size of the area (in metric units) within the physical boundaries defined for the assessment and the size of physical features such as stream reaches, roads, wetlands, or forested areas. The report should provide a map of the area, showing all physical features at a minimum resolution equivalent to a 7.5' USGS quadrangle map, marked to show any changes to the topography up to the present time. This map should include all potentially affected areas linked to the contaminated zone by pathways of concern through any media, sampling locations, and any reference areas selected for the investigation. An example of such a map is given in Figure 6.1.

A brief description of the contamination that led to listing of the site, or a reference to such a description should be included, giving dates where possible.

The description of the site and study area should provide a full accounting of the ecosystems and populations potentially exposed to contamination. This may be accomplished with a narrative description of each habitat (e.g., oak-hickory forest, *Spartina* salt marsh, etc.), accompanied by lists or tables of species collected or observed there. The resident and transient flora and fauna should be described, or if catalogued, the table can be referenced. Where relevant, it should be noted if a cited species is:

- Resident, breeding, or a rare or frequent transient (e.g., migratory waterfowl),
- Endangered or threatened, or
- A natural resource trustee concern.

The significance, uniqueness, or protected status of potentially exposed ecosystems (as discussed in Chapter 5) should also be noted and documented.

Other information with possible bearing upon the ecological characteristics of the site should be provided, such as current or projected land uses; proximity to population centers, industry, agriculture, or hunting areas; and special climatic conditions affecting movement, availability, or effects of contaminants.

Finally, the site description should include narrative characterizations of:

- Likely or presumed exposure pathways, such as surface water, air, soils, sediments, or vegetation; and
- Any readily observed effects potentially attributable to the site, such as stressed or dead vegetation, fish kills, or unusual changes in species composition or distribution in a habitat.

6.4 Describe Contaminants of Concern

The ecological assessment should specify which contaminants at a site are of particular concern from an ecological perspective. This list may differ somewhat from those contaminants that raise questions about human health risks. For example, a given chemical may exhibit low toxicity toward mammals but be highly toxic to fish, invertebrates, or plants. The fate of a contaminant in the environment may make it unavailable for human exposure while increasing exposure for other organisms. For instance, a chemical that is found to be adsorbing to soil and sediment particles may pose little risk to humans, but may cause considerable disruption of terrestrial vegetation or benthic invertebrates.

Results of chemical analyses should be presented in tabular form, identifying compounds and the media in which they were found. If tables of data from the human health evaluation are used by reference, it is important to report measurements of parameters affecting the toxicity to biota, such as alkalinity or total organic carbon. It is important to note the source of all analytical data, including laboratory, CLP certification, sampling and analytical method, and date of analysis. Data may be summarized, but both the mean and range should be included, along with an explanation of how and why calculations were made. The report should explain how non-detects, replicates, duplicates, etc. were treated in the statistical analysis. All sample data should be accounted for: infrequency of detection (rarity) is an unacceptable explanation for culling a particular data item from the sample. The report should describe both laboratory and field analysis of contaminants, along with variances from detection limits that affect the applicability of the data to the study.

6.5 Characterize Exposure

This section should identify actual and potential exposure pathways, taking into account environmental fate and transport through both physical and biological means. The analyst should consult the *Superfund Exposure Assessment Manual* and technical specialists to make sure that all likely exposure pathways have been considered. In discussing the investigation of exposure pathways, the report should describe each pathway by chemical(s) and media involved, and identify the pathway in space and time with respect to the site and the period of investigation. If contaminant concentrations and effects data (such as toxicity tests or population studies) correspond to identified

