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Ecological Research Strategy

Ecosystem interrelationships are critical considerations for managing surface water quality
"Salmon Leaping" photo by: Kennan Ward ©1998

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Foreword

The 1996 *Strategic Plan for the Office of Research and Development* (ORD) sets forth ORD's vision, mission, and long-term research goals. As part of this strategic process, ORD used the risk paradigm to identify EPA's top research priorities for the next several years. The ORD Strategic Plan thus serves as the foundation for the research strategies and research plans that ORD has developed, or is in the process of developing, to identify and describe individual high-priority research topics. One of these high-priority research topics is ecological risk assessment.

ORD prepared the *Ecological Research Strategy* in early 1997 and subjected it to an internal review by the ORD Science Council, the Program Offices within EPA, and representatives of other agencies through the Committee on Environment and Natural Resources. The outcome of this review is a strategy that establishes EPA's long-term Program goals and objectives for ecological research, and documents the rationale for the chosen Program direction.

A research strategy is different from a research plan. While a *research plan* defines the research program that EPA is pursuing, a *research strategy* provides the framework for making and explaining decisions about program purpose and direction as well as relative priorities and research distributions. The research strategy, as an overarching view of research needs and priorities, thus forms the basis for the research plan and provides a link between the ORD Strategic Plan and the individual research plan. In turn, the research plan links the research strategy to individual laboratory implementation plans (which serve as the blueprints for work at ORD's national laboratories and centers) by defining the research topic at the project level.

The key scientific questions this strategy sets out to address are:

- What is the current condition of the environment, and what stressors most significantly affect its condition?
- What are the biological, chemical, and physical processes affecting the exposure and response of ecosystems to stressors?
- What is the relative risk posed to ecosystems by these stressors, alone and in combination, now and in the future?
- What options are available to manage ecological risk or restore degraded ecosystems?

To answer these questions, this strategy groups its research priorities into the following four areas: (1) ecosystem monitoring, (2) ecological processes and modeling, (3) ecological risk assessment, and (4) ecological risk management and restoration.

This research strategy is an important tool for measuring accountability because it makes clear the rationale for, and the intended products of, EPA's ecological research. By specifying up front how EPA will manage its scientific data and information products, EPA can effectively communicate the results of its ecological research to its clients, stakeholders, and the public. This research strategy is also an important budget tool, enabling EPA to clearly track progress toward achieving its research goals as required by the 1993 Government Performance and Results Act.

Lawrence W. Reiter, Ph.D.
Acting Deputy Assistant Administrator for Science, ORD

Peer Review

Peer review is an important component of all research activities in ORD. In July 1997, the *Ecological Research Strategy* was provided to EPA's Science Advisory Board (SAB) Ecological Processes and Effects Committee, an independent panel of qualified experts. The results of that review were submitted directly to the EPA Administrator in December 1997, and the strategy was revised in a manner consistent with the suggestions made by the SAB panel. The SAB peer review committee included:

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Director, Carolina Federation for Environmental Programs, University of North Carolina, Chapel Hill, North Carolina

Dr. William H. Smith
Professor of Forest Biology, School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut

Dr. Terry F. Young
Environmental Defense Fund, Oakland, California

CONSULTANTS

Alison G. Power
Cornell University, Ithaca, New York

Leslie A. Real
Indiana University, Bloomington, Indiana

Authors

This document has been authored through contributions from many scientists within ORD, and their contributions are greatly appreciated. The following persons, who were responsible for the development of the strategy, are the editors:

Dr. Rick A. Linthurst, Associate Director of Ecology, National Exposure Research Laboratory

Mr. Lee A. Mulkey, Associate Director for Ecology, National Risk Management Research Laboratory

Dr. Michael E. Slimak, Associate Director for Ecology, National Center for Environmental Assessment

Dr. Gilman D. Veith, Associate Director for Ecology, National Health & Environmental Effects Research Laboratory

Ms. Barbara M. Levinson, Assistant Center Director, National Center for Environmental Research and Quality Assurance

Executive Summary

Background

In virtually every major environmental act, Congress has required that the U. S. Environmental Protection Agency (EPA) not only ensure that the air is safe to breathe, the water safe to drink, and the food supply free of contamination, but also that the environment is protected. As a result, EPA's Office of Research and Development (ORD) has established research to improve ecosystem risk assessment and risk management as one of the seven highest priority research areas for investment over the next 10 years.

To meet the combined requirements of the legislation, it is increasingly clear that scientific solutions to ecological issues can no longer be isolated to one stress, one scale, one level of biological organization, or one medium. It is also obvious that because of the complexity of environmental problems and the ecosystems on which they act, environmental problems are not as likely to be solved as they are to be managed. Because not all ecological changes are "bad," ecosystem management becomes more a matter of social tradeoffs among alternative uses rather than simply a matter of protection.

The goal, therefore, of the Ecological Research Program is to: "[p]rovide the scientific understanding required to measure, model, maintain, and/or restore, at multiple scales, the integrity and sustainability of ecosystems now, and in the future."

In the context of this Program, ecological integrity is defined in relative terms as "[m]aintenance of ecosystem structure and function characteristic of a reference condition deemed appropriate for its use by society." Sustainability is defined as "[t]he ability of an ecosystem to maintain relative ecological integrity into the future."

It is ORD's vision that by 2008, EPA researchers will have developed the next generation of measurements and models and technologies necessary to protect the present and probable future sustainability of ecosystems at local, watershed, and regional scales. Obviously, this is not a vision or goal that can be accomplished by ORD alone, but it is one that will be dependent on contributions from in-house and extramural programs, other agencies, the academic community, states, and others. Research within ORD must then be prioritized, capitalizing on the strengths of the organization and the needs of customers it most closely supports.

Consistent with the recommendations from a recent report from the National Research Council entitled, "Building a Foundation for Sound Environmental Decisions," the Ecological Research Program proposes to maintain a "core" research program and applies those same capabilities to the Program Office's high-priority needs. The core research ensures that ORD maintains the capability EPA needs now and in the future, whereas the program priorities ensure that the core program is applied to the most critical needs. Because of the demands on ORD from multiple customers, including Congress, the public, the scientific community, and the Program Offices (to mention but a few), organizing ORD's research can be approached from multiple directions driven by these different customers. The structure is not unlike a Rubik's cube, in that once one face is structured to take full advantage of all the expertise within ORD, the other sides are unlikely to be as consistent in pattern. The research presented in this strategy begins with the core research as the primary face of the strategy, and then the high-priority needs, as determined by the risk posed, as the secondary axis for organizing the research areas.

Program Objectives

The Program is developed around the following four fundamental research areas and objectives:

Monitoring Research. Developing indicators, monitoring systems, and designs for measuring the exposures of ecosystems to multiple stressors and the resultant response of ecosystems at local, regional, and national scales.

Processes and Modeling Research. Developing the models to understand, predict, and assess the current and probable future exposure and response of ecosystems to multiple stressors at multiple scales.

Risk Assessment Research. Developing and applying assessment methods, indices, and guidelines for quantifying risk to the sustainability and vulnerability of ecosystems from multiple stressors at multiple scales.

Risk Management and Restoration Research. Developing prevention, management, adaptation, and remediation technologies to manage, restore, or rehabilitate ecosystems to achieve local, regional, and national goals.

These four objective areas are consistent with the strengths of ORD's research (i.e., the core research of ORD). The specific research issues to which these capabilities are applied are, however, always changing.

More emphasis on the relative risk is at the forefront of improving the ability to make future ecosystem management decisions, considering EPA's move to more flexible regulations and decentralized decision making. Therefore, a better understanding of the impact of multiple stressors, at multiple scales, and at multiple levels of biological organization are underlying factors that run throughout the strategy. Although these are not new areas of research in ORD, the core, in-house program will emphasize research considering these factors over the next five to ten years. Further, the in-house program will primarily concentrate on aquatic endpoints. These will assist the Agency both on the short- and long-term to work toward water quality improvements (both biological and chemical) from a multimedia perspective. Terrestrial research will proceed, but again, primarily as it influences water quality. The ORD grants program complements the in-house research by expanding both the capability and the scope of the research.

Monitoring Research

What is the current condition of the environment, and what stressors are most closely associated with that condition?

With rare exceptions, ecosystem monitoring has been conducted to meet short-term or program-specific objectives. It is seldom harmonized or coordinated across large geographic areas. Comparable measurements are taken for only a short time (e.g., less than the length of many natural ecological cycles) across a large area, or, when they are made over a long period, they are usually restricted to one or a few study sites. Recently, however, there is revived interest in creating a multiagency ecological monitoring network that would monitor the condition of ecosystems and provide periodic "report cards" to the public.

Early experience with EPA's Environmental Monitoring and Assessment Program revealed that there remains a great deal of scientific controversy over what to measure, how to measure it, and with what network design. The emerging consensus, based in large part on the ecological risk assessment paradigm, is that indicators of exposure (i.e., the juxtaposition of a stressor and an ecological receptor in time and space at a comparable and appropriate scale and effect) should be monitored simultaneously. Additionally, environmental characteristics that modify the exposure-effect relationship, as well as exposure indicators that signify that an exposure has occurred in the past (perhaps in episodes or cumulatively over long periods of time) also need to be monitored.

Therefore, the core research in this area will include:

- Developing suites of new, field-applicable, biological indicators and criteria for measuring, understanding, and diagnosing lake, stream, and river exposures, effects, and recovery.
- Developing new chemical methods for collection and distribution environmental monitoring and measurement information to communities.
- Developing multiscale monitoring designs and statistical techniques for monitoring current conditions and trends in the condition and exposure of the nation's ecological resources.

Process and Modeling Research

What are the biological, chemical, and physical processes affecting the condition of ecosystems and their response to stressors?

Process and modeling research develops the basic understanding and modeling technology to predict future landscapes, stressor patterns, ambient conditions, exposure profiles, habitat suitability, and probable receptor responses as a function of risk management alternatives. Future models will consider multimedia, multipath sources, intermedia pollutant transfers, transport and transformations, micro-environments, and receptor activity patterns in the context of anticipated regional changes resulting from both natural and anthropogenic causes. In order to estimate the distribution of exposure to multiple stressors across vulnerable ecosystems, there is the need to understand and quantify the governing processes and develop models linking sources, transport, and transformations of pollutant stressors, along with physical stressor predictive models, to estimate exposures at appropriate temporal and spatial scales. These models must also be linked to landscape models to characterize future environments and habitats. In addition, ties to appropriate suites of biological response models are essential to the risk manager, as often the goal is to forecast the response of receptors to management actions.

For convenience and simplicity, current models used to predict the outcome of any individual management option are generally single-media models, involving only a single pollutant or stressor. Modeling must move past this piecemeal approach and represent the interactions that occur across scales, media, stressors, and multiple levels of biological organization. The complexity of the problems that EPA will face in the future will require models to predict beyond today's physical and chemical conditions to new, never-before measured conditions. Therefore, future models need to be based as closely as possible on first principles, and they need to be sufficiently complex in their description of underlying processes to become virtual realities. By doing so, scientists can best advance the understanding of the whole of the environment and develop anticipatory and more flexible management strategies that avoid unwanted futures. It is the vision for this area of research that future models will be interrogated as virtual realities in the same way that engineering tables and interactive CD-ROM encyclopedias are used today.

High-priority research will include:

- Developing a prototype modeling framework for EPA covering a full range of computing architectures from personal computers to scalable, parallel machines.
- Developing an air modeling system capable of handling multipollutant issues and multifunction interaction.
- Understanding, quantifying, and modeling key transport and transformation processes for nutrients, industrial chemicals, pesticides, metals, and radiatively important trace gases and incorporating these processes into terrestrial and aquatic exposure assessment models.
- Developing stressor/response analyses and techniques to establish cause-and-effect relationships and to improve effects models.

Risk Assessment Research

What is the relative risk posed to ecosystems by these stressors, alone and in combination, now and in the future?

EPA's Science Advisory Board (SAB) report, "Future Risk: Research Strategies for the 1990's," emphasized the need for a fundamental shift in EPA's approach to environmental protection and challenged ORD to provide leadership in the area of ecosystem science. This report provided the impetus to shift the approach previously used in ecological assessments by concentrating on the resources at risk and their composition within landscape, multiple stressor, and multiple assessment endpoints. In 1992, EPA published the *Ecological Risk Assessment Framework* as the first statement of principles for ecological risk assessment and, in 1996, published the first draft of the *Ecological Risk Assessment Guideline.* The final was published in 1998. The "Guidelines" describe methods for conducting the more conventional single-species, chemical-based risk assessments, discussing techniques for assessing risk to ecosystems from multiple stressors and from multiple endpoints.

The goal in this core research area will be to continue development of better ecosystem risk assessment methods. Specifically, high-priority areas will include:

- Developing risk assessment guidelines to improve and standardize ecological risk assessments within and outside EPA.

- Conducting ecological risk assessments at real places, on special problems, and for important chemicals.
- Developing new methods to conduct place-based, multiple-stressor assessments.

Risk Management and Restoration Research

What options are available to manage the risk to or restore degraded ecosystems?

Recently, ecosystem management and sustainability have moved to the forefront of both scientific and policy debates. Many of the issues raised remain unresolved (including a consensus on the meaning of sustainable ecosystems), but one thing seems clear—that increasing attention to ecosystem management, in tandem with the issue of sustainability, represents a significant reexamination of U.S. land and natural resources management practice and policy. Risk management actions are an important part of ecosystem management and typically occur at multiple scales. For example, transboundary issues, such as acid deposition and atmospheric levels of greenhouse gases, require risk reduction via widespread actions that are usually applied at every source. In most cases, active management and technology-based risk management (which often follow as an implementation requirement from policies and regulations) are typically applied to watersheds or ecosystems that can be defined by watersheds. Accordingly, the strategic choices for the scales of risk management research are (1) national, for regulatory-based transboundary consideration, and (2) the watershed, for most regulatory and local management effects.

Given the rate of development of the man-made environment, present regulatory approaches may not always limit risks to vulnerable ecosystems to tolerable levels. There is a need to develop new, cost-effective prevention and control, remediation approaches for sources of stressors, and adaptation approaches for ecosystems. Ecosystem stressors from both natural and anthropogenic sources are inevitable. Cost-effective stressor reduction may not always be feasible or practical as a means to reduce risks. Therefore, it is also important to invest in restoration technologies, including protocols and indicators, to diagnose ecosystem restoration needs, evaluate progress toward restoration, and establish ecologically relevant goals and decision support systems for state and community planners. This will facilitate consistent, cost-effective decisions on ecosystem restoration within watersheds.

The research in this core research area will focus on:

- Developing and verifying improved tools, methodologies, and technologies to improve or maintain ecosystem condition at watershed scales.
- Developing best management technologies to reduce the impact of watershed development on the biological and chemical condition of stream quality.
- Developing techniques to improve decontamination of stream sediments.
- Developing techniques to decrease the risk of degradation through adaptation of the landscape, ecosystems, and species.
- Developing the techniques to restore and rehabilitate ecosystems to achieve local, regional, and national goals.

High-Priority Environmental Research Issues

In addition to the core research, some capabilities (in no particular order) are used to address high-priority environmental research issues identified by the Agency:

- Acid Deposition
- Ozone
- Mercury
- UV-B
- Nitrogen
- Global Change
- Contaminated Sediments
- Wet Weather Flow
- Toxic Algal Blooms
- Eco Criteria
- Total Maximum Daily Loading
- Endocrine Disruptors
- Pesticides and Toxics
- Landcover Change

High-Priority Geographic Studies

Some locations offer particularly good opportunities to further integrate ORD research and assist the Regions with real problems. ORD has selected eight such locations which include, in priority order:

- Mid-Atlantic Research
- Pacific Northwest Research
- South Florida Research
- Great Lakes Research
- Gulf of Mexico Research
- Near Laboratory Ecological Research Areas
- Index Sites research
- National Studies

Research Planning and Coordination

The challenges for the ecological research planning process are to maintain core capability and competencies, apply them to the greatest environmental threats, meet the needs of the multiple customers, and continue to maintain a perspective on future environmental issues that have yet to become immediate threats or customer concerns (i.e., the Rubik's cube problem addressed earlier). In light of these often-competing interests, ORD ideally will undertake those projects that meet all of the following criteria:

- The project is related to improving the ability to measure, model and/or maintain/restore ecosystem sustainability.
- The project allows ORD to maintain a concentrated core competency and to anticipate future needs.
- The project reduces uncertainty in a high-priority environmental problem area.
- The project will benefit a short- or long-term need of the customer's office.

Research Coordination

There are several opportunities for coordination across laboratories and centers in the Ecological Research Program. These opportunities include a common core research theme, common (limited) high priority research topics and common locations. Through both active planning and these three natural integrative elements, the interaction among laboratories and centers has been significantly improved. In addition, the common research issues and locational research also facilitates interactions between ORD, the Program Offices, the Regions, and many local stakeholders.

The Mid-Atlantic Region has been chosen as the primary research location for ORD's ecologically related research and is viewed as the best opportunity to maximize coordination and meet the goal of the Ecological Research Program. The decision was based on the extensive monitoring data available in the area, the selection of this area as a multiagency monitoring and assessment pilot, and the interest and participation of the Region and states.

Data Management

To be successful, this Ecological Research Strategy will require significant investment in information technology resources. ORD scientists will require advanced data visualization, modeling, and communication approaches, as well as the computer tools to meet the challenge of integrating data from various sources, disciplines, and scales. Recognizing that the management of scientific data presents unique challenges, ORD has formed the Science Information Management Coordination Board (SIMCorB) to coordinate science information management activities within ORD. The board will insure that the information management resources of ORD will be able to support the assessment activities of its scientists. The board will operate through principal standing subgroups representing principal information management functions: Requirements Definition and Planning; Data Administration and Quality Assurance; Systems Engineering and Operations; Advanced Technology Evaluation and Modeling; Science Direction; and Outreach and Liaison. Recognizing that ecological data are an important corporate resource, SIMCorB will initially concentrate on preserving and facilitating access to environmental data by Agency scientists, federal partners, regional stakeholders, and the public. Additionally, the board will sponsor projects to increase the interoperability of ORD's evolving data systems.

SECTION 1

Introduction and Rationale

Although there remains a need for single stressor/single receptor/single scale research—and that research must continue—the long-term priority for the foundation, 'or core,' of the program will be on the most complex of relative risk evaluations—multiple stressors/multiple receptors/multiple scales—with aquatic resources as the endpoint of initial concern.

1.1 Rationale for the Program

Ecosystems provide valuable renewable resources and services such as food, fiber, water storage and flood control, wood for construction, biodegradation and removal of contaminants from air and water, pest and disease control, and amelioration of climatic extremes. To the extent that these goods and services are threatened by environmental pollution, they must be replaced at great expense by civil works, man-made chemicals, and increased use of nonrenewable energy supplies. Ecosystems also supply less critical — but nonetheless valuable — opportunities for recreation, scientific discovery, or even a simple walk in the woods or along the shore.

Considerable progress has been made in reducing the most egregious harm to the environment from air and water pollution (e.g., areas of devastation around industrial plants and burning rivers devoid of fish). Much remains to be learned, however, to understand and avoid potential disasters on a tragic scale, such as forest decline, widespread epidemics of toxic microorganisms in estuaries, reproductive failure of wildlife, redistribution of persistent organic pollutants, destruction of critical habitat, vector-borne epidemic disease, and global climate change.

In virtually every major environmental act, Congress has required that the United States Environmental Protection Agency (EPA) not only ensure that the air is safe to breathe, the water safe to drink, and the food supply free of contamination, but also that it protect the environment. As a result, EPA's Office of Research and Development (ORD) has established research to improve ecosystem risk assessment as one of the highest priority research areas for investment over the next ten years (EPA, 1997a).

1.1.1 A Changing Ecological Perspective

As more is learned from EPA's pollution control efforts, the more it is realized that past approaches are necessary but not sufficient to protect ecological resources. Although pollutant-specific and site-specific programs have resulted in a substantially cleaner environment, societal expectations for ecological and natural resource systems have not been achieved. The water may in fact be cleaner, but the fishery has not improved because of the continuing loss of stream-side habitat or diversion of water flow. More wetlands may be preserved, but duck populations may continue to decline because surrounding agricultural practices increase the number of duck predators. Toxic waste discharges into the Great Lakes have been reduced, but concerns still remain about fish contamination from toxic air pollutants transported from afar.

Comparable issues face other agencies. Under the Endangered Species Act, heroic and often socially disruptive efforts are made to save species that are approaching the brink of extinction, while awaiting the development of a broader approach to prevent rather than merely respond to such catastrophic events.

Problems such as these have led to great interest in the concept of *ecosystem management*— dealing with ecological systems as they are organized by nature rather than in piecemeal fashion or along political or program boundaries. Although there is widespread support for such a concept, it is not clear how best to put it into practice.

One of the major issues involved in the application of ecosystem management is the issue of ecological boundaries. Many ecological systems function over large areas that do not coincide with political and program boundaries. These large systems have internal linkages that can transmit or accumulate impacts in ways that are often not evident from site-specific observations. This occurs for systems that have extensive hydrologic interconnections, such as the South Florida (Everglades) Ecosystem, the Great Lakes, the Chesapeake Bay, the Columbia River, and the Ogalala Aquifer. Oyster populations in Chesapeake Bay may be influenced as much by land use practices miles away in the Susquehanna River watershed as by local actions. Other ecological systems include important species that require large areas to maintain their populations, such as spotted owls and grizzly bears, or species that move great distances as the seasons change, such as salmon, migratory birds, and sea lions. Adequate upstream spawning habitat for salmon is insufficient to maintain productive population levels if river impoundments block their passage to and from the ocean.

Even those ecological systems without tight internal linkages or wide-ranging species present boundary difficulties. It may be necessary, for example, for larger ecological systems to have a widely distributed pool of biological diversity that provides a genetic reservoir on which local ecosystems can draw to adapt to constantly changing environmental conditions and disturbances. Key elements of this pool of regional biodiversity are at risk from cumulative demographic and resource use pressures in large terrestrial ecoregions such as the Great Plains and the Appalachian Highlands. For example, maintaining the pools at a regional scale is currently a most uncertain exercise.

Another issue facing application of ecosystem management is the perception of the relationship between humans and nature. Until recently, a plentiful supply of unallocated open space provided a buffer for increased resource use and changing public values. This helped foster a “protectionist” approach to natural ecological systems, viewing these systems as something apart from human affairs that was to be set aside and kept pristine. This view of nature is rapidly changing as it becomes clearer that nature does not operate in small, separate pieces and that human activities now pervade the entire earth. There are no pristine ecosystems left. At a minimum, all natural systems are exposed to the changing composition of the atmosphere and solar radiation, and only a few are spared from the profound land use changes sweeping across the globe.

1.1.2 A Changing Regulatory Perspective

It is increasingly clear that solutions to ecological issues no longer can be isolated to one stress, one scale, or one medium. It is also obvious that, increasingly, environmental problems cannot be solved but rather must be managed interactively. Society, scientists, and regulators also now recognize that not all ecological changes are “bad.” In many instances, ecological change has to be evaluated in terms of what is wanted from ecosystems. Ecosystem management becomes more a matter of social trade-offs among alternative uses rather than simply a matter of protection. People are part of ecosystems—cultural, economic, and ecological well-being have become inextricably linked.

The regulatory approach within EPA also is evolving to meet the ecological protection challenges being faced. In particular, the following two changes will have a major impact on the future of environmental protection:

1. **Less centralized decision making.** In the past, there has been a “command and control” approach to regulation. Although that certainly will continue where it is the only way to achieve results, it is clear that when it comes to protecting ecosystems, the values of the community must factor into the process. As such, there will be increasing movement to community-based decision making.
2. **More flexible decision making**. As with centralized decision making, the regulations have been made clear, unbending, and applicable nationally. Recognizing that “one size does not necessarily fit all” and that alternatives do exist, the results are increasingly the central concern rather than the means to that end.

The combination of these two changes has significant implications for the research community. Perhaps most important scientifically, there must be a better understanding of ecosystem sustainability, so that within the boundaries chosen, the endpoints of interest to society, and the alternative management strategies chosen, EPA can ensure that the nation’s ecological resources will be protected and the desired environmental goals will continue to be met.

These changes in both the scientific understanding and the regulatory approach to protecting ecosystems provide the foundation of ORD's Ecological Research Strategy. The goal of this research is to determine how to sustain ecosystems and determine the relative risk posed to ecosystems as a result of exposure to multiple stressors and, possibly most important, at multiple scales.

1.1.3 Characteristics of Ecosystem Management

Although there is increasing agreement in principle with the concept of ecosystem management, there is no generally recognized model for its application. In attempting to provide the scientific basis for EPA's application of ecosystem management, this strategy assumes the following four characteristics must be met, all of which tend to represent the ideal rather than the current capabilities to achieve their intent:

1. **Ecosystem management is "place-based" management.** Ecosystems tend to be spatially defined. Therefore, this strategy will concentrate on geographical units that have ecologically determined boundaries.

2. **Ecosystem management must be holistic rather than piecemeal.** Ecosystems have multiple components and functions that are affected by multiple, interacting stressors. Therefore, ecosystem management must integrate all relevant ecological endpoints and stressors.

3. **Ecosystem management must occur at multiple scales**. Ecosystems function at multiple, interacting scales, and different management decisions are applicable at each scale. This strategy will deal explicitly with several ecological scales.

4. **Ecosystem management is driven by public values.** People and nature are not separate, and ecological systems provide multiple, often competing, values to society. Therefore, there is no single, scientifically derived endpoint for ecosystem management. Ecosystem management involves a balancing of competing interests.

Ecological research must be able to provide the scientific foundation to ensure that these characteristics are met if changes in the regulatory process are expected.

It is the intent of ORD's Ecological Research Program to further the understanding of ecosystems in order to improve the ability to conduct ecological risk assessments. To accomplish this objective, research is needed in the areas of monitoring, processes and modeling, assessment methods, risk management, and ecosystem restoration. These research areas will be the broad areas of interest for the core of this research strategy over the next five to ten years.

1.2 ORD's Ecological Research Program

ORD has previously developed and published a strategic plan to guide to how research will be conducted within the organization (EPA, 1997a). It presents the vision and mission of ORD, the strategic principles that are to be followed, and the foundation for selecting ecological research as one of the high-priority areas of research. The strategic plan also discusses the priority-setting process and how decisions are made to identify who should conduct the needed research within the priorities chosen. Therefore, these issues will not be revisited in this document. Rather, the reader is encouraged to review ORD's strategic plan because it provides, to a great degree, the "first order" boundaries on the Ecological Research Strategy.

The following two issues, however, must be discussed and considered in this document to provide additional perspective and boundaries for ORD's Ecological Research Program:

1. **The ecological risk assessment process**
2. **The Government Performance and Results Act (GPRA)**

Although the first item is discussed in the ORD strategy, it is worth additional attention here. GPRA is having a significant influence on the work to be done by ORD and it is evolving. As such, its discussion provides important background information for understanding the presentation of the ecological research to follow, but it is also likely to change following publication of this document.

1.2.1 Ecological Risk Assessment

The risk assessment paradigm shown in Figure 1-1 has been chosen as the organizational structure for, and the guiding approach to, all research within ORD. It also provides two key focal points of interest to the research efforts: (1) the characterization of risk (also discussed in this document in terms of vulnerability and sustainability), and (2) the provision of appropriate risk management strategies.

Most of the terminology and concepts have been derived from many years of research in the field of human health risk, the endpoint often being cancer risk. The application of the risk model for ecological risks presents some significant differences and increased complexities when compared to human health risks. Among them are the following:

- Multiple, interactive, and interdependent species of concern.
- Multiple scales of concern, over which these species exist and interact.
- Multiple, and often competing, endpoints that are of importance to society.
- Greater willingness to alter ecosystems to better meet multiple societal interests.

Stated most simplistically, the challenge in the ecological research area is to provide the information and methods to develop risk assessments and management strategies for:

- Single stressors (chemical and nonchemical, natural and anthropogenic) acting on simple receptors (ecosystems, ecosystem components, communities, populations, and valued societal goods and services—endpoints).
- Single stressors acting on multiple receptors.
- Multiple stressors acting on individual receptors.
- Multiple stressors acting on multiple receptors.

The uncertainty in risk characterization increases as the more complicated combinations are considered, particularly when the interactions among stressors and receptors are considered. Added to the complexity is the additional need to conduct risk characterization at multiple scales, and the fact that nonchemical stressors may be more important than chemical stressors (for which most of the concepts in risk assessment have evolved) in ecosystems.

Therefore, although there remains a need for the more "traditional" single stressor/single receptor/single scale research, the dominant long-term priority for the foundation, or "core," of the ecological research program will be on the most complex of relative risk evaluations—multiple stressors/multiple receptors/multiple scales—with aquatic resources as the initial endpoint of concern. If EPA's goal of providing more flexible and decentralized decision making (Section 1.1.2) is also to be met, it is increasingly important to continue to improve the ability to quantify ecological risks for that purpose.

It is also noteworthy that it is difficult to use the paradigm for selection of the highest priority research, as proposed in the ORD strategic plan (EPA, 1997a). Although there is general agreement on the criteria, there is no agreement on the relative risk posed by multiple stressors, at multiple scales, and on multiple endpoints, except in the most extreme situations. Thus, the priorities for research and regulatory action in the absence of scientific certainty introduce considerable subjectivity and variability to the selection process. One of the benefits of this research program will be to make the process of priority setting (i.e., determining what research to fund or what regulatory action to take) far more defensible over the next five to ten years.

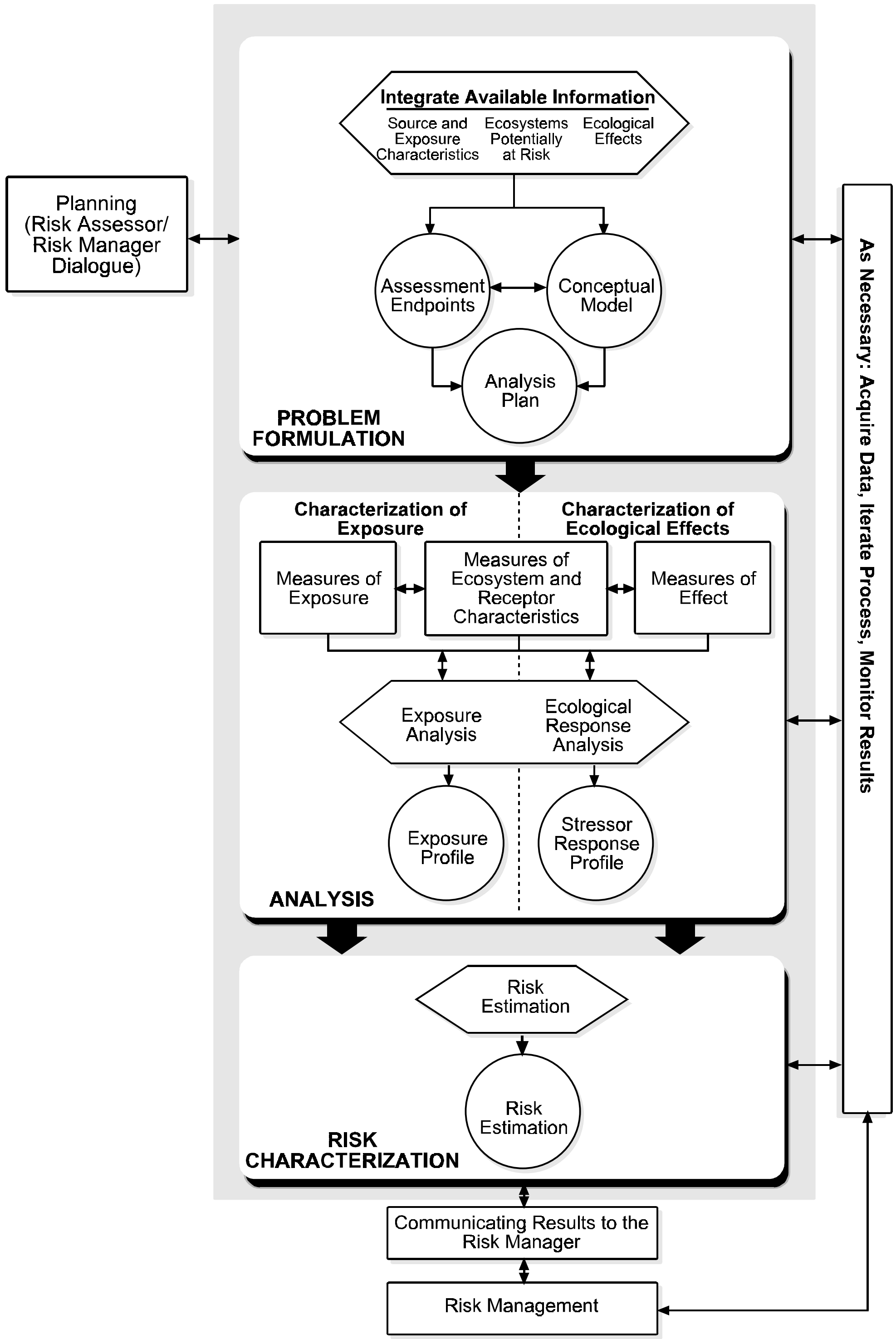

Figure 1-1.
The ecological risk assessment framework (adapted from EPA, 1992) shown as a three-phase process, with an expanded view of each phase. Within each phase, rectangular boxes designate inputs, hexagonal boxes indicate actions, and circles represent outputs.

1.22 Government Performance and Results Act (GPRA)

All federal agencies are required to better account for the success of their proposed actions. Therefore, EPA has been developing a cascading set of goals, objectives, subobjectives, milestones, measures, tasks, and products in compliance with GPRA (Figure 1-2). This figure also shows the management and staff level responsibilities associated with the hierarchy. Further, Figure 1-2 delineates the approximate level where the strategy ends (setting bounds for the program) and where specific research plans begin. As a strategy, this document deals with the issues of "what" and "why", not "how." There are currently ten EPA goals:

1. Clean air.
2. Clean, safe water.
3. Safe food.
4. Safe communities, homes, workplaces, and ecosystems.
5. Safe waste management.
6. Global and transboundary environmental risk reductions.
7. Empower people with information and education, and expanding their right to know.
8. Provide sound science to improve the understanding of environmental risk, and develop and implement innovative approaches for current and future environmental problems.
9. Provide a credible deterrent and promote compliance.
10. Effective management.

Appendix A provides a more complete description of those goals with objectives and subobjectives of of highest priority interest to the Ecological Research Program. As GPRA is an evolutionary process, the specific text and hierarchy is likely to change; however, the concepts and broad goals remain applicable.

ORD has a role to play in most, if not all, of these goals as the regulatory process is dependent on sound science. However Goal 8, "providing sound science," is the goal that serves as the foundation, or core, of ORD's Ecological Research Program. The specific objective associated with the ecological research is "Research for Ecosystem Assessment and Restoration" and provides the scientific understanding to measure, model, maintain, or restore, at multiple scales, the integrity and sustainability of ecosystems now, and in the future.

Goal 8 is the broad objective of the core research program that is presented in Section 3. The more problem-driven goals and objectives of the customer offices will be presented in Section 4. These later objectives and subobjectives determine how many of the core capabilities in the Ecological Research Program are applied to immediate EPA problems (see Section 2).

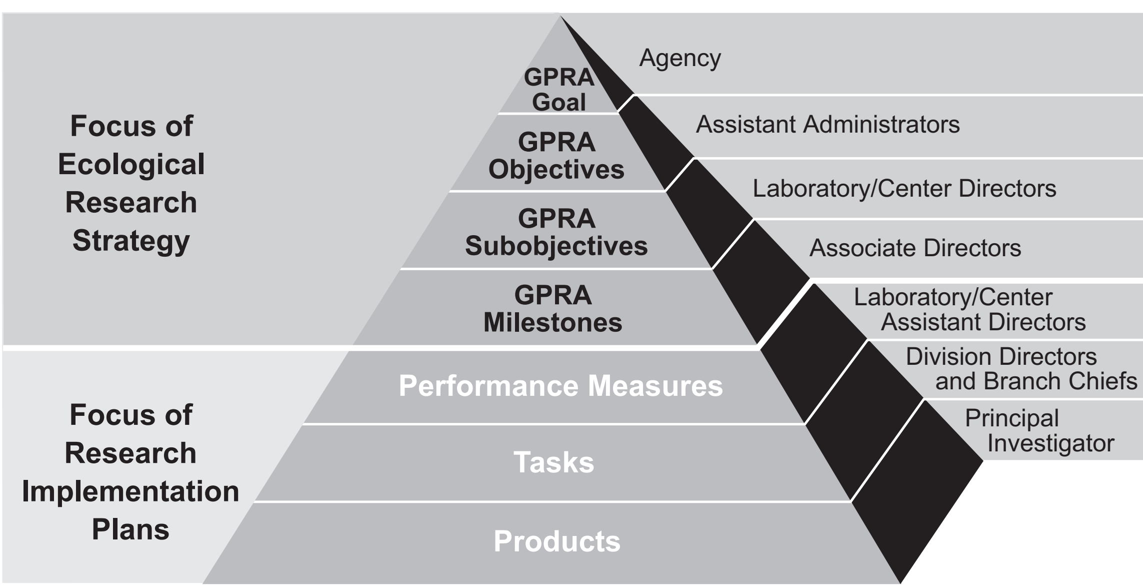

Figure 1-2.
GPRA Architecture.

1.3 Document Purpose and Structure

The purpose of this document is to present the goals, objectives, and priorities for the Ecological Research Program. The document presents an overview of the critical questions and activities that constitute the goal of the Ecological Research Program over the next five to ten years.

Section 2 introduces the basic themes of the strategy. Section 3 provides an overview of the priorities and direction of the core research program. Section 4 presents the high-priority EPA research selected for application of the core capabilities, and Section 5 deals with the geographic locations where many of these studies are being and will be conducted. Section 6 provides insights as to how the research program will be planned and conducted.

The intended audience for this document is the scientific community and Agency scientists. As noted previously, as a strategy, the document focuses on the direction of the Program, not its implementation (Figure 1-2). *The implementation of projects contributing to the programs outlined in this strategy is documented and reviewed separately from the strategy.*

SECTION 2

Ecological Research Program Strategic Direction

The common goal of the core Program across ORD on aquatic endpoints, relative risk of multiple stressors acting alone and in combination, the watershed and larger geographic scales, and the population, community, and landscape levels of biological organization is the strategic aim of long-term research and development of the foundation of science needed for future, increasingly complex, decision making.

2.1 Introduction

ORD's ecological research can improve the foundation necessary for local communities to avoid costly environmental management failures by better understanding stressor exposures to, effects on, and restoration of the nation's ecological resources. The common goal is to "provide the scientific understanding required to measure, model, maintain and/or restore, at multiple scales, the integrity and sustainability of ecosystems now, and in the future," with particular emphasis on aquatic ecosystems.

In the context of this Program, ecological integrity is defined in relative terms as "maintenance of ecosystem structure and function characteristic of a reference condition deemed appropriate for its use by society." Relative sustainability is defined as "the ability of an ecosystem to maintain relative ecological integrity into the future." The goal of ORD's Ecological Research Program, as stated in Section 1, is also the objective of EPA's GPRA sound science goal.

It is ORD's vision that, by 2008, EPA researchers will have developed the next generation of measurements and models necessary to assist in managing the present and influencing the future sustainability of ecosystems (specifically, surface waters) at local, watershed, and regional scales. Obviously, this is a vision that can not be accomplished by ORD alone, but will be dependent on contributions from in-house and extramural programs, other agencies, the academic community, states, and others. Research within ORD must then be prioritized, capitalizing on the strengths of the organization and the needs of customers most closely supported by it. The grants program, however, allows ORD to broaden both capacity and capability in those high priority areas when ORD has additional need.

2.2 Scientific Questions

Consistent with the Program objective, the following four broad scientific questions will be the primary areas of the core research:

1. **Monitoring Research.** What is the current condition of the environment, and what stressors are most closely associated with that condition?
2. **Process and Modeling Research.** What are the biological, chemical, and physical processes affecting the condition of ecosystems and their response to stressors?
3. **Risk Assessment Research.** What is the relative risk posed to ecosystems by these stressors, alone and in combination, now and in the future?
4. **Risk Management and Restoration Research.** What options are available to manage the risk to or restore degraded ecosystems?

The primary purpose of all activities is the relative risk posed by the stressors, because it represents an endpoint of the research that will not only assist EPA in making the most cost-effective and environmentally effective management decisions, but will also be critical in guiding the ecological research needs of this Program. If this Program is successful, the scientific understanding required to ensure that environmental decisions are concentrated on the problems of most significance will be improved significantly over the next ten years, and limited resources will be most wisely used.

2.3 Program Subobjectives, "Core" Research, and Goals

Consistent with the scientific questions, ORD's Ecological Research Program is developed around the following four broad, fundamental research subobjectives:

1. **Monitoring Research.** Developing indicators, monitoring systems and designs for measuring the exposures of ecosystems to multiple stressors and the resultant response of ecosystems at local, regional, and national scales.
2. **Processes and Modeling Research** Developing the models to understand, predict, and assess the current and probable future exposure and response of ecosystems to multiple stressors at multiple scales.
3. **Risk Assessment Research** Developing and applying assessment methods, indices, and guidelines for quantifying risk to the sustainability and vulnerability of ecosystems from multiple stressors at multiple scales.
4. **Risk Management and Restoration Research** Developing prevention, management, adaptation, and remediation technologies to manage, restore, or rehabilitate ecosystems to achieve local, regional, and national goals.

The goal of this Program is consistent with the objective of EPA's GPRA for "Sustainable Ecosystems and Restoration" and the objectives of the Program are the same as the GPRA subobjectives (see Section 1). Again, however, while not ignoring other resources, it is our expectation that the primary success will be in the area of surface water protection.

ORD has numerous customers that must be considered in the development of the research program. Although the research could be organized by the needs of any of these customer interests, the fundamental research program would then be difficult to present and extremely volatile because these needs do change. Using the university structure as an example, the departments do not change over time, but the research within the departments changes significantly for many reasons, such as new advancements in science or new opportunities for funding. Similarly, the Ecological Research Strategy is then first and foremost aimed at defining the fundamental core research program (Section 3). The application of these capabilities to specific, high-priority issues is presented in Section 4, and Section 5 concentrates on where some of the research is conducted. This approach might best be viewed as a Rubik's cube, and the elements are the research projects that can be arrayed many different ways (Figures 2-1a and 2-1b.) but do not clearly align in all ways (Figure 2-1b).

Based on recommendations from the report entitled *Building a Foundation for Sound Environmental Decisions* (NRC, 1997a), ORD has chosen to think about the development of the Programs in linear but not fully independent (in terms of human and financial resources or research projects) steps. That is, the NRC report states:

> "To develop the knowledge needed to address current and emerging environmental issues, EPA should undertake both problem-driven research and core research….Research activities within problem-driven and core research programs may often overlap."

We agree and expect that our core capabilities, research and knowledge will be applied to, and advanced by, specific problem areas for our customers at locations that will benefit multiple communities (Figure 2-2).

2.4 Strategic Principles

To meet the objective of the Program, there must be a close working relationship among EPA's laboratories and centers. To ensure this relationship, the laboratories and centers will share not only common objectives and core research, but also several strategic elements that will be common to the research (Figure 2-3).

