EPA/600/R-09/091

U.S. EPA Office of Research and Development

Ecosystem Services Research Program
Pollutant Specific Studies:
Nitrogen Regulation Services Implementation Plan

Linking ecosystem services and nitrogen: Science to improve management of nitrogen in air, land and water

J.E. Compton, R.L Dennis, H.A. Walker, W.B. Milstead, S.J. Jordan, B.H. Hill, K.M. Fritz, R. Devereux, B.R. Johnson, J.J. Beaulieu, J.S. Latimer, J.A. Lynch, R.G. Waite, and C.C. Davis.

Research Plan: Internal EPA Report

U.S. Environmental Protection Agency
Office of Research and Development
National Health and Environmental Effects Research Laboratory – Western Ecology Division
200 SW 35th St.
Corvallis, Oregon 97333

Title: Ecosystem Services Research Program Pollutant Specific Studies: Nitrogen Regulation Services Implementation Plan. Linking ecosystem services and nitrogen: Science to improve management of nitrogen in air, land and water

August 24, 2009

Recommending Officials:

Branch Chief 8/24/09
Tony Olsen, Freshwater Ecology Branch Date

Quality Assurance Manager 9/3/09
Robert Ozretich Date

Approving Official:

Division Director 8/28/09
Thomas D. Fontaine Date
Director, ORD/NHEERL, Western Ecology Divison

U.S. EPA Office of Research and Development

Ecosystem Services Research Program
Pollutant Specific Studies:
Nitrogen Regulation Services Implementation Plan

Linking ecosystem services and nitrogen: Science to improve management of nitrogen in air, land and water

Core Writing Team:
Jana Compton, EPA ORD NHEERL Western Ecology Division, Corvallis, Oregon
Robin Dennis, EPA ORD NERL Atmospheric Monitoring Division, RTP, NC
Henry Walker, EPA ORD NHEERL Atlantic Ecology Division, Narragansett, RI
Bryan Milstead, EPA ORD NHEERL Atlantic Ecology Division, Narragansett, RI
Stephen Jordan, EPA ORD NHEERL Gulf Ecology Division, Gulf Breeze, FL
Brian Hill, EPA ORD NHEERL Mid-Continent Ecology Division, Duluth, MN
Ken Fritz, EPA ORD NERL Ecological Exposure Research Division, Cincinnati, OH
Richard Devereux, EPA ORD NHEERL Gulf Ecology Division, Gulf Breeze, FL
Brent Johnson, EPA ORD NERL Ecological Exposure Research Division, Cincinnati, OH
Jake Beaulieu, EPA ORD NRMRL Sustainable Technology Division, Cincinnati, OH
Jim Latimer, EPA ORD NHEERL Atlantic Ecology Division, Narragansett, RI
Jason Lynch, OAR OAP Clean Air Markets Division, Washington, DC
Randy Waite, OAR Office of Air Quality Planning and Standards, RTP, NC
Christine Davis, OAR Office of Air Quality Planning and Standards, RTP, NC

Advisory Team:
Rochelle Araujo, EPA ORD National Exposure Research Laboratory, Athens, GA
Jeff Arnold, EPA ORD National Center for Ecological Assessment, RTP, NC
Tiffany Crawford, EPA OW Office of Science and Technology, Washington DC
Naomi Detenbeck, EPA ORD NHEERL Atlantic Ecology Division, Narragansett, RI
Jonathan Garber, EPA ORD NHEERL Atlantic Ecology Division, Narragansett, RI
Tara Greaver, EPA ORD National Center for Ecological Assessment, RTP, NC
Bill Hogsett, EPA ORD NHEERL Western Ecology Division, Corvallis, OR
Annie Neale, EPA ORD National Exposure Research Laboratory, RTP, NC
Anne Rea, OAR Office of Air Quality Planning and Standards, RTP, NC
Paul Ringold, EPA ORD NHEERL Western Ecology Division, Corvallis, OR
John Harrison, Washington State University, Vancouver, WA

Table of Contents

List of Acronyms

Acronym	*Definition*
APG	Annual Performance Goals
APM	Annual Performance Measures
CMAQ	Community Multiscale Air Quality model
EPA	Environmental Protection Agency
EPF	Ecological Production Function
ERF	Ecological Response Function
ES	Ecosystem Services
ESRF	Ecosystem Services Response Function
ESRP	Ecosystem Services Research Program
FY	Fiscal Year
GCC	Global Climate Change
GIS	Geographic Information Systems
HUC	Hydrologic Unit Code
LTER	Long Term Ecological Research
LTG	Long Term Goal
MARKAL	Market Allocation
MYP	Multi Year Plan
NAAQS	National Ambient Air Quality Standards
NASS	National Agricultural Statistics Service
NCEA	National Center for Environmental Assessment
NERL	National Exposure Research Laboratory
NHEERL	National Health and Environmental Effects Research Laboratory
NLCD	National Land Cover Data
NRMRL	National Risk Management Research Laboratory
NSF	National Science Foundation
OAQPS	Office of Air Quality Planning and Standards
OAR	Office of Air and Radiation
OAP	Office of Air Programs
ORD	Office of Research and Development
OW	Office of Water
PBP	Placed Based Projects
PI	Principal Investigator
SAB	Science Advisory Board
SPARROW	Spatial Referenced Regressions on Watershed Attributes (Model)
SWAT	Soil and Water Assessment Tool (Model)
TMDL	Total Maximum Daily Load
TIME/LTM	Temporally Integrated Monitoring of Ecosystems – Long Term Monitoring
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geologic Survey

Linking ecosystem services and nitrogen: Science to improve management of nitrogen in air, land and water

1 Executive Summary

The Ecosystem Services Research Program (ESRP) is a new, multi-year research initiative under development by the U.S. Environmental Protection Agency (EPA). The overall goal of the ESRP is to transform the way decision-makers understand and respond to environmental issues, making clear the ways in which their policy and management choices affect the type, quality, and magnitude of services we receive from ecosystems. The ESRP has chosen to focus on reactive Nitrogen (Nr) for stressor specific ecosystem research. Nr includes all biologically, chemically, and radiatively active nitrogen compounds in the atmosphere and biosphere. The amount of Nr applied to the nation's landscape and released to the nation's air and water has reached unprecedented levels, and these levels of Nr pollution will continue to influence air, land and water for the foreseeable future. Reactive Nitrogen (Nr) affects ecosystem services in both positive and negative ways, enhancing the production of food and fiber, but having adverse effects on other ecosystem services such as provision of drinking water, air quality, forest health, climate regulation, fisheries and aquatic habitat. Developing an approach for quantifying and comparing these effects is a key gap.

The broad goal of the ESRP Nitrogen Program (ESRP-N) is to connect the effects of increasing reactive nitrogen to ecosystem services. Individual ecosystems and ecosystem components respond to excess Nr in different ways, because the mechanisms of impact vary. We anticipate addressing our broad goal of connecting Nr to ecosystem services through a two-pronged effort, with national work where possible, and regional to smaller scale studies tackling specific problems and ecosystem types. This work is being done through collaboration with other projects within ESRP, and also through coordination across EPA, with the National Center for Environmental Assessment (NCEA), Office of Water (OW) and Office of Air and Radiation (OAR) playing key roles in providing input and review to ensure that the ESRP-N research is useful for their work. The ESRP-N effort will involve multiple place-based studies addressing a range of ecosystem types and mechanisms of impact in order to develop relationships between Nr and ecosystem services for a range of systems. It will also include a national effort, using data layers that are currently available for the entire nation in order to quantify ecosystem services affected by and affecting Nr.

The purpose of this document is to present the ESRP – N research approach for examining the impact of reactive nitrogen on ecosystem services, for external review and internal guidance.

2 Introduction

2.1 EPA's Ecosystem Service Research Program (ESRP)

The Ecosystem Services Research Program (ESRP) is a new, multi-year research initiative under development by the U.S. Environmental Protection Agency (EPA). This work will build on past success in the monitoring of ecological condition of the Nation's ecosystems to include information on ecosystem services (i.e., the benefits that humans derive from ecosystems [Daily 1997]). Although ecosystem services, such as the provisioning of clean air and water, have traditionally been considered to be "free gifts of nature" recent advances in ecological and resource economics (e.g., Costanza et al 1997, Chee 2004, Boyd & Banzhaf 2007) suggest that these services need to be included in economic analyses of costs and benefits. An ecosystem services approach results in increased awareness of the environmental and economic costs of all goods and services and will help promote effective environmental policy and management strategies.

The overall goal of the ESRP is to transform the way decision-makers understand and respond to environmental issues, making clear the ways in which their policy and management choices affect the type, quality, and magnitude of services we receive from ecosystems. To meet this goal the ESRP will conduct vital research that will serve as a catalyst for innovation in policies, rules, and governance by 1) Setting policies and guidelines, 2) Quantifying benefits for national rule making, 3) Developing environmental metrics and indicators for ecosystem services, and 4) Stimulating market innovations to engage the private sector in environmental protection.

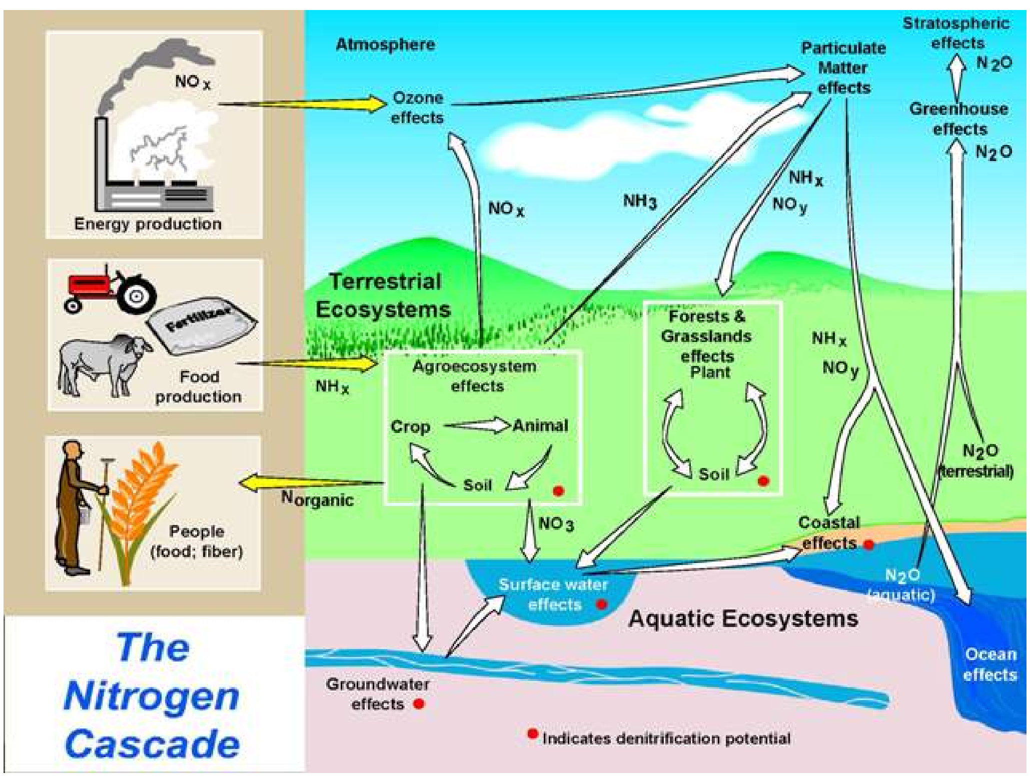
The ESRP has chosen to focus on reactive Nitrogen (Nr) for stressor specific ecosystem research. Reactive nitrogen affects ecosystem services in both positive and negative ways, enhancing the production of food and fiber, but having adverse effects on other ecosystem services on a range of spatial and temporal scales (see Galloway et al. 2003; Figure 1). The emphasis of the ESRP Nitrogen Program is on the effects of Nr on ecosystem services, which occurs in the context of a mosaic of environmental conditions such as soil type, ecosystem sensitivity, and mixture of other stressors that influence and modify the effects of reactive nitrogen. The purpose of this document is to present the ESRP – N research approach for examining the impact of reactive nitrogen on ecosystem services, for external review and internal guidance.

2.2 The Significance of Reactive 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 cannot 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; (3) and, the stressors exist in many forms that 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. Reactive nitrogen (Nr) includes all biologically, chemically, and radiatively active nitrogen compounds in the atmosphere and biosphere. It includes forms of nitrogen, such as ammonia (NH_3) and ammonium (NH_4^+), nitric oxide (NO), nitrogen dioxide (NO_2), nitric acid (HNO_3), nitrous oxide (N_2O), and nitrate (NO_3^-), and organic compounds such as urea, amines, proteins and nucleic acids (Galloway et al. 2003).

The significance of Nr stems from the complexity of its environmental impacts. The Millennium Ecosystem Assessment (WRI 2005) has underscored that understanding the tradeoffs inherent in controlling this class of environmental pollutant is one of the major challenges to be faced in the 21st century. On the one hand, nitrogen in its reactive forms 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. This increase in Nr pollution is accompanied by increased environmental and human health problems. Even if N loads remained the same into the future, the cumulative loading to ecosystems will continue to increase, which means our understanding of N saturation and tipping points in response is critically important.

Figure 1. Nitrogen cascade (Galloway et al., 2003).



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

- Increases in Nr deposition 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. (Figure 1)
- Depletion of stratospheric ozone.
- Climate change attributable to greenhouse gas emissions, especially nitrous oxide (N_2O).
- 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.
- 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.

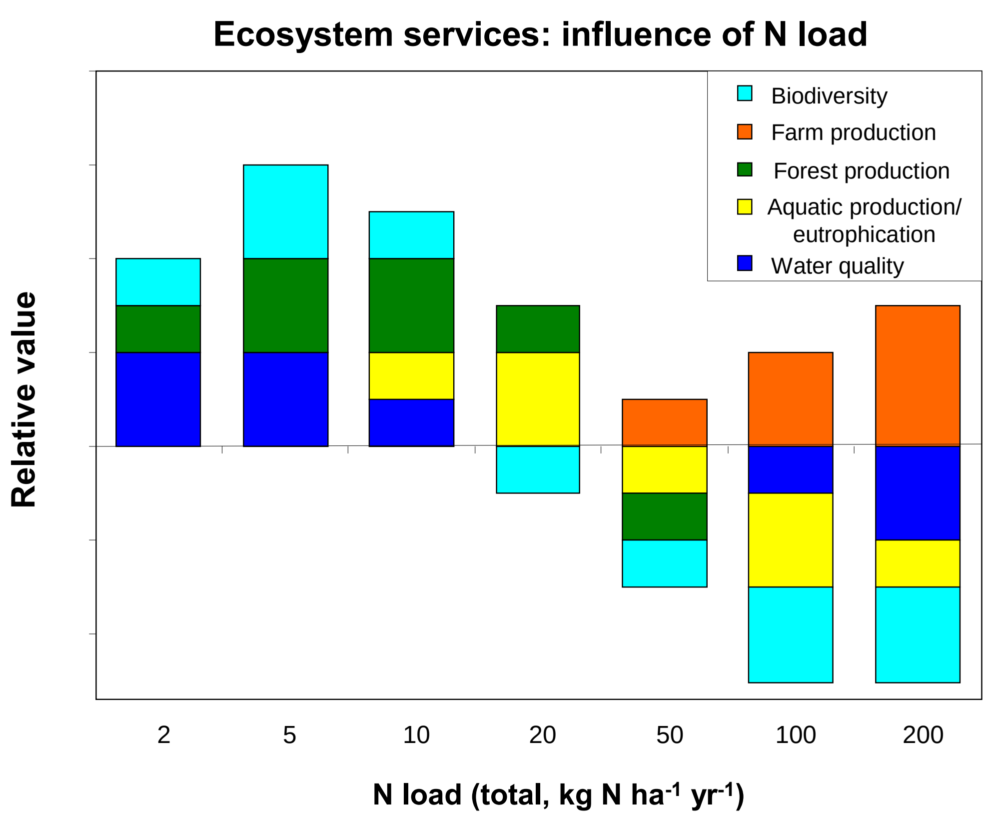
In addition, increasing the loading of Nr to surface waters through direct inputs of sewage, and diffuse non-point sources such as fertilizers, atmospheric deposition and animal wastes contribute to:

- 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.
- Generation of periodic hypoxic zones in coastal waters associated with eutrophication.
- Acidification of lakes and streams.
- Reduced buffering capacity of estuarine and marine waters.
- Succession of wetland plant communities.

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 nutrients and pollutants, make it necessary to forge an integrated research program capable of addressing these complexities and developing the new modeling and analytical tools needed to meet this challenge.

A key gap in our collective ability to assess the impact of reactive nitrogen is being able to see the entire picture and adequately illustrate the tradeoffs. Some of the impacts of increasing Nr can benefit ecosystem services, such as food, wood and fiber production (cropland and industrial forestry), yet many native ecosystems, particularly low biomass ecosystems, are negatively impacted by reactive nitrogen at much lower input levels (e.g., biodiversity of alpine grasslands and high altitude lakes). Figure 2 represents such a perspective illustrating the positive and negative impacts of nitrogen on important ecosystem services, across an N loading gradient. Developing a defensible accounting framework for ecosystem services would allow managers and regulators to see the range of effects of Nr. Development of this framework is an important objective of ESRP-N. Figure 2, while hypothetical and extremely preliminary, represents a long-term target for this work.

Figure 2. Hypothetical ecosystem services bundling by ecosystem type.

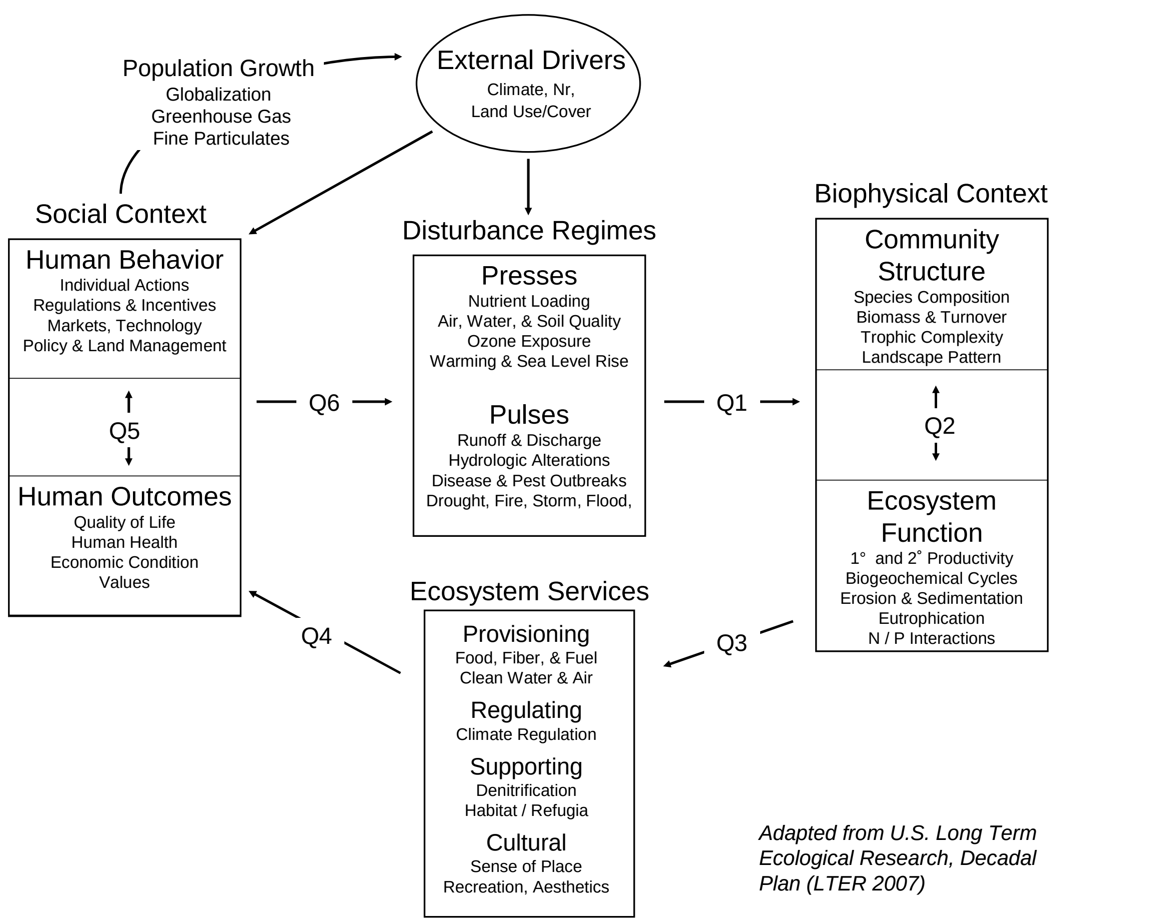


3 Strategic Direction

Our broad goal is to connect the effects of increasing reactive nitrogen to ecosystem services. This will be accomplished by identifying ecosystem services affected by Nr, identifying sensitive habitats, mapping Nr sources and loadings onto the landscape, determining ecological effects, and relating the effects to changes in ecosystem services. Individual ecosystems and ecosystem components, however, respond to excess Nr in different ways because the mechanisms of effect vary. Thus quantifying and comparing the effects will require an approach that recognizes these differences. These results will be useful to air and water regulations and responsibilities of EPA.

To help integrate research within the ESRP – N program, we propose a general conceptual framework (Figure 3). This framework is adapted from the National Science Foundation's Long Term Ecological Research Program Decadal Plan (LTER 2007). This framework clearly relates drivers of change and disturbance regimes to ecosystem structure and function (the biophysical context) and ultimately to ecosystem services. Changes in the availability and delivery of ecosystem services then affect human outcomes and behavior (the social context) leading to modifications in policies and management strategies.

Figure 3. ESRP-Nitrogen Conceptual Framework (modified from LTER 2007).



In this proposed conceptual framework, external drivers include natural disturbances and anthropogenic impacts such as climate change, reactive N inputs, other air pollutants, and land use. In conceptualizing ecosystem dynamics, one can address drivers of changes from the next larger scale (e.g., how national changes are influenced by global change), in addition to key processes operating at the next scale down (regional and local). Disturbance regimes are represented as mixtures of presses, operating gradually but with effects that accumulate on long time-scales, and pulses that operate on faster time scales often on more localized spatial scales. Interactions of presses and pulse disturbances on ecosystem dynamics, thresholds, and resilience have significant ecosystem service implications. Press disturbances include changes in nutrient loading, acid deposition, gradual but cumulative changes in land cover and land use, and gradual loss of soil acid neutralizing capacity. Examples of pulse disturbances include extreme climate events, point-source contributions of nutrients, toxins, and species introductions, and fires. It is also important to consider both spatial and temporal variability in these driving factors and disturbances, and in some cases there is a need to study the interaction between spatial variability (e.g., in N fertilizer use or deposition) and temporal variability (e.g., in rainfall). Reactive nitrogen increases are occurring globally as a result of human population growth and globalization, and changing locally as a result of management decisions affecting point and non-point sources at a range of scales. Ecological thresholds or tipping points that are not easily reversed may be reached. It is important to acknowledge these tipping points, particularly when crafting regulations, in order to maintain ecosystem health.

This conceptual framework is flexible and can be adapted to different ecosystem types and spatial scales as well as to stressor specific, and place-based studies. The conceptual framework is useful for developing questions to address direct and indirect interactions among the model components as well as feedback loops related to policy and planning. Careful mapping of research questions onto this framework also will expose potential gaps in our research plan and will suggest areas where collaboration may be needed. Common terms, metrics, and approaches can be used to represent each of the nodes (boxes) of the conceptual framework. For example, current or predicted changes in drivers and press disturbance regimes can be represented by up and down arrows, or deltas. In addition to nodal specifications, a series of causal pathway questions represented by arrows between nodes can be posed in relation to the general conceptual framework. Our general questions are shown below, with a simplified diagram illustrating the connections.

3.1 General Questions within the ESRP-N Conceptual Framework

Q1. How do changes in nitrogen loading interact with other disturbances and stressors to alter ecosystem structure and function?

Q2. How does community and ecosystem structure interact with ecosystem functions related to reactive N?

Q3. How does changing nitrogen alter ecosystem structure and function to affect ecosystem services?

Q4. How do changes in reactive nitrogen affect delivery of ecosystem services that alter human-relevant outcomes?

Q5. How do human outcomes related to changes in the delivery of ecosystem services affect human behavior?

Q6. Which human actions influence the frequency, magnitude, or form of reactive nitrogen disturbance regimes across ecosystems, and what determines these human actions?