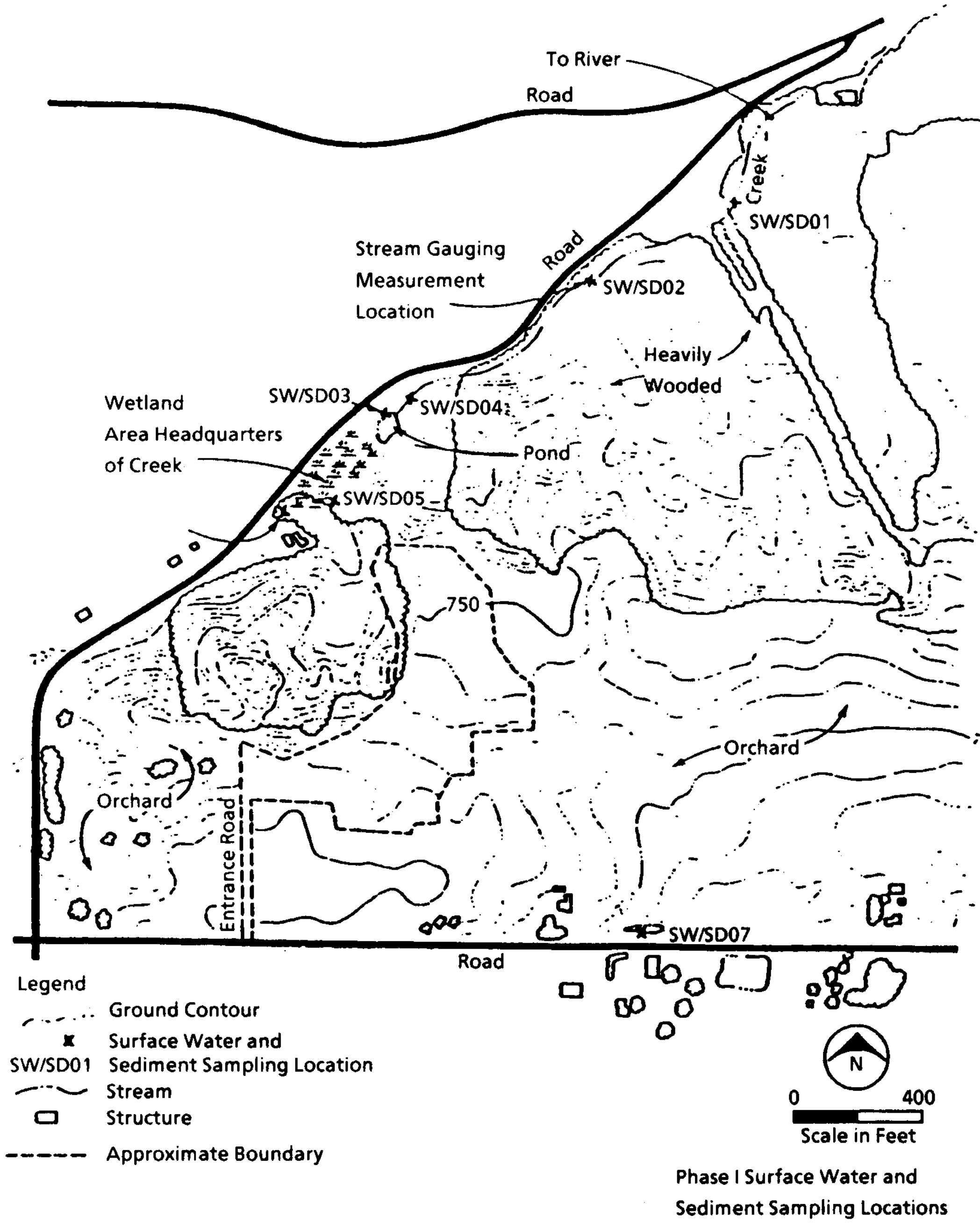

Figure 6.1 Example of study area map.

pathways by spatial or temporal gradient, their presentation should demonstrate the correlation.

If sampling stations have been selected to measure concentrations of contaminants along likely exposure pathways, the sampling data should be presented in such a way as to allow the reader to see quickly the relationship between a sample's location and its contaminant levels. For instance, stations can be numbered in a sequence that indicates their relative distance from the source of contamination, as shown on a map of the study area. Another method is to present the data on a scatter diagram, in which sampling locations are shown as points on a graph with distance from the source given on the X-axis and concentrations on the Y-axis. Ideally, concentrations of key contaminants should be displayed in graph form with geographic locations indicated (see Figure 6.2) or on a map (see Figure 6.3).