First, consistent with the reorganization of ORD, the risk paradigm, the objective of the Program, and the core research areas, two common endpoints have been chosen to guide research planning: (1) assessing ecosystem sustainability and (2) maintaining and restoring important ecosystems. Although there is considerable controversy about sustainability, its applicability as an endpoint, and even its definition,

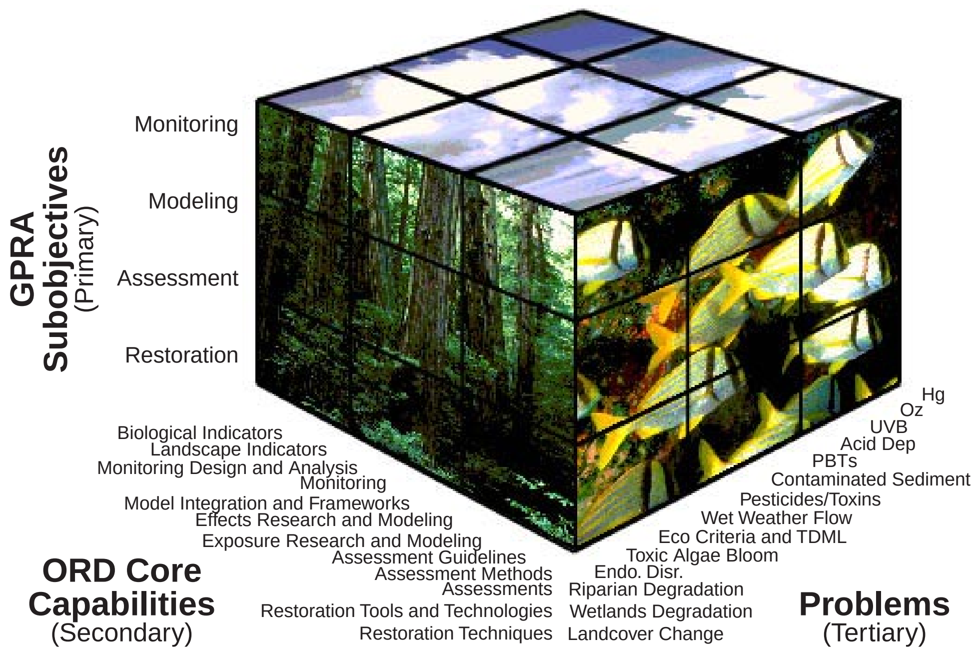

Figure 2-1a.
Primary structure of Ecological Research Program.

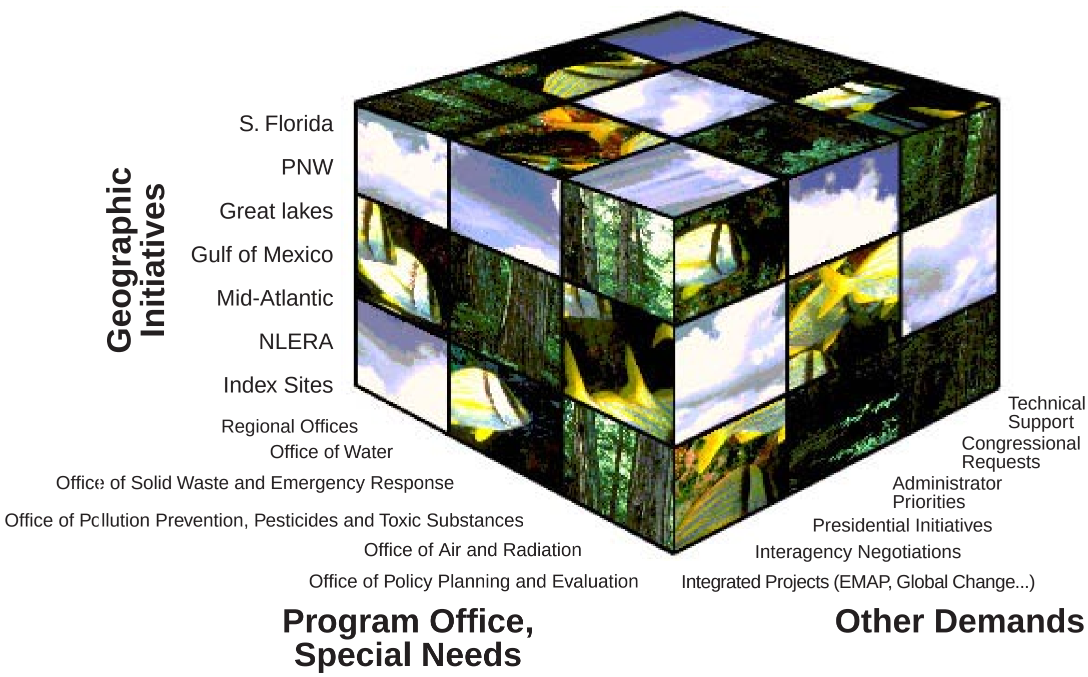

Figure 2-1b.
Alternative structure for the Ecological Research Program.

Figure 2-2.
Elements of the research structure.

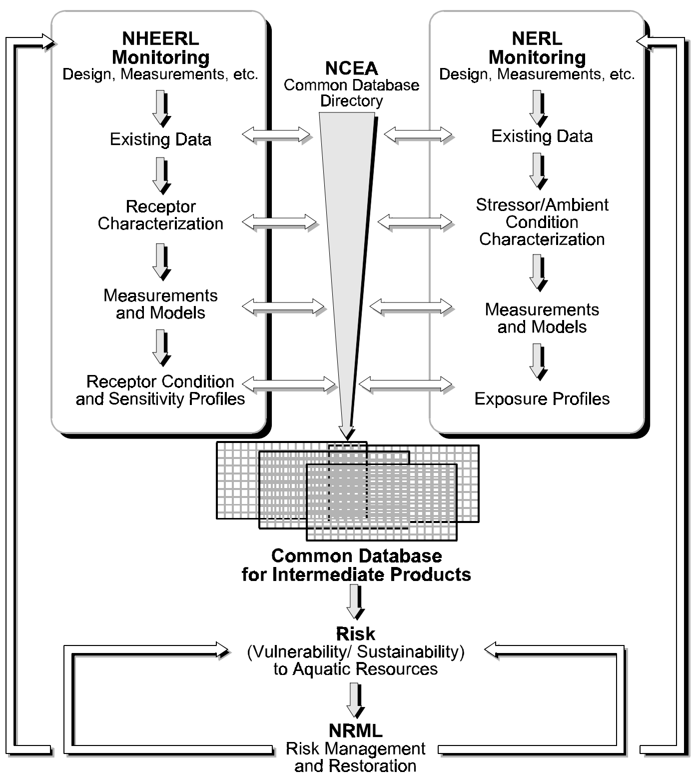

Figure 2-3.
Organizational model for ecological research.

(Note that the National Center for Environmental Research and Quality Assurance contributes to all compartments of the model.)

there remains a need to resolve this controversy, focus on it, and incorporate this broader directive into the risk assessment guidelines of the future.

In addition, three general issues need to be at the forefront of improving the ability to make ecosystem management decisions in the future (considering more flexible regulations and decentralized decision making) and to guide ORD research. These areas for research include more emphasis on relative risk, seeking a better understanding of the impact of *multiple stressors*, at *multiple scales*, and at *multiple levels of biological organization* (see Section 1). Although these are not new areas for research in ORD, the core program will emphasize research considering these interrelated issues over the next five to ten years.

Multistressor Research

To manage risks, it is important that the endpoint and the stressor affecting it be known. Also, to improve management success, it is equally important to understand all the other stressors that interact with the receptor. Thus, the challenge will be to compare the relative risk of multiple stressors acting alone and in combination on all levels of biological organization and geographic scales. Only with this information can action be taken that will ensure the desired result. Actions that have unintended consequences and fail to achieve the desired result because of a lack of understanding are too often taken. Therefore, the long-term research program will concentrate on ways of partitioning the influence of multiple stressors on individual and multiple receptors, particularly at watershed and larger scales.

Multiple Levels of Biological Organization

More research has focused on individual organisms and species than on any other level of biological organization. New technologies continue to make research at the molecular level easier. However, the higher levels of biological organization (e.g., populations, communities, systems) must be investigated as well. Therefore, the research will concentrate on developing an improved understanding of effects and exposure mechanisms at *all* levels of biological organization but will give a high priority to the molecular, community, and landscape levels.

Multiscale Research

It is clear that there is an improved awareness of the need to look more holistically at the environment. By not doing so, we risk the unintended consequences of ignoring the complex linkages among ecosystem elements. EPA now has taken a bold step forward to provide local decision makers with a more flexible decision process at watershed and other biologically and ecologically relevant scales. However, it is important to recognize that decisions at the local scale can collectively affect increasingly larger scales. Therefore, one of the important challenges facing ORD is to better understand the relationships of environmental processes at multiple scales to provide guidance at local, regional, and national levels of environmental management. In particular, the regional scale will receive priority because it is a scale that can be uniquely addressed by the federal government.

The common direction of the core Program across ORD will be toward aquatic endpoints, relative risk of multiple stressors acting alone and in combination, the watershed and larger geographic scales, and the population, community, and landscape levels of biological organization, which is the strategic aim for long-term research and development of the foundation of science needed for future, increasingly complex, decision making. The long-term core research will also be balanced (Section 4) with the immediate needs of EPA, which actually offer additional opportunities consistent with the strategic direction of the Program.

2.5 Administrative/Organizational Structure

In ORD, there are three laboratories and two centers. The research program is conducted throughout the three laboratories (the National Health and Environmental Effects Research Laboratory [NHEERL], the National Exposure Research Laboratory [NERL], the National Risk Management Research Laboratory [NRMRL]) and one center (the National Center for Environmental Assessment [NCEA]). The National Center for Environmental Research and Quality Assurance (NCERQA) is also part of the strategy. It provides the guidelines for EPA's Quality Assurance Program and the extramural grants program, a mechanism by which much of the needed research within the Program will be accomplished. Coordination with NCERQA is discussed in Section 6. To the extent possible, areas where extramural support is anticipated are noted in later chapters. For example, an area of significant interest to ORD and the Agency is in landscape indicator development. NCERQA has a request for proposals in this area which has increased ORD capability, brought new ideas to the Program, and just as importantly, provided resources to universities who will be training the landscape ecologists, geographers, and others that can be hired. It should be noted, however, that the primary concentration of this strategy is on the in-house program. Additional information about the organization of ORD and other components is presented in the ORD strategy (EPA, 1997a).

Each laboratory and center plays a unique role in these core research areas within the risk model. In addition, however, each must play secondary and supporting roles (Table 2-1).

Coordination across laboratories and centers—as well as participation by other agencies, institutions, and organizations—is essential to achieving the goal of the Program. Figure 2-3 shows the conceptual approach, mapped to the core research agenda, for research to be conducted within the base program. Of particular importance is the necessity for sharing information and planning research across organizations. These coordination and management issues will be discussed in Section 5.

2.6 Research Structure

Figure 2-4 provides an overview of the elements of the Program outlining the high priority core research areas, the highest priority environmental problems that will be addressed and, finally, where much of the large scale, holistic research will be conducted.

Table 2-1
Summary of general emphasis of core area research within the Ecological Research Program at the participating laboratories and centers.

Core Research Areas	National Health and Environmental Effects Research Laboratory	National Exposure Research Laboratory	National Center for Environmental Assessment	National Risk Management Research Laboratory	National Center for Environmental Research and Quality Assurance
Monitoring and Monitoring Research	Primary	Primary	Supporting	Supporting	Supporting
Processes and Modeling Research	Primary	Primary	Supporting	Supporting	Supporting
Assessment Research	Secondary	Secondary	Primary	Secondary	Supporting
Risk Management and Restoration Research	Supporting	Supporting	Supporting	Primary	Supporting

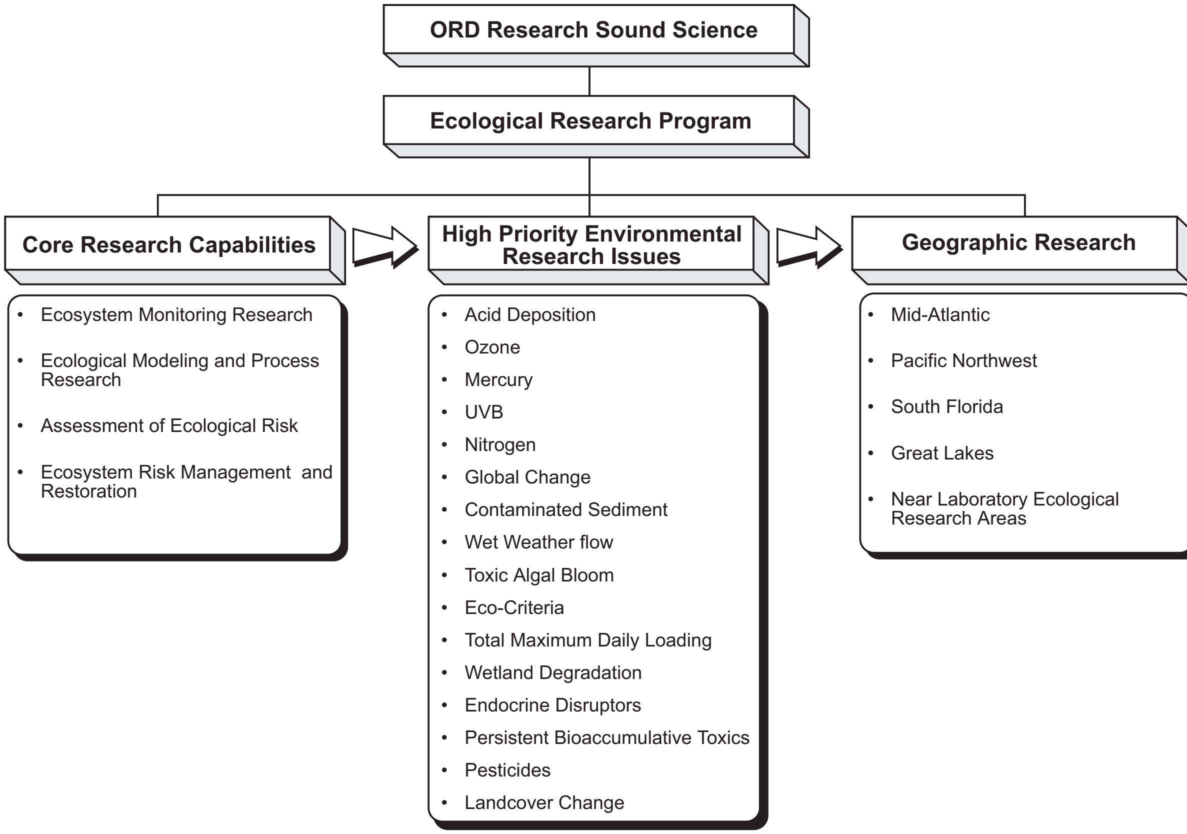

Figure 2-4.
Conceptual approach for research to be conducted within the base program.

SECTION 3

Core Research Objectives, Rationale, and Focus

A core research program is fundamental to being able to meet both the current and future needs of EPA. Therefore, ORD will maintain a fundamental and applied research program in the following areas:

- *Ecosystem monitoring research*
- *Ecological processes and modeling research*
- *Ecological risk assessment research*
- *Ecosystem risk management restoration research*

3.1 Introduction

Underlying the ability for ORD to be responsive to the current and future environmental protection needs of EPA is a long-term, fundamental and applied research program in four areas:

1. **Monitoring Research.** What is the current condition of the environment, and what stressors are most closely associated with that condition?
2. **Process and Modeling Research.** What are the biological, chemical, and physical processes affecting the condition of ecosystems and their response to stressors?
3. **Risk Assessment Research.** What is the relative risk posed to ecosystems by these stressors, alone and in combination, now and in the future?
4. **Risk Management and Restoration Research.** What options are available to manage the risk to or restore degraded ecosystems?

As discussed in Section 2, these four areas have historically been strengths in ORD and will continue to serve as the foundation for research into the future. How this expertise is applied to EPA's needs will change as environmental issues change, but a basic research program will be maintained in each of these major areas. Section 4 discusses how these core capabilities will be used to address high-priority issues over the next few years. Because of the close relationship in the core research and programmatic needs, there is some redundancy in the materials presented in Sections 3 and 4.

The sections that follow provide an overview of the direction of the core research program that will be undertaken over the next three to five years. As a strategy, the intent is to present what work is to be done and why, but not how. The research represents a composite of capability. However, the intent will be to concentrate on continually improving the ability to quantify relative risk to ecosystems and to manage those risks. The research goals for each area and the associated scientific questions are quite broad, as they should be given the mission of the Agency. However, because the capability and capacity of the in-house program is not unlimited, the core research emphasis will be primarily concentrated on water quality improvements (both biological and chemical). Thus in the later sections, a more specific scientific question will be presented that significantly narrows the central aim of the Program.

Additional research strategies and plans to complement both the core and problem-focused research (Section 4) are or will be made available. They provide more detailed information about how the research will be conducted. Table 3-1 lists those research strategies and plans that are applicable to the Ecological Research Strategy and are now being prepared or completed. This information will be useful to the reader seeking a more detailed understanding of the research to be conducted.

Table 3-1.
Companion ORD research plans or strategies to the Ecological Research Strategy.

Titles	Synopsis of the Plan
Endocrine Disruptors	The hypothesis that endocrine disrupting chemicals are causing adverse health in the wildlife and humans remains intriguing. Most of the knowledge and concerns to date have arisen from situations with relatively high-level exposure to persistent organic pollutants or therapeutic use of pharmacological agents. For proper regulatory action to occur, the understanding of the potential scope of endocrine disruption in humans and wildlife must be expanded, including definition of the range of health effects, critical life stages, sensitive species, and exposures relevant to alterations in endocrine function, as well as development of risk management options to reduce or prevent additional adverse effects in populations.
Environmental Monitoring and Assessment Program (EMAP)	This Program develops the science of measuring ecosystem health and monitoring the condition and trends of natural resources at the regional scale. Using the White House Committee on the Environment and Natural Resources (CENR) National Monitoring Framework and interagency workgroups as guides, EMAP supports complementary intramural and extramural Science to Achieve Results (STAR) research programs to develop more cost-effective ecological indicators and to design multiple-tier monitoring methods capable of detecting trends and associating ecological impacts with likely stressors. The indicators and monitoring designs intended to support state-, regional-, and national-level environmental report cards encompass multiple stressors and many resource classes such as estuaries, streams, lakes, wetlands, forests, and grasslands.
Global Change	Based on the findings of the Intergovernmental Panel on Climate Change (IPCC); guidance in ORD's strategic plan; and the priorities specified in FY97, Our Changing Planet by the U.S. Global Change Research Program (USGCRP), ORD will strategically invest in global change research. ORD's Global Change Research Program will concentrate on ecological vulnerabilities of ecosystems to climate change, the implications for human health, and mitigation and adaptation approaches. The research conducted will provide policy makers with information on potential ecological and human health consequences of climate change and technical data needed to evaluate alternative greenhouse gas emission reduction and adaptation approaches.
Waste	The goals of the ORD Waste Research Strategy are to set forth an effective research program to understand and reduce human and ecological exposure to toxic materials released during waste management, and to assess and remediate contamination that has occurred because of improper waste management. These goals are directed toward research on groundwater, soils, and the vadose zone at contaminated sites; on active waste management facilities; and on emissions from waste combustion facilities. Associated technical support activities to assist EPA Program Offices and regions and other stakeholders also are described.

Table 3-1.
Companion ORD research plans or strategies to the Ecological Research Strategy.
(Continued)

Titles	Synopsis of the Plan
Indicator Development	Measuring the integrity and sustainability of ecosystems requires the development and understanding of "indicators" of critical ecosystem characteristics. ORD's strategy for ecosystem protection and the subcomponent, EMAP, place a high priority on the development and implementation of effective measures of important ecosystem attributes. This research plan builds on past research in EMAP and will outline the major gaps in the ability to measure and interpret the integrity and sustainability of ecological resources at multiple spatial scales and to diagnose the causes of impairment. Based on these analyses, ORD will propose the portions of these gaps that will be addressed through research by the EPA ORD staff and prioritize the indicators that should receive research attention through the STAR grants program.
Ecosystem Restoration	An ecosystem restoration strategy and research plan has been prepared and peer reviewed by NRMRL. The strategy develops the rationale for restoring watersheds using an array of rehabilitation and stressor reduction technologies and for providing decision support systems for watershed restoration groups. The Program will be implemented via an in-house competitive proposal approach and participants are seeking partnerships with other ORD investigators in NERL, NCEA, and NHEERL. The Office of Water is included in the proposal evaluation stages to ensure relevancy. On-going and future restoration projects in the regions will be used as appropriate test beds for the developed technologies.
Contaminated Sediments	A contaminated sediment planning group has been convened within ORD to develop a research strategy. In some cases (e.g., sediment quality), criteria development has been an ongoing area of research that will continue. In other cases (e.g., remediation of contaminated sediments), new work has been initiated. In this case, and as a follow-up to the recent NRC recommendation on the subject, NRMRL has engaged the Corps of Engineers in a discussion of joint projects and programs.

3.2 Ecosystem Monitoring Research

Objective: Develop indicators, monitoring systems, and designs to measuring the exposures of ecosystems to multiple stressors and the resultant response of ecosystems at local, regional, and national scales.

Research Question: What is the current condition of the environment, and what stressors are most closely associated with that condition?

With rare exceptions, ecosystem monitoring has been conducted to meet short-term or program specific objectives, and it seldom is coordinated across large geographic areas. Comparable measurements are taken for only a short time (e.g., less than the length of many natural ecological cycles) across a large area, or, when measurements are made over a long period, they usually are restricted to one or a few study sites. Recently, there has been revived interest in creating a multi-agency ecological monitoring network that would monitor the condition of ecosystems and provide periodic "report cards" to the public.

Early experience with EPA's Environmental Monitoring and Assessment Program (EMAP) revealed that there remains a great deal of scientific controversy over what to measure and with what network design. The emerging consensus, based in large part on the ecological risk assessment paradigm, is that indicators of exposure (i.e., the juxtaposition of a stressor and an ecological receptor in time and space at a comparable and appropriate scale) and effect (i.e., the actual change in an ecological receptor, again at a number of relevant and appropriate scales in time and space) should be simultaneously monitored. Additionally, environmental characteristics that modify the exposure/effect relationship (i.e., characterization), as well as exposure indicators that signify the occurrence of a past exposure, perhaps in episodes or cumulatively over long periods of time, also need to be monitored.

With respect to monitoring design, there is also an emerging consensus that a hierarchical, tiered design is necessary. Such a design employs statistical surveys or coarse-scale coverage, using remote sensing to conduct periodic surveillance on large areas, along with more intensive monitoring (both in time and space), occurring at representative sites of interest. Indicators must be adapted to the appropriate tier of monitoring, and yet linked across the tiers.

The monitoring research strategy sets a course to improve monitoring technology in indicators, environmental characterization and network design. It retains a degree of disciplinary concentration (e.g., remote sensing, environmental analytical chemistry, landscape ecology, community ecology) necessary for progress, but it is the goal to insure that the interconnections among the indicators, design, and analysis elements lead ultimately to an integrated solution to a successful national ecological monitoring program.

3.2.1 Indicator Development Research

Monitoring serves multiple functions. It is certainly a tool to assist in determining if there is an environmental problem, and if so, how big the problem is and where it is of most concern. Monitoring is also essential to determine what is causing problems that are of concern and the relative importance of multiple stressors; it plays a role at all levels of the risk assessment process (Figure 1-1). Clearly, these functions of monitoring require utilization of retrospective monitoring (i.e., has a effect already occurred?) and prospective monitoring (i.e., given current or projected levels of stressors, is an effect likely to occur?). Both of these functions of monitoring assist in targeting resources, both resources directed at solving environmental problems and resources expended on research related to environmental concerns. Once decisions about management actions are made, monitoring becomes critical to determining if the decisions and actions resulted in the changes or improvements expected. Central to all of these functions are the decisions about what should be monitored to meet the objectives.

It is clearly impossible to measure all environmental changes, and the concept of indicators is simply an expression of efforts to summarize which elements of environmental change should be tracked and will provide the greatest information return for the least investment. The distribution and intensity of stressors generated by human activities and threatening ecological resources are uncertain. It is not known which stressors place ecosystems at most serious risk. Also unknown is the condition of the resources or the extent to which critical ecological processes are being impaired. There is fragmented knowledge of places with obvious, detrimental impacts but less knowledge about the more pervasive and extensive ecological problems. More limited means exist to sample and to make the measurements that will provide the kind of scientific data needed to understand, predict, and resolve potential environmental threats.

ORD research on indicators must contribute to developing an understanding of the conceptual basis for defining sustainability and integrity for single ecological resources and complexes of ecological resources. What are mechanistic models for these concepts from which can be developed a foundation for monitoring? What are the ecological units of organization for which sustainability and integrity can be described? Are watersheds, ecoregions, or landscapes the ecological units suited for describing sustainability and integrity? Can individual ecological resources such as lakes, streams, forests, or rangelands exhibit sustainability and integrity, or are these concepts applicable only to complexes of ecological resources types?

Sustainability and integrity do not necessarily imply a steady state or a desire to maintain the status quo. Ecosystems are dynamic both in space and time. Recognition of this dynamic character makes the selection of a benchmark or yardstick against which to evaluate current conditions a research challenge. Indeed, this has been the challenge throughout the development of chemical and biological criteria within EPA's Office of Water. When human health is the concern, dose-response studies of individual chemicals form a basis for the development of chemical criteria. The effort to develop similar criteria relevant to evaluating sustainability will be significantly more difficult. Prototypes do exist, and their strengths and weaknesses require careful evaluation.

The goal of the indicators research will be to develop suites of new, field-applicable biological indicators and criteria for measuring, understanding, and diagnosing ecosystem exposures, effects and recovery. An "Indicator Development Research Plan" for ORD that will organize and prioritize the in-house EPA research efforts on indicators is being developed. The ORD indicator plan will be available in the fall of 1998. This plan also will contain a refinement of the indicator development evaluation criteria described by Barber (1994). Therefore, what follows is only a brief summary of the process and areas for research.

3.2.1.1 Indicator Development Framework

Fundamentally, an indicator is:

"any expression of the environment that quantitatively estimates the condition of ecological resources, the magnitude of stress, the exposure of biological components to stress, or the amount of change in condition."

The indicator may be a single value or remotely sensed measurement or it may be an index based on multiple field or remotely sensed measurements. The output of a mathematical model may also be used as an indicator. ORD's four point goal is to identify and select indicators that (1) quantify biological condition relative to integrity and sustainability and quantify the stressors to which the biota are exposed, (2) meet the indicator selection criteria, (3) can be incorporated into one of the three monitoring tiers (index sites, regional surveys, remote sensing), and (4) can be used in ecological risk assessment.

The research plan and the criteria guidelines under development will outline in extensive detail the evaluations to which indicators will be subjected. However, these are five basic questions that must be answered.

1. **What should be measured?** Requires a conceptual model of the system, an evaluation of the potential use of various levels of biological organization, and the classes of stressors that are potentially important for that resource and scale. Table 3-2 summarizes the biological levels of organization that will be considered.
2. **How should the indicator be measured?** Requires that a standard protocol be defined.
3. **How responsive is the indicator?** Evaluating the degree to which a particular indicator actually responds to various stressor gradients at multiple scales, or if a stressor indicator responds to changes in the source emissions.
4. **How variable is the indicator?** The extent to which natural or introduced variability inhibits detection of the signal through the noise and distorts the description of status or the detection of trends.
5. **How can the indicator be used?** Demonstrating the indicator in a monitoring or assessment project to determine how it will evaluate condition, vulnerability or the magnitude of stressors.

Table 3-2.
Levels of biological organization to consider during indicator development with examples of structural and functional aspects of each level.

Structure	Level of Organization	Process
Heterozygosity	Gene	Polyploidy Rate Mutation Rate Recombination Rate
Condition Anomalies/Deformities Maximum Size Tissue Contamination	Individual	Metabolic Rate Growth Rate Fecundity
Abundance Age Class Distribution Size Class Distribution	Population	Reproduction Rate Growth Rate (of Population) Death Rate Evolution/Speciation
Relative Abundance Richness -Native Richness - Total Evenness Trophic Composition Reproductive Composition Habitat Guilds	Assemblage (Community)	Competition/Predation Disease/ Parasitism Mutualism Recovery Rate
Regional Diversity (gamma) Homogeneity Hot Spots Patches Patterns Fragmentation/Recovery	Watershed or Landscape	Water Delivery Chemical Delivery (Native and Exotic) Material Delivery (Sediment, Wood) Energy Flow Nutrient Cycles and Spiraling Population Sources and Sinks Fragmentation Rate/Recovery Rate

ORD will undertake research to develop indicators in two major areas.

- Landscapes (locally, regionally, and nationally)
- Aquatic Systems (estuaries, wetlands, rivers/streams, and lakes)

These will include both “condition” and “stressor” indicators but the balance will vary depending on the state of science in each area.

3.2.1.2 Landscape Indicators

It is becoming increasingly clear that many of the environmental threats today are caused by developmental pressures on the landscape. In many cases, habitat and landscape alterations pose far larger threats to the integrity and sustainability of ecosystems than do pollutants. As a result, ORD has developed a landscape characterization, indicator development and assessment capability to look not only at current conditions but also to document past changes and quantify future ones as well.

The objectives of the landscape indicators research are the following:

- Develop a set of landscape indicators that can be interpreted relative to status and changes in fundamental ecological and hydrologic processes that influence and constrain the sustainability of ecological goods and services valued by society.

- Develop a set of landscape indicators that can be interpreted relative to cumulative stress on areas ranging in size from local communities to regions.
- Determine the interrelationship and associations between cumulative stress and landscape conditions at multiple scales.
- Provide guidance to EPA on the measurement and application of landscape indicators.

The primary emphasis of this research will be on the development and application of approaches to analyze landscape composition and pattern relative to the sustainability of environmental values across scales ranging from local communities to regions. These approaches will take advantage of comprehensive spatial databases that are now available and those being used. High resolution, remote sensing imagery and field data will be used to validate and enhance landscape indicator interpretations. The ability to enhance the interpretation of landscape indicators through collection of finer scale data may also depend on hierarchical relationships among site, landscape, and regional conditions which will also be considered.

Indicators of Human Stress on Landscapes

The primary purpose of this research is to relate indicators of human patterns in landscape to exposure profiles (landscape composition and pattern) of indigenous ecosystems, including as forests, deserts, grasslands, and prairies, as well as larger systems, including watersheds. Correlations or linkages between human patterns and exposure profiles of landscapes provide a way to evaluate how human settlement in landscapes influence fundamental ecological and hydrological processes, because changes in landscape composition and pattern are tightly coupled to fundamental ecological processes.

Indicators of Landscape Condition and Vulnerability

If landscape composition and pattern indicators are to be used to evaluate the vulnerability of ecosystems at many scales across a region, they must be linked to ecological conditions at one to several scales. Therefore, the following areas of research will be undertaken.

Habitat Suitability and Landscape-Level Biotic Processes. Status and changes in landscape composition and pattern have significant consequences for plants, animals, and entire biotic communities, primarily through alteration of the amount and spatial pattern of suitable habitat. Changes in suitable habitat influence landscape-level processes of plant and animal metapopulations, including immigration, emigration, and population sizes; these in turn influence species' vulnerabilities to (probabilities of) extinction. The primary purpose of this research is to evaluate the degree to which certain landscape indicators co-vary with habitat suitability of species that interact with their environment at different scales. Moreover, the research will determine if critical thresholds exist between landscape indicator values and habitat suitability. If successful, this research will permit an assessment of vulnerability of certain habitats due to human-induced changes in the landscape. It also should facilitate an assessment of species extinction probability (vulnerability) through the use of landscape indicator input into metapopulation extinction models.

Water Resources and Hydrologic Processes. An increasing number of recent studies have suggested that landscape composition and pattern influence water quality, the biological health of streams, and the risk or vulnerability of watersheds to flooding. The primary purpose of this research is to evaluate the degree to which indicators of landscape composition and pattern co-vary with the water quality, stream biotic condition, and watershed vulnerability to flooding. An understanding of these relationships permits an assessment of the vulnerability of hydrologic processes to significant impairment due to human-induced landscape changes, as well as underlying landscape conditions (e.g., soils, topography) and biophysical processes (e.g., climate). This activity will include research to determine the role of riparian habitat in landscape-water interactions, and evaluation of critical threshold values of landscape indicators with regard to the quality of water resources.

Terrestrial Productivity. Status of and change in landscape composition and pattern have direct implications for potential vulnerability of terrestrial ecosystems to losses in productivity, especially in those situations where human pattern and uses influence soil loss. Soil loss reduces the ability of an area to sustain productive forests, rangelands, and prairies. It also results in increased need for fertilizers in agricultural landscapes, which can decrease farm profitability (and hence, farm sustainability), and results in decreased surface and ground water quality, as well as stream biotic conditions. The primary aim of this research is to develop and test landscape indicators, that when coupled with soil loss models, estimate the spatial variability of soil loss potential within and among watersheds. Within watershed analysis permits an assessment of the spatial variation of soil loss across a watershed, as well as an assessment of the vulnerability of streams to degradation due to soil loss. Other indicators, such as changes in the Normalized Difference Vegetation Index, will be evaluated relative to terrestrial productivity vulnerability. This research also will determine if critical thresholds exist between landscape indicator values, soil loss, and losses in overall productivity.

Effects of Data Properties on Landscape Indicator Interpretation

This research concentrates on two areas that can affect the interpretation of landscape indicator values relative to vulnerability analysis:

Statistical Properties of the Data. There are a number of properties of landscape data that influence the ability to interpret landscape indicators relative to landscape condition and vulnerability. These properties include the number of samples (in land cover maps, these can vary from a few hundred to several million), the number of attributes (e.g., land cover classes), and the scale dependency. This research will test approaches to reduce losses in interpretative power of landscape indicators resulting from statistical properties of the primary data.

Sensitivity of Landscape Indicators to Misclassification in the Data. Interpretability of landscape indicators is influenced by sensitivity of individual indicator to misclassification embedded within land cover and other primary spatial data. Moreover, many landscape indicators are calculated by overlaying different spatial coverages; for example vegetation (land cover data) adjacent to streams (digital line-graph data). This research will develop and test protocols to understand the influence of misclassification of spatial data on landscape indicators.

3.2.1.3 Aquatic Indicators (Estuarine, Wetland, Rivers/Streams, and Lakes)

The traditional focus of the Agency has been on aquatic resources, and the ORD research strategy reiterates this priority in its setting of goals for ecosystem protection. Indicators for estuaries, wetlands, rivers/stream and lakes are in a similar stage of development. The movement toward biocriteria within EPA and the States has pushed the use of biological indicators as tools needed to compliment the existing measures of physical and chemical integrity that have traditionally been used. The objectives of the aquatic indicators research are to:

- Develop a set of indicators for estuarine, wetland, riverine, and lake systems that can be interpreted relative to status and changes in fundamental ecological and hydrologic processes that influence and constrain the integrity and sustainability of these systems.
- Develop a set of aquatic indicators that can be interpreted relative to cumulative stress in areas ranging in size from local communities to regions.
- Develop a set of aquatic indicators that can be used to quantify the extent of chemical disturbance, physical habitat alteration, hydrologic alteration, and biological perturbations such as introduction of exotic species and overstocking/overharvesting.
- Determine the interrelationship/associations between primary stressors in aquatic systems (i.e., chemical, hydrologic, habitat and biological alterations) and aquatic conditions at multiple scales.
- Provide guidance to the Agency on the establishment of “expected conditions” for aquatic indicators of condition and stressors.

Community/Assemblage Level Indicators

The community or assemblage level of biological organization has emerged as the dominant level at which effective indicators of integrity and sustainability are being developed. This suggests that aquatic communities are a good reflection of the cumulative effect of the various stressors to which they are exposed. With a few exceptions, the species have moderate to rather short generation times and thus allow us to identify and react to problems before they become irreversible.

Most of the community- or assemblage-level indicators in aquatic systems come from analysis of the fish, benthic invertebrate, or algal communities. The sampling methodologies are reasonably well established, although they require greater quantification as to the amount of variability associated with the sampling process. Establishment of expected conditions for assemblage-level indicators will consume and extensive amount of the effort in aquatic indicator research. These "expectations" respond to a variety of natural drivers, and these must be accounted for in establishing the indicators. For example, a common metric in fish indices of integrity is species richness. Species richness in lake fish assemblages naturally varies with watershed area. Thus, an indicator with this measure must account for these natural differences. Similarly the benthic community in estuaries varies naturally with substrate type and salinity. Without an ability to include consideration of these types of natural drivers, an effective indicator will not be possible.

An added aspect of our research on aquatic indicators will be the consideration of the necessary suite of indicators for effective monitoring programs. For example, what is the added value of monitoring the fish assemblage, macroinvertebrate assemblage and periphyton assemblage? Each community of organisms has different life cycle characteristics and responds to slightly different stressors. This type of sensitivity analysis will be important in developing recommendations for aquatic indicators.

Molecular Indicators

Tools of chemistry and biology are able to be used in the ambient environment to quantify stressor-induced changes at the organismal level and below. Linkages, direct or indirect, continue to be made between stressors and these changes. Directly, chemical stressors may be detected and quantified by their covalent binding to biological macromolecules (e.g., DNA and protein [hemoglobin]) or by the appearance of parent compounds or their metabolites. Indirectly, chemical stressors may be detected by the appearance of induced biochemical structures, lesions or disease, brought about only by past exposure to specific stressors and occurring only after the progression of a cascade of cellular events. Although these changes may be detected at the molecular level, they may be interpreted at biological levels above that of the organism (e.g., reduced variability in DNA fingerprints of fish may indicate vulnerability of the population to further exposure). Besides the indication of chemical stress, molecular indicators can indicate habitat changes or act as indicators of ecosystem vulnerability (e.g., changes in sediment microbial metabolic activity indicate a vulnerability of the sustainability of stream integrity). Molecular indicators have been developed in the laboratory and are being validated in the field recognizing the importance of additional sources of variation in the ambient environment.

Specific areas of molecular indicator research include:

- **Biochemical indicators.** Measuring changes in cellular processes or structures after stressor exposure.

- **Toxicological indicators.** Improving toxicity tests which parallel the environmental conditions known to exist in areas that are the focal point of exposure characterization.

- **Genetic indicators**. Measuring heritable molecular structure of organisms and DNA and its RNA transcripts present a number of indicator- development opportunities that will be pursued including (1) indicators of genetic toxicity, (2) changes in the level of specific gene expression, and (3) fingerprinting DNA.

3.2.2 Monitoring Design Research

It is clear that we cannot monitor everything, everywhere, all the time. Historically, we have monitored an individual location because of our interest in that particular site, a point source discharge location or high priority resource. In doing so however, we have seldom given serious thought to how well we can actually detect the signal of environmental disturbance we are seeking and whether or not we will actually be able to identify a change, if it occurs, that is the result of our management action. We are even more in our infancy in monitoring large geographic portions of our country. In addition to lacking indicators, we have lacked any serious attention to the design of monitoring approaches that can describe the status of large regions and actually allow us to detect changes and trends. Our research in monitoring will range from the fundamental elements of taking measurements at the local scale to the designs necessary for describing status and detecting trends over large geographic areas. Our monitoring research will culminate in regional and national demonstrations which bring into light the results of our indicator development, monitoring design research, and process understanding research, and then apply them in regional assessments.

Most monitoring systems start fundamentally with "plot" measurements (i.e., the measurements or samples taken at a particular point in the environment). The "plot" measurement design is closely linked with the development of the particular "indicator" and the scale at which it is appropriate. This has variously been referred to as the "plot scale" protocol or the "response" design or "site" measurement design. It ranges from how one chooses to represent and sample a particular point (e.g., such as an air sample for chemical analysis), a small area of a resource (e.g., a stream "reach") or a different scale (e.g., a landscape viewed through remote imagery). Examples would be the plot design one uses to collect an effective representation of the fish assemblage structure within a stream, or the design one uses to collect "wet" and "dry" deposition at a location, or a sample of chemical contaminants in soil from a site.

A second element of monitoring systems design research relates to the way in which samples from multiple "plots" are aggregated together for an assessment across a broader geographical area. This may still depend upon the scale of the question of interest. For example, it may be of interest to characterize the extent and magnitude of soil contamination within a Superfund site which is still a relatively local scale, or the question may relate to the best design to use for selecting stream reaches in order to sample when the end result is supposed to be aggregated, and then to answer questions about the length of stream which is impacted within a state or EPA region.

Whatever the scale of interest, it is important to consider the entire "monitoring process" as the system of interest. Variability which will ultimately impact the assessment process can be introduced at several levels, starting with the design process itself (uncertainty in the source information used to develop the design, e.g., maps of stream reaches), the sampling (temporal and spatial variability at the sample location, crew errors, variability in implementing the field protocols), the sample processing and analysis (variability in analytical methods, variability in identification of biota), the sample aggregation process (combining data from multiple locations, e.g., a random sample from all possible streams that could have been sampled) to the data analysis phase.

Within ORD, the Environmental Monitoring and Assessment Program (EMAP) serves as the focal point for our monitoring research. EMAP is an ORD-wide program geared toward providing improved monitoring capabilities for regional and national scale assessment questions. The research on monitoring designs required to make EMAP successful are developed in more detail in the 1997 EMAP Research Plan.

3.2.2.1 Ecological Monitoring Research

The federal Committee for the Environment and Natural Resources (CENR) has proposed a national monitoring framework that recognizes the importance of different approaches to monitoring, from intensively studied, hand-selected sites, to regional and national probability surveys, and finally remote sensing where a complete census can be derived. The most significant aspect of this framework is that remote sensing, regional surveys, and site-specific monitoring should be coordinated, allowing the full range of integration that has so far been impossible. All three types of monitoring identified are essential for an integrated environmental monitoring capability. While key elements of the CENR framework can be put into place now, additional research will be required before complete implementation is possible. Within each of the three tiers described, research must be conducted at appropriate scales to improve survey and monitoring methods, to understand our ability to detect and interpret meaningful changes that are observed, and to link these results in the development of descriptive or predictive models. Research on our ability to determine cause and effect must integrate information on processes that occur across the range of scales from large regions to individual sites. Additionally, we must explore methods of designing each of these approaches such that they can be integrated and allow additional information to emerge that might not otherwise be available. ORD has already demonstrated this through a monitoring approach for detecting trends in aquatic systems which are sensitive to acidic deposition. This type of research must be extended to other systems and other types of stressors.

Specific objectives within this phase of research are:

- Develop plot scale designs for effective local monitoring to describe status and detect trends in local conditions.

- Develop survey designs for describing status and trends in regional populations of lakes, streams/rivers, wetlands, estuaries, and landscapes.

- Develop a process for determining the power of specific designs for detecting trends of varying magnitudes.

Atmospheric Monitoring. Increasingly, the chemical contaminants which were entering the biosphere via point sources are now being introduced via non-point source emissions. “Non-point source emissions” was, for a period, synonymous with the distributed introduction of chemicals overland into our water resources. More recently, we have become aware that many chemicals are also being introduced to the atmosphere and being transported locally and globally. They are returned to aquatic and terrestrial systems via wet and dry deposition. Research will concentrate on dry deposition estimates of nitrogen and sulfur, UV-B monitoring, and improvements in air toxics, ozone, and metals monitoring.

Soil and Sediment Monitoring. Soils and sediments represent a three-dimensional matrix that is extremely heterogeneous in each of its dimensions. As concerns increase about the safety of our water supplies in aquifers, the storage of contaminants in sediments of lakes, rivers and estuaries, and the viability of our soils for future production, it becomes more important to improve our ability to characterize this multi-dimensional matrix.

Aquatic Systems Monitoring. Extensive work has been devoted to our ability to characterize small streams that dominate the landscape in terms of their length and distribution. We have made significant advances in our ability to monitor the chemical, physical and biological quality of these systems. However, we have paid relatively little attention to larger riverine systems and how best to characterize any specific segment of a large system either from a chemical, physical or a biological perspective. Given our reliance on these systems for commercial fisheries, drinking water supplies and navigation sources, we must change this state of knowledge.

Survey designs, which can be applied to extensive aquatic resources such as wetlands and estuaries, are also a priority for research. The local variability within these systems, as well as the population or regional level of variability, are poorly understood. Quantification of these aspects of variability is essential before future designs can be recommended confidently.

Landscape Monitoring and Characterization. Landscape characterization documents the composition and spatial relationships (patterns) of ecological resources, including forests, streams, estuaries, urban environments, and agricultural and rangelands over a range of scales as it relates to ecological condition and resource sustainability. The approach also considers the spatial pattern of other biophysical attributes, including geology, climate, topography, hydrology, and soils, because they often influence or determine landscape composition and pattern, and the sensitivity of ecological resources to stressors within any given area. The goal of this research and coordination will be to develop comprehensive, consistent databases of the nation’s landscapes, resources, and physical features at multiple spatial and temporal scales.

