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Ecological Research Program Multi-Year Plan

FY 2008-2014

February 2008 Review Draft

Office of Research and Development

United States Environmental Protection Agency

ECOLOGICAL RESEARCH PROGRAM RESEARCH MULTI-YEAR PLAN (2008-2014)

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List of Acronyms

AmeriFlux	Long-term flux measurement network of the Americas
BOSC	Board of Scientific Counselors
CEAP	Conservation Effects Assessment Program
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
C-VPESS	Committee on Valuing the Protection of Ecological Systems and Services
CWA	Clean Water Act
DSP	Decision Support Platform
EMAP	Environmental Monitoring and Assessment Program
EO	Executive Order
ERP	Ecological Research Program
ESV	Ecosystem Service Valuation
GIS	Geographic Information System
HB	Hierarchical Bayesian
HHWB	Human Health and Well Being
IPCC	Intergovernmental Panel on Climate Change
LTER	Long Term Ecological Research
LTG	Long-term Goal
MEA	Millennium Ecosystem Assessment
MIMES	Multi-scaled Integration of Models for Ecosystem Services
MYP	Multi-year Plan
NAS	National Academy of Sciences
NAWQA	National Water Quality Assessment
NCEE	National Center for Environmental Economics
NEON	National Ecological Observatory Network
NEPA	National Environmental Policy Act
NESCS	Non-market Ecosystem Services Classification System
NGO	Non-governmental Organization
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRCS	National Resource Conservation Service
NSF	National Science Foundation
OE	Outreach & Education
OMB	Office of Management and Budget
ORD	Office of Research and Development
PART	Program Assessment Rating Tool
ReVA	Regional Vulnerability Assessment
SAB	Science Advisory Board
STAR	Science to Achieve Results
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WQP	Water Quality Plan
WRI	World Resources Institute

INTRODUCTION

The United States Environmental Protection Agency (EPA) is one of the few federal agencies that operates in both regulatory and scientific capacities. Through its Office of Research and Development (ORD), EPA conducts research necessary to ensure that the Agency's policies, programs, and regulations are based on a scientifically defensible foundation.

In Fiscal Year 2001, to help ensure that it continues to satisfy a dual responsibility of research that focuses on current as well as emerging issues in an effective manner, ORD initiated the process of developing research plans that look ahead 5 - 10 years. These "Multi-Year Plans" (MYPs) serve several purposes, including:

- Providing a clear strategy for each research program;
- Demonstrating how ORD’s research programs contribute to the achievement of the Agency's strategic goals;
- Providing information to support budget formulation decisions; and
- Informing performance and accountability reporting, including the OMB Program Assessment Rating Tool (PART) review.

This document presents the MYP for ORD's Ecological Research Program (ERP) for FY2008-FY2014. Over the past decade, ERP has focused successfully on ecosystem monitoring, diagnostics and modeling. The current program has evolved from three long-term goals (LTGs) articulated in the 2003 MYP:

1. National policy makers will have the tools and technologies to develop scientifically defensible assessments of the state of our nation’s ecosystems and the effectiveness of existing national programs and policies.
2. States and tribes apply improved tools and methods to protect and restore their valued ecological resources.
3. Decision-makers understand the importance of ecosystem services and make informed, proactive management decisions that consider a range of alternative outcomes.

From a scientific perspective, the program has made major advancements in developing and implementing statistically defensible, scientifically rigorous, and policy relevant monitoring designs. Accomplishments also include, but are not limited to, the identification of indicators to be used within these designs, the interpretation of these data, and extrapolation of local data within regional contexts.

The program has increasingly focused its attention on the third long-term goal, leading to some of the Agency’s most complex environmental management decisions. One of the unique features of this work has been the integration of multiple models, at multiple scales, to assess multiple impacts (positive as well as negative) over time. In short, the program is seeking to understand how alternative management scenarios will affect specific ecosystem functions.

In 1997, EPA established an independent Board of Scientific Counselors (BOSC) to provide advice and recommendations to ORD about its research programs and plans, including ways to improve the quality of ORD's research and to strengthen its relevance to EPA's mission. In 2005, the BOSC Subcommittee for the ERP conducted a full review of the Program. In its formal report to ORD, this Subcommittee highlighted the significance of ERP's research on ecosystem services:

> *The research, tools, and analytical technologies developed under the ERP represent the most comprehensive federal government research program examining the provision of ecosystem services and the communication of these to decision-makers. . . .*
>
> *. . . The goal and sub-questions form a body of work that should proceed as a whole. Because the ongoing work focuses on the delivery of tools to understand societal benefits of ecosystem services, new research on the provision of these ecosystem services is essential.*

Given the increasing importance of ecosystem services as a means of evaluating the efficacy of alternative management options and the positive perspective of the peer reviews, we chose to augment our effort in this area. Accordingly, this MYP will describe our proposed research on ecosystem services and their relationship to human health and well-being, and our ability to place a value on services in monetary or non-monetary terms, now the primary focus of the ERP.

ECOSYSTEM SERVICES -- BACKGROUND AND DRIVERS

A number of science drivers influenced the new direction. In a 1997 report on the role of EPA's research in support of environmental decisions (NAS 1997), the National Academy of Sciences highlighted the importance of ecosystem services:

> ***Human society is dependent on the goods and services provided by ecosystems, including clean air, clean water, productive soils, and generation of food and fiber. A growing recognition of this dependence alters the way we conceptualize environmental problems****. Reducing the harmful environmental impact of human activities on ecosystems, which in turn provide humans with essential goods and services, is of direct benefit to society.* [emphasis added]

The report emphasized the variety of factors, including social factors, that underlie environmental problems and suggested that EPA's research should include issues of: "resource utilization; diffusion of science into policy; individual and collective decision making; economic, social, political, and legal structures; human settlement and land use; ethics and equity; technological innovation and diffusion; and interactions of social processes with physical/chemical and biological processes."

The NAS' recommendation was widely reflected in research initiated by the ERP in the mid- to late-1990s. The ERP has been recognized for pioneering new research that makes ecology relevant to societal and policy issues; several examples are provided below. Through this MYP, ERP will continue to build on these innovations.

- *Research to develop Alternative Future Scenarios for place-based analyses*—Six major studies, at local to regional scales, in collaboration with stakeholders, resource management agencies, and academia, examined alternative management strategies and their effects on ecological and social outcomes. Surprisingly, the scenario endpoints used in these early studies closely mirror the Millennium Ecosystem Assessment (MEA) ecosystem service categories.

- *"Water and Watersheds" grants, co-sponsored with the National Science Foundation (NSF)*—Interdisciplinary watershed studies requiring, as a condition of funding, that grantees demonstrate research collaboration between physical, biological and social scientists.

- *Research to develop methods to assess regional-scale vulnerability to ecosystem stressors (Regional Vulnerability Assessment program, or ReVA)*—Providing regional-scale, spatially explicit information on the extent and distribution of both ecological stressors and sensitive resources, and developing methods so that management actions can be prioritized on the basis of relative risk. Products include web-based toolkits that enable users to predict the consequences of potential environmental changes under alternative future scenarios and to communicate economic and quality of life trade-offs associated with alternative environmental policies.

- *ERP's Landscape Ecology program*—Anticipating many ways that methods and products derived from landscape ecology principles can be used to advance our understanding of ecosystem services

- *Research on ecosystem restoration*—Recognizing that communities choose restoration priorities based on more than engineering criteria, the research program was broadened to include development and application of tools to address social and economic issues.

The MEA has also been an external driver of great significance to the program's current focus. The MEA, produced for the United Nations in 2005 by more than 1,300 scientists from around the world, is one of the most comprehensive reports to date on ecosystem services. Many of the document's suggestions and concepts have been adopted as part of ERP's new research strategy, including its depiction of the complex relationship that exists between ecosystem services and human well-being (MEA 2005; see Figure 1 and http://www.millenniumassessment.org/en/Condition.aspx).

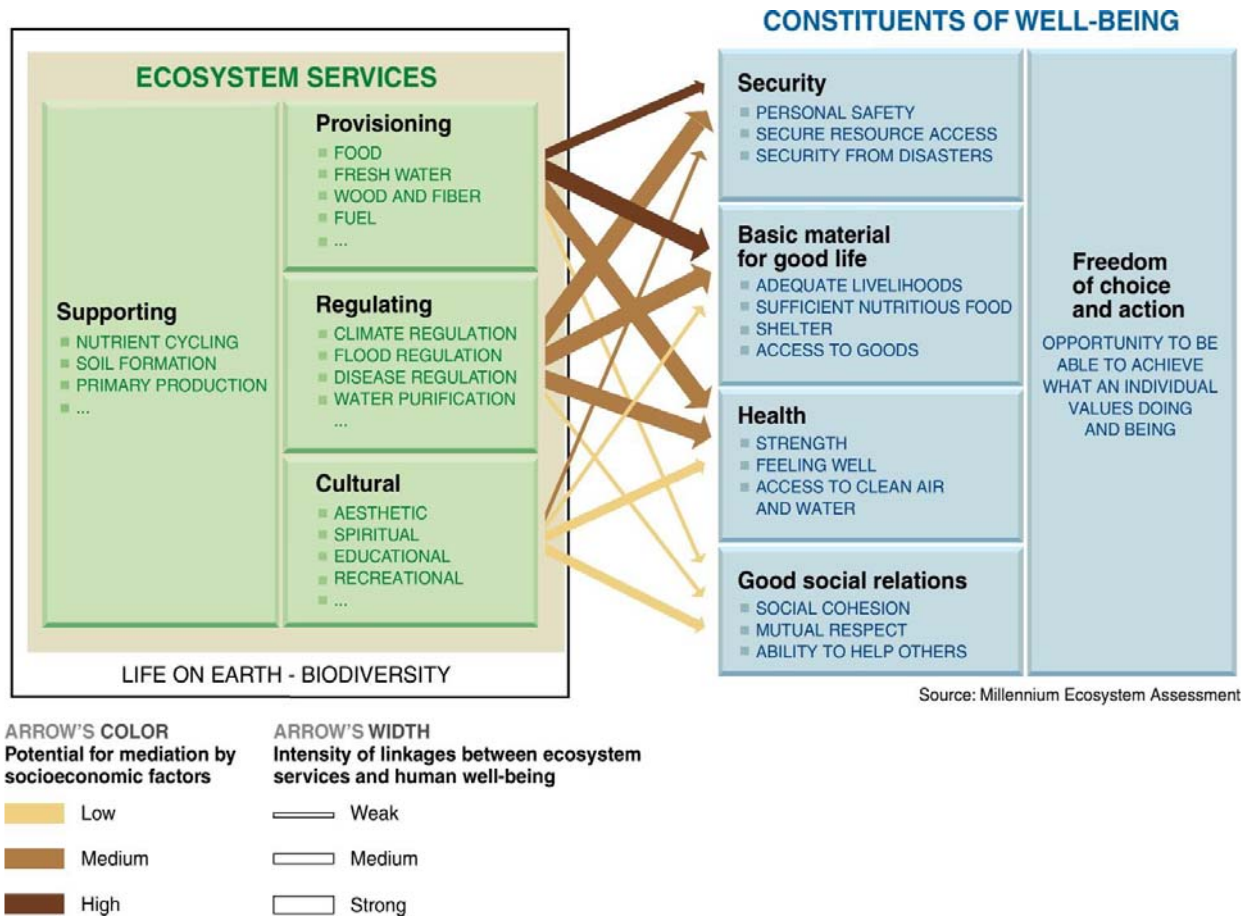

Figure 1 Relationships among ecosystem services and human well-being

One particular finding of the MEA that resonated with the ORD research team states:

> *Even today's technology and knowledge can reduce considerably the human impact on ecosystems. They are unlikely to be deployed fully, however, until ecosystem services cease to be perceived as free and limitless, and their full value is taken into account.*

This barrier may be the single most important concept that the ERP has been designed to address.

In 2006, EPA developed the *Ecological Benefits Assessment Strategic Plan* (U.S. EPA 2006; http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/EcologBenefitsPlan.html). The interdisciplinary ecological benefits assessment process in the Plan (page 9) has been adopted by the ERP. Also, based on this document as well as Boyd and Banzhaf (2006), we define ecosystem services as **the products of ecological functions or processes that directly or indirectly contribute to human well-being, or have the potential to do so in the future.** This definition provides a broad interpretation of ecosystem services to characterize services that may or may not be quantifiable. It is used to help us recognize the broad array of services we receive from ecosystems. The ERP definition is one of several definitions currently used in the literature. A more descriptive definition and helpful information is provided in the Ecological Society of America primer on ecosystem services (see http://www.actionbioscience.org/environment/esa.html). Table 1 is a catalogue of the range of ecosystem services that fit within the definition and are examples of those of highest priority to the ERP, many of which are within the purview and expertise of other Agencies.

While the MEA was a critical, initial step to demonstrate the potential for assessing global trends in ecosystem services, it is important to note that the MEA did not fully translate the global assessments to regional or even national scales of analysis. In May 2007, the World Resources Institute (WRI, the organization that initiated the MEA) released a follow-up document: “Restoring Nature’s Capital: An Agenda for Action to Sustain Ecosystem Services” (http://www.wri.org/publication/restoring-natures-capital).

The ERP is encouraged to note that many aspects of this new call to action by the initiators of the report reflect work underway or formally proposed by the ERP. These common themes include:

- Designing a system for monitoring ecosystem services, using the best scientific and communication technologies, and using the resulting information to conduct regularly recurring assessments of ecosystem services (reflected in new LTG 2).

- Increasing research on collaborative management of services across spatial scales, including investigating ways to make the concept of “ecosystem service districts” an operational management option (reflected in ERP's place-based research).

- Enhancing understanding of ecosystem impacts that emerge over longer time scales, including threshold responses or “tipping points” (reflected in ERP’s ongoing suite of grants investigating threshold behavior and regime shifts in aquatic ecosystems).

- Developing tools to identify and manage trade-offs among services, over time, and in relation to who receives the benefits and who bears the costs (reflected in new LTG 1 – Decision Support Platform).

- Disseminating information on ecosystem services in ways that make it useable by the public (reflected in new LTG 1 – Decision Support Platform).

- Conducting research on the relationship between participatory decision-making processes and social, environmental, and economic outcomes (reflected in new LTG 1 – Decision Support Platform and Outreach and Education) .

Table 1 Types of Ecosystem Services on Which the ERP Will Focus[1]

SUPPORTING SERVICES	*REGULATING SERVICES*	*PROVISIONING SERVICES*	*CULTURAL SERVICES*
Biogeochemical Cycling	Air quality regulation due to vegetation	**Food/Fiber Production**	**Recreational**
Carbon Cycling	Micro-climate regulation due to vegetation	Plant crops (grains, fruits, et	Hunting & Fishing
Carbon pool storages	**Disturbance & Natural Hazard Regulation**	*Animal protein* Terrestrial (livestock)	Ecotourism/Nature Viewing/ trekking/ camping
	Erosion Control	Wild aquatic (commercial fish)	Boating
Carbon sequestration	Flood Control	Grazing Forage Production	Recreational Sports
Nitrogen Cycling	Fire Control	**Fuels**	**Sense of place**
Nitrification	**Biological Regulation**	**Water provisioning**	**Spiritual value**
Denitrification (in rivers, lakes, reservoirs, wetlands)	Pollination	Quality	**Existence value / bequest value**
Habitat / refugia	Pest Control	Quantity	
Terrestrial	Disease Control	Surface water storages	
Aquatic - Fresh water		Groundwater	
Aquatic - Estuarine		Timing: Maintenance of base flow	
Aquatic - Near-coastal, marine		Hydrologic regime	
Biodiversity			

[1] A more detailed catalogue of services is provided as Appendix A.

Further, the WRI will be a partner in the research outlined in this MYP.

Most recently, EPA's Science Advisory Board's Committee on Valuing the Protection of Ecological Systems and Services (C-VPESS) is scheduled to conclude, in 2008, its four-year assessment of Agency needs in this area. The Committee has welcomed the ERP's focus as a way to strengthen the foundation for ecological valuation, and commends EPA for asking for further science from interdisciplinary experts. As with WRI, the ERP has enlisted the assistance of several of these Committee members as advisors to ensure the ERP continues on a path consistent with that outlined by the SAB.

In addition to these scientific drivers, several statutory and regulatory mandates for EPA support the shift to an ecosystem services focus, including:

- **Executive Order (EO) 12866.** EO 12866 requires an examination of the environmental costs and benefits of EPA's regulatory actions. Implementation of this Order has been hindered by the EPA's inability to account for the value of ecosystem services and any costs associated with service losses. Thus, tools that can help account for ecosystem services will benefit all EPA program offices responsible for implementing EO 12866.

- **Clean Water Act (CWA).** The CWA has several provisions that give EPA authority to conduct research on, and regulate impacts to, ecosystem services provided by aquatic systems. Section 404, covering permits for dredge and fill requests, requires that EPA issue guidance on procedures for evaluating and mitigating adverse environmental impacts to wetlands resulting from projects receiving federal aid. The CWA guidelines for implementing wetlands mitigation banking provide descriptions of wetland values and functions to consider for protection, and include the overall goal of "no net loss" in wetland values and functions, such as water purification and recreational value. In a broad sense, the CWA (Section 101) requirements for establishment of designated uses ("fishable, swimmable") and criteria that maintain those uses is a focus on protecting the services provided by aquatic ecosystems.

- **National Environmental Policy Act (NEPA).** The Council on Environmental Quality (CEQ) implementing regulations for NEPA provide authority for explicit valuation and consideration of ecosystem services when Federal agencies prepare environmental impact statements.

- **Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).** The regulations that guide the assessment of natural resource damages under CERCLA provide for compensation resulting from injury to natural resources and the loss of services those resources provide.

In addition, several statutes, including the Clean Air Act, the Clean Water Act, the Toxic Substances Control Act, the Federal Insecticide, Fungicide and Rodenticide Act, and the

Resource Conservation and Recovery Act either directly or indirectly authorize EPA to conduct research related to protecting ecosystem services. While these statutes pre-date the current use of the term "ecosystem services," they support the concept of protecting ecosystem services by protecting ecosystem structure and processes for their benefits to humans.

Collectively, the NAS, SAB, BOSC, grants research, in-house research, the MEA, the legislative mandates, and the expected future needs of the Agency each contribute to the foundation on which we are building the redirected ERP.

RESEARCH PLAN OVERVIEW

Vision: Contribute to a comprehensive theory and practice for characterizing, quantifying, and valuing ecosystem services, to ensure that their relationship to human well-being is consistently incorporated into environmental decision making.

Mission: Provide the information and methods needed by decision makers to assess the benefits of ecosystem goods and services to human well-being for inclusion in management alternatives.

Goal: To transform the way decision makers understand and respond to environmental issues by making clear the ways in which our policy and management choices affect the type, quality and magnitude of the goods and services we receive from ecosystems.

In general, ERP will measure this goal in terms of the increasing number of local, state, regional, national and/or other environmental decision makers confirming the use of ERP products, information and/or assistance to support their decision making.

General Research Questions

The overarching research questions for the Program are:

[2] As defined in the 2006-2011 EPA Strategic Plan, the Agency's four strategic goals are (1) Clean Air, (2) Clean and Safe Water, (3) Land Preservation and Restoration, (4) Healthy Communities and Ecosystems, and (5) Compliance and Environmental Stewardship (see http://www.epa.gov/cfo/plan/plan.htm).

- *What are the effects of multiple stressors on ecosystem services, at multiple scales, over time*?

- *What is the impact of changes in these services on human well-being and on the services' monetary and non-monetary value?*

To answer these questions we need to develop quantitative, operational definitions for ecosystem services; know how these services are distributed throughout the landscape, and in what quantity and quality; project how they will respond to combinations of large and small scale stressors; and determine alternative management options that would optimize their sustainability.

General Approach

Our objective is to inform a wide range of issues related to questions of social choice, with a special focus on informing the evaluation of trade-offs among ecosystem services provided under alternative management and policy decisions. To achieve this objective, we will undertake a multi-dimensional research plan that includes a range of focused investigations as well as integrating, thematic elements. The focused investigations will look at the provision of ecosystem services from three different perspectives: (1) the effect of a single, ubiquitous pollutant (reactive nitrogen) on service quality and quantity; (2) the dynamics of service flows in two priority ecosystems (wetlands and coral reefs); and (3) the dynamics of service flows in four geographic regions (Midwestern US; Willamette Basin, Oregon; Tampa Bay, Florida; and the Coastal Carolinas), that represent a spectrum of ecological and socioeconomic characteristics. The cross-cutting themes we will investigate include the relationship between ecosystem services and human health; landscape characterization; ecosystem service inventories; alternative management option modeling techniques; and ecosystem service valuation. We will integrate the research outputs from the focused investigations and the thematic work into a decision support platform and will convey the findings through an organized education and outreach effort.

Research Outputs

Our research will have four general types of outputs:

- ***Measures and dynamic maps of ecosystem services*** **–** Colloquially known as "maps," these products will reflect the most recent advances in ecological monitoring, spatial analysis, ecological mapping, and cartographic techniques in order to create spatial representations of ecosystem services over multiple scales and time-periods. They will be used for communication, outreach, planning, assessment, and resource management.

- ***Predictive models relating to the response of stressors*** **–** Models are the foundation of our ability to forecast change and proactively assess how ecosystem functions and services are likely to respond to natural and human stressors. These models will reflect a variety of techniques, including statistical, landscape, and process models. Modeling techniques will be matched to needs for temporal and spatial scales, the scope of stressors and endpoints to be considered, and intended use of model output.

- ***Management Options and Alternative futures*** **–** We will work with collaborators to develop and implement alternative future scenarios relevant to their interests in conserving ecosystem services. These scenarios will be implemented using our suite of modeling tools; results will be presented as maps and other visualization tools (e.g., "flyovers" and other animations).

- ***Decision Support Platform*** - We are developing a decision support platform to enable managers and decision-makers to explore how various policies affect the likely distribution of ecosystem services, and human health and well-being outcomes, both now and in the future. This decision support platform will be "powered" primarily by ERP modeling and scenario techniques. However, the design of the platform will proceed in close cooperation with ERP's teams for Outreach and Education and for Valuation, as well as with our non-governmental organization (NGO) partners. Doing so will ensure that the platform can capture user needs for decisions and effectively translate our analytical results in ways that are useful to policies, rules, market incentives, and environmental stewardship.

These outputs provide the ecological information and methods needed by decision makers to assess the benefits of ecosystem services and to identify strategic management options needed to meet our desired outcome for the Ecological Research Program, which is to secure the integrity and productivity of our ecological systems over space and time.

Figure 2 illustrates in a hypothetical example how ERP's research output might initially be communicated. In this chart, we depict nine different ecosystem types within a particular geographic district and indicate the magnitude of the specific services each ecosystem provides. The y-axis could be one of many measures, from monetary values to rates of change and are shown here simply as relative differences. There is no attempt in this example to pass any judgment on positive or negative being "good" or "bad."

Having established and depicted a base case for a particular set of related ecosystems, we can develop a second chart that depicts incremental changes in these services due to a management action or the effect of an environmental stressor. We can present this information in a variety of ways, including:

- Ecosystem services by ecosystem type;
- Bundled ecosystem services by ecosystem type; or
- Collective common services for the ecosystem service district.

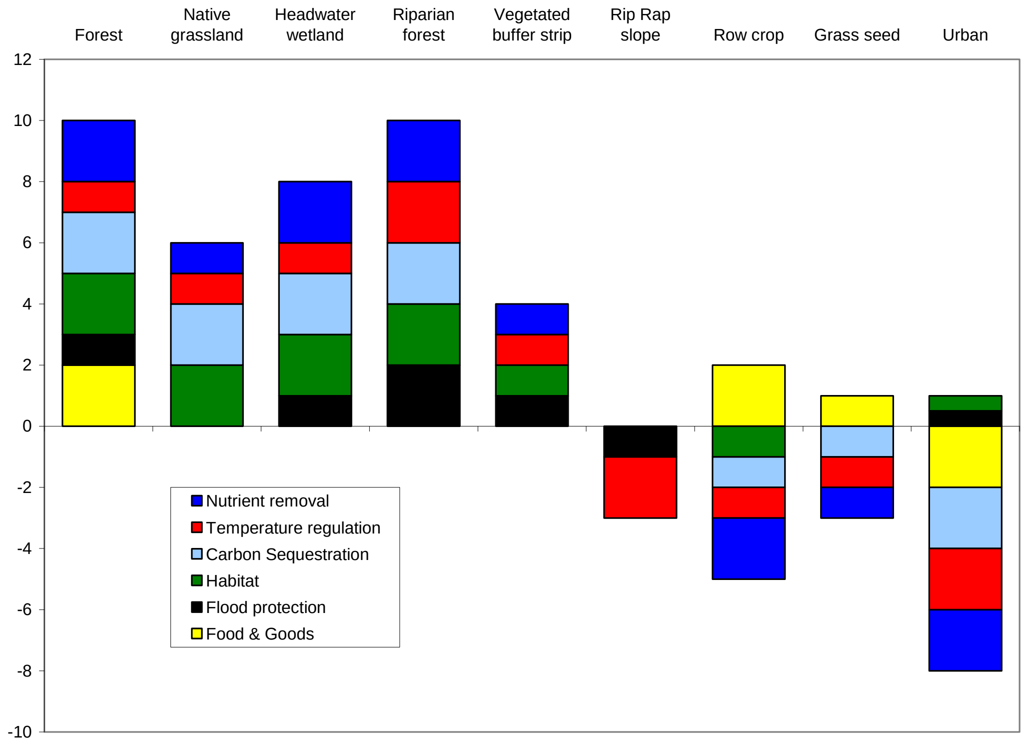

Figure 2 **Hypothetical ERP research output. Illustrative example of the services that would be expected to be provided (or consumed, if negative) within an ecosystem service district. All values are relative and could represent rates of production, current service provision, monetary value, or other relative measure.**

Figure 3 is a depiction of changes in services by type of ecosystem. In this hypothetical example, a riverine wetland provides a suite of services in its baseline condition (as illustrated in the stacked bar on the left). After significant alterations of the system for wild rice production (illustrated by the middle bar), the provision of all services except for food and fiber becomes negative. The bar on the right represents the difference between the baseline and altered services.

Thus, ERP research is designed to provide an understanding of the type, quantity, and distribution of services gained or lost as a result of alternative management options. This information enables economists and decision-makers a way to better account for the **full value** of those changes, many of which are currently not considered at all. We can then convey this information to decision makers using an innovative decision-support platform so that they can make informed, proactive choices when considering the alteration of an ecosystem.

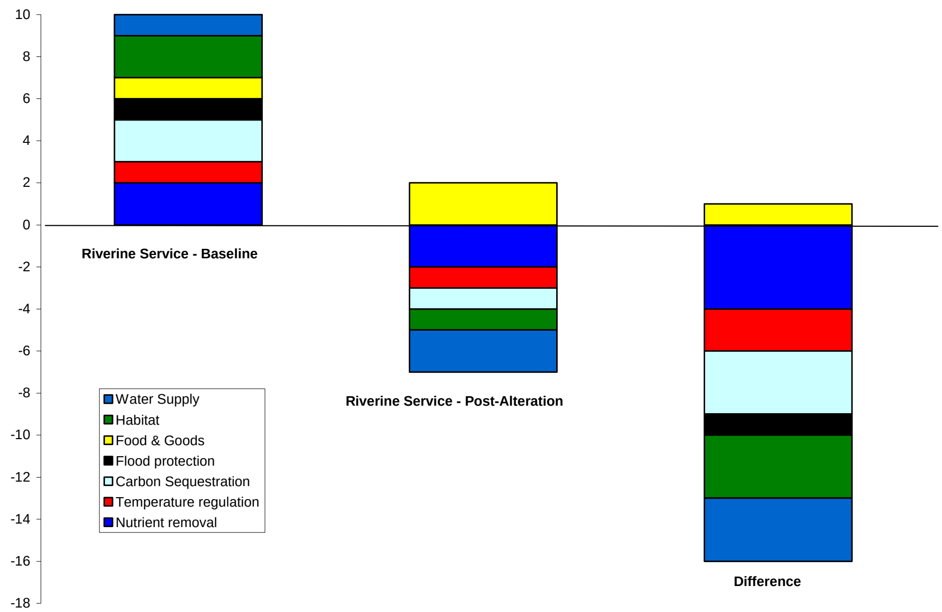

Figure 3 **Hypothetical example of research output as a depiction of the changes in specific ecosystem services resulting from ecosystem alteration. In this example, after significant alterations of the system for wild rice production (illustrated by the middle bar), the provision of all services except for Food & Goods becomes negative.**

Applications of Research Outputs

The ERP research program is designed to act as a catalyst for innovation in management actions, policies, rules, and governance by providing information to be used by the Agency and others in:

- ***Setting policies and guidelines*** that can achieve ecological protection through a variety of policy instruments that do not have the legal force of national rules;
- ***Quantifying benefits for national rule-making*** in response to the Office of Management and Budget data requirements for benefit–cost assessments;
- ***Developing environmental metrics and indicators for ecosystem services*** for use in periodic reports on the environment or for establishing environmental accounts within our national Gross Domestic Product accounts;
- ***Catalyzing market innovations*** that engage the private sector in achieving environmental protection objectives; and

- ***Evaluating management actions*** that assist decision makers and stakeholders in making choices with a common understanding of the implications and tradeoffs.

ERP research can also provide information useful for reducing transaction costs in, for example, market trading; estimating the availability, reproducibility, permanence and/or longevity of ecosystem services over space and time; identifying opportunities for maximizing multiple services per investment; recommending metrics for documenting environmental outcomes; and providing credible timelines required to achieve expected outcomes (given the lag that often exists between action and environmental response).

Logic Model

Figure 4 is a variation of a logic model[3] that is intended to summarize the ERP. The program planning is done from right to left, keeping the target vision, mission, and goal in mind. Subsequently, the program is implemented from left to right. For implementation, the first column represents the human and financial resources of the program, the second column describes the major categories of research activities, and the third column identifies a portfolio of research products and outputs. The logic model also summarizes the manner in which ERP will communicate research results to various users and the types of outcomes and specific environmental results that the research program is designed to achieve.

The logic model provides a clear link between research and intended outcomes, defined as "transfer to partners," creating an awareness of the steps required to accomplish the end (outcomes). All too often, the research in the first three columns (Resources, Research Activities, and Research Outputs) is the sole focus of the effort, thus missing the need to affect behavioral changes that will help ensure the outcomes. The cyclical nature of the model reflects the need for continuous feedback between outcomes and research, such that the latter can be modified or expanded to further enhance the former.

RESEARCH FRAMEWORK

To assist in achieving the goal of the Program, we have developed a research framework. ERP's research framework combines specific long-term goals and an organizational structure designed to facilitate cross-functional collaboration and cost-effectiveness.

Long-Term Goals

The ERP has defined five long-term goals (LTGs) to guide its research agenda. The goals reflect the general approach described above, namely three cross-cutting thematic elements (LTGs 1, 2 and 3) and two focused investigation approaches (LTGs 4 and 5). More broadly, these goals combine ERP's interest in (1) advancing research on tools

[3] See http://en.wikipedia.org/wiki/Logic_model for general information about logic models.