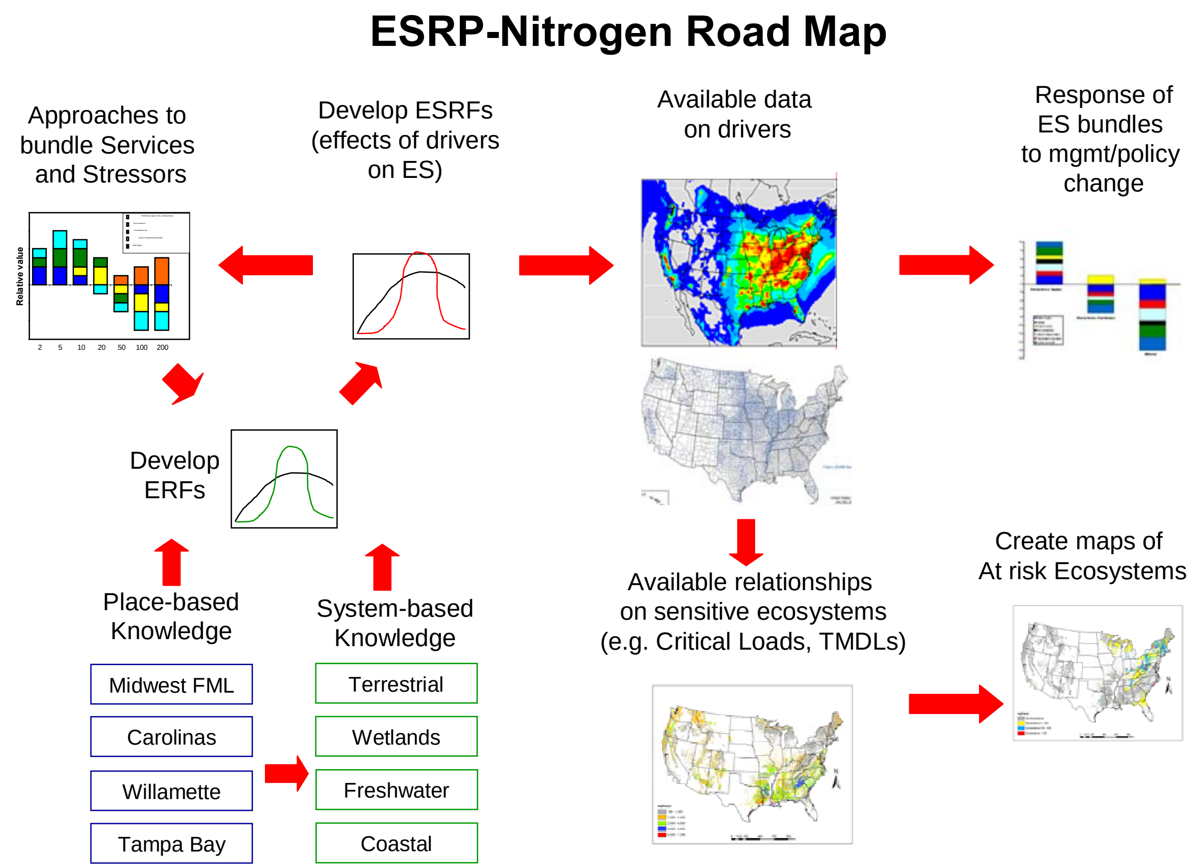
Answers to the general questions will help improve understanding of both ecosystem and social dynamics. Press disturbances can build gradually, but ecosystem responses may be non-linear and include rapid shifts in ecosystem structure and function when thresholds are reached. Some changes in ecosystem state are not easily reversed (hysteresis), and some changes such as species extinctions are irreversible. Also, how humans respond can be non-linear (policy shifts). Societal responses involve differences in goals, motives and levels of organization and can operate at global, national, state, county, and individual scales, sometimes at cross purposes. Collective changes in policies, rules, and governance (Q6) may alter external drivers, modify disturbance regimes (presses and pulses), or mitigate the effect of disturbances on ecosystem structure and function (Q1) affecting the availability and delivery of ecosystem services (Q3). Human outcomes, behavior (Q5) and actions (Q6) can favor the delivery of some ecosystem services at the expense of other uses. Answers to questions such as Q5 and Q6 could help suggest market innovations to better engage the private sector in environmental protection.

The conceptual framework (Figure 3), as well as a rich series of research questions (R1-R10 in section 4.1 below) related to effects of reactive nitrogen on both the biophysical and social dynamics is presented in the following approach section. Given current staffing and resource constraints, EPA ORD is well positioned to answer some, but not all of the general questions (Q1-Q6) posed. To manage ecosystem services more effectively, there is a need for integrative solutions involving a mixture of regulatory and non-regulatory decisions that yield high social utility (Scheffer et al. 1999). To help tackle such questions, ORD scientists will need to collaborate with economists, social scientists and stakeholders to address the rich context of how human perceptions, outcomes and actions affect the availability (e.g. Q4 - spatial extent and pattern) and delivery (Q5) of ecosystem services to society.

Our broad goal of connecting Nr to ecosystem services will be approached through a two-pronged effort: national-scale work where possible, and smaller scaled studies tackling specific problems and ecosystem types. The ESRP-N overall approach is shown in Figure 4 ("the Road Map")

We can begin on the upper left of the Road Map with identifying the ecosystem services impacted by reactive nitrogen and developing ways to measure and bundle these services. Then, ecological response functions (ERFs), comparisons of N inputs with changes in community structure/ecosystem function (e.g., N loading vs. forest fragmentation) will be developed. These ERFs will be based on literature values or targeted research. From these ERFs, we will identify a key set of ecosystem service response functions (ESRFs) that relate ecosystem changes (forest fragmentation) with the bundled ecosystem services (e.g., recreation). The ERFs will also allow us to identify sensitive ecosystems, particularly when overlain on current nitrogen loading data (e.g., air deposition, fertilizer inputs). Based on the loads where ecosystems respond and the current loading, we will then be able to map ecosystems at risk and develop management tools, based on the ESRFs, to quantify the impact of changes in N loading on bundles of ecosystem services.

Figure 4. The ESRP-N roadmap.



ESRP-N will synthesize existing knowledge of reactive nitrogen from monitoring, mapping, and modeling programs already completed by the EPA as well as from state and federal agencies and academic researchers. This work will occur in collaboration from the Mapping and Monitoring groups within ESRP, and also through coordination across EPA, with the National Center for Environmental Assessment (NCEA), Office of Water (OW) and Office of Air and Radiation (OAR) playing key roles. This effort will involve multiple case studies addressing a range of ecosystem types and mechanisms of impact. It will also include a national effort, using data layers that are currently available for the entire nation to quantify ecosystem services affected by and affecting Nr.

The end result of this work will be the development of credible, scientifically-based methods to:

- Inventory, measure and map ecosystem services affected by reactive nitrogen at multiple scales;
- Improve understanding of the effects of reactive nitrogen on ecosystem services using stressor-response relationships and predictive models;

- Help define compelling alternative management options related to reactive nitrogen, and in working with the ESRP modeling group, relate forecasts of future reactive nitrogen scenarios on possible outcomes and a variety of ecosystem services;
- Contribute to the ESRP decision support platform which will enable decision-makers to explore outcomes of alternative decision options related to reactive nitrogen; and
- Help identify the "art of the possible" by making intelligent, informed use of knowledge about effects of reactive nitrogen on ecosystem dynamics, thresholds, and resilience, and cross-scale connections among social drivers and natural systems.

Our overall strategy is to build upon the wealth of research that has been conducted in nitrogen biogeochemistry, ecology and water quality assessment associated with nitrogen as a pollutant and as a limiting resource in the past few decades. A great deal is known about the sources and rates of Nr inputs to the biosphere (Galloway et al. 2003; 2004), and about the impacts of large additions of Nr on fundamental ecosystem processes such as N cycling within terrestrial ecosystems and N leaching to aquatic ecosystems (Stoddard 1994; Aber et al. 1989; 1998; Vitousek 1997). A wealth of research has been conducted on nitrogen biogeochemistry, ecology and water quality assessments associated with nitrogen as a pollutant and as a limiting resource. Many millions of dollars have been spent to examine the impacts of nitrogen on terrestrial and aquatic ecosystem structure and function. A great deal of this work was recently summarized in EPA's Integrated Science Assessment (ISA) for Oxides of Nitrogen and Sulfur Environmental Criteria (US EPA 2008). We can use the recent ISA as a foundation, since it provides the current state-of-the-science on the problems associated with atmospheric Nr deposition.

We also recognize that a great many of the problems caused by increasing Nr are associated with inputs other than atmospheric deposition, which include application of Nr to agricultural lands, and inputs of waste to land or directly to waters. The recent EPA Wadeable Streams Assessment found that excess nitrogen was the most pervasive stressor impacting the condition of U.S. streams (US EPA 2006). Other leading stressors for aquatic ecosystems included phosphorus (P), riparian disturbance and excess streambed sediments (US EPA 2006). Although the ESRP-N effort will focus on nitrogen, and the regulatory process generally addresses stressors one at a time, ecosystem responses to N often are influenced by the availability of multiple nutrients (P in aquatic ecosystems, base cations in some terrestrial ecosystems) thus, N loadings and effects need to be considered in this larger context (Paerl, 2009). We will address interactions of nitrogen with other drivers. Consideration of the effects of Nr changes on stoichiometric relationships is one potentially rich area of research. Interactions with nitrogen and climate change are another wide research gap, and while not the focus of this program, we must include climate change as a driver constraining Nr effects on both terrestrial and aquatic ecosystems (see section 4.5.2 below).

A central goal of ESRP-N is to examine and synthesize previous research on the effects of Nr on the structure and function of ecosystems in the light of ecosystem services. In addition, we hope to identify and pursue directed research in new areas, which builds upon and adds strategically to the existing work.

3.2 Limitations and Bounds

In order to meet our broad goal of connecting Nr with services, we propose an approach that will allow us to assess the problem at two scales – 1) a regional-to-national approach, using the current "state of the knowledge" for well-understood ecosystem types or components of ecosystems (e.g. inputs, wetlands, coarse landscape input-output dynamics, acid-sensitive soils), and 2) a case-study approach at the regional or ecosystem scale where we can develop a more complete understanding of causal links between multiple stressors/drivers and multiple services.

This effort has both resource and scientific limitations. While we will assemble large data sets and develop relationships between Nr and ecosystem services, we will not create a dynamic, process-level model for nitrogen effects on ecosystem services. At this point, the relationships have not yet been developed to create this type of comprehensive model to apply across a range of ecosystems. Many drivers influence the response of ecosystems to nitrogen, for example, climate, soil properties, land-use history, and pathogens, to name only a few. Dynamic interactions between drivers are often difficult to represent, nitrogen is no exception. We will use models to develop our Ecological Response Functions (ERFs) and Ecosystem Service Response Functions (ESRFs). And we will compare model output across different places in order to understand the variation in response to changes in Nr within a given ecosystem type (e.g. forest, agriculture, wetlands) across regions. The approach would contain these relationships, but in this 5-year project will not be dynamic and will have a limited set of drivers and services. What we will be able to do is provide a set of relationships (ERFs and ESRFs) for a set of drivers and a group of ecosystem services. We also hope to have a tool which will combine relationships for multiple services, such that the impacts of a change in policies or management on a suite or bundle of ecosystem services (e.g. changes in air pollution regulation or TMDL implementation) could be assessed.

3.3 Strength of the strategy

For some ecosystems and regions, there are data available to generate a set of relationships (ecological response functions or ERFs) between Nr and ecosystem characteristics that could be used to predict the effects of changing Nr inputs on ecosystem response. In addition to a national effort built upon existing data, we will develop a set of case examples where we have a good understanding of the effects of the drivers on a bundle of services. The case examples proposed are in areas where there is already concern and interest in N pollution (see research themes under Approach).

End users of information and tools to tackle Nr as a pollutant are interested in many different impacts of this pollutant (air, forest health, food production, biodiversity, greenhouse gas regulation, aquatic eutrophication, drinking water). ESRP-N will focus on a small set of representative systems and also include a national assessment, in order to produce useful scientific information and tools for different user groups.

We also will determine how to link ecological response to ecosystem services. The issues surrounding Nr and agricultural land use represent a fundamental tradeoff among multiple ecosystem services: in this case, agricultural production and water quality. Fertilizers ensure good crop yields and returns, but can also lead to groundwater nitrate contamination and eutrophication in aquatic ecosystems. Human values dictate to what extent we search for sustainable means to have adequate supplies of food, fiber and clean water. We propose to develop a framework for measuring and illustrating these tradeoffs, for multiple case examples where increasing Nr can impact ecosystem services.

3.4 Unique Aspects of ESRP-N

This component of the program is the only pollutant-specific long-term goal, and thus could provide a basis for examination of other pollutants. The problems associated with increasing Nr span local to global scales, and while our work stops at the national scale, the problem has the largest potential scope of all efforts within ESRP. Problems associated with increasing Nr span media from air to land to fresh and saltwater, and thus require us to bring together diverse interests, seek input and maintain relevance for the Office of Air and Radiation and the Office of Water to support air and water quality regulations. Many human activities and land uses influence nitrogen cycling generating important point and non-point source issues which influence regulating nitrogen as a pollutant. This means that management practices have important implications for N loading, availability and movement.

Why focus on nitrogen when there are many pollutants that impact ecosystem services? Nitrogen was chosen as the major focus for a pollutant-based study (Long-term Goal 3) within EPA's Ecosystem Services Research Program for several reasons. Nitrogen is a remarkably pervasive pollutant, since it can impact air, biota, soils, freshwater, groundwater and coastal ecosystems. Few ecosystems remain unimpacted by nitrogen deposition. Nitrogen is a local- to global-scale issue, impacting such things as the diatom composition of small alpine lakes and atmospheric concentrations of the greenhouse gas N_2O (Wolfe et al. 2001; Nevison et al. 2007). Nitrogen can also have positive impacts on some ecosystem services which will require us to develop an approach to adequately represent trade-offs. Currently EPA is considering establishment of national secondary air quality standards for nitrogen oxides. This process is an opportunity for synergy within the research and regulatory arms of EPA, allowing ESRP-N to build upon the assessments NCEA and the Office of Air and Radiation conducted during 2007-2008. In addition, the recent Wadeable Streams Assessment (US EPA 2006) points to N as the most pervasive stressor to our nation's streams, providing impetus for further research on sources and approaches to deal with this widespread problem.

For the same reasons that Nr is important and far-reaching, it is also a complex pollutant, with multiple forms, sources and effects (Figure 1, the nitrogen cascade). This work is challenging, but the importance of the effects and the scale of the problem makes Nr a good candidate for the study of pollutant impacts on ecosystem services. In addition, nitrogen has positive and negative impacts on human endpoints (e.g., crop production, water quality), thus requiring the development of a framework for quantifying and assessing the tradeoffs of ecosystem services. Within EPA, this work will be most successful with input and collaboration from EPA's program offices (e.g., Office of Air and Radiation (OAR), Office of Water (OW) and Office of Wetlands, Oceans and Watersheds (OWOW)). There is also a great deal of research that has been conducted by US Geological Survey, USDA-Forest Service, USDA-Agricultural Research Stations and of course academic institutions. To be successful, ESRP-N must identify important agency connections with the relevant programs for understanding the impacts of changing Nr on ecosystem services.

4 Approach

Consistent with the ESRP goal, answers to research questions outlined in this section will help transform the way decision-makers understand and respond to environmental issues, making clear the ways in which their policy and management choices affect the type, quality, and magnitude of services we receive from ecosystems affected by reactive nitrogen.

We make use of the conceptual framework to organize a more specific set of research questions related to ecosystem services affected by Nr (see "R" questions in the following section). The questions relate causal pathways (arrows in Figure 3), and general questions Q1-Q6. EPA ORD has capacity to address some, but not all of these general questions. Questions that focus on how changes in ecosystem services affect human outcomes (Q4), and the interactions between human outcomes and human behavior (Q5), will necessarily involve the talents of social scientists and economists, whose expertise is presently missing from our current ESRP-N group. These skills will be added to our group as the research progresses. The matrix of research questions shown in Table 1 below illustrates our research focus and current gaps in expertise.

4.1 ESRP - N Research Questions

R1. What are the rates and forms of Nr and associated acidity inputs to the landscape? What is the rate of Nr transfer from land to water? What is the rate of Nr removal by different ecosystems? Q6-Q1 (links Q6 to Q1 in Figure 3)

R2. How do changes in nitrogen and phosphorus availability and acid deposition interact to alter the structure and function of aquatic and terrestrial ecosystems? Where are the sensitive aquatic and terrestrial ecosystems located, and how do nutrient and acidic loads (R1) overlay with sensitive ecosystems to identify at risk ecosystems? Q1-Q2

R3. How do changes in nutrient and acidic inputs affect the delivery of ecosystem services? Q1-Q2-Q3

R4. What are the key ecosystem services affected by disturbance of the nitrogen cycle? How can these key services be valued and bundled to best understand the outcomes of alternative management and policy strategies? Q3-Q4

R5. What are the key indicators and indices of human health and well-being and ecosystem health for assessing efforts to protect and restore ecosystem services related to nutrient and acidic deposition? Q3-Q4-Q5

R6. How do humans benefit from ecosystem services impacted by Nr and how do changes in the availability of these services affect human decisions? Q4-Q5

R7. What tradeoffs between ecosystem services arise over the management of land and water systems to reduce Nr inputs? Who is affected by these tradeoffs? Q5

R8. How well can technological fixes and restoration projects (e.g., water treatment plants, fish hatcheries, and wetland or river restoration) substitute for lost ecosystem services related to disturbances of the nitrogen cycle? What are the ecological and economic costs and benefits? Q4-Q5

R9. How effective are human policy changes and management (e.g., source reductions, liming for acidity, etc.) in reducing the amount and effects of anthropogenic inputs of reactive N and acidic species? Q5-Q6-Q1

R10. What human activities are linked to changes in reactive nitrogen (Nr) and acidic inputs to the landscape? And, how do human decisions on management of land and water systems affect Nr and acidic inputs? Q6

Research providing answers to questions R1-R10 will contribute to the ESRP Nr Research Program as well as to the National ESRP goal to map, monitor, and model ecosystem services affected by Nr. Maps of current and anticipated nutrient loading addressing R1 can be developed for national scale mapping and modeling. Additional research is needed to address many of the 10 questions. Although it is currently not within our capacity to approach these questions nationally, they can be approached regionally. Therefore, components of the ESRP Nr Research Program will need to work at several different scales. Cross-cutting themes will be utilized to foster additional integration among proposed ESRP Nr research components.

Table 1. Matrix of Research Questions linked to Research Components. Themes relate to ESRP-N research themes developed below in section 4.2. The blue boxes indicate areas of research within a given theme. Unfilled boxes indicate that the research does not currently address these areas.

Research Questions	Theme 1: Nutrient loading	Theme 2: Service Measures	Theme 3: Nutrient cycling	Theme 4: Tipping Points	Place-Based FML	Place-Based Tampa	System-Based Wetlands
R1. N delivery and removal							
R2. N impacts on structure and function (ERF development)							
R3. N impacts on multiple services (ESRF development)							
R4. Identification of key services impacted by N							
R5. Human health and well-being impacts							
R6. Human benefits & decisions impacted by N							
R7. Tradeoffs between N and services							
R8. Tech. fixes and restoration impacts on N							
R9. Effectiveness of management and policy options to reduce N							
R10. Human decisions and N delivery							

Given current EPA skill and capacity, much of the nitrogen research will focus on how changes in regulations and management practices affecting nitrogen modify the biophysical context and ecosystem services (right side of Figure 3). Of the R1-R10 question set, the proposed initial research focus of the ESRP-N research is illustrated in Table 1. Questions R6, R7, R8 relate to nitrogen affects on ecosystem service availability and delivery, human outcomes and behavior. We will gain collaboration with economists, social scientists, and others to explore social context questions (left side of Figure 3), such as how regulatory and non-regulatory decisions modify availability (spatial pattern and extent) and delivery of ecosystem services affected by Nr. There are clearly gaps in Table 1 which ESRP-N alone will not be able to address, and early in the implementation of this research we plan to reach out to social scientists to address these areas. It is important to conduct this outreach early, in order to ensure that our ecosystem endpoints have social and possibly economic relevance. We will fill in at least some of the blank areas in Table 1 as this program grows and develops.

One major issue facing ecosystem services assessment is scale: it is challenging to determine the appropriate scale for ecosystem services assessment. In some cases, a very local or even reach-scale effort might be appropriate (e.g. nutrient management of a farm-lined stream where water quality trading might occur), and for others, a national assessment might be more useful (e.g. understanding nitrogen deposition effects, where often a national standard is employed). One of the goals of ESRP-N is to have projects at several different geographic scales, and in some cases to share information across scales, to determine which approaches are more appropriate or suitable. In some cases we may apply indices developed at individual places to broader areas (ecological response functions), and in others we may use nationally available data sets (land-use, fertilizers or deposition). Both efforts may be informed by this approach. We may learn that for some inputs, we need better resolution (e.g. county level USDA NASS fertilizer records may not be appropriate for reach-scale efforts) or perhaps in some cases, the national-scale data will be suitable, particularly in the absence of other data. The USGS Collaborative Observation and Research of Effects (CORE) network is using an approach to use relationships and indices from intensively studied watersheds, and then test these at larger scales. These types of ideas could be adopted and modified for use by ESRP-N.

4.2 Cross-Cutting ESRP-Nr Research Themes

At this stage of research planning we have identified four ESRP Nr cross-cutting themes which will address subsets of the 10 ESRP Nr Research Questions (R1 – R10) at different spatial scales: a) nationally, and b) regionally, and will foster integration. Regional research within these themes will be conducted as case studies designed so that aspects could eventually be scaled up from regional to national. The four cross-cutting themes are:

- Theme 1: Nutrient Loading. **R1, R2, R3, R4, R5, R10** (National)
- Theme 2: Key Services, Service Bundles and Trade-offs. **R4** (National and Regional)
- Theme 3: Nutrient Cycling and Ecosystem Services. **R1, R2, R3, R4, R10** (Regional)
- Theme 4: Tipping Points in Ecosystem Condition and Services. **R1, R2, R3, R4, R5, R9, R10** (Regional)

Immediately below we briefly outline these cross-cutting themes - section 4.3 provides more complete information.

Theme 1: Nutrient Loading

Knowledge of reactive nitrogen inputs to land and water and the source attribution of those inputs across the landscape are important requisites for identifying where ecosystems may be at risk and for establishing pollution abatement or mitigation strategies. The T1 cross-cutting theme will consider the patterns and sources of inputs of nutrients at the national scale. At the same time we recognize that important regional variations also occur in the management of ecosystem services. National patterns of nutrient loading can, with the help of critical load or tipping point maps, help identify the regions in which ecosystems and services are potentially at risk.

Theme 2: Key Services, Service Bundles and Trade-offs

Awareness of ecosystem services depends on the type of service, the user and the spatial scale of its delivery. Human values dictate to what extent we search for sustainable means to have adequate supplies of food, fiber and clean water. The issues surrounding Nr and agricultural land use represent a fundamental tradeoff between multiple ecosystem services. Fertilizers ensure good crop yields and returns, but can also lead to nitrogen contamination of surface and groundwater and eutrophication of aquatic ecosystems. There is often a spatial mismatch between the places where humans use ecosystem services, the location of ecosystems that produce them and the origins of stressors and drivers that modify the services.

Although ESRP-N will not focus primarily on economic valuation, we will provide the quantitative basis on ecosystem services and endpoints that relate to Nr, which could be employed for further economic analysis. The goal of Theme 2 is to identify which key ecosystem services and endpoints (Boyd and Banzhaf 2007) are responsive to Nr. This goal will be addressed through a national effort to identify the key ecosystem services that respond to changing loads of Nr. Theme 2 considers the bundling of ecosystem services in light of the issues of spatial and temporal mismatch, the dynamics of systems and inter-dependencies and/or connections between elements of the ecological systems and services and the issues of human awareness of services. Because of the scaling and trade-off issues, and the fact that different ecosystem services are measured in different units, bundling, (i.e. aggregation of services to provide a holistic view of costs and benefits), requires some form of economic or social valuation. We will collaborate with social scientists on this issue, and will be pursuing this early in the implementation of this program. We have just brought in a colleague who has a law degree and MS in policy to assist (summer 2009). Some services (e.g., food production) can be expressed readily in monetary values, whereas others (e.g., biodiversity) may require specialized economic analysis, or are better expressed in relative social values. Although the research perspective will be national, the development of ecosystem services bundles will be informed by research developed in the regional studies of nutrient cycling and tipping points.

Theme 3: Nutrient Cycling and Ecosystem Services

The amount of Nr applied to the nation's landscape and released to the nation's air and water has reached unprecedented levels, and these levels of Nr pollution will continue to influence air, land and water for the foreseeable future. These increases in Nr pollution are accompanied by increased environmental and human health problems and declines in ecosystem services. ESRP Nr Research Questions R1, R2 and R3 relate to how press and pulse disturbances affect ecosystem structure and function, and in turn ecosystems services. Theme 3 considers how changes in nutrient loading impact nutrient cycling and the ecosystem services of nutrient retention by terrestrial, freshwater and estuarine systems. We recognize that ecosystem responses to Nr often are influenced by the availability of multiple nutrients (P in aquatic ecosystems, base cations in some terrestrial ecosystems) and other essential elements (e.g., carbon), thus we must place N effects in this context. Nitrogen deposition affects primary productivity, thereby altering terrestrial carbon cycling. This may lead to shifts in population dynamics, species composition, and community structure and, in extreme instances, ecosystem type. In terrestrial and wetland ecosystems, reactive nitrogen deposition alters biogenic sources and sinks of N_2O and methane, two potent greenhouse gases, resulting in higher emission rates to the atmosphere of these gases. The T3 nutrient cycling theme also recognizes that Nr emissions, processes and effects occur across a continuum of landscape scales and at time scales that range from hours to hundreds of years. T3 research will be conducted in some targeted case studies (described below as data syntheses and some new research on stream N removal) where nutrient cycling impacts can be identified and related to trade-offs in ecosystem services affected by Nr.

Theme 4: Tipping Points in Ecosystem Condition and Services

Combinations of press and pulse disturbances, whether intentional or unintentional, can tip ecosystems from one stable state to another, affecting ecosystem services, human outcomes and behavior. ESRP Nr Research Questions R1, R2 and R3 relate to how press and pulse disturbances affect ecosystem structure and function, and, in turn, ecosystem services. The T4 cross-cutting theme will consider how ecosystem threshold effects and tipping points relate to changes in related ecosystem services. In some cases threshold effects are known, and have predictable consequences on biotic systems, e.g., when acid neutralizing capacity (ANC) in aquatic systems affected by acid rain approaches zero. In other cases tipping points in ecosystems may only be recognized after the fact. Due to hysteresis, some types of ecosystem restoration can be extremely difficult and expensive. At such a point, managers may consider a technological substitute for lost ecosystem services, and R7 may be the relevant research question. Additional tipping points may relate to the availability (ecosystem and human land use spatial patterns), and delivery of ecosystem services to humans related to spatial patterns of resource availability. This tipping point theme relates to the complexity of both biophysical systems (right side of Figure 1) as well as complexity and scales of human decision making by institutions and governance structures, regulations and incentives, markets, and use of technology (left side of Figure 1). T4 research will be conducted in targeted case studies where tipping points can be identified and related to trade-offs in ecosystem services affected by Nr.

