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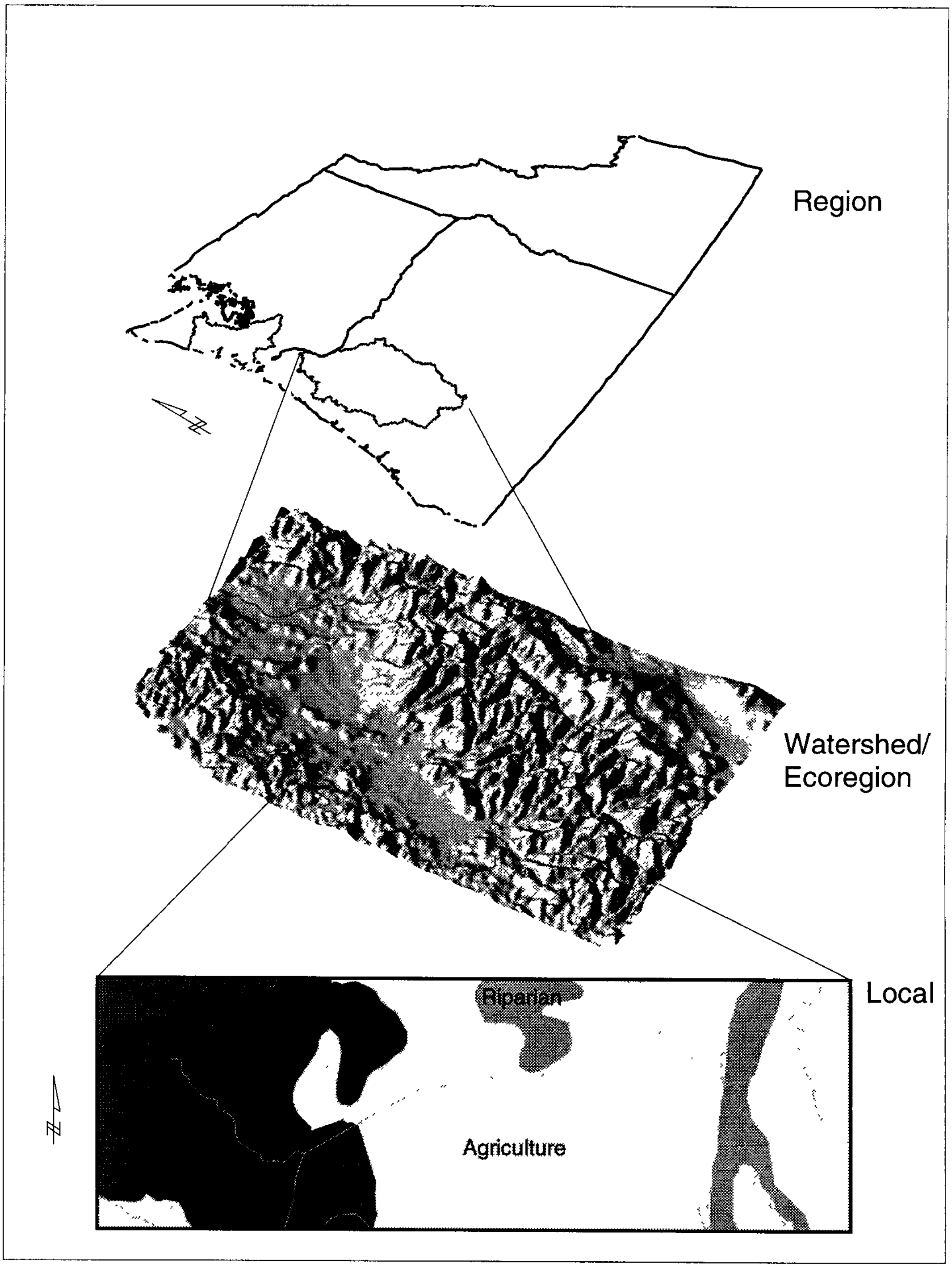
Ecosystem Management Research in the Pacific Northwest

Five-Year Research Strategy



EPA/600/R-95/069
May 1995

ECOSYSTEM MANAGEMENT RESEARCH

IN THE PACIFIC NORTHWEST

FIVE-YEAR RESEARCH STRATEGY

By

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ABBREVIATIONS AND ACRONYMS

AREM	Avian Richness Evaluation Method
ARS	Agricultural Research Service
BLM	Bureau of Land Management
BRC	Biodiversity Research Consortium
CLAMS	Coastal Landscape Analysis and Modeling Study
CTD	Conductivity-Temperature-Depth recorder
CV	Contingent Valuation
DQO	Data Quality Objective
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
ERL	Environmental Research Laboratory
FEMAT	Forest Ecosystem Management Assessment Team
FTE	Full-Time Equivalent
GAP	Gap Analysis Program
GIS	Geographic Information System
ha	hectare
IAG	Interagency Agreement
IRICC	Interagency Resource Information Coordination Council
km	kilometers
LMER	Land-Margin Ecosystem Research
m	meter
MOU	Memorandum of Understanding
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NAWQA	National Water-Quality Assessment
NBS	National Biological Survey
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NRC	National Research Council
NRCS	National Resource Conservation Service
OEPER	Office of Ecological Processes and Effects Research
OPPE	Office of Policy, Planning and Evaluation
ORD	Office of Research and Development

OSU	Oregon State University
OTA	Office of Technology Assessment
OTTER	Oregon Transect Ecosystem Research
PNW	Pacific Northwest
QA/QC	Quality Assurance/Quality Control
RAF	Risk Assessment Forum
RMC	Research and Monitoring Committee
SAB	Science Advisory Board
SCS	Soil Conservation Service
SWMG	Strategic Water Management Group
TEV	Total Economic Value
TM	Thematic Mapper
USDA	United States Department of Agriculture
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Service
UV	Ultraviolet
WRP	Wetlands Research Program

EXECUTIVE SUMMARY

ECOSYSTEM MANAGEMENT RESEARCH IN THE PACIFIC NORTHWEST FIVE-YEAR RESEARCH STRATEGY

IMPETUS FOR THIS RESEARCH

In 1993, President Clinton convened the Pacific Northwest Forest Conference to deal with the conflict in the region between protection of endangered species and timber production on federal lands. To resolve the conflict, the President created several interagency workgroups, charged with evaluating management alternatives using an "ecosystem approach to forest management." The President also formed an Interagency Ecosystem Management Task Force to implement ecosystem management throughout the federal government, defined by the Task Force as follows:

> "Ecosystem management is a goal-driven approach to restoring and sustaining healthy ecosystems and their functions using the best science available. It entails working collaboratively with state, tribal, and local governments, community groups, private landowners, and other interested parties to develop a vision of desired future ecosystem conditions. This vision integrates ecological, economic, and social factors affecting the management unit defined by ecological, not political boundaries."

A key feature of ecosystem management is the shift away from piecemeal agency or program mandates toward management of ecological systems within a geographic area as an integrated whole.

This research program is part of the follow-up to the President's Forest Conference in the Pacific Northwest. Ecosystem management must be based on sound science and accurate information. The role of research is to improve that science base. Therefore, as part of an interagency Memorandum of Understanding, the U.S. Environmental Protection Agency (EPA) committed to a five-year research program on ecological risk assessment research in the Pacific Northwest, which we refer to as the Pacific Northwest (PNW) research program. The research will be conducted by EPA's Office of Research and Development (ORD) and led by the ORD Environmental Research Laboratories in Corvallis (ERL-Corvallis) and Newport (ERL-Newport), Oregon, in partnership with EPA Region 10. Region 10 is contributing its insight into priority management questions that we should address, as well as facilitating our interactions with other environmental managers at federal, state, tribal, and local levels.

PROGRAM OBJECTIVES

The goal of the PNW research program is to contribute to the ecological understanding and approaches that federal, state, tribal, and local governments will need if they are to implement ecosystem management effectively in the Pacific Northwest. Although focused in the Pacific Northwest, our intent is to develop information and approaches that will also have broader applicability. Our challenge is to provide an improved scientific basis for a management approach that is only now being defined. The next five years will be a learning, adaptive process, both for the ecosystem management approach and for ecosystem management research.

We define four program-level objectives, which we believe represent the four general ecological research areas required to support ecosystem management (Figure 1):

1. Develop and demonstrate an overall ecological assessment process, along with the associated analytical tools, dealing with multiple endpoints[1] and multiple stressors[2] across multiple spatial scales, that will allow managers to:

    - Define realistic environmental goals.
    - Assess current ecological conditions relative to those goals and identify major environmental problems.
    - Evaluate and compare the ecological consequences of alternative management strategies.
    - Target geographic areas for protection, restoration, or other management action.

2. Advance the understanding of ecosystems, ecosystem dynamics, and ecosystem responses to human activities to reduce uncertainties in ecological assessments and improve confidence in ecosystem management decision making.

3. Develop and demonstrate a spatial framework that provides a common, effective basis for ecological assessments at multiple spatial scales, environmental goal setting, and extrapolation of research results.

4. Develop and demonstrate ecological monitoring designs that meet the needs of adaptive ecosystem management and are integrated across ecosystem types, spatial scales, and monitoring programs in different agencies.

STRATEGIC APPROACH

Our goal and objectives are broad and ambitious. We believe they can be achieved by adopting the following strategic approach.

---

[1] An *endpoint* is an ecosystem good, service, or societal value selected to serve as the focal point for management decisions and assessments. Examples include sustainable fishery yields and biological diversity.

[2] A *stressor* is any chemical, physical, or biological entity or activity that can induce an ecological effect. A stressor may be natural or it may result from human activity.

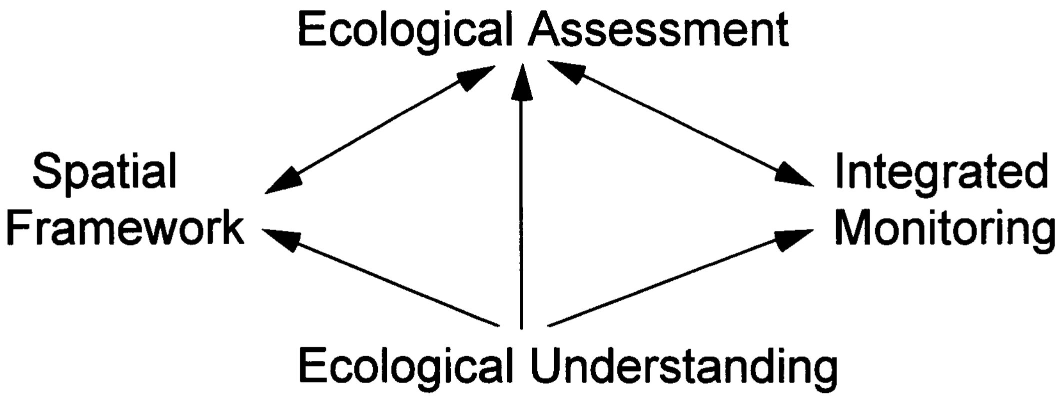

Figure 1. Four program-level objectives for the PNW research program.

Focus on selected case study examples. Within these case studies, we will address real-world, priority management questions identified by environmental managers and stakeholders within the region. The case study approach allows us, first, to concentrate our resources on a subset of issues and/or geographic areas (a cost-effective research approach), and second, to test and refine our approaches while also providing information needed by decision makers.

Develop transferable approaches that can be applied by others with reasonable effort. The case studies will neither address all management questions nor provide all the information needed by environmental managers in the region. Our approach is to use the case studies to develop, test, and demonstrate ecological approaches and analytical "tools" that could be applied to diverse management issues. We will consider our research successful only if these approaches are adopted and widely used by others (e.g., EPA Region 10, states, local governments), in which case the information generated as a result of the research program will extend beyond the specific analyses funded by the program.

Concentrate on integration and coordination with other researchers. EPA is unique among federal agencies, in that its legislative mandates cover both private and public lands; physical, chemical, and biological components of ecosystems; the atmosphere as well as terrestrial and aquatic resources; and estuarine and marine systems as well as freshwaters. EPA also has a history of interactions with state, tribal, and local governments and with private organizations. This broad spectrum of responsibilities and contacts provides EPA with a special role in ecosystem management—as integrator, or at least facilitator of this integration—across different ecosystem types, landuses, land ownership, and agencies. We also see integration as an important role of this research program. Thus, we will attempt to achieve our research objectives, in part, by working cooperatively with other ecological researchers in the area to synthesize and integrate existing knowledge, information, and approaches.

> "In all areas of ecology, and in science in general, the convergence and integration of information from different points of view, different disciplines, and different approaches are what lead to major advances and breakthroughs in understanding." (Gene E. Likens, 1992)

The case studies, and the example management questions addressed in these case studies, provide the focal point for this interdisciplinary integration. We are working with the interagency Research and Monitoring Committee, established to coordinate federal agency activities within the region, and we also will involve other interested researchers within the Pacific Northwest.

Leverage existing research programs and approaches. A number of other ongoing research programs have similar, or overlapping, research objectives and have developed approaches of direct utility for ecosystem management. By encouraging these programs to work within our case studies, and by providing supplemental funding as needed, we can achieve much more than would otherwise be possible for the funding allocated for this specific research program. The demonstration of the full capabilities and complementary nature of these various approaches in an integrated case study is of benefit both to our research program and to these others. Examples of research programs with which we have specific plans for cooperative research include the Environmental Monitoring and Assessment Program (EMAP), the interagency Biodiversity Research Consortium (BRC), the National Biological Survey's (NBS) Gap Analysis Program (GAP), EPA's Wetlands Research Program and ecoregion approach (developed by James Omernik and others at ERL-Corvallis), and the U.S. Forest Service (USFS) Coastal Landscape Analysis and Modeling Study.

Target research to key knowledge and research gaps. The process outlined in the foregoing paragraphs—of coordinating, leveraging, and integrating research within selected case studies—will facilitate the identification of remaining knowledge and information gaps. The identification of these gaps, and the initiation of appropriate research, will be an ongoing process throughout the five-year period. The President's Forest Ecosystem Management Plan has focused substantial federal research on forested lands. Thus, we view research on nonforested areas and on the interactions among forested and nonforested landscapes as general "research gaps" that we can fill. Some projects within the research program deal specifically with agricultural and other nonforested lands; others emphasize the integration of information across landuses.

SEVEN RESEARCH COMPONENTS

1. Regional Biodiversity	5. Integrated Monitoring
2. Watershed/Ecoregion	6. Ecological-Socioeconomic Linkages
3. Riparian Areas	7. Technology Transfer
4. Coastal Estuaries	

A basic premise of ecosystem management is that management must occur at multiple spatial scales (Figure 2). Long-term goals, priorities, and general guidelines are established at a large, regional scale. These regional goals and guidelines provide the starting point for more detailed analyses of trade-offs and specific management approaches at the intermediate spatial scale, which we refer to as the watershed/ecoregion scale. The objective of management at this intermediate scale is to determine the most efficient way—ecologically, economically, and socially—to achieve desired resource uses and environmental goals within the guidelines and constraints prescribed by the regional plan. The intermediate-scale planning document then provides context for management decisions, both at the local level and by public and private landowners on individual parcels of land. Local conditions and considerations can require adjustments to larger scale plans. Thus, ecosystem management involves a balance between top-down (large-scale) planning and bottom-up (small-scale) decision making.

To match this multi-scale management approach, the PNW research program includes major research components at regional and watershed/ecoregion scales (numbers 1 and 2 in the box above). Although specific to the spatial scale, the goals of these two research components match those of the overall research program: to conduct selected case study ecological assessments and associated ecological research at regional and watershed/ecoregion scales in order to improve the scientific basis for implementing ecosystem management.

The next two research components (numbers 3 and 4 in the box at the top of the page) deal with two important ecosystem types, which we believe represent key knowledge gaps in the Pacific Northwest: (1) riparian areas in agricultural settings and mixed landuse watersheds and (2) coastal estuaries and watersheds (excluding Puget Sound and the Columbia River estuary). We selected these systems for focused research because they are important ecologically and economically, yet ecosystem-level information is sparse relative to management needs. Riparian areas occur at the interface between terrestrial and aquatic environments and play important roles in improving water quality and serving as habitat for terrestrial and aquatic biota. Estuaries are sources of important ecological resources (e.g., oysters, salmon) that contribute significantly to the local and regional economy and are subject to a variety of

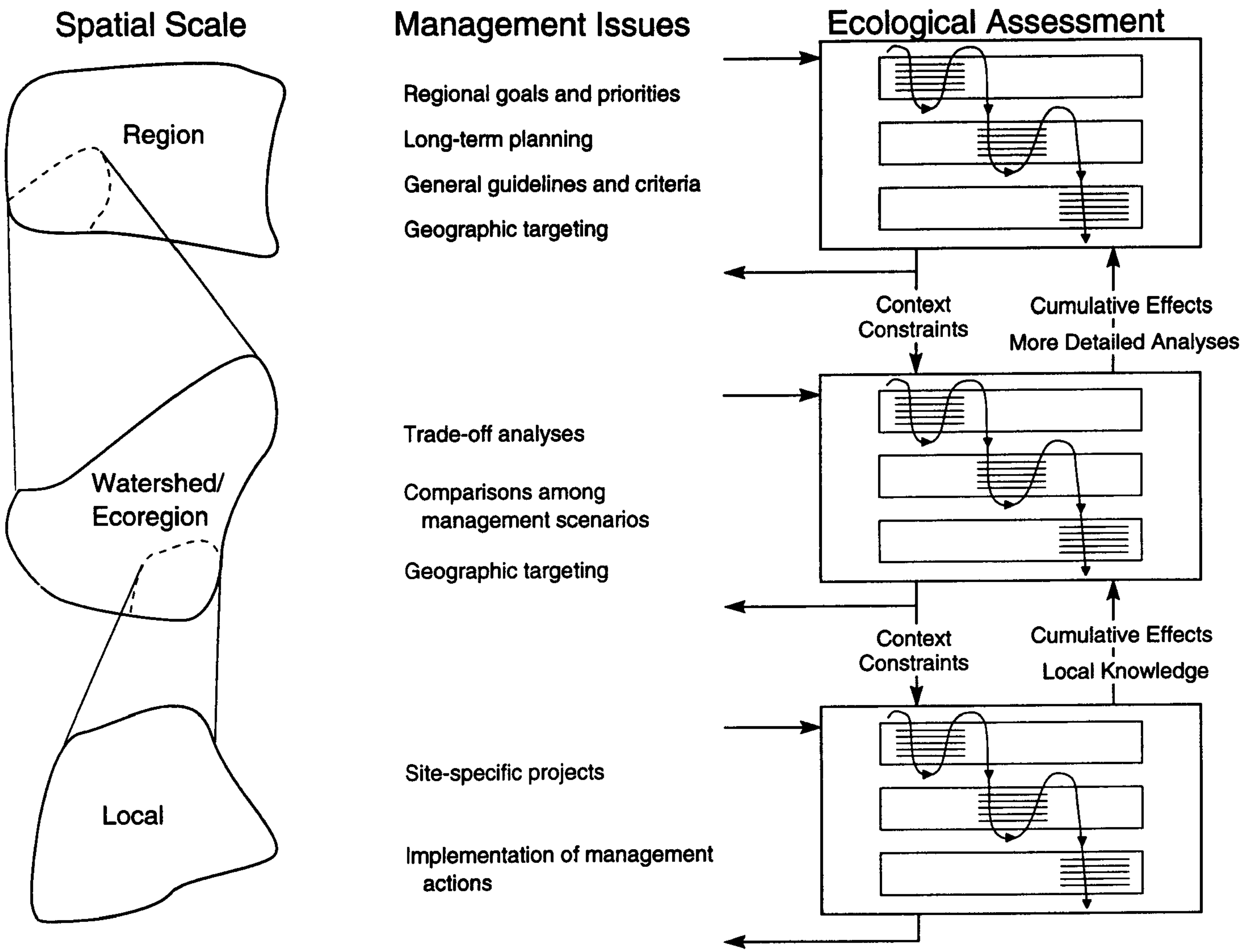

Figure 2. **Linkages across multiple spatial scales: management issues and associated ecological assessments. The ecological assessment process at each scale, shown diagrammatically here, is explained further in Section 3 and in Figures 3-11, 3-12, and 3-14.**

perturbations. The primary goal of these research components is to improve our understanding of riparian and estuary ecosystems and ecosystem responses to stressors and management actions.

The final major research component (number 5 in the box on page xviii) consists of designing and demonstrating an integrated ecological monitoring system. Ecosystem management within the Pacific Northwest includes the concept of adaptive management: monitoring ecosystem responses, evaluating the success or failure of management actions, and modifying management programs accordingly. Although we spend substantial effort and funds on monitoring, the monitoring data provided are not adequate for implementing an adaptive management approach. The goal of PNW monitoring research is to contribute to the design of an integrated monitoring system—integrated across ecosystem types, spatial and temporal scales, and organizations (federal, state, local, and private)—that will provide improved monitoring information at a cost equal to or less than the cost of current monitoring.

These five major PNW research components (regional biodiversity, watershed/ecoregion, riparian area, coastal estuaries, and integrated monitoring) are all interrelated. For example, monitoring demonstrations will be conducted, to the degree possible, in the PNW case study areas and will contribute to both regional and watershed/ecoregion case study assessments (and vice versa). Riparian and estuary research will contribute directly to the watershed/ecoregion case studies and to the selection of indicators for ecosystem monitoring. Relationships among research components, program-level objectives, and spatial scales are illustrated in Figure 3.

The PNW research program includes two additional components: ecological-socioeconomic linkages and technology transfer (numbers 6 and 7 in the box on page xviii). Both serve program outreach functions: to the economists and social scientists also involved in ecosystem management research and to the broad group of users of our ecological approaches and information, respectively.

The following paragraphs briefly describe the objectives and general approach for each of these seven research components. Testable hypotheses, which are central to the scientific method, are more appropriately defined at the project rather than the program level and, therefore, are not presented in this program strategy document. Eventually, detailed research plans will be prepared and peer-reviewed for individual projects funded under the PNW research program. These research plans will describe project-specific hypotheses, designs, and methods.

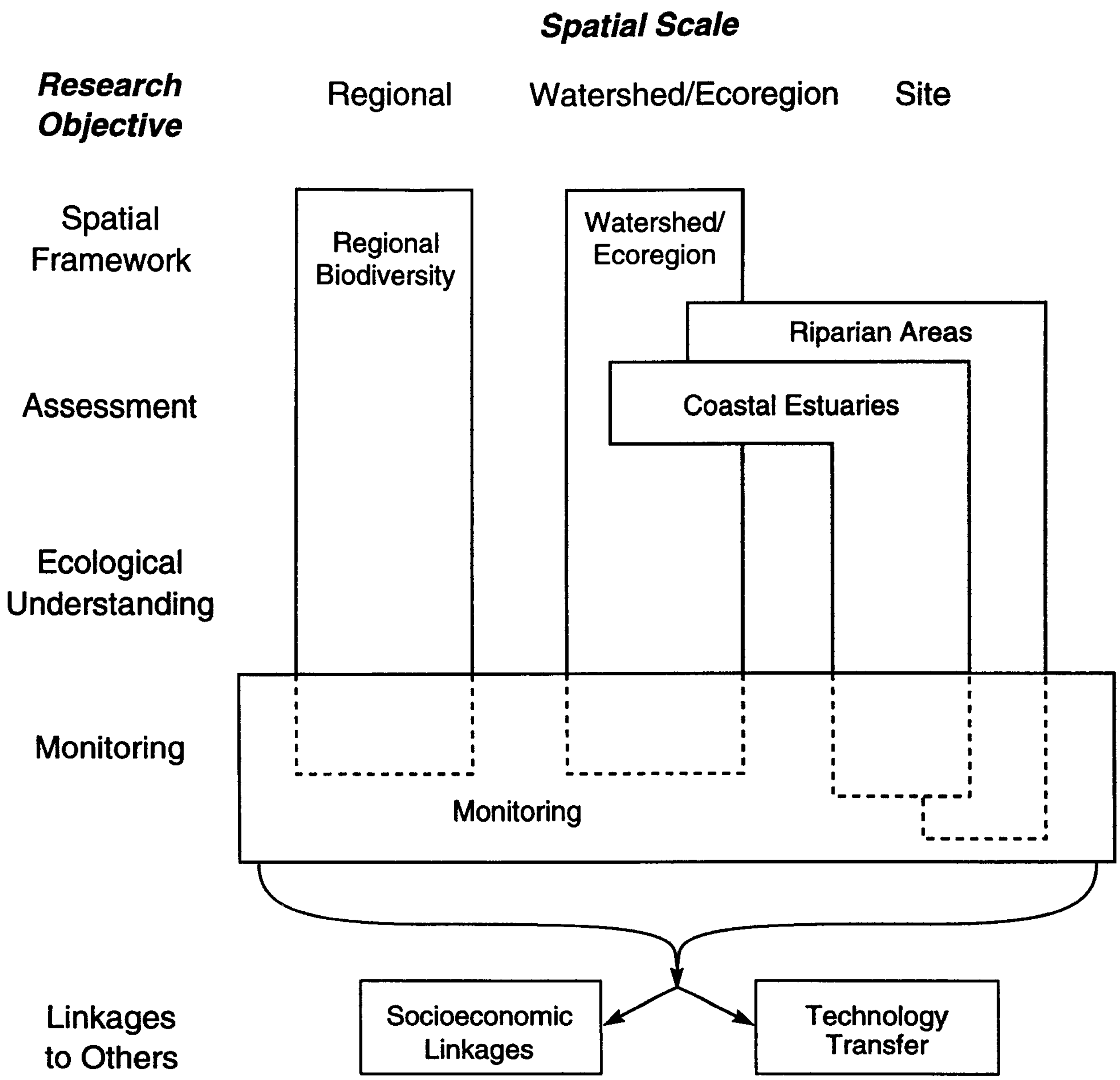

Figure 3. Major research components of the PNW research program, organized by program-level objective and spatial scale.

Regional Biodiversity Research

For the regional-scale case study, we will focus on regional analyses of biodiversity. We selected biodiversity as an example of an important assessment endpoint that must be addressed at a regional scale. Biodiversity, and threatened and endangered species, also are the focal point of regional analyses for the President's Forest Ecosystem Management Plan.

The major objectives of this research component are as follows:

- Develop and refine methods for integrating and interpreting data on biodiversity at a regional scale.
- Develop and demonstrate the ecological assessment process at a regional scale to support development of regional conservation strategies based on the best science available and stakeholder input.
- Conduct research targeted at testing the accuracy of assessment outputs, evaluating key assumptions, and addressing major knowledge gaps and uncertainties about regional ecosystems identified during the assessment process.

We propose a two-phase strategic approach to research on regional biodiversity. Phase 1 is to conduct a regional assessment based on existing data and knowledge, building on substantial efforts already ongoing in the NBS GAP and the interagency BRC. We will work directly with state agencies, BRC, and GAP to complete a consistent regional assessment of biodiversity for the Pacific Northwest as a whole (Washington, Oregon, Idaho). Our analyses will use the best available spatially explicit databases to estimate distributions of species, species assemblages, terrestrial habitats, and species richness, and to describe how these relate to spatial patterns of stressors and various levels of management protection. The assessment will identify areas rich in species and subject to (or likely to experience) significant stressors, making them high priority for management attention and further study.

Results from this assessment, including sensitivity analyses to identify key assumptions and uncertainties, will form the basis for prioritizing and designing subsequent research in phase 2. We will concentrate in 1995 and 1996 on the phase 1 assessment. Phase 2 research will begin in 1996 and expand in 1997 and beyond. The phase 1 assessment will represent, in essence, a set of hypotheses about regional biodiversity and factors that affect regional biodiversity, components of which will be tested in phase 2. Furthermore, the phase 1 assessment will provide a structure for (1) identifying the additional research and information most needed to increase our confidence in future assessments about regional biodiversity and (2) integrating this information, once obtained, into a format for decision makers.

Specific objectives and projects for phase 2 have not yet been selected, but will be a direct outcome of phase 1 research. Potential candidates, however, include the following:

- Field sampling in selected areas to evaluate the accuracy of regional distributions of species richness and habitat characteristics estimated in the phase 1 assessment.

- Collection of additional data and additional analyses for taxa not well represented in existing databases. To date, most of the effort has focused on terrestrial vertebrates, because of (1) the greater availability of species occurrence records for these organisms and (2) our ability to use remote sensing to characterize habitat (i.e., remote sensing estimates of vegetation type). The BRC conducts "sweep analyses" to evaluate the degree to which regional analyses based on data for terrestrial vertebrates adequately account for other terrestrial and aquatic groups. It is likely, however, that regional conservation strategies based strictly on data for terrestrial vertebrates will not be adequate for all other taxa. Thus, further data collection and analyses for other groups may be warranted.

- Process-related field studies or experiments. Strategies to sustain biodiversity cannot be based solely on analyses of spatial patterns of habitat and species distributions and their associations. They must also be based on a sound understanding of the ecosystem properties (processes, structure, components) required to sustain biodiversity and of ecosystem dynamics over time. An example of such an issue is the role of habitat corridors, which have been proposed as a means for extending the apparent size and effectiveness of individual habitat patches. Many questions remain, however, about the importance of corridors and increased habitat connectivity for species dispersal and maintenance of viable populations.

Watershed/Ecoregion Research

Watershed/ecoregion research will be conducted in two case study areas (Figure 4): (1) the Willamette River Basin and (2) the Washington Coastal Ecoregion. These areas were selected by EPA Region 10 and the States of Oregon and Washington as high-priority areas for ecosystem management research. In each case study area, we will conduct an integrated ecological assessment and associated research, addressing specific policy and management questions identified as high priority for that study area by managers and stakeholders. The strategic approach is similar to that for regional biodiversity. We will begin with an initial, qualitative assessment in 1995–96, using available data, followed by about 3 years of targeted research to fill the most important gaps in our understanding and data. We will conclude, in year 5, with a quantitative assessment that will address selected policy and management questions and also integrate and compare the approaches and analytical tools developed.

The objectives of the Watershed/Ecoregion research component are as follows:

- Conduct an initial assessment to determine the data and information available for the selected study areas; determine research needs based, partially, on information gaps.

- Demonstrate and evaluate methods for characterizing current ecological conditions at multiple spatial scales, cooperatively with research on monitoring designs.

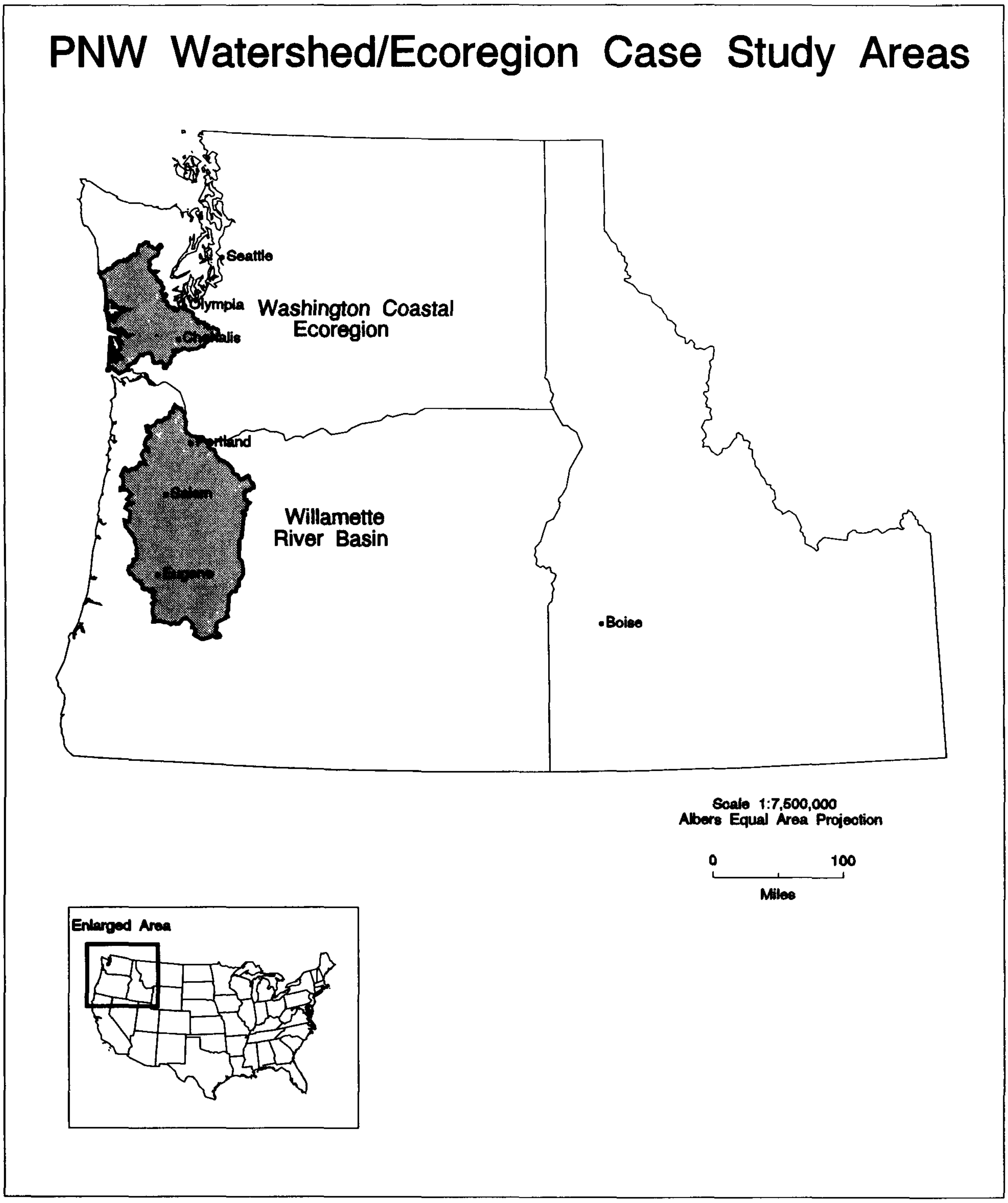

Figure 4. Watershed/ecoregion case study areas: Willamette River Basin and Washington Coastal Ecoregion.

- Select and test approaches for defining attainable ecological goals through the use of reference sites, ecological indicators, and other methods.

- Refine and demonstrate methods for targeting high-priority areas within a watershed/ecoregion for protection, restoration, or other management action, or for further study and/or monitoring.

- Construct simple watershed-scale interactive models to evaluate, project, and compare the consequences of alternative management strategies on key ecological endpoints.

- Compare the attributes of different spatial frameworks for summarizing information on ecological condition, setting attainable ecological goals, and organizing ecological research at the watershed/ecoregion scale.

- Evaluate techniques for extrapolating site-specific ecological information to other sites and spatial units at the watershed/ecoregion scale.

- Conduct a final integrated ecological assessment combining existing data and the results of the research conducted in this program to determine the best approaches for assessing management trade-offs in the study areas.

Major research activities will include the following:

- Cooperative efforts with EMAP to identify indicators of ecosystem condition appropriate for the region and to characterize current conditions, using an intensified EMAP sampling grid in the case study areas.

- Application and evaluation of Omernik's ecoregion approach, and comparison to other regionalization approaches, to delineate subregions with similar ecological potential and identify reference sites for setting attainable ecological goals. In particular, we will evaluate quantitative approaches to ecoregion delineation; extend Omernik's approach to riparian and terrestrial habitats as well as freshwaters; and evaluate the ecoregion approach using the EMAP field data.

- Development of spatially explicit models and decision support systems that can be applied at watershed/ecoregion scales with reasonable effort to evaluate the ecological consequences and trade-offs among various management options, including specific scenarios proposed by managers for ecosystem protection, restoration, pollution controls, and changes in land use and land and resource management practices.

- Development of landscape criteria for identifying high-priority sites within a watershed/ecoregion for protection, restoration, or other management action.

- Development and testing of landscape classification systems that can be used to extrapolate information from studied sites to other similar sites and to organize information about ecosystem functions, sensitivity to stressors, restoration potential, and best management practices and make it accessible to environmental managers.

Riparian Area Research

Research on riparian areas will address riparian area condition, restoration approaches, and "eco-opportunities" at both site and watershed scales (see Figure 3), with the following major objectives:

- Define reference conditions for riparian areas in agricultural settings.
- Establish indicators of riparian area condition in agricultural settings.
- Develop approaches for evaluating riparian area condition in mixed landuse watersheds.
- Develop approaches and performance criteria for restoring degraded riparian areas in agricultural settings.
- Develop approaches to locate promising areas for riparian restoration and to evaluate the attainable quality and restoration potential of riparian areas within mixed landuse watersheds.
- Evaluate practices that are ecologically and economically promising for managing riparian areas in agricultural settings.

We will assess the condition and restoration potential of riparian areas relative to three major riparian functions: (1) improvement of water quality, (2) habitat for aquatic biota, and (3) habitat for terrestrial biota.

Site-specific research will take place in agricultural settings, because of the relative lack of information on riparian areas in nonforested areas west of the Cascades. Study sites will include intact, fully functioning riparian areas, degraded systems, and restored riparian areas. One study, which began in fall 1994, is a cooperative research project with the Agricultural Research Service (ARS). By cooperating with the ARS, we take advantage of both their expertise in agricultural systems and their access to private farmlands. We hope to develop similar cooperative relationships with the ARS or others for the remaining riparian area projects, to begin in 1995 and later years.

Most of the study sites, as well as the watershed-scale riparian research, will lie within the two case study watershed/ecoregions identified in the discussion on the Watershed/Ecoregion research component (see Figure 4). Thus, information on riparian areas generated in this research component will contribute directly to the watershed/ecoregion case study assessments. In addition to carrying out site-specific studies, research activities will include (1) characterizing the occurrence and conditions of riparian areas in the landscape through the interpretation of satellite imagery, videography, or aerial photography (with appropriate groundtruthing), (2) using coupled geographic information system (GIS)-hydrologic models to develop indicators of riparian area performance and to evaluate promising locations for riparian area restoration, and (3) doing historical reconstructions of riparian areas prior to major hydrologic modifications. Additional approaches for watershed-scale analyses will be identified in workshops with agency, private, and university researchers, and field tested in the case study areas. We will also review, and possibly evaluate in the field, riparian management practices that have the potential both to maintain valued ecological functions and to provide financial return to landowners.

Research on riparian areas is taking place in close cooperation with similar research on wetland condition and restoration approaches within the Wetlands Research Program at ERL-Corvallis.

Coastal Estuaries Research

Research on coastal estuaries and their associated watersheds will address two of the program-level objectives: (1) developing and demonstrating assessment approaches and (2) improving our understanding of ecosystems and ecosystem responses to stressors and management activities. The assessment research will be conducted jointly with the Watershed/Ecoregion research component and will focus on an integrated ecological assessment for a single estuarine watershed, Willapa Bay, Washington. The Willapa Bay watershed is one of three watersheds within the Washington Coastal Ecoregion case study area (see Figure 4). The objectives and approach for the estuarine-watershed assessment are the same as those outlined for watershed/ecoregion assessments, although they focus on endpoints within the estuarine system.

Process-oriented research, to improve our understanding of estuarine ecosystems, will focus on two major stressors within Pacific Northwest coastal estuaries: sedimentation and biological stressors. The major objectives are as follows:

- Develop predictive relationships between ecosystem structure and habitat characteristics.
- Improve our understanding of the extent, loading, causes, and effects of sedimentation and associated parameters (such as nutrients) in Pacific Northwest coastal estuaries.
- Improve our understanding of the extent, causes, and effects of biological stressors (in particular, expansions of *Spartina*) and the effects of potential control strategies.

Although most of the process-oriented research will be conducted in Willapa Bay, Washington, certain questions can be addressed more effectively at other sites or through a comparative approach. Thus, we anticipate conducting some process-oriented research in selected Oregon estuaries, in particular Yaquina Bay, Tillamook Bay, and possibly in the South Slough of Coos Bay. Approaches developed in Oregon estuaries will be tested and integrated within the Willapa Bay case study assessment. Research activities proposed for each objective include the following:

Predictive relationships between ecosystem structure/functions and habitat characteristics

- Development and testing of cost-effective sampling techniques for characterizing salient physical/chemical habitat characteristics and key indicators of benthic and fish community structure/functions at a level of resolution sufficient to differentiate between major habitat types and stressed versus nonstressed systems.

- Evaluation of associations between habitat and benthic/fish indicators, and the application of these relationships to map benthic and fish communities in Willapa Bay.

Sedimentation and Associated Parameters

- Estimation of current and historical rates of sedimentation, using historical records, sediment cores, and sediment traps; and the relative contributions of marine and terrestrial sediments from the watershed, based on stable isotope ratios and other approaches.

- Evaluation of the association between historical sedimentation rates and watershed characteristics and events (e.g., major forest fires, clear-cutting).

- Development of hybrid models to predict sediment and nutrient loadings to Pacific Northwest coastal estuaries as a function of watershed characteristics and upland management practices.

- Development of approaches and models to predict changes in estuary circulation, and associated changes in temperature, salinity, dissolved oxygen, and other variables, as a function of sedimentation and runoff in Pacific Northwest coastal estuaries.

Biological Stressors and Potential Control Measures

- Field studies and laboratory/field experimentation conducted to evaluate the direct and indirect effects of *Spartina* on the Willapa Bay ecosystem; also the relative effects of *Spartina* versus chemical measures used to control or reduce *Spartina*.

Results from these studies will be combined with additional baseline data to identify the major stressors and evaluate alternative management scenarios in Willapa Bay as part of the case study estuarine-watershed assessment.

Integrated Monitoring Design

The major objectives of this research component are as follows:

- Identify the priority assessment questions for the Pacific Northwest that require monitoring information, and the ecological, spatial, and temporal scales at which each question must be addressed.

- Design elements of a fully integrated multi-scale ecological monitoring program for the Pacific Northwest.

- Demonstrate this integrated multi-scale ecological monitoring design in the Pacific Northwest (by leveraging other programs).
- Involve authorities with the mandate and resources to implement a monitoring program during all stages of the monitoring design effort.

The last objective is especially critical. The PNW research program has no long-term responsibilities for monitoring, nor does it have enough funding to conduct extensive field testing or demonstration studies. To achieve any of these objectives, and to develop a design that will eventually be adopted and used by others, we must work cooperatively with organizations that implement monitoring in the region, at federal, state, and local levels. Coordination with other federal agencies will be through the interagency Research and Monitoring Committee, through other organizations, and by direct contacts.

Near-term activities will include (1) compiling information on the administrative, management, and ecological needs for monitoring information in the region (federal, state, local, and other), (2) developing a consolidated list of assessment endpoints, and (3) reviewing existing monitoring programs in the region. This information will provide the basis for selecting measurement endpoints (indicators) and developing an integrated monitoring design.

Key issues in the monitoring design include how to (1) integrate information across ecosystem types (streams, forests, etc.) to evaluate the condition of the landscape, watershed, or ecoregion as a whole, (2) link data collected at different spatial and temporal scales (e.g., use regional-scale data to provide context for site-specific monitoring and more intensive site-specific monitoring to help interpret regional patterns and trends), and (3) combine the diverse monitoring needs (from compliance monitoring to assessment of ecosystem status and trends) and existing monitoring programs into an integrated monitoring system. We expect that monitoring will always be conducted by many different agencies and organizations (federal, state, tribal, local, and private). Thus, an important part of the monitoring design will be to develop an information management system that will allow data collected by different groups to be easily accessed, combined, and analyzed.

EMAP's objectives also include the design and demonstration of ecological monitoring, and a regional-scale EMAP initiative for the Pacific Northwest is currently being discussed, to begin in 1996. If this proceeds, the PNW Integrated Monitoring research component and EMAP will be closely coordinated. We will target resources within the PNW research program to supplement and enhance EMAP research, and rely heavily on EMAP and others for field demonstrations. A particular role for the PNW research program is to foster improved coordination among federal, state, and other monitoring programs in the region and to organize jointly funded, integrated pilot and demonstration studies. The interagency

Research and Monitoring Committee is coordinating an integrated monitoring program among federal agencies for the President's Forest Plan, with a regional demonstration scheduled for 1997. We hope to extend this effort to incorporate interested state, tribal, local, and private organizations.

Ecological–Socioeconomic Linkages

The goal of ecosystem management is to maintain both healthy sustainable ecosystems and healthy sustainable economies and local communities. Economic and social, as well as ecological, concerns must all be considered in management decisions. Our research program will contribute ecological information to aid decision makers. To be of maximum use, this ecological information must be in a form that integrates well with matching social and economic analyses. The objectives of this component of the PNW research program are not to conduct economic or social science research, but rather to do the following:

- Participate in developing an assessment framework and process that integrates ecological, economic, and social information into a form useful for decision makers.
- Ensure that the ecological research we conduct provides the types of ecological information needed for economic and social assessments in the Pacific Northwest.

Our primary mechanism for achieving these objectives will be through the National Research Council (NRC) Associateship Program. We plan to fund several economists or sociologists to work on site with ecologists at ERL-Corvallis or ERL-Newport for periods of 1–3 years each. Joint projects will be conducted using the ecological information we collect as part of an economic or social assessment within one or more of our ecological case studies. The exact nature of the economic/social research will depend on the expertise and interests of the NRC Associates.

Technology Transfer

Technology Transfer is a strategy integral to all components of the PNW research program. The major objectives are as follows:

- Ensure through feedback from managers that PNW research is relevant to policy and management needs.
- Ensure that the innovations, information, and approaches we develop are adopted and widely used by environmental managers at regional, state, and local levels.

Our approach is twofold: (1) involve a regional liaison directly in the research program, whose primary responsibility is to foster communication between PNW researchers and groups of environmental managers working in local governments, states, and EPA regional offices and (2) conduct collaborative projects, in which environmental managers work directly with PNW researchers. The regional liaison will work with EPA Region 10 to select collaborative projects that are relevant to the PNW research objectives and that will also serve the immediate needs of region, state, or other management groups.

SUMMARY

This document outlines our strategic approach for ecological research in the Pacific Northwest, the goal of which is to improve the scientific basis for implementing ecosystem management at multiple spatial scales. We are in the formative stages of a five-year research effort that will require extensive interaction and coordination with other researchers and with environmental managers in the region. This is not a detailed research plan, but rather an overview of the major program objectives, components, and general approach. Project-specific hypotheses and designs will be developed and peer reviewed before initiation of each project. In addition, we anticipate conducting program-level peer reviews every other year, to summarize progress to date and identify future research directions.

Our proposed research is technically diverse, but geographically focused. A primary benefit will be demonstration of how a variety of ecological concepts and approaches can be combined and integrated to address important management questions and needs, in selected case study assessments at regional and watershed/ecoregion scales.

1. BACKGROUND

This document outlines a five-year strategy for ecosystem management research in the Pacific Northwest, funded by the U.S. Environmental Protection Agency (EPA), Office of Research and Development (ORD), and led by the Environmental Research Laboratory in Corvallis (ERL-Corvallis). It presents the objectives of the research program and the strategic approach for achieving those objectives over the next five years. It is not a detailed research plan and does not describe specific hypotheses and technical approaches for individual research projects. Testable hypotheses are central to the scientific method, but it is more appropriate to define them at the project level rather than the program level. Research plans, which describe these project-level hypotheses and approaches, will be prepared and reviewed separately for each project funded as part of the research program. In addition, the entire program will be peer reviewed every two years to evaluate relationships among projects and progress towards the program-level objectives.

The goal of the research program is to contribute to the ecological understanding and approaches needed to implement ecosystem management effectively in the Pacific Northwest. Although focused on the Pacific Northwest, the research results should also have broader applicability, beyond the region. Section 1.1 discusses the concepts and goals of ecosystem management; Section 1.2 explains EPA's role in ecosystem management. Section 1.3 describes efforts to implement ecosystem management in the Pacific Northwest. Subsequent sections discuss our proposed research: the scope, objectives, and organization of the research program (Section 2); our approach to ecological assessment (Section 3); the specific objectives and research strategy for each major component of the research program (Sections 4 to 10); and summary of the program schedule and expected outputs (Section 11). References cited are listed in Section 12.

1.1 ECOSYSTEM MANAGEMENT

The more we learn from EPA's pollution control efforts, the more we realize that piecemeal approaches do not adequately protect our ecological resources. While pollutant-specific and site-specific management programs have resulted in a substantially cleaner environment, we still have not achieved societal expectations. We may clean up the water, but not save the fish, if there is continuing loss of streamside habitat or diversion of water flow. We may preserve wetlands, but not maintain duck populations, if surrounding agricultural practices increase the number of duck predators. We may reduce toxic waste discharges into the Great Lakes, but still not be able to eat the fish, if they are contaminated by toxic air pollutants transported from afar. Comparable issues face other government agencies. Under the Endangered Species Act, heroic and often socially disruptive efforts are made to save individual species that are approaching the brink of extinction; broader approaches are needed to prevent rather than react to such "train wrecks" (cf. Franklin 1993).

Problems such as these have led to increased interest in the concept of *ecosystem management*—dealing with ecological systems as a whole, rather than as an assemblage of parts, and as they are organized by nature rather than along political or program boundaries. The Interagency Ecosystem Management Task Force (1994), established by the Clinton Administration, defines ecosystem management as follows:

> "Ecosystem management is a goal-driven approach to restoring and sustaining healthy ecosystems and their functions and values using the best science available. It entails working collaboratively with state, tribal, and local governments, community groups, private landowners, and other interested parties to develop a vision of desired future ecosystem conditions. This vision integrates ecological, economic, and social factors affecting the management unit defined by ecological, not political boundaries." The goal is "to restore and maintain the health of ecosystems while supporting sustainable economies and communities."

Vice President Gore's National Performance Review recommended that an "ecosystem-based approach" be adopted across the federal government.

Different groups have used different terms—ecosystem management, ecosystem approach, ecosystem protection, watershed protection approach, integrated environmental management, sustainable development (World Committee on Environment and Development 1987, Cairns and Crawford 1991, U.S. EPA 1991, 1994a,b, Slocombe 1993, Allen et al. 1993, Bormann et al. 1994). Most, however, have the same basic themes:

- The need to balance ecological, economic, and social concerns.
- Stakeholder involvement. All parties with a stake (something to lose or gain) in a decision should be involved in analysis of the problem, goal setting, and development of the solution.
- Coordinated, integrated actions by federal, state, tribal, and local agencies, between government and private enterprises, and between government and local communities.
- Holistic assessments that consider the full range of goods, services, and values that ecosystems provide and the full spectrum of human activities that affect ecosystems.
- Management for the long term, designed to provide the set of multiple uses[1] of ecological resources that society now desires without undermining the system's capacity to provide these and other uses in the future (Box 1-A, Figure 1-1).

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[1] We use the term *use* broadly to include both consumptive uses, such as fisheries and forest harvesting, and nonconsumptive uses or values, such as the value some people assign to maintaining pristine ecosystems.

Box 1-A. Ecosystem Sustainability

"A 'sustainable biosphere' can be envisioned in which the diversity of life on earth persists, where the biosphere supports the current generation of humans while leaving an equitable share of resources for future generations. This concept of intergenerational equity is the backbone of sustainability" (Meyer and Helfman 1993, p. 569).

"Sustainability is a goal, like liberty or equality: not a fixed endpoint to be reached but a direction that guides a constructive change" (Lee 1993, p. 563).

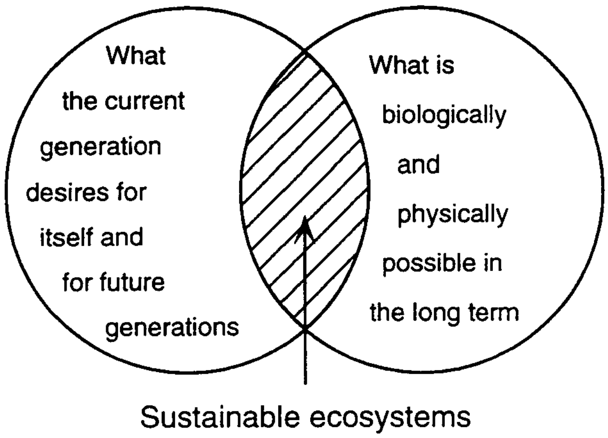

Figure 1-1. **Ecosystem sustainability: The degree of overlap between what is ecologically possible (i.e., the ecological capacity) and what the current generation desires for itself and future generations. Desires of the future generation must be protected by "maintaining options for unexpected future ecosystem goods, services, and states" (Source: Bormann et al. 1994, p. 3).**

We chose the term ecosystem management rather than ecosystem protection because we consider management more comprehensive than protection. To protect is to "cover or shield from danger or injury" (Webster Encyclopedic Dictionary of the English Language 1971). Management includes the option to protect, but also the option to restore and other approaches (e.g., landuse zoning) to influence human activities and their impact on ecosystems. We chose ecosystem rather than watershed (as in watershed protection approach; U.S. EPA 1991) to avoid preconceived notions about the best spatial unit for analysis. An "ecosystem" is a "spatially explicit unit of the Earth that includes all organisms, along with all components of the abiotic environment within its boundaries" (Likens 1992, p. 9). An ecosystem has no fixed size, but it might be "the entire planet Earth, a lake or a single rock in the desert" (Likens 1992, p. 9), the size and boundaries are selected to match the problems or questions being addressed.

The use of a specific term is less important than the concepts behind the term. Our research strategy assumes the following:

- **Ecosystem management is "place-based."** It is driven by the key environmental problems that occur in particular geographic areas. Places are defined along ecological boundaries, rather than political or administrative structures. For any given area, ecosystem management involves identifying the major problems, working with stakeholders to set measurable environmental goals, and developing and implementing management strategies to achieve those goals (U.S. EPA 1994a,b).

- **Ecosystem management is holistic rather than fragmentary.** Ecosystems have multiple, interacting components and processes that are affected by multiple, interacting stressors.[2] Ecosystem management must consider all relevant ecological endpoints[3] and stressors.

- **Ecosystem management is driven by public values**. Ecosystems include people; social, economic, and ecological well-being are inextricably linked (Figure 1-2). Ecosystems do not have a single "natural" state. They provide multiple and often competing uses. Not all ecological changes are "bad" and there is no single, scientifically derived endpoint for ecosystem management.

- **Ecosystem management must occur at multiple spatial scales.** Large-scale, long-term planning provides context and general guidelines for management decisions at smaller spatial scales. Yet, micromanagement strictly from the top is likely to be inefficient, because it does not take advantage of local knowledge about local conditions (Johnson 1992). Bormann et al. (1994) propose an iterative process between "top-down" (large-scale) planning and "bottom-up"

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2 A *stressor* is any chemical, physical, or biological entity or activity that can induce an ecological effect. Ecological effects encompass a variety of responses, ranging from mortality of an individual organism to a loss of ecosystem function (U.S. EPA 1992). A stressor may be natural or it may result from human activities.

3 We use the term ecological *endpoint* to refer to an ecosystem good, service, or other value selected to serve as the focal point for management decisions and assessments. Example endpoints are sustainable fishery yields, biological diversity, water quality, and aesthetics. Types of endpoints are discussed further in Section 3.

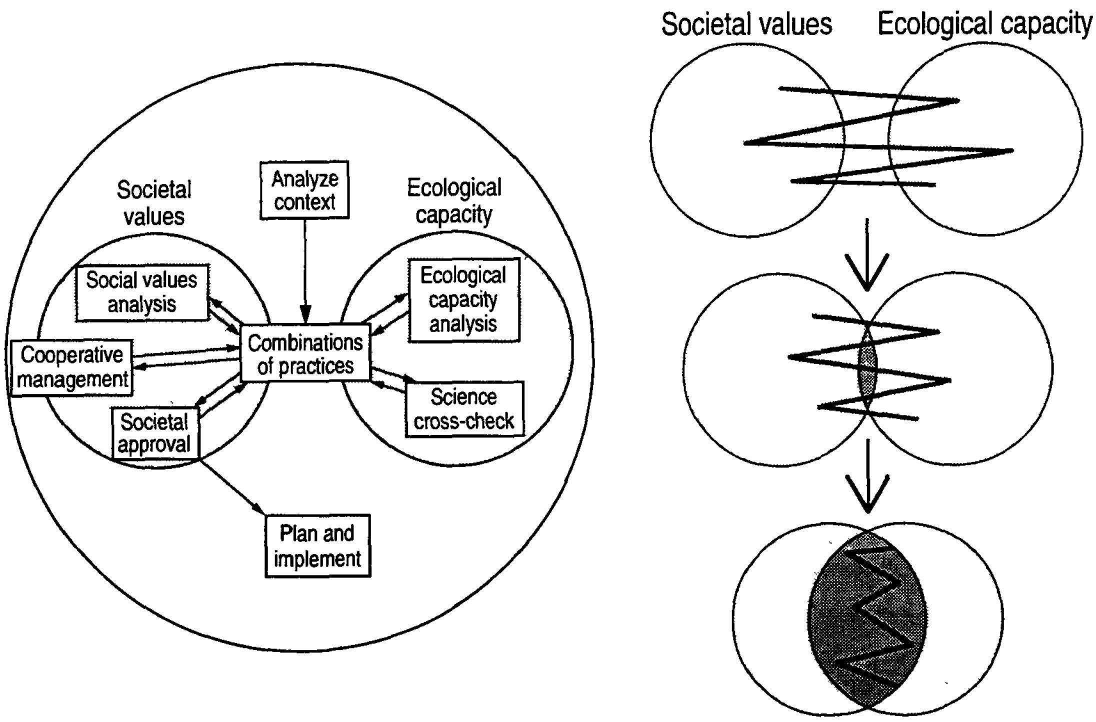

Figure 1-2. An iterative decision process for any geographic area and scale to "lace" together societal values and the ecological capacity of the ecosystem (i.e., what is possible biologically and physically in the long term). Success in this process will produce sustainable ecosystems as shown in Figure 1-1 (Source: Bormann et al. 1994).

(small-scale) decision making so that "the correct balance between what is desired, what is achievable, and what are the costs, benefits, and trade-offs can be made" (p. 40) (Figure 1-3).

Ecosystem management also frequently incorporates the concept of *adaptive management* (Walters 1986, Hilborn 1987), which explicitly recognizes that uncertainties will occur in management decisions and that mistakes will be made. Thus, we must monitor ecosystem responses and constantly re-assess the success or failure of management actions and the feasibility of management goals (Figure 1-4). We learn from past mistakes and adapt management programs accordingly. The concept of adaptive management can be extended to "management by experiment," in which the manager purposely implements a diverse array of management practices to increase learning opportunities (Walters and Holling 1990).

Finally, ecosystem management must be based on sound science and information. The role of research is to improve that science base. Major research needs derive from the holistic nature of ecosystem management: the need to (1) consider multiple endpoints, multiple stressors, and their interactions and trade-offs at multiple spatial and temporal scales, (2) synthesize information from many scientific disciplines, and (3) present scientific information in a user-friendly format useful for decision making and understandable to the wide array of stakeholders. Section 2 elaborates further on our view of the major research needs for ecosystem management.

The success of ecosystem management is not a given. Similar approaches (e.g., multiple-use resource management) have been attempted in the past with varying degrees of success. While the basic concepts are sound, the difficulty is in implementing the approach efficiently and effectively. Our challenge is to develop and implement a research program that serves the needs of a management approach that is only now being defined. The next five years will be a learning, adaptive process both for the ecosystem management approach and for ecosystem management research.

1.2 EPA'S ROLE IN ECOSYSTEM MANAGEMENT

EPA's legislative mandates, for the most part, are media or problem specific—the Clean Water Act, the Clean Air Act, Toxic Substances Control Act, etc.—and past efforts at environmental management "have been as fragmented as our authorizing statutes" (U.S. EPA 1994a, p. 1). As part of the Agency's commitment to implementing ecosystem management, EPA's Ecosystem Management Task Force recommends "changing the unit of work from piecemeal program mandates to the imperatives of a specific place. ... For any given place, EPA would establish a process for determining long-term

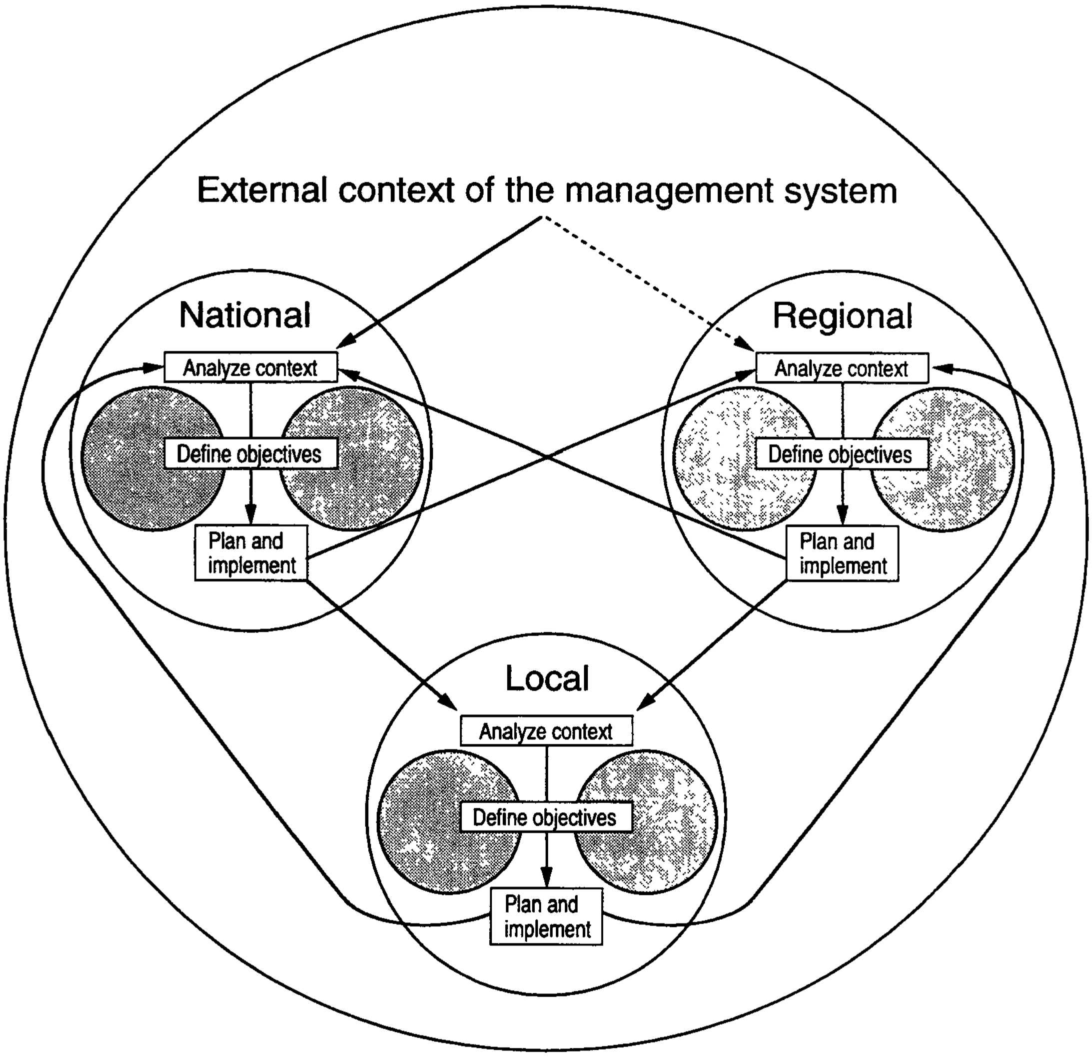

Figure 1-3. Information flow in the multi-scale ecosystem management model. Context for management decisions involves information from both larger and smaller geographic scales in an iterative process. The two shaded circles in each scale represent societal values and ecological capacity as shown in Figure 1-2 (Source: Bormann et al. 1994).

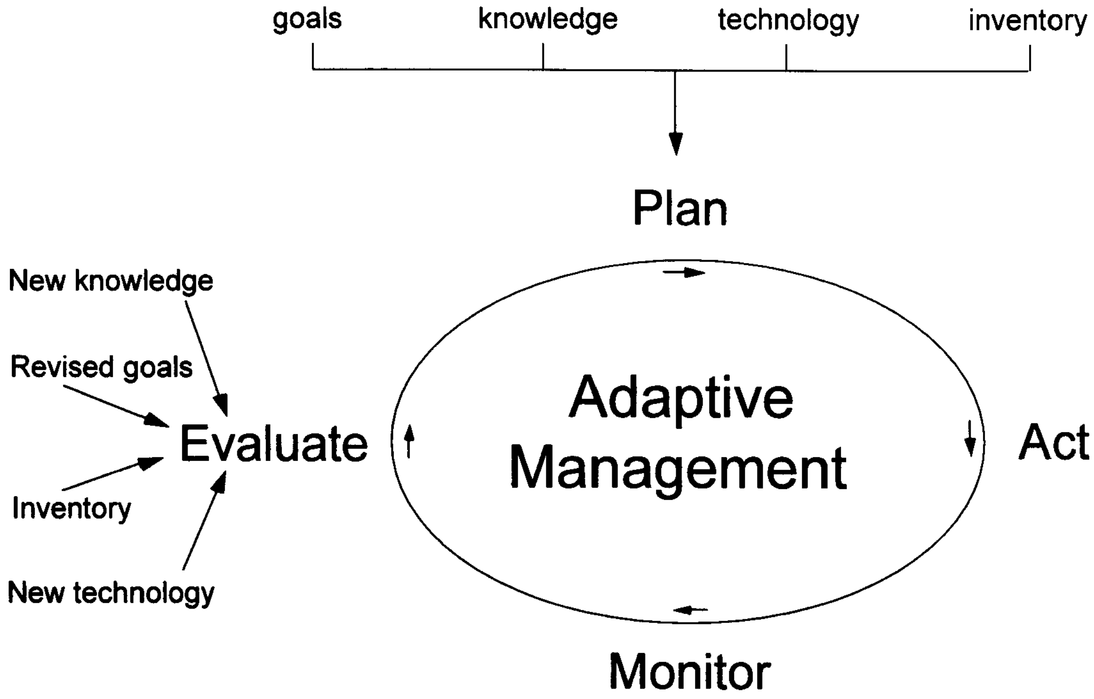

Figure 1-4. Adaptive management process (Source: Forest Ecosystem Management Assessment Team 1993).

ecological, economic, and social needs and would orient its work to meet those needs" (U.S. EPA 1994a, pp. 2, 3). The specifics of how this reorientation will be achieved are only now being developed.

National air and water quality criteria and discharge limits, EPA's primary management tools to date, have a role, but cannot be the sole or even the major mechanism for achieving the goals of ecosystem management. Thus, EPA is in the process of a cultural change, shifting from primarily a regulatory approach to a balance between regulations and incentives. Mechanisms include offering grants to support self-initiated community, tribal, and state efforts; actively convening and leading interagency collaborative efforts; and developing the process and guidelines for implementing ecosystem management, which can serve as a model. The Office of Water has aggressively promoted the watershed protection approach (Figure 1-5) since 1990 through financial support and active participation in numerous watershed partnerships (U.S. EPA 1991, 1993a).

Elements of the Watershed Protection Approach

Potential participants in watershed protection projects include:

State environmental, public health, agricultural, and natural resources agencies
Local/regional boards, commissions, and agencies
EPA water and other programs
Other federal agencies
Indian tribes
Public representatives
Private wildlife and conservation organizations
Industry sector representatives
Academic community

Risk-Based Geographic Targeting

Both human-derived pollution and natural processes pose risks to human health or the environment, or both, in many water body systems. The watersheds at highest risk are identified and one or more are selected for cooperative, integrated assessment and protection

Problems that may pose health or ecological risks in a watershed include:

Industrial wastewater discharges
Municipal wastewater, stormwater, and combined sewer overflows
Waste dumping and injection
Nonpoint source runoff or seepage
Accidental leaks and spills of toxic substances
Atmospheric deposition
Habitat alteration, including wetlands loss
Flow variations

Stakeholder Involvement

Working as a task force, stakeholders reach consensus on goals and approaches for addressing a watershed's problems, the specific actions to be taken, and how they will be coordinated and evaluated

Integrated Solutions

The selected tools are applied to the watershed's problems, according to the plans and roles established through stakeholder consensus. Progress is evaluated periodically via ecological indicators and other measures

Coordinated action may be taken in areas such as:

Voluntary source reduction programs (e.g., waste minimization, BMPs)
Permit issuance and enforcement programs
Standard setting and enforcement programs (nonpermitting)
Direct financing
Economic incentives
Education and information dissemination
Technical assistance
Remediation of contaminated soil or water
Emergency response to accidental leaks or spills

Figure 1-5. Elements of EPA's Watershed Protection Approach, developed by the Office of Water (U.S. EPA 1991).

EPA's legislative mandates cover (uniquely among federal agencies) both private and public lands; physical, chemical, and biological components of ecosystems; the atmosphere, as well as terrestrial and aquatic resources; and estuarine and marine systems, as well as freshwaters. EPA also has a history of interactions with state, tribal, and local governments, as well as private enterprises. This broad spectrum of responsibilities and contacts may provide EPA with a relatively unique role in ecosystem management—as integrator, or at least facilitator of this integration—across different agencies, public and private lands, different landuses, and different resource types (aquatic, terrestrial, marine, wetlands, etc.).

Ecosystem management involves a balanced evaluation of ecological, economic, and social concerns. The goal is to achieve both ecosystem health[4] and economic stability. We should note, however, that EPA's primary mandate is environmental protection. Other agencies have missions that focus on economic and (human) community stability. The essence of ecosystem management is that these two missions should be combined, changing adversarial relationships to coordination and cooperation as a more effective way to make the government "work better and cost less" (Interagency Ecosystem Management Task Force 1994, p. 1). Still, EPA's primary role within ecosystem management is as an advocate for ecosystem health, which may explain the preference for the term *ecosystem protection* within EPA documents as opposed to *ecosystem management*. The goal of EPA's ecosystem protection approach, as defined by the Ecosystem Management Task Force established by Administrator Browner, is "to help improve the Agency's ability to protect, maintain, and restore the ecological integrity[5] of the nation's lands and waters (which includes the health of humans, as well as plant and animal species) by moving toward a place-driven focus" (U.S. EPA 1994a, pp. 1-2). The Task Force goes on to note that the approach will "integrate environmental management with human needs" and "highlight the positive correlations between economic prosperity and environmental well-being" (U.S. EPA 1994a, p. 2). Thus, EPA must balance its roles as enabler and integrator for the overall process of ecosystem management with its role as advocate for environmental protection.

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[4] The meaning of the term *ecosystem health* is widely debated. We believe the health of an ecosystem must be defined in relation to a specific objective or societal value. Pristine ecosystems are healthy if the objective is to maintain ecosystems in their natural state but are not necessarily healthy if the primary objective is to achieve a sustainable forestry industry and diverse recreational opportunities. Because of the difficulty in defining the term, in general we avoid using it in this document. We use it here only to make direct reference back to the goal of ecosystem management as defined by the Interagency Task Force in Section 1.1.

[5] EPA's Ecosystem Management Task Force defines ecological integrity as "the interaction of the physical, chemical, and biological elements of an ecosystem in a manner that ensures the long-term health and sustainability of the ecosystem. Ecological integrity can be evaluated by measuring organism health, population viability, species and community diversity, and functions of an ecosystem (i.e., nutrient cycling, hydrology, biomass production). Historic ecosystem composition, structure, and function is a useful reference point, though not a recipe, for ecological integrity" (U.S. EPA 1994a, p. 1).