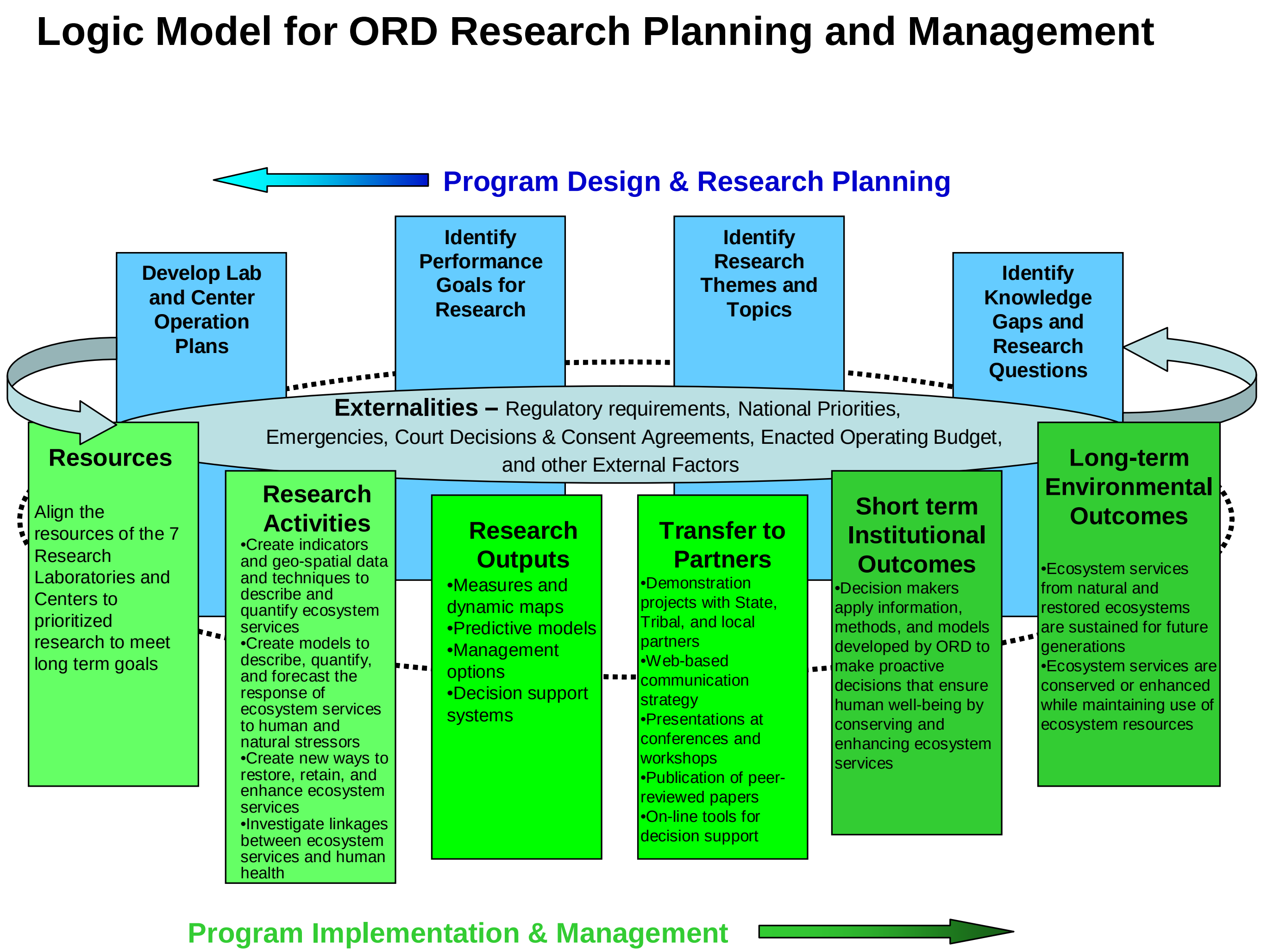

Figure 4 ERP Logic Model

needed to improve ecosystem management and (2) applying those tools in the context of real world issues facing decision makers. The five LTGs are:

1. Effective Decision Support. By 2014 ERP will provide innovative, online decision support that offers EPA, Regions, States, local communities and resource managers the ability to integrate, visualize, and maximize use of diverse data, models and tools at multiple scales to generate alternative decision options and to understand the consequences of management decisions on the sustainability of ecosystem services, their value, and human well-being. This long-term goal integrates the products of the other four long-term goals.

2. National Mapping, Inventory, and Modeling. By 2013 ERP will deliver publicly accessible, scalable, national atlas, inventory system, and models for selected ecosystem services that can be quantified directly or indirectly.

3. Nitrogen Assessment. By 2013 ERP will provide an assessment of the positive and negative impacts on ecosystem services resulting from changes in nitrogen levels at select locations and within select ecosystems.

4. Ecosystem Assessments. By 2013 ERP will provide guidance and decision support tools to target, prioritize, and evaluate policy and management actions that protect, enhance, and restore ecosystem goods and services at multiple scales for two specific ecosystem types: wetlands and coral reefs.

5. Place-Based Demonstration Projects. By 2013 ERP will complete four site-specific demonstration projects that illustrate how regional and local managers can proactively use alternative future scenarios to conserve and enhance ecosystem goods and services in order to benefit human well-being and to secure the integrity and productivity of ecological systems. The four locations for these projects (Midwest, Willamette, Tampa Bay and the Coastal Carolinas) represent a spectrum of physiographic and socioeconomic characteristics; local, regional, and national drivers of ecosystem change; and the type and potential impact of resource management decisions.

The second half of this document describes ERP's planned research with respect to the achievement of each of these goals and the annual performance goals that ERP will use to track its progress.

Organizational Structure

The ERP has established an organizational research structure to maximize coordination, integration, consistency, and team effectiveness dynamics. The matrix provided as Figure 5 is a diagram of this research structure and is an important part of the Program's strategic plan.

Along the top and left side of the matrix are the goals (and, as appropriate, subcomponents of the goal) and the percent of total internal effort ERP currently expects to apply to each. The column on the far right of the matrix identifies the lead scientists

FIGURE 5

Ecological Research Program Planning and Implementation Framework

			DEMONSTRATION PROJECTS						Theme Leads
			LTG 4 Ecosystem Studies (23%)		LTG 5 Place-Based Demonstration Projects (28%)				
			Wetlands (19%)	Coral Reefs (4%)	Willamette (5%)	Tampa Bay (7%)	Mid-West (7%)	Coastal Carolinas (9%)	
CROSS PROGRAM THEMES	LTG 1 Effective Decision Support (7%)	Integrated Decision Support Platform (3%)							
		Valuation of Ecosystem Services (2%)							
		Ecosystem Services and Human Health (1%)							
		Outreach & Education (1%)							
	LTG 2 Mapping, Modeling, and Monitoring Ecosystem Services at Multiple Scales (37%)	Landscape Ecology and Mapping (10%)							
		Indicators and Monitoring of Ecosystem Services (21%)							
		Modeling for Scenarios and Forecasting for Alternative Management Options (6%)							
	LTG 3 Pollutant-Specific Studies	Nitrogen (5%)							
Project Leads									
					Place Based Coordinator				

responsible for conducting research for each of the goals. Similarly, the row of cells at the bottom of the matrix identifies the leads for the column goals and their components.

Unique to this ORD Program is the fact that each interior cell in the matrix identifies scientists who are responsible for participating in both "row" and "column" discussions, strategy development, and research. This structure optimizes interaction within the program. Behind the matrix in a third dimension are the staff of ORD that are participating in the program within the bounds of the LTGs.

RESOURCES

The ERP proposed budget for fiscal year 2008 is approximately $68 million. The FY2008 budget is sufficient to support the salary, travel, and operating expenses of an approximately 280-person staff (scientists and administrative support personnel). Given the expertise of the ERP staff, the planned allocation of ORD effort for each goal by 2010 is roughly as follows:

Long-term goal 1:	7 percent
Long-term goal 2:	37 percent
Long-term goal 3:	5 percent
Long-term goal 4:	23 percent
Long-term goal 5:	28 percent

These allocations pose some specific challenges for the program that will be explained in later sections. In particular, accomplishment of LTG 1, one of the most critical of our goals, will depend on partnerships that complement the capacity and capability of current ORD staff.

RELATIONSHIP TO OTHER RESEARCH PLANS

As described earlier, ORD organizes its overall research agenda via MYPs prepared for 13 complementary research areas that have scopes ranging from very broad to problem-specific.[4] Table 2 summarizes the scope of ORD's research programs. As a basic research program with a broad scope, the ERP focuses primarily on advancing fundamental research capabilities and anticipating important emerging issues rather than on shorter-term, regulatory agenda-driven problem solving. As such, ERP's research can and does contribute to the ecological dimensions of other research plans. More broadly, the ERP's approach to quantifying linkages between ecosystem services and human well-being offers potential for framing the management of ecological risk in new and productive ways that cut across environmental media and scientific disciplines. This framework can also be used to help communicate research results from other ORD programs. For example, the Sustainability Program conducts research to advance new technologies that better conserve energy and materials. The ERP complements the Sustainability Program by providing ways to assess options for conserving ecosystem services for which there are no readily available technological substitutes.

[4] See http://epa.gov/osp/myp.htm.

TOPICAL RESEARCH		BROADLY APPLICABLE RESEARCH	
Overarching Issues	Sustainability	**Ecological Research Program**	**Human Health Research Program, including Human Health Risk Assessment**
	Global Change		
Program Office Alignments	Air quality		
	Water quality		
	Drinking water		
	Land		
	Safe pesticides/Safe products		
High Priority Topics	Endocrine disruptors		
	Mercury		
	Nanotechnology		

Table 2 Summary of ORD Research Plans

The ERP seeks to advance the state of the science on the role of ecosystem services in human health and well-being at individual to societal levels. Clearly, the Human Health Research Program (HHRP) is ORD's primary instrument to evaluate multiple environmental insults to the human organism. Currently, however, the focus of the HHRP is on elucidating chemical source-to-effect pathways; it does not encompass the role of the natural environment in exposure mitigation or health promotion, nor does it address aspects of human well-being other than individual burden of disease. There is no formal relationship between the two plans at this time, but we continue to seek opportunities to develop this linkage.

The ERP maintains a close working relationship with the Global Change and Water Quality Programs in order to identify areas of productive collaboration and avoid duplication. Research products from each program are often applicable to the other, and some ORD scientists split their time between the programs and develop complementary collaborations. For example, the ERP complements the Global Change Program by providing data and methods on a broad range of natural and human stressors to ecosystems. In turn, the ERP looks to the Global Change Program for climate change scenarios, which the ERP includes as one of the drivers in its development of alternative future scenarios, in order to provide a more comprehensive context for considering management options.

There has also been collaboration among the extramural components of the ERP and the Global Change Program, especially with respect to ecosystem services. For example, in 2005, the ERP STAR grant program funded eleven exploratory research grants to quantify non-linear thresholds in aquatic ecosystems shifts related to a variety of stressors, including climate change, and their subsequent effects on ecosystem services (http://es.epa.gov/ncer/rfa/2004/2004_aqua_sys.html). In 2007, the Global Change

Program awarded grants from a follow-up solicitation on non-linear responses to climate change (http://es.epa.gov/ncer/rfa/2005/2005_nonlinear_responses.html).

The primary distinction between the ERP and the Global Change Program with respect to ecosystem services is that this topic is the sole focus of the ERP, which is seeking to develop a systematic and comprehensive approach for proactively incorporating services into decision-making in the public and private sectors, at all levels of governance. The major focus of the Global Change Program is to meet EPA's client needs for adaptation and mitigation strategies and to fulfill EPA's responsibilities for the research agenda as described by the ICCP.

Similarly, ERP and the Water Quality MYP (WQ MYP) both address watershed management issues, but from complementary perspectives. For example, the ERP includes water-related ecosystem services as one of its core services for research. The ERP is developing new methods to enhance, maintain, or restore the full range of water-related ecosystem services, including water provisioning, biogeochemical cycling, nutrient cycling, water quality, mitigation of flood and storm surges, and aquatic habitat. The primary focus of the WQ MYP is research that addresses narrower regulatory goals aimed at particular water quality issues. The intersection of ERP and WQP research is typically observed in the context of watershed management.[5]

To avoid unnecessary duplication of research efforts, screening of ERP and WQP projects occurs at several levels. At the Division level, the Division Directors review all staff projects. At the Laboratory and Center level, the Associate Laboratory Directors identify cross-division overlap. In addition, the National Program Directors for these two programs routinely share project information to flag potentially duplicative efforts. Nevertheless, a bright line does not always exist between some of the projects needed to achieve the long-term goals of these two Programs. As with the ERP and Global Change Programs, some ORD staff split their time between the ERP and Water Quality Programs to take advantage of potential synergies.

Table 3 highlights the complementary nature of the ERP, Global Change, and Water Quality Programs in terms of their research focus, endpoints, clients, and staffing. Only through a multivariate look at the three programs can one discern most clearly the similarities and differences. Improving further the interaction among these programs is a management effort still in process in ORD.

[5] See http://epa.gov/osp/myp.htm - wq.

	EPA ORD Research Plan		
	ERP	**Global Change**	**Water Quality**
Focus	Broad Scientific Scope	Problem-specific	Regulatory agenda
Ecosystems	Multiple	Multiple	Aquatic
Stressors	Multiple	Climate Change	Multiple
Work Force	Internal	Internal and Extramural	Internal
Primary Clients	Multiple Program Offices/ Regions	Multiple Program Offices/Regions	Office of Water/Regions
Endpoints	Multiple	Multiple	Water Quality

Table 3 Comparison of Highly Related ORD Research Programs. Only through a multivariate comparison are some differences discernable.

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LTG 1—EFFECTIVE DECISION SUPPORT

1.0 Introduction

Incorporation of ecosystem services and values into policy development and environmental decisions has been impeded by lack of understanding as to their potential applicability to decision making, a dearth of tools for quantification and comparative analysis, and barriers between disciplines. The purpose of LTG 1 is to reduce these impediments so that decision makers have the knowledge and an array of products that allow them to think more broadly about the impacts their decisions have on ecosystem services and to understand, in qualitative or quantitative terms, the implications of these impacts on human well-being. The information and tools will also enable decision makers to include the impacts on ecosystem services and human well-being in their decision-making process.

LTG 1 includes four elements that together with the input from the other LTGs form the foundation for providing decision makers what they need to make better decisions.

- **Human health and well-being** (HHWB) will help decision makers better understand the vital link between ecosystem service provision and priority societal issues such as illness and disease, livelihood, homeland security, cultural preservation, and spiritual fulfillment.
- **Ecosystem service valuation** (ESV) will give decision makers the constructs to describe the diverse values that ecosystems provide in a way that can support the assessment of tradeoffs among decision alternatives.
- **Outreach and education** (OE) will reach out to decision makers to ensure that the research, tool development, and decision support approaches we develop will meet their needs and be applied with confidence.
- **Decision support platform** (DSP) will host and make available an array of tools designed for decision makers operating in different circumstances, communities, spatial scales, and levels of complexity and uncertainty.

LTG 1 is central to the overall success of the ERP. First, it integrates the scientific and socioeconomic dimensions of ecosystem services by asking questions about the relationships between these services and human health and well-being, as well as the way society assigns value (monetary and non-monetary) to them. Second, this goal includes the communication of research results to the public and to decision makers, providing the latter in particular with a collection of tools in a framework that enables them to make the most informed judgments from a holistic view of alternative management options. Furthermore, as a way to maximize their utility, ERP intends to engage decision makers in the development of these tools. While fully dependent on the science contributed by the other components of the program, the ERP comes together in LTG 1.

LTG 1 is also an area in which ORD has the least capability and institutional capacity. While this presents a significant challenge, our intent is to enlist assistance from other parts of the Agency, other agencies, non-governmental organizations, academia, and even the private sector, as partners to achieve our vision for this goal. For example, the valuation component of the research and coordination will draw on the expertise of the Agency's National Center for Environmental Economics (NCEE). This partnership is of particular importance given that NCEE is the part of the Agency that is responsible for the environmental economics research that supports benefit-cost analyses for regulatory actions. Their interest in advancing the science supporting benefit-cost analysis ensures that the information provided in the program can be used as it becomes available. All parts of LTG 1 will be equally dependent on such relationships.

1.1 Ecosystem Services and Human Well-being

Implicit in the concept of ecosystem services are benefits to human society. The Millennium Ecosystem Assessment (MEA; World Resources Institute 2005) describes these benefits in terms of human well-being, comprising health, security, social relations, and freedom of choice and action. The ERP is, on a small and exploratory scale, beginning a unique area of study to characterize the linkages between ecological services and human well-being, with an emphasis on health issues at individual to societal levels. This work, summarized in Figure 6, will incorporate data on human morbidity, mortality and vulnerability, as well as expenditures and other proxies for health outcomes and risks, that are meaningful to decision-makers weighing competing societal concerns. As HHWB measures and indicators are expressions of societal value, valuation is inherent in this work and will be coordinated closely with the ESV component described in Section 1.2. However, the main research emphasis is on documenting the contributions of ecosystem services to diverse aspects of HHWB.

The connections between human health and clean air, land and water are obvious and are already central to EPA research and policy. Largely omitted from consideration, however, is the fundamental role of ecosystems in supplying these and other essentials of life support. An ecological perspective makes clear the relationship between nature's purification, provisioning, and regulating services and such health issues as polluted drinking water, fish and shellfish contamination, and flood-related destruction and displacement. This focus represents a shift from a stressor-driven approach to protecting human health to one that considers the role of ecosystem services in overall human well-being, including disease prevention, health promotion, and community welfare.

Research will address connections between ecosystem services and quality of life—individual and community characteristics including adequate livelihoods, security from natural disasters, spiritual fulfillment, and recreation. Results will populate decision support systems in order to characterize the implications for human well-being of policy action or inaction that affects the provision of ecosystem services. Because of the prime importance to society of human health and well-being, dedicated effort within the ERP is needed to inform emerging research on ecosystem services with data and knowledge from anthropocentric disciplines including public health, epidemiology, sociology, and environmental psychology.

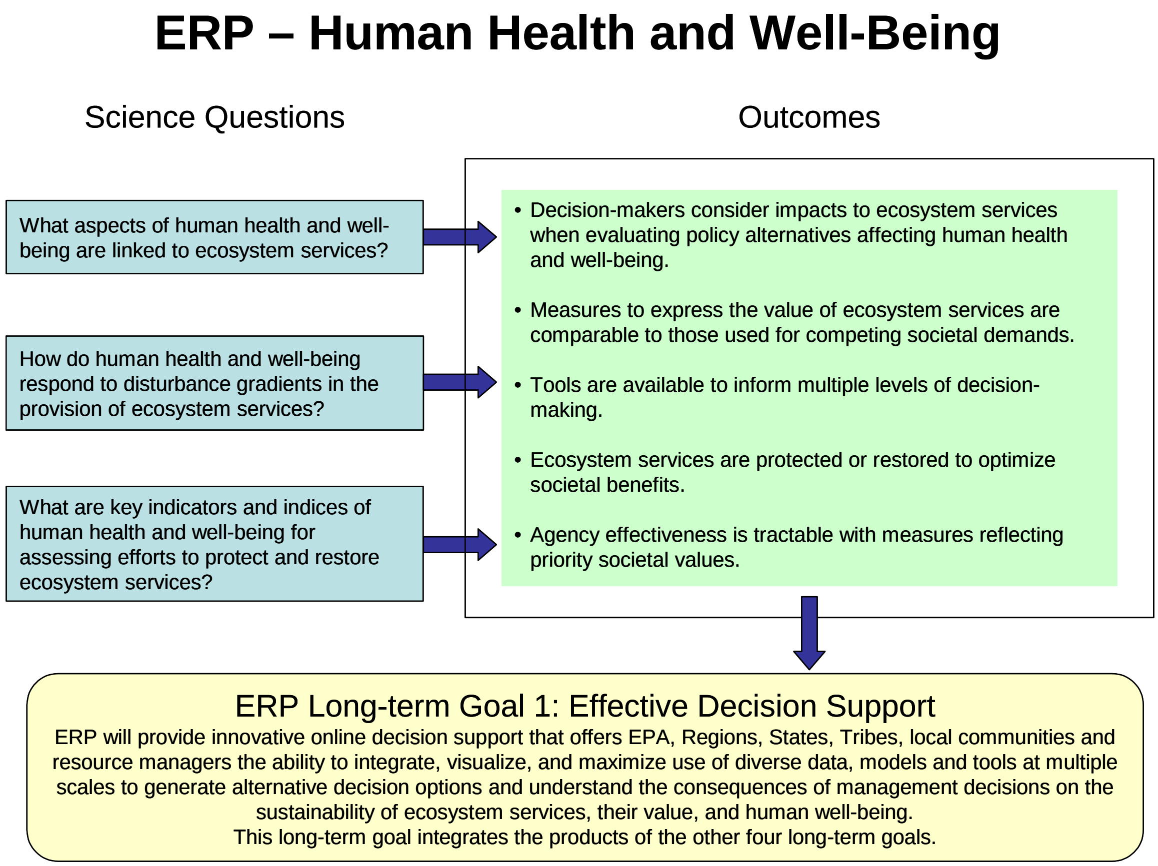

Figure 6 Overview of LTG 1 - Human Health and Well-Being Component

1.1.1 Characterization of ecosystem service provision in terms of HHWB endpoints

One of the primary ERP emphases is to understand how the condition of an ecosystem affects performance of its natural functions, and how these in turn translate into the provision of ecosystem services. Research under the HHWB component will take these findings and characterize their societal implications, with an emphasis on population and community health issues. For example, the ERP will explore a bundle of services provided by wetlands. HHWB research will provide the information needed to value the status of identified wetland services in terms of homes protected from flooding, recreational user-days supplied, water-treatment costs averted, or other measures relevant to ERP research findings about the type, quality and quantity of wetlands service provision. The HHWB component will also address potential disservices, which for wetlands may include risk of mosquito-borne disease.

Characterization of ecosystem services in terms of HHWB is needed in all ERP project areas. In the Willamette Service District, for example, services generated from forests and surface waters will require translation into HHWB benefits, while the parameters of a healthful urban ecosystem invite exploration in Tampa Bay. Urban ecosystem services flow from both green infrastructure and the built environment, and contribute to HHWB endpoints such as physical fitness, mental health, and neighborhood stability.

Research to classify and quantify HHWB endpoints is necessary in order to assign value to ecosystem services that can be compared to the traditionally valued benefits and costs of environmental protection activities. In the early stages of the program, HHWB endpoints may be most feasibly expressed in monetary terms, such as reduced flood insurance payments, recreational expenditures, and reduced costs of mosquito-control measures per wetland area. As the state of the science advances, health endpoints will be further quantified in terms of population risk of illness or mortality. The HHWB research component will seek a comprehensive evaluation of societal endpoints to facilitate a robust consideration of benefits and costs associated with projected changes in the bundle of services provided by an ecosystem or geographic area.

Projects under consideration would deliver outputs such as:

- Associations between the condition of stream habitat and sportfishing revenue.
- Associations between the availability of urban green space and indicators of mental function.
- Models linking wetland condition, type, quantity, and placement to incidence of mosquito-borne disease in sentinel species.

1.1.2 Analysis of the effect of service disruption on HHWB endpoints

A second emphasis of the ERP is to elucidate the role of stressors in disrupting ecosystem services. Significant ERP effort will address the mechanisms by which nitrogen is transported and transformed through ecosystem processes. The place-based initiatives will address additional stressors. HHWB research will focus on human vulnerability to the disruption of ecosystem services. Examples include pathogen levels associated with eutrophication of recreational waters, and the risk of tick-borne disease from fragmentation of forest habitat. Again, initial studies will address readily measured and proxy HHWB endpoints in order to populate ERP decision support tools. Quantification of health risks will require a longer-term effort.

Life stage and socioeconomic status affect the manifestation of numerous HHWB effects related to the disruption of ecosystem services. Children and seniors are more vulnerable than the general population to air pollution, Lyme disease, and loss of autonomy in the built environment. The elderly are also the most susceptible to heat-island effects and mortality from natural disasters. Subsistence cultures are particularly at risk from the loss or degradation of wild food sources. In addition to dietary effects, Tribal Nations suffer unique cultural and spiritual impacts from diminished wildlife populations and habitat. Design of HHWB studies to illuminate life-stage and socioeconomic susceptibility will facilitate ERP alignment with other environmental health research activities, potentially enhancing both in-house and external efforts to evaluate stressor pathways, interactions, and outcomes.

Projects under consideration would deliver outputs such as:

- Trends analysis of wetlands loss and economic impacts from flood damage.
- Models of vector-borne disease risk from habitat encroachment and changes in biodiversity.
- Estimates of morbidity and mortality from air pollution levels under alternative scenarios of urban design.

1.1.3 Development of HHWB indicators and indices

Accountability is an essential requirement for the ERP and across the Agency. HHWB research will seek to provide highly-valued measures of accountability for EPA decisions to protect and restore ecosystem services. Tracking these measures will also facilitate validation of models and scenarios in ERP decision support tools. As data on critical HHWB endpoints may be inaccessible or nonexistent at relevant spatial or temporal scales, research will explore proxy metrics such as sales and distribution of pharmaceuticals and medical supplies. Where linkages between ecosystem services and human health are documented and the ecological data are more accessible at appropriate scales, results will include ecological indicators for use by other EPA programs in health accountability. Core research will also explore definitions and measures of individual and population health beyond incidence of disease and mortality. This work may include developing quality-of-life indicators and indices of population or community health that relate to flows of ecosystem services. Mature indices will be normalized for geography and demographic profile, with estimates of background variation in the absence of ecosystem service degradation. Regionally and nationally tractable measures and indicators will contribute to EPA's Report on the Environment to reflect societal impacts of status and trends in ecosystem services.

Examples of projects/concepts now being considered include:

- Spatiotemporal analysis of links between disease rates and the sale or distribution of medical supplies/pharmaceuticals.
- Analysis of morbidity/mortality statistics and measures of ecosystem condition/function/services.
- Ecological indicators of human health risks.
- Indices of well-being.

It bears repeating that this entire area is exploratory, small, and offers the beginning of such research in ORD. The degree to which it is able to evolve into a larger effort remains to be seen. However, there is no doubt that it is important to assisting decision makers understand any direct or indirect implications on the communities they serve. As such, it is an endpoint in the ERP that is anticipated to provide significant added value.

Table 4 summarizes the Annual Performance Goals associated with the HHWB component of LTG 1.

	Description	**Year Due**
APG 1	Develop and test preliminary indicators of human health and well-being for use in assessing the results of protecting and restoring ecosystem services.	2010
APG 2	Characterize benefits to human health and well-being associated with the provision of selected ecosystem services in the ERP place-based initiatives.	2011
APG 3	Document relationships between disturbance to ecosystem services and changes in human health outcomes or exposures.	2012
APG 4	Develop, test, and implement an index of well-being applicable to multiple ecosystems, stressor scenarios, and ERP place-based initiatives.	2014

Table 4 APGs for LTG 1 - Human Health and Well-Being Component

1.2 Ecosystem Service Valuation

The information provided to decision makers, and to society as a whole, must be in forms most useful for establishing policy and evaluating alternative decision options. Research output associated with LTGs 2-5 will quantify ecosystem services and policy-relevant changes in their delivery, but this output will address only one part of the challenge. The best environmental decisions are those informed by the values society places on the services provided by ecosystems. The central role played by societal values in decision-making requires the ERP to acknowledge valuation of ecosystem services as a key element of decision support.

By 2014, the ERP will provide the information needed by environmental decision makers to use the values of ecosystem services and changes therein to make proactive policy and management decisions that ensure ecological and human well-being. Coordination of approaches and methodologies to value ecosystem services across all elements is required to ensure that we reach this goal. Coordination will:

- Facilitate development of information about ecosystem services and their production that is most critical to the valuation process;
- Encourage appropriate levels of standardization and consistency of approaches and measurement units to maximize comparability of the knowledge developed across program elements;
- Optimize programmatic efficiencies by ensuring transferability of knowledge among program elements, and ultimately to decision makers and the public; and
- Fill critical voids in ERP valuation expertise by fostering strategic alliances internally and externally.

The MEA (World Resources Institute 2005) and notable predecessor efforts (e.g., Daly 1997, Costanza et al. 1997) brought international attention to the contributions made by ecosystems to human well-being. Although concepts of ecosystem services and their socioeconomic worth were introduced a century ago, the science underlying environmental policy based on this awareness remains underdeveloped. Significant and substantial contributions by natural and social scientists are needed to advance ecosystem service science to the degree required for effective decision support. Transdisciplinary partnerships and collaboration are needed to produce:

- New concepts for defining and classifying ecosystem services and bundles of those services;
- Improved approaches and information for describing the production of services; and
- Enhanced and supplemental methods for quantifying the values of ecosystem services and innovative ways of using this knowledge in proactive environmental management decisions.

The research required to achieve these advances is described below and summarized in Figure 7.

1.2.1 Ecosystem Service Definitions and Classification

Ecosystem services, and the ecological structures and processes that produce them, are varied and often interconnected. The MEA and others (e.g., Costanza et al. 1997, de Groot et al. 2002) offer definitions of particular ecosystem services and schemes to classify them, but typically do so only in broad terms. Individual services not currently traded in markets often lack standard definitions and units of measurement, and efforts to characterize their production quantitatively remain largely unguided. A concerted effort toward standardization of the definitions and measurement of ecosystem services will enhance the transparency and transferability of ERP research outputs.

An important research contribution of the ERP by 2012 will be a Non-market Ecosystem Services Classification System (NESCS) based on the precepts of the U.S. Census Bureau's North American Industrial Classification System (APG 5). The purpose of NESCS is to define and classify ecosystem services in a system that tracks their production, consumption, trade and markets. NESCS will aggregate ecosystem services in a hierarchical classification system based on similarities in their production and substitutes or complements in their consumption. Such standardization will enhance the value of ERP research to evaluations of policy alternatives, development of ecosystem service atlases, reports of trends in ecosystem services, and development of ecosystem service trading markets.

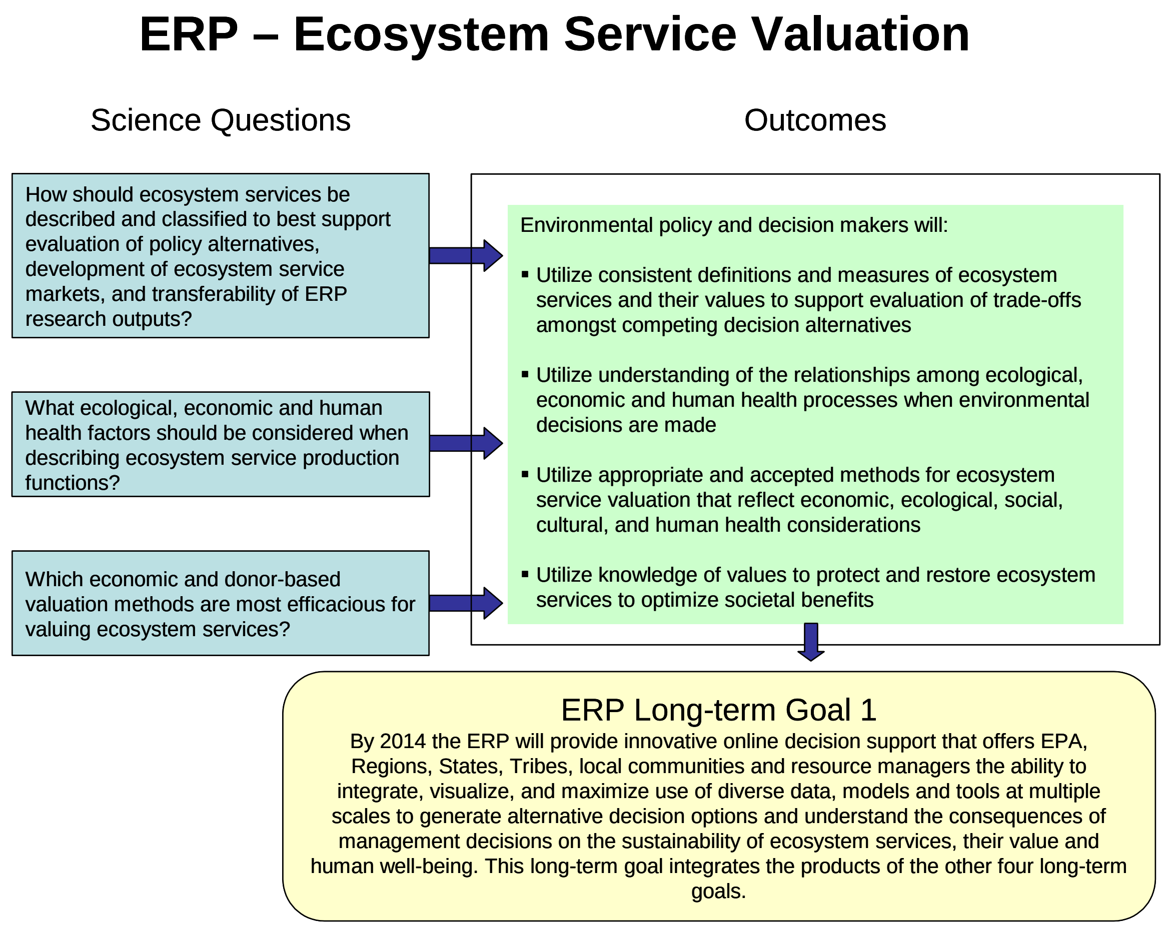

Figure 7 Overview of LTG 1 - Valuation Component

1.2.2 Ecosystem Service Production Functions

Ecosystem services are produced by the structures and processes of ecosystems, as influenced by human activity. These ecological features and their interactions can be described as the *ecological* (or *biophysical*) *production function*. The relationship between ecosystem services and human health might be characterized by a *health production function*. The economic value to society of an ecosystem service refers to its contribution to human welfare (through improving health, recreation, goods and services, or other aspects of well-being). Economic value is measured as society's willingness-to-pay to preserve the ecosystem service, which is influenced by the quality and reliability of the service, its scarcity and degree of substitutability by other services, and the availability of complementary services—the *economic production function*. Once the physical effects of ecosystem services (and changes therein) on human health and well-being have been quantified, economic methods can be used to estimate the value of these changes. Thus, defining and quantifying these three components of the ecosystem service production function are necessary ingredients to understanding value.

As with most things in nature and society, the details of production functions are situationally-dependent. Yet, the science of ecosystem services, and its role in decision making, will benefit from guidance communicating: 1) general issues to consider when describing ecosystem service production functions, 2) critical ecological, economic, and human health elements to include, and 3) important requirements to consider in support of the decision-support process. Like ecosystem service definition and classification, an appropriate degree of standardization in characterizing ecosystem service production functions will improve the transparency and transportability of the science we produce.