4.3 ESRP-Nr Theme-Based Research

4.3.1 National Scale Themes

4.3.1.1 Theme 1: Nutrient Loading to air, land and water

A national approach is being pursued where capability exists or is within reach of our resources. Mapping at the national scale is being developed with an initial focus on selected studies of nitrogen inputs to the landscape. This work is being conducted in a collaborative manner with the ESRP Mapping Team. The ESRP Mapping Team is taking the lead on creating the layers, while the Nitrogen Team will provide data, model outputs and will contribute to designing the mapping approach. Three major Nr inputs and transfers have been selected as initial cases for the national mapping: fertilizer input, atmospheric deposition, and nitrogen transfer from land to water. Additional cases will be selected as the interaction with the mapping team matures. Currently there exist several excellent models of quantifying nitrogen loading at large scales - for this quantification we will draw heavily on this prior work (Boyer et al. 2002; Howarth et al. 2006), and also include forthcoming national-scale N source analyses currently in preparation (E.W. Boyer, personal communication). We include sulfur (S) in the deposition measurements because of potential acidification effects, which interact and combine with Nr.

Research Questions

1. What are the atmospheric fluxes of Nr and S to the continental US? What are the limitations and uncertainties associated with different estimates? **R1**

2. What is the rate of fertilizer application to the continental US at the county scale? Is this a useful scale? Can we partition the fate of the applied Nr to different loss pathways? **R1**

3. What is the rate of transfer of nitrogen from land to water? How is this related to N loads? How is it affected by landscape biogeochemical condition? How does the transfer rate vary by place, by state, and by region? **R1, R2**

4. What is the rate of N removal by the following landscape components: terrestrial, wetland, river networks? What key variables (for example, soils, geology, ecosystem type, slope) help predict terrestrial and wetland N removal? Is the removal rate related to loading rates? **R1, R3**

5. What would the potential N removal be if we change wetland or riparian restoration strategies? **R10**

6. Is N removal an endpoint service or an intermediate service? How do we assign N removal a value? **R4, R5**

7. How variable are estimates of N transfer from land to water via different modeling approaches, such as SPARROW and GlobalNEWS? How do we combine different model estimates to better understand our uncertainties associated with N transfers? **R1, R10**

Atmospheric deposition. Atmospheric deposition is an important source of nitrogen to terrestrial and aquatic landscapes. There is direct deposition to the landscape and transfer of the deposition from the terrestrial landscape to water bodies. Atmospheric deposition of sulfur, oxidized nitrogen, reduced nitrogen, ozone, and mercury are simulated by CMAQ on an hourly time scale for a 12km grid size for the eastern US and the continental US. Typical compilations of deposition are monthly and annual accumulated deposition amounts. A base year of 2002 is available to represent current conditions. Other years within a 2001-2006 window may be available. New projections of deposition for 2020 and 2030 that represent the implementation of nitrogen oxide controls to meet health standards for ozone and PM2.5 under the 1990 Clean Air Act Amendments will be available for mapping as well. Such projections show a significant reduction in oxidized-N deposition across the eastern US. The 12-km CMAQ grid can be mapped to 12-digit HUCs or any other desired set of polygons. The CMAQ data will be augmented by National Atmospheric Deposition Program (NADP) wet deposition data in the mapping exercise. The use of CMAQ dry deposition combined with NADP wet deposition will be compared to use of CMAQ dry deposition combined with precipitation-corrected CMAQ wet deposition, given the data needs of the community.

Fertilizer input. Commercial fertilizer is an important source of nitrogen to the landscape. The chemical form in which Nr enters the estuary can be important, since organic nitrogen forms such as urea have been implicated in stimulation of hazardous algal blooms (HABs) (Glibert et al. 2001, Berg et al. 1997). This is important for estuaries downstream of agricultural areas because of the increasing use of urea as a fertilizer. The bi-directional air-surface exchange of ammonia processes formulated in CMAQ (Community Multiscale Regional Air Quality model) requires a national estimate of fertilizer timing and rates of application. This estimation model is being developed within the NERL Atmospheric Modeling Division as part of CMAQ development. The National Nutrient Loss & Soil Carbon Database (NNLSCD) containing commercial fertilizer use information by state, crop, irrigation mode, application timing class, number of applications and nutrient rate class will be used. The Biogenic Emissions Land-use Database version 3 (BELD 3.0) vegetation species coverage is currently being updated to reflect 2000 agricultural crop distributions and to be consistent with NLCD 2001. BELD reports 230 vegetation types at a resolution of 1-km, with 17 agricultural crops and 194 tree and shrub species. The state level commercial fertilizer application rates will be applied to the BELD species distribution to develop county-level crop-area-weighted estimates of commercial fertilizer application rates. These will then be mapped to CMAQ grid squares and also coordinated with the ESRP mapping team for use in the national Atlas and by the ESRP Nr Team.

Other inputs. The Mapping Team within ESRP has begun generating a national map of CAFOs from which nitrogen sources may be estimated. The mapping team is also working to derive nitrogen inputs from human sewage waste either by using population and housing density estimates along with export coefficients, by creating maps of municipal waste facilities from the EPA National Pollutant Discharge and Elimination System, or by some combination of the two methods. They are also investigating estimating industrial point sources from the NPDES. In addition, we are working with the Place-Based Projects, in particular the Tampa Bay project, to increase our representation and understanding of urban N sources and dynamics.

Nitrogen transfer from land to water - Collaboration with ESRP Landscape Mapping Team. We will use two means of estimating hydrologic N loading from land to water: a look-up table approach and a modeling approach. Both of these approaches will be conducted in conjunction with the ESRP - Mapping project.

For the "look-up table" approach, hydrologic loading value will be considered to be an indicator of an ecosystem service, with low nitrogen concentrations (mg N L^{-1}) and flux rates (kg N ha^{-1} yr^{-1}) indicating provision of water with good quality. This is a very simple, "first cut" approach based on literature-derived coefficients of N loading by land use category combined with a GIS tool to place these values across the landscape (using ATtILA; http://www.epa.gov/esd/land-sci/attila/index.htm; or InVEST; http://www.naturalcapitalproject.org/toolbox.html#InVEST). If more specific values are available by region (dry vs. wet areas) these values would be used. InVEST uses a spatially explicit approach to simulate the movement of water across a landscape - after working with several of these GIS approaches, we will choose the most appropriate approach in 2009 and begin working on this.

Hydrologic N tranfers will also be calculated for the entire US. We propose to compare several different model outputs for this approach, and initially are pursuing Global NEWS (http://marine.rutgers.edu/globalnews/mission.htm) and SPARROW (http://water.usgs.gov/nawqa/sparrow/) for this effort. This model allows for large-scale estimates of dissolved inorganic, organic and particulate nitrogen in runoff and removal based on the best available data. We are currently working out the details of a collaborative agreement with John Harrison of Washington State University to conduct this modeling work; Dr. Harrison is the US lead of the Global NEWS effort. Global NEWS has been used in previous scenario analyses based on Millennium Ecosystem Assessment, and will be used in our work to estimate the sources of N to the land, sources of N to waters, and rates of N removal by different components of the US (regionally and by broad ecosystem type). Global NEWS is unique in that it examines multiple forms of N (and P) and can be applied to a variety of scales. We also propose to apply a downscaled version of this model to the Mississippi Basin, in order to determine the applicability and ease of use for smaller-scale ecosystem service applications. We also propose to compare SPARROW output with Global NEWS output as a way of examining the uncertainties associated with nitrogen sources (and removal as described below).

Nitrogen removal as supporting the ecosystem service of water quality regulation - by terrestrial ecosystems, wetlands, riparian areas, streams and lakes. ESRP-N proposes national efforts in these key areas:

Terrestrial Ecosystems. Nitrogen removal by terrestrial ecosystems, in particular via storage and denitrification in soils, is one of the most important components of the global nitrogen cycle (Seitzinger et al. 2005). Removal is also spatially variable, temporally variable, responsive to N load, and impacted by human perturbation. We propose to estimate N removal by different classes of terrestrial ecosystems across the country using a large-scale modeling approach. In addition to the Global NEWS modeling described above, we propose to work with the USGS SPARROW modeling team in the northeastern and perhaps southeastern US to use their model to calculate N removal for several ecosystem types (terrestrial ecosystems by broad land use category, wetlands and streams/rivers). This collaboration would allow us to work together with USGS to use the SPARROW model in a new way to address ecosystem services. We also propose to compare SPARROW output with Global NEWS output described above, as a way of examining the uncertainties associated with nitrogen sources and removal.

Riparian Areas. We will collaborate with the Landscape Mapping Team to quantify and map the services realized from nitrogen retention in riparian zones to moderate and mitigate the transfer of Nr from land to water. This effort will be based on GIS analysis that is currently being conducted nationally by the Mapping team, and will build upon the review by Mayer et al. (2007). This work will be described in more detail in the Mapping team Implementation Plan. We feel that this approach is a key component of this project, since it may allow calculation of N removal services in areas with and without natural vegetation buffers, illustrating the value of this service in naturally vegetated systems.

Wetlands. In addition to the modeling described above, we will review the literature as described below in the section on system-based research. This work is currently outlined in the ESRP - Wetlands Implementation Plan.

Streams and Rivers. In addition to the modeling described above, we will conduct research as described below in Theme 3.

Removal rates for many systems can decrease with increasing Nr supply (Perakis et al. 2005; Mulholland et al. 2008), and we must account for these relationships in our work.

Expected Outcomes

1. National maps of fertilizer loading; national maps of Nr and acidic deposition; national maps of Nr and oxidized nitrogen deposition by economic sector **R1, R10** *2010*

2. National maps of nitrogen transfer from land to water **R1** *2011*
3. National maps of riparian zones and their nitrogen retention service **R1** *2012*
4. National maps of the decrease in oxidized Nr and acidic deposition anticipated to result from Clean Air Act health regulations on emissions and air quality **R1, R9, R10** *2010*

4.3.1.2 Theme 2: Intersection of Nitrogen and Ecosystem Services

The goal of Theme 2 is to identify which key ecosystem services and endpoints (*sensu* Boyd and Banzhaf 2007) are responsive to Nr. This goal will be addressed through a national effort to identify the key ecosystem services that respond to changing loads of Nr. This section presents our approach for linking reactive nitrogen to ecosystem services. Two major activities are described in this section: 1) a review of the literature relating nitrogen and ecosystem services and development of conceptual models linking nitrogen and ecosystem services that can apply to a variety of ecosystems (national scale view); and 2) detailed studies of the linkages between nitrogen and ecosystem services for case studies across the nation. The Ecosystem Service Research Program has developed a number of place-based studies that are key to the Nitrogen program. These studies will serve as a place to improve conceptual models and demonstrate the utility of applying an ecosystem services perspective to policy and management related to nitrogen.

The broad linkage between nitrogen and ecosystem services will be developed via selection of ecosystem services of study, common terms, metrics and approaches to quantifying ecosystem services related to reactive Nitrogen. This effort will draw upon studies conducted by various groups with a stake in managing Nr loading to air and water.

Theme 2 Approach

<u>Part 1. Literature review</u>

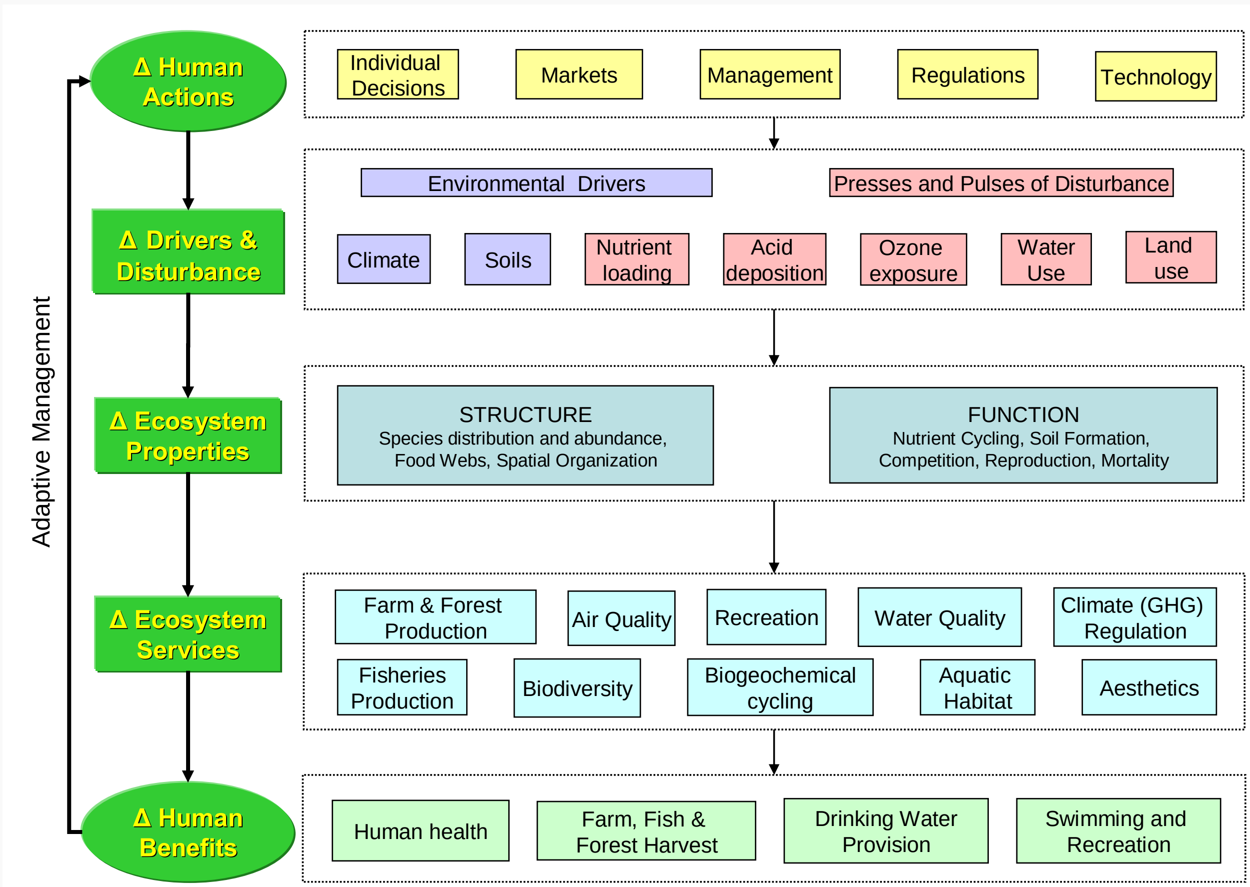
The literature review will involve initially identifying the major linkages between nitrogen and ecosystem services, then in-depth review of the literature

Identification of key ecosystem services affected by changes in Nr. Many studies have examined ecosystem services and impacts on hydrology, water quality and aquatic ecosystems, but we know of no studies which specifically present the impacts of reactive nitrogen on ecosystem services. We will explore the literature to identify the key services that respond to changes in reactive nitrogen. Figure 5 below outlines our conceptual model that is the basis for this approach.

Initially we will focus on the following set of key ecosystem services related to Nr:

- Ecosystem Production, Biogeochemical Cycling and Biodiversity - Supporting
- Water Quality - Regulating/Provisioning
- Air Quality - Regulating/Provisioning
- Climate Regulation (greenhouse gases) - Regulating
- Food, Fisheries and Fiber Production - Provisioning
- Recreation and Aesthetics - Cultural

Figure 5. ESRP-N Organizational Model.



This literature review will be conducted in 2009-2010, and will draw upon several recent documents that review the impacts of nitrogen on US ecosystems. Specifically, there are some recent key documents from the National Ambient Air Quality Standards process including the Integrated Science Assessment (ISA) for Oxides of Nitrogen and Sulfur – Ecological Criteria (Final report December 2008) and the Risk and Exposure Assessment for the NOxSOx Secondary NAAQS review (EPA 2009). In addition, EPA's Science Advisory Board has recently produced two important review documents the report of the Integrated Nitrogen Committee (Link to draft report March 2009; final report will be available in Fall 2009) and the Gulf of Mexico Hypoxia 2007 report (Link to SAB Gulf).

Part 2. Place-based research and Case Studies

Development of an approach to link ecological response to ecosystem services and endpoints. Currently, there are 5 place-based studies (Future Midwestern Landscapes, Tampa Bay, Southwestern US, Willamette River Basin and Coastal Carolinas). Four of these place-Based Projects will play a role in ESRP-Nitrogen: the Future Midwestern Landscapes, Southwestern US, Tampa Bay and the Coastal Carolinas programs view nitrogen as a major factor in their study area, and we will use the results of these studies to strengthen our understanding of nitrogen impacts on ecosystem services. Descriptions of the individual place-based studies can be found in Appendix 2 below.

The overarching goal of the ESRP place-based research is to complete, by 2013, five 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. Place-based studies will provide an opportunity to create a complete chain from ecological responses to ecosystem services to decisions.

A key element of the place-based studies described above is the close link between ecological researchers, stakeholders and decision makers. The place-based studies are working with local/regional decision makers and stakeholders to determine the links between human actions, ecosystem services and human benefits that are most important in that geographic area. Each study is going through a process of identifying which ecological responses are most important to people in the local area.

In addition to the ESRP Place-based studies, we will also consider the methods and approach developed by EPA's Office of Air Quality Standards and Planning (OAQPS). This effort has generated a summary of models and methods that could be used to help link changing NOx and SOx deposition to changes in ecosystem services and associated changes to human welfare (EPA 2008). These case studies are described in Appendix 3. As part of the NOxSOx Secondary NAAQS review, EPA is focusing on acidification and nutrient enrichment effects and their associated ecosystem services in several sensitive locations nationwide. These analyses are described in detail in the 2nd draft risk and exposure assessment (EPA 2009). While this approach uses case studies as a basis for developing ecosystem service metrics and indicators, it will be used to set a nationwide standard and, thus we consider this a national theme effort. OAQPS employed four types of case studies (terrestrial acidification, aquatic acidification, terrestrial nutrient enrichment and aquatic nutrient enrichment), and have assembled the data which forms the basis of a quantitative accounting and valuation of ecosystem services. We propose to closely examine these case studies, and choose at least one of them for a test case in order to develop an assessment tool to link Nr loading to ecosystem services endpoints. These case studies are described in Appendix 2, Section 7.2. This approach has an advantage for ESRP-N because it specifically focuses on nitrogen effects on ecosystem services.

Within each of the major place-based or case studies examining nitrogen, the following three questions will be addressed.

1. **Identify the dominant source(s) of anthropogenic nitrogen in a place-based location and why is it there (e.g., for FML fertilizer to grow crops).** For some places the dominant nitrogen source may not be associated with a direct or immediate benefit derived from nitrogen addition. For example, we do not put nitrogen into the atmosphere for a direct benefit, but as a by-product of human activities (e.g., fossil fuel combustion, CAFOs). Other sources may be due to inefficiencies in handling and treating waste (e.g., leaky infrastructure, improperly working septic systems).

2. **What service(s) are being the most compromised by that source of anthropogenic nitrogen?**
3. **What is the spatial distribution of the service(s) that contributes to nitrogen loading and the service(s) that is compromised by excess nitrogen?** For example, nitrogen

fertilization results in increased agricultural production in the Upper Midwest, where human benefits likely dissipate with distance, but compromised water quality may be over a larger scale (i.e., into Gulf). Also the human benefits derived from the compromised service may not improve as quickly (or may not improve) with distance from the source as the decline of benefits from the nitrogen-dependent service.

The place-based studies serve as central sites for linking ecosystem services to inputs of reactive nitrogen. Most of the place-based sites have a significant agricultural land-use component. Thus the impacts of fertilizer N on vital ecological functions such as terrestrial production, C sequestration, nutrient leaching and aquatic productivity will be focal points. Common models will be used at multiple sites (SWAT, SPARROW, CMAQ), and this provides an opportunity to compare model outputs and functional relationships as calculated within models (e.g., N retention rates in forests, N loading by land use type, N removal by wetlands). Since many of the water quality issues at the place-based studies also relate to other drivers such as P or sediments, part of the ESRP-N charge is to examine the interactions among these drivers. We are currently developing ways to incorporate N-P interactions, with Office of Water input. We are also discussing the influence that anthropogenically derived nutrients may have on the stoichiometry of nutrient delivery, which in turn can alter ecosystem services in sensitive aquatic ecosystems (Ptacnik et al. 2005).

From these place-based studies, several needs of ESRP-N will be met:

- development of place-specific Ecosystem Response Functions (ERFs) and Ecosystem Service response functions (ESRFs) (see Figure 4 above for the role in the overall ESRP-N roadmap),
- testing the utility of national data for accuracy in place-based examinations: for example, which national N data, (e.g., fertilizer loads, land use) are appropriate for more local/place-based ecosystem service assessments?,
- feedback from local stakeholders on utility of the ecosystem service quantification approach, particularly in regards to air and water quality related issues.

The purpose of this part of the plan is to synthesize findings from the place-based studies in order to gain a better understanding of how reactive nitrogen affects ecosystem services. We would like to know what more we can learn from the synthesis of the place-based results that the national efforts cannot provide. One potential avenue is the variation in land area across the place-based study locations, ranging from multi-state regions (i.e., FML, Northeastern US) to a metropolitan complex (i.e., Tampa Bay). How might policy decisions made at various scales affect reactive nitrogen pollution and related ecosystem services? Are ecosystem services related to reactive nitrogen scale dependent? Can valuation of these services be translated across spatial scales?

Theme 2 Expected Outcomes

1. Report on the key ecosystem services impacted by changes in reactive Nitrogen. **R4** 2010
2. Report outlining methods and specific indicators for linking ecosystem service response to ecosystem endpoints, drawing from the ESRP place-based studies and the OAQPS case studies. **R4, R5** 2012

4.3.2 Regional Scale Themes

A regional approach will be pursued for those questions in the ESRP Nr Research Program that can not currently be approached nationally. Case studies for the regional approach have been selected that have national significance and importance and for which we desire to develop a national approach. The objective is to extend the regional case studies through a synthesis of methods to be able to encompass a national perspective. These regional case studies will also interact with the Place-Based Studies, and ecosystem-specific studies (Wetlands and Corals).

4.3.2.1 Theme 3: Nutrient Cycling and Ecosystem Services

The impact of nutrient cycling on ecosystem structure and function has a high degree of regional diversity and heterogeneity and varies with ecosystem type. Targeted regional studies have been selected that hold promise for being extended to a national scope and that address broad regional differences across the US.

Theme 3 Case study 1: Northeastern Freshwater Systems

EPA-ORD-NHEERL-Atlantic Ecology Division lead

Northeastern lakes, ponds, and reservoirs (hereafter lakes) provide a full range of ecosystem services to New England residents and visitors. The provisioning of abundant, clean water for consumption, agriculture, and industry are easily identifiable services of lakes, as are cultural services that provide opportunities for recreation, aesthetics enjoyment, and wilderness experience and enhance local economies and quality of life. Less understood, but equally important, are the roles of lakes in protecting all life through supportive services such as nutrient cycling and the provisioning of habitats. Lakes also provide crucial regulating services that affect local, regional, and global water cycles, waste treatment, and climate.

Due to their economic and ecologic importance, lakes are highly managed, regulated, and monitored at multiple temporal and spatial scales. Simple individual actions such as choosing where to fish or swim along with formal management decisions by home owners, lake associations, conservation groups, business, and government (local, regional, and international) continually interact with natural biophysical processes to influence the availability and delivery of ecosystem services. As a result, it is imperative that economic, sociological, and ecological information be available to inform management decisions.

This project will focus on the ecological importance of reactive nitrogen and other nutrients in lentic systems of the Northeast. This work will involve interactions with EPA regions, other agencies and academic institutions conducting similar work. We recognize the need to develop new collaborations that will allow us to address the following management questions:

Management Questions

1. What are the ecological services provided by lentic ecosystems in the Northeast and who are the beneficiaries. **R4 & R5**
2. Which ecosystem services are most highly valued by lake residents, visitors and local communities and how can they be measured. **R4 & R5**
3. What options are available to lake and watershed managers and how do they affect delivery of ecosystem services in northeastern lakes? **R9 & R10**
4. What trade-offs among user groups need to be considered before implementing management actions? **R7**
5. Do managers consider the full spectrum of possible ecosystem service effects that result from choices of management options? If social-ecological management models are available will they be used in the decision making process? **R9 & R10**

Based on these management questions, EPA researchers have formulated the following research questions:

Research Questions

1. What are the N and P sources and loading rates to Northeast Lakes and Reservoirs? **R1**
2. How does the amount, location, and configuration of N and P sources effect loading rates, TN concentrations, TP concentrations, and/or Chl-a in Northeast Lakes and Reservoirs? **R2**
3. Do probabilistic survey estimates of lake trophic status, based on TN, TP, and Chl-a concentration correlate with model based estimates of the proportion of lakes and reservoirs in the northeastern U.S. in different trophic categories? **R2**
4. Can we identify lakes that are at risk of changing from clear water stable states to more turbid eutrophic states, based on SPARROW modeled input and output nutrient fluxes (lake nutrient attenuation), and model based estimates of TN and TP concentrations in lake polygons? **R2**
5. Can probability survey results of current conditions be combined with model based estimates of nutrient fluxes to identify lakes at risk of changing trophic state? **R2**
6. How well do survey estimates of the presence of cyanotoxins correlate with estimates of lake and reservoir trophic status based on probabilistic surveys, and modeled estimates of nutrient fluxes and concentrations? Does the presence of toxins correlate with pigments measured using hyperspectral sensors? **R2**
7. What key ecosystem services associated with lakes are affected by changes in the nitrogen cycle? **R3**
8. How do variations in measured or modeled lake trophic status, water clarity, cyanotoxins and lake habitats correlated with changes in availability and delivery of ecosystem services? **R3**
9. Are thresholds in lake stable states affected by Nr, related to tradeoffs in ecosystem services? **R3**

10. Can estimates of N and P flows along with existing condition assessments be used to estimate ecosystem service availability at regional level? **R3**
11. How do human activities affect Nr disturbance regimes in the Northeast (presses and pulses)? **R4**

Nitrogen and phosphorus have a direct impact on the trophic status of fresh water lakes. Excesses of these nutrients can lead to eutrophication, toxic cyanobacteria blooms, decreased biodiversity, and loss of ecosystem function leading to a reduction in the availability and delivery of critical ecosystem services provided by lakes. To improve lake monitoring and management it is necessary to understand the relationships between assessed water condition, trophic status (TN, TP, Chl-a), harmful algal blooms (HABs) (Jupp et al. 1994), and ecosystem services. Many factors, such as geology, soils, anthropogenic impacts, and limnological processes vary considerably across the nation. Therefore, as a starting point we have decided to concentrate on a regional scale understanding Northeastern US lakes. If successful, this approach can later be extended nationally. Northeastern lakes are good models for this work because of the availability of high quality monitoring data from EPA's EMAP, National Lake Assessment, and REMAP programs as well as the earlier National Eutrophication Survey (1972-1975) and ongoing state programs. The New England Lakes and Ponds (NELP) REMAP effort includes additional Chl-a collected using hyperspectral sensors in selected lakes. If successful, pigment estimates could be rapidly derived using aircraft hyperspectral and satellite spectral sensors at local to regional scales (Kutser, 2004).