Another important role for EPA is to contribute technical support and scientific information (U.S. EPA 1994a,b). Effective ecosystem management requires information on ecosystem status and trends and an understanding of how ecosystems operate and respond to human activities and management approaches. This is the role that this research program attempts to fill. The Pacific Northwest research program described here is part of an overall ORD effort to restructure its research to better serve the needs of EPA's ecosystem management/protection approach.

EPA obviously is not the sole source of scientific information supporting ecosystem management. As in other aspects of ecosystem management, coordination and cooperation among agencies are critical. Efforts to fill knowledge gaps and participate in and encourage collaborative research projects are an important part of our research strategy, as described in later sections.

1.3 ECOSYSTEM MANAGEMENT IN THE PACIFIC NORTHWEST

Our study area is the Pacific Northwest. This section defines what we mean by the Pacific Northwest, provides basic descriptive information for the region, explains why the region was selected, and discusses ongoing efforts to implement ecosystem management in the area.

How do we define the Pacific Northwest? What are the boundaries of our study region? The appropriate spatial scale and boundaries for any study depend on the questions being addressed. Because we will be addressing a wide range of questions, we prefer not to select one, rigid definition of the study region.

Within EPA, our major client for this research is Region 10, the regional office responsible for Washington, Oregon, Idaho, and Alaska (Figure 1-6). Administrator Browner, in her 24 May memorandum to EPA's Ecosystem Management Task Force, noted that the EPA regions were key to EPA's implementation of ecosystem management, because of their close ties with state, local, and tribal governments We consider the research program to be a partnership between ORD and Region 10. The role of Region 10 is to provide the connection to the broader group of stakeholders, government agencies, and private organizations dealing with environmental management issues in the area; to encourage and facilitate the adoption of an ecosystem management approach; and to help incorporate the research results into the ecosystem management process.

Thus, we consider our core study area to be the three states served by Region 10, Washington, Oregon, and Idaho, excluding Alaska. State boundaries are rarely appropriate, however, for ecological analyses. Therefore, the actual boundaries used for any given analysis or research project will be tailored as needed. For example, hydrological units (Figure 1-7) are more appropriate for analyses of water quality.

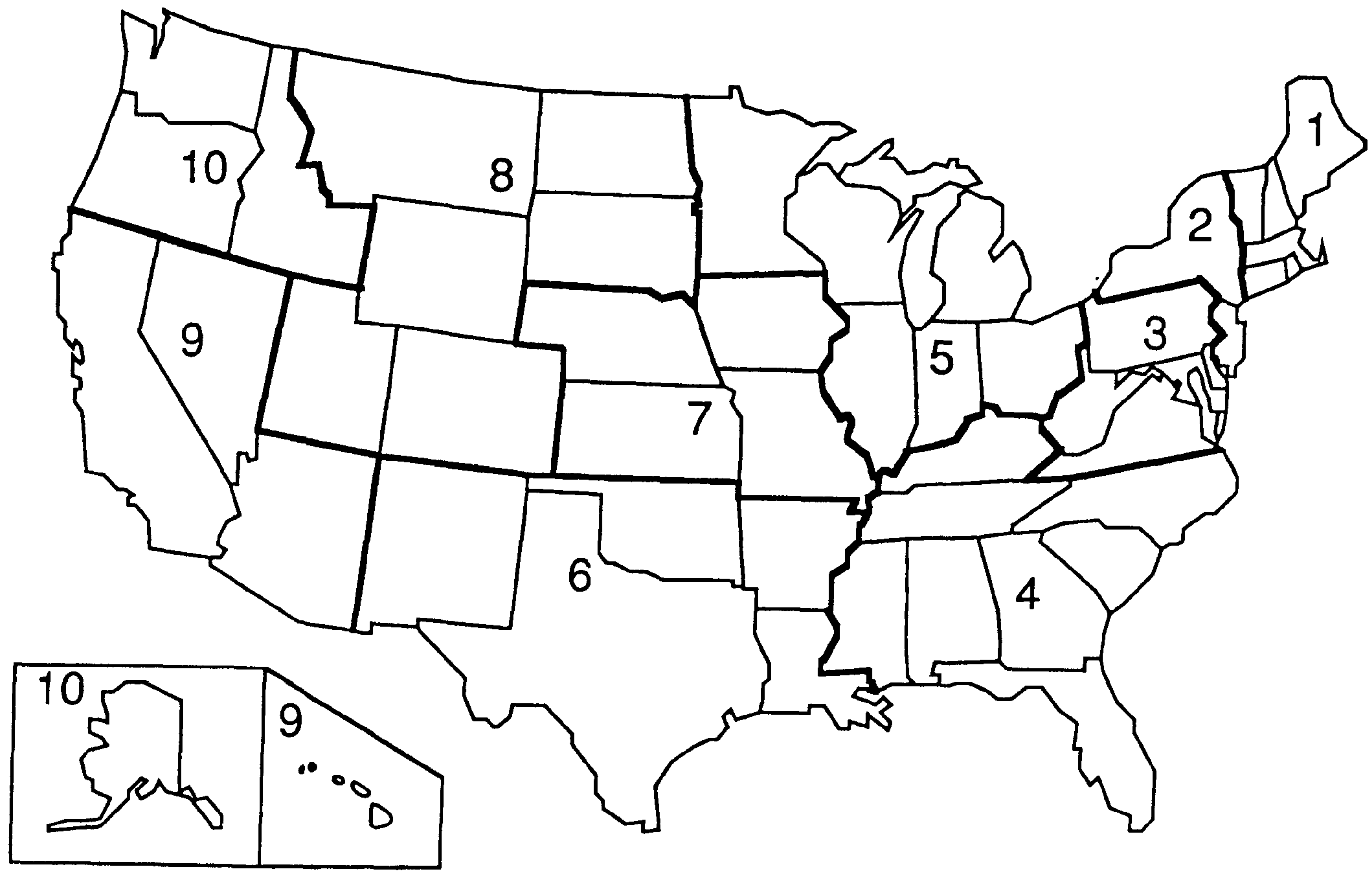

Figure 1-6. **U.S. Environmental Protection Agency regions.**

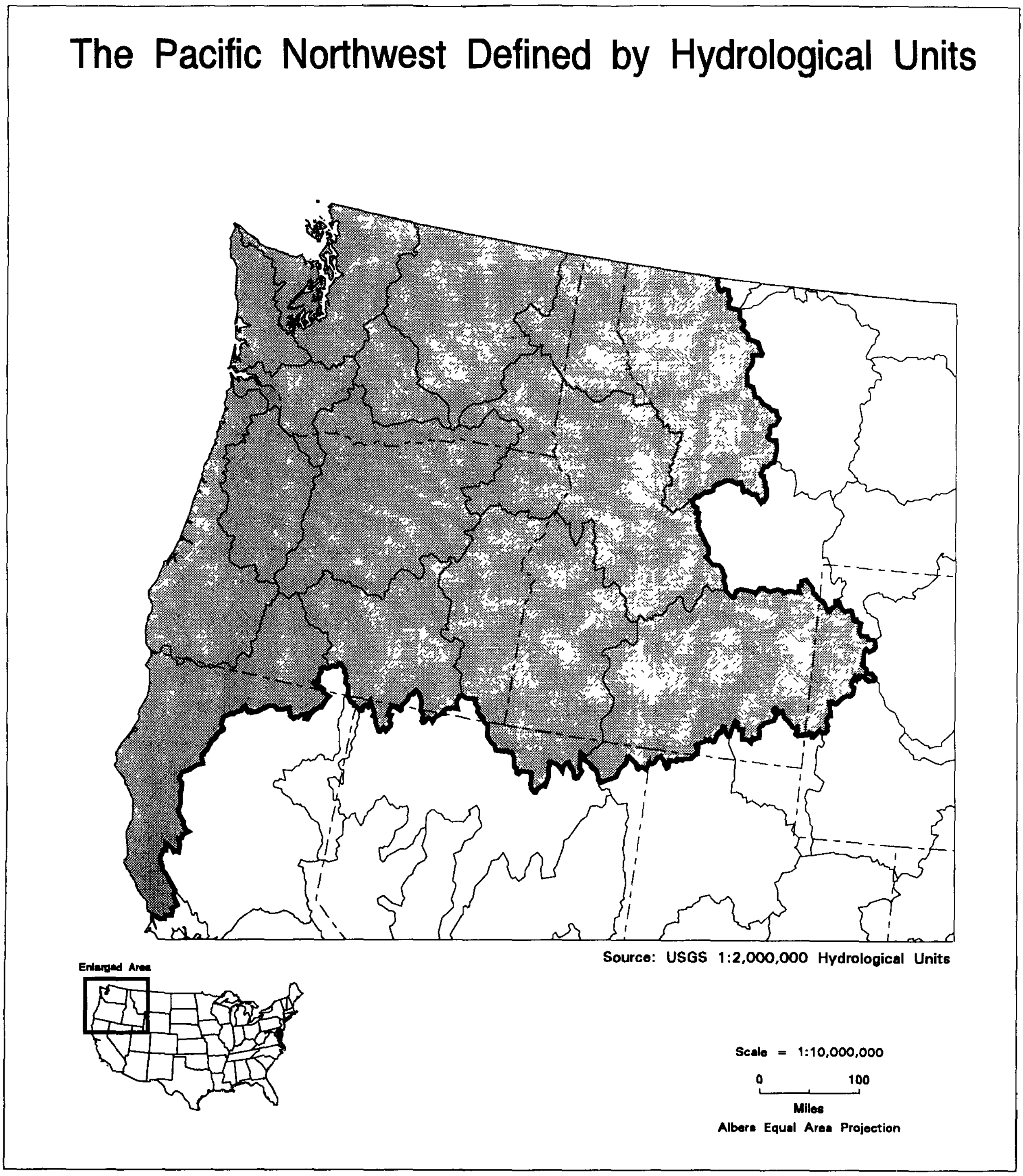

Figure 1-7. **U.S. Geological Survey Hydrological Units in the Pacific Northwest.**

Ecologically defined regions (e.g., Figure 1-8) may be more appropriate for analyses of terrestrial biodiversity or similar issues. In the remainder of this document, we use the term *Pacific Northwest* to refer to our core study area—Washington, Oregon, and Idaho, an area of about 650,000 km^2. Box 1-B provides basic descriptive information for the region.

Why was the Pacific Northwest selected as the study area for a major ORD research effort on ecosystem management? The impetus was the so-called gridlock or "train wreck" in the region between timber jobs and protection of endangered and threatened species on federal lands, in particular the northern spotted owl, popularly characterized as "owls versus jobs."

By 1993, a series of court orders had brought timber harvesting on federal lands to a virtual halt within the range of the northern spotted owl (in western Oregon and Washington and northern California; see Figure 1-9). Federal courts ruled that the U.S. Forest Service (USFS) and Bureau of Land Management (BLM) had failed to produce plans satisfying the requirements of several laws, including the National Forest Management Act of 1976, the Endangered Species Act of 1979, and the National Environmental Policy Act of 1969 (Forest Ecosystem Management Assessment Team, FEMAT 1993). Regulations issued for the USFS under the National Forest Management Act require that "fish and wildlife habitat shall be managed to maintain viable populations of existing native and desired non-native vertebrate species in the planning area" (36 CFR Ch. II; 7-1-91 Edition 219.19) and require provision "for diversity of plant and animal communities and tree species" (id., 219.26 and 27). The Endangered Species Act protects all species formally listed as endangered or threatened.

Legal battles focused initially on the northern spotted owl, listed as threatened by the U.S. Fish and Wildlife Service. Northern spotted owls are closely associated with habitat found most often in old-growth forests, that is, forest stands where many old, large trees remain in the overstory. Gradually, the debate shifted from dealing with one species, the northern spotted owl, to considering all species associated with old-growth forests in the Pacific Northwest.

Historically, timber harvests from federal lands accounted for about one-third of total timber sales in western Oregon and Washington and northern California (FEMAT 1993). Loss of these timber harvests resulted in severe economic disruption, particularly in small communities heavily dependent on timber from federal lands for jobs. In response to this problem, President Clinton convened a day-long conference on 2 April 1993 in Portland, Oregon. He posed the following question, "How can we achieve a balanced and comprehensive policy that recognizes the importance of the forests and timber to the economy and jobs in this region, and how can we preserve our precious old-growth forests, which are part of our national heritage and that, once destroyed, can never be replaced?"

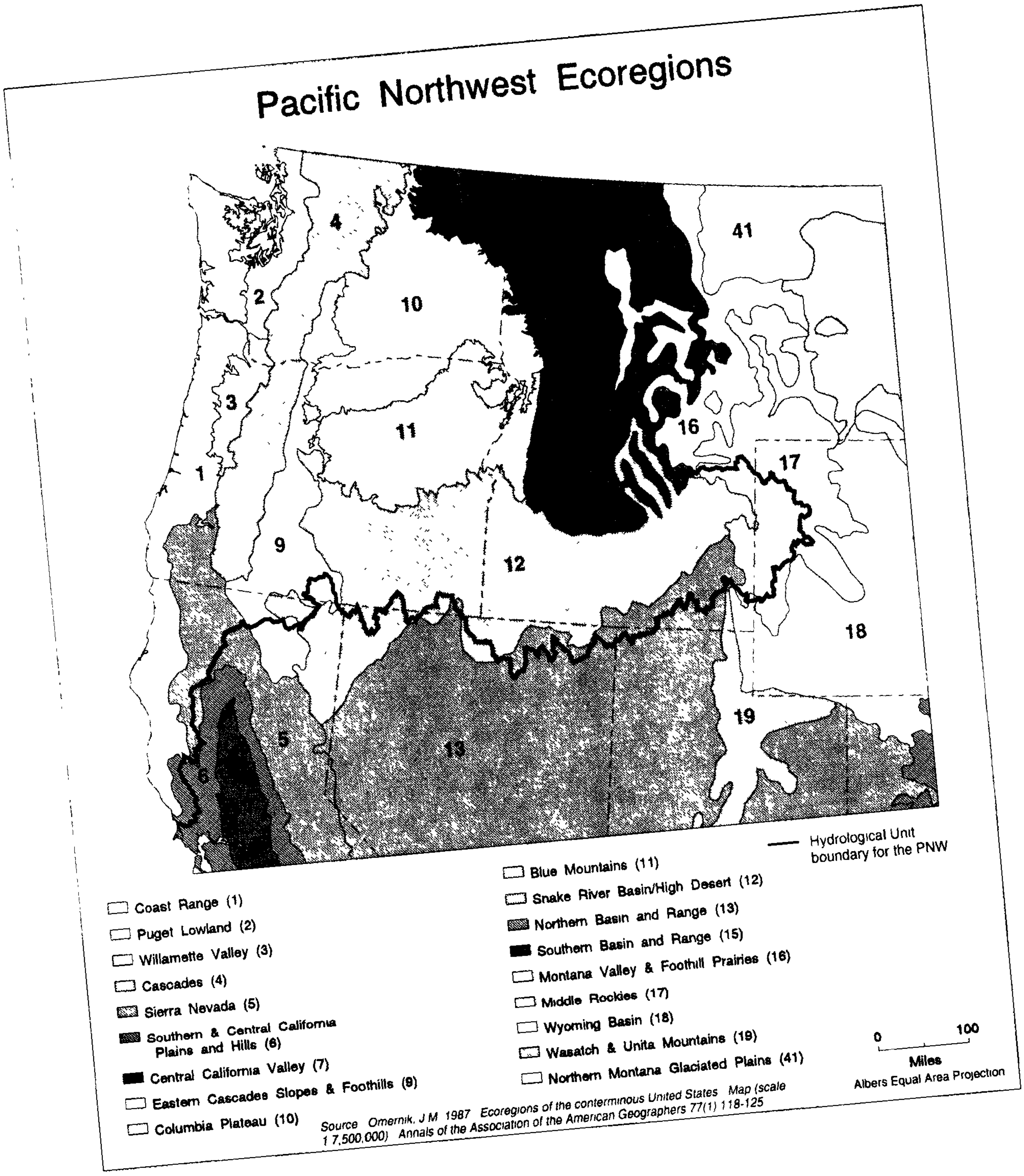

Figure 1-8. **Ecoregions, as defined by Omernik (1987), in the Pacific Northwest.**

Box 1-B. The Pacific Northwest

The Pacific Northwest can best be described by the dichotomy created by one of its major features, the Cascade Mountain range. This string of volcanic peaks runs north-south approximately 150–250 km inland from the Pacific Ocean through Washington and Oregon. Included in this string of mountains are Mt. Rainier, Mt. St. Helens, Mt. Hood, and Mt. Jefferson. This massive landform is the reason for differences in precipitation, climate, and land cover and landuse. Basic generalizations can be made for the Pacific Northwest by comparing the western side of the Cascades to the eastern side.

Climatically, the western side of the Cascades is known for high amounts of precipitation (as little as 500 mm in the south to over 2500 mm on the Olympic Peninsula), low annual temperature ranges, and long freeze-free periods—mild, wet winters and cool dry summers. Most of the eastern side is directly opposite, with low precipitation (200 to 1000 mm), great annual temperature ranges, and variability in freeze-free periods—cold, dry winters and hot, dry summers. These differing climates create an opportunity for diversified landuse/land cover throughout the region.

Natural vegetation is subdivided into three basic provinces: Forest, Alpine, and Shrub-steppe. For the most part, the western and eastern foothills of the Cascades and the Rocky mountains of Idaho fall in the forest provinces. Shrub-steppe is characteristic of the eastern Cascades and the lower part of Idaho. Alpine areas are found above the tree lines of the Cascades and Rocky Mountains.

Agriculturally, the eastern side grows crops such as wheat, dry peas, and potatoes, whereas the western side grows grass seed, various vegetables, mint, grapes for wine, and bush berries. Thirty-two percent of the Pacific Northwest land area is in agricultural landuse. Of this, 59% is livestock grazing and 41% is farms. Thirty percent of the farmland is irrigated.

Natural resource uses in the Pacific Northwest include mainly commercial timber harvests, fishing, some mining, and recreational opportunities. Commercial timber lands cover 36% of the land area. Timber lands are predominantly Douglas fir in the west and pine species in the east. Nine percent of the national total of fish catches are brought into Oregon and Washington ports. Salmon species are the most commercially important, but oysters, shrimp, groundfish, and tuna also are significant components of the total harvest.

The Pacific Northwest is the nation's leader in hydroelectric power generation. There are 11 dams along the Columbia River mainstem, most notably the Grand Coulee dam. Half of the energy consumed in the region is hydroelectric.

Three percent of the national population occurs in the Pacific Northwest. The highest concentrations of people (50%) are found in Seattle and within the Willamette valley of Oregon. Two-thirds of them work in the service and professional industry, one-fourth in manufacturing, and the rest in agriculture, logging, and commercial fishing.

A large proportion of the land in western states is federally owned: 52% of Oregon, 28% of Washington, and 64% of Idaho. Most of the federal lands are managed by the U.S. Forest Service and the Bureau of Land Management.

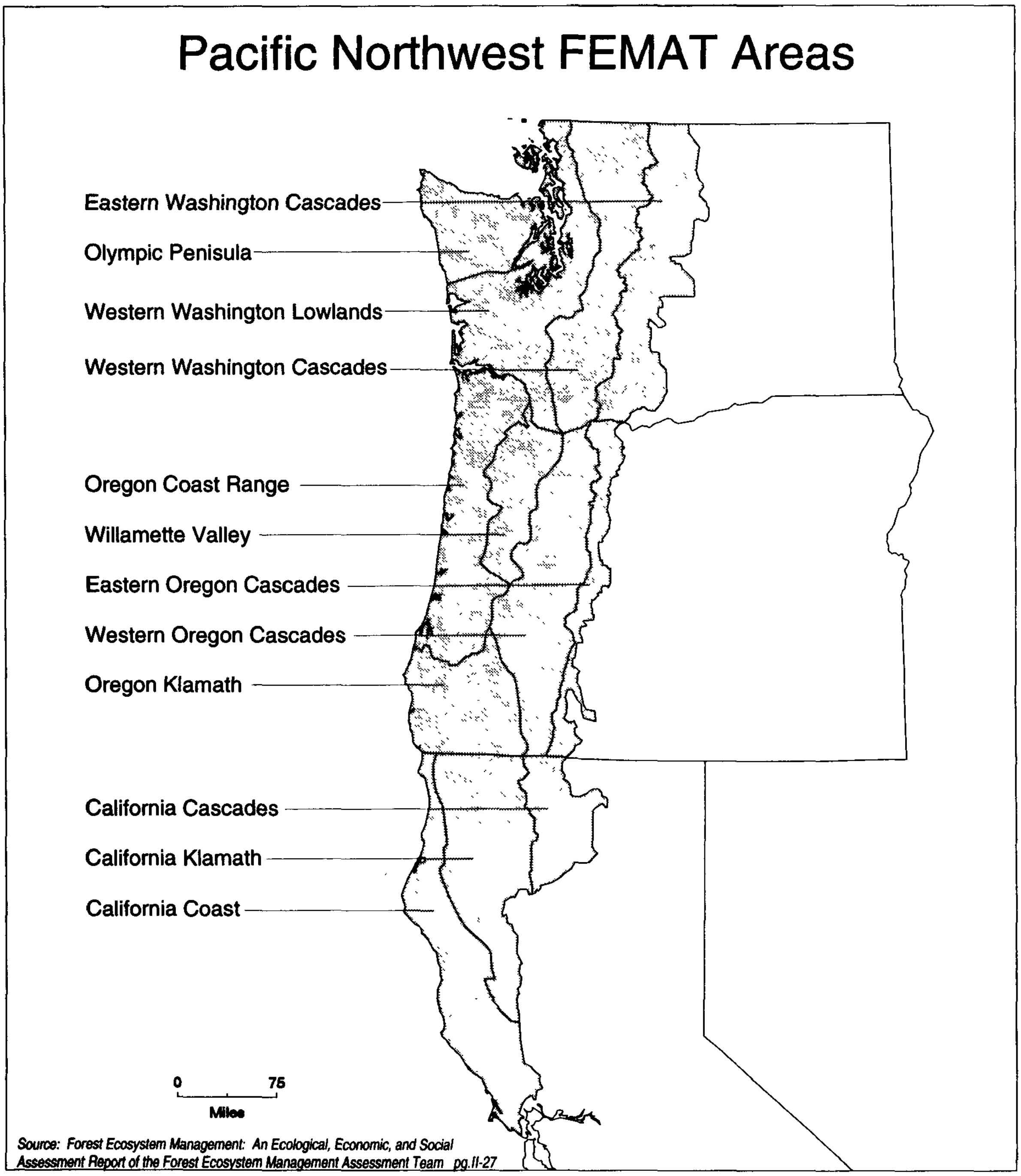

Figure 1-9. Physiographic provinces within the area covered by the Pacific Northwest Forest Ecosystem Management Plan (FEMAT 1993).

Following the conference, President Clinton created three interagency working groups: the Forest Ecosystem Management Assessment Team (FEMAT), the Labor and Community Assessment Team, and the Agency Coordination Team. The charge to these interagency working groups was "to identify management alternatives that attain the greatest economic and social contribution from the forests of the region and meet the requirements of the applicable laws and regulations... Your assessment should take an ecosystem approach to forest management..." (FEMAT 1993). The FEMAT report was published in July 1993 (FEMAT 1993). It outlines a series of management options and an approach for implementing these options at four spatial scales:

- **Region:** Development of regional conservation strategies to protect valued ecosystems, habitats, species and species assemblages, and biodiversity.
- **Physiographic Provinces or River Basins**: Identification of beneficial uses and ecosystem values for large river basins or physiographic provinces in the region (see Figure 1-9).
- **Watersheds**: Analyses of the most efficient ways—ecologically, economically, and socially— to achieve desired uses of natural resources while providing the ecosystem protection prescribed by the Regional Conservation Strategy.
- **Site-Specific**: Specific actions to be taken by public and private landowners and resource managers to achieve watershed ecological protection and restoration objectives.

The interagency working groups established by President Clinton represent the start of ecosystem management in the Pacific Northwest. The President emphasized that agencies of the federal government must work together. "We will insist on collaboration not confrontation" (FEMAT 1993, p. ii). EPA, both Region 10 and ORD, are active participants on the FEMAT, as well as on subsequent interagency task groups and committees responsible for implementing FEMAT recommendations, including the interagency Regional Ecosystems Office and interagency Research and Monitoring Committee. Funding for this research program is listed within a FEMAT-related interagency memorandum of understanding signed by, among others, EPA Administrator Browner.

The Forest Conference, FEMAT, and follow-up implementation efforts still have a relatively narrow focus—management of federally owned forests, in particular old growth forests, to preserve both biological diversity and sustainable timber harvests, along with associated timber jobs. This effort is viewed as the pilot test for federal interagency coordination within the region. The intent of ecosystem management, however, is to go beyond politically defined boundaries (all lands versus just federal lands) and to consider the system as a whole, not just forested lands and one resource conflict.

Thus, our research program is not limited to the original "owls versus jobs" controversy and old growth forests. In fact, because most of the effort to date has focused on forested lands, parts of our research program purposely concentrate on nonforested lands, to provide balance to the federal research effort. Consistent with the discussion in Section 1.2 on EPA's role in ecosystem management, we view our role in ecosystem management research in the Pacific Northwest as (1) encompassing private as well as public lands, and multiple landuses and ecosystem types, (2) enabling the integration of scientific information and coordination of research efforts across federal agencies and other research organizations, and (3) serving the needs of ecosystem managers within federal, state, tribal, and local governments, as well as private landowners, across the entire Pacific Northwest. We are building on the impetus and ideas provided by FEMAT, and extending these concepts to other parts of the region and other environmental problems. Section 2 provides further information on the scope of the research program.

2. SCOPE, OBJECTIVES, AND ORGANIZATION OF THE PNW RESEARCH PROGRAM

This section provides an overview of ORD's research program on ecosystem management in the Pacific Northwest, which we refer to subsequently as the PNW research program. Section 2.1 defines the program scope and guiding principles. Section 2.2 presents the major, program-level objectives. Sections 4–10 provide more detailed research objectives for each component of the program. These components and the program organization are explained in Section 2.3. Section 2.4 describes efforts to coordinate with other research programs and agencies. Section 2.5 discusses program budgets and funding mechanisms. The section ends (Section 2.6) with a discussion of our approach to quality assurance and quality control.

2.1 PROGRAM SCOPE AND GUIDING PRINCIPLES

We begin by defining the boundaries of the research program, in terms of the types of research considered within and beyond our scope. This discussion also identifies several important principles that guide the design of the research program.

ERL-Corvallis is a research laboratory within ORD's Office of Ecological Processes and Effects Research (OEPER). Our expertise is ecology, and ecological research is the primary means by which we can contribute to ecosystem management. Thus, the research program we propose is *ecological.* It deals with research on ecosystems (i.e., spatially explicit units of the Earth that include all organisms and all components of the abiotic environment within the boundaries of the unit; Likens 1992) and the responses of ecosystems to human activities, planned and unplanned. Humans are a part of ecosystems. However, research on human health is beyond the scope of this program. Likewise, ecosystem management requires information on economics, sociology, and human values, as well as ecology. However, with the exception of attempts to link ecological and socioeconomic analyses described in Section 9, research on these other topics is outside our scope.

The research program will be highly applied and assessment driven. We define *assessment* as the rigorous interpretation of scientific information to address specific policy and management questions. Our role is to improve the scientific basis for assessments related to ecosystem management, in two ways: (1) by improving our understanding of ecosystems and ecosystem dynamics, and of the ways ecosystems respond to management options, and (2) by improving approaches for synthesizing and integrating ecological information in a format useful for decision makers, that is, by improving the assessment process and associated analytical tools. Within the scope of this research program, we will not be able to resolve all knowledge gaps and research needs. Our basic strategy is to select important example assessment questions to serve as the focal point for our research. These case study assessments will drive our research priorities and design. Assessment questions will be selected, based on two criteria, in consultation with Region 10 and other ecosystem managers in the area:

- Questions considered high priority by managers and stakeholders in the area that will contribute significantly to improved decision making.
- Questions unique to the ecosystem management approach (e.g., involving trade-offs among multiple endpoints and comparisons among management approaches) that will allow us to test and improve our overall assessment approach.

Many of the issues we must deal with will require long-term, fundamental research to significantly improve, for example, our ability to predict how ecosystems will respond to various management options. Thus, the research program includes a balance between short-term incremental improvements—applying, adapting, and expanding existing understanding and methods—and longer-term fundamental research needed to make quantum improvements in our understanding, methods, and, ultimately, decision making for ecosystem management.

The focus of the research program is the Pacific Northwest and particular case study areas within the Pacific Northwest (see Sections 5–7). However, we cannot afford to conduct research in individual locales that is applicable only to those locales. Plans for transferring research results to other areas and other regions must be built into the research program. This transferability can be direct—in terms of data and understanding used directly to make inferences about other areas (through statistical or other techniques for extrapolating research results)—or it can take place via the transfer of methods or models developed in one area that, once developed, can be readily applied (with appropriate testing or calibration) in other areas. Thus, the research design and priorities balance efforts to provide region-specific information (or specific to a given case study area) with the development of basic ecological understanding and methods that are broadly applicable and readily transferable. Given that our goal is to develop approaches that others will eventually use, the emphasis is on usable methods that can be applied with reasonable effort and data.

The scope of the research program is limited to ecological systems, but it is comprehensive in terms of the types of ecosystems studied. To serve the needs of ecosystem management, the research encompasses all ecosystem types and all landuses: forests, agricultural and urban lands, wetlands, surface waters, estuaries, etc. In particular, the focus is on the integration and interactions among these systems within the landscape.

A diversity of stressors affects the ecological resources within a given area. Key questions in ecosystem management include: What are the relative merits of alternative management options—including ecosystem protection, ecological restoration, changes in landuse and land and resource management practices, and controls on specific pollutants? Where, in what geographic areas or sites, should we focus our efforts to produce the greatest net gain in ecological benefits? Thus, the research program also emphasizes spatially explicit analyses, interactions among multiple stressors, and comparisons among management options.

"...(E)cological research is needed at scales commensurate with restoration and management of entire natural systems" (Lubchenco et al. 1991, p. 393). Ecosystem management occurs at multiple spatial scales (Section 1.1); thus research supporting ecosystem management must also occur at multiple spatial scales. Furthermore, different ecological processes operate at different scales. We gain insight into how ecosystems operate and respond by examining them at different spatial, as well as temporal, scales (O'Neill et al. 1986, Wiens 1989). "For any level of aggregation, it is necessary to look both to larger scales to understand the context and to smaller scales to understand mechanisms; anything else would be incomplete" (Allen and Hoekstra 1992, p. 8).

Our research must be cost effective in terms of the net gain in ecological knowledge and improved methods. Ours is not the only research program studying ecosystems in the Pacific Northwest. Thus, our research priorities and projects must be designed to provide the greatest value added relative to the existing knowledge base and other ongoing research.

There is no one best research approach. Consistent with the recommendations of Likens (1992) and Holling (1993), we will attack the diversity of research issues we face using multiple sources of evidence and a variety of research approaches. Our emphasis, however, will be on research methods that provide insight into system-level interactions and moderate- to large-scale ecosystem responses. Examples include (1) comparative ecosystem studies that compare, for example, systems exposed to stressors of different types and magnitudes or different management actions (Steele et al. 1989, Cole et al. 1991), (2) field experiments of appropriate spatial scale, intensity, and duration, commensurate with ecosystem management questions (Schindler 1990, Mooney et al. 1991), (3) retrospective analyses based on time-series data or paleoecology, especially when the system experienced a known, distinct perturbation in the past (Likens 1985, Smol et al. 1986), (4) empirical observations of patterns and relationships over space and time (Baker et al. 1990, Sinclair et al. 1990, Newell 1993), (5) computer modeling, to integrate and evaluate process-level formulations in an ecosystem context (Shugart 1989, Turner and Gardner 1991), and (6) quantification of system-level responses to planned and unplanned interventions (Walters 1986). Sections 4–10 describe the approaches proposed for each research component in more detail.

A final guiding principle for the research program is integration. As noted in Section 1.2, an important role for EPA is to facilitate integration—working with other researchers in the area to integrate and synthesize data from different studies, across disciplines, across ecosystem types, and across spatial and temporal scales.

> "Ecosystem management requires information from a multitude of disciplines; to be useful, that information must be integrated" (Bormann et al. 1994, p. 21).
>
> "In all areas of ecology, and in science in general, the convergence and integration of information from different points of view, different disciplines, and different approaches are what lead to major advances and breakthroughs in understanding" (Likens 1992, p. 24).
>
> "It is this science of integration and synthesis that has been ill served by funding agencies and universities. It is where the priority should lie for investments in research and education" (Holling 1993, p. 554).

2.2 PROGRAM OBJECTIVES

The fundamental policy question for ecosystem management is:

> How should we manage the ecological resources, and human activities affecting those resources, within a given area to provide the set of multiple uses (and non-use values) that society now desires without undermining the system's capacity to provide these and other uses in the future?

The goal of this research program is to improve the scientific, ecological basis required to answer this question and implement ecosystem management effectively—most specifically in the Pacific Northwest, but in other regions as well.

The four program-level objectives are as follows (see Figure 2-1):

1. Develop and demonstrate an overall ecological assessment process, and associated analytical tools, dealing with multiple endpoints and multiple stressors across multiple spatial scales that will allow managers to:

    - Define realistic environmental goals.
    - Assess current ecological conditions relative to those goals and identify major environmental problems.
    - Evaluate and compare the ecological consequences of alternative management strategies.
    - Target geographic areas for protection, restoration, or other management action.

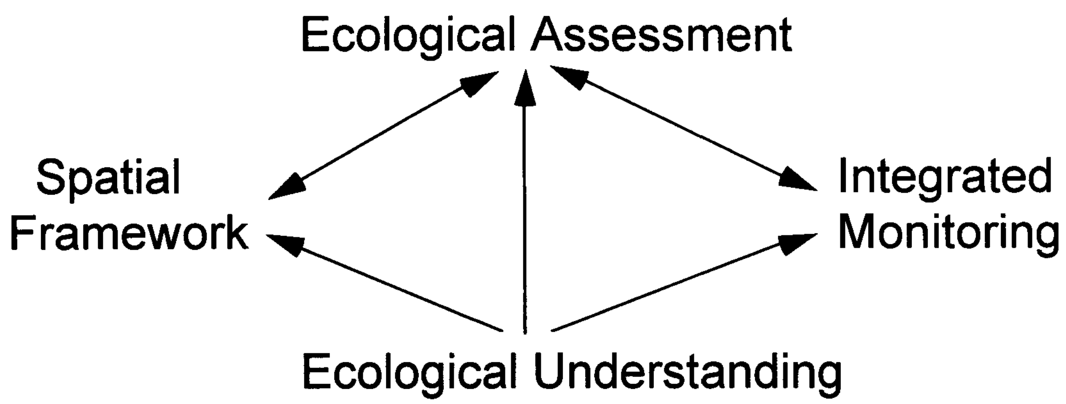

Figure 2-1. Four program-level objectives for the PNW research program.

2. Advance the understanding of ecosystems, ecosystem dynamics, and ecosystem responses to human activities to reduce uncertainties in ecological assessments and improve confidence in ecosystem management decision making.

3. Develop and demonstrate a spatial framework that provides a common, effective basis for ecological assessments at multiple spatial scales and extrapolation of research results.

4. Develop and demonstrate ecological monitoring designs that meet the needs of adaptive, ecosystem management and are integrated across ecosystem types, spatial scales, and monitoring programs in different government agencies.

For each objective, the major program-level research questions are as follows:

<u>Assessment</u>

- What types of management questions and ecological endpoints are best addressed at each spatial scale?

- How can regional-scale ecosystem sustainability requirements be translated into geographically specific guidelines or constraints for actions at smaller spatial scales?

- How can we conduct useful assessments where data are limited? What do we gain from more data and more effort-intensive analyses?

Ecological Understanding

- What are the fundamental ecosystem properties (processes, structure, components, scale) that must be maintained in order to ensure ecosystem sustainability?
- What are the linkages and trade-offs among alternative resource uses and environmental goals?
- How will ecosystems respond to natural and anthropogenic stressors and alternative management actions?
- How do multiple stressors interact to affect ecosystems?
- How can we alter an ecosystem's resilience or recovery rate through specific management actions, such as ecological restoration?

Spatial Framework

- What are the natural ecological linkages and boundaries that define ecological systems?
- What ecological units are appropriate for analysis at various scales?
- Is a nested, hierarchical framework desirable and feasible?
- Can a uniform spatial framework be developed for general use, or is it necessary to have multiple, overlapping frameworks for different purposes?
- At what spatial scale are ecological systems no longer unique, so that they can be categorized and dealt with by category rather than individually?
- How can we group ecological units into classes, so that the characteristics of any one unit can be inferred from prior studies of other units in the same class?
- How can we select and use reference sites to define attainable ecological goals?

Monitoring

- What monitoring objectives and questions are best addressed through monitoring at each spatial scale?
- How can we measure ecological condition? What are appropriate indicators of ecological condition? Do they vary with spatial scale?
- What survey and sampling designs are efficient at each spatial scale to address the priority monitoring objectives and questions in the Pacific Northwest?
- How can we identify causes of observed trends in ecological condition, through diagnostic indicators or analyses?
- How do we design monitoring networks so that the data collected at each spatial scale are complementary and linked? For example, what designs would relate site-specific monitoring to a

broader, regional context, or how could we use more intensive monitoring at individual sites to enhance the value of regional-scale monitoring?

These broad, program-level objectives and questions provide the foundation for the more specific research objectives and questions defined for each research component in Sections 4–10. Research priorities discussed in each of these sections, and the potential for value-added research, determine the relative weighting given to the various program-level objectives and questions within each component.

2.3 PROGRAM ORGANIZATION AND MAJOR COMPONENTS

The PNW research program is organized into seven major components (Figure 2-2):

1. Regional Biodiversity
2. Watershed/Ecoregion
3. Riparian Areas
4. Coastal Estuaries
5. Integrated Monitoring
6. Ecological -Socioeconomic Linkages
7. Technology Transfer

None of these components is independent; coordination and information exchanges among all components are essential.

As noted in Section 2.1, selected case study assessments will serve as the focal point for PNW research. We will use these assessments to:

- Develop and demonstrate the ecological assessment process and analytical tools.
- Identify critical knowledge gaps and uncertainties in our ecological understanding in order to set priorities for research on ecosystems, ecosystem dynamics, and ecosystem responses to human activities and management actions.
- Evaluate and demonstrate the application of monitoring data and the spatial frameworks within the assessment process, and help set priorities for research on improved approaches for monitoring and extrapolation.

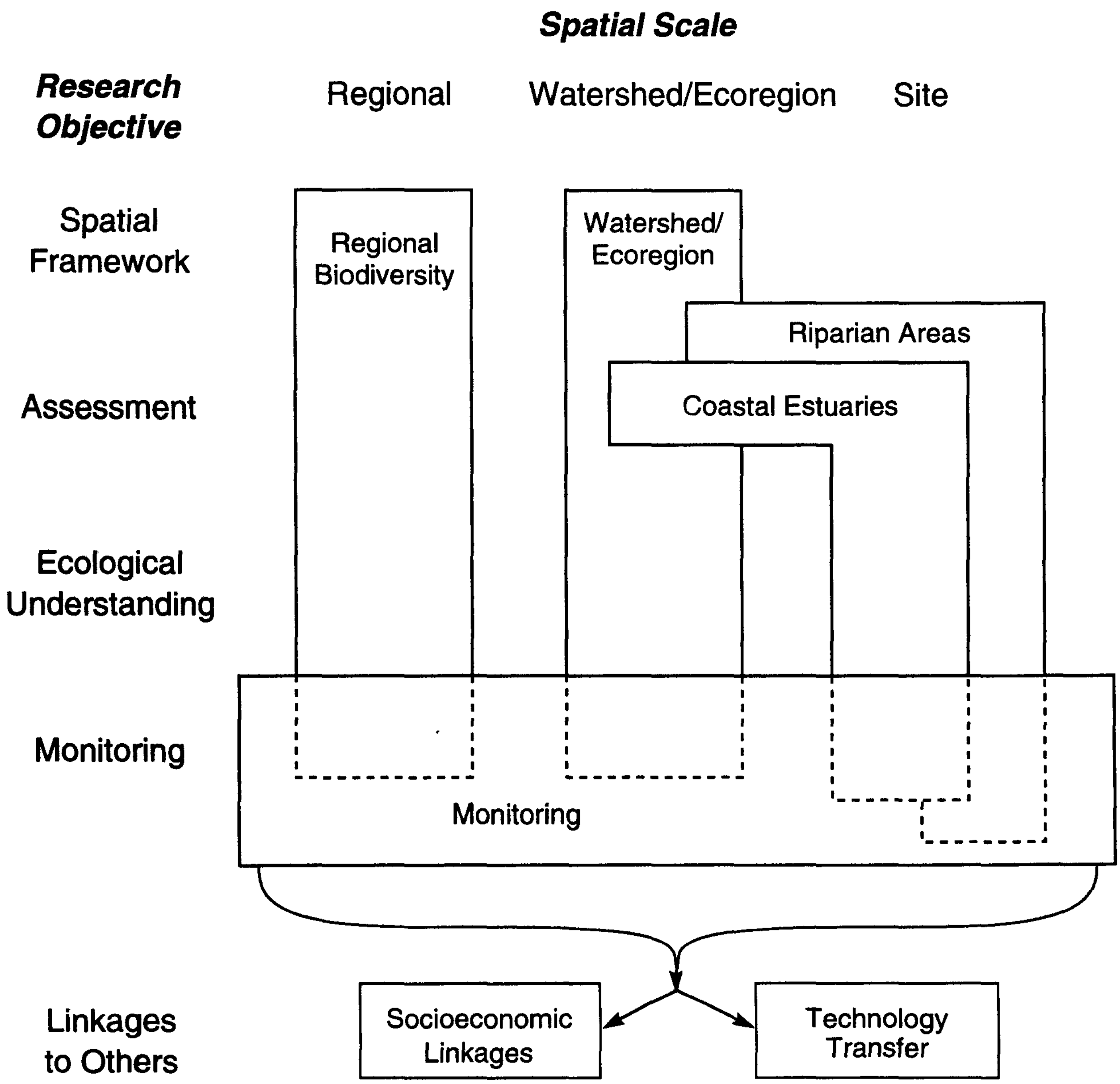

Figure 2-2. **Major research components of the PNW research program, organized by program-level objective and spatial scale.**

Case study assessments will be conducted at two spatial scales, region and watershed/ecoregion, and will provide the focal point for research within the Regional Biodiversity and Watershed/Ecoregion research components, respectively.

Consistent with the framework developed by FEMAT, the emphasis of regional-scale research (Section 4) is to develop a scientific, ecological basis for regional conservation strategies that will protect valued ecosystems, habitats, species and species assemblages, and biodiversity. Thus the major objectives of the Regional Biodiversity research component are as follows:

- Develop and refine methods for integrating and interpreting data on biodiversity at a regional scale.
- Develop and demonstrate the ecological assessment process at a regional scale to support development of regional conservation strategies based on the best science available and on stakeholder input.
- Conduct research targeted at testing the accuracy of assessment outputs, evaluating key assumptions, and addressing major knowledge gaps and uncertainties about regional ecosystems identified during the assessment process.

The watershed/ecoregion scale is the intermediate spatial scale for ecosystem management. At this spatial scale, trade-offs among specific management options are considered and decisions are made about the most efficient ways—ecologically, economically, and socially—to achieve the desired uses of ecological resources while still providing the level of ecosystem protection prescribed by the regional conservation strategy (see Section 1.3). The major objectives of the Watershed/Ecoregion research component are as follows:

- Conduct an initial assessment to determine the data and information available for the selected study areas; determine research needs based, partially, on information gaps.
- Demonstrate and evaluate methods for characterizing current ecological condition at multiple spatial scales, cooperatively with research on monitoring designs.
- Select and test approaches for defining attainable ecological goals through the use of reference sites, ecological indicators, and other methods.
- Refine and demonstrate methods for targeting high-priority areas within a watershed/ecoregion for protection, restoration, or other management action, or for further study and/or monitoring.
- Construct simple watershed-scale interactive models to evaluate, project, and compare the consequences of alternative management strategies on key ecological endpoints.
- Compare the attributes of different spatial frameworks for summarizing information on ecological condition, setting attainable ecological goals, and organizing ecological research at the watershed/ecoregion scale.

- Evaluate techniques for extrapolating site-specific ecological information to other sites and spatial units at the watershed/ecoregion scale.
- Conduct a final integrated ecological assessment combining existing data and the results of the research conducted in this program to determine the best approaches for assessing management trade-offs in the study areas.

The next two research components, Riparian Areas and Coastal Estuaries, deal with specific high-interest ecosystem types. We selected these ecosystem types for concentrated study because they have important functions in Pacific Northwest landscapes, yet there are major uncertainties about how stressors and management actions affect these functions. Research objectives are twofold: (1) improve our understanding of ecosystem functions, processes, and responses and (2) generate information and analyses that will feed directly into the case study assessments, particularly case study assessments at the watershed/ecoregion scale.

Riparian areas are major hydrological source areas for stream flow, they exert a strong influence on the quality of stream environments (even when other parts of the landscape are intensively managed for timber or agricultural products), and they provide important habitat for many terrestrial and aquatic species. Unfortunately, the ecological functions of riparian areas are easily impaired by landuse activities, and have been impaired in a significant part of the Pacific Northwest. Establishment of ecologically sound ways to manage riparian areas was identified by EPA Region 10 as a key issue facing ecosystem managers in the region. For these reasons, we include a research component focused specifically on riparian area ecosystems (Section 6). Research will be conducted both at individual sites and at the watershed-scale (Figure 2-2). Information on riparian area condition and restoration approaches collected at individual research sites will result in improved watershed-scale assessments. Watershed-scale riparian research will be closely coordinated with and feed directly into assessment research conducted as part of the Watershed/Ecoregion research component. The major objectives of the Riparian Area research component are as follows:

- Define reference conditions for riparian areas in agricultural settings.
- Establish indicators of riparian area condition in agricultural settings.
- Develop approaches for evaluating riparian area condition in mixed landuse watersheds.
- Develop approaches and performance criteria for restoring degraded riparian areas in agricultural settings.
- Develop approaches to locate promising areas for riparian restoration and to evaluate the attainable quality and restoration potential of riparian areas within mixed landuse watersheds.
- Evaluate practices that are ecologically and economically promising for managing riparian areas in agricultural settings.

Estuaries are frequently centers for human population growth, are sources of important resources (e.g., oysters, salmon, shrimp, Dungeness crab) that contribute significantly to local and regional economies, and are subject to a variety of perturbations. As in the Riparian Areas component, this research component includes both assessment research and research conducted to improve ecological understanding; and both site-specific and watershed-scale research (see Figure 2-2). The focus is on the effects of multiple stressors, ecosystem-level responses to individual stressors, and the linkages between upland watersheds and estuaries. Assessment research on estuarine watersheds will be conducted cooperatively with the Watershed/Ecoregion research component. The major objectives of the Coastal Estuaries research component are as follows:

- Develop predictive relationships between ecosystem structure and habitat characteristics.
- Improve our understanding of the extent, loading, causes, and effects of sedimentation and associated parameters, such as nutrients, in Pacific Northwest coastal estuaries.
- Improve our understanding of the extent, causes, and effects of biological stressors (in particular, expansions of *Spartina*) and the effects of potential control strategies.

Integrated monitoring research (Section 8) cuts across all spatial scales and ecosystem types (Figure 2-2), consistent with the program-level objective of developing monitoring designs that integrate information from multiple spatial scales, multiple ecosystem types, and multiple agencies. We decided that these cross-scale and cross-ecosystem linkages were so important that a single, coordinated monitoring design component was essential. Interactions between monitoring research and the other components of the research program are extensive and important, however. In particular, the Integrated Monitoring research component does not include adequate funding for extensive testing and demonstration of monitoring designs (see Section 2.5). Research and field sampling conducted as part of the Regional Biodiversity, Watershed/Ecoregion, Riparian Areas, and Coastal Estuaries research components will contribute, in part, to testing and demonstrating aspects of the monitoring design. However, the primary means for testing and demonstrating the proposed design will be through cooperative efforts with those organizations ultimately responsible for implementing long-term monitoring in the region (federal, state, and tribal agencies, and private landowners). The development of an integrated monitoring design will be a joint effort with these other organizations. The major objectives of the Integrated Monitoring research component are as follows:

- Identify the priority assessment questions for the Pacific Northwest that require monitoring information, and the ecological, spatial, and temporal scales at which each question must be addressed.
- Design elements of a fully integrated multi-scale ecological monitoring program for the Pacific Northwest.

- Demonstrate this integrated multi-scale ecological monitoring design in the Pacific Northwest.
- Involve authorities with the mandate and resources to implement a monitoring program during all stages of this monitoring design effort.

The remaining two program components deal with interfaces between our research program and other groups (see Figure 2-2). The Ecological-Socioeconomic Linkages component (Section 9) involves joint research with economists and/or sociologists. The ultimate goal is to develop a comprehensive assessment process for ecosystem management that incorporates ecological, social, and economic information. We hope to achieve this by developing closer working relationships with these other experts and a better understanding of the terms, approaches, and information needs of their fields.

The goals of Technology Transfer (Section 10), the final component of the program, are twofold: (1) to ensure through feedback from managers that PNW research is relevant to policy and management needs and (2) to ensure that the innovations, information, and approaches we develop are adopted and widely used by environmental managers at regional, state, and local levels. The principal activity will be collaborative research projects, in which we work directly with regional, state, tribal, and local managers to apply our techniques to real-world concerns and problems. Collaborative projects, and technical information transfer in general, are an integral part of the PNW research program.

A senior EPA scientist has been designated as lead scientist for each of the seven research components just discussed. All but the Coastal Estuaries research component are directed by scientists at ERL-Corvallis. The ORD Environmental Research Laboratory at Newport, Oregon, also within OEPER, has the lead for Coastal Estuaries research. The lead scientist is responsible for designing and implementing the technical approach, coordinating projects within that research component, conducting active research on one or more projects, overseeing project-level quality assurance/quality control (QA/QC), and integrating results across projects for the research component.

Coordination among these seven components is the responsibility of the EPA program coordinator for the PNW research program at ERL-Corvallis. The program coordinator will maintain control of the budget, review all research plans and research products, and manage program-level QA/QC. Through these functions, the program coordinator will ensure that the cross-component linkages and cooperative research efforts outlined above (and in Figure 2-2) occur, that research approaches are generally consistent among projects and with the overall assessment process outlined in Section 3, and that the program-level goal and objectives are achieved.

2.4 COORDINATION WITH OTHER AGENCIES AND RESEARCH PROGRAMS

The purpose of this section is to emphasize the importance we place on coordinating our efforts with other agencies and other research programs. Here we discuss the overall strategy for coordination and the key groups important at the program level. Sections 4–10 describe coordination and cooperative research efforts at the project level for each research component. We consider two types of coordination: with ecosystem managers and with other researchers. Both occur at all phases of our research—planning, implementation, and production of the final products.

Interactions with ecosystem managers help us define our research priorities, given that our goal is to provide an improved scientific basis for implementing ecosystem management in the region. In particular, as noted in Section 2.1, managers within each study area will propose high-priority policy and management questions to address as part of assessment demonstrations. We will continue to interact during project implementation, in order to keep managers apprised of interim findings, make mid-course corrections as needed, and vest the manager in the project's success. We believe that by making selected managers partners in our research efforts, we increase the likelihood that we will produce useful products and that these products will be widely adopted.

Our major management-oriented partner in this research effort is EPA Region 10. In addition to giving us guidance on its perspective of research needs and priorities, Region 10 has agreed to act as our conduit to other ecosystem managers at the federal, state, tribal, and local level. In cooperation with Region 10, the states of Washington and Oregon organized meetings in spring 1994 involving interested federal and state agencies and tribes within each state. At those meetings, we outlined our research strategy and invited input on high-priority geographic areas for study. The case study areas selected for research at the watershed/ecoregion scale (Section 5) resulted directly from those meetings. Each state is in the process of organizing second-tier meetings for interested managers for each case study area, which will probably involve representatives from local governments and major private landowners, as well as from federal and state agencies and tribes. We anticipate similar meetings with representatives from Idaho, beginning in 1995 or 1996. We plan to meet regularly with these groups of interested managers throughout the course of the five-year research program. Additional interactions with managers occur as part of the collaborative projects funded under Technology Transfer (Section 10).

Two important guiding principles for our research program dictate that we expend considerable effort coordinating with other researchers: our desire to conduct value-added research and our emphasis on integration (Section 2.1). Specific ecological research projects will be selected to fill major knowledge and information gaps not currently being addressed by other researchers in the area. Furthermore, during assessment demonstrations at the regional and watershed/ecoregion scales, we propose to synthesize and integrate information collected by a diversity of investigators, research programs, and agencies. We hope to accomplish this, not by taking data from others, but by involving these other researchers and research organizations in the assessment process, particularly major research organizations/programs, such as the Environmental Monitoring and Assessment Program (EMAP) (see Box 2-A), the USFS Pacific Northwest Forest and Range Experiment Station, the National Biological Survey cooperative research programs in the Pacific Northwest, the National Resource Conservation Service (NRCS) [formerly the Soil Conservation Service (SCS)], the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program, state agencies of environmental quality, and others. Box 2-B outlines ongoing and planned research in other federal agencies related to ecosystem management.

A first step toward achieving this technical coordination is to determine who's doing what research and where, relative to each major research component. We completed general reviews of this nature as part of preparing this research strategy. More detailed surveys, specifically for our case study areas, are ongoing. The resulting databases—summaries of current and past (within 15 years) research, research objectives, available data and analyses, findings, and research planned for each area—will be made available to all interested parties (through the Internet) and updated regularly. These databases are our first step towards coordination. The second will be a series of technical coordination meetings involving researchers with similar interests or common data needs. These meetings, and the interactions that follow, will provide a basis for identifying and pursuing productive collaborative research relationships.

At the federal level, several formal organizations have been established to facilitate interagency coordination, as part of the follow-up to the President's Forest Conference (see Section 1.3). The interagency Research and Monitoring Committee, with a permanent staff of three senior scientists, is responsible for developing plans and guidelines to coordinate research and monitoring activities among federal agencies and to encourage information sharing and improved communication. Inter-agency province teams coordinate management activities on federal lands within the range of the spotted owl (see Figure 1-9). Whenever possible, we will work through these existing groups and procedures for interagency coordination.

A common procedure for conducting collaborative research is through joint funding. Section 2.5 discusses the use of interagency agreements, and associated memoranda of understanding, to encourage the coordination of federal research within the region.

Box 2-A. Environmental Monitoring and Assessment Program (EMAP) (Source: Thornton et al. 1993).

EMAP is an interdisciplinary, interagency program designed and initiated by ORD within EPA. EMAP's objectives are as follows:

- Estimate the current status, trends, and changes in selected indicators of the Nation's ecological resources on a regional basis with known confidence.
- Estimate the geographic coverage and extent of the Nation's ecological resources with known confidence.
- Seek associations between selected indicators of natural and anthropogenic stresses and indicators of condition of ecological resources.
- Provide annual statistical summaries and periodic assessments of the Nation's ecological resources.

Four major activities within EMAP are (1) indicator development, (2) sampling design, (3) resource monitoring, and (4) assessment. *Indicators* are defined as "any characteristic of the environment that can provide quantitative information on the condition of ecological resources, magnitude of stress, exposure of a biological component to stress, or the amount of change in condition" (Thornton et al. 1993, p. 8). EMAP emphasizes indicators of ecological condition that can be explicitly linked to major social values. EMAP uses a probability-based sampling design to quantify the status and trends in selected ecological indicators. Samples are spatially distributed using a systematic hexagon grid superimposed over the United States. Most sites are sampled once every four years, with about one-quarter of all sites sampled each year. EMAP monitors all major categories of resources: agroecosystems, arid ecosystems, estuaries, forests, the Great Lakes, surface waters, and wetlands. In addition, the Landscape Ecology group monitors landscape patterns and EMAP-Landscape Characterization provides landuse/land coverage and estimates the geographic coverage and extent of ecological resources using Satellite Thematic Mapper images and other information. Monitoring results are interpreted in periodic assessments to address policy-relevant questions about the condition of the Nation's ecological resources at regional scales.

Relationship to PNW Research Program. The PNW research program has much to gain from working cooperatively with EMAP. EMAP research on indicators and sampling designs will contribute directly to the PNW Integrated Monitoring research component. EMAP assessment approaches developed to evaluate current ecological condition, trends, and diagnostics are equally valid for PNW assessments at the regional and watershed/ecoregion scale. Beginning in 1996, EMAP will initiate regional surveys in the Pacific Northwest that will provide information of direct use for all aspects of the PNW research program. Current plans are to implement sampling of wadeable streams, forests, and estuaries, as well as landscape characterization. Proposed applications of EMAP data and approaches are discussed in each section (4–8). We believe that the research we undertake will also be beneficial to EMAP, in particular by demonstrating the value of EMAP within the context of a broader regional assessment activity.

Box 2-B. Planned and Ongoing Research by Other Federal Agencies Related to Ecosystem Management in the Pacific Northwest.

Other federal agencies have begun research supporting various aspects of ecosystem management in the Pacific Northwest. The USFS and BLM continue to address issues raised in the FEMAT (1993) report regarding management of federal forested lands west of the Cascades (USFS 1994). Similar ecosystem-based management efforts and associated research are underway for federal lands east of the Cascades (Bormann et al. 1994). The National Biological Survey and U.S. Geological Survey (USGS) have proposed a joint ecosystem research initiative for the Columbia River Basin. Its principal objective is "to provide the unbiased information and data needed by management and regulatory agencies for successfully managing aquatic and terrestrial ecosystems, and for balancing economic concerns in the Columbia River Basin" (USGS 1994, p. 1). The U.S. Bureau of Mines is examining both ecosystem-based regulations and the minerals industry, and has established a research program "to increase the understanding of the relationships between ecosystem health and functions and economic activity focusing on the minerals sector" (Bureau of Mines 1994, p. 1). EPA, the U.S. Fish and Wildlife Service (USFWS), and the National Marine Fisheries Service signed an interagency memorandum of understanding "creating a new ecological partnership for the Pacific Northwest," including research coordination. The coordination and integration of these activities will be a major challenge, much of which will be handled through the interagency Research and Monitoring Committee established within the Regional Ecosystems Office as part of the follow-up to the FEMAT report and implementation.

In cooperation with other agencies, EPA is engaged in several other large-scale ecosystem management initiatives, with associated research programs. Examples of these programs include the Chesapeake Bay Program, the Great Lakes Program, the South Florida Initiative, and the National Estuaries Program. The National Science Foundation also supports integrated research programs, e.g., the Land-Margin Ecosystem Research (LMER) program. We have much to gain from exchanging ideas and information with these programs. Although no formal mechanisms exist for such exchanges, we will actively pursue opportunities for communication and sharing of ideas and research results.

2.5 BUDGETS AND FUNDING MECHANISMS

It is difficult, if not impossible, to design a research strategy without some idea of the amount of time, effort, and funding available to get the job done. EPA budgets, however, are decided annually and it is likely that the budget allocated for the research program will fluctuate over the course of the next five years. For this strategy document we assume constant funding of $3593K per year (the level of funding in FY95) over the next five years through FY99. Table 2-1 shows the proposed distribution of this budget among research components. If funding is reduced, components of the research program will be reduced or eliminated.

Table 2-1. **Assumed Annual Budget, by Research Component, for the PNW Research Program.**

Research Component	**Annual Budget (in thousands of dollars)[a]**
Regional Biodiversity	$650K
Watershed/Ecoregion	$865K
Riparian Areas	$865K
Coastal Estuaries	$650K
Integrated Monitoring	$260K
Ecological-Socioeconomic Linkages	$88K
Technology Transfer	$215K
TOTAL	**$3593K**

[a] These budget numbers do not include costs for EPA salaries and associated expenses. They represent dollars available for extramural funding. Our current plans are to maintain approximately level funding in each component of the research program over the five years.

We also must have some idea of the how the work will or can get done. Some research will be done in-house, by EPA scientists. As noted in Section 2.3, EPA researchers serve as program coordinator and lead scientists for each research component. Other EPA personnel include the QA coordinator (see Section 2.6) and the administrative staff. An additional five EPA research scientists will work on the Coastal Estuaries research component at ERL-Newport.

The largest part of the research, however, will be done by non-EPA scientists, funded extramurally. Three major types of funding mechanism are available: interagency agreement (with other federal agencies), cooperative agreement (with universities, states, and other nonprofit research organizations), and contract (used for procuring goods and services of direct benefit to the federal government). Our approach is to use all three of these funding mechanisms, in approximate balance, to provide the diversity of research assistance required.

At present, we have two interagency agreements (IAG) to support the PNW research program: (1) a five-year agreement with the USFS Pacific Northwest Forest and Range Experiment Station and (2) a three-year agreement with the U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS). The USFS agreement covers all aspects of the PNW research program; the ARS agreement is specific to research on riparian areas. Additional IAGs may be initiated in the future, as other opportunities for collaborative research arise. Joint funding of research, through an IAG, serves to formally coordinate federal research. We also have a Memorandum of Understanding (MOU, signed 14 April 1994) with the USFWS and National Marine Fisheries Services that calls for, among other things, coordinated research and environmental programs to protect Pacific Northwest ecosystems. A broader MOU, to coordinate all federal research in the Pacific Northwest relating to the President's Forest Plan, is currently being drafted under the auspices of the interagency Research and Monitoring Committee.

Cooperative agreements, as their name suggests, allow for cooperative research between EPA scientists and scientists in universities, states, or other nonprofit organizations. We envision two types of cooperative agreement: (1) small, project-specific agreements and (2) a larger, 5-year cooperative agreement with a consortium of universities and other research institutions designed to provide support for the overall PNW research effort. We believe the latter agreement is essential for integration among projects and across disciplines, a priority within our research program. For this reason, the majority of cooperative research will be conducted through this larger, single cooperative agreement, which includes specific requirements for incorporating efforts from the broad ecological research community. All cooperative agreements will be awarded competitively, through open national competition.

Contracts provide greater control by the government over the specific products produced; they can be used for research purposes if the objectives and expected outputs from the research are clearly defined. ERL-Corvallis and ERL-Newport have several major on-site and off-site contracts, which were awarded competitively. These contract mechanisms will provide support in the areas of computing, information management, geographic information system (GIS), and data analysis, as well as a means for conducting specific research tasks (e.g., development of models).

A fourth funding mechanism that deserves mention is the National Research Council (NRC) Research Associateship Program. This program allows us to bring post-doctoral and senior research associates on site to work on specific research projects for periods of 1 to 3 years. We anticipate providing a number of such positions during the course of this program. In particular, the NRC will be the major funding mechanism used for the Ecological-Socioeconomic Linkages research component, to bring experts in economic or sociological research to ERL-Corvallis to work jointly with ERL-Corvallis and ERL-Newport ecologists (see Section 9).

2.6 QUALITY ASSURANCE/QUALITY CONTROL

Policies initiated by the EPA Administrator in memoranda dated 30 May and 14 June 1979 require that all EPA laboratories, program offices, and regional offices participate in a centrally managed QA program. This policy extends to all monitoring and measurement efforts supported or mandated through contracts, cooperative agreements, IAGs, and other formal agreements. The intent is to develop a unified approach to QA that ensures the collection of data that are scientifically sound, legally defensible, and of known and documented quality.

The PNW program coordinator will be responsible for program-level QA, assisted by an EPA scientist assigned full time as QA coordinator for the PNW research program. Key elements of the PNW QA program, and all QA programs, include the following:

- **Data Quality Objectives (DQOs):** DQOs will be developed as part of the planning process for each project before data collection. They are intended to help guide the design of sampling and analytical protocols and to ensure that data collected are adequate for the proposed use. They also will provide an objective basis for evaluating the quality of data actually collected.
- **QA Project Plan:** QA project plans will be based on the project-specific DQO requirements and will include QA and QC procedures. Resources needed to accomplish project objectives will also be specified.
- **Audits:** Audits will be conducted to evaluate conformance of data collection, analysis, and management to the DQOs and QA project plan.
- **Reporting:** All data must be reported at a quality level adequate for its intended use. Journal articles and reports developed as products must include QC information supporting the data.

To comply with the QA policies of EPA and of the participating ORD laboratories (ERL-Corvallis and ERL-Newport), the PNW research program will address QA at two different levels:

1. A QA program plan will be prepared that describes the Program's overall QA philosophy and approach.
2. Individual QA project plans will be developed as part of the detailed work plans prepared for each study.

Both of these QA planning documents will be revised as needed.

2.6.1 PNW Quality Assurance Program Plan

The PNW QA coordinator will prepare the QA program plan, in consultation with the PNW program coordinator, project lead scientists, and QA staff from ERL-Corvallis and ERL-Newport. This document will provide overall guidance on QA activities that is consistent with the QA policies of the Agency and of each laboratory. The document will define the QA goals, outline methods for achieving those goals, and describe QA responsibilities within the Program. The QA program plan will be updated and revised annually, or as needed, as experience is gained through implementation and as program objectives change. The QA program plan also will identify existing approved QA project plans and future planned research that will require QA project plans.

PNW research activities will be diverse, involving sampling in different media (water, land, air), in different ecosystem types, and at different spatial scales. Chemical, physical, biological, and landscape data will be measured (in the field and through remote sensing), sampled, collected, and analyzed, both by EPA personnel and by cooperators and contractors. The QA program plan will address QA issues with respect to each of the kinds of data to be collected, as well as data management.

2.6.2 Individual QA Project Plans

Individual QA project plans will be prepared for each study as part of the detailed work plan developed for that research. These individual QA project plans will follow the QA requirements specified in the document, "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans" (U.S. EPA 1980). The QA project plan will define specific DQOs for the study, along with the research design, sample collection procedures, analytical protocols, and data analysis methods. These plans will ensure that data quality is adequate for the use intended. To assure that PNW studies meet the QA requirements of the Agency and of each Laboratory, QA project plans will be reviewed by the PNW QA coordinator and by the appropriate laboratory QA staff. These plans must be approved by the laboratory EPA QA Officer prior to collection of any project data.

3. APPROACH TO ECOLOGICAL ASSESSMENT

One of the major objectives of the PNW research program is to develop and demonstrate an ecological assessment approach useful for ecosystem management. The concepts, terms, and major steps of this assessment process are introduced here, because they provide context for all components of the research program. Assessment questions drive the research priorities and design. Sensitivity analyses can help identify key uncertainties and assumptions that warrant further research. Assessment outputs, themselves, represent a form of hypothesis (i.e., they reflect current understanding and information), which can be tested in subsequent research projects. We use assessments to focus and integrate our research. Assessments also represent the final step in the delivery of research results to ecosystem managers.

Our assessment process builds on other approaches that have been proposed (Streets 1989, Hunsaker et al. 1990, U.S. EPA 1992, 1994c, Bartell et al. 1992, Leibowitz et al. 1992a, Suter 1993), but emphasizes those aspects most relevant to ecosystem management. Because our program involves primarily ecological research, we limit this discussion to ecological assessments, that is, assessments that interpret *ecological* knowledge for a policy or management purpose. Ecosystem management requires information on the ecological, human health, economic, and social consequences of management options. Section 9, which describes plans to link our ecological research to comparable socio-economic research, discusses assessments in this broader context.

Section 3.1 reiterates key features of ecosystem management and, thus, of ecological assessments in support of ecosystem management. Section 3.2 discusses important underlying ecological concepts and terms. Section 3.3 presents the basic assessment framework and process.

3.1 KEY FEATURES OF ASSESSMENTS SUPPORTING ECOSYSTEM MANAGEMENT

Section 1.1 presents important features of ecosystem management. These same features, with a few additions, describe the essential characteristics of assessments in support of ecosystem management:

- **Place-Based.** The focal point of an assessment is a specific geographic area, e.g., agricultural field, small watershed, or entire region, rather than a specific stressor. The spatial unit of analysis (size and boundaries) should be tailored to the questions being asked.

- **Multiple, Linked Spatial Scales**. Full implementation of ecosystem management requires management decisions at multiple spatial scales: global, national, regional, subregional, and local. Ecological assessments are needed to support management decisions at each spatial scale. Analyses at each scale must be linked, and the process (of both management and assessment) iterates back and forth across scales.

- **Restoration as Well as Risk Reduction**. EPA's Risk Assessment Forum (RAF) defines ecological risk assessment as "a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors" (U.S. EPA 1992, p. 2). EPA's Science Advisory Board (SAB 1988, 1990) recommended that the Agency target its environmental protection efforts on those stressors likely to result in the "greatest risk reduction." Both statements focus on stressor reductions as the primary management tool. Ecosystem management considers the full range of management options, some of which would not normally be considered under the headers *stressor* or *risk reduction*, including ecological restoration as well as ecosystem protection, pollutant control, and changes in landuse and land and resource management practices.

- **Benefits as Well as Adverse Effects**. As just noted, *risk* assessments estimate the likelihood of *adverse* ecological effects (U.S. EPA 1992). This concept presumes that we can define *a priori* an adverse effect. A basic assumption of ecosystem management is that ecological resources have multiple, often conflicting, uses, as well as intrinsic values. Thus, *adverse* is a matter of perspective. There is no one consensus definition of a healthy ecosystem (i.e., a single state for an ecosystem that is socially desirable and has integrity). Rather, ecological systems can have multiple states of health, and the choice among these states is determined by societal desires. The traditional risk assessment approach generally deals with one or a few assessment endpoints and asks how far we should go towards protecting or restoring that endpoint at what cost (i.e., what level of stressor reduction is needed and worthwhile?). In contrast, ecosystem management is more a matter of social trade-offs among multiple, alternative endpoints. Principe (1994) refers to this alternative perspective as *ecological benefits assessment* (see Box 3-A; Figure 3-1a,b).

- **Long and Short Term**. We must account for not only current uses and societal desires, but also desires and potential uses of future generations. Ecological assessments must provide information on both the short- and long-term ecological consequences of management actions, and evaluate management approaches that maintain options for the future (often referred to as bequest values).

Box 3-A Ecological Benefits Assessment

Principe (1994) identifies four groups, or types, of ecological benefits (also see Westman 1977):

- Market benefits, such as lumber, commercial fisheries, water use for irrigation, and grazing, for which markets exist that can be used to estimate their value.

- Nonmarket, use benefits, such as recreational fishing, hiking, and tourism, for which there are no markets.

- Nonmarket, non-use benefits, which include existence values (the benefit associated with maintaining the option to use the resource in the future even though the resource is not currently being used), bequest values (the satisfaction derived from preserving the resource for future generations), intrinsic values (the value assigned by some to the intrinsic right of ecosystems to exist apart from their utility to humans), historical, heritage, cultural, spiritual, and other similar values.

- Neglected benefits, such as climate modification, pollution sequestration, and genetic diversity for future biotechnology applications, which are seldom included in benefit analyses because they are so difficult to characterize, both physically and monetarily.

Thus, the term *ecological benefits* refers to the full complement of goods, services, and values that humans derive from ecosystems. Economists often use the term *benefit* to refer specifically to a monetized valuation of an economic good or service. However, we use the term to refer to all goods, services, and values whether or not a monetary value can be assigned or estimated.

Principe (1994) defines an ecological benefits assessment as comparison of the ecological benefits profile among alternative management scenarios, as illustrated in Figure 3-1 (a and b). Benefits are presented in relative, physical terms (e.g., small or large amount of available fishing or small or large contribution to flood control), not as monetary values. One limitation of this approach is that the visual impact of the figure is influenced by the degree of aggregation among benefits (e.g., how many individual benefits are listed within a given category) and the criteria used to define high and low.