By 2011, in association with construction of the NESCS, the ERP will develop broad guidance for characterizing ecosystem service production functions (APG 6). Production functions for key ecosystem services will be conceptualized to support understanding of policy-related linkages and to target critical components of those functions to ensure their conservation. Important attributes of conceptual production functions include their scalability and transportability across ecological and social settings. R. Costanza (personal communication) has classified the ecosystem services described in Costanza et al. (1997) based on the spatial characteristics of their production and consumption (Table 5). This classification suggests nuances important to the characterization of the ecological, economic, and human health and well-being production functions. The research described in Section 1.1 will inform guidance for health and well-being production functions; research associated with LTGs 2-5 will inform guidance for ecological production functions. Other considerations influence the degree of mechanistic understanding needed to describe ecological and socioeconomic processes in production functions—generally, transferability of production function knowledge increases with mechanistic detail. The guidance and examples produced by the ERP will serve to clarify relationships among intermediate and final (or "directly enjoyed") services to minimize problems of "double accounting" when values are determined and aggregated, and will be communicated as a module of the ERP decision support platform (described in Section 1.4).

Service Class	Class Attributes	Example Ecosystem Services
Global/Non-proximal	Benefit does not depend on proximity of service	Climate regulation – carbon sequestration
		Climate regulation – carbon storage
		Existence value
Local Proximal	Benefit depends upon proximity of service	Disturbance regulation/storm protection
		Waste treatment
		Pollination
		Biological control
		Habitat/refugia

Service Class	Class Attributes	Example Ecosystem Services
Direction Flow-related	Benefit received at points downstream of service production	Water regulation/flood protection
		Water supply
		Sediment regulation/erosion control
		Nutrient control
In situ	Benefit received at point of service production	Soil formation
		Food & non-timber forest production
		Raw material production
User Movement Related	Benefit received by people flowing to point of service production	Genetic resources
		Recreation opportunities
		Unique cultural/aesthetic natural features

Table 5 Classification of ecosystem services by spatial characteristics of their production (modified from Costanza, personal communication)

1.2.3 Valuation Methods

The ERP is pursuing economic methods as the primary strategic approach to valuation of ecosystem services, in part to support customary (and often mandated) decision processes based on benefit-cost analysis, and in part because money is an easily understood common denominator. Environmental economics is a well-established field, with formalized theory and concepts underpinning its valuation methods. Preliminary mappings of economic valuation methods onto arrays of ecosystem services are conveniently summarized by de Groot et al. (2002), Farber et al. (2006) and others. But the list of important ecosystem services is diverse and their production varied—economic valuation remains vexing for certain services not traded in markets (for which value cannot therefore be observed directly). Clarity and consensus about valuation methods most appropriate for various ecosystem services and policy contexts will facilitate proactive policy and management decisions that ensure human well-being (de Groot et al. 2002). And although the recent activities of the SAB C-VPESS have helped to inform EPA in this regard, outstanding issues remain with respect to the efficacy of certain valuation methods in specific situations. Approaches for economic valuation of bundles of services also will be needed to advance the ERP mission.

General priorities for research improving valuation methods, and ecosystem services in general, is informed by considering the relative difficulties currently faced in developing ecological and economic production functions. When arrayed as a two-by-two matrix, ecosystem services falling into the “easy-easy” cell include those traded in markets and for which ecological production is well understood. Carbon sequestration, and the associated market for carbon offsets, is an example of this group. Conversely, some services—e.g., certain cultural and aesthetic services—are "difficult-difficult" because their ecological production is uncertain and their definition as commodities is challenging. The need for accepted valuation methods for services in the two economically "hard" cells of this matrix is acute if the values of these services are to contribute to decision making.

In collaboration with our partners, the ERP will identify and participate in the valuation method research most critical to moving important services from "hard" to "easy" cells of the matrix. The upcoming report of the SAB C-VPESS on valuation methods for environmental decision-making will inform us of additional developmental needs.[6] Specific research will be designed in future workshops, and strategic alliances will be developed to leverage the ERP's limited expertise and financial resources. Our STAR grant program, through the NCEE, will encourage the academic community to engage in exploration of novel economic methods.

Neoclassical economic valuation methods are grounded in concepts of human utility, providing information about the value of ecosystem services as held by the receivers of those services—human society. As recommended by the SAB C-VPESS and others, and reflecting ORD's current expertise, the ERP will pursue development of donor-based methods of valuation to supplement economic approaches. Donor-based approaches—often based on analysis of the stocks and flows of energy—use biophysical input accounting methods that provide alternative perspectives on nature's worth and sustainability. The ERP will apply our resident expertise to elucidate the contributions of donor-based valuation methods as supplements or alternatives to economic methods in environmental decision support. Additionally, the ERP will encourage development and evaluation by our partners of other non-economic valuation methods to supplement existing economic approaches. By 2014, the results of these efforts will be incorporated into the ERP decision support platform together with enhanced methods for economic valuation to facilitate quantification of ecosystem service values (APG 7).

Table 6 summarizes Annual Performance Goals associated with the Valuation component of LTG 1.

[6] The draft SAB C-VPESS report is available at http://www.epa.gov/sab/pdf/c-vpess_draft_03-09-07.pdf

	Description	**Year Due**
APG 5	Non-market Ecosystem Service Classification System (NESCS) incorporated into DSP.	2012
APG 6	Refined guidance of characterizing ecosystem service production functions for single and bundled services added to DSP.	2011
APG 7	Enhanced economic and supplemental donor-based valuation methods fully incorporated into DSP.	2014

Table 6 APGs for LTG 1 - Valuation Component

1.3 Outreach and Education

The goal of Outreach and Education (OE) in the ERP is to ensure that ecosystem services are translated into terms, and communicated as concepts and products, in a way that compels decision makers and the public to informed action (as summarized in Figure 8).

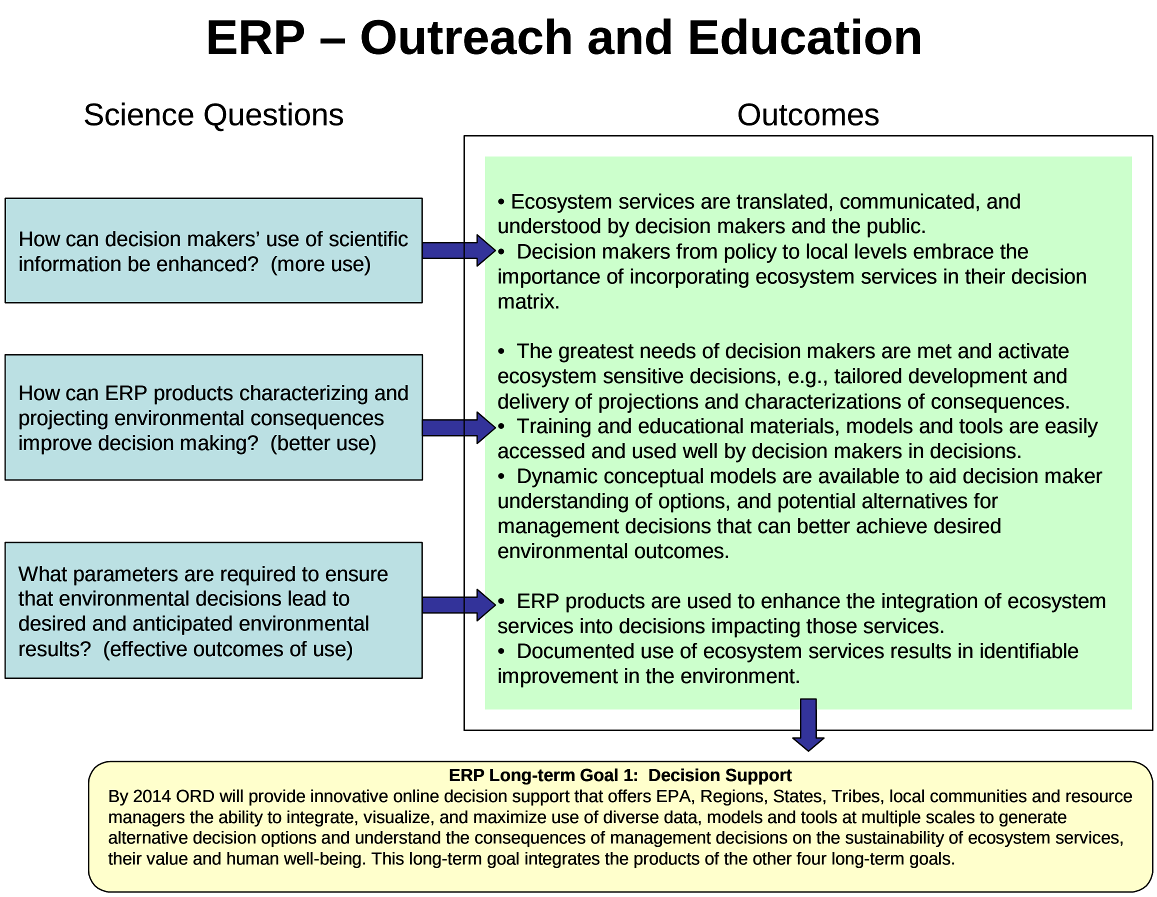

Figure 8 Overview of LTG 1 - Outreach and Education Component

Specific objectives to achieve this goal are to:

- Determine what decision makers understand and need, and translate ecosystem services in a way they understand and can use.
- Produce and deliver educational products to enable decision makers to evaluate management options for achieving both human and environmental goals.
- Ensure decision-makers know about and use ERP products effectively to enhance the integration of ecosystem services into decisions impacting those services.

Under OE there is a dual need for fostering a strong connection with and understanding of client values and motivations, and creating an educational framework that ensures understanding and action. Satisfying this need will help us to bridge the gap between what people say they need and how they make decisions, and what they actually do. We will seek input from potential clients to determine what they want, and how to engage and assist them in product use and application for achieving environmental results.

Outreach and Education depends on the use of existing capabilities, steady exchange among ERP projects and themes, as well as learning from others who are effectively connecting with local constituencies on environmental issues. In addition, establishing strong partnerships with organizations with missions complementary to the ERP will be an important component. One such organization, the World Resources Institute (WRI), has stated that one of its goals is to "Mainstream Ecosystem Services." Discussions with WRI have suggested that, from an international and business community perspective, they could move us forward most quickly. Other NGOs that we have approached have also expressed interest our OE activities. OE will maximize use of existing and planned venues offered by independent organizations as a backdrop for outreach and education. As illustrated in Figure 9, the Outreach and Education Team has the task of ensuring connection with the entire array of participants within and outside EPA to foster communication, exchange, and mutual understanding of the products and purpose of the ERP.

1.3.1 Establish client base, determine needs, values and understanding of ecosystem services to enhance ERP research

Successful outreach is founded upon multi-way communication. For success we must seek input from a broad array of clients, create opportunities for clients and our team to exchange knowledge and perspectives, and ensure effective delivery of information. While outreach is an immediate need with primary efforts up front, ongoing interface with clients will characterize this research component. Research will also include evaluating what others have done that can compliment our work. We have three primary objectives: (1) define and engage diverse client groups, know who they are, what they know and don't know about ecosystem services, and what they need to use ecosystem services in decision making, (2) capitalize on known decision processes to determine how and what to communicate to clients to enhance awareness and understanding of ecosystem services, related issues, and scientific advancements, (3) create a process to

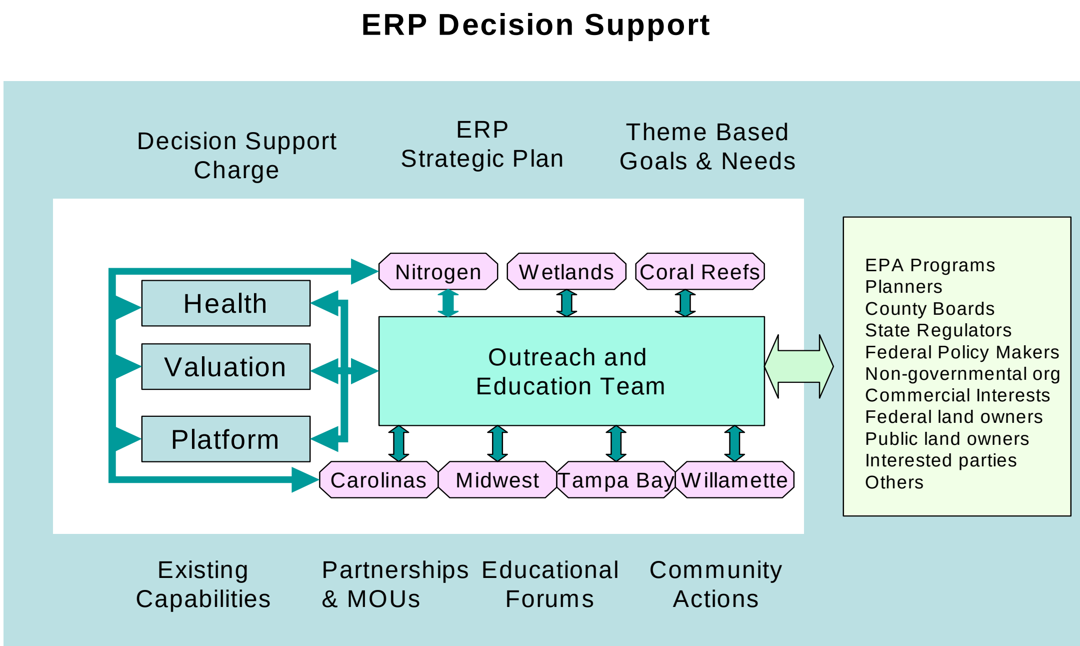

Figure 9 Integrating Role of the Outreach and Education Team

develop and nurture partnerships and collaborations with key internal and external decision makers, other clients, and the public.

To accomplish OE objectives, a communication strategy will be developed upfront that includes processes for reaching appropriate audiences, and designing products and delivery mechanisms that will cause clients to use the concept of ecosystem service values in decisions. OE market research will include identifying individual and client categories, targets of opportunity for exchange, and existing and potential decision categories. The ERP goal is to provide research products and support to a broad clientele at multiple decision levels (e.g., EPA program offices and Regions, federal and non-federal partners, politicians, state land use and regional planners, scientists, conservation organizations, developers, ecologists, economists, educators and other interested parties). In partnership with the ERP place-based and ecosystem type projects, OE will identify and characterize potential clients and categories of decisions to better understand the breadth of problems to be addressed, the types of questions being asked, and who will likely make decisions about them. This information will be used to determine the types of products of greatest use to clients, and the types and challenges inherent in decision required for a variety of decision situations.

In addition, outreach interviews and workshops will be conducted to gather information and exchange ideas. These exchanges will provide essential information for generating terms and descriptions that effectively translate the concept of ecosystem services that make it readily recognized by the public. OE is planning three workshops in different locations across the country to provide a platform for exploring the major stumbling blocks and opportunities for incorporating ecosystem services in local, regional and national decisions. These will supplement ERP place based workshops they may be planning.

To better understand how to approach client decision processes, OE will incorporate lessons learned from the in-depth evaluation of existing decision tools being conducted by the Decision Support Platform (DSP) Team on the uses, strengths, limitations, potential applications and demonstrated value of on-line applications. We also will be seeking greater understanding about what on-line applications *cannot* accomplish and plan for alternative venues for education and decision support.

1.3.2 Translate ecosystem services into a useful and useable conceptual framework for decision-makers

As previously noted, translation of ecosystem services into something dynamic and useful for a broad clientele is needed to captivate the interest of very busy decision makers with ample economic and political pressure to think one-dimensionally about the values of development over conservation. Currently the expression "ecosystem services" means little to most people, with low recognition or emotional appeal in the decision community or general public. In fact, for many, the expression is obscure enough to be met with suspicion and rejection. It will not be enough to generate research and publish papers on ecosystem services or to place products on a web site to transform the health and environmental decision process. We need products and processes that energize clients, present new and sometimes non-intuitive outcomes that they would not have understood or recognized without these new approaches.

Early efforts in outreach will provide information on what is and is not understood, and where challenges exist. Using this information and existing materials, overview and fact sheets will be improved, and an educational primer and new presentations will be generated to offer background information on the different elements of ecosystems services and human well being, developed within the specific context of client-based questions and decisions. Case study examples will be used to augment the primer.

Ecosystem service-based decisions and implementation require local and generally voluntary commitment. Although information provides a critical foundation, much more is needed to bring ecosystem services into decision making. Hands-on learning and powerful demonstrations illustrating how to achieve successful implementation and desired environmental and societal results are critical to decision makers' interest in using this perspective. As a first step, a dynamic conceptual model builder is envisioned. While people use conceptual models in their daily lives, normally they do not commit them to paper. By giving mental constructs physical form, conceptual models render the ideas within them available to critical evaluation. They also provide a forum for exploration, and most important, for shared learning. Project teams working under the ERP will be generating conceptual models that characterize the relationships and issues unique to the place or demonstration projects under development. OE will use these conceptual models, as well as others in the literature or generated by clients or OE, to create case examples of problem solving using ecosystem services as an organizing element. Conceptual models can then provide the structure for future tutorials on ecosystem services.

1.3.3 Produce first generation guidance on decision pathways and applications of ecosystem service-based decisions and implementation for educational use

Even with the use of typical conceptual models, the complexity of ecosystem services and human well-being in a decision context is well beyond the ability of individuals or groups to grasp. Thus our task is to create an understanding sufficient to tackle this complexity so that decisions will move away from being based on economics *or* health *or* ecosystems alone, but instead to understand their influences on each other. Models that can handle complex and trans-disciplinary dynamic systems characterized by emergent properties are central to tackling this challenge. Using existing dynamic systems approaches and software, we plan to design an on-line model connector that can assist clients in building dynamic and illuminating models from those made available through the program and from others that open opportunities for creative thinking, better science questions, enhanced problem solving, improved decision making, and better solutions. In addition, clients who access and use these models have a powerful opportunity to educate others, and to offer feedback directly to the Program..

Guidance and model development needs to undergo testing in case studies to determine the effectiveness of our approaches. We will select one or more existing or ongoing activities within the ERP and within and outside government that are likely to offer good case study examples of communities using ecosystem service-based decisions making and implementation. Objective criteria for case selection will be generated and used to include an existing local or regional decision team interested in incorporating ecosystem services into their decision matrix.

Products will be uploaded onto the DSP for beta testing among a diverse clientele to seek input on successful use, value, and opportunities for improvement.

1.3.4 Activate education/training products and evaluate implementation of ES based decisions on achieving environmental results

In the final phase, OE products will be finalized and activated on the ERP DSP (see Section 1.4.4) including educational materials, case studies, and dynamic systems training modules. Final on-line testing of training modules will be completed with selected partners.

Although the DSP is to consolidate a broad array of information, case studies, projects, models and other products for the entire ERP to make it accessible to a broad audience, just using a DSP can be overly challenging. OE will assist in engaging users through the education and training products.

Finally, providing information on a great DSP alone will not achieve environmental results. Specific outreach work will be conducted to document the environmental and social outcomes realized when clients incorporated ecosystem service thinking and approaches into their decision matrix. Lessons learned from successes as well as challenges will provide next steps for outreach activities and decision support.

Table 7 summarizes Annual Performance Goals associated with the Outreach and Education component of LTG 1.

	Description	**Year Due**
APG 8	Create diverse client base, determine client needs, values, understanding of ecosystem services to enhance research and decision support development	2009
APG 9	Translate ecosystem services into a useable conceptual framework for decision makers	2012
APG 10	Produce first generation case study application of ecosystem service-based decisions and implementation for education	2013
APG 11	Activate education/training products and evaluate implementation of ES based decisions on achieve environmental results	2014

Table 7 APGs for LTG 1 - Outreach and Education Component

1.4 Decision Support Platform (DSP)

Making the information available to all those who can use the information, in a form they can best use it, is fundamentally important to the ERP. Thus, as summarized in Figure 10, we have set as a goal that by 2014, the ERP will provide an innovative online decision support platform (DSP) that offers regional, state, tribal, and local decision-makers resources, tools, models and integrated decision analysis capabilities to help inform decisions at multiple scales and increase the understanding of the consequences of these decisions on the sustainability of ecosystem services and human well-being. To maximize their application to the field of ecosystem services, and to improve the value of decision support, we will develop a DSP that integrates, applies, and effectively and logically delivers to both technical and non-technical audiences the research outputs (i.e., case studies, models, maps, and other tools) associated with Long-term Goals 2-5. This is the overall purpose for the DSP. Direct input from ERP clients (as collected through ERP Outreach and Education) as well as evaluation of other relevant decision support

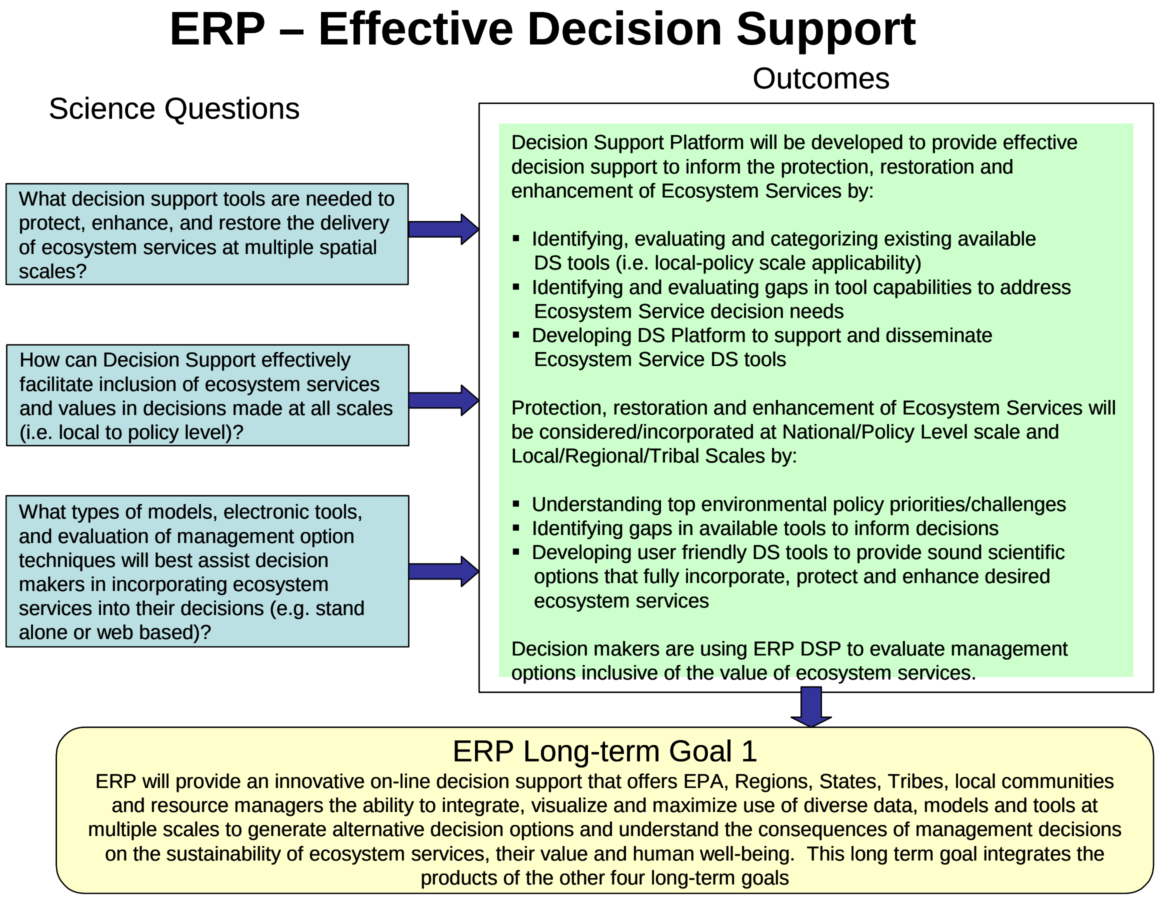

Figure 10 Overview of LTG 1 - Decision Support Platform Component

approaches, will also contribute to development of the DSP. Careful consideration is required to determine how these products/approaches will be harmonized and presented, when they will be interactive and synthesized for decision analysis or delivered as interactive or passive educational materials. In some cases the DSP will need to serve as a portal for accessing ERP, ORD and outside resources.

The ERP DSP team comprises individuals with expertise and experience in decision support, statistics, software development, web-based systems, modeling, decision analysis, program management, and includes representatives from all other ERP teams. Many of the DSP team members have developed decision support tools and systems in the past, and therefore understand the necessity of involving users/clients in the very early stages of, and throughout, development in order to meet their needs. Partnerships must be developed with both government (federal, state, local, and tribal) and non-government organizations. Expertise from outside of EPA will also be continually sought to guide the development of the DSP.

Creation of an effective decision support platform faces many challenges, including:

- The diversity of the audience for which the DSP is intended – from local level decision makers to policy level decision makers and the multiple scales at which they are making their decisions.

- The numerous types of ERP products, e.g., electronic and non-electronic, web-based or non-web-based, etc., which have different architectures but need to be housed and potentially integrated on one platform.

- The obstacle of getting people to use decision support tools/systems.

A number of research and design activities are needed to ensure the DSP overcomes these challenges and meets the objectives of the ERP. The DSP Team will rely heavily on results of other ERP teams to achieve its overall goal. The primary activities the DSP team will undertake are:

- Identification of ERP and non-ERP products such as tools, approaches, models, techniques, etc. to address client needs (as determined through Outreach and Education) and the development of DSP architecture foundation requirements. This will be done in close coordination with other ERP teams.

- Development of the DSP architecture including design and delivery options for multiple users at multiple scales for best access and use.

- Population of modules of the DSP (with assistance from other ERP teams) and dissemination (with assistance from Outreach and Education) for interactive beta testing and client feedback.

- Release of fully functional, on-line DSP and tracking its use and usefulness.

1.4.1 Identification of Products Such as Tools, Approaches, Techniques, Models, etc. and DSP Architecture Foundation Requirements

As part of the ERP, the DSP team must prepare a research and implementation plan detailing activities and milestones for the team. This plan will be developed with input from all other ERP teams. It will be peer-reviewed prior to implementation.

The DSP needs to meet the needs of all types of decision makers at multiple scales. This daunting task will be attacked in several different ways.

- The ERP is in the process of developing a multitude of products for different types of decision-makers. All of these products (e.g., decision support tools, models, approaches, techniques, etc.), or the knowledge provided by them, need to be incorporated into the DSP. This will be a significant undertaking and the DSP team plans to coordinate directly with all other ERP teams in order to ensure that the ERP products developed are appropriately placed on the DSP either as a stand-alone product, a resource link, or as an integrated part of the decision analysis capability and in the appropriate module. This is an on-going process; however, the initial collection of information regarding products should be complete by 2009.

- In FY08, the Outreach and Education Team (in close coordination with the DSP team) will be conducting client-focused assessments and workshops to better understand the breadth of problems to be addressed (e.g., why ecosystem services are not valued or incorporated into decisions), the types of questions being asked, and who will likely address them. This information, in concert with information from other ERP-related workshops, will be used by the DSP team in FY09 to determine the types of products of greatest use to clients and the types and challenges inherent in decisions required for a variety of decision situations.

- EPA and other agencies and organizations have developed a multitude of decision support tools/approaches/techniques that are relevant to the work of the ERP including valuation of ecosystem services and human health and well-being. While no one tool/approach/technique will likely be wholly adopted for use in the ERP, it is important to learn what others have done successfully and then incorporate those successful aspects into the ERP DSP while considering both the ERP products and the needs of clients. This evaluation effort should be completed by 2009.

1.4.2 Development of DSP Architecture

After the information collection step is complete and documented, the DSP Team will be able to determine the requirements for the DSP architecture foundation. In other words, the team will be able to lay out a conceptual model for the DSP to demonstrate how the pieces will all fit together.

ERP products will be in many different forms and architecture (e.g., electronic, non-electronic, web-based, non-web-based, open source software, commercial software, etc.) that need to be brought together in one platform. Because the ERP DSP is intended to be an on-line platform, it is necessary to determine the software/server needs required by the applicable products identified above (e.g., tools, approaches, models, techniques). Through 2009, the DSP team will evaluate and determine software/server needs and requirements and provide software architecture guidelines to electronic tool/model developers. This work will be done in concert with the product identification step and will engage EPA's Office of Environmental Information and other information technology experts. Platform architecture design will occur in 2010, with a period of review by ERP teams and other clients following in FY2011. By the end of FY2011, the platform architecture will be revised, refined, and enhanced, at which point the "skeleton" of the DSP will be available on-line.

1.4.3 Population of DSP Modules and Dissemination

Goosen et al. (2007) warn that many decision support tools and systems are not being used to the extent intended. This paper provides suggestions for how to improve the "success rate" for decision support tools and systems. The ERP DSP team will strive to overcome others' mistakes in this area so that the DSP is actually used by those for which it was intended.

Once the "skeleton" of the DSP is available, ERP teams can begin to populate the DSP with products (e.g., tools, approaches, models, techniques). It is envisioned that separate modules will exist in order to meet the different needs of different decision-makers. It is desirable to include information, resources, approaches, techniques, tools, models, and integrated decision analysis for each module; however, in practice, it is likely that different modules will be populated at different rates and with different types of products. It is the goal of the DSP team to populate at least two modules of the DSP in 2012 in order to disseminate these for interactive beta testing and client feedback. The dissemination process will be primarily performed by the ERP Outreach and Education team who will educate and encourage the use of the DSP. Feedback will be obtained via several mechanisms including workshops, conferences, beta test projects, and an on-line mechanism. This feedback will be used to refine and enhance the first two modules and inform the development of additional modules.

1.4.4 Release of DSP and Tracking Results

The fully functional DSP will be released in 2014. Web-statistics and testimonials will be collected for an additional period of time yet to be determined. The DSP team will attempt to collect information related to how the DSP:

- Informs the protection, restoration, and enhancement of ecosystem services,
- Enables decision makers to evaluate management options inclusive of the value of ecosystem services and human health and well-being,
- Encourages the consideration/incorporation of ecosystem services in decisions at the national/policy-level scale and at the local/regional/tribal scales.

ERP will also attempt to measure additional positive outcomes, such as:

- An increase in the number of decisions which include traditionally non-market costs and benefits
- Increased availability of ecosystem services

Table 8 summarizes Annual Performance Goals associated with the Decision Support Platform component of LTG 1.

	Description	**Year Due**
APG 12	Identify ERP and non-ERP products such as tools, approaches, techniques, models, etc. to address user needs and develop DS Platform architecture foundation requirements	2010
APG 13	Develop Decision Support Platform Architecture	2011
APG 14	Populate two modules of the DS Platform and disseminate for interactive Beta testing and client feedback	2012
APG 15	Populate additional modules of the DS Platform and disseminate for interactive Beta testing and client feedback	2013
APG 16	Fully functional DS Platform is on-line and utilized by clients to incorporate ecosystem services into the decision process.	2014

Table 8 APGs for LTG 1 - Decision Support Platform Component

1.5 References

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LTG 2—NATIONAL INVENTORY, MAPPING, AND MONITORING

2.0 Introduction

Research and products developed in support of long-term goal (LTG) 2 will enable Agency, state, and local governments, non-government organizations, and other decision-makers to assess the likely effects of management actions on ecosystem services. Assessments can be retrospective (evaluating the effectiveness of past management practices) or prospective (in order to anticipate and better protect against unintended consequences). Ecological monitoring, modeling, and mapping have been mainstays of ecological science, both within the Agency and for the discipline as a whole. This LTG builds upon the strengths and successes of the ERP, particularly its extensive landscape ecology, and ecological modeling experience, and its implementation of the Environmental Monitoring and Assessment Program (EMAP).

Within the ERP, ecological *monitoring* is essential for ensuring that assessments of ecological condition, integrity, and ecosystem services are unbiased and representative. *Modeling* is an essential analytical tool for forecasting changes, while *mapping* has long been fundamental to resource management, both for resource conservation, and for resource development. Technologies for monitoring, modeling, and mapping have improved dramatically in the last decade. ERP research associated with LTG 2 will bring these three capabilities together in innovative ways that strengthen and mutually reinforce our ability to assess, explore, and sustain the provision of ecosystem services in the United States.

2.1 Research on Monitoring Approaches for an Ecosystem Services Inventory

Decision-makers need consistent and credible assessments of the quantity, quality, and location of ecosystem services at the local, state, regional and national levels; effective monitoring plays a key role in producing these assessments. First and foremost, monitoring produces quantitative descriptions of services' current status and, over time, trends in the characteristics of interest. With this information, decision makers can assess whether a problem is big or small, whether it is it widespread or localized in hotspots, and whether there is an observable response to policy measures (i.e., are things getting better or worse?). In addition, an effective monitoring program will provide the input data necessary to run forecasting models. The monitoring component of LTG 2 will comprise development of a framework for supplying the data necessary to fulfill these two primary monitoring functions. In collaboration with other organizations within and outside of EPA, ERP will then test and demonstrate the framework's utility.

and Banzhaf 2005, Kremen and Ostfeld 2005, Repetto 2007), but to date, these efforts

The primary objective for the ERP's ecosystem service inventory is to conduct research on quantifying ecosystem services and proposing a design that will lay the foundation for the United States to implement a national ecosystems services inventory. We propose to develop the scientific tools and technologies that will allow the nation's ecosystem services to be periodically assessed and interpreted by decision-makers and the public. The framework must consist of at least two dimensions. Knowing what to measure to most effectively represent the ecosystem services of interest is a necessary first step in the design of an ecosystems services inventory. Second, implementing the design also requires specification of the spatial units within which measurements will occur, whether the same spatial unit can be used for all metrics measured, how inferences will be made to more than the few systems measured, how the information will be summarized and reported, and how frequently the attributes must be measured. We also believe that the development and implementation of a national ecosystem services inventory will take place within the context of existing Agency programs. Research on the design of an inventory framework will consider each of these issues.