3.2.2.2 Integration of Monitoring Approaches

Given the increased importance of understanding our actions over broad geographic regions, improved network design is a major research issue. Monitoring designs most often are directed at narrowly defined problems and are seldom explicit in terms of quantifying bias, predictive power, or value to a concept for holistic risk assessment. In the United States, there are dozens of intensive study sites and hundreds of specialized monitoring sites nationwide with no unifying scientific concept to integrate data. Monitoring data cannot often be aggregated to answer larger questions.

Specifically, the objectives of this research are:

- Develop approaches for integrating different types of monitoring, including probability surveys, remote sensing, and data from hand-selected sites.
- Estimate on a regional basis, with known confidence, status, changes, and trends in landcover.
- Estimate on a regional basis, with known confidence, status, changes, and trends in condition of estuaries, streams/rivers, and wetlands.
- Estimate on a regional basis, with known confidence, status, changes, and trends in condition of landscapes.
- Seek associations between indicators of condition in aquatic resources and landscapes and indicators of natural and anthropogenic stressors.

ORD will stimulate an effort aimed at improving multi-tier designs and engaging design specialists in all agencies. Key areas in this research will be the evaluation of the role of sample surveys (statistical or probability based surveys) in characterizing ambient stressor and condition information both for estimates of status (current situation) and trends.

Within terrestrial monitoring agencies, sample surveys are a standard operational tool. Within the aquatic monitoring agencies sample surveys are almost unheard of as a standard tool. The historic reasons for this are important. We have traditionally monitored aspects of terrestrial systems which are of economic importance (e.g., crop production, availability of timber for harvest). Historically, we have relied on rigorous statistical estimation when financial resources are of concern, hence the use of rigorous surveys. We have not historically viewed aquatic systems from the same perspective in spite of their obvious economic importance. Additionally, aquatic monitoring comes predominantly from a background of concern about point-source discharges of pollution. This naturally leads to more localized designs and an upstream/downstream monitoring perspective. As we acknowledge the importance of non-point source pollution and other stressors to aquatic systems as well as the geographic breadth of our concerns, we need to evaluate more applicable monitoring network designs.

This area of research will focus on advancing our understanding of survey designs for monitoring inland aquatic, estuarine and wetland resources as well as landscapes. The options available for monitoring status, trends or blending the needs of both will be evaluated. The concern will also extend to differences in survey design approaches for extensive resources such as estuaries, linear systems such as streams, discrete resources such as lakes, and wetland systems which have elements of each of the above characteristics.

The Mid-Atlantic Region will serve as the first demonstration project for pulling these monitoring efforts for aquatic resources and landscapes together in conjunction with indicators of stressors that may be impacting these systems.

In support, there will be an expanded environmental statistics research program. There are very specific aspects of environmental statistics that require research for improving our monitoring capabilities. We know that there are both spatial and temporal dimensions to the environmental characteristics that we will choose to monitor. There is also a great deal of both natural and introduced variability in the resulting picture that we develop. At the interface of indicators and monitoring design is the need to develop a process or framework for measuring, describing and understanding these dimensions of variability. In some cases, the monitoring system can be designed to minimize the extraneous or introduced variability, in other instances such as natural dimensions of variability we cannot minimize it, but we can describe it so that we understand how it clouds our ability to describe status and detect trends. This framework for evaluation of variability has begun with the Environmental Monitoring and Assessment Program (EMAP) and can be expanded to other research efforts within ORD and expanded within EMAP. This is truly an integrative area linking our indicator research and monitoring design research, and impinging upon the risk assessment products that can be developed. This area of research will require extensive evaluation of indicators over broad geographic regions, as well as temporally within and across years. The variability analyses that results from these data will then be brought to bear on evaluating monitoring design options for programs being developed within ORD and other parts of EPA and the States. Research will include:

- The development of designs and composite estimators for surveys over time, should lead to improved efficiency of estimation and hence reduction of cost for conducting large-scale status and trend monitoring.

- Statistical models, which improve the spatial-temporal linkages of information from intensively monitored, hand-selected networks and probability survey, have received little attention to date and will be a key goal of research on streams in the Mid-Atlantic.

- The accuracy of remotely sensed data for evaluating the reliability of our monitoring of changes in landcover and landscapes will be assessed.

- Methods for analysis of massive data sets from remote sensing platforms must be developed to reduce the time between acquisition of data from the satellite and availability of product. Given that changes in land cover are among the most significant stressors in impacting ecological resources, the length of this delay must be resolved soon.

- A concentration on spatial statistics and analysis must result in the development of new data analysis tools to help describe, understand, and interpret environmental data over large regions and capture its critical spatial characteristics.

3.2.3 Anticipated Products

- **By 2000,** make publicly available digital land cover data for a baseline period (1990/1993) and all Regions from which changes in land cover can be accurately and quantitatively documented.

- **By 2001,** complete an evaluation of a multi-tiered, ecological monitoring system for the Mid-Atlantic Region of the U.S. and its applicability to other areas of the country.

- **By 2002,** publish a design and guidelines for establishing multi-tiered monitoring systems capable of assessing, optimally, the current and long-term trends in the exposure to, and condition of, ecosystems at multiple geographic and temporal scales.

3.3 Ecological Processes and Modeling Research

Objective: Develop the models to understand, predict, and assess the current and probable future exposure and response of ecosystems to multiple stressors at multiple scales.

Research Question: What are the biological, chemical, and physical processes affecting the condition of ecosystems and their response to stressors?

Process and modeling research develops the basic understanding and modeling technology to predict future landscapes, stressor patterns, ambient conditions, exposure profiles, habitat suitability, and probable receptor responses as a function of risk management alternatives. Future models will consider multimedia, multipath sources, intermedia pollutant transfers, transport and transformations, microenvironments, and receptor activity patterns in the context of anticipated regional changes resulting from both natural and anthropogenic causes.

To estimate the distribution of exposure to multiple stressors across vulnerable ecosystems, there is a need to understand and quantify the governing processes and develop models linking sources, transport, and transformations of pollutant stressors, along with physical stressor predictive models to estimate exposures at appropriate temporal and spatial scales. These models also must be linked to landscape models to characterize future environments and habitats. In addition, ties to appropriate suites of biological response models are essential to the risk manager, because often the goal is to forecast the response of receptors to management actions.

For convenience and simplicity, current models used to predict the outcome of any individual management option are generally single media, involving only a single pollutant or stressor. Modeling must move past this piecemeal approach and represent the interactions that occur across scales, media, stressors, and multiple levels of biological organization (Figure 3-1). The complexity of the problems that EPA will face in the future will require models to predict beyond today's physical and chemical conditions to new, never-before-measured conditions. Therefore, future models need to be based as closely as possible on first principles. They need to be sufficiently complex in their description of the underlying processes that they become virtual realities. By doing so, scientists can best advance the understanding of the whole of the environment and develop anticipatory and more flexible management strategies that avoid unwanted results. It is envisioned that future models will be interrogated as virtual realities in the same way engineering tables and interactive CD-ROM encyclopedias are used today.

The next generation of models developed by ORD to predict exposure to and the effects of multiple stressors on ecosystems will be based on:

- Developing a "community"-accepted systems approach (a common framework) to support multimedia and multistressor modeling, both within and outside of ORD.

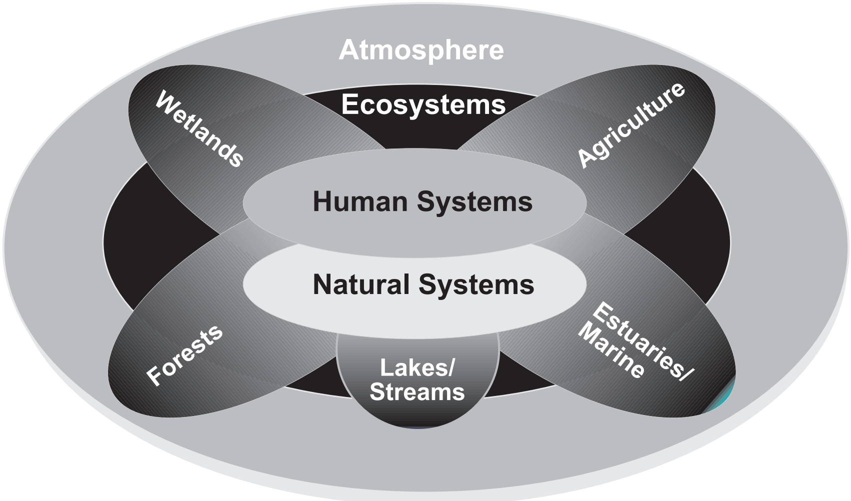

Figure 3-1.
Interactions across scales, media, stressors, and multiple levels of biological organization to be considered in multimedia processes and modeling research.

- Developing state-of-the-science process algorithms and component computational models with flexible scaling to provide problem-solving methodologies that are applicable at multiple geographic and temporal scales and, therefore, are useful to environmental managers locally, regionally, and nationally, and for critical event, daily, seasonal, yearly, decadal, and longer timeframe assessments.

- Systematic development and incorporation of state-of-the-science atmospheric, terrestrial, aquatic, and biotic compartment stressor and effects models necessary to predict real world conditions into the common framework.

- Improving the ability to interconnect, "cooperate," and exchange information in one system (e.g., the atmosphere), with another system (e.g., surface water ecosystems) with a different framework.

3.3.1 A Common Framework for Multimedia Exposure and Integrated Effects Modeling

Historically, three distinct classes of assessment problems at EPA independently have set the stage and defined the needs for an integrated multistressor, multimedia, multipathway stressor exposure modeling system:

1. Regional air pollutant exposure assessments (e.g., acid deposition).
2. Watershed pollutant, temperature, and sediment assessments (e.g., non-point source best management practice [BMP] strategies, total maximum daily loads [TMDLs], and water-quality-based permits).
3. Groundwater system threat assessment (e.g., hazardous waste sites permits and pesticide management plans).

The latter two problem classes involve the direct interaction of the land surface with the hydrologic cycle producing runoff of water and eroded soil (and related pollutants) to and through surface water ecosystems (fresh and estuarine) and the percolation of water and related pollutants to and through groundwater systems. Both are directly impacted by human activity (intensity and location) but also are linked naturally to atmospheric processes and forcing functions.

In addition, the development of regional atmospheric pollutant fate and exposure models launched ORD into the high-performance computing age. Although limited in multimedia scope, the early regional models had to address the atmospheric gas phase and the atmospheric cloud water phase, accommodate biogenic emissions from the terrestrial component, and account for removal by rain and by dry interaction with the land surface and vegetation.

Since 1992, the computational aspect of modeling in EPA has become state-of-the-art. ORD developed a prototype, air-oriented environmental modeling framework, Models-3, that contains data and model management, data processing, parallel and cross-platform computing, and output visualization and analysis capabilities that generally are applicable to a variety of environmental assessment yields. Models-3 is an obvious starting point for a broader multistressor, multimedia model framework development effort. This next effort will be called the Multimedia Integrated Modeling System (MIMS).

The objectives of developing MIMS are to:

- Foster and establish a "community approach" to a multistressor, multimedia, multiscale environmental modeling system involving federal agencies, research institutes, and academia.
- Foster active participation in the community development of scientific, technical, computational, and procedural guidance to facilitate the formulation and development of interoperable environmental modeling systems, interchangeable science process components, and network-accessible environmental data repositories.
- Construct and maintain an open-architecture software system that enables (1) data access and management; (2) development, linkage, and execution of simulation modules at various spatial and temporal scales; and (3) visualization, analysis, and interpretation of model outputs across a full range of computing technologies from desktop PCs to scalable, parallel supercomputers across networks.
- Formulate and develop state-of-the-science process and component modules that can serve as the fundamental building blocks for framework implementation.
- Develop innovative techniques to resolve spatial and temporal mismatches encountered in multiscale, multimedia modeling, including tight integration of geospatial analysis and environmental process simulation.
- Develop efficient computational approaches to meet increased demands of complex, multiscale, multimedia, multidimensional environmental models.
- Develop dynamic, intelligent computer interfaces to assist users in access and synthesis of data, information, and knowledge related to environmental assessment issues. This includes model parameterization, uncertainty/sensitivity analysis, and innovative output techniques for visualization, multivariate analysis, and interpretation.
- Ensure appropriate framework links are available to ecological receptor effects databases, microenvironmental and effects databases, activity pattern databases, and socioeconomic, demographic, and climatic predictive forcing functions to assemble relevant, problem-solving methodologies using the framework.

3.3.1.1 Framework Development

As indicated in the previous section, development of an integrated community framework for multistressor, multimedia, multipathway exposure (and risk) assessment modeling, and eventually, effects modeling as well, is needed (1) to take advantage of rapidly improving computer software and computational capabilities, (2) to provide a standardized, less duplicative, more efficient assessment platform that is accessible by a wider range of environmental assessors and managers, and (3) simply to cope with the expanding scope of emerging environmental management and remediation problems.

The approach will be to exploit and expand the software features of the Models-3 prototype into the general framework and to incorporate developmental and existing media computational models, themselves to be systematically upgraded with respect to their process descriptions (i.e., transport, transformation, sources, and sinks algorithms), in a phased manner based on application priorities and resources availability.

The overarching longer-term objectives for the framework development were provided in the previous section. Shorter-term objectives include:

- Plan and conduct a comprehensive, multimedia, multistressor ecosystem exposure assessment case study on a selected subregion of the Mid-Atlantic Integrated Assessment Area (MAIA) to provide a rapid prototype focal point for framework development.

- Write draft coding guidelines for community review and acceptance, with emphasis on code and data set integration.
- Obtain general use and distribution licensing for software for framework development.
- Develop a data dictionary for those data shared by the media-specific modules anticipated for use in the ecosystem exposure assessment case study.
- Evaluate and revise the Multiple Resource Land Cover (MRLC) database for use in the ecosystem exposure assessment case study.
- Phase in, as rapidly as possible, the integration into the framework of media/component modules anticipated for use in the ecosystem exposure assessment case study.
- Start simple linkages with to-be-selected predictive meteorological and land use change models for the ecosystem exposure assessment case study (incorporate socioeconomic drivers to the extent possible).
- Address spatial and temporal mismatches for those modules to be used in the ecosystem exposure assessment case study.

The following research will be areas for the further development of the framework.

Atmospheric-Terrestrial Interaction

Water exchange is the principal basis of pollutant transfers and subsequent transport. Gases and aerosols can be stored and freely exchanged between the atmosphere and the biosphere. Modeling these reservoirs and fluxes requires an intricate understanding of many different processes, including bacteria, plant physiology, micrometeorology, and biochemistry. Biogenic processes, many of which are perturbed by anthropogenic activity, can cause emissions of volatile organic compounds (VOCs) from vegetation; nitric oxide, nitrous oxide, carbon dioxide (CO_2), and carbon monoxide (CO) from bacteria in soil; methane from wetlands; and sulfurous compounds from water bodies. Biological processes also can transform, reroute, and reschedule the exposure pathways of anthropogenic compounds such as dioxin, mercury, and nutrients. In addition, plant matter can store many pollutants, which then can be either ingested by animals or rereleased into the environment. Because these processes involve several compartments and media (water, air, soil, vegetation, bacteria, and other living organisms), requiring an understanding of complex processes and interactions, developing net flux and other transfer linkages between compartmental models will continue to be a long-term research challenge for the framework development. The initial emphasis will be on those compartment modules needed for the multimedia, multistressor ecosystem exposure assessment case study within MAIA. Flux rate, transformation, sorption, and other process algorithms will be developed/upgraded for the needed component modules, based on the research described below.

Spatial Scales

The nesting feature of the Models-3 prototype computational framework already can handle a wide variety of spatial scales. However, the environmental process modules and databases have a much more limited range of applicable spatial scales. Resolving the incompatibilities in the spatial scales of different processes is a significant research area requiring additional process understanding for each media/compartment. Sub-grid scale features must be handled within current science formulations; however, process formulations typically are based on site measurement studies that may not represent the full texture and complexity of the grid scale modeled. For example, dry deposition formulations based on single land use type in a grid cannot represent the deposition resulting from heterogeneity resulting from its actual multiple land use. Transport processes (such as those involved in convective turbulence or clouds) are known to be scale-specific, but their formulations may be inadequate for the modeling of wide scale ranges. Linkages between atmospheric processes and between atmospheric and land/water surfaces may be crucial for accurate simulations of pollutant concentration and deposition fields. However, process formulations often are oversimplified, and the resulting linkages are poorly or inadequately modeled. Most of these spatial scale issues must be handled within the various compartment transport modules (e.g., air, lakes, estuaries, watersheds, etc). The first framework scalar issue is likely to be the ecosystem exposure assessment case study within

MAIA, particularly if the selected subregion problem involves nitrogen and estuaries.

Temporal Scales

Time scales for modeling ecosystems extend over a vast range, from seconds and minutes for chemical processes to minutes to hours to daily to seasonal for atmospheric and hydrologic transport and deposition processes, and to decadal and beyond for ecosystem response to bioaccumulation and climate and land use change. The linkages among the media components, whose processes often operate on vastly different time scales, must be recognized, and suitable operational techniques developed and implemented in the framework to deal with those mismatches. The degree of direct process coupling (e.g., wind and wave/currents, toxic exchanges between air and water, etc.), versus linking of module outputs and inputs for the different media also needs to be examined and optimized. The first practical attempts to deal with this problem will be the ecosystem exposure assessment case study within MAIA (i.e., for the compartment modules to be integrated within the framework for that study and the human health case study).

Grid Structure for Coupling Processes/Models

The underlying computational grid structure used to simulate physical, chemical, and biological processes in two or more dimensions is dependent on the nature of the process, the underlying assumptions of the scientific theory, and the computational approach. Therefore, underlying grid structures may vary with each process, both within and across media/compartments. To facilitate the transition from one-dimensional models toward higher dimensional models with spatial and temporal coupling at either the process or module level, there must be a tight coupling of science process models with geospatial analysis techniques to enable interprocess exchange of data.

Another major difficulty with many multimedia models is the labor-intensive nature of the input data preparation because of the type, complexity, and spatial variability of the required input data, especially where unstructured, irregular grids are involved (e.g., in estuarine and large lake hydrologic and pollutant transport module boundary conditions). Embedded spatial analysis capabilities can reduce the burden involved with preparing spatially and temporally varying input data for models. For the framework development process, this will become a very acute issue as river, lake, and estuary compartment modules are integrated therein.

Databases

The initial concentration on databases relative to the framework will be to identify those needed for the ecosystems exposure assessment case study. Once identified, a data dictionary must be developed, and code guidelines established and implemented to facilitate their access and use. There are some obvious candidates. Another critical linkage required is to pollutant transport and transformation parameter databases and computerized estimation systems. Development of these estimation techniques is discussed under Section 3.3 of this strategy.

3.3.1.2 Integrating Exposure and Effects Modeling

It is important to ensure that the developmental exposure assessment framework will possess the appropriate linkages to ecological effects databases and models for all levels of biological organization. This includes habitat suitability in the broadest sense for terrestrial, surface water-sediment, and soil-subsurface environmental compartments. Another concern is the activity-ranging patterns and predator-prey interrelationships needed for food-web exposure and impact analysis and the habitat suitability assessment for key ecological species and populations.

Some of these connections will be more definitively identified and implemented at the media component level in support of selected "community-based ecoprotection" projects (see Figure 2-2). More detailed connectivity identification will be a feature of the integrated, multistressor, multimedia ecosystem exposure assessment case study within the Mid-Atlantic. Once the case study has been completed, and expanded framework development and implementation is initiated, those effects models and databases found to be most useful for general "risk characterization-assessment" will be linked to the framework.

Specifically, the objectives of this research are to:

- Develop state-of-the-science, tailored, linked, compartment and multimedia exposure-risk assessment frameworks in support of selected community-based ecoprotection efforts and case studies, and assist in their field testing and application.

- Identify and establish appropriate links for general effects databases and models, such that the developmental framework can address both pollutant and nonpollutant stressors, including habitat alteration/loss, climate change, etc.

- Ensure socioeconomic drivers and climate change are accounted for relative to predicted land use change and habitat alteration, both terrestrial and aquatic, within the framework.

- Focus special attention on the development of and linkage to a spatially distributed watershed response model as a major required new component model for multimedia, multistressor eco-risk characterization, assessment, and restoration design and as a framework element.

- Test these developmental compartment risk assessment modules and especially the prototype multimedia, multichemical, multipathway ecosystem risk assessment module for restoration design, watershed diagnosis, and regional ecosystem assessment and rule-making, via application in South Florida-Everglades and the MAIA ecosystem exposure assessment case study and subsequent regional assessments.

The main areas are the integrated exposure-effects compartment models needed for the Mid-Atlantic assessments and their development and implementation. Habitat change and suitability predictive modeling are other areas that will be pursued in the context of demographic development, socioeconomic, and climate change forcing functions. The long-range goal involves the systematic and phased integration of these linked, compartmental models and databases into the general framework.

Multiscale Modeling

Answers and knowledge requirements about stressor exposures and habitat alteration, and the resulting ecological responses, are required for different temporal, spatial, and ecological scales. A great range of scales must be considered in the context of local and regional decision making. A region such as the Mid-Atlantic is at mid-scale, encompassing scales of local concern and thereby providing a context within which local-scale problems can be considered. At the other end of the range of scales, global changes (both climatic and other human-induced changes) affects regional and larger scale processes. The uncertainty in climate change and development-demographic projections makes predictions of regional changes more difficult. Problems often occur in attempting to apply knowledge gained from studies at a given scale to a very different scale, such as the routine application of a process description developed in a laboratory setting to a field-scale projection. The major difficulty to be overcome is whether any description used is an adequate model of the process as it functions in the environment, where influencing factors cannot be controlled. ORD will bring many such scale problems to the fore and prepare for greater research effort to be directed to the application of tools developed for local-scale, or even scale-free, generic applications to subregional and regional ecosystem assessments.

The integrated goal is to determine how regional ecosystems are vulnerable to socioeconomics/ demographics, land use change, climate change, habitat alteration, modifications to ecosystem structure and diversity, and other large-scale environmental perturbations such as mercury, acid deposition, pesticides, or eutrophication. The primary goal will be on methodology application to the Mid-Atlantic and Southeastern United States. Results of this work will permit advances in regional- and state-level vulnerability assessments and national-level integrated assessments. This will enhance EPA's ability to develop realistic bounds on the nature and magnitude of the vulnerabilities identified and to assess the costs of mitigation and adaptation strategies, particularly where habitat, chemical, climate, and management stressors interact.

Model Coupling

Model coupling will be performed at all scales and for all ecosystem endpoints of concern through the general multimedia modeling framework previously described. In the framework developmental-transition period, model coupling, which links related ecosystem impact assessment modules, will be at the watershed and site scale. Prototype component/media ecosystem assessment models already exist at watershed, large lake, estuary, and site scales. These will be updated with respect to stressor exposure algorithms, effects, and activity database linkages and impact assessment modules during the transition period (two to five years), and then incorporated into the general framework in a planned, phased approach.

3.3.1.3 Anticipated Products

- **By 1999,** provide updated methodologies and models for regional ecological exposure assessment.
- **By 2001,** complete development of ecological models for regional vulnerability assessment. Publish significant research findings from mesocosm experiments, field studies, and modeling studies on reducing global and transboundary risks.
- **By 2004,** complete exposure assessment of ecosystem vulnerability to pesticide contaminants over regional scales. Recommend, evaluate, and adopt a modeling architecture for integrating atmospheric, terrestrial, and aquatic exposure and effects models.
- **By 2004,** develop and demonstrate a multiple pathway, multiple chemical model that integrates human health and ecological cumulative exposure and risk assessments.
- **By 2005,** develop advanced measurement, computing, modeling, and data management technologies, and integrate them into an effective system for real-time delivery of multimedia, multipollutant environmental status and risk.
- **By 2008,** deliver an integrated exposure and effects modeling system to be tested and evaluated.

3.3.2 Improving Atmospheric Exposure Modeling

Consistent with the development of a common modeling framework is the need to improve the exposure and effects models that will go into the framework. The next section will present the high-priority research areas in atmospheric exposure modeling where the goal is to develop a state-of-the-art air quality modeling system capable of handling multipollutant issues and multimedia interactions, and a second such system capable of handling multipollutant issues and multimedia interactions.

Atmospheric pollutant fate and transport research is concentrated on the Models-3, third-generation modeling system. This platform provides an integrating mechanism for this research across EPA and the atmospheric modeling community at large. The initial version of Models-3 focuses on urban- to regional-scale air quality simulation of ground-level ozone, acid deposition, visibility, and fine particulate matter. The Models-3 framework provides an interface between the user and operational models, between the scientist and models under development, and between the hardware and model software. This allows the user to perform a wide range of environmental tasks, from regulatory and policy analysis to understanding the interactions of atmospheric chemistry and physics, while rapidly adapting to new technology.

Atmospheric processes research focuses on the formation, chemistry, transport, and behavior of gases and aerosols in the atmosphere, plus fundamental research in source apportionment, aerosol physics, and particulate matter chemistry and fate. Pollutants of interest include ozone, nitrogen oxides (NOx), NOy, and VOC species and urban hazardous air pollutants.

The objectives of this research are to:

- Develop a state-of-the-art, “one-atmosphere,” air quality modeling system capable of handling multipollutant issues.
- Provide advanced air quality modeling capabilities with the flexibility to operate at a spectrum of spatial scales, including regional, urban, and point source.
- Provide a standard interface that facilitates interchange of science modules.
- Serve as a basis for research into advanced science issues, multiscale interactions, mixed- and cross-media issues, and physical and chemical processes.
- Serve as a basis for diagnostic evaluation and continuing modeling system development.
- Incorporate an advanced approach to sensitivity and uncertainty analysis.
- Couple meteorological models closely with chemistry-transport models.
- Take advantage of the enhanced computational capabilities provided by high-performance computing and communications architectures.

- Offer sufficient extensibility to address and fulfill EPA's anticipated air quality research modeling needs.

- Couple these models with terrestrial and aquatic exposure models in MIMS.

3.3.2.1 Emissions Process Research

Specification of the emissions source terms is a critically important factor in accurate air/water quality modeling applications. Generally, the emissions fluxes contain the most inherent errors and uncertainties of all of the required input parameters in air/water quality simulation. Yet, it is these fluxes that are the independent variables that are modulated in modeling exercises to seek the optimum emissions control strategies for the improvement of environmental quality. Thus, ORD maintains a strong research emphasis on the understanding of source emissions processes and improvement in the estimation of emissions fluxes.

The objectives of emissions process research within ORD are:

- To characterize and refine the emissions factors for significant anthropogenic and biogenic sources that contribute to air/multimedia pollution problems.

- To determine the chemically speciated source profiles of significant emission source processes.

- To characterize levels of anthropogenic and biogenic emissions activity as a function of emissions process, location, and time (by hour, day, month, or season, as appropriate).

- To build, refine, and maintain models and databases of emission factors, source profiles, and activity levels applicable to North American locations that may be used in air/multimedia quality modeling applications.

3.3.2.2 Wet/Dry Deposition Research

Deposition is the main pathway for all pollutants from the atmosphere to the biosphere (land and water) and the geosphere. All pollutants moving from the atmosphere to plant communities, animals, soils, water, etc., do so by this route. Thus, to understand exposure of ecosystems to airborne pollutants, an understanding of deposition processes is essential. Deposition is dependent on pollutant, plant species, plant physiology, surface properties, and atmospheric transport and diffusion. To understand and model deposition, all the above processes must be understood. From the atmospheric perspective, deposition is also a major loss pathway for pollutants. Atmospheric models must accurately account for deposition in order to model chemical transport, transformation, diffusion, and fate correctly.

The objective of this research is to understand wet and dry deposition processes, develop and improve deposition models, evaluate models with deposition data, and describe the spatial and temporal extent and trends in deposition. More specifically, the objectives of this research will be to:

- Measure fluxes of sulfur dioxide (SO_2), ozone, and nitric acid (HNO_3) to forests and to evaluate existing point and regional deposition models.

- Measure fluxes of SO_2, ozone, and HNO_3 to surface waters, fresh and estuarine, and to evaluate existing point and regional deposition models.

- Develop methods to measure net intermedia fluxes of NO, nitrogen dioxide (NO_2), ammonia (NH_3), mercury, toxics, pesticides, and fine particles, and to develop and evaluate intermedia transfer models.

- Measure fluxes of SO_2, ozone, and HNO_3 over land and surface waters during the winter and evaluate existing intermedia transfer models.

- Develop techniques to measure fluxes over complex terrain, and apply and evaluate intermedia transfer models.

- Conduct analyses of air pollutant dry and wet concentration, deposition velocity, and dry, wet, and total flux. These analyses will address temporal behavior, spatial distribution, climatological/meteorological variables, transformation processes, and coupling with emissions.

- Develop third-generation deposition models that take into account the cell level chemical reactions that occur in the leaf.

- Develop a better understanding of the turbulent processes that control some deposition processes and incorporate them into operational deposition models, including LES (Large Eddy Simulation) modeling.

- Through experiments and modeling, develop an understanding of nocturnal processes, both at the plant and atmospheric level, that control, develop and apply methods to measure fluxes of aerosols and develop, refine, and evaluate existing models.

3.3.2.3 Community Multiscale Air Quality (CMAQ) Modeling

EPA is developing an advanced air quality modeling system, Models-3/CMAQ, as a state-of-science assessment tool for scientific analyses of air pollutants, their loadings and distributions, as well as to provide a tool for determining the efficacy of various control scenarios. The chemical composition of air (and in the case of airborne particles, their size distribution) is controlled by numerous atmospheric processes that operate over large ranges of temporal and spatial scales. Models-3/CMAQ is a flexible and general modeling system designed to support computational scalability for multipollutant and multiscale air quality simulation, while taking advantage of the enhanced computational capabilities provided by state-of-the-art architectures. CMAQ is an emissions-based, Eulerian, air quality modeling system that integrates state-of-the-science physical and chemical process algorithms with efficient numerical solvers and data linkages. The inclusion of particles in air quality simulation models will allow the capability for modeling heterogeneous processes. The various processes inclusive of transport and deposition, as well as the chemistry, are therefore much more adequately and credibly simulated. Models-3/CMAQ will provide a basis for understanding the complex temporal and spatial distribution of air pollution on scales ranging from airshed/watershed to regional (subcontinental) scales. In addition to its use as an implementation tool for simulating ground-level ozone, acid deposition, visibility, and fine particles, CMAQ is designed to be implemented for assessments of transport and deposition of heavy metals (including mercury), toxic semivolatile organic compounds (SVOCs), and nitrogen and other airborne nutrients that impact sensitive receptor ecosystems. The primary objectives will be to:

- Develop SVOC capability in Models-3/CMAQ with particulate matter.
- Add mercury and other heavy metal deposition to CMAQ.
- Develop aggregation schemes for application studies.
- Perform model evaluation.

3.3.2.4 Anticipated Products

- **By 1999,** Phase I of diagnostic evaluation of Models-3/CMAQ is to be completed against comprehensive field study data sets.

- **By 2000,** Phase II of diagnostic evaluation of Model-3/CMAQ is to be completed against comprehensive field study data sets. Mercury modeling capability is incorporated into Models-3/CMAQ.

- **By 2001**, more advanced chemical kinetic mechanisms and meteorological process algorithms are to be incorporated and tested in the Models-3/CMAQ system. Phase I evaluation of mercury modeling, using Models-3/CMAQ framework, is to be completed, and an integrated, evaluated air chemistry, fate, and transport model for coupling to existing terrestrial and aquatic models is to be delivered.

- **By 2002,** methods for assessing the errors and uncertainties in air quality predictions from the Models-3/CMAQ system are to be incorporated and tested, and SVOC modeling capability is to be incorporated into Models-3/CMAQ.

- **By 2003,** model evaluation exercises are to be conducted with a newly revised version of Models-3/CMAQ; the evaluation focuses on urban- and local-scale pollution problems and the larger scale influences on those problems; preliminary evaluation of Models-3/CMAQ for SVOCs is to take place.

3.3.3 Improving Aquatic and Terrestrial Exposure Models

The uncertainties associated with predicting terrestrial and aquatic ecosystem exposures and responses to pollutant stressors are heightened greatly by ORD’s frequent inability to incorporate quantitative descriptions of these stressors’ cycling, speciation, intermedia transfers, sorption, and transformation/degradation. These processes determine not only the ambient concentrations of pollutants and their transformation products available for direct and indirect ecosystem receptor exposure, but also the pathogenic, chemical, toxicity, oxidation-reduction potential, and sediment and nutrient status factors relative to general habitat suitability and overall risk characterization.

Based on an assessment of the state of the science, the major process uncertainties exist for: (1) pathogenic bacteria and virus viability kinetics and partitioning; (2) speciation and sorption of ionizable organic chemicals and metals; (3) microbial transformation kinetics and pathways, particularly anaerobic transformation of hazardous chemicals; (4) phytotransformation process kinetics and pathways; (5) abiotic redox transformation process kinetics and pathways; and (6) terrestrial biospheric cycling/storage/release of nitrogenous and carbonaceous greenhouse gases and nutrients. Consequently, these areas will constitute the major processes research areas for both terrestrial and aquatic systems.

As indicated in previous sections of this strategy, stressors other than pollutants must be assessed at various geographical and temporal scales, in various media, and in conjunction with pollutant stressors. One major goal of the effort to improve aquatic and terrestrial component stressor exposure modules must include the development and incorporation of those physical descriptors necessary to define "suitable habitat" (e.g., temperature, sediment deposition-scone transport, shear stress, riffles-pools, land forms, and distribution, "patchiness," corridors, edge-to-volume configurations, etc.). This requirement will necessitate a vigorous program to link geographic information system (GIS) technology to existing and developmental aquatic and terrestrial component exposure modules. It also will necessitate a comprehensive evaluation and upgrade of the hydrologic, hydraulic, and sediment transport algorithms in existing and developmental component modules, along with the pollutant transport and transformation process descriptions. Finally, in order to accelerate the development of these new multistressor aquatic and terrestrial component modules for both regulatory support application and for general framework incorporation, ORD will initially concentrate on linked, watershed response system modules, including associated terrestrial and groundwater components, and site screening modules.

3.3.3.1 Biogeochemical Processes

The internal cycling, storage, and intermedia exchanges of nitrogenic and carbonaceous greenhouse gases, particularly their net releases to or removal from the atmosphere, and the factors that determine the same are major unknowns relative to the projection of global climate change and any feedback effects that the terrestrial biosphere may impact thereon. In addition, nitrogen and, to a lesser extent, phosphorus cycling and storage within various land use categories is a major unknown relative to the ability to predict nutrient exports from these land forms to groundwater and surface aquatic systems at a watershed or regional scale, given the potential mix of nutrient inputs to these various land forms (i.e., natural and anthropogenic atmospheric nitrogen deposition, fertilizers, animal wastes, and biosolids).

The objectives of this research are to:

- Quantify the net carbon and nitrogen greenhouse gas fluxes between the terrestrial biosphere and the atmosphere as a function of selected land use changes and management practices.
- Quantify and model carbon and nitrogen gas cycling, storage, and release from the terrestrial biosphere for coupling to an ESM for use in projecting long-term regional climate (precipitation) changes.
- Quantify and model nutrient storage and release form major land use categories (i.e., forests, row crops, pastures, etc.) as a function of total nutrient inputs and management practices.

3.3.3.2 Transport Properties and Processes for Organic and Inorganic Pollutants

Before any defensible terrestrial or aquatic ecosystem exposure assessment can be conducted, key pollutant source-sink processes must be characterized, modeled, and integrated into the appropriate media exposure-risk assessment methodology (or general model framework). As indicated previously, a state-of-the-art assessment has identified those "most uncertain" pollutant transport processes to be addressed in this strategy as follows:

- Understand, quantify, and model the

speciation of complex molecules (organics and metal/nonmetal inorganics) in natural soil water and sediment water systems.

- Quantify and model the sorption-desorption-complexation interactions of ionizable pollutants with natural mineral surfaces, humic-coated natural materials and dissolved organic matter.

- Expand, test, and link to selected media compartment exposure assessment models (or general framework) the SPARC computerized organic pollutant transport process parameter estimation expert system.

3.3.3.3 Transformation Processes of Pollutants

The key transformation processes to be characterized, modeled, and incorporated into the aquatic and terrestrial ecosystem compartment exposure-risk assessment models (framework modules) are microbial transformations (both aerobic and anaerobic) and phytotransformation (plants and enzymes).

Specifically, the objectives of this research are to:

- Understand pathways and quantify and model the kinetics of previously uncharacterized sink-source processes for pollutants in soil-water and sediment-water systems, particularly microbial and phytotransformations. Emphasis is on anaerobic transformations of chlorinated aromatic compounds and aerobic transformations of PAHs and chlorinated aliphatics.

- Develop organometallic formation and degradation kinetics and pathways data for selected metals of concern, particularly mercury, arsenic, and lead.

- Characterize and model abiotic (heterogeneous) reductive transformation rates and pathways for selected classes of organic pollutants of concern to EPA.

3.3.3.4 Anticipated Products

- **By 2000**, estimate kinetics of contaminant release from sediment models to determine or predict the bioavailability and residue-based approaches for chemical stressor.

- **By 2002**, estimate the effects of sorption on biotic and abiotic transformation rates in sediments. Produce prototype model(s) at the watershed scale integrating landscape conditions and biophysical and socioeconomic variables for application in different regions of the United States.

- **By 2003**, evaluate publicly available water flow and quality simulation models in terms of their ability to evaluate risks associated with various control technologies for wet weather flows in a watershed.

- **By 2004**, provide next generation of water and soil transport and fate models to predict the distribution of chemical and other stressors.

3.3.4 Improving Effects Modeling

The use of the ecological risk assessment process as a foundation for environmental decision-making is currently limited by the science supporting the activities of problem formulation, analysis, and risk characterization. Research to improve knowledge of the ecosystem processes that will enhance effects modeling will reduce the scope of these limitations. In prioritizing areas of ecological effects research, ORD has identified the following scientific uncertainties as the aims of research for the next five years:

- Identification of scientifically credible assessment endpoints that accurately reflect management goals and societal values.

- Availability and use of measures of effects and measures of ecosystem characteristics to represent assessment endpoints adequately.

- Understanding of ecological processes, mechanisms, and relationships that support development of stressor-response analyses and cause-and-effect relationships.

Risk assessment endpoints must be ecologically relevant, susceptible to known or potential stressors, and represent management goals. Risk assessment endpoints directly influence the type, characteristics, and interpretation of data and information used for analyses and the scale and character of an assessment. Failures to define assessment endpoints properly often limit the usefulness of ecological risk assessments. Developing the proper linkages of assessment endpoints to the scale of a risk assessment is a significant challenge and requires an improved understanding of the relationships between levels of biological organization and the hierarchical relationships of ecosystem components and processes across space and time. Understanding relationships between risk assessment endpoints and the presence of multiple stressors is also a critical issue. The presence of multiple stressors in many ecological risk assessments requires the selection of assessment endpoints that respond differently to stressors to evaluate cumulative effects and to discriminate effects among stressor types. Multiple stressors may act at different spatial and temporal scales and levels of biological organization and require selection of an appropriate array of endpoints that capture both indirect and direct effects.

Although assessment endpoints must be defined in terms of measurable attributes, their selection does not depend on the ability to measure these attributes directly. In cases where the assessment endpoints cannot be measured directly, their response may be predicted based on responses of surrogate or similar entities (i.e., measures of effects). In addition, measures of ecosystem characteristics are often needed to improve the means of interpreting assessment endpoints or measures of effects. Methods to link assessment endpoints with measures of effects must be applied in a manner consistent with sound ecological principles. Empirical and process-based approaches for linking measures of effects to assessment endpoints are used to varying degrees depending on the scope of the assessment and the data and resources available. Empirical and process-based models can range from the use of uncertainty factors to the application of complex models that require extensive inputs. The development of improved empirical and process-based models is required to aid in extrapolating measures of effects to assessment endpoints. The development of decision trees for selecting modeling approaches and “standard” models or parameter sets to simplify comparisons among stressors and species, populations, communities, and ecosystems are also needed.

The goal of the research to be discussed in this section will be on understanding processes and developing models for determining the relationship between stressor levels and ecological change. These effects may be manifested at several different spatial scales ranging from regions to sub-organism that require different approaches and techniques. The nature, extent and type of stressor along with the uses and applications of the information often influences the scale that is most appropriate to study. The descriptions that follow have been organized into three basic categories:

1. **Watershed and Regional Responses.** Research addressing responses of a mosaic of ecosystems to broad or cumulative impacts of wide-spread stressors such as regional air quality or land use practices.
2. **Ecosystem Modeling.** Research addressing responses of ecosystems to physical, chemical and biological stressors as influenced by abiotic and biotic interactions.
3. **Ecotoxicology.** Research addressing responses at the organism and sub-organism level primarily to chemical stressors and factors that influence those responses.

At the same time, it is recognized that in order to properly understand and predict responses to stressors, research must be undertaken that not only improves our understanding at these different levels but also provides insights as to how to extrapolate results across these levels. Thus, close coordination of all of these studies is necessary to address the overall research questions.

3.3.4.1 Understanding and Predicting the Effects of Watershed and Regional Change

Ecological risk assessments typically are conducted on single human-induced stressors (e.g., a single contaminant introduced into a stream) at a single level of biological organization. For toxicological issues, the biological organizations usually range from the cellular to the species. For ecological issues, populations of species, communities, and ecosystems may be added. The interaction of the biologic and abiotic components in ecosystems greatly increases the complexity of the assessment. Although endpoints are relatively easily described up to the population level, defining endpoints for ecosystems becomes much more challenging because concepts like health and sustainability often are introduced. At the larger scale, ecosystems are structurally and functionally integrated because of the interactions and exchange of energy and nutrients between the mosaic of terrestrial and aquatic components. An understanding of how these systems respond to human activities requires research to be conducted in the context of the surrounding landscape from the watershed to regional scale. The research to be conducted by ORD includes studies to facilitate the prediction and extrapolation of the effects of real or potential changes in landscape characteristics on a variety of ecosystem endpoints of concern. Methods to evaluate the effects of future change and diagnose causes of responses to change will be developed. In addition, a number of studies on specific regional issues that require the integration of data across multiple systems will be conducted in various areas of the nation. These efforts will provide an opportunity to test ideas, develop methods, and address issues across a wide array of biogeographic regions.

Watershed and Regional Responses

Research will be directed toward improving methods and models to understand linkages among ecosystem components within watersheds and regions and the degree to which landscape patterns affect the sustainability of ecosystems. These efforts will contribute to an improved ability to predict cumulative impacts and to diagnose causes of impairment. The ability to predict the response of systems at the watershed and regional scale to a variety of potential landscape changes will be an important objective. Scientific investigations will be conducted on: (1) watershed structure/function relationships and the degree to which changing landscape patterns affect integrity and sustainability; (2) the extent to which cumulative impacts can be differentiated or partitioned among chemical, physical, and biological stressors; and (3) how effects are integrated across hierarchical scales. Understanding these relationships requires a knowledge of landscape component functions, relationships between location in the landscape and the sensitivity of ecosystems to stressors, and the effect of landscape pattern on the transfer of energy, materials, or populations across ecotones. Results of the research also are anticipated to improve understanding of diagnostic indicators of ecological sustainability.

Integrated Effects in the Mid-Atlantic Region

Regional and watershed research in the Mid-Atlantic Region is focused on the development and application of methods to conduct integrated ecological resource assessments on regional spatial scales. The goals of this research are to: (1) develop a framework that can be used to conduct integrated resource assessments across various levels of geographic scale; (2) evaluate the use of historical data as a means of testing the assessment process;, (3) identify research gaps that must be addressed to reduce uncertainties in conducting such assessments; and (4) develop an information management system that can be used effectively and efficiently in future regional assessments. The experience gained from this research will be applied and transferred to other geographical areas to conduct these assessments more cost-effectively.