Results of toxicity tests may also be effectively displayed using maps. For example, in a study of the effects of PCBs and other contaminants at a Northeastern site, the researchers showed the results

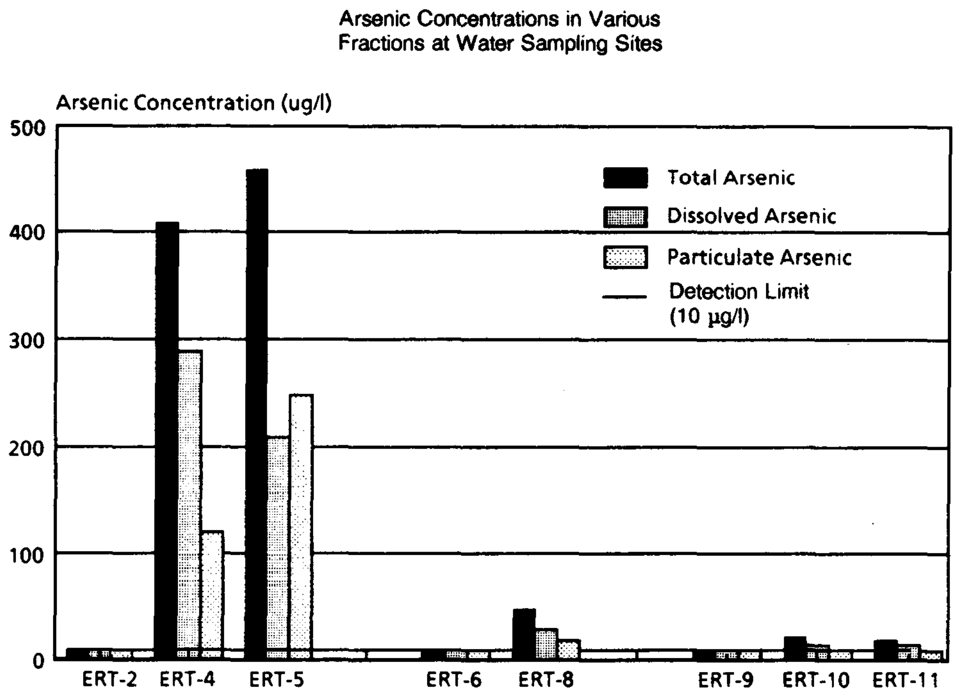

Figure 6.2 Graphic display of contaminant concentration.

of toxicity testing on a map of the affected area (Figure 6.4). This type of presentation makes readily apparent the relative hazard associated with different locations.

If such gradients are not apparent, or are contradicted by other data, the analyst should discuss the possible reasons for the discrepancy in the report. If exposure pathways are modeled, the report should clearly state the limiting assumptions of the model(s) used. A full reference for every model used in the assessment should be included. The analyst should characterize the uncertainty associated with all parameters that are measured or modeled, and specify statistical significance levels for quantitative results.

If the analysis uses data from toxicity tests, population studies, or other effects-related investigations, to demonstrate that exposure has occurred, the report should carefully explain the limitations of the data. For instance, the site and reference area might differ in terms of the degree of physical disturbance, which may account for some of the observed effects. If toxicity test results are presented in the form of LD_{50}s or ED_{50}s, they should be shown graphically on a log probit scale.

6.6 Characterize Risk or Threat

In characterizing risks or threats to environmental receptors associated with Superfund sites, the analyst should try to answer the following questions:

- What is the probability that an adverse effect will occur?

- What is the magnitude of each effect?

- What is the temporal character of each effect (transient, reversible, or permanent)?

- What receptor populations or habitats will be affected?

Depending on the assessment objectives and the quality of the data collected, the answers to these questions will be expressed quantitatively, qualitatively, or a combination of the two.