Boyd and Banzhaf (2005) suggested useful characteristics of an ecosystem service inventory that might constrain design alternatives. They also argued that rigorously and consistently defined ecosystem service metrics (units, in their terminology) must be consistent with the principles of the underlying ecology and with the economic accounting system to which they will be applied. They propose the following definition: "Final ecosystem services are components of nature, directly enjoyed, consumed, or used to yield human well-being." They explicitly exclude ecological processes and functions as services and intermediate services. Subsequently, they note that ecosystem services occur in a spatial context that can affect the quantity of the service provided. The implication is that the design of an inventory of ecosystem services must include the spatial context. Construction of an ecosystem services index requires not only estimates of the quantity of the services but also a "weight" or value assigned to the service. The social value of the quantity of ecosystem services produced is also spatially dependent. This further argues for the design of an inventory program that is spatially explicit. Little attention has been given, however, to what spatial units may be appropriate in measuring ecosystem services. They only note that the services "should be measured in the most spatially explicit manner that is practicable" and that they "envision mapping each service at a relatively fine resolution." Ecosystem service benefits also differ in the spatial characteristics of their production. Benefits received from services production may be global/non-proximal, local proximal, direction flow-related, in-situ, or user movement related (see the Valuation component of LTG 1).

Figure 11 illustrates the five primary science questions for the monitoring component of LTG 2 and the outcomes we intend to achieve by answering these questions.

Science Question #1: Are there direct measurements of ecosystem services that can be monitored or is it necessary to measure other ecosystem attributes and infer or model ecosystem services from them?

The ERP has committed to providing tools to address the ecosystem services listed in Table 9.

Supporting Services	Regulating Services	Provisioning Services	Cultural Services
• Carbon storage • Habitat/ maintenance of biodiversity	• Nutrient cycling • Flood reduction • Storm-surge protection	• Food and fiber production • Fuels • Water-provisioning (described separately as water quality, quantity, and timing of flows)	• Recreational opportunities • Sense of place

Table 9 Core ecosystem services

Any monitoring framework related to ecosystem services will necessarily provide indicators related to each of these services. A fundamental need is to identify if, and when, direct measures of these services are possible and when surrogates are necessary.

It is instructive to consider the data gaps identified by Carpenter et al (2006) that impeded the Millennium Ecosystem Assessment. Many of the specific data gaps are associated with ecosystem attributes that are fundamental to the services, rather than the services themselves. These gaps are: 1) global time series on land cover change, 2) location and rate of desertification, 3) global maps of wetlands distribution, 4) systematic information on stocks, flows, and economic values of many ecosystem services (e.g., freshwater fisheries, natural hazard regulation, groundwater, pollination), 5) trends in human reliance on ecosystem services, 6) systematic local and regional assessments of the value of ecosystem services, and 7) connections between data on human services and ecosystems.

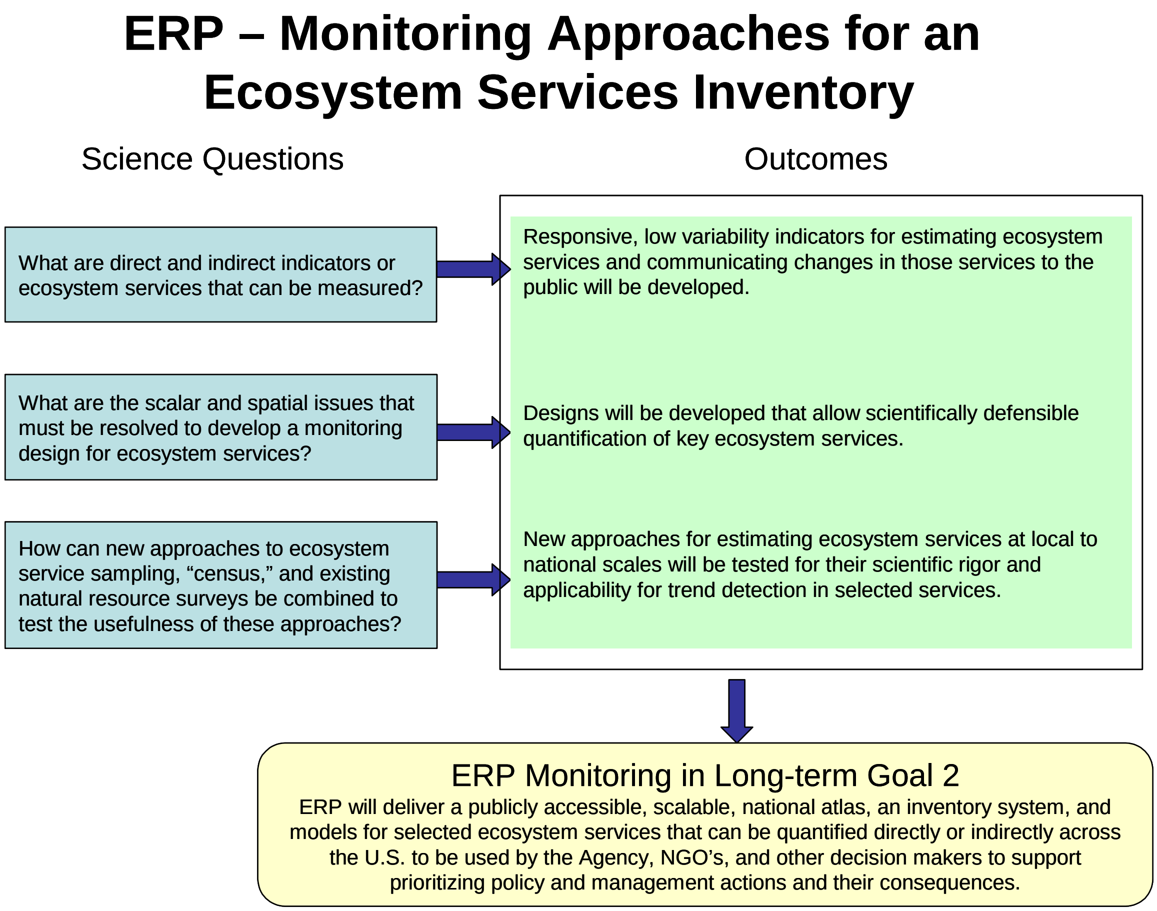

Figure 11 Overview of LTG 2 - Monitoring Component

A review of the ecological indicators selected by the National Research Center (2000), Heinz Center (2002), and EPA (2003), shows almost none of the indicators would be direct measures of ecosystem services but rather measures of ecological characteristics fundamental to the availability of services from these systems. Recognition of this has given rise to a focus on "Nature's Capital" (Irwin and Ranganathan 2007), which refers to the fundamental characteristics, both structure and function, of ecosystems that must be protected and maintained if services are to be available. To a large extent, the characteristics described in this context are more amenable to monitoring and yet fundamental to maintenance of ecosystem services. For example, biodiversity is an ecosystem characteristic that is directly measurable and critical to the provisioning of services in each of the four major categories of ecosystem services (supporting, regulating, provisioning and cultural). Land cover provides another example, where remote sensing provides a powerful tool often used to generate complete and detailed "maps" of land cover and can be effectively monitored over time. Land cover itself is not a direct measure of ecosystem services. However, land cover can be combined with other information layers and models to generate maps of expected ecosystem services. Thus, an ecosystem services monitoring framework must ensure that the underlying ecosystem characteristics are measured as well as the necessary supporting data to translate those characteristics into ecosystem services.

ERP research will:

- Review major ecological assessments and identify indicators that can be directly measured.
- Identify indirect measures of ecosystem services.
- Collaborate with other components of ERP to establish the relationship between direct measures of ecosystem structure and function that can be quantifiably linked to ecosystem services.
- Identify measurable indicators of the direct and indirect drivers of changes in ecosystem services.

Science Question 2: What are the implications for inventory design when ecosystem services must be reported at multiple scales?

If ecosystem services are to be incorporated into the decision-making process in the United States, then it will be necessary to know the type, quantity, and distribution of ecosystem services provided at multiple scales. A national ecosystems services index (ESI) or "green GDP" account requires reporting at the national scale. Components of an ESI, as well as the ESI, could be included in EPA's Report on the Environment (EPA 2007) or the Heinz Center's State of the Nation's Ecosystems report (Heinz Center 2002). These reports provide state-of-the-nation information useful for tracking progress and seeing the effects of policy decisions. Regional and state decision-makers are likely to want information specific to their geopolitical region. From an ecological perspective reporting the quantity and quality of ecosystem services using non-geopolitical regions (e.g. ecoregions or hydrologic regions) may be useful. Planning and decision making occurs at multiple spatial scales and for many different types of spatial regions. The place-based demonstrations within the ERP (LTG 5) provide examples of different types of regions where decisions need to occur.

ERP research will:

- Identify the requirements for reporting at multiple spatial scales.
- Determine whether this places constraints on the design of an inventory for ecosystem services.

Science Question #3: What spatial units are appropriate for measuring ecosystem services and what are the advantages and disadvantages of measuring ecosystem services by ecosystem types or with a common spatial unit?

As Banzhaf and Smith (2002) suggest,

> [J]udgments would have to be made about the best way to describe the services these assets provide and thus to collect the relevant data. Market goods generally come to consumers in reasonably well-defined units, often - discrete packages. Even services available from private markets typically have a unit of account that has been determined by the market. But what are the "units" we should use to measure changes in air quality? From one place to another and from one time period to another, air quality may be impaired by different pollutants, and furthermore each pollutant may be important to people for different reasons. Some pollutants may have cumulative impacts resulting from long-term exposure. Others may have serious effects following acute episodes. Moreover, these ambient concentrations can vary continuously over space and time, rather than being sold in discrete packages at discrete locations.

How are ecosystem services best captured - by examining individual ecosystem types (e.g., forests, wetlands, streams, etc), by examining collections of ecosystems which provide the necessary service, or are both needed? The MEA (2005) suggests that one can look to individual types of systems (e.g., marine, inland waters, forests, wetlands, dry lands). This approach of developing designs based on ecosystem types (and classes within these types) is consistent with the basic monitoring already done in the US (e.g., EPA and States for freshwater systems, the United States Department of Agriculture (USDA) for forests and agricultural systems, the National Oceanic and Atmospheric Administration (NOAA) and EPA for coastal systems). What is/are the critical scales of the monitoring design? Are ecosystem services best viewed at a single scale or are their compelling reasons to estimate services over multiple spatial extents? Currently, monitoring is done at the plot scale in the US and then inferences are made to larger geographic areas statistically, based on the sampling design criteria.

In the past, significant time and effort have been spent debating the appropriate spatial framework to use for monitoring and reporting: watersheds, ecoregions, hydrologic units (HUCs), geopolitical areas, soil and geological regions. This issue is perhaps even more pressing for monitoring ecosystem services, where spatial characteristics govern the "production" and "use" of these services (Costanza 2007). As frequently has been the case, and as we believe will be the case for ecosystem services, there is no unique solution. We must find a productive way to incorporate each of these perspectives.

Designing a monitoring network also requires a very explicit description of the answers that are expected to be provided. It is often useful to think of the one or two key graphs, charts, or tables in a report that would be used to communicate the results. For example, EPA's Office of Water made explicit decisions that it was necessary to report on the length of stream and river having certain characteristics (e.g., length of river with nitrogen exceeding expected background levels) and for estuaries to report on the estuarine area having certain qualities (e.g., area of estuary with benthic index below a certain threshold). Special attention will have to be given to ensuring congruency between the underlying ecology of ecosystems and the services provided with the desires of policy makers for reporting. For example, it is possible to conceive of the biological integrity, nutrient concentrations, or habitat quality of any point or segment of a stream. We can develop the indicators, monitor specific locations and report the results in the context of use for policy (e.g., length of stream with nutrient concentrations exceeding a critical threshold). Can we conceive of ecosystem services in a similar way? Does a particular point on a stream provide storm-surge protection or nutrient removal? Or do the measurements and assessment have to occur at a different scale? And if so, at what scale should they occur? Will ecosystem service indicators need to reflect the spatial scale, pattern, or connectivity of the underlying biophysical and landscape features that govern production of the service? Will indicators need to vary by ecosystem service of concern? If this latter view is true, it significantly complicates the framework for a monitoring design. This level of specificity is necessary to design a useful monitoring framework.

ERP research will:

- Identify the specific forms of answers that are needed about ecosystem services and identify the design constraints arising from them.
- Evaluate existing federal monitoring efforts for compatibility with ecosystem service reporting needs.
- Evaluate the congruency between the underlying ecological meaning of the indicators and the desired reporting frameworks.

Science Question #4: Can an ecosystem services inventory be based on a "census" or will it be necessary to sample the nation's ecosystems?

Banzhaf and Smith (2002) state

> "more data would need to be collected on a more systematic basis to represent the condition of the services being provided by diverse natural assets on a national scale. Even where government agencies and private parties are currently collecting data, they frequently target problem areas, rather than developing a sample that would adequately represent the country."

Collecting national, representative data on ecosystem service indicators is an enormous undertaking. Currently, no national effort exists to provide the data. Olsen et al (1999) reviewed major natural resource monitoring and inventory programs; they concluded that gaps exist, but that existing programs could form a foundation for a coordinated national monitoring and inventory program. Recently, the National Academy of Public Administration (NAPA 2007) recommended institutional options for developing a national system of environmental indicators. Building upon existing agencies' efforts is essential, although many unanswered questions and gaps remain. The Heinz Center

(2006) identified the priority gaps in monitoring necessary to provide the indicators that they had identified as essential and concluded that additional monitoring and funding were needed to accomplish the task.

A critical question to be addressed is whether it is possible, and cost-effective, to directly measure ecosystem service metrics everywhere, and to repeat the measurements every five to ten years. Such a census approach to an inventory is appealing as it enables the information to be used at multiple spatial scales. Certainly, we can census land cover using satellite imagery and then apply models and other data layers to "map" areas of potential ecosystem services.

When a census approach is not feasible, or cost-effective, an alternative is to conduct surveys similar to current natural resource surveys (e.g., the U.S. Forest Service's Forest Inventory and Analysis (FIA), the USDA National Resource Conservation Service's (NRCS) National Resource Inventory, EPA's national aquatic assessments, and USDA's National Agricultural Statistic Service surveys). There would be substantial benefit to using data from existing monitoring networks for assessing ecosystem services, but such an approach has not been demonstrated for use in determining ecosystem services.

A second alternative to a census is monitoring a limited number of "representative" sites. This is a common approach in networks that are primarily research networks such as NSF's Long Term Ecological Research Network (LTER) and NSF's proposed National Ecological Observatory Network (NEON). While this approach has been effective for research, it has seldom been adopted as the primary design framework for long-term monitoring networks that require estimates of uncertainty in their assessments.

ERP research will:

- Investigate issues associated with combining spatial data based on different spatial units.
- Evaluate alternatives for development of a national ES inventory, including census and probability-based survey designs.
- Propose design framework requirements for a national ES inventory..

Science Question #5: What demonstrations are needed to fill gaps in the Inventory Framework?

National-scale data exist on recent land cover/use in the National Land Cover Dataset (NLCD, see LTG 2 Mapping) across the contiguous US. The survey programs noted above area also a source of national-scale data. In addition, the EPA's Office of Water conducts National Aquatic Resource Surveys (using probability-based monitoring designs and condition indicators), which provide nationally representative data on the condition of aquatic ecosystems at the regional and national levels. While these data are at the national-scale, an important question is whether or not they can be used to construct selected indicators of ecosystem services and thereby provide for the rapid development of at least select components of a national inventory.

The monitoring research will collaborate with the place-based research and ecosystem-based research components of the ERP. Both have identified objectives and questions relevant to the monitoring framework objectives. For example, the ERP wetland component has as a research question: "What is the relationship between the abundance, distribution, and condition of wetlands in the landscape and the delivery of ecosystem services?" And, the Willamette Ecosystem Services component of the ERP has as one of its objectives: "Develop an approach to inventory and map ecosystem services … based on current conditions and available data in order to establish a base line for future conditions." Interaction will also occur with the mapping component of LTG 2 that has as one of its primary goals the development of a publicly accessible and scalable National Atlas of Ecosystem Services. These collaborations are essential for the ERP to provide credible and consistent recommendations at all scales for a national ecosystem services inventory.

EPR research will:

- Evaluate the Office of Water's national aquatic survey indicators for direct and indirect indicators of ecosystem services.
- Generate interim national estimates of several ecosystem services for aquatic systems.
- Collaborate with the mapping team to develop recommendations on national monitoring of land cover.
- Collaborate with the mapping team to provide change estimates of ecosystem services derived from land cover.

Table 10 summarizes the Annual Performance Goals associated with the monitoring component of LTG 2.

2.2 Integrated Modeling of Ecosystem Services

Modeling forms a bridge between empirical monitoring of ecosystem services and mapping of those services. For LTG 2, the ERP will use, develop, adapt, or refine models to quantify the key interactions among the structure and function of ecosystem components, including the services they provide; to quantify stressor-response relationships among common stressors and ERP-selected ecosystem service endpoints; to explore likely future conditions, using forecasting methods and scenario-building techniques; and to estimate major sources of uncertainty in our understanding of ecosystem behavior. The models will provide important analytical capabilities within the context of the proposed Decision Support Platform (see LTG 1).

	Description	Year Due
APG 17	Peer reviewed research and implementation plan for developing a national ecosystem services inventory.	2009
APG 18	Direct or indirect measures for select ecosystem services have been established.	2011
APG 19	Implications for combining monitoring data based on different spatial scales understood.	2012
APG 20	Suitability of existing federal monitoring efforts for assessing ecosystem services has been determined.	2013
APG 21	Design requirements for reporting at multiple spatial scales have been determined.	2013
APG 22	A monitoring framework for a national ecosystem services inventory is available.	2014

Table 10 APGs for LTG 2 - Monitoring Component

The ERP has extensive experience in ecological modeling, but has never before set for itself the challenge of creating a community of practice for models that have ecosystem service endpoints. In recent years, the scientific community has begun developing new ways to model ecosystem services. However, these techniques are in their infancy, creating an opportunity for ERP to become a leader in the ecosystem service modeling field. We have designed the program to promote interaction and learning among the Modeling Team, the four place-based demonstration projects (LTG 5), and the two ecosystem assessments (LTG 4), so that the program is able to test and refine its modeling concepts for a set of core ecosystem services across varied geographic settings and different spatial scales (from 250 km^2 to 2.4 million km^2).

Figure 12 illustrates the three primary science questions for the modeling component of LTG 2 and the outcomes we intend to achieve by answering these questions.

Science Question #1: What are the Program's high priority needs for forecasting and scenario development, including ecosystem service endpoints, spatial extents, and temporal resolution?

The ERP's place-based demonstration projects and ecosystem assessments are addressing services of particular interest to their location, system type, and stakeholder interests.

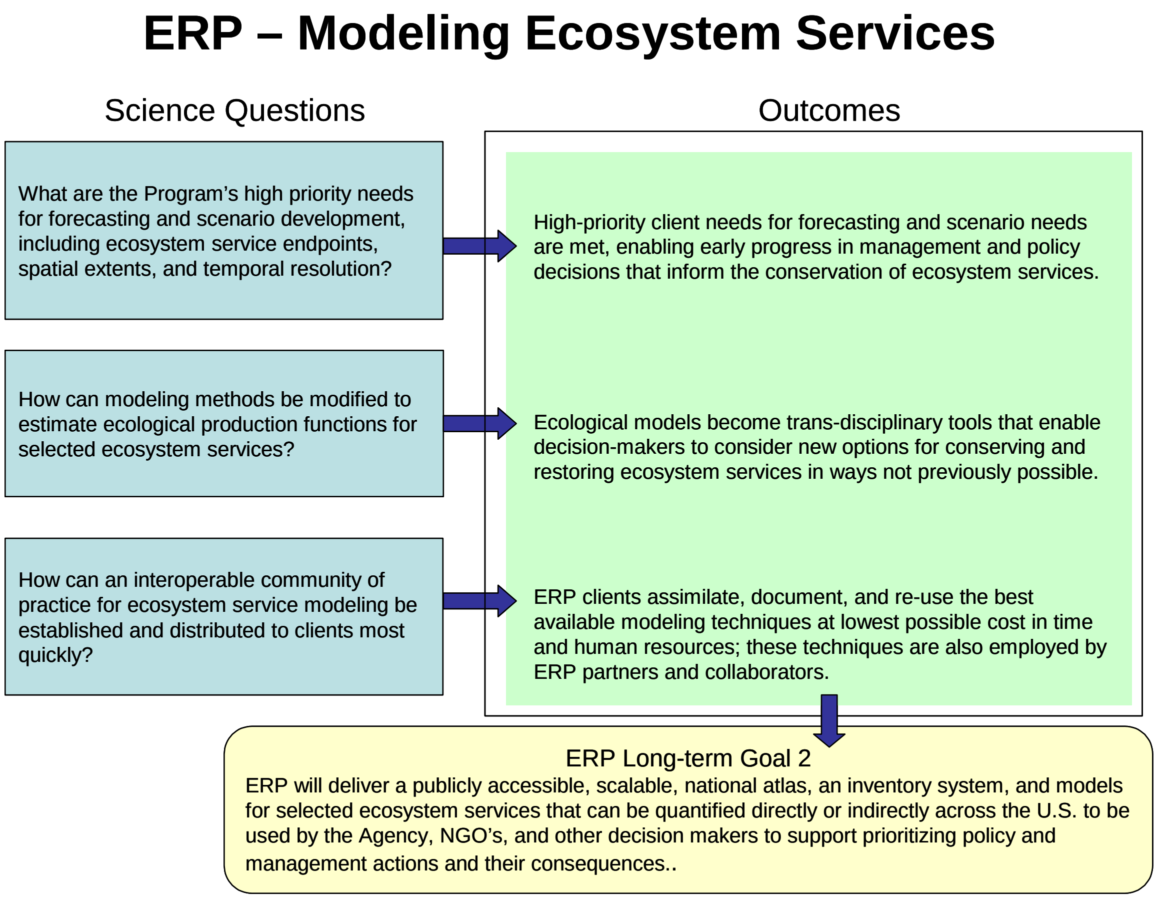

Figure 12 Overview of LTG 2 - Integrated Modeling Component

However, each will also address several of the core ERP ecosystem services listed in Table 9.[7]

Among the first activities for the modeling team will be an assessment of available models that can be used to address these services at the required time-steps and spatial extents, and the identification of gaps that warrant modification of existing models or development of new models. In addition, the modeling team will investigate and recommend options for developing a tiered approach to modeling, in order to better accommodate a specific model application for its intended use.

Science Question #2: How can modeling methods be modified to estimate ecological production functions for selected ecosystem services?

[7] See Appendix A for a description of the associated units, spatial extents, and temporal resolution for these services.

Economists use the concept of a "production function" to describe the mathematical relationship between inputs (e.g., capital, labor) and goods produced (see Section 1.2.2). Historically, production functions were presented as mathematical descriptions of the goods and services that can be produced from inputs of natural and human capital, labor, and other resources. Although such production functions have previously included natural resources, it was usually only in terms of inputs as raw materials, rather than as services resulting from ecosystem structure and function. Today there is growing recognition that we need new ways to identify and envision genuine ecological production functions, and to be able to describe these production functions within different spatial boundaries, and over different time frames. Such production functions are important for several reasons:

1. They help individuals, governments, and private entities assess the multiple services derived from ecosystem functions.

2. They help us identify instances in which management strategies can yield expanded ecosystem services and reduce conflicts.

3. They help us understand how our choices affect the production of ecosystem services over space and time.

Most existing ecological models do not include ecological production functions, and most also stop short of estimating true ecosystem service endpoints. For example, they may estimate habitat condition, but not extend to include estimates of how habitat conditions are likely to affect fisheries productivity or recreational opportunities. In addition, as noted in the valuation component of LTG 1, ecosystem services have inherent spatial characteristics that further complicate the estimation of service production across a landscape or coastal area (see Table 5).

The spatial dimensions of ecosystem service production have rarely been explicitly considered in model development, yet they strongly control the provision of services. Services affected by the interactions among land management practices, flood risks, aquatic habitat, provisioning of water quantity, and protection of water quality may be best handled within a drainage network. Other services may best be handled by entirely different spatial configurations; for example, storm surge protection, enhancing fisheries productivity, and restoring resilience and sense of place to coastal cities may depend more on the pattern and ecological condition of barrier islands, deltas, and estuaries over a regional coastal area. Some services depend on movement to, from, or through specific areas. People who want to enjoy the sense of place provided by beautiful natural areas often need to travel to these comparatively rare locations. Similarly, conserving biodiversity often requires the maintenance of interconnected, high-quality habitat in order to support viable metapopulations. These types of "movement" related services might be best modeled by way of contagion theory or using individual-based models; such analyses might suggest a wide variety of non-intuitive "node and network" spatial patterns for conservation and restoration efforts.

Moreover, humans increasingly dominate many ecosystems, necessarily imposing patterns of settlement and infrastructure upon coastal areas, estuaries, agricultural areas, forests and rangelands. In order to meet demands for ecosystem services, we need modeling and scenario techniques to enable us to investigate how alternative strategies for managing the pattern and connectivity of ecosystem structures and functions can help us to maintain, restore, or enhance the desired mix of ecosystem services that can be provided from within these highly modified environments.

Developing techniques to address the issues of ecological production functions is likely to be the most challenging, but also the most fundamental, issue facing the modeling team. A variety of modeling methods show promise for addressing these complex issues, but few have been tested in the context of modeling ecosystem services. These methods include: hierarchical Bayesian techniques, landscape models, individual-based models, process-models that can simulate endpoints that reflect ecosystem services, and optimization models. Hierarchical Bayesian (HB) will likely play a major role in bridging top-down and bottom-up modeling approaches. HB holds promise for putting empirical data and process models on equal footing, whereby the uncertainties of each are specified with conditional probability statements. HB is a hierarchically specified visual modeling approach, and thus compatible with the mapping component of this LTG. HB approaches are quickly becoming mainstream, with new applications in the realms of biodiversity, fisheries, population dynamics, genomics, and human clinical trials. In addition, the Intergovernmental Panel on Climate Change (IPCC) used HB modeling extensively in constructing their climate change forecasts.

The modeling team has identified potential partners for the development of new methods. For example, the ERP has a Memorandum of Understanding (MOU) with the Gund Institute for Ecological Economics. This MOU will allow ERP to share data from its study sites for testing and further refinement of the Multi-scaled Integration of Models for Ecosystem Services (MIMES) simulation approach initially developed at the Gund Institute. Other external experts and partners have been identified, but formal arrangements for working with them are still pending.

Science Question #3: How can an interoperable community of practice for ecosystem service modeling be established and distributed to clients most quickly?

In addition to the scientific and technical challenges related to modeling, there are also programmatic issues to be addressed. These include:

- The status and experience of modeling teams for place-based projects and ecosystem assessments; some are in initial start-up phases, others are more mature.

- Varying problem statements (e.g., different drivers of change, and different services of interest).

- A wide range in the status of existing model assessment and selection.

- Number and skill mix of modelers for ERP studies varies from having a critical mass to a limited few.

We propose to develop an ERP Community of Practice for Modeling. Figure 13 presents a schematic representation of this proposed Community. This Community of Practice begins by taking stock of its various theme- and place-based approaches to identify opportunities for consensus approaches, in order to facilitate wide sharing of modeling methods and technologies across the ERP. To assist this, we will investigate how modeling technologies may contribute to managing both the scientific and programmatic needs of the ERP. In addition, the ERP will use open source standards wherever possible to facilitate community participation and avoid unnecessary restrictions on software access and reuse. Other benefits include:

- Minimized production of non-science software (more resources focused on science components).

- Model execution management (time savings and quality assurance).

- Data flow management (quality assurance).

- User interfaces (assessment level to individual components).

- Modeling support software (data access/retrieval/processing, visualization, quality assurance).

Similarly, modeling infrastructure can be used to manage considerable complexity, while at the same time satisfying modeling requirements for model coherence, transparency, reproducibility, characterization of uncertainty, and quality assurance.

ERP will publish modeling components according to a community standard format that facilitates immediate application for both research and regulatory decision making. A model, database, or assessment methodology, when published, will be accompanied by metadata that explain the component, its content, its domain of application, its basis of theory, and its uncertainty in a quantifiable format. Furthermore, metadata will be consumable by modeling infrastructures and search and query software so that decisions regarding deployment with other components and in other infrastructures can be readily determined and implemented.

Table 11 summarizes the Annual Performance Goals associated with the modeling component of LTG 2.

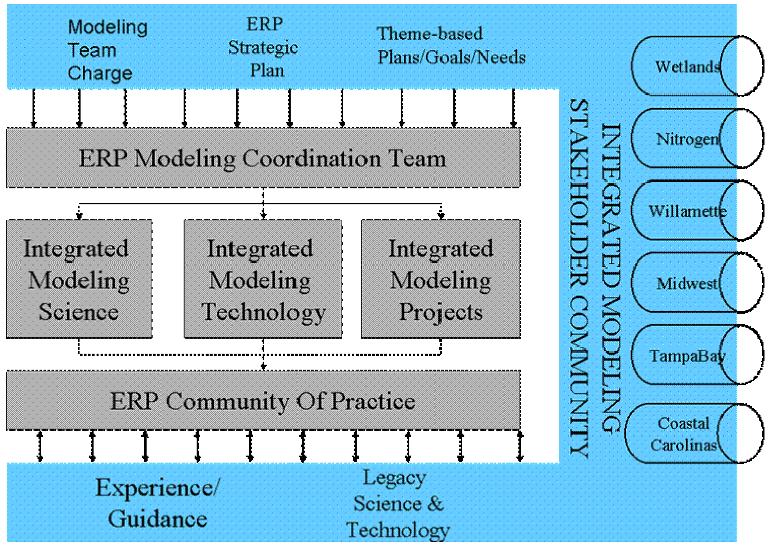

Figure 13 Proposed ERP Integrated Modeling Community of Practice (EPA 2008)

	Description	Year Due
APG 23	Peer reviewed research plan that outlines a systematic approach to meeting high-priority modeling needs for ecosystem services, including a tiered approach for matching model complexity with scale, scope, and intended uses.	2009
APG 24	New approaches for integrated modeling of high-priority ecosystem services are identified in collaboration with clients, social scientists, and economists, including ecological production functions required for valuation.	2011
APG 25	Assessment methods incorporate ecological production functions for high-priority services, including requirements for transparency, reproducibility, and characterization of uncertainty.	2012
APG 26	Community-wide standards of practice for ecosystem service modeling research and scenario development are identified.	2013
APG 27	Monitoring and Modeling components are published according to a community standard format, accompanied by metadata.	2013
APG 28	An ERP expert knowledge data base for modeling is available for inclusion in the ERP decision support platform.	2014

Table 11 APGs for LTG 2 - Modeling Component

2.3 Mapping Ecosystem Services

The mapping component of LTG 2 has two main objectives: 1) to develop and deliver a publicly accessible and scalable National Atlas of Ecosystem Services, and 2) to provide integrated ecosystem services landscape science support to the ecosystem assessments and place based projects that ERP will undertake to support LTGs 4 and 5. The methods to accomplish these tasks will draw heavily from experience in the science of landscape ecology and landscape characterization, in concert with ORD's experience in other science disciplines, such as wetland ecology, hydrology, soil sciences, physical sciences, terrestrial biology/ecology, and aquatic biology/ecology.

Ecosystem services mapping is a critical component of the ERP, as it provides decision-makers and other key users with a visual and comprehensible method for interpreting and understanding how the delivery of ecosystem services can be conserved and enhanced, while maintaining the use of ecosystem resources. Accordingly, ecosystem services models/maps will provide users the ability to assess choices in a spatially explicit context.

As described below, ERP's implementation plan will address three key issues related to ecosystem services mapping: identification of mapping units, spatial characteristics of ecosystem services, and "bundling" of ecosystem services.

2.3.1 Identification of mapping units

Ecosystem services mapping requires what may be a less-than-straightforward selection of appropriate units as well as scales. For example, the appropriate analysis/mapping unit for water quality and supply services would seem to be the watershed. If so, a choice of scale is necessary, from catchment (i.e., NHD Plus) to broad-scale watersheds (e.g., 8-digit Hydrologic Accounting Units). However, the use of a watershed unit could be challenging; for example, in flat, coastal areas watersheds can be very difficult to delineate.

In other circumstances, ecological units that directly provide services to humans may be considered an appropriate mapping unit, especially for services related to biological diversity and habitat functions. The United States Geological Survey (USGS) and others, for example, are mapping fine scale ecosystems using biophysical components of the environment. Another potential mapping unit, and one that has been successfully used before, is equally sized grid cells or some other definitively shaped polygons laid out across the U.S. As an example, the conterminous U.S. contains approximately 865,000 3x3 km^2 grid cells, which may be an appropriate unit for services related to carbon cycling. Similarly, local community planners may want the option of using counties or parcels as a mapping unit. All of these options are certainly possible with current technology and knowledge.

