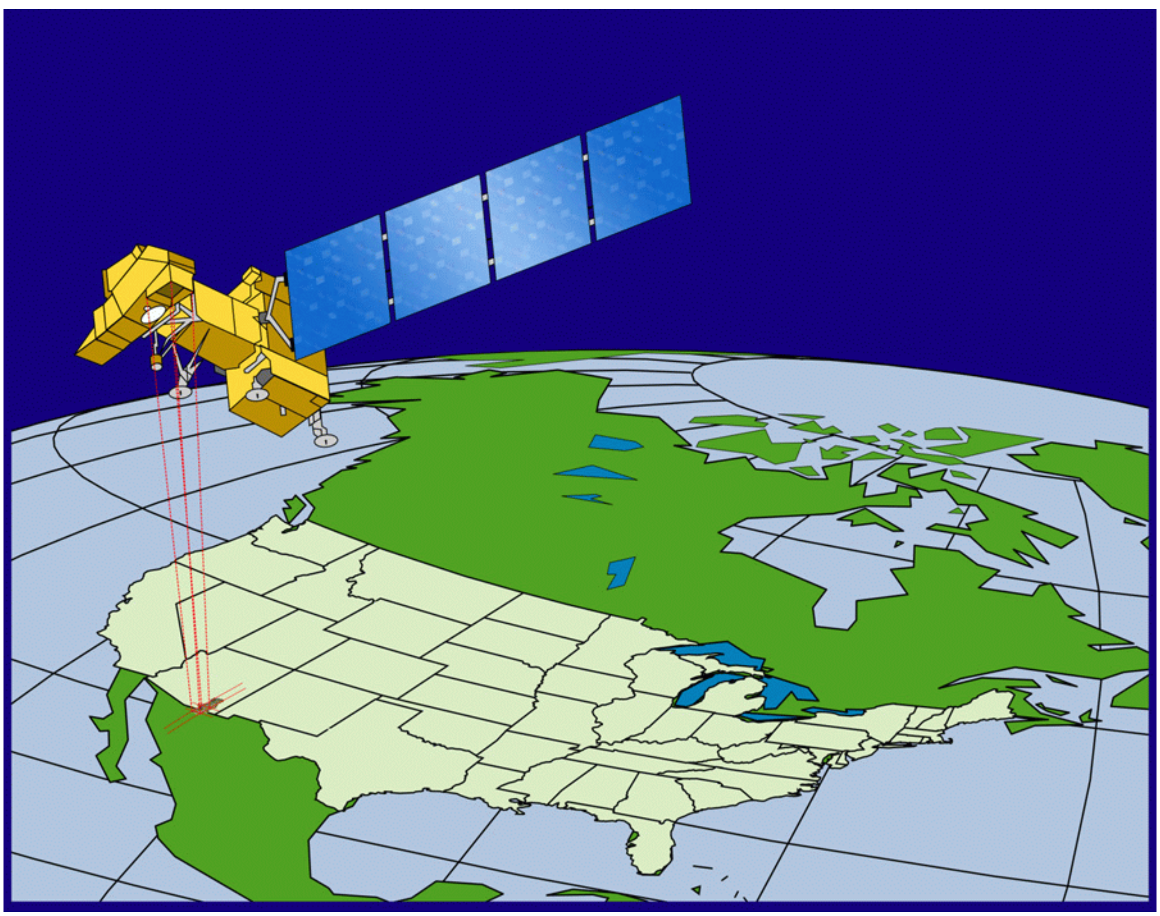
United States
Environmental Protection
Agency

Office of Research and
Development
Washington, D.C. 20460

EPA/600/R-00/001
January 2000

A National Assessment of Landscape Change and Impacts to Aquatic Resources

A 10-year Research Strategy for the Landscape Sciences Program



EPA/600/R-00/001
January 2000

A National Assessment of Landscape Change and Impacts to Aquatic Resources

A 10-year Strategic Plan for the Landscape Sciences Program

by

K. Bruce Jones[1]
Llewellyn R. Williams[1]
Ann M. Pitchford[1]
E. Terrence Slonecker[1]
James D. Wickham[1]
Robert V. O'Neill[2]
Donald Garofalo[1]
William G. Kepner[1]

[1] United States Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Environmental Sciences Division

[2] Oak Ridge National Laboratory
Oak Ridge, Tennessee

Interagency Agreement No. DW89938037

Notice

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development (ORD), partially funded and collaborated in the research described here. It has been peer reviewed by the EPA and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA for use.

Acknowledgements

We are grateful to the Megan H. Mehaffey, Deborah J. Chaloud, Donald W. Ebert, Maliha S. Nash, Anne C. Neale, Curtis M. Edmonds, Timothy G. Wade, Daniel T. Heggem, David F. Bradford, Nita G. Tallent-Halsell, George T. Flatman, Michael P. Bristow, Robert D. Schonbrod, Clayton E. Lake, Phillip A. Arberg, David B. Jennings, David J. Williams, Mary Lacerte, S. Taylor Jarnagin, Rick W. Kutz, Elizabeth R. Smith, and Ross Lunetta of our Landscape Sciences Program, Joe Walker of CSIRO-Australia, and Dennis Yankee and Roger Tankersley of the Tennessee Valley Authority for helping us establish the vision for a national landscape assessment. We thank Gil Veith, Steve Paulsen, Michael McDonald, Tom Barnwell, Jay Messer, Tom DeMoss, and Joel Scheraga of the EPA for their support of landscape research in EPA. We thank the EMAP Surface Waters, Near Coastal, and Information Management groups for providing numerous ideas and comments on landscape research over the years. We are grateful to Frank Golley (University of Georgia), Monica Turner (University of Wisconsin at Madison), Ingrid Burke (Colorado State University), Ed Martinko (Kansas University), John Jensen (University of South Carolina), Jingle Wu (Arizona State University), and John Lyon and Susan Norton (EPA) for review of this plan. We thank our colleagues June Thourmosguard, James Vogelmann, and Tom Loveland of the USGS EROS Data Center for making regional-scale, ecological assessments possible. Finally, we thank Rick Linthurst (EPA) for his unwavering support of the Landscape Sciences program, for none of what is proposed in this plan would have been possible without Rick's vision, leadership, and encouragement.

Table of Contents

List of Tables

List of Figures

Executive Summary

Introduction

This 10-year strategic plan (the Plan) describes the rationale and approach for research activities proposed by the Landscape Ecology and Landscape Characterization Branches (Landscape Sciences Program) of the National Exposure Research Laboratory (NERL). The 10-year goal of the Landscape Sciences Program is to conduct a national assessment of landscape change between the early 1970s and the early 2000s at relatively fine spatial scales (60-meter resolution) and to evaluate the consequences of observed change on aquatic resources, including streams and estuaries. An emphasis on aquatic resource endpoints is based on legislative mandates and the important role that the EPA plays in monitoring and protecting these resources. However, the research strategy recognizes the importance of the terrestrial characteristics and processes in determining the condition of aquatic resources; therefore, many of the indicators being developed by the Landscape Sciences Program are terrestrial-based.

Five priority research and development areas have been identified to achieve this 10-year goal: (1) acquisition and assembly of spatial databases on the environment that permit generation of landscape indicators (as defined by O'Neill et al. 1988, 1997; Jones et al. 1996; 1997) for four dates (early 1970s, mid-1980s, early 1990s, and early 2000s), (2) development of new remote sensing methods to improve the quality of spatial databases and to measure landscape indicators of stress (e.g., grazing, mining, urbanization, other land uses), (3) development of methods that permit an analysis of landscape change (Change Detection) based on different satellite sensors, including Landsat Multi-Spectral Scanner (Landsat MSS) and Landsat 4, 5, and 7 Thematic Mapper (Landsat TM) imagery, (4) development and selection of landscape indicators based on the degree to which they explain variability in aquatic resource conditions, and (5) development of landscape assessment approaches and watershed models that permit an analysis of multiple landscape indicators. The projects will yield information needed to understand how the activities of humans disturb the quality of our Nation's waters and the habitats they provide. The Plan describes the "landscapes approach" as we will apply it to better understand both the causes and consequences of landscape change.

The Plan is organized in six sections and leads the reader through the sequence of events from the identification of the research needs, the development of appropriate approaches, the gathering and analysis of the critical data to close information gaps, to the validated indicators, models, and databases that are the major research products of the Landscape Sciences Program. The objectives of the program are to: (1) develop new remote sensing data collection and processing techniques that measure the extent and magnitude of watershed-level stressors, including grazing, mining, and different agricultural practices, that will improve future landscape change estimates, (2) quantify relationships between measures of landscape attributes (landscape indicators) and parameters representing aquatic resource conditions, and determine of how these relationships vary within and among regions of the U.S., (3) compile a national comprehensive landscape-change database representing dates from the early 1970s, the mid 1980s, the early 1990s, and the early 2000s, and make these data available to the public on the Internet, (4) develop methods to analyze changes in landscape indicators between the early 1970s and the early 2000s and evaluate the consequences of observed change on our Nation's aquatic resources, (5) demonstrate how the landscape sciences can contribute to the assessment of the condition of our Nation's resources, and (6) provide tools and guidance to the Federal, State, and other resource managers and the public such that they may confidently apply landscape science techniques to ecological assessments in various regions of the country. The relationships of these outcomes to higher order goals and objectives of the EPA and Congress, and to specific environmental laws, are described in Appendix II.

Approach

Successful implementation of this Plan requires close coordination among three organizational units in the NERL: the Landscape Ecology Branch, in Las Vegas, Nevada, the Landscape Characterization Branch in Research Triangle Park, North Carolina, and the Environmental Photographic Interpretation Center, in Reston, Virginia. It also requires coordination with the Agency's Environmental Monitoring and Assessment (EMAP), Regional Vulnerability Assessment (ReVA), Global Change, and other EPA Programs. The Plan is designed to facilitate that coordination, to provide guidance to the staff involved, and to help Agency managers and the Congress understand our long-term research agenda and the resources needed to accomplish it.

The "landscape approach" (Jones et al. 1996, 1997, O'Neill et al. 1997) relies on the measurement of the spatial pattern of ecological characteristics relative to the condition of aquatic resources and associated processes. In this approach, metrics of spatial pattern are used as surrogates or indicators (landscape indicators) of aquatic resource conditions. Moreover, changes in landscape indicator values can be used to evaluate the consequences of landscape change on aquatic resources. However, we currently lack sufficient knowledge to interpret many of the landscape metrics with regards to aquatic resource conditions and, therefore, have emphasized this kind of research in the plan.

The Plan includes examples of how the approach can be used to address problems related to broad geographic areas (e.g., vulnerability of streams to nutrient inputs). Because certain data, such as those derived from satellites, can be composited over a large area, landscape analysis can be performed at different spatial levels such as states or parks, watersheds or ecoregions. Improved resolution of more recent data allows landscape indicators to identify both the nature and the location of problems. And the ability to use data that have already been gathered, often for very different purposes, can make the approach highly cost-effective. To implement such an approach nationally, however, requires the development of landscape indicators that capture important aspects of landscape change and an ability to relate the indicators to aquatic resource conditions.

Priority Research

We have focused our proposed research program on evaluating those aspects of landscape change that pose the greatest ecological risk to aquatic resources, including (1) hydrologic alteration, (2) habitat conversion, (3) turbidity/sedimentation, (4) habitat fragmentation, (5) pesticides, and (6) nutrients (EPA 1999). The resulting Program is consistent with an EPA NERL strategic goal, ". . . to facilitate environmental management and decision making by providing the scientific tools needed to estimate (and ultimately reduce) risks posed by exposures . . . [and] for protecting ecosystems at the complex levels at which ecological processes actually operate."

Implementing the Program involves a variety of research activities, focused in five broad and overarching areas summarized in Table 1. In addition to these five broad areas, the Program will also address three more focused research areas of high priority to the EPA: (1) methods to assess stream vulnerability to pesticides and toxic substances, (2) methods to target areas that are most like to have high values for Total Maximum Daily Loads (TMDLs), and (3) methods to evaluate status and trends of riparian ecosystems. A more complete listing of planned research activities -- with time lines and critical milestones over the 10-year life of the Plan -- is found in Appendix I.

Common to all the research and assessment activities will be a process to (1) understand stakeholder needs, (2) develop and test methods and approaches, (3) assess method performance for different geographic areas (including Agency priority study areas), (4) collaborate with other EPA and external organizations to integrate results across the major research areas, (5) highlight assumptions, critical steps, and interdependencies, (5) provide user-friendly products (indicators, models, guidelines, and assessments); (6) make data and information generated from the program readily available to participating scientists, clients, and the public, and (7) identify future research needs and opportunities. The Plan presents an extensive list of current and planned research collaborations that leverage limited resources to address this aggressive research agenda.

The success of this Program will be evaluated in terms of our ability to satisfy our various clients with useful, timely products and knowledge that enhance their ability to measure, monitor, and assess those changes in landscape level conditions that impact negatively upon the quality of our Nation's aquatic resources. Our clients include the Congress (annual measures under the Government Performance Results Act), other Agency programmatic and regional offices, other Federal and State staff, the external scientific community and the general public. Specific products are described in the Plan or are identified in Appendix I.

Section I
Purpose, Context, and Organization of this Plan

This Plan presents the rationale and a blueprint for those research activities to be conducted over the next 10 years by the Landscape Sciences Program of the U.S. EPA's National Exposure Research Laboratory (NERL) needed to achieve a national assessment of landscape change between the early 1970s and the early 2000s and to assess the consequences of those changes on aquatic resources. The Plan describes a strategic approach for implementing key research activities that will ultimately lead to the national assessment. It describes the linkage between our 10-year goal and the goals and objectives described in the Strategic Plan for the Office of Research and Development (ORD, EPA 1997) and the ORD's Ecological Research Strategy (EPA 1998a, see Appendix II), both of which embrace a focus on an ecological risk assessment paradigm and a shift away from "at the pipe" monitoring to more integrated, multiple scale environmental monitoring and assessment (EPA 1988, NRC 1997). It also reflects recent recommendations from a peer review of the Landscape Sciences Program (Golley et al. 1997). The Plan presents the goals, objectives, and priorities of the Program and projects the outputs and outcomes to be realized through successful completion of the research objectives outlined herein.

The Plan describes how multi-disciplinary research projects in five critical research areas will address critical gaps in the science and provide the tools (indicators, databases and models) and the process knowledge required to assess changes in landscape characteristics and properties that adversely affect the quality of our Nation's waters and the ecological habitats they provide. The Plan will define and explain the "landscapes approach" and how it can be applied to determine the status and trends in both ecological resources and the key components that alter those resources. The information that will be generated from research activities in this Plan will reduce future uncertainty in forecasting changes in our Nation's resources that result from the activities of humans.

The proposed research activities are placed in the context of the broader ecological risk assessment paradigm (Graham et al. 1991, Hunsaker et al. 1990, EPA 1998b) under which the ORD has organized its major ecological research goals and objectives (EPA 1998a). It is our belief that the science of landscape ecology and related disciplines are integral to the assessment of the vulnerability and sustainability of ecosystem processes and functions. The combination of landscape ecology with advanced technology such as remote sensing, geographic information systems, and computer science is widely recognized as an effective approach to assess the potential impacts of complex natural and anthropogenic forces on the structure and function of ecological resources at various temporal and geographical scales.

The Plan provides a rationale for the research areas selected based upon the 10-year project goal, national goals developed under the Government Performance Results Act (GPRA 1993), Agency priorities, and peer input from the scientific community. It is designed so that the reader can follow the logical sequence from recognition and prioritization of the research needs and information gaps to development of hypothesis-driven research approaches to the acquisition, processing, interpretation and reporting of the critical data required to close that gap or fill that need. Products developed in the process will be made available to both Agency users and the broader scientific community as tools for reducing the uncertainty of our future estimates and projections of the conditions of our ecological resources.

This plan is designed to serve multiple purposes. It will function as the principal guidance document for the staff of the Landscape Ecology and Landscape Characterization Branches in planning their specific research activities. It will help managers of the National Exposure Research Laboratory and of the ORD set resource priorities and identify opportunities for in-house collaboration. It will also help top Agency administrators and the Congress understand the long-term ecological research agenda and the resources required to accomplish that agenda. Finally, it will be made publicly available via the Internet to describe the nature, rationale, and direction of Agency research and to invite collaborative research efforts toward a common purpose. By providing information on how we plan and prioritize our research and by providing specific goals, objectives, products, and timetables, we also are providing yardsticks by which the progress of our research can be assessed by all of our stakeholders.

The plan will not include detailed descriptions of individual research components, such as sets of hypotheses to be tested, detailed study designs, and resources allocated to individual projects. Rather, those details will be included in individual research plans for specific projects (see Appendix I for a list of projects).

The Landscape Sciences Strategic Plan includes an executive summary, six sections, and three appendices:

- Section I introduces the Plan, its purpose, objectives, context, and organization;
- Section II introduces the need for regional- and national-scale landscape assessments, the overall goal and objectives of the Program, the Program's relationship to broader EPA goals and objectives, and the scope of the program;
- Section III identifies and describes the five priority research areas within the Program;
- Section IV provides detail on implementation strategies, program assumptions, project priorities, partnering with potential collaborators, a description of anticipated products, and a discussion of how the research activities relate to other current and anticipated initiatives;
- Section V describes the measures of success;
- Section VI provides a list of references cited in the Plan.