If water quality or other criteria have been exceeded at a site, this may be sufficient in some cases to justify remediation. In presenting the data, the analyst should document the number and location of sampling results that exceed the acute and/or chronic

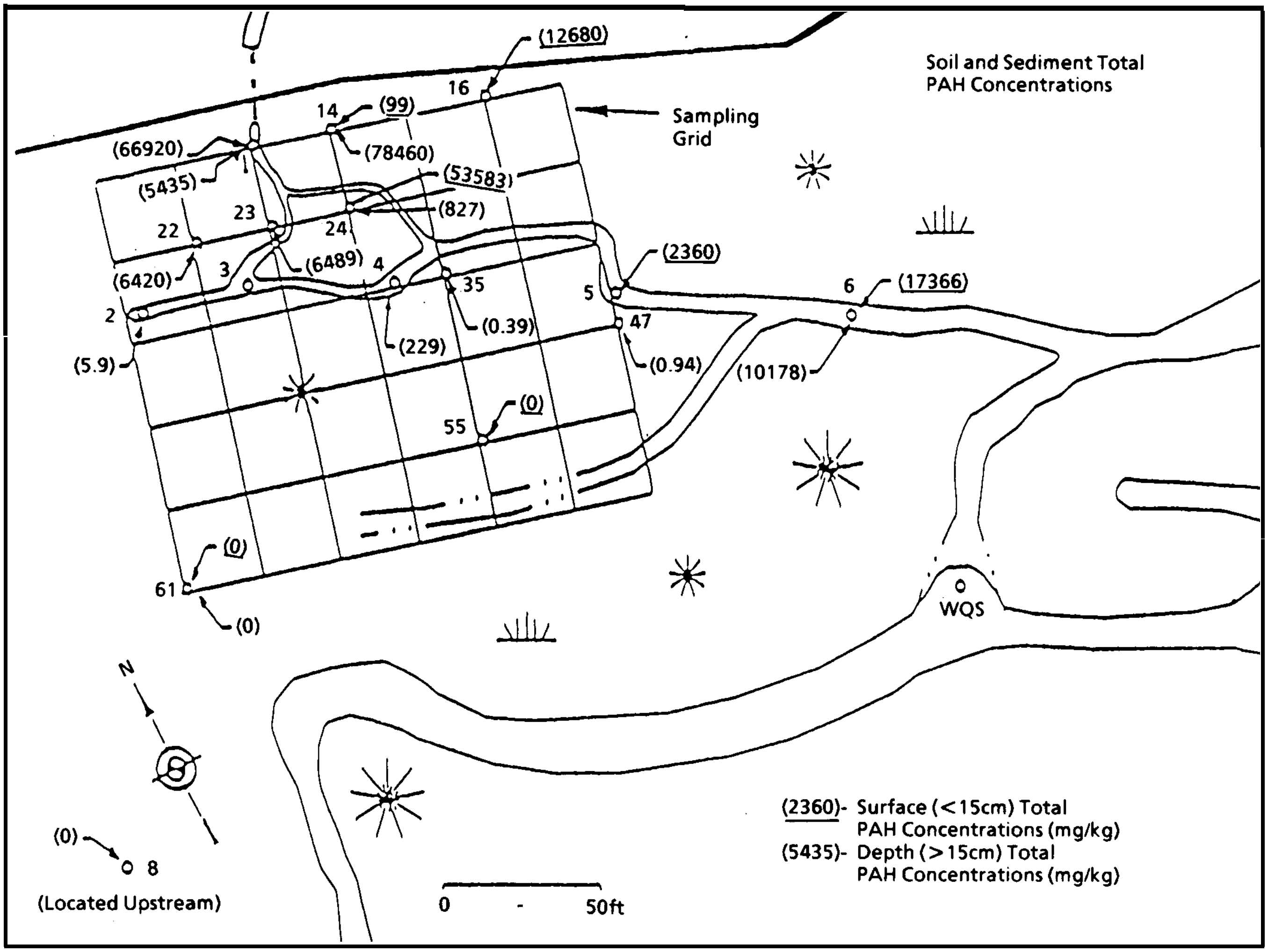

Figure 6.3 Map display of contaminant concentrations.

criteria for the protection of the species and habitat of concern at a site. The number of exceedences can be compared to the number of total measurements for each contaminant in a table. In addition, the locations of all exceedences and the locations of all measurements can be shown with different symbols on a map. Use of a map can be especially helpful if contaminant concentrations form a reasonably clear gradient leading away from the source.