- **Comparisons Among Management Strategies**. A major thrust of ecological assessments for ecosystem management is to evaluate and compare the ecological consequences of alternative management strategies. What management actions are likely to yield the greatest return, in terms of reduced risks or increased ecological benefits? Analyses are not limited to management actions that fall within the domain (legislative mandates) of any one agency, but encompass all reasonable options.

- **Geographic Targeting**. A second important question for ecosystem management is, "Where—in what areas and at what sites—will management efforts make the greatest difference?" What are the highest priority sites for restoration or other management action, which will result in the greatest net gain in ecological benefits or reduction in risks? We may also target geographic a)

Old Growth Forest – Forest Intact

(for illustrative purposes only, points shown are not data)

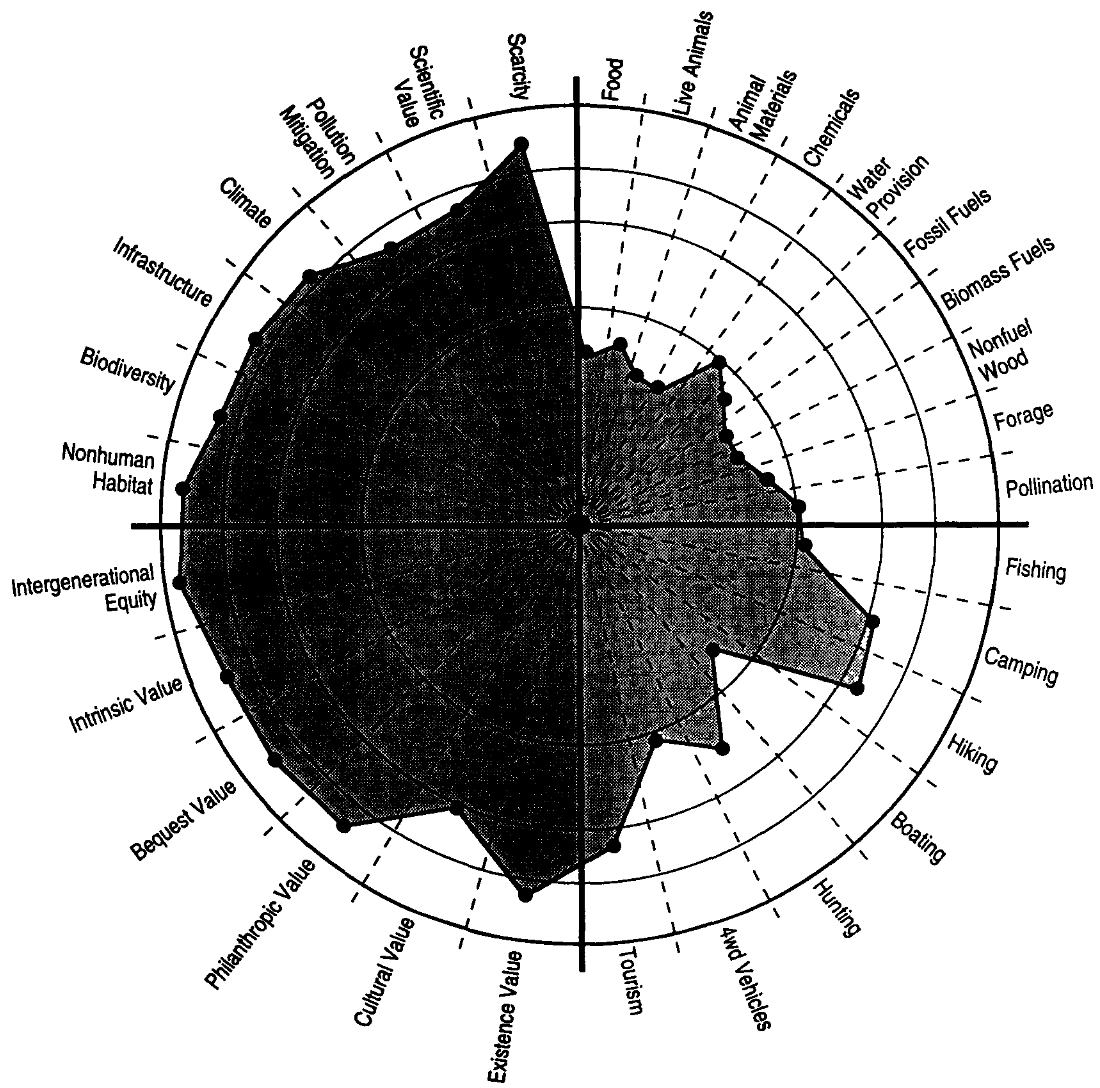

Figure 3-1a. **Hypothetical ecological benefits profile for old growth forest, comparing two management strategies: (a) preservation of old growth forests and (b) forest harvests through clearcutting. These figures are for illustration only; they are not based on real data. Also, the visual impact of each figure is affected greatly by the degree of aggregation among benefit types and the criteria used to assign high and low values (Source: Principe 1994).**

b)

Old Growth Forest – Forest Clear-Cut

(for illustrative purposes only, points shown are not data)

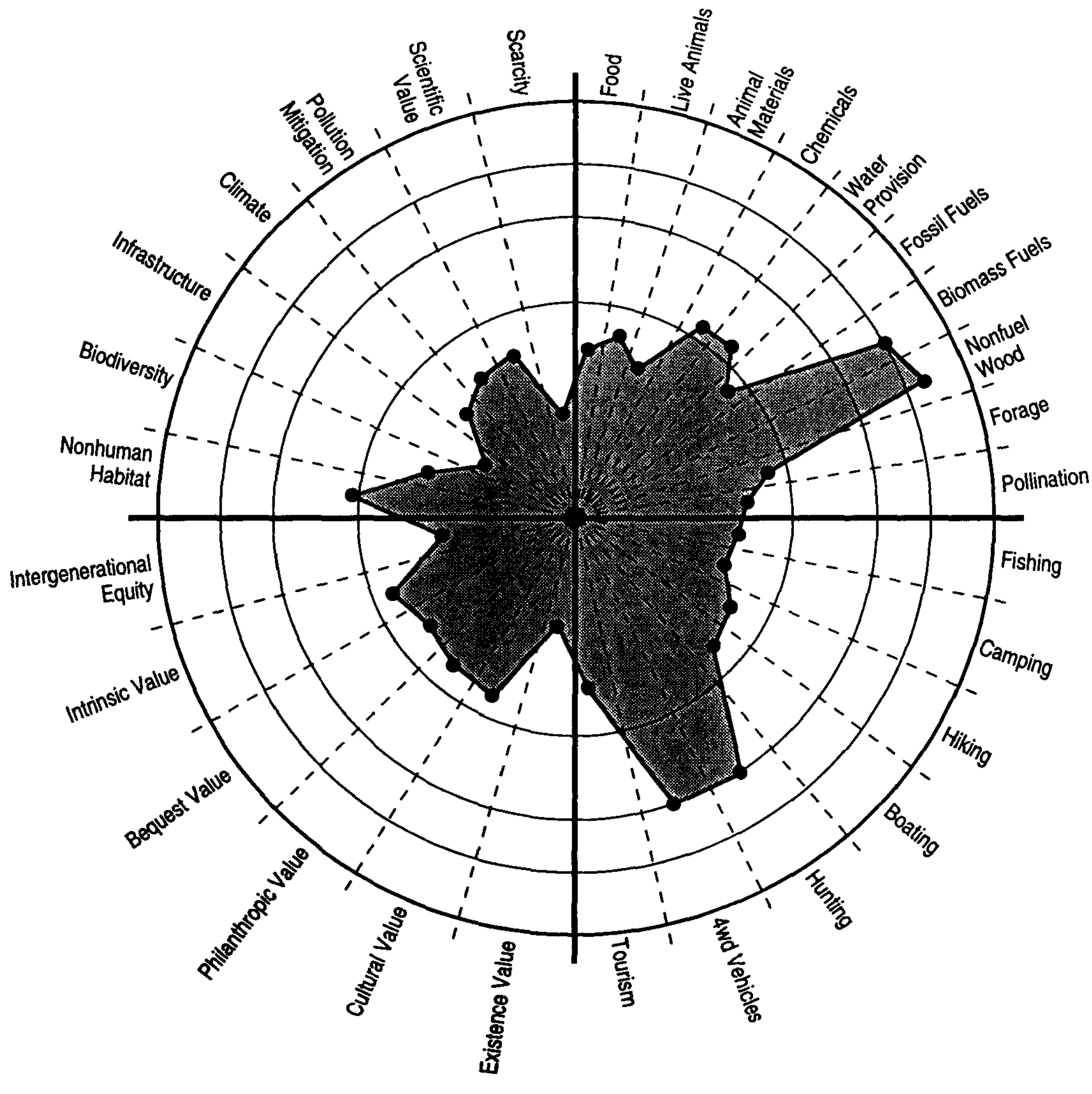

Figure 3-1b. **Hypothetical ecological benefits profile for old growth forest, comparing two management strategies: (a) preservation of old growth forests and (b) forest harvests through clearcutting. These figures are for illustration only; they are not based on real data. Also, the visual impact of each figure is affected greatly by the degree of aggregation among benefit types and the criteria used to assign high and low values (Source: Principe 1994).**

areas for further study. High-priority areas for management attention are often high-priority areas for further data collection and more intensive analyses to support decision making.

- **Structured Use of Expert Judgment**. Thus, ecological assessments must deal with multiple endpoints, multiple stressors, interactions, and trade-offs. The emphasis is on system-level integration and policy relevance. To achieve this, we must, at times, sacrifice analytical rigor and proceed despite data gaps and uncertainties. Some information, although uncertain, is better than no information. It is not acceptable to omit key components from an assessment (e.g., endpoints or stressor interactions) simply because "sufficient data are not available." Rather, where data and quantitative analyses are lacking, we propose to proceed through the structured use of expert judgment. Given the current state of assessment science, we can achieve the holistic assessments required to support ecosystem management only by using expert judgment to fill data gaps and missing links. We use the term *structured use* of expert judgment to refer to techniques that produce repeatable results and convey the variability among experts. Box 3-B provides further discussion of the use of expert judgment in assessments.

- **Iterative Process**. Figure 1-4 emphasizes the iterative nature of ecosystem management and of ecological assessments supporting ecosystem management. Managers define questions, assessments provide best available answers, decisions are made and management actions implemented, monitoring provides information on the success or failure of the management program, additional research is conducted to address major uncertainties, managers refine the questions, assessments are redone or updated, and additional decisions are made and management programs modified accordingly, consistent with the adaptive management concept. Even within a given assessment cycle, the assessment process will often be implemented iteratively, increasing the level of effort at each stage and continually focusing on those aspects that will contribute the most to reducing uncertainties and decreasing the chance of making an erroneous management decision. An initial assessment based solely on expert judgment may be conducted. Depending on the results and desired level of confidence, it may or may not be necessary to proceed with more quantitative analyses. The next iteration, if needed, may rely on data that already exist or are readily obtainable. At each iteration, additional data collection activities or more intensive analyses would focus on those issues, endpoints, stressors, or geographic areas expected to result in the greatest net contribution to improved decision making. Ultimately, the objective is to select the appropriate level of effort required to achieve the desired level of confidence in management decisions at reasonable cost (Figure 3-2; Leibowitz et al. 1992a). Spatially hierarchical implementation of assessments is fundamental to ecosystem management. Large-scale analyses, which are often more qualitative, provide a basis for identifying smaller subareas

Box 3-B. Structured Use of Expert Judgment

The formal elicitation of expert judgment has played an important role in decision analysis for years (e.g., Raiffa 1968, Spetzler and Staël von Holstein 1975) and in a wide range of risk analyses (e.g., Electric Power Research Institute 1986, Nuclear Regulatory Commission 1989, Keeney and von Winterfeldt 1989, 1991, Morgan and Henrion 1990, Whitfield et al. 1991). Otway and von Winterfeldt (1992) note:

> "Expert judgment has always played a significant, if often unrecognized, role in [risk] analysis; however, recent trends are to make it formal, explicit, and documented so that it can be identified and reviewed by others. ... Formal expert judgment processes employ protocols and procedures to define clearly the nature of the judgments, to make explicit the assumptions and reasoning behind them, to expose their inherent uncertainties, and to counter possible biases. Open and documented elicitation processes allow results to be evaluated by other experts and by the lay public as well" (pp. 83-84).

"The question is not whether we should use expert judgment, but how best to elicit and use it" (Winkler et al., in prep.). Winkler et al. (in prep.), Keeney and von Winterfeldt (1991), and others outline methods for eliciting consistent and usable judgments from a given expert or group of experts. Results from different experts can be combined, and variability and uncertainties quantified, using Bayesian statistics (Berger 1985). Bayesian statistics also can be used to combine data and judgment, as well as to combine data from different sources. For example, Reckhow (1988) presents a Bayesian model for predicting the effects of surface water acidification on brook trout populations in lakes in the Adirondack Region of New York, based solely on expert judgment. Warren-Hicks (1990) presents a similar model, for predicting the effects of acidification on brook trout, using Bayesian statistics to combine laboratory bioassay and field survey data. The third variation, combining data and judgment, would also have been feasible using the same basic statistical model.

We propose to develop and evaluate (1) systematic methods for obtaining and using expert judgment that result in representative, repeatable, and defensible outputs and (2) methods for combining data-based and expert judgment analyses to take maximum advantage of each. We will also demonstrate the use, and value, of these techniques in the overall ecological assessment process (see Section 3.3).

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that are high priority for more intensive analysis, as just discussed in the paragraph on geographic targeting.

- **Extensive Interactions with Stakeholders**. "People will not support what they do not understand and cannot understand that in which they are not involved ... The process of planning is often more important than the plan itself" (FEMAT 1993, pp. II-80-81). The assessment process must be open and understandable to those who will use the assessment results. Assessments are science-based, but require input from stakeholders (managers as well as interested citizens) at several points (e.g., setting analysis priorities and selecting realistic management scenarios for evaluation). Interactions between stakeholders and assessors are discussed further in Section 3.3.

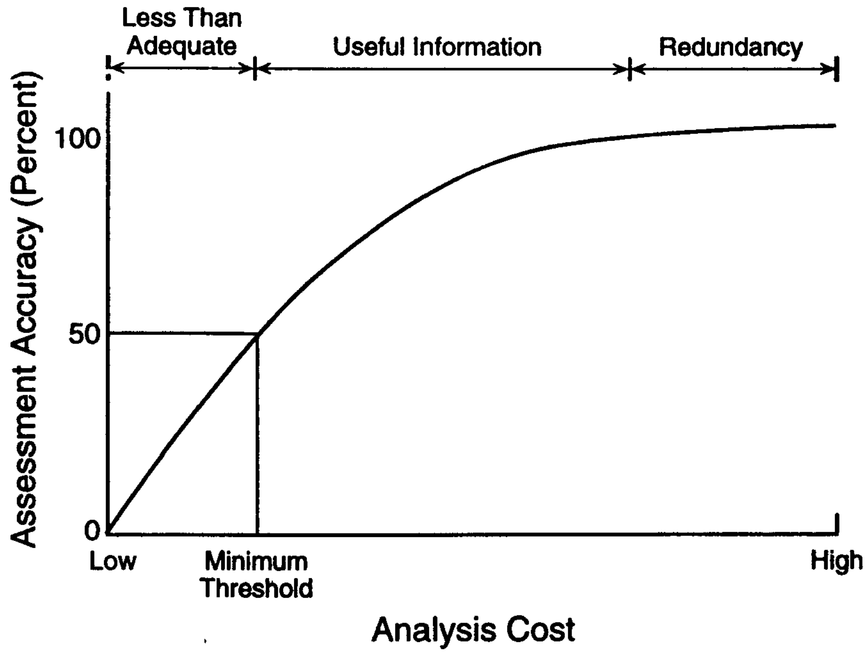

Figure 3-2. **The benefits of an ecological assessment, measured in terms of the accuracy of the results as a function of the assessment costs. At the very minimum, the assessment must provide results that are better than chance alone, e.g., greater than 50:50 for binary decisions (Source: Leibowitz et al. 1992a).**

- **Explicit Recognition of Uncertainties and Assumptions.** Assessments must provide ecosystem mangers with better information than is currently available, but they rarely provide perfect information. Furthermore, ecosystems are inherently variable and unpredictable. Even with perfect knowledge, we cannot predict the future with certainty. "Effective policies are possible under conditions of uncertainty, but they must take uncertainty into account" (Ludwig et al. 1993, p. 38). Uncertainties and assumptions must be clearly communicated to decision makers, not just as a list or a "±" estimate, but in a form that allows decision makers to understand the implications of these uncertainties and assumptions for various management options. Ludwig et al. (1993)

and Hilborn and Ludwig (1993) outline several basic principles for decision making in the face of uncertainty that provide insight into the types of information that assessments must provide:

- Favor actions that are robust to uncertainties.
- Consider a variety of plausible hypotheses and a variety of possible strategies. Select management actions based on their aggregated performance under a variety of plausible hypotheses.
- Favor actions that are reversible.
- Hedge (e.g., include safety factors to avoid irreversible results if errors are made).
- Favor actions that are informative; probe and experiment; monitor results; update assessments; and modify policy accordingly.

3.2 ECOLOGICAL CONCEPTS AND TERMS

In any assessment, an important first step is to develop a conceptual model of how the system operates—the major components, how they interact, and how they are affected by external factors (U.S. EPA 1992, 1994c). This section presents a general conceptual model of ecosystems within landscapes[1] (Section 3.2.1), which allows us to define basic ecological concepts and terms used in subsequent sections. Section 3.2.2 discusses ecological concepts relevant to developing an appropriate spatial framework for ecological assessments.

3.2.1 General Conceptual Model of Ecosystems and Landscapes[2]

Most assessments begin by asking what people value about ecosystems (U.S. EPA 1992, 1994c). Leibowitz et al. (1992a) and Principe (1994) expand this by asking, "What functions do ecosystems play in the landscape?" *Ecosystem functions* combine what people value with other, often overlooked but important roles of ecological systems, such as the role of ecosystems in flood control, climate

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1 Forman and Godron (1986, p. 11) define landscape as "a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout." Neither ecosystems nor landscapes have an inherent size, e.g., both regional ecosystems and regional landscapes are valid concepts. Thus, we distinguish between landscape and ecosystems not on the basis of size, or on which contains which, but rather on the basis of primary focus. For ecosystems, the primary interest is interactions among and between the biotic and abiotic components; for landscapes the focus is on spatial structure. This distinction is consistent with Allen and Hoekstra (1992): "Landscape ecology investigates the consequences of spatial structure ... Landscapes become the spatial matrix in which organisms, populations, communities, ecosystems, and the like are set" (p. 56).

2 Much of the information in this section was summarized from Leibowitz et al. (1992a,b), prepared as part of the Wetlands Research Program at ERL-Corvallis.

modification, or attenuation of pollutants. Ecosystem functions can be derived from both ecosystem *structure* (the combination of biotic and abiotic components that make up the ecosystem) and ecosystem *processes* (the transformation of energy and matter within the ecosystem). Westman (1977) uses the term "ecological goods and services." Principe (1994) uses the term ecological benefits (see Box 3-A). We prefer the broader, less value-laden term *ecosystem functions*. Example ecosystem functions are listed in Table 3-1.

Table 3-1. Examples of Ecosystem Functions.

- Production of harvestable products, such as timber, sport and commercial fish, hunted wildlife (e.g., deer, waterfowl)
- Water supply for municipalities, irrigation, hydropower generation
- Source of genetic materials for applications in medicine, agriculture, or biotechnology
- Habitat for rare, threatened, and endangered species
- Habitat for aquatic and terrestrial biodiversity
- Habitat for human recreation (e.g., hiking, boating) and aesthetic enjoyment
- Habitat for livestock grazing
- Improvement of water quality, for example, through sediment trapping and the absorption and breakdown of nutrients and toxic pollutants
- Climate modification, for example, by affecting rates of evapotranspiration, air movements, and carbon sequestration
- Flood control
- Erosion control
- Cultural and spiritual values
- Intrinsic value of maintaining pristine, undisturbed ecosystems apart from any human-related function

Many ecosystem functions depend not only on the characteristics of the system but also its position in the landscape. For example, a riparian areas may have the capacity to remove sediments from runoff. It functions as a sediment trap (or sink), however, only if there is an upstream sediment source (i.e., its water quality improvement function depends both on its capacity and on landscape inputs). Likewise, a riparian area may have the capacity to serve as habitat for certain terrestrial species, but it will function as terrestrial habitat only if the surrounding landscape matrix is also suitable (e.g., if the riparian area is connected via corridors to source areas for the species or to areas suitable for breeding and reproduction).

Leibowitz et al. (1992a,b) present a general conceptual model for landscapes that considers individual ecosystems as sources or sinks of materials[3] linked within the landscape. The function of any individual ecosystem depends on three factors: (1) the magnitude of the ecosystem as a source or sink, (2) the transport mechanism for the material (e.g., gravity, channelized flow, or migration), and (3) the spatial relationship between the sources and sinks in the landscape.[4] An ecosystem that serves as neither a source nor a sink can still play important roles as a conduit or barrier (Forman and Godron 1986). A *conduit* is "an ecosystem that assists movement of materials through different parts of the landscape" (e.g., habitat corridors for animal movements). A *barrier* is "an ecosystem that inhibits material movement." For example, streams act as barriers to organisms that are unable to swim or fly (Leibowitz et al. 1992b, p. 74).

A stressor, or environmental disturbance,[5] can alter both the magnitude and type of ecosystem functions. Declines in function are referred to as *functional loss*. Functional loss can result from a change in a forcing function (i.e., an external driving factor)—for example, a hydrologic diversion that affects the transport of water to and from the ecosystem—or a direct impact on ecosystem structure (e.g., harvesting of timber) or processes (e.g., nutrient enrichment). It is also possible that certain stressors, or intermediate levels of a stressor, might actually increase certain ecosystem functions. For example, in some systems intermediate levels of habitat disturbance can increase habitat diversity and species richness.

Because natural disturbances are common, most ecosystems have some ability to resist or adapt to anthropogenic disturbance. An ecosystem's response to disturbance depends on its resistance (ability to resist disturbance) and its resilience (ability to return to its previous state) (Figure 3-3) (Forman and Godron 1986, Odum et al. 1987, Leibowitz et al. 1992b). The system is said to recover if it returns to its previous state or, more appropriately, its previous range of behavior (see Figure 3-3).

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[3] Material is defined broadly to include both biotic and abiotic materials. In the case of biological materials, an ecosystem would be a sink if emigration were less than immigration, which would occur if the death rate exceeded the birth rate. The model also recognizes neutral ecosystems, which neither add nor remove the particular material.

[4] Leibowitz et al. (1992a,b) use the term *landscape function* to refer to ecological functions that depend on the interactions between ecosystems. These larger scale functions could just as well be viewed as functions associated with a larger, more encompassing ecosystem (see footnote 1). For this reason, we use just one term—ecosystem function.

[5] Some authors use the term *disturbance* to refer only to natural factors that affect ecosystems and *stressor* for human-caused stress. We use the terms interchangeably. Both terms include both natural and anthropogenic causes.

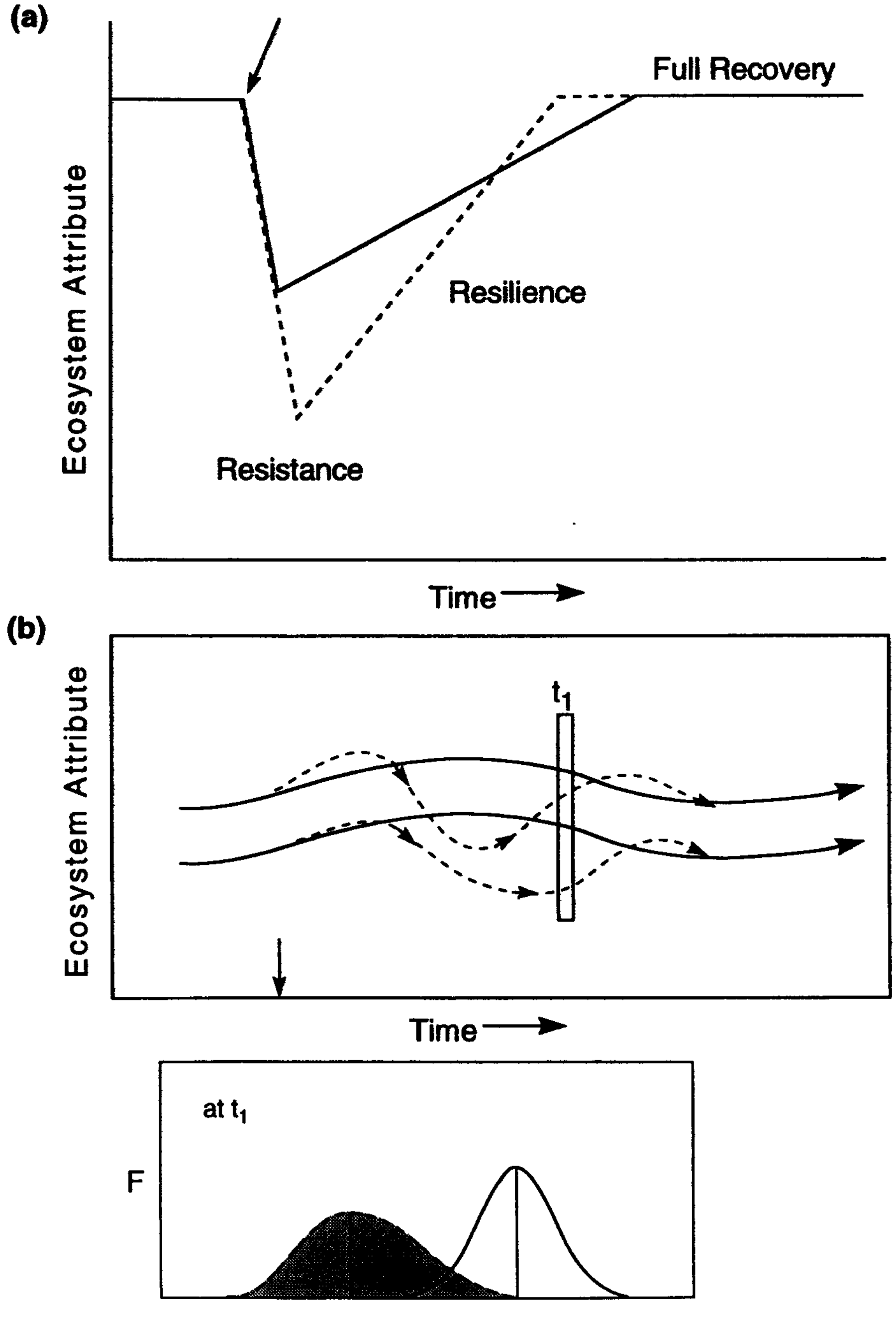

Figure 3-3. Conceptual presentations of ecosystem response to disturbance: (a) Stylized definitions of the terms *resistance* and *resilience*. The solid line illustrates a system with greater resistance (less change in response to the disturbance) but lower resilience (longer recovery period) compared to the dashed line. (b) Graphs showing that ecosystems are dynamic. An undisturbed system exhibits time-varying states within some nominal range of behavior (solid lines). The disturbed system (dashed lines) likewise shows some range of response. [Sources: (a) Leibowitz et al. 1992b, (b) Bartell et al. 1992].

Catastrophic disturbances or long-term chronic disturbances may alter an ecosystem so drastically that it never recovers (at least in human terms of recovery), but instead shifts to a new, alternate state or range of behavior (Allen et al. 1977, Phillips 1993). O'Neill et al. (1989) speculated that increased system variability combined with increased times for system recovery may be indicators of an imminent change in system state. Chaos theory suggests that even in the absence of a disturbance, a system can exhibit temporal behavior that not only departs from the normal behavior range, but also becomes aperiodic and unpredictable, or chaotic (Prigogine 1967, 1982). Ecosystems are fundamentally dynamic in time and space (e.g., Walker 1981).

Different ecosystems respond differently to a given disturbance or stressor (Figure 3-4). The nature of an ecosystem's stressor-response curve provides one basis for identifying systems where management actions might provide the greatest net return. Systems with a high risk of functional loss are those that (1) have a high probability of being exposed to a stressor and (2) are on the area of the curve with maximum slope, where a given unit increase in a stressor will result in the greatest decline in ecosystem function.

An ecosystem's recovery curve may not be the exact reverse of its stressor-response curve (Figure 3-5). *Restoration potential* refers to the ability to recover ecosystem function through stressor reduction or specific restoration activities. An ecosystem with high restoration potential is one for which a given unit of management action would result in the greatest net increase in ecosystem function (i.e., it is on the area of the recovery curve with maximum slope). Restoration ecology applies ecological principles to the management of ecosystems to accelerate the recovery process (Cairns 1993). In many cases, ecological restoration requires restoring both the ecosystem's capacity and the landscape matrix (i.e., other ecosystems that serve as important sources, sinks, conduits, or barriers for the restored ecosystem). For example, re-establishment of locally extinct populations in a restored ecosystem will occur only if there are nearby sources and appropriate conduits for the movement of those organisms into the restored ecosystem.

Disturbances occur at different spatial and temporal scales (Figure 3-6). The term *cumulative impacts* refers to disturbances that overlap either in space or in time (Beansland et al. 1986). Time-crowded disturbances are those that are so frequent in time that the ecosystem does not have a chance to recover between disturbances; space-crowded disturbances are those so close in space that their effects overlap.

Delineation of conceptual models is an important step in the design and conduct of a research project. The conceptual model represents the researcher's hypothesis about how the ecosystem operates and responds to stressors. It is the visual representation of the specific hypothesis to be tested. We present

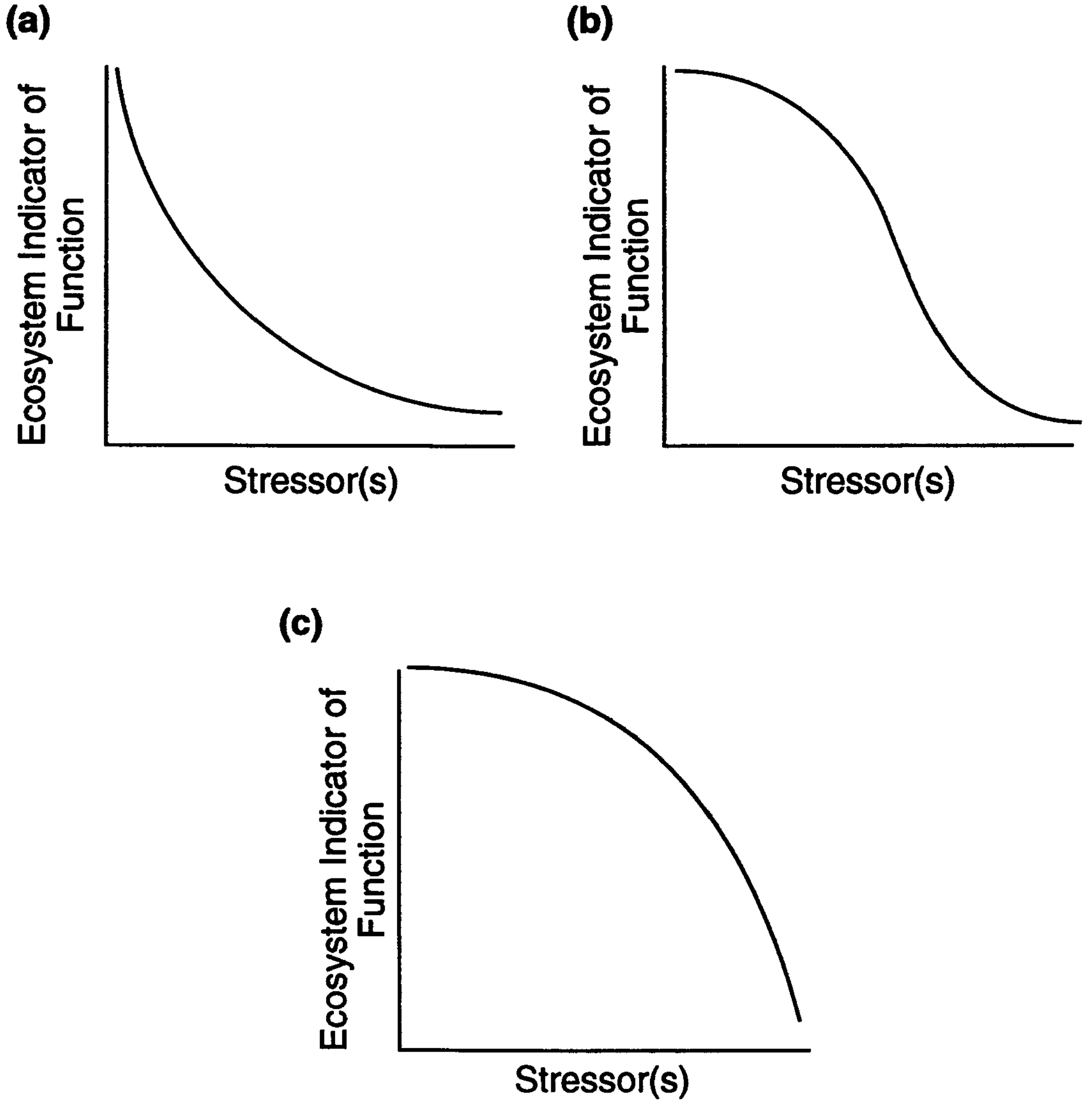

Figure 3-4. **Example hypothetical stressor-response curves, illustrating potential relationships between ecosystem function (e.g., biodiversity or overall water quality improvement) and increasing levels of some stressor or multiple stressors (e.g., hydrologic modification, toxic contaminants). In curve (a) ecosystem function declines sharply even with low levels of stressor; curves (b) and (c) suggest that, because of the system's resistance, it can initially absorb some level of stressor without a measurable loss of function. The portion of the curve with the greatest slope can be used to identify those ecosystems where the greatest return (increase in function) could be achieved per unit of ecosystem protection (reduction of stressor) (Source: Leibowitz et al. 1992a).**

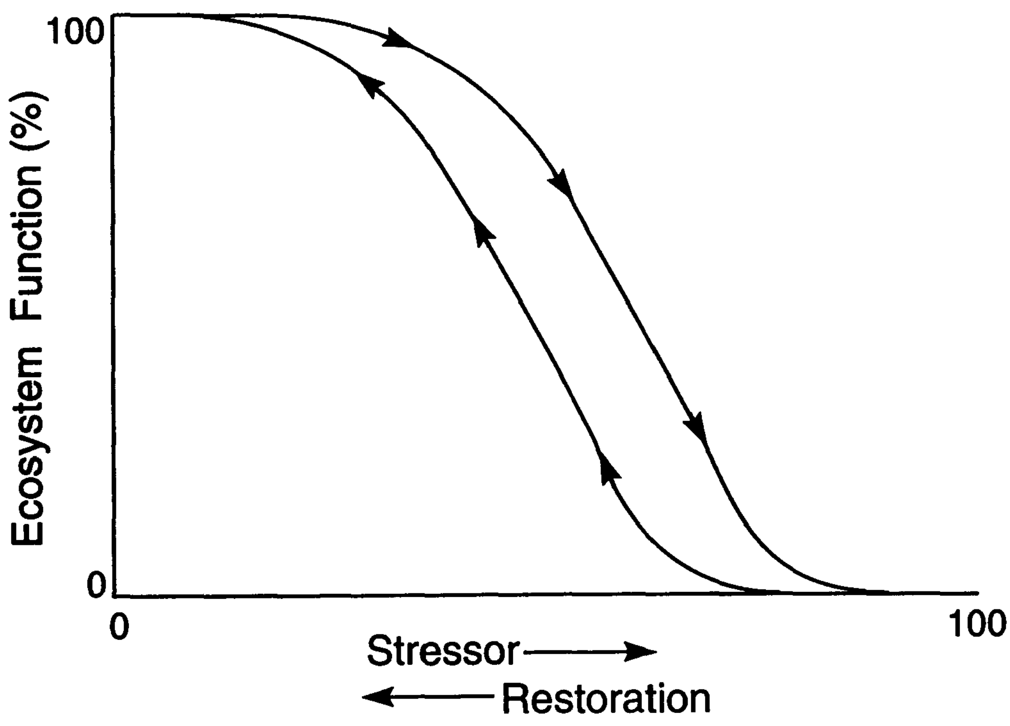

Figure 3-5. **Example hypothetical relationships between ecosystem function and increasing levels of stressor and increasing restoration activity, illustrating that ecosystem responses to restoration (or stressor reduction) may not mimic the initial ecosystem response to increased stressor.**

here a generic conceptual model of how ecosystems interact within the landscape, primarily to help define terms and major processes. We have not included additional generic models for individual components of the PNW research program, because we feel that conceptual models are of greatest value when defined for specific systems and research questions, i.e., at the project level rather than at the program level. Conceptual models and testable hypotheses will be described in project research plans, which will be prepared for each project funded under the PNW research program.

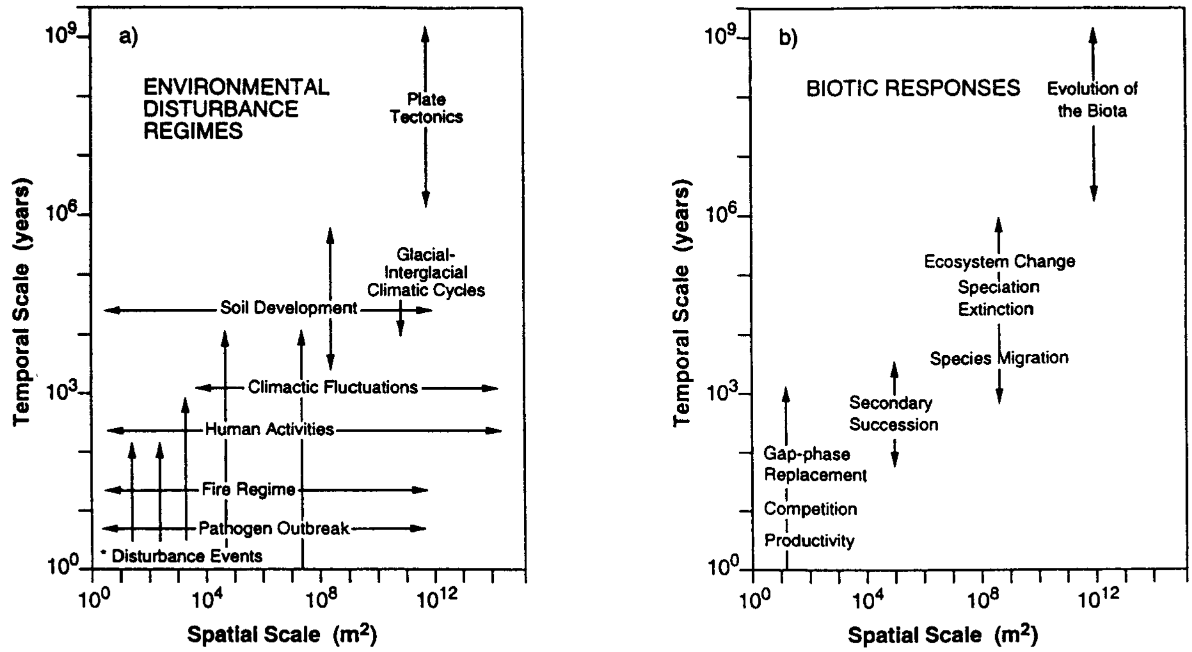

Figure 3-6. Spatial and temporal scales for (a) example disturbances and (b) biotic responses. (Source: Leibowitz et al. 1992b, adapted from Delcourt et al. 1983).

3.2.2 Spatial Framework for Ecological Assessments

A major objective of the PNW research program is to develop and demonstrate a spatial framework that provides an effective basis for making ecological assessments at multiple spatial scales, setting environmental goals, and extrapolating research results (Section 2.2). This section reviews several related concepts: hierarchy theory, classification, regionalization, and extrapolation from smaller to larger scales.

3.2.2.1 Hierarchy Theory

Hierarchy theory suggests that ecological systems are, or at least appear to be, hierarchical in their organization (Allen and Starr 1982, O'Neill et al. 1986, Allen and Hoekstra 1992). Complex systems are viewed as a hierarchy of embedded subsystems at different scales or levels of organization. At any given level, a system is composed of interacting components and is itself a component of a larger system. The classical hierarchy in ecology (from small to large) is cells, organisms, populations, communities, ecosystems, landscape, biome, and biosphere. Many other hierarchical organizations are possible, however, depending on the frame of reference, and these other organizations often provide more useful ways of organizing our understanding of ecological systems.

Of particular interest are organizational frameworks based on multiple levels of temporal and spatial scales. The term *scale* pertains to "size in both time and space; size is a matter of measurement, so scale does not exist independent of scientists' measuring scheme" (Allen and Hoekstra 1992). Scale is determined by the *grain* (limit of resolving power of individual measurements) and the *extent* (spatio-temporal extent of the data) required to see the entities that characterize the level.

Perceiving something at large scale requires observations over relatively long periods of time or across large parcels of space, or both. Theoretically, we could study large-scale systems at a fine-grain level of resolution, but besides being impractical and expensive, often the detail obscures the overall pattern.

> "Landscapes are analogous to pointillistic paintings. If the viewer is too close (too fine a resolution), the objects of interest cannot be seen. If the viewer is too far away (at too coarse a resolution), again, the objects of interest cannot be seen" (Hunsaker et al. 1990, p. 330).

Scale-dependent attributes or processes are those that differ qualitatively, depending on the scale used to observe them. For example, two species may be negatively associated when studied within small geographic areas, if they compete for the same resource, but positively associated when examined over large areas, where common patterns of habitat selection dominate (Wiens et al. 1986, Carpenter and Kitchell 1987, Sherry and Holmes 1988). Meentemeyer (1984) observed that differences in litter decomposition at the local scale were explained by properties of the litter and decomposers, whereas at broad regional scales climatic variables accounted for most of the variation.

The levels of organization in a hierarchy are interrelated; Allen and Hoekstra (1992, p. 10) define *hierarchy theory* as "a formal approach to the relationship between upper level control over lower level possibilities." Larger scales (spatial and temporal) provide context, role, and significance. Smaller scales provide insight into explanatory mechanisms, as the component subsystems that make up the larger whole. Therefore, to adequately understand any one scale, we must study at least three: the level of interest and the levels immediately above and below it.

3.2.2.2 Classification

Bailey et al. (1978, p. 650) refer to *classification* as "ordering or arranging objects into groups or sets on the basis of their similarities or relationships. The product of this process is a classification system, and the subsequent placement of objects into the system is called 'identification' (Sokol 1974)." Gilmour (1951) states that, "Classification is a prerequisite of all conceptual thought, whatever the subject matter of that thought. The primary function of classification is to construct classes about which we can make inductive generalizations."

Our primary interest is classification of landscape units (i.e., areas of land and their associated ecosystems), which we refer to as *landscape classification*. We may also wish to classify specific ecosystem components [e.g., soil classification; USDA Soil Conservation Service (SCS) 1975] or ecosystem types (e.g., a stream or wetland classification; Naiman et al. 1992, Brinson 1993a). In all cases, the objective is to group the units into classes with similar characteristics. The characteristics of the class, or any individual unit within the class, can then be inferred from studies of other representative[6] members of the same class. A classification system thus provides a basis for extrapolating research findings from studies at one or a few sites (or landscape units) to other similar sites within the same class.

Examples of classifications abound. Some were developed for particular purposes. For example, Hamlett et al. (1992) classified 104 watersheds within Pennsylvania according to their agricultural pollution potential, based on four variables: a runoff index, a sediment production index, an animal loading index, and a chemical-use index. Huang and Ferng (1990) subdivided the Tanshui River Basin in Taiwan into 250 m x 250 m grids and then classified each grid unit into one of four classes of sensitivity to landuse activities and potential contribution to nonpoint source pollution, based on data on surface runoff, surface erosion, and distance to the nearest stream. The Gap Analysis Program (e.g., Scott et al. 1991) and related Biodiversity Research Consortium (Kiester et al. 1993) classify land areas according to their potential contribution to regional terrestrial biodiversity, based largely on vegetation type (estimated using remote sensing), the relationship between vegetation type and species distributions, and available data on species occurrences.

Classification systems may also be developed for broad, general use. Obviously, general-purpose classifications provide less precise results than single-purpose classifications when applied for that particular purpose. On the other hand, the common use of a single classification system can facilitate data sharing and communication (USFS 1993a). Many of the regionalization approaches to classification discussed later in this section are general, multi-purpose classifications. Naiman et al. (1992) outline a system for classifying streams according to their *conservation potential*, defined broadly as a stream's ecological potential and sensitivity to natural and human disturbance. The classification approach relies on the full range of small- and large-scale factors that influence stream characteristics (Figure 3-7).

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6 In general usage, the term *representative* refers to a typical example. A rigorous definition of the term requires a statistical probability sample to assure that a subset of class members is truly representative.

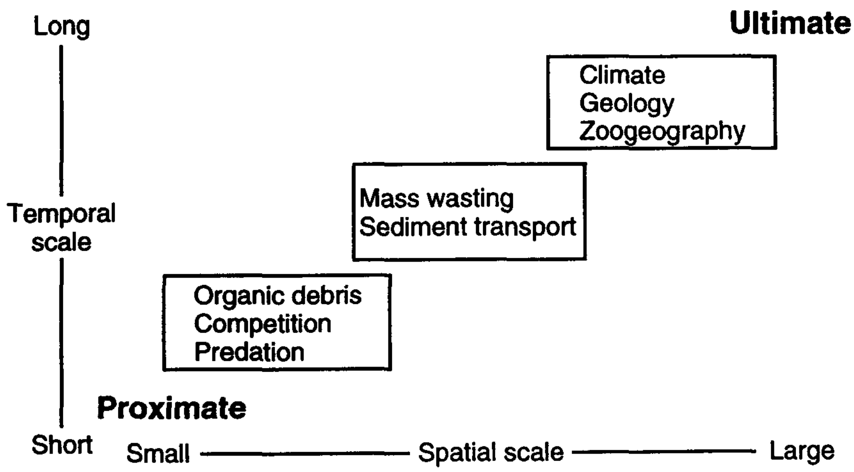


Figure 3-7. Proximate and ultimate controlling factors in determining stream characteristics and their relation to spatial and temporal scales (Source: Naiman et al. 1992).

Classifications may be single-level (such as the Pennsylvania watershed classification already mentioned in this section) or multiple-level (e.g., the SCS soil classification). Multi-level classifications may or may not be hierarchical (with each higher level an aggregation of the classes, and only those classes, at the next lower level of classification). The fixed relationship among levels in a hierarchical classification can be advantageous, but also reduces flexibility.

3.2.2.3 Regionalization

Regionalization is a type of landscape classification. Bailey et al. (1978) describe two approaches to landscape classification: taxonomy and regionalization. Taxonomic approaches begin with predefined, generally small landscape units (e.g., small watersheds or the 250 x 250 m grids used by Huang and Ferng (1990). These units are then grouped into classes based on similarities in important characteristics. Regionalization, on the other hand, begins with the whole land area (e.g., a continent), which is then subdivided into smaller and smaller units, termed *regions*.

> "A region is a more or less homogeneous area that differs from other areas. To use a more contemporary jargon, within-region variance is less than between-region variance" (Hart 1982).

An *ecoregion* is a region of relative homogeneity in ecological characteristics or in relationships between organisms and their environments (Bailey 1976, Omernik 1987, Gallant et al. 1989). Like taxonomic classifications, ecoregions can be delineated at any spatial scale and customized to fit any particular purpose—single purpose or general, multi-purpose classifications. Regionalization systems can be single- or multiple-level and hierarchical or nonhierarchical, although multiple-scale hierarchical systems are most common.

Regions can be delineated using either qualitative or quantitative techniques or a combination of the two (Gallant et al. 1989):

- Qualitative delineation employs continual, interactive expert judgment to select, analyze, and classify data and differentiate regions. Judgments are based on the quality and quantity of data and on relationships among environmental factors. The qualitative approach allows the expert to account for difficult-to-quantify variations in the quality and resolution of data and among-region variations in associations among environmental variables (Omernik et al. 1988, Gallant et al. 1989).

- Quantitative delineation uses statistical comparisons (e.g., spatial concordance) among data layers to identify regions of relative homogeneity. Advantages of the quantitative approach are that the systematic methodology can be reproduced, boundaries among regions can be readily revised as new data become available, the process of delineation requires explicit choices among important variables, and transition zones between regions can be quantified (Bernert et al. 1993).

Qualitative regionalization approaches have been applied more widely than quantitative approaches, in part because of the limited amount of consistent, high-quality regional data available. In a review of EPA's ecoregion approach, the SAB (1991) recommended further exploration of quantitative approaches.

Commonly used examples of general, ecologically based regionalizations in the United States include the following:

- Land Resource Regions and Major Land Resource Areas (USDA 1981), developed largely from soils maps to provide a geographic basis for managing agricultural concerns.

- Bailey's Ecoregions (Bailey 1976, 1989a,b), developed initially to provide a spatial framework for the U.S. Fish and Wildlife Service (USFWS) National Wetland Inventory, but now expanded to include continental and global applications.

- Omernik's Ecoregions (Omernik 1987, Gallant et al. 1989), developed initially to classify streams for water resource management, derived from those factors considered most important in controlling water quality in a given area, most notably land-surface form, potential natural vegetation, soils, and landuse. Omernik's ecoregion approach has been applied at a national scale (1:7,500,000 resolution, Figure 3-8; Omernik 1987), smaller scales (1:250,000) for state-level management concerns (Figure 3-9; Gallant et al. 1989, Thiele et al. 1993), and, recently, at a landscape or basin scale (1:100,000; Thiele 1992).

- ECOMAP, the USFS National Hierarchical Framework of Ecological Units (USFS 1993a), developed to provide a consistent framework for the implementation of ecosystem management by the USFS at the national, regional, and forest planning levels. "The primary purpose is...to identify land and water areas at different levels of resolution that have similar capabilities and potentials for management" (USFS 1993, p. 3). The map units are differentiated by multiple factors, including climate, physiography, geology, soils, water, and potential natural communities. At large scales, abiotic factors dominate, whereas both abiotic and biotic factors are important at smaller scales.

Ecoregions, areas of relative ecological homogeneity, represent an important component of a spatial framework for assessments—as spatial units for organizing and presenting information, setting environmental goals, and extrapolating to other units. As with taxonomic approaches to classification, research findings from studies at one or a few sites should be generally applicable to other sites in the same class, or ecoregion. Omernik and associates (Hughes et al. 1986, Gallant et al. 1989) use regional reference sites to define regionally attainable stream quality:

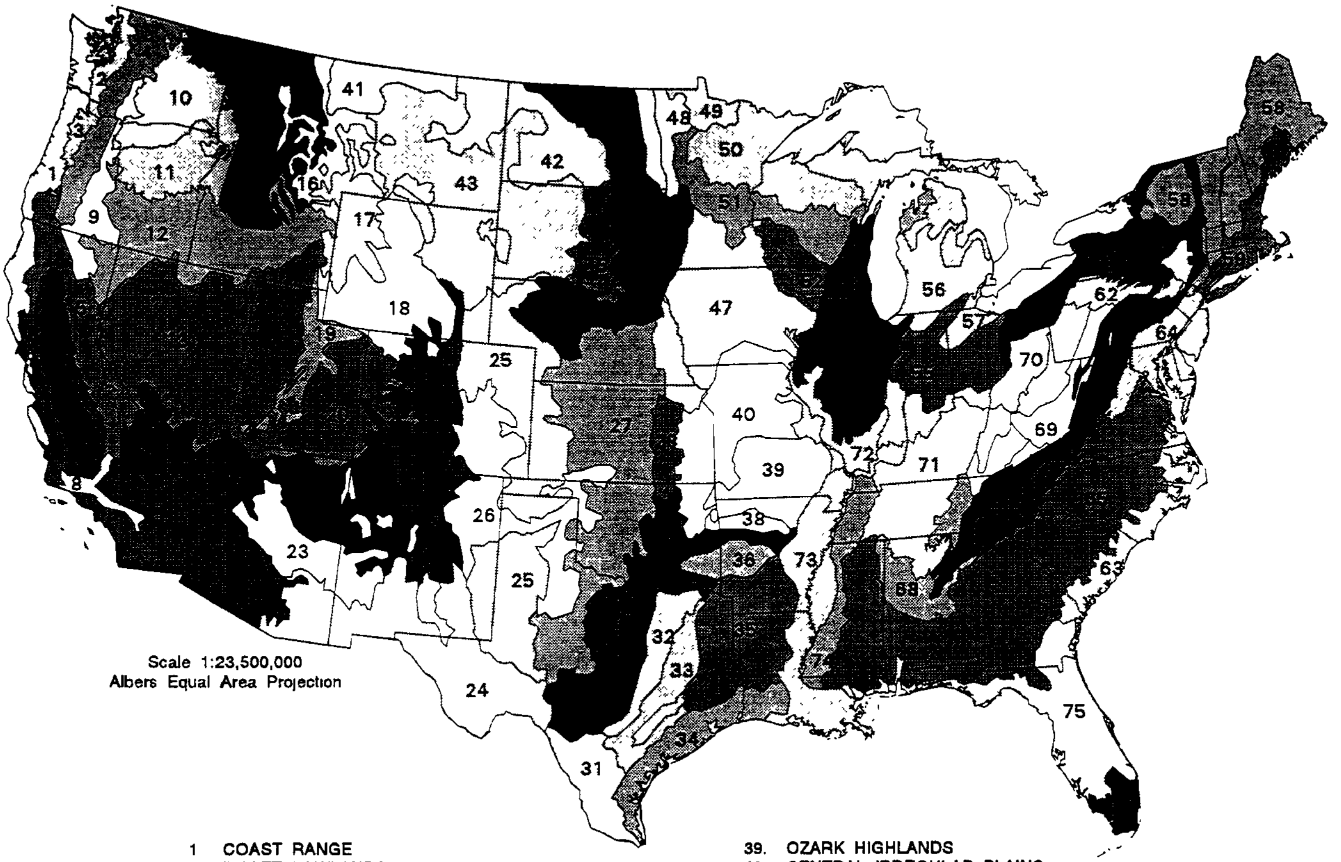
> "... attainable quality can be approximated by measuring physical, chemical, and biological quality of streams draining watersheds that are representative of the natural environmental characteristics typifying the region and subject to the least possible amount of human influence" (Gallant et al. 1989, p. 5).

Hydrologic units (regions defined based on topographic drainage divides) are another commonly used spatial unit (e.g., U.S. Geological Survey, USGS 1982). Analyses for which hydrologic movements are a major forcing function are best done within hydrologic units. In general, however, a given river basin or watershed includes a diversity of ecological characteristics, from the steeper, often more forested head-waters to the broader, generally more highly developed lower valleys. Hydrologic units include multiple ecoregions, and a given ecoregion may cross several hydrologic units. Both types of units are needed in a spatial framework for assessments, for different purposes (see Omernik and Griffith 1991). It is for this reason that we refer to our intermediate scale of analysis as watershed/ecoregion (Section 5).

3.2.2.4 Extrapolation from Smaller to Larger Scales

The final topic reviewed deals with extrapolating from smaller to larger scales. Most ecological studies, particularly process-related research, are conducted at relatively small spatial and temporal scales, because of the intense effort involved and the greater ease of controlled experimentation. To what degree can information obtained at small scales be used to estimate conditions and ecosystem responses at larger scales? For example, can studies of individual trees, and leaves on those trees, be used to predict the response of the entire forest? Can ecosystem responses observed over a period of one to two years be used to predict long-term ecosystem dynamics?

ECOREGIONS OF THE UNITED STATES



1 COAST RANGE
2. PUGET LOWLANDS
3. WILLAMETTE VALLEY
4 CASCADE
5. SIERRA NEVADA
6. SOUTH. AND CENT CALIF PLAINS AND HILLS
7. CENTRAL CALIF. VALLEY
8. S. CALIF. MOUNTAINS
9. EASTERN CASCADES SLOPES AND FOOTHILLS
10. COLUMBIA PLATEAU
11. BLUE MOUNTAINS
12. SNAKE RIVER BASIN/HIGH DESERT
13 NORTHERN BASIN AND RANGE
14. SOUTHERN BASIN AND RANGE
15. NORTHERN ROCKIES
16. MONTANA VALLEY AND FOOTHILL PRAIRIES
17 MIDDLE ROCKIES
18. WYOMING BASIN
19. WASATCH AND UINTA MOUNTAINS
20. COLORADO PLATEAU
21. SOUTHERN ROCKIES
22. ARIZONA/NEW MEXICO PLATEAU
23. ARIZONA/NEW MEXICO MOUNTAINS
24. SOUTHERN DESERT
25. WESTERN HIGH PLAINS
26. SOUTHWESTERN TABLELANDS
27. CENTRAL GREAT PLAINS
28 FLINT HILLS
29 CENTRAL OKLAHOMA/TEXAS PLAINS
30. EDWARDS PLATEAU
31. SOUTHERN TEXAS PLAINS
32. TEXAS BLACKLAND PRAIRIES
33. EAST CENTRAL TEXAS PLAINS
34. WESTERN GULF COASTAL PLAIN
35. SOUTH CENTRAL PLAINS
36. OUACHITA MOUNTAINS
37. ARKANSAS VALLEY
38 BOSTON MOUNTAINS
39. OZARK HIGHLANDS
40. CENTRAL IRREGULAR PLAINS
41. NORTHERN MONTANA GLACIATED PLAINS
42. NORTHWESTERN GLACIATED PLAINS
43. NORTHWESTERN GREAT PLAINS
44 NEBRASKA SAND HILLS
45. NORTHEASTERN GREAT PLAINS
46 NORTHERN GLACIATED PLAINS
47. WESTERN CORN BELT PLAINS
48. RED RIVER VALLEY
49. NORTHERN MINNESOTA WETLANDS
50. NORTHERN LAKES AND FORESTS
51. NORTH CENTRAL HARDWOOD FORESTS
52 DRIFTLESS AREA
53. SOUTHEASTERN WISCONSIN TILL PLAINS
54. CENTRAL CORN BELT PLAINS
55. EASTERN CORN BELT PLAINS
56 S.MICHIGAN/N.INDIANA TILL PLAINS
57. HURON/ERIE LAKE PLAIN
58. NORTHEASTERN HIGHLANDS
59. NORTHEASTERN COASTAL ZONE
60. NORTHERN APPALACHIAN PLATEAU AND UPLANDS
61. ERIE/ONTARIO LAKE PLAIN
62. NORTH CENTRAL APPALACHIANS
63. MIDDLE ATLANTIC COASTAL PLAIN
64. NORTHERN PIEDMONT
65. SOUTHEASTERN PLAINS
66. BLUE RIDGE MOUNTAINS
67. CENTRAL APPALACHIAN RIDGES AND VALLEYS
68. SOUTHWESTERN APPALACHIANS
69 CENTRAL APPALACHIANS
70. WESTERN ALLEGHENY PLATEAU
71. INTERIOR PLATEAU
72. INTERIOR RIVER LOWLAND
73 MISSISSIPPI ALLUVIAL PLAIN
74. MISSISSIPPI VALLEY LOESS PLAINS
75. SOUTHERN COASTAL PLAIN
76. SOUTHERN FLORIDA COASTAL PLAIN

Figure 3-8. Omernik's ecoregions of the United States (Source: Omernik 1987).

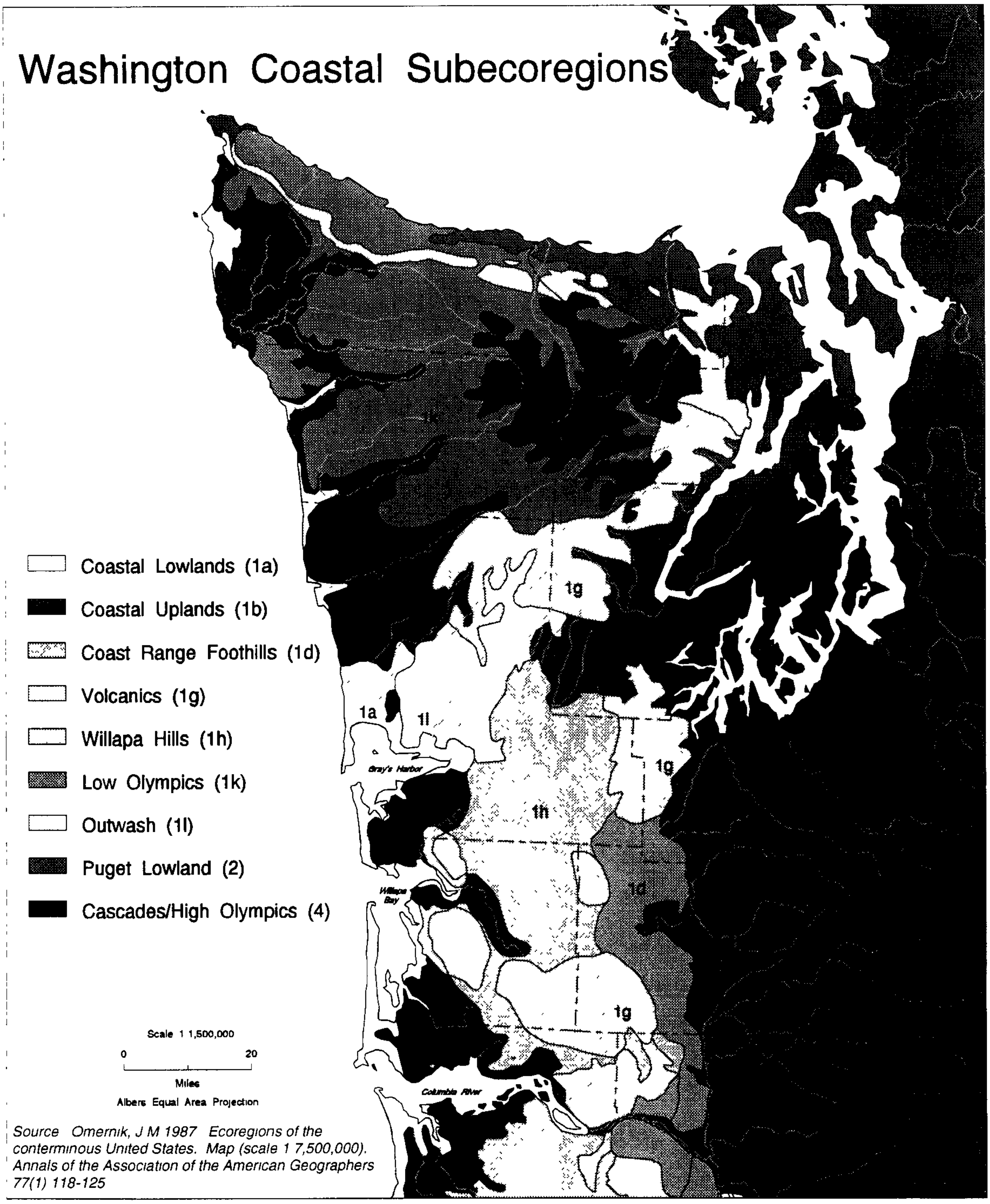


Figure 3-9. Omernik's subecoregions within the Coastal Ecoregion of Washington (Source: Thiele et al. 1993).

Scale-dependent properties and emergent properties cannot be directly estimated from studies at smaller scales. For example, the term *meta-population* refers to the total, combined populations of a species in an area inhabiting habitat patches that are connected by movements of individuals among patches (Henderson et al. 1985, Merriam and Wegner 1992). The influence of landscape features, such as habitat patch size and distance between patches, on the dynamics of a meta-population is an emergent property and cannot be predicted based solely on studies of population dynamics within individual habitat patches. Other examples of scale-dependent properties are presented in Section 3.2.2.1 (Hierarchy Theory).

Process-based models are commonly used to apply fine-grain knowledge obtained at small scales (e.g., individual leaves and trees) to predict coarse-grain, large-scale ecosystem properties (e.g., forest responses to stressors). Because of the impracticality of handling large numbers of small-scale components individually (e.g., all leaves or all trees), individual components typically are lumped and treated collectively (Zeigler 1976, 1979). The aggregation process itself can introduce errors, because of variation among the aggregated components, although mathematical techniques have been proposed to reduce these errors (Gardner et al. 1982, Rastetter et al. 1992). As important, or more so, is the assumption of scale independence of the basic processes, an assumption that has rarely been rigorously tested because of the lack of appropriate data at large scales.

Hunsaker et al. (1990) note that some large-scale stressors can be viewed as an aggregation of local effects, while others cannot. For example, regional estimates of the effects of acidic deposition on lakes in the United States were estimated through statistical aggregation of effects on individual lakes (Landers et al. 1988, Church et al. 1989). Each lake responded to acidic deposition relatively independently, and individual lakes sampled were selected randomly from a defined population of lakes so that the sample was truly representative. In contrast, the combined effects of sewage discharges on river basin water quality cannot be treated as an aggregate of local problems and analyses, because of the importance of hydrologic connections and interactions. Likewise, the effects of habitat alteration on meta-populations of birds in agricultural landscapes (e.g., Freemark and Merriam 1986) cannot be estimated by evaluating the effects on individual local habitats, because of the importance of population interactions among habitat patches.

The appropriate scales for analysis and approach depend on the nature of the stressors and of the ecosystem functions of interest. Improper scale selection can lead to serious errors in assessments (Allen and Starr 1982). Issues relating to extrapolating from smaller to larger scales remain major challenges for ecological research and assessment.

3.3 ECOLOGICAL ASSESSMENT PROCESS

The RAF within EPA is a standing committee of EPA scientists and managers charged with developing risk assessment guidance for Agency-wide use. In 1992, they published their framework for ecological risk assessments (U.S. EPA 1992). This framework report describes terms, starting principles, and the basic elements and structure for "evaluating scientific information on the adverse effects of physical and chemical stressors on the environment" (U.S. EPA 1992, p. ix). A variety of case study applications are underway to test and refine the framework. Based on results from these studies, more detailed guidance on conducting ecological risk assessments will eventually be published.

The RAF assessment framework, and framework report, also provide a sound starting point for ecological assessments supporting ecosystem management. We have adopted their basic framework and terms, although we emphasize certain aspects and expand on others as needed, to achieve the key features of ecosystem management assessments outlined in Section 3.1. We begin this section by outlining a set of basic assessment questions that would be addressed in a typical ecosystem management assessment (Section 3.3.1). We then relate these questions to the RAF framework in Section 3.3.2. Finally, in Section 3.3.3, we discuss implementation of the framework in a manner consistent with the principles outlined in Section 3.1.

3.3.1 Assessment Questions

Ecological assessments for ecosystem management are place-based. For a given geographic area, the following questions constitute a typical set of basic (first-order) questions that would be addressed in an assessment:

1. **Ecosystem Functions**: What functions do ecosystems play in this area and how do these functions interrelate?

2. **Societal and Ecological Values**: Which of these functions are most important?

3. **Attainable Goals**: What are realistic attainable goals for each of these valued ecosystem functions?

4. **Current Conditions**: How do current ecological conditions compare to these goals?

5. **Major Stressors and Problems**: What factors (natural and anthropogenic) play the greatest roles in observed differences between current conditions and attainable goals?

6. **Risks of Functional Loss**: What will happen in the future (e.g., extent and magnitude of future, additional functional loss) if current trends continue?

7. **Risk Reduction and Restoration Potential**: What management options are available to reduce the risk of functional loss and restore ecosystem functions? What are the likely ecological consequences of each of these management options on the full suite of valued ecosystem functions?

8. **Comparisons Among Management Scenarios**: How do these management options compare? Which management scenario is likely to result in the greatest net reduction in risk and/or gain in valued ecosystem functions?

9. **Geographic Targeting**: In what geographic areas and sites should management actions concentrate to achieve the greatest net reduction in risk and/or gain in valued ecosystem functions per unit of management effort?

10. **Uncertainties**: How robust are answers to each of the above to major uncertainties and assumptions made during the analysis?

The weight given to each question and the level of resolution required for each answer will vary among assessments, and by spatial scale (see Section 3.3.3). Note that input from stakeholders and managers is needed particularly for questions 2 (selecting the subset of most important functions) and 7 (selecting feasible management scenarios).

Steinitz (1990) presents an equally valid set of assessment questions, covering the same set of issues although using slightly different terms and organization. He refers to these as the six "levels of inquiry," each of which has an associated modeling type:

I. How should the landscape be described (in terms of content, boundaries, space, and time)? (representation models)

II. How does the landscape operate? What are the structural and functional relationships among its elements? (process models)

III. Is the landscape working well? How does one judge whether the current state of the landscape is working well? What are the metrics of judgment? (evaluation models)

IV. How might the landscape be altered: what, where, when? How might the landscape be changed by current trends? How might the landscape be changed through management intervention and action? (change models)

V. What differences might the changes cause? (impact models)

VI. Should the landscape be changed? How is the decision to be made? How is a comparative evaluation to be made among alternative courses of action? (decision models)

Choosing between these two lists, or others, is personal; the wording and order are not as critical as the concepts. Both lists have their strengths. For example, Steinitz (1990) makes explicit the need to understand how the system operates (Question II). Such an understanding is only implicit in the first list, but clearly essential to answering questions about trade-offs among ecosystem functions (Question 1), ecosystem responses to stressors (Questions 5 and 7), and most of the other questions presented. In general, we use the first list of questions as our basic set of assessment questions, because it is more consistent with the conceptual model and terms described in Section 3.2.

3.3.2 Assessment Framework

The RAF risk assessment framework consists of three major phases: problem formulation, analysis, and risk characterization (Figure 3-10). Problem formulation emphasizes the need to carefully frame, plan, and define the assessment objectives before beginning detailed analyses. As described by the RAF, the problem formulation phase involves a preliminary characterization of stressors, the ecosystem potentially at risk, and ecological effects, which leads to the selection of assessment and measurement endpoints and development of a conceptual model. Endpoint is defined (after Suter 1990) as "a characteristic of an ecological component (e.g., increased mortality of fish) that may be affected by exposure to a stressor" (U.S. EPA 1992, p. 12). Assessment endpoints are "explicit expressions of the actual environmental value that is to be protected" (e.g., sport fishing yields) (U.S. EPA 1992, p. 12). Often, assessment endpoints cannot be measured or assessed directly. In these instances, the assessor also identifies measurement endpoints, which are measurable responses to a stressor related, qualitatively or quantitatively, to the assessment endpoint. The conceptual model represents a series of working hypotheses regarding how stressors might affect ecological components of the natural environment (NRC 1986), describes the ecosystem potentially at risk, and delineates relationships between assessment and measurement endpoints.

We agree wholeheartedly with the need for careful attention to problem formulation. Ecosystem management, by definition, is all encompassing. It is not possible, however, to study in detail all endpoints, stressors, areas, issues, etc. An important task during problem formulation is to identify those endpoints, stressors, areas, and issues that will contribute the most to improved decision making and, thus, on which subsequent analyses should focus. Assessment endpoints, in our terminology, are explicit expressions of the valued ecosystem functions (question 2, Section 3.3.1), that is, the subset of all ecosystem functions considered most important for the purposes of a given assessment. Measurement endpoints, or indicators, are measurable or observable attributes that can be related to the assessment endpoints and thus used to approximate the level of ecosystem function. Examples are presented in Table 3-2.