Section II
Introduction

A. Background

There is a growing interest among Federal agencies, States, and the public to evaluate environmental conditions at community, watershed, regional, and national scales. Numerous consortia have been formed to address broader-scale environmental problems. These include the Great Lakes Program, the Chesapeake Bay Program, the Gulf of Mexico Program, and the Grand Canyon Trust, to name a few. In some cases, interagency teams have been formed to evaluate status and trends in environmental conditions, e.g., the Pacific Northwest Initiative, the Interior Columbia Basin Assessment, and the Mid-Atlantic Integrated Assessment. Finally, the Committee on the Environment and Natural Resources (CENR), chaired by the Vice President of the United States, has initiated a national assessment of the environment.

Each of these multi-agency organizations is faced with the daunting task of acquiring and analyzing data that are of sufficient spatial and temporal similarity to permit regional and national scale assessments. Moreover, because most existing data have been collected by different agencies for different reasons, they are generally incompatible. Some agencies have established their own monitoring programs specifically to address regional and national scale issues. For example, the Environmental Monitoring and Assessment Program (EMAP) was designed to assess the status and trends of ecological resources at regional and national scales (Messer et al. 1991). But these programs are often limited to a specific set of questions and ecological resources (e.g., timber resources, impacts of agriculture, water quality of streams), and, therefore, they are not generally comparable.

The relatively high cost of collecting environmental data has limited the implementation of regional- and national-scale monitoring programs. However, a new set of land cover databases being developed by the Multi-resolution Land Characteristics Consortium (MRLC), a historical landscape database developed by the North American Landscape Characterization (NALC) Program, and development of landscape pattern indicators from spatial data (O'Neill et al. 1997), offers an unprecedented opportunity to assess ecological resource conditions at community, watershed, regional, and national scales over the next five to 10 years. In 1996, a regional-scale land cover database was developed for the five-state area of the United States Mid-Atlantic Region, and this database, along with other regional landscape coverages (e.g., topography, soils, road networks, stream networks, and human population density), was used to assess landscape conditions across the entire region down to a scale of 30 meters (Jones et al. 1997). The assessment used a set of landscape indicators (O'Neill et al. 1988, 1997) to evaluate the spatial patterns of human-induced stresses and the spatial arrangement of forest, forest-edge, and riparian habitats as they influence forest habitat suitability and aquatic resources. Advances in computer technology and geographic information systems (GIS) have made it possible to calculate landscape metrics over large areas (e.g., regions) at relatively fine scales.

Costs of spatial data derived from satellites and other sources are relatively low when compared to similar spatial coverages acquired from finer-scale monitoring studies. Additionally, spatial data lend themselves to analysis in a Geographic Information System or GIS (Ball 1994). Because certain data, such as those derived from satellites, can be combined (in a mosaic) for a large area, landscape analysis can be performed on different spatial units, including natural units such as watersheds and ecoregions and political units such as parks, counties, and states. This makes it possible to report landscape statistics at a number of scales for many different types of units and to determine cross-scale relationships between landscape composition and pattern, fundamental ecological processes, and ecological goods and services. Finally, because they can be generated from data that cover an entire region at scales as fine as 30 meters (as opposed to a sample that covers only a small portion of the total area in a region), landscape indicators can provide information both on the magnitude of problems and where the problems exist. As a result, this information can be used to develop multi-scale plans to reduce vulnerability or risk and prioritize activities to restore ecological function, condition, and sustainability.

Despite these new data and the development of landscape pattern indicators, the current state-of-science precludes a national assessment of landscape change and the consequences of observed change on aquatic resources. Significant scientific gaps exist in:

- our ability to detect and evaluate change in important stressors at watershed scales, including mining, urbanization, and agricultural land uses,
- our ability to detect landscape change between the early 1970s and the early 2000s using different types of remote sensing imagery (e.g., Landsat Multi-spectral Scanner (MSS) and Thematic Mapper (TM)),
- our knowledge of quantitative relationships between landscape metrics and aquatic resource condition parameters within and among regions, and
- our ability to assess consequences of landscape change based on multi-indicator data sets.

To eliminate the gaps in implementing a national landscape assessment, we propose research in each of these areas (see Section III).

B. Landscape Approach

The landscape monitoring and assessment approach involves the analysis of the spatial patterns of ecological characteristics such as soils, topography, climate, vegetation, land use, and drainage pathways as they relate to processes affecting ecological and hydrological conditions on areas ranging in size from small watersheds (a few hundred hectares) to entire basins (several million hectares) (Forman 1990, O'Neill et al. 1994, Kepner et al. 1995, Jones et al. 1997.). Landscape metrics can be used as indicators (landscape indicators) of the condition of ecological resources because changes in landscape pattern result in changes to ecological processes that sustain such resources (Turner 1989, Forman 1990, Figure 1). For example, losses of forested riparian habitats in a watershed reduce that watershed's ability to filter sediment from overland surface flows (Karr and Schlosser 1978, Lowrance et al. 1985, Peterjohn and Correll 1984). This results in reduced water quality in the streams of that watershed. Similarly, clear-cutting of forests on areas with steep slopes results in soil loss which in turn can decrease the likelihood of sustaining harvestable forests on those areas and can increase sediment loadings to streams (Lee 1989, Franklin 1992).

Five characteristics distinguish a landscape monitoring and assessment approach from most traditional field or site-based monitoring programs:

(1) it involves analysis of spatial patterns of ecological characteristics (e.g., forests near streams) to interpret ecological conditions,

(2) it applies the concept from the field of landscape ecology that changes in landscape patterns result in changes in fundamental ecological processes, including fluxes in energy, biota, materials and nutrients, and water,

(3) it applies the concept of ecological hierarchy theory that changes in landscape pattern and ecological processes at relatively broad scales (e.g., river basins) constrain and influence the condition of imbedded ecological resources (e.g., stream segments),

(4) it uses digital maps or coverages of biophysical (e.g., soils, vegetation, topography, and climate) and human use (e.g., land use, population distribution) characteristics to analyze and interpret landscape patterns relative to ecological condition, and

(5) it includes humans as part of the environment.

C. Goals and Objectives

The Landscapes Sciences Program seeks to establish landscape ecology and related disciplines as integral to the assessment of the condition, vulnerability and sustainability of ecosystem processes and functions. The 10-year goal of the Program is to assess landscape changes between the early 1970s and the early 2000s and to evaluate the consequences of observed change on aquatic resources nationally. The assessment of landscape change consequences is focused on aquatic resources because the EPA has a primary responsibility in assuring their protection and restoration. However, the landscape approach evaluates many aspects of the terrestrial environment because these attributes are intricately linked to ecological and hydrological processes that influence aquatic resource conditions, as predicted from ecological hierarchy theory (O'Neill et al. 1986). The objectives of the Program are to:

- Develop new remote sensing data collection and processing techniques that measure the extent and magnitude of watershed-level stressors, including grazing, mining, and different agricultural practices, and that will improve future landscape change estimates,

- Quantify relationships between measures of landscape attributes (landscape indicators) and parameters representing aquatic resource conditions, and determine how these relationships vary within and among regions of the U.S.,

- Compile a national comprehensive landscape-change database representing dates from the early 1970s, the mid 1980s, the early 1990s, and the early 2000s, and make it available to the public on the Internet,

- Develop methods to analyze changes in landscape indicators between the early 1970s and the early 2000s and evaluate the consequences of observed change on our Nation's aquatic resources,

- Demonstrate how the landscape sciences can contribute to the assessment of the condition of our Nation's resources, and

- Provide the tools and guidance to the Federal, State, other resource managers, and the public so that they may confidently apply landscape science techniques to ecological assessments in various regions of the country.

These goals are related to higher goals established by Congress, the EPA, and ORD. Appendix II relates various aspects of this Strategic Plan to higher-order agency and government objectives.

D. Scope of the Program

The 10-year goal of the Program is national in scope and ambitious. It seeks to provide an unprecedented assessment of landscape change across the US at scales relevant to environmental decision makers and the public. It builds upon ideas and concepts highlighted in the Program's 1994 National Research Plan (O'Neill et al. 1994) and the Mid-Atlantic Landscape Indicator Development Plan (Kepner et al. 1995).

At this time, we do not anticipate having the resources to assess landscape change across the State of Alaska between the early 1970s and the early 2000s. However, we will explore the possibility of assessing landscape change from the early 1980s to the early 2000s using data from the Advanced Very High Resolution Radiometer (AVHRR), which has a 1-kilometer resolution.

The Plan is the culmination of extensive efforts to define those areas of scientific uncertainty upon which the resources of this Program can have the greatest impact. The Program sought (and continues to seek) peer input from international leaders in ecological risk assessment and risk characterization in developing its proposed research agenda. The resulting Program is mainstream with respect to one of three long-term strategic goals of the National Exposure Research Laboratory, i.e., ". . . to facilitate environmental management and decision making by providing the scientific tools needed to estimate (and ultimately reduce) risks to ecosystems posed by exposures. . . . [and] for protecting ecosystems at the complex levels at which ecological processes actually operate."

Findings of a formal expert panel peer review of the Landscapes Sciences Program (Golley et al. 1997) helped to sharpen the research focus and to identify areas for disinvestment and areas for intensification. Recognition of key research thrust areas as Congressional priorities reinforced our confidence that the research program goals and products proposed are broadly supported, politically as well as scientifically. One such product, *A Landscape Atlas of the Mid-Atlantic Region*, released in 1997, received wide acclaim and provided additional support for the approaches proposed in this Plan.

Based on the overall goal of the Program (see previous discussion) and the current state-of-the-science (see later discussions), we identified five broad and three more specific areas of research as the foci of the Landscape Program. These are discussed in greater detail in Section III.

E. Statement of Capabilities

The Landscape Sciences Program consists of approximately 40 full-time scientists and technical experts that are assigned to two research branches in the Environmental Sciences Division: the Landscape Characterization Branch which is located at Research Triangle Park, North Carolina, and the Landscape Ecology Branch located at Las Vegas, Nevada, and Reston, Virginia. The Reston, Virginia office, also know as EPIC, is co-located with the USGS in its National Headquarters. Co-location with the USGS provides access to a number of USGS scientists working on national-scale assessments. The two branches have a wide range of scientific expertise including: (1) aquatic and terrestrial biology, (2) biochemistry, (3) biogeography, (4) quantitative ecology, (5) landscape ecology, (6) hydrology, (7) remote sensing applications, (8) remote sensing engineering, (9) geographic information systems, (10) atmospheric sciences, (11) multi-variate statistics, and (12) spatial statistics. The staff have produced numerous publications and have organized national and international symposia.

Scientists are supported by state-of-the-art computing, including multiple workstation, UNIX and NT networks, and a wide range of remote sensing, GIS, and modeling software. Basic remote sensing and GIS support also are provided through a contract. Four scientists have a Q security clearance, which permits them to access National Technical Means (NTM) data.

The Landscape Sciences Program collaborates with scientists from a number of other Federal agencies, including the USGS Earth Resources Observation System (EROS) Data Center, the DOE Oak Ridge National Laboratory, the USGS Biological Resources Division (two locations), the US Forest Service, the USDA Agricultural Research Service, the Tennessee Valley Authority, and the USGS Water Resources Division. Additionally, the Landscape Sciences program collaborates with scientists from other ORD Laboratories.

Section III
High Priority Research

We will focus our research and development in five general areas that currently prevent implementation of a national landscape change assessment (e.g., gaps in the science). These include (1) spatial data acquisition, assembly, and accuracy assessment, (2) development of new remote sensing methods, (3) landscape change detection, (4) quantification of the degree to which existing and new landscape indicators explain variation in aquatic resource conditions, and (5) development of multi-indicator assessment techniques. Progress in all of these research areas will be needed to implement and complete the national assessment. Additionally, we will evaluate landscape indicators and watershed models for their applicability to three other types of assessments of high priority to the EPA -- (1) estimates of pesticide and other toxic chemical risks to aquatic resources, (2) identification of aquatic resources at risk to high levels of nutrient and sediment loading (TMDLs), and (3) determination of status and trends of riparian ecosystems.

A. Spatial Data Acquisition, Assembly, and Accuracy Assessment

Spatial Data Acquisition and Assembly

At the core of a landscape approach to monitoring ecological status and trends is the basic need for quantifiable and consistent spatial data of biophysical characteristics (e.g., land use and land cover) on national, regional and local scales. These data permit the calculation of landscape indicators which we then intend to compare to aquatic resource conditions to build and execute spatially-distributed models over regional scales (see Sections D and E). Multiple date landscape data permit calculation of landscape indicators at different time intervals, and changes in these values can then be interpreted with regards to potential changes in aquatic resource conditions (see later discussion).

Land use and land cover data are most often derived from some type of overhead, remotely sensed imagery such as aerial photographs and digital, satellite, remote-sensing data. Various classifications of land use and land cover are derived from imagery based on manual interpretations or a variety of digital processing techniques, depending on the application. Remote sensing data and resources also provide valuable environmental monitoring services such as change detection, topographic analysis, various types of mapping, indicator development and analytical support to environmental regulatory programs.

This program will use existing and emerging remote sensing technology and resources as the primary source of data for landscape analyses. Therefore, the goal of this part of the program is to assemble a set of primary landscape data that permits an evaluation of landscape status and change nationally. The principal sources of remote sensing and spatial data needed for landscape assessments are listed below:

North American Landscape Characterization (NALC)

The NALC project is a cooperative effort between the National Aeronautics and Space Administration (NASA), the EPA, and the U.S. Geological Survey (USGS) to make historical satellite-imagery data available to the widest possible user community for scientific research and general public interest. The objectives of the NALC project are to (1) develop standardized remotely sensed data sets and standard analysis methods in support of investigations of changes in land cover, (2) to develop inventories of terrestrial carbon stocks, (3) to assess carbon cycling dynamics, and (4) to map terrestrial sources of greenhouse gas (CO, CO_2, CH_4, and N_2O) emissions. NALC is a component of the NASA Landsat Pathfinder Program used to study global change. The NALC database consists of Landsat MSS scenes from three decades (1970s, 80s, and 90s), referred to as a "Landsat Triplicate" and digital elevation model data. The goal is to produce these data sets for 536 Landsat World Reference System-2 path/row locations (scenes). Each scene is approximately 185 x 185 km (Lillesand and Kieffer 1994). Satellite data used in the NALC project include (whenever possible) Landsat MSS data from the years of 1973, 1986, and 1991, plus or minus one year. The Landsat MSS data is the principal source of satellite data used in the NALC program for several reasons, including the 20-year Landsat MSS digital data archive and the relatively low data costs as compared to other sources of satellite imagery.

The NALC represents an invaluable source of historical information on landscape condition and change because it provides low-cost, consistently processed, temporal Landsat data for major portions of North America. However, as much as 15% of the scenes from the early 1970s are of insufficient quality to produce reliable landscape indicator estimates. Therefore, a primary task is to replace poor quality scenes with higher quality scenes from the USGS's Earth Resources Observation System (EROS) Data Center archive.

A significant challenge to this project is the generation of high quality, land cover data from which landscape indicators can be generated for the early 1970s, the mid-1980s, and the early 1990s. NALC data acquired from EROS Data Center are spatially registered, and most of the triplicates are terrain corrected but are not classified into land cover. Additionally, each triplicate set (total of 536) comes in a separate file and, therefore, must be electronically joined or stitched together into a mosaic in order to analyze conditions across the region. A major task of this project will be to take the NALC data and produce digital land cover maps for the three periods. We will use historical aerial photography and NTM imagery (see discussion in Section B) to calibrate and assess the accuracy of the derived land cover databases. We will test the effectiveness and accuracy of our image classification through a series of small studies in different regions of the country. This approach is necessary because variations in climate, topography, and vegetation among the regions present different types of classification problems. For example, clouds and atmospheric haze in the eastern U.S. can make classification difficult, whereas low overall greenness, low soil moisture, and shadows (from high topographic relief) can make differentiation between desert land cover types challenging.

Multi-Resolution Land Characteristics Consortium (MRLC)

As a result of the increasing recognition of the need for current land cover data, several federal agencies formed the MRLC in 1995. The MRLC is a cooperative effort for the purpose of sharing the costs, data, and effort associated with the development of national land cover databases. The participating agencies include the EPA, USGS, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Department of Agriculture Forest Service (USFS). The goal of the consortium is to produce seamless, conterminous national land cover data using a consistent classification, and, to the extent possible, quantifiable accuracy assessments of that data.

The MRLC vision is to facilitate the development of a national, multi-resolution, land cover database from Landsat TM satellite imagery and field data.

MRLC is producing two data sets that will be major sources of data for our program. First, the MRLC has effected a common acquisition and preprocessing of Landsat TM data for the entire conterminous United States. This pre-processed data, all in the 1991-1994 time frame, is available to all participating agencies through the USGS EROS Data Center. Second, MRLC is now in the process of creating a consistent, national land cover data set from the 1991-94 Landsat TM imagery. Completion of the full national data set is scheduled for 1999.

The MRLC classification consists of 23 land cover classes, nationally (Table 2). This level of classifications should permit an analysis of the impact of general types of land use, including agriculture and urbanization, on aquatic resources within watersheds. However, other sources of imagery will be needed to evaluate the impact of specific agricultural and urban land uses on aquatic resources (see below).

The MRLC program is currently planning to repeat the national Landsat TM data purchase and land cover database development in the year 2000. Although still in the planning stage, this second collection of pre-processed satellite imagery and derived land cover data would represent a consistent and unprecedented national data set for multi-temporal landscape analysis for the early 1990s and the early 2000s.