Beyond criteria exceedences, however, risk characterization is most likely to be a weight-of-evidence judgment. The analyst should present a summary of the risk-related data concerning the site, including

- Environmental contaminant concentrations,
- Contaminant concentrations in biota,
- Toxicity test results,
- Literature values of toxicity,
- Field surveys of receptor populations, and
- Measures of community structure and ecosystem function.

If the contaminants at the site are exerting a clear effect, the data from all of these studies will, on balance, support the conclusion that an effect is occurring. If the data are ambiguous, the analyst should try to discern the reasons for conflicting results and present those reasons along with the rationale for the conclusion reached.

Ecological risk characterization entails both temporal and spatial components. In describing the nature and probability of adverse effects, the analyst should also consider such questions as:

- How long will the effects last if the contaminants are removed? How long will it take for receptor populations to recover from the effects of the

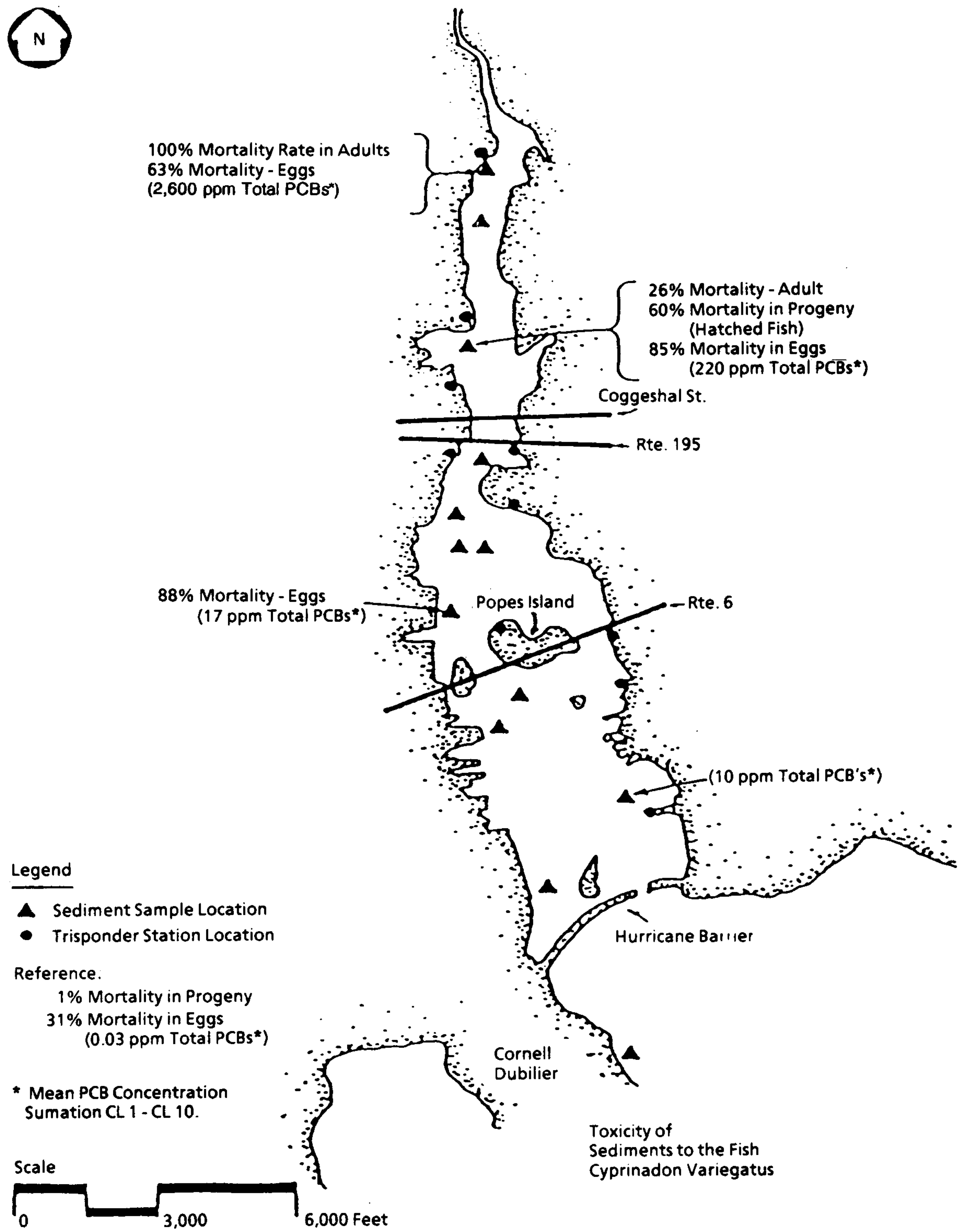

Figure 6.4a Map display of toxicity test results.