There are many monitoring and water quality data available for the northeast lakes but it is somewhat difficult to compare them as each study uses different naming or identification systems for the water bodies. To overcome this problem we are developing a spatial database (geodatabase) of all the lakes in the Northeast based on the National Hydrography Dataset. In the end each water body will have a unique identifier (WaterbodyID). Once we map all the names and identifiers used in the monitoring databases to a WaterbodyID we can bring the data into a single database that can be analyzed together. Ancillary dataset, such as landcover/landuse change analysis or census data, will also be matched (related) to the WaterbodyID or spatially joined to the geodatabase. Dasymetric mapping is a GIS methodology that is used to increase the spatial resolution of census data. Since the census data are available in polygons of irregular shapes and areas, land cover data are used to redistribute the data to areas that are most likely to be inhabited (e.g., developed areas as opposed to natural, agriculture or open water areas). The database is listed as a product because we plan to make it available to interested researchers. This will allow all to work from the same standardized set of data and will further our goals of open data access and reproducible research.

To synthesize and draw inference from these databases, we will use two modeling approaches. Lamon & Qian (2008) have used a Bayesian approach to assess the probability of algal blooms (Chl-a), a proxy for trophic status, as a function of total nitrogen (TN) and total phosphorus (TP). These data can be used to predict trophic status using various modeling approaches, and may help assess the probability of cyanobacteria blooms. We are in contact with Lamon and currently adapting the model for use with the National Lakes Survey and NELP data. Once validated with NLA and NELP data, the Lamon & Qian model will be used to evaluate how lake conditions vary across disturbance gradients. Ultimately, the model will provide insight into how ecosystem service availability and delivery respond to variation in nitrogen inputs at a regional level.

The next step will be to extend the results to a watershed or individual lake level. This will allow for the creation or use of specific models for the evaluation of management scenarios. These could be existing models with a new configuration, but we are working with the modeling team to build on their expertise and experience with other ESRP projects. Since field data are not available for all Northeast lakes we will rely on estimates of nitrogen and phosphorus flows generated by the USGS SPARROW model (http://water.usgs.gov/nawqa/sparrow/). A version of SPARROW based on new NHDplus (National Hydrography Dataset) stream datalayer is currently being calibrated with 2002 data for the Northeast (Major River Basin 1). We currently discussing these goals with USGS and they are interested in collaborating with EPA on generating estimates of nitrogen and phosphorus concentrations in northeast lakes from SPARROW for modeling with the Lamon & Qian approach. This will allow us to fill in the probability survey across the region to provide a spatially complete mapping view of lake condition by lake type.

This research will be led by the Atlantic Ecology Division in collaboration with other ORD divisions, using in-house resources, and in collaboration with USGS VT-NH Office (SPARROW - MRB1), & NASA-Langley (aircraft remote sensing). Following a successful demonstration for the Northeast, the analysis can be extended to the Southeast in collaboration with Coastal Carolinas research using the new SPARROW calibration for the Southeast region (MRB-2). The analysis can also be extended in the Northeast to address acidity in the northeastern lakes. The Northeast results can be compared with the acidification critical load efforts within the Adirondacks project within EPA, described below in relation to tipping points (Theme 4) in lake conditions (Carpenter, 2003; Carpenter and Lathrop, 2008) and services.

Collaborative relationships with economists and social scientists will be sought to help relate research on the "biophysical context" (Figures 3 & 4) supporting lake ecosystem services to the "societal context" questions (R6, R7, and R8) related to ecosystem service management.

Expected Outcomes

1. Fully functional relational database of Northeast lakes, including dasymetric population datasets for 1990 and 2000 census data 2010
2. Statistical (R) scripts and sample data for repeating analysis and modeling work 2010-2012
3. Publications and presentations exploring the effects of reactive nitrogen inputs on lake ecosystem functioning and the delivery of ecosystem services 2010-2012
4. Publications and presentations on the role of landscape heterogeneity (i.e. landscape pattern) on reactive nitrogen in Northeast lakes 2012
5. Contribution to interactive model of lake ecosystem services including both biophysical and societal contexts 2012
6. Maps of lake risk (e.g. high probability of changing trophic status, high probability of cyanotoxins blooms, etc.) 2012

Theme 3 Case study 2: Eastern Coastal Estuary/Ocean Systems

EPA-ORD-NHEERL-Atlantic Ecology Division lead

Estuaries in the Northeast provide a wide range of ecosystem services (provisioning, regulating, supporting, and cultural) to local inhabitants, visitors, and to the U.S. economy in general. Recreational services include fishing, swimming, aesthetic enjoyment, and boating. Important commercial services include food production (aquaculture and commercial fishing) and transportation, e.g. ports for import and export. Estuaries receive nutrients from multiple sources, including rivers, point sources such as wastewater treatment plants, and atmospheric deposition. Estuaries are highly productive ecosystems that provide habitat for aquatic vegetation, essential breeding and nursery habitat for a wide range of fish and shellfish species, and temporary or permanent habitat for a wide range of aquatic and avian species. Estuaries serve as sinks for nutrients (a supporting service), thus decreasing the impacts of nutrients on fringing embayments and coastal waters.

Nitrogen is usually the limiting nutrient for estuaries, although phosphorus can be important locally. Excessive nitrogen loading leads to eutrophication with algal blooms, loss of dissolved oxygen with large areas of the bottom hypoxic or anoxic, loss of desirable habitat and productivity such as submerged aquatic vegetation (SAV), shellfish and finfish kills and loss of secondary productivity. These nitrogen loadings are the result of direct inputs of wastewater and atmospheric deposition of Nr to estuaries and indirect inputs via watershed processing of atmospheric deposition and other wastewater, agriculture and other non-point sources of Nr. The USGS SPARROW model accounts for Nr inputs to the watershed and transport and transformation of Nr downstream to become an Nr load to an estuary. In particular, the Northeast (MRB-1) SPARROW model can be used to define nitrogen loading to coastal estuaries in the Northeast from Virginia northward. The model outputs will be used to assess the sources of N into the estuaries (atmospheric nonpoint, point, land nonpoint), so that changes in loading can be related to select estuarine ERFs. Narragansett Bay is moving to tertiary treatment in the next few years. This will be a valuable “experiment” to analyze the effects of a change in nitrogen loading on estuarine ecosystem services. This work focuses largely on the northeastern US, but future work could use this approach in other estuaries along the east coast of the US.

Nitrogen retention and denitrification in watersheds, stream/lake networks, and estuaries may also be regarded as an ecosystem service since they can reduce eutrophication of estuaries. Retention and denitrification will be assessed as nitrogen is processed and transported though the watershed, streams and estuary. The SPARROW model estimates nitrogen retention and denitrification during stream transport. Retention and denitrification losses of Nr within estuaries can be treated as first-order loss processes (Dettmann 2001).

Simple, empirically-based models will be used for selected estuaries. In the ORD Water Quality (WQ) research plan, simple, empirically-based models are being developed to relate N load to concentrations, and to chemical (DO) and biological (SAV) conditions expected due to the N loading for selected estuaries. Process-level models could be adapted for selected estuaries to estimate chemical and biological condition gradients that affect ecosystem services. Progress has been made in development of models relating Nr and phytoplankton chlorophyll a in estuarine embayments and riverine estuaries, to assess the effect of Nr on estuarine trophic status that could affect the likelihood of HAB events. Aircraft and satellite remote sensing will provide additional information on primary production, water clarity, and spatial and temporal bloom dynamics that can help in estuarine and coastal ecosystem service management (Bob Connell-NJ DEP, personal communication). Ongoing research is assessing the applicability of these techniques to coastal ponds and barrier lagoons (E. Dettmann, Atlantic Ecology Division, personal communication). Results of the research can inform estuarine ecosystem service management decisions.

We will evaluate ecosystem services provided by benthic communities that are lost as a result of hypoxia/anoxia resulting from excessive inputs of nitrogen in coastal waters. Benthic secondary production, recycling services, water filtration, bioturbation, and role in biogeochemical cycles are impaired or lost as a result of anoxia in areas such as Chesapeake Bay, Long Island Sound, Narragansett Bay, and the "dead zone" in the Gulf of Mexico off the mouth of the Mississippi River.

Research is proposed to evaluate and model the nitrogen removal/ ecosystem services provided by filter-feeding shellfish populations in estuaries. Collaborative relationships will be sought to help relate existing literature and novel field and controlled experimental research on the 'biophysical context' and supporting estuarine ecosystem services to the "societal context" questions related to ecosystem services management in estuaries on the eastern seaboard. Specifically, we will take advantage of the current multi-stakeholder national effort to restore estuarine structure and function. A major component of this effort is the restoration of filter-feeding shellfish populations for the regulating, supporting and cultural categories of ecosystem services they provide. The priority supporting service to be considered here is filtration by shellfish reefs, which promotes Nr removal. Reducing Nr levels promotes improved water clarity and SAV. Other services associated with filter-feeding shellfish (e.g. reducing seston and providing habitat for increased biomass, biodiversity and fish production) will be linked to the coastal Carolinas place based studies.

Initially this research will aim to review the literature and understand existing knowledge gaps. This information will inform our decisions regarding the design of both field and laboratory experiments to quantify Nr removal by shellfish in a range of estuarine habitats and condition (water flow) gradients. We anticipate the work will occur in more than one estuary. Estuaries with advanced shellfish restoration programs include Narragansett Bay, Delaware Bay, Chesapeake Bay and Pamlico Sound. Other opportunities in the Gulf of Mexico and the northwest coast will be explored. Additionally, the research will investigate the differences in Nr removal between restored shellfish reefs and aquaculture operations. This research could involve collaboration with The Nature Conservancy, NOAA Restoration Center, Natural Resources Conservation Service, National Fish and Wildlife Foundation, State Departments of Environmental Management, National Estuary Program managers and shellfish industry representatives.

Questions

1. What are N and P sources and loading rates to Northeast estuaries? **R1, R10**
2. How do changes in Nr loading to estuaries that are related to human activities affect estuaries in the Northeast? **R2**
3. How does hypoxia and anoxia caused by excessive nitrogen loading to estuaries affect ecosystem services provided by benthic communities? **R3**
4. How are ecosystem services provided by shellfish affected by changes in N loading? **R3**

5. What key ecosystem services associated with estuaries are affected by changes in nitrogen loading and cycling? **R2, R3, R4**
6. Can biological condition gradients in estuaries affected by Nr be related to estuarine ecosystem services? **R3**
7. How do losses of Nr to denitrification and other loss processes such as shellfish filtration in estuaries affect ecosystem services in adjacent and downstream systems? **R2, R3, R4**
8. How are variations in estuary trophic status, water clarity, SAV distribution, HABs, and habitats correlated with changes in availability and delivery of ecosystem services? **R3, R4**
9. How do shellfish abundance, spatial extent and water flow conditions interact to affect the rate of water filtration and Nr removal? **R3, R4**

Biological indicators and the ES indicators, and corresponding bundles of ecosystem services for the estuaries still need to be developed. Some of this development can occur in the ESRP Place Based studies, in Tampa Bay and Coastal Carolinas, and perhaps applied in the U.S. Northeast estuaries in conjunction with the Modeling Team of LTG-2. The WQ research could relate changes in estuarine loading and estuarine ERFs due to anticipated reductions in atmospheric deposition from CMAQ simulations for 2020 and 2030. If appropriate estuarine ESRFs can be developed, this information could be added to such assessments.

Collaborative relationships will be sought to help relate research on the "biophysical context" and supporting estuarine ecosystem services (e.g. Nr filtration and denitrification) to the "societal context" questions related to ecosystem service management in specific estuaries. In particular, protection and restoration of shellfish provisioning and supporting ecosystem services is a major focus in Narragansett Bay, Delaware Bay, Coastal Carolinas. "Societal context" research on shellfish protection and restoration could involve collaboration with the NOAA Restoration Center, The Nature Conservancy, state departments of environmental management, National Estuary Program managers, and shellfish industry representatives.

Expected Outcomes

1. Better understanding of nitrogen and phosphorus loading to estuaries (SPARROW MRB-1) 2010
2. Report describing the ecosystem services provided by shellfish reefs in estuarine and coastal waters nationally, through a literature study and data mining exercise 2010
3. Publications and presentations on the effects of Nr inputs on ecosystem trophic state and functioning (e.g., nutrient retention) 2010-2012
4. Models relating nitrogen loads and concentrations in selected estuaries (10, coordinated with place-based estuaries) 2011-2012
5. Use of existing classification schemes for estuaries to test sensitivity to Nr and phosphorus 2012
6. Examples of biological condition gradient responses to observed changes in Nr loading (e.g. Boston Harbor, Narragansett Bay) 2015

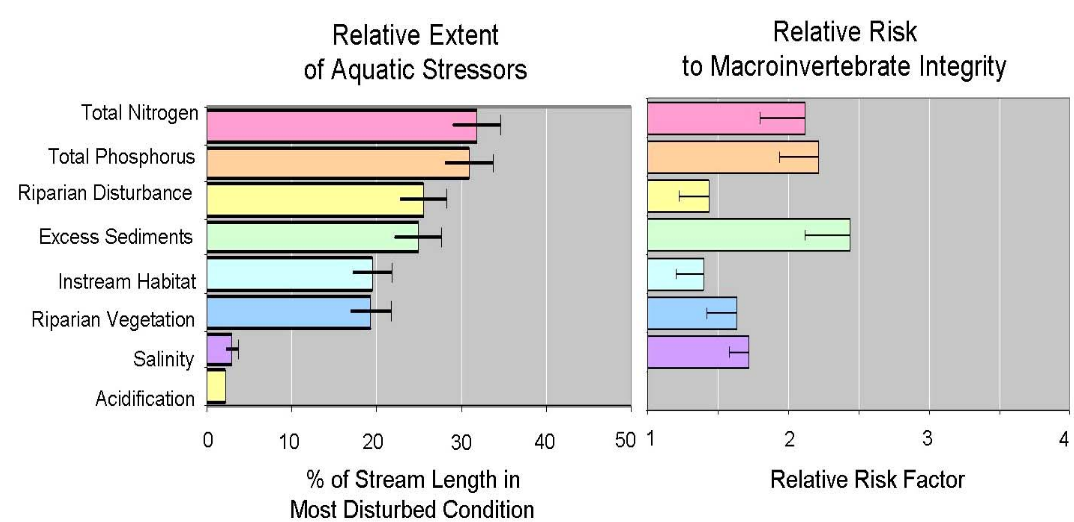
7. Better understanding of effects of hypoxia and anoxia on provision of ecosystem services by benthic communities 2015
8. Development of indicators of ecosystem services provided by estuarine communities 2015
9. A model will be developed of nitrogen removal promoted by varying shellfish populations and estuarine conditions 2015

Theme 3 Case study 3: Nitrogen removal potential of the Nation's rivers and streams

Brian H. Hill, EPA-ORD-NHEERL-Mid-Continental Ecology Lab (Duluth, MN) lead

Nitrogen export to the Gulf of Mexico has increased dramatically from the 1950s, and is correlated with an even greater increase in N fertilizer application in the Mississippi River basin (Turner and Rabalais 1991, Donner et al. 2004). In addition to the impacts on the Gulf of Mexico, water quality throughout the Mississippi River basin has been degraded by excess nutrients, and most States in the basin have significant river miles impaired by high nutrient concentrations and are not fully supporting aquatic life uses. The recent EPA Wadeable Streams Assessment indicated that excess nitrogen was the most pervasive stressor impacting the condition of U.S. streams (Figure 6).

Figure 6. Nitrogen was one of the most pervasive and important stressors in a national survey of wadeable streams (USEPA 2006).



The Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico (Mississippi River/Gulf of Mexico Nutrient Task Force 2001) suggests two basic approaches to reducing hypoxia in the Gulf of Mexico: 1) reducing N export from streams draining the Mississippi River basin and 2) restoration of watershed processes that enhance nitrogen retention and/or removal within the basin. There are three factors regulating N export from watersheds: influx of N from atmospheric and terrestrial sources, in-stream processing (e.g., nitrification/denitrification), and long-term storage (Alexander et al. 2000, Wollheim et al. 2006, Mulholland et al. 2008). The first approach recommended in the Action Plan, reducing export, may be achieved as simply as reducing N inputs by reducing the amount of fertilizer runoff from agricultural lands to receiving streams. Reducing N export may also be achieved by in-stream processing of N, or by increasing long-term storage as buried sediments in stream channels and adjacent riparian areas. The second approach, restoration of processes, is a targeted approach incorporating all three regulating factors.

Critical to estimating N removal potential of streams is the calculation of N uptake velocity (Vf), the theoretical rate at which N moves through the water column to the stream substratum. Uptake velocity may be estimated by mass balance of N inputs and outflows, or as a function of stream depths, stream velocity, and N uptake over a stream reach. Either approach must also account for the inverse relationship between Vf and N availability (Alexander et al. 2000, Dodds et al. 2002, Wollheim et al 2006, Mulholland et al. 2008). A final piece of the puzzle is the measurement of denitrification rates in stream sediments to confirm the predictions of these models.

This work will serve an important role as a comparison study to the research on Nr within the Willamette Ecosystem Services Project (see following section below) and also ongoing research in EPA's Water Quality Multi-Year Plan as part of the Non-Navigable Streams and Wetlands (NSW) research project (Wigington et al. 2007). In the NSW project, similar questions will be addressed related to the potential of small streams and wetlands to remove nitrogen from flow paths to larger streams and rivers.

An additional strength of this work will be empirical models for N removal that can be compared to, perhaps even inform, the SPARROW models.

Questions The three phases of our projects address the following questions:

1. How does watershed N yield vary across broad regional and national scales? **R1, R2**
2. How does N removal potential vary across stream sizes? Across regions? Nationally? **R1, R2, R3**
3. What is the role of microbial activity in sediments and biofilm in regulating N processing in streams and rivers? **R2**
4. What is the cumulative N removal for stream networks at regional and national scales? **R3, R10**
5. What is the value of N removal as an ecosystem service at regional and national scales? **R3, R10**

Approach

Phase I—Potential N removal based on existing monitoring data: Mississippi River basin - 2009

Stream chemistry and physical attributes collected from streams and rivers sampled as parts of the US EPA's Wadeable Streams Assessment (WSA) and the Environmental Monitoring and Assessment Program (EMAP) on great rivers will be paired with estimated hydrology (NHD Plus), land cover data (2001 NLCD), and atmospheric N deposition (NADP and CMAQ). Total N export will be calculated for each site as the product of N concentrations of the stream or river, adjusted mean annual discharge. Basin-wide estimates of N export will be based on the regression export against watershed area extrapolated to the total area of the basin. N yields will be estimated by dividing export by watershed area, and basin-wide estimates of N yield will be calculated as basin-wide export divided by basin area. Nitrogen removal potential will be estimated by combining known relationships between N uptake and stream depth, discharge, and stream N concentration

Phase II—Potential N removal based on enhanced monitoring data: Mississippi River basin - 2012

Phase II of this project is similar to Phase I in that it relies on data collected during the Office of Water's national survey of rivers and streams. The survey used in Phase II is the 2008-2009 National Rivers and Streams Assessment (NRSA) of 900 wadeable streams and 900 non-wadeable rivers in the conterminous United States. Chemistry, hydrology, land cover, atmospheric N deposition, and the calculation of N export, yield, and removal remain the same. In addition to these measures and estimates, nitrification and denitrification rates will be measured on sediments, and microbial enzyme activities will be measured on sediments and biofilm collected from these 1800 sites.

This work will also benefit from coordination with the cross-site research on river network N removal described in section 4.4.1.1 below (Cross-site research on the ecosystem service of N removal by river networks).

Phase III—National-scale estimate of potential N removal by streams and rivers - 2013

Stream chemistry and physical attributes collected from streams and rivers sampled as parts of the US EPA's Wadeable Streams Assessment (WSA) and the Environmental Monitoring and Assessment Program (EMAP) on great rivers will be paired with estimated hydrology (NHD Plus), land cover data (2001 NLCD), and atmospheric N deposition (NADP and CMAQ). Total N export will be calculated for each site as the product of N concentrations of the stream or river, adjusted mean annual discharge. Basin-wide estimates of N export will be based on the regression export against watershed area extrapolated to the total area of the basin. N yields will be estimated by dividing export by watershed area, and basin-wide estimates of N yield will be calculated as basin-wide export divided by basin area. Nitrogen removal potential will be estimated by combining known relationships between N uptake and stream depth, discharge, and stream N concentration. The Phase III project is identical to the Phase II project, except that it is applied to the conterminous United States.

This work will also benefit from coordination with the cross-site research on river network N removal described in section 4.4.1.1 below (Cross-site research on the ecosystem service of N removal by river networks).

Expected Outcomes for Stream and River N removal

1. Quantification of the roles of sediment and biofilm microbial assemblages in regulating N processing in streams and rivers? **R2** 2012
2. Regional and national scale estimates and maps of cumulative N removal as an ecosystem service **R3, R10** 2010-2013
3. Regional and national scale estimate and maps of denitrification by streams and rivers **R1, R2, R3** 2010-2013
4. Regional and national scale estimates and maps of N yield to streams and rivers **R1, R2** 2010-2013

5. Regional and national scale estimate and maps of potential N removal by streams and rivers **R1, R2, R3** 2010-2013

4.3.2.2 Theme 4: Tipping Points in Ecosystem Condition and Services

The critical loads or tipping points approach can provide a useful lens through which to assess the results of current policies and programs and to evaluate the potential ecosystem-protection value and ecosystem services value of proposed policy options. A major stressor of concern with serious consequences for freshwater aquatic and terrestrial systems is acidification from atmospheric deposition of reactive nitrogen (Nr) and sulfur (S). Several federal agencies are working together on regional pilot projects across the US to explore the possible role a critical loads approach can have in air-pollution control policy in the US. The ESRP Nr Research Program has selected three of the regional pilot projects that provide an excellent opportunity for the ESRP program to work within and build onto their efforts. These regional critical load mapping studies address aquatic and terrestrial systems. These studies are expected to come to fruition in 2010, after which a synthesis effort will be undertaken to determine how best to create national critical load mapping capabilities for the US EPA Office of Air Programs (OAP). Major players in these pilots are the US EPA, the National Park Service (NPS), and the US Forest Service (USFS). This research will involve a close coordination between ORD (NERL/AMD, NHEERL/WED, NHEERL/AED) and OAP/CAMD (Clean Air Markets Division) and OAR/OAQPS. Jason Lynch of CAMD will oversee this coordination. More information about this coordination can be found in Appendix 4.

Blue Ridge Mountains Aquatic Systems. Streams in the northern Blue Ridge Mountains were selected for a multi-agency critical loads (CL) pilot project for CL analysis and mapping because previous studies have identified this area as being very sensitive to acidic deposition and it has good data availability to foster the development of a critical load model for this region. The critical loads approach will be used to assess aquatic condition and impact with the chemical indicator of condition being acid neutralizing capacity (ANC). The MAGIC model will be used to estimate ANC for a subset of 66 water bodies out of a total of 400 sites with chemical data. CMAQ and NADP data will be used to provide deposition inputs to the model. Based on MAGIC predictions of ANC, a statistical model will be developed to relate biogeoclimatic data (landscape data) to CL's. The statistical model will be tested on water bodies with chemical data. The statistical model will then be used with biogeoclimatic data for the entire region to estimate CL's for all water bodies in the domain of study.

The difference between CL's and current deposition will be used to map water bodies at risk across the Blue Ridge region. It is expected that one of the first relevant biological end points related to ANC will be fish diversity, using a logistic function ecological response function (ERF), based on empirical data. A bundle of ecosystem services would then be defined and developed for the aquatic resources in this region. Resources have not yet been identified to do this bundling. Future changes in ANC, biological end points and ecosystem services will be explored under different future scenarios of atmospheric deposition, out to 2020 and well beyond using CMAQ simulations for guidance. A decision support system is being developed as part of the multi-agency pilot project that will be built upon the USDA-Forest Service's Ecosystem Management Decision Support (EMDS) system. Lessons learned as this decision support system is being developed will be communicated to the ESRP LTG-1 team. This project is being supported by EPA (NCEA and OAP) and the USFS with the ESRP N-Team invited to join and actively participate.

Adirondacks Terrestrial Systems. The New England Governors and Eastern Canadian Premieres initiated a critical loads study for soils and forests which is being extended to New York and the Adirondacks, including TIME/LTM lakes, by EPA (OAR/OAP). The analysis relates deposition of Nr and S to soil acidity and release of aluminum using a Steady State Critical Loads Mass Balance model. The choice of model and methods was made in coordination with Canadian scientists as part of a forest mapping group. National soils information is used to help map the critical loads and locations at risk (exceedances). The USFS has a lead role in the mapping. A biological indicator for ecosystem impact has not yet been selected to relate condition to a biological response. Good candidates are sugar maple and red spruce. The ERF for forests is expected to be complicated, but some research on a sugar maple ERF is taking place in New York with participation of USGS. A bundle of ecosystem services will need to be defined and developed for the terrestrial resources in this region. As with the aquatic systems, future changes in aluminum and soil acidity, biological end points and ecosystem services will be explored under different future scenarios of atmospheric deposition, out to 2020 and 2030 using CMAQ simulations. This project is being supported by EPA (OAP) and the USFS with the ESRP N-Team invited to join and actively participate.