Mapping unit identification will be an important consideration for the ERP Mapping Team. The output of the team's work may suggest that different mapping units are appropriate for describing different ecosystem services. If this is the conclusion, we will propose the development of a hybridized and flexible approach, which will allow for the configuration and reconfiguration of ecosystem services across different mapping units, as needed.

2.3.2 Spatial characteristics of ecosystem services

Mapping ecosystem services is completely different from mapping ecosystem attributes and presents many new challenges to the environmental science community. Ecosystem services exhibit spatial characteristics that are unique to the conveyance of a benefit. Proximity is one of these spatial characteristics and is important to the delivery of some ecosystem services but not all. For example, climate regulation services, such as carbon sequestration, or cultural/existence values of ecosystems do not depend on proximity since recipients at all locations could derive the same benefit. In contrast, flood attenuation and storm surge protection are obviously very much dependent on proximity; those living closest to the ecosystem delivering the service benefit the most.

Flow-related direction is another important characteristic of ecosystem services; many water quality, nutrient retention, and soil erosion/sedimentation services, are flow-related. Recipients of flow-related ecosystem services may be hundreds or even thousands of miles away from the location where an impact on services might be observed. Nutrient retention in the Midwest, for example, provides benefit to those who depend on the fisheries in the Gulf of Mexico. The fisheries are affected by land-use decisions in the Midwest where application of fertilizers and tilling practices are directly related to the amount of nutrients flowing to streams and then on to the major tributaries of the Mississippi River and eventually to the Gulf of Mexico. Spatial characteristics are a complex topic that must be addressed by the mapping team.

2.3.3 "Bundling" of ecosystem services

Benefits to society from an individual ecosystem service are not provided in isolation and, for this reason, it is important for the mapping component of ERP to develop methods to combine or "bundle" ecosystem services together, allowing the user to visualize the full potential of multiple services provided by a given spatial unit. One simple possibility for bundling ecosystem services is to develop a scoring system whereby individual ecosystem services can be scored across a region, with scores summed (with or without weighting, depending on needs of user) and then displayed as one value for any given spatial unit.

2.3.4 Research development considerations

The two main objectives of the mapping team are to 1) deliver a National Atlas of Ecosystem Services and 2) provide integrated landscape science support to place-based, pollutant-based, and ecosystem-based research. The two functions complement each other well as both can benefit from science undertaken in support of the other. Achievement of the two objectives will entail consideration and coordination of a common set of elements:

- Land cover/use and land cover/use change.

- Geographic exploration of environmental data, such as human population, stream characteristics, topography, soil conditions, and atmospheric deposition.

- Landscape indicator development.

- Geospatial/statistical model development (e.g., SWAT, Markov, RUSLE/SEDMOD, SPARROW).

- Associating landscape indicators and ecosystem services.

- Scale.

- Identification of spatial mapping unit.

As shown in Figure 14, the outcomes of the mapping component of LTG 2 will address the following fundamental and challenging science questions:

1. How can ecosystem services be measured and mapped at multiple spatial scales for the U.S?

2. What are the relationships between drivers of change (i.e., land use, global climate change, and other environmental policy decisions) and the distribution and extent of ecosystem services at multiple spatial scales?

3. How can ecosystem services mapping be used to inform the decision-making process and ensure that the consequences to ecosystem services delivery are included in land use and other environmental policy decisions?

Science Question #1: How can ecosystem services be measured and mapped at multiple spatial scales on a national level?

Mapping ecosystem services presents new challenges because of their inherently unique spatial attributes. The mapping of ecosystem services will use a combination of direct attributes and model-derived attributes.

The ERP mapping team will draw on its vast experience in the fields of landscape ecology, GIS, hydrology, wetland ecology, remote sensing, biology, modeling, and spatial analyses to create maps of ecosystem services at multiple spatial scales. ORD's experience includes conducting many national and regional landscape assessments where features of the landscape (e.g., percent natural landcover, percent riparian buffer with natural landcover, percent agriculture on steep slopes, and average permeability of soils)

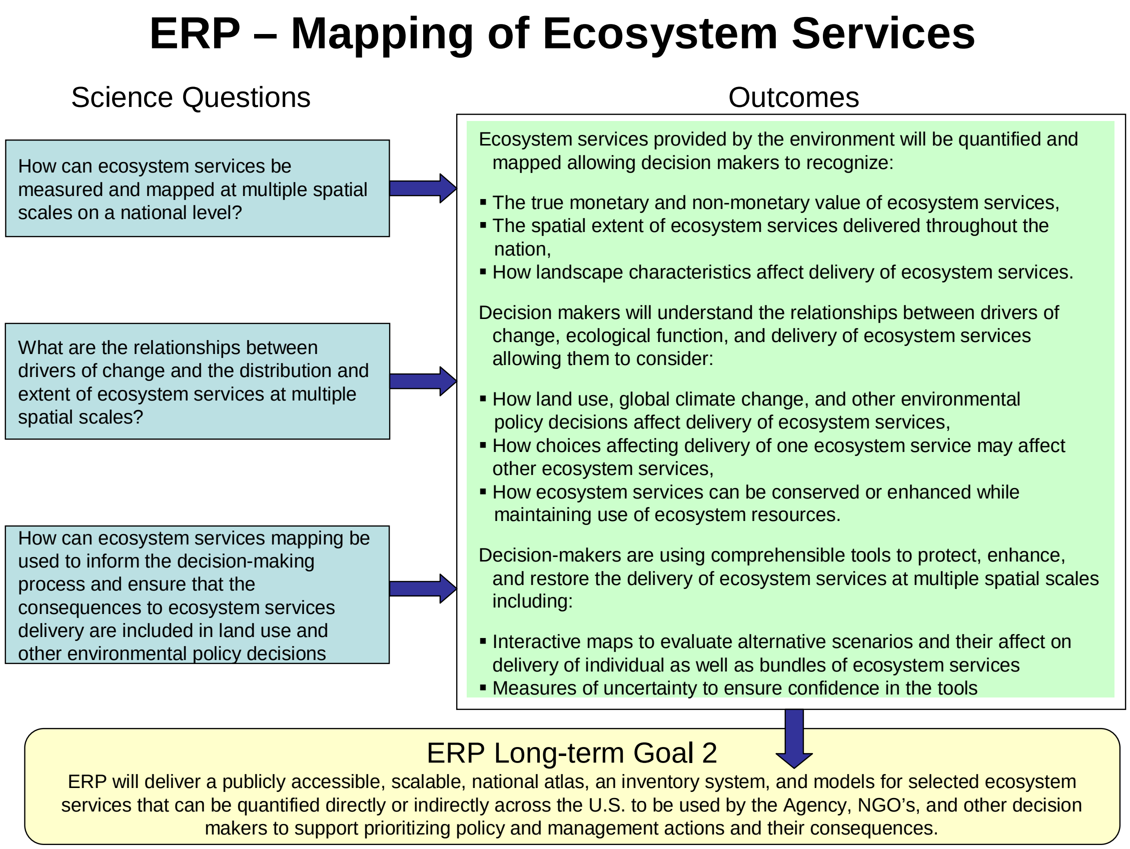

Figure 14 Overview of LTG 2 - Mapping Component

have been mapped at different scales, in a multitude of regions throughout the U.S., and at several scales. For example, one recent project mapped multiple landscape metrics for over 2.5 million NHD-Plus surface-water catchments across the U.S. ORD experience also includes extensive work modeling the predictive relationships between landscape features and environmental endpoints, including:

- Probability of fecal coliform impairment in South Carolina, Maryland, and the Ozarks.
- Predicted sediment loads in the Mid-Atlantic region, Ozarks, and elsewhere. Predicted nutrient loads in the Mid-Atlantic region and elsewhere.
- Probability of pesticide occurrences in the Mid-Atlantic coastal plains.
- Bird diversity in the Mid-Atlantic and elsewhere.
- A landscape analysis of the quality of New York City's water supply.

- Using Landscape Metrics to Develop Indicators of Great Lakes Coastal Wetland quality

Many of the landscape metrics that ORD has calculated in the past can serve as inputs to the quantification of ecosystem services. For example, the percent of impervious surfaces, an input to the quantification of water provisioning, nutrient regulation, flood attenuation, soil and sediment regulation, and atmospheric and climate regulation services, has been calculated for more than 865,000 3x3 km^2 grid cells and more than 2.5 million NHD-Plus catchments across the U.S. In many cases, models exist that will further enable the quantification of such relationships.

Existing ORD landscape science expertise, combined with ORD traditional science expertise, monitoring data, and progressive modeling techniques will be used to develop the best methods possible for mapping ecosystem services. This is an ambitious undertaking that will require engagement of expertise from other agencies such as USGS, USDA, and NOAA as well as expertise from academia to ensure that we fully utilize currently available science. Accordingly, data will be used that are or will be available nationally, such as the National Land Cover Data (NLCD), NOAA Coastal Change Analysis Program (C-CAP) data, the U.S. General Soil Map (STATSGO) and Soil Survey Geographic (SSURGO) data, National Hydrography Data (NHD), Watershed Boundary Data (WBD), National Elevation Data (NED), and U.S. Census Bureau population data. National data sets that will be added to the ERP Library will also include air quality (e.g., Community Multiscale Air Quality [CMAQ]) and climate (e.g., Parameter-elevation Regressions on Independent Slopes Model [PRISM]) data.

ERP mapping teams are being assembled to address specific ecosystem services in conjunction with mapping teams that are being assembled to assist each of the place-based, pollutant-based, and ecosystem-based teams. Individuals will often be a part of multiple teams; this diffuse and integrated team structure creates a cross-ORD foundation of ideas and expertise that can be shared and built upon throughout the ERP. Teams are developing methods and demonstrating ecosystem service mapping techniques with the vision that the methods must be applicable at national and/or regional scales. Teams are currently identifying the best models to use for their research approaches and will heavily rely on the Modeling Team within the ERP. A set of criteria will be developed to accept or reject methods for mapping ecosystem services before they are considered for inclusion in the National Atlas. Examples of currently active teams include:

- Coastal storm surge protection team
- Net primary productivity team
- Carbon storage team
- Water provisioning team
- Nutrient regulation team
- Inland flood attenuation team
- Habitat characteristics team
- Fisheries team

Science Question #2: What are the relationships between drivers of change and the distribution and extent of ecosystem services at multiple spatial scales?

In addition to mapping ecosystem services at a static point in time, the ERP must characterize the relationships between these services and drivers of change such as climate change, land use changes, and other changes influenced by environmental policy decisions. This is a critical component of the ERP mapping work, as it will result in tools that allow decision-makers to visualize the consequences of choices for the delivery of ecosystem services. This work will draw heavily on ORD's landscape science and modeling experience and will initially utilize mature and tested data sets. For example, the NLCD is available for two time frames, 1990 and 2001 with planning for a 2006 release likely. NOAA Coastal C-CAP data are or will be available for three time frames, 1995, 2001, and 2005. The same mapping teams identified above will be responsible for this aspect of the work and will be required to demonstrate their methods through regional pilot projects before undertaking national scale efforts. Each team must address spatial scale when establishing relationships between drivers of change and ecosystem services, as these relationships often change depending on resolution. One cannot assume that a relationship observed at one scale holds for another scale (or that a finer scale will produce stronger relationships).

Science Question #3: How can ecosystem services mapping be used to inform the decision-making process and ensure that the consequences to ecosystem services delivery are included in land use and other environmental policy decisions?

In addition to producing maps of ecosystem services and demonstrating and mapping the relationships between these services and drivers of change, ORD must also be able to make resulting information readily available to decision-makers and other interested users. To ensure the National Atlas of Ecosystem Services meets the intended purpose, it will be:

- Available online;
- Interactive;
- Digital;
- Updated as new/improved information becomes available;
- Scalable – user will be able to select scale desired;
- Widely available;
- Inclusive of a baseline condition;
- Capable of assessing the consequences of choices;
- A living product, layers of information can be added as they become available;
- Distributed by a high-visibility venue (e.g., National Geographic);
- Capable of bundling ecosystem services; and
- Capable of assessing changes over time.

The availability of the National Atlas is closely linked with the Decision Support and Outreach and Education components of LTG 1. It is anticipated that the Atlas will be distributed through an EPA Decision Support system, coordinated through LTG1. In addition to distribution through EPA, the maps are also expected to be available through cooperating institutions, such as the National Geographic, through whom they can reach a wider audience.

Table 12 summarizes the Annual Performance Goals associated with the mapping component of LTG 2.

	Description	**Year Due**
APG 29	Completion of an integrated multi-year research and development plan for a national atlas, an inventory system, and models for selected ecosystem services	2009
APG 30	Methods developed and demonstrated for modeling and mapping ecosystem services related to wetlands, nitrogen cycling, and water quality including demonstrations at multiple spatial scales in place-based research areas	2010
APG 31	Methods developed and demonstrated for modeling and mapping ecosystem services related to carbon cycling, water provisioning, aquatic habitat and fisheries, and storm surge protection including demonstrations at multiple scales in place-based research areas	2011
APG 32	First national ecosystem services maps related to wetlands, nitrogen cycling, and water quality are available.	2011
APG 33	First national ecosystem services maps related to carbon cycling, water provisioning, aquatic habitat and fisheries, and storm surge protection are available	2012
APG 34	Methods developed and demonstrated for bundling of ecosystem services	2013
APG 35	Interactive maps are available to decision-makers to help them protect, enhance, and restore the delivery of ecosystem services at multiple spatial scales	2014

Table 12 APGs for LTG 2 - Mapping Component

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LTG 3 NITROGEN ASSESSMENT

3.1 Introduction - The Significance of Nitrogen

EPA is faced with developing strategies to deal with classes of stressors that do not behave like traditional toxic chemicals in the environment. Habitat change, exotic species, climate change, greenhouse gas emissions, sediment loads, and nutrient over-enrichment are examples of stressors that affect the ability of the nation's ecosystems to deliver goods and services essential to the quality of our standard of living. The risks these stressors pose to human health and ecosystems can not be easily managed if at all within EPA's existing regulatory structures because (1) the effects cross traditional regulatory media; (2) the effects are highly place-dependent and (3) the stressors exist in many forms and interact strongly with one another. Further complicating the picture is the fact these stressors lead to both desirable and undesirable changes. Nitrogen is one such stressor.

The significance of reactive nitrogen (Nr), which includes all forms of the element that are environmentally significant, stems from the duality of its environmental impacts. The MEA has underscored that understanding the tradeoffs inherent in controlling this class of environmental pollutant is one of the major challenges the EPA will face in the 21st century. On the one hand, reactive nitrogen is one of life's essential nutrient elements. It is required for the growth and maintenance of all of earth's biological systems. For humans, there are several sets of services provided by natural and anthropogenic sources of reactive nitrogen, including the production of plant and animal products (food and fiber) for human consumption and the combustion of fuels that support our energy and transportation needs. Population growth and increased demands for energy, transportation and food lead to greater demand for Nr. While releases of nitrogen are associated with societal benefits, Nr is a powerful environmental pollutant. Over the past century, human intervention in the nitrogen cycle and use of fossil fuels has led to substantial increases in human and ecosystem exposure to Nr. The amount of Nr applied to the nation's landscape and released to the nation's air and water has reached unprecedented levels, and projections show that Nr pollution will continue to increase for the foreseeable future. These increases in Nr pollution are accompanied by increased environmental and human health problems.

Release of Nr, in both oxidized (NOx) and reduced (mostly ammonia and ammonium) forms contributes to:

- Depletion of stratospheric ozone.

- Climate change attributable to greenhouse gas emissions, especially nitrous oxide (N_20).

- Fine particle formation and the resulting effects of fine particles on human health, air clarity, visibility, and the radiative properties of the atmosphere.
- Formation of ozone in the troposphere, and subsequent human health effects associated with ozone inhalation, as well as damage to plants that reduces crop and forest production.
- Increases in deposition of ammonia and nitrogen oxides to terrestrial and aquatic ecosystems, which generates a "cascade" of direct and indirect effects on soil fertility, plant productivity, water quality and estuarine productivity, and human structures.

Direct application of nitrogen fertilizers to fields, rangelands, and forests, in combination with the wet and dry deposition of nitrogen from the atmosphere, contributes to:

- Direct damage to plant foliage that reduces production and increases susceptibility to insect and diseases.
- Long-term loss of soil fertility through the soil acidification, depletion of base cations, changes in element ratios, and increases in availability of harmful aluminum in soils.
- Shifts in plant community composition and loss of biodiversity.

In addition, direct deposition of Nr to surface waters through precipitation and dry deposition, direct inputs of sewage, and diffuse non-point sources of Nr contribute to:

- Nitrate contamination of drinking water supplies.
- Eutrophication-related algal and other vegetation blooms, loss of dissolved oxygen, fish kills, loss of productivity, and loss of desirable habitat.
- Acidification of lakes and streams.
- Reduced buffering capacity of estuarine and marine waters.

Furthermore, both the benefits and problems associated with Nr are intricately linked to other essential elements (e.g., carbon, sulfur, trace elements in soils) and pollutants such as volatile organic compounds (VOCs), ozone, and fine particulate matter that affect the quality of air, water and soils. Nr emissions, processes, and effects occur across a continuum of landscape scales and at time scales that range from hours to hundreds of years. These realities, together with the linkage of Nr to other essential elements and pollutants, make it necessary to develop modeling and analytical tools that account for many variables.

Given the current magnitude and future trajectory of Nr emissions combined with the complexity of chemical and biological transformations of Nr as it moves through the landscape and the array of effects associated with nitrogen pollution, the fundamental challenge facing the EPA is to transform major environmental policies in ways that make clear the consequences of choices that affect how emissions of pollutants of national scale result in changes in the type, quality, and magnitude of the services-- clean air, clean water, productive soils and generation of food and fiber—that we receive from the nation's ecosystems .

3.2 Research Direction

At the strategic level, the research is to provide a scientifically sound methodology for a pollution control outcome that is based on quantification of the tradeoffs among ecological services, affected positively and negatively, by changes in amount of that pollutant released to the environment. The organization of research for this pollution-specific component of the ERP requires a series of data collection and modeling steps that move in sequence toward the goal of identifying, quantifying, and valuing the changes in all ecological services affected by changes in anthropogenic Nr emissions in the system, landscape type, or geographic area of concern. Measured or scenario-driven changes in Nr inputs, applications, and emissions are used as a starting point to determine the measured or modeled responses in ecological structure and function.

The scale and complexity of Nr pollution, suggests that solutions to the problem will require supporting data collection and modeling efforts capable of assessing all Nr flow pathways and related environmental receptors and effects at a national --or hemispheric, or even global--scale. That approach is not practical as a starting point. However, problems associated with spatial scale and system complexity become more tractable when the research is aimed at developing one or more proofs-of-concept for the overall approach.

As a small program at this point, we will start by taking advantage of the ongoing studies in wetlands, coral reefs, and in particular, the place-based demonstration projects to study Nr pathways and effects. It is desirable to scale up to the national scale from an EPA policy level but we believe considerable progress can be made initially at our smaller scales representing very different ecosystem service districts, yet maintaining a national perspective and developing national tools and inputs where required and where practical. Specifically, we will develop research projects that focus on the science questions, and the intended outcomes, highlighted in Figure 15. The Annual Performance Goals associated with LTG 3 are listed in Table 13.

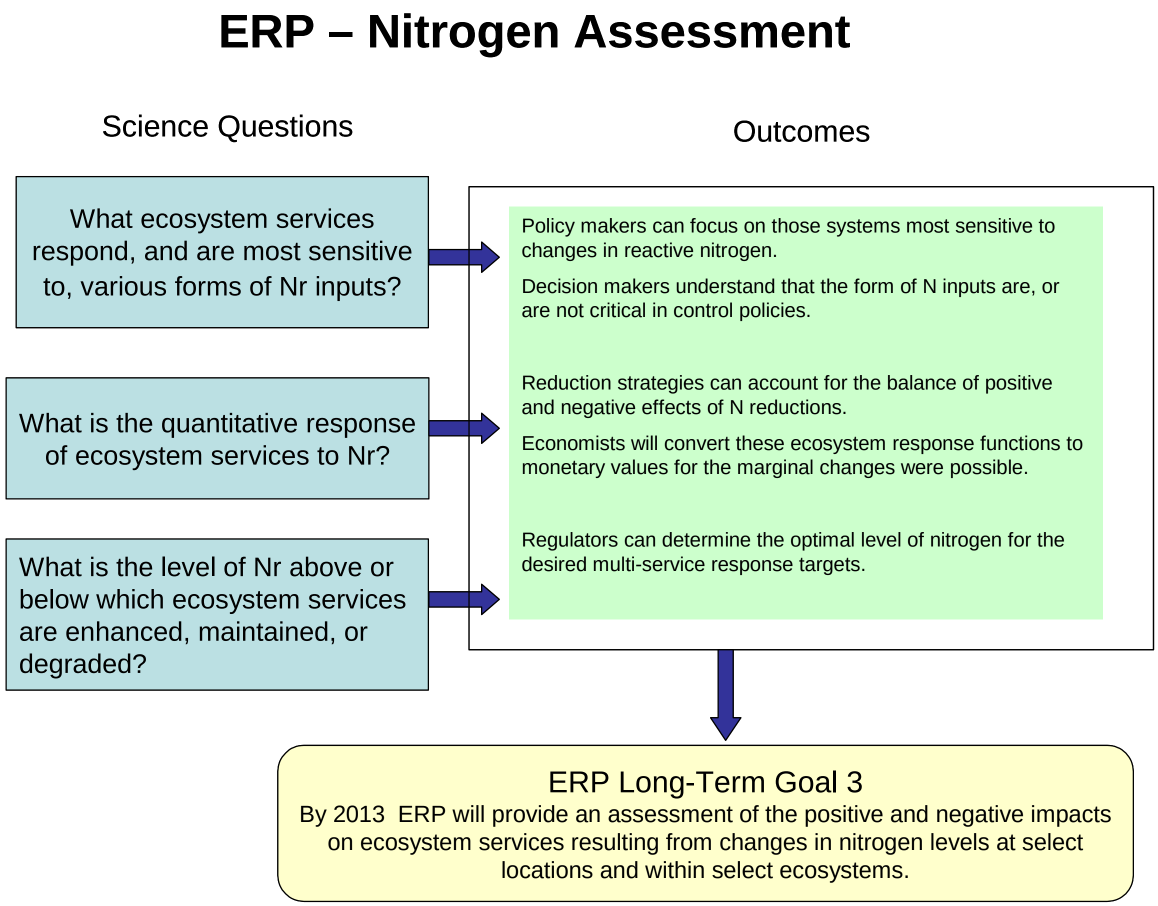

Figure 15 Overview of LTG 3

	Description	**Year Due**
APG 36	Complete an implementation plan for the ERP nitrogen research effort.	2008
APG 37	Report on the state of the science on ecosystem services and reactive N using national and international data sources, including the Science Advisory Board Committee studying reactive nitrogen.	2009
APG 38	Provide ecosystem service response functions for reactive N and responsive ecosystem services for multiple ecosystems, including wetlands, for the place based ecosystem services districts.	2010
APG 39	Research report on thresholds of change in key ecological services affected by changes in emission rates of Nr to the atmosphere.	2011
APG 40	Report on the value of ecological services provided by Nr and costs associated with the services affected by Nr within the place-based demonstration projects based on alternative management options.	2012
APG 41	Provide the modeling framework as a multi-media decision-support tool for Nr based on the optimization of ecological services affected by changes in forms and flows of Nr from anthropogenic sources affecting the place-based demonstration projects.	2013

Table 13 APGs for LTG 3

LTG 4 – ECOSYSTEM ASSESSMENTS

4.0 General Introduction

The Millennium Ecosystem Assessment (MEA) produced a compelling synthesis of the global value of ecosystem services to human well-being (MEA 2005). While the MEA was a critical, initial step to demonstrate the potential for assessing global trends in ecosystem services, it is important to note that the MEA did not attempt to down-scale such assessments to regional or even national scales of analysis, nor did it attempt to create methods and tools to support decision-makers at any level of governance, industry, or citizen action. Carpenter et al. (2006) identified many uncertainties and research needs evoked by the Millennium Ecosystem Assessment. These include characterizing ecosystem services, linking ecosystem condition and function to services and human well-being, predicting the effects of changes in ecosystem services on human well-being, and improving the identification, quantification, and communication of uncertainty, and in turn provoke the following research questions:

- What are the current spatial extent and condition of ecosystems?
- How are wetland structure, function, and processes related to the provision of ecosystem services?
- What ecosystem drivers affect ecosystem services provisioning and how do human uses mollify or exacerbate these drivers?
- How can ecosystem services be aggregated across the landscape at various spatial scales, while retaining important ecosystem heterogeneity and the ability to detect change at the various scales?
- How can ecosystem services be linked to the maintenance and support of human well-being?
- How do changes in ecosystem functions and services affect future human well-being?

The ERP will focus on the dynamics of service flows in two priority ecosystems – wetlands and coral reefs. Both of these ecosystems deliver a wide range of ecosystem services (e.g., fish and fiber production, water supply support, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, and tourism) that support human incomes, livelihoods, and social, cultural, and spiritual enjoyment. Yet wetlands and coral reefs are in serious decline (Dahl 2005; Wilkinson 2004) and efforts to manage and protect them have been inadequate, often lacking both monetary resources and management expertise. For example, the most recent National Wetlands Inventory Status and Trends report (Dahl 2005) reported a net gain in total wetland acreage between 1998 and 2004, yet significant losses still occurred in specific wetland types (e.g., 61% of freshwater wetland losses were due to urban and rural development).

As human population continues to increase, especially in coastal environments, wetlands and coral reefs worldwide are projected to suffer continued loss and degradation, thus reducing the capacity of these ecosystems to provide valued services that contribute to human well-being. Rapid development and population growth concurrently intensifies the demand for ecosystem services. Major policy decisions in the next decade must address trade-offs among current and future uses of wetland and coral reef resources. Particularly important trade-offs involve those between coastal land use and human safety during floods or storm surges; agricultural production and safe water supplies; land use and biologically diverse terrestrial ecosystems; water use and biologically diverse and productive aquatic ecosystems; and current water use for irrigation and future agricultural production (MEA 2005). Such decisions must also consider the full range of benefits and values to human well-being provided by different wetland and coral reef ecosystem services.

Costanza et al. (1997) estimated the average global value of wetland ecosystem services in US 1994 dollars to be almost \$15K ha^{-1} yr^{-1}, which is the highest value reported for any biome, and urged that future environmental decision-making processes weigh the value of ecosystem services as an important contribution to human well-being. Since environmental valuation was first applied to coral reefs (Spurgeon 1992) there have been several significant studies that describe valuation approaches and estimates of coral worth (e.g., ICLARM 2001). One frequently cited study (Costanza et al. 1997) estimated the global value of corals at \$377B yr^{-1}, or \$0.60 m^{-2} yr^{-1}. A subsequent study, using more realistic estimates of coral distribution but omitting some important services, estimated the global value as \$30B yr^{-1}, or \$0.10 m^{-2} yr^{-1} (Cesar et al. 2003). Global estimates, by their very nature, are coarse and not necessarily relevant to local management decisions. As illustration, a recent insurance claim for a ship grounding in Yemen was settled at the equivalent of \$30 m^{-2} yr^{-1}, representing a much higher local value for coral reefs than average global values (Spurgeon 2004).

Improved environmental management will therefore require procedures to valuate wetland and coral reef services at the scale of management decisions. Variability in services and valuation of services is likely to differ among jurisdictions; therefore tools and procedures are needed that can be applied to local conditions by local resource managers. Immediate needs include tools and procedures to quantitatively characterize the linkages between ecosystem services and ecosystem attributes (biological, physical and chemical components); to valuate ecosystem services; to assess extent and condition of the ecosystems; to quantify effects of human activity on delivery of services; and to forecast alternate futures from the range of management decisions under consideration.

The goal of the ORD Ecological Research Program is to evaluate ecosystem services using three research approaches: pollutant-driven, ecosystem-driven, and place-based. This section outlines our initial research focus within the ecosystem-driven approach to evaluate ecosystem services provided by wetlands and coral reefs. The long-term goal for the ecosystem component of the ERP is:

By 2015 ERP will provide guidance and decision support tools to target, prioritize, and evaluate policy and management actions that protect, enhance, and restore ecosystem goods and services at multiple scales for two specific ecosystem types: wetlands and coral reefs.

In order to accomplish this outcome, the objectives of this program are to produce the cutting-edge science necessary to:

1) Identify, characterize, and assess ecosystem services of wetlands and coral reefs that contribute to human well-being at multiple spatial and temporal scales;

2) Identify, characterize and assess environmental conditions and human activities that influence the delivery of ecosystem services from wetlands and coral reefs;

3) Provide maps, models, information and decision support tools to forecast local and regional sustainability of wetland and coral reef ecosystems and the services they provide; and

4) Apply information on the benefits of ecosystem services of wetlands and coral reefs to valuation and decision-making processes for resource management, environmental protection, and ecosystem restoration.

4.2 Wetland Ecosystems

4.2.1 Introduction

Wetlands are ecotones, or zones of transition, between land and water (Johnston 1993). As such wetlands have been recognized as important regulators of the flows of materials and of other processes occurring across the landscape (Risser 1993). Thus, wetlands contribute to the services provided by aquatic and terrestrial ecosystems, in addition to providing unique services. Although much is known, conceptually or qualitatively, about the links between wetland condition, function, and services, research is needed to quantify those links at multiple scales and to demonstrate the impact of alternative futures on the ability of wetlands to provide services and to affect human well-being. In the long-term, other ecosystems can also be assessed and integrated by adapting the models developed for wetlands.

ORD will initiate the ecosystem-based portion of its research strategy by assessing the services of wetlands at multiple scales. Wetlands were identified as a priority for preservation, restoration, and enhancement by the President on Earth Day 2004 (CEQ 2006). Recognizing the array of benefits provided by wetlands to the economic, ecological, and cultural heritage of all Americans, this new national initiative went beyond the “no net loss” policy with a goal to restore or create, protect, and improve at least 3 million acres of wetlands by 2009 (CEQ 2006). Multiple Federal agencies, including EPA, are working to achieve the President’s goal, providing ample opportunity for leveraging partnerships and resources. ORD’s research will help inform Agency decisions on the location and scale at which certain types of wetlands should be protected, enhanced, or restored to optimize wetland services. ORD has unique competencies that provide operational leadership on multiple wetland science topics, including ecosystem services, which directly address the needs identified in the MEA and those of the Federal agencies tasked with achieving the President's goal. As illustrated above by the MEA (2005), a rich history exists for evaluating ecosystem services of wetlands. Ecological functions of wetlands are well-defined and have been related to outcomes valued by humans (e.g., see "Regional Guidebooks for Applying the Hydrogeomorphic Approach" at http://el.erdc.usace.army.mil/wetlands/wlpubs.html).

4.2.2 Multi-Scale Research Approach

In this ERP MYP 2009-2014, ORD proposes a coordinated, comprehensive research approach to assess the multiple services provided by different types of ecosystems and the impact of changes in the landscape on the provisioning of services and human well-being. Ecosystem services are provided at a range of spatial and temporal scales from short-term/site-specific to long-term/global, and benefit humans at multiple institutional scales from the individual to community to international (Hein et al. 2006). Effective assessments of ecosystem services and their connection to human well-being, therefore, cannot be conducted at a single temporal or spatial scale to determine the full benefits to humans. This research will focus on developing and applying the necessary tools to assess wetland ecosystem services at national, regional, and sub-regional scales (e.g., watersheds).

Much is known about the structure and function of wetlands (both qualitatively and quantitatively) and conceptual models have been developed to link function to ecosystem services and values (King et al. 2000); yet the complexity of wetland ecosystems has hindered the valuation of multiple services at regional and larger scales (NRC 2005). Wetland services have historically been valued at fine scales because the benefits of restoration or protection activities have been perceived as limited to individual land owners or residents living in or near a particular ecosystem. Because some generalizations may be made about ecosystem services across scales, ecologists often aggregate the value of individual services to larger scales. However, understanding the scales at which wetland services are realized and quantifying the uncertainty inherent in aggregation across scales is critical for appropriate valuation (Mitsch and Gosselink 2000; NRC 2005). For example, individual wetlands in a watershed may have quantifiably different capacities to store water but this function becomes important as an ecosystem service only when sufficient wetland area in the landscape is available to desynchronize the flow of floodwater. Hey and Philippi (1995), for example, estimated that the restoration of approximately 13 million acres of wetlands in the Upper Mississippi and Missouri River basins would be necessary to provide enough flood storage to protect the residents in that region from excess river flow due to extreme flood events.