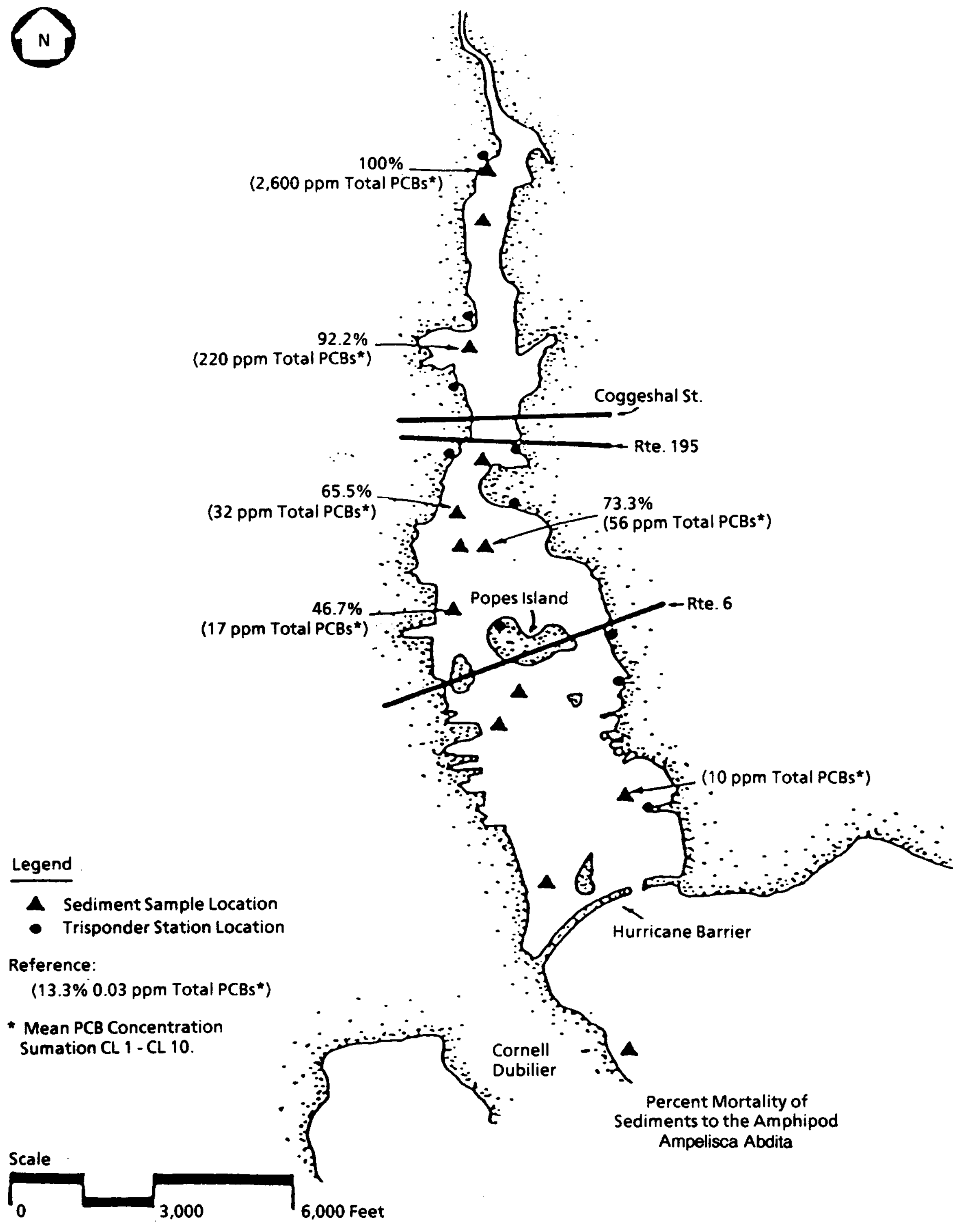

Figure 6.4b Map display of toxicity test results.

contaminants? Will there be intergenerational effects?

- Will the contaminants move beyond the current area of study through biotic transport? What effect will remediation have on this movement?

- If there are community and ecosystem effects of the ontamination, is removal of the contaminants sufficient to restore community structure and ecosystem function? If not, what else will be needed?

- How do the data on exposure and observed or predicted effects relate to the rapidity of response required? Which responses are required immediately? Which can or should be undertaken later?

- What limits will proposed remediation or mitigation actions place on future options for further remediation, follow-up assessment, and resource use?

Table 6.1. Example of Presentation of Criteria Exceedences

Mean and Maximum Surface Water Concentrations (µg/l) in On-Site Lakes at a Landfill

	Observed Concentrations		Water Quality Criteria[a]	
Chemical	Mean	Maximum	Acute	Chronic
Ammonia	160*	6,800*	20	20
Copper	16	50*	48	29
Cyanide	NE	0.04*	ND	ND
Iron	125	1,300*	300	300
Zinc	20	150*	30	30
Phenol	NE	2.1*	1	1

[a] Federal, state, or county criteria used as available
Key NE = Not evaluated
ND = No detectable amount permitted
* = Criteria exceeded

Questions like these will most likely be answerable only in narrative form, as an expression of best professional judgment by a qualified ecologist. Nonetheless, they lie at the heart of ecological assessment. Many populations and ecosystems exhibit considerable resilience in the face of disturbance; in fact, change is more common in ecosystems than stability. Populations are continually increasing and decreasing due to natural cycles and chance occurrences. In many situations, when a source of contamination