Other Satellite Sensors

Data from other satellite systems will be acquired and analyzed on an individual project basis for landscape analyses of specific watersheds (e.g., Sections B and D) or for site-specific or technical-support projects. These data, along with aerial photography (see below) also will be used to identify the geographic distribution of more detailed features of the landscape that present potential risks to aquatic resources, including grazing and timber harvest, agricultural land uses, and urban land uses (e.g., golf courses), that the MRLC classification cannot identify. Numerous remote-sensing systems are currently available or planned for deployment in the near future that will provide additional spectral, spatial and temporal resolution data sets for landscape analysis.

Aerial Photographs

Archives of historical aerial photographs represent one of the most comprehensive sources of landscape information available. High-resolution aerial photographs from as early as the 1930's are routinely available for most parts of the United States and can be used for a variety of analytical purposes including change detection and landscape analysis. Such photos, because of their analog format and limited footprint of coverage, are best suited to smaller, site-specific types of analyses. They do, however, provide an excellent complement to broad-area satellite coverage and can be used as a source of data for calibration and quality control for satellite land cover data.

Large archives of aerial photographs are available from a variety of Federal, State, local and commercial sources including the U.S. Geological Survey, the U.S. Department of Agriculture, U.S. Forest Service, and the National Archives and Records Administration. Additionally, the Environmental Photographic Interpretation Center, a field station of the Environmental Sciences Division, has over twenty years of experience in aerial photographic applications and maintains a library of historical aerial photographic holdings.

The primary use of historical aerial photography will be to calibrate and perform accuracy assessments of digital land cover maps generated from NALC imagery (see below).

National Technical Means

The civilian agency use of data gathered by the U.S. intelligence infrastructure, termed "National Technical Means" (NTM), has long been recognized as a vital and proper use of nationally funded resources. Especially in terms of remote sensing technology (satellite and aircraft imaging), NTM data are inexpensive and of high technical quality compared to unclassified sources. The active use of classified information sources could provide the EPA with unique archives of environmental data and state-of-the-art scientific capabilities.

NTM collection systems have proven their utility in a wide variety of environmental applications. Projects completed to date include large-area site discovery and inventory, disaster monitoring, coordination and assessment of environmental emergencies, natural-resource inventories, pesticide-application activities, noise abatement and control as well as basic land use and land cover mapping. DOD remote sensing technology provides the civil Federal community with a variety of sensors that have great potential for fulfilling Agency needs for spatial information. Although these sensors are classified and cannot be discussed outside a classified arena, the derived cartographic output products derived from them are not; they have been used successfully on hundreds of occasions in many of the major research and development programs within the Agency.

The primary use of the NTM data will be to calibrate and conduct accuracy assessments of the digital land cover maps derived from NALC imagery (see below).

Other Spatial Data

In addition to land cover data, other spatial data will be necessary to calculate landscape indicators. These data will also be useful in improving the accuracy of NALC land cover maps and in evaluating the spatial pattern of error. We will acquire national spatial-data coverages as follows:

- digital elevation models (30-meter resolution) from the U.S. Geological Survey
- national stream networks (River Reach File 3) from the U.S. EPA
- soils (STATSGO and SSURGO) from the USDA Natural Resources Conservation Service
- human population or census data from the U.S. Department of Commerce
- road distribution and density data from the U.S. Geological Survey
- geology from the U.S. Geological Survey

In some cases, it may be necessary to construct regional mosaics of these data as the data are usually provided in geographic pieces.

Accuracy Assessment

Quantifiable information on the thematic and spatial accuracy of land use and land cover data derived from remotely sensed sources is required if these data are to be used to develop larger landscape metrics and relationships. The development of viable accuracy assessment data requires the comparison of the remote-sensing-derived land cover data with reference-test information, often referred to as ‘ground truth’ data (Jensen 1986). The reference-test data is usually developed with some of type of statistical sampling design and contains an inherent level of accuracy that is known and significantly higher than the remote-sensing-derived land cover data. Ideally, ground truth data is developed by actual field visits and *in-situ* sampling of the landscape and its attributes. However, in practice this is rarely accomplished because: (1) the field work is too time consuming and expensive, (2) field visits and sampling require prior landowner approvals, and (3) significant amounts of time often elapse between the date of imagery acquisition and the field work, creating temporal change inaccuracies in the reference data set.

Because of these problems, a priority research area will be the development and implementation of methods to document the accuracy of classified land cover and land characteristics databases, such as MRLC and NALC (see previous discussion). This will require the development of techniques that can quantify the accuracy and precision of derivative products such as land cover surface maps. Part of the research will focus on image classification techniques; it will involve the application of high-spatial-resolution stereo imagery that will be commercially available beginning in 1998 and historical imagery from aerial photographic and NTM archives. Other portions of this activity involve enhancement of the statistical rigor for determining uncertainty and the development of sampling designs and sampling techniques for determining accuracy of derivative classification products.

Accuracy assessments are included in the MRLC effort, and results will be made available as a standard MRLC product. However, since the NALC program does not include digital land cover maps, no accuracy assessment is available. We will use historical aerial photography to calibrate digital land cover maps produced from NALC imagery of the 1970s, 1980s, and 1990s. We will evaluate different accuracy-assessment sampling designs and test the application of historical imagery derived from aerial photography and NTM in the initial NALC study areas (see previous discussion).

We will use a range of methods for error evaluation in classified imagery, including (1) methods to assess the accuracy of individual date remote sensing classification maps and landscape indicators (Congalton and Green 1999), and (2) methods to assess the accuracy of change detection products (Khorram et al. 1999).

Advances in statistical ecology will be needed to take advantage of the new data sources and estimates of accuracy (Gardner and Turner 1991). For example, existing statistical methods are limited to dealing with data on a single spatial scale (Turner et al. 1991). Classification errors are more likely to occur at the edge, rather than the center of a patch.

We know little about how to incorporate such *a priori* knowledge into analyses and assessments (O’Neill et al. 1982). Holling (1992) has suggested that important impacts result simply from the disruption of the scaled structure of landscape patterns, but we have no sensitive methods to analyze those scales (Turner et al. 1991).

These, and similar statistical problems, may be the limiting factors in our ability to analyze and apply the new sources of data. We will evaluate the spatial pattern of error in classifying the land cover in each of the NALC study areas and develop statistical approaches to assist us in identifying such patterns.

B. New Remote Sensing Methods Development

The goals of this key research area are to: (1) enhance our interpretation of landscape change from the early 1970s to the early 2000s, (2) improve our ability to detect the spatial distribution and magnitude of stressors (e.g., surface mines and grazing) that cannot be readily detected by conventional remote sensing approaches, and (3) improve future landscape analyses through the use of new remote sensing imagery (e.g., Moderate Resolution Imaging Spectrometer (MODIS)).

The science of remote sensing is currently undergoing a revolution in terms of both technical capabilities and the number and quality of data sources. Advances in spatial and spectral resolution, new platforms and continually improving digital analysis techniques are creating significant new data sources for landscape-level analysis. Government remote-sensing programs, such as NASA's Earth Science Enterprise (ESE), are currently developing a wide range of aircraft and space-borne remote-sensing capabilities. In addition, recent commercialization of space-borne, remote-sensing has resulted in plans by the commercial sector to develop several high-resolution sensors that promise to provide global coverage at unprecedented levels of detail. Table 3 shows a partial list of relevant new sensors and capabilities that will be available in the near future. The new sensors may be especially important in estimating the magnitude and distribution of landscape-level stressors that go undetected by Landsat sensors; these include grazing, timber harvesting, mining, and certain agricultural activities (e.g., raising hogs and chickens). These sensors and data sources are likely to play a significant role in the future of the Landscape Sciences program, not only from the perspective of additional sources of data for the development of the current suite of landscape indicators, but also from the perspective of new scientific techniques that could enhance landscape analysis.

Data derived from these new sensors will not contribute directly to our national assessment of 30-years of landscape change. However, they may play an important role in identifying land use stresses on watersheds that affect landscape conditions observed during the early 2000s samples. Moreover, the new data will provide a higher resolution baseline from which future landscape change can be evaluated.

The following are brief summaries of (1) some of the major new capabilities and (2) research we plan to conduct.

Digital Photogrammetry

Photogrammetry is the science of extracting reliable measurements from imagery and, until recently, generally involved complex optical instruments and computationally intensive techniques. The basis for nearly all precision mapping, photogrammetry was once limited to aerial photographs acquired with precision mapping cameras. However, recently developed digital techniques can be applied to a wide range of imagery, including that from satellite systems, and can be used in a desktop computing environment. Products that may be relevant to landscape analysis include vegetation-height measurements, precision measurements of slope, volume, and fill, and the development of sub-meter digital elevation models. We will evaluate the application of digital photogrammetry in each of the NALC study areas.

High-Spatial-Resolution Satellite Remote Sensing

Several new sensors, such as IKONOS 2, which is scheduled for launch in 1999, will deliver global multispectral imagery at the 3-meter level of spatial resolution (1 meter panchromatic). This level of spatial detail is an order of magnitude better than previous satellite imaging capabilities and could be significant in the development of landscape indicators of land use stressors. We will evaluate whether this sensor can be applied effectively to estimate the spatial distribution of such land use stressors as mining, urban sprawl, hog and chicken operations, and specific cropping practices and the potential risks they pose to aquatic resources. For example, an improved estimate of the spatial distribution of crop types should improve our ability to estimate pesticide loadings to streams. Where possible, we will conduct these tests in areas already under study (e.g., NALC studies). However, it may be necessary to add additional study areas to evaluate certain stressors (e.g., grazing in the western U.S.).

Microwave Remote Sensing

Active microwave remote sensing, also known as radar, is available through a number of operational satellites such as RADARSAT, ERS-1 and the Shuttle Imaging Radar (SIR) experiments. These systems are active remote sensing instruments in that they operate independently of reflected electromagnetic energy and transmit their own microwave energy toward the earth's surface and record the reflected signal. For this reason, they have unique almost all-weather, day/night capabilities. Because of the special wavelength characteristics in this part of the EM spectrum, microwaves provide unique information about the landscape such as soil- and leaf-moisture content, the dielectric properties of materials, and the physical structure of the landscape. Also, microwave systems have been shown to increase land cover classification accuracy when merged with traditional Landsat data (Haack and Slonecker 1994), especially relative to wetlands that are covered by vegetation. Our primary goal will be to develop methods to improve our estimate of wetlands, especially in areas where wetlands lie under extensive canopy cover (e.g., the southeastern U.S.).

Thermal Infrared Remote Sensing

Although Thermal Infrared (TIR) remote sensing has existed for decades, new technological developments and systems will create the potential for a new range of environmental applications. TIR measures *emissive* energy in the 3-5 and 8-14 micron wavelength range and is generally related to the heat budget of surface phenomena.

Until recently, TIR data were acquired mainly by sophisticated aircraft-based sensors and/or satellite systems that collected data at spatial resolutions that were often inappropriate for landscape-level analysis. New sensors such as MODIS and Landsat 7 will deliver TIR data that can be used to add a thermal dimension to landscape classification and analysis, such as to determine the role of urban heat islands in ecosystems processes.

High Spectral Resolution Remote Sensing

The most promising new technology in environmental remote sensing is the development of hyperspectral and ultraspectral instruments and analytical techniques. Traditional multispectral systems, such as the Landsat Thematic Mapper, capture data in broad spectral bands selectively placed across the reflective spectrum. Hyper and ultra-spectral systems gather data in hundreds and thousands of discrete, narrow, contiguous bands.

As a result, landscape features can be analyzed using the same types of spectroscopic techniques that are traditionally used in chemistry and astronomy. Figure 2 show a graphic comparison of multi, hyper, and ultra-spectral data collection.

These spectral analysis techniques record the interaction of photons with material at the molecular level and return unique spectral 'fingerprints' of the material being sensed. Figure 3 shows hyperspectral fingerprints of various minerals, as acquired from the NASA Advanced Visible Infrared Imaging System (AVIRIS) instrument.

Spectral remote sensing has the potential to deliver critical new capabilities to the Landscape Sciences Program, such as vegetation species identification, air and water pollutant identification, and improved monitoring, e.g., of pesticide fate and transport. However, this technology is in its infancy, and significant research is required, especially in the area of environmental applications. We will evaluate the application of AVIRIS in the NALC study areas and in those areas selected indicator quantification studies (see later discussion). Emphasis will be given to detecting gradients of stressors as well as to improving land cover maps.

Another priority need is likely to fall in the area of cross-scale analysis. The new imagery will provide simultaneous measures on individual, population, community, ecosystem, watershed, and regional levels. Our ability to integrate this multi-scaled data is in a primitive state (Rastettler et al. 1991). Hierarchy theory (O'Neill et al. 1986) provides a general framework – it indicates that finer scale data can provide mechanisms, and coarser scale data can provide the constraints. But the theories need to be developed into practical techniques for routine analysis of multi-scaled data.

The most advanced thinking in cross-scale analysis has occurred in the national monitoring and the global-change programs. The EPA's Environmental Monitoring and Assessment Program developed a hexagonal spatial grid that facilitates the extrapolation of plot-scaled measurements to regional assessments in a statistically valid manner (Overton et al. 1990). The Global-modeling program has developed methods for extrapolating primary productions on individual plots to carbon exchange across a continent (King et al. 1989). But these efforts only scratch the surface of the problem (Risser 1987). New approaches will take advantage of the emerging vector and parallel processing computers (Casey and Jameson 1988) to link ecosystem models across a spatial grid (e.g., Running et al. 1989, Burke et al 1990). Further breakthroughs will be required to make most effective use of the multi-scaled data that the new sensing technologies will provide.

C. Change Detection

Identification, development and refinement of the means to detect change in landscape pattern and composition over time is central to the scientific objectives of this strategic plan. Landscape patterns, processes and trends are directly related to natural and anthropogenic uses of land and to the subsequent changes in those uses over time. Several key landscape indicators of ecological conditions, such as vegetation gain/loss, human landscape alteration patterns and forest fragmentation require assessment of changing landscape conditions (Jones et al 1997). Accurate delineation of landscape change is fundamental to landscape ecology in general and is required to fully understand the interface between dynamic biophysical and anthropogenic systems (Jensen 1986).

Detection of changes in landscape attributes involves the comparison of multi-temporal data sets to discriminate areas of land use or land cover change. This is generally accomplished by comparing thematic or spectral spatial data sets, usually in a GIS environment.

Landscape change is identified using the direct spatial comparison of either the thematic landscapes attributes, in the case of land cover data, by differences in reflected electromagnetic energy in the case of remote sensing data, or by the calculation and comparison of changes in landscape indicators derived independently from each time period. A critical issue relative to detecting change over the 30-year period is the comparability of imagery generated from the different sensors. The early to mid-1970s Landsat MSS data, the mid-to-late 1980s Landsat MSS data, the early 1990s Landsat TM data, and the early 2000s Landsat TM data represent different instruments that in some cases were or will be on platforms with different orbits and that have different band characteristics. Moreover, differences in data collection dates and within and among-year variations in climate will make comparisons across dates even more difficult. A major task of ours will be to develop and test approaches within and among regions so that landscape change can be accurately detected. We will focus our research on landscape change in the NALC study areas (see previous discussion).

There are several technical considerations that can affect the quality of landscape change estimates derived using these approaches, and they must be taken into account in planning change detection research (Lillesand and Kieffer 1994). These include the spatial, spectral, radiometric and temporal resolution of the remote sensing systems used. Several environmental considerations, such as growing season, atmospheric conditions, and tidal stage can also be critical. Major differences in any of these parameters can create erroneous positive or negative change estimates and generally result in very noisy data. Additionally, the majority of change detection research concentrates on relatively small, site-specific applications. Attempting to develop change detection data on regional or national scales becomes more complicated because of the need for temporally and spatially consistent data over large landscape units.

Change detection methods that overcome inherent spatial and temporal limitations of base data are needed. Potential new methods include data development from new and improved sensors, band differencing and ratioing techniques, data-set calibration by high-resolution sensors and statistical development techniques such as those demonstrated in Jones et al (1997), pages 67-71. Methods from Landscape Ecology must be adapted to distinguish natural changes, such as those related to fire (irregular edges set by topography, dry sites, fuel-rich stands), from those related to harvesting (straight edges, mature stands) or to development (straight edges, low topography) (Krummel et al. 1987).

As demonstrated by the contributions of percolation theory (Gardner et al. 1987), fractal theory (Milne 1988), and lacunarity theory (Plotnick et al. 1993), there is a need for land use change theory to produce neutral models (Dunn et al. 1991). The neutral model provides a “null hypothesis” that can then be tested statistically against the noisy change data (Gardner et al. 1989). This approach helps distinguish random errors from significant trends of change over a landscape or region.

Landscape change theory has largely developed in the field of economic geography where it predicts how to maximize utility by the spatial distribution of economic activities on the landscape (Sklar and Costanza 1991). Recent approaches have used Von Thunen theory to predict change as a function of distance to the nearest developing urban center (Wickham et al. 1999).

Additionally, we will evaluate a sampling strategy to assess changes in landscape indicators by ecoregion. An initial test of a landscape sampling design will be made in the mid-Atlantic Region.