A landscape perspective is critical to understanding the services associated with the ecological functions of wetlands. While some wetland functions (e.g., habitat) may be defined at the scale of individual wetlands, most functions and values (e.g., biodiversity, water-quality improvement, flow moderation) depend on the type, abundance, and distribution of wetlands across a watershed or landscape (Detenbeck et al. 1999, and the references cited therein). Bedford (1996) observed that the ecological services provided by wetlands result from the hydrogeologic characteristics of the landscape that cause specific wetland types to form and support their characteristic structure and function. Her findings were echoed by the National Research Council (NRC) (2001) in operational guidelines for creating or restoring wetlands that are ecologically self-sustaining. Specifically, the NRC called for adopting a dynamic landscape perspective in wetland management that paid special attention to hydrological and topographical variability, subsurface characteristics, and the hydrogeomorphic and ecological landscape and climate.

Although knowledge of the spatial and temporal thresholds at which wetland functions are altered and services are impacted is necessary to inform management and policy decisions, large gaps remain in our understanding of regional (and larger) scale impacts of changes in wetland functions on services and human well-being. Wetland regulation and management have historically occurred at the scale of individual wetlands. The best known example of this approach is compensatory mitigation required in permits issued under Section 404 of the Clean Water Act. These individual wetland decisions can, cumulatively, reconfigure the wetland resource over large geographic areas (Kentula et al. 1992; Kentula et al. 2004). Shifting the scale of research and management to the broader landscape will involve the consideration of ecologically meaningful regions of assessment, such as watersheds, aquatic ecoregions (Omernik 1987), hydrologic landscape regions (e.g., Winter 2001, Wolock et al. 2004) and how they interface with the political units associated with land use planning, and resource regulation and management.

4.2.3 Conceptual Model

Figure 16 is a conceptual model illustrating key relationships associated with the provision of wetland ecosystem services. As summarized in Figure 17, ERP research will enhance the scientific understanding of these services by answering the following research questions:

> **Research Question 1.** How do drivers of change affect the ecological function of wetlands and the delivery of services at multiple spatial scales?
>
> **Research Question 2.** What is the relationship between the abundance, distribution, and condition of wetlands in the landscape and the delivery of ecosystem services?
>
> **Research Question 3.** What decision support tools are needed to protect, enhance, and restore the delivery of wetland services at multiple spatial scales?

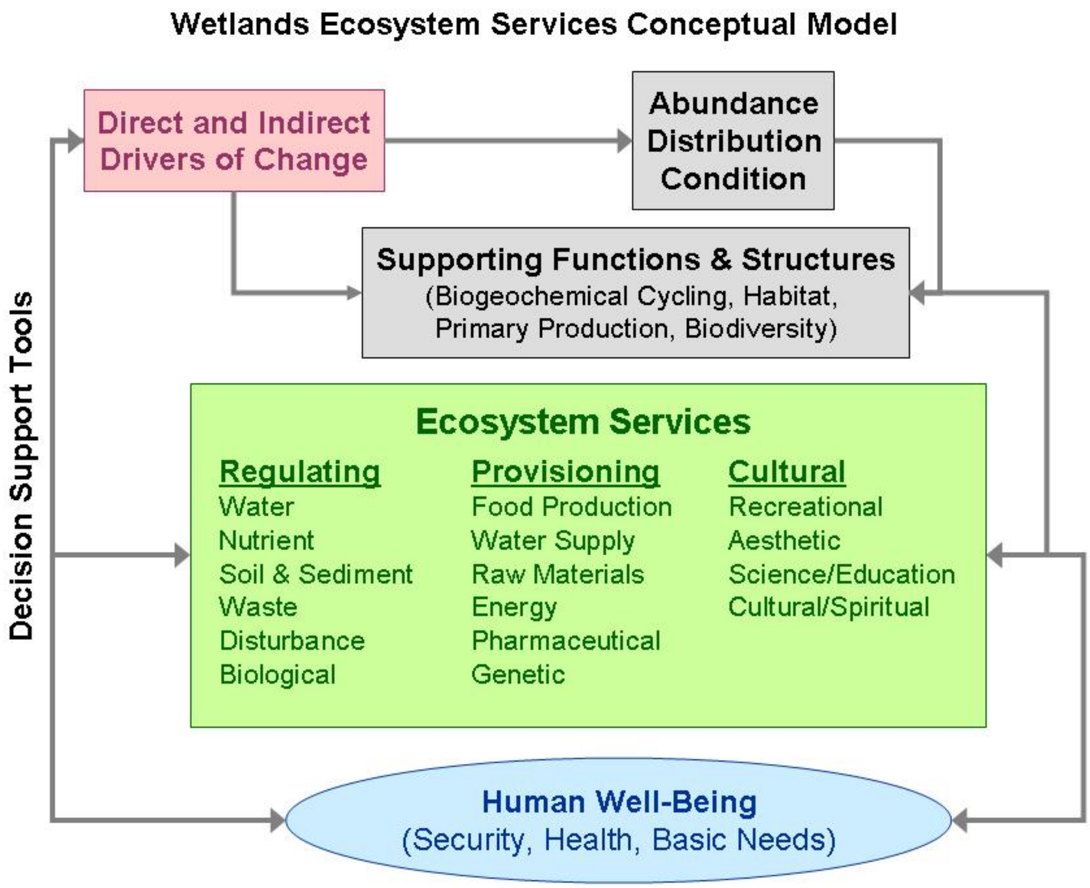

Figure 16 Conceptual model for wetlands showing the relationship between drivers of change, ecological functions, ecosystem services and human well-being.

4.2.4 Research Questions

ORD's proposed research will be organized around the characteristics of the wetland resource that affect the production of services, including the relative abundance of functional wetland type, their distribution and position in the landscape, and their ecological condition. There is a strong scientific basis for the relationship between these characteristics and the ecological function of wetlands (Brinson 1993, Bedford 1996). This research will build on the emerging concept of a biological or ecological condition gradient, which describes a series of changes in community composition, structure, function, and processes along an axis of human disturbance. If we can describe how wetland mosaics change along a gradient of human disturbance, we can evaluate the cumulative impact of change on emergent properties (such as habitat use by species which use more than one habitat type). Research that demonstrates how these concepts can be quantified and applied to resource management is limited, especially in terms of wetland services.

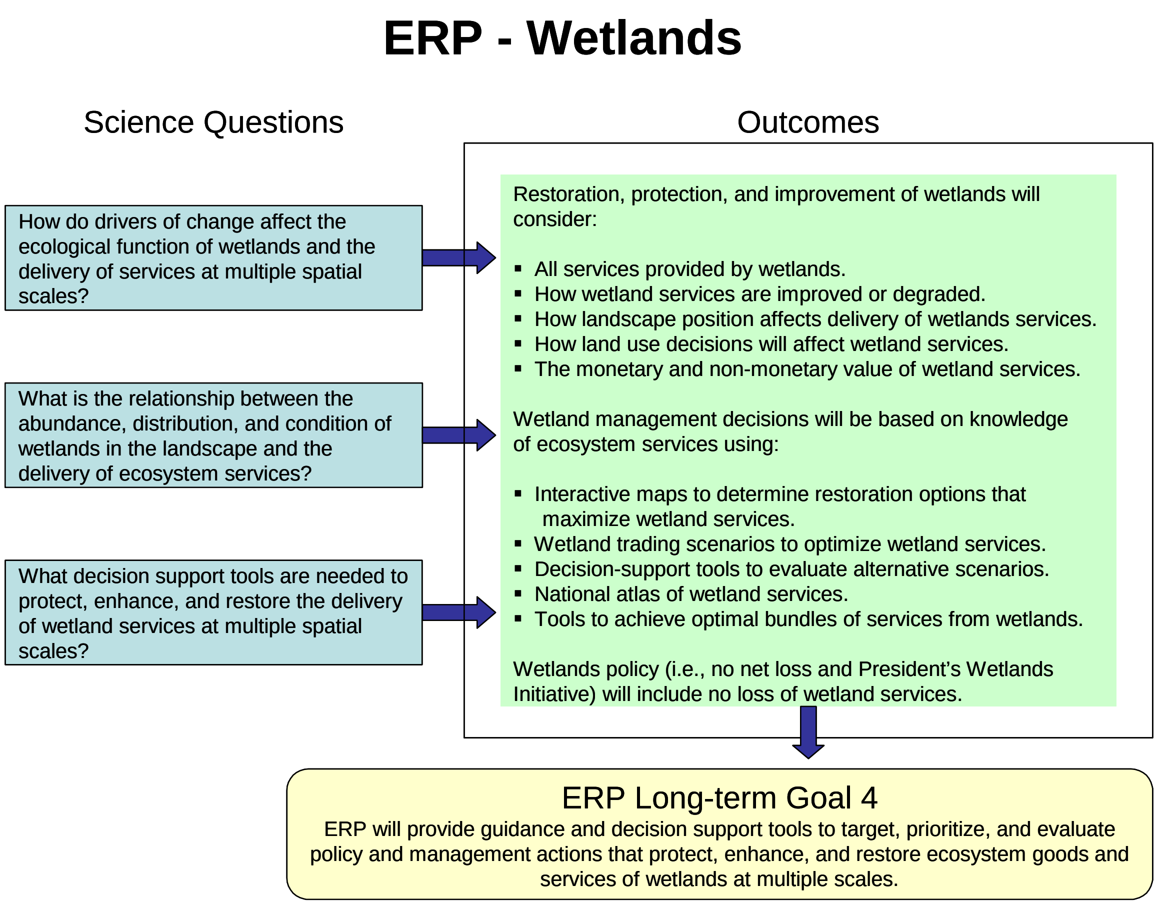

Figure 17 Overview of LTG 4 - Wetlands Component

<u>Research Question 1:</u> How do the drivers of change influence the ecological function of wetlands and the delivery of services at multiple spatial scales?

The primary indirect drivers of wetland loss and degradation are population growth and development for economic gain. The primary direct drivers of adverse change in the ability of wetlands to provide services are infrastructure development, land conversion, water withdrawal or augmentation, pollution, over harvesting and exploitation, and the introduction of invasive species (MEA 2005). Although the most recent status and trends report described a net gain of 191,750 acres of wetland in the conterminous U.S., losses of specific wetland types still continued to occur, primarily as a result of human actions that destroy wetland hydrology (Dahl 2005). Sixty-one percent of U.S. wetland losses are attributed to urban and rural development (Dahl 2005). In addition to causing losses of wetland area, the drivers of change also affect the ability of existing wetlands to deliver ecological services. Information on the effects of human use on the delivery of wetland services at multiple scales is limited, especially in regard to performance by wetland type and location.

ERP research will:

- Establish the relationship between ecological function and delivery of services by wetlands.

- Determine the effect of drivers of change on wetland structure, ecological functions, and the delivery of specific ecosystem services and bundles of services.

<u>Research Question 2:</u> What is the relationship between the abundance, distribution, and condition of wetlands in the landscape and the delivery of ecosystem services?

Functional classes of wetlands (e.g., HGM classification of Brinson (1993)) have been related to ecological functions of wetlands (Magee et al. 1999, Shaffer and Ernst 1999, Shaffer et al. 1999). Changes in the relative abundance of wetland functional classes in a landscape result in a change in the relative abundances of ecological functions and the related services (Kentula et al. 2004). The relative abundance of functional classes is called a *landscape profile* (Gwin et al. 1999). Current and limited research on the use of landscape profiles shows that units of the landscape have different profiles depending on hydrogeomorphology, geology, and climate. Use of landscape profiles is a first step in characterizing the ecological functions and associated wetland services in an area of interest. To date, such profiles have been generated by surveys of wetlands (e.g., Gwin et al. 1999, Kentula et al. 2004) and through geographic information system (GIS) modeling by Johnson (2005).

The use of landscape profiles for wetlands is only a first step in understanding the potential delivery of ecosystem services. There is also a need to consider the wetland resource as part of a *functional surface*. A functional surface is the mosaic of land cover and land use types in which wetlands occur (Forman 1995). The distribution pattern of wetlands on the functional surface is also tied to the hydrologic, geologic, and topographic characteristics of the landscape (Bedford 1996). Therefore, functional types of wetlands occur in different spatial and temporal settings and combinations throughout the landscape; this mosaic determines the level to which ecosystem services are or can be derived.

ERP research will:

- Determine how surveys of wetland condition can be used to estimate the delivery of ecosystem services by wetlands.

- Develop landscape approaches (i.e., landscape profiles, functional surfaces) for determining the hydrologic and ecological functions of wetlands and associated delivery of ecosystem services.

- Develop landscape models predicting the delivery of specific ecosystem services and bundles of services based on wetland landscape profiles, empirical stressor-response models, and published literature.

<u>**Research Question 3:**</u> **What decision support tools are needed to protect, enhance, and restore the delivery of wetland services at multiple spatial scales?**

ERP's research will build on current research on surveys of wetlands condition to develop approaches for effective wetland management. In addition to describing the ecological status of wetland resources, surveys provide data about the likely causes of wetland degradation (e.g., Wardrop et al. 2007, Whigham et al. 2007). Survey information and decisions can then be used to prescribe management options and best management practices, or to contribute to the production of a restoration opportunities map (Figure 18). For example, in an evaluation of restoration options for the Sanyang wetland in China, Tong et al. (2007) determined the drivers, condition and function of wetlands and modeled the ecosystem services and their current and potential value. They found that material production provided the highest current value but that the current value of environmental purification was negative (i.e., money was "owed" for this service due to water pollution and the lack of wetland vegetation). The potential value of the wetland to provide environmental purification was very high, accounting for 43 percent of the total potential value. The decision, then, was to restore the structure and function of the wetland to support environmental purification. Although this example illustrates the decision process for determining restoration priorities for a single wetland system, our approach must address multiple scales. We need to have decision support tools that can inform management decisions at the local, regional, and national scales.

ERP research will:

- Develop interactive mapping tools that provide decision makers with accurate place-based information on wetland ecosystem services and value and the effects of local and landscape manipulations, including protection, restoration, enhancement, and degradation, on the provision of wetland ecosystem services and summary landscape valuation.

- Report on recommended approaches to incorporate the protection, enhancement, and restoration of wetland services into wetland management strategies.

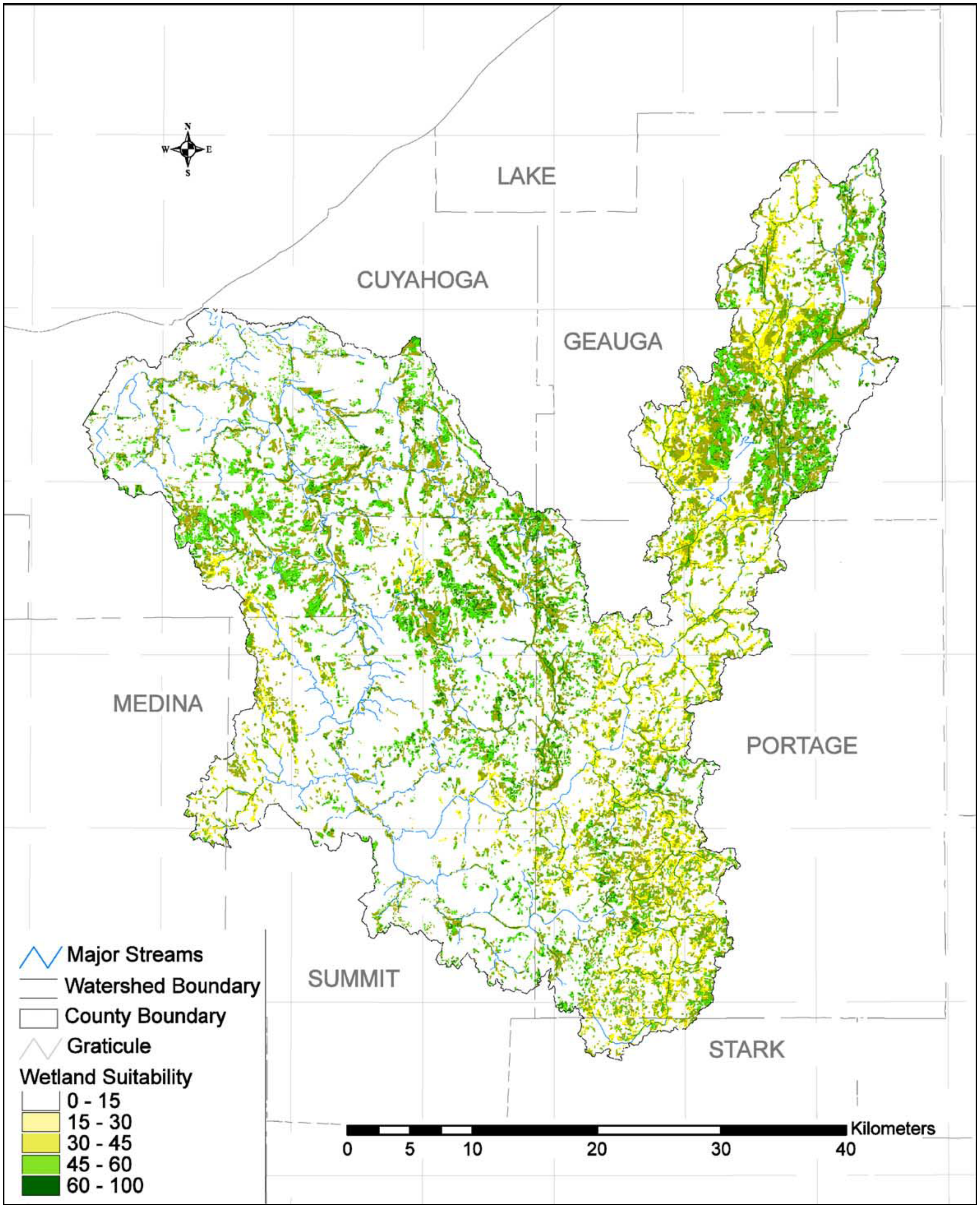

Figure 18 Map of the Cuyahoga watershed in Ohio showing the relative suitability for wetland restoration (from White and Fennessy 2005).

The research described above will fill long-term needs. In the short-term, ERP will initiate an ambitious research effort to incorporate the wetland research program into a comprehensive approach for ecosystem services research, assessment, and management. This approach will use the modeling strategy developed to evaluate alternative futures in the Willamette River Basin (Baker et al. 2004) and the Tampa Bay watershed, in combination with valuation of wetland services. The proposed research will:

- Determine the best methods (monetary and non-monetary) to value wetland services at multiple scales.
- Apply current classical and exploratory valuation methods to quantify the local and landscape provision of ecosystem services across wetland types, sizes, location, condition, and hydrogeomorphic setting.
- Develop decision support tools that allow manipulation of wetland sizes, functional types, placement in the watershed, and potential wetlands stressors and provide the graphical ability to output maps that visually detail the changes and effects of the different scenarios.
- Determine the consequences (relative risks) of optimizing for a particular service.

4.3 Coral Reef Ecosystems

4.3.1 Introduction

ERP's research on coral reef services is organized to improve the understanding, delivery and sustainability of ecosystem services from coral reefs. This includes an inventory and characterization of the services provided by coral reefs (ecosystem assessment), the influences of natural and anthropogenic activities on those services (quantifying agents of change, both adverse and beneficial), and the outlook for sustained services under alternative future scenarios (forecasting service sustainability). These three aspects are captured in the research questions detailed below and summarized in Figure 19. The research is organized by flow of information (Figure 20): (1) ecosystem assessments to inventory the extent and condition of coral reefs and to quantify linkages between reef attributes and ecosystem services; (2) quantifying environmental agents of change, particularly adverse, anthropogenic drivers on existing reef attributes and their services; (3) forecasting sustainability of existing attributes and services in view of future environmental changes and potential management activities; and (4) validating success of management actions and refining forecasts. Through this process tools and models will be developed that will allow managers to incorporate environmental valuation methods into coral reef management.

While ERP research will eventually examine all relevant coral reef ecosystem services, the initial efforts will focus on the four services currently believed to have the greatest

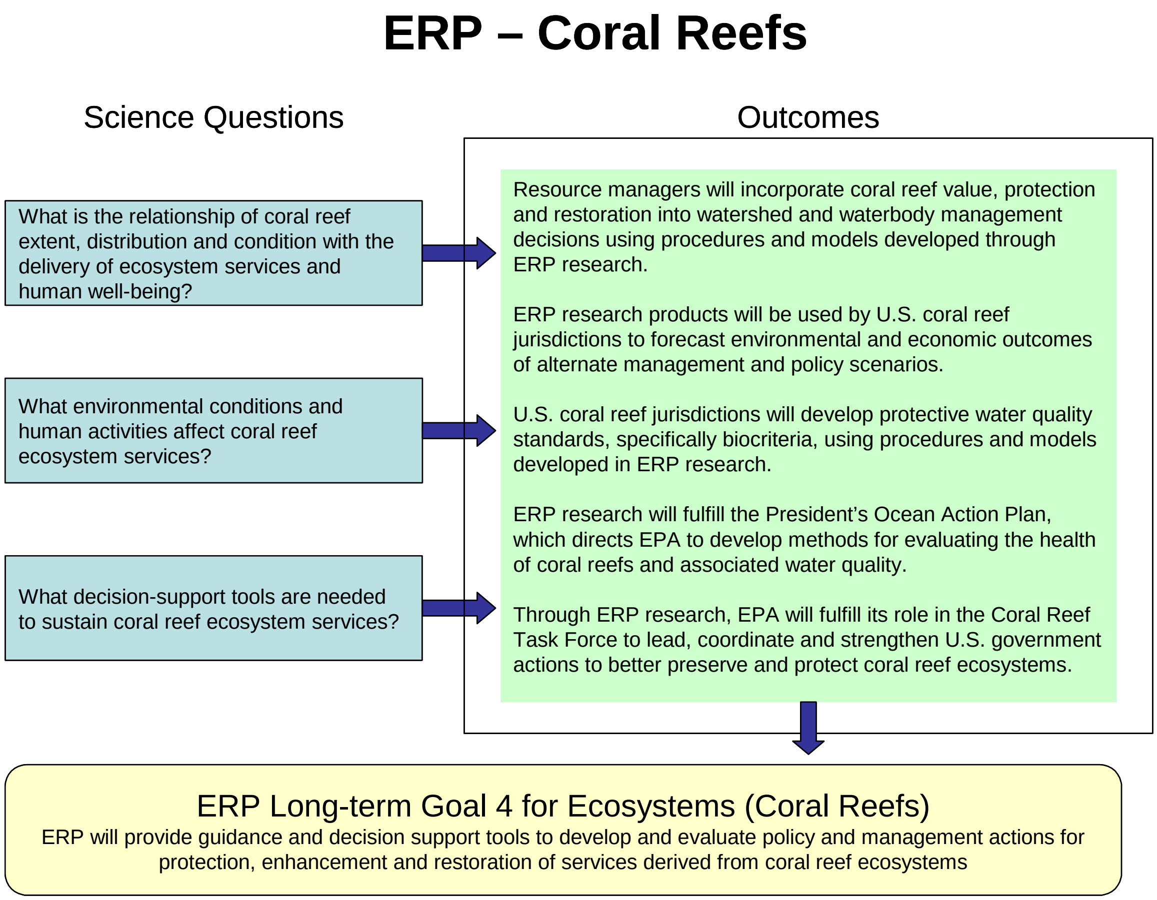

Figure 19 Overview of LTG 4 - Coral Reef Component

value; shoreline protection, tourism, fish production, and biodiversity (Costanza et al. 1997, Cesar et al. 2003) and their relationships to social well-being. The reef attributes that provide these services include stony corals, soft corals and sponges, fish, and benthic invertebrates. Some of these attributes provide the service directly (e.g., stony corals provide coastline protection); others support the production of fish—notably habitat provided by stony corals, soft corals and sponges and benthic invertebrates as fish prey (Figure 21). All of these attributes contribute to biodiversity. Additional attributes and services will be investigated as necessary. Much of the initial research for Coral Reef Services will occur in U.S. Caribbean jurisdictions (U.S. Virgin Islands); however, it is anticipated that information and decision support tools will be useful and transferable to the entire eastern Caribbean.

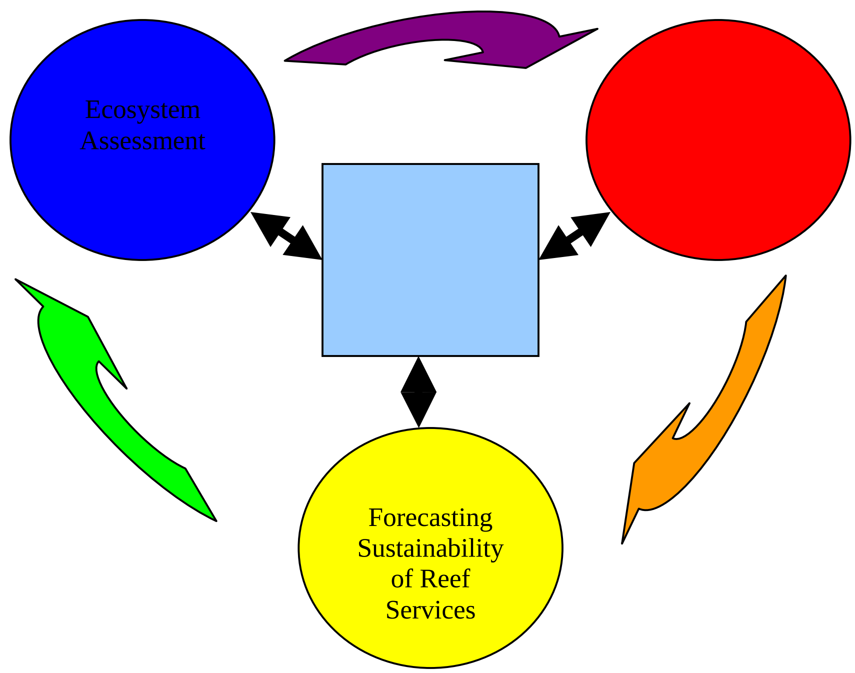

Figure 20 **ERP research on coral reef ecosystems will target ecosystem assessment (reef attributes that provide services), quantifying environmental agents of change (natural and anthropogenic), and forecasting sustainability of reef services under different management scenarios. Arrows represent the flow of organization and information that will lead to improved indicators, links, and models to valuate, assess and forecast coral reef ecosystem services.**

4.3.2 Research Questions

<u>Research Question 1:</u> What is the relationship of coral reef extent, distribution and condition with the delivery of ecosystem services and human well-being?
Environmental valuation requires that values (worth) are applied to use and non-use services of an ecosystem, that the extent and condition of the ecosystem is known, and that linkages between services and reef attributes are quantified. Methods to valuate coral reef services have matured over the last two decades. The most important services described by these methods of valuation include shoreline protection, fishing, tourism and non-use aspects (biodiversity, aesthetics). To estimate value from these services it is necessary to know the extent, distribution, and condition of the resource. Linear extent and distribution of coral reefs, particularly in the eastern Caribbean, have been described

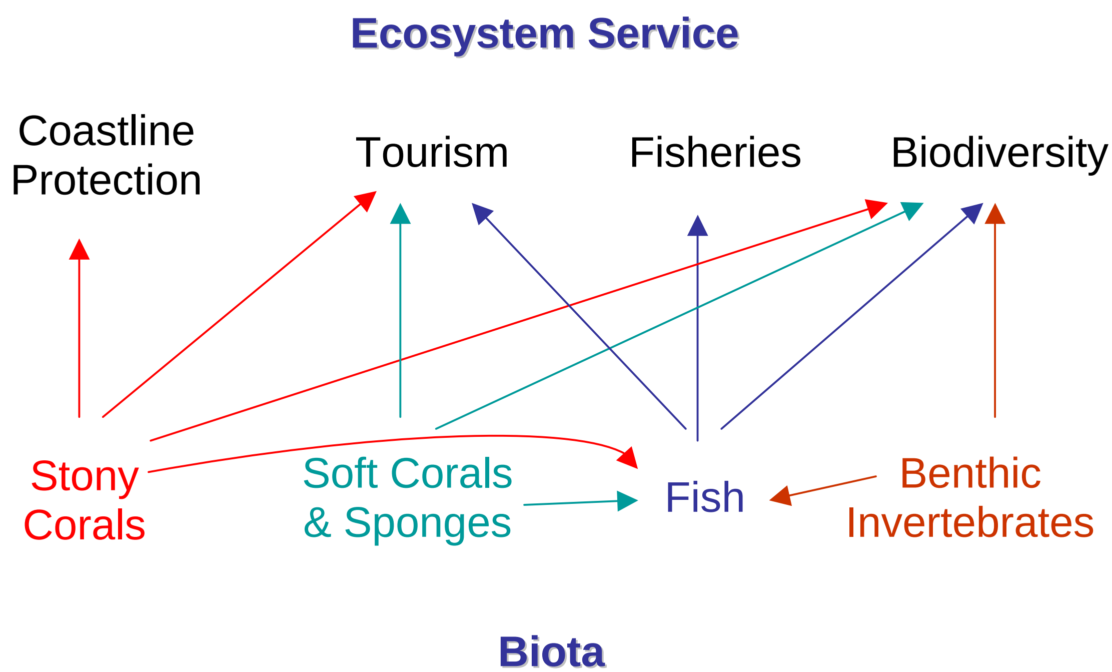

Figure 21 **Conceptual diagram of the relationship between various coral reef attributes (biota) and four major ecosystem services. These linkages will be quantitatively characterized in the Ecosystem Assessment portion of ERP research.**

through satellite and sonar imagery (Kendall et al. 2004). However, certain reef attributes that are critical to ecosystem services (e.g., reef complexity, coral condition) have not been. Moreover, most reef services have not been quantitatively linked to the reef attributes that provide them. To defensibly associate reef attributes to provision of service will require quantitative evaluation.

ERP Research will:

- Inventory and characterize services derived from coral reefs in the eastern Caribbean.

- Describe potential methods for valuation of these services. Quantitatively link the structural and functional attributes of coral reefs that underpin ecosystem services.

- Describe the spatial distribution of ecosystem services based on distribution, attributes and condition of existing coral reefs.

- Identify different spatial scales that best capture benefits derived from coral reefs.

<u>Research Questions 2:</u> What environmental conditions and human activities affect coral reef ecosystem services?

Environmental change has been shown to affect coral reef ecosystems dramatically. This was never more evident than the destruction of over 16 percent of the world's coral during a 1998 climate-induced bleaching event (Wilkinson 2000). Both natural and anthropogenic changes must be considered in coral reef management, yet only local, anthropogenic changes can be influenced by local management decisions. Changes in reef attributes can be converted, by virtue of linkages described above, to changes in ecosystem services. This process will identify the costs of human disturbances, which can be used to better inform management decisions (e.g., forest clearing) and better focus management actions (e.g., reduce fishing).

ERP Research will:

- Determine the relative influence of local versus regional environmental condition on coral reef services.
- Identify human activities that have the greatest impact on coral reef ecosystems.
- Quantitatively relate human stressors to declines in reef attributes and loss of services.
- Identify regulatory and management activities that will improve delivery of services through protection and restoration of reef attributes.

<u>Research Question 3:</u> What decision-support tools are needed to sustain coral reef ecosystem services?

Implicit in this research question is the need to forecast sustainability of coral reef attributes that provide valued services. The question is focused on decision-support tools, rather than generalized solutions, because variability of reef attributes and human disturbances is very high across reefs. Resource managers need the capacity to forecast sustainability for their particular locale. Forecasts could rely on tools as simple as trend analysis for reef extent or condition. Trend analysis would not, however, provide insights into environmental change or management alternatives. For these, sustainability models must be developed, models that consider the existing attributes and provide a dynamic platform for examining the consequences of various environmental scenarios and management activities. Sustainability models will require information generated partly from (local) ecosystem assessments and partly from research performed to address specific model needs (for example, coral growth rates and erosion rates). The models must also have spatial flexibility to be applicable at multiple management scales. Models may therefore be coupled to interactive mapping tools.

ERP research will:

- Provide tools to forecast reef sustainability and future delivery of ecosystem services.

- Forecast effects of selected regulatory, restoration, or management activities on reef sustainability and future services from an eastern Caribbean jurisdiction.

- Examine consequences of management alternatives that optimize particular coral reef services.

Table 14 summarizes the Annual Performance Goals associated with both the wetlands and coral reef ecosystem assessment components of LTG 4.

	Description	**Year Due**
APG 42	Provide a scientifically defensible approach for conducting the research to support policy and management actions that protect, enhance and restore the ecosystem goods and services of wetlands and coral reefs.	2009
APG 43	Characterize the relationships between ecological function and delivery of services by wetlands and coral reefs.	2010
APG 44	Evaluate how surveys of condition can be used to estimate the delivery of ecosystem services by wetlands and coral reefs	2011
APG 45	Develop landscape approaches for determining the hydrologic and ecological functions of wetlands and coral reefs	2011
APG 46	Develop landscape models predicting the delivery of specific ecosystem services and bundles of services based on wetland landscape profiles, empirical stressor-response models, and published literature.	2012
APG 47	Characterize effects of environmental change on the delivery of ecosystem services provided by wetlands and coral reefs.	2013
APG 48	Develop interactive mapping tools for decision makers to evaluate the effects of local and landscape manipulations, including protection, restoration, enhancement, and degradation, on the provision and value of wetland ecosystem services.	2014
APG 49	Develop and demonstrate decision support tools that will protect and sustain coral reef ecosystem services	2015

Table 14 APGs for LTG 4

4.4 References

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LTG 5—PLACE BASED DEMONSTRATION PROJECTS

5.0 Place as a Concept and Approach

The concept of place is central to the development of the science of ecology, and is critical to the investigation of ecosystems services. The nature, the structure, the value, and the aggregations of ecosystems services are all place-dependent. Therefore, none of the research being proposed by in this multi-year plan can be carried out without consideration of place. Place structures the work in two primary ways.