Rocky Mountain Aquatic Systems. Atmospheric Nr deposition is increasing in the western US raising concern about the loss of ecosystem services. A Multi-Agency Western Critical Load Pilot project involving EPA (OAP), NPS, USGS and USFS has been established to examine the deposition and input of nitrogen to Rocky Mountain high elevation lakes. The project will establish critical loads for the eutrophication of lakes and map the CLs across the Rocky Mountains. A key objective is to address the spatial variability of lake status and critical loads to support regional mapping. The project will also develop ERFs connecting levels of nitrogen loading to diatom diversity and shifts in productivity related to changes in diversity. Development of these ERFs is well-advanced. Funding is from EPA (OAP), NPS, USGS and USFS with the ESRP N-Team invited to join and actively participate.

Drawing in research from place-based studies and other nitrogen-related case studies. In addition to this work on Critical Loads, we will identify key ecological response functions and tipping points from the place-based and other case studies described in Themes 2 and 3 above.

Expected Outcomes

1. Regional maps of tipping points (critical loads) related to acidic deposition with complete spatial coverage for aquatic and terrestrial systems. Regional maps of at-risk ecosystems related to acidic deposition **R1, R2** *2010*
2. Synthesis of critical load mapping methodologies to provide “models” to extend the regional critical load mapping approaches to national scales **R1, R2** *2012*
3. Relevant biological end points and ecosystem response models important to identifying ecosystem services impacted by acidic deposition; bundles of ecosystem services and ecosystem service response models associated with critical loads of acidic deposition **R2, R3, R4, R5** *2012 for individual and 2013 for bundles*

4. Projections of future Nr and acidic deposition, identification of the main sectors responsible for the precursor emissions to the deposition and identification of management action effectiveness **R9, R10** *2010*
5. Assessment of the strengths and weaknesses of the USDA-FS's decision support system **R10** *2011*

4.4 Cross-ESRP Coordination and Integration with ESRP-N

EPA's Ecosystem Services Research Projects have established an organizational research structure to maximize coordination, integration, consistency, and team effectiveness dynamics. There are a number of important long-term goals of this program. The key components of this large research program are important EPA approaches (Long-term Goals 1 and 2), pollutant-specific research (Goal 3, of which nitrogen was chosen as the first example), and ecosystem-specific studies (Goal 4). In addition, there will be several place-based demonstration projects to provide a context for defining and measuring ecosystem services at a scale relevant for state, local and regional management.

The matrix provided in Figure 7 illustrates this research structure and is an important part of the Program's strategic plan.

Figure 7. Matrix of Research Activities within ESRP.

Projects and Long term Goals →		LTG 3 Pollutant-Specific Studies: 6%	LTG 4 Ecosystem Specific Studies: 23%		LTG 5: Community Based Demonstration Projects: For National, Regional, State and Local Decisions 28%					Theme Leads
	Cross Program Themes and Research Objectives	Nitrogen (6%)	Wetlands (22%)	Coral Reefs (5%)	Willamette (11%)	Tampa Bay (4%)	Mid-West (4%)	Coastal Carolinas (8%)	Southwest (1%)	
Integration, Well-Being, Valuation, Decision Support, Outreach and Education LTG 1 9%	Ecosystem Services and Human Well-Being (3%)									Laura Jackson
	Valuation of Ecosystem Services									Wayne Munns--Consultation Committee
	Decision Support (6%)									Ann Vega
	Outreach & Education to									Open
Inventory, Map, and Forecast Ecosystem Services at multiple scales LTG 2 31%	Landscape Characterization and Mapping (12%)									Anne Neale
	Inventory and Monitoring of Services (14%)									Mike McDonald
	Modeling (5%)									Tom Fontaine--Consultation Committee
Pollutant Specific Studies LTG 3	Nitrogen (6%)									Jana Compton
Eco-system Specific Studies LTG 4	Wetlands (22%)									Janet Keough
Project Area Leads	Rick Linthurst and Iris Goodman	Jana Compton	Janet Keough	Bill Fisher	David Hammer	Marc Russell	Randy Bruins/ Betsy Smith	Deborah Mangis	Nita Tallent-Halsell	Rick Linthurst and Iris Goodman
					Hal Walker: Place Based Coordinator					

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 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 the Ecosystem 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 is the staff of ORD that is participating in the program within the bounds of the LTGs.

ESRP-Nitrogen will be integrally linked to many of these pieces, in particular the Mapping, Ecosystem-specific and Place-based studies. We describe these linkages below.

4.4.1 Integration of Nitrogen research from ESRP Place-Based Projects

4.4.1.1 Cross-site research on the ecosystem service of N removal by river networks

Brian H. Hill, EPA-ORD-NHEERL-Mid-Continent Ecology Division (Duluth, MN) lead

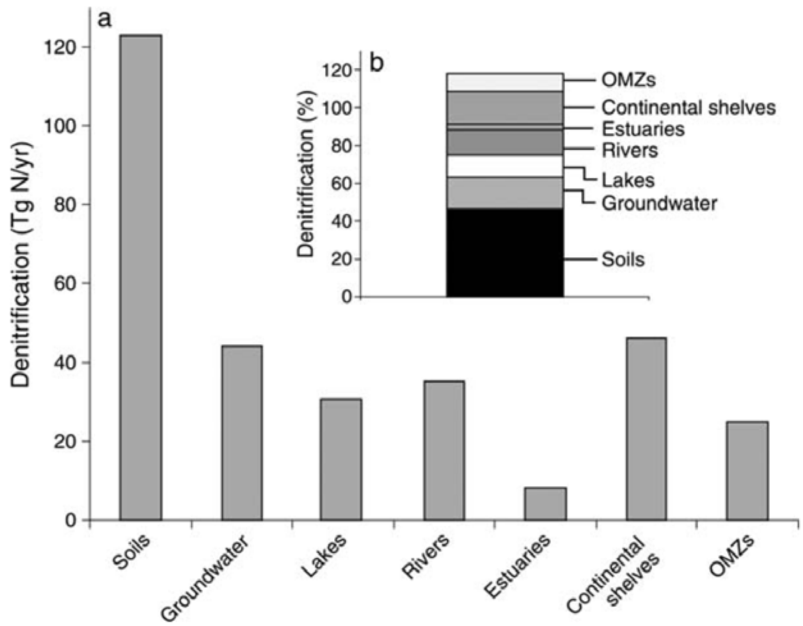
In addition to the broader goals above, we propose cross-site research in one area of study: the removal of N across a river network. We chose this scale because it represents an area of importance for EPA policies and regulations. TMDLs (total maximum daily loads) for pollutants, nutrient criteria, and Best Management Practices are all applied at the river network scale. Thus, understanding how the cumulative behavior of individual stream reaches determines the fate and transport of Nr at the river network scale will be of great use in those efforts.

While human activities such as fertilizer production and fossil fuel combustion have greatly increased nitrogen (N) loading to streams and rivers, substantial amounts of this nitrogen are removed from the water column via biological uptake and denitrification. In fact, recent work has shown that removal of nitrogen by aquatic ecosystems can be substantial, perhaps 15% of the nitrogen input to the landscape (Seitzinger et al. 2006; see Figure 9 below). The removal of N by river networks represents an important ecosystem service; however, a small fraction of the N that is removed can be converted to nitrous oxide (N_2O), a potent greenhouse. Thus, the biological removal of N from river networks may represent a form of “pollution swapping” whereby water quality is alleviated at the expense of air quality. Because these processes cannot be measured at the river network scale, simulation models have become an important tool for examining Nr removal and N_2O production in rivers and streams.

River network simulation models can account for the simultaneous input, removal, and downstream export of Nr throughout a river network. **However, current model estimates are highly uncertain partly due to these three factors:**

- The difficulty of including the smallest, but most abundant, streams into river network models;
- Poorly constrained in-stream N removal rates; and
- The omission of important complexities such as hyphorheic flow paths or N removal in floodplains from river network models.

Figure 9. Denitrification of land-based N sources in terrestrial, freshwater and marine ecosystems globally in terms of (a) Teragrams N yr^{-1} denitrified and (b) percentage of land-based N sources (270 Teragrams N yr^{-1}) denitrified for each system. OMZs are oxygen minimum zones in the ocean. (Seitzinger et al. 2006).



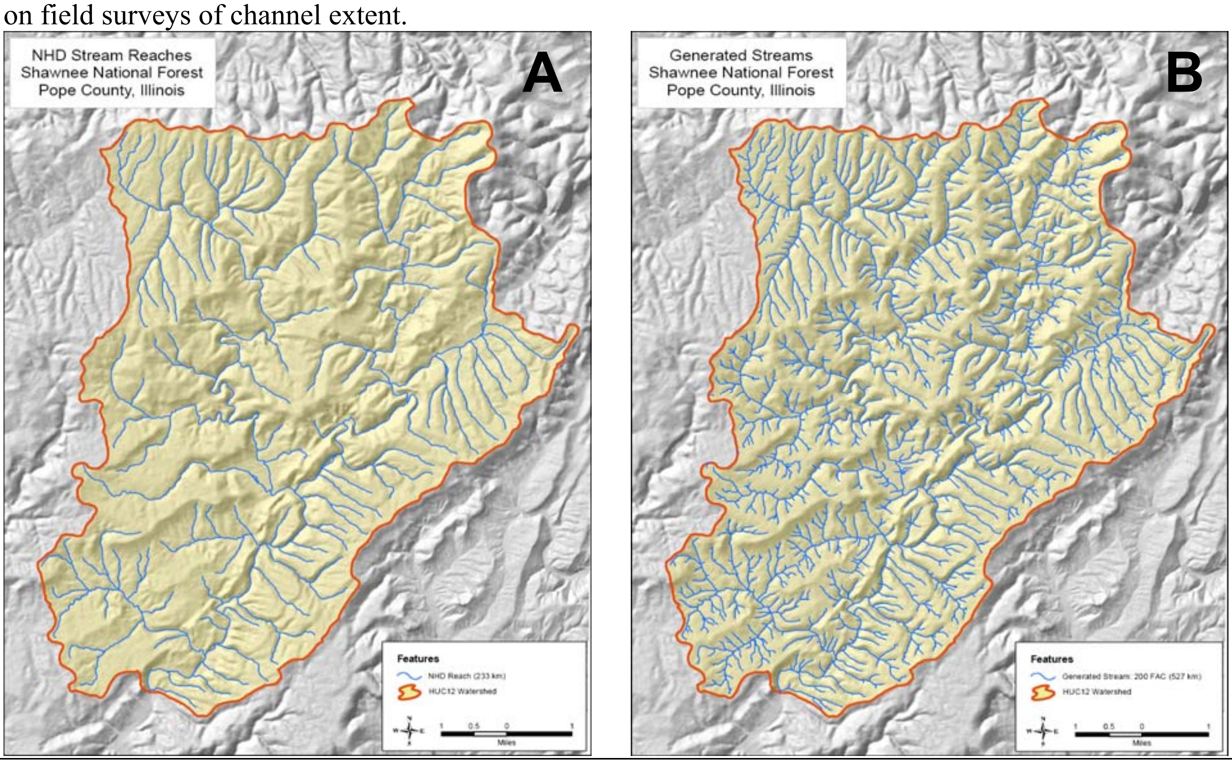
Potential importance of unmapped small streams

Small streams can efficiently remove nitrogen from the water column because their shallow depth promotes contact with the sediment where nitrogen removing bacteria reside (Craig et al. 2008). However, very small headwater streams are often overlooked in river network models because stream network maps are not available in sufficient resolution to include these features. In the figure below, N removal by small streams is likely encompassed in the "soil" component. This results in N removal by small streams being underestimated, or considered to be part of the broader landscape (as soil in the figure below) rather than recognizing their role in stream networks. We propose to assess the importance of N removal by the smallest streams in the river network in each of the place based study sites. This will be accomplished using GIS to add unmapped small streams to existing river network models. For each place based study site we will utilize the ArcHydro data model and tools to process elevation data, calculate flow direction, flow accumulation and the drainage network, watersheds and sub-catchments associated with that site (Maidment and Morehouse, 2002). Within ArcHydro, flow accumulation (derived from the elevation data) is used to delineate stream initiation locales and the subsequent stream network. We will adjust the flow accumulation threshold so that stream delineations (mapped within the GIS) are extended upstream to intersect stream initiation locations identified in the field. Concurrently, this is applied across the area, effectively mapping all small streams within a particular watershed. These newly derived stream/river networks and their lengths, will be compared with those from existing stream/river networks, mapped using medium and high resolution NHD (National Hydrology Database) maps to assess the potential affect of this approach within a basic biogeochemical model. See Figure 10 for an example of the differences in drainage networks at two levels of resolution.

Poorly constrained in-stream N removal rates,

Most simulation models greatly simplify nitrogen biogeochemistry by assuming that Nr removal rates are constant across time (e.g. seasons) and space (e.g. entire river networks). Furthermore, very few models link in-stream Nr removal and N_2O production. These simplifications have lead to a great deal of uncertainty in model estimates of Nr removal and N_2O production. We propose to refine model estimates by measuring whole stream Nr removal and sediment N_2O production rates in samples of the smallest streams at each of the place based study sites. We chose to focus on the smallest streams because many of these systems alternate between a dry and flowing state and stream ecologists have focused most of their attention on streams that flow year-round, whereas their terrestrial counterparts have focused attention on uplands outside of the channel network. Among our place based research sites, these small streams should show significant variation in factors (and features) that are important to nitrogen retention and transformation. We hope to leverage this variation to identify the factors that control sediment N_2O production and Nr removal rates. These relationships will then be used to parameterize our simulation models.

Figure 10. Maps showing stream channels with the Shawnee 12-digit HUC (Pope Co., Illinois) based on 1:24K NHD (A; 233 km of stream channel) and predicted channels (B; 527 km of stream channel) based on field surveys of channel extent.



Overly simplistic river network models

River network models tend to greatly simplify the physical aspects of streams and rivers (e.g. depth, width) and as a consequence overlook potentially important complexities such as flow paths at the aquatic-terrestrial interface (e.g. riparian zone), water and nutrient storage in floodplains, and hyporheic flow paths. To identify sites where this simplification of the river network yields unrealistic model estimates, **we propose to apply a uniform biogeochemical and hydrologic model to the main river basins represented at the Place Based study sites.**

We will apply a basic biogeochemical model which incorporates nitrate flux into (upstream inputs and loading from the landscape) and out of (downstream export and biological removal) defined stream segments within a river network. N-inputs to the stream segments will be optimized to reproduce the spatial distribution of nitrate concentrations measured throughout the river network. These predicted N loading rates will then be compared to published N loading rates in the literature. A model which produces unrealistic loading rates suggests that we are missing key components of the N cycle in the basin. The basin in question could then be examined for characteristics which are inconsistent with the model assumptions (e.g. large floodplains, pelagic uptake, hyporheic flowpaths) and could point the way toward new research. Alternatively, we could simulate spatially explicit N loading rates to the river network based on detailed land use maps for the basin. Then we could test the model by comparing predicted and observed stream water nitrate concentrations.

Model testing: We are currently targeting two potential sites for this work – the Upper Mississippi Basin and the Willamette River Basin. Within the Willamette River, we are working in a smaller basin where a dense network of 75 sites was sampled synoptically within the network for stream chemistry. This kind of information could be combined with hydrologic information being produced within EPA's Water Quality multi-year plan (Wigington et al. 2008), to produce spatial maps of N removal by streams. And this validation data set will be of use in its own right, but will allow testing of the model described above, to determine its utility.

Cross-site river network nitrogen research - Outcomes and relevance to clients

Goal: A better understanding of the properties and characteristics of streams, in particular headwater streams, related to their management, prioritization for restoration, for example their utility in a water quality trading or TMDL approach.

Office of Water connections: EPA's Office of Water (OW) faces important challenges related to reactive nitrogen, and requires improved modeling tools to support the implementation of an effective nutrient water quality trading program. To improve model simulations of nitrogen fate and transport throughout at the river network scale we should build from and integrate with existing EPA models such as BASINS. Models that increase our understanding of the effects of nutrient pollution on local waters, downstream transport processes, and loading dynamics from land based sources are of particular interest to the Office of Water. The ability to evaluate "what if" scenarios for the identification cost effective approaches to enhance ecosystem services in local freshwaters systems and downstream, estuarine and marine waters is highly desirable. We envision a framework that will identify watershed characteristics (e.g., land use, soil type, slope, riparian vegetation, etc) that are good predictors of water quality (e.g. N, P, biological condition, etc.) and can be used to identify levels of degradation risk and opportunities for preservation and restoration of water resources. We suggest that our work would be of use to the Office of Water, in particular for addressing these three issues:

- ***Significant nexus (Rapanos/Carabell), the influence on downstream waters*** – improve understanding of the influence of small streams on navigable systems. Develop models that could be used to determine benefits (e.g. N removal) provided by small headwater streams to the larger systems and to the landscape in general.
- ***Biological Condition Gradient*** – improve characterization of condition of US waters, more resolution allows for earlier identification of decline or improvement. Ecosystem function (including those related to nitrogen) is an attribute that states and tribes currently do not have the means in which to assess. However, because the processes that take place in streams are critical to assessing the overall health of ecosystems (i.e., tell us how a systems is operating), there is a need to develop techniques that can be implemented by state and tribal regulators.
- ***TMDLs*** – characterization of potential "hot spots" of nutrient transformation in stream networks. Specific nitrogen sources may not be as apparent given the current resolution of stream networks and monitoring efforts. Combining better characterization of small streams within networks (See #1 above) and of atmospheric nitrogen deposition may improve our ability to track specific sources of nitrogen loading. This will lead to more effective watershed planning to protect downstream water bodies.

4.4.2 Integration with Other Components of ESRP

4.4.2.1 Mapping, Modeling and Monitoring

Mapping ESRP-N has a close connection with the Mapping group, with emphasis on quantification of nitrogen removal as an ecosystem service at a national scale. We will work together on national data layers of N inputs, N outputs. Together, we are developing a riparian buffer project to quantify and map nitrogen removal by the nation's riparian areas (see section 4.3.1.1).

Modeling Desired connections but unclear at this point. We are using models, and the place-based studies are using models. We would like to develop a more explicit model to collate the ERFs and ESRFs to examine scenarios associated with Nr. We are currently in the process of hiring an expert to conduct national scale models of nitrogen removal by various landscape components (terrestrial, wetland, stream, lakes).

We'd also like to create a visualization tool to examine N loads for a particular landscape. OAR's Clean Air Markets Division is doing this already, but we could provide assistance and perhaps testing.

4.4.2.2 Decision Support, Outreach and Human Well-Being

Decision Support Desired connections but unclear at this point. The decision support platform group has proposed some nitrogen-related work, including organizing a workshop to discuss the use of ecosystem services in the management and policy related to nitrogen.

Valuation and Human Well-Being Logical connections, particularly through drinking water, visibility and air quality, but have not developed any specific ties yet.

Outreach We have interacted with the outreach group, and plan to have stronger ties in the coming year. Our clients are largely the program offices, in particular for the national-scale research, and much of the outreach has been done. The current challenge is to continue to make sure we provide the science that will be used by the Offices in their assessments and decisions. We are working on a specific project, to coordinate with the Office of Air in providing a science basis for using ecosystem services as an assessment tool. The Outreach program within ESRP has been made aware of this, and we hope will continue to provide insight and advice as needed.

4.4.2.3 Ecosystem-based Projects (Wetlands and Coral Reefs)

The ecosystem-specific studies within LTG 4 allow for development of relationships between N load and ecosystem services.

System-Based Study 1 - Wetlands

Wetlands lead for ESRP-N: Steve Jordan

Wetlands receive reactive nitrogen (Nr) from aquatic, terrestrial, and atmospheric sources, process it in various ways, and deliver the products, transformed or not, to other systems. Reactive nitrogen also exerts biological and ecological effects on wetland ecosystems (Figure 11).

Wetlands can be important sinks for Nr by means of (1) plant uptake and incorporation in long-lived biomass, (2) burial in sediments, and (3) microbial transformations of Nr to N_2. These processes contribute an important service by reducing standing stocks of Nr. Both natural and constructed wetlands are used in some areas as tertiary treatment systems for wastewater. The capacity of wetlands to remove Nr from ecosystems varies widely across wetland types; for example, cypress swamps in Florida and southern Louisiana can absorb and process substantial loads of Nr, benefiting water quality and wetland productivity (USEPA 2006), whereas some wetland types are net sources of Nr through nitrogen fixation (Hurd et al. 2001). A regional-scale analysis of N retention by natural wetlands in the Baltic Sea drainage basin indicated substantial (5-13%) retention of the total N load by existing wetlands, with much greater potential if original wetlands were restored (Jansson et al. 1998).

The capacities and tolerances of wetlands for Nr are important research questions that cut across the wetlands and nitrogen elements of the ESRP. Even though some wetlands may remove substantial amounts of Nr, it will be important to understand how varied rates of N loading affect overall wetland condition and services.

Questions

1. What are the trade-offs between removing and sequestering N (and carbon), versus potential degradation of other functions and services? **R2, R4, R7**
2. Could wetland protection and restoration be used effectively in Nr management, not in a site-specific sense, but as a component of regional or national nutrient management strategies (Mitsch et al. 2005)? **R8, R9**
3. How would the aggregate net values of wetlands used for nutrient reduction compare with nutrient removal in wastewater treatment plants? **R8**

Wetland Approach

The research approach to these questions will begin with a literature review and synthesis to glean available information on Nr processing rates in wetlands, as well as effects of Nr loading on the ecological condition and services supplied by major classes of wetlands, and how these processes are affected by important covariates such as hydrology, climate, and other stressors. Once synthesized, this information can be used in models at various scales to address the research questions. Our goal for this element of coordinating the wetlands and nitrogen research is to generate a national perspective on the interactions between wetland ecosystems and nitrogen. More detailed, regional studies will be conducted by the place-based research teams as described above.

Wetland Expected Outcomes

1. Wetlands APG 43 (2010) - Characterize the relationships between ecological function and delivery of services by wetlands **R2**
2. Wetlands APM 341 (2009) - State of the science report on relationships among stressors, wetland functions and ecosystem services at multiple scales: Gulf of Mexico coastal wetlands (EPA-ORD-NHEERL-GED), Great Lakes coastal wetlands (EPA-ORD-NHEERL-MED), and isolated wetlands in selected states (EPA-ORD-NERL-EERD) **R3, R4**
3. Wetlands APM 310 (2010) - Report on the effects of nitrogen loading and nitrogen removal on ecosystem services in wetlands at the national scale, by wetland type and position in the landscape (Jordan) **R3, R4**

System Based Study 2: Coral reefs

N lead for Coral Reefs - Jim Latimer

Coral reef ecosystems and services derived from coral reefs will be studied in three U.S. jurisdictions: Florida, U.S. Virgin Islands and Puerto Rico with anticipated byproducts for Pacific jurisdictions and the greater Caribbean region. Coral reefs provide considerable services to society—food, recreation, education, health, coastal protection, land accretion, carbon stores, water quality, support of other ecosystems and species, support of human incomes, livelihoods, and social, cultural, and spiritual enjoyment. Yet coral reefs are in serious decline and efforts to manage and protect them have been inadequate, often lacking both monetary resources and management expertise. Over the last two decades, economic approaches (environmental valuation) have gained recognition as potentially powerful tools needed to reverse this trend. Estimates of worldwide value for coral reefs have ranged from \$30B yr-1 to \$377B yr-1, but these are coarse, extrapolated values that are not particularly useful for resource management. It is an objective of the ESRP to ensure that coral reef ecosystem services are routinely considered in regional policy and local management decisions. This requires a process for local determinations of ecosystem services and values. Implementation plans for the ESRP coral reef project will be prepared in 2009. Interim planning has employed the DPSIR (Driving forces, Pressure, State, Impact, and Response) conceptual model to capture the breadth of activities needed to achieve project goals. Driving forces include the underlying systems to support commercial, residential and industrial aspects of society. Each generates goods or services, but by-products such as pollution generate Pressures, such as excessive nutrients and sediment, that change the State (condition) of the reef ecosystem. Impacts, in the ESRP context, are changes in ecosystem services and values delivered by the reefs. If these impacts can be reliably quantified and communicated to decision makers and stakeholders, then better decisions will be made to reduce adverse driver impacts (Response). Understanding the impact of pressures (e.g., high nutrients) on reef attributes and the consequent delivery of ecosystem services is essential to successful completion of ESRP goals.

Reactive nitrogen (Nr) is only one of many interactive pressures that affect coral reefs. In fact, worldwide, significant reef damage is attributed to elevated temperatures associated with global climate change. Since climate change is not locally controlled, coral reef conservation requires emphasis on understanding and controlling effects of other pressures, such as Nr, that arise from local human activities. Existing protection efforts for coral reefs come almost exclusively from Marine Protected Areas—however these can only protect a small fraction of reefs and cannot protect them from coastal and watershed pollution. Greater protection is needed to prevent pollution in the coastal zones and upstream watersheds. Sediment, nutrients, contaminants and microbial pathogens, all known to have detrimental effects on corals and reef ecosystems, are transported to reef locations from the watershed (or airshed).

The effects of Nr on corals and coral reefs appear to depend on several different factors. Stony corals, the principal reef-building corals, obtain energy from photosynthesis (via symbiotic algae) and from capture of small prey with their polyp tentacles. Nr can benefit coral predation (secondary production), but can interfere with photosynthesis. In particular, excess Nr can stimulate chlorophyll in the water column (which inhibits light penetration) and growth of macroalgae on available substrate (in direct competition with stony corals). Different locations are likely to be influenced differently by Nr. Dependencies include the amount of influent Nr, assimilation potential by reef organisms, tidal and current flows, and level of herbivory (e.g., fish, sea urchins). The coral reef project will evaluate the effects of Nr and other pressures on coral reef attributes and services at spatial scales relevant to regional policies and local management decisions.