This region possesses enough variability in land cover types and human uses of the landscape to test the sensitivity of the sampling design. Moreover, it will be the first region with wall-to-wall land cover change estimates from the early 1970s to the early 1990s. The goal is to see whether or not variability in landscape change can be reduced via a classification scheme and whether change can be estimated through a sample-based approach. Additional evaluation studies will likely be needed in topographically diverse areas of the western U.S. The sample-based approach is viewed as a viable back up to the wall-to-wall assessment proposed in this project, especially if wall-to-wall coverages of land cover data are not available.

D. Quantification of Landscape Indicators Relative to Condition of Aquatic Resources

Landscape indicators are defined as a measure, an index of measures, or a model that describes the condition of an ecosystem or one of its critical components (Hunsaker et al. 1990). An indicator may reflect biological, chemical or physical attributes of ecological condition. The primary uses of an indicator are to characterize current status and to track or predict significant change. A landscape indicator may also be used to identify major ecosystem stress (Jones et al. 1997).

As our primary goal is to evaluate landscape change and aquatic-resource conditions, our research will focus on landscape indicators that relate to changes in hydrological and ecological processes.

Assessing the consequences of landscape change on aquatic resources requires a thorough understanding of the degree to which aquatic resource conditions vary with landscape pattern. Hierarchy theory (O'Neill et al. 1986) suggests that individual stream segments, wetlands, and estuaries should be constrained by landscape composition and pattern within their watershed areas. A number of studies have shown the strong relationships of water quality, water quantity, and runoff to landscape characteristics. Water quality of streams, wetlands, and estuaries is dependent on the landscape's ability to collect and purify water. A decrease in natural vegetation indicates a potential for future water quality problems (Walker et al. 1993, Hunsaker and Levine 1995). Many studies have shown that the land uses within a watershed can account for much of the variability in stream water quality (Omernik 1987, Hunsaker et al. 1992, Charbonneau and Kondolf 1993, Roth et al. 1996). Agriculture on slopes greater than 3 percent, for example, increases the risk of erosion (Wischmeier and Smith 1978). Empirical studies have established the significant causal relationship between watershed characteristics and nutrient and sediment loads (Levine et al. 1993).

A drastic change in vegetation cover, such as clear cutting in the Pacific northwest, can produce 90% more runoff than in watersheds not altered by human practices (Franklin 1992). The linkage between intact riparian areas and high water quality is well established (Karr and Schlosser 1978, Lowrance et al. 1985). Riparian habitat functions as a "sponge," greatly reducing nutrient and sediment runoff into streams (Peterjohn and Correll 1984).

The percentage and location of natural land cover influences the amount of energy that is available to move water and materials (Hunsaker and Levine 1995). Forested watersheds dissipate energy associated with rainfall, whereas watersheds with bare ground and anthropogenic cover are less able to dissipate that energy (Franklin 1992). The percentage of the watershed surface that is impermeable, due to urban and road surfaces, also influences the volume of water that runs off and therefore the amount of sediment that can be moved (Arnold and Gibbons 1996). Watersheds with highly erodible soils tend to have greater potential for loss of soil to streams than watersheds with non-erodible soils.

Moreover, intense precipitation events may more easily exceed the reduced energy threshold and move large amounts of sediment across a degraded watershed (Junk et al. 1989, Sparks 1995). It is during such events that human-induced landscape changes have their greatest negative impact. The anoxia or hypoxia problem in the Gulf of Mexico results from extensive agriculture, loss of riparian zones, and channelization throughout the Mississippi River Basin that permits mass movements of sediment into the Gulf during extreme precipitation events, as witnessed in 1993 (Goolsby et al. 1999).

Growth of human populations often results in increasing water use and consumption. Historical responses to these needs have often been the construction of dams and diversion of water from streams and rivers. Dams create barriers to fish migration and often disrupt natural hydrological patterns resulting in fundamental changes in aquatic habitats. Dams, therefore, can decrease both the size and diversity of habitats and stream network connectivity. This, in turn, generally increases the likelihood that whole fish populations will be lost due to a combination of the higher extinction rates associated with smaller habitat sizes and the decreased probability of recolonization.

Differential responses of fish and benthic communities to landscape changes may reflect major differences in life histories between these two types of organisms (Schlosser 1990, Poff and Allan 1995). Because of larger home ranges and migrational requirements, fish populations may respond to changes over an entire network of streams, including barriers to migration, and to overall habitat suitability. Conversely, benthic populations are more likely to respond to landscape and habitat changes in local sites or individual stream segments. Research is needed to test this hypothesis.

Considerable progress has been made in the development and application of landscape indicators in measuring landscape conditions within watersheds that affect aquatic resources (Hunsaker and Levine 1995, Jones et al. 1996, 1997, O’Neill et al. 1997). These indicators include simple metrics generated from a single spatial database (e.g., the percentage of the watershed surface with crop land calculated from a land cover database), metrics generated by combining or overlaying spatial data (e.g., the proportion of stream miles in a watershed with forested riparian cover calculated by intersecting spatial coverages of streams and land cover), or metrics generated through the implementation of relatively simple, spatially distributed models (e.g., estimation of soil loss with models incorporating the Universal Soil Loss Equation). The following summarizes more recent advances in the application of landscape indicators:

1. quantification of landscape composition and pattern from remotely sensed and other spatial data (U.S. EPA 1994, Riitters et al. 1995, Jones et al. 1996, O’Neill et al. 1988, 1997),
2. (statistical independence of landscape metrics (Riitters et al. 1995),
3. influence of grain and pixel size in determining landscape composition and pattern (Wickham and Riitters 1995),
4. influence of sample and assessment-unit size on landscape-indicator performance (Hunsaker et al. 1994, Wickham and Riitters 1995, O’Neill et al. 1996),

5. scale relationships between landscape composition and pattern in different environmental settings (O'Neill et al. 1991, Rastetter et al. 1991),

6. sensitivity of landscape indicators to human-use gradients (Wickham et al. 1997a),

7. sensitivity of landscape indicators to misclassification of remotely sensed data (Wickham et al. 1997a),

8. relationships between environmental stressors and landscape pattern (Krummel et al. 1987, O'Neill et al. 1988, McIntyre 1995, Wickham et al. 1997b),

9. analysis of landscape indicators to assess relative watershed conditions at the regional scale (Jones et al. 1997, Wickham et al. 1999a and b),

10. relationships between landscape pattern and aquatic resources (Hunsaker et al. 1992, 1995, Charbonneau and Kondolf 1993, Walker et al. 1993, Poff and Allan 1995, Frenzel and Swanson 1996, Roth et al. 1996),

11. spatial GIS models (spatially distributed models) that relate landscape characteristics to: water balance (Storck et al. 1998), nutrient loadings to surface waters (Soranno et al. 1996,Young et al. 1996), erosion (Mitasova et al. 1996, Zhang et al. 1996), soil chemistry (Burke et al. 1990), and nitrogen mineralization (Fan et al. 1998) at watershed to regional scales,

12. biogeographic models that explicitly consider landscape composition and pattern (Wiens 1985, Wiens et al. 1993, 1997, Schumaker 1996, Riitters et al. 1997).

The outstanding progress in all of these research areas, new spatial databases covering large areas at relatively fine scales (e.g., 30 meters), and new computing capabilities make us optimistic that the remaining critical gaps can be filled in a timely manner. However, despite these advances, we lack a comprehensive understanding of how landscape pattern influences aquatic resources and associated processes. For example, although we are aware of landscape factors that influence water quality, recent papers (e.g., Roth et al. 1996, Weller et al. 1996) suggest that the importance of landscape features may change in different environmental settings, or when moving from one spatial scale to another. Differences in biophysical attributes of watersheds (e.g., size, gradient, precipitation, soils, geology) may explain why these studies had different results. Moreover, we lack knowledge of how these relationships vary among different regions of the country. For example, highly variable precipitation and topographical patterns make the western US hydrologically and ecologically distinctive from the eastern US, and these differences are likely to result in different spatial and temporal relationships between landscape conditions and aquatic resources. To fill some of these important gaps, our research will attempt to:

1. establish quantitative relationships between various indicators of landscape pattern and water quality, discharge, and biota in different biophysical settings (e.g., watershed size, gradient, geologic setting, climate regime);

2. determine how the importance of different landscape patterns in explaining water quality, discharge, and biological condition varies within and among different regions of the US; and

3. determine which stressors contribute most to observed landscape condition.

We propose to establish several paired watershed studies in regions of the country where relationships between landscape pattern and aquatic resources and associated ecological and hydrological processes are likely to be different. We will use existing spatial databases of landscape attributes and biophysical characteristics; national coverages of these data at relatively fine scales (30-60 meters) should be available within the next two to five years. We will use existing stream and estuary samples, primarily from the EMAP Surface Waters and USGS National Water Quality Assessment (NAWQA) programs, to evaluate nutrients, sedimentation, and indicators of stream biological conditions.

We will "pair" each set of aquatic and landscape indicator data related to the site's watershed area. Using a range of multi-variate statistics, we will determine which landscape indicators explain the greatest variability in aquatic site conditions.

From these results, we will develop empirical models to be used in the assessment process. In conducting these studies in different locations across the US, we will consider how different temporal and spatial scales of the data might affect our results. The results will also be critical in deciding which landscape indicators to use in the assessment process, in parameterizing watershed models to assess the consequences of landscape change on water resources, and in the development of landscape indices (statistical combination and weighting of landscape indicators).

E. Assessment Methods Research and Development

We have two primary assessment goals related to the project: (1) an assessment of how landscapes have changed from the early 1970s to the early 2000s across the U.S., and (2) an assessment of the consequences of observed change on aquatic resources based on quantification studies (see previous discussion). The primary objective of the assessment is to identify and prioritize those areas that have undergone changes in landscape pattern that are likely to pose significant risks to water quality and biota in streams and estuaries. The assessment will depend on progress made in all of the high priority research areas discussed in this plan, and will require close coordination between basic data gathering and processing, multi-watershed research, and implementation of the resulting products. To achieve the overall assessment objectives, project components must be carefully sequenced within each region (Figure 4).

One key issue in the assessment phase of this strategy is the selection of appropriate assessment units. We propose to use two general types of assessment units: (1) a watershed-level unit to identify and demonstrate those biophysical attributes that mediate the response of the aquatic resources to landscape change, and (2) a unit that relates to the aquatic resource itself (e.g., a stream segment or individual estuary). Research described in the previous sections should assist us in determining how aquatic resources respond to landscape indicators in different biophysical settings. The aim of this research will be to develop a watershed classification that characterizes different aquatic resource responses based on biophysical properties of the environment (e.g., watershed size, topography, climate; see Maxwell et al. 1995).

Another potential way to approach this problem is to report out on risks to individual stream segments and estuaries based on landscape indicator values for watershed or drainage areas for each of these aquatic resources. Instead of coding watershed risks based on landscape change, we would code the risk to each individual stream and estuary. To do so will require research and development in computer data analysis, including watershed-level applications of GIS, primarily because of the large number of watersheds and associated indicators that would have to be generated for each stream segment or estuary. An assessment of individual stream segments and estuaries is important because the EPA's Office of Water and individual Regional Offices need robust and systematic approaches to identify those water bodies that are most likely to exceed certain water quality standards.

Another key assessment issue is how to report results of multiple indicator sets relative to aquatic resource conditions. At least four approaches are possible:

1. report values for those landscape indicators that explain the highest proportion of variation in aquatic resource condition (based on quantification studies), but do not combine landscape indicators into an index;

2. apply multi-variate statistical approaches, such as cluster and principal components analyses, to determine those watersheds and individual aquatic resources at greatest risk (see Jones et al. 1997 and Wickham et al. 1999c);

3. develop empirical models from the quantification research (see previous section) that combine landscape indicator values into an index or relative risk characterization;

4. apply process models that utilize landscape indicators to estimate changes in specific aquatic variables (see Fan et al. 1998 and Storck et al. 1998 for examples).

It is likely that a combination of all four of these assessment approaches will be used. Again, results from the quantification studies should assist us in deciding which approaches to use. For example, we may find that one or two landscape indicators explain most of the variation in certain water quality parameters. In this case, we might want to report out on only these two landscape indicators without combining them into a multi-variate model.

Another important scientific gap in our ability to assess relative risk is the inability to deal with synergistic effects. One assessment of the mid-Atlantic States (Jones et al. 1997) used the relative magnitude of stressors: the greater the number and magnitude of stressors, the greater the relative risk. But this approach assumes that the stressors act independently (Hunsaker et al. 1990). What is needed is a mechanistic understanding of how the stressors interact to impact aquatic resources. This is a major research area, but every incremental improvement in our understanding can improve our ability to prioritize.

Risk assessment is basically a quantitative method (Barnthouse et al. 1982, O'Neill et al. 1982). The approach estimates the probability of an undesirable impact as a function of uncertainties in measurements (O'Neill et al. 1981), natural variability (O'Neill 1979), model assumptions (Bartell et al. 1983), etc. Although we can begin to rank impacts to water resources using qualitative approaches (Graham et al. 1991) ultimately, we must move to quantitative estimates of risk (Barnthouse et al. 1983). This is an important area of research, with long-term implications for our ability to manage the Nation's water resources.

A number of ecosystem and hydrologic models could be applied to prioritizing impacts. Unfortunately, few of these models have been tested across regional scales. As a result, we cannot confidently move the models across the full range of biophysical conditions in the Nation without first confirming their "transportability." Statistical models are largely limited to specific watersheds and, in general, cannot be applied to watersheds in different biophysical settings. Therefore, research is needed to determine the applicability of these models in assessing landscape change and its consequences on water resources.

Each of these assessment issues will be evaluated in geographic areas where other research activities have been initiated, including NALC, stressor gradient, and indicator quantification studies.

Section IV
Strategic Approach for Implementing Research and the National Assessment

Our strategic approach will be to implement research and assessment activities in a systematic manner within each region (see Figure 4). Significant progress in spatial data assembly and in key research areas is needed to complete a national landscape assessment. Our approach will be to implement the program on a "region-by-region" basis through a series of focused studies. Where possible, we will conduct key research activities in the same geographic areas. This will depend upon the degree to which certain study areas possess data and the physical environment to address the range of research questions. Once the studies have been completed, we will apply the methodologies to the regional spatial databases to conduct the national assessment.

A proof of concept of our approach will be carried out in the mid-Atlantic Region of the U.S. as this area will be the first to have all key aspects of the approach completed.

A. Implementation Themes

A number of themes will be central to all of the research and assessment activities. These themes include:

- understanding stakeholder needs,
- highlighting assumptions, critical research steps, and interdependencies,
- setting research and development priorities,
- developing and testing a method or approach
- assessing the method performance for different geographic areas,
- considering ORD's high priority geographic areas in the selection of study areas,
- managing information for use by collaborating scientists, clients, and the public,
- collaborating within the EPA and with academia, federal agencies, and others, and
- collaborating within the EPA and with academia, federal agencies, and others, and
- providing customer services and products

These themes are discussed further below.

Stakeholder Needs

To better understand stakeholder needs, we will seek the assistance of Regional and Program Offices, and various laboratories and programs (e.g., EMAP) in ORD. Through an ongoing process of workshops, informal and formal meetings, surveys, and working with existing forums (such as the ORD Landscape Working Group) we will refine our understanding of their priorities and long-term concerns. Data quality objectives and assessment questions will be developed. We will solicit input and feedback on interim results through various mechanisms, including Internet web pages and user conferences (discussed further under customer services).

Highlighting Assumptions, Critical Research Steps, and Interdependencies

Within each research area, clearly articulating our assumptions, critical research steps, and interdependencies will be essential to the communication and interpretation of our interim products and results. For example, additional land use data for the year 2000 is critical to performing a 30-year assessment, so the acquisition of these data is a high priority for the Landscape Sciences Program. NALC data variability from the 1970's compared to the 1980's and 1990's may prevent some types of land cover and change analyses, so this potential problem will need to be addressed early in the program's development through the focused NALC studies. Transferring approaches or indicators from one region of the country to another may pose unexpected problems. Finally, the transition from research mode to full-scale application mode will require careful judgements about the adequacy of research results across multiple geographic areas. The research community and other stakeholders will need to be involved in these decisions in some capacity. Full-scale national production will depend on the outcome of these interactions. These topics will be discussed in detail in the individual research plans and also will be revisited as the program develops.

Setting Priorities

Implementation of a national landscape change assessment requires establishment of priorities for data collection and research activities. Priority setting across the entire Landscape Sciences Program will rest with the Environmental Sciences Division management, subject to approval by NERL management. Research projects within the program will be sequenced using a "fast-fail" approach so that a workable plan to achieve the national assessment is established as early as possible in the program development.

There are a number of priorities relative to accomplishing the national assessment, but some of the activities must be completed within the first three years of the project to determine the feasibility of the approach. The two most important priorities relative to the approach are:

- determining whether landscape change can be estimated accurately across different sensors in different regions of the US
- determining whether landscape indicators explain variation in aquatic-resource parameters in different regions of the US

These priorities are reflected in the number and type of research activities planned in the early years of the project (see Appendix I). If the results of either of these two research areas are poor or inconsistent, then a national assessment of landscape change (from the 1970s to the early 2000s) and its consequences on aquatic resources may not be possible. However, if the results suggest that the basic concept will work, then the next most important priority will be the assembly of spatial databases needed to generate the indicators nationally. Since the MRLC will be generating land cover for the early 1990s and 2000s, our emphasis will be on the generation of early 1970s and mid-1980s digital land cover maps from the NALC database. To do so will require replacement of poor quality 1970s scenes, classifying the imagery into land cover, and assessing the accuracy of the land cover databases. If the classification of early 1970s and mid-1980s NALC proves infeasible, we will limit the wall-to-wall assessment of landscape change from the early 1990s to the early 2000s. Alternatively, we might deploy a sample-based approach to assess landscape change between the early 1970s and the early 2000s (see early discussion); such an approach might require far fewer images.