is removed, natural systems will rapidly recover their former appearance. Hence, for the same amount of chemical released, the risk associated with an acutely toxic but short-lived chemical may be considered important but less so than a moderately toxic chemical that is highly persistent.

6.7 Describe the Derivation of Remediation Criteria or Other Uses of Quantitative Risk Information

If water quality or other criteria are available for comparison to observed concentrations of contaminants, the analyst should try to show the data along with applicable criteria so that exceedences are easily apparent. Table 6.1 is an example of this kind of presentation. If criteria exceedences occur along a clearly identified gradient, the data may best be presented in a map.

Remediation criteria may also be derived from risk information developed for use under other environmental statutes, such as the Toxic Substances Control Act or the Federal Insecticide, Fungicide and Rodenticide Act. If the report recommends remediation criteria based on such information, the analyst should give a full reference citation for the source of reference doses, standards, or risk assessments use in calculating the criteria. In addition, the analyst should provide an explanation of, or reference for, the calculation method used to develop the criteria. Equations and parameters (such as exposure factors) used in the calculations should be provided in the text or referenced.

6.8 Describe Conclusions and Limitations of Analysis

Assessment of Superfund sites will depend primarily on the weight of evidence supporting particular conclusions, since ecological effects seldom occur in isolation from other stresses. To accomplish this, it may be necessary to use a variety of measurements in an effort to establish that a trend is likely in the data.