Coral Reef Research Questions related to Nr

1. What are the sources of Nr to coral reef ecosystems? **R1**
2. What are Nr loads to coastal reef systems at regional and local scales? **R1**
3. How does temporal and spatial variability of Nr loading depend on landscape characteristics, hydrology and demography? **R1**
4. What are pressure-related states/conditions of coral reef organisms and communities to Nr? **R2**
5. Based on coral reef attributes, how does Nr affect value of ecosystem services? **R3**
6. What are the influences of particular drivers (and pressures) on ecosystem services? **R3**

Coral Reef milestones related to Nr

1. Complete nutrient delivery laboratory test system for stony corals 2010
2. Report on effects of nitrogen on stony coral growth and calcification **R2** 2012
3. Complete model to integrate effects of Nr and other pressures on coral communities **R2** 2013

4. Report on effects of Nr and other pressures on coral reef communities and delivery of ecosystem services **R3** 2015

Expected Outcomes: Decision makers will routinely incorporate coral reef ecosystems services in decision processes; this will be facilitated by maps, models and reports that characterize the effects of Nr and other major pressures on the sustainability of coral reefs and ultimate delivery of ecosystem services.

4.5 Coordination and Outreach across EPA

4.5.1 Coordination with EPA Program offices

As EPA research scientists, we have an opportunity to work closely with EPA program offices and NCEA in providing information that is directly relevant for the process of determining and evaluating air and water quality standard criteria. As we put together our plan for N, we can start with the 2008 Integrated Science Assessment for NOx/SOx Secondary Standards and current assessment findings by OAQPS as a terrific place to start and justify the research in N that needs to be done. We envision that the results of this research will be useful for subsequent Science Assessments, and are working with NCEA directly to ensure that this potential exists. In the same way, we also expect that these N load relationships could be a useful guide toward understanding the effects of all nitrogen inputs on water quality, and are pursuing those links as well, through N-wetlands linkages, Office of Water and the link to the Mapping and Monitoring groups.

4.5.2 Coordination on Global Climate Change research

Climate change is expected to have impacts on nitrogen fluxes and related services, resulting from alterations in temperature and the amount and distribution of precipitation. Climate change also has important potential impacts on nitrogen-related services such as coastal nutrient loading and stratification of estuaries, which interact to regulate hypoxia in the coastal areas. Currently there exists a Global Climate Change (GCC) research program within EPA, and across other agencies as well. Several of the place-based studies discussed in Theme 2 research above (and see Appendix 2 for more details) are addressing specific issues related to climate change. Building a research effort examining nitrogen and GCC interactions will require a coordinated approach and this will take time. We cannot currently outline a detailed program in this area. In light of these limitations, the following section identifies some important links between climate change and nitrogen, and provides a short list of questions examining the potential impacts of climate change on N-related ecosystem services. In parallel with the "R" questions we established earlier, we pose 4 climate related questions below. In addition, we provide some potential junctions for fostering collaboration based on ongoing work. We expect the extent of collaboration to grow over time.

C1. How will climate-related changes in precipitation and/or temperature affect the Nr transfer from land to water or from watersheds to estuaries? (Extends Research Question R1)

C2. How will climate-related changes in temperature and/or precipitation alter the structure and function and the levels of critical loads determined for aquatic and terrestrial ecosystems? (Extends Research Question R2)

C3. How will N affect C allocation, C sequestration and greenhouse gas fluxes? How will climate-related changes in temperature and precipitation alter these relationships? (Extends Research Question R3)

C4. How will climate-related changes in temperature and precipitation affect the delivery of ecosystem services associated with nitrogen? (Extends Research Question R3)

The initial junction to collaboration on the N effects on greenhouse gas fluxes is to summarize international studies of the relationships and then try to adapt the general relationships to the US where feasible. We will begin examining climate change effects on biogeochemical cycling and water quality by addressing the climate questions in the context of Themes 3 and 4 at the regional scale. The research would extend climate-related ecosystem changes in cycling and tipping points to changes in ecosystem services through the results of Theme 2 and the services aspects derived in Themes 3 and 4. EPA ORD has limited capacity to address these climate questions, but important advances and connections can, nonetheless, be made. Initially, climate theme research will be conducted in targeted case studies.

The meteorology downscaling work within NERL as part of EPA ORD's climate change program has the potential to develop metrics of climate change that will be important to ecosystems. We anticipate collaborating with this part of the program as part of the Nr work to help identify the most informative metrics, map them nationally and use them locally at finer spatial scales than typically available from the climate models. We anticipate this collaboration will also allow us to connect to the IPCC climate scenarios in a way meaningful to the ecosystem services research. We also anticipate collaborating with other groups within ORD, such as NCEA, and OAR on climate change aspects related to N. Initially we will organize a workshop to help guide this research and coordination.

Workshop session to identify key climate-nitrogen linkages

Climate-nitrogen linkages will be a session at the Nitrogen workshop planned for 2010. As previously mentioned, temporal variation and extremes of temperature and precipitation are predicted to be altered by future climate change. These factors interact with numerous aspects of ecological function and structure that are simultaneously affected by nitrogen loading. In addition, climate change potential can be characterized by the increased concentration of green house gases (GHGs) in the atmosphere, including carbon dioxide, methane and nitrous oxide. N loading can alter ecosystem biogeochemistry and community composition in such a way that alters the biogenic flux of GHGs. Alternatively, increasing CO2 concentrations may alter stomatal behavior and plant physiology that in turn effects how N is cycled within ecosystems. This workshop session will focus on how climate and GHGs interact with nitrogen loading to influence ecosystem response.

Carbon-nitrogen interactions in terrestrial ecosystems

Plant biomass is considered a dominant terrestrial sink for carbon dioxide. Carbon sequestration is commonly discussed as an important ecosystem service that is a potential tool to offset CO_2 emissions and mitigate climate warming. C cycling is a complex process that can be quantified into ecosystem C budgets on the basis of net ecosystem productivity (NEP), defined as gross primary productivity (GPP) after subtracting the ecosystem respiration (autotrophic + heterotrophic respiration). Factors that may increase terrestrial CO_2 sinks on a regional scale are increased net primary productivity (NPP), and decreased respiration of CO_2 from above- and below-ground compartments. Productivity and respiration can be altered by (1) atmospheric deposition of N, and (2) temperature and precipitation associated with climate change.

This research will evaluate current literature on N effects on C budgets with a focus on studies that evaluate total ecosystem carbon flux and ecosystem C allocation. Stimulation of C sequestration in forests is most commonly discussed in the literature without consideration of how N may affect the carbon flux of other types of ecosystems. It is possible that N may stimulate respiration more than productivity resulting in a net loss. The effects of N on carbon budgets of ecosystems are complicated by the interacting effects of temperature and precipitation. For example, increasing temperature is known to increase C loss via respiration while decreased precipitation may increase water stress leading to diminished carbon capture. Published results on the effects of N on the carbon flux and allocation of multiple types of ecosystems in the U.S. will be evaluated to determine general trends for U.S. ecosystems and identify underrepresented areas in the U.S. Interactions with precipitation and temperature will be evaluated.

Expected Outcomes: A literature review of N effects on C flux and allocation in the U.S. is planned. Study sites where interactions between N and C flux or C allocation will be mapped to help indentify underrepresented ecosystem types and regions in the U.S. This work will build on current efforts conducted by NCEA **C3 and C4, 2010**

Nitrous oxide-nitrogen interactions in ecosystems

Nitrous oxide (N_2O) is a climate-forcing GHG. Biogenic sources are the dominating contributors (>90%) to atmospheric N_2O. Although the atmospheric concentration of N_2O (319 ppb in 2005) is much lower than carbon dioxide (379 ppm in 2005), its global warming potential is 296 times that of carbon dioxide. Human activities have increased the atmospheric concentration of N_2O by 18% since preindustrial times (IPCC, 2007). According to the 2007 GHG inventory, 6.5% of GHG emissions are from N_2O, making it the third largest contributor after carbon dioxide and methane.

Terrestrial ecosystems are the largest source of N_2O, accounting for 60% of global emissions (IPCC 2001). Nitrous oxide production in the soil is mainly governed by microbial nitrification and denitrification. Denitrifying bacteria produce N_2O during the reduction of nitrate or nitrite under anaerobic condition. In an aerobic environment, N_2O is released as an intermediate product when nitrifying bacteria oxidize ammonium to nitrate. The increase in N_2O emission following nitrate or ammonium addition was observed in many experiments, mainly attributed to the increased N supply to nitrifying and denitrifying bacteria. Denitrification is assumed to be the major microbial process responsible for N_2O consumption by reducing N_2O to N_2. Low mineral N and low oxygen pressure appear to favor N_2O consumption. However, the mechanisms controlling N_2O consumption are still not well understood. This research will evaluate current literature on N effects on N_2O flux.

An understanding of the sources of the N_2O flux would be informative. Following the bi-directional ammonia development of CMAQ for Theme 1 and the fertilizer input tool to support CMAQ ammonia flux estimates, CMAQ could be extended to address a soil compartment in its land-surface model to estimate N inputs and associated N_2O flux. A further potential CMAQ development of an advanced land-surface model would link it to hydrology to complete the connection of atmospheric deposition of N to potential fluxes of N_2O. This development would depend on successful CMAQ development and on the above research as well as the research in

Case 3 of Theme 3 on the nitrogen removal potential in rivers and streams to help parameterize N_2O flux associated with N loading. This would lead to a capability to estimate N_2O fluxes associated with atmospheric deposition of N as well as fertilizer application of N to provide a broader sense of source attribution of N_2O.

Expected Outcomes: We will conduct a literature review of N effects on N_2O flux in the U.S. that includes a map of study sites to help indentify underrepresented ecosystem types and regions in the U.S. This work will build on current efforts conducted by NCEA **C3 2010**. CMAQ estimate of N_2O emissions associated with N deposition and fertilizer application for specified regions of the US **C1, C3, C4 2015**

Climate-critical load impacts

The delineation and assessments of critical loads in Theme 4 consider how ecosystem threshold effects and tipping points relate to changes in related ecosystem services. In some cases threshold effects are known, and have predictable consequences on biotic systems, e.g., when acid neutralizing capacity (ANC) in aquatic systems affected by acid rain approaches zero. What has to be done to restore lost ecosystem services is an important management question. Due to hysteresis, some types of ecosystem restoration can be extremely difficult and expensive. Climate change may also impact the efficacy of ecosystem restoration efforts as typical conditions such as mean temperature and precipitation are expected to change.

Critical loads of N and S deposition associated with acidic deposition have been extensively studied for the Adirondacks lakes and streams. The relation between deposition load and stream chemistry has been investigated through data and biogeochemical cycling models. Model assessments have been made regarding reductions in load required to restore ANC to levels that will fully support biological diversity. These assessments have assumed constant climate. This research will examine and delineate how changes in temperature and precipitation associated with potential climate change will affect the biogeochemical cycling of N through the system and affect the critical loads and the relative effectiveness of load reductions. This work will be based on model analyses of aquatic and soil systems that have extensive data records and are best understood, starting with the Adirondacks. A leading model for the analyses is Pnet-BGC, developed at Syracuse University, due to its process representation of N cycling. The extension from critical loads to services will draw from relationships developed under Themes 2 and 4. Results are expected to have broad applicability in regard to the effects of climate change on critical loads.

Expected Outcomes: A case study assessment of the impact of potential climate change on critical loads and on the rate of restoration for select aquatic systems **C2**, **2012**

4.6 Coordination with Other Agencies and Researchers

4.6.1 Multi-Agency Critical Loads Efforts

Between 2002 and 2006, several federal agencies, specifically US EPA, National Park Service (NPS), US Forest Service (USFS) and USGS, convened conferences and workshops to review critical loads experience in other countries, discuss critical loads science and modeling efforts, and to explore the possible future role of a critical loads approach in air-pollution control policy in the U.S. This multi-agency effort has fostered a series of regional critical load mapping projects or pilot studies being carried out across the US, funded in part by the Clean Air Markets Division (CAMD) of EPA's Office of Air Programs (OAP). These regional pilot studies are expected to reach fruition in 2010. These current research projects provide an excellent opportunity for the ESRP to work within and build onto their efforts and bring in an ecosystem services perspective.

4.6.2 USGS SPARROW Efforts

The SPARROW model allows the determination of N loading and sources to the landscape, as well as calculating hydrologic N export for large areas. Some of the estimates of export and removal by streams and wetlands are direct measures of ecosystem service of nutrient removal, and thus SPARROW model output could be used to estimate these services. USGS is currently conducting regional runs of this model, which provide an excellent opportunity for us to collaborate at regional or site-level projects, in addition to contributing and testing ideas at the national scale. We are in the process of identifying opportunities to collaborate with the USGS-SPARROW modeling group in order to develop this capacity of SPARROW. We will participate in a joint EPA-USGS workshop to identify these opportunities in early 2009.

5 Outputs and Measures of Success

5.1 Outputs

EPA tracks scientific products through Annual Performance Goals (APGs) and Annual Performance Measures (APMs). The APGs and APMs and associated with ESRP-Nitrogen were initially identified in the Ecological Services Research Program Multi-Year Plan, which was reviewed by the SAB in early 2008. These goals and measures have been modified since that time, and the current version is shown below.

APG 25 2008: Complete an implementation plan for the ERP nitrogen research effort.

> ***APM 567 2008***: Draft for peer review of multi-year research and implementation plan for nitrogen assessment, including expectations of demonstration sites and wetlands. NHEERL-WED Jana Compton - *Completed in 2008*

APG 42 2010: 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.

> ***APM 299 2010***: Report on the impact of reactive nitrogen on ecosystem services, and nitrogen-related ecosystem services. NHEERL-WED Jana Compton
>
> **Expected Impact:** Will benefit Office of Air by providing more information on the impacts of nitrogen on ecosystem services for future nitrogen-related air quality standards review.

APG 56 2011: Report synthesizing information on nitrogen sources and nitrogen-related services for to the conterminous US.

APM 109 2011: Maps of nitrogen sources and nitrogen-related services for the conterminous US. NHEERL-WED Jana Compton

Expected Impact: Will provide data sources for place-based studies in ESRP. Will provide better information for local and regional management of nitrogen (TMDLs, standard development, assessing impacts of increasing nutrients).

APG 59 2012: Research report on sensitivity of change in key ecological services affected by changes in emission rates of Nr to the atmosphere. NHEERL-WED Jana Compton

APM 2012: Report identifying sensitive ecosystems to increased Nr for US, based on regional and national critical loads work and other related work.

Expected Impact: Will benefit Office of Air by connecting the research on air deposition effects on ecological systems to a broader ecosystem services framework, fills a gap in the risk assessment.

APG 26 2013: Provide ecosystem service response functions and connect nitrogen impacts to ecosystem services for multiple ecosystems, including the place-based and other demonstration projects. NHEERL-WED Jana Compton

APM 2012: Report incorporating ecosystem service response functions (ERFs) generated across place-based studies within ORD.

Expected Impact: Provides a tool for illustrating and quantifying the broad impacts of nitrogen loads to air, land and water, clients include Office of Air and Office of Water.

APG 2014: Provide the modeling "weight-of-evidence" output for nitrogen loading to the nation's air, land and water. NHEERL-WED Jana Compton

APM 2014**:** Provide multiple model outputs estimating nitrogen sources, removal and response to future scenarios at national and regional scales.

Expected Impact: Provides a tool for illustrating improved estimates of nitrogen loads to air, land and water from multiple sources in a watershed context, clients include States, Regions and Office of Water.

APG 2015: 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. NHEERL-WED Jana Compton

APM 2015**:** Demonstration of decision-support tool for examining ecosystem service response to and effects on Nr for place-based studies.

Expected Impact: Provides a tool for managing and regulating nitrogen from multiple sources in a watershed context, clients include States, Regions and Office of Water.

5.2 Measures of Success

One of the challenges of this project is to meet Long Term Goals. To determine if these goals are met, Performance Measures must be in place. These Measures attempt to quantify research product completion, customer satisfaction, research partner success, and others. There are five main goals that will be measured:

1. Selection of the appropriate set of ecosystem services and response functions:
   - Measure --> Feedback from program offices and regions
2. Successful production of ecological response functions and ecosystem service response functions.
   - Measure --> Testing in case studies, adaptation and use of case studies across multiple sites
3. Quantification of ecosystem services.
   - Measure --> Ecosystem services are given specific values
4. Successful publication of research products and syntheses.
   - Measure --> Publication in peer-reviewed journals. ESRP-N publications used in subsequent Air and Water Quality Standard development process
5. Successful development of Case Studies & Research partnerships:
   - Measure --> Discussions, and Partnerships established, tracked, and feedback and usefulness rated

6 References

Aber, J., W. McDowell, K. Nadelhoffer, A. Magill, G. Berntsen, M. Kamakea, S. McNulty, W. Currie, L. Rustad, and I. Fernandez. 1998. Nitrogen saturation in temperate forest ecosystems: hypotheses revisited. BioScience 48:921-934.

Aber, J. D., K. J. Nadelhoffer, P. Steudler, and J. M. Melillo. 1989. Nitrogen saturation in northern forest ecosystems. BioScience 39:378-386.

Alexander, R. B., R. A. Smith, and G. E. Schwarz. 2000. Effects of stream channel size on the delivery of nitrogen to the Gulf of Mexico. Nature 403:758-761.

Alexander, R. B., R. A. Smith, G. E. Schwarz, E. W. Boyer, J. V. Nolan, and J. W. Brakebill. 2007. Environmental Science and Technology 42:822-830.

Berg, G.M., P.M. Gilbert, M.W. Lomas, and M.A. Burford. 1997. Organic nitrogen uptake and growth by the chrysophyte *Aureococcus anophagefferens* during a brown tide event. Marine Biology 129: 377-387.

Boyd, J. and S. Banzhaf. 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63(2-3): 616-626.

Boyer, E., C. Goodale, N. Jaworski, and R. Howarth. 2002. Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern USA. Biogeochemistry 57:137-169.

Carpenter, S.R., 2003. Regime Shifts in Lake Ecosystems. Ecology Institute, Oldendorf/Luhn, Germany.

Carpenter, S.R. and R.C. Lathorp. 2008. Probabilistic estimate of a threshold for eutrophication. Ecosystems 11:601-613.

Chee, Y. E. 2004. An ecological perspective on the valuation of ecosystem services. Biological Conservation 120: 549-565.

Compton, J.E., M.R. Church, S.T. Larned and W.E. Hogsett. 2003. Nitrogen export from forested watersheds in the Oregon Coast Range: The role of N_2-fixing red alder. Ecosystems 6:773-785.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.

Craig, L.S., M. A. Palmer, D. C. Richardson, S. Filoso, E. S. Bernhardt, B. P. Bledsoe, M. W. Doyle, P. M. Groffman, B. A. Hassett, S. S. Kaushal, P. M. Mayer, S. M. Smith, and P. R. Wilcock. 2008. Stream restoration strategies for reducing river nitrogen loads. Frontiers in Ecology and the Environment 6:529-538.

Daily, G. 1997. Nature’s services. Island Press, Washington, D.C., USA.

Dettmann, E.H. 2001 Effect of water residence time on annual export and denitrification on nitrogen in estuaries: A model analysis. Estuaries 24(4): 481-490.

Fenn, M. E., J. S. Baron, E. B. Allen, H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, and D. W. Johnson. 2003a. Ecological effects of nitrogen deposition in the western United States. BioScience 53:404-420.

Fenn, M. E., R. Haeuber, G. S. Tonnesen, J. S. Baron, S. Grossman-Clarke, D. Hope, D. A. Jaffe, S. Copeland, L. Geiser, and H. M. Rueth. 2003b. Nitrogen emissions, deposition, and monitoring in the western United States. BioScience 53:391-403.

Fenn, M. E., L. Geiser, R. Bachman, T. J. Blubaugh, and A. Bytnerowicz. 2007. Atmospheric deposition inputs and effects on lichen chemistry and indicator species in the Columbia River Gorge, USA. Environmental Pollution 146:77-91.

Galloway, J. N., J. D. Aber, J. W. Erisman, S. P. Seitzinger, R. W. Howarth, E. B. Cowling, and J. Cosby. 2003 The Nitrogen Cascade. BioScience 53 341-356.

Galloway, J. N. and E. B. Cowling. 2002. Reactive nitrogen and the world: 200 years of change. Ambio 31: 64-71.

Galloway, J. N., F. J. Dentener, R. W. Howarth, S. P. Seitzinger, G. P. Asner, C. C. Cleveland, P. A. Green, E. A. Holland, D. M. Karl, A. F. Michaels, J. H. Porter, A. R. Townsend, and C. J. Vorosmarty. 2004. Nitrogen cycles: past, present, and future. Biogeochemistry 70:153–226.

Gilbert, P.M., R. Magnien, M.W. Lomas, J. Alexander, C. Fan, E. Haramoto, M. Trice, and T.M. Kana. 2001. Harmful algal blooms in the Chesapeake and coastal bays of Maryland. USA: Comparison of the 1997, 1998, and 1999 events. Estuaries 24: 875-883.

Goolsby, D. A., W. A. Battaglin, B. T. Autenbach, and R. P. Hooper. 2001. Nitrogen input to the Gulf of Mexico. Journal of Environmental Quality 30: 329-336.

Hoos, A. B. and G. McMahon. 2009. Spatial analysis of instream nitrogen loads and factors controlling nitrogen delivery to streams in the southeastern United States using spatially referenced regression on watershed attributes (SPARROW) and regional classification frameworks. Hydrological Processes: DOI: 10.1002/hyp.7323.

Howarth, R. W., D. P. Swaney, E. W. Boyer, R. Marino, N. Jaworski, and C. Goodale. 2006. The influence of climate on average nitrogen export from large watersheds in the Northeastern United States Biogeochemistry 79:163-186.

Hurd, T.M., D.J. Raynal, and C.R. Schwintzer. 2001. Symbiotic N_2fixation of *Alnus incana* ssp. rugosa in shrub wetlands of the Adirondack Mountains, New York, USA. Oecologia 126:94-103.

Jansson, Å., C. Folke, and S. Langaas. 1998. Quantifying the nitrogen retention capacity of natural wetlands in the large-scale drainage basin of the Baltic Sea. Landscape Ecology 13:249-262.

Jupp D.L., J.T.O. Kirk, and G.P. Harris. 1994. Detection, identification and mapping of cyanobacteria using remote sensing to measure the optical quality of turbid inland waters. Aust. J. Mar. Freshwater Res. 45, 801-828.

Kutser, T. 2004. Quantitative detection of chlorophyll in cyanobacterial blooms by satellite. Limnol. Oceangr. 44(6): 2179-2189.

Landers, D., R. McKane, J. Compton, D. White, J.R. Brooks, D.L. Phillips, M.G. Johnson, P. Rygiewicz, C. Anderson, P. Beedlow, S. Klein, W.E. Hogsett, C. Burdick. 2008. Willamette Ecosystem Services Project (W-ESP) Research Plan. EPA-ORD-NHEERL WED-08-048.

Maidment, D.R. and Morehouse, S. 2002. Arc hydro: GIS for water resources. Redlands, California: ESRI Press.

Mayer, P. M., S. K. Reynolds, M. D. McCutchen, and T. J. Canfield. 2007. Meta-analysis of nitrogen removal in riparian buffers. Journal of Environmental Quality 36:1172-1180.

McIssac, G. F., M. B. David, G. Z. Gertner, and D. A. Goolsby. 2001. Nitrate flux in the Mississippi River. Nature 414: 166-167.

Millennium Ecosystem Assessment Board (MEA). 2005. Ecosystems and Human Well-being: Current State and Trends, Volume 1. R. Hassan, R. Scholes, and N. Ash, eds., Washington: Island Press. http://www.millenniumassessment.org/documents/document.766.aspx.pdf.

Mitsch, W. J., J. W. Day, L. Zhang, and R. R. Lane. 2005. Nitrogen retention in wetlands in the Mississippi River Basin. Ecological Engineering 24:267-278.

Mulholland, P. J., A. M. Helton, G. C. Poole, R. O. Hall Jr, S. K. Hamilton, B. J. Peterson, J. L. Tank, L. R. Ashkenas, L. W. Cooper, C. N. Dahm, W. K. Dodds, S. E. G. Findlay, S. V. Gregory, N. B. Grimm, S. L. Johnson, W. H. McDowell, J. L. Meyer, H. M. Valett, J. R. Webster, C. P. Arango, J. J. Beaulieu, M. J. Bernot, A. J. Burgin, C. L. Crenshaw, L. T. Johnson, B. R. Niederlehner, J. M. O'Brien, J. D. Potter, R. W. Sheibley, D. J. Sobota, and S. M. Thomas. 2008. Stream denitrification across biomes and its response to anthropogenic nitrate loading. Nature 452:202-206.

Neitsch, S. L., J. G. Arnold, J. R. Kiniry, R. Srinivasan, and J. R. Williams. 2004. Soil and Water Assessment Tool Input/Output File Documentation. Version 2005

Nevison, C. D., N. M. Mahowald, R. F. Weiss, and R. G. Prinn. 2007. Interannual and seasonal variability in atmospheric N2O. Global Biogeochemical Cycles 21:GB3017, doi:3010.1029/2006GB002755.

Paerl, H.W. 2009. Controlling eutrophication along the freshwater-marine continuum: dual nutrirent (N and P) reductions are essential. Estuaries and Coasts 32: 593-601.

Perakis, S. S., J. E. Compton, and L. O. Hedin. 2005. Nitrogen retention across a gradient of ^{15}N additions to an unpolluted temperate forest soil in Chile. Ecology 86:96–105.

Scheffer, M. W. Brock, and F. Westley. 2000. Socioeconomic mechanisms preventing optimum use of ecosystem services: an interdisciplinary theoretical analysis. Ecosystems 3:451-471.