Priority must also be given to upgrading computing capability within the Landscape Ecology and Landscape Characterization Branches. We will analyze and identify current and anticipated needs for hardware and software to meet both our near-term priorities and those of the 10-year national assessment goal.

Table 4 summarizes the respective duties and responsibilities of the three organizational units that comprise the Program and how they will be coordinated.

Developing and Testing Approaches and Methods

Each of the major research areas involves developing and testing a combination of landscape ecology, landscape-characterization, watershed-modeling, and remote-sensing approaches. While working within such diverse disciplines, many differences in approach are expected. However, some commonalities are expected. Typical stages will include specification or refinement of the parameters upon which the research is based; identification or development of appropriate conceptual models related to the parameters of interest; determination of what landscape scales and units are appropriate; selection of a procedure (or an indicator in the case of indicator development) that is consistent with the parameters and conceptual model; selection of a geographic area for initial testing; acquisition of data to test the approach; and extension of the testing to additional geographic areas. In the process, quality assurance approaches and methods for data analysis and interpretation will be developed and tested. As mentioned earlier, research will be conducted in a limited number of geographic areas. The number of different study areas established will depend on the degree to which multiple research objectives can be accomplished in individual geographic areas.

Study areas will be selected based on: (1) landscape data availability, (2) aquatic resource data availability, (3) stressor and biophysical spatial gradients, (3) importance to, and support from EPA Regional Offices, and (4) importance to integrated programs of ORD (e.g., EMAP). The third criterion is critical because EPA Regional Office collaboration is essential in achieving a meaningful national assessment.

Assessing the Method Performance for Different Geographic Areas

With the goal of a national assessment, validating each procedure or indicator for multiple geographic regions becomes a high priority. We anticipate finding differences between regions in the temporal and spatial scales at which biophysical and landscape characteristics influence water resources. We also expect to find differences in the importance of landscape pattern among regions. Therefore, multi-regional studies are needed.

While initial testing will be performed in an area selected for scientific considerations, accessibility, or availability of data, a successful procedure or indicator must be re-evaluated for application in other geographic areas. We expect that 10 or possibly 11 areas of the U.S. including the Northeast, the Mid-Atlantic, the Southeast, the Midwest/Central Plains, the Upper Midwest, the Upper Great Plains, the Pacific Northwest, the Pacific Southwest, the Southwest, the Inter-Mountain West, and the South-central U.S. will be needed. These geographic regions are consistent with broad-scale ecoregions and physiographic provinces for the lower 48 States. Some procedures or indicators will require more or less testing to determine their geographic transportability; the research will be planned accordingly (see Appendix I).

Integration issues arise when results from multiple research activities and diverse geographic areas are combined to create a coherent national assessment. Data collected by one method in one part of the U.S. may or may not be comparable to data collected by a similar method at another location. Differences may develop in interpretive analysis methods due to inherent differences from one ecosystem to another. Methods and sensors used historically may not agree with methods and sensors in current use. Quality of remote sensing data and derived results may differ from one region to another because of the availability of cloud-free days. Timing of projects and data delivery will be a critical factor in planning for a smooth flow of information so that synthesis and integration issues can be addressed properly. Because of the importance of the integration issues, the difficulty in predicting specific problem areas so early in the program, and the potential for "show-stoppers," this topic will be revisited frequently in the dynamic planning of the program.

Considering ORD's High Priority Geographic Areas in the Selection of Study Areas

When considering where to test initially and how to expand the testing process geographically, certain options offer special advantages. Significant opportunities for sharing existing data and leveraging sampling activities are available by working in one of the high priority areas of interest to the ORD. These areas currently include the Pacific Northwest, Great Lakes, Gulf of Mexico, and South Florida. In addition, the ORD Ecological Research Program has designated the Mid-Atlantic region as a single, primary area of coordination for ORD with other federal and state agencies. Finally near-laboratory sites, which serve as field laboratories, have been designated and include the Savannah, Neuse, Lower Colorado, and Little Miami River watersheds. These geographic areas offers different types of ecosystems, topography, climate, and local issue priorities.

Managing Information for Use by Collaborating Scientists, Clients, and the Public

The acquisition, manipulation, analysis, and dissemination of large databases associated with this research program require the development of a comprehensive information management plan. The plan must address a number of key issues needed to support a program of this magnitude, including:

(1) exchange of data, analysis programs, and information among participating scientists located across the country;
(2) availability of data and information on results to the scientific community and the public;
(3) documentation of analytical methodologies and data quality such that the methods and results can be replicated;
(4) archiving of data and analysis programs and results.

The plan also must consider upgrades to the computer system and network that will be needed to support the increasing scope of the project over the next 10 years. As a result of these needs, we propose to develop and implement a comprehensive information management plan by September 2000. This plan will be coordinated with the EPA Office of Information Resources Management, as well as several collaborating organizations, including EMAP and the EROS Data Center.

Collaborating within the EPA and with Academia, Federal Agencies, and Others

Because of the size of this national assessment, intellectual and financial collaboration both within and outside the EPA is essential. Within the EPA we will solicit partners who share our research interests and priorities. Because the EPA Regional Offices will be key to the implementation of the national goal, we train and assist Regional Office staff to compile landscape data, generate landscape indicators, and conduct regional-scale assessments. Regional Offices have already started to reorganize and pull together a critical mass of landscape and GIS staff. The EMAP Western Pilot will be a test of the proposed joint ORD/Regional Office implementation of the Program. Additionally, implementation of the Program will correspond to national implementation of EMAP Surface Waters and Near Coastal Programs. Close coordination with these two groups will be necessary to conduct landscape indicator/aquatic resources quantification (see earlier discussions). Two additional ORD programs are available to Regional Offices desiring ORD support: the Regional Applied Research Effort (RARE); and the Regional Environmental Monitoring and Assessment Program (REMAP). Studies under these programs are developed jointly by the Regional Office and ORD staff and typically last one to two years. Such studies, when focused within one of the key research areas listed above, can help us to test our concepts and research results in settings which have high priority to a Regional Office. Additionally, EMAP provides EPA Program Offices (e.g., the Office of Water) an opportunity to be involved. Part of the focused research is aimed directly at their needs; leveraging ORD resources with Program Office funds is also an option. We anticipate that EPA's Offices of Water; Prevention, Pesticides and Toxic Substances; Policy, Planning and Evaluation; International Affairs; Administration and Resource Management; Solid Waste and Emergency Response will benefit from this research and may be involved directly as partners and collaborators. In the ORD, a number of programs within the National Research Laboratories and Centers offer opportunities for collaboration, as listed in Table 5. In some cases, we have long-standing cooperative efforts, while in other cases, we will be developing new relationships. The STAR Grants Program is a competitive, peer-reviewed, investigator-initiated, EPA-funded, research grants program to foster innovative and far-reaching scientific projects and facilitate cooperation between EPA and the scientific community. Each year research categories are designated to which potential grantees respond. We anticipate working with NCERQA to develop research opportunities that can complement the scientific discovery taking place within the Agency.

Outside the EPA, opportunities for collaboration exist among federal and state agencies, especially with the Departments of Interior, Commerce, Agriculture, and Energy, and NASA. Some of these relationships are summarized in Table 6. Two existing collaborative efforts illustrate these relationships. The MRLC was developed to provide the capability for broad-based research on current and future conditions of the physical and biological resources of the United States, and the NALC Project was developed by EPA and the EROS Data Center/USGS to provide a standardized digital-data set of satellite images for the 1970s, 1980s and 1990s for the contiguous 48 states and Mexico (see earlier discussions).

Providing Customer Services and Products

Customer services and products will be an important factor in achieving the long term goal of the Landscape Sciences Program. These will include the following:

- Peer-reviewed research plans, revised as needed and annually updated appendices that list products, completed outputs and expected outputs,
- Journal articles that provide current research results to technical audiences,
- Guidance and user manuals that provide systematically organized advice, instruction, and recommendations to technical audiences, especially within the Regional Offices and States,
- Data management via EPA's Environmental Information Management System (EIMS) and associated databases to make data available to interested users inside and outside the agency. These databases are expected to include NALC, MRLC-92, MRLC-2000, and others,
- Two Internet web sites, one for Remote Sensing Methods, and one for Landscape Indicators to make research results and guidance available to technical audiences and the general public,
- Computer Landscape Assessment Tools to assist Regional Offices in conducting landscape analysis relative to aquatic resources,
- Biannual User Conferences on Remote Sensing and Landscape Indicators, hosted by the Landscape Science Program. These conferences will offer sessions on research results, Regional and Program Office applications, and training. These will be the primary mechanisms for our outreach efforts (methods and indicator guidance). They will result in wide recognition and use of our research products and lead to consensus on research needs and priorities, and
- Training of the Regional and Program Office staff upon request.

We will prioritize among these product types based on feedback from our stakeholders.

B. Research Plans

A key component of the research strategy will be development and peer review of individual research plans for specific research activities outlined in this plan. These plans will follow the form of National Science Foundation research grant proposals, including a description of the research area, a review of the state-of-science, statement of hypotheses and questions to be addressed, a description of the study and analysis designs, and time lines, resource needs, and backgrounds of principal and co-principal investigators. The research plans will provide details on individual projects that were too voluminous to describe in this plan. Generally, these research plans will cover a two to three-year study period. Some research activities, including Regional Environmental Monitoring and Assessment Program (REMAP) projects that already have research plans will not require a new plan. Research plans will not be required for development of analysis tools and web sites.

C. Time Line for Research and Assessment Implementation

Appendix I provides a road map of activities and milestones to achieve the goal of the program. These projects represent a diversity of programs funded by the EPA, including EMAP, the Regional Environmental Monitoring and Assessment Program (REMAP), the Regional Vulnerability Program (ReVA), and the Global Change Research Program (GCRP). Although not listed, the EPA funds a number of external grants (Science to Achieve Results (STAR) Grants) that will contribute to our knowledge of landscape change and how it affects aquatic resources. Information on the EPA External Grants program can be found at http://es.epa.gov/ncerqa/grants/.

We believe that the national landscape assessment can only be achieved by coordinating and leveraging these individual programs. We anticipate that the road map will change somewhat, especially in out years where initiation of specific activities is dependent on significant research progress, completion of national-scale data sets, and funding. Appendix III provides an example of milestone outputs.

Section V
Measures of Success

The measures of success for the Landscape Sciences Program include publication productivity, client satisfaction, recognition by the science community, successful outside evaluations, the successful completion of GPRA objectives and milestones, and the adoption of our methods and approaches by others, ranging from county planners to other countries. Productivity can be evaluated in terms of the quality and quantity of our publications and databases when considered in relation to our assignments, budget, and staff. Our scientists produce technical journal articles, databases, reports, and research plans. As this list suggests, the wide range of activities conducted within the Program does not always lead to journal articles. However, we consider journal articles highly desirable because of the peer review and recognition inherent in the process. We are striving to increase the numbers of journal articles and databases by focusing our efforts in this area, while continuing to produce the other products when needed. Client satisfaction involves the quality, relevance, and timeliness of our products and support (Table 7), as perceived by our many stakeholders. We provide our clients several different means for giving feedback on our work, including meetings to discuss results and tear-off pages with product questionnaires in the back of reports. Recognition by the science community can be judged by the number of requests received for invited presentations, and consultation and collaboration with our scientists, and citations of our papers in other scientific publications.

Outside evaluations take several forms, including technical program reviews conducted by a panel of academics and leaders in similar programs from other federal agencies. Such reviews, scheduled every three years, in accordance with ORD policy, consist of comprehensive presentations to the review panel of our research results, work in progress, and plans for the future. Program peer review results are summarized in a report by the reviewers. Our progress in meeting these measures is tracked both formally and informally. Published journal articles are listed for each Branch in monthly reports, as are major requests for consultation or collaboration. Client satisfaction as indicated by tear sheets is tallied and examined for trends, and delivery of key products is evaluated by follow-up visits or telephone conversations by senior managers. This combination of measures provides a sound basis for the ongoing evaluation of the Landscape Sciences Program.

Section VI
References Cited

Arnold, C.L., and C.J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. J. American Planning Assoc. 62:243-258.

Ball, G.L. 1994. Ecosystem modeling with GIS. Environ. Man. 18:345-349.

Barnthouse, L. W., D. L. DeAngelis, R. H. Gardner, R. V. O'Neill, C. D. Powers, G. W. Suter, II, and D. S. Vaughan. 1982. Methodology for environmental risk analysis. ORNL/TM-8167. 67 pp.

Barnthouse, L. W., G. W. Suter, II, and R. V. O'Neill. 1983. Quantifying uncertainties in ecological risk analysis. pp. 487-489. IN J. F. Bell and T. Atterbury (eds.), Renewable Resource Inventories for Monitoring Changes and Trends. College of Forestry, Oregon State University, Corvallis, Oregon.

Bartell, S. M., R. V. O'Neill, and R. H. Gardner. 1983. Aquatic ecosystem models for risk assessment. pp. 123-127. IN W. K. Lauenroth, G. V. Skogerboe, and M. Flug (eds.), Analysis of Ecological Systems: State-of-the-Art in Ecological Modeling. Elsevier Scientific Publishing, New York.

Brady, W., D.R. Patton, and J. Paxson. 1985. The development of Southwestern riparian gallery forests. US Forest Service Gen. Tech. Rpt. No. RM-120, p 39-43.

Burke, I. C., D. S. Schimel, C. M. Yonker, W. J. Parton, L. A. Joyce, and W.K. Lauenroth. 1990. Regional modeling of grassland biogeochemistry using GIS. Landscape Ecology 4:45-54.

Casey, R. M. and D. A. Jameson. 1988. Parallel and vector processing in landscape dynamics. Applied Mathematics and Computation 27:3-22.

Charbonneau, R., and G.M. Kondolf. 1993. Land use change in California, USA: nonpoint source water quality impacts. Environ. Man. 17:453-460.

Congalton, R.G., and K. Green. 1999. Assessing the accuracy of remote sensing data: principles and practices. Lewis Publ, Boca Raton, Florida. 137 p.

Dunn, C. P., D. M. Sharpe, G. R. Guntenspergen, F. Stearns, and Z. Yang. 1991. Methods for analyzing temporal changes in landscape patterns. Pp 173-198. IN M. G. Turner and R. H. Gardner (eds.) Quantitative Methods in Landscape Ecology. Springer-Verlag, NY.

EPA. 1988. Future risk: research strategies for the 1990s. EPA Science Advisory Board. Washington, D.C.

EPA. 1994. Landscape monitoring and assessment research plan. EPA 620/R-94/009, Washington, D.C.

EPA. 1997. 1997 update to ORD’s Strategic Plan. EPA/600/R-97/015, Washington, D.C.

EPA. 1998a. Ecological research strategy. EPA/600/R-98/086, Washington, D.C.

EPA. 1998b. Guidelines for ecological risk assessment. EPA/630/R-95/002F. Washington, D.C.

EPA. 1998c. National Exposure Research Laboratory Research Strategy. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Draft.

EPA. 1998d. Federal Water Pollution Control Act. EPA-840-R-98-001, U.S.C.A. Sect. 1251 et seq.; Public Law 100-202.

EPA. 1999. EXPOSITION: Integrated environmental decision-making in the 21st Century. EPA Science Advisory Board, Washington, D.C.

Fan, W., J.C. Randolph, and J. L. Ehman. 1998. Regional estimation of nitrogen mineralization in forest ecosystems using geographic information systems. Ecol. Appl. 8:734-747.

Forman, R.T.T. 1990. Ecologically sustainable landscapes: the role of spatial configuration. Pp. 261-278, in Forman, R.T.T., and I.S. Zomeveld (eds.), Changing landscapes: an ecological perspective.

Franklin, J. F. 1992. Scientific basis for new perspectives in forests and streams. pp. 25-72. in R. J. Naiman (ed.) Watershed Management. Springer-Verlag, NY.

Frenzel, S.A., and R.B. Swanson. 1996. Relations of fish community composition to environmental variables in streams of central Nebraska, USA. Environ. Man. 20:689-795.

Gardner, R. H., B. T. Milne, M. G. Turner, and R. V. O'Neill. 1987. Neutral models for the analysis of broad-scale landscape pattern. Landscape Ecology 1:19-28.

Gardner, R. H., R. V. O`Neill, M. G. Turner, and V. H. Dale. 1989. Quantifying scale dependent effects with simple percolation models. Landscape Ecology 3:217-227.

Gardner, R. H., and M. G. Turner. 1991. Future directions in Quantitative Landscape Ecology. Pp. 519-525. in M. G. Turner and R. H. Gardner (eds.) Quantitative Methods in Landscape Ecology. Springer-Verlag, NY.

Golley, F.B., J. Jensen, J. MacMahon, C. Pease, and D. Slack. 1997. Peer review of the Landscape Sciences Program in the Environmental Sciences Division, Las Vegas, Nevada USA, December 6-8, 1996. 35 pp.

Goolsby, D.A., W.A. Battaglin, G.B. Lawrence, R.S. Artz, B.T. Aulenbach, R.P. Hooper, D.R. Kenney, and G.J. Stensland. 1999. Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin. NOAA/Topic 3 Report. Paper submitted to the White House Office of Science and Technology Policy Committee on Environment and Natural Resources - Hypoxia Work Group.