Conceptual models are an important part of problem formulation. Often, multiple models are needed, to provide different levels of detail or to represent different plausible hypotheses about system interactions. Of particular interest for ecosystem management are conceptual models that define relationships *among*

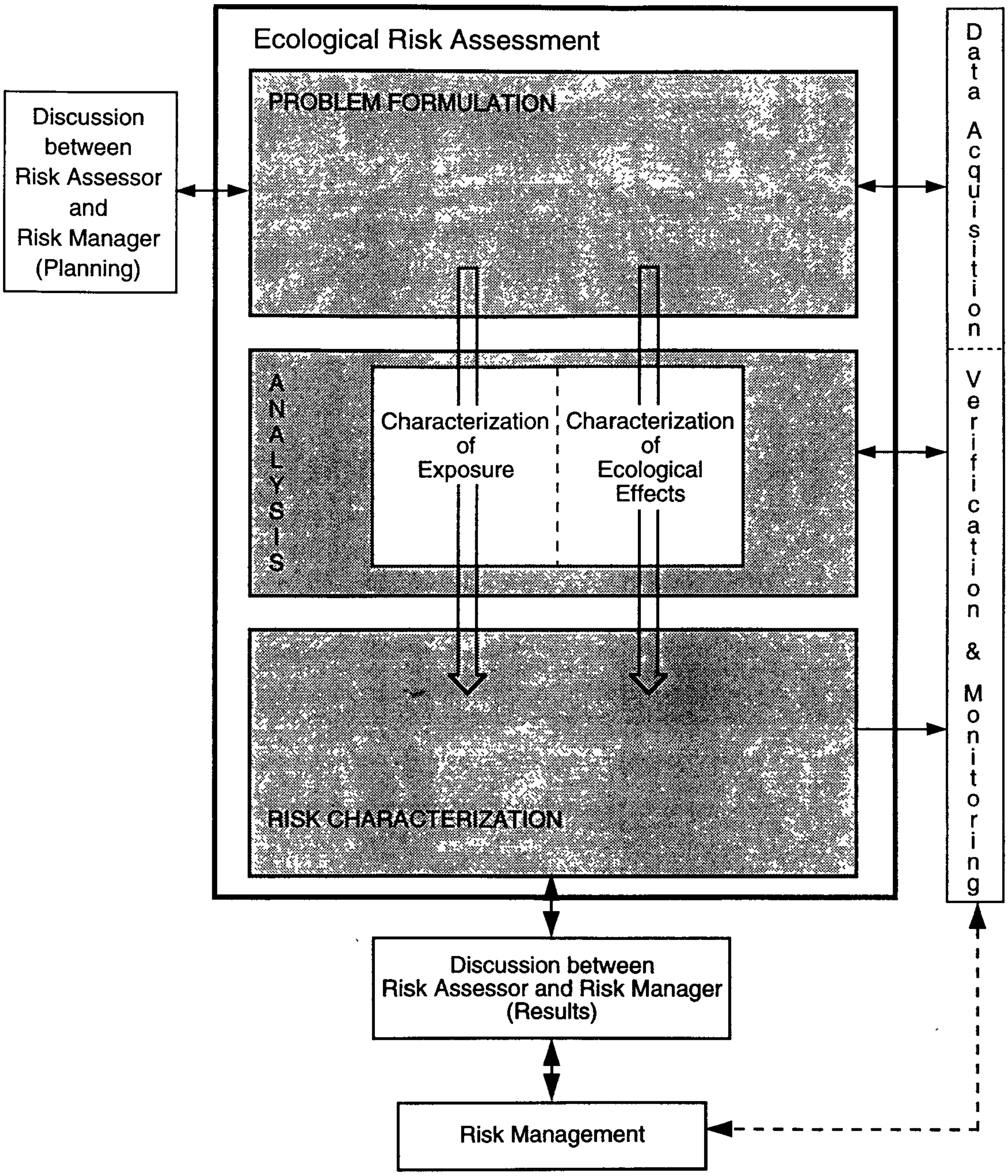


Figure 3-10. Risk Assessment Forum's framework for ecological risk assessment (Source: U.S. EPA 1992).

Table 3-2. Examples of Assessment Endpoints and Indicators (or Measurement Endpoints) for Selected Ecosystem Functions (see Table 3-1).

Valued Ecosystem Function	Assessment Endpoints	Indicators
Production of fish for commercial harvest	Sustainable salmon yields	Weight of salmon harvest/year Number of migrating adults Abundance of juveniles Water temperatures and flow during migration Suitable spawning habitat (well oxygenated, clean gravel)
Habitat for rare, threatened, and endangered species	Sustainable meta-population of spotted owl	Occurrence of spotted owl Reproduction rate ^{3} death rate Extent of old growth forests (OGF) Maximum patch size of OGF Connectivity of OGF patches
Habitat for aquatic biodiversity	Stream ecological integrity	Species richness Index of Biotic Integrity (Karr et al. 1986) Habitat variables (temperature, oxygen, substrate, etc.,) within natural range
Water quality improvement	Riparian area extent and condition	Extent of riparian area Location relative to pollutant sources (landscape inputs) Width and other indicators of riparian area capacity to retain sediments and pollutants
Habitat for human recreation	Aesthetics	Visual diversity of landscape Extent of visible human disturbances Abundance of litter Extent of pristine or relatively undisturbed ecosystems Ease of access Frequency of human contact

ecosystem functions and *among* stressors, which provide a basis for evaluating potential trade-offs among conflicting ecosystem uses and the relative merits of alternative management strategies, respectively.

Another important task during problem formulation is delineating appropriate spatial and temporal boundaries and levels of resolution (see Section 3.2.2). What are the most appropriate spatial units of analysis, given the types of questions being addressed, the priority assessment endpoints, major stressors, and conceptual models? How does this assessment relate to other assessments and management decisions at larger and smaller spatial scales? What spatial and temporal resolution is appropriate? How far into the future should ecosystem responses be projected?

Which of the assessment questions listed in Section 3.3.1 are addressed during problem formulation? Our answer is all of them. Steinitz (1990) proposes that the first step in any assessment should be to cycle once, forward and backward, through the full set of assessment questions (Figure 3-11), to help set priorities and context and then select methods for subsequent analyses. The justification for proceeding backwards, as well as forwards, is that answers to later questions (e.g., IV., How might the landscape be altered?) often provide insights that lead to better answers to earlier questions (e.g., I., How should the landscape be described?). During problem formulation, answers to the assessment questions are largely qualitative and based on best professional judgment.

Thus, problem formulation represents the first iteration of the overall iterative approach to assessments described in Section 3.1 (Figure 3-12). Furthermore, the results from problem formulation are not static. The conceptual models, spatial and temporal boundaries, and priority endpoints and stressors should be continually re-visited and refined during subsequent iterations.

Extensive interactions occur between the assessors (those conducting the assessment) and stakeholders during problem formulation (see Figure 3-12). Ecological knowledge is required to identify the full suite of functions that ecosystems provide (question 1 in Section 3.3.1).

Prioritization of those functions (question 2, Section 3.3.1) requires input from stakeholders and ecologists. Those functions valued most highly by society are likely to play the greatest role in decision making and thus are of high priority. However, societal values are often based on incomplete information; stakeholders may undervalue important ecosystem functions. Because of this uncertainty, both societal values and technical information are considered in the prioritization process. The dialogue between technical experts and stakeholders during this phase may also lead to greater recognition by decision makers of these undervalued, yet important functions.

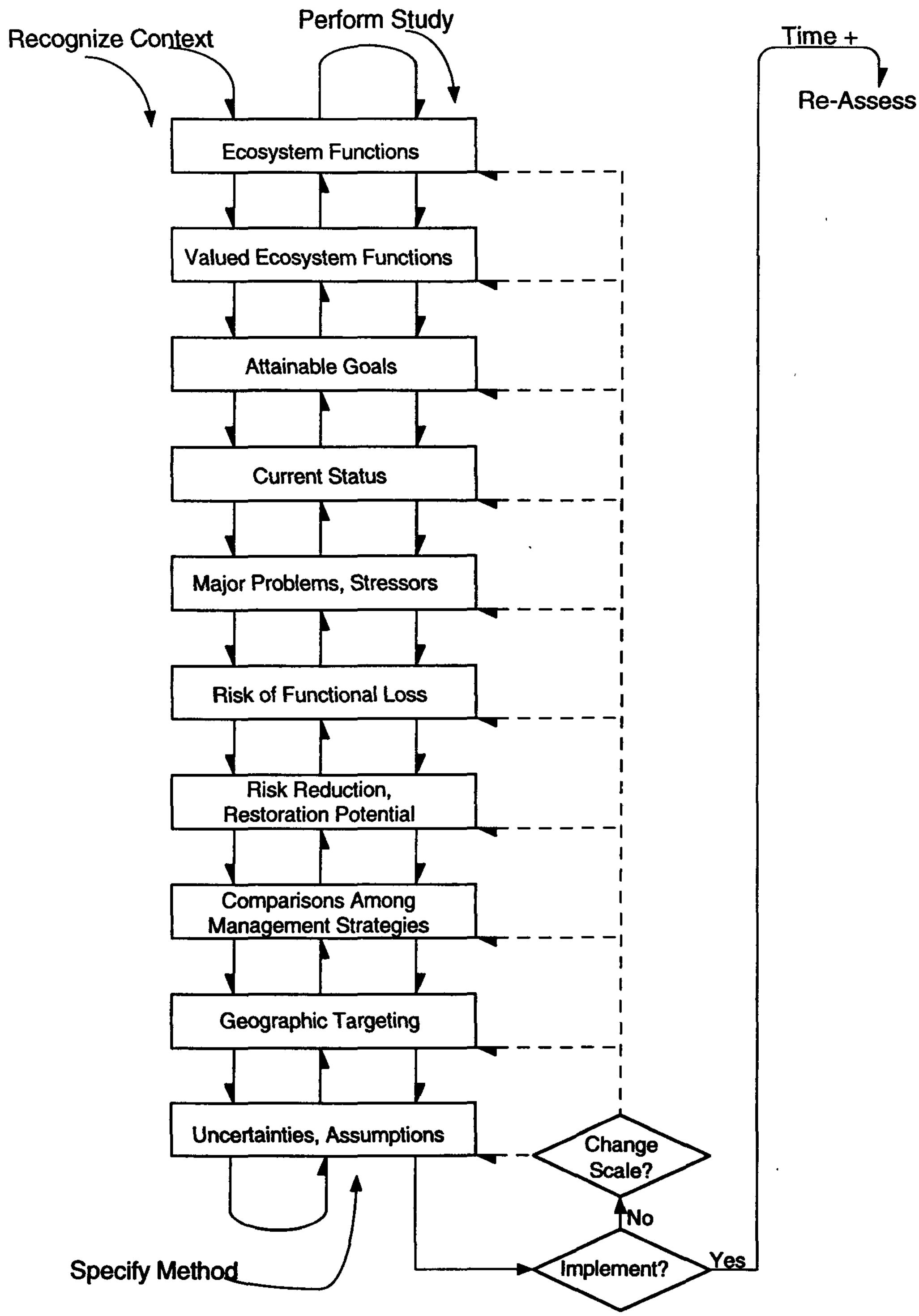


Figure 3-11. Iterative process through basic assessment questions (after Steinitz 1990).

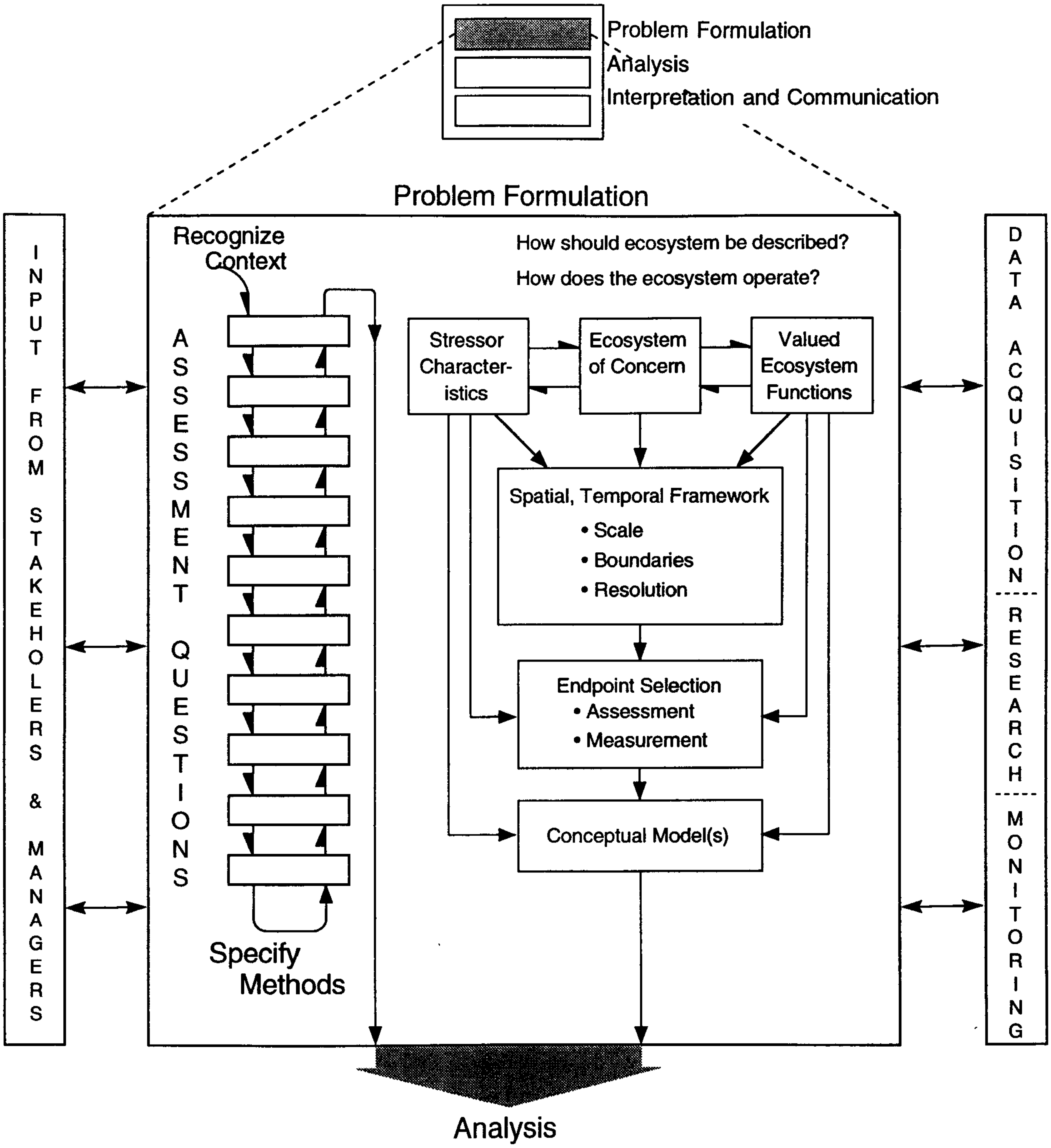


Figure 3-12. **Problem formulation phase of ecological assessments for ecosystem management. Figure 3-11 provides further details on the assessment questions.**

Stakeholders and managers also have significant input to questions 6 through 9 during problem formulation, to define (1) constraints on management options, (2) realistic projections of future trends in human population growth and development, and (3) reasonable alternative management strategies to evaluate in questions 7–9.

The second major phase of the RAF framework is analysis, which consists of two activities (Figure 3-10): (1) characterization of exposure (spatial and temporal distribution of stressors and their co-occurrence with ecological components of concern) and (2) characterization of ecological effects (stressor-response relationships). In the third and final phase of the RAF framework, risk characterization (Figure 3-10), information on the exposure profile and stressor-response relationships is combined to estimate the likelihood of adverse effects occurring as a result of specific stressor or management scenarios. Uncertainties, strengths, and weaknesses of the assessment also are summarized and communicated to the risk manager.

We agree with the two step process, which highlights the distinction between analysis and communication of the analysis results to decision makers. The latter phase, which we prefer to call interpretation and communication, emphasizes the importance of presenting results in a format that is understandable and most directly useful for management decisions. In particular, information should be conveyed on the implications of uncertainties, as outlined in Section 3.1.

The RAF's separation of analyses of exposure and effects during the analysis phase is problematic, however. One reason is that in ecosystem management the distinction between exposure and effect blurs. For example, tree harvesting is the exposure responsible for effects on the spotted owl. Yet, the loss of trees is itself an endpoint of interest, ecologically as well as aesthetically. Thus, a change in forest pattern is both an exposure and an effect. Removal of water for irrigation of agricultural lands is a desired resource use, and thus a valued ecosystem function. Yet, the same water removal is also a stressor for in-stream biota that may be adversely affected by reduced stream flows.

Our approach is to include in the analysis phase all technical analyses of data, expert judgment, or analytical models required to address each question listed in Section 3.1. All these analyses rely on the conceptual models defined during problem formulation, which hypothesize effects pathways for each endpoint of interest as well as interactions among endpoints and stressors. Examples of the types of analysis that may be involved for each of the basic assessment questions outlined in Section 3.3.1 are as follows:

- **Ecosystem Functions** (question 1): Statistical associations among indicators of ecosystem function, to help define and quantify linkages and potential trade-offs among valued ecosystem functions.

- ***Societal and Ecological*** *Values (question 2): Spatial association between the locations of* ecosystems (e.g., wetlands) that have the potential to reduce flood peaks and downstream human population densities and property values, as one component of assessing the societal value of ecosystem functions.

- **Attainable Goals** (question 3): Retrospective analyses of indicators of valued ecosystem functions and statistical summaries (median, variability) of indicator data for minimally impacted reference sites (see Section 3.2.3), to define attainable ecological goals. U.S. EPA (1993) and (1994c) provide more detailed descriptions of approaches for quantifying attainable goals. EMAP uses the terms *nominal* and *subnominal*. Nominal conditions mean "the societal value (e.g., desired use) is being achieved compared with specific criteria" (U.S. EPA 1994c, p. 33), and thus are one form of an attainable ecological goal.

- **Current Conditions** (question 4): Statistical summaries of monitoring data for indicators of valued ecosystem functions, to characterize current conditions. U.S. EPA (1994c) outlines methods for analyzing EMAP data to characterize current conditions; one output is the estimated percentages of the total resource in a geographic area with nominal and subnominal conditions (Figure 3-13).

- **Major Stressors and Problems** (question 5): Statistical associations (over space and time) between indicators of ecosystem functions and stressors, weight of evidence, and process of elimination approaches, to identify the stressors and factors most likely to be responsible for subnominal conditions. U.S. EPA (1994c) outlines approaches for such diagnostic analyses, which they and the NRC (1991) refer to as environmental epidemiology. Other statistical approaches include (1) Bayesian statistics (Berger 1985) to calculate the likelihood of obtaining the observed data for a given set of alternative hypotheses and (2) path analysis (Hayduk 1987, Johnson et al. 1991) to calculate the strength of associations among multiple potential pathways of effects, both direct and indirect.

- **Risks of Functional Loss** (question 6): Projected future trends in indicators of ecosystem condition assuming current trends continue, estimated by (1) direct extrapolation of measured past trends or (2) projected future trends in stressors (e.g., projected trends in human population growth and development in the area, obtained from local managers) and estimates or analytical models of stressor-response relationships. Section 5.3 discusses our approach to ecosystem modeling.

- **Risk Reduction and Restoration Potential** (question 7): Application of analytical models to predict the ecological consequences of specific management strategies, or simpler classification approaches based on the concepts discussed in Section 3.2 (e.g., Figures 3-4 and 3-5).

- **Comparisons Among Management Scenarios** (question 8): Evaluation of the relative effectiveness of different management approaches, based on comparison of results from question 7 for different management strategies.

- **Geographic Targeting** (question 9): Geographic Information System (GIS) overlays of geographic patterns of indicators of ecosystem functions, landscape characteristics, and stressors, to identify areas at risk of functional loss and thus high priority for management attention. Spatially explicit modeling (which combines GIS and modeling) can also help target management actions to specific areas and sites.

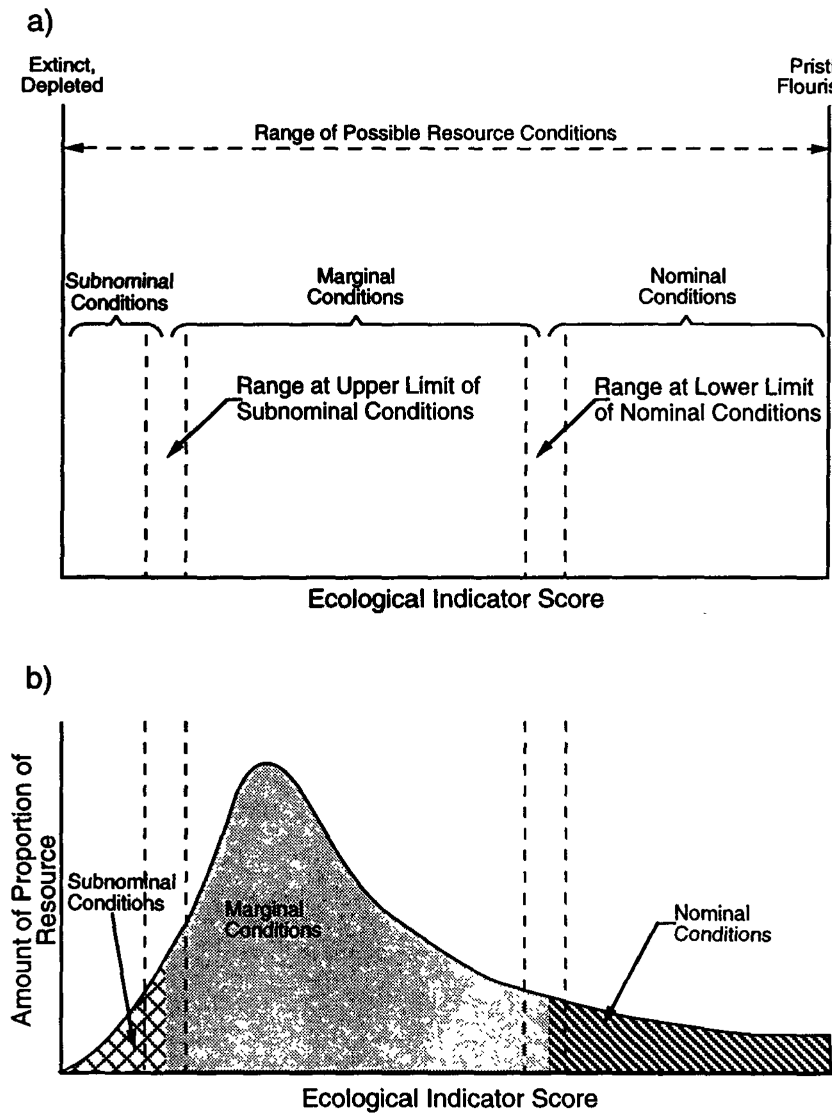


Figure 3-13. Ranges of subnominal, marginal, and nominal conditions (upper figure) and estimated proportion of total resource in each category (lower figure) Source: U.S. EPA 1994c).

- **Uncertainties** (question 10): Comparisons among different analytical approaches (e.g., different models) evaluating the same management scenario, in particular when different approaches reflect different plausible assumptions regarding, for example, stressor-response relationships. Dovers and Handmer (1993) outline what they refer to as an "analytical framework for ignorance auditing."

The above list is illustrative only and by no means exhaustive. It is beyond the scope of this document to outline the wide array of analytical approaches useful for assessments. Sections 4.3 and 5.3 provide additional examples of relevant analyses. The appropriate analytical technique depends, to a large degree, on the types of data available and the desired level of spatial and temporal resolution, quantification, precision, and accuracy (see Section 3.1).

The analysis phase is the second iteration through the basic assessment questions (Figure 3-14). The results for each question are then conveyed to interested stakeholders and managers in the third phase (interpretation and communication), which is the third iteration through the questions (Figure 3-14). Discussions between assessors and stakeholders/managers at this phase frequently identify additional information needs—for example, requests for more detailed analyses for specific subareas, specific stressors, or certain management scenarios. Thus, the iteration continues, back to problem formulation (to revisit the conceptual models, selected endpoints, spatial boundaries, etc.), analysis, and finally interpretation and communication (Figure 3-14). In some cases, more detailed analyses may require additional data collection, but others involve simply more effort-intensive analysis or modeling of existing data. Thus, assessments are viewed as an ongoing process of frequent and continual interactions between assessors and managers, consistent with the adaptive management approach (Figure 1-4).

3.3.3 Implementation of the Assessment Framework

Rarely does a manager request, "Tell me all the ecological information I need to know to manage this geographic area better." In general, the basic assessment questions outlined in Section 3.3.1 will be addressed within the context of more specific management questions. These specific management questions may reflect major environmental problems as perceived by the public (e.g., public concern about the potential extinction of spotted owls in the Pacific Northwest) or particular management opportunities (e.g., the influx of federal dollars to fund ecological restoration as part of the economic assistance to the region following the President's Forest Conference). The goal within ecosystem management is to consider even specific management questions within a broader context. A few examples follow:

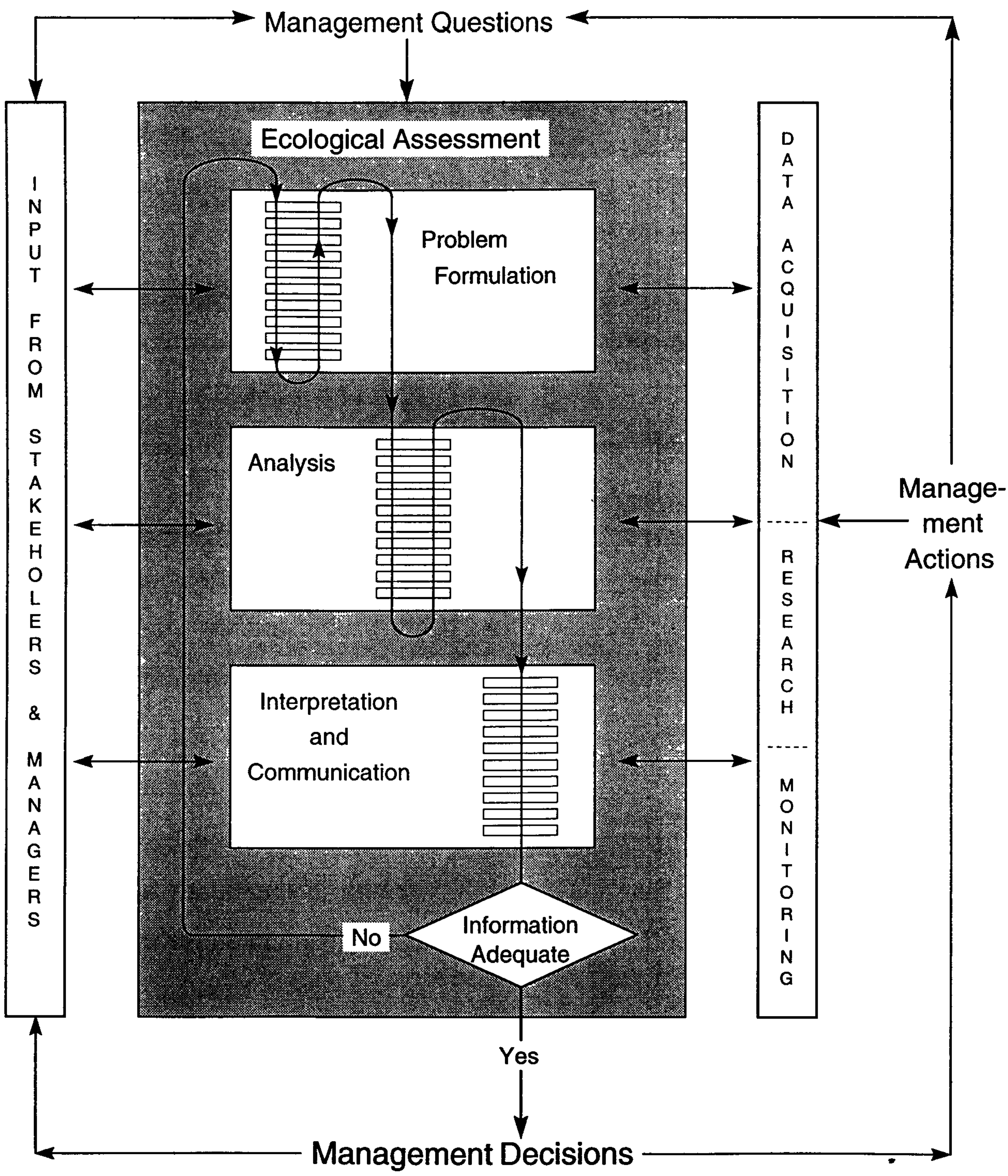


Figure 3-14. Ecological assessment framework for adaptive, ecosystem management.

- Timber harvests were halted on federal lands in the Pacific Northwest because the courts ruled that the USFS and BLM had not developed adequate plans to protect the spotted owl (see Section 1.3). Thus, the initial management question was, "How should we manage timber harvests on federal lands to protect a specific threatened species?" FEMAT expanded this question to evaluate the effects of alternative forest management approaches, not only on spotted owls, but on other endangered, threatened, and at risk species and stocks (e.g., salmon) and on the maintenance of old growth forests and associated biodiversity overall. The final plan (FEMAT 1993) included regional-scale guidance, as well as procedures for more detailed analyses and decision-making on a watershed and local scale.

- How should we allocate available federal funds for ecological restoration? Public attention focuses on salmon and the need for jobs. Potential benefits to salmon and local jobs are important considerations, but they should not be the sole basis for decisions. Restoration activities can also benefit other aquatic and terrestrial species (e.g., through the restoration of riparian areas) and reduce downstream sediment loads to lakes and estuaries. Ongoing efforts to develop a comprehensive strategy for allocating restoration dollars include large-scale (statewide) planning efforts to identify high-priority basins, more detailed analyses within high-priority basins to identify high-priority watersheds, and more detailed analyses within high-priority watersheds to select specific sites and restoration techniques.

- The State of Oregon is considering recertifying the operation of dams on the Willamette River. Thus, the management question is, "How should we operate these dams in order to provide an appropriate balance among water uses while still maintaining adequate flood control?" Initial concerns focused on trade-offs between using water for irrigated agriculture and for municipal water supplies. Our approach would be to simultaneously consider potential effects on in-stream water quality and biota (including migratory salmon) and on the restoration potential of riparian areas. These riparian areas provide, in turn, habitat for terrestrial and aquatic biota, and also contribute to flood control. Changes in landuse patterns also will influence potential future flood regimes, and could be factored into analyses of alternative options for dam operation.

- *Spartina*, an aquatic plant common in southern and eastern estuaries, is invading Willapa Bay, Washington. Thick growths of *Spartina* can eliminate habitat for oysters. Thus, concerns over reduced oyster harvests have prompted local managers to begin herbicide applications to limit *Spartina* growth. Should herbicides be applied and, if so, how much? A classical assessment might ask how effective the herbicide applications are at reducing *Spartina* growths and what other estuarine organisms may be adversely affected? We would expand the analysis to also ask, "Do some valued ecosystem functions benefit from *Spartina* growths? For example, does *Spartina* serve as habitat for young salmon or add to the carbon budget and overall productivity of the Bay? If *Spartina* growths are reduced through herbicide applications, will oyster harvests improve, or are other factors currently limiting oyster productivity (e.g., high rates of sedimentation)? If high rates of sedimentation are also a problem, would it be more effective to reduce sediment loads, through restoration activities within the watershed, or to apply herbicides to *Spartina*? What other ecosystem functions would benefit from reduced sediment loads?"

For each management question (or set of questions), we proceed iteratively through problem formulation, analysis, and interpretation and communication, through as many cycles as are needed to reach the level of resolution desired by the manager, at reasonable cost and within resource and time constraints (Figure 3-2). During each cycle, management questions are refined and analyses focus on the subset of endpoints, stressors, areas, issues, and types of analyses expected to contribute the most to improved decision making. Within each phase (problem formulation, analysis, and interpretation and communication), we iterate once through the basic assessment questions presented in Section 3.3.1 as they relate to the specific management questions. For each basic question, more specific assessment questions are defined to reflect the specific issues of interest (Box 3-C). In some cases, only a subset of the basic assessment questions will apply, or some questions may be given more weight than others. For example, an assessment dealing with the allocation of restoration funding might focus on geographic targeting (question 9), whereas comparisons among different management scenarios (question 8) would be a major focus of assessments related to dam operations or *Spartina* control.

A final issue in implementation is relationships across spatial scales. The basic management approach is as follows (Figure 3-15):

- Long-term goals, priorities, and general guidelines are established at a regional scale. For example, in FEMAT (1993), regional analyses were used to subdivide the area of interest (Figure 1-9) into seven categories or zones. Within each category, standard management guidelines apply (e.g., specified width of riparian reserve where tree harvesting is prohibited), unless additional analyses at the watershed scale demonstrate that the standard guidelines are unnecessarily prohibitive. Selected key watersheds were identified as high priority for further study and protection.

Box 3-C. Examples of Specific Assessment Questions Defined for a Given Management Question. Assessment questions are numbered to be consistent with the numbered list in Section 3.3.1.

Management Question: How should we operate the dams along the Willamette River to provide an appropriate balance among water uses while still maintaining adequate flood control?

Assessment Questions:

1. Ecosystem Functions. What ecosystem functions are affected, directly or indirectly, by dam operations and decisions about water allocations in the Willamette River Basin? What ecosystem functions affect basin hydrology, including the occurrence of floods, and thus might influence dam operations? How are these different functions related to each other?
2. Valued Ecosystem Functions. Which of the ecosystem functions identified in question 1 are most important ecologically (e.g., are critical for sustainability or play the most significant role in watershed ecosystems)? Which are valued most highly by local and regional stakeholders? Assumed answer (selected assessment endpoints): water uses for irrigation and municipalities; in-stream flow for aquatic ecosystem integrity and salmon; riparian area condition and restoration as habitat for aquatic and terrestrial biodiversity and as a contributor to flood control and improved water quality.
3. Attainable Goals. What levels of aquatic ecosystem integrity and salmon production are realistically attainable within the Willamette River and major tributaries? How should these attainable conditions be expressed (indicators and values or ranges)? What levels of riparian area condition are realistically attainable and how should they be expressed?
4. Current Conditions. How do current levels of aquatic ecosystem integrity, salmon production, and riparian area condition compare to attainable levels?
5. Major Stressors and Problems. What are the major reasons why current levels are below reasonably attainable levels? In particular, what roles do in-stream flows, water diversions, and dam operations play, relative to other stressors that may adversely affect these endpoints? What other stressors, unrelated to dam operations and water diversions, limit current condition levels?
6. Risk of Functional Loss. If current trends and existing management plans continue unaltered, what changes will occur in valued ecosystem functions? If dam operations and water diversions remain unchanged, will the condition of aquatic ecosystems, salmon, and riparian areas decline? (or improve?). How much are water diversions for agriculture expected to increase (input from managers)? What effect would these increased diversions have on other valued ecosystem functions?
7. Risk Reduction and Restoration Potential. How many acres, and where, of riparian area could be restored if downstream flows were increased during selected months? What benefits would riparian area restoration have in terms of increased aquatic and terrestrial biodiversity, flood control, and water quality improvement? How could land management plans for the Valley be changed to reduce the damages associated with major floods?
8. Comparison Among Management Scenarios. If in-stream flows are increased by changing dam operations, will salmon populations increase, or will other stressors prevent or limit the net benefits to salmon? What combination of water allocations, and associated dam operations, provides the greatest total net increase in ecosystem functions?
9. Geographic Targeting. Which areas and sites along the Willamette have the greatest potential for riparian restoration, i.e., where can the greatest increase in valued ecosystem functions be achieved at least management cost/effort? Which dams have the greatest influence on stream flow as they relate to effects on aquatic integrity, salmon, and riparian area condition? In what locales in the watersheds would wetlands or land management practices have the greatest influence on basin hydrology and reduce the potential for major floods?
10. Uncertainties. How robust are answers to each of the foregoing questions, given our uncertainties and major assumptions? If hypothesis B is true rather than hypothesis A, how would answers to the questions change? What chance is there that any of the management options might lead to irreversible ecological effects?

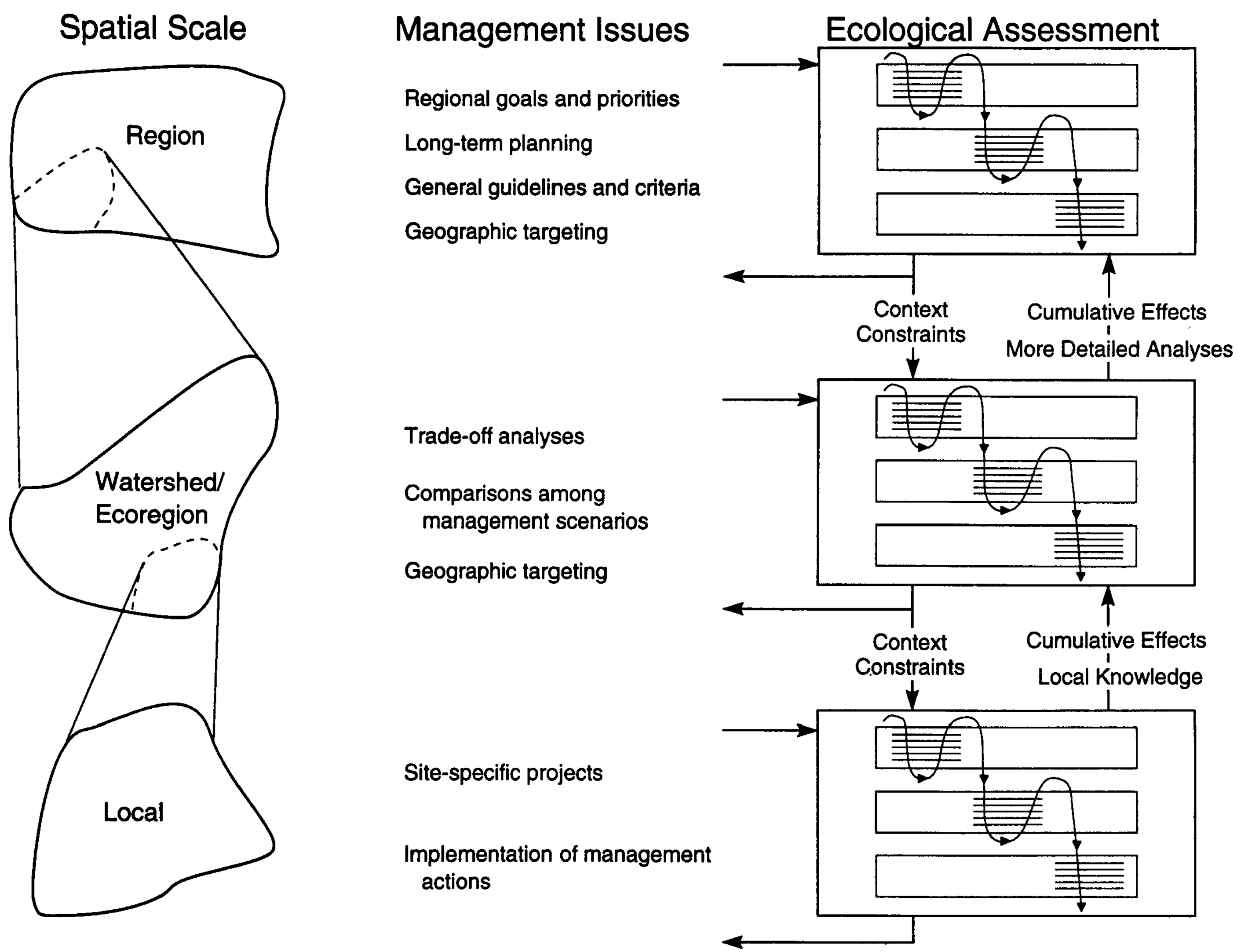


Figure 3-15. Linkages across spatial scales: Ecological assessment process at each scale follows the basic framework outlined in Figure 3-14.

- Regional goals and guidelines provide the starting point for more detailed analyses of trade-offs and specific management approaches at intermediate spatial scales (e.g., ecoregion or watershed) based on information on conditions within that area. The objective of these intermediate-scale analyses is to determine the most efficient way—ecologically, economically, and socially—to achieve desired resource uses within the guidelines and constraints prescribed by the regional plan. The output is a more detailed, spatially explicit planning document that sets more specific objectives, guidelines, and procedures for the area of concern.

- The intermediate-scale planning documents provide a basis for decisions and actions at the local scale and by public and private landowners on individual parcels of land. Site-specific characteristics, as well as feasibility and economic considerations, however, influence the specific actions implemented. Local conditions and considerations can require adjustments to larger scale plans and guidelines; ecosystem management involves a balance between top-down (large-scale) planning and bottom-up (small-scale) decision making (see Section 1.3).

- The combined, cumulative effects of actions taken at individual sites must be assessed to determine if the goals set at intermediate and regional scales are being achieved. Information derived from studies at smaller scales may lead to modification of regional- and intermediate-scale plans, which in turn affects local management decisions.

The activities and decisions at all scales are linked, and the process iterates back and forth across scales. Strategies developed at large scales provide context for and guide implementation at smaller scales, while information from smaller scales provides feedback on assumptions and decisions made at larger scales.

Ecological assessments provide the scientific information that facilitates and informs management decisions at each of these spatial scales. The basic approach to assessment is the same, although the types of questions vary to match the management approach and goals at each scale (Figure 3-15). At regional scales, analyses are generally of coarser scale (larger grain). A major focus is geographic targeting of subareas considered high priority for further study or management attention. Comprehensive assessments (involving detailed analyses of all 10 assessment questions) occur most often at the intermediate spatial scale, where decisions are made about the relative merits of different management strategies and trade-offs among endpoints. Site-specific assessments often focus on individual, locally important stressors, the potential effects of a specific proposed project, or alternative implementation designs (e.g., for restoration projects). An assessment at any given scale may also require analyses at larger and smaller scales to provide context and mechanistic information, respectively, as well as to address scale-dependent and emergent properties as discussed in Section 3.2.2.

By no means have we resolved all the details and difficulties of conducting ecological assessments for ecosystem management. This section simply outlines our general approach and starting point. Like the RAF (and in cooperation with the RAF), our next step is to further develop and refine the assessment approach through case study applications, described in Sections 4–7. These case studies should also contribute to Agency-wide efforts under the RAF to develop ecological assessment protocols.

4. REGIONAL BIODIVERSITY

This section describes proposed research at a regional scale. Section 4.1 provides background information on regional assessments and biodiversity, Section 4.2 presents the research objectives, Section 4.3 describes the strategic approach, and Section 4.4 lists the major contributions of this work. We will focus on developing and improving approaches for conducting regional assessments, as well as on supporting the advancement of ecological information, analyses, and understanding. The assumed budget is $650K per year over five years (see Table 2-1).

4.1 BACKGROUND

Ecological assessments are necessary at a regional scale for issues that have broad geographical extent and need integration and coordination across a large regional area. Depending on the policy needs to be addressed and the availability of information, regional assessments can take several forms, including (1) retrospective assessments of the status and trends of regional resources, (2) geographic targeting of high-priority subareas that deserve further study or focused management attention, (3) comparative risk/benefit assessments of alternative management options, and (4) evaluations of the effectiveness of previous management actions. The outcomes of these regional assessments can lead to development or modification of strategy plans that include regional goals and planning targets. Consequently, they represent a source of guidance for decision makers from local to regional scales and a feedback mechanism on the success or failure of the combined environmental management actions at regional, state, and local levels (see Figure 3-15). Regional assessments can also provide a forum for bringing diverse stakeholders together before an action is taken to identify the many issues and their implications and to combine wise management of ecological resources and societal expectations into an integrated plan.

Most regulatory and land management decisions are made within the context or constraints of the mission or legislative authority of an individual organization. There may be little attempt to factor in the implications of the decision over larger spatial or temporal scales or in the context of other, often conflicting management concerns. In many cases, a larger contextual framework may not even exist to be considered in the decision making. A common, unstated assumption is that if the decision is acceptable at the scale (or within the context) being considered, it is acceptable at all scales [and contexts; see Knopf and Samson (1994) for example]. There is a need to inform and coordinate these many individual decisions around an information base and a plan that represent the best available science, with consideration of the various scales affected and input from stakeholders.

Regional assessments supporting development of these regional plans or strategies will roughly follow the assessment framework of EPA's Risk Assessment Forum (RAF) (U.S. EPA 1992), as discussed in Section 3. However, regional assessments have features that require an extension and expansion of the RAF framework. Probably the greatest need for expansion comes in the problem formulation phase, due to the magnitude of the problem. Although the RAF framework document was intended to guide the development of ecological assessments for one or multiple stressors at any spatial scale, it does not provide sufficient guidance for regional-scale assessments where several environmental stressors interact across the jurisdiction of a multitude of government organizations involving a variety of public and private stakeholders. Problem formulation involving communication with decision makers and scientists within an organization is now recognized as essential, but communication involving decision makers and scientists from a variety of organizations with differing missions, legislative authorities, and philosophies is perhaps the greatest challenge for implementing ecosystem management.

Risk assessments of any type provide information of value in supporting management decisions that combine managers' perceptions of environmental goals with the best available scientific information, help managers understand the nature of the tradeoffs associated with different management options, and increase the likelihood that goals will be achieved effectively and efficiently. The process of risk assessment at the regional scale, although more complex in many ways than assessments at smaller spatial scales, is even more important because of the diversity of decision makers and stakeholders involved. The assessment process can help make the scientific issues and tradeoffs more transparent, thereby facilitating the dialogue over the most central issues affecting decisions.

As part of establishing the scope and content of a regional assessment, it is important to evaluate what ecological endpoints and/or functions may be at risk at the regional level. What environmental issues are beyond the purview of local and state governments and require a broader perspective or context for sustainable management? It is also important to recognize that many resources require management on scales larger than the region (e.g., migratory bird populations, anadromous fish). In such cases, regional assessments must consider the region's contribution to the overall management of the resource (e.g., as laid out in a multi-national agreement).

We could consider a great many issues at a regional scale, but one of the endpoints of high priority for regional assessments is biodiversity. In the United States, 2954 species have been listed by the federal government as threatened or endangered or are under consideration for such listing (Table 4-1). Four percent of the 1556 bird and mammal species and 12% of the 20,000 plant species are listed as threatened. In 1990, the SAB issued "Reducing Risk: Setting Priorities and Strategies for Environmental Protection," which ranked the greatest environmental risks according to a panel of experts (SAB 1990).

Table 4-1. Taxonomic Comparison of Listed and Proposed Threatened and Endangered Species (Source: Flather et al. 1994).

Taxon	Federally Listed[a]	Category 1[b]	Category 2[c]
Mammals	65	7	202
Birds	85	5	54
Reptiles	34	1	54
Amphibians	11	4	50
Fish	91	15	118
Snails	13	27	143
Clams	42	2	59
Crustaceans	10	2	91
Insects	23	9	584
Arachnids	3	1	27
Plants	351	526	1572
Other[d]	0	0	14
TOTAL	728	597	2954

[a] As of 31 August 1992.

[b] As of 1989–1990. Category 1 includes those species for which sufficient biological evidence exists to support official listing, but proposed rules have not yet been listed.

[c] As of 1989–1990. Category 2 includes species for which some evidence indicates that listing may be appropriate, but conclusive biological evidence to support issuing proposed rules is lacking.

[d] Includes sponges, hydroids, flatworms, earthworms, and millipedes.

"Species extinction and overall loss of biodiversity" and "habitat alteration and destruction" were listed as two of the top four high-risk issues. Similarly, the Ecological Society of America identified the ecology and conservation of biological diversity as a critical element of its "The Sustainable Biosphere Initiative: An Ecological Research Agenda for the Nineties" (Lubchenco et al. 1991). Because of the integrative nature of biodiversity and its importance as a regional-scale assessment endpoint, we selected biodiversity as an initial focus for regional-scale research within the PNW research program.

What is biodiversity? Biodiversity is a complex quality that goes beyond the notion of species diversity. It includes both the number and relative frequency of biological entities from genes through populations, species, communities, and ecosystems. It represents "the variety of life, and its processes; including the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur" (Keystone Center 1991). Society recognizes a large variety of aesthetic, economic, conservational, and educational values associated with biodiversity. All of these depend on the following "first principles." Biodiversity is a manifestation of genetic diversity. It is the primary raw material that is filtered by natural selection, resulting in evolutionary and ecological adaptation of biota and their associated ecosystems to environmental conditions. Minimizing additional loss of biodiversity will provide the best assurance that biota will adapt to environmental change.

Of the approximately 10 million species (total) on the Earth, the majority exist in human-managed ecosystems (Pimentel et al. 1992) and many exist only on privately owned land. Several attempts have been made to use measures of biodiversity (usually species richness or distributions of rare or unprotected species) in landuse planning and for decisions on protecting biodiversity. In Australia, for example, plant and animal distributions have been used in spatially explicit analyses for selection of reserve areas (Margules and Nicholls 1987, Margules et al. 1988, Pressey and Nicholls 1989, 1991, Nicholls and Margules 1993). These analyses have shown that many combinations of reserves can be selected to achieve complete coverage of all or most species. Some species may occur in very limited ranges, making those areas essential to conservation strategies. However, many species are more widely distributed and many combinations of reserves may exist that include those species.

Within the United States, the objective of the National Biological Survey (NBS) Gap Analysis Program (GAP) is to identify gaps in the current system of land management for protecting biodiversity, that is, areas of high biodiversity that are not currently in protected areas (Scott et al. 1993). Spatially explicit data on the known occurrence of terrestrial species are combined with information on species-habitat associations and distributions of vegetation types to estimate regional species distributions.

To date, GAP has relied primarily on data for terrestrial vertebrates, because of the relative lack of information for other biological groups. Given the unequal completeness of abundance and distribution data across taxa, an important question is, "To what degree do areas of high biodiversity for one taxa coincide with those of other taxa?" Prendergast et al. (1993) found that in Great Britain, areas species-rich for one taxa were not predictive of areas species-rich for other taxa. Also, many of the rare species in this analysis did not occur in the most species-rich areas. Thus, efforts to conserve biodiversity using available but limited databases may not be adequate; at least they should be handled cautiously with regard to the extent to which they include species not covered in the data set.

The long-term management of biodiversity will require more than a system of habitat reserves (Franklin 1993). Although a well-designed system of protected habitats is important, and probably essential for some species, it is equally important to recognize that the human-managed landscape matrix is a critical component of biodiversity management and may greatly affect the success of the reserve system. The landscape matrix is critical to the conservation of biodiversity for (1) providing habitat at smaller spatial scales, (2) increasing the effectiveness of reserve areas, and (3) providing connectivity in the landscape (Franklin 1993). Much of the focus on connectivity has been on the use of habitat corridors, although there is considerable debate as to their effectiveness (Simberloff and Cox 1987, Simberloff et al. 1992, Hess 1994).

Strategies for sustaining biodiversity cannot be based solely on analyses of spatial patterns of habitat and species distributions. They must also be based on a sound understanding of the ecosystem properties (processes, structure, components, scale) required to sustain biodiversity and of ecosystem dynamics over time. Two areas can have similar levels of biodiversity, even though the actual assemblages and processes that shape them may be fundamentally different. Low species diversity can reflect, for example, competitive exclusion, a period of isolation from a larger pool of species (e.g., on remote islands), or high pollution loads. Under some circumstances, the highest levels of biodiversity can occur at intermediate levels of disturbance, rather than in pristine habitats. Biodiversity analyses and management plans must also account for long-term variations in climate, succession, stochastic variation, and the many natural factors that make local extinctions and reinvasion a frequent occurrence.

Given the integrative nature of biodiversity as a measure of anthropogenic changes in the environment, there is a need to continue the development of methods for using biodiversity-related data in scientifically defensible regional conservation strategies. As defined by FEMAT (1993; see Section 1.3), the purpose of a regional conservation strategy is to protect valued ecosystems, habitats, species and species assemblages, and biodiversity. We propose to focus our research on regional-scale methods, analyses, and ecological assessments of biodiversity to support development of regional conservation strategies, as one example of a management issue that must be addressed at a large spatial scale. This case study assessment will also provide the focal point for more process-related research, designed specifically to test key assumptions and address major uncertainties in our understanding of regional ecosystems identified in the assessment process. Consistent with the approach outlined in Section 2.1, the assessment process will be used both to prioritize research needs and as a framework for integrating research results in a format useful for decision makers.

4.2 OBJECTIVES

Thus, the major objectives of the Regional Biodiversity research component are as follows:

- Develop and refine methods for integrating and interpreting information on biodiversity at a regional scale.
- Develop and demonstrate the ecological assessment process at a regional scale to support development of regional conservation strategies based on best available science and stakeholder input.
- Conduct research targeted at testing the accuracy of assessment outputs, evaluating key assumptions, and addressing major knowledge gaps and uncertainties about regional ecosystems identified during the assessment process.

4.3 APPROACH

We propose a two-phase strategic approach to research on regional biodiversity. In phase 1, we propose to conduct a regional assessment based on existing data and knowledge, building on substantial efforts already ongoing through GAP and the interagency Biodiversity Research Consortium (BRC). Results from this assessment, including sensitivity analyses performed to identify key assumptions and uncertainties, will form the basis for prioritizing and designing subsequent research in phase 2. We believe this approach offers the most effective means of advancing our understanding of regional biodiversity and will provide sound science to support ecosystem management decisions at a regional scale. Decisions about phase 2 will be made following one or more workshops in which our state of knowledge on regional biodiversity will be critically summarized and evaluated and then contrasted with regional management needs for information on biodiversity. We will concentrate in FY95 and FY96 on the initial assessment. Phase 2 research will begin in FY96 and expand in FY97 and beyond. Approximate budgets per year for these two activities are presented in Table 4-2.

Table 4-2. Anticipated Distribution of Resources for the Regional Biodiversity Research Component for FY95 through FY99 (in Thousands of Dollars).

Project	FY95	FY96	FY97	FY98	FY99
Phase 1: Initial Regional Assessments of Species Diversity	$650K	$400K	$250K	-0-	-0-
Phase 2: Targeted Research on Biodiversity	0	$250K	$400K	$650K	$650K
TOTAL	$650K	$650K	$650K	$650K	$650K

4.3.1 Regional Assessment of Species Diversity

This project will integrate and supplement, as needed, ongoing species diversity analyses in the region in order to provide the best possible regional-scale assessment of species diversity. Application of the tools and information generated in this project will help to determine (1) what species and communities are unprotected or poorly protected and need consideration in the face of current and possible future stressors, (2) what technical options exist for conserving biodiversity on a regional scale, and (3) what research is most needed to increase our confidence in future assessments and policy decisions. We will also work with state and federal managers and other stakeholders within the region to facilitate the integration of this scientific information on species diversity with related social and economic concerns in order to support development of a regional conservation strategy.

Project-Level Objectives

- Enhance methods for determining species-rich areas that are high priority for further study and management attention.
- Develop a multi-scale regional assessment of species diversity, including the threats to species diversity and options for its conservation.
- Identify major knowledge gaps and research needs for improved regional-scale assessments of biodiversity.

Approach

This project builds directly on the approaches and databases currently being used by GAP and the BRC. Proposed research activities are designed to supplement and expand ongoing activities as needed, to provide a uniform database, consistent approach, and regional-scale assessment for the Pacific Northwest.

The USFWS (now NBS) initiated GAP to map species distributions and identify priority areas containing species not now represented in areas managed for their natural values (Scott et al. 1990). Vegetation maps are constructed from Landsat imagery, generally thematic mapper (TM) imagery, but sometimes multi-spectral scanner (MSS) (Jennings 1993). For each species of terrestrial vertebrate in an area, a habitat association model is used to identify polygons on the vegetation map considered suitable habitat. Known occurrences of each species are compiled by county, from published literature and museum records. Range maps for the species are then estimated as those polygons with vegetation classes considered suitable habitat that lie in counties with known species occurrence.

GAP is organized, for the most part, at the state level, as a cooperative effort of the NBS and other public and private organizations with expertise and data on biodiversity. For example, in Oregon the NBS, through the Idaho Cooperative Wildlife Unit, is working cooperatively with the Oregon Department of Fish and Wildlife, The Nature Conservancy, and Defenders of Wildlife. Initial GAP analyses were completed recently for Idaho and are underway in Oregon and Washington.

The BRC is an interagency consortium that includes the NBS (and GAP), the EPA, the U.S. Forest Service (USFS), the Bureau of Land Management (BLM), the U.S. Geological Survey (USGS), the Department of Defense (DoD), and The Nature Conservancy (TNC) (Kiester et al. 1993). The BRC was established in 1993 to enhance GAP by extending the analysis to examine additional data layers and methods of analysis, and also to encourage data sharing and consistency among federal agencies. The geographic units for the various databases are standardized to correspond to the EMAP hexagon grid (see Box 2-A; Figure 4-1). Spatial patterns of species richness, generally using databases the same as or similar to those of GAP, are being compared to databases on land ownership and anthropogenic stressors, to determine areas of high biodiversity that need additional investigation and possible protection or management consideration. Databases on habitat fragmentation, pollution, exotic species introductions, and nonanthropogenic stressors, such as climatic variables and topography, are included in the analyses so that their association with and influence on regional patterns of species diversity can be evaluated. Figure 4-2 and Box 4-A provide an overview of the BRC analysis approach.

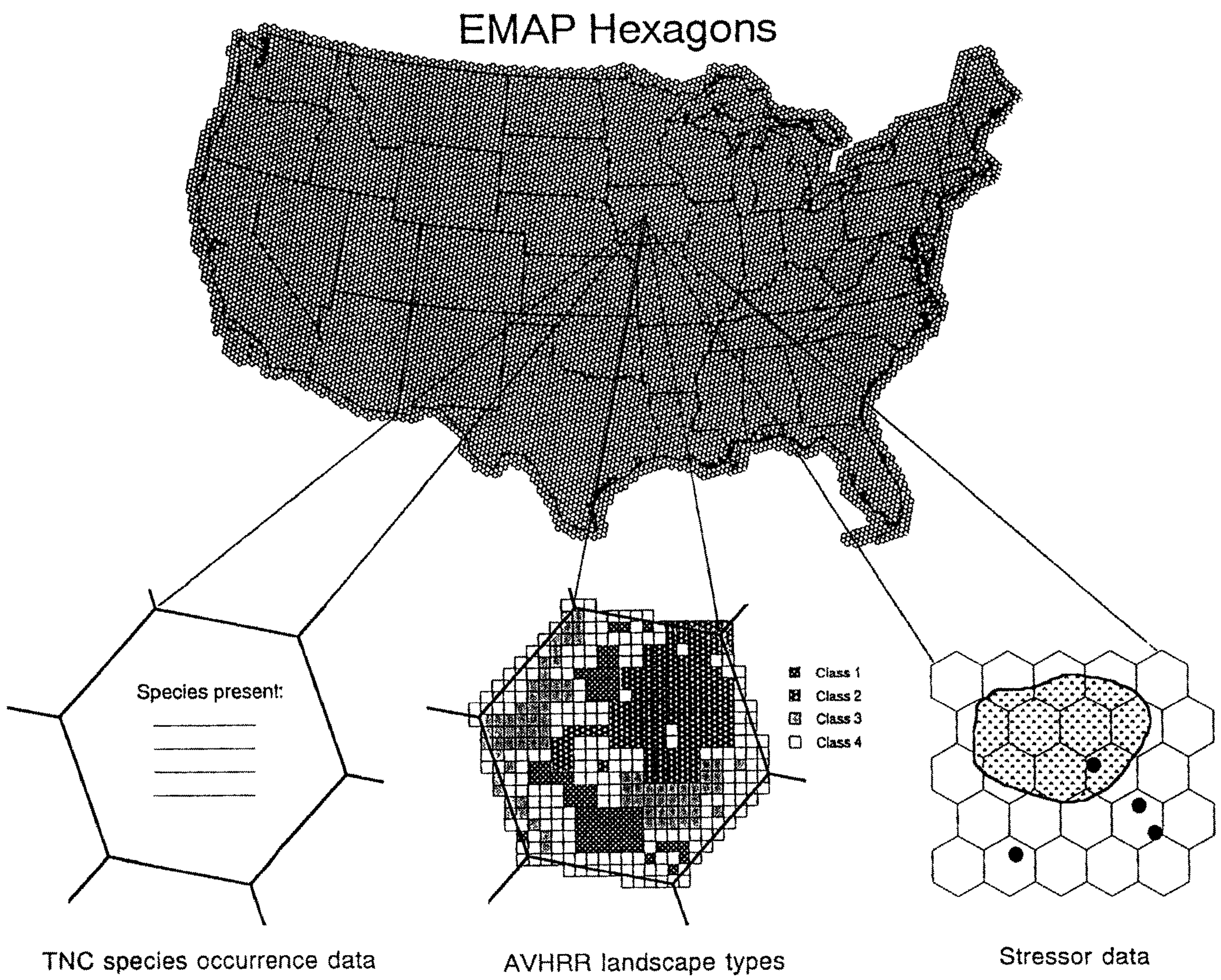


Figure 4-1. Spatial framework for Biodiversity Research Consortium analyses. For each EMAP hexagon, data are compiled on species present, landscape types, and stressors (Source: Kiester et al. 1993).

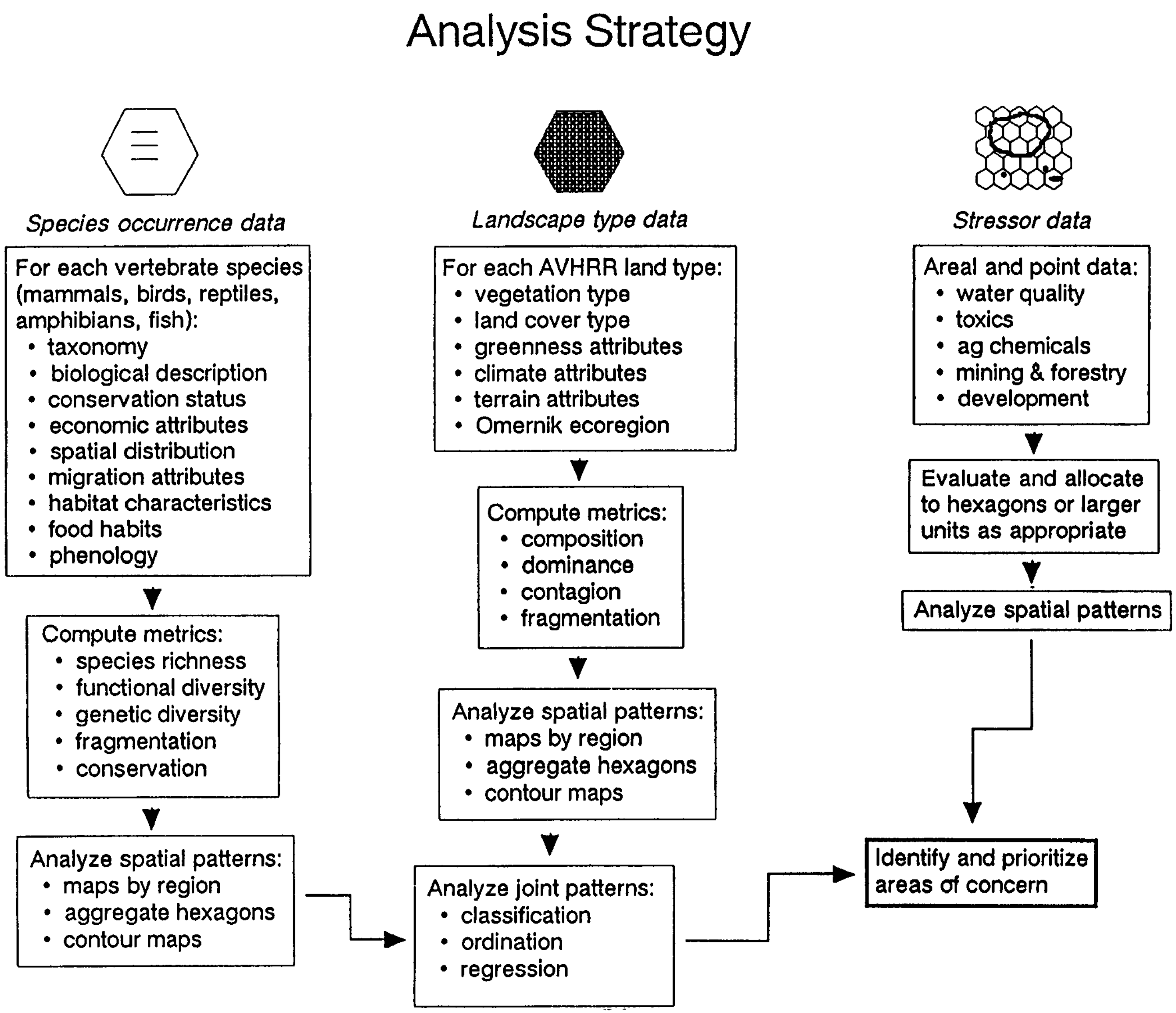


Figure 4-2. Biodiversity Research Consortium analysis strategy (Source: Kiester et al. 1993).

Box 4-A. Overview of Biodiversity Research Consortium Analysis Approach.

The Biodiversity Research Consortium (BRC) is actively developing and testing regional-scale approaches for assessing biodiversity and the association between biodiversity and stressors. This box provides an overview of BRC ongoing and planned analyses, based on Kiester et al. (1993) and discussions with BRC investigators.

Biological and Environmental Diversity. The BRC uses a variety of quantitative approaches (termed *richness analyses*) to determine combinations of EMAP hexagons in which (1) all or nearly all species are represented, (2) all threatened and endangered vertebrates species are represented, and (3) all or nearly all vegetation types or land covers are represented. Analyses (termed *sweep analyses*) are also being conducted to determine how well various measures of diversity represent other measures, for example, (1) how well those areas that incorporate all or nearly all vegetation types or land covers (environmental diversity) also incorporate all or nearly all species (species diversity), (2) how well areas in which species diversity is well represented also represent environmental diversity, and (3) how well areas in which threatened and endangered vertebrates are represented also represent total species diversity. Finally, a GAP analysis will determine the degree to which species are already represented in areas managed for their natural values.

Natural Factors Affecting Biodiversity. Many natural factors affect regional patterns of biodiversity. The BRC includes analyses of spatial associations between biodiversity and various natural factors, in part, to better detect effects from anthropogenic stressors. Variables included in these analyses were selected based on two major theories of how natural factors affect and control biodiversity. The first suggests that a greater amount of available energy (e.g., as measured by the total photosynthetic capture of carbon) results in a greater amount of biodiversity (Wright 1989, Currie 1991). Thus, BRC analyses include variables that predict photosynthesis and primary production, that is, various weather and climate variables (e.g., temperature, rainfall). The second theory is that there is a relationship between structural complexity and diversity (MacArthur 1965, Williams 1972, Bell et al. 1991) at various scales. This theory leads to the inclusion of variables indicative of topographic diversity at the largest scale. Data for selected variables are summarized by EMAP hexagon. Many BRC analyses and data collection efforts are built around these two hypotheses; however, the development of databases of multiple environmental factors also provides for exploring alternative hypotheses that could relate regional-scale biodiversity to environmental factors.

Anthropogenic Stressors. The relationship between biodiversity losses and human activities is very complex. It is unlikely that direct causal linkages can be demonstrated, especially on a regional scale, because of the incommensurate nature of biodiversity and stressor data. Thus, BRC analyses focus on broad-based indicators of major stressors and variables likely to predict potential future losses of biodiversity. Specifically, analyses include indicators of human population growth rate and the level of human activity as evidenced by (1) road density and distribution, (2) intensity of agriculture, (3) intensity of grazing, and (4) intensity of forest harvesting. Stressor indicators are computed for each EMAP hexagon using a variety of existing data sets.

Associations Between Biodiversity and Stressors and Hexagon Prioritization. Information on stressors is used in two ways: (1) to evaluate spatial associations between observed patterns of biodiversity and anthropogenic stressors, using information on natural factors to adjust for background noise, and (2) to prioritize EMAP hexagons for further attention based on both the current level of biodiversity and the level of stressors that may adversely affect biodiversity. The Classification and Regression Tree (CART) approach (Breiman et al. 1993) and various other multi-variate techniques (e.g., Simpson analyses) are being used to assign relative weights to the importance of natural factors and anthropogenic stressors. Prioritization analyses will be based on a composite stressor index and composite diversity index, to identify hexagons that have both high diversity and high levels of stressors that may lead to eventual biodiversity losses.

Pilot BRC studies are ongoing in Oregon and Pennsylvania, as is methods development work in several other states in other areas of the country (including Idaho). In Oregon, all data layers (i.e., species, landscape diversity, and stressors) have been compiled and initial analyses have been completed to identify areas within Oregon (i.e., the subset of hexagons) in which the state's species diversity is completely or nearly completely represented. Associations between species diversity, environmental factors, and stressors (see Box 4-A) will be examined over the next year.

EMAP will provide additional information on regional landscape characteristics. Working with the NBS, USGS, and others, EMAP is in the process of acquiring and classifying Landsat TM imagery for the entire United States. Classification of the Pacific Northwest is likely to occur in 1995 or early 1996.

Both GAP and BRC use existing data on species occurrences, remote sensing imagery, and information on species-habitat associations to estimate regional distributions.of species and species richness. To date, most of the effort has focused on terrestrial vertebrates, because of the greater availability of species occurrence records for these organisms, along with our ability to use remote sensing to characterize habitat (i.e., remote sensing estimates of vegetation type). Thus, regional assessments based on GAP and the BRC will also be biased toward terrestrial vertebrates, with significantly greater uncertainty for other terrestrial and aquatic groups. Within Oregon, BRC biodiversity data layers include information on mammals, birds, reptiles, amphibians, butterflies and skippers, fish, freshwater mussels, and trees.

We propose to expand on the work of GAP and the BRC to complete consistent, state-of-the-art (given currently available data and tools) regional analyses of species diversity for the Pacific Northwest (Oregon, Washington, and Idaho). This effort will require standardizing data sets for species, habitats, and stressors for the three states to the EMAP hexagon grid. Also, BRC analyses will be expanded by (1) identifying habitats at risk by examining the size frequency distribution for each habitat type and evaluating the extent to which habitat types are included in areas currently managed for their natural values, (2) conducting richness and sweep analyses (see Box 4-A) for threatened, endangered, and candidate plant species, (3) conducting analyses by taxonomic group, (4) conducting analyses by ecologically defined regions (e.g., vegetation polygons or subecoregions) rather than EMAP hexagons, and (5) evaluating the influence of spatial scale and level of resolution on the selection of priority areas.

We do not expect to be able to develop quantitative stressor-response relationships that could be applied at a regional scale. Rather, the goal is to develop a compendium or synthesis of information adequate to identify the most significant stressors within a given area, to develop a qualitative profile of the potential effects from various stressors, and to assist in relative assessments of the costs and benefits of various management scenarios. Options for these more refined analyses will be considered as part of the synthesis workshop to be held in 1997.

These technical analyses will provide a basis for an integrated regional assessment of species diversity. The assessment will follow the basic assessment framework and approach outlined in Section 3. Interactions with stakeholders will be organized through EPA Region 10 and state agencies. Initial steps will include (1) developing a conceptual model, (2) delineating linkages between species diversity and regional stressors, and between species diversity and other assessment endpoints of interest, (3) clearly defining the assessment questions and objectives within the context of biodiversity, and (4) identifying management goals and constraints. The assessment will describe the current status of species diversity in the region, identify the most important anthropogenic stressors on species diversity, and suggest alternative approaches for conserving species diversity in the face of current and future stressors. Various combinations of areas rich in species diversity will emerge that, as a synthesis of the above analyses, represent scientifically defensible sets of areas in which biodiversity conservation goals might be reached. The emphasis will be on targeting areas considered high priority for further study and management attention. The assessment will consider the entire region—areas managed for their natural values as well as the human-managed matrix and its role in an overall conservation strategy.