For example, in a study of an arsenic-contaminated site and a nearby river system, the analysts compared several different indices of species diversity for benthic invertebrates (Figure 6.5) and examined differences in the trophic structure at the various sampling locations (Figure 6.6). Analysts next combined these data with information on contaminant concentrations and toxicity tests. They concluded that arsenic concentrations in the stream sediments were significantly affecting benthic invertebrates downstream from the contamination source.

In presenting conclusions from an ecological assessment, the analyst should address the degree of success in meeting the objectives of the evaluation. The report should present each conclusion, along with the items of evidence that support and fail to support the conclusion, and the uncertainty

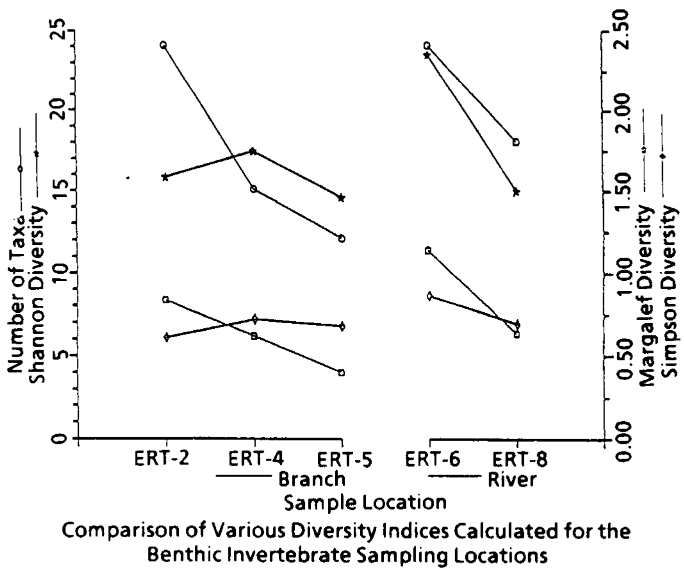

Figure 6.5 **Graphic display of species diversity indices.**

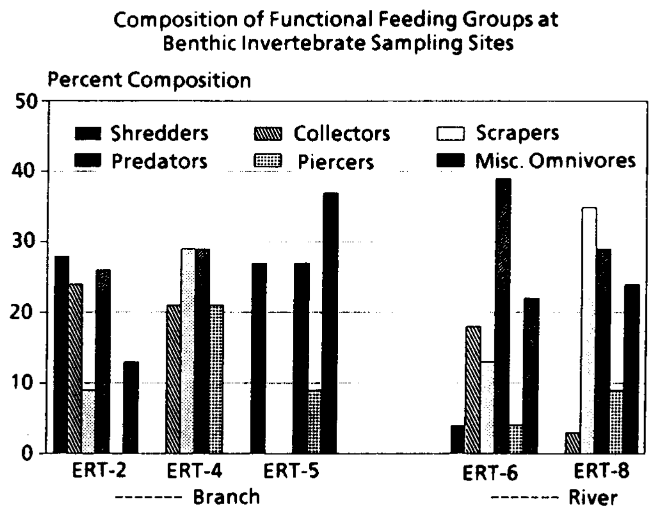

Figure 6.6 **Graphic display of trophic structure.**

accompanying the conclusion. Analysts should also describe factors that limited or prevented development of definitive conclusions.

The process of assessing ecological effects is one of estimation under conditions of uncertainty. To address this necessary reality, the analyst should provide information that indicates the degree of confidence in the data used to assess the site and its contaminants. In summarizing assessment data, the RPM or OSC should specify sources of uncertainty, including:

- Variance estimates for all statistics;

- Assumptions underlying use of statistics, indices, and models;

- The range of conditions under which models or indices are applicable; and

- Narrative explanations of other sources of potential error in the data (e. g., unexpected weather conditions, unexpected sources of contamination).

Ecological assessment is, and will continue to be, a process combining careful observation, data collection, testing, and professional judgment. By carefully describing the sources of uncertainty, the analyst will strengthen the confidence in the conclusions that are drawn from the analysis.

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