Government Performance Results Act (GPRA). 1993. Government Performance and Results Act of 1993 (GPRA), Public Law 103-62, signed August 3, 1993.

Graham, R.L., C.T. Hunsaker, R.V. O'Neill, and B.L. Jackson. 1991. Ecological risk assessment at the regional scale. Ecol. Appl. 1:196-206.

Haack, B.N., and E.T. Slonecker 1994. Spaceborne radar and thematic mapper data fusion for location villages in Sudan. Photogr. Eng. Remote Sens. 55:1253-1257.

Holling, C. S. 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. Ecological Monographs 62:447-502.

Hunsaker, C. T., R. L. Graham, G. W. Suter, II, R. V. O'Neill, L. W. Barthouse, and R. H. Gardner. 1990. Assessing ecological risk on a regional scale. Environmental Management 14:325-332.

Hunsaker, C.T., D.A. Levine, S.P. Timmins, B.L. Jackson, and R.V. O'Neill. 1992. Landscape characterization for assessing regional water quality. Pp. 997-1006, in D.H. McKenzie, D.E. Hyatt, and V.J. McDonald (eds.), Ecological indicators. Elsevier Appl. Sci., New York.

Hunsaker, C.T., and D.A. Levine. 1995. Hierarchical approaches to the study of water quality in rivers. BioScience 45:193-203.

Jensen, J.R. 1986. *Digital Image Processing*, 2nd Edition, Prentice-Hall, Englewood Cliffs, NJ.

Jones, K.B., J. Walker, K.H. Riitters, J.D. Wickham, and C. Nicoll. 1996. Indicators of landscape integrity. Pp 155-168, *in* J. Walker and D.J. Reuter (eds.), Indicators of catchment health: a technical perspective. CSIRO Publishing, Melbourne, Australia.

Jones, K.B., K.H. Riitters, J.D. Wickham, R.D. Tankersley, R.V. O’Neill, D.J. Chaloud, E.R. Smith, and A.C. Neale. 1997. An ecological assessment of the United States mid-Atlantic Region: a landscape atlas. EPA/600/R-97/130.

Junk, W. J., P.B. Bailey, and R.E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Can. Spec. Publ. Fish. Aquat. Sci. 106:110-127.

Karr, J. R., and I. J. Schlosser. 1978. Water resources and the land-water interface. Science 201:229-233.

Kepner, W.G, K.B. Jones, D.J. Chaloud, J.D. Wickham, K.H. Riitters, and R.V. O’Neill. 1995. Mid-Atlantic landscape indicators project plan. EPA/620/R-95/003.

King, A. W., R. V. O'Neill, and D. L. DeAngelis. 1989. Using ecosystem models to predict regional CO2 exchange between the atmosphere and the terrestrial biosphere. Global Biogeochemical Cycles 3:337-361.

Khorram, S., G. Biging, N. Chrisman, D. Colby, R. Congalton, J. Dobson, R. Ferguson, M. Goodchild, J. Jensen, and T. Mace. 1999. Accuracy assessment of land cover change detection. American Soc. Photogr. Remote Sens. Monogr. Series #1, Bethesda, Maryland.

Krummel, J. R., R. H. Gardner, G. Sugihara, R. V. O'Neill, and P. R. Coleman. 1987. Landscape patterns in a disturbed environment. Oikos 48:321-324.

Levine, D.A., C.T. Hunsaker, S.P.Timins, and J.J. Beauchamp. 1993. A geographic information system approach to modeling nutrient and sediment transport. Oak Ridge Nat. Lab, Report No. 6736.

Lee, M.T. 1989. Soil erosion, sediment yield, and deposition in the Illinois River Basin. Pp. 718-722, *in* S.Y.Y. Wand (ed.), Proceedings of the International Symposium on Sediment Transport Modeling. American Soc. of Civil Eng., New York.

Lillesand, T.M., and R.W. Kieffer. 1994. Remote sensing and image interpretation. JohnWiley & Sons, Inc. New York.

Lowrance, R. R., R. Leonard, and J. Sheridan. 1985. Managing riparian ecosystems to control nonpoint pollution. Journal of Soil and Water Conservation 40:87-91.

Maxwell, J.R., C J Edwards, M.E. Jensen, S.J. Paustian, H. Parrott, and M. Donley. 1995. A hierarchical framework of aquatic ecological units in North America. Gen. Tech. Rep. NC-176, U.S. Dept. of Agr., Forest Serv., North-Central Forest Exp. Stat, St. Paul, Minnesota. 72 p.

McIntyre, N.E. 1995. Effects of forest patch size on avian diversity. Landscape Ecology 10:85-99.

Messer, J.J., R.A. Linthurst, and W.S. Overton. 1991. An EPA program for monitoring ecological status and trends. Environ. Man. 17:67-78.

Milne, B. 1988. Measuring the fractal geometry of landscapes. Appl. Math. and Comput.. 27:67-79.

Mitasova, H., J. Hofierka, M. Zlocha, and L.R. Iverson. 1996. Modeling topographic potential for erosion and deposition using GIS. Int. J. Geogr. Inform. Sys. 10:629-641.

NRC (National Research Concil). 1997. Building a foundation for sound environmental decisions. National Academy Press, Washington, D.C.

Omernik, J.M. 1987. Ecoregions of the United States: Map at a scale of 1:7,500,000. Suppl. Annals American Assoc. Geogr. 77(1).

O'Neill, R. V. 1979. Natural variability as a source of error in model predictions. pp. 23-32 IN G. S. Innis and R. V. O'Neill, Systems Analysis of Ecosystems. International Cooperative Publishing House, Fairland, Maryland.

O'Neill, R. V., R. H. Gardner, F. O. Hoffman, and G. Schwarz. 1981. Parameter uncertainty and estimated radiological dose to man from atmospheric 131I releases: A Monte Carlo approach. Health Phys. 40:760-764.

O'Neill, R. V., R. H. Gardner, L. W. Barnthouse, G. W. Suter, S. G. Hildebrand, and C. W. Gehrs. 1982. Ecosystem risk analysis: A new methodology. J. Environ. Toxicol. Chem. 1:167-177.

O'Neill, R.V., D.L. DeAngelis, J.B. Waide, and T.F.H. Allen. 1986. A hierarchical concept of ecosystems. Princeton University Press, Princeton, NJ.

O'Neill, R.V., J.R. Krummel, R.H. Gardner, G. Sugihara, B. Jackson, D.L. DeAngelis, B.T. Milne, M.G. Turner, B. Zygmunt, S.W. Chistensen, V.H. Dale, and R.L. Graham. 1988. Indices of landscape pattern. Landscape Ecol. 1:153-162.

O'Neill, R. V., S. J. Turner, V. I. Cullinen, D. P. Coffin, T. Cook, W. Conley, J. Brunt, J. M.Thomas, M. R. Conley, and J. Gosz. 1991. Multiple landscape scales: an intersite comparison. Landscape Ecology 5:137-144.

O'Neill, R.V., K.B. Jones, K.H. Riitters, J.D. Wickham, and I.A. Goodman. 1994. Landscape monitoring and assessment research plan. PEA-620/R-94-009. 53 pp.

O Neill, R.V., C.T. Hunsaker, S.P. Timmins, B.L. Jackson, K.B. Jones, K.H. Riitters, and J.D.Wickham. 1996. Scale problems in reporting landscape pattern at the regional scale. Landscape Ecology 11:169-180.

O'Neill, R.V., C.T. Hunsaker, K.B. Jones, K.H. Riitters, J.D. Wickham, P. Schwarz, I.A.Goodman, B. Jackson, and W.S. Baillargeon. 1997. Monitoring environmental quality at the landscape scale. BioScience 47:513-520.

Overton, W.S., D. White, and D.L. Stevens. 1990. Design report for EMAP (Environmental Monitoring and Assessment Program). EPA/600/S3-91/051.

Peterjohn, W. T., and D. L. Correll 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. Ecology 65:1466-1475.

Plotnick, R.E., R. H. Gardner, and R. V. O'Neill. 1993. Lacunarity indices as measures of landscape texture. Landscape Ecology 8:201-212.

Poff, N.L, and J.D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variables. Ecology 76:606-627.

Rastetter, E. B., A. W. King, B. J. Cosby, G. M. Hornberger, R. V. O'Neill, and J. E. Hobbie. 1991. Aggregating fine-scale ecological knowledge to model coarser-scale attributes of ecosystems. Ecological Applications 2:55-70.

Riitters, K.H, R.V. O'Neill, C.T. Hunsaker, J.D. Wickham, D.H. Yankee, S.P. Timmins, K.B. Jones, and B.L. Jackson. 1995. A factor analysis of landscape pattern and structure metrics. Landscape Ecol. 10:23-29.

Riitters, K.H., R.V. O'Neill, and K.B. Jones. 1997. Assessing wildlife habitat at landscape scales: a multi-scaled approach. Biological Conservation 81:191-202.

Risser, P. G. 1987. Landscape ecology: state of the art. Pp. 3-14. IN M. G. Turner (ed.) Landscape Heterogeneity and Disturbance. Springer-Verlag, NY.

Roth, N.E., J.D. Allan, and D.L. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple scales. Landscape Ecology 11:141-156.

Running, S. W., R. R. Nemani, D. L. Peterson, L. E. Band, D. F. Potts, L. L. Pierce, and M. A. Spanner. 1989. Mapping regional forest evapotranspiration and photosynthesis by coupling satellite data with ecosystem simulation. Ecology 70:1090-1101.

Schlosser, I.J. 1990. Environmental variation, life history attributes, and community structure instream fishes: implications for environmental management and assessment. Environ. Man. 14:621-628.

Schumaker, N.H. 1996. Using landscape indices to predict habitat connectivity. Ecology 77:1210-1225.

Sklar, F. H., and R. Costanza. 1991. The development of dynamic spatial model in landscape ecology: a review and prognosis. In M. G. Turner and R. H. Gardner (eds.) Quantitative Methods in Landscape Ecology. Springer-Verlag, NY.

Soranno, P.A., S. L. Hubler, and S.R. Carpenter. 1996. Phosphorus loads to surface waters: a simple model to account for spatial pattern of land use. Ecol. Appl. 6:865-878.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. BioScience 45:168-182.

Storck, P., L. Bowling, P. Wetherbee, and D. Lettenmaier. 1998. Application of a GIS-based distributed hydrology model for prediction of forest harvest effects on peak stream flow in the Pacific Northwest. Hydrol. Processes. 12:889-904.

Turner, M. G. 1989. Landscape ecology: the effect of pattern on process. Annu. Rev. Ecol. Syst., 20, 171-97.

Turner, S. J., R. V. O’Neill, W. Conley, M. R. Conley, and H. C. Humphries. 1991. Pattern and Scale: statistics for landscape ecology. Pp. 17-49. In M. G. Turner and R. H. Gardner (eds.) Quantitative Methods in Landscape Ecology. Springer-Verlag, NY.

U.S. EPA. 1994. Landscape monitoring and assessment research plan. U.S. EPA 620/R-94/009, Office of Research and Development, Washington, D.C.

Walker, J., F. Bullen, and B.G. Williams. 1993. Ecohydrological changes in the Murray-Darling Basin. I. The number of trees cleared over two centuries. J. Appl. Ecol. 30:265-273.

Weller, M.C., M.C. Watson, and D. Wang. 1996. Role of wetlands in reducing phosphorus loading to surface water in eight watersheds in the Lake Champlain Basin. Environ. Man. 20:731-739.

Wickham, J.D., and K. H. Riitters. 1995. Sensitivity of landscape metrics to pixel size. Int. J..Remote Sensing 16:3585-3594.

Wickham, J.D., R.V. O'Neill, K.H. Riitters, T.G. Wade, and K.B. Jones. 1997a. Sensitivity of landscape pattern metrics to land cover misclassification and environmental condition gradients. Photogram-metric Engineering and Remote Sensing 63:397-402.

Wickham, J.D., J. Wu, and D.F. Bradford. 1997b. A conceptual framework for selecting and analyzing stressor data to study species richness at large spatial scales. Environ. Man. 21:247-257.

Wickham, J.D., R.V. O'Neill, and K.B. Jones. 1999a. A geography of ecosystem vulnerability. Landscape Ecology, submitted.

Wickham, J.D., K.B. Jones, K.H. Riitters, T.G. Wade, and R.V. O'Neill. 1999b. Transitions in forest fragmentation: implications for restoration opportunities at regional scales. Landscape Ecology 14:137-145.

Wickham, J.D., K.B. Jones, K.H. Riitters, R.V. O'Neill, R.D. Tankersley, E.R. Smith, A.C. Neale, and D.J. Chaloud. 1999c. An integrated environmental assessment of the US Mid-Atlantic Region. Environ. Manag., in press.

Wiens, J.A. 1985. Vertebrate responses to environmental patchiness in arid and semi-arid ecosystems. Pp. 169-193, *in* Pickett, S.T.A., and P.S. White (eds.), The ecology of natural disturbance and patch dynamics. Academic Press, New York.

Wiens, J.A., N. C. Stenseth, B. Van Horne, and R.A. Ims. 1993. Ecological mechanisms and landscape ecology. Oikos 66:369-380.

Wiens, J.A., R.L. Schooley, and R.D. Weeks, Jr. 1997. Patchy landscapes and animal movements: do beetles percolate? Oikos 78:257-264.

Wischmeier, W. H., and D. D. Smith. 1978. Predicting rainfall erosion loss: A guide to conservation planning. Agricultural handbook 537. U. S. Department of Agriculture, Washington, D.C.

Young, W.J., F.M. Marston, and J.R. Davis. 1996. Nutrient exports and land use in Australian catchments. J. Environ. Man. 47:165-183.

Zhang, L., A.L. O'Neill, and S. Lacey. 1996. Modelling approaches to the prediction of soil erosion in catchments. Environ. Software 11:123-133.

Appendix I

List of Research and Assessment Activities by Geographic Areas by Fiscal Year (FY)

Research Area or Activity	Geographic Area(s)	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
Mid-Atlantic Region											
Replacement of Poor Quality NALC Imagery	40+ Watersheds in Mid-Atlantic Region	x									
NALC Land Cover Classification	Entire Mid-Atlantic Region	x	x								
Change Detection Across Sensors	Selected Watersheds in Mid-Atlantic Region	x	x								
Landscape Indicator/Stream Correlations	600 Watersheds in Mid-Atlantic Region	x									
Landscape Indicators of Pesticides and Toxics	50 Watersheds in Mid-Atlantic Region	x	x	x							
New Remote Sensing Methods to Evaluate Surface Mining Stress	Mining Gradient in Mid-Atlantic Region	x	x	x							
New Remote Sensing Methods to Evaluate Hog and Chicken Farms	Agricultural Gradient in Neuse River Watershed	x	x	x							
Validation of Remote Sensing Approach to Detect Riparian Habitat Condition	Urban to Rural Gradient in Mid-Atlantic Region	x	x								
Landscape Indicator/Estuary Correlations	20+ Large Watersheds in Mid-Atlantic Region	x	x	x							
National Landscape Sampling Design Pilot	5 Different Ecoregions in Mid-Atlantic Region	x	x	x							

Appendix I. *Continued*

Research Area or Activity	Geographic Area(s)	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
Mid-Atlantic Region, Continued											
Landscape Change Consequences - Proof of Concept (1970-1990)	Entire Mid-Atlantic Region	x	x	x							
Watershed Classification to Characterize Responses of Streams to Landscape Characteristics	Entire Mid-Atlantic Region	x	x	x							
Landscape Assessment Approach to Target Water Bodies at Risk to Loadings	Selected Watersheds in Mid-Atlantic Region		x	x	x						
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region					x	x	x			
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region							x	x		
Northeastern Region											
NALC and Thematic Mapper Land Cover Classification	New York City Watersheds	x									
Change Detection Across Sensors	New York City Watersheds	x	x								
Landscape Indicator/Stream Correlations	New Jersey; New York City Watersheds		x	x							
Landscape Indicator/Estuary Correlations	New England Coast				x	x	x				
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region					x	x	x			
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region							x	x		

Appendix I. *Continued*

Research Area or Activity	Geographic Area(s)	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
Southeastern Region											
Landscape Indicator/Stream Correlations	Savannah River Watershed	x									
Landscape Indicator/Stream Correlations	Alabama Watersheds		x	x							
Landscape Indicator/Stream Correlations	SAMAB Region		x	x	x						
Landscape Assessment Approach to Target Water Bodies at Risk to Loadings	South Carolina	x	x								
Landscape Indicator/Estuary Correlations	Alabama, Florida, South Carolina		x	x	x						
Validation of Remote Sensing Tech to Assess Impervious Surface	SAMAB Region				x	x	x				
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region					x	x	x			
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region							x	x		
Mid-West Region											
Landscape Indicator/Stream Correlations[1]	Kansas, Nebraska, Missouri	x	x	x							
Landscape Indicators of Pesticides and Toxics	Kansas, Nebraska				x	x	x				
Replacement of Poor Quality NALC Imagery	Kansas, Nebraska, Missouri			x							
NALC Land Cover Classification	Kansas, Nebraska, Missouri				x	x					
Change Detection Across Sensors	Selected Areas of Kansas, Nebraska, Missouri					x	x				