Seitzinger, S., J. A. Harrison, J. K. Bohlke, A. F. Bouwman, R. Lowrance, B. Peterson, C. Tobias, and G. Van Drecht. 2006. Denitrifiction across landscapes and waterscapes: A synthesis. Ecological Applications 16:2064-2090.

Seitzinger, S. P., J. A. Harrison, E. Dumont, A. H. W. Beusen, and A. F. Bouwman. 2005. Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: An overview of Global Nutrient Export from Watersheds (NEWS) models and their application. Global Biogeochem. Cycles 19

Stoddard, J. L. 1994. Long-term changes in watershed retention of nitrogen: Its causes and aquatic consequences. Pages 223-284 in L. A. Baker, editor. Environmental chemistry of lakes and reservoirs. American Chemical Society, Washington, D.C., USA.

Townsend, A. R., R. W. Howarth, F. A. Bazzaz, M. S. Booth, C. C. Cleveland, S. K. Collinge, A. P. Dobson, P. R. Epstein, E. A. Holland, D. R. Keeney, M. A. Mallin, C. A. Rogers, P. Wayne, and A. H. Wolfe. 2003. Human health effects of a changing global nitrogen cycle. Frontiers in Ecology and the Environment 1:240-246.

U.S. EPA. 2008. Methodology development for linking ecosystem indicators to ecosystem services. Office of Air Quality Planning and Standards. EPA Contract Number EP-D-06-003.

U.S. EPA. 2006. Draft Nutrient Criteria Technical Guidance Manual: Wetlands. Office of Water, EPA-823-B-05-003. Washington, D.C.

U.S. EPA. 2006. Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams. Office of Research and Development, Office of Water. EPA 841-B-06-002. Washington, D.C.

U.S. EPA. 2009. Integrated Science Assessment (ISA) for Oxides of Nitrogen and Sulfur Environmental Criteria. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-07/145A.

U.S. EPA. 1997. Mercury Study Report to Congress. EPA-452/R-97-003 (8 volumes). U.S. Environmental Protection Agency, Office of Air Quality Planning & Standards and Office of Research and Development, Research Triangle Park, NC, December 1997. Available at http://www.epa.gov/mercury/report.htm

U.S. Long Term Ecological Research Network (LTER). 2007. The Decadal Plan for LTER: Integrative Science for Society and the Environment. LTER Network Office Publication Series No. 24, Albuquerque, New Mexico. 154 pages. http://www.lternet.edu/decadalplan/

Vitousek, P. M., J. D. Aber, R. W. Howarth, G. E. Likens, P. A. Matson, D. W. Schindler, W. H. Schlesinger, and D. G. Tilman. 1997. Human alteration of the global nitrogen cycle: sources and consequences. Ecol. Appl. 7:737-750.

Wigington, P.J., S. Leibowitz, J. Ebersole, M.R. Church, J.E. Compton, J.R. Brooks, R.L. McKane, and R. Comeleo. 2008. Influence on non-navigable streams and wetlands on navigable waters. US EPA-ORD-NHEERL WED-08-023.

Wolfe, A. H. and J. A. Patz. 2002. Reactive nitrogen and human health: acute and long-term implications. Ambio 31:120-125.

Wolfe, A. P., J. S. Baron, and R. J. Cornett. 2001. Anthropogenic nitrogen deposition induces rapid ecological changes in alpine lakes of the Colorado Front Range (USA) Journal of Paleolimnology:1-7.

Xian, G., M. Crane, and D. Steinwand. 2005. Dynamic modeling of Tampa Bay urban development using parallel computing. Comput. Geosci 31:920-928.

7 Appendices

7.1 Appendix 1. ESRP-N Writing and Implementation Team

Jana Compton - ESRP N Lead

United States Environmental Protection Agency National Health and Environmental Effects Laboratory Western Ecology Division, 200 SW 35th St. Corvallis, OR 97333 Phone: 541-754-4620; Fax: 541-754-4799; Email: compton.jana@epa.gov

SCIENTIFIC EXPERTISE

Forest soils, Biogeochemistry, Watershed science, Nutrient cycling, Stable isotopes, Land use and species influences on soil and watershed processes

EDUCATION

Ph.D. June 1994, University of Washington, Biogeochemical cycling.

M.S. Dec. 1990, University of Washington, Forest Ecosystem Analysis.

B.A. April 1988, Earlham College, Richmond, Indiana, Biology/Chemistry.

PROFESSIONAL EXPERIENCE

1999-present Ecologist, US Environmental Protection Agency, Corvallis, OR

1996 - 1999 Assistant Professor of soil biogeochemistry, University of Rhode Island

1994 - 1996 Post-doctoral Research Associate, Harvard Forest, Harvard University

RELEVANT PUBLICATIONS

Compton, J.E., T.D. Hooker and S.S. Perakis. 2007. Nitrogen distribution and $\delta^{15}N$ in a 115-year white pine chronosequence. Ecosystems 10: 1197-1208.

Asano, Y., J. E. Compton, and M. R. Church. 2006. Hydrologic flowpaths influence inorganic and organic nutrient leaching in a forest soil. Biogeochemistry 81:191–204.

Compton, J. E., C. P. Andersen, D. L. Phillips, J. R. Brooks, M. G. Johnson, M. R. Church, W. E. Hogsett, M. A. Cairns, P. T. Rygiewicz, B. C. McComb, and C. D. Shaff. 2006. Ecological and water quality consequences of nutrient addition for salmon restoration in the Pacific Northwest. Frontiers in Ecology and the Environment 4:18-26. (EPA STAA Level II award)

Perakis, S.S., J.E. Compton, and L.O. Hedin. 2005. Nitrogen retention across a gradient of ^{15}N additions to an unpolluted temperate forest soil in Chile. Ecology 86: 96-105.

Compton, J.E., L. Watrud, L.A. Porteous and S. DeGrood. 2004. Response of soil microbial biomass and community composition to chronic N additions at Harvard Forest. Forest Ecology and Management 196:143-158.

Compton, J.E., M.R. Church, S.T. Larned and W.E. Hogsett. 2003. Nitrogen export from forested watersheds in the Oregon Coast Range: The role of N_2-fixing red alder. Ecosystems 6:773-785. (EPA STAA Level II award)

Robin L. Dennis - N lead for Integration of Theme-based research

US EPA, Atmospheric Modeling Division, NERL (919) 541-2870 Dennis.robin@epa.gov

EDUCATION

Ph.D. In Physics, 1972, University of Wisconsin-Madison

M.S. in Physics, 1969, University of Wisconsin-Madison

B.S. in Physics Magna cum Laude, 1966, University of Redlands, Redlands, California

EMPLOYMENT

Senior Scientist, US EPA/ORD/NERL/AMD, RTP, NC 2008 to present

Senior Scientist, NOAA/ASMD in partnership with US EPA/ORD/NERL, RTP, NC 1998 to 2008

Physical Scientist, NOAA/ASMD in partnership with US EPA/ORD/NERL, RTP, NC 1984 to 1998

Staff Scientist, Environmental and Societal Impacts Groups, NCAR, Boulder, CO 1979-1984

Senior Fellow, Advanced Study Program, NCAR, Boulder, CO 1978-1979

Research Scholar, Envir. Prog., Internat'l Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria 1976-1978

NSF Post-Doctoral Fellow, Environment Program, IIASA, Laxenburg, Austria 1975-1976

Project Associate, Energy Systems and Policy Research Program and Air Pollution Research Program, Institute for Environmental Studies, UW-Madison 1972-1975

RESEARCH INTERESTS

Environmental problem solving and bringing science to bear to inform and guide decision making.; the diagnostic evaluation of regional air quality models; the application of regional air quality models for cross-media assessments, linking air and water for critical loads and coastal estuarine assessments, with attention to atmospheric deposition.

SELECTED HONORS/MAJOR AWARDS

NOAA, NOAA Administrators Award, 2007

US EPA, NERL Science Achievement Award for Cross-Media Linkage, 2006

US EPA, Bronze Medal for CMAQ Model Development and Evaluation, 2005

US EPA/SETAC, Scientific Achievement Award for Air-Water Linkage for Chesapeake Bay, 1999

SELECTED PUBLICATIONS

Dennis, R.L., R. Haeuber, T. Blett, J. Cosby, C. Driscoll, J. Sickles and J.M. Johnston. Impact of sulfur and nitrogen deposition on terrestrial and freshwater ecosystems, Air & Waste Management Association Environmental Manager, December 2007, pp 12-17.

Sullivan, T.J., B.J. Cosby, J.R. Webb, R.L. Dennis, A.J. Bulger, F.A. Deviney, Jr. Steamwater Acid-Base Chemistry and Critical Loads of Atmospheric Sulfur Deposition in Shenandoah National Park, Virginia, Environmental Monitoring and Assessment, vol. 137, No. 1-3, pp 85-99.

Gilliland, A.B., R.L. Dennis, S.J. Roselle and T.E. Pierce, 2003. Seasonal NH3 Emissions Estimates for the Eastern United States based on Ammonium Wet Concentrations and an Inverse Modeling Method, Journal of Geophysical Research - Atmospheres, vol. 108, No. D15, 4477 doi:10.1029.2002JD003063, 2003.

Mathur, R. and R.L. Dennis, 2003. Seasonal and Annual Modeling of Reduced Nitrogen Compounds Over the Eastern United States: Emissions, Ambient Levels and Deposition Amounts, Journal of Geophysical Research - Atmospheres, vol. 108, No. D15, 4481 doi:10.1029.2002JD002794, 2003.

Paerl, H.W., R.L. Dennis and D.R. Whitall, 2002. Atmospheric Deposition of Nitrogen: Implications for Nutrient Over-enrichment of Coastal Waters, Estuaries, 25, No. 4B, 677-693.

Meyers, T., J Sickles, R. Dennis, K. Russell, J. Galloway, and T. Church, 2001. Atmospheric nitrogen deposition to coastal estuaries and their watersheds, in R.A. Valigura, R.B. Alexander, M.S. Castro, T.P. Meyers, H.W. Paerl, P.E. Stacey and R. E. Turner (Eds.) Nitrogen Loading in Coastal Water Bodies: An Atmospheric Perspective, American Geophysical Union, Coastal and Estuarine Studies, Washington, D.C., 254 pp.

Dennis, R.L. and R. Mathur, 2001. Airshed domains for modeling atmospheric deposition of oxidized and reduced nitrogen to the Neuse/Pamlico system, 2001, Hydrological Science and Technology, Special Issue, 17, No. 1-4, 107-117.

Linker, L.C, G.W. Shenk, R.L. Dennis, J.S. Sweeney, 2000. Cross-Media Models of the Chesapeake Bay Watershed and Airshed, Water Quality and Ecosystem Modeling, 1, 91-122.

R.L. Dennis, Using the Regional Acid Deposition Model to Determine the Nitrogen Deposition Airshed of the Chesapeake Bay Watershed, in Joel E. Baker, editor, Atmospheric Deposition to the Great Lakes and Coastal Waters, Society of Environmental Toxicology and Chemistry, Pensacola, FL, pp 393-413, 1997.

Henry A. Walker - Theme Based Research - Northeast Aquatic Systems

US EPA, ORD, NHEERL, Atlantic Ecology Division NHEERL (401) 782-3134
walker.henry@epa.gov

EDUCATION

PhD 1991, Biological Oceanography, University of Rhode Island

M.S. 1979, Experimental Statistics, University of Rhode Island

M.S. 1976, Marine Sciences, University of Massachusetts - Amherst

B.A. 1971, Biology, Colby College, Waterville, ME.

EMPLOYMENT

Research Environmental Scientist, Atlantic Ecology Division, National Health and Environmental Effects Research Laboratory, ORD, U.S. EPA, Narragansett, RI. 1986 – present

Work Assignment Manager. Science Applications International Corporation 1984-1985

Technical Project Leader. Applied Technology Division, Computer Sciences Corporation. 1985-1986 Research Associate. Institute for Statistical and Mathematical Modeling, University of West Florida, Pensacola, Florida. 1983-1984

RESEARCH INTERESTS

Developing and applying methods to distinguish between anthropogenic and natural changes in coastal ecosystems for use in integrated assessments of the joint effects in coastal receiving waters of anthropogenic changes in nutrient loading, regional climate variability, and potential consequences of regional climate change.

SELECTED HONORS / MAJOR AWARDS

US EPA Science Achievement Award Biology/Ecology. 2008

US EPA, Science and Technology Achievement Awards: 2002, 2003, 2008

US EPA National Coastal Assessment Team Awards: 2004, 2005, 2007

US EPA, Bronze Medal for the National Assessment Team for production of the first U.S. National Assessment Report: "Climate Change Impacts on the United States". 2000

SELECTED PUBLICATIONS

Contributor: USEPA In Press National Coastal Condition Report III. www.epa.gov/owow/ocean/nccr

Hollister, J.W., H.A. Walker, J.F. Paul. In Press. CProb: A Computational Tool for Conducting Conditional Probability Analysis. Journal of Environmental Quality. 37(6).

Hollister, J.W., P.V. August, J.F. Paul, H.A. Walker. 2008. Predicting estuarine sediment metal concentrations and inferred ecological conditions: an information theoretic approach. Journal of Environmental Quality. 37(1):234-44

Cronin TM and Walker, HA. 2006. Restoring Coastal Ecosystems: Surprises from Abrupt Climate Change. Climate Change. 74(4): 369-376

Contributor: USEPA. 2006. National Estuary Program Coastal Condition Report. EPA-842/B-06/001 www.epa.gov/owow/ocean/nepccr/index.html

Contributor: USEPA 2005. National Coastal Condition Report II. EPA-620/R-03-02. www.epa.gov/owow/ocean/nccr

Keith, D.J., H.A. Walker, and J.F. Paul. 2002. Terrestrial vegetation greenness of the Lower Galveston Bay watershed from satellite remote sensing and its relation to water use and the salinity regime of the Galveston Bay estuary (USA). International Journal of Remote Sensing. 23(5): 905-916.

Walker H.A, B. Keim B, and M.B. Arndt. 2001. Chapter 3: Natural and anthropogenic factors affecting global and regional climate. In Preparing for a Changing Climate: The New England Regional Assessment Foundations Report. B. Rock (ed.),108 pp

Walker H.A. 2001. Understanding and managing the risks to health and environment from global atmospheric change: a synthesis. Human and Ecological Risk Assessment 7(5): 1195-1209.

Walker, H.A., J.S. Latimer, and E. H. Dettmann. 2000. Assessing the effects of natural and anthropogenic stressors in the Potomac estuary: implications for long-term monitoring. Environmental Monitoring and Assessment, 63: 237-251. EPA Contribution

Najjar, R G., H.A.Walker, P.J. Anderson, E.J. Barron, R. Bord, J. Gibson, V.S. Kennedy, C.G. Knight, P. Megonigal, R. O’Connor, C.D. Polsky, N.P. Psulty, B. Richards, L.G. Sorenson, E. Steele and R.S. Swanson. 2000. The potential impacts of climate change on the Mid-Atlantic coastal region. Climate Research. CR Special 7 14(3): 219-233. EPA Contribution

Brian H Hill - Theme-Based Research on Streams and Rivers

U.S. Environmental Protection Agency National Health and Environmental Effects Laboratory Mid-Continent Ecology Division 6201 Congdon Blvd. Duluth, MN 55804-2595 Phone: 218.529.5224 FAX: 218.529.5003 E-mail: hill.brian@epa.gov

EDUCATION B.A. in Botany, University of Montana, Missoula, MT (June 1974) M.A. in Biology, Mankato State University, Mankato, MN (August 1977) Ph.D. in Botany, Virginia Polytechnic Institute & State University, Blacksburg, VA (June 1981)

PROFESSIONAL EXPERIENCE Supervisory Research Ecologist (GS-0408-15), Watershed Research Branch, National Health and Environmental Effects Laboratory, Mid-Continent Ecology Division, U.S. Environmental Protection Agency, Duluth, MN (May 2003-present).

SELECTED PEER-REVIEWED PUBLICATIONS

Stevenson, RJ, BH Hill, AT Herlihy, L Yuan & S Norton. 2008. Algal-phosphorus relationships, thresholds, and frequency distributions guide nutrient criteria development. Journal of the North American Benthological Society27:783-799.

Hill BH, CM Elonen, TM Jicha, AM Cotter, AS Trebitz & NP Danz. 2006. Sediment microbial enzyme activity as an indicator of nutrient limitation in Great Lakes coastal wetlands. Freshwater Biology 51:1670-1683.

Hill, BH, AT Herlihy, PR Kaufmann, MA Vander Borgh & SJ DeCelles. 2003. Assessment of streams of the eastern United States using a periphyton index of biotic integrity. Ecological Indicators 2:325-338.

Hill, BH, AT Herlihy & PR Kaufmann. 2002. Benthic microbial respiration in Appalachian Mountain, Piedmont, and Coastal Plains streams of the eastern U. S. A. Freshwater Biology 47:185-194.

Hill, BH RK Hall, P Husby, AT Herlihy & M Dunne. 2000. Interregional comparisons of sediment microbial respiration in streams. Freshwater Biology 44:213-222.

Hill, BH, RJ Stevenson, AT Herlihy PR Kaufmann & FH McCormick. 2000. The use of periphyton assemblage data as an index of biotic integrity. Journal of the North American Benthological Society 19:50-67.

Hill, BH, AT Herlihy, PR Kaufmann & RL Sinsabaugh. 1998. Sediment microbial respiration in a synoptic survey of Mid-Atlantic streams. Freshwater Biology 39:493-501.

Hill, BH, JM Lazorchak, FH McCormick & WT Willingham. 1997. The effects of elevated metals on benthic community metabolism in a Rocky Mountain stream. Environmental Pollution 96: 183-190.

Hill, BH & WT Perrotte. 1995. Microbial colonization, respiration, and breakdown of maple leaves along a stream-marsh continuum. Hydrobiologia 312:11-16.

Hill, BH, TJ Gardner & OF Ekisola. 1992. Benthic organic matter dynamics in Texas prairie streams. Hydrobiologia 242:1-5.

Hill, BH, TJ Gardner, OF Ekisola & GM Henebry. 1992. Microbial use of leaf litter in prairie streams. Journal of the North American Benthological Society 11:11-19.

W. Bryan Milstead, Team Member, Theme-Based Research and Northeastern Lakes

Post-Doctoral Ecologist U.S. Environmental Protection Agency National Health and Environmental Effects Research Laboratory 27 Tarzwell Drive, Narragansett, R.I. 02882 USA bryan.milstead@epa.gov; (401) 782-3015

SCIENTIFIC EXPERTISE

Population, community, and human ecology, Monitoring, Ecosystem services, Data Analysis, GIS, field biology

EDUCATION

Ph.D. May 2000, Northern Illinois University, Biology. Chair: Peter Meserve. Title: The demographic and genetic structure of arid-land small mammal populations in north-central Chile: rainfall, refuges and ratadas.

M.S. July 1983, University of Oklahoma, Biology. Chair: Dr. Stephen Threlkeld. Title: An experimental analysis of the effects of darter predation on a population of Hyalella azteca.

PROFESSIONAL EXPERIENCE

2008-present Post-Doctoral Ecologist, US Environmental Protection Agency, Narragansett RI USA.

2007-2008 Interim Director of Science, Charles Darwin Research Station, Puerto Ayora, Galápagos, Ecuador.

2006-2008 Head of the Vertebrate Department, Charles Darwin Research Station, Puerto Ayora, Galápagos, Ecuador.

2002-2006 Inventory and Monitoring Coordinator, Northeast Coastal and Barrier Network, National Park Service. Kingston RI USA.

2001-2002 Ecological Monitoring Program Coordinator, Organ Pipe Cactus National Monument, National Park Service, Ajo AZ USA.

2000-2001 Post-Doctoral Research Associate, Northern Illinois University, DeKalb IL USA.

1995-2000 Graduate Research Associate, Northern Illinois University, DeKalb IL USA.

1991-1995 Research Coordinator for an NSF project, La Universidad de La Serena, Departamento de Biología, La Serena, Chile.

RELEVANT PUBLICATIONS

Milstead, W.B., P.L. Meserve, A. Campanella, M. A. Previtali, D. A. Kelt, and J. R. Gutiérrez. 2007. Spatial ecology of small mammals in north-central Chile: role of precipitation and refuges. Journal of Mammalogy 88(6):1532-1538.

Wang, Y., M. Traber, B. Milstead, and S. Stevens. 2007. Terrestrial and submerged aquatic vegetation mapping in Fire Island National Seashore using high spatial resolution remote sensing data. Marine Geodesy 30: 77–95.

Ken M. Fritz - N lead for Future Midwest Landscapes

USEPA, National Exposure Research Laboratory Ecological Exposure Research Division, Ecosystem Research Branch

26 W. Martin Luther King Avenue Mailstop 642 Cincinnati, OH 45268

513-569-7092 (voice) 513-569-7609 (fax) fritz.ken@epa.gov

EDUCATION

Ph.D. 2003, Auburn University, Auburn, Biological Sciences.

M.S. 1997, Kansas State University, Manhattan, Biological Sciences.

B.S. 1993, Southern Illinois University, Carbondale, Zoology.

PROFESSIONAL EXPERIENCE

2003-present USEPA/ORD/NERL/EERD, Cincinnati, OH, Research Ecologist, (GS 13)

2002-2003 USEPA/ORD/NERL/EERD, Cincinnati, OH, post-doctoral fellow

RECENT AWARDS AND HONORS

2006 ORD Non-Supervisory Award for Advancing Environmental Protection

2006 NERL Special Achievement Teamwork Award

2008 Federal Service Excellence Award Nominee for Project Team Award

RECENT PUBLICATIONS

Fritz, K. M., M. G. Gangloff, J. W. Feminella. 2004. Stream habitat modification by the riverine macrophyte, *Justicia americana* (L.) Vahl. Oecologia 140(3):388-397.

Dodds, W. K., K. Gido, M. R. Whiles, K. M. Fritz, W. J. Matthews. 2004. Life on the edge: ecology of Great Plains prairie streams. BioScience 54(3):205-216.

Fritz, K. M., M. A. Evans, and J. W. Feminella. 2004. Factors affecting biomass and biomass allocation in the riverine macrophyte, *Justicia americana* (L.) Vahl. Aquatic Botany 78(3):279-288.

Fritz, K. M. and W. K. Dodds. 2005. Harshness: characterisation of intermittent stream habitat over space and time. Marine and Freshwater Research 56(1):13-23.

Fritz, K. M. and J. W. Feminella. 2006. Differential response of stream periphyton and invertebrate grazers to habitat modification by the emergent macrophyte *Justicia americana*. Marine and Freshwater Research 57(2):207-214.

Fritz, K. M., C. Colson, J. W. Feminella, B. G. Lockaby, and B. Rummer. 2006. Biomass and decay rates of riparian roots and detritus within sediments of 3 intermittent Coastal Plain streams. Hydrobiologia 556(1):265-277.

Fritz, K. M., B. R. Johnson, and D. M. Walters. 2006. Field operations manual for assessing the hydrologic permanence and ecological condition of headwater streams. EPA/600/R-06/126. U.S. Environmental Protection Agency, Washington, D.C.

Richard Devereux - N lead for the Tampa Bay Place-Based Study

Research Microbiologist U. S. Environmental Protection Agency National Health and Environmental Effects Research Laboratory Gulf Ecology Division 1 Sabine Island Dr. devereux.richard@epa.gov Gulf Breeze, FL. 32561-3999 Phone: (850) 934-9346 Lab: 934-9219 Fax: 934-2401

EDUCATION

University of St. Thomas, Houston TX, B.A. 1978

Biology University of Houston, M.S. 1981, Ph. D. 1986

Biology Postdoctoral Research Associate, 1986 – 1990; University of Illinois at Champaign-Urbana

RELEVANT PUBLICATIONS

Kurtz, J.C., D.F. Yates, J.M. Macauley, R.L. Quarles, F.J. Genthner, C.A. Chancy, and R. Devereux. 2003. Effects of light reduction on growth of the submerged macrophyte Vallisneria americana and the community of root-associated heterotrophic bacteria. J. Exp. Mar. Biol. Ecol. 291: 199-218. (EPA Level III STAA Award).

Smith, A.C., J.E. Kostka, R. Devereux and D.F. Yates. 2004. Seasonal composition and activity of sulfate-reducing prokaryotic communities in seagrass bed sediments. Aquat. Microb. Ecol. 37: 183-195.

Devereux, R. 2005. Seagrass rhizosphere microbial communities. In: Interactions Between Macro- and Microorganisms in Marine Sediments. Coastal and Estuarine Studies Series, vol. 60. E.K. Kristensen, R.R. Haese and J.E. Kostka (eds.). pp. 199-216. American Geophysical Union, Washington, D.C.

James, J.B., T.D. Sherman and R. Devereux. 2006. Analysis of bacterial communities in seagrass bed sediments by double-gradient denaturing gradient gel electrophoresis of 16S rRNA genes. Microb. Ecol. 52: 655-661.

Küsel, K., T. Trinkwater, H.L. Drake, and R. Devereux. 2006. Comparative evaluation of anaerobic bacterial communities associated with roots of submerged macrophytes growing in marine or brackish water sediments. J. Exp. Mar. Biol. Ecol. 337: 49-58.

Hines, M.E., P.T. Visscher, and R. Devereux. 2007. Sulfur Cycling. In: Manual of Environmental Microbiology (3rd ed.). C.J Hurst, R.L. Crawford, J.L Garland, D.A. Lipson, A.L. Mills and L.D. Stetzenbach (eds.). pp. 497-510. ASM Press, Washington, D.C.