Predicting Effects in South Florida

Activities in the Everglades Agricultural Area (EAA), located south of Lake Okeechobee, utilize herbicides and pesticides for plant and animal control and fertilizers to promote yield. Drainage from the EAA is channeled through a series of canals into Biscayne Bay, the Gulf of Mexico, or Florida Bay. There is an increased awareness by the public and scientific communities of a mercury problem in South Florida. Warnings against eating gamefish have been issued, as concentrations of 0.5 to 1.5 ppm of mercury are common. In addition to the transport of mercury, herbicides, and pesticides, flows within the South Florida system contain nutrients in the form of nitrates and phosphates. If excessive nutrients are discharged into Florida Bay, the potential exists for impacting algal, phytoplankton, and submerged aquatic vegetation populations. Through these impacts to the system's plant communities, broader effects to biota including local finfish and shellfish populations are possible.

The objectives of this research are to develop the data and predictive mathematical models to assess the effects of mercury, herbicides, pesticides, and nutrients—alone or in combination—on stability of amphibian, reptilian, fish, bird, plant, and coral populations; diversity of communities; and the condition of the Florida Bay ecosystem. Relevant field data will be collected to develop four mechanistic, ecological models to assess and understand better the ecological conditions and their causes in South Florida estuaries and coastal waters. The four proposed models are: (1) a population model of the relationship between reproductive success and endocrine disruptors; (2) an ecological model of pesticide and mercury flow and fate and their effects on biota; (3) a model of the nutrient dynamics in Florida Bay and the effects on trophic structure; and (4) a community model of UV-B, contaminant, and nutrient dynamics and their aggregate effects on coral assemblages.

Cumulative Effects on Pacific Northwest Estuarine Systems

The high rate of human population growth in the Pacific Northwest is subjecting estuaries and coastal watersheds to many anthropogenic stresses. The amount of this stress will continue to increase as population growth continues and the Northwest further develops economically. Activities that jeopardize the ecological sustainability of estuarine and coastal watershed resources include watershed alterations, such as urbanization and other land use changes, road construction, and agricultural and forestry practices. These activities result in increased nutrient and sediment loads, alteration, and loss of habitat, including elevated stream temperatures, pollution, exotic biotic introductions, and alterations in extreme natural events such as floods and disease or pest outbreaks. Determining the effects of stressors is complicated by the fact that they have different ecological effects and act at various, often overlapping, spatial and temporal scales.

The purpose of this research is to develop methods and models for predicting the cumulative effects of multiple stressors on ecologically and economically important estuarine assessment endpoints at multiple spatial and temporal scales. This involves: (1) determining single and multiple stressor-response relationships; (2) developing spatially and temporally explicit sampling procedures and models; (3) quantifying the variability of multiple stressor effects; and (4) distinguishing multiple stressor effects from natural variability. The goal is to produce a framework, including a scientifically credible approach and set of analytical tools, to predict the combined effects of important stressors on the trajectory of ecological assessment endpoints over time.

Great Lakes Effect Modeling

The St. Lawrence, the Great Lakes, and associated drainage have been subjected to a wide array of stressors for several centuries. In response to previous degradation, The Great Lakes Water Quality Agreement calls for the restoration and maintenance of the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem. The governments of the United States and Canada, which provide joint oversight of the lakes, cite four general issues that encompass a broad array of problems and outline the major stressors on aquatic life and wildlife: (1) the loss of biodiversity and biological integrity; (2) degradation and loss of habitat, including tributary, near-shore, and coastal wetlands areas; (3) impacts of persistent toxic contaminants; and (4) eutrophication in certain areas. Because of the vast size of the Great Lakes, contrasting ecoregions and habitats, multiple stressors with different modes of action and behavior, stressor interactions, and numerous sources and media, the development of management strategies often has been hampered. The Great Lakes Water Quality Agreement requires a holistic, ecosystem approach for the management of the Great Lakes. Recognizing the need to synthesize interdisciplinary information for forecasting capabilities, mathematical modeling has been accepted as an essential component of environmental management decision making. Research will be undertaken to develop, refine, apply, and verify mathematical ecosystem response models for the Great Lakes. Research will address uncertainties and validate model predictions for the stressors of greatest environmental concern, using field data specifically collected for such purposes. Uncertainties in predicting eutrophication, bioaccumulation, and ecosystem productivity will be emphasized.

3.3.4.2 Ecosystem Modeling

Although many improvements have been made over the last few decades, the Nation's freshwater, marine, and terrestrial ecosystems continue to be threatened by a variety of anthropogenic stressors. While the effects of chemical stressors remain a significant issue in many waters, the effects of physical and biological disturbances are also widespread problems. The successful protection of freshwater and marine ecosystems depends on an understanding of the interactions and cumulative impacts of a complex mixture of stressors at various temporal and spatial scales. Within terrestrial ecosystems, understanding of the functioning and response of plants and the vegetative component to environmental stress is most limited. In the past, vegetation was considered to be an easily regenerated and manipulated natural resource that was relatively insensitive to environmental stress. However, understanding and concern for this basic component of the biosphere has changed, with effects of atmospherically mediated stressors, such as regional air pollution and climate change, and the interaction of these stressors with land and resource use, as primary concerns.

Based on an evaluation of the state-of-the-science, as well as the scientific and ecological risk assessment uncertainties identified in CENR and EPA strategic plans, process and modeling effects research undertaken by ORD will be directed towards the following areas: (1) characterizing and predicting the responses of ecosystems to physical, biological and chemical stressors; (2) advancing techniques to extrapolate and interpret effects across levels of biological organization; and (3) developing ways to measure the integrity and sustainability of ecosystems and diagnose causes of degradation. This research will involve the development of sound methods and models to screen, diagnose and predict ecological effects for both prospective and retrospective ecological risk assessments. Coordination with environmental monitoring research, as described previously, will be a critical aspect of success in this research effort. For example, monitoring can provide correlations between ecological condition and potential stressors that then become hypotheses for the more mechanistic stressor-response research described below. Similarly, the multi-tier designs and evaluations conducted as part of environmental monitoring research can provide information useful in research on the uncertainties associated with extrapolating predictions of effects across spatial and temporal scales. Finally, the development of ways to measure integrity and sustainability as well as diagnose causes of degradation may provide useful insights into the selection of appropriate indicators for environmental monitoring. The discussion below describes the research directions that support the three areas listed above as they relate to freshwater, marine/estuarine and terrestrial ecosystems.

Freshwater Ecosystems

The goal of this research is to understand how stressors modify constraints on aquatic ecosystem structure and function to reduce uncertainties in effect extrapolations from the laboratory to the field and to develop and evaluate measurement techniques for components and processes that describe the responses of aquatic ecosystems to these stressors. In contrast to the research described later on ecotoxicology, the stressors of primary interest are physical, biological and chemical stressors other than toxic chemicals. Historically, much of the stressor-effects data used in ecological risk assessments is obtained from laboratory tests and present significant extrapolation challenges when assessment endpoints are at the population, community or ecosystem level. Whole-ecosystem studies or studies of intact ecosystem components are rarely performed because of high cost and time commitments. In addition, the high degree of variability among natural ecosystems makes extrapolations from examined systems to other systems difficult. In turn, these uncertainties impact ecological effect characterizations and risk assessments which are designed to protect aquatic communities and ecosystems. Research will be designed to advance an understanding of population, community and ecosystem organization and dynamics to improve predictive components of prospective risk assessments, interpretations within retrospective assessments, and the linkage of ecological indicators to measures of effects and ecosystem characteristics in a risk assessment context. Research at the population, community, and ecosystem level will incorporate modeling, laboratory investigations and field studies.

Initial choices for ecosystems of primary interest are those that are believed to be important in the context of whole systems but to date have been poorly or little studied. Of particular interest are coastal wetlands and near shore areas of the Great Lakes. Field studies will involve intensive study sites within a multi-watershed design and will result in models that link watershed function and landscape effects on wetlands and the near shore environment of large water bodies. Strategic choices have also been made to aim this research toward the assessment endpoints of sustainable fish assemblages and water quality.

Marine Ecosystems

ORD is responsible, in part, for conducting research in the estuaries and coastal waters of the Nation to provide rigorous, quantifiable methods and models that will allow managers to carry out environmental regulations. The goal of this research effort is to develop approaches to predicting the response of estuarine systems to environmental stressors across various levels of biological organization and geographic extent. The results of this research will provide the critical scientific information necessary to address the fundamental question of what effect specific changes in anthropogenic inputs will have on the integrity of these systems. This research effort will develop the theoretical framework and ecological approaches to characterize, quantify, and predict the ecological integrity of estuarine and marine ecosystems at the management unit scale of a watershed sub-basin. This will be accomplished through an integrated approach capable of describing the complexity within an estuarine ecosystem and also aggregating that complexity into meaningful ecological indicators. Within this framework, key structural and functional components will be quantified for coastal wetlands, fish habitats, benthic community, and the overall trophic structure of estuaries. The physiological, pathological and reproductive systems of key estuarine organisms will be characterized to assist in predicting their responses to stressors. For the concept of ecological integrity to be useful in a scientific and regulatory context, it must be quantified relative to an expected condition or reference state. As a consequence, the research effort will also examine the structural and functional basis to defining ecosystem similarity, both spatially and temporally.

Natural and anthropogenic stressors affect estuarine and coastal environments at all levels of organization, yet effects research historically has focused on organism or sub-organism responses. However, assessment endpoints for ecological risk assessments are typically at the population, community or ecosystem level. As a consequence, there is a need to improve the extrapolation of effects across levels of biological organization. Efforts to improve the means of predicting population-level responses will be accomplished by improving the understanding of influences on population dynamics as well as by explicitly incorporating stressor-response relationships into population models. Stressors can also act as strong selective agents in an evolutionary context by eliciting compensatory mechanisms that allow a population to persist in the stressed environment. These compensatory mechanisms, expressed at a range of biological organization from molecular adaptation to life history strategy alterations, will be explicitly incorporated into population models to improve the means of forecasting ecological effects. Choices of populations to study will be made through consideration of key biological components of estuarine systems, current knowledge of the biological interactions within these systems and the availability of the data that forms the foundation for model development.

While chemical stressors remain a concern, nutrient enrichment, climate change, and other types of habitat alteration have been ranked as significant current and future stressors of coastal ecosystems. As a result, research is needed to better characterize causal linkages between physical, biological and chemicals stressors and coastal ecosystem responses, and to develop the means of quantifying future coastal zone change. Research will identify the factors that regulate the way in which nutrient enrichment and eutrophication are expressed in estuarine ecosystems. The effort will lead to community/ecosystem mechanistic mathematical models to assess effects of nutrient enrichment on selected system endpoints such as: 1) hypoxia/anoxia; 2) loss of submerged aquatic vegetation (SAV) habitat through mechanisms dependent on enrichment; 3) increases in nuisance and toxic phytoplankton blooms; 4) qualitative and quantitative changes in linkage between primary and secondary productivity; and 5) the relationships of trophic cascading and nutrient supplies as effects of the estuarine eutrophication process. Research addressing effects on SAV will be emphasized because it provides essential nursery habitats for a wide variety of economically important fish and shellfish, stabilizes sediments and reduces erosion of shorelines. The widespread loss of SAV communities worldwide has been attributed to increased water turbidity due to dredging and runoff, increased nutrient loading and algal production, and direct physical damage from recreational activities. Potential long-term effects from global climate change are also plausible.

The research described above cannot possibly be conducted at all parts of the vast extent and geographic distribution of the Nation’s estuaries. Therefore, the goal will be on developing approaches at a selected number of sites that can subsequently be applied to estuaries of future concern. These sites will include representative locations from the Atlantic seaboard, the Gulf of Mexico, and the Pacific Northwest. The degree to which these estuarine methods and models can be used to extrapolate predictions of responses to stressors between sites will be an important component of the long-term research effort.

Terrestrial Ecosystems

Understanding the effects of environmental stressors on terrestrial ecosystems has most often involved collection of experimental data at the level of the individual and populations. Frequently, the studies have involved single species and single pollutants resulting in exposure-response functions characterizing the effects on biomass or reproduction (crop yield) at the individual or population level of that species. Experimental observations of effects at higher levels of biological hierarchy (community and ecosystem) or increasing biological complexity (species diversity, stand structure, and presence of trophic functional groups) are limited. Invariably, the data from one set of experiments is extrapolated to predict the species' response nationwide. This often includes extrapolating the response in natural environments with all the concomitant moisture, nutrient, and competitive stresses that may be in place across the spatial and temporal extent of the species in question, even though the data sets do not include these conditions. In addition, only a very small representation of species is ever studied and yet frequently, these data are used to represent all vegetation, crop or forest tree species. At ecosystem and landscape scales, even less information is available to predict changes with changing pollutant exposure scenarios or changing global climate. To develop the necessary linkages, an approach is required to extrapolate experimental data taken at the individual level, often in artificial conditions, to suggest changes occurring in more complex native environments to individuals or populations. Equal attention is needed to understand changes at higher scales of biological organization as well as landscapes. A multifaceted, interactive research approach is necessary, including experimental and modeling components, with each informing the other. The objective of this research is to provide a scientifically sound understanding of error sources in extrapolating from individual responses to ecosystem responses and across geographic scales. Additionally, a mechanistic knowledge of the ecosystem processes is needed to predict to multiple environmental stressor. The research will involve experimental, modeling, and field studies at a range of scales from the individual to the landscape.

Compared to above-ground components of terrestrial systems, we know much less about the below-ground area. Yet there is increasing evidence that the rhizosphere may play a critical role in the response of vegetative systems to stress. For example, ORD's research has shown that ozone stress may be first manifest in the rhizosphere. Increasing our understanding of the role of the rhizosphere appears to offer promise for improving our capability to assess the overall condition of terrestrial systems and predicting their response to stress. As the rhizosphere is the interface between the primary carbon processes (i.e., aboveground carbon acquisition) and primary nutrient and water processes (i.e., below ground nutrient and water acquisition), it is essential to understand how specific stressors will affect this interface. The goal of the rhizosphere research is to determine the effects of atmospheric pollutants and global change components (e.g., CO_2, precipitation, temperature, etc.) on key processes in controlling the exchange of C and N between the root/soil and the plant canopy. For example, elevated CO_2 increases fine root growth and fine root life span. In contrast, elevated ozone decreases fine root growth and is hypothesized to decrease fine root size span as it decreases fine root carbohydrate levels.

In situ techniques and microbiological and molecular (DNA fingerprinting) approaches will be applied. Intensive sampling in terracosms and at field sites will provide the data necessary to parameterize ecosystem models that are used to develop a predictive understanding of the multiple stress effects on carbon and nitrogen cycling in forest ecosystems.

3.3.4.3 Ecotoxicology

ORD conducts research to provide scientific information on the toxic effects of chemical stressors to aquatic life and wildlife in order to reduce uncertainty in risk assessments and support risk management options. The research is designed to develop a mechanistic understanding to establish cause and effect relationships for chemical stressors already in the environment and predict responses to stressors not yet present or released. As a result, research involves the development of sound methods and models to screen, diagnose and predict ecological effects in both prospective and retrospective ecological risk assessments. Effects research undertaken is designed to improve knowledge bases, mechanistic understandings and techniques in the context of the problem formulation, analysis and risk characterization phases of ecological risk assessments.

Ecological risk assessments of chemical stressors are typically confronted with a lack of toxicity data for either the chemical or species of concern. Owing to the complexity of most environmental problems, and because of limited testing capability, there is also a need to extrapolate existing information to untested species and/or exposure scenarios. Although understanding of the lethal effects of xenobiotics to aquatic organisms continues to expand and support improved extrapolations across chemicals and species, there is significant uncertainty when reproductive and developmental endpoints are considered along with the influence of environmental factors on the toxicity of single chemicals and mixtures. In addition, the quantitative extrapolation of adverse reproductive and developmental effects at the organismal-level to population-level responses remains a challenge in ecological risk assessments.

Based on an evaluation of the state-of-the-science, as well as the scientific and ecological risk assessment uncertainties identified in the CENR and EPA strategic plans, ecotoxicology research will be focused in the following areas:

- Understanding and predicting basic biological and chemical mechanisms of toxicity.
- Measuring and predicting the uptake, distribution and elimination of xenobiotics in aquatic life and wildlife.
- Predicting reproductive and developmental effects of chemical stressors.
- Predicting the effects of mixtures and/or multiple stressors in water and sediment.

Addressing these issues is essential to improving the ability to extrapolate the effects of chemicals across the range of untested chemicals as well as untested biological species.

Biochemical and Cellular Toxicology

The goal of this research is to advance understanding of biochemical and cellular toxicodynamics and xenobiotic metabolism to reduce uncertainties in extrapolating toxic effects across chemicals and species. In the field of environmental toxicology, and especially aquatic toxicology, quantitative structure-activity relationships (QSARs) have developed as scientifically credible tools for predicting the acute, and in some instances sub-chronic, toxicity of chemicals when little or no empirical data are available. In addition to the use of these predictive toxicology models, there has also been an increased call for the complementary use of *in-vitro* or short-term *in-vivo* experimental models to provide the ecotoxicological data required for preliminary or screening-level effect characterizations. Challenges to improve the use of predictive models and screening assays for either “chemical” or species extrapolations, center on uncertainties in understanding mechanisms of chemical toxicity and xenobiotic metabolism, as well as the linkage of cellular or biochemical effects and processes to organismal-level responses. Tissue, cellular and subcellular models will be used in research designed to explore the relationships between chemical structures and properties and biological activity. A significant challenge to the research will be to link biochemical and molecular biological responses to cellular and subcellular structure and to the intact organism. Metabolism research will be undertaken to help expand understanding of specific mechanisms of action and bioaccumulation of xenobiotics, with a bias to experimental designs that further the means of relating kinetics of metabolic reactions to chemical structure.

Toxicokinetics and Dosimetry

The goal of this research will be to develop physiologically based toxicokinetic models as components to a biologically-based approach to reducing uncertainties in species extrapolation and the interpretation of toxic effects. Toxicokinetic and dosimetry research is concerned principally with the uptake and disposition of chemical stressors by individual organisms, recognizing that in many cases this uptake is part of an extended chain of events involving entire food webs. The quantitative nature of toxicokinetics lends itself to the development of mathematical models that formalize, simplify and codify complex information that can be used to extrapolate limited effect information. Research will be conducted in support of model development and as a means of evaluating model performance. Descriptive research will be undertaken frequently in advance of mechanistic research to define the system under study and to collect an empirical data set which then becomes the basis for subsequent development of mechanistic hypotheses. Metabolic biotransformation and bioavailability have been identified as scientific uncertainties that represent the highest priority areas of research in understanding the effects of chemical stressors. Metabolism research will be directed toward developing the capability to model the rates of parent compound disappearance and formation of biotransformation products. An emphasis will be placed on compounds that undergo metabolism to more reactive species, although consideration will also be given to metabolism as a pathway for chemical elimination (particularly in the case of bioaccumulative organic compounds). Bioavailability research will concentrate initially on the dietary uptake of hydrophobic organic compounds, followed by studies on the waterborne and dietary uptake of metals. Efforts will be initiated to expand modeling activities to include other taxa, including piscivorous wildlife, invertebrates, amphibians, and marine mammals.

Reproductive and Developmental Toxicology

Research efforts in this area will involve investigations of the reproductive and developmental effects of xenobiotics on aquatic life and wildlife to reduce uncertainties in predicting effects and interpreting population and community level responses. An increased mechanistic understanding of developmental and reproductive toxicants at the organismal-level is needed to support the relevancy of in vitro and/or structure activity relationship based screening assays designed to identify potentially potent compounds. An understanding of those organismal-level attributes and processes that primarily constrain population dynamics is also needed to ensure that relevant toxicological responses are addressed. ORD has a long history in developing aquatic toxicity testing methods and techniques used nationally and internationally. Experience has been gained with invertebrates, small aquarium fish and large coldwater fish. However, studies with species for which extensive molecular biological information is available (e.g., zebrafish, medaka) are limited, while techniques and basic physiological and toxicological information is limited for species representative of declining amphibian and mollusk populations. Studies and bioassay approaches specifically designed to optimize exposures within developmental windows controlled by specific hormonal axes, and to properly identify and quantify associated adverse effects, are not available. To address these issues a systematic evaluation of compounds known or suspected to disrupt endocrine function through interaction with the aryl hydrocarbon, estrogen, androgen, thyroid and/or retenoic acid receptors will be evaluated in a variety of fish species. In addition, amphibian species (such as *Rana pipiens* and *Xenopus laevis*) will be used to embark on a systematic examination of comparative physiological and toxicological responses to provide more detailed insights into the strengths and weaknesses of different models in terms of mechanistic and ecological relevancy.

Ecotoxicity Characterization

The goal of this research effort is to investigate the interaction of chemical and non-chemical stressors on aquatic life to reduce uncertainties in predicting the joint action of stressors and diagnosing cause and effect relationships in impacted ecosystems. Knowledge gaps that limit the advancement of aquatic life and sediment criteria, and which reflect limitations in current scientific understanding, can be grouped into four broad categories:

1. Interactions of physical and chemical factors
2. Organismal variability
3. Dose characterization
4. Chemical mixture interactions

Future research will build upon the existing ecotoxicological knowledge base to address specific high priority topics that reflect important scientific uncertainties that are relevant to classes of ecological risk assessments that confront the Agency. Research will address the need for assessment approaches that integrate aquatic life effects, and stressor interactions, within the water column and sediments. Research to be undertaken to improve understanding in the areas of physical/chemical interactions will include studies that address metal bioavailability and toxicity and the role of UV in photo-activating organic compounds. Dose-characterization research will improve the means of interpreting the adverse effects of superhyrophobic chemicals in the context of measured or predicted organismal or tissue bioaccumulation. Chemical mixture research will concentrate on the completion of toxicity identification evaluation techniques and be followed by efforts to improve predictive techniques. Efforts will also be maintained to ensure that the results of ecotoxicological studies are available to the risk assessment communities at the federal, state and local levels through the ECOTOX database.

3.3.4.4 Anticipated Products

- **By 1998,** publish a report on wastewater streams as a source of sediment contamination in the Gulf of Mexico.
- **By 1999,** complete ORD Research strategy for harmful algal bloom species.
- **By 1999,** develop an approach for establishing sediment quality criteria for PAH mixtures.
- **By 2000,** publish a report on a method using surrogate, nonendangered test species for assessing risks to endangered species.
- **By 2001,** develop conceptual, empirical, and mechanistic models to evaluate the role of wetlands within the landscape.

- **By 2001,** develop methods and guidance to evaluate the effects of stressor mixtures in sediments at different levels of biological organization.

3.4 Assessment of Ecological Risk

Objective: Develop guidelines, assessments, and methods that quantify risks to ecosystems from multiple stressors at multiple scales and multiple endpoints.

Research Question: What is the relative risk posed to ecosystems by these stressors, alone and in combination, now and in the future?

Since the 1970s, EPA has implemented numerous environmental statutes (e.g., Clean Air Act [CAA], Clean Water Act [CWA], Toxic Substances Control Act [TSCA]). Using an "end of the pipe" regulatory approach, releases to the environment have been significantly reduced from smokestacks, wastewater treatment facilities, and solid and hazardous wastes. As a result, regional and global scale problems, including habitat alteration, loss of biodiversity, climate change, and land-use changes, are currently considered greater risks to ecosystems than site-specific problems (EPA, 1987). The early 1980s saw both the emergence of risk assessment as a regulatory paradigm (NRC, 1983) and the first widespread use of ecological impact findings to influence regulatory and policy decisions. The use of ecological information for decision making has expanded slowly through the 1980s. This trend is illustrated by Federal actions to address the adverse impacts of acid deposition on lakes and forests and the damaging effects of ozone on crops, as well as regulation of diazinon that was based on its impacts to birds. During the mid to late 1980s, tools and methods for conducting ecological risk assessments were compiled in documents such as the Ambient Water Quality Criteria methodology (EPA, 1985), Standard Evaluation Procedures (EPA, 1986) for pesticides, and Superfund's Environmental Evaluation Manual (EPA, 1989).

The EPA Science Advisory Board's (SAB) report, titled Future Risk: Research Strategies for the 1990s (1988), emphasized the need for a fundamental shift in EPA's approach to environmental protection and challenged ORD to provide leadership in the area of ecosystem science. This report provided the impetus to conduct ecological assessments focused on the resources at risk and their composition and distribution within a landscape, multiple stressors, and multiple assessment endpoints. In 1992, EPA published the Framework for Ecological Risk Assessment as the first statement of principles for ecological risk assessment (EPA, 1992) and, in 1998, published the Ecological Risk Assessment Guideline (EPA, 1998a). These documents describes not only methods for conducting the more conventional single-species, chemical-based risk assessment, but also for assessing risks to ecosystems from multiple stressors and multiple endpoints. The publication of these important documents argued for an organization that would focus on enhancing EPA's ability to do better ecological assessments. This is the goal of the NCEA within ORD.

Ecological risk assessment occupies a central position in the continuum from data collection to management decisions. As discussed in Sections 1 and 2, the ability to assess risks to ecosystems must be based on a knowledge of ecosystem functions, behavior, and processes. Other elements of this strategy (effects research and research on ecological exposure, models, and monitoring) present the scope and nature of the research being conducted by the other ORD laboratories to specifically address the critical information needs prerequisite to a robust assessment process. To be effective, the outcome of an ecological risk assessment, i.e., identifying and characterizing risks and determining at what level ecosystems should be protected to ensure their sustainability, requires an essential conjunction of risk assessment and risk management processes. A research approach to advancing the science of multiple-scale, multiple-stressor, and multiple-endpoint ecological assessments is presented in this section. This emphasizes three key areas:

1. Developing risk assessment guidance
2. Performing risk assessments
3. Conducting research on methods

3.4.1 Developing Ecological Risk Assessment Guidance

The development and publication of risk assessment guidelines are important functions managed by the Risk Assessment Forum (RAF), an interagency group of risk assessors, administered by NCEA. Risk assessment guidelines provide consistent procedures for risk assessors to follow standard methods in conducting risk assessments. Using these guidelines, risk managers can better concentrate on actions that will reduce or ameliorate risks, rather than debating the technical merits of the risk assessments. The development process is dynamic, involving individuals with many different scientific disciplines, perspectives, and environmental interests. The refinement of existing ecological risk assessment guidelines and the development of new guidelines are major components of NCEA's risk assessment research program.

Guidelines Development

Proposed guidelines for ecological risk assessment were published in the *Federal Register* on September 9, 1996. After further revision, final guidelines were published. These guidelines are a broad-based expansion of the principles contained in an earlier report (Framework for Ecological Risk Assessment, EPA, 1992). One or more cross-agency colloquia will be organized under the auspices of the RAF to identify and prioritize topics for specific guidance. Next, teams will be formed to develop the guidance documents. Finally, the guidance documents will be peer reviewed and published.

The development of place-based guidelines for those assessments that involve specific places such as watersheds, Superfund sites or other biogeographically defined areas are a high priority for NCEA. These will include conceptual models and their optimization, the involvement of stakeholders, the evaluation of ecological information, and economic considerations in an assessment process.

Ecological Values

EPA's SAB has recommended that EPA devote more resources to evaluating risk to the environment (EPA, 1988), due to the lack of a clear consensus, both within the Agency and with the public, on the value of components. Recently, a multi-program work group identified a common set of agency-wide priorities for ecological protection that help to focus the issues considered by EPA risk managers and decision makers (EPA, 1997b). ORD proposes to build on this project by obtaining the additional EPA review and consensus necessary to finalize the objectives and to begin the process of defining the range of outcomes for an endpoint (i.e., providing bounding estimates for acceptable and unacceptable effects). Combined with other Agency initiatives in this area, this effort could contribute significantly towards the development of EPA-wide risk management guidelines that consider such important issues in the risk assessment process as valuation of ecological systems, cost-benefit analysis, risk communication and perception, and stakeholder involvement in the risk assessment process. Providing guidance for risk managers on the use of ecological risk assessment information should be highly effective in advancing the consideration of ecological risks in decision making at the EPA.

Training and Consultation

Development of ecological risk assessment training is a logical follow-up to the publication of final EPA-wide Ecological Risk Assessment Guidelines (EPA, 1998a). Training can strengthen the use of ecological risk assessment approaches across EPA, draw on the experiences of EPA risk assessors to identify significant issues, and generally improve the ecological risk assessment process. Options could include a short course for managers, a longer program for risk assessors, and an interactive computer-based course. A critical element is the preparation of a range of ecological risk assessment case studies that can be used to tailor the training to a particular audience (e.g., Superfund, pesticides, etc.). Training materials will receive periodic review during development to ensure that the course will be relevant and useful to EPA's customers.

3.4.2 Assessments

The type of ecological assessments conducted by NCEA are selected because they meet one of the following criteria: they offer opportunities to advance the state of science, they are unusually important in that they represent important cross-program and interagency problems (e.g., dioxin, invasive species, global climate change), or the risk assessment may lead to new methods and procedures in assessing risks to ecological systems. Specific assessments may be organized around a set of ecological receptors that are at risk at a particular place (e.g., a watershed), a chemical that is known to pose major risks to ecological resources, or special ecological issues of concern.

3.4.2.1 Place-Based Ecological Risk Assessments

EPA has placed increased emphasis on community and place-based approaches to environmental management. This represents a fundamental change from traditional single-media-based approaches for environmental regulation to a concern for the impact of multiple stressors over a broad range of spatial scales. The purpose of place-based research is to develop and demonstrate methods to assess the impact of multiple chemical, physical, and biological stressors at several different ecological scales. The way communities and entire ecosystems respond to stressors is the goal of our ecological risk assessments. Eventually, we may be able to sufficiently define impacts on ecosystems, including the significance of stressors and management actions, sufficiently well that they will be useful in assessments done at the watershed scale. The research will develop and demonstrate tools, methods, and techniques to better quantify uncertainties associated with risk assessment.

Watersheds

ORD is applying the general principles outlined in the Ecological Risk Assessment Guidelines to five competitively selected watersheds located in different regions across the United States. These ecological risk assessments were undertaken to address local or state concerns and to analyze stressors and resulting ecological effects. Developing and evaluating these demonstration projects will improve place-based risk assessments methods. The approach brings numerous organizations together to address and analyze an environmental problem and stimulates public awareness and participation in decision making for reducing ecological risks. The five watershed-level ecological risk assessment case study sites are:

1. **Big Darby Creek, OH.** A watershed relatively free of pollution that is highly valued for its scenic beauty, its high water quality, and for recreational opportunities.
2. **Clinch Valley Watershed, VA.** The assemblage of fish and freshwater mussel species in the rivers in this watershed is among the most diverse in North America.
3. **Middle Platte River Wetlands, NE.** The Platte River provides water for agricultural irrigation, electric power production, recreation, fish, wildlife, and community and industrial water supplies.
4. **Waquoit Bay Estuary, MA.** A shallow Cape Cod estuary fed by groundwater and freshwater streams is prized by residents and visitors for its aesthetic beauty and recreational opportunities.
5. **Middle Snake River, ID.** The west-central Snake River plain of southern Idaho is the most degraded stream reach of the Snake River.

The planning and problem-formulation stage in all five watershed case studies were completed and presented to the SAB for review in June 1996. Risk analyses are currently underway and are expected to be finished in 1999.

Large-Scale Place-Based Assessments

Complementing the watershed studies are larger scale place-based studies. These studies are important for developing additional guidance on increasingly complex environmental problems. Such studies include both chemical-specific and multiple-stressor assessments. For example, ORD is working with EPA's Region 10 to apply the ecological risk assessment paradigm and to build an ecological information management system database for the river basins that include the entire state of Idaho. This system will develop a streamlined process that can be used to quantify total maximum daily pollutant loadings at multiple spatial scales. In a cooperative effort including all ORD laboratories and Centers and contributing to a similar effort by the interagency Committee on Environment and Natural Resources, an integrated assessment of the Mid-Atlantic area is being conducted. The first effort will be the development of a "state-of-the-region" report on the condition of the ecological resources and the magnitude and extent of stressors in the Region. The role of climate change as an exacerbating influence on these and other stressors will be a major component of this assessment.

3.4.2.2 Chemical-Based Risk Assessments

Although EPA is moving towards implementing community or place-based approaches to environmental protection, chemical-based assessments retain their importance to some EPA programs. There is still a need to improve the science in assessing the risks from chemicals. Assessment methods for chemicals will, however, require emphasis on those that: (1) address chemical mixtures; (2) address cumulative risks from combinations of chemical and nonchemical stressors; (3) can be used to prioritize places and systems for more intensive work; and (4) place impacts of chemicals in a landscape perspective.

While risk assessments from the single-chemical, single-species perspective is well developed, more work is needed on higher levels of biological organization: populations, communities, ecosystems, and landscapes. One of the most pressing questions requiring more research is whether it is possible to extrapolate ecotoxicological information from a single surrogate test species in a single test medium to ecosystem-scale risks. Criteria for prioritizing chemical assessments include: (1) multimedia, multi-program, or contentious issues; (2) assessments that provide examples or prototypes or allow for methodology development; and (3) assessments that provide the opportunity to improve the state-of-the-art as used in EPA's programs and regions through technology transfer and support. Considering these criteria, dioxin and endocrine-disrupting chemicals are strong candidates for ecological risk assessments.

Another important chemical-based activity will be the inclusion of ecotoxicology data in the Integrated Risk Information System (IRIS). This database has become an important reference source for chemical-based risk assessments and is widely used throughout EPA and other federal agencies and in the private sector as a peer-reviewed source of the most important information on the fate and effects of toxic chemicals. The database is now available via the Internet.

3.4.2.3 Special Ecological Assessments

There is a growing concern for the need to understand and assess important ecological issues that transcend the more traditional chemical-based or recently developed, place-based approaches. Some of these are multiple-stressor issues involving global climate change, habitat loss, acid deposition, and a worldwide decrease in biological diversity. These and other regional- and global-scale problems, such as non-point source pollution, may present greater risks to public and environmental health than specific chemicals alone (EPA, 1987). As part of NCEA's mission to advance the science of risk assessment, it will conduct assessments on important ecological issues. Examples of some of the special assessments are identified here.

Acid Precipitation

Since 1990, monitoring networks have provided new data that clarify trends in deposition and have improved the understanding of the relationship among emissions, deposition, and effects. Improved models allow us to reconstruct historical conditions as well as project future scenarios. As a result of these developments, there is a better understanding of the relationship between sulfur and nitrogen emissions and acid deposition and its ecosystems effects. Title IX of the CAA Amendments requires the National Acidic Precipitation Assessment Program (NAPAP) to prepare a scientific assessment of the current state of knowledge of acid precipitation and its effects. ORD will work with a NAPAP interagency team that conducted a preliminary assessment in 1996 and is responsible for a more thorough assessment by the year 2000. The study will focus on the assessment of improvements in aquatic and terrestrial ecosystems resulting from reductions in sulfur emissions.

Disease-Causing Shrimp Viruses

The worldwide shrimp industry has grown at a tremendous rate since the 1950s, largely due to the increase in shrimp aquaculture around the world. Along with the expansion in shrimp aquaculture, there has been an increase in the occurrence of disease-causing shrimp viruses, which have caused catastrophic mortalities and economic losses throughout this worldwide industry, including the United States. The threat of these viruses to shrimp aquaculture is well known. However, there is little or no information on the potential impact of these viruses on wild shrimp fisheries. In response to the growing concerns for pathogenic shrimp viruses, ORD is working on a coordinated government effort to conduct an interagency assessment to deal with the impact of disease-causing shrimp viruses on the wild stocks and on the shrimp aquaculture, importation, and processing industries. ORD is leading the effort to define the problem and frame the boundaries of the risk assessment. The assessment will help support risk management actions to control the impact of these viruses on the wild shrimp fishery and to protect the shrimp aquaculture industry.

Regional Vulnerabilities to Global Climate Change

ORD's Global Change Research Program (GCRP) will focus on integrated assessments of the potential ecological risks of climate change on coastal, freshwater, and terrestrial ecosystems from different regions across the United States, and it will extend the analysis to include implications for human health. The direct impacts of global climate change, such as the increased frequency and intensity of heat waves, hurricanes, and storms, have significant implications for environmental equity concerns. Often the elderly, poor, infirm, or mentally ill people suffer the most from extreme weather events. The goal of this project is to identify the patterns of human health impacts caused by extreme weather events and to develop a plan to reduce the risk of similar damages in the future.

Indirect impacts of climate change on human health are those that are mediated through ecological systems that may be impacted or altered by global climate change, namely, vector-borne diseases, such as encephalitis. Alterations in the patterns of temperature and precipitation will have impacts on the ecology of both the vector host (e.g., mosquitoes), as well as on the parasite or pathogen (e.g., arboviruses in the case of encephalitis).

Assessment of Biodiversity Loss

There is a worldwide concern about the loss of biodiversity. For example, frog and toad populations throughout the world have long been used by scientists as biological indicators of environmental concerns. The rapid decline of frog species worldwide has been associated with a variety of environmental degradation factors, such as habitat loss and fragmentation, chemical pollutants, increased UV radiation, and acidic precipitation. Thus, frog population declines may be a harbinger for environmental degradation. Recently, severely malformed frogs have been reported in wetlands areas in the Midwestern United States and in Canada. A variety of frog species has been found with deformities of the hind limbs (missing limbs, extra limbs, bony limb-like protrusions), other muscular and digit deformities, and deformities of the eye and central nervous system. Although the exact cause of the increase in the observed frequency of such deformities in frog populations is as yet unknown, many theories exist.

Another concern is for the loss of neotropical migratory bird species, those that breed in North America and over-winter in Central and South America. A number of these species are showing significant declines in their breeding populations, and the causes of these decline are not clear. It may be a combination of factors, including habitat loss and fragmentation, excess UV radiation, endocrine-like chemicals, decline in insect numbers (an important food for bird fledglings), or other causes of unknown origin. As with amphibians, migratory birds are considered barometers of environmental quality. While the research on fundamental causes and effects is ongoing, close association with the risk assessment process will help to ensure that experimental and field data will be most useful to environmental decision making. The primary goal will be to identify the problems using current guidelines for ecological risk assessment.

3.4.3 Risk Assessment Methods Research

Considerable progress has been made in assessing the ecological risks from the most serious forms of pollution, such as contaminated areas around industrial plants or sediments and soils highly contaminated by pesticides and toxic chemicals. In many instances where cause-effect relationships can be estimated prospectively, ecological risk assessment has drawn from what is known as the "quotient method" (EPA 1986). Using normative procedures, a hazard and an exposure value may be derived such that when the former is divided by the latter and estimate of risk can be made. That is, the closer the quotient is to 1, the more likely there will be an unacceptable risk. Quotients at values significantly less than 1 may be considered acceptable, depending on the certainty in the derived components (hazard and exposure values) of the risk assessment. This method has been extremely useful in conducting a "comparative" risk assessment (the process of comparing the risk of one chemical or stressor with that of another), but is limited in its utility when applied to assessing "absolute" risks to specific receptors. Thus, new methods are needed to assess risk from multiple stressors, assess risk across multiple-scales, link sources, stressors, and effects in terrestrial and aquatic systems, and integrate human health and ecological risks. The ability to assess risks from such major environmental threats as global climate change, forest decline, reproductive failure and decline in species, loss of genetic or biological diversity and decreases in habitat availability, requires the development of new assessment methods that adequately incorporate the complexity of the environment. When successfully implemented, these newer methods may help us to better understand how multiple stressors effect the vulnerability and sustainability of important ecological resources at a range of spatial and temporal scales.

Although there is much to be done in methods development research, the following areas are considered most important and highest priority for ORD.

Place-Based Methods

The primary challenge to place-based assessment methods is how to incorporate the complex relationships of landscapes, ecological receptors, and condition. Traditional concepts (e.g., those used for assessment of the risk for a single chemical to a single receptor) for the characterization of hazard, exposure, receptors, and vulnerability have to be reconsidered. One approach is to broaden the application of the stressor-response curve which is an essential element for evaluating risk management alternatives. For example, how would the x and y parameters be derived in a stress-response curve when the stressor is an invasive species and the response is habitat alteration? In close cooperation with extensive data collection programs described elsewhere in this strategy and by applying ecological risk assessment principles at watershed and regional scales, effective methods to conduct place-based risk assessments will be developed.

Assessment Endpoints and Indicators

The identification of what resources to protect, and at what level to protect them, and the measure of success in protecting the resource are critical components of this research strategy. Initial work already has begun through a joint NSF/EPA solicitation proposals on research in ecological values. The early results of research demonstrate how ecological values are identified and incorporated into measurements and assessment endpoints. Much of the research will be carried out in those places where work is already underway, the five watershed case studies, the Mid-Atlantic area, and EPA's Region 10.

The development of ecological indicators is highlighted as a major research priority ORD (EPA, 1997b) and an aim of this strategy. Indicator selection and development and their use in determining the condition of ecosystems, "ecological condition," will be described elsewhere (Indicator Evaluation Guidelines, in preparation). Predetermined environmental values and the recognized need for monitoring them, are primary factors in selecting assessment endpoints and the measurement endpoints derived from them. Accordingly, the choice of indicators is driven by societal values and the management goals that are articulated for protecting and restoring ecosystems. It would be tragic to develop indicators of ecological condition that have no relationship to assessment endpoints. Thus, a principal objective of this strategy is to show the linkages between indicator development and risk assessment methods development. This indicator research will be conducted in a highly cooperative, coordinated manner across the ORD divisions and their ecological research units. The research in indicator development and risk assessment methods will necessarily include the collection and synthesis of ecological values from a variety of stakeholders, using sociological measurement methods.

Extrapolation

Most ecological research on the issue of ecosystem stress is addressed by selecting a simple system to study (e.g., hot springs), and applying the results to a more complex system (e.g., rocky tidal interfaces). This "reductionist" approach to complex systems has helped to better understand many of the components of ecosystems and how they function. However, modeling efforts to attempt comparison of the responses of these simpler systems and those of more complex ones have resulted in significant disagreement between measured and predicted responses. Applying a "systems" or holistic approach will lead to better understanding of complex ecosystem responses and improve our capability to extrapolate the results from single species to populations, communities, and ecosystems; from surrogate test species to target species; from one watershed or region to another; or from simple systems to more complex systems. As discussed in Section 1 of this strategy, there remains a substantial amount of research to be done to assess multiple stressors, multiple endpoints, and multiple scales, all of which will add significantly to useful systems modeling and extrapolation capability.

Our approach will take advantage of the fact that risk assessments like the MAIA are designed not only to assess the risks to that area but to advance the science of risk assessment. The term integrated assessment refers to integration across resources (e.g., aquatic versus terrestrial), scale (e.g., national versus regional) and sector (e.g., "natural" processes versus human-induced impacts). Many agencies at all levels of government and other organizations, are attempting to generate assessments, but in the absence of standardized methods, more organized hierarchical approaches, and the development of "objective-values-endpoints-measures" paradigms, these assessments often end up being little more than interpretive reports. A major research need is to concentrate on the development of multiple large scale (watershed and regional) ecological assessments where results from smaller scale experiments are extrapolated and applied to other, different types of ecological systems. This will include the development of methods to combine data from disparate sources (e.g., from different states) into an integrated assessment.

Integration of Human Health and Ecological Risk

Over 40 years ago, dead and dying cats and birds provided an early warning of mercury-contaminated fish that subsequently resulted in widespread human health effects in Minimata, Japan. Soon thereafter, Rachel Carson's *Silent Spring* (1962) made the acceptance of wildlife as indicators of environmental contamination commonplace. Today, there are new examples of animals serving as sentinels of potential environmental health effects. Environmental endocrine disruptor effects observed in wildlife offer valuable insight into potential human health effects, and other environmental issues are being continually identified, such as the increased occurrence of deformed frogs in the Midwest. Research will be conducted to build on the frequently underutilized commonalties between human health and ecological risk assessment and to develop, validate, and test new approaches for using animals as environmental sentinels for problems with potential human health consequences.

For example, research on sentinel species can draw upon a broad range of available information to address critical human health and ecological issues. Consistent with the purpose of this integrated assessment initiative then would be to develop, validate, and use sentinel species approaches to improve human health and ecological risk assessments. A range of techniques will be evaluated, including further use of disease information from companion and/or prey species, stress response data from surveys of aquatic animals and wildlife, and the use of in situ monitoring for ecosystem change. Correlations between occurrences of human and animal environmental diseases will be evaluated. The interpretation and appropriate use of these data in risk assessment will be emphasized.