We will also work with EPA Region 10 and the states to demonstrate how this scientific assessment could be used in the formulation of a regional or statewide conservation strategy. In particular, management options identified or evaluated in the assessment will be evaluated and revised in a forum consisting of technical experts, regional decision makers, and other stakeholders. We will participate in, and partially fund, state efforts to combine our technical analyses with matching information on social and economic concerns, at regional, state, and local levels. Local-scale analyses will be conducted for selected areas identified as high priority in the regional assessment. These local-scale analyses will serve two purposes: (1) to groundtruth regional-scale estimates of species diversity and stressors and (2) to test and demonstrate, at a smaller spatial scale, the cross-scale linkages between regional plans and management decisions and supporting technical analyses. In the selected areas, finer scale information on landuse, vegetation, and terrestrial vertebrate species will be compiled (and new data collected as needed) and compared to regional-scale estimates. Working with local stakeholders and decision makers, we will define a series of alternative future scenarios that consider various levels of human population increases and existing and proposed landuse plans, and expected effects on species diversity in the specific area and region. In addition to providing a test of the larger scale assessments, these local-level analyses will identify information gaps and other technical issues that need to be considered in the state and regional assessments and in the future design and implementation of regional conservation strategies.

Clearly, the existing data and analysis approaches have limitations, recognized by both GAP and BRC researchers. Both programs are working actively to address these limitations within the constraints of their available resources. Some of the limitations result from the quality and availability of data for the types of analyses described above. There are also significant uncertainties in our understanding of the ecological processes and associations involved in maintaining functional ecosystems. These uncertainties and limitations must be clearly conveyed to decision makers.

Timeline

We believe it is essential to involve state agencies directly in the regional assessment of species diversity, and in subsequent efforts to translate this scientific information into regional or state conservation strategies. For this reason, cooperative agreements with appropriate state agencies will be a major (although not the only) funding mechanism. Analyses in Oregon will begin in 1995; similar efforts in Washington and Idaho will begin in 1996. Analyses for each state will be a two-year effort. Combining of these state analyses into a regionwide assessment will begin in 1996 and continue to expand as additional information becomes available.

4.3.2 Phase 2 Research

We can view the phase 1 assessment as a hypothesis or set of hypotheses about the distribution of species diversity in the Pacific Northwest and the environmental factors that affect species diversity, based on current understanding and information. In phase 2, we propose to test this hypothesis, that is, to evaluate key components of the assessment output, underlying assumptions, and uncertainties. Clearly, we cannot test the assessment *in toto*, because of the large spatial scales and long time frames involved. We believe, however, that field studies and experiments can be designed to evaluate selected, important components or aspects of the assessment. For example, the simplest (although not necessarily the most important) would be to evaluate the accuracy of estimated regional patterns of species diversity. More difficult would be testing the validity of stressor-response relationships derived from observed spatial associations between species diversity and environmental factors, or testing the basic assumptions about important processes responsible for observed patterns.

Project-Level Objectives

We have not selected specific objectives for projects to be implemented in phase 2. Rather, project objectives (and testable hypotheses) will be derived directly from the regional analyses and assessment process described in Section 4.3.1. Decisions about phase 2 will be structured following one or more workshops in which our state of knowledge on regional species diversity will be critically summarized and evaluated, and then contrasted with regional management needs for information on biodiversity.

The overall objective of phase 2 research is as follows:

- Conduct research to test the accuracy of assessment outputs, evaluate key assumptions, and address major knowledge gaps and uncertainties about regional ecosystems identified during the assessment process in a manner relevant to the formulation of regional policy.

Approach

High-priority research for phase 2 will be selected based on (1) sensitivity analyses conducted as part of the regional assessment in Section 4.3.1 and (2) synthesis and evaluation workshops planned for 1996 and 1997. The workshops will involve external scientists, not involved in the PNW research program, as well as scientists actively engaged in PNW research, and current and potential users of this information. The purpose will be twofold: (1) to identify the major weak links in the regional biodiversity assessment that are amenable to further research, based on a review of the assessment results (including sensitivity analyses) and the overall conceptual model for regional biodiversity, and (2) to identify issues whose resolution would contribute to current and future management decisions.

Examples of the types of research envisioned include gathering improved information on biodiversity as a whole, rather then emphasizing terrestrial vertebrates species, and analyzing more rigorously the landscape patterns and processes that control biodiversity. Examples of the latter include studies of the roles connectivity and the human-managed landscape matrix play in the conservation of biodiversity and (2) an expanded analysis of anthropogenic stressors, to develop a more detailed framework for evaluating and prioritizing potential effects of stressors on biodiversity. The fundamental goal is to improve our understanding of the basic ecosystem properties (structure, processes, dynamics) required to sustain and manage biodiversity. Brief discussions of these research areas are provided in the paragraphs that follow. Specific research plans will be developed as a result of the synthesis and evaluation workshops. These plans will be subject to external peer review before implementation.

Biodiversity. Phase 1 analyses will consider all taxa for which adequate data exist to estimate regional distributions. Because of data limitations, however, these analyses will be most thorough, certain and consistent for species of terrestrial vertebrates. Terrestrial vertebrates represent only one component of species diversity. It is unlikely that strategies designed to manage this component of biodiversity would effectively or efficiently contribute to the management of other taxa (see Prendergast et al. 1993). Thus, in phase 2, we may decide that additional research is warranted on other components of biodiversity. This research could address other taxa or other levels of biodiversity, such as populations within species, gene pools, or communities.

Aquatic biota represent an important component of species diversity. More than one-third of the animals listed by the federal government as endangered or threatened are aquatic (see Table 4-1) and these animals are directly affected by one of EPA's key statutes, the Clean Water Act. Thus, a high priority may be given to additional work on aquatic biodiversity in particular. Data collection activities would be fully coordinated with EMAP and with other interagency efforts, such as FEMAT, that may collect data on aquatic species. Data would be acquired to characterize both the regional patterns of aquatic biodiversity and the natural and anthropogenic stressors most likely to affect aquatic biodiversity. Analysis of existing and new data could identify gaps in management efforts to protect aquatic species, as well as in understanding and information.

Process Studies. The goal of this research is to identify the features, processes, and properties of the landscape that are most important in sustaining regional biodiversity and, therefore, to inform decisions about regional biodiversity management. Two potential general research areas (landscape patterns and stressors) are discussed as examples. Research activities may include field studies, field experiments, modeling, and more refined analyses of spatial patterns, in a mode of hypothesis testing rather than an exploratory mode.

A. Landscape patterns. Regional conservation strategies must consider not only establishment of habitat reserves, but also sound management of the entire landscape matrix. Habitat fragmentation has been implicated as a major cause of biodiversity declines (Forman 1990, Saunders and Hobbs 1991, Flather et al. 1992, Soule et al. 1992, Van der Zee et al. 1992). Habitat linkages or corridors have been proposed as a means of extending the apparent size and effectiveness of individual habitat patches (Noss 1987, 1992, Csuti 1991, Saunders and Hobbs 1991). Many questions remain, however, about the importance of connectivity and role and effectiveness of habitat corridors (Simberloff and Cox 1987, Simberloff et al. 1992, Hess 1994). Other issues include the role that basic patterns of clumping and distributing habitat may have on the viability of species (e.g., Wilson and Bossert 1971, Andrewartha1972, MacArthur 1972, Lamberson et al. 1992, 1994). Furthermore, ecosystems are dynamic; the characteristics and configurations of ecosystems within the landscape are likely to change over time, independent of any regional management plan, due to long-term environmental trends, both natural (e.g., long-term climate trends, natural patterns of forest growth and succession) and anthropogenic (e.g., global climate change, expanding human population). All of these factors must be considered in designing a regional conservation strategy.

We will derive priority questions and hypotheses to be tested in future research, to a large degree, directly from the regional analyses and biodiversity assessment described in Section 4.3.1. For example, we expect observed spatial patterns of species diversity to lead to questions about the value of, and need for, connectivity among specific protected areas and the species that could benefit most by inclusion of habitat corridors in a Pacific Northwest conservation strategy. Questions and proposed studies will be prioritized for funding based on their feasibility and potential for significantly reducing uncertainties in regional assessments. Spatially explicit simulation models may be used (or developed) to test hypotheses about the role of connectivity using existing information. Large-scale field studies may be required to test hypotheses about species dispersal and species' utilization of habitat corridors. Whenever possible, field studies on the ecological contribution of habitat corridors will be conducted as extensions of other ongoing field studies on the movement and dispersal of species and species assemblages in relation to habitat parameters.

B. Stressors. The ecological literature is rich in descriptions of how diverse stressors can affect individual organisms, species, and communities based on laboratory tests, field observations, and a very few ecosystem-level manipulations, especially associated with a particular stressor or a single source. It is much rarer to find examples of studies that start with patterns of species diversity and seek to explain them. As described in Box 4-A, the BRC (and the approaches that will be implemented in phase 1 of this program) uses existing data on stressors, both as part of the prioritization process and to examine potential associations between patterns of biodiversity and patterns of anthropogenic stressors (and also natural factors that may influence biodiversity). We will fund additional work of this nature as part of the phase 1 regional analyses and assessments. To date, however, BRC analyses have emphasized habitat-related stressors, because they are likely to affect biodiversity over larger scales and because databases suitable for GIS analysis are available. Many other stressors can affect biodiversity, but data are inadequate for the correlative analyses conducted by the BRC or the stressors may act at different scales than those used in the BRC analyses. Thus, we expect additional research on stressors to be warranted, targeted specifically to major uncertainties and gaps identified in the BRC database and analyses. As a complement to this extension, we may identify a series of well-defined laboratory or field tests designed to evaluate mechanisms that may be responsible for observed patterns of species distributions.

Timeline

Phase 2 research will begin in 1996 and expand in 1997. We will conduct workshops in both years to synthesize and evaluate results from regional assessments and to provide the basis for identifying high-priority research questions to be addressed in phase 2.

4.4 MAJOR CONTRIBUTIONS

The major contributions expected to result from the phase 1 research outlined in Section 4.3.1 are as follows:

- Enhancement of methods for assessing the status and spatial patterns of biodiversity and for identifying species not represented in areas managed for their natural values.
- Integration of biodiversity data from several state efforts for a broader Pacific Northwest regional assessment.
- Demonstration of biodiversity methods at local levels to refine data needs and approaches for regional assessments.
- Development of a regional assessment of the threats to some elements of biodiversity, including options for reducing or mitigating stressors to regional biodiversity.
- Synthesis and evaluation of existing information and management needs to focus longer term research.

5. WATERSHED/ECOREGION

This section describes research proposed for the watershed/ecoregion scale. Research goals are to provide the ecological understanding and evaluate the assessment approaches needed to implement ecosystem management effectively at the watershed/ecoregion scale in the Pacific Northwest and elsewhere. Section 5.1 provides background information, including a definition of the watershed/ecoregion scale and examples of the types of management questions being addressed at this scale in the Pacific Northwest. Section 5.2 presents research objectives, and Section 5.3 describes the approach we plan for achieving those objectives. Section 5.4 summarizes the major contributions expected from this component of the research program.

5.1 BACKGROUND

We use the term *watershed/ecoregion* to refer generally to the intermediate spatial scale at which ecosystem management will actually be practiced. Candidate spatial units of analysis at this scale include USGS hydrological accounting units (Figure 5-1), smaller watersheds nested within these larger basins (Figure 5-2), and ecologically defined areas, such as Omernik's ecoregions (Figure 3-8) and subecoregions (Figure 3-9). All of these units are potentially useful for analysis, depending on the question and level of resolution required. As noted in Section 5.2, an important objective of our research is to demonstrate how these different units can be used in combination to address the types of management questions being asked concerning ecosystem management in the Pacific Northwest.

Applied environmental research historically has taken a single stressor, single endpoint approach to addressing environmental problems. For example, the effect of treated sewage effluent on water quality might be the focus of research on the mainstem of a small river in a watershed. In this same watershed, a study might be conducted to determine the effect of siltation from logging operations on aquatic life, including salmon reproduction. Although valuable information could be gained from both studies, by combining these studies with other information to form an integrated watershed perspective, much more information of considerably greater value to watershed management could be obtained. A properly designed integrated study could evaluate the cumulative impacts of these unrelated activities and examine the trade-offs that would be faced by the management entity. Scientists and managers are recognizing that an integrated approach to watershed management is required to address the conflicting current and projected future demands being placed on the Nation's natural resources:

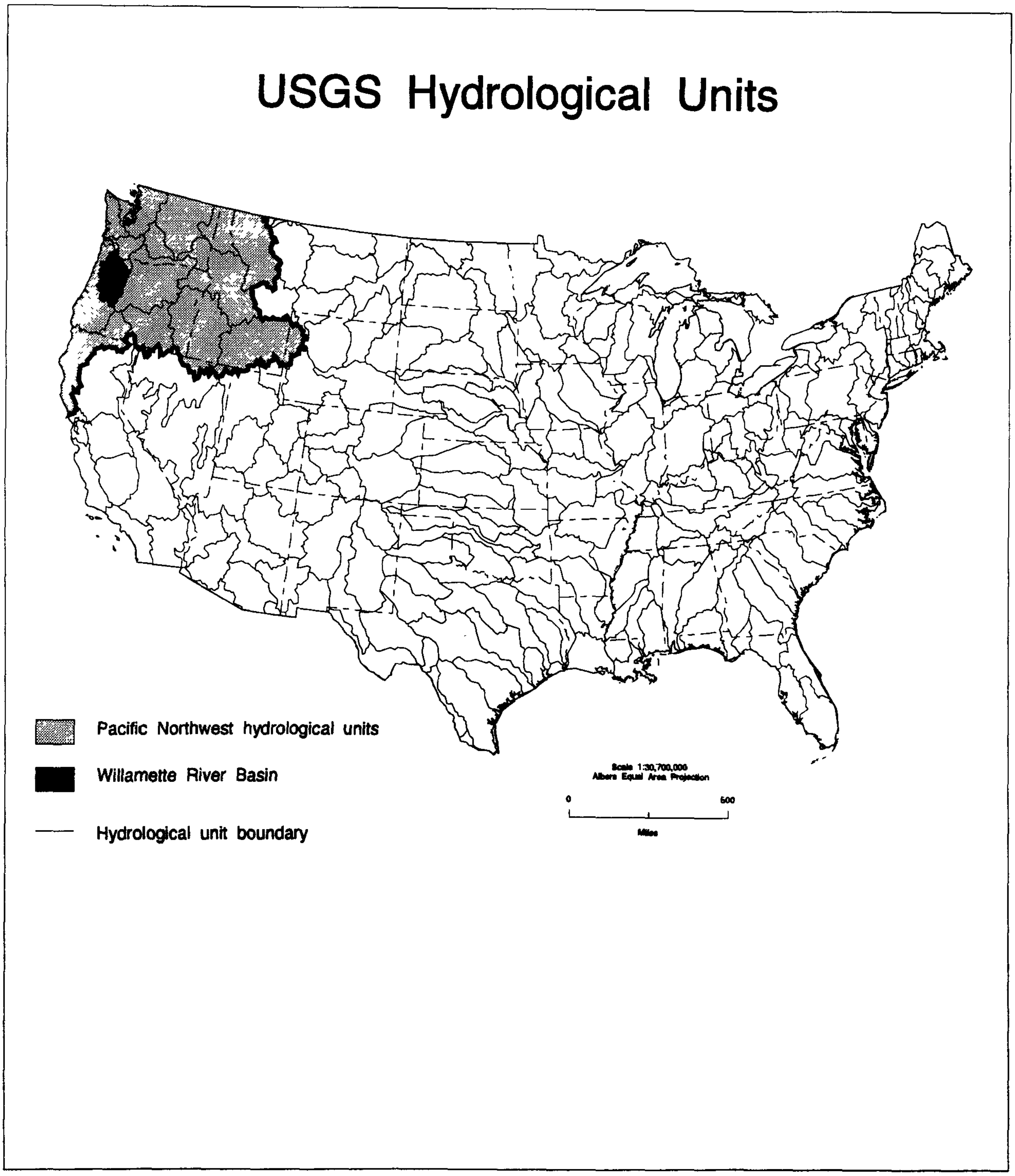


Figure 5-1. U.S. Geologic Survey national map of hydrologic units.

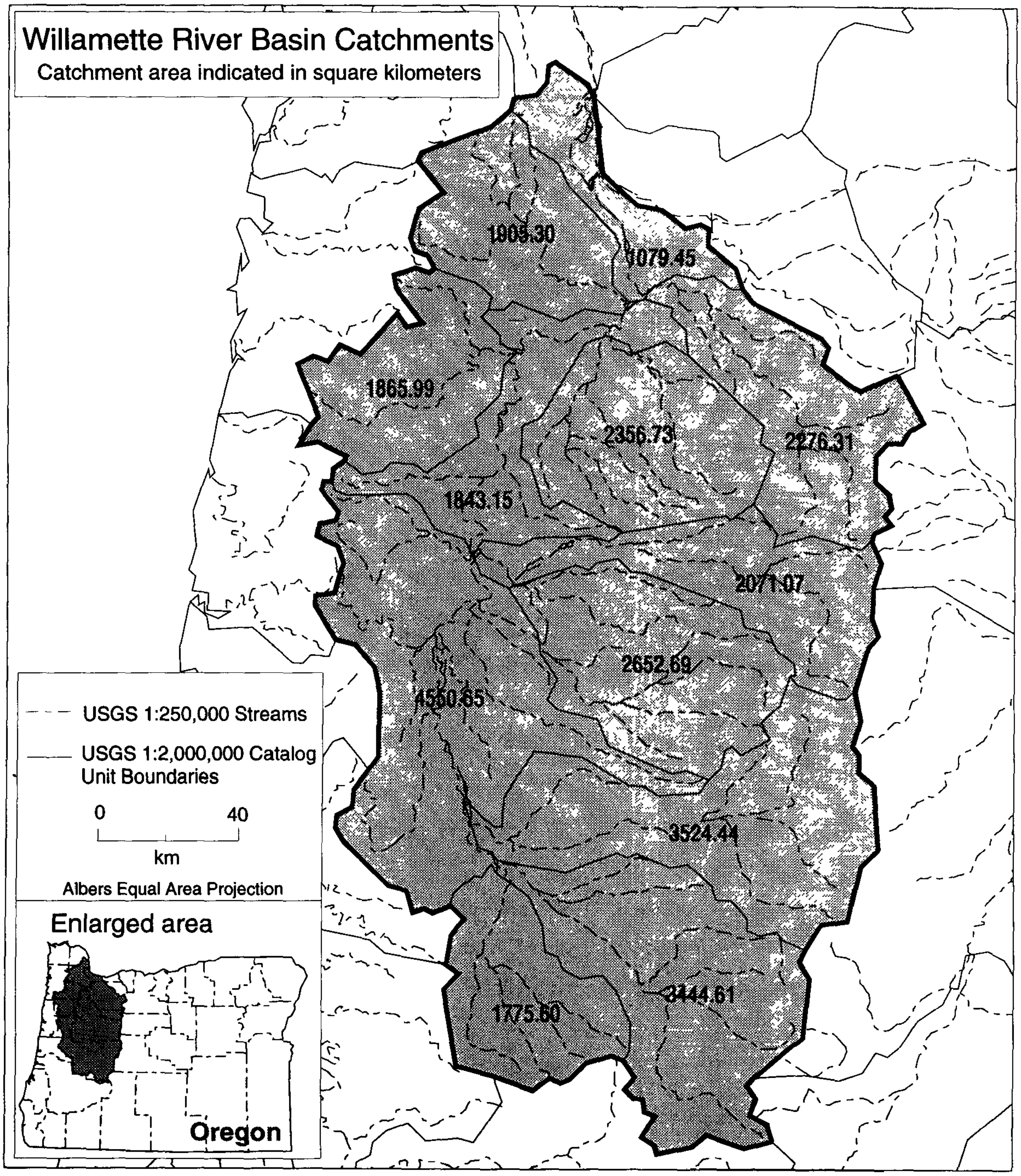


Figure 5-2. **Map of the Willamette Hydrologic Unit (i.e., Willamette River watershed) showing the major river catchments of which it is composed. Catchment areas are shown in km^2.**

"Resolution of these conflicts requires new perspectives that combine social, economic, and environmental concerns with an approach to watershed management where forest, range, agricultural, wetland, and urban parcels are treated in an integrated manner" (Naiman 1992, p. 3).

Much of the focus in the Pacific Northwest is on forest management practices widely perceived to have failed. New tools for assessment and management are needed:

"In actuality, the clear failure of traditional intensive forest practices to maintain many forest organisms and values provides the strongest evidence supporting the need for alternative or new silvicultural practices. While we may not know precisely the effectiveness of some of the new techniques, we do know that traditional approaches are not working well for many values, and are no longer socially acceptable" (Franklin 1992, p. 60).

The basic management objective at the watershed/ecoregion scale is to determine the most efficient way—ecologically, economically, and socially—to achieve desired uses of ecological resources while still providing the level of protection prescribed by regional guidelines, e.g., a regional conservation strategy (Section 4). It is at this scale that trade-off analyses become most important—analyses that assess the relative advantages and disadvantages of alternative management approaches—and that the assessment process outlined in Section 3 is implemented most completely.

Recognizing the need for planning based on natural boundaries and conducted at an intermediate scale, watershed councils have formed throughout the Pacific Northwest. Generally, these councils are organized voluntarily by local communities. Their operation is based on a process of cooperation and partnerships, rather than government authority. Their influence results from their knowledge of local concerns, public interest and support, and, most importantly, the opportunity to reconcile local resource and management conflicts. Watershed councils in Oregon are formerly endorsed and encouraged by state legislation and coordinated through Oregon's Strategic Water Management Group (Oregon SWMG 1992).

Examples of the types of issues being addressed by watershed councils, and other similar organizations, include the following:

- **McKenzie Watershed Program (OR).** Initiated in 1992 to "establish an integrated, comprehensive watershed management program that includes governmental and citizen participation." Competing demands on watershed resources identified in the program's scoping document include domestic water supply, hydropower, agriculture, scenic values, wildlife and fisheries habitat, recreation, public access, private property rights, forestry, and sand and gravel operations (Lane Council of Governments 1992).
- **John Day River Basin Council (OR).** Established initially in the 1980s as an advisory group to the State of Oregon for the John Day Basin Plan, the Council has continued and "serves as a forum for balancing objectives of different groups." Major problems addressed include declining

fisheries, high winter flows, low summer flows, and high temperatures in the river and major tributaries. Activities have included development of a water optimization plan, a stream restoration program, and numerous demonstration projects (e.g., methods for managing beaver and juniper in the watershed) (Oregon Watershed Forum 1992).

- **Tillamook Bay National Estuary Project (OR).** A joint local/state/federal effort, funded by EPA, this project was established to evaluate environmental problems in the Tillamook Bay watershed and develop a comprehensive management plan. Three major problems identified are sedimentation, contamination from dairy operations, and habitat degradation.

- **Willapa Alliance (WA).** This nonprofit organization, composed of local residents, landowners, and members of the Shoalwater Bay Indian Tribe, has the following goal: "To enhance the diversity, productivity, and health of Willapa's unique environment, to promote sustainable economic development, and to expand the choices available to the people who live there" (Wolf 1993, p. 46). Willapa Bay produces one of every six oysters consumed in the United States and supports major fisheries for Pacific salmon, other fish, Dungeness crab, and shellfish. Nearly two-thirds of the watershed is commercial forestland. Thus, Willapa's economy is largely ecosystem-based. For this reason, the Alliance was formed to encourage cooperative problem-solving at the local level and environmentally-sound, sustainable resource use.

- **Mid-Snake River Planning Group (ID).** Organized in 1990 by the four counties in the middle Snake area to develop a comprehensive plan that addresses priority environmental problems while sustaining the economic activity of the region. Major problems are competing water uses, for irrigation, hydropower, and maintenance of in-stream flows for fisheries; sedimentation; and excess nutrient loading from point and nonpoint sources.

- **FEMAT Province Teams.** FEMAT teams are responsible for implementing the President's Forest Plan (Section 1.3) and ecosystem management on federal lands within physiographic provinces (see Figure 1-9. Key issues identified include distribution of threatened and endangered species or stocks, patterns of historical and current resource use, water quality, identification of (human) communities at risk, and management of multiple reserve systems. The FEMAT province teams also prioritize smaller watersheds for further study (FEMAT 1993).

The purpose of our research is to facilitate and improve management decisions made at the watershed/ ecoregion scale by producing relevant ecological information and tested methods concerning the most pressing questions and promising approaches for implementing watershed management.

5.2 OBJECTIVES

The major objectives of this research component mirror three of the four objectives of the overall program (Section 2.2): (1) develop and test large-scale assessment approaches, (2) evaluate spatial frameworks, and (3) improve ecological understanding. More specific objectives are as follows:

- Conduct an initial assessment to determine the data and information available for the selected study areas; determine research needs based, partially, on information gaps.

- Demonstrate and evaluate assessment methods for characterizing current ecological condition at multiple spatial scales, cooperatively with research on monitoring designs (Section 8).

- Select and test approaches for defining attainable ecological goals through the use of reference sites, ecological indicators, and other methods.

- Refine and demonstrate methods for targeting high-priority areas within a watershed/ecoregion for protection, restoration, or other management action, or for further study and/or monitoring.

- Construct simple watershed-scale interactive models to evaluate, project, and compare the consequences of alternative management strategies on key ecological endpoints.

- Compare the attributes of different spatial frameworks for summarizing information on ecological condition, setting attainable ecological goals, and organizing ecological research at the watershed/ecoregion scale.

- Evaluate techniques for extrapolating site-specific ecological information to other sites and spatial units at the watershed/ecoregion scale.

- Conduct a final integrated ecological assessment, combining existing data and the results of the research conducted in this program, to determine the best approaches for assessing management trade-offs in the study areas.

5.3 APPROACH

Our proposed approach is represented in Figure 5-3. We plan to begin with an initial assessment in the first year, followed by about three years of targeted research to fill the most important gaps in our understanding, and concluding with an assessment in the final year that would integrate and compare tools and approaches. Proposed research activities at the watershed/ecoregion scale are described in the following sections. Section 5.3.1 discusses the selection and use of case study areas. Subsequent sections describe our approaches to achieve each objective. Tentative budgets by project are presented in Table 5-1. We assume an annual budget of $865K for research at the watershed/ecoregion scale. An additional $200K is designated for research on an estuarine watershed, to be conducted jointly with the Coastal Estuaries research component (and appears for accounting purposes in the Coastal Estuaries budget, Section 7).

Ongoing research at ERL-Corvallis and elsewhere provides useful approaches that can contribute to watershed/ecoregion assessments. We plan to draw on these programs as appropriate and possible. The Environmental Monitoring and Assessment Program (EMAP) (Paulsen et al. 1991, Thornton et al. 1993), the Wetlands Research Program (Leibowitz et al. 1992a,b), and the ecoregion approach developed by Omernik and others (Hughes et al. 1986, Omernik 1987, Gallant et al. 1989) are three such programs with which we hope to coordinate. In the absence of any one program, we will develop alternative approaches for meeting our objectives or modify the objectives if alternatives are not satisfactory.

Watershed/Ecoregion Scale Approaches

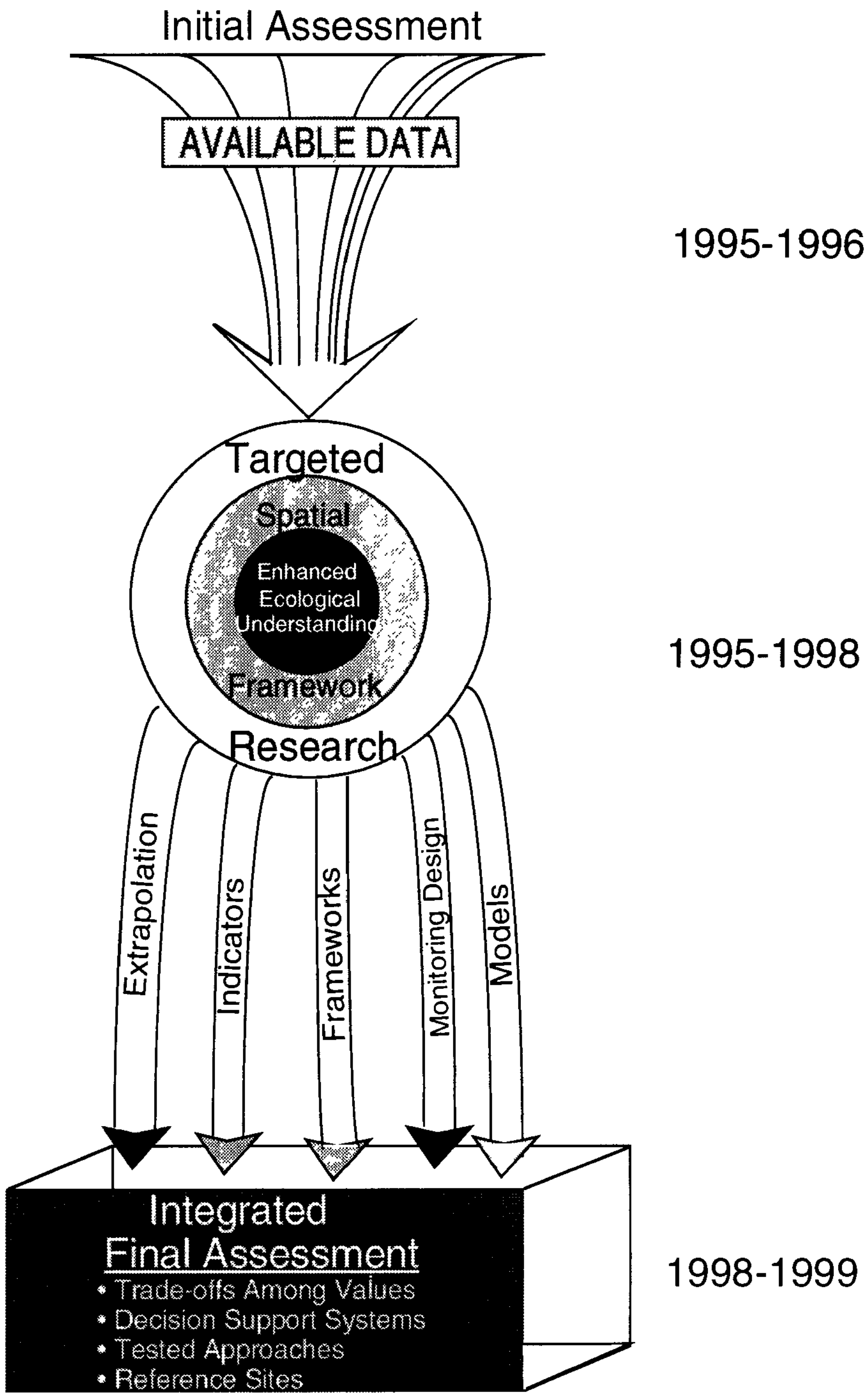


Figure 5-3. Conceptual approach to achieving the watershed/ecoregion-scale assessment and research objectives.

Table 5-1. Estimated Budget for Each Watershed/Ecoregion Project Area by Fiscal Year (FY) (in Thousands of Dollars).

ACTIVITY	FY95	FY96	FY97	FY98	FY99
Integration[a]	**100**	100	100	150	200
Current conditions, diagnostics	**200**	200	150	150	50
Attainable conditions	**100**	100	50	50	50
Geographic targeting	50	50	50	50	50
Spatial framework	50	-0-	50	50	50
Development models and decision support systems	**150**	150	200	200	200
Extrapolation	**115**	115	115	115	115
Ecological research	**100**	150	150	100	150
TOTAL	865	865	865	865	865

Initial Assessment   Targeted Research   Final Assessment

[a] Includes the compilation and evaluation of existing data and analyses. Also includes among-method comparisons to evaluate the value of more effort- and data-intensive analyses.

One of our major contributions is to demonstrate how inferential (EMAP) and extrapolation (ecoregion) approaches can be used together, and linked to one another, as elements of an integrated ecological assessment. In addition to developing and testing applications for integrating and refining existing elements to create new approaches, we propose other research activities. We plan to develop models and decision support systems for ecosystem management (Section 5.3.6). We will evaluate approaches for regionalizing research findings from studies at a few sites to other similar spatial localities, as well as among local, watershed/ecoregional and regional scales (Section 5.3.8).

5.3.1 Case Study Areas

The research needs for ecosystem management are many and varied and it will not be possible to accomplish all objectives for every area of interest. For example, it will not be possible to answer all important management questions for all areas of the Pacific Northwest. We could distribute our watershed/ecoregion research across the region, addressing different types of questions and doing different types of research in different areas. That approach would perhaps be most equitable in terms of the number of stakeholders and managers that would benefit directly from the information produced. However, it also would critically dilute our effort in any specific area and we do not believe that this approach to ecosystem management research will ultimately lead to the greatest net increase in our knowledge base.

Instead, we have chosen to concentrate our research in a few selected case study areas, for two major reasons. First, the development and testing of assessment approaches is an important objective of the research program. We must determine if simpler methods yield results consistent with those from more data- and effort-intensive analyses that would not be practical to apply routinely. We will make comparisons by developing, demonstrating, and evaluating multiple methods applied by independent researchers in the same areas. Second is our emphasis on integration and holistic assessments. We want to deal with multiple endpoints and multiple stressors, and the interactions and trade-offs among them. We want to demonstrate the value of integrating data from different disciplines, different media, and different ecosystem types. To do so, we need information and research on many of these aspects from the same basic geographic area—e.g., forested, agricultural, and urban areas; surface waters; wetlands; and terrestrial ecosystems—all within the same watershed/ecoregion.

We have selected two watershed/ecoregions for initiation of watershed/ecoregion research in 1995. These case study areas were selected for use as intensified "demonstration" areas, and we will focus our research efforts within them. We used the following five criteria to select the two initial case study areas:

1. **West of the Cascades.** Because our research funds were allocated as part of the FEMAT effort (see Section 1.3), our initial case study watersheds/ecoregions are restricted to the FEMAT study area—the Cascades and west. In future years (post-1999), we hope to add a third case study watershed/ecoregion east of the Cascades to incorporate irrigation and grazing stressors into our research. Although serious environmental concerns exist both west and east of the Cascades, western areas have the highest human population densities, a particularly high rate of population growth and urban development, and a wide range of landuses and land ownership patterns (see Box 1-B).

2. **Diversity of stressors, ecosystem types, landuses, and valued ecosystem functions.** We seek to conduct research in areas that provide good prototypes for ecosystem management and the types of multi-stressor, multi-endpoint analyses required to support ecosystem management. In particular, we sought watersheds/ecoregions with significant amounts of agricultural and/or urban lands, in addition to forested land. Much of the ecosystem management research done by other federal agencies under FEMAT focuses on forested lands. Thus, we view agricultural and urban lands, by comparison, as a knowledge gap.

3. **Significant amount of nonfederal lands** (multiple-use, multiple-ownership lands). FEMAT efforts have focused on federally owned lands. As noted in Section 1.3, an important role for EPA is to extend the FEMAT concepts, and ecosystem management in general, to nonfederal lands with multiple owners. At the same time, we want to integrate FEMAT analyses on federal lands into our larger watershed/ecoregion assessment. Thus, a related criteria is that the case study areas include some of the upland, forested watersheds on which FEMAT analyses are ongoing or planned.

4. **Need for scientific input to management decisions.** Because of our interest in working actively with ecosystem managers, we prefer areas currently impacted by multiple stressors and at high risk of losing valued ecosystem functions, where managers feel that scientific input is critically needed and will contribute to improved decisions over the next five or so years.

5. **Sufficient existing information.** Enough information on ecological conditions and stressors must be available for preliminary assessments to be completed within 1–2 years.

Together with EPA Region 10, we presented these criteria to groups of environmental managers organized by the states of Washington and Oregon. The groups included representatives from federal agencies and tribes, as well as from state agencies. Based on our criteria, and their management needs, these groups selected the Willamette River Basin in Oregon (Figure 5-4) and the lower part of the Washington Coastal Ecoregion (Figure 5-5) as our two initial case study areas.

5.3.1.1 The Willamette River Basin

The Willamette River Basin in Oregon falls between the Coast Range and the Cascade Mountains. It is approximately 29,400 km^2 in area, 240 km long by 120 km wide, and has a 3000-m elevation range from the valley floor to the top of the Cascades. The river basin has 21,216 km of streams [EPA RF-3 geographic information system (GIS) database], with as many as 14 impoundments on the mainstem of the Willamette and its tributaries. The valley has a moderate marine climate with an average annual precipitation of about 100 cm over an average of 150 days. Summers tend to be hot and dry; winters are cool and wet with minimal snowfall on the valley floor (Tetra Tech 1992).

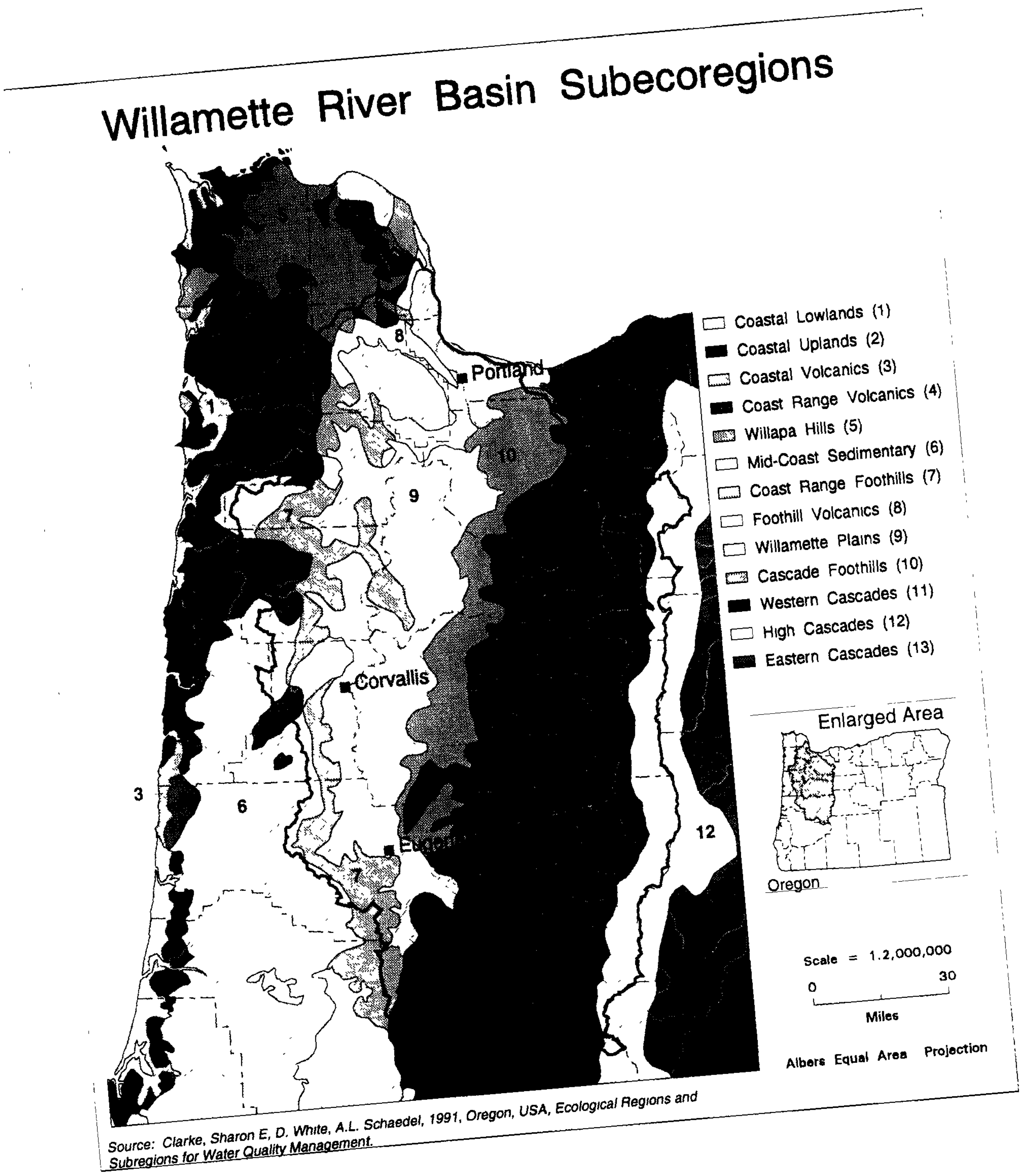


Figure 5-4. **Willamette River watershed, showing the subecoregions it contains.**

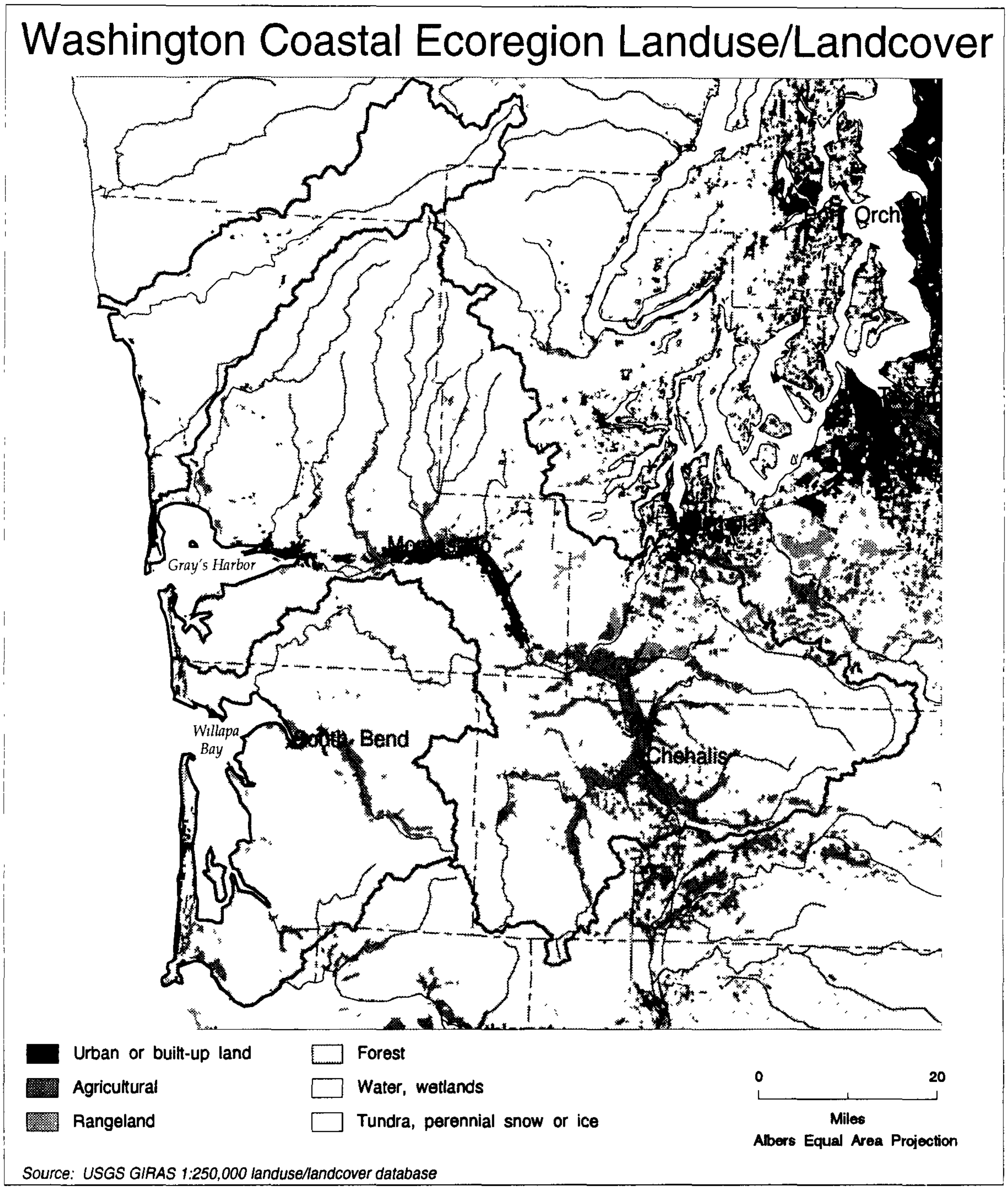


Figure 5-5. Landuse map of the Washington Coastal Ecoregion.

The major landuses in the Willamette Basin are forestry (69% of the total basin), agriculture (20%), and urban areas (4%). The remaining areas are either grass/brushlands or water bodies (Oregon GAP Vegetation GIS coverage). Logging contributes to sediment production in the river network, particularly along slopes greater than 12% and during seasonal rain and snow events (Tetra Tech 1992). Irrigated croplands are also major contributors to soil erosion and the transport of nutrients and pesticides to the river system. There are over 91,058 irrigated ha in the Willamette Valley, out of a total of 728,460 ha of cropland. Gross sales from agriculture in the valley exceed $1 billion annually, accounting for over 50% of Oregon's total farm crop sales (Tetra Tech 1992). Urban areas contribute the most intense nonpoint source pollution to the Willamette River. Pollutants include nutrients, organic matter, bacteria, pesticides, and toxic compounds (Tetra Tech 1992). There are 87 major and minor National Pollution Discharge Elimination System (NPDES) permit sites within the Willamette River Basin (EPA Region 10 GIS NPDES digital coverage). In addition, four sites in the basin are designated as part of EPA's Superfund cleanup program, and numerous other sites are under investigation (Oregon Environmental Atlas 1988).

Air quality is also a problem in the valley, both currently and historically. Mountainous terrain, calm winds, and temperature inversions all contribute to poor ventilation in the valley part of the river basin. In addition to car and industrial sources, massive field and slash burning are major sources of air pollutants (Oregon Environmental Atlas 1988).

5.3.1.2 <u>Washington Coastal Ecoregion</u>

The lower part of the Washington Coastal Ecoregion encompasses 10,476 km^2 in the western Washington lowlands, including the Quinault, Chehalis, and Willapa watersheds (Figure 5-5). It was selected by the state of Washington as an area of active economic transition, from a forest-based economy to an "as yet unknown future."

> "Communities, industry, and government are now making decisions that will affect this region for many years. Having quality research available as these decisions are made will significantly improve the future of the people, resources, and industries of this area" (Letter from Jennifer M. Belcher, Washington Commissioner of Public Lands, and Harry Thomas, State Director for Governor Mike Lowry, to Tom Murphy, Director ERL-Corvallis, 13 April 1994).

The area is mostly privately owned, with about 15 major landowners and many small holdings. Three Native American reservations occur within the case study area: the Chehalis, Quinault, and Shoalwater tribes. Forests in the area have been intensively managed and harvested for many years; logging activity occurs in most watersheds. Seven to eight percent of the land is classified as agricultural, which includes dairy operations, grazing, cranberry growing, and row crop production. Less than 5% of the area is urban, although major areas of urban and commercial development pressures are nearby, including the I-5 corridor and the cities of Portland and Seattle. Anadromous fish and shellfish resources from the area are of national significance (e.g., Willapa Bay is the largest producer of oysters in the Nation) and of major importance to the local economy. Water quality problems periodically result in closure of the shellfish industry. Declining salmon stocks have severely limited returns from salmon fisheries. Threatened and endangered species occur in upland, wetland, and coastal areas as a result of habitat fragmentation, loss, and changes. Table 5-2 summarizes major management issues in the area, identified by the State of Washington.

We will focus part of our research in the Washington Coastal Ecoregion on Willapa Bay and its associated watershed (Figure 5-6). Intensive estuarine studies will be conducted in the Bay (see Section 7), and some research will be conducted in the watershed. The focus for this work will be on developing linkages between the upland parts of the watershed and the estuary. Sediment generation, transport, and deposition are likely to be paramount issues. We also propose to conduct research in other areas of the Washington Coastal Ecoregion. Work is underway to develop a cooperative research effort with the Quinault Indian Nation, to assist them in developing an integrated management strategy that combines concerns over fish, wildlife, and forest resources. This work will focus on the main river, its tributaries, Quinault Lake, and associated riparian zones. Approaches developed in one watershed will be regionalized within the Washington Coastal Ecoregion using spatial frameworks such as ecoregions. The usefulness of such extrapolation approaches will be quantitatively evaluated.

Most of the research described in subsequent sections will be conducted in the two case study areas. There will be significant spatial and technical overlap between research on watersheds/ecoregions and research on riparian areas (Section 6), estuaries (Section 7), and monitoring (Section 8). Where possible, sites at which data will be collected to meet different objectives will be co-located in the case study areas to facilitate integration of results.

5.3.2 Integrated Ecological Evaluations: Assessments

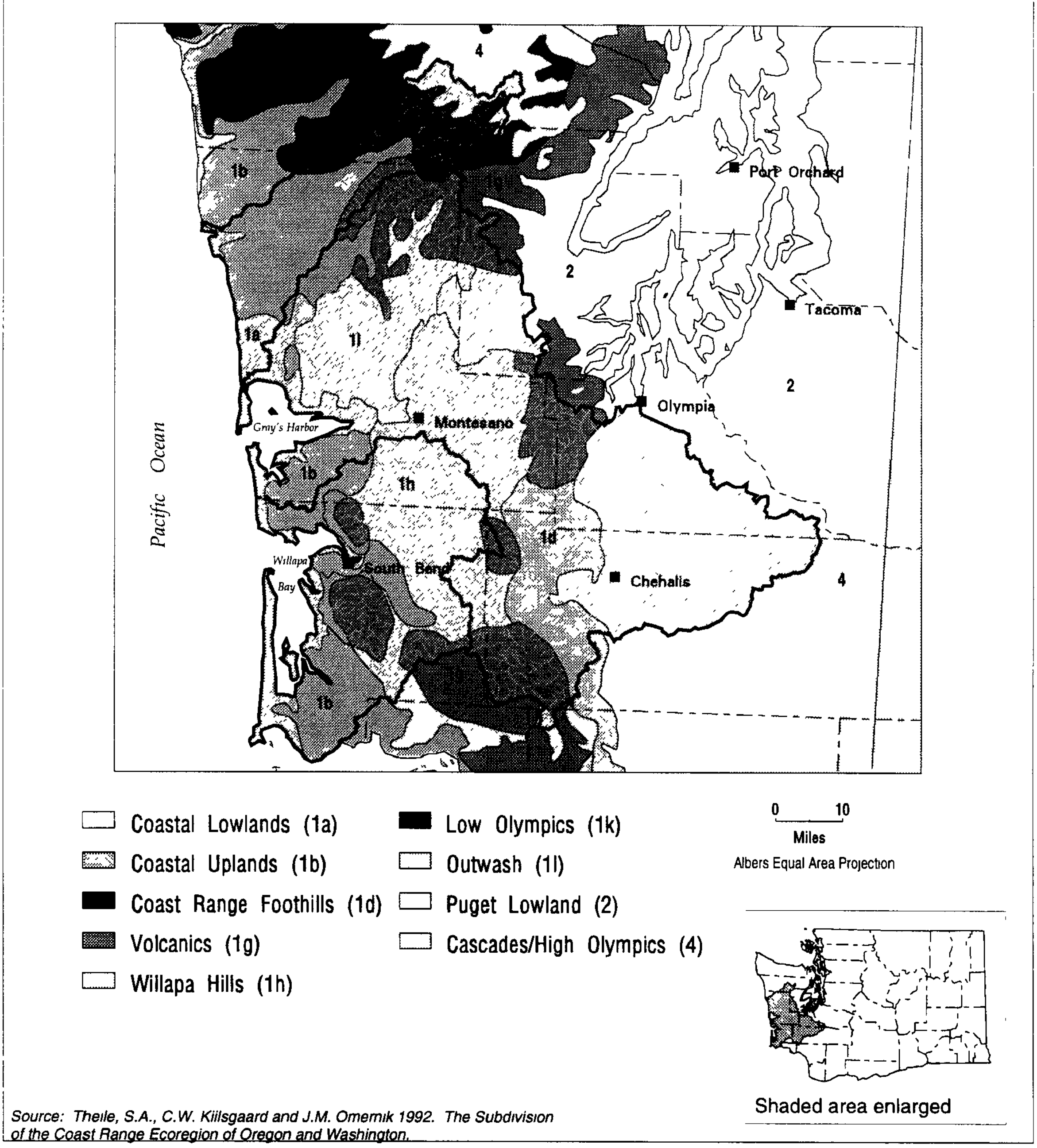
Project-Level Objectives

- Conduct an initial assessment to determine the data and information available for the selected study areas; determine research needs based, partially, on information gaps.
- Conduct an integrated ecological assessment at the end of the research period, combining existing data and results of research conducted in this program to determine the best approaches for assessing management trade-offs in the study areas.

Table 5-2. Major Management Concerns for the Washington Coastal Ecoregion Identified by the State of Washington.

Environmental Issues (partial list):
Spartina encroachment and control in Willapa Bay
Water quality in Chehalis River
Ghost shrimp in Willapa Bay
Dredging impacts on crabs in Grays Harbor
Erosion of shorelines in Willapa Bay and at Westport
Forest Practices:
Road construction
Road maintenance
Timber harvest and/or management
Riparian area protection
Agricultural Practices:
Dairy waste
Riparian area protection
On-Site Sewage Disposal:
Failing or inadequate septic tanks
Septic inspections
Development-Related Storm Water and Erosion:
Contaminated stormwater runoff
Groundwater contamination
Other Nonpoint Sources:
Sedimentation
Fish and Wildlife:
Shellfish harvest
Shellfish bed contamination
Maintaining habitat for spotted owl and marbled murrelet
Loss of wetlands to industrial and urban development

Subecoregions of the Washington Coastal Ecoregion



Source: Theile, S.A., C.W. Kiilsgaard and J.M. Omernik 1992. The Subdivision of the Coast Range Ecoregion of Oregon and Washington.

Figure 5-6. Map of the Willapa Bay watershed showing the subecoregions it contains.

- Evaluate the relative advantages—in terms of increased confidence in and utility of assessment results—of applying analytical tools that require greater levels of effort and data compared to simpler, less data- and effort-intensive assessment methods.

Approach

An important goal of this research is to test, refine, and demonstrate an integrated assessment process at the watershed/ecoregion scale. Assessments are important because they provide managers with a clear view of the competing factors within a watershed/ecoregion and identify the possible approaches managers can use to evaluate the consequences of various management actions or inaction. To achieve the goal just stated, we will conduct initial and final assessments in each of the case study areas. The initial assessment will be conducted with existing data and will focus on determining what is known about the watershed/ecoregion with regard to stressors, condition of ecological systems, and managerial issues. It will be conducted at the watershed/ecoregion scale and will be organized so that it spatially represents the available information. The primary result of the initial assessment effort will be identification of the critical data that will have to be obtained via targeted research.

We anticipate that the availability and quality of assessment information will vary widely and will, in all probability, fall short of the requirements for a thorough integrated assessment. Based on the initial assessment results, appropriate aquatic, estuarine, and terrestrial endpoints will be identified for the case study areas, along with approaches for defining linkages among these components. The watershed/ ecoregion scale research will be designed and conducted (see Sections 5.3.3–5.3.9) to fill the most inportant information gaps, so that a successful final assessment can be conducted that includes the most important ecological components of the watershed (Figure 5-3). The final assessment will occur during the final two years of the program and will incorporate all targeted research components and other data sources, including EMAP, FEMAT, and the initial assessment.

Both initial and final assessments will address real-world management questions relevant to the ecosystem management approach, similar to the examples presented in Section 3.3, and will follow the basic assessment approach outlined in Section 3. The states of Washington and Oregon are in the process of organizing a group of selected state, tribal, and local managers to serve as our primary management contacts for each case study area. These groups will identify their high-priority management questions for the Willamette River Basin and the Washington Coastal Ecoregion. These policy questions will serve as a basis for formulating our specific research objectives for the case study areas. The final assessment will address these issues directly, using a combination of existing data and the targeted research conducted as part of this program. The final assessment will focus particularly on trade-offs among conflicting resource uses and among alternative management approaches. It will address a set of watershed management questions that will demonstrate the full range of concerns of interest and the diversity of assessment analyses.

An additional objective of the final assessments is to evaluate the benefits of more effort- and data-intensive analyses in ecological assessments. To be worth the added effort, such analyses must provide outputs of more direct use to decision makers (e.g., outputs that are more spatially explicit or that are tailored for specific management issues) and/or outputs that are more accurate or precise, or in which we generally have greater confidence. Our general approach to achieving this objective will include: (1) identifying specific science objectives that require different levels of effort, and assessment methods that require different types of data (see in particular Sections 5.3.5 and 5.3.6), (2) applying these different approaches within the same case study area to address the same or similar management questions, and (3) comparing the results for consistency, usefulness to managers, and relative precision and level of confidence.

From the perspective of ecosystem management, the most useful aspect of this approach will probably be the identification of trade-offs among competing ecological uses. The integrated or holistic approach we intend to follow will make these tradeoffs explicit, including quantifying them where possible.

Timeline

The initial assessment will be conducted in 1995–1996, the final assessment in 1998–1999.

5.3.3 Current Ecological Conditions and Diagnosis

Project-Level Objective

The objective is to demonstrate and evaluate assessment methods for characterizing current ecological conditions at multiple spatial scales, cooperatively with research on monitoring designs (Section 8).

Approach

The initial assessment will rely on evaluating existing data regarding current conditions and stressors for each case study watershed/ecoregion. We will compile, analyze, and summarize relevant existing data sets. To the degree possible, these analyses will be conducted cooperatively with the agencies or investigators responsible for the original data collection. Part of this effort will be directed toward developing a conceptual model of the case study area and identifying dominant ecological processes expected to be impacted most negatively by human activities (e.g., sediment transport and deposition).

We plan to collect new data on ecological condition cooperatively with EMAP (see Box 2-A) and the federal interagency Research and Monitoring Committee (RMC). In current plans for EMAP, that program focuses on the Pacific Northwest as one of three study areas in the United States. If EMAP plans change, alternative approaches will be explored. As discussed in Section 8, the Monitoring Workgroup of the RMC plans to conduct ecological monitoring demonstrations, beginning in FY96–FY97, on federal lands in one or more of the FEMAT provinces (see Figure 1-9), which may overlap with our case study areas. Our case study areas also include several of the smaller, upland watersheds in which FEMAT watershed analyses are underway or planned. Information from these and other FEMAT-related activities will provide useful information on ecological conditions that will be incorporated into our watershed/ecoregion final assessment.

EMAP has invested considerable effort into developing probability-based sampling methods to characterize ecological conditions, quantitatively, over large spatial scales for major resource groups (surface waters, estuaries, forests, agroecosystems, etc.). We anticipate applying and testing some of the EMAP methodologies at the watershed/ecoregion scale, using a spatially intensified probability sampling approach appropriate for the management questions being raised at that scale. We intend to make the linkage to the regional-scale EMAP activities explicit and to coordinate activities from both EMAP and PNW perspectives (see Section 8) to demonstrate the utility of this quantitative approach within the overall assessment process. The most important aspect of this linkage is regionalizing site- and watershed/ecoregion-scale studies to the next larger scale, the region.

EMAP plans to develop sampling approaches and indicators in the Pacific Northwest over the next several years. EMAP-Landscape Characterization plans to analyze thematic mapper (TM) remote sensing data for the entire region, including the case study areas. EMAP-Surface Waters, Forests, and Estuaries may also conduct field sampling to assess the condition of streams, forests, and possibly estuaries, respectively. Although some of the EMAP probability sites are scheduled to fall within the case study areas, the number of sites will not be large enough to adequately characterize ecological conditions at the resolution required for watershed/ecoregion-scale assessments. Thus, the PNW research program intends to support sampling at additional sites, selected by intensifying the EMAP grid within the case study areas. Current plans call for sampling design, logistics, and QA/QC to be handled by EMAP. We will decide what additional EMAP-type sampling or other research activities to fund depending on (1) the quality and types of existing data, (2) results from the initial assessment, and (3) distribution and number of sites to be sampled as part of the EMAP regional demonstrations. Ongoing surveys of streams in the

Washington Coastal Ecoregion, as part of Regional EMAP (a cooperative program between EMAP and EPA regional offices), may provide adequate resolution on stream condition in that area (Figure 5-7).

One of the fundamental uses planned for the EMAP data is to provide a probability framework with which to relate the intensively studied sites in the case study areas to other areas in the Pacific Northwest. The EMAP quantitative probability-based sampling frame, landscape characterization data, and indicator data will provide us with a rigorous framework with which to evaluate various approaches for extrapolating site- or watershed-specific data to other similar landscapes within the region. After this work is completed, the results will stand as a spatial hypothesis until the projections can be confirmed via additional EMAP sampling on a subset of these units at a scale similar to that performed on the case study watersheds. Section 5.3.8 provides more information on the issue of extrapolation.

The Integrated Monitoring research component, described in Section 8, has primary responsibility for evaluating EMAP and other monitoring designs relative to the needs of ecosystem management. The data collection and analysis activities described here will contribute both to watershed/ecoregion research and to the development of monitoring designs, and thus will be designed jointly by these two research components.

Timeline

Work on assessment of current ecological conditions will take place during the years 1995–1998.

5.3.4 Attainable Ecological Goals

Project-Level Objective

The objective of work in this area is to select and test approaches for defining attainable ecological goals through the use of reference sites, ecological indicators, and other methods.

Approach

Defining attainable ecological goals within the case study areas is a necessary early step in the assessment process (see Figure 3-11) and is required for comparing current conditions to those that could be attained, if desired. Three types of information can help to define attainable ecological conditions: (1) historical reconstructions, (2) reference sites, and (3) modeling approaches.

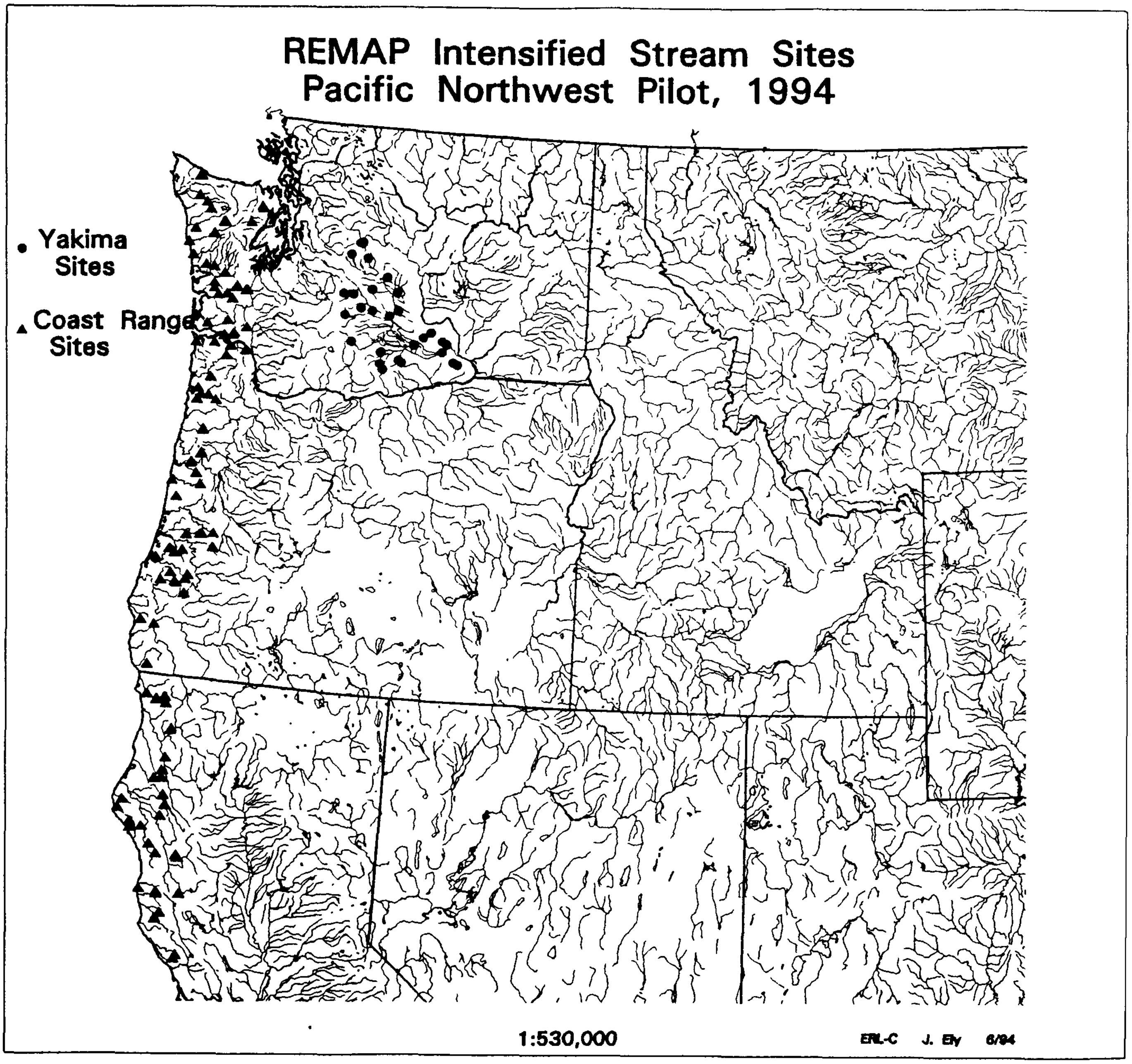


Figure 5-7. Map of the EMAP Pacific Northwest Pilot Study Area, showing stream sites sampled as part of the Regional Environmental Monitoring and Assessment Program (Regional EMAP) in 1994.

Historical Reconstructions. Historical conditions (before modern human disturbances or when human disturbances were less intense) provide one basis for comparison to present-day conditions. Historical reconstructions also can provide information on major natural forcing functions, such as hydrologic and fire regimes. For example, the USFS and others have extensively analyzed historical patterns of the frequency, extent, and distribution of fires in the Pacific Northwest (Spies and Franklin 1988, Morrison and Swanson 1990, Teensma et al. 1991, USFS 1993b) to gain a better understanding of the natural dynamics of forest systems and the relationship between these natural dynamics and biodiversity. Analyses of sediment cores in lakes have been used to evaluate historical trends in trophic state (Frey 1969), sedimentation rates (Robbins 1978, Gubala et al. 1990), contaminant loadings (Charles and Norton 1986), acidity (Charles et al. 1987, Ford 1990), and vegetation community composition in surrounding areas (Davis 1983, Spear 1989).

It is well established that the Willamette River has undergone tremendous hydrologic modification and loss of riparian areas in the last two hundred years (Sedell and Froggatt 1984). As part of initiating the PNW research program, in 1994 we funded a comprehensive historical reconstruction of hydrological conditions in the Willamette River mainstem and lower tributaries, based on extensive records available from the U.S. Army Corps of Engineers and others dating back to the late 1800s (Gregory et al. 1994; see Section 6). This information, on hydrological forcing functions in the Willamette, is essential to assessing the restoration potential of riparian areas along the Willamette.

The Riparian Area and Coastal Estuaries research components (Sections 6 and 7) propose specific plans for some historical reconstructions—the hydrological reconstruction of the Willamette mentioned above for riparian areas and analyses of historical sedimentation rates for estuaries. Both studies also will contribute to the watershed/ecoregion assessments, in the Willamette and Washington Coastal Ecoregion, respectively. We will evaluate the need for further reconstructions based on results from the initial assessments. Research will be conducted as required to determine the historical environmental conditions and the magnitude of changes that have occurred in the two study areas.

Reference Sites. In some instances, historical conditions may no longer be attainable, if human activities have caused irreversible changes in the environment. It is unrealistic to assume that sites which are now important agricultural or urban lands will be converted to their historical, pre-disturbance state. Moreover, it is likely that the presence of agricultural and urban activities within a watershed parcel affects conditions outside of their direct geographic location. For example, anadromous fish and migrating birds may be exposed to high doses of contaminants, high temperatures, etc., as they move through such areas. In these cases, we want to define realistically attainable conditions within or with relation to agricultural or urban settings.

We use the term *reference site* to refer to a minimally impacted site within a similar environmental setting used to define a realistically attainable ecological goals. The concept of reference sites is well developed for streams (see Section 3.2.2; Hughes et al. 1986) and has been applied as the basis for stream biological criteria in Ohio (Rankin et al. 1992). Leibowitz et al. (1992a) extend the concept to wetlands, using reference sites to define performance criteria for wetland restoration projects. Regional EMAP projects, in the Coastal Ecoregion and in Yakima Basin in the Pacific Northwest and in the Mid-Atlantic Highlands, will further evaluate the reference site approach by comparing ecological conditions at hand-picked reference sites in streams to regional distributions generated from EMAP probability samples of streams. This will be a powerful approach to defining the efficacy of hand-picked sites vs. those at the upper end of a cumulative frequency distribution.

We believe that reference sites, used to define attainable ecological conditions, are a key component of ecological assessment and monitoring programs. As part of the PNW research program, we will demonstrate the definition and use of reference sites in watershed/ecoregion assessments and evaluate the utility of the reference site concept for other ecosystem types. Research on reference conditions for riparian areas is described in Section 6. As part of the Watershed/Ecoregion component, we will conduct research to evaluate the feasibility and usefulness of applying this approach to more upland areas (grasslands and forested systems).

Modeling. A third approach to setting attainable ecological conditions is through ecological models. By simulating the responses of systems to various management scenarios, we gain insight into the possible range of end results and conditions. Section 5.3.6 discusses proposed modeling activities in greater detail.

Timeline

Work on determining attainable ecological goals will take place during the years 1995–1999.

5.3.5 Targeting Geographic Areas

Project-Level Objective

The objective of this effort is to refine and demonstrate methods for targeting high-priority areas within a watershed/ecoregion for protection, restoration, or other management action, or for further study and/or monitoring.

Approach

In what geographic areas and at what specific sites should we concentrate our management efforts (or research and monitoring activities) to get the most value for the time and money invested? Spatially explicit modeling, as described in Section 5.3.6, is one way to answer these questions. This section describes nonmodeling techniques that may be simpler and less costly to apply. Modeling and non-modeling approaches will be compared in the final assessment, as discussed in Section 5.3.2.

Our proposed approaches draw heavily on methods developed initially for evaluating the role of wetlands in the landscape, as part of the Wetlands Research Program at ERL-Corvallis (Leibowitz et al. 1992a). Here we discuss two approaches: synoptic assessment and general landscape criteria.

Synoptic Approach. The synoptic approach is a method for ranking spatial subunits within a larger area of concern (e.g., the case study watershed/ecoregion) according to various environmental factors that influence their priority for management action or further study. The approach was designed specifically to provide a broad, qualitative understanding of the environment in situations where more detailed assessments are impractical because of limited time or resources. It identifies target areas (e.g., priority watersheds or ecological units within a larger basin), not specific sites.