Appendix I. *Continued*

Research Area or Activity	Geographic Area(s)	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
Mid-West Region, Continued											
Validation of Remote Sensing Approach to Detect Riparian Habitat Condition	Nebraska, Kansas						x	x			
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region						x	x	x		
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region								x	x	
Upper Mid-West Region											
Landscape Indicator/Stream Correlations	Minnesota, Wisconsin	x	x	x							
Replace Poor Quality NALC Imagery[2]	All Watersheds Feeding into the Great Lakes		x								
NALC Land Cover Classification	All Watersheds Feeding into the Great Lakes			x	x						
Change Detection Across Sensors	St. Claire Watershed (WS/MN)		x	x							
Landscape Assessment Approach to Target Water Bodies at Risk to Loadings	Selected Watersheds in Wisconsin, Illinois and Indiana			x	x	x					
Landscape Indicators of Pesticides and Toxics	Selected Watersheds in Wisconsin, Illinois and Indiana					x	x	x			
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region						x	x	x		
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region							x	x		

Appendix I. *Continued*

Research Area or Activity	Geographic Area(s)	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
Pacific Northwest Region											
Landscape Indicators/Stream Correlations[3]	Northwest Oregon, Willamuth Basin, Deschutes Basin		x	x	x						
Watershed Classification to Characterize Responses of Streams to Landscape Characteristics	Columbia River Basin	x	x	x							
Watershed Classification to Characterize Stream Loadings Risk	Columbia River Basin	x	x	x							
Landscape Indicator/Estuary Correlations[4]	Selected Watersheds in PNW			x	x						
Landscape Indicators of Pesticides and Toxics	Selected Watersheds in Columbia River Basin				x	x	x				
Validation of Remote Sensing Approach to Detect Riparian Habitat Condition	Selected Watersheds in the Columbia River Basin				x	x	x				
Additional Landscape Indicator Studies (if needed)	To Be Determined					x	x	x			
Validation of Remote Sensing Tech to Assess Impervious Surfaces	Selected areas within Region				x	x	x				
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region						x	x	x		
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region							x	x		
Pacific Southwest Region											
Landscape Indicator/Stream Correlations[3]	Southern LA Basin		x	x							
Landscape Indicators of Pesticides and Toxics	Central Valley, other areas in California				x	x	x				
Validation of Remote Sensing Approach to Detect Riparian Habitat Condition	Selected areas in California			x	x	x					

Appendix I. *Continued*

Research Area or Activity	Geographic Area(s)	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
Pacific Southwest Region, Continued											
Landscape Indicator/Estuary Correlations	Coastal areas of California				x	x	x				
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region						x	x	x		
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region							x	x		
Northern Great Plains Region											
Landscape Indicator/Stream Correlations[3]	Selected Watersheds in Upper Missouri Basin		x	x	x						
Landscape Assessment Approach to Target Water Bodies at Risk to Loadings	Selected Watersheds in the Upper Missouri Basin			x	x	x					
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region						x	x	x		
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region								x	x	
Inter-Mountain Region											
Landscape Indicator/Stream Correlations[1]	Humbolt River Basin		x	x	x						
Validation of Remote Sensing Approach to Detect Riparian Habitat Condition	Selected areas of Nevada and Utah				x	x	x				
Watershed Classification to Characterize Responses of Streams to Landscape Characteristics	Nevada, Utah				x	x	x				
New Remote Sensing Method to Detect Grazing Pressure	Nevada, Utah				x	x	x				

Appendix I. *Continued*

Research Area or Activity	Geographic Area(s)	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
Inter-Mountain Region, Continued											
Validation of Remote Sensing Method to Detect Mining Stress	Nevada, Utah					x	x	x			
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region						x	x	x		
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region								x	x	
Southwestern Region											
Change Detection Across Sensors	Upper San Pedro River Basin	x	x								
Hydrologic Model Development to Assess Consequences of Landscape Change on permanent and intermittent streams	Selected Watersheds in the Lower Colorado River Basin	x	x	x	x						
New Remote Sensing Method to Detect Grazing Pressure	Grazing Pressure Gradients in California, Nevada, Arizona, and Utah		x	x	x						
Landscape Indicator/Stream Correlations	Selected Watersheds in Arizona and New Mexico			x	x	x					
Additional Landscape Indicator Studies (if needed)	To Be Determined					x	x	x			
Landscape Assessment Approach to Target Water Bodies at Risk to Loadings	Selected areas of California, Arizona				x	x	x				
Watershed Classification to Characterize Responses of Streams to Landscape Characteristics	Arizona, New Mexico				x	x	x				
New Remote Sensing to Detect Riparian Habitat and Hydrologic Conditions	Selected Watersheds in Arizona, New Mexico, and Utah	x	x	x							
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region						x	x	x		

Appendix I. *Continued*

Research Area or Activity	Geographic Area(s)	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
Southwestern Region, Continued											
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region								x	x	
Rocky Mountain Region											
Landscape Indicator/Stream Correlations[3]	Southwestern Portion of Rocky Mtns.	x	x								
Additional Landscape Indicator Studies (if needed)	To Be Determined				x	x	x				
New Remote Sensing Approaches to Detect Surface Mining Stress	Selected areas in Colorado			x	x	x					
New Remote Sensing Approaches to Detect Grazing Stress	Selected gradients in Colorado, Wyoming, and Montana			x	x	x					
Watershed Classification to Characterize Responses of Streams to Landscape Characteristics	Colorado, Wyoming			x	x	x					
Landscape Assessment Approach to Target Water Bodies at Risk to Loadings	Selected Areas on the Colorado Plateau				x	x	x				
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region						x	x	x		
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region								x	x	
South Central Region											
Change Detection Across Sensors	Tensas River Basin	x									
Landscape Indicator/Stream Correlations	Selected Watersheds in Texas					x	x	x			
Landscape Indicator/Estuary Correlations	Watersheds Feeding into Louisiana and Texas Estuaries						x	x	x		

Appendix I. *Continued*

Research Area or Activity	Geographic Area(s)	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08
South Central Region, Continued											
Additional Landscape Indicator Studies – If Needed	To be Determined						x	x	x		
Validation of Remote Sensing Approach to Detect Riparian Habitat Condition	Selected Watersheds in Louisiana and Texas					x	x	x			
Acquisition of All Primary Spatial Data Needed to Generate Landscape Indicators Across the Three Dates	Entire Region						x	x	x		
Analysis of Landscape Change and Its Consequences on Aquatic Resources	Entire Region								x	x	
National Assessment											
Compilation of Findings from Regional Studies	Lower 48 States[4]									x	x
Publish National Assessment	Lower 48 States[4]										x

[1] Regional Environmental Monitoring and Assessment Program Project
[2] Work will include the Canadian Watersheds Feeding into the Great Lakes
[3] Western EMAP Landscape Project
[4] If funds are available, may also include Alaska and Hawaii

Appendix II

Relationships to EPA Goals and Objectives

The Program is integral to EPA goals and objectives as articulated in the NERL Strategic Research Plan (EPA 1998c), the Strategic Plan for the Office of Research and Development (ORD Strategic Plan, EPA 1997) and the ORD Ecological Research Strategy (EPA 1998a) which respond, in turn, to national goals, e.g., the Governmental Performance Results Act (GPRA 1993) or to specific legislative mandates, e.g., Amendments to the Clean Water Act (CWA). The following are examples of specific goals and objectives which this Program directly addresses or supports.

ORD Strategic Plan (EPA 1997):

- To provide credible, state-of-the-art risk assessments, methods, models, and guidance
    - Assessing the risks to ecosystems from non-chemical stressors (e.g., habitat loss and uvB due to stratospheric ozone depletion)
    - Developing and supporting the implementation of guidelines for assessing the ecological impacts of environmental stressors
    - Integrating scientific and technical information from ORD Laboratories and other sources to provide a sound scientific base and technical support for Agency decisions and policy
    - Assuring adequate quality assurance for all research, testing, and applications
- To provide common-sense and cost-effective approaches for preventing and managing risks
    - Developing diagnostic and characterization methods and protocols for use in determining appropriate ecosystem restoration goals and requirements for specific sites, watersheds, landscapes, and ecoregions
- To provide leadership . . . in identifying emerging environmental issues, characterizing the risks . . . developing ways of preventing or reducing those risks
    - Provide national and international leadership in risk assessment and its application for risk reduction and risk management
    - Conduct/sponsor workshops . . . reaching consensus on crucial research needs, and defining the role of ORD and others in addressing those needs
- To develop scientifically sound approaches to assign and characterize risks to human health and the environment
    - Establish approaches to characterizing and understanding risks to ecosystems and, in cooperation with other agencies, develop a national, multi-scale, integrated environmental status and trends program

- ◦ Characterizing national land cover/land use patterns and developing measures of landscape condition at multiple scales for specific sites, watersheds, landscapes, and ecoregions

ORD Ecological Research Strategy (EPA 1998a; Government Performance and Results Act of 1993).

- Goal 8 (Sound Science), Objective 1 -- Provide the scientific understanding to measure, model, maintain, or restore, at multiple scales, the integrity and sustainability of ecosystems now, and in the future.
    - S1.1 -- By 2008, develop 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.
    - S1.2 -- By 2008, develop models to understand, predict and assess the exposure and response of ecosystems to multiple stressors at multiple scales.
- Develop a prototype multimedia, effects and exposure modeling framework for evaluating the impact of watershed management practices, at multiple scales, on stream and estuarine condition
- Develop advanced measurement, computing, modeling, and data management technologies, and integrate them into an effective system for real-time delivery of multi-media, multi-scale, multi-parameter information on environmental statue and risk

Clean Water Act Amendments (EPA 1998d):

- Provide improved, cost-effective mechanisms for the estimation of Total Mean Daily Loads (TMDL's) of pollutants within watersheds

From the NERL's [draft, 8/28/98] Research Strategy (EPA 1998c), one of three strategic goals:

- " . . . facilitate environmental management and decision-making by providing the scientific tools needed to estimate (and ultimately reduce) risks to ecosystems posed by exposures. . . . Landscape, biological, and modeled indicators (used in an integrated manner at multiple scales) can answer questions of importance for protecting ecosystems at the complex levels at which ecological processes actually operate."

Appendix III

Anticipated Outputs of the Research

- Web sites
  - Remote sensing
  - Landscape indicators
- Quantification of landscape indicators in each major region (Reports & input to web)
- Western region landscape assessments (western EMAP)
- Quantification of landscape indicators in each major region (Reports & input to web)
- Models to evaluate consequences of landscape change
  - 3 to 4 regions of U.S.
- National landscape assessment
- Journal articles on indicator applications
- Journal articles on new remote sensing application
- National & regional databases on landscape @ 30-90 meter resolution
- Remote sensing method to evaluate riparian habitat condition
- Landscape indicator to evaluate vulnerability of water resources to pesticides & toxics
- Models to evaluate vulnerability of water resources to pesticides & toxics
- Landscape assessment methods to target high priority area for TMDL mitigation & 303 (d) CWA designations
- Remote sensing methods to evaluate surface/watershed impacts of surface mines

Appendix IV

Acronyms

AMI	Advanced Monitoring Initiative
AVHRR	Advanced Very High Resolution Radiometer
AVIRS	Advanced Visible Infrared Imaging System
CENR	Committee on the Environment and Natural Resources
CSIRO	Commonwealth Scientific and Industrial Research Organization
CWA	Clean Water Act
DOD	Department of Defense
DOE/ORNL	Department of Energy/Oak Ridge National Laboratory
EIMS	Environmental Information Management System
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
EPIC	Environmental Photographic Interpretation Center
EROS	Earth Resources Observation System
ESE	Earth Science Enterprise
GCRP	Global Change Research Program
GIS	Geographic Information Systems
GPRA	Government Performance Results Act
MODIS	Moderate Resolution Imaging Spectrometer
MRLC	Multi-resolution Land Characteristics Consortium
MSS	Multi-spectral Scanner
NAWQA	National Water Quality Assessment
NASA	National Aeronautics and Space Administration
NCERQA	National Center for Environmental Research and Quality Assurance
NERL	National Exposure Research Laboratory
NHEERL	National Health and Environmental Effect Research Laboratory
NOAA	National Oceanic and Atmospheric Administration

NRC	National Research Council
NTM	National Technical Means
OARM	Office of Administration and Resources Management
ORD	Office of Research and Development
OPPE	Office of Policy, Planning and Evaluation
RARE	Regional Applied Research Effort
REMAP	Regional Environmental Monitoring and Assessment Program
ReVA	Regional Vulnerability Assessment
SIR	Shuttle Imaging Radar
STAR	Science to Achieve Results
TIR	Thermal Infrared
TM	Thematic Mapper
TMDL	Total Maximum Daily Loads
USDA-ARS	United States Department of Agriculture-Agricultural Research Service
USFS	United States Forest Service
USGS	United States Geological Survey
USGS-BRD	United States Geological Survey-Biological Research Division
USGS-WRD	United States Geological Survey-Water Resources Division
UV	Ultraviolet

Table 1. Research Topic Areas and Goals

Research Topic Area	Purpose, Goal or Objective of Activity
Change Detection	Develop methods to monitor landscape change using current remote sensing systems; perform change detection analysis/interpretation; make findings public.
New Remote Sensing Methods	Capture new technologies for synoptic coverage and enhanced resolution to support cross-scale analyses; improve analysis of watershed-level stresses on aquatic resources.
Spatial Data Acquisition and Accuracy Assessment	Exploit data sources and develop and implement methods to document the accuracy of classified and other land cover and land characteristics databases.
Landscape Indicators of Water Resource Vulnerability Assessing the Consequences of Landscape Change	Develop quantitative linkages between a variety of existing and new landscape indicators and aquatic resource conditions.
Multi-Indicator Assessment Approaches Including Watershed Models	Develop multi-indicator assessment techniques including watershed models to prioritize vulnerable areas and evaluate consequences of landscape change on water resources.

Table 2. MRLC Land Cover Classes

Class #	Class Name
Water	
11	Open Water
12	Perennial Ice/Snow
Developed	
21	Low Intensity Residential
22	High Intensity Residential
23	Commercial/Industrial/ Transportation
Barren	
31	Bare Rock/Sand/Clay
32	Quarries/Strip Mines/Gravel Pits
33	Transitional
Vegetated; Natural Forested Upland	
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest

Class #	Class Name
Vegetated; Natural Shrubland	
51	Deciduous Shrubland
52	Evergreen Shrubland
53	Mixed Shrubland
Vegetated; Non-Natural Woody	
61	Orchards/Vineyards/Other
Herbaceous Upland Natural/Semi-natural Vegetation	
71	Grasslands/Herbaceous
Herbaceous Planted/Cultivated	
81	Pasture/Hay
82	Row Crops
83	Small Grains
84	Fallow
85	Urban/Recreational Grasses
Wetlands	
91	Woody
92	Emergent Herbaceous

Table 3. New Remote Sensing Systems

Satellite	Owners/Operators	Proposed Launch Date	Sensors	Spatial Resolution (m)	Number of Color Bands
EOS AM-1	Japan/U.S. Gov	1999	Multispectral	15	14
KOMSAT	Korean Gov	1998	Panchromatic	10	
CRSS-2	U.S. Commercial	1998, 1999	Panchromatic	10	
Landsat-7	U.S. Gov	1999	Panchromatic	15	
			Multispectral	30	7
IRS-P5, IRS-2A	Indian Gov	1998, 1999			
CBERS 1,2	China/Brazil Gov	1998, 1999			
OrbView-3,4	U.S. Commercial	1998, 1999	Panchromatic	1	
			Multispectral	4	
			Hyperspectral	8	200
IKONOS 2	U.S. Commercial	1999	Panchromatic	1	
			Multispectral	4	4
NEMO	U.S. Gov	2000	Panchromatic	5	
			Hyperspectral	30, 60	210
Warfighter	U.S. Gov	2000	Panchromatic	1	
			Multispectral	4	4
			Hyperspectral	8	80, 200
EO-1	U.S. Gov	1999	Multispectral	30	9
ENVISTAT	ESA	1999	Radar	30	
IRS 1-D	Indian Gov	1998	Panchromatic	10	
			Multispectral	20	4
QuickBird 1	U.S. Commercial	1999	Panchromatic	1	
			Multispectral	4	4

Table 3. *Continued*

Satellite	Owners/Operators	Proposed Launch Date	Sensors	Spatial Resolution (m)	Number of Color Bands
QuickBird 2	U.S. Commercial	1999	Panchromatic	1	
			Multispectral	4	4
Spot-5A	French Gov	1999	Panchromatic	5	
			Multispectral	10	4
EOS PM-1	U.S Gov	2000			
HRST	U.S Gov	2000	Hyperspectral		
ARIES	Australia	2000	Hyperspectral		
EOS CHEM-1	U.S. Gov	2002			
EOS AM-2/Landsat-8	U.S. Gov	2004	Panchromatic	10	
			Multispectral	30	7
Spot-5B	French Gov	2004	Panchromatic	5	
			Multispectral	10	4

Table 4. Landscape Sciences Program Responsibility Matrix

Responsibility	LEB	LCB	EPIC
1. Coordination of spatial data mosaic completion; MRLC; NALC; complete data acquisition and processing	CP	CP	
2. Landscape indicator development; indicator quantification[1]	CP		CP
3. New remote sensing systems capabilities; access; pilots		CP	CP
4. Exploitation of National Technical Means data/systems			P
5. Remote sensing technical support to EPA regions and program offices			P
6. Change detection (NALC; and others)	CP	CP	CP
7. Landscape indicator/model interface[2]	P		S
8. Land cover classification; operations and research and development		P	
9. Accuracy assessment of databases/land cover	CP	CP	CP
10. Regional landscape assessments[3]	P		
11. Remote sensing support to research operations			P
12. Regional vulnerability assessments	CP	CP	CP

Note: We anticipate some areas of overlap between the EPIC and the LCB in the area of remote sensing research and development, but in order to maximize the use of our currently small qualified research and development staff, it is appropriate and necessary that some research and development be accomplished at both RTP and Reston. This can best be accomplished with close communication between the groups and in the spirit of coordination and cooperation.