First, consideration of a stressor such as nitrogen, or a resource such as wetlands, and the policies that affect them, require an assessment at a regional or national level that responds to the scale of these problems. Nitrogen sources, and the form of the nitrogen introduced, differ by location – with air emissions (NOx) important in the east, fertilizer (NO_3) in the Midwest, and livestock wastes (NH_3) in specific concentrated locations throughout the country. Likewise, the ecosystem functions that transport and transform nitrogen vary with location and ecosystem structure. Thus, policy decisions that address reductions of atmospheric emissions of nitrogen at the regional or national level (e.g., the Clean Air Interstate Rule) or the reductions of watershed-derived nitrogen to coastal waters (e.g., to control coastal eutrophication or to reduce Gulf hypoxia) must consider the spatial considerations of sources, ecosystem functions, and ecosystem services in order to optimize and evaluate the effectiveness of national and regional policies.

The second element of place-based research addresses the ways in which a full suite of ecosystem services derives from the characteristics of a place and changes in response to alterations in that place. In this context, ecosystem services, and the values associated with them, represent a key mechanism for (1) representing values that have not been traditionally incorporated into decision making, which has predominantly reflected economic and political considerations, and (2) providing an additional or alternative unit of equivalence (to $) when evaluating alternate scenarios, trade-offs, and optimization in decision making.

In this case, ecosystems services are derived from ecosystem functions that are, in turn, associated with biogeographic characteristics of a specific place. Likewise, the responses of those services to natural and human drivers of change are predicated on and conditioned by the particularities of place. It follows, then, that research of this nature is highly dependent on place-specific data and information and that mapping of ecoservices, drivers, and outcomes will be key both to the research and to incorporating the products of research into decision making.

Therefore, the ERP has chosen place based studies to address this second element. Sites were selected using the following general criteria:

- Sites of interest near existing EPA research facilities;
- Sites with a rich database in place;

- Supported by EPA regional offices;
- Likelihood of active partnerships with other agencies and scientists;
- Expressed interest of the Division Director; and
- Sites that would be in very different parts of the country with both similar and dissimilar issues to address.

These criteria are more opportunistic than they are strategic, but we believe that, through our coordinated approach, they will fully meet our immediate needs. Should we find critical gaps, additional sites could be added should appropriate staff and/or monetary resources be available.

5.1 The Cross Place Based Quintain

A quintain (kwin'ton) is the function or condition studied in multiple cases to evaluate similarities and differences in order to better understand the whole (Stake 2006). Other government programs focused on ecological communities are actively utilizing this method, including the NSF-sponsored LTER, and the USDA Conservation Effects Assessment Project (CEAP). Each of these studies has its own quintain or purpose that ties the multiple study locations together. The ERP has selected four areas to study the quintain of ecological services as they occur across geography, climate, and drivers of change.

Figure 22 is a map indicating the four study sites selected to improve our understanding of ecosystem services and, in turn, support sustainability efforts and good stewardship of our ecosystems. Each site is located in a geographically distinct region of the United States:

1. The **Tampa Bay** region includes a handful of basins surrounding the city of Tampa Bay in Florida. Decision makers need information to help them better balance rapid urban growth while preserving unique estuarine habitats and economically important recreation and tourism industries.

2. The **Future Midwestern Landscapes** includes 13 "bread basket" states where agriculture is predominant. Economic incentives for the development of biofuels produced from crops are causing rapid changes in land cover in this region. Decision makers at national, state, and local levels responsible for guiding these changes need tools to help balance the ecosystem services associated with agriculture, including food and energy production, with other services that are associated with healthy soils, streams, and wildlife habitat.

3. The **Willamette River** basin is located in an Oregon river valley between mountains and the ocean, where local interest in sustainable economic growth is strong. Of particular concern is maintaining and improving agricultural lands, forests, and riparian wetlands which influence river conditions.

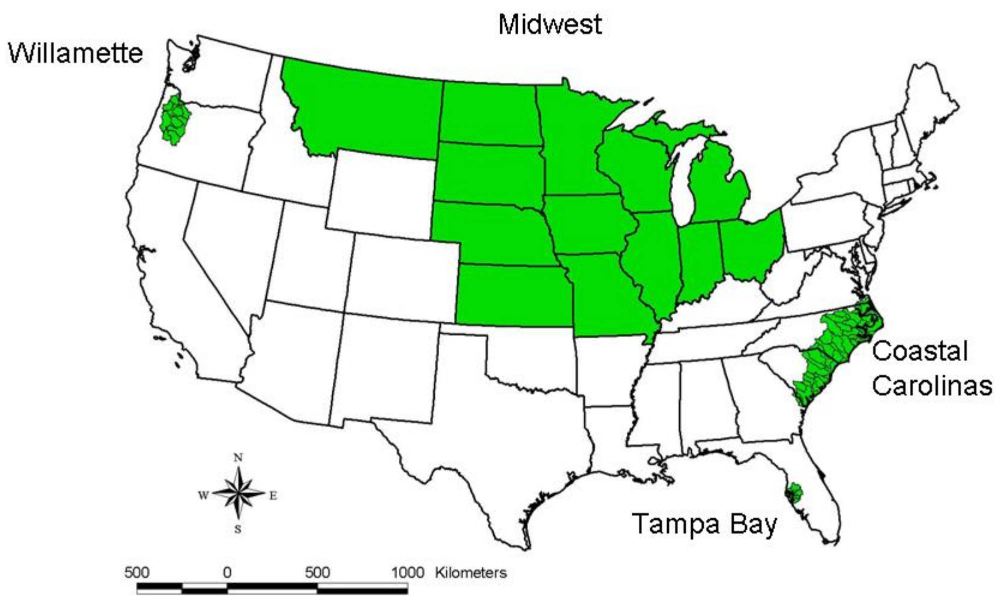

Figure 22 ERP Place Based Demonstration Projects Locations

4. The **Coastal Carolinas** includes coastal North and South Carolina. Counties in the region are facing agricultural shifts and rapid development that is causing continued stress to their wetlands, sensitive habitats, and protected species. Much of the coastline also is expected to be affected by future sea level rise and increased tropical storm frequency and intensity, leaving many decision makers trying to determine what can be done to diminish impacts.

Ecosystem services by their very nature are spatial; therefore, models or measures of services must be able to incorporate or extrapolate to and from a spatial format. Each of the ERP study areas will tap into readily available national datasets such as the NLCD, EPA's EMAP, and the USGS National Water Quality Assessment (NAWQA). The national datasets can then be supplemented with more detailed regional data from studies like the CEAP, AmeriFlux, and the LTER, which will allow analysis of ecological patterns and services that occur at a finer scale.

Given that each site has a different focus, no single statistical or analytical tool is ideal for addressing the range of services it provides. However, a common set of services will be the starting point for evaluation (see Table 15). Many of these services can be directly measured such as soil organic matter, temperature, crop yield, or habitat. Others can be derived from survey data such as fertilizer application, livestock numbers, national park visits, or predicted from models (i.e. soil erosion rates, surface water runoff, carbon storage). However, there are a number of services particularly those related to processes, which will be more difficult to describe (i.e. energy dissipation, habitat quality, and biodiversity) for which we may need to use surrogates or indirect measures. Lead scientists will bring together a team to work with the disparate datasets and link them to spatially explicit outputs that can be used in a web based decision support system.

The success of such a large multi-site, multi-scale, multi-investigator study depends on preserving site-based differences while including a sufficient number of common ecosystem measures to allow for evaluation of basic patterns and interaction. Some comparability will be obtained by using common approaches to modeling, while others will be facilitated, for all four place-based studies, through a focus on measures of a common core list of services from among the broader list of services listed in Table 15.

Table 15 Ecosystem Services for Place Based Study Sites (Core Services Indicated in)

Service	Informing Indicators & Measures
Biogeochemical Cycling	
Carbon Cycling	
Carbon pool storages	Standing biomass
	Soil organic content
	Net primary production
Nitrogen Cycling	
Nitrification	Grams nitrogen / unit area / unit time
Denitrification (in rivers, lakes, reservoirs, wetlands)	Microbial abundance; oxidation rate, (see Wolheim and others for proxies)
Habitat / refugia	
Terrestrial	Nature, location, quantity & arrangement
Aquatic	
	Nature, location, quantity & arrangement
Fresh water	Nature, location, quantity & arrangement
Estuarine	Nature, location, quantity & arrangement
Near-coastal, marine	Nature, location, quantity & arrangement
Biodiversity	Species counts
Air quality regulation due to vegetation	Removal of pollutants
Micro-climate regulation due to vegetation	Changes in diurnal temperature ranges from background
Disturbance & Natural Hazard Regulation	
Erosion Control	kg/ha/year reduced

Service	Informing Indicators & Measures
[redacted]	Change in flood peaks (2-yr., 10-yr., 50-yr. recurrence interval)
Fire Control	Fuel load
Biological Regulation	
Pollination	Increased production due to pollinators
Pest Control	Diversity/distance from ideal/fragmentation
Disease Control	Host vector habitat
Food/Fiber Production	
Animal protein	
Terrestrial (livestock)	lbs/ha, animals/ha
Wild aquatic (commercial fish)	"yearling" estimates, catch, change in catch, change in fish advisories
Plant crops (grains, fruits, etc.)	Bushel /ha/year
Grazing Forage Production	Livestock supported/ hay bale/ha
Fuels	Net energy production
Water provisioning	
[redacted]	EMAP condition indicators
[redacted]	
Surface water storages	Usable volume/capacity
Groundwater	Maps of regional and alluvial aquifers Recharge rates per unit area Est'd. change in aquifer storage, or piezometric head., ft. above reference
[redacted]: Maintenance of base flow	Statistical measures of baseflow characteristics, and change in same
Hydrologic regime	Statistical measures of flow regime, and change in same
Recreational	
Hunting & Fishing	Licenses/take
Ecotourism/nature Viewing/ trekking/ camping	Visits /year
Boating	Rentals/docking fees
Recreational Sports	Rentals
[redacted]	Spatially explicit visualization of change in landscape for selected service endpoints
Spiritual value	Spatially explicit estimates of change in indigenous non-consumptive use service endpoints
Existence value / bequest value	Spatially explicit visualization of change in landscape for selected service endpoints, including non-consumptive use endpoints

These measures will likely come from existing process or empirical models. However, there may also be a need to develop new models using existing data. One potential method is to use output from site-specific process models within each place based study to determine critical variables for a simpler model that applicable across a greater spatial scale. For example PnET-CN is a moderately complex process model from which it is possible to pull single equation models to predict N mineralization for particular forest types in order extrapolate to a larger area (Aber et al. 1997). The final set of model outputs will provide the necessary information for a general assessment of core services, which can then be compared across sites, as well as information on patterns of spatial organization, component interactions, and temporal lags in ecosystem services.

Figure 23 provides a conceptual overview of the proposed place based approach, using the Willamette site as an illustrative example. Again, each site has scale and stressor considerations that are not identical; thus, the flexibility of many aspects of the approach remain site specific.

5.2 Place Based Project Goal

The overarching goal of the ERP place based research is to complete, by 2013, four site-specific demonstration projects that illustrate how regional and local managers can use alternative future scenarios to proactively conserve and enhance ecosystem goods and services in order to benefit human well-being and to secure the integrity and productivity of ecological systems.

5.3 Common Research Questions and Outcomes

While each of the place based research sites will support a distinct set of models and assessments, all will to some extent address the questions and seek the outcomes noted in Figure 24.

Table 16 summarizes the Annual Performance Goals that are common to all of the place-based demonstration projects. The following sections provide descriptions of each place based project and note project-specific annual performance goals.

	Description	**Year Due**
APG 50	Plausible future scenarios are developed for place based studies (with informed input from national, regional and local managers).	2010
APG 51	Ecosystem services are quantified spatially (and decision makers informed)	2011
APG 52	The value of ecosystem services is determined within each place based study and provided to decision makers.	2012
APG 53	Ecosystem services and their value are included in a tool for decision making.	2013

Table 16 APGs for LTG 5

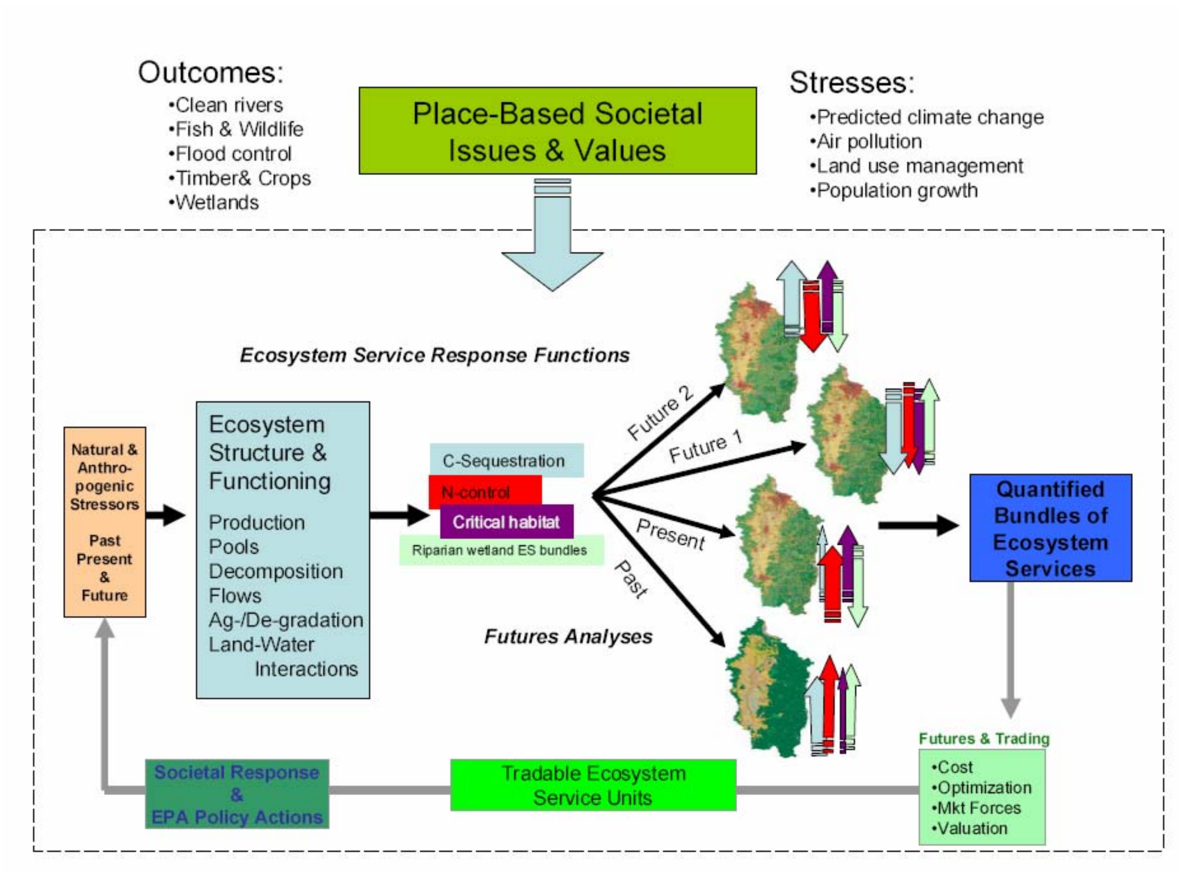

Figure 23 **Flow path illustrating the project goals of quantifying ecosystem services through impact on the web of complex ecosystem processes and pools, and understanding how these ecosystem processes provide services of interest. The project builds upon a strong foundation of research on landscape condition and projected future change from the Baker et al. study (2004).**

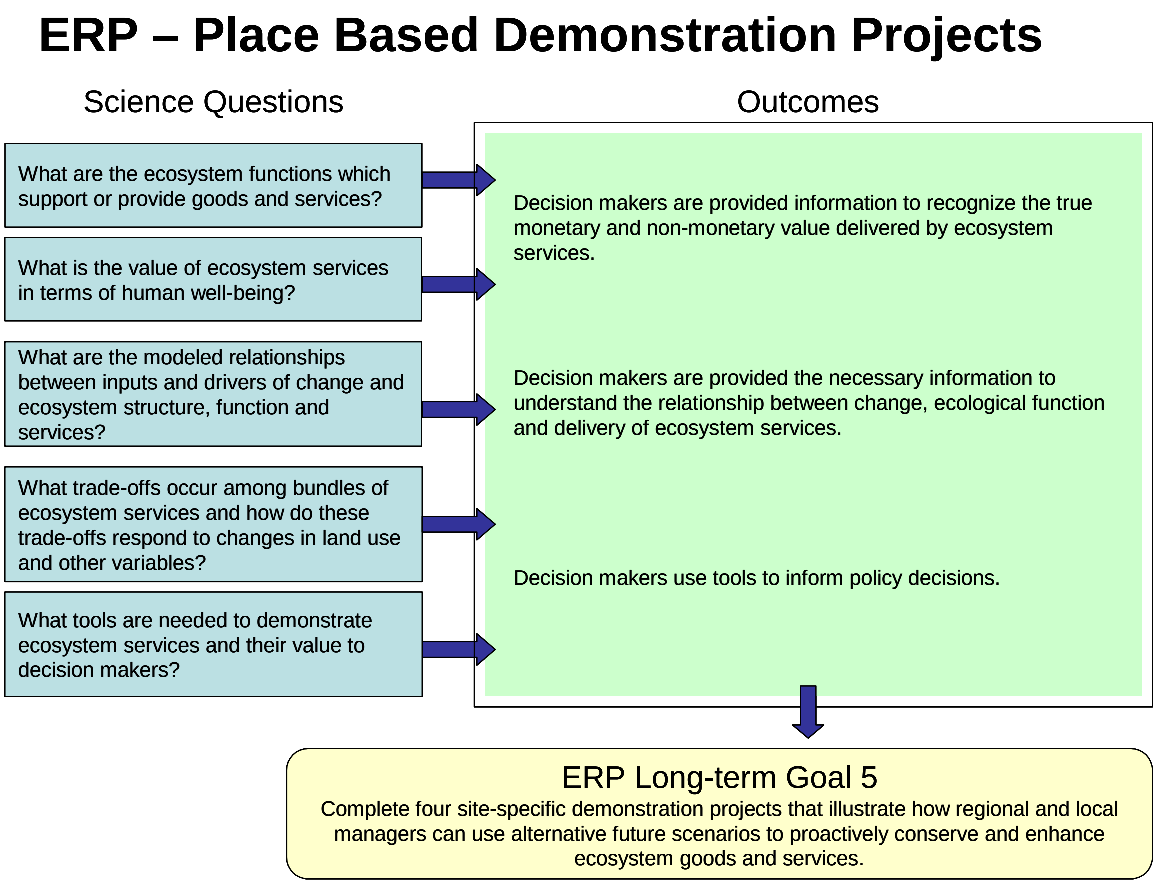

Figure 24 Overview of LTG 5

5.4 Willamette Demonstration Project

The "Willamette Ecosystem Service District" comprises an area of western Oregon roughly defined by the Willamette River Basin, but including counties, ecological regions, and other components of the appropriate spatial context (Heal et al. 2001) (Figure 25). However, the quantification of some services, such as carbon sequestration may require a larger, regional perspective.

Oregon’s Willamette River is located in western Oregon, has a drainage area of 29,727 square kilometers, and has the thirteenth highest streamflow of rivers in the conterminous United States. The Willamette Basin has a Mediterranean climate with dry summers and wet winters. Most precipitation occurs between November and March. The Willamette River drains the Coast Range on the west side of the basin, the Willamette Valley, and the Cascade Mountains to the east.

Figure 25 The Willamette Ecosystem Service District

Forests dominate the Coast Range and Cascade Mountains, while the valley is home to a diversified agricultural industry and a growing component of urban and suburban land. Pasture and grass seed fields occupy 60 percent of the valley's agricultural area, with grass seed production occurring primarily on the extensive areas of poorly drained soils. The Willamette River network supports a wide variety of native and exotic fish species. In general, lowland (valley) stream and river systems support greater numbers of fish species than higher elevation, headwater streams and rivers. Several fish species in the region are listed under the Endangered Species Act (ESA) or are being considered for listing, including: Oregon chub (*Oregonichthys crameri*), spring Chinook salmon (*Oncorhynynchus tshawytscha*), steelhead trout (*Oncorhynynchus mykiss*), coho salmon (*Oncorhynynchus kisutch*), cutthroat trout (*Oncorhynynchus clarki*), and bull trout (*Salvelinus confluentus*).

Population in the Willamette Basin is concentrated in the four major urban centers of Portland, Salem, Corvallis, and Eugene. City limits and urban growth boundaries determine the geographic extent of high density development today and in the future. The 1990 estimate of population in the Basin was 2,300,000. By 2050, the total population of the Basin will grow to 4,000,000. Increasing population is a major forcing variable or stressor on the Basin and the delivery of ecosystem services.

The dominant ownership classes in the Basin are private (64 percent of the land area), followed by the U.S. Forest Service (USFS, 28 percent) and Bureau of Land Management (BLM) O&C lands (5 percent). The Willamette Valley Ecoregion (WVE) is almost exclusively in private ownership, while the Cascades Ecoregion (CE) is largely Federally-owned (primarily USFS) with some private industrial forest ownership as well.

Land use zoning is the result of Local Comprehensive Plans completed by cities and counties under Oregon 1973 Statewide Land Use planning guidelines and regulations. Zoning is one of the implementing measures along with land-division ordinances and the establishment of urban growth boundaries. The legal framework of land use planning is largely responsible for determining what land management practices are permitted under each zoning classification. The result in Oregon over the last thirty-five years is a relatively stable base of forest and agricultural land use.

Presettlement vegetation of the Willamette Valley comprised a complex mosaic of forest, savanna, prairie and wetlands. The conversion of these lands to agricultural land use represents the largest and most extensive alteration of ecosystem structure and function in the Basin. Table 17 provides a comparison of Land Cover types in 1851 and 1990. Notably, land cover types such as Natural Grass (Prairie), Savanna and Wetland are largely missing from the 1990 landscape.

Development	0	175,928	0.0	10.7	N/A
Agriculture	0	552,552	0.0	33.5	N/A
Natural Grass	310,823	9,333	18.9	0.6	-97.0
Natural Shrub	219,275	124,895	13.3	7.6	-43.0
Hardwood Forest	89,249	107,901	5.4	6.5	20.9
Mixed Forest	60,476	255,299	3.7	15.5	322.1
Conifer Forest	603,050	384,967	36.6	23.3	-36.2
Savanna	213,580	0	13.0	0	-100.0
Wetland	130,324	7,221	7.9	0.4	-94.5
Water	21,275	25,635	1.3	1.6	20.5

Table 17 Willamette Valley Land Cover Change 1851-1990 (from Hulse et al. 2002).

5.5 Tampa Bay Demonstration Project

The Tampa Bay demonstration project will focus on the region defined as the Tampa Bay Estuary Watershed (Figure 26). Tampa Bay, Florida's largest open-water estuary, covers 398 square miles at high tide and comprises six major sub-watersheds. Popular for sport and recreation, the Bay also supports one of the world's most productive natural systems. More than 100 tributaries flow into Tampa Bay, including dozens of meandering, brackish-water creeks and four major rivers -- the Hillsborough, Alafia, Manatee, and Little Manatee. Estuaries like Tampa Bay, where salt water from the sea and fresh water

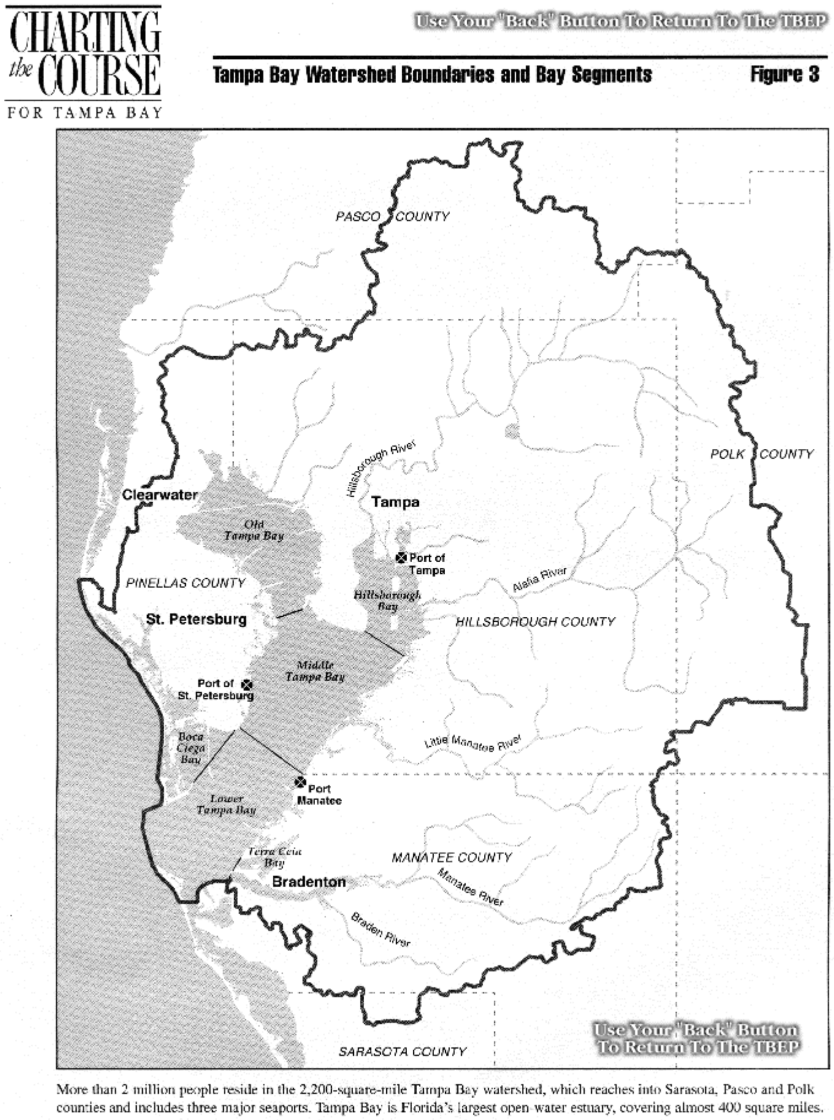

Figure 26 Tampa Bay Estuary Watershed (Source: Tampa Bay Estuary Program 2006)

from rivers and uplands mix, are nurseries for young fish, shrimp, and crabs. More than 70 percent of all fish, shellfish, and crustaceans spend some critical stage of their development in these nearshore waters, protected from larger predators that swim the open sea.

Wildlife abounds along the shores of Tampa Bay. Mangrove-blanketed islands in Tampa Bay support the most diverse colonial water bird nesting colonies in North America, annually hosting 40,000 pairs of 25 different species of birds, from the familiar white ibis and great blue heron to the regal reddish egret -- the rarest heron in the nation. Others, including sandpipers and white pelicans, are seasonal visitors. The Bay also is home to dolphins, sea turtles, and manatees.

Co-located with this extremely productive natural ecosystem is a very large urban center of commerce, transportation, and industry. In fact, the success of these human uses depends on the quality of the Tampa Bay ecosystem. The Port of Tampa is Florida's largest port and consistently ranks among the top 10 ports nationwide in trade activity. Two additional ports, St. Petersburg and northern Manatee County, also add to the Bay’s commercial value. Combined, the three ports contribute an estimated $15 billion to the local economy and support 130,000 jobs. More than four billion gallons of oil, fertilizer components, and other hazardous materials pass through Tampa Bay each year. The Tampa-St. Petersburg area annually contributes billions to the region's economy and is home to more than 2.3 million people.

Tampa Bay is also a focal point for the region’s premier industry – tourism. The Bay and the sparkling beaches of the surrounding barrier islands attract nearly five million visitors each year. Fort DeSoto Park, at the mouth of Tampa Bay, was named the number one beach in the continental United States in a 2004 annual survey. Sport fishing, boating, kayaking, and wildlife watching are increasingly popular activities among both visitors and residents – an interest fueled by steady improvements in water quality. Today, one-sixth of the Gulf Coast population of Florida manatees spend the winter near power plants bordering the bay, and more than 200 species of fish spend some part of their lives within the Tampa Bay estuary.

The number of people in this area is expected to grow by nearly 19 percent by the year 2015, as approximately 500 people move each week to one of the watershed's three counties. According to a study completed by the University of Florida, the west-central region of Florida will experience "explosive" growth, with continuous urban development from Ocala to Sebring, and St. Petersburg to Daytona Beach (Zwick and Carr 2006). The I-75 and I-4 corridors are expected to be fully developed. Most of Florida's Heartland will convert to urban development, resulting in a dramatic loss of agricultural character and native Florida landscape that define this region today (Figure 27). Seminole, Orange, Brevard, Indian River, Pinellas, and Manatee Counties are expected to build out in the period from 2020 to 2040, so population is projected to spill over into surrounding counties in the region. Virtually all the natural systems and wildlife corridors in this region will be fragmented, if not replaced, by urban development.

Thus, the Tampa Bay ecosystem represents a nearly perfect example of projected stress of human development on a natural ecosystem that is valued (economically, aesthetically and culturally) in its present state. With such fast-paced growth, redressing past damage to Bay habitats and protecting them in the future will remain the greatest challenge for managers in this region. Maintaining the water quality gains of recent decades will require more effort every year to compensate for increased pollution associated with growth.

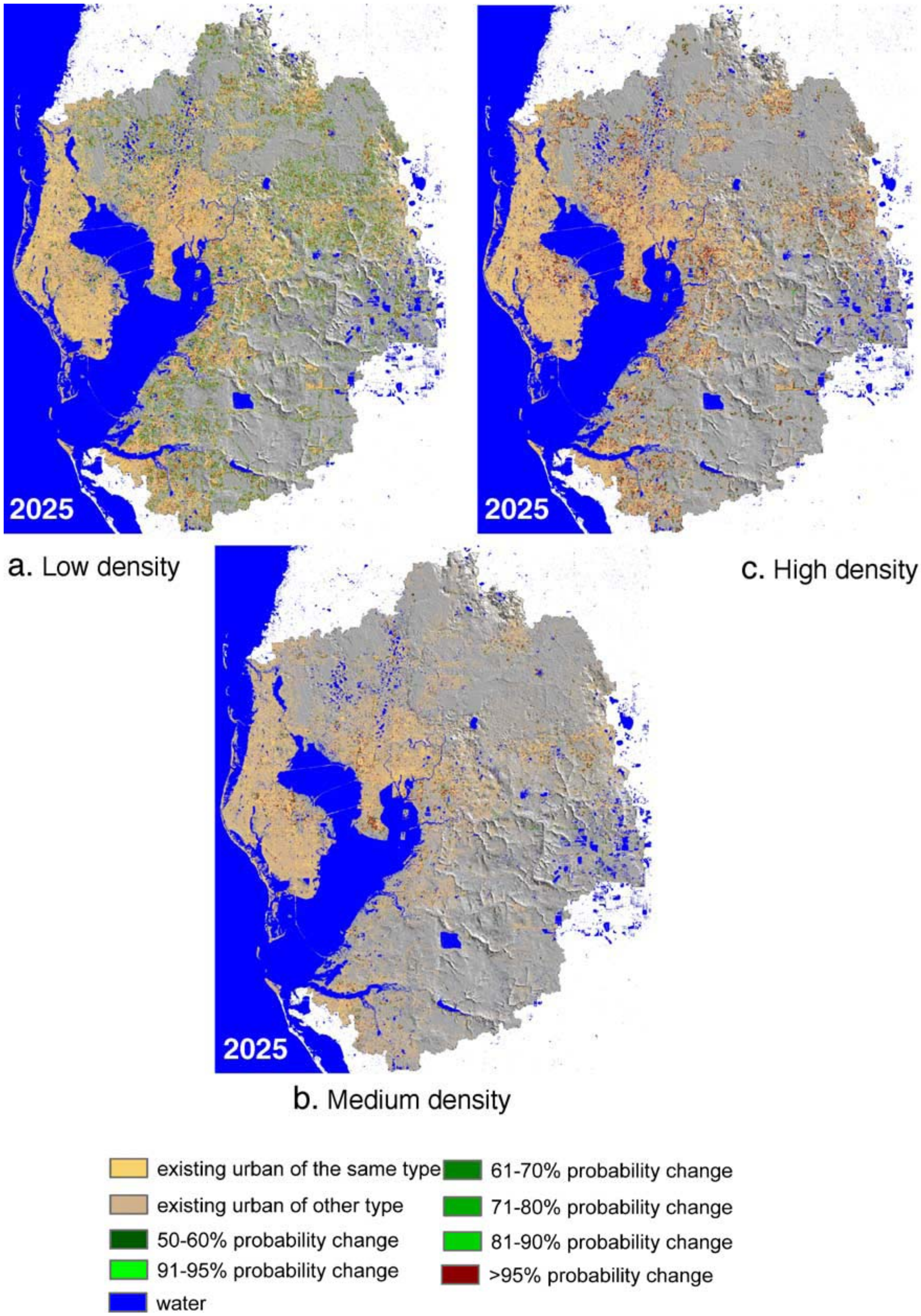

Figure 27 Predicted low, medium and high-density imperviousness in the Tampa Bay region in 2025

5.6 Future Midwestern Landscapes Demonstration Project

The Midwestern United States, comprising the Eastern, Central and Western plains, is responsible for a significant proportion of the world's grain production. However, growing U.S. energy needs, shrinking domestic energy reserves, and instability of foreign supplies are causing a growing segment of Midwestern agriculture to be shifted from production of food to production of energy feedstocks. The actions of multiple Federal agencies are driving this shift, including the Internal Revenue Service (tax incentives), the Departments of Agriculture and Energy (grant and loan programs), Customs and Border Protection (fuel ethanol import duties), and EPA (renewable fuel content standards) (Yacobucci 2006; OTAQ 2007). These federal policies are augmented by many state and local incentives.