The synoptic approach, in its entirety, is a mini-assessment, beginning with defining management questions and objectives and developing a conceptual landscape model for the study area. In our case, these steps will be followed as part of the initial assessment process described in Section 5.3.2. From that point, the synoptic approach uses best professional judgment and available data to select the best available synoptic indicators of current condition, past impacts, current stressor levels, risk of functional loss, and restoration potential. Available data for each indicator are summarized by spatial subunit, and subunits are ranked accordingly. Subunits may be ranked, for example, according to the estimated percent of wetlands lost, calculated from the estimated original wetland area, assumed equal to the area of hydric soils, minus the estimated current wetland area (from USGS landuse/land cover maps) divided by the estimated original area (Abbruzzese et al. 1990). Areas with a high historical loss rate are considered higher priority for management attention and further study. Areas with a very low historical loss rate may be considered candidate areas for conservation and preservation. Leibowitz et al. (1992b) describe the synoptic approach in greater detail.

We will apply the synoptic approach during the initial assessment for each case study watershed/ecoregion based on existing data. To evaluate the accuracy of the initial assessment, results from this initial analysis will be compared to results from modeling (Section 5.3.6) and to results from an updated synoptic analysis (based on additional data) conducted for the final assessment. Both watersheds and ecoregions will be evaluated (and compared) as analysis subunits, consistent with the spatial framework approach discussed in Section 5.3.7.

General Landscape Criteria. Leibowitz et al. (1992a) also propose the use of general landscape criteria for targeting areas for management and/or further study. They limit the analysis to structural landscape features, such as patch size, connectivity, and porosity (Forman and Gordon 1986). We expand the concept to include any indicator of the relative contribution of specific areas or sites to important landscape functions, the risk of functional loss, or restoration potential. Thus, the approach is similar, conceptually, to the synoptic approach, but results are summarized according to natural landscape features (by overlaying GIS data layers) rather than by spatial subunit. For example, FEMAT (1993) identified areas at high risk for landslides and debris flow in streams, based on slope steepness (from a 30-m resolution digital elevation model) and rock type. Gosselink et al. (1990) identified high-priority areas for protection in the Tensas Basin, Louisiana, based on a criterion of maximizing the patch size of remaining bottomland hardwoods, considered important habitat for black bears in the area.

Selection of the landscape indicators is critical, and must be based firmly in the conceptual landscape model developed for each case study area. Two concepts discussed in Section 3.2.1 are particularly relevant:

- The generic model of landscape processes. The influence of any individual ecosystem component on overall landscape functions depends on three factors: (1) the degree to which the ecosystem acts as a source or sink, (2) the transport mechanism for the material (e.g., gravity, channelized flow, migration), and (3) the spatial relationship between the sources, sinks, and transport mechanisms in the landscape.

- The nature of the stressor-response relationship (Figure 3-4). An understanding of the shape of the stressor-response, or recovery, curve can help identify categories of ecosystems where management actions will result in the greatest net gain (i.e., area of the curve with maximum slope).

Data on current conditions, discussed in Section 5.3.3 (including remote sensing and field data), will be used to identify high-priority areas for management or further study based on the selected landscape criteria.

Timeline

Targeting high-priority areas for management action or further study will occur in 1996–1998.

5.3.6 Models and Decision Support Systems

Project-Level Objective

The objective of this work is to construct simple, watershed-scale interactive models for evaluating, projecting, and comparing the ecological consequences of alternative management strategies on key ecological endpoints.

Approach

A model is a simplified, formal representation of the real world. For our purposes, models express relationships among ecosystem components, functions, stressors, and management options. The relationships may take the form of maps, graphs, tables, equations, and/or algorithms, and are often implemented in computer programs. In assessments, models are used to explore "what if" questions. For example, if urbanization continues as currently projected, what will be the long-term consequences on water quality, terrestrial habitat, and biodiversity? Models can also be used for goal-based analyses, where a management objective is specified and the system searches for management options (e.g., landuse/stressor combinations) that will achieve that objective (e.g., geographic areas that must be protected or restored to achieve water quality criteria and sustain biodiversity given current projected increases in human population growth and urbanization and our understanding of ecosystem functions and response to stressors).

Many existing simulation models describe specific components or types of ecosystems (e.g., in-stream aquatic systems) or specific stressor-response relationships. Examples are presented in Table 5-3. Our primary interest for ecosystem management, however, is models that have the following characteristics:

- Incorporate multiple ecological endpoints, both aquatic and terrestrial, and linkages among these endpoints.
- Allow the user to evaluate the ecological consequences of and trade-offs among alternative management options, for example, ecosystem protection, restoration, pollution controls, and changes in landuse and land and resource management practices.
- Are spatially explicit, to allow for geographic targeting of management efforts, and appropriate for applications at relatively large spatial scales.
- Can be applied with reasonable effort and reasonably attainable data.

Table 5-3. Example Models for Ecosystem Processes and Components Relevant in the Pacific Northwest.

Model	Purpose	Advantages	Disadvantages	Source
SLOSS and PHOSPH	Estimate watershed sediment and phosphorus yield based on topography and soil characteristics	Few parameters. Uses existing mapped data.	Difficult to validate. Designed for small-scale calibration (multiple land cells per watershed)	Tim et al. (1992)
Erosion Productivity Impact Calculator (EPIC)	Cropland simulator. Includes crop growth, nutrient cycling, soil erosion.	Widely used in agricultural research, at field to regional scales.	Requires extensive input data and parameter estimation. Designed for field scale.	Williams and Renard (1985), Sharpley and Williams (1990)
Woody debris loading model	Estimate natural rates of woody debris input to stream channels.	Few parameters. Physically-based.	Requires rare-event probabilities, so parameter estimation is difficult.	Van Sickle and Gregory (1990)
Sockeye salmon recruitment model	Estimate smolt survival and spawning returns in large river system	Incorporates predation, migration, density-dependent mortality,	Requires long annual time series of smolt and spawner densities. Valid for unregulated river.	Crittenden (1994)
Forest fire model	Project evolution of a fire's size and shape, based on percolation theory.	Stochastic contagion model is widely applicable.	Model is theoretical. No parameter estimation methods available.	von Niessen and Blumen (1988)
Forest succession models	A large class of models for simulating stand growth and succession	Widely used for long-term projections. Validation possible via space-for-time substitution.	Parameterized at small spatial scale (one or a few trees).	Shugart and West (1980)
Duck population management model	Simulate effects of habitat modification on mallard population density.	Empirical components use available survey data.	Validation difficult. Designed for prairie wetland habitats. For breeding success only.	Cowardin et al. (1988)
Wildlife response to habitat	Project population density response to habitat loss. Applied to deer, SE Alaska.	Bioeconomic model. Simple, few parameters.	Theoretical. Parameter estimation and validation difficult.	Fagen (1988)
Precipitation-runoff model	Simulate streamflow as function of precipitation, soils, vegetative cover, topography.	Process-based. Incorporates snow melt, vegetative cover.	Small space/time scales, many parameters.	Wigmosta et al. (1994)

Few, if any, existing models meet these criteria. Our objective is to develop such models, using the watershed/ecoregion assessments as pilots. Thus, our focus will be on relatively simple models that will address the management questions and needs of the case study assessments discussed in Section 5.3.2. At the same time, however, we will be successful only if these models have broader applicability and can be readily adapted and applied in other areas and for other, related management issues.

The first step is to better define the modeling objectives and desired model features (e.g., types of output, level of precision, flexibility). Input will be received from the management groups for the case study areas (see Section 5.3.1), as well as from managers (potential model users) outside these areas, facilitated through the Technology Transfer component of the program (Section 10). This information will be synthesized to identify the management questions of highest priority for each study area. Scientists will then define the problems to be addressed by modeling along with the assumptions, scope, available tools, available data, etc. At this point, available models will be evaluated; for models identified for further consideration, analyses will be performed to determine which ones best fit the modeling objectives and desired features. Table 5-3 identifies some of the advantages and limitations of some example models. Based on this review, we will propose specific models and modeling approaches, structures, and procedures to be pursued.

We anticipate developing or adapting a number of models that address different types of management questions and require different levels of effort, data, and technical sophistication to apply. Levins et al. (1989) identify three properties of models—realism of function, generality of application, and precision of representation—which they argue are mutually exclusive. The relative importance of these three properties depends on the intended model use. Our measure of model success is whether the model provides information of direct use to decision makers at effective cost. Higher costs for model calibration and application are justified only if the return is an equivalent increase in assessment accuracy (see Figure 3-2) or in management's acceptance of results.

Clearly, then, we want parsimonious models, i.e., models that are no more complicated, data-intensive, or effort-intensive than is necessary to achieve the desired types of outputs and levels of precision and accuracy. An essential ingredient of selecting or developing a parsimonious model is to define the data quality needs and the required precision and accuracy of the intended models early in the process. One approach to developing parsimonious models is to simplify complex models: begin with detailed, process-based models and then use statistical and other techniques (e.g., Monte Carlo sampling) to identify components and processes that can be eliminated or aggregated without seriously affecting model performance (e.g., Bartell et al. 1988, Rastetter et al. 1992). Our bias, however, is to begin with simple models and simple modeling approaches, and add complexity or pursue more complex approaches only as needed to achieve our modeling objectives. Modeling approaches that we will explore include (but are not limited to) cartographic models (Burrough 1986, Remillard and Welch 1993) and Bayesian modeling techniques that combine expert judgment and data (Reckhow 1988).

A related objective is to develop models that can be applied with readily attainable data, in particular data available through remote sensing. The Oregon Transect Ecosystem Research (OTTER) project is an example of a large-scale application of an ecosystem simulation model (in this case, a model of carbon, nitrogen, and water fluxes in forested systems) using remotely sensed data (Peterson and Waring 1994). The OTTER project included research on both improved methods to collect and analyze remote sensing information, by the National Aeronautics and Space Administration (NASA), and extensive groundtruthing of remotely sensed data and model predictions. Similar efforts are planned as part of this research program, to evaluate the feasibility, cost-effectiveness, and accuracy of using various forms of remote sensing information as input to assessment models.

Models represent, in essence, our assumptions about how a system operates. Uncertainties about these assumptions are a major source of modeling uncertainty and uncertainty in decision making. Hilborn and Ludwig (1993) propose that management actions should be chosen based on their "aggregated performance under a variety of plausible hypotheses" (p. 552) (see Section 3.1). Bayes' theorem provides a tool for quantifying probability distributions for various hypotheses and incorporating these uncertainties into a modeling and decision analysis framework. We will consider modeling approaches that allow us to incorporate, explore, and compare multiple assumptions about ecosystem processes and responses.

We also include in this objective the development of decision support systems. We view decision support systems simply as methods (computer-based systems or guidance manuals) that facilitate the application of assessment tools (models as well as other assessment methods). Development of these decision support systems must go hand-in-hand with development of the assessment approaches, not as an afterthought. The application of these decision support systems to problems associated with ecosystem management will add relevance to this research.

Our approach to developing decision support systems is similar to that for model development. First, we will interact extensively with managers (in the case study areas and elsewhere) to establish the system design objectives and desired features. We will then review the characteristics, software requirements, and utility of existing decision support systems relative to our design criteria. Following this review, we will propose our specific approaches (which will be peer reviewed at that time). Several ongoing efforts are developing decision support systems for large-scale management applications, including the multi-agency

TERRA program (Terrestrial Ecosystems Regional Research and Analysis; DeCoursey et al. 1993). Cooperative research will be considered, whenever appropriate.

Eventually, we plan to develop and demonstrate decision support systems that incorporate the full range of analytical tools available for watershed/ecoregion assessments. The system will be designed to guide the user to refine the questions and endpoints of interest, select the most appropriate methodology for addressing questions at the desired level of precision and quantification, and identify data requirements. The outputs will be presented in a user-friendly format and will include qualitative and, to the degree possible, quantitative characterizations of uncertainties.

Timeline

Development of models and decision support systems will take place during 1995–1999.

5.3.7 Spatial Framework

Project-Level Objective

The objective of this effort is to compare the attributes and relative merits of different spatial frameworks for summarizing or synthesizing information regarding ecological condition, setting attainable ecological goals, and organizing ecological information and research at the watershed/ecoregion scale. Research on regionalization also relates directly to the definition and use of spatial frameworks, but is discussed in Section 5.3.8.

Approach

Spatial framework refers to the delineation of spatial units at multiple spatial scales to organize sampling and analysis activities for assessing or connecting landscapes. ORD's Integrated Ecosystem Protection Research Program includes research on spatial frameworks at a national scale. Our objective is to test, refine, and demonstrate the use of these techniques (see Section 3.2.2) in addressing questions relevant to ecosystem management in the Pacific Northwest.

Three basic types of spatial frameworks are potentially of use: political, hydrologic, and ecological. Management decisions are generally made within the context of a political framework (e.g., cities, counties, states, nation). We cannot ignore the political framework; we must formulate our results in a manner that is useful in that context (e.g., development of statewide conservation strategies in Section 4). However, we will not use political units as primary spatial units for analysis.

Our consideration and selection of spatial scales is grounded in two assumptions, stated here as hypotheses:

1. Both hydrological and ecological units are needed for ecological assessments; these two types of units serve different, but complementary purposes.

2. Omernik's ecoregion approach (Omernik 1987, Gallant et al. 1989) provides an adequate ecologically based spatial scheme for ecological assessments at the regional and watershed/ecoregion scale.

We will evaluate these hypotheses as we conduct the overall integrated final assessment discussed in Section 5.3.2. Examples of specific questions of interest include the following: Do we need both hydrological and ecological units to conduct our analyses and summarize our results (e.g., hydrologic units for water quantity and possibly water quality modeling; ecological regions for defining attainable ecological goals)? Do Omernik's ecoregions provide a useful ecologically based spatial unit, for defining attainable ecological goals, extrapolating site-specific information, summarizing monitoring data, and conducting other analyses? Within the case study watershed/ecoregions, how can we apply, and how important are, subecoregions and landscape-level ecoregions in assessments? To what extent are ecological indicators spatially characterized by ecoregions or subecoregions? Is there a significant difference in the utility of ecoregions defined using qualitative, best-professional-judgment techniques vs units defined based on quantitative techniques, which may be more easily automated and replicated? What are the relative merits (compared to Omernik's ecoregion approach) of other approaches to regionalization that have been proposed for the Pacific Northwest (e.g., the FEMAT physiographic provinces; Figure 1-9).

5.3.8 Extrapolation

Project-Level Objective

The objective of extrapolation work is to evaluate techniques for extrapolating site-specific ecological information to other sites and spatial units at the watershed/ecoregion scale.

Approach

The problem of extrapolation is a central issue in ecological research (Lubchenco et al. 1991). It is not possible to study every organism, every locale, or every individual pollutant or environmental problem.

We must devise ways of extending or extrapolating what we learn from a given study or set of studies to other organisms, locales, and/or problems. There are many different forms of extrapolation. For example, a major issue frequently discussed in ecological risk assessment, especially assessments of chemical pollutants, is how we extrapolate from bioassays to infer risks to populations or communities outside the context of the bioassay environment (e.g., laboratory bench or field mesocosm). Projecting future trends through time is another form of extrapolation. The most important aspect of extrapolation in watershed/ecoregion-scale research, however, is spatial extrapolation, that is, "How can we extrapolate research findings from studies at one or a few sites to infer characteristics or responses at other sites within a specific watershed/ecoregion or to other locations within other watersheds/ecoregions?"

We have two long-term extrapolation objectives: (1) developing methods for (spatial) extrapolation that can be broadly applied and (2) testing these methods within the case study areas to extrapolate site-specific studies to broader areas. We use the second objective as a pilot test for the first objective. In this five-year research program, we will consider our research successful if we satisfy the second objective in a manner that permits us to select extrapolation approaches for further study in other areas and provides a solid foundation for achieving the first objective in later years.

There are three general approaches to spatial extrapolation: statistical (empirical) modeling, process-based (mechanistic) modeling, and nonmodeling or classification approaches. These categories are not distinct, and often a given extrapolation approach draws upon aspects of all three. In this section, we focus on nonmodeling, classification approaches. Section 3.2.2 provides background information on landscape classification and regionalization.

We propose to develop a process-based taxonomic approach to classification, that is, a classification system based on our understanding of important physical, chemical, and biological processes and how these processes relate to the classification endpoints of interest. We will classify landscape units (i.e., areas of land and their associated ecosystems) according to characteristics that interest ecosystem managers and that address the needs of the assessments discussed in Section 5.3.2. Examples include classification systems that group landscape units according to their (1) contributions to important eco-system functions (e.g., water quality improvement or as habitat to support biodiversity), (2) sensitivity or responsiveness to specific stressors or management actions, (3) expected best management practices, or (4) restoration potential.

Major research questions include the following:

- Can a small number of classification systems be developed that would be adequate for most management applications, or is it necessary to develop a separate classification for each endpoint? We do not believe that a single classification system will be adequate. At the same time, it may be impractical and unnecessary to develop a separate classification for each endpoint, even though special purpose classification can provide more accurate results.

- At what spatial scale are landscape units no longer unique, so that they can be categorized and dealt with by category rather than individually?

- How should we define the landscape units to be classified? Options include arbitrary units, such as pixels or hexagons, and natural units, including small watersheds or landscape-level ecoregions.

- Should we use one set of units for all classifications (i.e., all classification endpoints) or should we tailor the unit to fit the objective of the classification? The first approach is simpler; we work with the same set of units and simply regroup them as needed, depending on the classification objective. The second approach would probably lead to more accurate classifications.

- What are the best approaches to grouping ecological units into classes, so that the characteristics of any one unit can be inferred from prior/current studies of other units in the same class? As already discussed, we propose a process-based classification, in which classes are defined based on those physical, chemical, or biological processes considered most important in determining the characteristics of a unit, or the responses of that unit to some stressor or management action. Thus, for each classification endpoint of interest, we will develop a conceptual model of landscape processes and the relationship of these processes to the endpoint, based on literature reviews and a series of workshops. This conceptual model will provide the basis for the proposed classification systems.

- What is the relationship between the process-based classification and attributes that can be observed or measured? To be usable, the process-based classification must be keyed to observable and measurable attributes, that is, characteristics or indicators that can be observed or measured to determine in what class a specific landscape unit belongs. We refer to this as the *taxonomic key.*

Development of the taxonomic key is one of the most difficult tasks in landscape classification. We propose three parallel activities (Figure 5-8). As part of the literature review and workshops on the process-based classification, likely indicators of and surrogates for important processes will be identified and a preliminary key defined based on current scientific understanding. Second, existing intensively studied sites in the region will be grouped into classes based on previous research at the sites. Multivariate discriminant analyses, and other appropriate statistical analyses, will then be used to identify attributes useful for distinguishing among classes, and associated classification error rates. The third approach begins with spatially extensive data sets, such as remote sensing data and the field data that will be collected by EMAP in the region and case study areas. Statistical analyses (e.g., cluster analysis) of these data will be conducted to identify groups of landscape units with similar indicator characteristics. The relationship between these clusters and the process-based classes will then be evaluated through more intensive sampling at representative sites within each cluster. Studies at these sites may involve field measurements of process-related variables, calibration and application of process-based models (e.g., to evaluate the sensitivity of the landscape unit to stressors or restoration activities), and, at a small

PROCESSED-BASED TAXONOMIC CLASSIFICATION

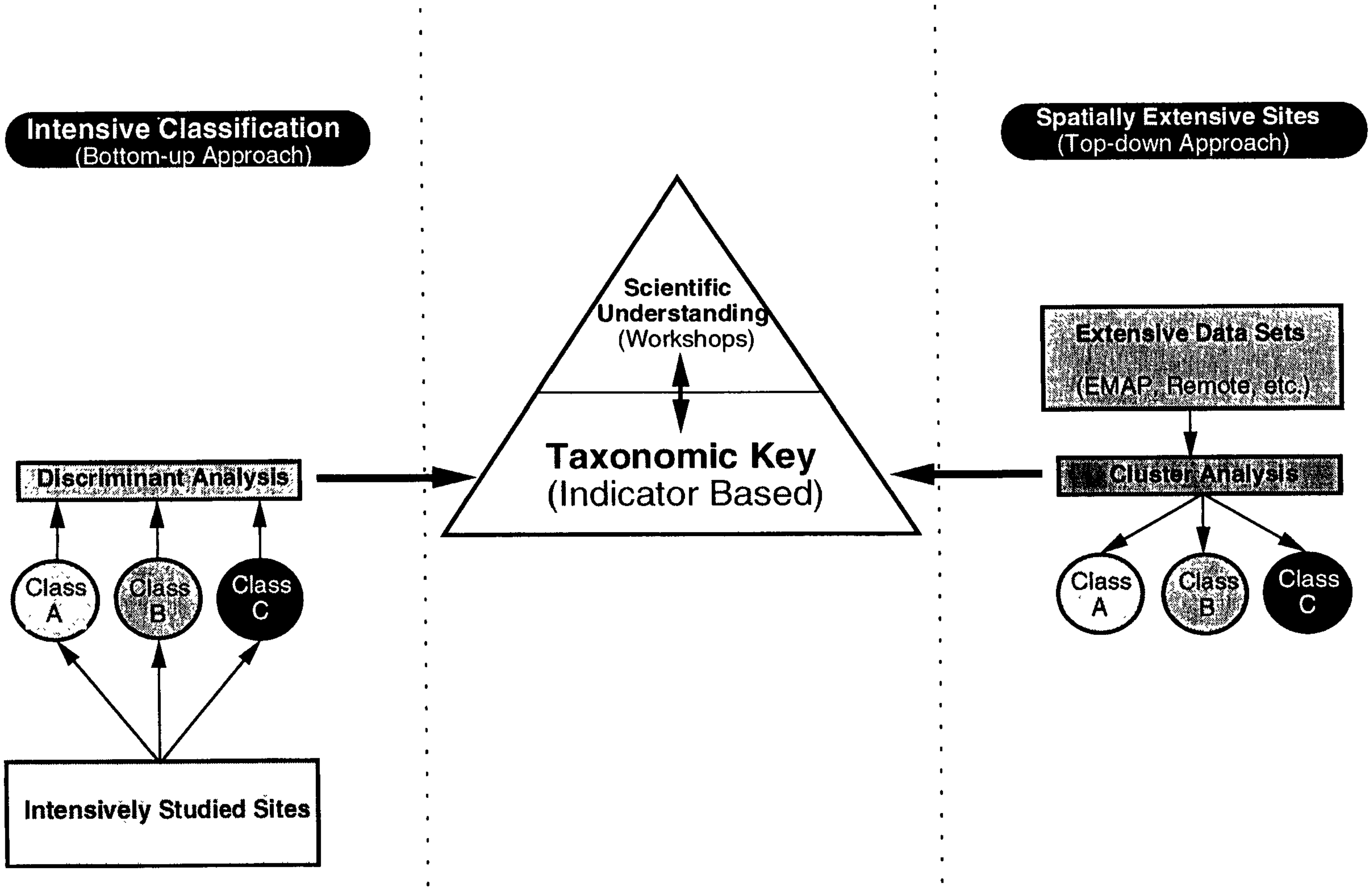


Figure 5-8. Three approaches to developing a taxonomic key, based on site-specific indicator characteristics, for landscape classification.

number of sites, whole-system manipulations, in cooperation with local managers (i.e., management experiments).

To the degree possible, taxonomic keys will emphasize attributes (i.e., indicators) that are relatively easy to observe or measure, so that the key and classification system can be applied readily and cost effectively by ecosystem managers. Strong preference will be given to attributes available from existing maps or through remote sensing. We propose, however, to develop several keys, or a single key with multiple levels, for each classification, such that the more data available for a given landscape unit, the more precisely and accurately the user will be able to identify the class within which the landscape unit belongs.

Landscape classification provides a bridge between intensive, site-specific research and extensive surveys and a basis for extrapolating findings from studies at one site to other similar sites in the same class (see Section 3.2.2 for examples). It is a method for organizing information about ecosystem processes, functions, responses to stressors, restoration potential, and best management practices so that technical information is more readily available to managers. The characteristics of a given landscape unit can be inferred from prior studies of other landscape units in the same class. Spatial units within the case study watershed/ecoregions will be classified and characterized, using the landscape classification approach, based on site-specific research both in the case study areas as well as at other similar sites in the region as a whole. We will compare the results from and utility of the bottom-up classification approach to the top-down classification approach used to define the spatial framework (Section 5.3.7).

5.3.9 Targeted Ecological Research

As a final objective of the watershed/ecoregion component, we leave open the option to conduct ecological research targeted specifically at major unknowns and uncertainties relative to our understanding of ecosystems and how ecosystems respond to stressors and management actions. Sections 6 and 7 discuss major research projects designed to improve our understanding of riparian systems and estuaries, which will contribute to watershed/ecoregion assessments. We expect additional research needs to be identified during the initial assessments for the case study areas. From one to several small projects, with budgets of $200K or less, can be accommodated within the existing research strategy (see Table 5-1). Larger projects, to address critical research needs not addressed in Sections 5.3.2–5.3.9, 6, or 7, would require restructuring and reprioritization of the research program.

5.4 MAJOR CONTRIBUTIONS

The major contributions of Watershed/Ecoregion research to the PNW research program and EPA Region 10, state, and local priorities will include the following:

- An ecological assessment process, and associated analytical tools, appropriate for addressing ecosystem management questions at a watershed/ecoregion scale.
- Models and decision support systems that will allow managers to assess the ecological consequences and trade-offs among alternative management strategies that can be applied with reasonable effort and data.
- Landscape classification systems for (1) extrapolating site-specific research findings to other similar sites and areas and (2) organizing information about landscape functions, responses to stressors, and restoration potential in a manner that makes it readily accessible to managers.
- Ecological information and analyses that address specific questions of interest to managers in the two case study watersheds/ecoregions in the Pacific Northwest.

Major program deliverables for the Watershed/Ecoregion research component are listed in Section 11.

6. RIPARIAN AREAS

In this section, we present the Riparian Area research component. The riparian research will be closely coordinated with Watershed/Ecoregion research efforts (Section 5). Section 6.1 provides an overview of the ecological significance of riparian areas in general and in the Pacific Northwest. Section 6.2 identifies the riparian research major objectives. Section 6.3 describes the riparian strategic approach and includes a discussion of the ecological functions on which the riparian research will focus and a description of specific research projects (Sections 6.3.1–6.3.5).

6.1 BACKGROUND

Riparian areas are critically important interfaces between terrestrial and aquatic ecosystems. They are major hydrologic source areas for stream flow (Hewlett and Hibbert 1967, Dunne et al. 1975), exert a strong influence on the quality of stream environments (Karr and Schlosser 1978, Decamps 1993), have diverse plant communities (Gregory et al. 1991), and are important habitat for a large number of terrestrial animal species (Naiman et al. 1993). Furthermore, riparian areas are one of the most dynamic parts of the landscape (Swanson et al. 1988). Unfortunately, riparian areas, especially riparian woodlands, are among this country's most heavily modified natural vegetation types (Swift 1984). In some regions of the United States, the extent of riparian forests has been reduced by as much as 80%.

6.1.1 Ecological Importance

Gregory et al. (1991) present a ecosystem-based conceptual model that is helpful in understanding the form and function of riparian areas. In this model, they define riparian areas as three-dimensional zones or areas of direct interaction between terrestrial and aquatic ecosystems. The boundaries of riparian areas extend outward to the limits of flooding and upward into the canopy of streamside vegetation. The size of the zone of influence for a specific ecological process or function is determined by the unique spatial patterns and temporal dynamics of each process or function. Spatial and temporal variance of hydrologic and geomorphic processes, terrestrial plant succession, and the nature of adjacent aquatic ecosystems define the attributes of riparian areas (Figure 6-1). The model of Gregory et al. (1991) is based on the assumption that geomorphic processes create a mosaic of stream channels and floodplains within the valley floor, which in turn provides a physical template for the development of riparian plant communities. Valley floor landforms and associated riparian vegetation create the array of physical habitats within the active channels and floodplains. Within the context of these habitats, streamside plant communities act as major controls of the flux and quality of nutrients to stream ecosystems.

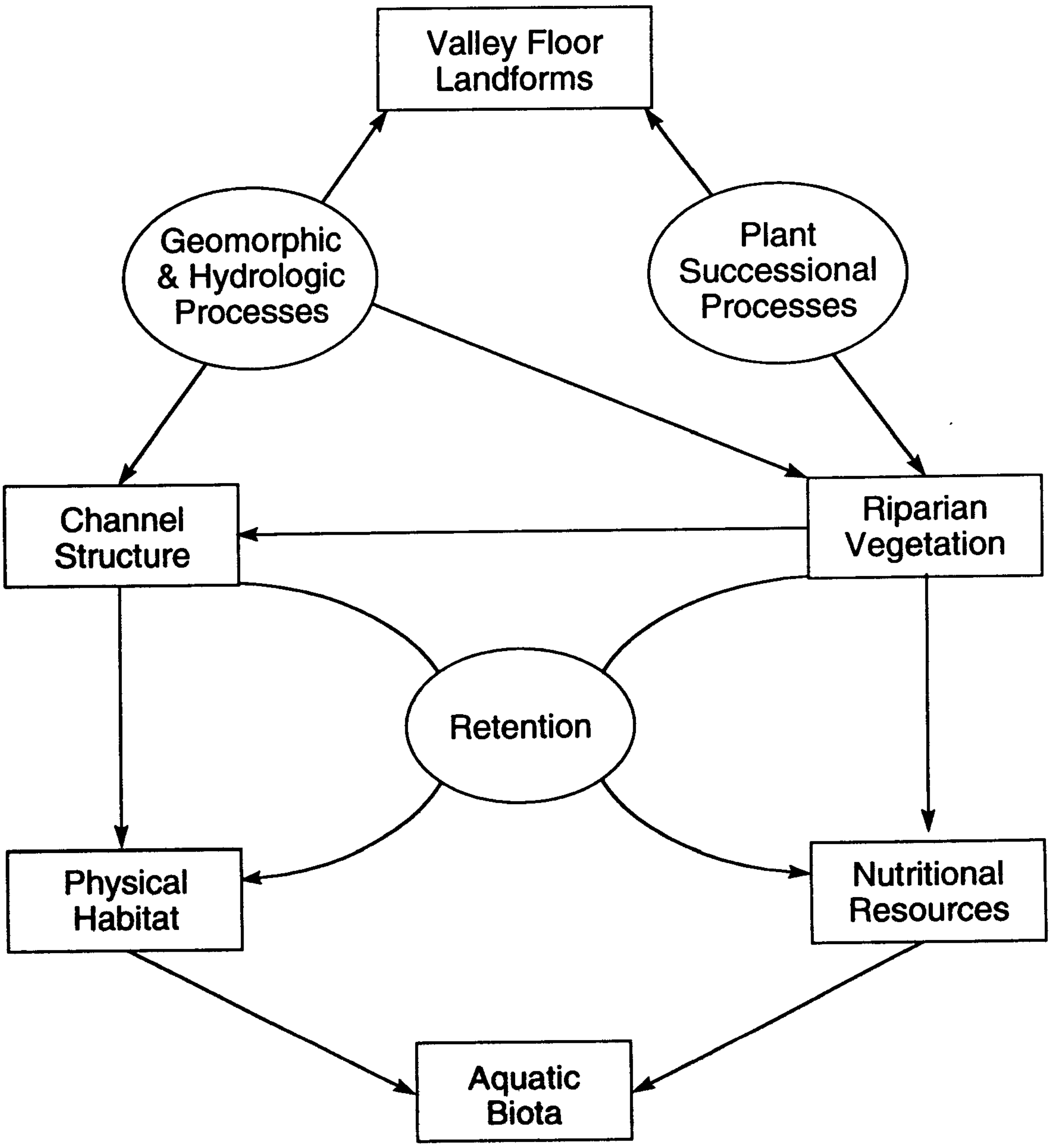


Figure 6-1. **Relationships among geomorphic processes, terrestrial plant succession, and aquatic ecosystems in riparian zones. Directions of arrows indicate predominant influences of geomorphic and biological components (rectangles) and physical and ecological processes (circles) (Source: Gregory et al. 1991).**

Riparian areas should not be considered solely in the context of a single stream reach or landscape position. Brinson (1993b) describes how riparian areas in the headwaters of a watershed are related to and can effect riparian and aquatic ecosystems of the higher order streams. Decamps (1993), while discussing the water quality improvement aspects of riparian areas, noted that this riparian function evolves in response to hydrological variability and to patch dynamics. Therefore, managing the buffering/retention function of riparian areas is possible only if the shifting patchiness of the entire river basin is managed. Decamps (1993) concluded that a riparian ecosystem management approach should be used both at the floodplain scale itself and at the hydrologic network level. Naiman et al. (1993) concluded that consideration must be given to maintaining hydrologic connectivity and variability of riparian corridors from the headwaters to the sea. This means that riparian corridor management strategies must include headwater stream reaches as well as broad floodplains downstream.

Although riparian areas are interconnected within a watershed or river basin, riparian areas typically have different attributes depending on their location within a watershed (Gregory et al. 1991). Figure 6-2 illustrates typical patterns of natural plant community occurrence within Northwest riparian areas. In constrained stream reaches, common in low-order streams of the Northwest mountains, flood plain zones are small and consequently riparian plant communities are narrow and closely resemble those of upslope forests. In unconstrained reaches, common in large valleys, flood plain zones are much larger and riparian plant communities are typically complex, heterogeneous patches of different successional stages, including herbs and grasses, deciduous trees, and coniferous stands of many ages. This difference in plant communities reflects the sharp geomorphic differences in the two landscape settings. Furthermore, the geomorphic and plant community differences are commonly reflected in the other ecological processes and functions in the riparian areas.

Where forested riparian areas are located adjacent to land that is being intensively used for agriculture, urban development, or silviculture, the riparian areas can dramatically improve the quality of water draining from a watershed to a stream (Karr and Schlosser 1978, Peterjohn and Correll 1983, Lowrance et al. 1984, 1985). Sedimentation deposition, denitrification, and nutrient uptake are some of the processes in riparian areas that have been observed to improve water quality. For riparian areas to be effective at removing pollutants from agricultural or other lands, a major portion of the water from the upslope part of the watershed must pass through the biologically active rooting zone of the riparian area. Phillips et al. (1993), working in the Delmarva Peninsula, found that denitrification occurs in forested wetlands (riparian areas) in which water moves through an anaerobic rooting zone. In other settings, nitrate-rich groundwaters had deep flowpaths and were discharged into the stream without significant contact with the riparian area.

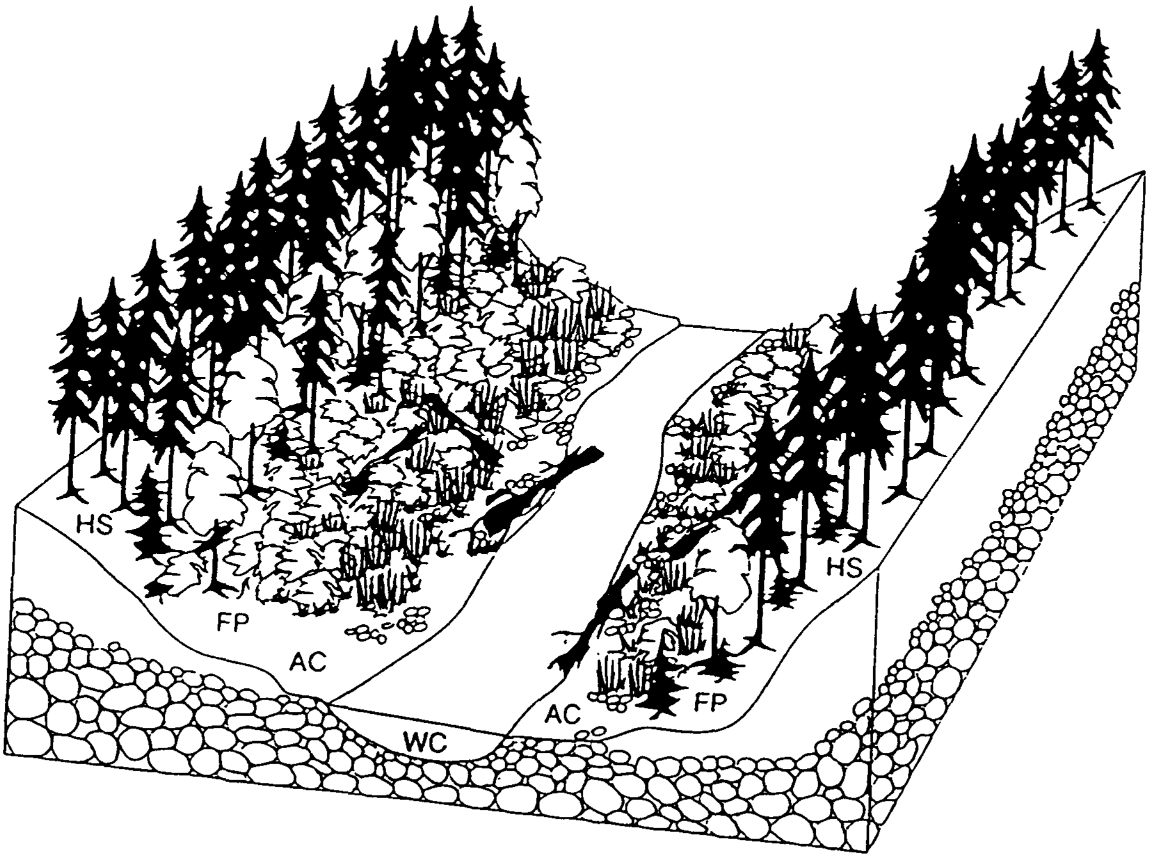


Figure 6-2. Typical patterns of riparian plant communities associated with different geomorphic surfaces of river valleys in the Pacific Northwest. Scattered patches of grasses and herbs occur on exposed parts of the active channel (AC). Litter terrestrial vegetation is found within the low-flow wetted channel (WC). Floodplains (FP) include mosaics of herbs, shrubs, and deciduous trees. Conifers are scattered along floodplains and dominate older surfaces. The overstory species in riparian forests on lower hillslopes (S) consist primarily of conifers (Source: Gregory et al. 1991).

Riparian areas have a profound effect on the physical, biological and chemical characteristics of streams (Figure 6-1). Gregory et al. (1991) state that the structure and processes of streams, more than other ecosystems, are determined by their interface with adjacent ecosystems. Narrow, ribbon-like networks of streams intricately dissect the landscape, accentuating the interaction between aquatic ecosystems and surrounding terrestrial ecosystems. As previously described, streamside plant communities act as major controls of the flux and quality of nutrients to stream ecosystems (Gregory et al. 1991). Schlosser (1991) noted that, because the various life stages and species of fish in streams require different kinds of physical habitats, spatial heterogeneity and the maintenance of connectivity between habitat patches is critical for fish reproduction and survival. The terrestrial-aquatic interface in upstream areas, or at the stream margin or floodplain, provides environmental conditions combining high spatial heterogeneity, a large supply of organic matter, and shallow habitats with relatively few aquatic piscivores. Consequently, they are critical areas of the landscape where most fish reproduction occurs.

Riparian areas are also important as habitat for terrestrial animals . Riparian vegetation occupies one of the most dynamic areas of the landscape. Vegetation communities reflect both fluvial disturbance from floods and nonfluvial disturbance regimes of adjacent upland areas, such as fire, wind, plant disease, and insect outbreaks (Gregory et al. 1991). Consequently, riparian areas are the most diverse, dynamic and complex biophysical habitats on the terrestrial part of the Earth (Naiman et al. 1993), and a wide variety of bird, mammal, reptile, and amphibian species depend on riparian areas for habitat (Stauffer 1980, Hawkins et al. 1983, Croonquist and Brooks 1991, Keller et al. 1993, Mitsch and Gosselink 1993).

6.1.2 The Pacific Northwest

In both the moist landscapes west of the Cascade Mountains and the arid landscapes east of the Cascades, riparian areas perform essential ecological functions (Elmore and Beschta 1987, Gregory et al. 1991). Unfortunately, the ecological functions of riparian areas are easily impaired by a myriad landuse activities, and have been impaired in a significant part of the Pacific Northwest. During the past few years, issues regarding the management of riparian areas in forests have been key elements of the policy debate about forest management in the Northwest (FEMAT 1993). Establishment of ecologically sound ways to manage and protect riparian areas is one of the key issues facing federal land management agencies, EPA, and private landowners.

Riparian research efforts in the Pacific Northwest during the last decade have focused largely on forests and the relationship between forest riparian areas and habitat for salmonids, and are essential to learning how to manage riparian ecosystems responsibly. However, there are still significant knowledge gaps about riparian areas that hamper effective management of these ecosystems. Although a number of riparian research projects have been conducted in rangelands of the Pacific Northwest (Van Deventer 1990), important questions related to ecosystem management remain. Very little is known about the status and ecological role of riparian systems in agricultural landscapes of western Oregon and Washington or in urban settings (Van Deventer 1990). Further work is also needed on development of indicators of riparian condition in all landuse settings. Furthermore, as ecosystem management plans and strategies are developed and implemented, sound approaches for establishing restoration locations, performance criteria, and attainable quality will be needed (Kusler and Kentula 1990). As discussed in Section 6.1.1, recent papers by Gregory et al. (1991), Naiman et al. (1993), and Decamps (1993) emphasize the importance of the integrated role of riparian systems within entire drainage networks. However, little progress has been made in this area of riparian investigation/management.

6.2 OBJECTIVES

The research needs identified in Section 6.1.2 lead us to establish three major classes of objectives to be addressed by EPA riparian research.

1. Evaluation and assessment of riparian area condition:
   - A. Define reference conditions for riparian areas in agricultural settings.
   - B. Establish indicators of riparian area condition in agricultural settings.
   - C. Develop approaches for evaluating riparian area condition in mixed landuse watersheds.
2. Restoration of riparian areas:
   - A. Develop approaches and performance criteria for restoring degraded riparian areas in agricultural settings.
   - B. Develop approaches to locate promising areas for riparian restoration and to evaluate the attainable quality and restoration potential of riparian areas within mixed landuse watersheds.
3. Economic/Ecological Opportunities (Eco-opportunities):
   - A. Evaluate practices that are ecologically and economically promising for managing riparian areas in agricultural settings.

6.3 APPROACH

Because the PNW research program is supported by FEMAT-related funding, initial activities will be conducted in western Oregon and Washington (Section 5.3.1). We have chosen to focus our initial site-scale riparian research (objectives 1A, 1B, 2A, and 3A) on agricultural lands, because of the need for information about riparian areas in agricultural lands west of the Cascades and because the USFS and other federal agencies conduct the majority of their riparian research in this area on forested landscapes. Watershed-scale research (objectives 1C and 2B) will be conducted in the same case study areas selected for the Watershed/Ecoregion component of the research program: the Willamette River Basin and the Washington Coastal Ecoregion (Section 5.3.1). Watershed-scale riparian research will contribute directly to the watershed/ecoregion-scale assessments described in Section 5. We will also concentrate site-specific research in the case study areas, although some site-specific research may occur in other areas of western Washington and Oregon to evaluate riparian areas in other settings and to take advantage of sites well suited to accomplishing project objectives (e.g., existing riparian restoration activities). If the PNW research program extends beyond the first five-year study period, we will expand our efforts to include riparian areas in arid landscapes of the Pacific Northwest. These arid land investigations will allow concepts and approaches developed in the early part of the program to be evaluated in the dramatically different landscapes that occupy a significant part of the Northwest.

An important part of our research strategy is to evaluate major risks to high-priority ecological functions of riparian ecosystems (see Section 6.1.1). The riparian functions on which we will focus during this five-year study are as follows:

- **Water quality improvement**: the ability of forested riparian areas to control and frequently improve the quality of water draining from watersheds into streams.
- **Aquatic habitat**: the influence that riparian vegetation exerts on physical habitat, for fish and other aquatic organisms, in adjacent streams.
- **Terrestrial habitat**: the provision of habitat for terrestrial plants and animals within riparian areas.

In each of the projects described in Sections 6.3.1–6.3.4, we will develop and test specific hypotheses to address project objectives. The hypotheses will center on the processes associated with our key riparian functions. Examples of site-level hypotheses that will be tested as part of the riparian water quality study (Section 6.3.2) include:

- Grass seed agricultural lands with adjoining naturally vegetated riparian areas export water of higher quality to streams than do grass seed fields without naturally vegetated riparian areas.
- Grass seed agriculture/riparian complexes with predominantly shallow hydrologic flowpaths, which ensure transport of subsurface water through rooting zones in riparian areas, export water to streams with lower concentrations of nitrogen, phosphorus, and Diuron than do complexes with deep flowpaths.
- During wet seasons, riparian area soils have low E_h values (reducing condition) which result in the decrease of shallow groundwater nitrogen concentrations through the process of denitrification.

- Riparian areas reduce the transport of sediment, phosphorus, and Diuron from grass seed agricultural fields to streams by trapping and storing sediment in overland flow moving from grass fields across riparian areas to streams.

We have developed five projects to address our major research objectives for the three priority riparian functions just identified. Table 6-1 summarizes the major objectives and riparian functions that each project addresses. Sections 6.3.1–6.3.5 describe the rationale, specific project-level objectives, and approach for each project.

Table 6-1. Major Riparian Research Objectives and Ecological Functions Addressed by Riparian Research Projects.

	Major Objectives[a]					
Project	**1A**	**1B**	**1C**	**2A**	**2B**	**3A**
Landscape Evaluation of Riparian Complexes (Section 6.3.1)	WQ[b] AH/TH	WQ AH/TH	WQ AH/TH		WQ AH/TH	
Water Quality Relations of Riparian Areas (Section 6.3.2)	WQ	WQ		WQ		
Habitat Function/Restoration of Riparian Areas (Section 6.3.3)	AH TH	AH TH		AH TH		
Riparian Area Condition and Restoration in Mixed Landuse Watersheds (Section 6.3.4)			WQ AH		WQ AH	
Riparian Eco-Opportunities (Section 6.3.5)						WQ AH

a Numbers and letters are keyed to the list of major objectives in Section 6.2.

b Function definitions: WQ = water quality; AH = aquatic habitat; TH = terrestrial habitat.

The riparian research described in Sections 6.3.1–6.3.5 is based on a funding assumption of approximately $865K per year. Table 6-2 presents the expected distribution of riparian funding by project for the five-year period covered by this strategy document. Most funding categories remain fairly constant over the five years. One exception is the Riparian Eco-Opportunities Project. We envision that there will be a relatively intensive initial effort to ascertain promising riparian management practices that have the potential to maintain or enhance ecological functions and also to provide economic returns to landowners (see Section 6.3.5). After the initial work, a lower level of activity will be maintained during the remainder of the five-year study period.

Table 6-2. Distribution of Riparian Funding ($K) by Project During the Five-Year Study Period.

	Fiscal Year				
Project	**FY95**	**FY96**	**FY97**	**FY98**	**FY99**
Landscape Evaluation of Riparian Complexes	100	175	175	175	175
Water Quality Relations of Riparian Areas	220	190	175	150	150
Habitat Function/Restoration of Riparian Areas	450	375	375	400	400
Riparian Area Condition/Restoration in Mixed Landuse Watersheds	45	100	115	115	115
Riparian Eco-Opportunities	50	25	25	25	25

Cooperation and integration with other PNW research components and with EPA's EMAP will be essential to a successful riparian research effort. The Regional Biodiversity research component (Section 4) will examine issues related to the use and design of habitat corridors as landscape linkages for the conservation of biodiversity. The Riparian Habitat Project (Section 6.3.3) will be closely coordinated with this effort. The Watershed/Ecoregion component will develop integrated watershed assessment approaches, and riparian considerations will be important assessment issues. The Riparian Mixed Landuse Watersheds Project (Section 6.3.4) will contribute critical riparian information for these watershed-level assessments. EMAP-Surface Waters is developing indicators of stream and riparian condition for use in upcoming systematic stream surveys in the Pacific Northwest. As each of the PNW riparian projects is developed, we will take advantage of opportunities for cooperative efforts with EMAP whenever feasible.

We also recognize that EPA alone cannot accomplish its PNW objectives. Cooperation with other federal agencies, state agencies, universities, and other groups will be necessary for significant progress to be made. An important component of our research strategy is based on good communication and cooperation with appropriate public and private organizations.

Riparian research in the Pacific Northwest is a partnership between EPA's PNW research program and EPA's Wetlands Research Program (WRP) (Leibowitz et al. 1992a). The PNW research program provides the leadership and most of the funding for riparian research in the Pacific Northwest. The WRP provides the leadership and most of the funding for EPA's wetlands research nationwide. Both programs consider research on riparian systems a priority. The PNW research program is studying riparian areas only in the Pacific Northwest, but the WRP has studies of riparian systems in several regions, including the West. Therefore, a good opportunity exists for cooperative research and for placing the Pacific Northwest results in a national context. The cooperation will avoid duplication and ensure the efficient use of funds.

6.3.1 Landscape Evaluation Of Riparian Complexes

As we stated in Section 6.1.2, there is a general lack of information about riparian ecosystems in agricultural settings in western Oregon and Washington. Informal assessments by scientists involved in riparian research in the Pacific Northwest invariably support the notion that agricultural riparian systems have been dramatically altered by land management practices. However, we do not know much, quantitatively, about the landscape interactions between agriculture and riparian areas within watersheds. An overall picture of current stressor/riparian relationships in agricultural landscapes is needed to establish the context for site-scale research and to supply information for developing mixed landuse watershed-scale riparian evaluation techniques (Section 6.3.4). Similar needs also exist for rangelands in arid landscapes east of the Cascades.

Project-Level Objectives.

- Quantify, at a landscape scale, the occurrence of and landuse stressors to riparian areas.
- Develop relationships between agricultural stressors and riparian area condition.

Approach

We will characterize the occurrence and characteristics of riparian areas in agricultural settings in the two watershed/ecoregion case study areas, the Willamette River Basin and the Washington Coastal Eco-region, by interpreting satellite imagery, videography, or aerial photography. Some groundtruthing may be required to confirm riparian vegetation characteristics interpreted from remote sensing techniques. We will seek to determine the types of agricultural-riparian or rangeland-riparian complexes that occur in major landscape settings. In other words, we will quantify the areal extent to which major crops adjoin riparian systems. We will also quantify and classify riparian resources with regard to watershed/ ecoregion attributes, such as stream order and geomorphic position. In this way, we can determine the types of riparian systems most influenced by agriculture in the case study areas.

To complement these analyses, we will evaluate the major stressors, other than habitat modification, that major agricultural systems are likely to exert on riparian systems. Our main data sources will be published summaries of pesticide usage, erosion rates, and related information for the major agricultural systems in the case study areas. Information on habitat modification will be obtained from our remote sensing activities, described in the previous paragraph, in the Riparian Habitat Project (Section 6.3.3), and in the Riparian Mixed Landuse Watersheds Project (Section 6.3.4).

To the extent possible, and in cooperation with other riparian projects, we will test relationships between attributes of the landscape complexes and riparian condition. We will also seek to identify candidate reference sites for use in other riparian research projects. The relationships that we develop will also serve as useful background information for site-level and watershed-level efforts to develop and evaluate restoration approaches (Sections 6.3.3 and 6.3.4).

In addition, we will coordinate research activities with other groups in the Northwest using remote sensing data and GIS approaches. We will seek to fill in gaps of data coverages and analyses from the work of other agencies. We also hope to contribute any imagery or data that we acquire to the collection of data available to all agencies and groups working on ecosystem management in the Pacific Northwest.

Timeline

As discussed above, the project will focus on agricultural lands in the two case study areas west of the Cascades during the five-year study. After that time, if possible, we will expand our efforts to include arid landscapes east of the Cascades.

6.3.2 Water Quality Relations Of Riparian Areas

Water quality is an important watershed management issue in the Pacific Northwest because of concerns about the status of numerous salmonid species and other aquatic organisms, and about water supply for recreation and domestic use. Throughout the United States, agriculture is a major source of nonpoint source pollution (U.S. EPA 1988).

Grass seed production is the predominant cropping system west of the Cascades in the interior valleys of Oregon and Washington. Grass seed cropping systems in this region account for more than 90% of the domestic forage and turf grass seed production and typically occur in poorly drained soils bordered by a diverse array of landscapes, including riparian ecosystems. The Willamette Valley of Oregon is a typical example and accounts for 180,000 ha of grass seed production annually (CH2M Hill and Oregon State University 1991). Intensive activity in grass seed production coincides with the rainy season in the Northwest, with rainfalls in excess of 115 cm/yr. The soils under grass seed production are therefore susceptible to surface water runoff and soil erosion. This is of concern because grass seed cropping systems are amended with fertilizers and are highly managed with pesticides to control weeds, diseases, and insect pests. Grass seed fields typically receive in excess of 200 kg of nitrogen per hectare per year. Diuron (3-(3,4-dichlorophenyl)-1,1-dimethylurea) is a common pesticide for the control of weeds in grass cropping systems and is typically applied at a rate of 0.9 to 2.6 kg/ha. Sediment loading to surface waters diminishes water quality and acts as a vector for pesticide transport.

As discussed in Section 6.1.1, forested riparian areas can dramatically improve the quality of water draining from agricultural lands to streams. Nutrient and pesticide removal by plant uptake, gaseous loss, metabolism, and stabilization into soil organic matter pools are mechanisms by which riparian areas can alleviate nonpoint sources of pollutants. The uptake of nitrogen and other nutrients is highly dependent on riparian zone vegetation type and age and soil characteristics (Hicks and Frank 1984). Nutrient and pesticide uptake is maximal in young vegetation and during certain phenological events, such as time of flower and fruit production (Kozlowski et al. 1991). Denitrification potentials in riparian zone surface soils near the border of agricultural lands may remove nitrogen from shallow ground water (Lowrance 1992, Jordan et al. 1993). These soils are characterized by strong reducing conditions, E_h less than -90 mV, which are capable of supporting significant amounts of denitrification. Pesticide degradation may be diminished, however, under low oxygen soil conditions compared to fully oxygenated conditions. Riparian zone vegetation and litter accomplish sediment removal by impeding surface water flow and may play a crucial role in stabilizing phosphorus and pesticides in surface water runoff (Cooper and Gilliam 1987, Cooper et al. 1987, Lowrance et al. 1988).

Most of the published data about the water quality functions of forested riparian areas is for the eastern United States. Virtually no quantitative information has been published regarding the role of forested riparian areas in controlling water quality from agricultural lands in western Oregon and Washington.

Project-Level Objectives

The purpose of this project is to gain a better understanding of the function of riparian ecosystems in maintaining water quality in intensively managed agricultural landscapes. To address this goal, we propose the following specific research objectives:

- Determine the spatial and temporal distribution of nutrients, pesticides, and sediments within riparian zones and in adjacent agricultural soils.
- Determine the dominant biological, chemical, and transport processes responsible for reductions in nutrient, pesticide, and sediment concentrations and transport to surface and ground waters.

Approach

During the first three years of this project, we will utilize a simple study design to establish water quality relationships between forested riparian areas and adjoining grass seed agricultural fields. We will evaluate these water quality relationships at two sites in the Willamette Valley of western Oregon. One site will be on poorly drained soils and one site will be on moderately drained soils (Table 6-3). The conditions at these two sites will bound the hydrologic conditions common to grass seed agriculture in the western interior valleys of Oregon and Washington. In fact, the soil types to be studied represent landuse areas typical of nearly 50% of the total cropping systems area in the Willamette Valley. In addition, this project will provide excellent information with which to establish water quality reference conditions for riparian areas in agricultural settings and performance criteria for riparian restoration projects. Each site will have two research subunits, one subunit with a well-established, forested riparian area and one subunit with a narrow riparian area with no woody vegetation.

The selection of specific sites will take into account information from established experiments investigating the effects of agronomic practices and pesticide use histories. In addition, we are working closely with grass seed commodity groups to assist in the location of sites, which will be on private farmland, and to define typical practices for grass seed agriculture in the Willamette Valley. We expect site selection to be complete in summer 1995.

Table 6-3. Time of Initiation for Components of Research Experimental Design.

Riparian Forest Condition	Soil Drainage Class	
	Poorly drained	**Moderately drained**
Well established	Year 1	Year 2
Nonexistent/minimal	Year 1	Year 2
Intermediate	*	*

* To be determined after first three years.

During the first year of the study, we will instrument the poorly drained site (both mature vegetation riparian and minimal riparian subunits) to collect shallow groundwater and overland flow using a combination of automated and passive wells and sampling devices (Table 6-3). Continuous measurements will also be made of soil, water and air temperature, and precipitation. A hillslope segment, consisting of an agricultural field and riparian zone, will be the basic experimental unit. Groundwater wells will be placed to track nutrient and pesticide movement and transformations from agricultural fields through riparian zones to streams. Water samples will be analyzed for sediment, nitrogen, phosphorus, and Diuron.

During the second year of the study, we will instrument the moderately drained study site. The experience gained during the first year at the poorly drained site, which is more difficult to instrument because of the presence of standing water during the wet season, will allow instrumentation and monitoring to occur more efficiently at the moderately drained site. We may also include additional instrumentation (e.g., soil lysimeters), based on the first year experience. In total, monitoring will occur for three years at the poorly drained site and two years at the moderately drained site. We believe that we will have sufficient data at both sites, assuming cooperative climatic conditions, to allow quantitative definition of the spatial and temporal distribution of nutrients, pesticides, and sediment in agricultural fields and riparian zones. Using our study design, we will also be able to explicitly test the hypothesis that riparian areas actively reduce transport and concentrations of nutrients, pesticides, and sediments from agricultural land to receiving waters. Coincident with the groundwater and surface water monitoring, we will also conduct plot-level studies to elucidate processes controlling nutrient flux from the riparian areas. Process studies may be added to quantify processes controlling the movement of Diuron, depending on observed levels of this pesticide exported to streams.

Our research dealing with grass seed agricultural systems of the Willamette Valley will be a cooperative effort between EPA and the USDA Agricultural Research Service (ARS), National Forage Seed Grass Production Research Center. Both EPA and ARS are contributing scientific personnel and funding for the project. After the initial three years of study, we anticipate extending the water quality riparian research to include other agricultural settings, or rangelands, or to further quantify relationships between riparian zone attributes (e.g., width, vegetation species composition) and water quality. As the project is expanded during years four and five, additional research groups are likely to be involved.

Timeline

As noted in the foregoing discussion, during years 1–3, we will focus on the field study of agricultural-riparian interactions in the Willamette Valley. During years 4 and 5, we will extend our research efforts to include other agricultural settings or to further quantify relationships between riparian zone attributes and water quality.

6.3.3 Habitat Function/Restoration of Riparian Areas

As shown in Section 6.1.1, natural riparian areas have diverse plant communities that serve as rich terrestrial habitats and have a profound influence on aquatic habitats. In agricultural and rangeland landscapes, these plant communities and associated habitats have been degraded. There is need for information on how to manage and restore agricultural and rangeland areas to provide or increase this habitat function.

Project-Level Objectives

- Define terrestrial and aquatic habitat reference conditions for riparian areas in agricultural settings.
- Establish indicators of riparian area habitat condition in agricultural settings.
- Develop approaches and performance criteria for restoration of degraded riparian habitat in agricultural settings.

Approach

To accomplish these objectives, we will conduct a five-year field research effort that will be initiated in FY95. In the Pacific Northwest, there is a large pool of researchers who have many years of excellent experience dealing with riparian habitat issues. We plan to accomplish most of the riparian habitat research through cooperative agreements with universities. Through the solicitation process, researchers will have the opportunity to determine the best field approaches and study designs for addressing the project objectives. Specific project research plans will be peer reviewed before implementation. The following discussion provides an overview of the type of habitat research that is likely to emerge from this process.

An important first step will be to select the specific riparian aquatic and terrestrial habitat functions on which to focus (e.g., habitat for which species). Cooperating scientists, working with EPA scientists, will perform a risk analysis to determine which species are dependent on riparian habitats in agricultural settings and have been or are likely to be affected by agricultural practices. Amphibians and salmonids are two groups that will be included in this analysis.

Working cooperatively with other federal agencies, such as the ARS and the Soil Conservation Service, we will select several agricultural landuses to be included in the study. Preliminary output from the Riparian Landscape Project (Section 6.3.1) will be important information for this process. Tilled cropland, such as grass seed agriculture, and pastureland are two likely choices.

To evaluate reference conditions and indicators of riparian area condition, we envision establishing a series of 15 to 30 riparian study sites in agricultural lands west of the Cascades. The sites will be selected to include the priority classes of agricultural lands and to allow a range of riparian conditions to be evaluated. Agricultural sites with intact, fully functional riparian areas will allow quantification of reference conditions. More degraded sites will be included to allow evaluation of indicators of riparian ecological functions across a range of conditions.

To evaluate the effectiveness of restoration practices in improving aquatic and terrestrial habitat, we anticipate conducting site-level research at perhaps 15 to 30 additional sites, where riparian restoration has occurred. As much as possible, we will evaluate riparian restoration efforts that previously have been performed. Re-establishment of riparian vegetation and associated riverine landforms are likely to be the primary restoration activities evaluated. To supplement existing sites, we will evaluate new restoration approaches that we implement as part of this study. These restoration studies will build on the reference site and indicator field research described in the previous paragraph. Restoration studies will provide needed information about restoration techniques, criteria for determining restoration potential of riparian systems, and criteria for the prioritization of restoration efforts.

EPA's WRP is conducting a study that is (1) characterizing avian use of riparian habitats in the Willamette Valley Plains Ecoregion and (2) evaluating the accuracy of the Avian Richness Evaluation Method (AREM) in predicting avian composition and richness (Adamus 1993). This research will add to the information base about the habitat value of riparian areas, and will develop a rapid assessment method that has potential for use throughout the Pacific Northwest. We will explore opportunities for incorporation and expansion of the WRP avian habitat research to better address our project objectives.

Timeline

One or more cooperative agreements will be funded during FY95 to establish a habitat research group. Field work will begin during 1996 and continue for four years. If possible, we will expand our efforts to include riparian areas in rangelands east of the Cascades after the first five-year study. AREM field work is beginning during winter 1995; we will be working with the Wetlands Research Program in early 1995 to determine if expanded, collaborative efforts are possible.

6.3.4 Riparian Area Condition and Restoration In Mixed Landuse Watersheds

The ecological functions of riparian areas cannot be considered in an isolated fashion at the site scale (see Section 6.1.1). Riparian management needs to consider the interconnectedness of riparian systems along all the stream reaches within watersheds or basins. Given that resources to restore or to protect riparian areas are always likely to be limited, it is essential to develop approaches to identify high-priority areas for riparian restoration or protection within watersheds.

Project-Level Objectives

- Develop approaches to evaluate riparian area condition in mixed landuse watersheds/basins.
- Develop approaches to locate the most promising areas for riparian restoration and to evaluate the attainable quality and restoration potential of riparian areas within mixed landuse watersheds/basins.

Approach

Based on results from the site-specific work in other riparian projects, published literature, and research results from other agencies, we will develop approaches to evaluating riparian area condition, restoration potential and attainable quality of riparian areas, and priority locations for riparian restoration activities within mixed landuse (e.g., forests, agriculture, urban) watersheds in the Pacific Northwest. Assessment endpoints will be water quality (e.g., sediment, nutrients, agricultural chemicals) and habitat (aquatic and terrestrial).

Several types of activities are envisioned. One approach will be to use coupled GIS-hydrologic models to develop indicators of riparian area performance and to evaluate promising locations for riparian area restoration (Phillips 1989, 1990). Other landscape/watershed approaches also may be employed. We are currently in the process of recruiting a National Research Council post-doctoral research associate to undertake this work.

We have established a cooperative agreement with Dr. Stanley Gregory at Oregon State University[1] to examine riparian area condition and restoration opportunities for the Willamette River. Research tasks include (1) historical reconstruction of the Willamette River channel, floodplain, and riverine forests and (2) analysis from remote sensing of the riparian forests and floodplains of the river using aerial photography and satellite images. Dr. Gregory and his colleagues will be working to establish a landscape perspective for ecological restoration of the Willamette River and to create alternative scenarios for future conditions of the Willamette Valley ecosystem.

The Wetlands Research Program has sponsored three projects in the West that examined watershed-level approaches to prioritizing riparian restoration. Dr. Richard Harris' group at the University of California, Berkeley, used existing, readily available mapped information and field studies to evaluate riparian areas in the San Luis Rey watershed of southern California. Dr. Charles Hawkins' group at Utah State University used aerial videography and GIS modeling approaches to prioritize restoration of riparian areas in the San Luis Rey watershed. Dr. Tom O'Neill's group at Utah State University used aerial videography and GIS modeling approaches to prioritize riparian restoration in the upper Arkansas River of Colorado. As part of the PNW riparian research effort, we will evaluate results of these three projects for use in the PNW study areas.

We will convene a workshop of agency, private, and university researchers to address the topic of how to evaluate riparian area condition and restoration potential at the watershed scale. Assessment approaches developed at the workshop will then be tested and refined in the field. The first field evaluation will be conducted in a watershed in one of the case study areas west of the Cascades (see Section 5.3.1). A second field test will be conducted when a case study watershed is selected east of the Cascades. After the field tests are completed, a final workshop will be held to finalize operational riparian assessment approaches for use by agencies in the region. Our desire is for this project to serve as one way of integrating the efforts of agencies (e.g., USFS) and investigators working on riparian areas in forested lands with those of EPA and other groups working in other parts of the landscape.

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[1] The cooperative agreement with Dr. Gregory was selected based on peer review of proposals received in response to a competitive, open solicitation conducted in spring/summer 1994.

Timeline

Watershed-scale modeling activities and the Gregory et al. study in the Willamette will begin in late 1994 or early 1995 and continue for two to three years. The watershed-scale riparian workshop will occur in 1995. The first field evaluation will begin in 1996. Operational watershed-level riparian assessment approaches will be available in 1999.

6.3.5 Riparian Eco-Opportunities

Agricultural lands and associated riparian areas in most regions, including western Oregon and Washington, are typically in private ownership, which makes the implementation of sound agricultural riparian area management more complicated than on public lands. Landowners need incentives to alter the ways in which they manage riparian areas. Ideally, these incentives should not have to take the form of government subsidy programs or regulations. Instead, we hope to find ways in which agricultural areas can be managed that would maintain or enhance riparian ecological functions and also provide financial return to the landowner.

Project-Level Objective

The.objective of this work is to evaluate ecologically and economically promising practices for the management of riparian areas in agricultural settings.

Approach

During the first year of the project, we will identify riparian management practices with potential for both ecological and economic value to landowners. Literature reviews and interviews with researchers, agency personnel, conservation groups, and landowners will be the main part of this effort. Based on established ecological and economic principles, we will evaluate identified practices for ecological soundness and for the potential to provide financial return to landowners. Also, we will identify field locations where promising practices are being implemented.

Based on the first-year results, we will decide whether or not field evaluation of one or more promising practices would be useful. If promising practices are identified, field evaluation of the practices could begin during the second year of the project and last for one to three years. Any field testing would be conducted as part of the Riparian Habitat Project (Section 6.3.3). Whether or not field studies are conducted, a low-level effort to identify new practices will continue throughout the five-year period of study.

Timeline

The survey of promising riparian management practices will be completed in 1995. Decisions regarding the need for field studies will be made in late 1995. If field studies are implemented, they will be initiated during 1996 at the earliest.

6.4 MAJOR CONTRIBUTIONS

The major contributions of the Riparian Area research component will be as follows:

- Characterization of the extent, condition, and stressors of riparian areas in agricultural and rangeland landscapes of the case study areas.
- Evaluation of landscape-level relationships between agriculture and riparian area condition.
- Quantification of the influence of riparian areas on improving water quality in grass seed agricultural lands.
- Determination of major processes controlling water quality in grass seed agriculture/riparian area complexes.
- Indicators of aquatic and terrestrial riparian habitat condition in agricultural and rangeland settings.
- Reference conditions, approaches, and performance criteria for restoration of degraded riparian areas in agricultural and rangeland settings.
- Approaches to evaluate riparian area condition, restoration potential, attainable quality, and priority restoration locations within mixed landuse watersheds.
- Summary of promising eco-opportunities for riparian areas in the Pacific Northwest.

7. COASTAL ESTUARIES

This section describes proposed research on estuaries and their associated watersheds. Research efforts will address two of the program-level objectives presented in Section 2.2: (1) the development and demonstration of assessment approaches and (2) an improved understanding of ecosystems and ecosystem responses to stressors and management actions. Conducted jointly with the Watershed/ Ecoregion research component (Section 5), assessment research will involve an integrated assessment for a single estuarine watershed, Willapa Bay, Washington. We will conduct process-oriented research in Willapa Bay and selected Oregon estuaries. We have selected specific research topics to help improve our understanding of (1) estuarine ecosystem-level responses to major stressors, (2) the effects of multiple stressors on estuaries, and (3) watershed-estuary linkages, in particular the effects of watershed alterations, such as logging, on estuaries. Process-oriented research will also contribute to the development of estuarine indicators, useful for monitoring (Section 8). For the research described in this section, we view watersheds as a forcing function on estuaries and our goal is to understand how watershed management practices affect estuaries, rather than evaluate watershed management practices directly.

Our estuarine research strategy assumes an extramural budget of $650K per year for five years, in addition to in-house research conducted by five senior-level EPA scientists at ERL-Newport. Approximately $300–450K of the extramural budget will be used for the process-oriented research and $200–350K for the integrated assessment in Willapa Bay, depending on the stage of the project.

7.1 BACKGROUND

Several reasons led us to choose estuaries and coastal watersheds as a focus for EPA research. The first was management priorities. As discussed in Section 5, the State of Washington identified coastal watersheds as its area of highest priority for ecological research in support of ecosystem management. Most of the small communities along the coasts of Washington and Oregon have similar economic bases, relying historically on the harvesting and processing of timber, salmonids, coastal bottom-fish, shrimp, oysters, and/or Dungeness crab; dairy farming; and shipping of raw and processed commodities. Reductions in timber harvests from federal lands, combined with recent declines in salmon and other fisheries, have caused severe economic hardships. Managers have requested assistance and improved ecological information to aid in evaluating future ecosystem management options.

The second reason was a relative lack of information. Our ability to predict how estuarine ecosystems will respond to single and multiple stressors is at a rudimentary level, because of deficiencies in our basic knowledge about estuaries and the lack of appropriate ecosystem-level approaches. During the last two decades, there have been major advances in methods of evaluating point-source pollutant discharges to coastal systems. Many of these methods are based on toxic effects or bioaccumulation by a few laboratory bioassay species (e.g., Swartz 1987, Lee et al. 1993). Although the use of toxicity/bioaccumulation to surrogate species has proven useful in regulating individual chemicals, toxic pollutants appear to play a fairly minor role in most Pacific Northwest coastal estuaries.[1] In addition, the classical approaches developed for single pollutants are generally inadequate to determine the effects of nonchemical stressors, the impact of multiple interacting stressors, the cumulative effects of habitat alteration, overall system response, or the linkages between the management of coastal watersheds and estuarine ecosystems. We have little quantitative information on the effects of watershed alteration and resultant loadings of estuaries by a variety of potential stressors, such as sediments, nutrients, and toxic substances. Our knowledge of circulation, sedimentation, and runoff in Pacific Northwest coastal estuaries is also rudimentary, making it impossible to predict direct physical effects on biota or the physical transport of particulate-associated or dissolved stressors, such as nutrients. Similarly, quantitative relationships between the loss of specific habitats, or the application of certain biocides, and changes in estuarine structure and functions generally are lacking. If federal, state, and local governments are to effectively manage this region, existing knowledge must be synthesized and analyzed from an ecosystem perspective, and critical data gaps must be filled.

The final reason was a practical one. Including an estuarine research component allows us to take advantage of the in-house EPA expertise at ERL-Newport. Five senior scientists at ERL-Newport will work full-time on this effort, significantly enhancing the value of relatively modest extramural funding.