Table Keys

P = Principal Role CP = Co-principal Role

S = Supporting Role

[1] We anticipate significant interaction and collaboration with EMAP Surface and Coastal Waters groups

[2] We anticipate significant interaction and input from NERL-Athens

[3] We anticipate significant interaction and collaboration with EPA Regional Offices

Table 5. Existing and Potential Collaborators Within ORD

Collaborator	**Project**
National Health and Environmental Effects Research Laboratory (NHEERL)	Environmental Monitoring and Assessment Program (EMAP)
NHEERL	Anthropogenic nitrogen [in streams]
National Risk Management Research Laboratory	Riparian Restoration Program
Global Climate Change Research Program (OPPE)	Global Change Research Program
National Center for Environmental Research and Quality Assurance	Science to Achieve Results (STAR) Grants Program
NERL/Ecosystems Research Division-Athens	Modeling research
NERL/Atmospheric Modeling Division-RTP	Climatological effects assessment
NERL/Ecological Exposure Research Division-Cincinnati	Biomarkers research

Table 6. Ongoing Collaboration Organized by Topic

Topic	Internal Partners	External Partners
Remote sensing data acquisition and classification	MRLC--OARM	USGS-EROS Data Center
New Remote Sensing Methods Development	AMI	NASA, USGS EROS Data Center
Landscape characterization and assessment research	STAR Grants Program – NCERQA, EPA Regional Offices	University grantees
Spatial data acquisition and accuracy assessment		USGS-EROS Data Center, NTM
Change detection		NASA, USDA-ARS
Landscape indicators	EPA Regional Offices	DOE/ORNL, USGS-BRD, USDA-ARS, CSIRO-Australia
Regional assessments	EMAP--NHEERL, EPA Regional Offices	USGS-WRD, USDA
Regional to local scale assessments	REMAP, RARE, EPA Regional Offices	
Neuse River Basin data acquisition		State of North Carolina

Table 7. List of Clients and Customers

Customer	Landscape Science Products Provided
EPA Regional Offices	Ecological assessments, e.g., Atlas; databases
EPA Offices of Water; Prevention, Pesticides and Toxic Substances; Policy, Planning and Evaluation; International Affairs	Research and consultation; guidance documents
EPA Regional Offices and Office of Solid Waste and Emergency Response	Remote sensing and aerial photography analyses and reports for hazardous waste site evaluation
Academia	Databases for use in research
Public	Data and analyses; consultation

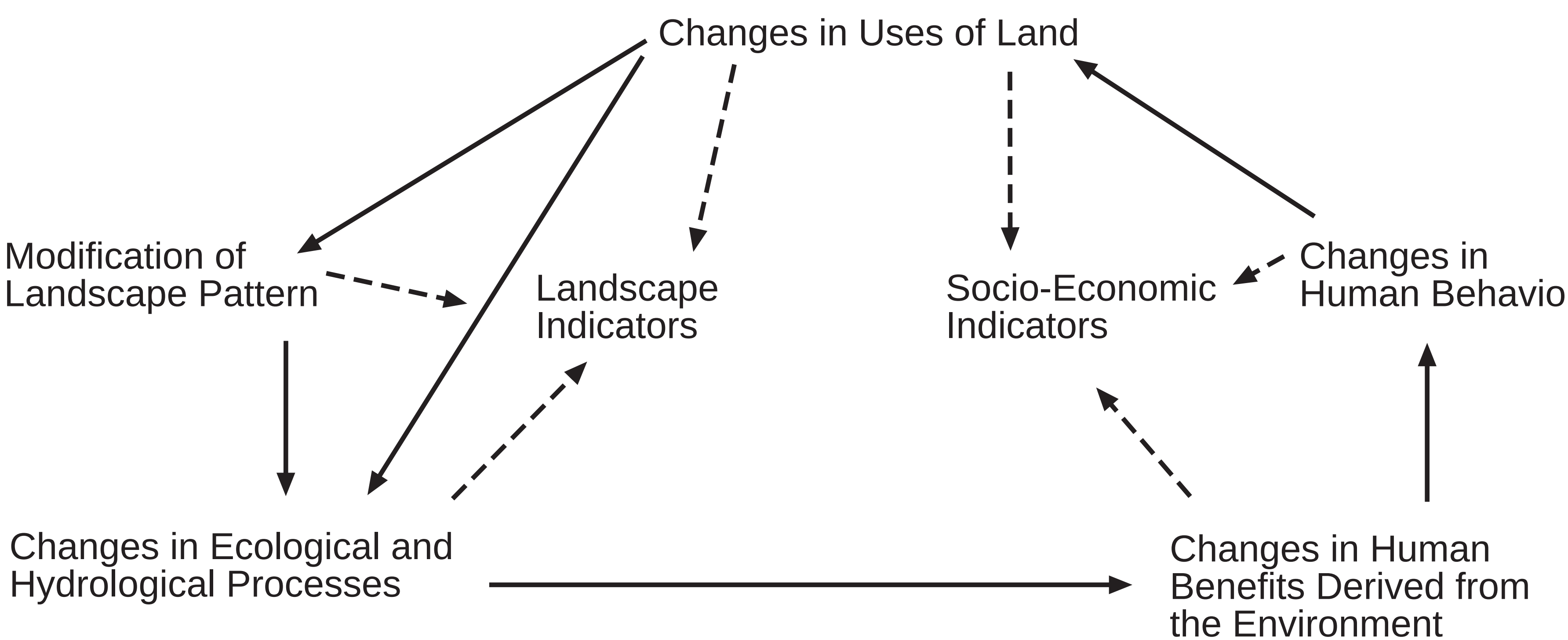


Figure 1. General conceptual model of landscape change and sustainability of environmental attributes values by society.

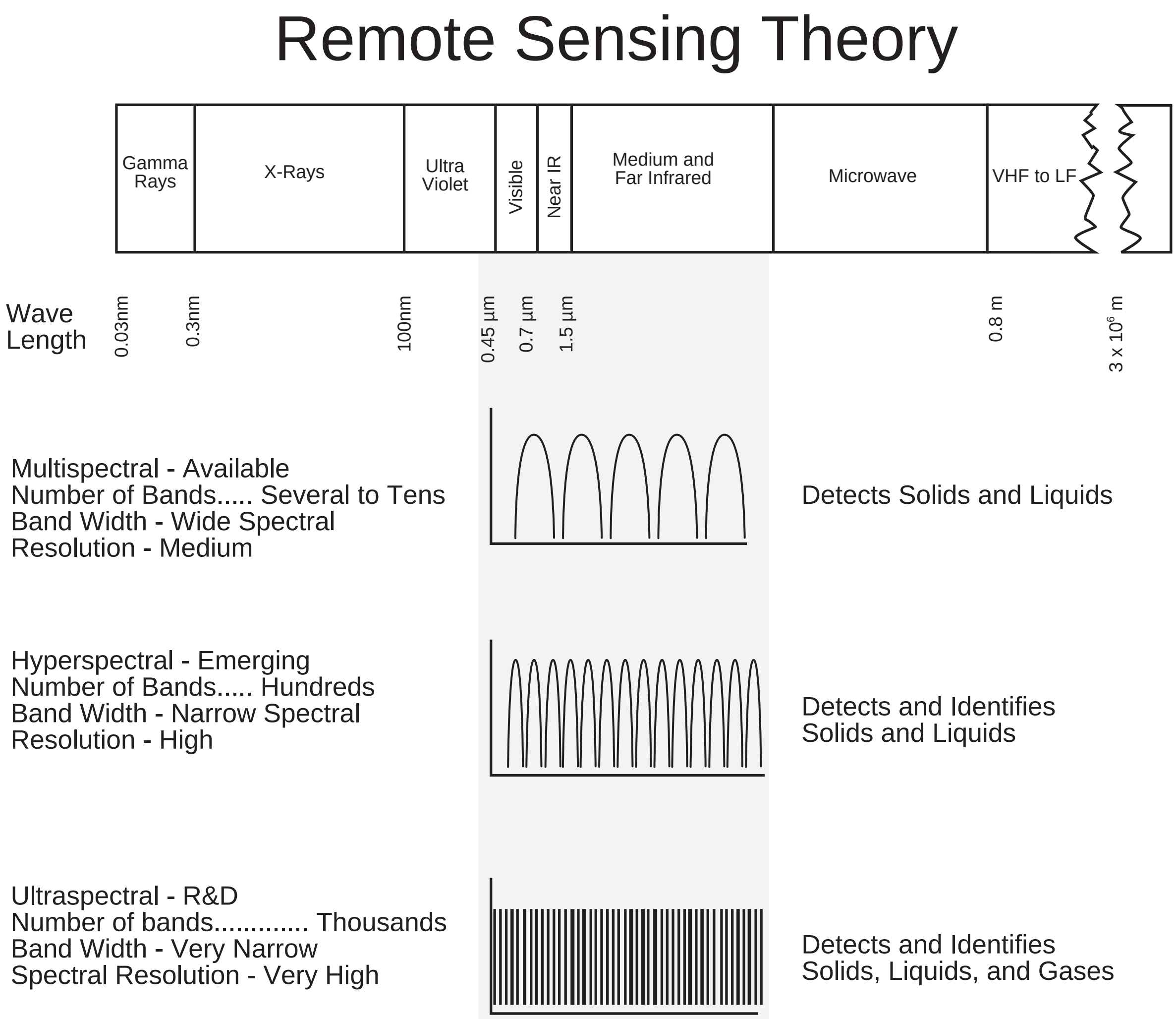


Figure 2. Comparison of multispectral, hyperspectral, and ultraspectral signatures.

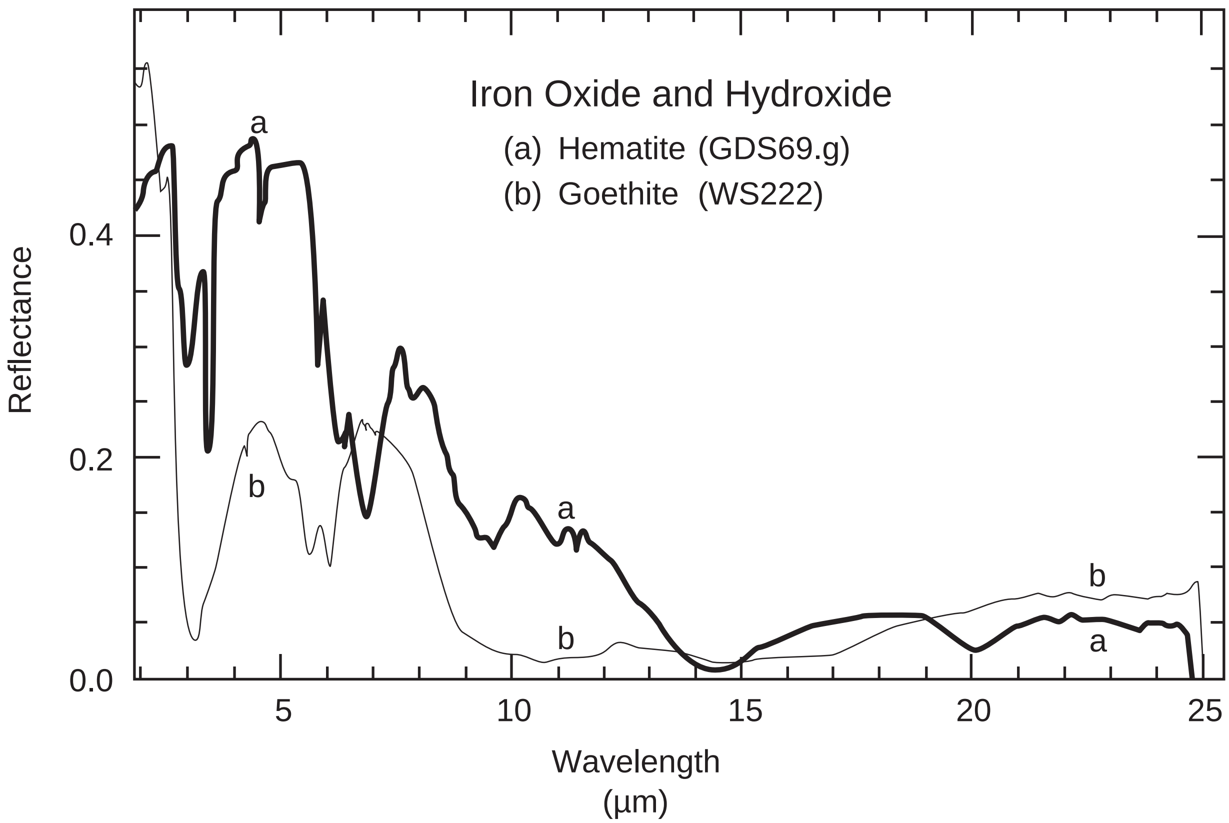


Figure 3. Unique reflectance spectral of minerals as derived from NASA's AVIRIS instrument.

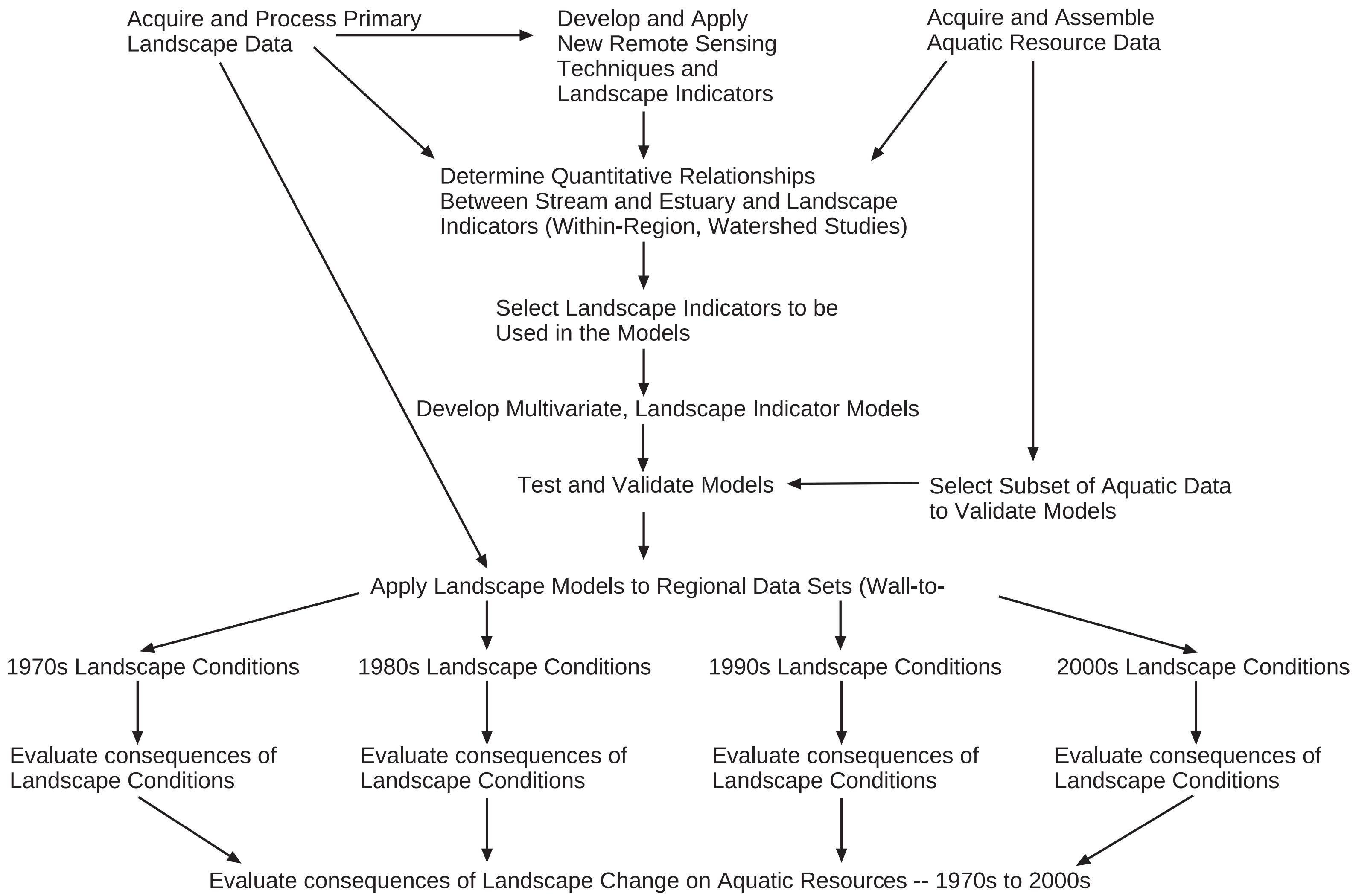


Figure 4. General implementation strategy for landscape research and assessments proposed in the Plan. The strategy will be implemented on a region by region basis.