3.4.4 Anticipated Products

- **By 2001,** complete an assessment estimating the relative vulnerability of forests and small streams in the Mid-Atlantic Region of the United States to multiple stressors, including habitat change, acid deposition, acid mine drainage, global change, ozone, pesticides, and nitrification.
- **By 2002,** issue guidance on methods to conduct place-based risk assessments.
- **By 2005,** prepare a synthesis report on conducting ecological risk assessments at watersheds, and indicate how these results can be applied to watershed-scale risk assessments.

3.5 Ecosystem Risk Management and Restoration

Objective: Develop prevention, management, adaption, and remediation technologies to manage, restore, or rehabilitate ecosystems to achieve local, regional, and national goals.

Research Question: What options are available to manage the risk to or restore degraded ecosystems?

Ecosystem management and sustainability recently have moved to the forefront of both scientific and policy debates (Christensen et al., 1996; Baker, 1996; Morrissey, 1996). Many of the issues raised remain unresolved (including consensus on the meaning of sustainable ecosystems), but one thing seems clear: the increasing attention to ecosystem management, in tandem with discussions of sustainability, represents a significant reexamination of U.S. land and natural resources management practice and policy (Haeuber and Franklin, 1996). Risk management actions are an important part of ecosystem management and typically occur at multiple scales. For example, transboundary issues such as acid deposition and atmospheric levels of greenhouse gases require risk reduction via widespread actions that usually are applied at every source. In most cases, active management- and technology-based risk management (which often follows as an implementation requirement from policies and regulations) is typically applied to watersheds or ecosystems that can be defined by watersheds. Accordingly, the strategic choices for the scales of risk management research are "national" (for regulatory based transboundary considerations) and "watershed" (for most regulatory and local management efforts). Current EPA regulatory, oversight, and policy instruments for risk management include chemical-specific regulation via registration, control, and classification processes (FIFRA); discharge and use permits that require compliance with ecologically based criteria (CWA and CAA); technology-based requirements for specific point and non-point pollutant sources and constituents (CWA, Coastal Zone Management Act [CZMA], and CAA); policy initiatives often in concert with other international, federal, or state agencies (Montreal Protocol, Climate Convention); review and approval of environmental impact statements for federally funded projects (NEPA); and site remediation as part of mandated clean-up programs (SARA, RCRA).

Significant attention will be given to Community Based Environmental Protection and watershed planning for flexible local implementation of selected regulatory requirements, as well as for reaching local environmental goals that can be above the regulatory floor. These local, collaborative planning efforts often attempt to integrate community values for economic, social, and environmental concerns to reach locally defined sustainability goals and offer new research opportunities.

Technological and policy-based risk management options are now available. However, given the rate of development of the man-made environment, present regulatory approaches may not always limit risks to tolerable levels for vulnerable ecosystems. There is a need to develop new, cost-effective prevention, control, and remediation approaches for sources of stressors and adaptation and restoration approaches for ecosystems. Risk management options, from pollution prevention through ecosystem restoration, correlate in sequence with the steps of the Ecological Risk Assessment Paradigm in the sense that some options can eliminate stressors at their source, and some can manage stressors to acceptable levels, whereas others adapt to unavoidable stressors and repair damaged ecosystems to functioning levels. Ultimately, the risk management research products must be fully integrated with risk assessment research products and support decision-making needs of risk managers in meeting regulatory or community-based goals.

3.5.1 Ecosystem Risk Management

A number of issues have been identified that provide the rationale for ORD risk management research, the highest priority of which are:

- Land use changes and pollutant loadings from urban and infrastructure development needs, agriculture, and other economic development, which are increasingly responsible for ecosystem degradation and loss of ecosystem function.
- Non-point sources of pollutants (including atmospheric sources), which remain the largest uncontrolled pollutant problems in watershed and aquatic ecosystems.
- The need for remediation of contaminated sediments for coastal and freshwater ecosystems.
- The lack of data, tools, and demonstrated technologies to design and implement successful risk management programs for ecosystems for local communities.

The science and engineering needs for stressor source characterization, prevention, reduction, and other management alternatives to address these priorities include:

- Developing and applying stressor source characterization methodologies, such as Environmental Life Cycle Assessment.
- Developing the pollution prevention approaches, source control technologies, remediation practices, and watershed planning methods to manage or reduce stressors to levels that protect ecosystems and meet public health goals.
- Identifying criteria for the optimum mix of risk management policies, technologies, and approaches within watersheds, based on effectiveness and economics.
- Developing watershed management decision support systems to assist local planners in evaluating options in the complex integrated airshed/watershed/groundwater context and transferring the information to the user community.

There will be three areas of ecosystem management research: (1) pollution prevention; (2) control technology; and (3) remediation.

Pollution Prevention

Pollution prevention (P2) has been applied primarily as a way for industries to reduce costs to meet national effluent and emission standards and is still being developed as a means to further reduce ecologically important emissions (e.g., chlorofluorocarbon [CFC] and solvent substitutions). A broader application of P2 in a watershed context offers promise as a part of achieving sustainable communities, including ecosystems. As development within watersheds proceeds, particularly in those urban fringe areas susceptible to sprawl, community planners are asking long-term questions regarding how housing, commercial buildings, roads, and other infrastructure elements can be designed and operated to minimize resource consumption and the pollutants that affect nearby ecosystems. For example, Environmental Life Cycle Analysis is a well-developed analytical tool to enable systematic examination of the tendencies for a given design of a process, system, structure, or product to consume resources and to generate pollutants. Using such a tool, in combination with risk assessment information, it is possible to characterize sources of stressors and identify designs that minimize their occurrence. Research objectives within this area will concentrate on examining the most beneficial pollution prevention approaches for remaining major industrial problems and identifying the most cost-effective applications for pollution prevention within a watershed context.

ORD's research in ecologically related pollution prevention will be directed to these objectives:

- Develop stressor-source characterization approaches based on Environmental Life Cycle Analysis and related approaches. Life cycle analysis and other P2 tools developed for industrial applications will be evaluated and modified as appropriate for application to watershed and ecosystem management.

- Identify chemical substitutions and other P2 solutions that are most cost-effective for alternative solvents and tropospheric ozone precursors. Opportunities to reduce major and widespread stressors that present exposures to ecosystems over large areas and that contribute to transboundary problems will be exploited. Criteria for reducing the highest risks to ecosystems will be applied to research projects traditionally focused exclusively on the industrial sector.

- Identify criteria for the most cost-effective applications of pollution prevention for design of new development in a watershed context. Cost accounting approaches, valuation research from the grants program, and the integration of P2 and business cycles will be exploited for application to watershed and ecosystem management.

Control Technologies

Ecosystem research is often characterized as "place-based" because the stressors, their impacts, and their reduction and management are most often ecosystem specific and can only be understood and reduced "in-place." Notable exceptions to this characterization exist; among these are control technologies that reduce emissions to the atmosphere or to aquatic systems that are applied to all sources.

Watershed management has evolved during the past two decades to depend heavily on defining and implementing best management practices (BMPs) that are directed primarily at non-point source problems, including wet weather flows. BMPs are designed to minimize the ecosystem (and human health) impacts of the watershed activity while permitting their continuation. Examples are erosion controls for urban development, nutrient and pesticide management for agriculture, and storm water management in urban watersheds. BMPs are not new. Although uncertainties remain about their cost-effectiveness, a considerable body of research has been completed and BMPs are now widely promoted by both watershed managers (federal, state, and local agencies; planning commissions; etc.) and land use managers (farmers, foresters, developers, miners, etc.) The ongoing research program in wet weather flow control technologies and related watershed planning issues is described in more detail in Section 4.

Control technology research will be focused on:

- Defining, developing, and demonstrating the most cost-effective control technologies for reducing greenhouse gas emissions, wastes, and waste waters; pollutants in effluents and emissions; and BMPs for managing storm water runoff.

- Identifying, developing, and demonstrating the most cost-effective combinations of pollution prevention approaches and control technologies for reducing stressors to major ecosystems in the United States.

- Defining, developing, and demonstrating cost-effective control approaches for emerging risks, including endocrine disruptors, cryptospiridium and other pathogens, and atmospheric deposition, and for multimedia effectiveness, including impacts on ground- and surface waters.

Remediation

Remediation of contaminated portions of watersheds is often desirable, if not necessary. Since 1980, almost all remediation research has been directed to waste site cleanup and has usually been driven by human health risk concerns. Increasingly, data are showing that contaminated sediments threaten ecosystems, and that waste sites having contaminated groundwater and soils pose threats to ecosystems. Although the actual ecological risks of contaminated media remain uncertain, EPA has clear mandates for action to clean up sites, and aggressive risk management steps are contemplated. Remediation approaches for contaminated media within ecosystems must be modified to concentrate on reducing stressors while sustaining ecosystem functions. Reducing specific chemical contaminants to risk-based toxicological levels may not be sufficient remediation if the technology used to reduce such levels introduces additional or unacceptable risks. For example, dredging contaminated sediments for high-energy treatment in engineered treatment systems is generally more costly and may be more ecologically disruptive than strategies for in situ bioremediation coupled with partial or complete containment. Similarly, phytoremediation (using plants to remediate soils and groundwater) applied in strategic locations in watersheds may be effective in passive cleanup of widespread contamination from pesticides and waste site residuals.

Research in the remediation area will be limited primarily to:

- Defining the most applicable existing remediation technologies for contaminated media within vulnerable ecosystems.

- Developing new, cost-effective technologies for in situ treatment of contaminated sediments.

- Defining or developing remediation options for reduction of lower level, but still ecologically relevant, concentrations of spatially dispersed contamination, including pesticides in groundwater, plumes from waste sites, and contaminated sediments.

- Defining conditions where ecosystem restoration approaches (described below) increase the resilience of ecosystems to levels that reduce requirements for remediation of contaminated media.

3.5.2 Adaptation and Restoration

Adaptation activities are efforts enabling improved accommodation to inevitable stressors, exposures, and habitat alteration. Climate change impacts, for example, and the residual and cumulative impacts from other multiple stressors will likely require adaptation and restoration measures to sustain ecosystems for future generations. Adaptation is closely linked to ecosystem restoration, described in more detail below. Rehabilitating an ecosystem may decrease significantly its vulnerability to stressors. For example, restoring riparian zones within watersheds is an adaptation measure that may be applicable for certain land use activities within the watershed that cannot be excluded for economic or political reasons. Adaptation includes intentional introduction of nonnative species or biotechnological modifications of species to alter vulnerabilities and carries notable risks with it.

Adaptation

Ecosystem stressors from both natural and anthropogenic sources are inevitable. Cost-effective stressor reduction, as a means to reduce risks, may not always be feasible or practical. Investments in stressor reduction are quite large, and innovative technologies could emerge for virtually every circumstance. Investments made now in developing adaptation approaches for ecosystems that make them more resilient to inevitable stressors are directed toward sustaining ecosystems into the future.

Adaptation is not simply a means to enhance the assimilative capacity of ecosystems so that they can tolerate increases in stressors, including pollutant loads and land use changes. Rather adaptation is a means to enhance the sustainability of ecosystems after stressor reductions and pollution prevention have reached their maximum achievable levels.

Research in the adaptation area will focus on:

- Defining, developing, and evaluating adaptation options for climate change and other transboundary stressors, including the costs and effectiveness of these options.

- Developing adaptation approaches to accommodate ecosystems to inevitable stressors.

- Identifying circumstances where adaptation measures are less costly and produce lower ecological risks than does remediation of contaminated ecosystem media.

- Evaluating the practicality of effective eradication of undesirable nonindigenous species and prevention of their future invasion, including cost-effective approaches for the most serious terrestrial and aquatic problems.

Habitat Modification and Restoration

Increasingly, ecologists are noting that loss of habitat and degradation of ecosystems are derived from land management practices, intensive watershed development, hydrologic modifications, erosion and sedimentation, and human infrastructure "build out." This increased recognition also is emerging in risk-based watershed assessments. Related stressors are multiple, and impacts are both direct (e.g., loss of wetlands and riparian zones to construction and development) and indirect (e.g., nutrient enrichment and herbicide impacts on field-edge vegetation and related impacts on fauna).

Changes in landscape composition and pattern can influence significantly the fundamental ecological processes of water, nutrient and materials, energy, and biotic flows and fluxes at a variety of scales which, in turn, affect the risk to and sustainability of desired conditions in valued ecological goods (e.g., high-quality and abundant water, productive forests, and abundant and diverse wildlife) and services (e.g., watershed resistance to flooding). It is through the modification of these patterns (e.g., increasing forest fragmentation, roads crossing streams, and agricultural on steep slopes) that humans threaten sustainability of ecological goods and services that permit local and regional socioeconomic stability and resilience.

EPA's mandates for assessing ecological risks from this array of activities and for mitigating their impacts through restoration programs are both long-standing and emerging. The CWA requires wetland mitigation as part of the joint EPA/Corps of Engineers (COE) implementation programs. Non-point source control programs, as part of the CWA and the CZMA, require EPA to identify problems, provide solutions, and promulgate programs and regulations. NEPA requires environmental impact assessments for certain federal projects. More recently, litigation centered around the TMDL process apparently will lead to incorporating ecosystem restoration and habitat modification limitations into water quality management at the watershed scale.

In any case, the relative risks posed by the full array of stressors, in combination with calls for risk management options for sustaining ecosystems for coming generations, signal the need for an active research program. Risk management considerations will be engaged at local and national scales and will address both improvements to restoration approaches and the technical foundation for restoration policies developed by others.

All elements of the ecological risk assessment process must be involved to evaluate damaged ecosystems and to provide the ecological basis for managing the risks and restoring the ecosystems. Although chemical-pollutant-based risk assessments enjoy a relatively long history of both research and application within EPA, habitat modification and restoration are emerging as important issues, both scientifically and operationally.

Specifically, research will focus on the need to develop: (1) protocols and indicators to diagnose ecosystem restoration needs; (2) criteria to evaluate progress toward restoration; (3) analysis of technical issues related to riparian zone policies; (4) data for costs and effectiveness for watershed ecosystem restoration practices; and (5) decision support systems for state and community planners and their supporting consultants to establish ecologically relevant goals and facilitate consistent, cost-effective decisions on ecosystem restoration within watersheds.

Landscape Characterization

In many cases, habitat and landscape alterations pose far larger threats to the integrity and sustainability of our ecosystems than pollutants do.

Landscape characterization documents the composition and spatial relationships (patterns) of ecological resources, including forests, streams, estuaries, urban environments, and agricultural and rangelands, over a range of scales, as it relates to ecological condition and resource sustainability. Spatial patterns of other biophysical attributes, including geology, climate, topography, hydrology, and soils, often influence (or determine) landscape composition and pattern and the sensitivity of ecological resources to stressors within any given area. Therefore, characterization of landscape composition and pattern is fundamentally important in understanding the relative vulnerability of and the risks to ecological goods and services valued by society.

Additionally, an understanding of the relationships between landscape composition and pattern and conditions of ecological goods and services can lead to formulation of a set of alternatives to reduce vulnerability and risk. Development of methodologies and tools to characterize landscapes should significantly reduce the uncertainty in vulnerability and risk assessments and in formulation and implementation of risk reduction strategies at a variety of scales.

Eco-criteria for Habitat Modification and Restoration

Protecting aquatic ecosystems requires moving beyond a dependency on traditional chemical-specific criteria and whole-effluent testing. Additional stressors, such as habitat modifications, increased sediment loads from erosion, and overenrichment of nutrients, are often cited as causes of ecosystem degradation. EPA is moving toward a more comprehensive watershed approach to ecosystem protection to accommodate these and other human-induced stressors. Methods are needed to establish biological criteria, to assess the cumulative impacts of human activities in a watershed, and to diagnose causes of degradation.

The development of criteria to protect and sustain ecosystem resources also depends on research to better understand how populations, communities and ecosystems operate and how they respond to stressors introduced by human activities.

Sustainability also depends not only on the integrity of individual ecosystems, but also on the exchange of materials and energy within and among ecosystems within a watershed or region.

Riparian Zones

The Office of Water, the regions, and the federal natural resource management agencies have placed considerable emphasis in the last one to two years on the concept of stream corridor and riparian zone management and restoration. Research has demonstrated that riparian zones can be effective in reducing pollutant loads to streams, and stream corridor management and restoration is known to increase the quality of stream habitat for fish and other aquatic species. A leading question for future ecosystem restoration policy development is the extent to which many watershed restoration goals can be met by focusing on stream corridors and riparian zones.

Watershed Restoration

The developing fringe upstream of Metropolitan Statistical Areas (MSAs) and coastal and estuarine areas have been under stress for some time and, increasingly, communities are engaged actively in watershed management. These areas support over 60% of the U.S. population, and roughly one-half of its population increase during the last three decades has occurred in coastal and estuarine areas. These watersheds, in contrast to nationally recognized ecosystems (e.g., the Florida Everglades), are not heavily funded “research and application test beds” that have both research and operational budgets. Rather, such watershed restoration programs are typically organized as part of community-based initiatives.

These watersheds include areas that extend upstream of new development into agricultural and forested areas. In many cases, wetlands have been lost or degraded, riparian zones have been neglected or overdeveloped, soil has eroded severely, and, as a result, habitats are impaired by reductions in species diversity. In other cases, stream flow rates have been altered to the detriment of aquatic species. Tools, databases, and decision support systems are needed urgently by local planners and risk managers for these situations.

The Office of Water is actively promoting watershed restoration in these circumstances and most recently, President Clinton announced the American Heritage Rivers initiative that targets rivers to focus restoration and protection efforts. Although numerous advocacy programs have been launched, systematically collected data to identify the cost-effectiveness of such efforts are sparse, and large uncertainties exist about the long-term success of restoration projects.

Decision Support for Risk Managers

Ecosystem restoration within watershed settings will become increasingly important in protecting and sustaining ecosystems as communities and watershed management organizations employ such restoration methods. The most common needs for decision information will be those of local groups committed to restoration and those of regional and state programs that promote restoration as part of total water quality management programs. The Office of Water anticipates that the waste load allocation process, which uses TMDLs as a means to allocate obligations for improvement in water quality, will increase dramatically the demand for restoration practices. Thus, restoration goals and opportunities must be considered in both water quality and ecological contexts. In these contexts, decision-support systems are central to efficient and systematic planning and implementation.

The form and content of decision-support systems not only will build on the specific restoration technologies under development within ORD, but also will consolidate and integrate data, case studies, and information produced by others, including the ORD STAR Program. Where appropriate, remotely sensed data, diagnostic indicators, and EMAP results will be combined to provide relevant decision support for watershed managers.

3.5.3 Anticipated Products

Ecosystem Management

- **By 2000**, identify and test one chemical replacement for existing CFC substitutes having high global warming potential.
- **By 2002**, develop global change adaptation strategies and costs for pollution control, water supply, and related infrastructure.
- **By 2005**, demonstrate at least two reliable and cost-effective in situ technologies for the treatment or containment of in-place contaminated sediments.
- **By 2003**, complete an assessment of the requirements and costs of mitigating and adapting to the watershed vulnerabilities identified in the Mid-Atlantic regional vulnerability assessment.
- **By 2008**, demonstrate cost-effective adaptation and mitigation technologies for watershed and regional systems in at least two regions of the United States, including the Mid-Atlantic Region.

Adaptation and Restoration

- **By 2003**, complete an assessment of the requirements and costs of mitigating and adapting to the watershed vulnerabilities identified in the Mid-Atlantic regional vulnerability assessment.
- **By 2004**, provide diagnostic tools and models for assessing feasibility, priorities, and measures of success for watershed restoration projects and issue guidance on the application of the tools and models.
- **By 2005**, complete an assessment of the regional sustainability/vulnerability of ecosystems in the Southeastern United States; provide decision support tools for watershed restoration projects.
- **By 2008**, complete an assessment of the regional sustainability/vulnerability of ecosystems to local, regional, and national stressors, now and in the future; demonstrate cost-effective adaptation and mitigation technologies for watershed and regional systems in the Mid-Atlantic Region of the United States and in one additional region.
- **By 2008**, complete three pilot restoration projects for developed and partially developed watersheds with different endpoints of societal value.

SECTION 4

High Priority Environmental Research Issues

Using ORD's ecological core capabilities and research to address high-priority customer needs

4.1 Introduction

As the underlying concept for the Ecological Research Strategy (Section 2), and as consistent with the recent NRC report (NRC, 1997a), the Ecological Research Program has begun by defining the in-house, core research and core capabilities (Figure 2-4). This is the foundation from which all of the in-house, short- and long-term research is based. These core capabilities and research for the core ecological research program are presented in Section 3. Part of that core capability is clearly applied to these future, expected, high priority needs of the Agency: for example, the next generation of exposure and effects models for environmental management across large areas of the country; the development of large scale regional assessment methods; new monitoring instruments, designs, and statistical techniques; and alternative restoration options. ORD's goal is to see that this research will lead us to the innovative environmental management discoveries for the 21st Century.

These core capabilities are also the foundation for meeting the shorter-term needs of the Agency. The environmental problems or hazards, real and potential, identified by the Agency, Congress, the public, and others are clearly the required focus of most of the ORD research. In many cases, it is not clear where the core (fundamental) research program ends and the more immediate, problem focused (applied) research begins. As ORD works at the interface between the fundamental and applied sciences, it is expected that differentiation between the two designations would be difficult. It might best be thought of as a three-part system as shown in Figure 4-1. Obviously, this core capability is finite and therefore must be focused for both the maintenance of the trunk of the tree and the ever changing canopy in areas that are of high priority and where ORD can, in fact, make a difference.

For the purpose of this document, ORD has focused on the core program and its direction (Section 3), how these talents and maintenance of a core program address Agency issues of importance (Section 4), and how to assist in integrating the research, to address real problems in research (Section 5) (Figure 2-4). However, the Ecological Research Strategy may be best represented in an interactive, three-dimensional web of core capabilities, problems and field locations where the capabilities are applied to the problems, and where all of the elements dependent on each other to varying degrees (Figure 4-2).

Figure 4-1.
Office of Research and Development's research elements
(fundamental, core, and problem focused) portrayed as a tree.
Concept derived from NRC report, "Building a Foundation for Sound Environmental Decisions," (NRC, 1997a).

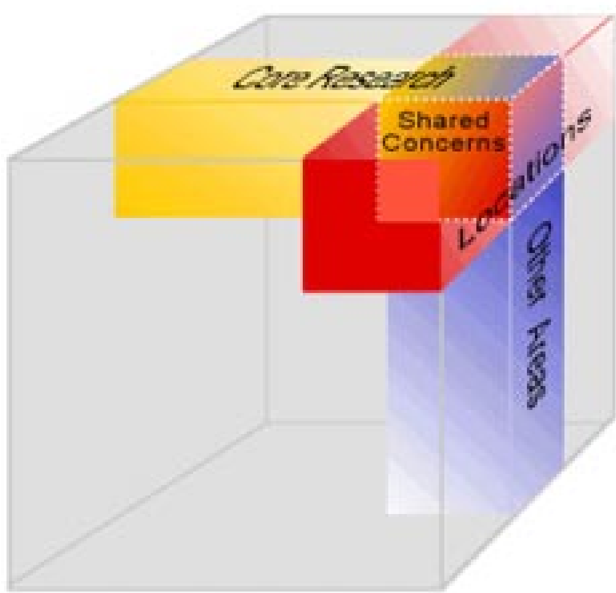

Figure 4-2.
Considerable overlap is necessary between core, geographic issues, Program Office needs,
Congressional interests, and other interests,
making clean separation among such related topics unrealistic.

This section of the Strategy is devoted to presenting research directions relative to the high priority problem areas that have been identified for concentrated effort over the next three to five years. The scientific questions are those that are receiving the primary emphasis by the in-house research program, and by omission, the research that is **not** expected to receive significant effort in the in-house program. These “problems” or “environmental hazards” are not independent of each other (Figure 4-2), and no attempt to separate them has been made. For example, it would be foolish to assume there would be no overlap of funding for scientists working on acid deposition, nitrogen research, landscape changes, and/or eutrophication. However, we have attempted to identify the scientific questions that are most appropriate to each high priority problem area in order to assist our customers, not all of whom need to address cross media and multiple stressor issues, in identifying their specific areas of interest.

Table 4-1 provides an overview of the high priority problems and the organization within the Agency most interested in these issues. It is useful to emphasize that it is the regional offices who may be the primary customers for the whole of the Program as they are forced by requirement to think about the environment holistically.

4.2 Acid Deposition Research

Government Performance and Results Act Subobjective: Reduce ambient sulfates and total sulfur deposition by 20% to 40% and reduce ambient nitrates and total nitrogen deposition by 5% to 10%.

Acid deposition effects on lakes and streams have been well documented, and the CAA Amendments of 1990 have required reductions in sulfur and nitrogen deposition. Recent evaluations of long-term sulfur and nitrogen air concentration and wet deposition trends appear to show that the above subobjective has been met for both sulfur and nitrogen as the result of Phase I emissions reductions. Concern continues, however, as to whether these reductions protect the most sensitive surface waters and forests. Title IX of the Clean Air Act Amendments requires a comprehensive assessment of the Acid Deposition Control Program in the year 2000 and every four years thereafter. ORD will, therefore, continue to conduct relevant ecological research to assist with this requirement. The research will focus on evaluating existing and future monitoring data, monitoring of high elevation index sites, continued monitoring of representative lakes and streams in sensitive areas of the Northeast and Mid-Atlantic, and conducting research at index sites to better understand acidification and recovery processes and modeling.

Process research will focus on evaluating (1) relative effects of sulfur versus nitrogen deposition, (2) responses to reduced deposition (including causes of reduced base cation concentrations in Northeastern lakes), and (3) needs for future process research, monitoring, and predictive modeling.

4.2.1 Research Questions

- What are the current status and future trends in sulfur and nitrogen air concentrations and wet and dry deposition?
- What is the contribution of cloud water deposition to total deposition at the high elevation index sites?
- What is the optimal network design for monitoring long-term local and regional trends in deposition?
- How is dry deposition best measured and estimated over regional scales?
- What are the trends in the chemistry of lakes and streams in response to decreased acidic deposition?
- How can the use of probability surveys and fixed site networks be optimized for measuring long-term regional trends in chronic and episodic surface water acidification?
- How can we improve the use and interpretation of surface water/watershed acidification models?
- What are the relative future effects of sulfur versus nitrogen deposition?
- How does current monitoring compare to model projections?
- What are the causes and relative regional controls of decreased base cation concentrations in NE surface waters (and, thus, what aren’t they recovering more in the wake of drastically reduced deposition)?

Table 4-1.
Summary of high priority environmental problems of interest to the Agency.
(Shaded box represents primary customer interest.)

<table>
<tr><th></th><th></th><th colspan="6">Customers</th></tr>
<tr><th></th><th>Research Problems</th><th>Regional Offices</th><th>Office of Air and Radiation</th><th>Office of Water</th><th>Office of Pollution Prevention, Pesticides and Toxic Substances</th><th>Office of Solid Waste and Emergency Response</th><th>Office of Policy Planning and Evaluation</th></tr>
<tr><td>1.</td><td>Acid Deposition</td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td></td><td></td><td></td></tr>
<tr><td>2.</td><td>Ozone</td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3.</td><td>Mercury</td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td></td></tr>
<tr><td>4.</td><td>UVB</td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td></td><td></td><td></td></tr>
<tr><td>5.</td><td>Nitrogen</td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td></td><td></td><td></td></tr>
<tr><td>6.</td><td>Global Change</td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td></td><td></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td></tr>
<tr><td>7.</td><td>Contaminated Sediment</td><td style="background:#e5e5e5"></td><td></td><td style="background:#e5e5e5"></td><td></td><td style="background:#e5e5e5"></td><td></td></tr>
<tr><td>8.</td><td>Wet Weather Flow</td><td style="background:#e5e5e5"></td><td></td><td style="background:#e5e5e5"></td><td></td><td></td><td></td></tr>
<tr><td>9.</td><td>Toxic Algal Bloom</td><td style="background:#e5e5e5"></td><td></td><td style="background:#e5e5e5"></td><td></td><td></td><td></td></tr>
<tr><td>10.</td><td>Eco-Criteria</td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td></tr>
<tr><td>11.</td><td>Total Maximum Daily Loading</td><td style="background:#e5e5e5"></td><td></td><td style="background:#e5e5e5"></td><td></td><td></td><td></td></tr>
<tr><td>12.</td><td>Endocrine Disruptors</td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td style="background:#e5e5e5"></td><td></td><td></td></tr>
<tr><td>13.</td><td>Pesticides</td><td style="background:#e5e5e5"></td><td></td><td style="background:#e5e5e5"></td><td></td><td></td><td></td></tr>
<tr><td>14.</td><td>Landcover Change</td><td style="background:#e5e5e5"></td><td></td><td style="background:#e5e5e5"></td><td></td><td></td><td style="background:#e5e5e5"></td></tr>
</table>

4.2.2 Implementation

The Office of Air and Radiation will maintain a national deposition monitoring network, while ORD will continue the annual monitoring of a representative set of 100 lakes in the Northeast and 100 streams in the Mid-Atlantic that are appropriate for estimating the regional changes in acidification in surface waters in these two regions of the United States (TIME Program). More frequent monitoring and data analysis will be conducted on 30 lakes in the Northeast and 15 streams in the Mid-Atlantic (the LTM Program). ORD will also maintain three mountain cloud chemistry sites in the northern and southern Appalachians to better quantify the contribution of clouds to total deposition at high elevations. In addition, ORD will conduct watershed modeling to evaluate controls on responses of watersheds and surface waters to forms and levels of acidic deposition as well as to help explain and predict possible future responses of watersheds and surface waters.

Finally, ORD will continue to conduct research on dry deposition measurement and estimation methods and network optimization. All of the ORD research will be done in-house with cooperators from other agencies , universities, or through contracts (see also anthropogenic nitrogen research in the multimedia section). Further, however, research on acidification and recovery processes will be conducted through grants provided by the EMAP, DISPro Program (see Section 5.8).

4.2.3 Anticipated Products

- **By 1999**, report on the trends in dry deposition of sulfur and nitrogen in the eastern United States between 1989 and 1995/1996. (NERL)

- **By 2000**, assess ecological improvements in surface water condition based on the Long Term Monitoring (LTM) Program as they relate to the reduction of SO_2 emissions in the Adirondacks. (NHEERL)

- **By 2000**, a report that quantifies the relative contribution of wet, dry, and cloud deposition to selected Eastern high elevation forest sites. (NERL)

- **By 2001**, report on the relationships between observed trends in deposition chemistry and the chemical response of lakes and streams. (NHEERL and NERL)

- **By 2001**, report on improved model projections of potential future effects of sulfur and nitrogen deposition on surface waters. (NERL)

- **By 2003**, reevaluate the improvements of surface water chemistry in the Northeastern and Mid-Atlantic regions of the U.S. using probability-based sampling of the Temporally Integrated Monitoring of Ecosystems (TIME) studies. (NHEERL)

4.3 Ozone Research

Government Performance and Results Act Subobjective: Develop tropospheric ozone precursor measurements, modeling, source emissions, and control information to guide cost-effective risk management options and produce health and ecological effects information for National Ambient Air Quality Standards related to ozone risk assessments

Chronic ozone exposures have been shown to cause significant forest and crop damage in North America. Since 1970, the CAA has treated ozone as a “criteria pollutant” by mandating National Ambient Air Quality Standards (NAAQS) and establishing sanctions against states that fail to meet the prescribed targets. Although considerable progress has been made since the 1970s in reducing the highest ambient levels of urban ozone exposures through national and local precursor emissions controls, there are still 106 counties not meeting the current NAAQS for ozone. The perceived failure of the current Program to achieve greater health and ecosystem protection has led to continued interest and attention to the problem.

The ORD Ecological Research Program is focusing attention on two primary areas, exposure modeling and remediation research, and forest effects research.

4.3.1 Research Questions

4.3.1.1 Ozone Exposure Modeling and Remediation Research

For over 25 years, many air quality research and management groups throughout North America have struggled with the best approach to managing the ozone levels in urban and rural environments. NRC addressed many of the issues in their 1991 publication, *Rethinking the Ozone Problem in Urban and Regional Air Pollution*. One of their major conclusions was that scientific progress had been hampered by the lack of a coordinated national strategy to address the issues in a systematic manner. Heeding the advice of NRC, ORD, along with NOAA and the Electric Power Research Institute, initiated discussions among most of the sponsors and participants in tropospheric ozone research in North America. The continental research program known as the North American Research Strategy for Tropospheric Ozone (NARSTO) was officially launched in 1995, with a charter signed by over 70 members of the public, private, and academic research communities, a comprehensive 10-year research strategy, and an organizational structure.

There are four technical teams within NARSTO:

1. Modeling and Chemistry Team
2. Observations Team
3. Emissions Team
4. Analysis and Assessment Team

Collectively, they are addressing the following scientific questions:

- How does ozone accumulation on urban (<200 km) and regional (200 to 2,000 km) scales depend on the precursor source strength and location? How does it depend on the relative contribution from urban and regional sources?
- What do recent assessments indicate about the relative contribution of NO_X, VOCs, and CO to ozone accumulation on urban and regional scales in North America?
- For a given area, what portion of the ozone problem is local and what portion is transported into the area? What portion of the problem is essentially irreducible (natural sources) and what portion is potentially controllable?
- What are the strengths and limitations of the current scientific methods and tools in assessing tropospheric ozone issues and developing emissions management strategies?
- What approaches are required to determine historic concentration trends of ozone and its precursors on urban and regional scales?
- What is required to demonstrate the effectiveness of emissions control strategies over time?
- What are the relationships among the control strategies designed to manage tropospheric ozone and those designed to manage other pollutant regimes of concern?
- What are current exposure profiles in the Mid-Atlantic and how are they expected to change over time?

4.3.1.2 Ozone Effects Research

ORD is limiting ozone effects research to the function and response of natural vegetation in terrestrial ecosystems. There are many questions regarding terrestrial wildlife, but many of these are being addressed by other research, including that of the Department of Interior. Less attention traditionally has been given to environmental stress on vegetation. In the past, vegetation has been considered to be an easily regenerated and manipulated natural resource that was relatively insensitive to environmental stress. However, the understanding and concern for this basic component of the biosphere has changed. Emerging knowledge of long-distance transport of tropospheric ozone and the persistence of this large-scale regional air pollutant in remote nature leads to concern over potentially widespread degradation of ecosystem processes and loss of biotic diversity in terrestrial vegetation.

Two scientific questions are of particular importance for EPA regarding ecological effects of tropospheric ozone.

- What is the role of ozone on the rhizosphere, and how does that affect nutrient cycling in the terrestrial ecosystem?
- What are the best procedures for extrapolating experiment results from individual sites or chambers to larger scale impacts?

4.3.2 Implementation

The exposure modeling and remediation research in-house program in NERL and NRMRL conducts applied research in the areas of chemical kinetic mechanism development, advanced meteorological and air quality modeling; new mobile source emissions factor and model development (modal mobile source models); new biogenic source models (Biogenic Emissions Inventory System); chemical and meteorological instrumental methods development; and innovative, cost-effective NO_X source emissions controls. Extramural research, through contracts and cooperative agreements, is mainly awarded for support of the goals of the continental NARSTO programs and assessments and the continuing Southern Oxidants Study (SOS), a university-led consortium studying the physical and chemical aspects of ozone climatology in the southeastern United States. Complementary research projects in both fundamental and applied ozone research are awarded through the extramural grants program administered by NCERQA.

The ecological effects of tropospheric ozone research program at NHEERL/WED utilize open-top chambers, state-of-the-art environmentally controlled sun-lit mesocosms, and field sites in the ponderosa pine forests of eastern Oregon for addressing ecophysiological questions of ozone effects on forest trees and communities. Several studies are being initiated in FY98:

1. Investigation of the role of below-ground hyphal connections in inter-species transfer of carbon and water and the role of these interconnections in the response of plant communities to ozone.
2. Ecosystem response, (i.e. carbon dynamics, water utilization and nitrogen dynamics), in a reconstructed ponderosa pine system to exposure of elevated CO_2 and ozone.
3. The role of age and size of trees in response to ozone exposure: Water utilization as a surrogate for ozone uptake in ponderosa pine and modeling/ extrapolation of long-term effects of ozone.

4.3.3 Anticipated Products

- **By 1998,** characterization of ozone risk to forest species using tree and stand model simulations to account for environmental (multiple stresses) and species interactions in the response. (NHEERL)
- **By 1999**, define the role of competitive interactions in the response of tree species to ozone and confirm the nitrogen budget in trees in response to ozone exposure. (NHEERL)
- **By 1999**, evaluation of Terracosm performance in study of combined ozone-carbon dioxide exposure of ponderosa system. (NHEERL)
- **By 1999**, provide state-of-science assessment of tropospheric ozone issues by NARSTO. (NERL)
- **By 1999**, provide an enhanced understanding of the atmospheric processes (chemistry, meteorology, and precursor emissions) responsible for the photochemical ozone problem in the Middle Tennessee Region (part of the Southern Oxidants Study). (NERL)
- **By 1999**, analysis of Southern Oxidants Study data from the 1995 field program in the Nashville/Middle Tennessee Region. (NERL)
- **By 1999**, develop an efficient and accurate method for including complex chemical reaction mechanisms in photochemical pollution models, including EPA's third generation model (Models-3). (NERL)
- **By 2000**, complete the release of a new model that will provide more exact estimates of the wide variety of volatile organic compounds (VOCs) emitted from biogenic (natural) sources. (NERL)
- **By 2000**, analysis and interpretation of Southern Oxidant Study field data using advanced (observations-based) diagnostic techniques and (emissions-based) air quality simulation models. (NERL)
- **By 2000**, report on laboratory simulations of ozone- and particulate matter-forming potentials of anthropogenic and biogenic emissions. (NERL)
- **By 2003**, conduct model evaluation exercises with a newly revised version of Models-3/ Community Multi-scale Air Quality (CMAQ) Model. The evaluation will focus on urban- and local-scale pollution problems and the larger scale influences on those problems. (NERL)
- **By 2003**, produce ecological effects information for NAAQS-related ozone risk assessments. (NHEERL)

4.4 Mercury Research

Substantial accumulations of mercury, in the form of methylmercury, occur in fish, the consumption of which provides the dominant mode of human exposure. Similarly, ecological exposures to mercury occur predominantly through aquatic food chains. Although some of the first, severe incidents of mercury contamination resulted from direct methylmercury discharges, atmospheric sources of mercury are believed to be responsible for most of the contamination found in wildlife today. The global background of atmospheric mercury is currently triple that of the pre-industrial era, and local sources can substantially augment atmospheric deposition of mercury in aquatic and terrestrial ecosystems.

The current and primary focus of mercury research in the EPA is on South Florida, due to the high concentrations of mercury that have been reported in fish and wildlife, including the endangered Florida panther. Air emissions from the urbanized eastern shore of South Florida are suspected to be a major source of mercury. The challenging atmospheric dynamics of the peninsula and the enormous potential for mercury methylation and bioaccumulation in the freshwater wetlands of the Everglades may contribute to toxic levels of contamination.

4.4.1 Research Questions

(see also Section 5.4)

- What are the sources of mercury to the South Florida wetlands ecosystems? To what extent do internal transport and transformation dynamics influence the location and intensity of methylmercury concentrations in water, sediment and biota?

- What are the relative contributions of local versus global sources of atmospheric mercury to South Florida? What are the chemical forms of mercury emitted from important anthropogenic sources to the atmosphere? What oxidation and reduction reactions of mercury occur in the atmosphere? What are the important aqueous phase oxidants? Are these reactions important on local or global scales?

- How does absorption of mercury by particulate matter in the atmosphere affect the reduction-oxidation balance of mercury and its subsequent deposition to terrestrial and aquatic ecosystems?

- What system characteristics determine the rates of methylation and demethylation of mercury? Which forms of mercury (organic or inorganic complexes, mineral) are bioavailable for uptake or transformation?

- How do methylation and demethylation of mercury interact with other biogeochemical cycles, including phosphorus and sulfur? How will those interactions be modified by Everglades restoration scenarios?

- What effect will hydrologic restoration of the Everglades have on ecological exposures to mercury?

4.4.2 Implementation

Although the bulk of ORD's mercury research is currently being carried out in South Florida, several Regional Environmental Monitoring and Assessment Program (REMAP) projects are investigating similar processes in lakes, including lakes of northern New England and the Great Lakes (Regions 1 and 5), and Clear Lake in Region 9. Mercury inputs into the northern lakes are primarily atmospheric, and research there is focussed in orographic influences on atmospheric deposition, internal biogeochemical cycling of mercury, and food chain exposures. Clear Lake is a Superfund site that receives mine tailings; the research issues are the geochemical forms of mercury available for biotransformation and biouptake, and food chain controls on exposure to aquatic organisms. Although no formal mechanisms exist for integration of those research results with those of South Florida, several principal investigators conduct projects in more than one geographic area, and models under development incorporate process knowledge from a number of sources.

In South Florida, ORD is a member (with EPA Region 4, the state of Florida, South Florida Water Management District, USGS, National Park Service, U.S. Fish and Wildlife Service, and academic and industry groups) of the Interagency Mercury Science Program, which maintains an integrated, peer-reviewed research plan (IMSP, 1996). The principal areas of research include: development of measurement methods, including sampling and analyses; monitoring and modeling for atmospheric transport and transformation; modeling, monitoring and process studies for mercury cycling between sediments, water and biota; and food chain studies, including bioaccumulation models. The EPA Region 4 REMAP study will continue to monitor mercury in the sediments, water, and biota at a statistically selected set of sites in the Everglades, as well as intensive sampling at four sites co-located with extramurally funded process studies. ORD is primarily responsible for the atmospheric and wetlands modeling components of the interagency effort. The Mercury Cycling Model is being modified by contract for incorporation into a linked atmospheric/hydrologic/ecologic model being developed by ORD scientists in conjunction with other agencies. Process studies that address critical model uncertainties (e.g., atmospheric chemistry and biogeochemistry) are supported by interagency and cooperative agreements. ORD-developed models will function as the organizational framework for process integration and as the basis for evaluating the impacts of ecosystem management on mercury contamination.

4.4.3 Anticipated Products

- **By 1998,** Provide mercury program input to COE Restudy Draft Report to Congress. Screening model report for mercury in the Everglades. (NERL)
- **By 1999,** Develop methods for measurement of atmospheric oxidation states of mercury. Bioaccumulation model for mercury (BASS). (NERL)
- **By 2000,** Produce a process based model for mercury transformations in water, sediments, biota. Atmospheric model, based on CMAQ, with oxidant chemistry and particle interactions. (NERL)
- **By 2002,** Apply atmospheric and mercury spatial process models, for current and restoration scenarios. (NERL)

4.5 UV-B Research

Government Performance and Results Act Objective: Ozone concentrations in the stratosphere will have stopped declining and slowly begun the process of recovery.

The release of chlorinated fluorocarbons (CFCs) to the atmosphere has led to the thinning of the stratospheric ozone layer around the globe and to the ozone holes over the Poles. This effect is being enhanced through cooling of the stratosphere by increasing inputs of carbon dioxide and other radiatively important gases derived from human activities. The stratospheric ozone layer filters out much of the harmful UV radiation (UV-B radiation) before it reaches the Earth's surface; so, as the ozone layer thins, the Earth's ecosystems and humans are exposed to higher levels of UV-B. Detection of increasing UV-B radiation at the earth's surface is, however, difficult because of considerable variability caused by such factors as weather and atmospheric particulate matter. Establishing long-term trends relevant to ecological and health effects research will require precise, spectrally resolved monitoring of UV-B over at least a 5-year period.