7.1.1 Characteristics of Pacific Northwest Coastal Estuaries

There are several major and a number of smaller estuaries along the coasts of Washington and Oregon (Figure 7-1), all of which have important features in common. The entire coastal region has a moderate climate, with very wet winters and dry summers (see Box 1-B). Watersheds tend to be heavily forested, dominated by conifers such as Douglas fir, alder in disturbed areas, and dense undergrowth, including salal and blackberry (see Schultz 1990 for review). Estuaries in the region also tend to have similar benthic and fish communities, although the relative importance of species varies among systems (for overviews see Kozloff 1983, 1987, USDA 1985, Emmett et al. 1991). In general, Pacific Northwest coastal estuaries are fairly shallow with extensive intertidal zones, which can exceed 50% of the area of the estuary. As a result, benthic primary and secondary production contribute a substantial part of total system productivity, while phytoplankton contribute a relatively smaller amount. For example, phytoplankton

[1] The term *coastal estuaries* excludes Puget Sound. As discussed in Section 7.3.1, we do not propose to conduct research in Puget Sound or in the Columbia River estuary.

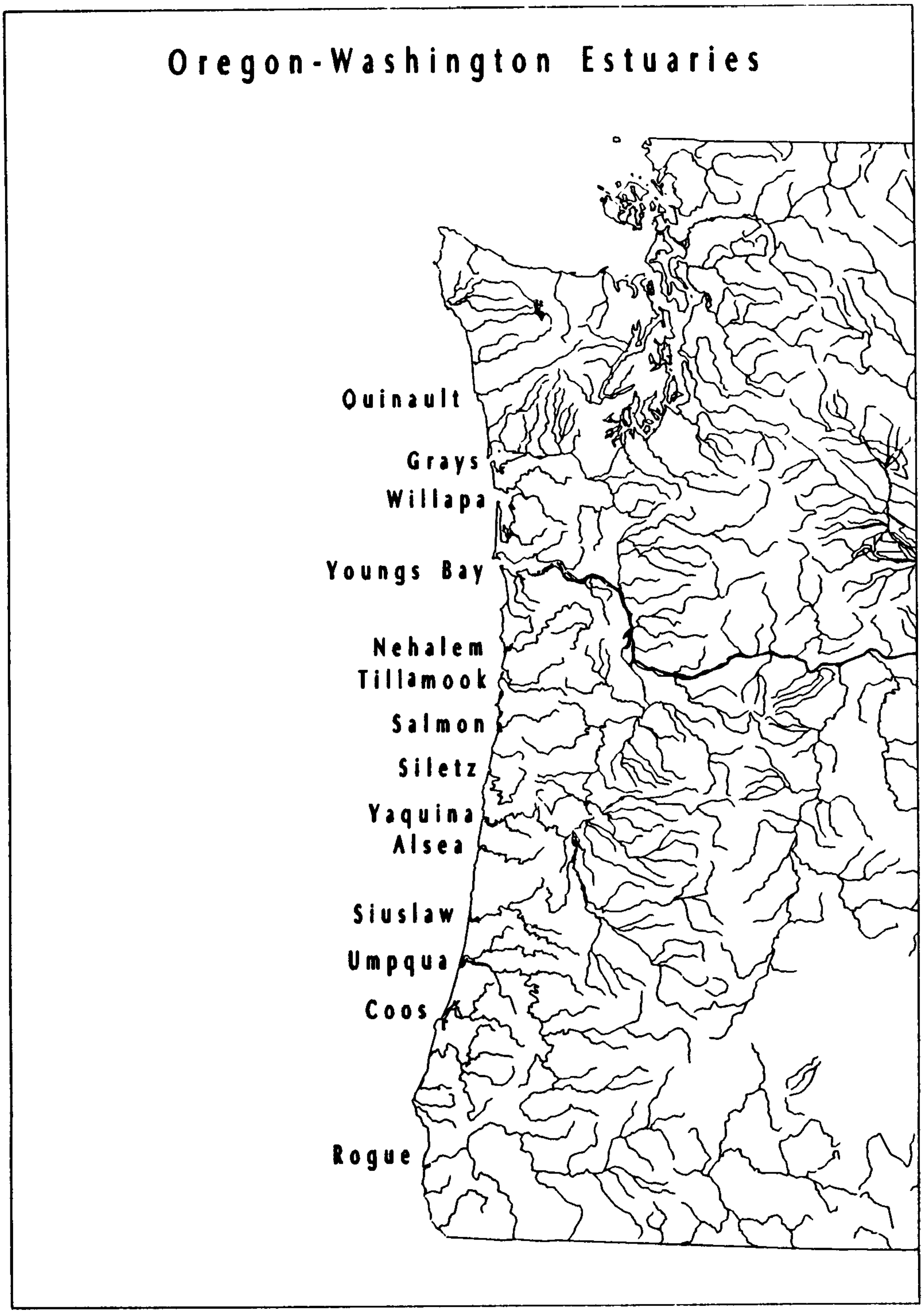

Figure 7-1. Coastal estuaries in the Pacific Northwest.

production constitutes 10–25% of the total productivity in Grays Harbor (Thom 1981) vs. about 50% in a North Carolina estuary (Peterson and Peterson 1979).

Differences among systems largely appear to be variations in scale or extent, rather than qualitative differences in processes or stressors. Main differences include the relative magnitude of tidal flushing vs. river runoff, the history and extent of logging and associated effects on sedimentation and runoff, extent of dairy farming and agriculture in the watershed, and the type and extent of introduced (non-native) estuarine species.

7.1.2 Priority Stressors

Pacific Northwest coastal estuaries appear to be relatively clean in terms of classic toxic pollutants, such as DDT and cadmium (e.g., see Lee et al. 1993, 1994 for sediment concentrations in Yaquina Bay). Nonetheless, these systems have undergone and continue to undergo major ecological changes. Indicators of these basic changes include declines in commercial levels of shellfish production, precipitously declining levels of salmonid recruitment, saturation harvesting of bottom-fish stocks, expanding populations of non-native species, and the loss of coastal habitats. Based on the scarcity of discharges of toxic pollutants by coastal industries and the long history of exploitation of natural resources in the Pacific Northwest, the direct and indirect effects of resource utilization and development, rather than chemical contamination, appear to be the major causes for these changes. This is not to state that chemical pollutants are not having any impact and, as described in Section 7.3.4, part of the research will be to evaluate the relative impacts of chemical vs. nonchemical stressors.

Overharvesting of estuarine-associated fishes and shellfish has been a classic problem in the Pacific Northwest going back to the 1850s (Fagan 1885). By the turn of the century, it had become necessary to refurbish depleted oyster beds by transplanting east coast oysters (McGuire 1895–6, Moore 1897, Washburn 1901). This overexploitation has contributed to declining stocks of many commercial species. Overharvesting also has indirect effects, including increased sensitivity of populations to other anthropogenic and natural disturbances, introductions of exotic species with the stocking of east coast oysters, and the need for extreme management techniques in some instances (e.g., spraying of pesticides to maintain oyster production, salmon hatcheries).

Besides overexploitation of target resources, conflicts occur among resource uses. Classic examples are the increased sedimentation that can occur from clear-cutting of timber and agriculture, which in turn can lead to reduced shellfish production and increased dredging costs. Other problems result from the continued expansion and development of coastal (human) communities. The increase in population, housing, commercial development, and attendant infrastructure has resulted in extensive loss or modification of estuarine habitat, as well as of habitats in surrounding watersheds. Besides the direct impacts on habitat, increased development has resulted in further pressure on ever scarcer supplies of water, increased disposal of sewerage, and increased pollutant discharges.

Table 7-1 summarizes the major stressors affecting Pacific Northwest estuaries, including their sources, spatial scale, and types of ecological effects. All of these stressors will be considered in literature reviews, the case study assessment for Willapa Bay, and conceptual models. However, process-oriented research will concentrate on two broad types of stressors: (1) sedimentation and associated changes in habitat, salinity, temperature, and nutrients and (2) biological stressors. We selected sedimentation and its associated parameters because of its potientially widespread effect in Pacific Northwest estuaries and because of the role of watershed activities as a major cause of increased sediment loads and habitat changes. Biological stressors are of particular concern in Willapa Bay, where recent expansions of introduced cordgrass (*Spartina alterniflora*) and population explosions of mud shrimp (*Upogebia pugettensis* and *Callianassa califoniensis*) are resulting in major habitat alterations and in the application of pesticides as control measures. These priorities may evolve as the program progresses. Brief background reviews for these stressors are provided in the following sections.

7.1.2.1 Sedimentation and Associated Parameters

Sedimentation is a natural process, but excess sedimentation is a serious and common problem in estuaries. Siltation is reported as one cause for nonsupport of designated uses of 12% of the Nation's estuaries (U.S. EPA 1994d). Excess nutrient loading, which is often related to sedimentation and runoff, adversely affects 55% of estuaries (U.S. EPA 1994d). Sedimentation problems are especially acute in the Pacific Northwest because of the steep coastal watersheds, high rainfall, timber harvesting, and dairy farming immediately adjacent to estuaries. In Willapa, invasion by *Spartina* is also resulting in enhanced sedimentation. The potential extent of changes due to sedimentation is illustrated in Tillamook Estuary, where it has been estimated that the volume and average depth have declined by ~60% since the 1930s, as a result of high sediment loads caused by major forest fires in the watershed (referred to as the Tillamook Burn) and subsequent salvage logging and road building (James 1970).

Erosion in drainage basins in coastal areas has been accelerating since the advent of large-scale timber harvest in the 1850s (e.g., Shotwell 1977). Feeder streams to riverine systems were indiscriminately yarded with harvested logs; splash dams were routinely used to sluice literally millions of logs down to the estuaries, scouring the entire length of the drainage of any obstruction (Maser and Sedell 1994). This indifference to multiple uses of the drainage basin led to the obliteration of structures within the

Table 7-1. High-Priority Ultimate Stressors On Pacific Northwest Estuarine Ecosystems.

Stressor	Sources	Spatial Scales	Potential Vulnerabilities	Potential Effects
Siltation and sedimentation	Dredging, clear cutting, development, *Spartina*, mudshrimp	Localized to watershed	SAV, salmon, benthos, oysters,	Reduced depth range of SAV, smothered filter-feeders, reduced primary productivity, altered benthic communities
Habitat loss	Dredging, development, filling, siltation, sea level change, water diversion, introduced species (*Spartina*)	Localized to global	Species with specialized habitat requirements, salmon, intertidal benthos	Reduced populations, localized extinction
Temperature increases	Reduction in water flow, increase in intertidal area, global warming	Localized to global	Mean temperature, maximum temperature in summer	Changes in species composition, benthic and fish die-offs
Changes in salinity	Water diversion, drought, channelization, flooding, changes in estuary morphology	Estuary to regional	Stenohaline species	Changes in species composition and distribution
UV-B radiation	Stratospheric ozone depletion	Global	Surface and intertidal organisms, smaller organisms	Reduced primary production, effects on food webs, direct effects on fish larvae
Nutrient inputs, organic loading, reduced DO	Dairy farms, runoff from logging, septic tanks, sewage, fisheries wastes, sediment regeneration	Localized to watershed	Fish more sensitive than most benthos to reduced DO, SAV, phytoplankton	Changes in dominant primary producer (macroalgae rather than SAV), promotion of toxic blooming, fish and benthic kills due to low DO
Increased predation	Protection of marine mammals, introduced species	Estuary to regional	Salmon (seals), Sea urchins (otters)	Changes in species composition and distribution, reduced prey populations
Increased competition, decreased food availability	Introduced species, El Niño, toxic algal blooms, hatchery releases (salmon)	Estuary to global	Salmon, infaunal benthos to introduced species, SAV to introduced *Spartina*, phytoplankton to El Niño	Changes in species composition, change in ecosystem from pelagic to benthic, decreased 2° production
Neutral organics (chlorinated, PAHs, and high Kow)	Sewage and industrial discharges, in-place sediments, nonpoint runoff, boating and shipping (PAHs)	Localized to watershed	Sediments act as sink, some chlorinated compounds biomagnify	Direct effects at moderate to high concentrations, wildlife and human health at low to moderate concentrations
Low Kow herbicides and pesticides	Nonpoint run-off, sewage and industrial discharges, in-place sediments, direct application (carbaryl, glyphosate)	Localized to watershed	Sediments act as sink but less so than for high Kow	Direct effects at moderate to high concentrations on SAV and phytoplankton (glyphosate), crustaceans (carbaryl)

Localized – Operates over a small part (<25%) of an estuary. Estuary – Operates over a high proportion (≥25%) to all of an estuary. Watershed – Operates over most or all of the estuary and the stressor is related to alterations of the watershed. Regional – Operates over several estuaries or watersheds in a biogeographic region. Global – Operates over several biogeographic regions encompassing a major portion of the globe.

SAV – Submerged aquatic vegetation; DO – dissolved oxygen.

streambeds that sorted and retained the normal flux of sediment. The destruction of riparian vegetation and scouring of the landform in harvested areas led to widespread mass wasting on many steep, now unprotected slopes. In addition to logging, habitat alteration, coastal development, and farming can also increase sedimentation and runoff to estuaries.

Direct effects of sedimentation in estuaries include reductions in light penetration in the water column and associated reductions in primary productivity and contraction of depth distributions for submerged aquatic vegetation; covering of hard substrates, which can suffocate oysters and other filter feeders or hinder their settlement; and changes in grain size and sediment organic content with concomitant changes in benthic communities. The direct, adverse effects of excessive sedimentation were recognized early on, as exemplified in this statement by Fasten (1931) about Yaquina Bay, Oregon: "The eastern oysters were planted in a bad region, which received large quantities of silt, mud and sand, burying the oysters, killing many of them off and preventing spat from settling on their shells..."

Increased sediment loads, sedimentation, and runoff have a number of indirect effects, which may be as important, or more so, than the direct effects. As mentioned, sedimentation has reduced Tillamook Bay's depth and volume, thereby reducing the biotic potential of the Bay. One potential result of significant shallowing of estuaries is a concomitant increase in temperature, as intertidal areas act as heat sinks. The inability to survive rapid (evolutionary speaking) temperature change is a potential threat to a number of native amphipod species, which constitute important prey species for salmonids. Temperature fluxes are critical as spawning signals for numerous fish and invertebrates, and sediment-related changes in the temperature regime may interrupt life cycles. Increased erosion may also increase nutrient loadings, which may change the composition of the phytoplankton and/or the relative extent of primary production by benthic (e.g., macroalgae) vs. pelagic primary producers. In extreme cases, erosion, especially from agricultural land, can result in eutrophication, though eutrophication does not appear to have occurred to the same extent in the Pacific Northwest as in some east coast estuaries. There also may be substantial anthropogenic inputs of nutrients without substantial increases in sedimentation, such as from dairy farming, sewage discharges, or septic systems. Nutrients are considered under sedimentation in this section for convenience, but the research described under sedimentation (7.3.3) and the case study (7.3.5) will assess inputs not related to sediments (e.g., septic systems, marine inputs) as appropriate.

7.1.2.2 Biological Stressors

Estuarine ecosystems can be subjected to biological stressors resulting from invasions by nonindigenous species and population explosions of native species. These biological agents can have substantial impacts on individual populations (Race 1982), community structure (Nichols et al. 1990), ecosystem functions, (Nichols 1985), and harvesting of shellfish (Bernard 1969). The total economic impact is impossible to quantify, but the Office of Technology Assessment (OTA) estimated that the cumulative economic losses from just six nonindigenous fish and aquatic invertebrates was more than $1,500,000,000 from 1906 to 1991 (OTA 1993).

The three predominant biological stressors in Pacific Northwest estuaries are the invasion by *Spartina alterniflora* (smooth cordgrass), population explosions of the native mud shrimp, and the increasing number and severity of toxic algal blooms. Because of their importance in Willapa Bay, our process-oriented research will focus on *Spartina* primarily and mud shrimp secondarily. Toxic algal blooms, which appear to be increasing globally (Hallegraeff 1993) as well as regionally, will be treated as a response rather than a stressor. There are many other non-native species in the Pacific Northwest besides *Spartina*; for example, it has been estimated that at least 30% of the benthic species in Yaquina Bay are introduced (J. Chapman, Oregon State University, pers. comm.). But because of resource limitations, research on introduced species will focus on *Spartina*, although it might be expanded to include other species in later years, either as part of benthic mapping (Section 7.3.2) or the case study (Section 7.3.5).

The invasive growth of the introduced *Spartina alterniflora* has been documented in several Pacific Northwest estuaries, including Willapa Bay, Grays Harbor, Puget Sound, and Siuslaw Estuary in Oregon (Mumford et al. 1991). The problem is especially acute in Willapa Bay, however, where over 9.7 km^2 of intertidal mudflat were covered in 1989. It is projected that without control, up to half of the Bay's flats will be converted into elevated saltmarsh over the next 20 years (Wolf 1993). Once established, *Spartina* has numerous direct and indirect impacts (Mumford et al. 1991). It can displace native plants, such as *Zostera marina*, a vital marine resource in the Pacific Northwest (Wyllie et al. 1994). Benthic microflora and invertebrates are greatly reduced within *Spartina* beds, which may disrupt food chains. Given sufficient invasion, *Spartina* could alter the food web throughout the Bay by reducing nutrient availability for phytoplankton while at the same time augmenting the detrital food web. Besides the direct biological effects, *Spartina* traps sediments, which can convert tidal flats to nontidal land, resulting in a loss of habitat equivalent to that caused by diking. While increasing sedimentation in one area, *Spartina* is removing sediment from others, potentially resulting in both erosion and deposition.

Because of concerns about ecological and commercial impacts, efforts are being made to control or eradicate *Spartina*, including the application of herbicides (glyphosate). It is possible that thousands of acres of intertidal area could be sprayed. Although it is obvious that *Spartina* has a dramatic local impact, it is not possible to predict, with any accuracy, its impacts on the ecosystem level, the factors promoting its success, or the relative ecological impacts of control measures. Such information is required, if we wish to conduct a quantitative comparative risk of various management options, ranging from widespread, long-term herbicide application to a *laissez-faire* approach, in which the infected bays are allowed to reach new ecological states.

Mud shrimp (*Upogebia pugettensis* and *Callianassa califoniensis*) have undergone population explosions in Willapa Bay. Both species create deep burrows and process massive amounts of water and sediment. As the major bioturbators in Pacific Northwest estuaries, mud shrimp can affect many ecosystem processes (see Lee and Swartz 1980), including nutrient regeneration, sediment deposition and transport, and water quality. By reducing sediment stability, they degrade habitat quality for oyster production and change the benthic community. In an attempt to control mud shrimp, hundreds of acres in Willapa Bay are sprayed with carbaryl annually, on a rotating basis. Although spraying is illegal in Oregon, there have been reports of midnight spraying in Tillamook Bay.

7.2. OBJECTIVES

The overall goal of the Coastal Estuaries research component is to evaluate and predict the effects of major ecosystem stressors on the productivity, diversity, and stability of coastal estuaries in the Pacific Northwest, with sufficient resolution to allow ecologically sound management at the ecosystem/watershed level. Productivity is used in a broad sense, and includes the production of key species, as well as the primary and secondary production of the system. Also used in a broad sense, diversity includes habitat diversity, species diversity, and diversity of ecosystem functions. Stability refers to maintaining patterns (temporal and spatial) of ecosystem structure, processes, and functions that would exist in the absence of anthropogenic stressors—including sustainability of resources, such as oysters. Diversity, productivity, and stability were chosen as overall endpoints because they are generally recognized indicators of ecosystem integrity.

We mention resolution explicitly because it is important to recognize that there will be considerable uncertainty in at least some of the ecosystem-level methods and predictions. This uncertainty results both from scientific uncertainty, because of the infancy of ecosystem research, and management "uncertainty" about how to weight multiple conflicting goals. Some of the uncertainty also relates to the inherent variability at this scale. Uncertainty analysis will be incorporated into the research, especially the case study

The major objectives of estuarine process-oriented research are as follows:

- Develop predictive relationships between ecosystem structure and habitat characteristics.

- Improve our understanding of the extent, loading, causes, and effects of sedimentation and associated parameters, such as nutrients, in Pacific Northwest coastal estuaries.
- Improve our understanding of the extent, causes, and effects of biological stressors (in particular, expansions of *Spartina*) and the effects of potential control strategies.

The objective of the Willapa case study assessment, conducted jointly with the Watershed/Ecoregion research component (Section 5), is to develop and demonstrate assessment approaches that help managers:

- Set attainable ecological goals for the estuary and watershed.
- Characterize current ecological conditions relative to those goals.
- Identify major problems and the relative importance of stressors affecting valued estuary ecosystem functions.
- Identify linkages among stressors, including estuarine responses to watershed alterations.
- Determine whether the integrated effects of stressors result in unacceptable alterations to the estuarine system, even if the stressor does not violate regulatory criteria at any individual site.
- Evaluate the ecological consequences of, and trade-offs among, alternative management strategies.
- Target areas for protection, restoration, or other management action.

Table 7-2 lists the broad research topics that will be addressed; Table 7-3 outlines research topics not included, or given low priority, for the PNW research program. It is important to note that, although targeted salmon studies *per se* are not included within the Coastal Estuaries research component, the research will generate information directly relevant to salmon management. For example, predicting the effects of sedimentation on benthic communities will generate information on how upland management practices affect the density of salmon prey species.

7.3 APPROACH

Four projects are proposed:

1. Predictive relationships between physical habitat characteristics and estuary structure/functions.
2. Extent, causes, and effects of sedimentation and related parameters.
3. Extent, causes, and effects of biological stressors and effects of chemical control measures.
4. Willapa estuary/watershed case study assessment and data synthesis.

Table 7-2. Approximate Resource Allocations for Coastal Estuaries Research Component (Top, $K; Bottom, EPA FTE).

Research Topic and (Section)	FY95	FY96	FY97	FY98	FY99	Total	Location
Predict Ecological Functions (7.3.2)	125 2.2	150 2	160 2	160 1.5	75 0.5	670 8.2	Willapa Bay and Yaquina Bay
Sedimentation and Associated Variables (7.3.3)	215 1.7	215 1.7	215 1.4	185 1.3	150 0.8	980 6.9	Willapa Bay and ERL-Newport for sediment trap work and some chemical analysis
Biological Stressors (7.3.4)	75 0.5	75 0.8	75 0.6	75 0.7	75 0.7	375 3.3	Willapa Bay ERL-Newport for some lab experiments
Case Study: Baseline Information (7.3.5)	235 0.6	210 0.5	200 0.5	200 0.5	200 0.5	1045 2.6	Willapa Bay ERL-Newport for some chemical analysis
Case Study: Ecosystem Model and Data Synthesis (7.3.5)	0 0	0 0	0 0.5	30 1.0	150 2.5	180 4	Willapa Bay Synthesis covers all PNW coastal estuaries
Total $K Total FTE	650 5	650 5	650 5	650 5	650 5	 25	

Table 7-3. Lower Priority Topics and Topics Outside the Scope of the Coastal Estuaries PNW Research Program.

Topic	Status	Rationale	Potential Interactions
Studies in Puget Sound	Outside program	1. Other state and federal agencies have large ongoing programs 2. Lower priority for State of Washington	Some research, especially ecological functions of various habitat types, should apply.
Assessing effects of stressors on salmon stocks and other fisheries stocks	Outside program	1. Other state and federal agencies have large ongoing programs 2. Assessing fish stocks is not mandate of EPA	Some research, especially ecological functions of various habitat types, should apply.
Bacterial/viral contamination	Outside program	1. Human health rather than ecological concern	Will take samples for other agencies, if feasible.
Effects of ultraviolet-B radiation	Outside program	1. Covered under EPA's Marine Stratozone Program, which is at ERL-Newport 2. Origin of stress (UV-B) not related to coastal watershed	UV-B and ecosystem research will be closely coordinated and may involve joint research.
Regional-scale monitoring of coastal estuaries	Outside program	Covered by EMAP and REMAP	When possible EMAP sampling methods will be used.
Development of socioeconomic models or analyses of different management practices	Outside program	1. Not ecological questions 2. Not EPA expertise	Ecological results and models will be made available for economic models.
Studies in the Columbia River	Lower priority	1. Other state and federal agencies have large ongoing programs 2. Lower priority for State of Washington	Some research, especially ecological functions of various habitat types, should apply.
Open ocean near coastal systems (e.g., rocky intertidal, ocean beaches, dunes)	Lower priority	1. Not at as great a risk as estuarine ecosystems 2. Not as tightly linked to watershed management practices as estuarine ecosystems	Development of upland GIS and/or runoff models could relate to predicting effects on open beaches in the future.
Marine mammals	Lower priority	1. Many of the stresses related to fisheries management rather than ecosystem stresses 2. More marine rather than estuarine	Some research, especially ecological functions of various habitat types, should apply. To extent marine mammals impact ecosystem structure/function, they will be included.
Mechanistic understanding of the effects of individual stressors or how multiple stressors interact	Lower priority	1. Because of complexity of problem, best to start with "grosser" scale models and then develop mechanistic understanding	Research will identify the key stressors/ receptors requiring mechanistic study.
Localized stressors, even if locally severe	Lower priority	1. Program focus on stressors that have an effect on a wide spatial area and/or multiple components of the ecosystem 2. Severe localized stressors usually studied/regulated under water quality or sediment quality criteria	Research will help rank the importance of stressors in terms of their ecosystem impact.
Developing/testing restoration methods	Lower priority	1. Except for wetlands, which are covered under another program, our understanding is too preliminary to initiate restoration 2. Expensive	Research will help identify which habitats need restoration and range of variability expected.

Although listed as separate projects, all of these activities will be highly interdependent, with extensive data sharing and feedbacks. For example, the predictive relationships between physical habitat and ecosystem functions, from project 1, will contribute directly to evaluating the effects of sedimentation and the associated habitat loss/alteration in project 2. The case study assessment, project 4, will integrate results from process-oriented research in projects 1–3. Much of the process-oriented research will be conducted in Willapa Bay, the site for the case study, allowing for comparisons among stressors. Although not called out explicitly, inherent in each project is research that will contribute to the identification of estuary indicators and the development of ecosystem-level sampling and analysis methods.

There will be interactions between the proposed research program and efforts by other federal, state, local, and tribal agencies, as well as by universities. The purposes of these interactions include obtaining required expertise, determining stakeholder interests, developing coordinated programs without overlap, and obtaining assistance in conducting the research and monitoring. Partnerships will probably range from simply sharing data to augmenting existing efforts and funding new research efforts.

Table 7-2 presents the proposed budget, the EPA FTEs (full-time equivalents), and the locations for each project. The budget is based upon the assumption that in many cases PNW resources will be used to leverage other programs and/or that several of the research topics will be closely coordinated for a cost savings (e.g., sharing boat time). In addition, we plan to involve local volunteer organizations in collecting routine environmental data, especially in Willapa Bay. EPA has already successfully used volunteers to collect data (see U.S. EPA 1993c), and volunteer groups exist in Willapa Bay. Without these cost-saving measures, it is likely that the scope of the program would have to be reduced. Further details on each project are provided in Sections 7.3.2–7.3.5. The selection of study sites is discussed in Section 7.3.1.

7.3.1 Site Selection

The program will focus on coastal estuaries and watersheds of Oregon and Washington, excluding the Columbia River. This area was chosen because it is important ecologically and economically, because there is a paucity of integrated studies, and because the major stressors appear to be ecosystem-level ones (e.g., multiple stressors or stressors linked to watersheds), rather than classic pollutant problems. The Columbia River and Puget Sound are excluded because of the number of previous, ongoing, and planned large-scale studies conducted on these systems, including the Puget Sound Ambient Monitoring Program, EMAP in Puget Sound in FY95 or FY96, the National Oceanic and Atmospheric Administration (NOAA) Columbia River Estuary Program, the Columbia River Bi-State Water Quality Program, and the USGS National Water Quality Assessment Program of the Columbia watershed.

Section 5 describes the criteria and process used to select the southern part of the Washington Coastal Ecoregion as one of two watershed/ecoregion case study areas. Because of the interest expressed by the State of Washington in coastal watersheds, we decided to select one estuarine watershed within that area for the integrated case study assessment, to be conducted jointly with the Watershed/Ecoregion research component.

Factors used to select specific estuaries and watersheds to study, for both the assessment and the process-oriented research, include the following:

- Availability of ecological and historical information on the estuarine system and on watershed and upland management.
- Extent and nature of ongoing research and whether the PNW research program could substantially augment or leverage ongoing activities.
- System subjected to ecosystem-level stressors.
- Sites appropriate for testing a specific hypothesis or conducting certain types of study.
- Political/Economic interests of the states of Washington and Oregon and local organizations.
- Similarity to other estuaries and watersheds within the region, so that research findings will be as broadly applicable as possible.
- Geographic proximity to the EPA's ERL-Newport (for research to be conducted by EPA scientists).

Based on these criteria, Willapa Bay, Washington (Figure 7-2) was selected for the case study assessment; certain process-oriented research will also be conducted at Willapa Bay (see Table 7-2). Major reasons for selecting Willapa Bay, rather than Gray's Harbor or the Quinault River Estuary (the other two coastal estuaries within the Washington study area), are its size (second only to the Columbia River Estuary), local interests in ecosystem management on the part of the Willapa Alliance and other organizations, and the occurrence of major biological stressors.

Although most of the work will focus on Willapa Bay, certain process-oriented questions can be addressed more effectively at other sites or through a comparative approach. The primary Oregon estuary selected for process-oriented research is Yaquina Bay (Figure 7-3), primarily because of its proximity to state-of-the-science research facilities at ERL-Newport, its extensive historical biological and physical/chemical databases, and its more manageable size, compared to Willapa Bay. The work in Yaquina Bay will focus on developing relationships or models that can be directly extrapolated to other estuaries and on conducting controlled laboratory experiments. Another priority site is Tillamook Bay (Figure 7-4), which is part of the National Estuary Program. The goal of the National Estuary Program in Tillamook Bay is to

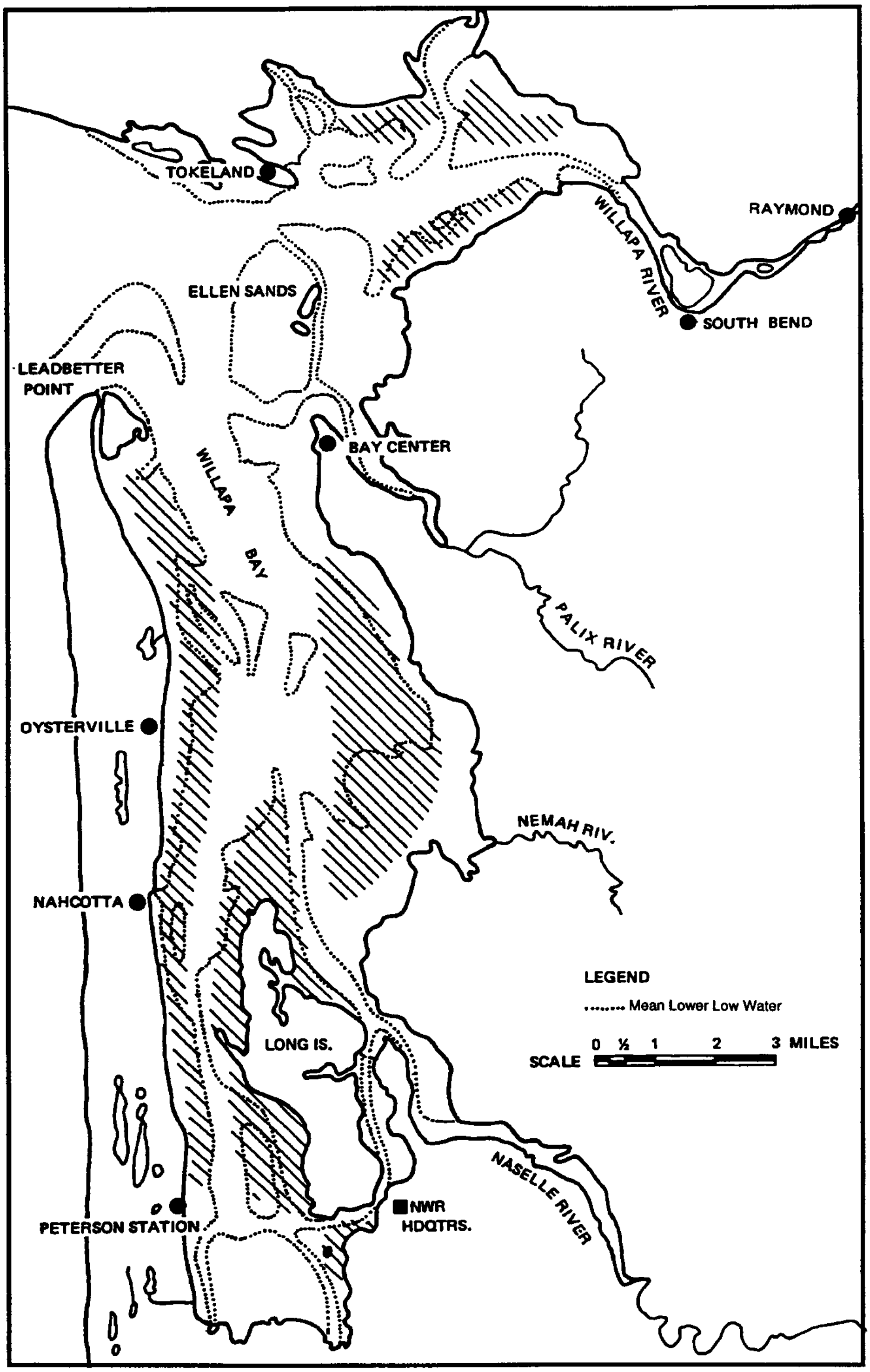

Figure 7-2. Map of Willapa Bay, Washington. Cross-hatched areas show eelgrass distribution (Source: Hedgepeth and Obreski 1981).

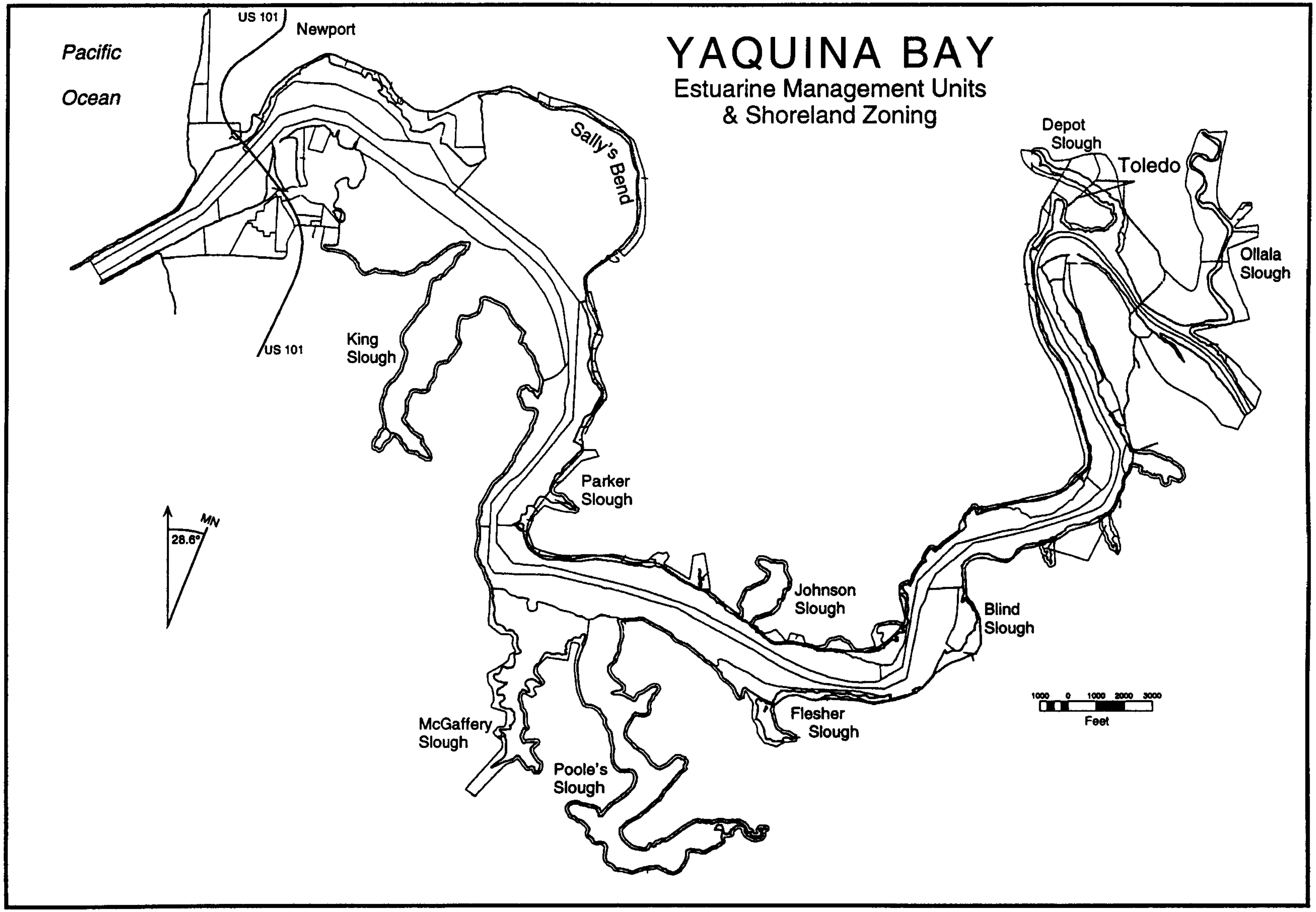

Figure 7-3. Map of Yaquina Bay, Oregon.

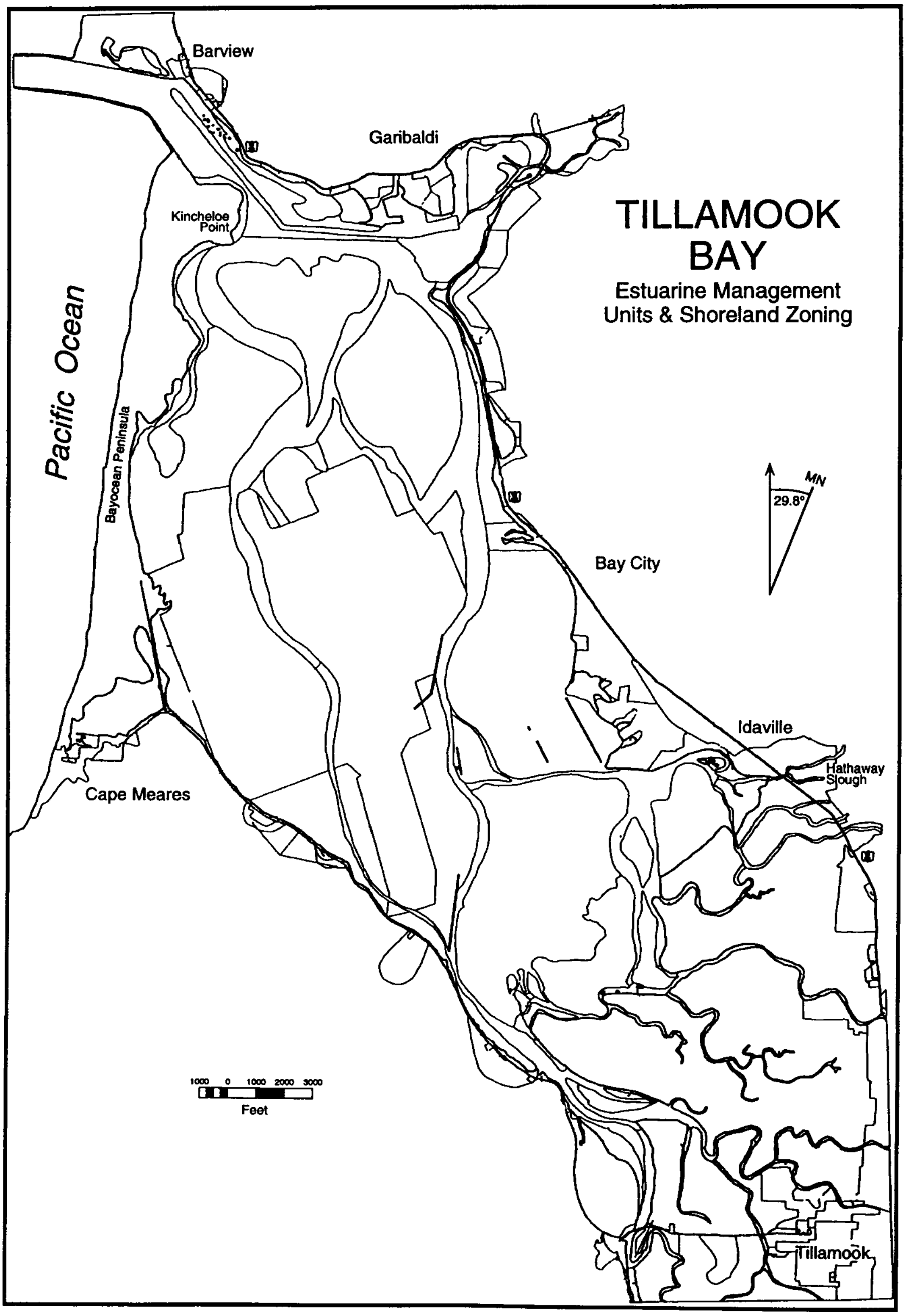

Figure 7-4. Map of Tillamook Bay, Oregon.

develop a comprehensive management plan for the estuary and associated watershed. Thus, research on Tillamook Bay provides a unique opportunity to contribute directly to an active watershed-scale planning effort. Because of budget limitations, the initial interactions in Tillamook Bay will take place largely through participation in the Scientific and Technical Advisory Committee of the Tillamook Bay National Estuary Program and in collaborating in defining the key questions and approaches related to ecosystem management. In later years, Tillamook Bay may be the best site for testing specific hypotheses related to sedimentation (because of the extensive sedimentation from the Tillamook Burn) or to nutrient loading (because of the extensive coastal dairy farming). The next priority site is the South Slough (Figure 7-5), which is part of NOAA's National Estuarine Sanctuary Program (Munson et al. 1984). As with Tillamook, South Slough may be a site for targeted research in later years of the project, depending upon the budget and the specific question. For all three Oregon estuaries, existing information will be adequate to allow comparisons among estuaries for a number of basic ecosystem parameters (e.g., temporal variation in salinity), though not full-scale ecosystem comparisons.

The four study estuaries range in size from fairly small (South Slough, about 2 km^2) to large (Willapa Bay, 320 km^2) (Table 7-4). Willapa Bay is second in size only to the lower Columbia among Pacific Northwest coastal estuaries. The only large estuary not included is Gray's Harbor in Washington. Very small systems, where rivers or streams enter almost directly into the ocean, were not considered for intensive study because of their lesser importance, both economically and ecologically. These four estuaries represent a good cross section of the types of estuarine watershed systems in the Pacific Northwest, in terms of the relative importance of river vs. tidal influence, types of stressors, history of watershed perturbations, and importance of introduced species. Given the similarities in climate, biological communities, ecological processes, and economic base in the Pacific Northwest coastal ecoregion (Section 7.1.1), it should be possible to extrapolate the basic ecological principles and ecosystem assessment methods developed at one site to other Pacific Northwest coastal estuaries and watersheds. Results from certain process-oriented research, such as relating benthic functions to physical characteristics, should be directly applicable across Oregon and Washington coastal estuaries. Other process-oriented conceptual or computer models, such as runoff or circulation models, would have to be parameterized to the particular type or scale of system, although the general approach and type of ecological response should be applicable to other sites.

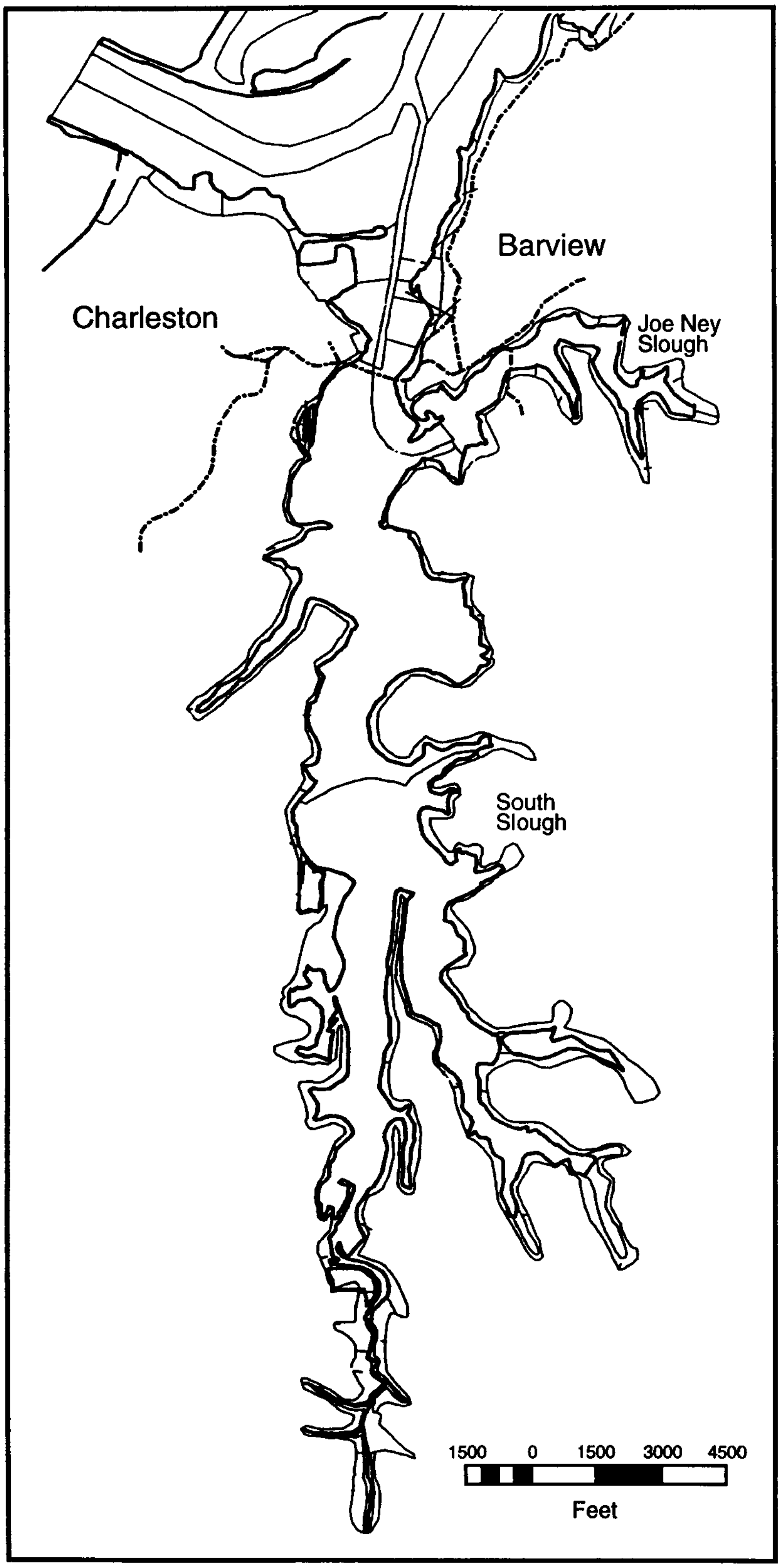

Figure 7-5. Map of South Slough of Coos Bay, Oregon.

Table 7-4. Summary of Physical/Chemical Characteristics of Target Estuaries.

Parameter	Willapa Bay [1,8,9]	Tillamook Bay[2,3]	Yaquina Bay[2,3]	South Slough[4–6]
Area, km^2, @MHW	320[1] 356[8] 238[9]	35.9	17.1	~2.0
MLW Area, km^2	~160[1] ~166[8] –	15.1	11.1	~0.125
Intertidal area, km^2 (% of total)	~160[1] 166[8] – (~50%) (~47%)	20.8 ~58%	6.0 ~35%	~1.875
% Intertidal area filled, km^2	~30%[1]	0.45	1.13	(?)
Wetland area, km^2	~50.5[1] 54[8]	–	–	~1.2
Wetland area filled or diked, km^2 (% of total)	25.6[1] 27.2[8] (~50%) (50.3%)	–	–	(?)
Number of main tributaries	3	5	2	1
Drainage basin area, km^2	1,865[1] 2,428[8] 2,849[9]	1,398	655	~4.2
Average depth, m	~1 m tidal flats[1] ~9–15 m in channels[1] 3.2 m[9]	~2 m	~ 3 m	~1 m (?)
Mean flow and range, m^3/s; Per day as % bay volume	132.9[1] 167[9] ≥45,312[1] 0.004% of bay vol.[1]	~108 – 0.00023% of tidal prism	30.5 – 0.00013% Of Tidal Prism	~17[7] 1–39 No accurate estimate available
Est. sediment rate (tons/yr); (tons/yr/km^2)	– –	135,000 (ca.1973) 3,760/km^2	30,000 (ca.1974) 1,754/km^2	–
Mixing classification	Vertically homogeneous	Well Nov–May, Partial June–Oct	Well Nov-May, Partial Jun-Oct	Well Nov–May, Partial Jun–Oct
Major stressors; (approximate areas affected)	*Spartina* (~11 km^2), mud and ghost shrimp (~88 km^2); pesticides for control; sediment; development; nutrients	Sediment Diking wetlands Eutrophication	Sediment Diking wetlands	Diking wetlands
Main commercial activities	Shipping Oysters Fishing Logging	Oysters Fishing Dairy Recr/Tour Logging	Shipping Fishing Fish Proc Recr/Tour Logging ·	Estuarine sanctuary Comm. oystering
Hydraulic modifications	Jetties Dredging	Jetties Dredging	Jetties Dredging	Some diking

1. In or recalculated from Hedgepeth and Obreski (1981); 2. Percy et al. (1974); 3. Shirzad et al. (1988); 4. Munson et al. (1984); 5. Harris (1979); 6. Oregon South Slough Estuarine Sanctuary Management Commission (1978); 7. Estimated from Munson et al. (1984); 8. Wolf (1993); 9. In or recalculated from NOAA (1985).

7.3.2 Predictive Relationships Between Physical Habitat and Estuary Structure/Functions

A basic tenet of ecology is that there is a predictable relationship between the natural physical/chemical environment within a biogeographic region and ecosystem structure/functions.[2] Many stressors, including sedimentation, habitat loss/alteration, and, to some degree, biological stressors, affect ecosystem endpoints by changing the physical/chemical characteristics of estuaries (e.g., substrate type, salinity, temperature). Thus, to predict effects from these stressors, we must first gain a better understanding of the relationships between estuary ecosystem structure/functions and physical/chemical habitat features. Then it will be possible to do the following, based upon information on historical and present habitat characteristics (derived from the projects described in Sections 7.3.3–7.3.5):

- Hindcast the types of ecosystem structure/functions that have changed over time.
- Assess the status of the existing system compared to its minimally disturbed state.
- Predict changes in ecosystem structure/functions that will occur as a result of management practices.

<u>Project-Level Objective</u>

The goal of this research is to establish predictive relationships between readily measured habitat characteristics and indicators of important ecosystem structure/functions in Pacific Northwest coastal estuaries.

<u>Approach</u>

Predictive relationships will be developed both for aggregate, community-level indicators of estuary structure/functions and for species-specific indicators for selected economically important or key species. Key species are those that have a disproportionate effect on the structure and function of estuarine ecosystems (e.g., bioturbators, such as mud shrimp, or preferred prey species). It is likely that aggregate indicators will be predicted with greater confidence than species-specific indicators. Predictive relationships will be developed for both benthos and fish. Although discussed separately, the water quality data for developing these relationships for benthos and fish will be closely coupled with the baseline assessment of Willapa Bay, as discussed under the case study in Section 7.3.5. Development of similar predictive relationships between phytoplankton and water column chemical/physical parameters is also discussed in Section 7.3.5.

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[2] Biotic interactions may modify these relationships, but still physical and chemical characteristics are major determinants of habitat suitability and of the types of biological communities and level of productivity likely to occur at a given site.

With fixed resources, the three parameters that need to be optimized in a sampling strategy are the number of samples per habitat, the number of habitats sampled, and the resolution per sample. Resolution, or information per sample, includes factors such as level of taxonomic identification and number of pollutants quantified. Classic studies of a site usually include many samples per habitat with high resolution, but few, or only one, habitats sampled. In general, EMAP samples from several to many habitats and uses moderate to high resolution, but very low sampling density per habitat. We believe that for deriving ecosystem relationships, it is important to have an adequate sample density throughout the estuary, both to capture the majority of the habitats and to have enough precision within habitat types to assess spatial and temporal trends. Therefore, the approach we will use is to maximize the number of samples per site and number of habitats, but use lower resolution measures when possible. Specifics are given in the discussion on benthos.

We will use EMAP's probability-based sampling strategy for much of the sampling, which will assure unbiased estimates of the spatial extent of habitats, populations, and degraded environments. In some cases, however, it may be more fruitful to sample along a defined gradient to develop relationships between an ecosystem characteristic and a specific environmental parameter. The estuary chosen for such gradient sampling would depend upon the specific question, and could include one of the Oregon estuaries. We will use probability sampling to test the accuracy of relationships developed from sampling along a gradient. To the extent appropriate, we will use EMAP sampling techniques for the benthos, fish, and water quality parameters (see Schimmel 1994). In addition to the field sampling, we may conduct laboratory or field experimentation in later years to quantify specific ecosystem functions. For example, *in situ* chambers could be used to determine benthic nutrient regeneration by benthic habitat type so as to allow predictions of how increased sedimentation could indirectly impact nutrient concentrations.

The influence of temporal variations in ecosystem parameters will be approached in four ways. First, probability-based sampling of many of the parameters will be repeated for 3–5 years, and statistical approaches will be used to separate spatial from temporal variation. Second, several permanent sites will be established and resampled. Determining the number and location of these permanent sites will be part of the research program. Third, historical records (e.g., World War II photos) and measurements of sedimentation records (e.g., ^{210}Pb or pollen) can generate insight into the temporal fluctuations of a few parameters, in particular changes in sea grasses and sedimentation rates (see Sections 7.3.3.1 and 7.3.4). The first and second approaches quantify the variation associated with short time scales, whereas the third approach generates more limited information but on medium to long time scales. The fourth and most satisfying approach is the development of mechanistic models on an ecosystem level. The mechanistic approach should work best for biotic characteristics that are closely coupled to basic estuarine conditions (e.g., salinity effect on submerged aquatics) rather than on oceanic or watershed conditions (e.g., salmon) or chaotic events (e.g., introduction of exotic species).

Benthos. As discussed in Section 7.1.1, benthic communities constitute key ecosystem elements in Pacific Northwest estuaries, in part because of their extensive intertidal zones. Benthic community structure and function are frequently used as indicators of effects from both chemical (e.g., Lee et al. 1994) and nonpollutant (e.g., Rhoads et al. 1978, Swartz et al. 1980) stressors, as well as integrative measures of ecosystem status (Scott 1990). For example, long-term changes in benthic density were significantly coupled with indices of phytoplankton abundance (Buchanan 1993), whereas temporal patterns in coastal benthic biomass were correlated with changes in freshwater runoff, which presumably increased nutrient inputs and phytoplankton production (Josefson 1990). Therefore, assessing benthic structure/function will be a powerful tool in determining the present status of an ecosystem. Developing empirical or mechanistic models to relate benthic structure/function to habitat characteristics, and coupling these with GIS maps of habitat types, will help us to predict the system-wide effects of stressors. The indicators of benthic ecosystem functions that we will attempt to predict from the physical/chemical environment include (1) structure and integrity of the benthic community, (2) range of primary and secondary production, (3) nutrient regeneration, (4) density of prey items for salmon and other key predators, and (5) suitability of habitat for oyster and/or clam production.

The first step is to integrate cost-effective methods of characterizing the salient physical/chemical habitat characteristics—of the sediment, water column, and biological habitats (e.g., aquatic plant beds)—into cost-effective sampling strategies for characterizing important ecosystem structures/functions. Proposed water quality and habitat measures are given in Table 7-5.

A key question is, "What level of resolution and sampling density are required for ecosystem analysis?" We suggest that, for ecosystem analysis, the appropriate sampling density is somewhere between those used by a site-specific study and by EMAP. The number of sites depends on the question, but it could be up to 500–1000 sites for an estuary the size of Willapa Bay. To obtain this sampling density, it will be necessary to use inexpensive measures ($10–100/site) at many of the sites, with more detailed but expensive measures at a limited number of sites. To test this approach, we will use readily measured (rapid assessment) indicators of the physical/chemical environment and benthic structure/function at all sites, and more costly measures (e.g., species diversity) at a limited subset of the sites (see Table 7-5). Evaluation of this approach will require oversampling, at least initially, to allow an appraisal of different sampling strategies. Some of the general questions that can be addressed include:

Table 7-5. Potential Parameters Used to Characterize Habitats (Page 1 of 2).

Parameter	Range Seasonally	Range Tidally	Sampling Frequency[a]	Used to Estimate[b]
Water Quality				
Salinity	High	High	All	Habitat type
Temperature	Low-mod subtidal Mod-high intertidal	Low subtidal Mod-high intertidal	All	Habitat type
Dissolved oxygen	High	Moderate	Frequent	Habitat type Input of organic matter
pH	Low-moderate	Low	Frequent in lower salinity	Habitat type
Turbidity and suspended solids	Moderate-high	Moderate	Periodic	Primary production Sediment inputs
Nutrient concentrations	Moderate-high	Low	Periodic	Primary production Inputs from watershed
Phytoplankton production /Standing stock	High	Low	Infrequent	Primary production
Phytoplankton composition	Moderate-high	Low	Infrequent	Food availability, toxic tides
Chlorophyll a and other pigments	High	Low	Frequent Experimental	Primary production Condition of phytoplankton Dominant taxa
Oyster growth/condition	Moderate-high	Low	Infrequent	Integrative measure food and water quality
Toxicity to phytoplankton or zooplankton	Uncertain	Low	Experimental	Presence of unknown toxicants
Pollutant concentrations	Low (?)	Low	Infrequent-depends upon toxicity	Quantifies known toxicants
Habitat Characteristics				
Tidal height	Low-moderate	NA	All	Habitat type
Grain size - visually	Low	Low	All	Habitat type
% silt-clay	Low	Low	Periodic	Habitat type
TOC	Low	Low	Periodic	Habitat type Organic inputs
Softness of sediment	Low	Low	All	Habitat type Oyster production
Submerged aquatic vegetation cover	Low-moderate	Low	All	Habitat type Primary production
Macroalgal cover	High	Low	All	Habitat type Primary production
Microalgal cover (visual estimate)	High	Low	All	Primary production

Table 7-5. Potential Parameters Used to Characterize Habitats (Page 2 of 2).

Parameter	Range Seasonally	Range Tidally	Sampling Frequency[a]	Used to Estimate[b]
Sediment chlorophyll	High	Low	Periodic	Primary production
Proximity to stream/marsh	Low	Low	All	Terrestrial inputs
Known disturbances	Low (?)	Low	Estimate for locale	Impacts not related to measured parameters
Pesticides in bird eggs and/or seal blood	Low-moderate	Low	Experimental	Integrative measure of pollutant loading
Benthic Parameters				
Total infaunal density & biomass	Moderate-high	Low	Periodic	Community structure Prey availability Secondary production
Density "key" benthic species (abundant and/or large)	Moderate-high	Low	Frequent	Prey availability Nutrient regeneration Clam production
Density of burrows	Moderate	Low	All	Habitat type Bioturbation Oyster production
Infaunal diversity	Low-moderate	Low	Infrequent	Community structure
Amphipod toxicity	Low	Low	Infrequent	Presence of unknown toxicants
Sediment pollutant concentrations	Low for chlorinated Moderate-high for lower Kow biocides w/seasonal use	Low	Infrequent-depends upon toxicity & inputs	Quantifies known toxicants
Tissue residues in bivalves	Low for chlorinated Moderate-high for lower Kow biocides w/seasonal use	Low	Infrequent-depends upon toxicity & inputs	Quantifies known toxicants
Benthic profiler (camera)	Low-moderate	Low	Experimental	Habitat type

[a] Part of the research problem is to determine the optimal sampling schedule for these parameters. The frequencies mentioned here represent a first-cut plan. All = at all sites where meaningful (e.g., no intertidal measures for subtidal sites). Frequent = at most stations (may not be repeated for adjoining stations sampled at the same time, such as during an intertidal transect). Periodic = at about 10–25% of the sites. Infrequent = at less than 10% of the sites. Experimental = to be evaluated as to usefulness.

[b] Predictive relationships will be developed relating habitat type to key ecosystem functions, such as nutrient regeneration, so estimation of functions is not limited to those explicitly identified. Production will be estimated from standing stocks based on a general knowledge of the life histories of the key species and their size distributions.

- What level of resolution is required to capture the ecosystem-level functions important to the management of the system?
- What is the optimum sampling strategy for assessing these ecosystem-level functions?
- What is the optimum sampling strategy for assessing the sources of ecosystem-level stressors?
- Does the EMAP sampling strategy adequately describe the status of the bay?
- Can a cost-effective tiered approach be developed for monitoring ecosystem functions?

For the rapid assessment methods, taxonomic identifications will focus on the genus or family level, rather than the species level, which should greatly reduce processing costs but still generate sufficient information (see Ferraro and Cole 1990, 1992). This assumes that the key species and ecosystem structures/functions can be determined from the numerically dominant taxa and/or from the larger taxa that modify habitat (e.g., macroalgal mats, major bioturbators) or major predators. We also assume (and will test) that semi-quantitative (e.g., photos of density of mud shrimp burrows) or qualitative (e.g., visual descriptions of habitat type) can generate information predictive of ecosystem functions. This approach maximizes the areal extent sampled, but sacrifices information on less common species and smaller organisms, including juvenile stages, as well as indices based on species richness.

The data (i.e., benthic mapping) for Willapa Bay will serve to quantify the existing condition of the system, as a benchmark for future assessments, and to provide a basis for quantifying spatial associations between physical/chemical habitat characteristics and indicators of ecosystem structure/functions. The final step is to test how site specific these relationships are by applying them to other Pacific Northwest estuaries. The extent of this field validation at independent sites will depend upon resources. No large-scale validation will be attempted until the later part of the project, though smaller scale comparisons may be undertaken synoptically with the Willapa case study.

Fish and Megabenthos. For fish, we want to quantify, by time and habitat type, the use of estuarine habitats by major fish species, especially anadromous salmonids, commercially important flatfish and herring, and other species of fish that spawn in estuaries, are known prey for salmonids, or represent a large biomass. This research will also include the megabenthos, the larger epifaunal invertebrates sampled by trawls rather than by benthic grabs. The most important types of megabenthos are shrimp and crabs, especially the commercially important Dungeness crab. The habitat utilization study will examine benthic and vegetation types, salinity, temperature, life stage, feeding habits, and correlations with seasonal and tidal patterns. Potentially important fish species, their distributions within estuaries, and their seasonal abundance are given in Table 7-6.

Table 7-6. **Juvenile Fish: Occurrence and Relative Abundance by Month in Yaquina, Tillamook, and Willapa Bays (Source: Monaco et al. 1990).**

	Yaquina	Tillamook	Willapa
Species	JFMAMJJASOND[a]	JFMAMJJASOND[a]	JFMAMJJASOND[a]
Herring (MS)[b]	AMJJASON	AMJJASO	JFMAMJJASOND
Anchovy (MS)	MJJASON	MJJASO	JFMAMJJASOND
Surf smelt (MS)	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND
Topsmelt (MS)	MAMJJASOND		
Stickleback (TMS)	JF MJJASOND	JJASOND	JASOND
Staghorn (TMS)	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND
Sand lance (S)	AMJJA	MAMJJAS	JFMAMJJASOND
Cutthroat trout (TMS)	AMJJASO	MAMJJASO	MAMJ
Steelhead (TMS)	AMJ	MAMJ	MAMJ
Coho salmon (TMS)	AMJJASO	MAMJJAS	AMJ
Chinook salmon (TMS)	AMJJASOND	JFMAMJJASOND	JFMAMJJASOND
Chum salmon (TMS)	FMAM	FMAMJJ	FMAMJJ
English sole (MS)	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND
Starry founder (TMS)	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND

[a] Presence by month (e.g., MJJA = May, June, July, August).
Abundance (e.g., MA MJ JAS = common March–September, abundant April–July; highly abundant May–June).

[b] Location: T = tidal fresh; M = mixing; S = seawater

We will begin by identifying general presence/absence/density trends, by time and habitat type, and prey preferences from published information. Based upon these data, we will formulate and conduct a detailed sampling study for one or more estuaries to determine (1) fish and megabenthos population sizes by habitat type, (2) diel, tidal, and annual patterns in presence, distribution, and activities by habitat type, and (3) feeding preferences by habitat type.

Location

Most of the sampling conducted to develop these relationships will take place in Willapa Bay, although specific sampling along gradients may occur in other estuaries as appropriate.

Timeline

Because of the ecological importance of benthic systems in Pacific Northwest estuaries, this project will be given high priority and will begin in FY95. Field components for fish must await development of the estuarine benthic habitat target map for the subject estuaries. Thus sampling for fish will not begin before the second year of the project.

7.3.3 Extent, Causes, and Effects of Sedimentation and Associated Parameters

We propose to conduct three interrelated activities to evaluate the extent, causes, and effects of sedimentation and associated parameters in Pacific Northwest coastal estuaries: (1) estimates of current and historical sedimentation rates in relation to estuary and watershed type and history, (2) application of watershed models to simulate precipitation, runoff, and associated sediment and nutrient loadings as a function of watershed characteristics and activities, and (3) development or application of models to predict the effects of sedimentation on circulation, temperature, nutrients, and other key physical/ chemical parameters. Results from these studies can then be coupled with the benthos and fish habitat-ecosystem relationships described in Section 7.3.2 or the phytoplankton relationships described in Section 7.3.5 to predict biotic effects. We describe each of these activities (subprojects) in the following sections.

7.3.3.1 Estimating Sedimentation Rates and Estuary History

To determine the current status of estuaries, it is necessary to estimate the extent of net sedimentation that has occurred over the historical past. To model the relationship between sedimentation and watershed history and management practices, we need to determine whether the sediment is terrestrial or marine in origin and, if possible, to relate the sedimentation to specific natural or anthropogenic activities.

Project-Level Objectives

- Estimate current and historical sedimentation rates in the target estuaries.
- Identify the relative contributions of different sediment sources.
- Develop conceptual or statistical models relating estuary sedimentation rates to natural or anthropogenic watershed characteristics and events.
- Develop approaches for estimating sedimentation that can be applied in other estuaries.

Approach

Because of the complexity of estuary-watershed linkages and because of the spatial/temporal variations in sedimentation, a variety of methods, each with its own advantages and disadvantages, will be considered with regard to information gained and cost-effectiveness for estimating sedimentation and sources of sedimentation (Table 7-7). Estimating sedimentation from changes in bathymetry from historical records is a relatively rapid method of estimating net deposition over wide areas. Bathymetric records and photographs taken over the last 150 years will be obtained from a variety of sources, such as the Navy, Coast Guard, USGS, NOAA, NASA, state agencies, and historical societies. These data will be entered into GIS systems and compared to present bathymetry to determine net changes over the historical past. As needed, present intertidal bathymetry will be estimated from photographs taken throughout a tidal cycle and subtidal bathymetry extracted from sounding records. Several studies are ongoing in Pacific Northwest estuaries, in particular, the remote sensing of intertidal areas to monitor *Spartina* expansion in Willapa Bay by Washington's Department of Natural Resources (T. Mumford pers. comm.) and the historical reconstructions being put together for Tillamook Bay under the National Estuary Program. Because of these ongoing studies, the major role of this project will be to collate the data into a single repository, fill in any spatial or conceptual gaps, and/or use the data to address ecosystem-level problems that may not have been the focus of the original study.

Within-sediment tracers, which can be expensive, require undisturbed, layered sediment. However, they can generate information on temporal variations in sedimentation rates and on the history of the site. In the target estuaries, we will collect cores from undisturbed depositional sites. Initial dating of the cores will be conducted using ^{210}Pb geochronology (Huh et al. 1990). Samples of sediment from periods of interest will be analyzed for (1) geological indices such as grain size, mineralogy, and weathering characteristics and (2) chemical indices such as total organic carbon (TOC) and nitrogen (TON); petrogenic and pyrogenic polynuclear aromatic hydrocarbons (PAH) that could signature specific oil spills or forest fires (Readman et al. 1987); and nuclear bomb residues (e.g., ^{137}Cs) that can provide useful sediment

Table 7-7. Methods of Estimating Sedimentation Rates.

Method	Interval	Features	Advantages	Costs ($)
Sediment trap	1–2 days	1. Diel cycle integration 2. Water column data	1. Real-time rate 2. Fresh sample collected	1.5K/trap
Bathymetric maps	0–100 years	1. Broad scale change	1. Entire bay 2. Relative rate	>5K/bay
Sediment profile imaging	Major events	1. Visual markers	1. Sediment types mapped 2. Rapid, inexpensive	100/sample
^{137}Cs	0–30 years	1. Discrete sites 2. Sedimentary record 3. Single horizon (ca. 1963)	1. Net rate	1K/core
^{210}Pb	10–100 years	1. Discrete sites 2. Sedimentary record	1. Net rate 2. Temporal resolution	1–2K/core
^{14}C	500–9000 years	1. Discrete sites 2. Sedimentary record	1. Absolute dates pre-1950	1–2K/core

horizons. We also may analyze for persistent pollutants at certain sites, either as temporal tracers (e.g., DDT) or as a history of past stressors. Inexpensive biotic indicators of sedimentation or changes in communities, such as buried oyster shells, will be examined at several sites; at selected sites, biological indices (Whitlock 1992) of both watershed flora (e.g., pollen from forest vs. grassland taxa) will be examined if appropriate. Though potentially expensive, pollen analyses provide climate and vegetation data for the watershed within a given stratum and can be used to identify major shifts in the watershed that may be related to changes in sedimentation (e.g., increases in grass pollen may correspond to increased sedimentation due to fire).

For present-day sediment processes, sediment traps provide a direct measurement of the rate of deposition as well as a method of determining the flux of carbon and other natural and anthropogenic materials to the benthos. For an area with highly variable deposition rates, monthly trap deployments over a 3-year period should provide a realistic average rate, based on work in other estuaries (e.g., Sigleo and Shultz 1993). Sediment traps can be used both to determine present undisturbed sediment flux, and the effects of specific watershed alterations when the traps are deployed during a disturbance (e.g., clear-cutting). Sediment traps will be used to establish parameters and/or conduct field validation for runoff models and probably will not be deployed until later in the project.

Determining the source of historical or present sedimentary material is still an art and often is based on circumstantial evidence. However, it should be possible to separate marine sands in the mouth of the estuary from terrestrial sediments transported from the watershed. Also, ratios of stable isotopes, particularly those of nitrogen (14 and 15), carbon (12 and 13), and oxygen can be used to determine environmental source (Rau et al. 1981, Peterson et al. 1985, Sigleo and Macko 1985). However, stable isotopes also can indicate certain processes (e.g., nitrification vs. denitrification) and should be used with caution.

The results will be used to develop empirical models furthering the understanding and predictive capability of the effects of specific watershed events (e.g., major fires or storms, disease, infestation, logging, agriculture, urbanization) on the types and rates of sedimentation in target estuaries of the Pacific Northwest. The data can also be used to estimate the relative contributions from marine vs. watershed inputs, as well as to evaluate various runoff models, as discussed in Section 7.3.3.2.