While current biofuel production is based on grain, the president's Alternative Energy Initiative (The White House 2006) calls for research to extend the range of feedstocks to include cellulosic materials. A 2005 study by USDA and the Department of Energy (DOE), referred to as the "Billion-Ton Study," concluded that "the land resources of the United States are capable of producing a sustainable supply of biomass sufficient to displace 30 percent or more of the country's present petroleum consumption" (Perlack et al. 2005). This conclusion was based on the potential availability of more than 1.3 billion dry tons of biomass feedstock per year, of which one billion would originate from agricultural resources – especially residues such as corn stover and perennial crops such as grasses. Achieving these production and use figures, the study notes, would entail changes in land use and land management practices. These changes may have important ramifications, both positive and negative, for the ecosystem services that are associated with Midwestern agricultural landscapes (see for example Hill et al. 2006). Furthermore, until the much-anticipated cellulosic conversion technologies are fully available, surges in demand for corn as fuel feedstock will generate environmental concern (see for example NASS 2007).

A National Biofuels Action Plan is being drafted to lay out a coordinated federal strategy for bioenergy development. Under this plan, an interagency team including EPA's Office of Transportation and Air Quality is expected to conduct full life-cycle analyses of environmental and human health risks and impacts associated with alternative feedstocks and processes. To complement this examination of risks and impacts (i.e., harms), ERP proposes a landscape-level analysis, referred to as the "Future Midwestern Landscapes" (FML) study, of the ecosystem services (i.e., benefits) associated with each alternative. This analysis would include as many as possible of the provisioning, regulating, cultural, and supporting services (as defined by the Millennium Ecosystem Assessment (2005)) that are associated with alternative, future Midwestern landscapes. Taken together with the life-cycle studies, this analysis would afford a more complete picture of the trade-offs associated with each alternative.

The spatial boundaries for this study will be established to define a relatively contiguous area of the Midwest comprising the areas most likely to be affected by biofuels development. The current area of concentration of ethanol biorefineries suggests approximate study boundaries (Figure 28). However, when cellulosic technologies

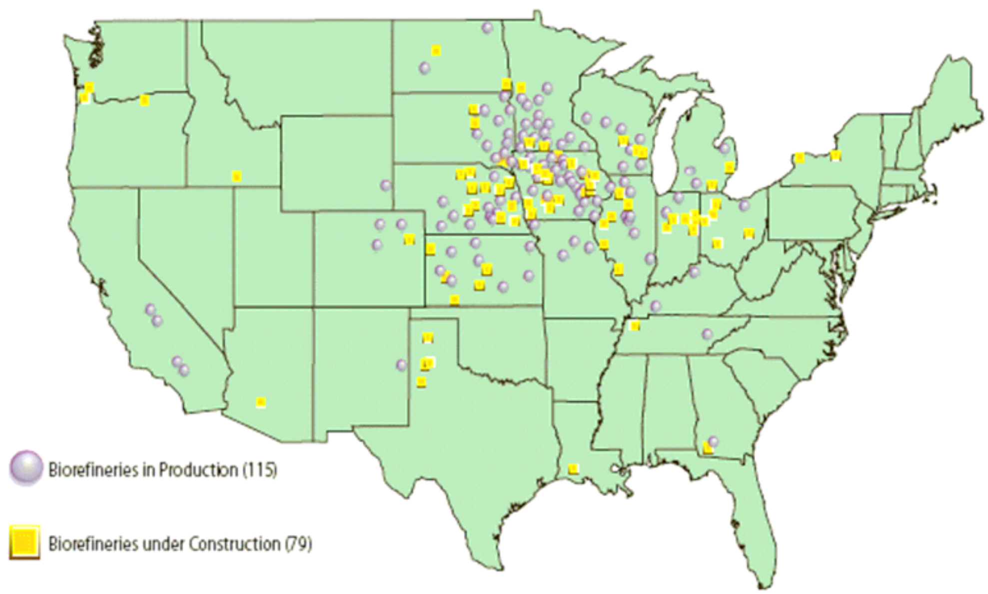

Figure 28 U.S. ethanol biorefinery locations, in production and under construction, as of April 2007 Source: Renewable Fuels Association 2007.

become competitive, biofuels production areas will include more western areas of the Great Plains. Areas to be included also will depend on data availability and the commitment of Federal or state partners to provide needed support. Within this large area, smaller-scale areas may also be defined for scenario development and analysis exercises that respond to the needs of regional planners or watershed groups.

5.7 Coastal Carolina Demonstration Project

The Coastal Carolinas demonstration project is still in the conceptual stage and does not, at this time, have a formalized research agenda. This study will focus on identifying and quantifying ecosystem services, and establishing the relationships of air, land, and aquatic processes to coastal ecosystem functions in order to support decisions that promote healthy and sustainable coastal communities.

The Coastal Carolinas (Figure 29) encompass the tidal counties from Currituck Sound south to the Savannah River, and include the Albemarle and Pamlico Estuaries, Cape Hatteras, and the Outer Banks, and the major cities of Wilmington, Myrtle Beach, and Charleston. These areas are experiencing unprecedented pressures from population growth, landscape alteration, and climate change, including anticipated impacts from rising sea levels.

North Carolina has 37 coastal counties that contain 40 percent of the state's land area and 23 percent of the state's population (as of 2004). South Carolina has 22 coastal counties, containing 50 percent of the state's land area and 40 percent of its population (as of

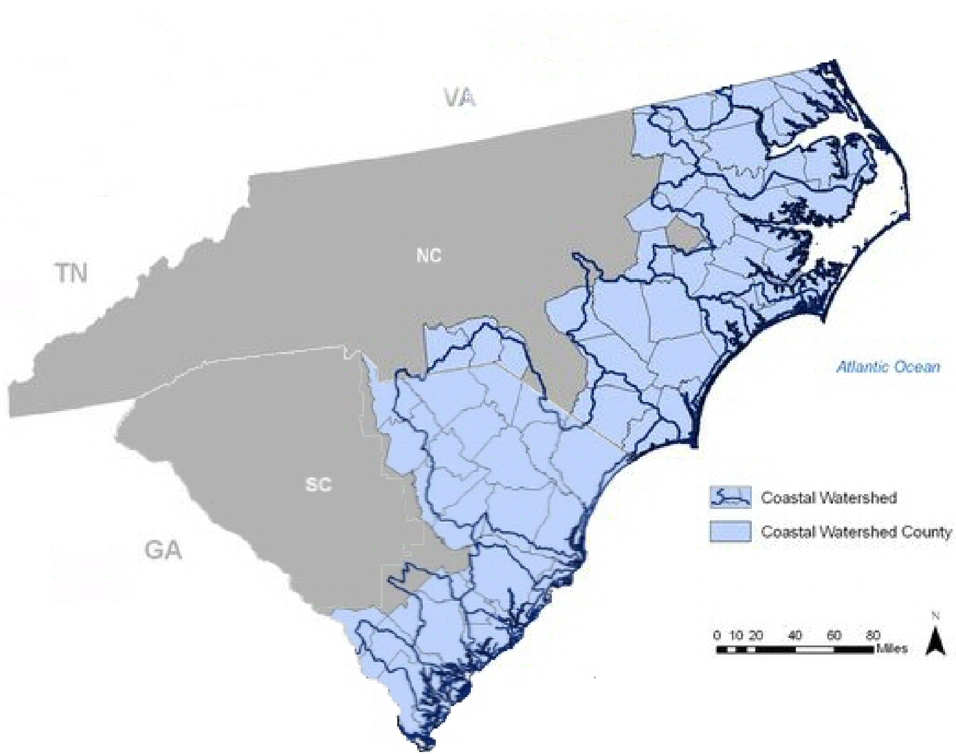

Figure 29 Coastal counties (blue) and tidal watersheds (dark blue outlines) of North and South Carolina.

2004). Population shifts in these coastal counties have varied dramatically, with some of the more rural counties losing as much as five percent of their population during the period 2000 to 2004, while the population in others (four in North Carolina and two in South Carolina) grew by 10 to nearly 20 percent in that same brief period. These shifts are reflected in changes in ecological systems and services.

Housing construction and infrastructure development in immediate coastal areas frequently occurs in high risk landscapes - the 'ocean view' is the most desirable property, despite storm exposure and impacts to nearby wetlands and other near-shore ecosystems. Increasingly higher costs of property with appropriate elevation, drainage, and adequate infrastructure is pushing development into less suitable areas. Low-lying areas along the coasts of North and South Carolina are at particular risk of anticipated increases in the frequency, intensity, and duration of tropical and subtropical storms resulting from the gradual warming of the surface waters of the Atlantic Ocean. In addition, these areas will also experience the greatest impacts from sea level rise, as high tides extend farther inshore and higher up existing terrain. Barrier islands and tidal marshes will tend to move inland with advancing sea levels, regardless of existing human construction, increasing the cost of maintaining existing structures in immediate coastal areas.

Principal shifts anticipated in rural coastal counties are increased food crop production as a result of the increasing emphasis on biofuels production in the Midwest, and the wholesale conversion of large areas to high ethanol-yield corn. These changes may be accompanied by increased rates of fertilizer application, with resultant changes in nutrient loading to coastal watersheds. Depending on the demand, some managed forest areas may be converted to open agriculture, with associated additional sediment and nutrient runoff.

The goal of the Coastal Carolinas demonstration project is to provide local, state, and regional decision makers in North and South Carolina with integrated tools and information that incorporate the concepts and measures of ecosystem services. ERP's expectation is that decision makers will then use these tools and data to appropriately assess the full costs and benefits of land use decisions, including the ability to evaluate the long term value of such ecosystem services and the probable future impacts and costs of such decisions under a variety of possible future scenarios.

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6.0 PERFORMANCE MEASURES

Measuring the performance of a research program is a significant challenge. The Office of Management and Budget (OMB) uses the Performance Assessment Rating Tool (PART) as a means to periodically evaluate the progress and efficiency of the ERP in meeting its goals. The mission of the PART is to establish clear measures and milestones against which the program can be monitored and assessed with respect to its overall stewardship of the public trust and the progress it has made towards outcomes that demonstrate or reflect benefit to the American public.

Appendix C summarizes OMB's assessment of the ERP with respect to the goals from the 2003 MYP.[8] ERP's aggregate PART ratings from the last three assessments are as follows:

Ecosystems Research PART Ratings

Year	Score	Rating
2003	40.0%	Results Not Demonstrated
2005	46.0%	Ineffective
2007	71.2%	Moderately Effective

Improvements in the PART rating are closely associated with improvements in our ability to define specific metrics, establish baselines and, as a result, observe measurable changes in those metrics over time. The ERP has not yet defined the performance measures for the work proposed in this MYP.

6.1 Reviews

The ERP MYP undergoes several period reviews, including:

- Every four to five years:
    - A BOSC full Program Review (next review tentatively scheduled for 2009); and
    - A PART review (next review tentatively scheduled for 2011).
- Every 2 years, a BOSC mid-cycle review to examine the program's progress.
- Additional reviews, as desired (for example, a Science Advisory Board review of the MYP).

[8] See http://www.whitehouse.gov/omb/expectmore/detail/10001135.2007.html for the complete OMB assessment.

These reviews are critical to the scientific integrity of the program. The most recent mid-cycle BOSC review occurred in May 2007, with a primary objective of evaluating the existing program and outlining, conceptually, the new research program.[9] The BOSC offered a number of comments which have influenced the direction and/or approach described in this MYP.

In brief, they advised the ERP to:

- Improve performance measure recommendations;
- Improve outreach; and
- Enhance leadership and collaboration.

The ERP is acting on all of these recommendations. A team has been formed to review and revise the metrics specific to the program, an education and outreach effort has been added to the program, and all of the program participants are charged with finding partners for collaborative undertakings. With regard to this third recommendation, ERP is engaged in discussions with several organizations, including:

- National Geographic, for the purpose of developing a national atlas of ecosystem services.

- The Natural Capital Project (comprising The Nature Conservancy, the World Wildlife Fund, and Stanford University), for the purpose of developing and refining methods to map and value ecosystem services. Initial efforts will focus on the Willamette River Basin.

- The World Resources Institute, for the purpose of making ecosystem services a mainstream component of business decision-making.

- The Gund Institute for Ecological Economics at the University of Vermont, for the purpose of testing and refining the MIMES at ERP's place-based study areas.

- Harvard University, where environmental law students would conduct research on (1) how existing laws address ecosystem services, and (2) how new laws could be crafted to address legal, social, geographic, and ecological issues associated with ecosystem services.

6.2 Agency Interactions

This program has been assembled primarily within the Office of Research and Development with less-than-usual input from stakeholders within the Agency. Given the program's core science focus, we believe the program's scientists can best propose a long-term strategy. Subjecting this document to peer review is expected to confirm our belief that the proposed research will make important scientific contributions. We will also

[9] See http://www.epa.gov/osp/bosc/pdf/ecomc082307rpt.pdf.

engage the Agency in discussions to determine how we can collaborate to advance goals in areas of mutual interest. Information from these discussions will be a critical input during the development of MYP implementation plans (due in mid-July 2008), in which research leads will outline schedules for the achievement of specific goals.

The target audiences for ERP's research output include local decision makers, whose daily decisions affect the quantity and quality of ecosystem services; staff in EPA Regional Offices who must implement regulations that affect these services and who must consider the impact of many small decisions on the larger regional scale; and EPA's national program managers, who are responsible for implementing regulations on a national scale. Interaction with these audiences will help ensure that the ERP research framework achieves its intended science and regulatory goals.

APPENDIX A DETAILED CATALOGUE OF ECOSYSTEM SERVICES

Service	Informing Indicators & Measures	Spatial extent; spatial and temporal resolution	Spatial characteristics of service
Biogeochemical Cycling			
Carbon Cycling			
Carbon pool storages	Standing biomass	Regional: Seasonal time-step National: Seasonal time-step	Global non-proximal (does not depend on proximity)
	Soil organic content	Regional: Annual time-step National: Annual time-step	Global non-proximal
Carbon sequestration	Net primary production	Regional: Annual time-step National: Annual time-step	Global non-proximal
Nitrogen Cycling			
Nitrification	Grams nitrogen / unit area / unit time	Local: Regional: National:	Local proximal (depends on proximity)
Denitrification (in rivers, lakes, reservoirs, wetlands)	Microbial abundance; oxidation rate, (see Wolheim and others for proxies)	Regional: National:	Local proximal (lotic) Directional flow-related (lentic)
Habitat / refugia		Regional: Annual time-step Local: Annual time-step	
Terrestrial	Nature, location, quantity & arrangement	National: Annual time-step Regional: Annual time-step Local: Annual time-step	
Aquatic - Fresh water	Nature, location, quantity & arrangement	National: Annual time-step Regional: Annual time-step Local: Annual time-step	
Aquatic - Estuarine	Nature, location, quantity & arrangement	National: Annual time-step Regional: Annual time-step Local: Annual time-step	

Service	Informing Indicators & Measures	Spatial extent; spatial and temporal resolution	Spatial characteristics of service
Aquatic - Near-coastal, marine	Nature, location, quantity & arrangement	National: Annual time-step Regional: Annual time-step Local: Annual time-step	
Biodiversity	Species counts	National: Annual time-step Regional: Annual time-step Local: Annual time-step	
Air quality regulation due to vegetation	Removal of pollutants	National – annual time-step Regional – annual time-step Local – annual time-step	
Micro-climate regulation due to vegetation	Changes in diurnal temperature ranges from background	Regional –summer season Local – summer season	
Disturbance & Natural Hazard Regulation			
Erosion Control	kg/ha/year reduced		Directional flow-related
Flood Control	Change in flood peaks (2-yr., 10-yr., 50-yr. recurrence interval)		Directional flow-related
Fire Control	Fuel load		Local proximal
Biological Regulation			
Pollination	Increased production due to pollinators		Local proximal
Pest Control	Diversity/distance from ideal/fragmentation		Local proximal
Disease Control	Host vector habitat		Local proximal
Food/Fiber Production			
Plant crops (grains, fruits, et	Bushel /ha/year	Regional: Annual time-step	In-situ
Animal protein Terrestrial (livestock)	lbs/ha, animals/ha	Regional: Annual time-step	In-situ

Service	Informing Indicators & Measures	Spatial extent; spatial and temporal resolution	Spatial characteristics of service
Wild aquatic (commercial fish)	"yearling" estimates, catch, change in catch, change in fish advisories	Regional: Annual time-step Local: Annual time-step	Local proximal
Grazing Forage Production	Livestock supported/hay bale/ha		In-situ
Fuels	Net energy production	Regional: Annual time-step	In-situ
Water provisioning			
Quality	EMAP condition indicators	National: rotating assessment	Local proximal *and* directional flow related
Quantity			Local proximal *and* directional flow related
Surface water storages	usable volume/capacity	National:	Local proximal
Groundwater	-- Maps of regional and alluvial aquifers -- Recharge rates per unit area -- Est'd. change in aquifer storage, or piezometric head., ft. above reference	National: Regional: Local:	Local proximal
Timing: Maintenance of base flow	Statistical measures of baseflow characteristics, and change in same	Regional: Local:	
Hydrologic regime	Statistical measures of flow regime, and change in same	Regional: Local:	
Recreational		All recreation are Regional & Local: Annual time-step	User movement related *and* local proximal
Hunting & Fishing	Licenses/take		User movement related *and* local proximal
Ecotourism/Nature Viewing/ trekking/ camping	Visits /year		User movement related *and* local proximal
Boating	Rentals/docking fees		User movement related *and* local proximal
Recreational Sports	Rentals		User movement related *and* local proximal
Sense of place	Spatially explicit visualization of change in landscape for selected service endpoints	Regional: Local:	Local proximal

Service	Informing Indicators & Measures	Spatial extent; spatial and temporal resolution	Spatial characteristics of service
Spiritual value	Same as Sense of Place, plus spatially explicit estimates of change in indigenous non-consumptive use service endpoints	National, Regional, Local	Local proximal *and* Global non-proximal
Existence value / bequest value	Spatially explicit visualization of change in landscape for selected service endpoints, including non-consumptive use endpoints	National: Regional: Local:	Global non-proximal

APPENDIX B ECOLOGICAL RESEARCH PROGRAM ANNUAL PERFORMANCE GOALS

	Description	**Year Due**
APG 1	Develop and test preliminary indicators of human health and well-being for use in assessing the results of protecting and restoring ecosystem services.	2010
APG 2	Characterize benefits to human health and well-being associated with the provision of selected ecosystem services in the ERP place-based initiatives.	2011
APG 3	Document relationships between disturbance to ecosystem services and changes in human health outcomes or exposures.	2012
APG 4	Develop, test, and implement an index of well-being applicable to multiple ecosystems, stressor scenarios, and ERP place-based initiatives.	2014
APG 5	Non-market Ecosystem Service Classification System (NESCS) incorporated into DSP.	2012
APG 6	Refined guidance of characterizing ecosystem service production functions for single and bundled services added to DSP.	2011
APG 7	Enhanced economic and supplemental donor-based valuation methods fully incorporated into DSP.	2014
APG 8	Create diverse client base, determine client needs, values, understanding of ecosystem services to enhance research and decision support development	2009
APG 9	Translate ecosystem services into a useable conceptual framework for decision makers	2012
APG 10	Produce first generation case study application of ecosystem service-based decisions and implementation for education	2013
APG 11	Activate education/training products and evaluate implementation of ES based decisions on achieve environmental results	2014

	Description	**Year Due**
LTG 1 - Decision Support Platform Component		
APG 12	Identify ERP and non-ERP products such as tools, approaches, techniques, models, etc. to address user needs and develop DS Platform architecture foundation requirements	2010
APG 13	Develop Decision Support Platform Architecture	2011
APG 14	Populate two modules of the DS Platform and disseminate for interactive Beta testing and client feedback	2012
APG 15	Populate additional modules of the DS Platform and disseminate for interactive Beta testing and client feedback	2013
APG 16	Fully functional DS Platform is on-line and utilized by clients to incorporate ecosystem services into the decision process.	2014
LTG 2 - Monitoring		
APG 17	Peer reviewed research and implementation plan for developing a national ecosystem services inventory.	2009
APG 18	Direct or indirect measures for select ecosystem services have been established.	2011
APG 19	Implications for combining monitoring data based on different spatial scales understood.	2012
APG 20	Suitability of existing federal monitoring efforts for assessing ecosystem services has been determined.	2013
APG 21	Design requirements for reporting at multiple spatial scales have been determined.	2013
APG 22	A monitoring framework for a national ecosystem services inventory is available.	2014
LTG 2 - Modeling		
APG 23	Peer reviewed research plan that outlines a systematic approach to meeting high-priority modeling needs for ecosystem services, including a tiered approach for matching model complexity with scale, scope, and intended uses.	2009
APG 24	New approaches for integrated modeling of high-priority ecosystem services are identified in collaboration with clients, social scientists, and economists, including ecological production functions required for valuation.	2011
APG 25	Assessment methods incorporate ecological production functions for high-priority services, including requirements for transparency, reproducibility, and characterization of uncertainty.	2012

	Description	**Year Due**
APG 26	Community-wide standards of practice for ecosystem service modeling research and scenario development are identified.	2013
APG 27	Monitoring and Modeling components are published according to a community standard format, accompanied by metadata.	2013
APG 28	An ERP expert knowledge data base for modeling is available for inclusion in the ERP decision support platform.	2014
LTG 2 - Mapping		
APG 29	Completion of an integrated multi-year research and development plan for a national atlas, an inventory system, and models for selected ecosystem services	2009
APG 30	Methods developed and demonstrated for modeling and mapping ecosystem services related to wetlands, nitrogen cycling, and water quality including demonstrations at multiple spatial scales in place-based research areas	2010
APG 31	Methods developed and demonstrated for modeling and mapping ecosystem services related to carbon cycling, water provisioning, aquatic habitat and fisheries, and storm surge protection including demonstrations at multiple scales in place-based research areas	2011
APG 32	First national ecosystem services maps related to wetlands, nitrogen cycling, and water quality are available.	2011
APG 33	First national ecosystem services maps related to carbon cycling, water provisioning, aquatic habitat and fisheries, and storm surge protection are available	2012
APG 34	Methods developed and demonstrated for bundling of ecosystem services	2013
APG 35	Interactive maps are available to decision-makers to help them protect, enhance, and restore the delivery of ecosystem services at multiple spatial scales	2014
LTG 3 - Nitrogen Assessment		
APG 36	Complete an implementation plan for the ERP nitrogen research effort.	2008
APG 37	Report on the state of the science on ecosystem services and reactive N using national and international data sources, including the Science Advisory Board Committee studying reactive nitrogen.	2009
APG 38	Provide ecosystem service response functions for reactive N and responsive ecosystem services for multiple ecosystems, including wetlands, for the place based ecosystem services districts.	2010
APG 39	Research report on thresholds of change in key ecological services affected by changes in emission rates of Nr to the atmosphere.	2011

	Description	**Year Due**
APG 40	Report on the value of ecological services provided by Nr and costs associated with the services affected by Nr within the place-based demonstration projects based on alternative management options.	2012
APG 41	Provide the modeling framework as a multi-media decision-support tool for Nr based on the optimization of ecological services affected by changes in forms and flows of Nr from anthropogenic sources affecting the place-based demonstration projects.	2013
LTG 4 - Ecosystem Assessments		
APG 42	Provide a scientifically defensible approach for conducting the research to support policy and management actions that protect, enhance and restore the ecosystem goods and services of wetlands and coral reefs.	2009
APG 43	Characterize the relationships between ecological function and delivery of services by wetlands and coral reefs.	2010
APG 44	Evaluate how surveys of condition can be used to estimate the delivery of ecosystem services by wetlands and coral reefs	2011
APG 45	Develop landscape approaches for determining the hydrologic and ecological functions of wetlands and coral reefs	2011
APG 46	Develop landscape models predicting the delivery of specific ecosystem services and bundles of services based on wetland landscape profiles, empirical stressor-response models, and published literature.	2012
APG 47	Characterize effects of environmental change on the delivery of ecosystem services provided by wetlands and coral reefs.	2013
APG 48	Develop interactive mapping tools for decision makers to evaluate the effects of local and landscape manipulations, including protection, restoration, enhancement, and degradation, on the provision and value of wetland ecosystem services.	2014
APG 49	Develop and demonstrate decision support tools that will protect and sustain coral reef ecosystem services	2015
LTG 5 - Place-Based Demonstration Projects		
APG 50	Plausible future scenarios are developed for place based studies (with informed input from national, regional and local managers).	2010
APG 51	Ecosystem services are quantified spatially (and decision makers informed)	2011
APG 52	The value of ecosystem services is determined within each place based study and provided to decision makers.	2012
APG 53	Ecosystem services and their value are included in a tool for decision making.	2013

APPENDIX C: 2003 ERP MYP PROGRAM PERFORMANCE MEASURES

Note: As ERP completes work associated with the 2003 MYP, and as work associated with the 2008 MYP commences, a new set of performance measures will replace the ones described below.

Measure: Utility of ORD's causal diagnosis tools and methods for States, tribes, and relevant EPA offices to determine causes of ecological degradation and achieve positive environmental outcomes.

This measure captures the assessment by an independent expert review panel of the appropriateness, quality, and use of the program's research under 2003 Long-Term Goal 1. This measure was established during the 2005 PART review, though the wording was modified slightly to conform with a new rating methodology developed through an OMB/ORD/Board of Scientific Counselors (BOSC) workgroup. Using a well-defined, consistent methodology, the BOSC will provide a qualitative rating and summary narrative regarding the performance of each 2003 Long-Term Goal. Rating categories include: Exceptional, Exceeds Expectations, Satisfactory, and Not Satisfactory. Full ratings are expected approximately every 4 years, though the BOSC will provide progress ratings at the mid-point between full program reviews.

Term	Type	Year	Target	Actual
Long-term	Outcome	2009	Exceeds Expectations	
		2013	Exceeds Expectations	

Measure: Utility of ORD's environmental forecasting tools and methods for States, tribes, and relevant EPA offices to forecast the ecological impacts of various actions and achieve positive environmental outcomes.

This measure captures the assessment by an independent expert review panel of the appropriateness, quality, and use of the program's research under 2003 Long-Term Goal 2. This measure was established during a 2005 PART review, though the wording was modified slightly to conform with a new rating methodology developed through an OMB/ORD/Board of Scientific Counselors (BOSC) workgroup. Using a well-defined, consistent methodology, the BOSC will provide a qualitative rating and summary narrative regarding the performance of each 2003 Long-Term Goal. Rating categories include: Exceptional, Exceeds Expectations, Satisfactory, and Not Satisfactory. Full ratings are expected approximately every 4 years, though the BOSC will provide progress ratings at the mid-point between full program reviews.

Term	Type	Year	Target	Actual
Long-term	Outcome	2009	Exceeds Expectations	
		2013	Exceeds Expectations	

Measure: Utility of ORD's environmental restoration and services tools and methods for States, tribes, and relevant EPA offices to protect and restore ecological condition and services to achieve positive environmental outcomes.

This measure captures the assessment by an independent expert review panel of the appropriateness, quality, and use of the program's research under 2003 Long-Term Goal 3. This measure was established during a 2005 PART review, though the wording was modified slightly to conform with a new rating methodology developed through an OMB/ORD/Board of Scientific Counselors (BOSC) workgroup. Using a well-defined, consistent methodology, the BOSC will provide a qualitative rating and summary narrative regarding the performance of each 2003 Long-Term Goal. Rating categories include: Exceptional, Exceeds Expectations, Satisfactory, and Not Satisfactory. Full ratings are expected approximately every 4 years, though the BOSC will provide progress ratings at the mid-point between full program reviews.

Term	Type	Year	Target	Actual
Long-term	Outcome	2009	Exceeds Expectations	
		2013	Exceeds Expectations	

Measure: States use a common monitoring design and appropriate indicators to determine the status and trends of ecological resources and the effectiveness of programs and policies.

Data reflect the number of States with which the program has worked collaboratively to assist in using a common monitoring design and developing appropriate indicators.

Term	Type	Year	Target	Actual
Long-term	Outcome	2008	35	
		2015	50	

Measure: Percentage of Ecological Research publications rated as highly-cited publications.

This metric provides a systematic way of quantifying research performance and impact by counting the number of times an article is cited within other publications. The "highly cited" data are based on the percentage of all program publications that are cited in the top 10% of their field, as determined by "Thomson's Essential Science Indicator" (ESI). Each analysis evaluates the publications from the last ten year period, and is timed to match the cycle for independent expert program reviews by the Board of Scientific Counselors.

Term	Type	Year	Target	Actual
Annual	Outcome	2005	Baseline	19.40 %
		2007	20.40 %	21.10 %
		2009	21.40 %	
		2011	22.40%	

Measure: Percentage of Ecological Research publications in "high-impact" journals.

This measure provides a systematic way of quantifying research quality and impact by counting those articles that are published in prestigious journals. The "high impact" data are based on the percentage of all program articles that are published in prestigious journals, as determined by "Thomson's Journal Citation Reports" (JCR). Each analysis evaluates the publications from the last ten year period, and is timed to match the cycle for independent expert program reviews by the Board of Scientific Counselors.

Term	Type	Year	Target	Actual
Annual	Outcome	2005	Baseline	19.30 %
		2007	20.30 %	20.80 %
		2009	21.30 %	
		2011	22.30%	

Measure: Number of States using a common monitoring design and appropriate indicators to determine the status and trends of ecological resources and the effectiveness of programs and policies.

Data reflect the number of States with which the program has worked collaboratively to assist in using a common monitoring design and developing appropriate indicators. The actual number for 2007 was not yet available at the time this document was prepared.

Term	Type	Year	Target	Actual
Annual	Outcome	2005	20	22
		2006	25	25
		2007	30	
		2008	35	
		2009	40	
		2010	45	
		2011	50	

Measure: Percentage of planned outputs delivered in support of State, tribe, and relevant EPA office needs for causal diagnosis tools and methods to determine causes of ecological degradation and achieve positive environmental outcomes.

Annual research outputs are included in the program's Multi-Year Plan. At the end of the fiscal year, the program reports on its success in meeting its planned annual outputs. The program strives to complete 100% of its planned outputs each year.

Term	Type	Year	Target	Actual
Annual	Outcome	2005	100 %	100 %
		2006	100 %	86 %
		2007	100 %	
		2008	100 %	
		2009	100 %	
		2010	100 %	

Measure: Percentage of planned outputs delivered in support of State, tribe, and relevant EPA office needs for environmental forecasting tools and methods to forecast the ecological impacts of various actions and achieve positive environmental outcomes.

Annual research outputs are included in the program's Multi-Year Plan. At the end of the fiscal year, the program reports on its success in meeting its planned annual outputs. The program strives to complete 100 percent of its planned outputs each year.

Term	Type	Year	Target	Actual
Annual	Outcome	2005	100 %	83 %
		2006	100 %	100 %
		2007	100 %	
		2008	100 %	
		2009	100 %	
		2010	100 %	

Measure: Percentage of planned outputs delivered in support of State, tribe, and relevant EPA office needs for environmental restoration and services tools and methods to protect and restore ecological condition and services to achieve positive environmental outcomes.

Term	Type	Year	Target	Actual
Annual	Outcome	2005	100 %	50 %
		2006	100 %	100 %
		2007	100 %	

Measure: Percent variance from planned cost and schedule.

This measure captures the ability of the program to increase cost effectiveness based on the extent to which it delivers annual research outputs relative to the amount of funds spent. Using an approach similar to Earned Value Management, the data are calculated by: 1) determining the difference between planned and actual performance and cost for each 2003 Long-Term Goal, 2) adding these data together to generate program totals, and 3) dividing the Earned Value of all work completed by the Actual Cost of all program activities. One hundred percent or above represents an ideal level of cost effectiveness.

Term	Type	Year	Target	Actual
Annual	Efficiency	2004	Baseline	-8.10 %
		2005	N/A	-15.60 %
		2006	-13.60 %	Data lag
		2007	-11.60 %	
		2008	-9.60 %	
		2009	-7.60 %	

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