UV-B radiation can cause significant damage to plants and animals, including humans, through such mechanisms as impairing critical physiological functions (e.g., photosynthesis) and larval development of aquatic organisms, altering carbon and nutrient cycles, causing skin cancers, and reducing the immune response in humans. Increased UV-B exposure in aquatic ecosystems has also been linked to climate change that results in increased UV-B penetration into the water. Recent laboratory studies by ORD have demonstrated that exposures of amphibian embryos to UV-B radiation at less than sunlight intensities can lead to developmental abnormalities. UV-B radiation has also been found to increase the toxicity of certain common sediment contaminants (polycyclic aromatic hydrocarbons) through a process of photoactivation. The increase in toxicity can be several orders of magnitude and could significantly alter estimates of ecological risk from that previously estimated.

4.5.1 Research Questions

Evaluations of regional scale biological effects of enhanced UV-B radiation on terrestrial and aquatic ecosystems require the development of appropriate observational approaches and models. Resources for UV-B will be used to enhance research in the evaluation of the biological effects of UV-B. This enhancement will be generated in conjunction with the integrated long-term research network being developed. Data collected from this network will be used to perform trend analyses, characterize the occurrence and distribution of UV-B, and model the variability in irradiance resulting from environmental factors.

Research also will focus on the effects of UV-B on aquatic and terrestrial systems, including the effects of UV-B on sensitive biota (e.g., larval stages of aquatic organisms) and phototoxic interactions between UV and widespread aquatic pollutants such as PAH. The indicators research will include freshwater watershed indicators, such as (1) the degree of shading, UV-B penetration, altered redox state and nutrient cycles, (2) terrestrial indicators of forest integrity and sustainability in response to multiple stressors, and (3) estuarine indicators, such as changes in carbon and nitrogen cycles and in community trophic levels resulting from interactions between enhanced UV and human and climatic perturbations (altered basin-scale hydrology and temperature change).

Monitoring the effects of UV-B radiation on regional ecosystems, even to subsample within a limited region, requires the development of spatial tools and necessitates the incorporation of satellite observations into the network of other measurements. In addition to measuring atmospheric ozone concentrations (e.g., with the Total Ozone Mapping Spectrometer (TOMS) data), and using these data to estimate ecosystem exposure to UV-B, a potentially more important role for satellite observation is to monitor the ecosystems to detect changes in functioning due to UV-B effects.

At the present time, the greatest use of optical sensors in both marine and terrestrial systems has been to map variations in chlorophyll pigment concentrations using spectral reflectance in the red wavelength region or ratios of the red and near-infrared wavelength regions.

In addition to observational approaches, models that incorporate solar UV-B radiation as a forcing variable are required in order to integrate, evaluate and predict ecosystem effects and related feedbacks on a regional scale. Further research efforts will focus on determining which technological advances would have the greatest incremental impact on greenhouse gas emissions and will leverage funding available in other federal agencies and industry to catalyze the development and demonstration of the most promising no- or low-global-warming technologies.

Key questions include:

- What are the effects of UV-B on larval stages of aquatic organisms, including amphibians?
- What factors affect UV-B exposures?
- What factors are of primary significance in decreasing the effect of UV-B exposures to terrestrial, freshwater, and estuarine biota?
- Do UV-B interactions with certain sediment contaminants increase the potential ecological risk of these chemicals?
- How are carbon and nutrient cycles altered by enhanced UV-B exposures?
- What are the trends in UV-B at index locations?
- How can a long-term trend in UV-B radiation be derived from highly variable signals recorded by ground-level monitors?
- What model is most effective for predicting UV-B exposures at multiple spatial and temporal scales?
- What are the biological/ecological effects of UV-B exposure on plant phenology and reproduction?
- What are the biological/ecological effects of UV-B exposure on coastal estuarine systems?
- What are the biological/ecological effects of UV-B exposure on coral systems?

4.5.2 Implementation

ORD will develop both a monitoring program to measure regional levels of UV-B radiation and a research program to examine the effects of UV-B radiation on sensitive plant and animal species, such as humans and early developmental stages of selected organisms, including amphibians. A monitoring network of 22 spectrophotometers will measure spectrally resolved UV-B and UV-A on a daily basis. Fourteen of the monitors will be at index sites in National Parks, while the other eight will be in urban locations, and the complete network is expected to be operational in mid-1998. The Demonstration Index Site Program (DISPro; see Section 5.8), a joint EPA and National Park Service (NPS) project, addresses long-term monitoring of environmental stressors (air quality, deposition, visibility, UV-B and toxic chemicals) in 14 national parks and research to link ecological effects and exposure under field conditions including interaction of multiple environmental factors.

Ecological effects of UV-B research is conducted through RFAs. The research proposals are currently under peer-review. The proposals of UV-B effects research will address a range of questions including forests, amphibian populations, coral structure, and the spatial variation of the stress over landscapes, as well as development of indicators of UV-B stress in plants and animals. Research in this area over the next few years will be directed toward investigating the mechanisms by which these abnormalities occur and towards determining whether UV-B radiation is, in fact, a contributing factor causing malformations in amphibians under actual field situations.

The program will also examine other biological effects interactions between UV-B and nutrient cycles, and enhanced UV phototoxicity that involves PAH from fossil fuel usage. In collaboration with efforts of other Agencies, the UV-B monitoring program will be supplemented by remote sensing of changes in ecosystem components related to productivity, such as variations in chlorophyll pigment concentrations. Research will be conducted to investigate the mechanisms involved, develop structure-activity models that predict the chemicals for which this is important, and the degree to which this interaction influences the ecological effects of these chemicals in real-world environments.

ORD's UV-B monitoring network and effects research will be supported by ORD's global change budget. The sites themselves will receive additional funding through the EMAP program, although the instruments for monitoring UV-B radiation and the research examining the effects of UV-B radiation on ecological systems and human health fall under the regional vulnerabilities component of the Global Change Research Program.

4.5.3 Anticipated Products

- **By 1998**, establish monitoring systems at National Park sites. (NERL)
- **By 1999**, report on sensitive populations to UV-B in regions of high biodiversity. (NHEERL)
- **By 1999**, report on the distribution of stressors and exposures in the Mid-Atlantic, including ozone, acid deposition, UV-B, acid mine drainage, nitrogen, sedimentation, and pesticides. (NERL)
- **By 2000**, develop community model of UV-B, contaminant and nutrient dynamics and its effects on coral reef assemblages. (NERL)
- **By 2002**, provide improved radiative transfer models for predicting UV exposure. (NERL)
- **By 2002**, provide initial analysis of changes in stratospheric ozone concentrations. (NERL)
- **By 2003**, provide a trend estimation for regional changes in UV-B. (NERL)
- **By 2003**, provide a summary of UV monitoring data at urban and rural sites. (NERL)
- **By 2005**, report on UV-B flux from 1998-2004. (NERL)
- **By 2005**, assess global climate change risks to coastal ecosystems in the eastern US. (NERL)

4.6 Nitrogen Research

Government Performance and Results Act Objectives: Restore and protect watersheds, develop tools to reduce loadings, improve water quality, and reduce ambient nitrates and total nitrogen deposition by 5 to 10%

The amount of biologically active nitrogen circulating in the biosphere has increased dramatically during the last several decades. Increasing use of industrial fertilizers, increased cultivation of nitrogen-fixing crops, animal farming and wastes, deforestation, wastewater disposal, and fossil fuel combustion have contributed to increasing loads of nitrogenous compounds to the world's ecosystems. On an annual basis, anthropogenic sources of fixed nitrogen now account for more than half the biologically active nitrogen entering terrestrial, freshwater, and coastal marine ecosystems (Mackenzie, et al., 1993; Galloway, et al., 1995; Vitousek, et al., 1997).

Although the short-term effects of nutrient over-enrichment (eutrophication) of lakes and some coastal water bodies can be modeled with reasonable fidelity, the long-term effects of altering the ecological cycling of nitrogen — an important nutrient element — are not known. For example, the roles of nitrous oxide in contributing stratospheric ozone depletion and of sewage nitrogen contributing to hypoxia in coastal waters are fairly clear. However, recent findings have implicated nitrogen over-enrichment as a causal factor in reducing aquatic and terrestrial biological diversity (Wedin and Tilman, 1996) and, perhaps, in triggering noxious algal blooms in estuaries and near coastal water (Smayda, 1989).

Further, the role of atmospheric nitrogen deposition to nitrogen saturation of terrestrial ecosystems and to the acidification of poorly buffered lakes and streams is poorly known. Prior research priorities mandated a focus on the more clearly evident acidifying effects of sulfur deposition. ORD's contributions to sulfur deposition research and modeling set the stage well for continued progress in determine the effects of nitrogen deposition.

The ability to predict the ecological benefits gained by reducing nitrogen emissions is limited by the absence of empirical cause-effect relationships that link ecological — particularly biological — responses to changes in the pathways and rates of nitrogen inputs to major components of landscape over a range of time frames and spatial scales. Therefore, the long-term goal of ORD's research and modeling efforts on nitrogen is to provide the assessment methods, predictive cause-effects models, and syntheses of environmental trend data needed to determine the ecological risks to terrestrial and aquatic ecosystems posed by increasing inputs of anthropogenically-fixed nitrogen. This research will be to assist the development of biological indicators and management strategies needed to protect particularly vulnerable ecosystems from the harmful effects of nitrogen over-enrichment. Because the biogeochemistry of nitrogen is very complex, and potential problems traverse atmospheric, terrestrial, and aquatic media, the Program requires a balance of solid fundamental scholarship, empirical studies, well-targeted monitoring data, simulation modeling, and mechanistic studies.

4.6.1 Research Questions

- How much nitrogen enters the nation's terrestrial and aquatic ecosystems?
- What are the factors affecting nitrogen deposition, transport and fate?
- How much nitrogen entering the nation's major watersheds ultimately reaches fresh and marine waters?
- What are the current and predicted biogeochemical mass balance budgets for biologically important forms of nitrogen for the nation's major watersheds and biogeographic regions?
- How are terrestrial, freshwater, and coastal marine systems likely to change as a consequence of changing nitrogen and sulfur loads?
- How does aquatic and terrestrial productivity change in response to changes in annual nitrogen loads (measured as the formation rate of organic matter and determined at watershed and water body scales)?
- What are the best indicators, particularly biological indicators, of nitrogen effects from acidification and eutrophication on terrestrial and aquatic ecosystems?
- What factors control the assimilative capacity of terrestrial and aquatic systems with respect to nitrogen loads?
- Which ecosystems or landscape components are at greatest risk from nitrogen over-enrichment/acidification?
- What would the levels of nitrogen have to be entering watersheds of different types, below which no detrimental effects would be likely?

4.6.2 Implementation

The primary focus of in-house research will involve:

- Collecting, synthesizing, analyzing, and mapping existing data to develop inventories and budgets for nitrogen emissions and loading rates to the atmospheric, terrestrial, and aquatic reservoirs.
- Determining the types and locations of watersheds, landscape components, and ecosystems that are most susceptible to the effects of nitrogen over-enrichment effects.
- Developing indicators of nutrient over-enrichment as well as current and potential future watershed nitrogen saturation and

surface water acidification.

- Developing and applying predictive theories and models for effects and exposure at regional scales.

The extramural component of the Program will focus on using existing microcosm, mesocosm, and field enclosure capabilities and watershed manipulations at various academic institutions to develop system-level dose-response relationships for nitrogen, to explore factor interactions, and to assist with simulation model development. The extramural effort also will be needed to carry out field studies in conjunction with regional monitoring of nitrogen emissions, deposition, effects on soils and surface waters, and intensive data collection at index sites.

4.6.3 Anticipated Products

- **By 1998**, develop the strategy and implementation plan for ORD-wide cross-media research on the ecological risks posed by anthropogenic nitrogen. (ORD)

- **By 1998**, complete ongoing place-based research on coastal eutrophication. (NHEERL)

- **By 1999**, complete on-going studies of nitrogen sources, fate, and effects in targeted terrestrial and aquatic ecosystems. (ORD)

- **By 2000**, evaluate instream, riparian, and landscape-level controls on hydrology/ retention time, nitrogen export and processing in tributaries to western Lake Superior. (NHEERL)

- **By 2001**, complete research on the relationship between eutrophication and phytoplankton community dynamics. (NHEERL)

- **By 2002**, complete development of a numerical simulation model of nitrogen effects on northern Gulf of Mexico estuaries. (NHEERL)

4.7 Global Change Research

Human-induced factors are now formally recognized by the international scientific community to significantly influence climate change, leading to unprecedented rates of warming over the next century. In 1990 and 1995, the multinational IPCC group summarized the consensus state of knowledge and major uncertainties in the science of global climate change. The detailed impacts of climate change are still uncertain. EPA, along with other federal agencies coordinated through the U.S. Global Change Research Program (USGCRP) and the international community, has a substantial program underway to conduct a national assessment of the consequences of climate variability and change for the United States.

4.7.1 Research Questions

EPA's research program is directed towards understanding the vulnerability of regional-scale ecosystems to climate change in the context of other stressors. EPA plays a unique role in the interagency global change research community because the agency promotes environmental protection for the benefit of human health, as well as that of global ecosystem integrity. ORD's Global Change Research Program will focus on integrated assessments of the consequences of climate change and variability to coastal, freshwater, and terrestrial ecosystems in selected regions of the United States, and then extend the analysis to include implications for human health. EPA will concentrate on studying *regional-scale* ecosystems with their embedded landscape mosaics because (1) regional analyses may be more readily linked with policy development, and (2) the ecological mechanisms causing an observed effect can be best identified on a regional scale.

ORD's Global Change Research Program design is twofold: (1) to improve the scientific basis for evaluating important ecological and human health impacts of climate change by analyzing the regional ecological vulnerabilities to temperature and hydrologic changes associated with projected climatic changes in the context of other stressors; and (2) to develop programs to reduce the most significant risks posed by climate change by identifying and evaluating the cost-effectiveness of global change mitigation and adaptation strategies in target areas of the United States.

The questions for the research program include:

- What are the best indicators (sentinels) of climate change at population, community, and ecosystem levels of organization?

- What future coastal ecological vulnerabilities, on a range of spatial scales, result from the joint effects of changes in climate, sea level, and other stressors, such as pollutants and land use?

- How do climate-induced changes in temperature, moisture, and atmospheric composition affect biogeochemistry of regions or ecosystems?
- How do climate-induced changes in biogeochemistry affect species distribution and diversity; productivity; sustainability; and integrity of terrestrial, freshwater, and coastal ecosystems?
- How will climate change affect human health directly and indirectly, via ecologically mediated factors?
- How do the vulnerabilities of natural systems to global climate change influence regional economies?
- What societal and environmental infrastructures are most likely to be impacted by global change?
- What options are available for adapting ecosystems to climate change?
- What technologies are most appropriate for greenhouse gas reductions?

4.7.2 Implementation

ORD will achieve its Global Climate Change Research Program mission through a combination of research by the laboratories and centers, including: (1) basic experiments focused on understanding climate change and variability impacts on biogeochemical cycles in a variety of ecosystems; (2) participation in national and regional assessments of the consequences of climate change and variability on ecosystems; and (3) comparisons and evaluations of greenhouse gas reduction technologies. This research will be done by a combination of in-house researchers and those who are funded by EPA's extramural grants program.

4.7.3 Anticipated Products

- **By 1999**, provide a hybrid method to classify and label land cover pattern change using remotely sensed processes. (NERL)
- **By 2000**, contribute to the National Assessment of the Consequences of Climate Variability and Change for the United States. This assessment will be conducted under the auspices of the USGCRP. (NCEA/ORD)
- **By 2001**, publish significant research findings from mesocosm experiments and field and modeling studies. (NCERQA)
- **By 2001**, complete a comparison of greenhouse gas emission reduction alternatives. (NRMRL)
- **By 2002**, complete analysis of North American Landscape Characterization (NALC) data for change indicators. (NERL)

4.8 Contaminated Sediments Research

Government Performance and Results Act: Provide means to identify, assess, and manage aquatic stressors, including contaminated sediments.

Aquatic sediments represent the ultimate repository for many contaminants in surface waters. Sediment-associated contaminants not only serve as a source of toxicity to benthic organisms living in contact with these sediments, but also can reintroduce contaminants into the water column or aquatic food chain. Recently, an EPA report on the National Sediment Quality Survey (EPA, 1997c) reported that 26% of the more than 21,000 sampling stations in watersheds across the United States associated adverse effects of contaminated sediments on aquatic life with human health. Associated adverse effects for an additional 49% of the sampling stations are considered possible, but expected infrequently. Although sediment contamination decreases with distance from near-shore sources, widespread, low-level contamination of deep water sediments of Puget Sound, for example, has been detected. Cancerous lesions and other effects have been observed in several bottom-dwelling fish species and approximately 1,200 state fish-consumption advisories have been issued.

According to the NRC's 1997 report entitled "Contaminated Sediments in Ports and Waterways-Cleanup Strategies and Technologies," (NRC, 1997b) an estimated 5% to 10% of all sediments dredged in the United States are contaminated, meaning that 14 to 28 million cubic yards of sediment must be managed annually. The NRC report identifies many current deficiencies in the cost-effective management of contaminated sediments, ranging from the lack of comprehensive risk assessments to the lack of systematic performance data on engineered and in situ remediation technologies. Three general problems arise:

1. Determining the ecological risks from contaminated sediments;
2. Managing risks from contaminated sediments in aquatic ecosystems where the sediments need not be removed for navigational clearance; and
3. Managing risks from contaminated sediments removed from waterways for navigational purposes — the dredge spoil problem.

4.8.1 Research Questions

4.8.1.1 Criteria

The Office of Water has promulgated sediment quality criteria as an extension of water quality criteria. Further development of such criteria and their site-specific application will require better understanding of the effects of contaminated sediments for both benthic communities and ecosystem level impacts. Research questions are:

- How can the biological effects of exposure to contaminated sediments be measured in the laboratory and in the field, and what are the most cost-effective ways to use such measurements in site-specific risk assessments?
- How can the biological effects of exposure to sediment contaminants be predicted, and how are such predictions factored in risk assessment?
- In cases where biological effects are demonstrated, what are the causes of those effects, and how is that information best used to devise risk management approaches?

4.8.1.2 Exposure — Fate and Transport

Current sediment quality criteria are based on equilibrium partitioning of hydrophobic chemicals between the sediments and the interstitial water. Further development of criteria will require a more complete understanding of the interactions of pollutants and sediments. Similarly, the remediation of sediments and the feasibility of natural attenuation are elucidated by knowledge of the fate of contaminants and the transport characteristics of both the sediments and sorbed materials. Research questions are:

- What is the appropriate equilibrium-partitioning model for polar organics, metals, and zwitter ions attached to sediments?
- What are the fate processes, rate constants, and degradation products for the array of chemicals found on contaminated sediments?
- How are contaminated sediments factored in the waste load allocation modeling process for Total Maximum Daily Loading (TMDL)?

4.8.1.3 Remediation Technologies for In-Place and Dredged Sediments

EPA is evaluating two stressor management approaches for contaminated sediments: (1) natural attenuation and (2) enhanced remediation. Enhanced remediation includes both in situ and ex situ techniques and employs various combinations of biological, physical, and chemical processes. Natural attenuation, on the other hand, is a process where unaided, naturally occurring biotic and abiotic mechanisms effectively restore ecosystems.

Investigations usually separate contaminated sediment requiring treatment into two categories: (1) dredged sediment created during navigational waterway maintenance and (2) sediment requiring action because of the risks posed to human or ecosystem health. System constraints on each category determine the solution effectiveness. Some conditions favor in situ treatment, whereas dredged sediment, by definition, requires ex situ treatment. A major challenge for remediation is the need to develop risk management approaches that restore ecosystems to functioning levels, in addition to reducing chemical concentrations to criteria levels.

Questions under investigation include:

- Among existing remediation technologies, which ones are most applicable for contaminated media within vulnerable ecosystems?

- What are the most appropriate and cost-effective technologies for in situ and ex situ treatment of contaminated sediments?

- What sediment management systems are most cost-effective in reducing risks?

- Under what circumstances do adaptation measures (e.g., in-place containment and low energy in situ treatment) for contaminated sediments cost less and produce lower ecological risks than alternative remediation?

4.8.2 Implementation

The work described in this problem area will be accomplished through a combination of intramural and extramural research conducted in all ORD laboratories. Within the federal research community, NOAA and the U.S. Army Corps of Engineers (COE) also conduct research on selected issues. The 1997 NRC report, "Contaminated Sediments in Ports and Waterways — Cleanup Strategies and Technologies," (NRC, 1997b) — contains recommendations for a more integrated federal research and development program. ORD intends to establish a more coordinated effort (and possibly a joint research strategy) with the COE to investigate the development and demonstration of innovative technologies for removing and managing contaminated sediments.

4.8.3 Anticipated Products

- **By 1998**, complete pilot-scale evaluation of three biotreatment technologies (bioslurry, land treatment, and composting) for the treatment of PAH contaminated sediment. (NRMRL)[1]

- **By 1998**, complete baseline lab studies on hydrogen and iron for dechlorinating organics in sediments. (NRMRL)

- **By 1999**, develop methods for screening aquatic systems, including sediments, for significant chemical stressors. (NERL)

- **By 1999**, publish peer-reviewed journal article on biotreatment of PAH contaminated sediment. (NRMRL)

- **By 1999**, publish peer-reviewed journal article on treatment of chlorinated organics in sediments. (NRMRL)

- **By 2000**, improve the understanding of the kinetics of contaminant release from sediments. (NERL)

- **By 2000**, provide a systematic framework for developing habitat criteria for aquatic systems. (NHEERL)

- **By 2000**, develop methods and models to assess bioaccumulation of sediment contaminants. (NHEERL)

- **By 2000**, quantify photo-activated toxicity of sediment-associated PAHs. (NHEERL)

- **By 2000**, develop methods to validate and predict lab bioavailability data for sediment contaminants to the field. (NHEERL)

- **By 2000**, develop methods and models to determine effects of spatial, temporal and other factors on toxicity of sediment contaminants. (NHEERL)

- **By 2000**, develop methods and indicators to assist in setting aquatic eco-criteria. (NHEERL)

- **By 2001**, develop risk estimates/criteria for specific contaminants or mixtures of contaminants protective of aquatic life and human health to develop assessments of human health risks and ecological risks for exposures to contaminants in ambient waters. (NCEA)

- **By 2001**, develop methods to assess the success of remediating stream ecosystems, including stressed riparian zones and metal-contaminated sediments. (NERL)

- **By 2002**, publish research methods to develop diagnostic indicators for benthic ecosystems to identify sensitive indicators of toxicity to benthic communities. (NERL)

- **By 2002**, document effects of sorption on biotic and abiotic transformation rates in sediments. (NERL)

- **By 2003**, develop or evaluate promising technologies for the ex situ and in situ risk

[1] Includes specific Laboratory or Center responsible. (See Table 2.1 for Laboratory and Center names.)

management of contaminated sediments. (NRMRL)

- **By 2003**, develop methods to assess reproductive effects of sediment contaminants. (NHEERL)

- **By 2003**, develop methods and models to predict effects of highly bioaccumulative contaminants on wildlife and other higher trophic-level organisms. (NHEERL)

- **By 2003**, determine effects of sediment contaminants at population, community, and ecosystem scales. (NHEERL)

- **By 2005**, develop technical resource documents on the risk management of contaminated sediments. (NRMRL)

4.9 Wet Weather Flow

Government Performance and Results Act Subobjective: Deliver decision support tools and alternative, less costly wet weather flow control technologies for use by local decision-makers involved in community-based watershed management

The urban wet weather flow (WWF) problem is caused by untreated discharges during storm events. Early drainage plans made no provisions to control impacts from this type of pollution. WWF comprises point source as well as diffuse non-point source discharges. There are three types of urban WWF discharges:

1. Combined sewer overflow (CSO), a mixture of storm drainage and municipal-industrial wastewater discharged from combined sewers or dry weather flow (DWF) discharged from combined sewers resulting from clogged interceptors, inadequate interceptor capacity, or malfunctioning CSO regulators.

2. Stormwater from separate stormwater collection systems in areas that are either sewered or unsewered.

3. Sanitary sewer overflow (SSO), which includes overflow and bypasses from sanitary sewer systems resulting from stormwater and groundwater infiltration or inflow.

Pollutants in WWF discharges from many sources remain largely uncontrolled. EPA, in both its 1992 National Water Quality Inventory and its 1995 Report to Congress, cited pollution from WWF as the leading cause of water quality impairment. WWF discharges is one of the greatest remaining threats to water quality, aquatic life, and human health that exist today. The Office of Water, in its "National Water Program Agenda, 1997-1998," identifies the management of WWF dischargers as one of the key areas still requiring attention in order to assure clean water and safe drinking water. Furthermore, this agenda states that, "[p]ollution from diffuse or non-point sources during and after rainfalls is now the single largest cause of water pollution." These discharges can produce widespread, short-term, high exposures to infectious agents that result in gastrointestinal illness and even death. In addition, there is an increase in long-term contamination of sediments and the aquatic food chain through the release of persistent, bioaccumulative toxic agents. Urbanization also creates higher stream flows, causing bank and bottom erosion and deposition and unacceptably high shear stresses for the benthic community.

The NRC concluded that correction of non-point source pollution problems is a major priority of surface water protection and should be implemented as a part of a large-scale, aquatic-ecosystem program. Pollution problems stemming from CSO, SSO, and storm water discharges are extensive throughout the United States, with the Northeast, Southeast, Midwest, and Far West being the principal areas of concentration. Almost 40% of rivers, lakes, and coastal waters monitored by states do not meet water quality goals, largely because of urban WWF discharges. Of special significance is the association between WWF discharges and exposure of microbes in recreational waters. A recent epidemiology study in Santa Monica Bay, California, documented an increased risk of illness associated with swimming near storm drains.

4.9.1 Research Questions

WWF problems can be addressed in the following three fundamentally different ways. Each of these potential solutions poses critical ORD research questions.

1. Watershed management (i.e., managing activities within the watershed in ways to minimize or prevent the unacceptable discharge of contaminants).

2. Control technology for drainage systems (i.e., using engineered control systems to treat or remove pollutants from WWFs).

3. Infrastructure improvement (i.e., developing new infrastructure systems that create fewer WWF problems, applying such concepts to existing infrastructure as it is replaced, and incorporating new concepts into planned development).

4.9.1.1 Watershed Management for WWF Impacts Abatement

Solving WWF problems through watershed management is consistent with the Office of Water strategy on watersheds and involves a progression of research questions and steps:

- How can effluent guidelines for WWF be established effectively in a watershed management strategy?
- What are the methods and data needed to diagnose problems, identify and characterize sources (including atmospheric deposition), and evaluate progress toward success in watershed management?
- Can more reliable test methods and indicators be developed to detect and measure human pathogenic microbes to allow local authorities to make appropriate decisions about beach advisories and closures?
- What are the relative risks of the various alternative risk management options?
- What innovative and less costly watershed management practices and WWF management networks need to be developed?
- Are riparian zone restoration and constructed wetlands most effective?
- What combination of best management practices, source controls, watershed restoration, and retrofitted technologies provide the most cost-effective strategy for improving water quality within the context of watershed management?

4.9.1.2 Control Technology for Drainage Systems

WWFs (including storm water) are increasingly suspected as, if not directly indicated to be, the cause of pathogenic contamination of shellfish beds, public beaches, and drinking water supplies. In some cases, control technologies and preventive measures are effective in reducing the toxicity of CSOs and other WWFs. Research questions/directions are:

- What is the effectiveness of disinfection techniques using measurements that account for microorganisms occluded by particles?
- How effective are innovative, low-cost, high-rate control/treatment technologies for removing toxics and other pollutants from WWF?
- How can toxic/pollutant discharges to receiving waters of the urban watershed be prevented and reduced effectively?

4.9.1.3 Infrastructure Improvement

A 1990 report by the Congressional Office of Technology Assessment identified environmental infrastructure problems in the areas of wastewater, drinking water, and municipal solid waste and evaluated the impacts of these problems on local communities. As is apparent, a community's environmental infrastructure needs are varied and interrelated. Communities may have the same generic needs (providing safe drinking water, protecting receiving waters, environmentally acceptable disposal of solid waste, etc.) and associated problems. However, the solutions to these problems can vary greatly with community size, because smaller communities can lack the financial (lower per-capita income, smaller tax base, etc.) and personnel resources (operation, maintenance, management, etc.) of larger ones, forcing the use of lower cost, less complex technologies. Questions are:

- What are the best approaches to assess, maintain, and rehabilitate existing sewer systems and to construct new sewer systems in urban settings?
- What are the most cost-effective approaches to design, construct, maintain, and rehabilitate

storage systems for storm water and wastewater to ensure optimum system performance and, thus, reduce the risks associated with the failure of such systems to the environment?

4.9.2 Implementation

Implementation will be guided by the "Risk Management Research Plan for Wet Weather Flows" and conducted in concert with the Office of Water. The research plan was peer reviewed by the Urban Water Resources Research Council of the American Society of Civil Engineers and the Water Environment Research Foundation of the Water Environment Federation. The Environmental Technology Verification (ETV) Program also includes a pilot program on urban WWF control systems which will expedite the development of WWF control technology and watershed management strategies (see Section 3.3).

The Office of Water's Office of Wastewater Management, Office of Science and Technology, and Office of Wetlands, Oceans, and Watersheds have parallel technology development and technology transfer programs that have been merged through joint management of projects of common interest. A portion of the WWF research plan's projects are being conducted collaboratively between the Office of Water and ORD, with funding through Section 104(b)(3) of the CWA.

4.9.3 Anticipated Products

- **By 1998**, provide data on high-rate disinfection and use of microcarriers to enhance WWF treatment. (NRMRL)
- **By 1998**, provide data on the effects of particle breakup on stormwater disinfection. (NRMRL)
- **By 1999**, develop and evaluate indicator methods to describe toxic input to watersheds from WWFs. (NERL)
- **By 1999**, publish peer reviewed results of WWF disinfection studies. (NRMRL)
- **By 1999**, publish peer reviewed results of treatment studies. (NRMRL)
- **By 2000**, link urban stormwater models to a geographic information system. (NRMRL)
- **By 2000**, develop methods to identify chemical stressors in toxic environmental mixtures. (NERL)
- **By 2001**, publish indicator methods to assess stream impacts from WWFs. (NERL)
- **By 2001**, develop rapid (less than three hours), specific methods for measuring the quality of bathing beach waters. (NERL)
- **By 2002**, publish methods for diagnosis of multiple stressors in watershed ecosystems. (NERL)
- **By 2002**, provide guidance for optimal monitoring of bathing beach waters and communicating risk associated with swimming activities to the public. (NERL)
- **By 2003**, use condition and diagnostic ecological indicators to evaluate WWF management strategies in preventing degradation of water and sediment quality by contaminated runoff. (NCEA)
- **By 2003**, evaluate publicly available water quality simulation models to evaluate risks associated with various control technologies for WWFs in a watershed. (NCEA)
- **By 2003**, deliver selected decision support tools and alternative, less costly WWF control technologies to state and local decision makers involved in community-based watershed management. (NRMRL)

4.10 Toxic Algal Blooms Research

Toxic and otherwise harmful algal blooms (HABs) are increasing in frequency, duration, and severity along virtually every U.S. coastal state, yet the causes of HAB outbreaks and their impacts on ecosystem integrity and human health are poorly defined. HABs, including new or previously undescribed species such as *Pfiesteria piscicida*, have caused large-scale aquatic mortalities, altered coastal ecosystem structure and function, impacted coastal economies, and threatened human health. HAB outbreaks in the U.S. reflect a global trend, yet the U.S. lags far behind many other countries in basic research necessary to develop and implement effective management programs to the multitude of problems caused by HABs and their toxins. Understanding the biological, chemical, and physical processes and interactions facilitating HAB development, maintenance, and decline will advance the national goal of preventing, managing, controlling, and mitigating HAB outbreaks and impacts, as well as EPA's mission to protect coastal ecosystems and human health. Understanding the causes of HABs requires a determination of the extent in which HAB outbreaks are due to natural processes or to anthropogenic influences related to changing coastal zone uses and eutrophication. Research will be focused on elucidating the environmental factors facilitating HAB development, growth, and toxicity, on developing unique indicators for rapid HAB identification and monitoring, on developing a field monitoring network and rapid response capability for HAB monitoring and forecasting, and on elucidating the short- and long-term fate and effects of HABs and their toxins on aquatic organisms, ecosystem condition, and human health. HABs defined herein consist of estuarine and marine eukaryotic and prokaryotic species, including *Pfiesteria piscicida* and *Pfiesteria*-like species.

4.10.1 Research Questions

- What are the critical environmental factors regulating the cell division cycle, life cycle, and toxicity of HAB species?
- What are the macro- and micronutrient requirements and uptake kinetics for growth and toxin production of HAB species?
- How are HAB species' nutritional requirements altered by physiological acclimation to different light, temperature, and salinity regimes?
- What is the relative role of mixotrophy in nutrient acquisition by HABs?
- What is the role of bacterial-HAB associations on HAB development, growth and toxicity? Are bacterial-HAB associations unique indicators of toxicity?
- What are the effects of increased nutrient loading, altered nutrient ratios, and atmospheric nutrient deposition on HAB development, growth, and toxicity?
- What molecular, biochemical, bio-optical, and/or other indicators are most effective for rapid identification and monitoring of HABs and their toxins?
- What is the relationship between HABs and grazers in bloom development and decline?
- What are the direct and indirect effects of HABs and their toxins on water quality, higher trophic level species, and ecosystem condition? Can these effects be predicted, and if so, what parameters or indicators are necessary for predictive models?
- How do HAB events affect ecosystem biogeochemical cycling and productivity on short- and long-time scales?
- What is the dose-response relationship for selected aquatic organisms exposed to HAB toxins?
- What indicators are most effective for identifying toxin exposure in aquatic organisms?
- What design strategies and parameters are required for effective field monitoring of HABs and their impacts, and for predictive model development?
- What are the direct and indirect effects of HABs and their toxins on laboratory model organisms and on human health?
- What are the effects of HAB toxins on respiratory, immune, and nervous systems of laboratory rodents?
- What are the effects of HAB toxins, in particular *Pfiesteria* toxins, on neurocognition in laboratory rodents and humans?
- What are the specific neuropathological changes that occur in aquatic animals and laboratory rodents exposed to specific HAB toxins?

4.10.2 Implementation

ORD will develop a HAB experimental culture and exposure facility and establish viable stock cultures of principal HAB species and clones using appropriate biological control techniques. This facility will be the focal point for controlled laboratory studies examining nutrient ecophysiology and toxin production, developing and evaluating molecular, biochemical, and bio-optical diagnostic indicators, and examining the effects of controlled exposures to HABs and toxins on selected aquatic organisms. In cooperation with other agencies and universities, ORD will seek to develop a suite of HAB real-time monitoring network sites in the Gulf of Mexico, making use of advanced measurement technologies for physico-chemical, bio-optical, and biological parameters, such as moored platforms outfitted with unattended sensors and satellite remote sensing. ORD will conduct shipboard surveys and process studies in the Gulf of Mexico to complement and extend the range of information provided by the network sites. With the cooperation of Gulf state agencies and institutions, ORD will expand the Gulf of Mexico Aquatic Mortality Response Network (GMNET) by developing a HAB home page to include, within the GMNET database, reports of HAB events in the Gulf of Mexico. The expanded GMNET database will contribute to understanding the causal relationships between aquatic mortalities and HABs. These research efforts will provide information crucial to identifying and understanding the mechanisms underlying HAB development, maintenance, decline, and impacts in coastal ecosystems, to developing forecasting capabilities, and ultimately to developing management strategies for minimizing or preventing HAB outbreaks and impacts. It is anticipated that this research will be a truly interdivisional program involving several ORD divisions focusing on both ecological and human health consequences of HABs.

4.10.3 Anticipated Products

- **By 1999**, publish a report on histopathology of HAB effects on fish. (NHEERL)
- **By 1999**, define the nutrient ecophysiology of HABs, and identify potential diagnostic indicators for HAB identification and monitoring. (NHEERL)
- **By 2000**, publish a report on effects of HAB toxins on selected aquatic organisms. (NHEERL)
- **By 2000**, publish a report on environmental conditions that facilitate HAB formation. (NHEERL)
- **By 2001**, publish a report on efforts to monitor the presence and extent of HABs. (NHEERL)
- **By 2001**, publish a report on diagnostic indicators for identifying toxin exposure in selected aquatic organisms. (NHEERL)
- **By 2001**, publish a report on development of a forecasting model to predict the occurrence of HABs based on environmental conditions. (NHEERL)

4.11 Eco-Criteria Research

GPRA Subobjective: By 2003, provide means to identify, assess, and manage aquatic stressors, including contaminated sediments.

Scientific criteria are needed as a guide in many decision-making processes intended to protect and restore the environment. Criteria to protect aquatic resources have been implemented through a wide variety of programs such as aquatic life criteria, wildlife criteria, wetlands criteria, sediment quality criteria and biocriteria, each of which has produced a series of standard practices that tend to address site-specific issues. However, the incorporation of many different scientific concepts and criteria into dozens of different federal, state and tribal regulatory processes can cause unanticipated impacts within the regulatory programs and the regulated community. A new perspective is needed to achieve a sound scientific foundation for the holistic examination of environment conditions and an optimal approach for environmental improvement and protection activities.

Creating that new ecological perspective and the scientific foundation for community-based environmental protection requires that we advance our understanding of how aquatic communities and foodwebs are impacted by human activities across entire watersheds. Moreover, sound scientific methods must be created for optimizing existing regional financial resources for compliance and restoration with a focus on sustainable water quality for the region. A simple example illustrates the dimension of new ecological criteria. NPDES permits are used to control point-source discharges using local water quality standards derived from national water quality criteria. Monitoring permit compliance and receiving water condition are added costs of implementing these standards. The water quality standards, however, vary with different local designated uses for the receiving waters. Hydrodynamic models are used to establish the relationship between the upstream permits and the receiving water quality, taking non-point sources of pollution into consideration. Adverse impacts are determined by comparisons with nearby reference sites.

When this process is applied to nutrient and persistent bioaccumulative chemicals, the most vulnerable ecosystem component and assessment endpoints are often far removed from the stream segments and mixing zones up in the watershed near the discharge. Setting permits based on local designated uses and reference conditions do not prevent the cumulative adverse effects in the regional-scale ecosystems. Nor does the protection of dozens of individual stream segments in a region necessarily lead to the development of sustainable land use practices. In particular, the current approach is poorly suited to address the loss of habitat that supports balanced aquatic populations and foodwebs.

An alternative approach is required to manage for the more holistic needs of ecosystems which are inextricably linked to the myriad of small watersheds and their local economies that depend on goods and services derived from the environment. Ecological criteria must identify the critical receiving waters and habitats for entire watersheds, establish cause-effect relationships and thresholds in those relationships that are protective of important ecosystem processes, and quantify the linkages between watershed uses so that the risks that exceed those thresholds can be minimized. Finally, holistic ecological risk assessment at later scales should minimize the application of pollution control measures that do not significantly improve water quality or the sustainability of designated uses.

4.11.1 Research Questions

The strategic direction of ecological criteria research will be the creation of a watershed hierarchy that identifies the critical ecosystem components and assessment endpoints and a common risk assessment framework for optimizing the implementation of control measures which result in the greatest improvement in the health of aquatic communities. Cornerstones of this approach are new methods for designating uses that reflect attainable and sustainable ecological conditions and new methods that allow pollution control to be driven by comprehensive data of the current conditions of streams, lakes, wetlands, and estuaries.

The research questions that must be addressed to design a condition-driven risk assessment process capable of spanning community, basin and large watershed scales and a common language for the impacts of toxic chemicals, nutrients, sedimentation, and loss of habitat quality include:

- Can concepts of ecological constraints , biogeography, and critical ecosystems give structure to more objective use attainment analyses for large watersheds?
- Can area-based socioeconomic indicators of sustainability be incorporated into regional guidelines for designating uses for aquatic resources?
- Can a nationwide survey of biological integrity of aquatic resources be designed to streamline performance and compliance monitoring as well as to identify impacted aquatic resources in a more ecologically meaningful manner?
- Can a single risk assessment method be developed that harmonizes the different approaches used to derive human health criteria, aquatic life criteria, wildlife criteria, and sediment quality criteria for discharges of toxic chemicals?
- Can water quality criteria for nutrients and clean sediments be formulated so that lakes, wetlands and stream segments as well as other critical ecosystems in the watershed are protected?
- Can the relationships between habitat quality indicators and the biological integrity of specific communities be quantified well enough to prescribe cost-effective restoration actions in areas impacted by habitat loss?
- Does current expert system technology permit the development of a decision-support system for the diagnosis of major stressors in watersheds based on survey data, landscape indicators, land use patterns and data on pollution sources?

4.11.2 Implementation

One of the greater challenges of the ORD Strategic Plans is the refinement of the ecological risk assessment process so that toxic chemicals, nutrients, and siltation from point and non-point sources can be integrated with other stresses such as loss of habitat quality so that the risks of land use changes can be managed. The Ecological Research Strategy outlines a comprehensive ORD plan to accept that challenge using long-term core research and problem-driven research which directly improves regulatory programs. The Office of Water is at a crossroads between the traditional point source waste load allocation and permitting programs and the control programs needed to also protect ecosystems from nonpoint sources and habitat disturbances. The hurdles which must be crossed are the development of new multimedia, multi-scale models for watershed simulations in the TMDL process, better landscape indicators of condition, and new methods for unifying the many facets of water quality criteria.

As described in other sections, multimedia modeling and monitoring are core research programs in ORD. Implementation of aquatic eco-criteria research will interface with that core research and will be closely coordinated with the Office of Water. The research will continue the support for the existing regulatory programs in water quality criteria, sediment quality criteria, and whole effluent toxicity assessment until new holistic methods and implementation guidelines are drafted in the next five years. Central to the entire effort is a national stream survey which must be initiated in 2000. The Environmental Monitoring and Assessment Program (EMAP) will begin testing the feasibility of large-scale survey designs in 1999. ORD will work with water quality monitoring programs in the Office of Water to evaluate options of combining resources for the national survey. The results of the national survey of biological condition will serve as the foundation for the design of holistic watershed risk assessments driven by assessed conditions.

4.11.3 Anticipated Products

- **By 1998,** Produce a research plan to remove major remaining uncertainties in existing chemical-specific water quality criteria. (NHEERL)
- **By 1999,** Produce a research plan to determine the importance of wetland quality and distribution of wetlands on biological integrity in large watersheds. (NHEERL)
- **By 2000,** Produce a report on the new methods for use designation and identifying critical habitats in watershed-scale risk assessment. (NHEERL)
- **By 2001,** Produce a report on methods for identifying critical stressors in watersheds. (NERL)
- **By 2003,** Produce a draft of new National Guidelines for Water Quality Criteria to protect aquatic life, wildlife, and human health. (NHEERL)
- **By 2004,** Produce a report on optimizing pollution prevention and ecological restoration methods in watersheds. (NRMRL)

4.12 Total Maximum Daily Loading Research

The Government Performance and Results Act Subobjectives are: (1) by 2003, to provide means to identify, assess, and manage aquatic stressors and (2) by 2003, to deliver decision support tools and alternative, less costly wet weather flow control technologies for use by local decision makers involved in community-based watershed management.

The Total Maximum Daily Load (TMDL) process, established within section 303(d) of the Clean Water Act, provides the States with the means of addressing nonattainment of designated uses of receiving water bodies in cases where technology-based control of point sources have been or will be implemented. These water bodies are classified as water quality limited. The TMDL process can have two meanings: 1) the TMDL process is used to implement State water quality standards — a planning process that will lead to the goal of meeting the standards in water quality limited receiving waters, and 2) the TMDL can be a quantitative value that determines the maximum load of a pollutant from point and nonpoint sources, as well as background, to receiving bodies such that state water quality standards will not be exceeded.

The TMDL process provides the means to establish a watershed-based approach to integrating the control of point and nonpoint sources of pollutants that are responsible for the impairment of water bodies. The process integrates monitoring and characterization of the States’ surface waters for designated uses, development and application water quality criteria for human health aquatic life and wildlife to help identify impairment and loading capacities for watersheds, and water quality and hydrodynamic modeling of the fate and effects of pollutants.

Numerous lawsuits have been filed concerning implementation of TMDLs. The suits deal with a variety of issues. In a broad sense, the States are being challenged with inadequate listing and prioritization of water bodies for TMDLs and arbitrary and capricious TMDL development and implementation. ORD has focused on improving the TMDL process and many of the research questions below are being used to guide the core research as well.