<u>Location</u>

Willapa Bay will be the focus for the analysis of historical bathymetry. The project also will interact with the Tillamook National Estuary Program in its historical reconstructions, both to fill research and/or GIS gaps and to learn its procedures for using the historical reconstructions. Evaluation of some within-sediment methods requires undisturbed sediments, so sites of opportunity will be used initially.

Timeline

Historical records of bathymetry for Tillamook Bay will be compiled in FY95 or FY96 by the National Estuary Program; analyses should be complete in FY96. Analysis of historical records in Willapa should be completed by FY97. Sampling for within-sediment techniques and sediment trap deployment will begin in FY95 or FY96 and expand to other estuaries in later years. Development of empirical models will begin in FY96 or FY97.

7.3.3.2 Predicting Runoff and Inputs from Coastal Watersheds

Runoff from streams and rivers, with the associated sediments, nutrients, and pollutants, transported into the estuary constitutes an important, if not the most important, link between coastal watersheds and estuarine ecosystems. The overall goal of the estuarine research is to predict the extent to which these watershed inputs affect estuarine ecosystems. Therefore, we must be able to predict how watersheds respond (e.g., changes in outputs) to major natural and anthropogenic alterations. This project calls for a mechanistic understanding of the watersheds.

Project-Level Objectives

- Develop or apply hybrid models to predict sediment and nutrient loads to Pacific Northwest coastal estuaries as a function of watershed characteristics and upland management practices.
- Collect the minimum data set required for these models and apply and test the models for Willapa Bay.

Approach

We propose to use existing (or modified) watershed and runoff models as the basis for predicting inputs into the estuary. The first step will be to assess the utility and data requirements of watershed runoff models relative to the Program's needs (desired resolution) and resources. A likely candidate is EPA's Hydrological Simulation Program Fortran (HSPF; Bicknell et al. 1993), which can predict flow rate, sediment load, and nutrient and pollutant concentrations based on watershed and climatic characteristics. Other potential candidates include the National Resource Conservation Service (NRCS) Watershed Model TR-20 (McCuen 1989) and the HEC-2 (Hydrologic Engineering Center 1982). If the data requirements for HSPF or similar models prove to be beyond the scope of the project, empirical (e.g., regression) models will be used. If greater accuracy is needed, and is within the budget, more mechanistic models (e.g., Wigmosta et al. 1994) will be considered.

We will obtain land use data for the models from GIS databases, and the Willapa Alliance is deriving data for the Willapa watershed. We will obtain hydrographic data from USGS gaging stations, which are available in Willapa, by placing *in situ* monitors in main tributaries, and from local groups collecting runoff samples, especially during periods of peak runoff. For the baseline assessment of Willapa Bay, as described in Section 7.3.5, we will position stations near the mouths of the rivers draining into Willapa Bay, which will provide additional data on inputs of sediments and nutrients. Existing data on runoff, sediment, and nutrient loading for coastal streams, such as data from USFS/OSU Forestry reports (D. Shults, pers. comm.), will also be used for model calibration or testing. Estimates of current and historical sedimentation rates, as described in Section 7.3.3.1, will be useful for evaluating model predictions.

In addition to runoff from the adjoining watershed, the influx of marine waters through the mouth of the estuary is a potential source of sediment, nutrients, and pollutants. Potential inputs from nearshore coastal waters, possibly including Columbia River water (see Ebbesmeyer and Tangborn 1992), will be evaluated in Willapa Bay. The importance of marine inputs will be evaluated through reviewing the literature, determining sources of sediments, and studying circulation patterns within the Bay (Section 7.3.3.3).

<u>Location</u>

Because of the close linkages between the data needed to set parameters and/or validate the runoff models and the data collected under the baseline assessment of water quality, Willapa Bay will be the focus of this research. To the extent that the National Estuary Program generates databases suitable for analysis, the models will be used to simulate conditions in Tillamook Bay.

<u>Timeline</u>

The review of existing runoff models will be completed in FY95. Data collection and/or model development for Willapa Bay should begin in FY96.

7.3.3.3 <u>Effects on Circulation and Associated Parameters</u>

Circulation models are essential to predicting which areas within an estuary will be directly impacted by sedimentation. Circulation models are also important tools for predicting (1) the nature and extent of indirect effects of sedimentation on bathymetry, temperature, nutrient loading, and transport of pollutants from the watershed and (2) the fate of biocides applied directly to the estuary.

Project-Level Objectives

- Collect the circulation data required to adequately describe the currents in Willapa Bay, and other target estuaries as feasible.
- Develop, modify, and verify approaches and models for predicting present circulation and changes in circulation as a function of sedimentation and runoff in Pacific Northwest coastal estuaries.
- Couple circulation models with other models to predict temperature, salinity, dissolved oxygen, suspended solids, nutrients, stratification, and other parameters of interest.

Approach

We will determine the seasonal circulation patterns of Willapa Bay by deploying a set of moored current meters—adequate to help separate inputs from oceanic water vs. river runoff. The current meters will also help to determine the fate of biocides applied to *Spartina* and mud shrimp beds, the movement of *Spartina* detritus and seeds, and the movement of sediment.

Circulation data will be used to develop and validate circulation models. At least two types of circulation models will be considered: (1) models that rigorously and directly address sedimentation and circulation and (2) simpler models that can be used as everyday conceptual tools by researchers or managers. If successful, the complex models may result in detailed maps of sedimentation 20 years into the future. The simpler models will tend to address more general but immediate concerns, such as predicting the tidal height and velocity at a specific point and time. The circulation models will be coupled with other models to predict temperature, salinity, suspended solids, nutrients, and stratification. In areas affected by agriculture, particularly dairy farming, it may be necessary to predict organic loading and corresponding spatial and temporal changes in dissolved oxygen. The objective will be to provide researchers and managers with a "numerical bottle of water" anywhere in the aquatic domain from which the ecosystem structure and function can be predicted.

Candidate circulation models (Table 7-8) will be assessed for their basic usefulness and those chosen will be adapted as appropriate. Verification data (e.g., currents) and required information (e.g., bathymetry) will be collected in Willapa Bay and extracted from the literature for other sites. Some effort will support the development of sophisticated primitive equation, finite element/difference, dynamical models for Willapa Bay. These models can generate high-resolution answers, but are often site specific and may be difficult to develop and run. Consequently, a concurrent effort will develop models, relatively simple, but still powerful, for predicting tides and basic current patterns, using, at a minimum, mass conservation principles (i.e., tide model in Table 7-8). Such a model might provide (1) boundary conditions for more sophisticated models (e.g., tidal heights) and (2) in a short time frame, a multi-purpose model capable of providing predictions accurate enough for many management decisions. The circulation models will be coupled with other models to predict various indirect effects. For example, predicting temperature changes would require the development of a simple heat budget for the intertidal zone.

The needs of end users will be factored into model development. Considered in this context will be emerging tools, such as Object Oriented Programming (C++) and the Windows operating system.

Location

The tide model will be developed initially for Yaquina Bay and then for Willapa Bay. The dynamic circulation models will be developed initially for Willapa Bay.

Timeline

We will begin collecting current data in Willapa Bay in the first year, and continue into the second year. Model development will begin in year 1. This research will be coordinated through Sea Grant. We anticipate that first-generation tidal models can be developed for all the target estuaries within two years.

7.3.4 Extent, Causes, and Effects of Biological Stressors and Potential Control Measures

This project will consider two major biological stressors in Willapa Bay: the invasion and expansion of *Spartina* and recent population explosions of mud shrimp. The expansion of *Spartina* is considered to have the greater ecological impact and will be given higher priority.

Project-Level Objectives

- Determine the direct and indirect effects of *Spartina* and mud shrimp on the estuary ecosystem.
- Evaluate the relative effects of *Spartina* and mud shrimp, vs. control measures for these organisms, on the estuary ecosystem.
- Identify likely linkages of *Spartina* expansions and increases in mud shrimp populations with water quality parameters and watershed management.

Table 7-8. Candidate Circulation, Sedimentation, and Transport Model Prototypes.

MODEL	Type	Output	Resources Labor	Resources Equip	Flexible	Power	Control	Status	Notes
DYNHYD 5	Dynamic Dispersion Stratified	Currents Pollutants	Med-High	PC	Moderate	High	Med-Low	EPA	
Reflux	Mass conserved	Currents Residence times	Med-Low	PC	Moderate	Med	Med-High	On hand	
SEDDEP	Sediment PVD Stokes settling	Sediment Distribution	Med	PC	Low	Med-Low	Med-Low	EPA	In debugging
Tide model	Harmonic Mass conservation	Current Tides Boundary conditions	Med-Low	PC	Med-High	Med	High	EPA	In develop-ment
POM	Finite Element	Current Dispersion Stratification	High	mini	Variable	High	Low	Public domain	
Koutitas	2.5 D	Current	??	PC	High	High	??	??	
DECAL	Sediment Coag/Floc	Sediment Distribution	Med-Low	PC	Low	Med-Low	Low	EPA	

Reflux: Puget Sound Reflux Model (Cokelet and Stewart 1985).
PVD: Progressive Vector Diagram approach.
POM: Princeton Ocean Model (Blumberg and Mellor 1987).
Flexibility estimates the potential for modifying the program.
Power estimates scientific rigor and the ability to include relevant mechanisms.
Control estimates user confidence and dominion.

Approach

The specific questions addressed regarding *Spartina* depend in part upon pending Washington State management decisions and court cases about the extent to which Rodeo will be used to control *Spartina*. If it is decided to control *Spartina* with herbicides, then the key questions relate to the toxicity, the recovery potential of different habitats, and the short- and long-term effects of killing *Spartina*. If the decision is not to control *Spartina,* or if the decision is delayed because of a lack of information, then the key questions relate to ecosystem effects of *Spartina*, both positive and negative. The Washington Department of Ecology has conducted extensive data reviews of *Spartina* and the impacts of chemical and nonchemical control strategies, and the Washington Department of Natural Resources has done field research on the fate and effects of glyphosate and surfactants in Willapa Bay (Simenstad et al. 1993), plus remote sensing of intertidal areas. Therefore, the roles of this project are to fill specific key data gaps, determine the relationship between *Spartina* expansion and water quality conditions and/or watershed management, and assess present and predicted effects at an ecosystem scale. Defining specific testable hypotheses will constitute the first step in the research. The research perspective will be at the ecosystem level, rather than localized impacts alone.

Although setting out a detailed research agenda for *Spartina* would be premature, it is possible to define potential research issues assuming no herbicide control. One key issue is the effect *Spartina* has had, and will continue to have, on habitat loss through increased sedimentation or changes in circulation. Habitat losses or changes can be documented by the remote sensing data collected by the Washington Department of Natural Resources. The habitat-environment relationships developed in Section 7.3.2 can be used to determine the ecological consequences of specific habitat alterations. Another broad issue is determining the effects on other communities and populations, either directly or indirectly. For example, there is a question about the fate of the considerable *Spartina* detritus and whether it fuels local detrital food webs. This issue could be addressed by examining various signatures (e.g., delta carbon ratios) and by constructing a food web through literature reviews, field studies, and the use of Cs/K ratios (Young et al. 1987). Another example is *Spartina*'s impact on the native submerged aquatic, *Zostera marina*, which could be determined through field monitoring; the mechanisms of interactions could be determined by means of laboratory/field experiments and biomarkers of plant health. Other potential issues include the effects of *Spartina* on juvenile fish, benthos (especially salmon prey species), migratory birds, and phytoplankton production through alteration of nutrient budgets.

If the decision is made to control *Spartina* through widespread application of herbicides, the questions relate to the indirect impacts of killing large masses of *Spartina* and the potential for recovery. Would there be a rapid release of nutrients and would this indirectly cause any adverse impacts? How quickly will the *Spartina* root mass decay? Will the accreted sediment erode, thus returning the site to its previous habitat type? To what extent and at what rate will the biotic communities recover, and how does recovery vary with environmental parameters such as current speed or salinity? Additional questions relate to ecosystem-level effects of herbicide application. As mentioned, there appears to be considerable information on toxicity. Any research in this area will focus on relating localized toxic effects to ecosystem integrity and/or conducting a comparative risk assessment for the Bay.

Another potential research area is determining the linkages between *Spartina* expansion and watershed management. Quantifying the linkages may be important, to identify potential control measures and/or to help predict the rate of expansion under different watershed management scenarios. This question can be addressed by relating *Spartina* past and present distributions and present health to various indices of the environment (e.g., nutrients) and/or historical watershed practices. Alternate possibilities, which will also be explored, are that there is no strong linkage to watersheds, and the expansion is a simple exponential growth or is related to large-scale weather patterns (e.g., El Niño).

Mud shrimp are native to Willapa Bay and thus their expansion differs qualitatively from that of *Spartina*. From a management perspective, the key ecological issue is the effect of mud shrimp relative to that of carbaryl (the chemical control measure). Considerable data on toxicity have been reviewed (Washington Department of Fisheries and Washington Department of Ecology 1992), thus little or no work on direct toxicity will be conducted, unless specific data gaps are identified. However, the total ecological impact also includes the indirect effects of a reduction in mud shrimp populations and an increase in oysters. Potential indirect effects of a reduction in mud shrimp also include a reduction in filtration of the water column with concomitant changes in water quality (the volume irrigated by shrimp may approach the summer river flow), drastic changes in the benthic community, and changes in prey availability. The nature and extent of these changes can be determined through literature reviews, field studies, and laboratory/field experimentation. As with *Spartina*, it will then be necessary to develop ecological approaches to evaluate the net effects of the pesticide application vs. the mud shrimp's natural expansion. If these results indicate a potential adverse ecosystem effect from current management practices, the linkages between mud shrimp populations and watershed inputs and/or reduced predation will be examined.

Location

This research will be carried out at Willapa Bay. Some of the laboratory experimental research on the direct and indirect effects of mud shrimp or *Spartina* may be conducted at ERL-Newport.

Timeline

Research on the ecosystem effects of *Spartina* and/or the reasons for its expansion will begin in the first year. Limited research on mud shrimp will begin in year 2 or 3, and will be expanded in the third and fourth years, if the results indicate substantial indirect effects.

7.3.5 Willapa Bay Case Study Assessment and Data Synthesis

The final research projects are the case study in Willapa Bay and the data synthesis. These projects will be conducted jointly with the Watershed/Ecoregion research component. The major objectives and approach were outlined in Section 5.3.2. We do not repeat that information here, but we supplement it by (1) describing proposed data collection activities specific to the Willapa estuary-watershed assessment and (2) discussing the relationship between this project and the process-oriented research in Sections 7.3.2–7.3.4.

The case study assessment for Willapa Bay is the focus of the Coastal Estuaries research component. An important goal of the case study is to evaluate the technical methods/approaches developed by the process-oriented research and to integrate research findings from this and other PNW research projects for a real world application. In addition, integrated case studies help to identify conceptual bottlenecks and data gaps, and conversely, instances of oversampling or collection of research data at a higher resolution than required for assessment applications. Of particular importance to the assessment will be approaches for evaluating the relative importance of various stressors and the ways in which different components of the estuary and watersheds interact. Although implicit in the projects described in Sections 7.3.2–7.3.4, these objectives and needs become explicit in an integrated estuary-watershed assessment.

"Willapa Bay is notable as one of the five largest oyster producing regions in the world and the cleanest large estuary in the continental U.S." (Colby 1992). However, as pointed out by Wolf (1993), declines in log diameters, average size of oysters, and number of salmon all indicate a system under increasing stress. The major stressors in Willapa Bay that appear to be having or could have the greatest impact on the ecosystem are (1) introduced cordgrass, *Spartina alterniflora*, and the application of glyphosate to control its spread, (2) population explosions of mud shrimp and the application of carbaryl to control them, (3) sedimentation, (4) nutrient and organic loading from logging, agriculture, and development, and (5) habitat loss. Except for the two pesticides being directly applied, toxic pollutants do not appear to be having a major impact on the ecosystem, although this assumption will be evaluated during the study.

These stressors potentially overlap spatially and vary temporally, resulting in a complex suite of multiple stresses on single habitats. There may also be complex ecological linkages among stressors, such as an increase in the expansion of *Spartina* through nutrient inputs because of logging. There is considerable controversy over how best to manage Willapa Bay, and the complex nature of the stressors suggests that effective management will require trade-offs among resources. In that sense, Willapa Bay is a fitting location to conduct a prototype ecosystem management assessment.

Project-Level Objectives

- Conduct an integrated assessment for Willapa Bay, Washington, that provides ecological information in a format useful for addressing real-world management questions about the Bay and the stressors and management strategies that affect the Bay.
- Develop and validate sound, cost-effective, scientific approaches to ecosystem assessment for the management of estuarine systems.

Approach

Besides integrating the process-oriented research, the case study will require site-specific data not collected as part of process-oriented research in the Bay. Acceptable ecosystem-level predictions require a reasonably detailed understanding of water chemistry and circulation patterns. This information can be used to (1) distinguish sources (e.g., nutrient inputs from dairy farming vs. Columbia River water), (2) predict the habitats at risk (e.g., of increased sedimentation from logging or pesticide spraying), (3) assess the present status or condition, and (4) determine short-term alterations by quantifying changes over the duration of the program and long-term alterations by making comparisons with historical data. Besides being major determinants of types of biotic community, water quality parameters such as salinity and nutrients change rapidly in response to changes in watershed and marine inputs. This rapid response makes them excellent parameters for monitoring the effects of watershed alterations (e.g., logging) or climatic conditions (e.g., rain storm). Therefore, one of the initial tasks (after establishing the assessment questions and overall assessment design; see Section 5.3) will be to collect information on temperature, salinity, nutrients, dissolved oxygen, turbidity and other basic water quality parameters in Willapa Bay. Phytoplankton production and composition will be measured because of their importance to oyster production and, as mentioned in Section 7.3.2, to benthic community structure. Monitoring the dominant phytoplankton species will also generate insight into the frequency and timing of the presence of toxic algae species. Assessment of glyphosate, carbaryl, and other toxic pollutants in water, sediment, and tissues will also be included in this research area if data reviews or monitoring indicate that these pollutants are important ecosystem stressors. Data for parameterization and validation of circulation models, as discussed in Section 7.3.3.3, will be collected. As mentioned, the collection of the water quality data will be closely coordinated with, or in some cases part of, the habitat-ecosystem relationships developed under Section 7.3.2.

The sampling program will be designed to have enough stations and sampling periods to map out the general spatial and temporal patterns of the water quality parameters and to differentiate inputs from the major potential sources. Because of the importance of continuous records, conductivity-temperature-depth (CTD) recorders will be used to collect time-series data at permanent stations. As discussed in Section 7.3.3.3, current meters will be deployed throughout the Bay to collect the data needed to develop an empirical understanding of circulation and to parameterize the circulation models.

The strategy will be to work with and leverage existing programs, in particular the Washington Department of Ecology's monthly sampling under its Ambient Monitoring Program, which began in 1967. To the extent feasible, EMAP techniques and QA/QC requirements will be used. The greatest problems with the CTDs and current meters are likely to be the loss of units and the need for relatively frequent recalibration, which suggests the need for forming local partnerships. For cost effectiveness, and for assuring integration of the physical and chemical data, current meters and CTDs will be deployed jointly. The results from the sedimentation/runoff models will be coupled with these results to determine linkages to the watershed.

Secondary goals of the case study in Willapa Bay are (1) field validation of the ecosystem-level tools and approaches (including EMAP) developed in other estuaries, (2) development of centralized databases and GIS systems for future research and/or management, and (3) synthesis of the information from all the Pacific Northwest estuaries into a format useful to managers.

Because ecosystem assessment and management are in their infancy, the data synthesis and development of ecosystem assessment paradigms are considered a separate research project, rather than just a report exercise. Section 3, as well as Section 5.3, outline the basic approach to conducting ecological assessments for ecosystem management. We will apply, test, and refine this approach for estuarine systems. One important component of this effort is the synthesis of ecological understanding into an overall conceptual/management model for the study area, parts or all of which may be expressed in a computer model. These models (both conceptual and computerized) will provide information for managers on major stressors and will predict for single or multiple stressors: (1) habitat and resources at risk, (2) nature of potential or actual ecosystem alterations, (3) extent of potential or actual ecosystem alterations, (4) time frame for ecosystem alterations, (5) linkages among estuarine and watershed ecosystem components and the ways alterations on one component affect other components, and (6) ranking of the relative importance of stressors to different parts of the estuarine ecosystem.

At this stage of the science, it is likely that there will be order-of-magnitude uncertainty associated with several, if not many, of the predictions. Development of practical ecosystem-level management models must incorporate this uncertainty into the decision making process. Therefore, an output of the case study will be to characterize the significance of these errors and identify the most efficient approach to reducing critical uncertainties (e.g., increasing replication vs. filling data gaps vs. developing a more complete conceptual model).

As discussed in Section 3, a successful assessment will require close coordination with stakeholders to define local, tribal, regional, and national concerns and priorities. "Strawman" management goals, developed in coordination with the stakeholders, will be established to facilitate the conducting of sensitivity analyses. Goals of the sensitivity analyses will include determining whether ecosystem management addresses problems not possible to address through simpler regulatory approaches and how to compare effects on different ecosystem components to allow trade-offs among these components (e.g., oyster yield vs. biotic diversity vs. direct effects of pesticides).

Location

We will conduct this work at Willapa Bay. It is possible that a more limited case study assessment may be conducted, if adequate information and resources are available, through the National Estuary Program in Tillamook Bay in later years of the program.

Timeline

As discussed in Section 5.3, an initial assessment using existing data will be conducted in year 1, to establish specific assessment and research questions and identify major data gaps and research priorities. Resources will be devoted to obtaining the necessary CTDs and current meters in the first and second years and baseline data collection will occur over the full five years. The final assessment for Willapa Bay and the data synthesis will occur in years 4 and 5.

7.4 MAJOR CONTRIBUTIONS

The major contributions of the Coastal Estuaries research component will be as follows:

- Models to predict changes in the function of benthic communities and key fish populations as a consequence of sedimentation and other habitat alterations.
- Estimates of net sedimentation in the target estuaries and models to predict sedimentation in estuaries as a function of watershed type and disturbance.

- Models to predict runoff and loadings of sediment and associated parameters, such as nutrients, as a function of watershed type and disturbance.

- Evaluation of the ecological effects of *Spartina* and mud shrimp vs. those of the chemical control measures.

- Baseline information on water quality and circulation in Willapa Bay.

- Case study assessment to support effective implementation of ecosystem management in Willapa Bay, which will include identifying the key stressors and development of an ecosystem management paradigm for estuarine ecosystems.

8. INTEGRATED MONITORING

This section discusses the research we propose for contributing to the development of an integrated[1] monitoring program for adaptive ecosystem management in the Pacific Northwest. It is not within the scope of the PNW research program to implement long-term monitoring. Federal land management agencies, the states, EPA Region 10, and others have monitoring responsibilities. Thus, we believe that our major contribution is to assist with monitoring design and coordination. Within ORD, EMAP has committed substantial resources to the design and demonstration of regional monitoring programs (see Box 2-A). Our role is to serve as a focal point for EMAP and interagency activities in the Pacific Northwest and to extend these efforts as needed to develop an integrated monitoring design that satisfies the diverse users of monitoring information within the region.

8.1 BACKGROUND

The impetus for federal interagency coordination within the region came from the President's Forest Conference, FEMAT (1993), and the final implementation plan, "President's Plan for the Management of Habitat for Late Successional and Old-Growth Forest Related Species Within the Range of the Spotted Owl" (USFS and BLM 1994a) (see Section 1.3). USFS et al. (1994) outline the monitoring requirements of this plan and a framework for federal interagency monitoring coordination. EPA (Region 10 and the PNW research program) participate in this effort through the Federal Interagency Research and Monitoring Committee (RMC) and the Monitoring Workgroup established under the RMC. The primary goal of the Monitoring Workgroup is to develop a coordinated interagency plan for monitoring in the Pacific Northwest in support of the President's Plan. A component of the research proposed in this section is in direct support of the RMC and the Monitoring Group.

Monitoring needs for ecosystem management extend beyond federal lands and the range of the spotted owl. Among federal agencies, an important task for EPA is to ensure the establishment of sound scientific foundations for a region-wide monitoring database that includes both federal and nonfederal lands and supports management decisions affecting ecological resources within the entire region in an integrated fashion over the long term. These efforts will require interactions with state, county, and municipal governments, tribes (Ward 1991), industry, and other organizations, in addition to federal agencies (Grayson et al. 1994, Smith 1994). Coordination with these nonfederal groups will take place through the

[1] The term *integrated* is used throughout this document. Its meaning within the context of a monitoring program is described in Section 8.3.3.

RMC as well as in direct discussions.[2] The development of a monitoring design that incorporates federal and nonfederal lands, and forested and nonforested lands, is also a major component of our effort.

The long-term goal of this effort (beyond the temporal scope of this five-year strategy) is to implement an integrated monitoring program within the Pacific Northwest. This program would combine the efforts of all organizations with a responsibility for ecological monitoring into a common integrated monitoring system. We expect that such a coordinated, integrated monitoring system would provide more and better information at less cost than is currently expended on monitoring within the region (Hicks and Brydges 1994). We will contribute to this goal by catalyzing an inter-organizational design effort that will proceed through demonstration and implementation phases.

The President's Plan requires monitoring not only of ecosystems, but also of social systems and administrative processes (see USFS et al. 1994). As do other parts of the PNW research program, the research described in this section focuses on ecological issues, specifically on improved approaches to monitoring ecosystems. We will not contribute directly to elements of an interagency plan to monitor social systems or administrative processes, except to the degree that ecological monitoring must account for these needs in its design.

Federal agencies, including EPA, have committed themselves to managing ecological resources of the Pacific Northwest using the adaptive management process (FEMAT 1993, USFS and BLM 1994a,b). This process is not new (Walters and Hilborn 1976, Grayson et al. 1994), although it has not been widely applied in this country. It is:

> "a process of action-based planning, monitoring, researching, evaluating, and adjusting with the objective of improving the implementation and achieving goals of the selected alternative ... The concept of adaptive management acknowledges the need to manage resources under circumstances that contain varying degrees of uncertainty, and the need to adjust to new information... Essential requirements for adaptive management include: clear goals, clear standards and guidelines, a process for changing standards and guidelines or goals, a monitoring and/or research program aimed at adaptive management questions" (USFS and BLM 1994a, p. E-13 - 14).

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[2] The scope of the RMC and the Ecosystem Monitoring Workgroup have not yet been finalized (as of 20 February 1995), in particular the degree to which the interagency monitoring plan will consider non-federal lands and monitoring for purposes other than those strictly defined in the President's Plan. The original intent was to include all stakeholders, including states, tribes, and other interested parties, in all major aspects of implementation of the President's Plan. However, given recent legal interpretations of the Federal Advisory Committee Act (Northwest Forest Resource Council vs. Espy 21 March 1994), the only tractable solution is to limit current coordination activities to federal agencies. We expect that some mechanism will eventually be established to allow for broader participation, but the specifics of this process are not yet clear.

Figure 1-4 underscores the central role that monitoring plays in the overall scheme of adaptive management. The needs of the adaptive management process are a major driving factor in the design of a cost-effective, policy-relevant monitoring program.

The policy community increasingly is recognizing that the questions they pose require information at multiple spatial scales (see Figure 3-15 and accompanying discussion). Although the specific management questions may change over time, the types of questions of interest can be categorized according to the temporal, spatial, and ecological scale at which they must be addressed. Issues of scale definition and role are not limited to monitoring. Ecologists and assessment analysts have concluded that the appropriate scale for analysis is tied to the question being asked and that there is no single proper scale of analysis for addressing all questions (Hirvonen 1992, Milne 1992). There is a continuum of temporal and spatial scales that could be relevant, depending on the question. FEMAT and the RMC use four: region, province, watershed, and site (see Section 1.3). For organizational purposes, we collapse this into three (region, watershed/ecoregion, and local/site), although research can occur at different scales within these three broad categories.

Both adaptive management and the nature of policy questions have important consequences for the design of a monitoring program. The monitoring program must consider the ecosystem management goals, recognize that they are subject to change over time, as policy and management questions change, and understand that monitoring information is needed at multiple temporal and spatial scales. The appropriate response is to define a set of relatively robust measurement endpoints, or indicators of ecosystem structure and functions at multiple scales, which provide insights relevant to a broad range of policy questions. This challenge is imposing. The monitoring program design (including information management and QA) must be robust and flexible enough to provide the information necessary to respond to current questions, while also envisioning and accommodating future policy and management questions.

8.2 OBJECTIVES

The major objectives of this research component are as follows:

- Identify the priority assessment questions for the Pacific Northwest that require monitoring information. Identify the ecological, spatial, and temporal scales at which each question must be addressed.
- Design elements of a fully integrated multi-scale ecological monitoring program for the Pacific Northwest.
- Demonstrate this integrated multi-scale ecological monitoring design in the Pacific Northwest.
- Involve authorities with the mandate and resources to implement a monitoring program during all stages of this monitoring design effort.

8.3 APPROACH

This section describes the approach we propose for achieving these objectives. We have organized our effort into four projects, which match the four objectives above, and a series of tasks under each project (Table 8-1). These projects and tasks may appear to be sequential, but this is not at all the case. For example, because the ultimate goal is to transfer the monitoring design to other organizations responsible for implementing monitoring, it is essential that these organizations be involved from the outset in developing the monitoring design (objective 4). Further, as discussed in Section 8.1, it is likely that the priority policy/management questions will change over time, necessitating additions to or alterations in the monitoring program. Thus, some attention must be given to designing a program that has flexibility, not only in the design stages, but also in the implementation stages.

Within the PNW research program, the assumed extramural budget for the Integrated Monitoring research component is $260K per year over five years (Table 2-1). Table 8-2 presents the proposed distribution of this extramural budget, by year, among the four projects/objectives. This table, however, does not fully describe the total effort that ORD will devote to these activities, including internal resources (e.g., travel and effort of federal personnel) as well as resources from other ORD programs, such as EMAP. Our approach will be to use the PNW budget to leverage, to the degree possible, the larger resources in EMAP and other monitoring programs, such as the USFS Forest Inventory Assessment Program and the National Resource Conservation Service (NRCS) National Resources Inventory. This is particularly true for objectives 3 and 4. Objective 4 (involvement of others) will require relatively little extramural funding, but substantial effort on the part of federal personnel assigned to the project. To accomplish objective 3 (monitoring demonstration), we will need to rely heavily on those programs that will eventually be responsible for monitoring implementation. The Integrated Monitoring component within the PNW research program is primarily a design effort, which will leverage the resources of other programs for some of its design activities and almost all of its demonstration activities. We discuss leverage opportunities we plan to explore in the subsections that follow on each project. Table 8-3 illustrates the diversity and relative magnitude of resources assumed by task and year.

Given this approach, coordination with other programs and organizations is essential for our success. Coordination with other federal agencies will occur through the RMC and its Monitoring Workgroup. Most of the activities proposed in this section are listed in the draft of the Monitoring Workgroup charter (RMC 1994). The Monitoring Workgroup will serve not only as a forum for coordinating projects already designed, but also as an information resource that will allow us to refine or redirect projects to fill important gaps left by others.

Table 8-1. List of Objectives (Projects) and Associated Tasks Proposed for the Integrated Monitoring Component of the PNW Research Program.

Objective/Project 1: Identify priority assessment questions and endpoints for the Pacific Northwest that require ecological monitoring. Task 1: Summarize the monitoring requirements of the existing FEMAT administrative record. Task 2: Establish a process to document users' and managers' needs for ecological information for the region now and as they evolve. Task 3: Support and participate in considering the ecological theory underlying ecosystem management and the requirements that these considerations impose on design of an integrated monitoring program. Task 4: Synthesize the previous tasks into a consolidated list of assessment endpoints, and specify the temporal and spatial scale relevant to each endpoint.
Objective/Project 2: Design elements of a fully integrated multi-scale ecological monitoring program for the Pacific Northwest. Task 5: Evaluate options for measurement endpoints. Task 6: Evaluate the merits of existing ecological monitoring programs within the region. Task 7A: Determine the requirements for an information management system and how these requirements influence the monitoring design. Task 7B: Determine requirements and formats for reporting monitoring results. Task 8: Develop options for the integrated monitoring design.
Objective/Project 3: Demonstrate and evaluate the proposed integrated monitoring design. Task 9: Conduct a monitoring demonstration project in one ecoregion in the Pacific Northwest.
Objective/Project 4: Involve other agencies and authorities at all stages. Task 10: Involve authorities with the mandate and resources to implement a monitoring program at all stages of the monitoring design and demonstration.

Table 8-2. Allocation of Extramural Funding for the PNW Integrated Monitoring Research Component by Objective and Fiscal Year (in Thousands of Dollars).

Objective	Fiscal Year				
	95	**96**	**97**	**98**	**99**
1. Question definition	105K	90K	80K	50K	50K
2. Monitoring designs	155K	170K	180K	210K	210K
3. Monitoring demonstration	0	0	0	0	0
4. Involvement of others	0	0	0	0	0
Total	260K	260K	260K	260K	260K

Table 8-3. The Nature and Magnitude of Resources Allocated to the Ten Monitoring Tasks over the Five-Year Research Strategy.

Objective	Task	Fiscal Year				
		95	**96**	**97**	**98**	**99**
1	1	$				
1	2	**$**	$	$	$	$
1	3	$	$			
1	4		**$**	$	$	$
2	5 – 8	**$**	**$**	**$**	**$**	**$**
3	9	X	X	X	X	X
4	10	P	P	P	P	P

Legend:

$	PNW extramural resources < $50K plus PNW personnel
$	PNW extramural resources > $50K plus PNW personnel
P	PNW personnel as a higher priority without extramural funding
X	Non-PNW extramural resources assumed along with PNW personnel
(Blank)	No significant amounts of personnel or extramural resources

The following subsections describe the nature and rationale for each project. More detail is provided for those tasks and projects that will be implemented earlier, because later tasks/projects depend on the outcomes of earlier tasks and projects.

8.3.1 Assessment Questions That Require Ecological Monitoring

Project-Level Objectives

- Summarize and categorize the monitoring requirements under FEMAT (task 1).
- Establish a process to document user and manager needs for large-scale, long-term ecological monitoring information in the Pacific Northwest, now and as they evolve (task 2).
- Participate in efforts to better define the ecological theory underlying adaptive ecosystem management, and the requirements that this management approach imposes on design of an integrated monitoring program (task 3).
- Develop a consolidated list of assessment endpoints that require ecological monitoring information, and the temporal and spatial scales relevant to each endpoint (task 4).

Approach

A monitoring program can be effectively designed only if the questions that it is to address are well defined (e.g. Landres 1992, Grayson et al. 1994, Hicks and Brydges 1994). Three inter-related types of information feed into delineating these questions and the approaches to addressing them: administrative requirements for monitoring, management issues and needs, and the scientific foundation for sound ecological monitoring. Tasks 1–3 address these three information sources. This information will then be synthesized into a consolidated list of priority assessment endpoints in task 4.

One important source of administrative requirements is the President's Forest Plan and the supporting documentation. The Record of Decision for the President's Plan is quite clear about the need for monitoring (see Box 8-A). The recent judicial ruling on the Forest Plan is equally clear about the need for monitoring:

> "The plan includes monitoring for implementation, verification as to results, and validation as to the underlying assumptions. The monitoring program is described above [in the Judges' ruling] in section V. As written it is legally sufficient. It remains, of course, to be carried out. Monitoring is essential to the plan's validity. If it is not funded, or not done for any reason, the plan will have to be reconsidered." (Dwyer 1994).

Box 8-A. Requirements for Monitoring in the Record of Decision for the President's Forest Plan.

Section IX.G. of the Record of Decision (pages 57 and 58) is the Section on Implementation of Monitoring.

"Monitoring is an essential component of the selected alternative. It ensures that management actions meet the prescribed standards and guidelines and that they comply with applicable laws and policies. Monitoring will provide information to determine if the standards and guidelines are being followed...verify if they are achieving the desired results..., and determine if underlying assumptions are sound...

Information obtained through monitoring, together with research and other new information, will provide a basis of adaptive management changes to the selected alternative, including changes to the Standards and Guidelines. In addition, the monitoring plan itself will not remain static, but will be evaluated periodically to ascertain whether the monitoring questions and standards remain relevant, and will be adjusted as appropriate.

Monitoring will be conducted at multiple levels and scales, ranging from site-specific projects to the planning area or region to allow localized information to be compiled and considered in a regional context. The monitoring plan provides standards that monitoring at any scale should meet in order to achieve this goal... Monitoring will be coordinated among agencies and organizations to enhance the effectiveness and usefulness of monitoring results.

Monitoring under the selected alternative will build on present monitoring efforts. Current monitoring efforts will continue where appropriate. Specific new monitoring protocols, criteria, goals, and reporting formats will also be developed."

Identifying the specific monitoring requirements is no small task, however, because of the extensive suite of documents appended to or referenced in that decision (e.g., appended Standard and Guidelines, USFS and BLM 1994a). The task is further complicated by the fact that many of the discussions of monitoring requirements are imprecise and require additional consideration before they can serve as the foundation for designing a monitoring program. Thus, **task 1** (see Table 8-1) will be to summarize and categorize the requirements and mandates for monitoring in the FEMAT documents. This activity will be fully coordinated with and largely implemented through the RMC, which lists development of such a document in the current draft of the charter for the Monitoring Workgroup (RMC 1994).

While the FEMAT process that resulted in the President's Plan was an intensive one, its boundaries were defined more narrowly than a regional-scale monitoring program should have to accommodate. The FEMAT process was restricted to federal lands within the range of the northern spotted owl and focuses on the need for habitat to sustain the northern spotted owl. Although FEMAT documents contain extensive discussion of other elements of the ecosystem, including aquatic ecosystems, and a list of over 400 plant and animal species whose sustained viability is uncertain, these elements are not as well developed. Ecosystems on federal and nonfederal lands in the region interact to provide valued ecosystem functions.

Thus, monitoring in support of ecosystem management within the Pacific Northwest (even just on federal lands) must account for and reflect ecosystems in the region as a whole. In addition, FEMAT documents represent the conclusions of one important set of resource managers and stakeholders at one point in time. Information must also be collected in a formal way on how these (and other) users' needs are changing and how users think their needs may change (e.g., Smith 1994) over the next decade and century, so that a monitoring program can attempt to anticipate and support these long-term needs.

Task 2 establishes a process that queries managers and other monitoring data users on their needs for, or decisions requiring, ecological monitoring information for the region as a whole. We will begin by identifying and classifying potential users and decision makers. Their views will be sought through direct interviews. Consistent with the geographic focus of other elements of this research program, this effort will focus on collecting information on monitoring needs in the two case study areas. To add another perspective to these findings and to provide some validation of responses, the survey will contain a retrospective element asking decision makers and decision influencers how they have used information from monitoring programs in past decisions. Both of these components (the prospective part dealing with future decisions and the retrospective part dealing with past decisions) will query potential users of monitoring information with respect to the value of a range of reporting approaches.

Thus, tasks 1 and 2 collectively summarize the user needs for information that can be provided by a monitoring program. Task 1 summarizes the needs of the existing FEMAT administrative record. Task 2 expands this to a broader user group and includes both administrative needs of this group as well as more general information needs that should lead to improved management decision making.

A clear statement of user needs is critical, but it is not the only foundation for a monitoring program. The monitoring design must also be based on sound ecological principles and an understanding of ecosystems and the scientific foundation of ecosystem management (White et al. 1989, Slocombe 1992, Barber 1994). Other components of the PNW research program will contribute to this science base. In addition, several broad-based and respected organizations (e.g., National Research Council 1994, Sustainable Biosphere Initiative 1994) have initiated theoretically based inquiries into the science of ecosystem management and how best to monitor ecosystems within a region. Connections to these theoretical inquiries can help ensure that the PNW monitoring design reflects current ecological thinking and that there is an appropriate level of communication between the application requirements of the monitoring program and theoretical advances in ecological science.

Thus, we propose in **task 3** to participate in and provide support for broad theoretical considerations of ecosystem management, particularly the role of monitoring and design of integrated monitoring programs.

Several issues fall under this heading. For example, what constitutes a regionally integrated monitoring system and how should we design it? Large-scale ecological monitoring programs (e.g., EMAP, USFS National Forest Inventory Assessment, NOAA's Coastal Watch Program) have tended to concentrate on individual ecosystem types rather than regional or landscape issues. They are designed to assess the status of a single ecosystem type rather than the status of ecosystems and ecological resources in a region as a whole. While differences between these two approaches may be subtle, ecosystem-specific monitoring may not adequately address questions for which connectivity among ecosystem types is important. For example, an important question for estuaries is the amount of sediment loading from the upland watershed. An estuarine program can monitor the sediment content of waters flowing into the estuary. However, without some explicit consideration of regional and landscape issues, it is unlikely that a terrestrial monitoring program would monitor soils and other watershed features in a manner that would be helpful in an assessment of estuarine status. This is more than an issue of measuring parameters in one ecosystem or component of the landscape that might be relevant to other ecosystems or components. Some multi-ecosystem landscape features are important to ecological functions of the region and can only be observed or measured at a larger spatial scale than that examined in most ecosystem-specific monitoring programs (e.g., Omernik et al. 1981, Hansen et al. 1991, Gosz et al. 1992, Hirvonen 1992, Hunsacker et al. 1992, O'Neill et al. 1992, Pulliam et al. 1992, Slocombe 1992). In this task we intend to define issues such as this from a broad theoretical perspective.

Task 3 will be implemented by sponsoring the development of a series of white papers prepared by ecologists whose research has emphasized theoretical issues. These papers will be presented and discussed at a workshop attended by ecologists having both theoretical and applied interests. The authors will be provided with information on the broad nature of the issues in the Pacific Northwest and asked to focus their papers on this region, but not to the exclusion of considering multi-scale ecological monitoring in general.

Tasks 1–3 will provide the foundation for designing an integrated monitoring program that is responsive to the requirements of FEMAT, consistent with ecological theory, and tied to user and management needs of the region as a whole, now and in the future. **Task 4** will integrate the information from tasks 1–3 into a common set of priority assessment questions and design constraints for the region. We will consolidate the information from tasks 1–3, identify the ecological spatial and temporal scales at which each assessment question must be addressed, and evaluate how robust the collection of assessment endpoints is likely to be in the face of changes in policy and management issues over time. The assessment questions and input from users must be specific enough to guide the monitoring design. For example, how confident and precise must answers and monitoring information be to satisfy the requirements of users and management decision makers? The product from task 4 will be realistic, ecologically meaningful, policy-relevant, quantitative statements that can serve as a foundation for rigorous design of a monitoring program.

8.3.2 Integrated Monitoring Design

The purpose of this project is to work with other organizations to design an overall integrated monitoring program and to design key elements of the program.

Project-Level Objective

Contribute to the design elements of an integrated ecological monitoring program, including:

- Measurement endpoint evaluation (task 5).
- Evaluations of existing monitoring programs (task 6).
- Consideration of the methods of data management and reporting (task 7).
- Integrated design (task 8).

Approach

Development of an integrated monitoring design will be an iterative, collaborative process, as follows: (1) collaborate with other agencies and organizations to define an overall strategy for an integrated design, (2) identify pieces of this design for which we will take responsibility, and (3) return, on an incremental basis, to the interagency process to ensure that the pieces that we and others design are consistent with the continued evolution of the overall design. Interagency cooperation on the overall design strategy is essential to ensure common, consistent, and interactive methods and protocols and to provide a mechanism for coordinating not only the design but also field investigations, demonstrations, and eventually implementation. In this section, we discuss four specific tasks (5–8), all of which are important. However, the exact role and level of effort we will apply to any of these tasks will reflect the results of our participation in this interagency forum.

Outputs from tasks 1–4 set the design requirements for an integrated monitoring program by identifying the assessment questions and endpoints that ecological monitoring in the region must address. However, as discussed in Section 3, assessment endpoints are not necessarily the features of an ecosystem we would be wisest to measure, either because they cannot be measured directly or because other endpoints provide a more tractable or cost-effective approach. Thus, the objective of **task 5** is to identify options for measurement endpoints (i.e., ecological indicators) for each assessment endpoint.

As part of this activity, we must define the relationship between measurement and assessment endpoints and how each measurement endpoint, or set of measurement endpoints, will be used to evaluate an assessment endpoint. Water temperature is an appropriate measurement endpoint related to habitat quality for salmonids. However, what do we need to know about water temperature to assess habitat quality? For example, should we know the annual average temperature, temperatures during a particular season, maximum or minimum temperatures? How accurately and precisely must temperature be measured? Should we measure it within ±0.1° C or ±1.0° C, or just determine whether it is above or below some threshold temperature? Answers to these simple questions have considerable bearing on the cost and feasibility of the monitoring program, as well as on the use of the data. For each measurement endpoint, we must establish data quality objectives that reflect the needs of the ultimate users of the monitoring results (see Section 8.3.1).

The identification of measurement endpoints may be trivially easy in some cases. In other cases, it may be quite difficult, requiring pilot studies to develop or evaluate the merits of alternative measurement endpoints. The PNW research program will work with other parts of ORD, especially EMAP, and with other agencies to partition the effort required to identify and evaluate the available options. The types of activities that may be involved include analyses of existing indicator data and sampling efforts; evaluation of the use, classification, and accuracy (through groundtruthing) of remote sensing data; short-term field projects; studies evaluating the use of volunteers for field sampling; and statistical or sampling methods development projects. EMAP has spent considerable effort on designing a process to identify, consider, test, and select indicators (Hunsacker and Carpenter 1990, Hunsacker 1991, Barber 1994). We intend to build on this expertise and work closely with EMAP on this effort.

For any ecosystem and assessment endpoint, there are numerous individual candidate measurement endpoints or indicators. Criteria for evaluating individual endpoints include: linkage to the ecosystem conceptual model or ecosystem functions, variability, uncertainty, usability, cost-effectiveness, responsiveness to stressors, the possibility for measurement through time, public value and clarity, scientific credibility, technical feasibility, temporal linkage to stressors, spatial representation, environmental impact associated with sampling, and identifiable threshold levels (White et al. 1989, Bruns et al. 1992, Hirvonen 1992, Landres 1992, Barber 1994).

FEMAT commitments, as well as common sense, require that new federal monitoring programs be built, to the degree possible, on existing programs (see Box 8-A, paragraph 4). The objective of **task 6**, therefore, is to review the characteristics of existing monitoring programs relative to the assessment questions, endpoints, and design criteria developed in tasks 1–5. The RMC has commissioned an initial effort in this direction, for monitoring activities on federal lands. A parallel effort is needed for monitoring on nonfederal lands. The purpose is not to criticize any one program, but instead to identify (1) any current monitoring objectives, (2) the magnitude of the resources currently engaged in monitoring in the region, (3) duplications and inefficiencies in the combined monitoring activities, which, if eliminated, could lead to cost savings, (4) gaps, that is, monitoring information needs identified in tasks 1–4 that are not currently being filled by existing monitoring programs, and (5) monitoring designs used in existing programs that may be particularly effective as part of an overall integrated ecological monitoring system.

The database and monitoring reports are usually considered end products of a monitoring program. We believe, however, that these products need to be given careful consideration early on during the design phase. Thus, **tasks 7A and 7B** define the requirements for an information management system and effective reporting, respectively.

One lesson of the FEMAT process is that data must be widely available to all interested parties. Monitoring data must be accessible in a user-friendly and documented information management system. This is an especially challenging task, because monitoring data will be collected by a large number of different organizations. The intent is to develop a region-wide information management system through which the user can access, relate, and analyze all relevant ecological monitoring data for the Pacific Northwest. As part of FEMAT, the Interagency Resource Information Coordination Council (IRICC) was established and has begun evaluating methods for coordinating, linking, and sharing data among federal agencies. EMAP also has substantial experience in the design of complex information management systems. We will draw on the IRICC, EMAP, and others to establish appropriate requirements for an information management system for a multi-scale, multi-organization, integrated, ecological monitoring system. The IRICC will also be involved, in some manner, in the design and implementation of the information management system. It is not yet clear, however, to what degree IRICC will provide information management support for region-wide ecosystem information beyond that specific to implementing the President's Plan.

Full monitoring reports will not occur within the five-year time frame of this document, but some attention must be given to long-term reporting formats and requirements to ensure that the monitoring program and information management system will effectively support these outputs. Initiation of this task (7B) must await identification of the assessment questions and endpoints in task 4 and measurement endpoints in task 5. However, elements of task 2 will provide significant, although preliminary, insight into task 7B.

Task 8, then, will develop design options for an integrated monitoring program based on the information generated from all prior tasks. A key issue is integration. In what ways will the monitoring program be integrated? We propose four types of integration: spatial, temporal, ecological, and organizational.[3] Spatial integration refers to integration across multiple spatial scales; in FEMAT, it means relating the monitoring data collected (and types of data typically collected) at a regional scale, at the province or basin level, within a given watershed, and at individual sites. The monitoring design must also incorporate and integrate monitoring data of varying temporal frequency and duration. Temporal and spatial scales are often correlated. Site-specific monitoring may involve relatively frequent measurements (e.g., seasonal) but for a limited duration, to address a specific management question, such as the effectiveness of a restoration project. Regional monitoring, in contrast, may be done annually or once every 5–10 years to detect long-term trends. Ecological integration reflects the need to understand interactions among ecosystem components (e.g., between forests and estuaries or forests and the atmosphere); ecosystem management explicitly recognizes these interdependencies and the linkages and trade-offs among ecosystem components (Section 1.1). Finally, organizational integration refers to the fact that monitoring in the Pacific Northwest will be conducted by a number of different agencies and organizations, each with its own objectives and methods. We want to integrate these efforts, and the monitoring data, into a usable region-wide system (Hicks and Brydges 1994, Ward 1991).

Each level within the spatial, temporal, ecological, and organizational framework for monitoring has its own set of assessment questions. For example, some important assessment questions deal with the status of an individual water body at a particular location monitored by a municipality under its NPDES permit issued by the state and overseen by the EPA regional office. Other important assessment questions concern regional patterns and trends. A major challenge for the monitoring design is to develop ways in which site- and issue-specific monitoring can contribute to evaluation of regional patterns and trends, and vice versa. In an integrated design, each component builds on the others.

We envision that development of these design options will be a collaborative effort involving a number of federal and state agencies along with outside experts in ecosystems, ecological monitoring, and statistical sampling design. The EMAP Statistics and Design Program is managed at ERL-Corvallis, which will facilitate interaction with individuals working on similar issues within EMAP. Statistical analyses will be conducted to evaluate the temporal and spatial requirements and scales of candidate measurement end-points. Besides integrating across spatial, temporal, ecological, and organizational elements, the design must also provide monitoring data and results that are of known quality and responsive to the user needs and data quality objectives defined in tasks 1–5.

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[3] The ecological component itself must further be nested or integrated within a system that accommodates other disciplines such as the social sciences (Ward 1991). As noted earlier, however, EPA/ORD will limit itself to ensuring that the linkages and integration are possible. We do not have the resources or the mandate to develop these areas.

8.3.3 Monitoring Demonstration

Project-Level Objective

- Demonstrate and evaluate the integrated monitoring design (task 9).

Approach

In **task 9**, we will demonstrate the integrated, multi-scale ecological monitoring design in one ecoregion in the Pacific Northwest. Criteria to be considered in selection of this ecoregion will include (1) diversity of land ownership, cover, and use, (2) existing information and monitoring programs in the area, and (3) management needs for the data generated from the demonstration. Our preference is to conduct the monitoring demonstration in one of the two watershed/ecoregion case study areas selected for the PNW research program (Section 5), to contribute to assessment demonstrations proposed for those areas.

This demonstration will be executed in partnership with other research and monitoring organizations, both in and out of the federal government. The current draft of the charter for the RMC Monitoring Workgroup indicates that a fully integrated monitoring demonstration is slated for FY97. While the work of this group is oriented towards implementing the President's Plan, this schedule is also appropriate for demonstrating a fully integrated monitoring program for the issues and lands of the region as a whole. The results of the demonstration activity will be used to modify the monitoring design, that is, to revisit task 8 based on experiences in the demonstration study.

The PNW research program does not have the resources to conduct this demonstration. We expect that EMAP resources will be available for this demonstration, as well as resources from other organizations with monitoring responsibilities. EMAP sampling is scheduled for this region in FY95 and beyond. The extent to which current plans for EMAP sampling would need to be modified to meet the needs of the PNW monitoring demonstration is not yet clear, but will become evident as tasks 1–8 progress.

8.3.4 Broad Involvement

Project-Level Objective

- Involve those authorities and organizations with the mandate and resources to implement monitoring at all stages of the program design and demonstration (task 10).

Approach

The ultimate objective of this entire effort is to transfer the knowledge gained in these projects to authorities with the mandate and resources to implement an integrated monitoring program. Thus, involving them at all stages is more a guiding principle then a specific project or task. These authorities include states, counties, municipalities, and tribes within the Pacific Northwest; the operational arms (as opposed to the research arms) of federal agencies, such as USFS, BLM, National Park Service, NOAA's National Ocean Service (particularly the Office of Coastal Zone Management), National Marine Fisheries Service, EPA Region 10, and others. This liaison must start at the outset of the research program to ensure that we fully account for the capabilities and interests of these authorities. Task 2 is designed to identify the needs of these groups and to help substantively involve them in the monitoring design and demonstration. The activities and collaborative projects proposed under Technology Transfer (Section 10) may also encourage greater and sustained involvement.

8.4 MAJOR CONTRIBUTIONS

Proposed research under the Integrated Monitoring component of the PNW research program will provide the following, selected major contributions:

- Summary of the monitoring requirements of the President's Forest Plan.
- Analysis of the theoretical need for and character of ecological monitoring within the context of ecosystem management and its specific implications for monitoring in the Pacific Northwest.
- Synthesis of user needs for ecological monitoring in the Pacific Northwest.
- Proposal for elements of a fully integrated multi-scale ecological monitoring program in the Pacific Northwest; contributions to the overall design.
- Results from demonstration of a fully integrated multi-scale ecological monitoring program in an ecoregion of the Pacific Northwest, that will contribute to addressing priority assessment questions for that area.

9. ECOLOGICAL–SOCIOECONOMIC LINKAGES

As discussed in Section 1, the goal of ecosystem management is to maintain both healthy, sustainable ecosystems and healthy, sustainable economies and local communities (Interagency Ecosystem Management Task Force 1994). Social, economic, and ecological factors all must be considered in management decisions. Our research program will contribute ecological information to aid decision makers. To be of maximum use, this ecological information must be in a form that integrates well with matching information on social and economic concerns. This section outlines our proposed approach to make those linkages. The assumed budget for this effort is approximately $88K per year.

9.1 BACKGROUND

The traditional approach to combining ecological and economic information for decision makers is cost-benefit analysis; economic and ecosystem values are compared by expressing them in a common unit, namely dollars. Research efforts have focused on estimating the total economic value (TEV) of environmental assets, in particular the dollar value associated with nonmarket and non-use ecosystem values, such as recreation, aesthetics, cultural values, existence values, and bequest values (Peterson and Sorg 1987, Randall 1991). Methods commonly used include indirect approaches, which rely on observed behavior to infer values (e.g., the travel cost model and hedonic pricing methods), and direct approaches, which use surveys to directly elicit information on "willingness-to-pay" or "willingness-to-accept" compensation (Braden and Kolstad 1991). The most common direct approach is contingent valuation (CV), which has been widely applied but remains controversial, especially CV estimates of non-use values (Bishop and Welsh 1992, Edwards 1992, Kopp 1992, Rosenthal and Nelson 1992, Arrow et al. 1993, Hausman 1993). Examples of ecosystem valuation studies conducted in the Pacific Northwest, for both nonmarket use and non-use values, include Johnson and Adams (1989), Donnelly et al. (1990), Johnson et al. (1990), Morey et al. (1991), Rubin et al. (1991), Hagen et al. (1992), Olsen et al. (1992), Berrens et al. (1993), and Fried (1993).

It is clear that information on how society values ecosystems is critical to ecosystem management decisions. EPA's Science Advisory Board recommended that "EPA should develop improved methods to value natural resources and to account for long-term environmental effects in its economic analysis" (SAB 1990). In response, the EPA Office of Policy, Planning and Evaluation (OPPE) formed the Ecosystem Valuation Forum to advance the state of art of ecosystem valuation (Bingham et al. 1995). Based on the Forum's recommendations, OPPE has initiated a series of case studies on ecosystem valuation and economic-ecological interactions.

Cost-benefit analysis, however, is a very simplified approach to combining ecological and economic information. It is unrealistic to assume that social choices can be expressed as neatly as a ratio of total costs to total benefits, especially given the large uncertainty and controversy associated with dollar estimates of ecosystem values.

> "...[T]hose social values for which our ability to define and measure is poorest are the very ones that appear to be of increasing importance in our society" (FEMAT 1993, p. II-64).

Thus, while ecosystem valuation is an interesting and important area of research, it is by no means the only research need.

Ecological economics is a relatively new field of study that focuses on the interactions between ecological and economic systems (Costanza 1992). Its basic premise is that ecosystems and the economy cannot and should not be analyzed and managed as separate systems. Ecological research, as proposed in the PNW research program, evaluates the effects of human activities (stressors and management actions) on ecosystems. Ecological economics considers not only how ecosystems respond to human activities, but also how ecosystems (and ecosystem conditions) affect human behavior and welfare, and the inter-dependence of long-term economic health and ecosystem health. In addition to ecosystem valuation, areas of research include integrated ecological-economic models (Russell 1993, Bockstael et al. 1994) and the concept of *minimum natural capital stock* (the minimum biological and physical conditions that describe a sustainable ecological path) and its application in economic analyses (Pearce and Turner 1990, Common and Perrings 1992).

To succeed, a management program must be not only ecologically sustainable and economically feasible, but also socially acceptable (Firey 1960). Social assessments consider public perceptions of risks, as well as expected effects on the broad concept of social well-being. For example, FEMAT (1993) discusses the potential effects of forest management options on the social fabric of local communities, social continuity, and cultural heritage. Like economic analyses, social analyses often evaluate the relative value society places on various ecosystem functions, although these analyses use public opinion surveys (e.g., Dunlop 1991) rather than attempting to quantify social values in dollars using CV or other similar techniques.

9.2 OBJECTIVES

Our objectives are relatively modest:

- Participate in developing an assessment framework and process that integrates ecological, economic, and social information into a form useful for decision makers.

- Ensure that the ecological research we conduct provides the types of ecological information needed for economic and social assessments in the Pacific Northwest.

9.3 APPROACH

We are not experts in social or economic sciences and we do not propose to conduct or fund social or economic research per se. Rather, our approach emphasizes education, communication, and interdisciplinary projects.

We want to conduct ecological research that provides the types of ecological information needed for economic and social analyses. To do so, we must better understand economic and social assessment approaches. We believe that the best way to achieve this is through joint projects, in which we work closely with one or more economists or social scientists who use our ecological data for their economic or social research or assessment. We also believe it is important for this research to occur on site, at ERL-Corvallis or ERL-Newport, to increase the interactions and communication between PNW research ecologists and economists and social scientists. In this case, the interactive research process itself is as important, or more so, than the research results.

Thus, we propose to use the National Research Council (NRC) Associateship Program to fund economists or social scientists to work at ERL-Corvallis or ERL-Newport for periods of one to two years. Positions will be announced and competed nationally. The NRC associate (post-doctoral or senior associate) will be required to conduct innovative economic or social research that uses our ecological data and contributes directly to one or more of the case study assessments described in Sections 4 and 5. The exact nature of the economic and social research, and the technical approach, will depend on the expertise and interests of the NRC associate. By funding several NRC associates over the next five years, we will be exposed to a variety of economic and social assessment approaches.

In addition to their own research interests, NRC associates (together with ecologists in the PNW research program) will participate in developing an overall assessment framework to integrate ecological, economic, and social information for decision makers. This effort will be conducted jointly with the EPA Ecosystem Valuation Forum or another relevant, existing work group. We anticipate funding seminars and several workshops or symposia on the topic, plus associated journal papers. Participation of NRC associates, and other interested economists and social scientists, in the assessment demonstrations discussed in Sections 4 and 5 will provide one means of evaluating and refining the proposed assessment approach.

Assessments are designed to help decision makers. Thus, another research area of interest is policy and decision analysis. By working closely with experts in policy or decision analysis, we may improve our ability to provide ecological information of the type and format most useful for management decisions. Thus, we will also consider funding one or more policy or decision analysts through the NRC Associateship Program to work at ERL-Corvallis or ERL-Newport for one to two years. We are particularly interested in policy and decision analysts with experience at state and local levels. The objectives will be to improve our assessment approach, the presentation and communication of assessment results, and the decision support systems discussed in Section 5.3.

9.4 MAJOR CONTRIBUTIONS

The major contributions expected to result from this research component are as follows:

- Assessment framework for synthesizing and integrating ecological, economic, and social information for decision makers.

- Two or more joint ecological-socioeconomic projects, in which the ecological data generated by the PNW research program are used to address economic and social issues relevant to ecosystem management in the Pacific Northwest.

- Improved ability to communicate useful results from ecological assessments to policy makers and managers.

10. TECHNOLOGY TRANSFER

This section describes Technology Transfer, the final component of the PNW research program. The principles of technology transfer are integral to all components of the program, but will be organized and enhanced by the activities outlined here. The assumed budget for projects targeted specifically at technology transfer is $215K per year over five years.

10.1 BACKGROUND

Technical information transfer does not occur automatically, but requires, or at least benefits from, focused effort and approaches. Technical information will spread only if it is first transmitted from its innovator to a receptive expert within an identified user group (Muth and Hendee 1980). Traditional approaches to technology transfer, such as publications and symposia, can successfully generate awareness and interest, but often they do not lead to the trial and adoption of technical innovations. Only by actively involving environmental managers in the process of research planning and demonstration can we significantly increase the likelihood that information and approaches we develop will become widely used.

Our approach to technology transfer is modeled after a similar effort within the Wetlands Research Program at ERL-Corvallis (see Leibowitz et al. 1992a). Since 1988, the procedures outlined here have resulted in the successful transfer of wetland evaluation and restoration approaches to both EPA regional offices and state agencies. For the PNW research program, we propose to extend this outreach to include local organizations, such as watershed councils and county/tribal governments, as well as EPA regions and states. Local outreach efforts will concentrate in, but not be limited to, the watershed/ecoregion case study areas (Willamette River Basin and Washington Coastal Ecoregion). The development of local working partnerships is an operational theme of both EPA's watershed protection approach and ecosystem management.

10.2 OBJECTIVES

We have two major objectives:

- Ensure through feedback from managers that PNW research is relevant to policy and management needs.
- Ensure that the innovations, information, and approaches we develop are adopted and widely used by environmental managers at regional, state, and local levels.

10.3 APPROACH

Sections 10.3.1–10.3.2 discuss the three key components of our strategy for technology transfer: effective communication, collaborative research projects, and dissemination of research results.

10.3.1 Communication

The first key component of technology transfer is two-way communication. Environmental managers must tell us their objectives, needs, and constraints. We must communicate our findings back to these managers in a form that they can readily understand and use. As described in Sections 2, 3, and 5, we anticipate having regular meetings and information exchanges with interested environmental managers working directly with us on our case study assessments.

We have also enlisted the help of a regional liaison to foster more direct communication between PNW researchers and environmental managers. A regional liaison is an EPA regional manager assigned to an ORD research laboratory. Specifically, the regional liaison assigned to ERL-Corvallis in 1988 to work with the Wetlands Research Program will now serve in the same capacity for the PNW research program. The responsibilities of the PNW regional liaison include the following:

- Help identify the technical needs of EPA Region 10, the states (Oregon, Washington, and Idaho), tribes, and local governments that are consistent with the goal and objectives of the PNW research program.
- Work to ensure that PNW projects address these priority technical needs to the degree possible within the constraints of the mandate and budget of the PNW research program.
- Encourage and coordinate the implementation of collaborative projects, involving shared expertise from both the PNW research program and EPA region, state, tribal, or local organizations.
- Involve EPA Region 10 staff from the beginning of the research process to the end, to ensure ownership and to further technology transfer through direct participation in the research process.
- Keep other EPA regional offices apprised of the results of PNW research and its applicability to their parts of the country.
- Identify state, tribal, and local organizations who are interested in innovations and piloting research.
- Distribute information on PNW projects and results to interested agencies, organizations, and individuals.

10.3.2 Collaborative Research Projects

Collaborative research projects, in which environmental managers work directly with PNW researchers, will be an important feature of the PNW strategy for technology transfer. Thus, one of the primary responsibilities of the regional liaison is to identify and act upon opportunities for PNW researchers to conduct studies that are relevant to the research program and that also support the more immediate needs of state, tribal, and local environmental managers. Our operating premise is that science is best introduced to environmental managers in the form of simple protocols, logic flows, and rules of thumb (Hirsch 1988).

Besides providing technical consultation to environmental managers, collaborative projects will be designed to serve two other important purposes. First, collaborative efforts will provide a forum for PNW researchers to receive feedback on the relevance of their proposed research, in particular the feasibility of proposed approaches, given the time and information demands typically associated with decision making in the public interest. Second, collaborative projects will directly involve environmental managers in the development of new science and innovations. The collaboration cultivates a sense of partnership, thereby increasing the likelihood that new innovations will be adopted and used in other situations and by other managers.

One or more collaborative projects will be funded in each year of the research program. A plan for selecting and implementing these projects is currently being developed by the regional liaison, in cooperation with EPA Region 10. The plan will include provisions for (1) establishing an EPA regional research committee, (2) developing collaborative project selection criteria, (3) soliciting proposals for collaborative projects, and (4) ranking, selecting, and implementing these studies.

The regional liaison will have an annual budget of about $215,000. These funds will be used as an incentive for PNW participation in scientific studies that directly advance the concepts of ecosystem management. Technology Transfer projects will build upon the research described in Sections 4–9, which deal more directly with the fundamental scientific objectives of the Program. For example, a collaborative project may be tiered onto a research project funded by the Riparian Area research component to specifically address a locally identified management question. Or, a collaborative study may address the extrapolation of PNW findings and approaches to management questions in other areas of the Pacific Northwest or even elsewhere in the country.

The actual allocation of funds for collaborative studies will usually be based upon a competitive solicitation of project proposals. The solicitation will be developed for a study within a particular geographical area. Its objectives will reflect the desires of EPA Region 10 staff and their colleagues within the states, consistent with the PNW Research Strategy. Proposals received from the solicitation will be evaluated based upon the respondents' local knowledge of ecological resources and their past experience in successfully working with local authorities and interest groups on related issues.

10.3.3 Dissemination of Research Results

The dissemination of our research results to a broad audience of managers and other interested parties is another important component of technology transfer. A major mechanism for this communication will be an informal PNW research update, distributed once or twice a year. This report will provide a brief overview of ongoing PNW research activities, the names of project scientists, conclusions from recently completed studies, and a list of recent publications available upon request. Interested representatives from EPA regions and program offices, other federal agencies, states, tribes, local governments, private organizations, and individuals will be included on the mailing list. Copies of all PNW research reports and publications also will be transmitted by the regional liaison to EPA Region 10 and appropriate state representatives.

No formal training programs are planned at this time. However, the regional liaison will organize periodic informal workshops within the region to discuss the research program, research findings, and future directions.

It is also important that the PNW research program provide visible and highly credible information to other researchers in the scientific community. PNW research results will be published regularly in peer-reviewed scientific journals and presented at regional and national symposia. Previous sections discuss plans for involvement in interagency coordinating committees and cooperative research with other agencies and research programs.

10.4 MAJOR CONTRIBUTIONS

Major contributions of the Technology Transfer component of the PNW research program will include the following:

- Research updates distributed annually or twice a year to all interested agencies, organizations, and individuals.
- Results from collaborative research projects that (1) demonstrate the application of PNW approaches to a variety of real-world management questions and (2) address more immediate management needs in the region.
- Guidance manuals, as appropriate, that describe procedures for applying PNW approaches in a format that facilitates their broad use.

11. EXPECTED OUTPUTS AND SCHEDULE

Sections 4–10 discuss expected timelines and contributions for each component of the PNW research program. We do not repeat that detail here, but instead provide a summary of the major deliverables planned and the expected year of completion. Each of these deliverables will be supported by numerous scientific papers published in peer-reviewed journals. Deliverables are organized by year, with the responsible research component noted in parentheses:

1995:

- Characterization of the extent, condition, and stressors of riparian areas in agricultural landscapes of the case study areas (Riparian Area)
- Summary of promising "eco-opportunities" for riparian areas in the Pacific Northwest (Riparian Area)
- Review of toxic algal blooms in the Pacific Northwest (Coastal Estuaries)
- Tidal-based circulation models for target estuaries (Coastal Estuaries)

1996:

- Biodiversity atlas for Oregon (Regional Biodiversity)
- Initial assessment of primary concerns and research needs for Willamette Watershed and Washington Coastal Ecoregion (Watershed/Ecoregion)
- Determination of landscape-level relationships between agriculture and riparian area condition (Riparian Area)
- Assessment of historic sedimentation rates in target estuaries (Coastal Estuaries)
- Synthesis of user needs and science requirements for ecological monitoring in the Pacific Northwest (Monitoring)

1997:

- Multi-scale biodiversity conservation: A prototype process for Oregon (Regional Biodiversity)
- Comprehensive evaluation of regional biodiversity analyses to date with recommendations on more promising future research directions (Regional Biodiversity)
- Quantification of the influence of riparian areas on improving water quality in grass seed agricultural lands (Riparian Area)
- Determination of major processes controlling water quality in grass seed agriculture-riparian area complexes (Riparian Area)
- Indicators of aquatic and terrestrial riparian habitat condition in agricultural settings (Riparian Area)
- Reference conditions, approaches, and performance criteria for restoration of degraded riparian areas in agricultural settings (Riparian Area)

- Models predicting estuary benthic ecosystem functions from cost-effective habitat sampling methods (Coastal Estuaries)
- Proposal for a fully integrated multi-scale ecological monitoring program in the Pacific Northwest (Monitoring)

1998:

- Biodiversity pattern assessment for Washington (Regional Biodiversity)
- Biodiversity pattern assessment for Idaho (Regional Biodiversity)
- Assessment of the relative ecosystem impacts of the expansion of introduced *Spartina* in Willapa Bay versus chemical control measures (Coastal Estuaries)
- Assessment of the loadings and nutrients from watershed and marine inputs into Willapa Bay and ecosystem effects on key ecosystem functions (Coastal Estuaries)

1999:

- Models and decision support systems that can be applied with reasonable effort and data to evaluate the ecological consequences and trade-offs among management strategies (Watershed/Ecoregion)
- Landscape classification systems for extrapolating site-specific research findings to other similar sites and for organizing information about landscape functions, responses to stressors, and restoration potential, in a manner that makes it readily accessible to managers (Watershed/Ecoregion)
- Integrated assessment of the Willamette Watershed and Washington Coastal Ecoregion that defines tools and their application for uses in watershed/ecoregion assessments (Watershed/Ecoregion)
- Approaches to evaluate riparian area condition, restoration potential, attainable quality, and priority restoration locations within mixed landuse watersheds (Riparian Area)
- Integrated ecosystem assessment of Willapa Bay (Coastal Estuaries)
- Results from demonstration of a fully integrated multi-scale ecological monitoring program in an ecoregion of the Pacific Northwest, which will contribute to addressing priority assessment questions for that area (Monitoring)

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