While the States are responsible for implementing TMDL programs, EPA's Regions are required to review the States' efforts and provide technical assistance. Therefore, the Regions are, at a minimum, indirectly involved in the suits.

4.12.1 Research Questions

The highest priority research questions include the following:

Monitoring (Landscape Characterization, Ecological Indicators)

- What land use and land cover data are available for forestry, vegetation (including riparian), urbanization, agriculture? What aquatic resource data are available for fish (by species), macro-invertebrate assemblages, and hydrogeographically linked water column physical/chemical data and river/stream physical data? What data are available on soil properties and location of forests, roads, and wetlands?

- What landscape characterization methods (using GIS cartographic products and remotely sensed imagery) are available to efficiently use coarser-scale watershed characteristics to predict finer-scale characteristics?

- What methods are available to distinguish loadings from anthropogenic sources from other sources, particularly for sources of fecal contamination in watersheds?

- What diagnostic indicators are available for assessing the interactive effect of multiple physical, biological and chemical stressors?

- What monitoring designs are available for identifying impacted water bodies, diagnosing cause and effect, gathering data for model parameters and tracking ecological condition following implementation of a TMDL?

Modeling

- What models are available for estimating water quality conditions in non-monitored segments and watershed subbasins?

- What watershed and basin-scale models are available to address: eutrophication (both periphyton and macrophyton algae), sediment loading, water temperature, and habitat degradation, for various places over time?

- What models are available that work with varied quantities of data and allow incorporation of margins of safety for highly variable non-point source loadings (e.g., ephemeral or intermittent flow, effluent dependent systems, flashy systems, wet-weather flow)?

- Have available model input data been adequately evaluated?

- What models are available to predict ecosystem/watershed recovery time frames in response to implementation of BMPs and load reductions?

Assessment

- What data systems are available and accessible for locating environmental data that is needed?

- What guidelines, tools and case-studies can be used to: (1) assess pollution problems when numeric criteria are not feasible or available (e.g., site-specific stressor-response profiles for sediments, nutrients, stressor "mixtures"); (2) predict pollution problems that can result from multiple sources (e.g., land use activities, point versus nonpoint discharges); (3) incorporate a temporal dimension to facilitate TMDLs expressed on daily, monthly, seasonal and annual basis and combined point versus non-point inputs; and (4) address impacts to wildlife?

- What methods are available to compare the risk from human versus non-human sources of fecal contamination in watersheds?

- What extrapolation techniques are available for estimating water quality conditions in non-monitored segments and watershed subbasins? That is to say, what watershed indices are available to facilitate extrapolating loading rates of key stressors (e.g., sediments, nutrients, toxics, pathogens) from well-studied watersheds?

Risk Management

- How can we effectively prevent and reduce nutrient and toxic pollutant discharges to receiving waters with different characteristics? What combination of best management practices, source controls, watershed restoration, and retrofitted technologies provide the most cost-effective strategy for improving water quality? What is their expected performance under different conditions?

- What are the characteristics of WWF and its impact on receiving-water bodies, and what tools are available to best measure them? What innovative and less costly watershed management practices and WWF management networks need to be developed?

- What methods are available for measuring and predicting (quantitatively with estimates of uncertainty) ecosystem restoration effectiveness and appropriateness by using indicators of ecosystem structure and function? What decision tools are available for state and community planners to evaluate probable outcomes of completing restoration alternatives?

- What watershed restoration goals can be met by focusing on stream corridors and riparian zones?

- What are the most appropriate and cost-effective technologies for in situ and ex situ treatment of contaminated sediments? Under what circumstances are adaptation measures (e.g., in-place containment and low-energy in situ treatment) for contaminated sediments less costly and produce lower ecological risks than alternative remediation?

4.12.2 Implementation

Implementation of this work will be guided by Office of Water needs and the short- and long-term strategies to improve the TMDL process. This work is being implemented in close coordination with the Office of Water's Office of Science and Technology and the Office of Wetlands, Oceans and Watersheds, and with the ORD Regional Scientists.

4.12.3 Anticipated Products

At the time of printing, the specific products were still being discussed with the Program Office and Regions.

4.13 Endocrine Disruptors Research

Government Performance and Results Act Subobjective: Identify and evaluate strategies to manage risks from exposures to endocrine-disrupting chemicals capable of inducing adverse reproductive and other effects in wildlife.

It has been suggested that humans and domestic and wildlife species have suffered adverse health consequences resulting from exposure to environmental chemicals that interact with the endocrine system. Collectively, these chemicals are referred to as endocrine-disrupting chemicals (EDCs). EDCs have been defined as exogenous agents that interfere with the production, release, transport, metabolism, binding, action, or elimination of the natural hormones in the body responsible for the maintenance of homeostasis and the regulation of developmental processes.

Despite reported adverse reproductive and immunological health effects, little is known about their causes and the concentrations of EDCs that would induce effects in various populations. Nevertheless, it is known that the normal functions of all organ systems are regulated by endocrine factors, and small disturbances in endocrine function, especially during certain stages of the life cycle, such as development, pregnancy, and lactation, can lead to profound and lasting adverse health effects. Based on recognition of the potential scope of the problem, the possibility of serious effects on the health of populations, and the persistence of some endocrine-disrupting agents in the environment, research on endocrine disruptors was identified as one of the high-priority topics identified in the ORD strategic plan (EPA, 1997a).

If future health effects and exposure studies conclude that humans and the ecosystem are at significant risk because of exposure to EDCs, research will be needed on how best to lower or eliminate the risk.

The broad objectives of the strategy to evaluate the ecological risk of EDCs are twofold:

1. Determine EDC risk relative to risk from other stressors on populations and communities, both prospectively and retrospectively
2. Develop or modify methods for testing and evaluating chemicals and environmental samples to ensure that those exerting toxicity through specific endocrine axes will be characterized.

Both objectives require a reduction in uncertainty in prediction of risk across levels of biological organization, including better linkage of measurement and assessment endpoints. More detailed information on the research priorities and the Program are available in the ORD Research Plan for Endocrine Disruptors (EPA, 1998b).

4.13.1 Research Questions

For the ecological research program, the key scientific questions that are of highest priority include:

- What effects are occurring in exposed wildlife populations?
- What are the chemical classes of interest and their potencies?
- Do current testing guidelines adequately evaluate potential endocrine-mediated effects?
- What extrapolation tools are needed?
- What are the effects of exposure to multiple EDCs?
- How, and to what degree, are wildlife populations exposed to EDCs?
- What are the major sources and environmental fates of EDCs?
- How can unreasonable risks be managed?

4.13.2 Implementation

In defining the specific role of ORD in endocrine disruptor research, it is important to note that there are clearly important areas for which other federal agencies have the research lead. This coordination occurs through the Committee on the Environment and Natural Resources (CENR). Topics most appropriate to assign to the intramural program include dose-response and mode-of-action studies on the development of the reproductive tract, central nervous system, and immune system in laboratory species; establishing a framework for multi-laboratory EDC studies to identify priority chemicals and exposure pathways, characterizing EDC exposures and action at selected near-laboratory sites; determination of EDC fate and transformation in sediments; and developing risk management tools for risk reduction or prevention.

Therefore, ecological effects research will focus on:

1. Better development of a comparative endocrinology/toxicology database for organisms like amphibians, nonteleost fish, and passerine birds.
2. Better definition of baseline conditions for general processes and specific endocrine function.

Exposure research will emphasize the development of methods and models to measure and predict exposure to these substances. Three primary areas will receive the most attention:

1. Better physico-chemical characterization of a few known or highly suspect EDCs.
2. Developing pathway models (e.g., compartmental transport, fate, or transformation) for chemicals that are likely to be endocrine disruptors.
3. Reducing uncertainties in the flux of EDCs.

More information on the Program at the following two web sites:

- *The Endocrine Disruptor Research Initiative website e*of the NSTC Committee on the Environment and Natural Resources: www.epa.gov/endocrine/edrifact.html
- EPA's *Endocrine Disruptor Screening and Testing Advisory Committee website:* www.epa.gov/opptintr/opptendo/index.htm

4.13.3 Anticipated Products

- **By 1999**, explore molecular and genetic methods to detect compounds that interact with the endocrine system. (NHEERL)
- **By 1999**, complete a risk management assessment for EDCs. (NRMRL)
- **By 2000**, initiate an environmental scenarios project to draw implications from selected environmental trends. (NCEA)
- **By 2000**, develop a preliminary EDC fate and transport model. (NERL)
- **By 2001**, develop and apply indicator methods to detect exposures of wildlife to compounds that interact with the endocrine system. (NHEERL)
- **By 2001**, evaluate indicator methods for endocrine disruptors at a local "source-based" scale. (NHEERL and NERL)
- **By 2003**, construct QSAR models of steroid receptor interaction and laboratory animal models of endocrine-disruptor-induced diseases. (NHEERL)
- **By 2003**, define modes of action for EDC classes on critical target organs. (NHEERL)
- **By 2003**, apply ecological indicator methods for endocrine disruptors at regional scales. (NERL)
- **By 2003**, develop an EDC model that includes exposure and effects linkages. (NERL)

4.14 Pesticides and Toxics

Government Performance and Results Act Subobjective: Provide state-of-the-science measurements, methods, and models for development of ecological effects, exposure, and risk assessment tools, protocols, and guidelines and strategies and provide the scientific basis for credible ecological vulnerability assessments and evaluations of the impacts of environmental stressors

The study of the deliberate release of toxic chemicals to control plant and animal pests always has been one of EPA's most important research programs. Thousands of pounds of pesticides are sprayed each year on crops and other components of the ecosystem to control the pests associated with agricultural production. The sophistication of the agricultural crop protection industry has produced an agricultural production system that is the envy of the world. The United States produces more goods in less "space" than any other country in the world, in part because of the extensive use of pesticides. Recognizing the significant risks posed by the deliberate release of "poisons," an elaborate registration and evaluation process is required before any pesticide can be used.

Research under this area focuses on individual chemicals/toxics, classes of chemicals/toxics, and other issues that may pose serious risks to both human health or ecosystems, are expected to require a shorter term, concentrated effort, and are of special concern to EPA or the administration. In 1998 and beyond, research efforts will be broadened to incorporate effects, exposure, and assessment questions for determining the reliabilities, uncertainties, and impacts of broad classes of environmental agents; the evaluation of methods and models for determining the impacts resulting from cumulative exposures; and effects of multiple chemicals within ecosystems and at various scales of ecological organization.

4.14.1 Research Questions

4.14.1.1 Test Methods

ORD will work with the Program Office to develop test methods that do a better job of screening for chemicals that cause effects on the endocrine system. As the role of endocrine-disrupting chemicals becomes more apparent, the need to develop more precise test methods is needed. These test methods, to be developed within NHEERL, will undergo field validation and verification so they can be used in the risk assessment process.

Additional research is needed to better understand and interpret higher tier test data such as full field tests for avian effects and mesocosm data used to assess the risks to aquatic systems. Analysis of these complex data sets will be important in understanding the limitations of extrapolating from simple single-species tests to complex ecosystem-level responses.

Research questions include the following:

- Are screening tests reliable and available to identify and characterize the exposure and effects of pesticides and other toxic chemicals (inorganic and organic)?
- What is the reliability of current test methods for assessing the acute and chronic toxicities of sediment-bound pesticides and other toxic chemicals?
- What refinements of existing fate, transport, and exposure models are needed?
- How and where are probabilistic assessments needed to predict distributions of exposure rather than point estimates?
- What are the uncertainties of scaling (watershed to regional) on current risk assessments of the impact of pesticides and toxic chemicals?
- Are current exposure-assessment models adequate for assessing larger regional-scale impacts?
- What are the uncertainties and variabilities of indicator and biomarker measurements and methods of exposure and effects?
- How are indicator and biomarker methods of exposure and effects to be incorporated into regional-scale assessments and other multimedia exposure and effects assessment models?
- What is the next level of multimedia assessment models needed for determining the impacts and risks posed by environmental agents?

4.14.1.2 Indirect Effects

Methods are needed to characterize and assess the indirect risks associated with pesticide use. For example, the synthetic pyrethroids (potent insecticides) are so powerfully toxic that they can wipe out all of the aquatic insects in nearby streams and lakes. Although they are not very toxic to fish, pyrethroids eliminate the food source of the fish and cause mortality by starvation (an indirect effect). Also, an entire field of insects can be eliminated with just one spraying, thus reducing or eliminating insect food for migratory birds. Herbicides have become so nontoxic to fish and wildlife, they usually pose little or no direct effects. However, they can drift into nearby riparian and fence row habitats and significantly reduce the ground cover of vegetation that is so important for wildlife species. These types of indirect effects now must be considered in pesticide regulatory decisions, and ORD will work cooperatively with the Program Office to develop the tools to adequately monitor and assess these indirect effects.

Research questions include:

- What indirect risks to ecosystems are associated with use, exposure, and effects of toxic chemicals?
- How can the indirect risks associated with pesticide use be characterized and assessed?
- What new exposure and effects methods and modeling needs can be identified for assessing cumulative and aggregate exposures and effects of pesticides and toxic chemicals within ecosystems for incorporation into regional-scale assessments?

4.14.1.3 Place-Based Methods

The emphasis on place-based assessment methods is a clearly stated, new direction in this research strategy. Although the Program usually does not regulate toxic chemicals in this context, assessing the risks of chemicals at a biogeographical setting like a watershed will enable the Program to add a "real world" component to their risk assessments. The emergency exemption provisions in the pesticide program are based in part on the place where the pesticide is to be used, and pesticide labels can be written to account for special places where use is prohibited, such as endangered species habitats.

Research questions include:

- Are new hazard tests needed for conducting place-based risk assessment?
- How can data be extrapolated from one place to another?
- How will the stakeholders be affected by a place-based approach?

4.14.2 Implementation

ORD's role is to develop the tools to conduct ecological risk assessments for toxic chemicals and pesticides. This is primarily an intramural program. The intramural program will expand to incorporate new methods and modeling frameworks for assessing the cumulative impacts of multiple stressors (pesticides and toxic chemicals) into site- to regional-scale assessments to support regulatory and policy decisions associated with potential impacts of pesticides and toxics to ecosystems and evaluations of the vulnerabilities of major geographic ecosystems resulting from the cumulative and aggregate exposures to pesticide and toxic chemicals. The extramural program will concentrate on new monitoring methods and quantitative tools for linking multimedia assessments.

4.14.3 Anticipated Products

- **By 1999**, develop and evaluate methods (indicators, biomarkers) for assessing population exposure and vulnerability to pesticides. (NERL)
- **By 2000**, develop improved capability to assess the presence and risks of pesticides in watershed ecosystems. (NERL)
- **By 2000**, publish methods at several levels of biological organization with specificity and sensitivity to diagnose the exposure of aquatic biota to individual pesticides and classes of pesticides. (NERL)
- **By 2001**, complete development of ecological models for regional vulnerability assessments. (NERL)
- **By 2001**, complete analysis of presence and physiological impacts of pesticides in aquatic biota. (NERL)
- **By 2001**, publish indicator and biomarker methods for vulnerability of aquatic systems to pesticide exposure. (NERL)
- **By 2002**, complete exposure assessment of ecosystem vulnerability to pesticide contaminants over regional scales. (NERL)
- **By 2002**, publish molecular methods to analyze exposure to single and multiple pesticide stressors. (NERL)
- **By 2003**, publish guidance for assessing ecological risks of pesticides and develop a landscape approach to assess ecosystem risk from pesticides and toxic substances. (NERL)
- **By 2004**, provide indicator data to support pesticide exposure modeling on a large scale. (NERL)
- **By 2005**, complete regional application of indicators for pesticides. (NERL)

4.15 Landcover Change Research

Conversion from natural to anthropogenic (agriculture and urban) land cover may be the most important factor threatening ecological attributes valued by society (Ojima et al. 1994). Conversion of forest to anthropogenic land cover not only reduces forest species, but also increases soil loss, sediment loads to streams, and flooding risks (Hunsaker and Levine 1995). Loss of riparian forest borders along fields also increase the amount of nutrients, sediment, and pesticide inputs into streams (Peterjohn and Correll 1984). Despite its importance, we lack both information on the magnitude and spatial distribution of land cover change at watershed and regional scales, and adequate methods and/or indicators to quantify the consequences with known accuracy and precision, including how the functional importance of landscape features (e.g., riparian zones versus land cover) relative to water quality may change in different environmental settings, or when moving from one spatial scale to another. We also lack socioeconomic models to project the pattern and magnitude of land cover conversions over the next 50 years. Such models will be important in projecting how human behavior will influence future risk to ecological resources.

4.15.1 Research Questions

- What proportion of the variation in water quality parameters, stream biological integrity parameters, and terrestrial habitat and productivity parameters is explained by land cover conversion on watersheds?
- How does the explanatory power (above) vary by the total amount of anthropogenic cover in a watershed? By the type of biophysical setting?
- What is the distribution and magnitude of land cover conversions since pre-European settlement? What have been the consequences of these changes on water, habitat, and terrestrial resources?
- How are the distribution and magnitude of

land cover conversions likely to change over the next 50 years? What will be the consequences of different change scenarios on water, habitat, and terrestrial resources?

- Do certain locales (e.g., geographic areas, stream junctions, ecosystem types (e.g., wetlands and riparian areas), or landscape features (e.g., habitat connectivity and complexity) play a particularly important role in sustaining the condition of water, habitat, and terrestrial resources, or in the sensitivity of these resources to land cover conversions or management actions?
- What kinds of restoration and/or protection activities reduce the impact of historical land cover conversions the most, and in what locales or ecosystem types?
- What kinds of restoration and/or protection activities reduce the impact of projected land cover conversions the most, and in what locales or ecosystem types?

4.15.2 Implementation

The primary focus of in-house research will be:

- Developing indicators and change detection methods that relate to land cover conversion across scales ranging from watersheds to regions.
- Quantifying relationships between land cover conversion and water quality, stream biological integrity, habitat, and terrestrial condition parameters.
- Quantifying land cover conversions since pre-European settlement.
- Evaluating the consequences of historical, as well as future land cover conversion on aquatic and terrestrial resources.

The primary purpose of the extramural component of the Program will be in developing socio-economic models that help project the future distribution and magnitude of land cover conversions.

4.15.3 Anticipated Products (1999-2004)

- By 1999, provide a set of landscape indicators and methods that document land cover conversion at watershed and regional scales. (NERL)
- An assessment of the ecological consequences of land cover conversion on aquatic and terrestrial resources in the Mid-Atlantic Region. (NERL)
- An assessment of the ecological consequences of alternative future landscapes in the Willamette River Basin, Oregon. (NHEERL)
- Socioeconomic models to project future land cover conversion magnitude and distribution. (NERL and NHEERL)
- An assessment of the consequences of projected land cover conversion on aquatic and terrestrial resources in the Mid-Atlantic Region of the U.S. over the next 50 years. (NERL)
- A set of landscape management alternatives to reduce detrimental land cover conversions. (NERL)

SECTION 5

High Priority Geographic Studies

Conducting research in real places with real problems for Regional and other customers.

5.1 Introduction

Previous sections have provided an overview of the core capabilities and the problem focused research for the Ecological Research Program. Another, but not independent, way of looking at the Program is from the perspective of where the work is being done. With the increased emphasis in the Agency on community-based or place-based decision making, it is important that ORD conduct studies, at multiple scales, in places where decisions are to be made. Long standing "geographic initiatives" have been underway for many years in the Agency. Among them are the Mid-Atlantic, the Pacific Northwest, South Florida, the Great Lakes, and the Gulf of Mexico (see Figure 5-1). These are not the only areas being studied but are among those that have received much of the attention. ORD has therefore focused on these areas whenever possible to conduct research.

The benefits of conducting research at these areas include:

- Access to data collected by multiple parties.
- Support from State and Regional staff.
- Access to user needs surveys.
- Diverse problems and scales of interest for conducting research.
- Common locations for ORD scientists encourage coordination and cross organizational research opportunities.

Therefore, the Program has adopted these for coordinated studies. While Program Offices have interest in the research being conducted in these areas, it is the Regional Offices that serve as the primary customers guiding these geographic research efforts.

As with the problem-focused research, it is unrealistic to separate all work in any single set of categories when they are so interdependent (Figure 5-2). Therefore, the information that follows describes the research underway in each of the geographic areas without regard to how it may or may not overlap with other research. These areas will likely change over time, but it is expected that for the next three to five years, the commitment will remain to conduct work in these locations and on the scientific questions listed in the description of research in each section to follow.

There are three additional "locational" studies discussed that have been selected specifically by ORD. First are the Near Laboratory Ecological Research Areas. These sites are near ORD facilities and offer opportunities to work with local scientists, encourage EPA staff to move to the field incurring minimal travel costs, and for cross-organizational interactions. Secondly, the Index Site Research has been implemented consistent with recommendations of the National Research Council in their review of the Environmental Monitoring and Assessment Program for multiagency, coordinated, long-term research (Section 5.8). Finally, much of the work that needs to be done should address a national perspective. To this end, there has been some progress at the national scale, in both modeling and monitoring, that will be continued for the next 3 to 5 years, minimally, to further advance the science of environmental management at larger scales.

Figure 5-1.
High priority regional research areas.

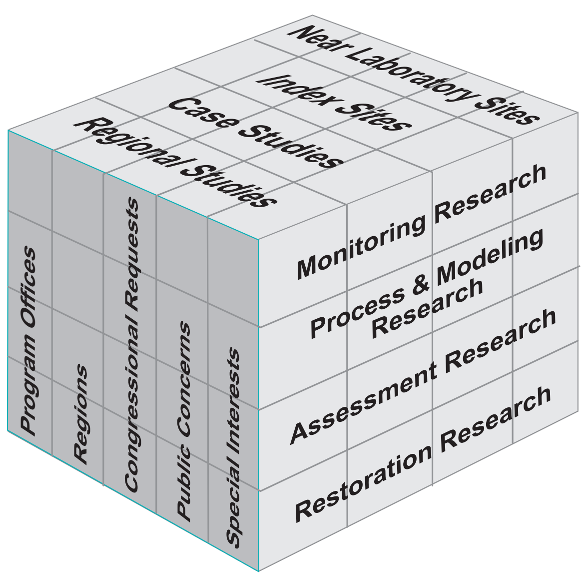

Figure 5-2.
Interdependency of core capabilities, multiple customers and locations where research is conducted (only examples of customers and locations shown in the cube above).

5.2 Mid-Atlantic Research

The Mid-Atlantic Region provides a fertile testing ground for ORD to partner with an EPA Regional Office in order to demonstrate and evaluate the monitoring, modeling, assessments and restoration research being conducted within EPA. This geographic area encompasses all of EPA Region 3 and parts of Regions 2 and 4 (see Figure 5-1). The region encompasses the Chesapeake Bay, the largest estuary in the world, and the uplands area is among the most diverse biological regions in the conterminous U.S. The Mid-Atlantic is also among those most affected by increasing population pressures and urbanization.

EPA Region 3 and the States within it have been some of the most progressive with respect to using environmental data to drive the strategic planning and decision making. Given ORD's research interest in improved environmental monitoring and ecological assessments, the partnership has been symbiotic. ORD, through EMAP, has made a long-term commitment to determine the condition of the ecological resources in this area beginning as early as 1989. The commitment, in addition to the work of the states, has lead to the wealth of data on ecological systems in this area. ORD will now bring all of its ecological research to bear on the issue of strategic planning in this area to determine the most effective approaches for determining how a Region could most effectively target its restoration, mitigation and regulatory efforts.

Currently, the Mid-Atlantic is also the location of a pilot study being conducted by federal and state agencies (including ORD, Region 3 and the Chesapeake Bay Program) under the auspices of the CENR. Several years ago the CENR established an interagency group to develop an improved framework for environmental monitoring and research. The developed framework endorsed the original EMAP framework for monitoring developed by ORD. The CENR pilot in the Mid-Atlantic is an effort to have the federal and state agencies come together in one region and test the concepts and applicability of the framework to real regional problems.

5.2.1 Research Direction

Given the historical work within the Mid-Atlantic on environmental monitoring, assessment and restoration, this region serves as a test bed for new research and environmental management concepts. If these concepts prove effective here in improving our environmental protection efforts, the likelihood is much greater that they will also work elsewhere.

Some of the proposed activities during the first three years focus on integration of ongoing programs at a subregional scale. The four sub-regions are defined by the three large watersheds of Delaware Bay, Chesapeake Bay, and Albemarle/Pamlico Sounds, and the Highlands, which is the major ecosystem containing the headwaters of these watersheds. Monitoring and related research activities within the four sub-regions vary in their extent and degree of coordination and focus. For example, the Chesapeake Bay Program includes an extensive monitoring program focused on the tidal Bay water quality and living resources with links and mechanisms to access other environmental monitoring data relevant to the Bay Program's restoration and protection goals. The Bay Monitoring Program operates through a formal committee management structure through which the *Regional Pilot* must work directly with in order to be effective. Integrated monitoring in other sub-regions is less formalized and mature in development. *Regional Pilot* efforts within the sub-regions are designed to accommodate the different degrees of development; in some sub-regions, the *Regional Pilot* will initiate or lead efforts for integrated monitoring, while in others the *Regional Pilot* will play a supporting and catalytic role for well-established strategic efforts already underway.

Within the CENR pilot activities, each Agency is providing the resources necessary to accomplish their part of the effort. Because of the broad environmental mandate of EPA, ORD and Region 3 are involved in each of the activities of the CENR pilot. We are conducting the inventory of existing monitoring programs and making that information available for public access through the Internet. EPA is partnering with USGS in the Highlands and Delaware Basins to demonstrate the linkage between sample surveys of aquatic systems and intensive monitoring of limited locations on aquatic systems. EPA has spearheaded the interagency effort to combine sampling efforts across estuaries using a common design and core indicators. EPA also initiated the interagency effort to develop the landcover data distributed through the Multi-Resolution Landscape Characterization Project. Finally, EPA has sponsored the production of a series of "state of the region" reports. These are being produced for estuaries, landscapes, streams/rivers, forests, groundwater, and agricultural systems. Research which is just beginning in ORD focuses on improving assessments, modeling futures, and developing restoration strategies.

5.2.2 Research Questions

The scientific questions driving ORD's research in the Mid-Atlantic are:

- How does one define and measure the condition of ecological resources within a region for streams/rivers, estuaries, forests, agricultural systems, and landscapes?
- What monitoring design will allow for these conditions to be estimated regionally and subregionally with known confidence and tracked for trends?
- How does one monitor the relative importance of stressors impacting this region and these ecological resources?
- How does one model the distribution of stressors over a region?
- How does one model the relative exposure of biological receptors to these stressors?
- How does one use management scenarios, demographics and socioeconomic information to model future changes in these environmental exposures?
- Given the information above, how does one conduct a regional ecological risk assessment?
- What are the most cost-effective restoration, mitigation and regulatory strategies for addressing the most severe ecological threats within the region?

5.2.3 Anticipated Products

- **By 1998**, Publish the State of the Estuaries Report.
- **By 1998**, Publish the Mid-Atlantic Landscape Atlas.
- **By 1998**, Publish the State of Highland Streams Report.
- **By 1999**, Publish the Stressor Profiles for Mid-Atlantic.
- **By 1999**, Publish the State of Forests Report.
- **By 2000**, Publish the Multiple Ecological Resource Assessment.
- **By 2000**, Publish the Integrated Relative Risk Assessment for Mid-Atlantic.

5.3 Pacific Northwest Research

President Clinton convened the Northwest Forest Conference in 1993 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 work groups charged with evaluating management alternatives using an "ecosystem approach to forest management."

Key elements of this approach include "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" and "using the best science available" to define management options that deal not just with the immediate crisis but also long-term solutions to "restoring and sustaining healthy ecosystems and their functions" (Questions and Answers on the Interagency Ecosystem Management Initiative, memorandum from W. Stelle, White House Office on Environmental Policy, 4 May 1994). The President's Forest Plan applied these principles to federally owned forest land in the Pacific Northwest.

The Regional Interagency Executive Committee oversees the implementation of this plan and coordinates research and monitoring activities designed to evaluate its effectiveness and improve the scientific underpinnings.

EPA's Pacific Northwest Geographic Initiative is part of the follow-up to the President's Forest Plan. Consistent with its broad authorities, EPA's research role complements those of other federal agencies by centering on non-forested lands and state, tribal, and privately owned lands and waters and by integrating ecological understanding across multiple land uses and all boundaries of ownership.

The fundamental goal of EPA's research program is to provide the ecological understanding and technical tools that federal, state, tribal, and local governments will need to implement an ecosystem approach to environmental management in the

Pacific Northwest (Baker, et al., 1995). The research design resulted from numerous meetings with state and tribal governments and local stakeholders to identify the major problems and areas of concern and types of scientific information most critically needed. The research evaluates the overall ecological effects of human activities and human use of land, water, and other natural resources at watershed to regional scales. The primary objective is to develop and demonstrate place-based ecological assessment approaches that provide the scientific basis needed to (1) evaluate and compare the ecological consequences of societal decisions and alternative management strategies regarding land, water, and resource use (alternative futures analysis) and (2) target geographic areas, ecosystem types, and landscape features that are particularly important for sustaining ecosystem condition, and thus most important to protect or restore (geographic prioritization).

5.3.1 Research Direction

EPA's Pacific Northwest Geographic Initiative was designed to include two case studies at the watershed/ecoregion scale and two at the state/regional scale. The watershed/ecoregion case study areas were selected by the States of Oregon and Washington as areas where the planned research would be of particular benefit to state and local decision makers: the Willamette River Basin in Oregon and Washington Coastal Ecoregion. In the Willamette Valley, major concerns are the effects of urbanization and agricultural on aquatic and terrestrial ecosystems. Lands in the Washington Coastal Ecoregion are largely privately owned forests. Major concerns are the impacts of forestry and other watershed activities on salmon habitat in streams and the productivity of coastal estuaries. In both areas, particular attention is being given to the ecological importance of riparian areas. These areas exert a strong influence on the quality of stream environments and provide important habitat for a large number of terrestrial animals.

An integrated alternative futures analysis will be completed only for the Willamette River Basin in Oregon. The Willamette Valley Livability Forum (WVLF) was established by the Governor's Office to "work with communities to build a vision to shape the Valley's growth for the next fifty years; and enable Valley leaders and citizens to work together to implement this vision." Working with the Forum, a series of alternative future landscapes will be defined for the basin for the year 2050, reflecting a realistic range of policy and management options. Models are being developed that will evaluate and compare the likely effects of these alternative futures on terrestrial vertebrate biodiversity, fish and benthic communities in streams, riparian areas and channel structure in the Willamette River, and selected economic endpoints. Future projections will be compared to present-day conditions as well as available information on historic and recent trajectories of change. EPA research complements ongoing research and analyses by the U.S. Forest Service in the forested upland areas of the Willamette Basin. The alternative futures analysis will be closely coordinated with analyses by the Corps of Engineers and Oregon Department of Water Resources to re-evaluate dam operations in the basin. The Oregon Department of Environmental Quality and U.S. Geological Survey are also conducting major studies of water quality in the basin, in particular the distribution and sources of toxic contaminants and nonpoint source loadings of nutrients.

At the state/regional scale, EPA research focuses on identifying high priority areas for sustaining the overall diversity of terrestrial and aquatic species in the region. Analyses for terrestrial vertebrates in the State of Oregon are largely complete. Work is continuing on similar analyses for the state of Washington and focused analyses on aquatic and aquatic-dependent species for the two-state region.

5.3.2 Research Questions

EPA research under the PNW Geographic Initiative will answer the following major scientific questions over the next three to five years:

- How can we effectively characterize ecosystem condition and trajectories of landscape change over relatively large geographic areas (large watersheds/ecoregions) and long time periods (50-100 years)?
- What are the major anthropogenic and non-anthropogenic processes affecting ecosystems in western Oregon and Washington and the consequences of their interaction?
- What are the likely ecological consequences of a range of options for managing future land, water, and resource use?

- Do certain locales, ecosystem types, or landscape features play particularly important roles in sustaining ecosystem condition or in the sensitivity of ecosystems to human-induced landscape change or management actions?
- What characteristics of riparian areas are most important to improve water quality and sustain aquatic and terrestrial biota?

5.3.3 Anticipated Products

Two major, integrative products are planned:

- **By 2001**, complete an analysis of the Ecological Consequences of Alternative Futures in the Willamette Basin, Oregon.
- **In 2002**, complete a report on Regional Priorities for Protection of Biodiversity in Oregon and Washington. Findings from individual projects and model applications will be published in preceding years.

5.4 South Florida Research

South Florida is simultaneously a unique national resource and one of the most intensively managed ecosystems in the U.S. Over the past one hundred years, about 50% of the historic Everglades has been drained, canals have been dug, and a complex water-management has been constructed. These human alterations in the hydrologic system have created water quality and quantity problems for South Florida’s natural systems, including the Everglades and the estuaries. Nutrient enrichment, habitat fragmentation, contamination, introduction of invasive non-native plants and animals, altered fire regimes, and declines in estuarine and reef resources have taken their toll. Populations of wading birds have decreased by almost 95%. Mercury contamination has resulted in a ban on the consumption of fish and has been implicated in the death of a Florida panther, an endangered species. Florida Bay is experiencing massive seagrass dieoffs, noxious algal blooms and coral reef deterioration.

The need to preserve and restore South Florida led to a Memorandum of Understanding among six federal agencies. The Interagency Task Force for the Restoration of South Florida (ITFRSF) was expanded to include state, local and tribal entities and codified into law by the Water Resources Development Act of 1996. In 1994, the Everglades Forever Act outlined a restoration plan for South Florida.

5.4.1 Research Direction

The Science Subgroup of the ITFRSF (1995) outlined a regional research approach to support the restoration goals, that is, to maintain viable populations of all native species in situ, to represent within protected areas all native ecosystem types, to maintain evolutionary and ecological processes (e.g., disturbance regimes, hydrologic processes, nutrient cycling), to manage over long enough periods of time to maintain the evolutionary potential of species and ecosystems, and to accommodate human use and occupancy within those constraints.

Numerous state and federal agencies and their academic partners have developed coordinated research programs, many of which are well documented on internet websites:

EPA www.epa.gov/gumpo/florida_bay
USGS sflwww.er.usgs.gov/sfep
South Florida Water Management District www.sfwmd.gov
National Park Service www.nps.gov/ever/eco/
NOAA www.aoml.noaa.gov/general/flbay_aoml.html
Fish and Wildlife Service www.fws.gov/~r9ecosys/r4wshp.html
US Army Corps Engineers http://flabay.saj.usace.army.mil www.restudy.org

In addition to its roles on the Interagency Task Force and the Science Subgroup, ORD supports a number of coordinated research initiatives to address identified research needs in a few focused areas. Specifically, EPA supports modeling, process studies, and monitoring of atmospheric deposition of mercury, internal transport and transformation of mercury and endocrine disruptor compounds leading to ecological exposures, and nutrient dynamics in wetlands, estuarine and coastal ecosystems. These research programs are designed to address the questions listed below.

5.4.2 Research Questions

- What levels of nutrient inputs into the ecosystem are consistent with natural vegetation and food chains?
- What combinations of hydrologic design and management practices will achieve desired nutrient levels?

- What is the extent of mercury and pesticide contamination in the terrestrial and aquatic ecosystems of South Florida?
- Which populations are at risk?
- What are the relative contributions of local versus global sources of atmospheric mercury to the Everglades?
- What is the relative importance of external or internal sources of mercury versus transformation reactions that make mercury bioavailable?
- Can mercury exposures be modified by management of sulfur or phosphorus?
- What are the implications of hydrologic restoration for mercury exposures?
- What is the condition of ecosystem resources in South Florida?
- What are the impacts of habitat loss and contaminants, including endocrine disruptors, on the reproductive success of fish, amphibians, reptiles and wading birds?
- What is the extent of coral decline?
- What are the potential mechanisms for observed declines?

5.4.3 Anticipated Products

In addition to research in support of legislatively mandated restoration efforts, such as the Environmental Impact Statement (EIS) for the Restudy Plan and water quality standards based on ecosystem endpoints, ORD expects to produce the following research outputs:

- **By 1998**, publish a screening model for distribution of mercury and methylmercury in marshes. Simulation analysis of mercury and pesticide bioaccumulation in Everglades fish. Condition of Estuarine Resources in West Indian Province including Florida Bay. Flux of Selected Contaminants and Nutrients from Taylor River Everglades Ecosystem Assessment.
- **By1999**, confirm methylmercury distributions as a response to spatial environmental conditions. Frequency and Trends in Disease Patterns in Coral Ecosystems in South Florida.
- **By 2000**, complete modeling of atmospheric deposition of mercury at local scales. Wading bird exposure study under current conditions and restoration scenarios.

5.5 Great Lakes Research

The St. Lawrence Seaway and the Great Lakes are the largest system of fresh, surface water on earth, containing roughly 18 % of the world supply. These Lakes and associated drainage basins have been subjected to a wide array of human-induced stressors for several centuries. While unmistakable and documented improvements have occurred during the past two decades, environmental alterations, ecological problems, and impaired beneficial uses remain. The governments of the U.S. and Canada, who provide joint oversight of the Lakes, cite four general issues which encompass a broad array of problems and outline the major stresses on these systems:

1. The loss of biodiversity and integrity.
2. Degradation and loss of habitat including tributary, near shore and coastal wetland areas.
3. Impacts of persistent toxic contaminants.
4. Eutrophication in certain areas of the Lakes.

Regulatory authority for the environmental management of the Great Lakes are found in various sections of the Clean Water Act, Clean Air Act, Great Lakes Critical Programs Act, and the Great Lakes Water Quality Agreement between the U.S. and Canada. In recognition of the international nature of the Great Lakes, the Boundary Waters Treaty of 1909 established the International Joint Commission to assist in helping to prevent and resolve disputes concerning water quantity and quality. ORD's research effort in the Great Lakes, conducted in partnership with numerous governmental and academic institutions, is focused on addressing scientific questions related to methods and models for predicting the causes and/or effects of the stresses outlined above for use in improved environmental management.

5.5.1 Research Direction

Due to their size and international importance, a wide variety of organizations from both the U.S. and Canada have significant ecosystem research activities in the Great Lakes. This research ranges from studies on physical processes such as water and ice movement, to predicting whole lake ecosystem responses. As part of an effort to coordinate these efforts and to increase collaborations and efficient use of research resources, the Council of Great Lakes Research Managers of the International Joint Commission, representing the major research organizations from both countries, maintains an exhaustive inventory of Great Lakes research on the Internet (www.ijc.org/cglrm/ri97home.html). This inventory provides information on current research from government agencies and academic institutions across the spectrum of biological, chemical and physical research. There are about 300 research projects listed for 1997. The inventory also provides a link to the Great Lakes Commission's Inventory of Aquatic Nuisance Species Research Relevant to the Great Lakes.

5.5.2 Research Questions

The principal scientific questions being addressed by ORD's ecological research on the Great Lakes are organized around understanding the effects of toxic chemicals on aquatic life and wildlife, improving our understanding of the significance of coastal wetlands and the near shore environment to maintaining the integrity of the Lakes, and understanding and predicting the role of watershed characteristics and land use practices on tributary water quality and fish communities.

- What are the effects of toxic chemicals and nutrients on Great Lakes ecosystems?
- What are the ecological functions of Great Lakes coastal wetlands? What are the factors that influence and/or these functions?
- How do land use practices in Great Lakes watersheds influence the sustainability of freshwater ecosystems in the basin?
- What are ecologically significant indicators of the condition of the Great Lakes?

Research directed toward predicting the effects of toxic chemicals on Great Lakes ecosystems is being addressed primarily through a multi-agency effort to develop mass balance models for specific lake systems and chemicals. Current efforts are focused on Lake Michigan and PCBs, mercury, trans-nonachlor, and atrazine. Much of the scientific activity is engaged in collecting and analyzing samples needed to develop and validate the models. At the same time, research is being conducted to improve our understanding of key environmental processes that govern the cycling, movement and effects of these chemicals. A eutrophication model previously developed for the Great Lakes is being enhanced to predict changes in phytoplankton community structure in response to changes in nutrient levels. Similarly, research is being conducted to develop tools for estimating bioaccumulation factors for a large array of organic chemicals from both water and sediments.

In addition to stresses from toxic chemicals, the impact of habitat alterations and land use practices are important questions associated with protection of the Great Lakes ecosystems. ORD is studying coastal wetland and nearshore systems to determine their role in maintaining the integrity and sustainability of fish communities in the Lakes and the factors which constrain the community composition and processes of these ecosystems. The results of this research should provide a foundation for the development of scientifically sound indicators of ecological condition. The impact of forestry practices and the extent and location of wetlands within the surrounding watersheds on the water quality and fish community structure of tributaries are being investigated in an array of watersheds in the Lake Superior basin.

5.5.3 Anticipated Products

- **By 1998**, develop a screening level mass balance model for atrazine in Lake Michigan.
- **By 1999**, develop a screening level mass balance model for mercury in Lake Michigan.
- **By 1999**, publish a report on bioaccumulation factors from water and sediments for selected chemicals.
- **By 2000**, publish a report on influences of landscape characteristics and in-stream habitat on fish communities.
- **By 2000**, publish a report on the factors influencing ecological processes in coastal wetlands.
- **By 2000**, publish a report on relationships between near shore benthic processes and forage fish populations.
- **By 2002**, develop a mass balance framework for PCBs in Lake Michigan.

5.6 Gulf of Mexico Research

The Gulf of Mexico and its coastal watersheds are collectively a complex ecosystem that is being adversely impacted from human activities in both the Gulf and its watersheds. Its coastal wetlands serve as essential habitat for migrating waterfowl and its estuaries serve as a nursery for commercial and recreational fisheries. Millions of people depend upon the Gulf of Mexico to earn a living; millions more flock to its shores and waters for recreation and the region is showing the symptoms of a stressed ecosystem including:

- Fish kills and toxic algal blooms are an increasing problem.
- Hypoxia is a growing problem.
- Over half of the shellfish-producing areas are permanently or conditionally closed.
- Valuable coastal wetlands are being lost at alarming rates.
- Fisheries are being threatened by both pollution and over-exploitation.

Public concern about these problems prompted creation of the Gulf of Mexico Program (GMP). GMP, as a multi-agency effort, is working with federal agencies, the Gulf states, citizens, and private sector to protect, conserve and preserve the ecosystem. The environmental issues have been characterized and GMP is now focusing its limited resources to address specific problems that have emerged.

5.6.1 Research Direction

The current research will focus on nutrient enrichment, public health, critical habitat, and introduction of non-indigenous species. The research for the first issue will focus on understanding the impacts of nutrient enrichment on the coastal ecosystem, specifically its relationship to problems such as coastal algal blooms and a very large zone of hypoxia (dissolved oxygen concentrations of less than two parts per million) along the Louisiana coast. The public health research focus will be on monitoring approaches to identify shellfish habitat and for characterization of the impact of human pathogens in coastal waters, especially recreational waters. The critical habitat research focus will be on identification of critical habitat and understanding human impacts on that habitat. Finally, the non-indigenous species research will concentrate on understanding the impact of introduction of non-indigenous species on important fisheries and critical habitat (e.g., shrimp virus from agriculture, biologicals from ship ballast, zebra mussel).

The ORD research activities will focus on:

- Characterization of ecological conditions in Gulf estuaries and coastal waters.
- Assessment of the threats of failed septic systems, overloaded sewage treatment facilities, and storm waters to public health as it relates to swimmable beaches and the viable production of the shellfish industry.
- Characterization of critical habitat in the Gulf ecosystem.
- Assessment of the causes and effects of hypoxia in coastal ecosystems and its relationship to nutrient enrichment in waters received from Gulf watersheds.
- Evaluation of landscape assessment and modeling approaches for understanding nutrient enrichment in Gulf watersheds.
- Characterization of the impact of non-indigenous species on the coastal ecosystem.
- Development of remote sensing approaches for monitoring algal blooms and condition of the coastal ecosystems.
- Determination of the natural and anthropogenic factors that lead to development of HABs in order to both control and forecast occurrence.
- Determination of the health and ecological effects of HABs and their toxins.
- Development of indicators of the condition of the coastal ecosystem.
- Development of an approach for an integrated coastal monitoring program.

5.6.2 Research Questions

- What are best measures or indicators of estuarine conditions?
- What are the causes and ecological or economic effects of the hypoxia zone along

the Louisiana coast? How is this hypoxia zone related to nutrient enrichment from the watershed and what and where are the sources of nutrients that cause the hypoxia?

- What do we model (and how) in the ecosystem to predict changes in nutrient loadings as a result of management actions to control nutrient enrichment?

- What is the best monitoring approach for tracking red tides and minimizing impacts on fisheries and public health?

- What can the overall incidence of aquatic mortality and the spatial/temporal scale of harmful algal blooms tell us about the condition of the Gulf ecosystem?

- What are the critical uses of habitat in the ecosystem and where are the critical habitats located? How much of each habitat is required to sustain a healthy aquatic system?

- How do we monitor and assess the impact of non-indigenous species on the ecosystem? What are the problems associated with exotic species in the Gulf ecosystem? What are the risks associated with these problems? What actions should be taken to reduce the risks?

- How do we integrate state and local monitoring data to assess the overall condition of the Gulf ecosystem?

5.6.3 Anticipated Products

- **By 1998,** publish the Region 6 Regional Applied Research Effort (RARE) Project report on evaluation of a landscape assessment approach to help characterize and model the impact of land use/cover on water quality of a low-relief watershed, part of a collaborative project in the Tensas River Basin of Louisiana.

- **By 1999,** as a participant in a coordinated effort through the Committee on Environment and Natural Resources, provide an integrated scientific assessment of the state of knowledge of the extent, characteristics, causes, and effects (both ecological and economic), of hypoxia in the northern Gulf of Mexico.

- **By 1999,** publish a report on a collaborative project among Texas A & M University, Naval Research Laboratory, USGS, and the GMP on the use of stable isotopes for identification of the sources of nitrogenous nutrients and of oxygen demand in the Mississippi River System and in the hypoxic region of the Mississippi River plume in the Gulf of Mexico.

- **By 1999,** publish a report describing the effects of ten typical Gulf of Mexico wastewaters on sediment quality in the receiving water.

- **By 1999,** publish a report on microbiological and chemical methods to enumerate bacteria associated with roots and seagrasses endemic to the Gulf of Mexico.

- **By 2000,** complete the EMPACT Project report on a remote sensing approach for characterization of the spatial and temporal occurrence of algal blooms in estuaries within the New Orleans metropolitan area.

- **By 2000,** publish a report on first pilot in the development of an integrated coastal monitoring program for the Gulf of Mexico ecosystem.

- **By 2000,** publish a report on fish and contaminant indicators of condition of estuaries of the Gulf of Mexico.

- **By 2000,** publish a report on the state of the Gulf of Mexico Estuaries.

- **By 2000,** publish a report on spatial and temporal variation in periphyton biometrics for three urbanized estuaries in the Gulf of Mexico.

- **By 2000,** publish a report on effects of changing sea levels in the Gulf of Mexico and southeastern United States on condition and distribution of benthic communities.

- **By 2000,** complete the merged GIS aquatic mortality database for five Gulf of Mexico states for interpretation and public access.

- **By 2000,** (EMPACT Project) complete the report of data and an assessment of the conditions of the immediately accessible waters along the public bathing beaches of the state of Mississippi and within the Bay of St. Louis.

- **By 2001,** publish a report on identification of sensitive benthic species to determine sediment toxicity in the Gulf of Mexico.

- **By 2001,** publish a report on comparative phytotoxicity of contaminated sediments collected from urbanized bayous of the Gulf of Mexico.

5.7 Near Laboratory Ecological Research Areas Research

The ORD has selected case study sites (Figure 5-3; see also Section 3.4.2.1) and field laboratories as another way for Divisions and Centers to work together at field sites close to their physical location. Under this new "Near Laboratory Ecological Research Area" (NLERA) Program, ecological scientists from four ORD facilities (Research Triangle Park, Cincinnati, Las Vegas, and Athens) have each selected a nearby watershed (shown in Figure 5-3) to serve as a focal point for their respective ecological field research.

NLERAs will provide a field research area that is well characterized (e.g., in terms of geology, physiography, hydrology, and ecology) and, at the same time, is near enough to facilitate cost-effective logistics for field-based efforts in ecosystem research. Under this concept, each NLERA becomes a platform from which the respective facility can stage field-based ecological research projects for their specific research missions (e.g., method/indicator development, model development/verification, development of, and ground-truthing activities for, various remotely sensed data sets), or other activities that are part of the core research programs. In the course of conducting their own field research, the Divisions will participate in ongoing efforts to find solutions to the recognized problems in these watersheds by collaborating with other watershed researchers from all governmental, academic, and corporate organizations. Collaborative arrangements will help leverage resources and to provide more comprehensive approaches to dealing with watershed problems on a basin-wide scale.

Having enhanced data sets and information on the NLERA (e.g., the types, spatial distribution, and intensity of the key stressor elements and receptors) a priori, will facilitate planning efforts for field research efforts for ecologists as the considerable amount of time routinely utilized in the collection of site description and background information can be focused directly on the planning of experimentation. Having a pre-described field site will likely encourage intra-Division/Laboratory/Center cooperation by providing investigators from disparate disciplines with a geographic focus, exposing the advantages of collaborative efforts. In addition, at least four NLERA, representing distinct ecosystems, will be developed. Thus the approach offers an opportunity for ORD scientists to more easily examine the applicability (or robustness) of methods or models developed in one ecosystem to another dissimilar system.

The four NLERA sites are:

1. Shoal Creek (Savannah River) Watershed in South Carolina and Georgia; Ecosystems Research Division, Athens, Georgia.
2. Lower Colorado River Watershed in Nevada, California, Arizona, Utah, and New Mexico; Characterization Division, Las Vegas, Nevada.
3. Little Miami River Watershed in Ohio; Ecological Exposure Research Division, Cincinnati, Ohio.
4. Neuse River Watershed in North Carolina, Air Measurements Research Division, Research Triangle Park, North Carolina.

5.7.1 Research Direction

The specific NLERA research projects proposed by the various Divisions (and the constellation of other federal and local collaborating agencies) and the important ecological problems vary across the four watersheds. However, in each case the research is in collaboration with the existing combination of local, state, and federal agencies. The research will compile existing data in order to characterize, over space and time and on a basin-wide scale, the existing resources and identify the most important environmental stressor elements. The spatial and temporal overlapping of stressors and resources are assumed to represent points of ecosystem vulnerability to impacts, either on water quality, on biological integrity, or on both. As an example of this process, USGS is conducting, through its National Water Quality Assessment Program, a detailed analysis of the physiography, hydrology, and water quality, as well as those human and natural processes effecting them, in the Little Miami River (Ohio) watershed. Similarly, the Ohio Environmental Protection Agency will conduct detailed surveys of the biological resources and stream habitat in the watershed as part of its on-going water quality monitoring program. Finally, the various municipal water treatment facilities (POTWs) in the Little Miami area have funded a study at the University of Cincinnati to characterize the nutrient budgets as a function of source, season, climate, and, location over the watershed. Under NLERA, ORD will work with these organizations in planning complementary research:

1. Developing methods for assessing the quality and quantity of riparian vegetation at a watershed scale.

2. Elucidating critical features of that vegetation which most effectively ameliorate non-point source stressor impacts (e.g., nutrients) and its role in the carbon cycling.

3. Determining approaches to evaluate the effectiveness of efforts at restoration of stream and riparian areas.

By providing linkages between riparian resources and biological integrity/water quality, the role of the riparian zone can be documented, and its rational use in watershed restoration can be suggested.

5.7.2 Research Questions

The scientific questions being asked differ at each of the four NLERA watersheds. However, a set of generic scientific questions being applied at each site include:

- Can gaps, disparities, and uncertainties in existing ecological data bases be identified?

- Where data are found to be inadequate, can new, improved indicators of watershed condition be developed to address the deficiencies?

- Can innovative approaches to the utilization of these data sets be employed to identify and display the vulnerabilities of indigenous ecosystems?

- Can these new data and displays be utilized in next-generation, multimedia models which permit the extensions of trends over time and space?

- Can these models be utilized to rank the various development and/or remedial options to assure that the watershed attains the stakeholders goals?

Figure 5-3.
Near Laboratory Ecological Research Areas and Index Sites

5.7.3 Anticipated Products

Due to the nature of the site (i.e., as field laboratories) the products are generally listed elsewhere.

5.8 Index Sites Research

The development and demonstration of the utility of a network of intensively monitored index sites is one of the four major components of EPA's next phase of EMAP. A review by the National Research Council suggested that the EMAP approach could benefit from the strategic placement of long-term monitoring sites that were intensively monitored to establish linkages between observed changes in environmental stressors and concomitant changes in ecological resources. This approach was incorporated into EMAP-Phase II planning in 1994 and resulted in the establishment of an Interagency agreement with the National Park Service/Air Resources Division (NPS/ARD) to establish DISPro (Demonstration Intensive Site Project) in 1996.

DISPro has three objectives:

1. To develop a sound scientific basis for understanding ecological responses to anthropogenic stresses including the interaction of exposure, environment/climate, and biological/ecological factors in the response, and the spatial and temporal nature of these interactions.
2. To demonstrate the usefulness of a set of intensively monitored sites for examining short-term variability in long-term trend behavior in the relationships between changes in environmental stressors, including anthropogenic and natural stresses, and ecological response.
3. To provide intensively monitored sites for development and evaluation of indicators of change in terrestrial systems.

5.8.1 Research Direction

DISPro has been developed as a network of long-term trend monitoring sites where research would be supported to examine the interactions of environmental stressors, climate factors, and environmental effects in a well characterized field setting. The research will focus on ecological effects of air or water pollution known or determined for the sites (i.e., specific relationships between stressors and effects), as well as the broader regional- and national-scale ecological effects research issues (e.g., air deposition patterns and their effects of terrestrial/aquatic ecosystems), and indicators of change/condition in natural resources. Indicators are measures that effectively integrate the environmental condition and response.

The index sites were not selected as representative of national trends in ecological behavior, but rather the sites could be used as a network of "outdoor laboratories" to examine realistically relationships between changes in environmental stressors and ecological response. Many of the DISPro parks offered gradients of environmental stressors (e.g., water and nutrient), and a few parks had demonstrated gradients of anthropogenic stressors (e.g., troporpheric ozone). In addition, the DISPro parks offered varied landscape factors that could be utilized in studying the spatial/temporal issues of environmental stresses.

The 14 National Parks included in the DISPro Intensive Site Network were selected because they are readily accessible, have a history of monitoring environmental stresses, represent a broad, sometimes unique, spectrum of ecological communities and landscapes across the U.S. The sites are listed here and their locations are shown in Figure 5-3.

1. Big Bend National Park, TX—arid and multiple elevations.
2. Everglades National Park, FL—tropical wetlands and lagoon coral reefs.
3. Virgin Islands National Park, VI—coral reefs, tropical estuaries, and tropical forests.
4. Sequoia National Park, CA multiple-elevation forests and unique species.
5. Rocky Mountain National Park, CO—high-elevation forests and lakes.
6. Great Smoky Mountains National Park, NC—multiple-elevation forests, lakes, and streams.
7. Shenandoah National Park, VA—multiple elevation forests, lakes, and streams.
8. Acadia National Park, ME—rocky fjord estuaries and northeastern coastlines.
9. Denali National Park, AK—arctic

ecosystems, high-elevation forests, glaciers, and tundra.

10. Olympic National Park, WA—Pacific Northwest, humid ecosystems, multiple-elevation forests and streams.

11. Glacier National Park, MT—high-elevation forests, lakes, and streams and glaciers.

12. Canyonlands National Park, UT—multiple elevations and arid ecosystems.

13. Theodore Roosevelt National Park, ND—grasslands.

14. Volcanoes National Park, HI—volcanoes.

Atmospheric monitoring at these sites includes tropospheric ozone, SO_2, NO_x, VOC, wet and dry deposition, visibility and (at some sites) UV-B (multiple bands), and meteorological data. EMAP, through DISPro, is examining whether a "network" of sites existing within the parks can be used to address monitoring issues for global-scale environmental stressors (e.g., air deposition) as well as locale-specific stressors (e.g., air deposition, water quality, toxics and pesticides) and coordinated with cause-effect, issue-based research related to these environmental stressors.

5.8.2 Research Questions

The research conducted in the parks will be accomplished by extramural scientists as well as NPS and EPA scientists and will be selected through a scientific peer review and agency relevancy review process. The selected research complements ongoing research programs in ORD laboratories and is consistent with the goals and objectives of the ecologically based monitoring programs in NPS's Air Resources Division. ORD's in-house program is focused on:

- Determination of ecological effects of anthropogenic pollutants such as tropospheric ozone and the effects of the elements of global climate change.
- Development of indicators of ecosystem integrity and sustainability.
- Development of an interrelated set of intensive monitoring/research sites to examine dose-response and stressor effects on ecosystem/community/population/organism function.
- Improvement of our ability to characterize environmental stressors and exposure.
- Establishment of extrapolative linkages between information at various spatial and temporal scales.

The NPS's research and monitoring strategy seeks to characterize the frequency, duration, and extent of air stressors within park boundaries and understand through interactive, interagency activities the relationships between changing air quality and ecological resources.

Extramural proposals were solicited through an RFA to do fundamental research on important scientific principles related to ecological response and/or exposure, and encouraged a diversity of research approaches in the following research areas:

- UV-B effects on aquatic and terrestrial systems. Ecological resources of most concern are coral ecosystems, near-coastal plankton communities and amphibian/reptile populations.
- Nitrogen effects on upland aquatic and terrestrial systems. Examination of the effects of air deposition of nitrogen on the biogeochemical cycles in forest, lakes, streams, and coastal waters.
- Tropospheric Ozone effects on terrestrial systems. This research would focus on the interaction of ozone and the natural and anthropogenic gradients within a park in affecting ecological resources. Examples of these gradients might be age-structure in forests, elevation gradients or precipitation gradients. Studies may be designed to address questions at population, community or landscape level.
- Problems of temporal and spatial variability in environmental measurements. This research would focus on assessing and quantifying gradients of environmental exposure in complex terrain within the selected parks. Characterization of the gradients and modeling the "exposure surfaces" for a park based on multiple sites will increase the ability to extrapolate stressor effects across a landscape or region. Important anthropogenic stressors include ozone concentrations, UV-B, deposition of contaminants and nutrients, and particulate air concentrations.

Important natural stressors include water availability, elevation, microclimates, frost zones and landscape aspect.

In addition to the solicited research, other ORD projects are planned for DISPro parks. These projects have been or will be peer reviewed before implementation:

- Development of a chemical monitoring protocol for toxic chemicals. Initial pilot studies will focus on all DISPro parks sampling top predator fish in selected streams within a park.
- Verification of General Ecosystem Model (GEM) parameterized for Oregon Cascade Forests in several western DISPro parks. This model provides a means to predict sensitivity or vulnerability of ecosystems to carbon dynamics, water, and nitrogen. Additional modules currently under development will add tropospheric ozone. This model is also being developed as a potential indicator for forests status.
- Spatial characterization of DISPro parks and integration of research results regarding spatial/temporal distribution of atmospheric stresses, landscape factors, distribution of experimental plots, and ecological response to stresses.
- Evaluation of amphibian survey techniques and statistical robustness of designs. This study will contribute directly to evaluation of possible amphibian monitoring as a measure of status and change in these parks, and to what extent this information can be extended beyond the parks. This is a project conducted by USGS through an Interagency Agreement (IAG) with the NPS. This project will be peer reviewed and reconciled before funding and implementation.

5.9 National Studies

Many of the policy questions that face EPA arise at the national level. They are questions that require decisions about prioritization of personnel and financial resources either geographically (e.g., what ecological resources or regions are at greatest risk) or by topic (e.g., are contaminated sediments of frequent enough occurrence to be a national, regional, or local concern). EPA currently produces several national assessments, the National Water Quality Inventory and Index of Watershed Indicators, which provide excellent frameworks for assessment but currently lack the environmental data to fully support and further develop them. With the advent of GPRA (see Section 1), the Agency has increased its attention on how best the Agency and various Program Offices can measure real environmental progress toward the goals that have been set. To do so in a cost effective and efficient manner will require a critical look at strategic monitoring within the Agency as a whole and, in some instances, a continuing shift from administrative measures of success (the number of permits issued, the number of pesticides registered, etc.) to measures that more directly evaluate the desired outcome (for example, improved fisheries, better water quality, cleaner air, healthy estuaries, productive bird populations). Currently, the Agency-wide Environmental Monitoring and Management Council (EMMC) has established a panel to address the question of the Agency's strategic monitoring needs as they relate to the GPRA goals and objectives.

ORD has been conducting research for the past several years on better measures of environmental quality and methods for monitoring at multiple scales as part of the core research program in monitoring. Most of this work has been, and continues to be, conducted through EMAP and one of its subcomponents, R-EMAP (the Regional Environmental Monitoring and Assessment Program). Most monitoring is not easily extrapolated (directly or indirectly) to provide information of known quality at multiple scales. The approach on how best to make national assessments of the environment remains a scientific as well as philosophical debate. The original intent of EMAP in 1990 was to conduct the research necessary to determine how to monitor the condition of the Nation's ecological resources (Messer, 1991). This goal has lead to a focused research program and, therefore, to significant advancements in cost effective, statistically based monitoring designs and measurements for forests, surface waters, wetlands, arid systems, and agricultural systems. These advances in the core program are now influencing the approach needed to solve some of the more immediate needs of the Agency, specifically at the national and regional scales.

5.9.1 Research Direction

Under the auspices of CENR, an interagency group was tasked to develop an improved framework for environmental monitoring and research in the U.S. The developed framework endorsed the original EMAP framework for monitoring developed by ORD (Messer, et al., 1991). The CENR is now conducting a regional pilot in the Mid-Atlantic to test the framework concepts. No agency, however, is conducting a national pilot of any of the framework elements, including the original EMAP framework.

Working with the Regions, the Program Offices, the states, and to the degree interested, other Agencies, ORD will continue studies on the development of effects and exposure measures and monitoring designs that best determine if ecosystems are degrading or improving nationally, and what rate and where. The goal over the next three to five years is to do field collection pilots at a national scale to evaluate the value added of the EMAP like framework in estuaries and streams for conducting national assessments. In addition, using remotely sensed data, studies will also include what can be done to improve watershed level assessments to allow an improved understanding of the influence of landscape changes as they affect water quality — one of the goals of the core program. Thus, this research has not only the Agency Program Offices as a customer but also ORD itself.

5.9.2 Research Questions

The scientific questions driving ORD's national pilots are the following:

- What are the best measures of the condition of ecological resources, regionally and nationally, for streams/rivers, estuaries, and landscapes/watersheds?

- What monitoring design will allow for these conditions to be estimated nationally and regionally with known confidence, and followed cost effectively for changes, and ultimately, detection of trends in the condition of these resources?

- How does one assess monitoring and survey information to define the relative extent of environmental hazards and the comparative risk of those hazards at both regional and national scales?

5.9.3 Anticipated Products

- **By 1999**, provide a draft of a State of the Nation's Estuaries Study.

- **By 2000**, complete a National Landcover map.

- **By 2000,** complete a State of the Nation's Estuaries report.

- **By 2001**, complete a National Landscape Atlas.

- **By 2002**, complete a State of the Nation's Streams and Rivers report.

SECTION 6

Planning and Management

> *The goals of the planning and management process will be to maintain ORD capabilities and to ensure that this limited capability and capacity is applied to projects that meet both ORD's Ecological Research Program goals and the highest priority needs of the regions and Program Offices.*

6.1 Introduction

In the last few years, both the capability and capacity of the laboratories and centers within ORD have declined as resources available directly to the laboratories and centers have shifted to grants. While the capability and capacity for the in-house program has changed only slightly, the ability to expand the capability and capacity by purchasing it through contracts has decreased significantly in the new organization. As a result, the Ecological Research Program has made a strategic decision to focus the in-house program on a limited number of research areas where it has the opportunity to be a scientific leader. These areas of primary interest are presented in Sections 3 and 4.

The challenge for the ecological research planning process is to maintain core capability or competencies and apply them to the greatest environmental threats, to meet the needs of the customers, and to continue to maintain a perspective on future environmental issues that have yet to become immediate threats or customer concerns. To this end, the first step in the process has been to concentrate on a common goal for the core Ecological Research Program. That is, the core program will be designed to:

> *"…measure, model, maintain and/or restore ecosystem sustainability at multiple scales, as influenced by multiple stressors acting alone and in combination, and with consideration of both multiple receptors and endpoints."*

Consequently, ORD ideally will undertake those projects that meet the following criteria:

- The project is related to improving the ability to measure, model, and restore ecosystem sustainability.
- The project reduces uncertainty in a high-priority environmental problem area.
- The project is consistent with a short- or long-term need of the customer office.
- The project allows ORD to maintain a compact core competency and to look ahead to future needs.

Not everything that needs to be done will fit the planning paradigm described above. Those research projects that are consistent with ORD's unique capabilities but do not meet all of the above criteria will be considered "special projects." The fewer there are of such projects, the stronger the research program is expected to be. This overall concept might best be understood diagrammatically as shown in Figure 6-1. For the planning process to be successful, ORD and the customer offices will need to seek areas of common interest.

Because much of the research needed by Program will come from those outside ORD, the Program will maintain a close interaction with both the grants program and those outside EPA who are interested in similar research. Coordination between the grants program and the in-house research is done in several ways:

- Topics are selected to complement ORD's in-house research to expand either capability or capacity.
- All grantees attend at least one meeting conducted annually by ORD to bring in-house

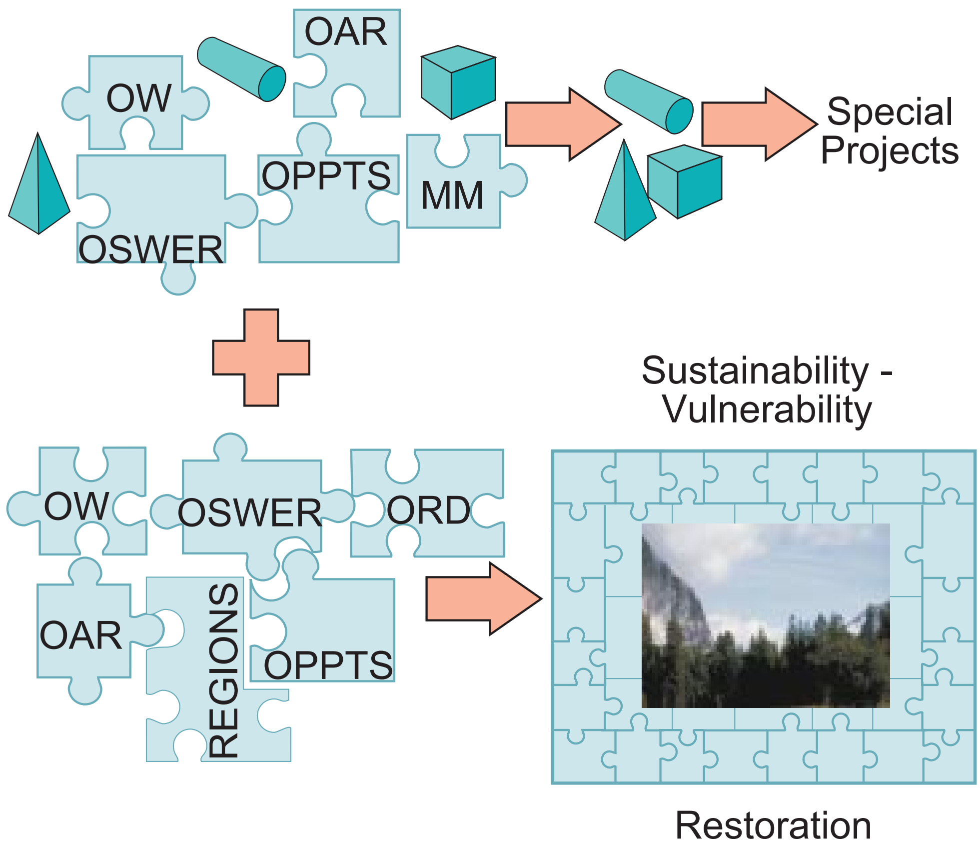

Figure 6-1.
Ecological Research Program planning strategy.

scientists and grantees together. These meetings are often set up at ORD Laboratories or national meetings.

- ORD scientists are provided annually with a list of awards and are encouraged to interact with those investigators of common interest.
- Should a true cooperative program between ORD scientists and grantees develop, mechanisms are in place for a principal investigator to convert a grant to a cooperative agreement.

6.2 Coordination and Management

The research program is organized with consideration given to the need for core research, new scientific challenges, and Program Office needs (Table 6-1). In addition, there are several opportunities for coordination across laboratories and centers in the Ecological Research Program. These opportunities include a common core research theme, common (limited) high priority research topics, and common locations. Through active planning and these three natural coordination elements, the interaction among laboratories and centers has been significantly improved. In addition, the common research issues and locational research facilitates interactions between ORD, the Program Offices, the Regions, and many local stakeholders.

Management of the Program is by laboratory and center. The Associate Directors for Ecology Research work as a team, meeting four times a year to discuss current research, new directions, and common needs. The largest, most fully integrated study, a test for the joint planning process and the research goals will be in the Mid-Atlantic Region (see Section 5.2).

Table 6-1.
Elements to be considered in the development of the Ecological Research Program

Core Research Area	New Ecological Research Challenges	High-Priority Ecological Research Issues	Common Interests Across Laboratories and Centers
Monitoring and Monitoring Research	Multiple Stressors	Acid Deposition Ozone Mercury UVB	Common Core Strategy
Processes and Modeling Research	Multiple Receptors and Endpoints	Nitrogen Global Change Contaminated Sediments	Common High Priority Research Areas
Risk Assessment Research	Multiple Media	Wet Weather flows Toxic Algal Blooms Eco-Criteria	
Risk Management and Risk Restoration Research	Multiple Scales	Total Maximum Daily Loading Endocrine Disruptors Pesticides Landcover Change	Common Locations

6.3 The Mid-Atlantic Integrated Assessment

Among the challenges facing ORD's ecological program is the demonstration that its research does in fact provide the scientific underpinnings for ecological risk assessments and relevant risk management decisions. This challenge suggests that a test of ORD's Program is to select a region of the country, conduct the monitoring and modeling activities necessary, produce a regional comparative risk assessment, and engage the regional managers in relevant risk management decisions. The Mid-Atlantic Region of the United States has been chosen by ORD for this purpose. It encompasses the states within EPA Region 3 (Delaware, Maryland, District of Columbia, Pennsylvania, Virginia, and West Virginia) and portions of New York, New Jersey, and North Carolina necessary to provide coverage of the entire Chesapeake Bay, Delaware Bay, and much of Albemarle-Pamlico Sound watersheds. Region 3 and the encompassed states have been progressive in their application of comparative risk assessments in decision-making and in improvements to their approaches for monitoring and managing the environment, and they provide eager partners in this endeavor. Early EMAP studies provided extensive monitoring coverage and assessments for terrestrial and aquatic systems and landscapes and, thus, are a rich data source for assessment. The added concern for ORD's regional vulnerability activities, risk management research, and ecological assessments will significantly expand these efforts. Additionally, the Mid-Atlantic Region has become the pilot area for the CENR federal monitoring framework.

EPA managers in the Mid-Atlantic Region have adopted a comparative risk perspective for setting their priorities. To enhance their ability to effectively embrace comparative risk assessments, they are willing to try improved approaches to monitoring, including new designs and real indicators of environmental progress, which will lead to geographic targeting and prioritization of problems. There is also clearly an interest in enhancing the capability of modeling exposure to stressors and predicting alternative futures under multiple management scenarios. These interests and needs are consistent with the strategic direction of ORD's ecological research and provide fertile ground for testing the applicability of results.

ORD will bring to bear the best of its research from NERL, NHEERL, and NRMRL, as well as the work performed at NCEA and under the grants awarded under NCERQA. The intended outcome of ORD's research is:

- Improved monitoring and assessment of the conditions of estuaries, streams/rivers, wetlands, and landscapes within the Mid-Atlantic Region and analysis of the relative magnitude of existing stressors.
- Modeling of stressor profiles across the Region juxtaposed with the presence of potential receptors to evaluate the relative vulnerability in the Region to the prevailing stressors.
- Predictive modeling of alternative futures under multiple management options.
- Comparative risk assessment for ecological systems within the Mid-Atlantic Region.
- Priorities among risk management options.

Working across the ORD laboratories and centers and in conjunction with Region 3, the states and other federal agencies, ORD's research will be subjected to the litmus tests of relevancy and applicability in real-life situations. ORD and Region 3 have begun to plan this process to ensure that it meets the expectations of all participants.

The Mid-Atlantic Integrated Assessment (MAIA) must, however, be understood not as a snapshot of coordinated field studies by EPA, but rather as a sequence of long-term commitments which is guided by the ecological risk assessment process itself. Identifying the major environmental problems and vulnerabilities cannot proceed without some description of the condition of the resources throughout the Region. Describing the condition of resources in a meaningful way requires ecological indicators and monitoring designs specifically tailored to answer the assessment questions of the local, state and national resource managers, and to serve as performance measures in measuring environmental gains in the future. Developing assessment questions is part of problem formulation in ecological risk assessment which is heavily dependent on creating a forum for stakeholders and scientists to discuss goals and frame the scope of the regional problems. Forging stakeholder consensus on assessment questions generally requires local leadership.

Experience in the Mid-Atlantic pilot suggests that, after the initial problem formulation phase, about three years are needed to gather existing data on sources of stressors in the Region, establish the necessary land cover and geographic information, and make measurements of the biological conditions of the natural resources in the Region with an unbiased design. A significant part of the three-year pilot effort refines the ecological indicators used to measure the condition of resources and permits adjustment of the scales used to associate and integrate data. After the initial three-year effort to describe the condition of the Region, the Ecological Research Program will devote an additional three years to the synthesis of the data into a “state of the region” report, which includes a regional assessment of the vulnerabilities of natural resources to various stressors, associations of losses of biological integrity with possible stressors, and a ranking of the spatial extent of each resource is diminished by anthropogenic influences in the Region. These assessments, conducted with the Regional Office and all stakeholders, sets the stage for environmental protection and ecological restoration research in the Region.

6.4 Information Management

From a research perspective, there are six challenges facing ecologists in dealing with environmental issues at the regional and global scales addressed in this strategy. These are: (1) developing non-experimental methods to conduct large-scale research; (2) incorporating information from new data sources and other disciplines; (3) standardizing and controlling the quality of data; (4) developing new statistical tools; (5) integrating, synthesizing and modeling knowledge about ecological systems; and (6) incorporating humans and their activities explicitly into ecological studies (Brown, 1994). Broadly viewed, these challenges can be considered requirements that will influence significantly the development of ORD environmental information management systems needed to successfully implement the ecological strategy.

Historically, most environmental analyses have been small in spatial scale, relatively short in duration, and performed by small, collocated teams of investigators. Consequently, the practice of environmental information management has been geared largely to provide databases and systems commensurate with this scope of activity. However, as evidenced in this strategy, the discipline of environmental science is changing. Issues of increased scale, availability of large volumes of remotely sensed data augmenting the overwhelming volume of data from traditional sources, inadequacy of commercially available software packages designed to handle these types of data, and an increased emphasis on multiple investigator research, requiring shared access to data, are driving changes in the way environmental information is managed.

A fundamental objective of the information management activities needed to support the ecological research strategies outlined is to capture, preserve, and enhance the exchange of use of data and information within ORD, and between ORD, regional stakeholders, and the public. ORD's information management resources must also reflect the flow of information between organizational units within ORD and meet the needs of the primary generators and the secondary users of environmental data. Figure 2-3 provides insight on information flow and the mapping of information resource management related functions among NCEA, NHEERL, and NERL. However, no one system is expected to meet the needs of ORD scientists.

ORD management recognizes that environmental information resources (data sets, databases, models, documents) represent and should be managed as corporate resources. ORD data systems, policies, procedures, and guidelines need to support this concept. Managing the network of environmental information management systems, and the development of the appropriate policies, procedures and guidelines, is being coordinated by the ORD Science Information Management Coordination Board (SIMCorB). This board contains individuals representing each ORD laboratory and center and is responsible for coordinating information management activities within ORD, and coordinating activities identified in the implementation plan being prepared by SIMCorB as the follow-on step to the Information Management Component of the ORD Strategic Plan (EPA, 1997d).

The ecological associate directors of ORD have endorsed a coordinated effort to bring the data management of scientific data into a uniform system paradigm. Progress in support of a coherent strategy to manage ecological data within ORD is underway and is being coordinated by the members of SIMCorB. This strategy will concentrate on developing technical and management solutions to the challenges outlined above, focusing specifically on improving ORD's ability to share data resources and increase the inter-operability of component systems. In developing this strategy, SIMCorB will build upon the progress made with existing information management systems by identifying common user requirements reflected in those systems, and defining requirements that are not being met by currently available systems.

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Appendix A

Agency Goals/Objectives (OBJ)/Sub-Objectives (S-O) that Relate to ORD

As of August 20, 1998

Goal 1: Clean Air

GOAL 1– Clean Air: The air in every American community will be safe and healthy to breathe. In particular, children, the elderly, and people with respiratory ailments will be protected from health risks of breathing polluted air. Reducing air pollution will also protect the environment, resulting in many benefits, such as restoring life in damaged ecosystems and reducing health risks to those whose subsistence depends directly on those ecosystems.

OBJ 1 (OAR, ORD): By 2010, improve air quality for Americans living in areas that do not meet the National Ambient Air Quality Standard (NAAQS) for ozone and particulate matter (PM).

S-O 1.4 (ORD): By 2001, develop tropospheric ozone precursor measurements, modeling, source emissions, and control information to guide cost effective risk management options; and by 2003, produce health and ecological effects information for NAAQS related ozone risk assessments.

S-O 1.5 (ORD): By 2001, provide measurements, modeling, source emissions, and control information for PM by species and size to guide risk assessment and PM risk management; and by 2003, develop a biologically plausible, quantitative health risk model for particulate matter based on epidemiological, toxicological, and mechanistic studies.

OBJ 2 (OAR, ORD): By 2010, reduce air toxic emissions by 75 percent from 1993 levels to significantly reduce the risk Americans of cancer and other serious adverse health effects caused by airborne toxics.

S-O 2.1 (ORD): By 2002, characterize emissions and attendant risks associated with new fuels and fuel additives; and by 2003, identify key pollutants responsible for urban air toxics risks and develop regional-specific, cost effective risk management strategies.

Goal 2: Clean and Safe Water

GOAL 2– Clean and Safe Water: All Americans will have drinking water that is clean and safe to drink. Effective protection of America's rivers, lakes, wetlands, aquifers, and coastal and ocean waters will sustain fish, plants, and wildlife, as well as recreational, subsistence, and economic activities. Watersheds and their aquatic ecosystems will be restored and protected to improve human health, enhance water quality, reduce flooding, and provide habitat for wildlife.

OBJ 1 (OW, ORD): By 2005, protect public health so that 95% of the population served by community water systems will receive water that meets drinking water standards, consumption of contaminated fish and shellfish will be reduced, and exposure to microbial and other forms of contamination in waters used for recreation will be reduced.

S-O 1.7 (ORD): By 2003, provide a stronger scientific basis for future implementation of the Safe Drinking Water Act.

OBJ 2 (OW, ORD): By 2005, conserve and enhance the ecological health of the nation's (state, interstate, and tribal) waters and aquatic ecosystems -- rivers and streams, lakes, wetlands, estuaries, coastal areas, oceans, and ground waters -- so that 75 % of waters will support healthy aquatic communities.

S-O 2.3 (ORD): By 2003, provide means to identify, assess, and manage aquatic stressors, including contaminated sediments.

OBJ 3 (OW, ORD): By 2005, pollutant discharges from key point sources and nonpoint source runoff will be reduced by at least 20% from 1992 levels. Air deposition of key pollutants impacting water bodies will be reduced.

S-O 3.3 (ORD): By 2005, deliver decision support tools and alternative, less costly wet weather flow control technologies for use by local decision makers involved in community-based watershed management.

Goal 3: Safe Food

GOAL 3– Safe Food: The foods Americans eat will be free from unsafe pesticide residues. Children especially will be protected from the health threats posed by pesticide residues because they are among the most vulnerable groups in our society.

OBJ 2 (OPPTS, ORD): By 2005, use on food of current pesticides that do not meet the new statutory standard of "reasonable certainty of no harm" will be substantially eliminated.

S-O 2.4 (ORD): By 2005, provide problem-driven research results to support the new FQPA regulatory standard of “reasonable certainty of no harm” for pesticides used on food.

Goal 4: Preventing Pollution and Reducing Risk

GOAL 4 – Preventing Pollution and Reducing Risk in Communities, Homes, Workplaces and Ecosystems: Pollution prevention and risk management strategies aimed at cost-effectively eliminating, reducing, or minimizing emissions and contamination will result in cleaner and safer environments in which all Americans can reside, work and enjoy life. EPA will safeguard ecosystems and promote the health of natural communities that are integral to the quality of life in this nation.

OBJ 2 (OPPTS, ORD): By 2005, the number of young children with high levels of lead in their blood will be significantly reduced from the early 1990's.

OBJ 3 (OPPTS, ORD): By 2005, of the approximately 2,000 chemicals and 40 genetically engineered microorganisms expected to enter commerce each year, we will significantly increase the introduction by industry of safer or "greener" chemicals which will decrease the need for regulatory management by EPA.

S-O 3.4 (ORD): By 2008, provide the scientific basis for support of Agency efforts to ensure safe communities, homes, workplaces, and ecosystems: improved methods, models, measurements and tools will be developed for use in guidelines, protocols, and risk assessment/risk management strategies covering the full range of ecosystem stressors and protecting human health.

OBJ 4 (OAR, ORD): By 2005, fifteen million more Americans will live or work in homes, schools, or office buildings with healthier indoor air than in 1994.

S-O 4.2 (ORD): By 2005, produce technical reports, methods, models, and other scientific information to improve the understanding of the effects of indoor contaminants on human health, the concentrations of these contaminants in micro environments, their sources, and risk management options to reduce exposure.

Goal 5: Better Waste Management

GOAL 5 – Better Waste Management, Restoration of Contaminated Waste Sites, and Emergency Response: America's wastes will be stored, treated and disposed of in ways that prevent harm to people and to the natural environment. EPA will work to clean up previously polluted sites, restore them to uses appropriate for surrounding communities, and respond to and prevent waste-related or industrial accidents.

OBJ 1 (OSWER, OECA, ORD, OAR, OP): By 2005, EPA and its partners will reduce or control the risk to human health and the environment at over 375,000 contaminated Superfund, RCRA, UST and brownfield sites.

S-O 1.6 (ORD): By 2008, provide improved methods and dose-response models for estimating risks from complex mixtures contaminating soils and groundwater; provide improved methods for measuring, monitoring, and characterizing complex wastes in soils and ground water; and develop more cost-effective and reliable technologies for clean-up of contaminated soils, sediments, and ground water. Also, by 2008, demonstrate/verify, via Superfund Innovative Technology Evaluation (SITE) program, more cost-effective technologies for remediation and characterization of contaminated soils, sediments, and groundwater, and more cost-effective restoration/rehabilitation of ecosystems impacted by these sources.

OBJ 2 (OSWER, OECA, ORD, OAR): By 2005, over 282,000 facilities will be managed according to the practices that prevent releases to the environment, and EPA and its partners will have the capabilities to successfully respond to all known emergencies to reduce the risk to human health and the environment.

S-O 2.6 (ORD): By 2008, provide multimedia, multipathway exposure and risk models for estimating the risk from waste facilities; develop methods and models for predicting human exposures via indirect or non-inhalation pathways associated with waste facilities; and provide improved techniques to control or prevent releases during waste management.

Goal 6: Reduction of Global and Cross-Border Risks

GOAL 6 – Reduction of Global and Cross-Border Environmental Risks: The United States will lead other nations in successful, multilateral efforts to reduce significant risks to human health and ecosystems from climate change, stratospheric ozone depletion, and other hazards of international concern.

OBJ 2 (OAR, OP, ORD, OGC): By 2000 and beyond, U.S. greenhouse gas emissions will be reduced to levels consistent with international commitments agreed upon under the Framework Convention on Climate Change, building on initial efforts under the Climate Change Action Plan.

S-O 2.3 (ORD): By 2000 and beyond, ORD will provide the capability to assess ecological and associated human health vulnerability to climate-induced stressors at the regional scale and assess mitigation and adaptation strategies.

GOAL 7 – Expansion of Americans' Right to Know About their Environment: Easy access to a wealth of information about the state of their local environment will expand citizen involvement and give people tools to protect their families and their communities as they see fit. Increased information exchange between scientists, public health officials, businesses, citizens and all levels of government will foster greater knowledge about the environment and what can be done to protect it.

OBJ 3 (OA, ORD, OP): By 2005, EPA will meet or exceed the Agency's customer service standards in providing sound environmental information to federal, state, local, and tribal partners to enhance their ability to protect human health and the environment.

S-O 3.2 (ORD): By 2005, implement a system to deliver ORD research results, tools and databases, manuals, guidance, and technical information to internal and external users to assist in decision making; by 2007, implement system to deliver reliable, timely, and consistent environmental monitoring and measurement information to the public and communities.

Goal 8: Sound Science

GOAL 8 – Sound Science, Improved Understanding of Environmental Risk and Greater Innovation to Address Environmental Problems: EPA will develop and apply the best available science for addressing current and future environmental hazards, as well as new approaches toward improving environmental protection.

OBJ 1 (ORD): By 2008, provide the scientific understanding to measure, model, maintain, or restore, at multiple scales, the integrity and sustainability of ecosystems now and in the future - the primary focus will be on streams, rivers, and estuaries as assessment endpoints; specifically, fish and shellfish.

S-O 1.1 (ORD): By 2008, provide the scientific understanding to measure, model, maintain, or restore, at multiple scales, the integrity and sustainability of ecosystems now and in the future - the primary focus will be on streams, rivers, and estuaries as assessment endpoints; specifically, fish and shellfish.

OBJ 2 (ORD): Provide the scientific basis for responding to a wide range of environmentally-driven human health problems by developing methods, models, and data that have, by design, broad applicability.

S-O 2.1 (ORD): By 2008, reduce reliance on default human health risk assessment assumptions by providing mechanistically-based understanding of toxicity and susceptibilities, and models to account for exposure scenarios that differ in media, pathway, temporal dimensions and other complexities.

OBJ 3 (ORD): By 2008, establish capability and mechanisms within EPA to anticipate and identify environmental or other changes that may portend future risk, integrate futures planning into ongoing programs, and promote coordinated preparation for and response to change.

S-O 3.1 (ORD): Priority research areas include: by 2008, developing strategies for managing risks of exposures to endocrine disrupting chemicals, and, by 2005, developing a strong scientific basis for understanding the health and ecological effects of air pollution mixtures under the One Atmosphere program.

OBJ 4 (ORD): By 2006, develop and verify improved tools, methodologies, and technologies for modeling, measuring, characterizing, preventing, controlling, and cleaning up contaminants associated with high priority human health and environmental problems.

S-O 4.1 (ORD): By 2006, develop and verify improved tools, methodologies, and technologies for modeling, measuring, characterizing, preventing, controlling, and cleaning up contaminants associated with high priority human health and environmental problems.

OBJ 5 (ORD): Provide services and capabilities, including appropriate equipment, expertise, and intramural support necessary to enable ORD to research innovative approaches to current and future environmental problems and improve understanding of environmental risks.

Goal 9: A Credible Deterrent

GOAL 9 – A Credible Deterrent to Pollution and Greater Compliance with the Law: EPA will ensure full compliance with laws intended to protect public health and the environment.

Goal 10: Effective Management

GOAL 10 – Effective Management: EPA will establish a management infrastructure that will set and implement the highest quality standards for effective internal management and fiscal responsibility.