Stephen J. Jordan - N Lead for the Wetland Ecosystem Specific Studies

Research Ecologist USEPA-ORD-NHEERL-Gulf Ecology Division (850)-934-9350
jordan.steve@epa.gov

EDUCATION

Ph.D., University of Maryland, College Park; MS, Morehead State University; BA, American University

PROFFESSIONAL EXPERIENCE

Special Assistant to the Director, Gulf Ecology Division, 2007-2008 Chief, Ecosystem Assessment Branch, EPA/ORD/NHEERL Gulf Ecology Division , 2002-2007 Director, Sarbanes Cooperative Oxford Laboratory, Maryland Dept. of Natural Resources, 1992-2002 Lecturer, Johns Hopkins University School of Arts and Sciences, 1994-2001. Chief, Habitat Impacts Program, Maryland Department of Natural Resources, 1985-1992 Research Associate, University of Maryland Eastern Shore, 1984-1985 Sea Grant Fellow, University of Maryland, Horn Point Laboratory, 1982-1984

RESEARCH INTERESTS AND SKILLS

Estuarine ecology, fisheries, statistics, modeling

SELECTED APPOINTMENTS/HONORS/MAJOR AWARDS

Citations from Governor of Maryland, U. S. Senate Citation (Senator Paul Sarbanes), Chesapeake Bay Program, Sigma Xi, NHEERL Awards for Teamwork and Future Issues.

SELECTED PUBLICATIONS

Jordan, S. J., S. E. Hayes, J. K. Summers, L. M. Smith, and W. H. Benson. Accounting for natural resources and environmental sustainability: linking ecosystem services to human well-being. Submitted to Environmental Science and Technology, 2008.

Jordan, S. J., L. M. Smith, and J. A. Nestlerode. Cumulative effects of coastal habitat alterations on fishery resources: toward prediction at regional scales. In revision for Ecology and Society, 2008.

Jordan, S. J., M. L. Lewis, L. Harwell, and L. Goodman. Fish communities in northern Gulf of Mexico estuaries: indices of ecological condition. Submitted to Transactions of the American Fisheries Society, 2008.

Lewis, M., S. Jordan, C. Chancy, L. Harwell, L. Goodman, R. Quarles. Summer fish community of the coastal northern Gulf of Mexico: characterization of a large-scale trawl survey. Transactions of the American Fisheries Society. (2007).

Kurtz, J.C., N.D. Detenbeck, V.D. Engle, K. Ho, L.M. Smith, S.J. Jordan and D. Campbell. Classifying Coastal Waters: Current Necessity and Historical Perspective. Estuaries and Coasts 29:107-123. (2006).

Jordan, S. J. and L. M. Smith. Indicators of ecosystem integrity for estuaries. In: S. Bortone (Ed.).Estuarine Indicators. CRC Press. (2005).

7.2 Appendix 2. Place-Based Studies as a testing ground for Ecosystem Service assessment.

This section outlines the 4 place-based studies which will serve as testing grounds for specific ideas in ESRP-N. Currently, there are 4 place-based studies (Upper Midwest, Tampa Bay, Willamette River Basin and Coastal Carolinas); another study site is currently emerging in the southwestern US. From these place-based studies, several needs of ESRP-N will be met:

- development of place-specific Ecosystem Response Functions (ERFs) and Ecosystem Service response functions (ESRFs) (see figure 4 above),
- testing of utility of national data for accuracy in place-based examinations (for example, which national N data, (fertilizer loads, land use) do not have the resolution necessary for more local/place-based ecosystem service assessments), and
- producing feedback from local stakeholders on utility of the ecosystem service quantification approach, particularly in regards to nitrogen impacts on air and water quality.

7.2.1 Place-Based Study 1. Future Midwestern Landscapes (FML)

Project Leads: Randy Bruins and Betsy Smith

FML study N Lead: Ken Fritz

Nutrient enrichment can improve or reduce the benefits derived from ecosystems. Application of commercial fertilizer to agricultural fields results in higher crop yields and improved human nutrition (e.g., essential amino acids). However, nutrient loading to adjacent water bodies increases primary production and organic carbon (i.e., eutrophication) that can then lead to steep diurnal swings in dissolved oxygen and impact aquatic life. Nitrogen is one of the important nutrients (along with phosphorus) that can limit primary productivity of all ecosystems. The widespread increase of nitrogen across the landscape through fertilizer application, biomass burning, and fossil fuel combustion has led to a dramatic rise of nitrogen loading to water bodies and has detrimental consequences to water quality (Goolsby et al. 2001, McIssac et al. 2001, Galloway and Cowling 2002,) and human health (Wolfe and Patz 2002, Townsend et al. 2003). The Ecosystem Services Research Program (ESRP) has chosen nitrogen as the primary pollutant of concern because of the profound environmental and socioeconomic implications for increasing or reducing nitrogen loading to ecosystems. ESRP is specifically focusing on reactive nitrogen (Nr) the biologically, chemically, and radiatively active forms of nitrogen compounds in the atmosphere and biosphere (e.g., ammonium, nitrous oxide, nitrate).

Among the ESRP place-based studies (see Future Midwestern Landscapes Study Implementation Plan), the Midwest (along with the Chesapeake) is one of the most studied regions in the United States regarding the exposure and environmental impacts of Nr (e.g., NOAA-led Hypoxia Working Group that produced a six volume evaluation of Mississippi River basin and the Gulf of Mexico, http://www.cop.noaa.gov/pubs/das/welcome.html; USGS National Water-Quality Assessment Program SPARROW, Alexander et al. 2000, Alexander et al. 2007). This benefits the FML study by having different models and independent analysis to which FML modeling efforts can be compared. One major difference among past studies investigating spatially explicit nitrogen loading in the Midwest and FML is the comparison across scenarios.

The scenarios chosen for the FML include base year (2001), biofuel target (2022), and multiple services (2022) landscapes. The specific year chosen for the base year (2001) is the most recent year available for the National Land Cover Dataset (NLCD). The biofuel target represents an alternative future landscape scenario driven by current energy policy and trajectories of other driving forces (e.g., population growth). The multiple services scenario represents a landscape where the services and benefits provided by ecosystems are considered in policy making and incentives, and therefore are reflected in land use decisions.

FML Questions

1. What are the sources and fluxes of Nr to the Midwest (IA, IL, IN, KS, MI, MN, MO, NE, ND, OH, SD & WI) across three modeled scenarios (base year landscape, biofuel targets landscape, and multiple services landscape)? **R1, R10**
2. What are the expected Nr loads to streams (by 8 digit HUC) across the three modeled scenarios? **R1, R10**
3. What are the relationships between Nr and ecosystem services? **R2, R3**
4. To what degree will ecosystem services differ between the future scenarios, and to what extent can those differences be correlated or attributed to differences in Nr? **R4, R7**

FML Approach

To address these questions we plan to integrate landscape, economic, air, and water quality modeling. Here we outline the general approach we are planning to use to derive Nr information.

We plan to use CMAQ (Climate Multiscale Air Quality) to characterize atmospheric deposition of nitrogen. This model will be linked to land cover (NLCD), cropland data (USDA NASS), crop management data (Purdue's CTIC) and Market Allocation (MARKAL) models to characterize emissions and deposition for the baseline and future scenarios. The deposition data along with data associated with NPDES permits (point source Nr) are to be linked to the Soil and Water Assessment Tool (SWAT) to then characterize Nr sources and fluxes. Spatially explicit fertilizer application information from farmer surveys is not releasable (in order to protect land owners) so we will likely have to rely on SWAT's built-in autofertilizer routine. The autofertilizer routine optimizes fertilizer application over the plant life cycle, providing nitrogen only as needed by the specific crop. This approach may underestimate applications if fertilizer typically is applied only once or twice annually, either at prescribed rates or "insurance application" rates. On the other hand, the assumption that prescribed rates are used may overestimate application where rates are adjusted to actual growing conditions (e.g., drought). (It is still unclear yet how expected changes in crop rotation will figure into the SWAT runs.)

Given the predominance of tilled agriculture in the study area and the limited spatial resolution of data available on fertilizer application, it is likely that many of the differences in Nr sources and fluxes between the base year and biofuel targets scenarios will reflect expected spatial changes associated with crop acreage (shifts to corn only and CRP to tilled agriculture). However, the multiple services scenario will be assumed to encourage a variety of improved land management practices, potentially including riparian buffers, conservation tillage, and more land set aside for conservation. Differences between either the base year or biofuel targets scenario and the multiple services scenario may therefore reflect a wider range of ecosystem processes, but our ability to examine these will be limited to (a) our ability to model the adoption of these practices and (b) the ability of SWAT to represent best management practices in its routines.

Relationships between various indicators of services or human benefits with Nr input and output parameters from the base year SWAT analyses could be assessed. Each independent HUC or aggregation of HUCs could be used as replicates and matched with services data gathered from various data sources. Examples of human health indicators include the prevalence of asthma, methemoglobinemia ("blue-baby" syndrome), and non-Hodgkin's lymphoma (see figure below from Townsend et al. 2003). Air quality indicators could include pollen counts, whereas indicators of recreation could include game fish production and number of canoe/kayak liveries. Finally, these relationships developed from the base year scenario could then be used to predict indicator values for the future scenarios given their associated levels of Nr from the SWAT analyses for the biofuel target and multiple services scenarios.

FML Expected outcomes

- Scoping analysis journal manuscript (September 2009): describe a conceptual framework for identifying the causal pathways between drivers, impacts, functions, and ecosystem services using a concept mapping tool, Cmap. **R2, R3**
- Base Year & Biofuel Target Scenario landscape report (September 2010): maps describing the base year and biofuels target landscapes will be created.
- Environmental Decision Toolkit for the Base Year (September 2010): a web-based statistical application that uses spatial data and model outputs for the base year landscape. Users will be able to visualize and evaluate baseline conditions (from existing data and model results); this includes tools for exploring and comparing status (including services) across various spatial scales and identifying vulnerabilities to changing stressors. **R1, R2, R3, R10**
- Multiple Services Scenario landscape report (December 2010): map describing the multiple services landscape will be created.
- Base Year Ecosystem Services Analysis report (September 2011): report will be prepared that includes Nr sources, fluxes, and relationships with ecosystem services for the base year landscape. **R1, R2, R3, R10**
- Ecosystem Services Analysis reports for the Biofuel Target and Multiple Services Scenarios (December 2011): report will be prepared that includes Nr sources, fluxes, and predicted ecosystem services for the alternative scenarios. **R1, R2, R3, R10**
- Environmental Decision Toolkit for the Biofuel Target and Multiple Services Scenarios (September 2012): a web-based statistical application that uses spatial data and model outputs for the biofuel target and multiple services landscapes. Users will be able to visualize and evaluate alternative future conditions (from model results); this includes tools for exploring and comparing status (including services) across various spatial scales and identifying vulnerabilities to changing stressors. **R1, R2, R3, R4, R7, R10**
- Environmental Decision Toolkit (Final version, September 2013): a web-based statistical application that uses spatial data and model outputs for all three landscapes. Users will be able to visualize and evaluate future conditions (from model results); this includes maps

and other tools that compare produced services (user-weighted in terms of quantity and quality) that highlight conservation opportunities, therefore facilitating trading (e.g., wetlands, nitrogen). **R1, R2, R3, R4, R7, R10**

7.2.2 Place-Based Study 2. Tampa Bay

Project Lead: Marc Russell

Tampa Bay N Lead: Richard Devereux

The Community Based Demonstration Projects Tampa Bay Implementation Plan is unique in the ESRP projects for its focus on connectivity at the local to regional scale, through hydrologic, atmospheric, and human transportation networks, between those ecosystems that produce valued ecological services and the consumption of those services by humans. Decision support tools were used to prioritize Tampa Bay research in concert with local and regional stakeholders and partners so that our endpoints will contribute to the decision making processes that are already established in areas such as the Tampa Bay Region.

Urban land use in the Tampa Bay area is expected to double between 1992 and 2025 (Xian et al., 2005). This presents the regional authorities with a challenge to balance urban growth with valuable ecosystem services that provide for human well-being. Rapid urban growth represents the main driver of stressors on ecosystem services for the Tampa place-based study wherein the effects of increased nitrogen loading will be given prominent attention. Land coverage in the Tampa Bay region includes built up urban areas, agricultural lands, range land, upland forests, and wetlands. Tampa Bay supports a large commercial shipping industry, commercial and recreational fishing as well as other recreational activities. The Tampa Bay estuary has recently seen some recovery of water quality and seagrass coverage resulting from improvements in waste water treatment. These gains could be lost if nitrogen removal processes in the Tampa Bay region fall off while nitrogen loadings increase.

Research questions:

1. What are the dominant sources of anthropogenic nitrogen in Tampa? R1-R3
2. What service(s) are most compromised by sources of anthropogenic nitrogen in the Tampa Bay region? R4-R7
3. What is the spatial distribution and response of ecosystem services associated with anthropogenic nitrogen use? R5-R7
4. What are the management opportunities associated with Nr research products, and how will policy and individual behavior interact to produce desired outcomes? R8-R10

Tampa Approach.

The focus of Nitrogen-related research in the Tampa place-based study will be to investigate how urban growth will affect ecosystem services in the region. We will develop models that quantify nitrogen loading, transport, and transformations for prominent land use types in the Tampa Bay region. These models will be used, under varying scenarios of predicted nitrogen loading and land use change, to look at how the rapid expansion in population will affect ecosystem services. The models will provide useful tools and insights for regional planning authorities.

Research related to nitrogen is contained within subgroups representing land coverage; agricultural, open waters, urban areas, upland forests, and wetlands. Population growth will greatly increase nitrogen loading in the region with significant contributions from waste water treatment, atmospheric deposition, and fertilizers. The Tampa place-based study is using Cmap Tools (available through the Institute of Human and Machine Cognition, Pensacola, Fl; http://cmap.ihmc.us/download/) to visualize conceptualization of stressors on ecosystem services.

Non-point sources account for the major nitrogen loads in the Tampa Bay watershed and will present a particular challenge to managing nitrogen effects in Tampa. Atmospheric deposition is considered the dominant source of nitrogen loading (46%) to the southeast U.S. including the Tampa Bay watershed according to a recent SPARROW modeling paper (Hoos and McMahon, 2009). Atmospheric nitrogen contributions are likely to increase with the increased emissions of combustion exhausts often associated with expanding transportation needs resulting from the spread of urbanization. Urbanization will also result in the formation of large tracts of impermeable surfaces, which will decrease landscape available for nitrogen attenuation, and lead to increased delivery of nitrogen to stream channels.

The following services are most compromised by sources of anthropogenic nitrogen in the Tampa Bay region: Nitrogen removal (Intermediate service), Food production (Final service) and Aesthetics (Final service).

Research activities

Research to identify dominant sources of N:

- Nitrogen emission quantification from transportation and road side buffer attenuation
- Source identification through stable isotope signatures
- Application of existing Tampa Bay nitrogen deposition model
- Development of county-scale net anthropogenic nitrogen and phosphorus input (NANI/NAPI) budgeting system which incorporates both inorganic and organic fertilizers associated with row crop and livestock production

Research to determine which services are most impacted by changing N supply:

- Measure mangrove and riparian forest denitrification potential along development gradients, assess their associated value, and social perceptions of riparian and mangrove ecosystems on private land.
- Measure wetland denitrification rates under different nitrogen loading levels and hydrologic regimes and relate productivity response to wildlife endpoints (birding).
- Quantify nitrogen exports from wetlands and resulting water clarity responses effect on sea grass support for recreational fisheries.
- Identify nutrient source areas through spatial apportioning of county level agricultural budgets to the landscape – NAPI/NANI maps

Research on spatial distribution and response of ecosystem services to changing N supply:

- Map functional rates (eg. quantity of nitrogen removed per acre per year) in various land cover types (Agricultural, forested, wetland, urban, and open water)

- Determine the relationships between where ecosystem services are produced and where they are used or consumed (eg. ease of access to recreation areas, distance from farm to market).
- Conduct survey of human perceptions about riparian and mangrove systems on private land.

Research on management opportunities associated with Nr research products:

- Construct dynamic models for predicting the production and delivery of ecosystem services under various alternative future scenarios.
- Estimate monetary and non-monetary values of ecosystem services.
- Develop visualization tool and reporting system to dynamically bundle services in a user defined area for consideration in land use/policy decisions.

Tampa Projected Outcomes

1. Multiple scale map layers quantifying ecosystem function and process rates in the Tampa Bay watershed and associated open water systems. **R1** 2009-2010
2. A suite of predictive ecosystem response functions for assessing the effect on receiving habitats to anthropogenic nitrogen loadings. **R2** *2011-2012*
3. Connectivity maps showing production, delivery, and consumption of ecosystem services. **R3** 2011-2012
4. Linked nutrient loading models derived from human activities with wetland removal capacity and seagrass responses using hydrologic modeling and system dynamics models. **R2, R3, R4, R10** *2011-2012*
5. Map layers quantifying road side buffer vegetation atmospheric regulation services production and their relationship to nitrogen emission from transportation sources. **R5** 2013
6. Web based dynamic visualization tool quantifying the spatial and temporal production, delivery, and consumption of ecosystem services at regional scales. **R6, R7** 2013
7. Predictive valuation models under scenarios of increasing nutrient loads and urbanization. **R8** *2012-2013*
8. Social survey of human perception of riparian and mangrove buffers and “willingness to pay” to implement policy decisions on private land. **R9** 2012

7.2.3 Place-Based Study 3. Willamette Ecosystem Services Project

Project Lead: D. Hammer

The Willamette Ecosystem Services Project (WESP) builds upon previous research examining alternative landscape scenarios on land use and human activities in the Willamette River Basin. The WESP project will focus on four key ecosystem services: 1) greenhouse gas regulation; 2) air quality regulation; 3) water quality regulation, and 4) habitat/biodiversity. For each service, the WESP project will use a risk assessment approach to identify the problem, analyze the available exposure and effects data, and characterize the risk. The risk characterization will provide the basis for the modeling, mapping and empirical research to be conducted in the project. Both current and future stresses, as well as relevant policy drivers, will be identified and used to formulate alternative scenarios of future change. One overarching element of the project is client and stakeholder involvement, which will help guide the research through all phases of the project.

7.2.4 Place-Based Study 4. Coastal Carolinas

Project Lead: Deb Mangis

The coastal Carolinas place-based research area includes the linear coastal counties of North and South Carolina, including the Albemarle-Pamlico Estuary watershed. The Pamlico Sound estuarine system is the second largest estuary in the eastern United States (ca. 80,000 km^2 drainage area) and generates >$3 billion dollars annually in fisheries and tourism alone. The coastal Carolinas contain extensive natural landscapes that are facing unprecedented pressures from population growth, landscape alteration, and climate change. Unlike the other place-based studies, the Coastal Carolinas implementation plan is not due until 2009, and thus the proposed work is more general here.

Reactive nitrogen is a key stressor in the Carolinas that results from atmospheric deposition, sewage discharge, fertilizer application, and high densities of concentrated animal feedlot operations (CAFOs). Loading of Nr to coastal ecosystems is expected to increase in the future as human population density increases and more land in the coastal plains is shifted to production of corn suitable for use in biofuel production. Though Nr is an important nutrient that can limit primary production, when present in excess it can lead to harmful algal blooms and reduced dissolved oxygen concentrations. Such declines in water quality degrade aquatic ecosystems and the services they provide, including health and integrity of coastal fisheries.

Highlights of the coastal Carolinas place-based research effort include:

- Focus on three major drivers of change to ecosystem services: 1) Sea level rise associated with climate change; 2) demographic shifts associated with increasing human populations along the coast; and 3) changing land use in the coastal plains associated with increased agricultural production for biofuels.
- Wetlands have been selected as a key ecosystem of focus given their abundance/diversity in the area and the multitude of services they provide to the Carolina coasts. Nearly 90% of commercial fishes harvested in North Carolina are dependent upon wetlands as nursery habitat. Loss of coastal wetlands could therefore dramatically affect the coastal fishery as well as rates of Nr storage and processing.
- Commercial and recreational fisheries will serve as a key ecosystem service given their tight linkages with many other services, functions, and ecosystem types. Fisheries are also easily valued monetarily and readily appreciated by the general public.

Coastal Carolinas General Approach and Expected Outcomes Alternative, though yet to be defined future scenarios will be developed based on the drivers highlighted above. Initial efforts will include use of CMAP as a conceptual tool for visualization of relationships among stressors, functions, and services. Mapping and modeling efforts that make use of existing data will then be undertaken to address Nr-related research questions. For example, the Climate Multiscale Air Quality (CMAQ) will be used to characterize atmospheric Nr deposition. Ground and surface water Nr fluxes and loadings will then be estimated by use of existing watershed models (e.g., SPARROW, WASP) and special emphasis will be placed on the Neuse and Cape Fear watersheds. The results of this research for alternative scenarios will ultimately provide tools for resource managers and local zoning commissions to maximize ecosystem services for the future.

7.2.5 Place-Based Study 5. Southwest Ecosystem Services Program

Project Lead: Nita Tallent-Halsell

EPA's Ecosystem Services Research Program (ESRP) in the Office of Research and Development (ORD) is studying ecosystem services and the benefits to human well-being provided by ecological services. As part of this research effort, the Southwest Ecosystem Services Research Program (SwESP) will identify and characterize the ecosystem services in the southwestern United States. These include services that supply water, protect water quality, protect against floods, support wildlife habitats, sequester carbon dioxide, a greenhouse gas, and provide food and fiber. The southwestern landscape is highly diverse with significant portions of forest, rangeland, agriculture and deserts (i.e., Great Basin, Mohave Chihuahuan and Sonoran). This region has experienced a 1,500% population increase over the past 90 years, which has placed pressure on the ecosystem services described above. The sustainability of these basic services is important to human health and well being, but these services are limited and heavily impacted by humans. Research to protect, enhance and restore the many vital services provided by ecosystems is needed to support future growth and a sustainable environment. The study will have two over-lapping foci: 1) the ecosystem services of the various landscapes that comprise the southwestern States, California, Nevada and Arizona and 2) the ecosystem services of specific study areas representative of the dominant land use types of the Southwest (e.g., San Pedro Watershed, AZ; San Luis Valley, NM).

The goals of the Program are to collaborate with local, state, and federal governments, Tribes and other partners to accomplish the following:

- Identify the dominant stressors that impact the southwestern United States.
- Identify critical knowledge gaps in the ecological processes underlying ecosystem services.
- Produce maps of ecosystem services in the Southwest based on current condition and available data
- Quantify linkages and trade-offs among bundles of ecosystem services in response to land use, climate and other variables
- Quantify the monetary and non-monetary value resulting in changes in ecosystem services due to an increase in human population and/climate change.
- Model the future responses of ecosystem services to probable future conditions
- Develop decision support tools to help decision makers in the Southwest apply the information and methods developed by this program.

Using these products, decision makers can implement proactive policy and management decisions. These decisions will help ensure human well-being by conserving and enhancing ecosystem services.

7.3 Appendix 3. Description of case studies developed by OAQPS

The reports associated with each of these case studies outlined below are available in the second draft Risk and Exposure Assessment for the NOxSOx Secondary NAAQS review (EPA 2009). ESRP-N will use the information provided in the case studies to quantify and assess the impacts of changing Nr inputs on ecosystem services. Each case study includes ecological indicators and measures of ecological effects due to current levels of Nr deposition on ecosystem services associated with a given ecological indicator of effect. There is a research and policy need to link these services to ecological effects and examine the net impact of changes in Nr. These case studies have set the stage for an ecosystem service assessment, for example via one of the integration tools (e.g., MIMES or INVeST).

We propose to use one or more of these case studies as a testing ground for use of an integrative modeling framework to assess the impact of changes in reactive N, for example, determining the net impact of a policy decision that decreases Nr inputs on a set of relevant ecosystem services. This testing will require collaboration with social scientists, and the ESRP-N team is currently seeking an internal or external partner to work with us on this effort.

Aquatic Acidification

- Endpoints affected by acidification include:
- Decline in fish stocks – provisioning, cultural
- Decline in biodiversity – cultural

Recreational fishing was the focus of the aquatic acidification case study as the most widely affected ecosystem service. The total value of the service in the Northeast was estimated from user surveys and contingent valuation studies. The possible incremental change in the value of the benefit of improving the ANC of a subset of lakes in the Northeast, specifically the Adirondacks, was estimated using the MAGIC model and a random utility model developed by Industrial Economics and the Clean Air Markets Division of OAR.

Terrestrial Acidification

A number of impacts on the endpoints of forest health, water quality, and habitat exist, including:

- Decline in forest aesthetics – cultural
- Decline in forest productivity – provisioning
- Increase forest soil erosion and low water retention – cultural and regulating

The ecosystem services associated with the terrestrial acidification case study included timber production, food, natural habitat, and tourism. Sugar maple and red spruce abundance and growth (i.e., crown vigor, biomass and geographic extent) were quantitatively linked to acidification symptoms through forest inventory and analysis (FIA) database analyses and analysis of timber production estimates using the Forest and Agriculture Sector Optimization Model (FASOM) model.

Aquatic Nutrient Enrichment

A number of impacts on the endpoints of fish population, water quality, and habitat quality and the related ecosystem services exist, including:

- Fish kills – provisioning and cultural
- Surface scum – cultural
- Fish/water contamination – provisioning and cultural
- Decline in fish population – provisioning and cultural
- Decline in shoreline quality (erosion) cultural and regulating
- Poor water clarity and color – cultural
- Unpleasant odors - cultural

The ecosystem services associated with the aquatic enrichment case study included fisheries, recreation and tourism. Fisheries (closings, decreased species richness) were quantitatively linked to eutrophication symptoms through monitoring data, and recreation activities were related to eutrophication symptoms through user surveys and contingent valuation studies.

Terrestrial Nutrient Enrichment

A number of impacts on the endpoints of terrestrial ecosystems exist, including –

Coastal Sage Scrub

- Decline in CSS habitat, shrub abundance, species of concern – cultural and regulating
- Increase abundance of non-natives – cultural and regulating
- Increase in wildfires – cultural and regulating

Mixed Conifer Forest

- Change in habitat suitability and increased tree mortality – cultural and regulating
- Decline in mixed conifer forest aesthetics – cultural
- Increase in fire intensity, change in forest's nutrient cycling, other nutrients become limiting - regulating
- Decline in surface water quality - regulating

The ecosystem services associated with the terrestrial nutrient enrichment case study included biodiversity, threatened and endangered species and rare species (both national and state), landscape view, water quality, and fire hazard mitigation. Due to the lack of data linking enrichment to endpoints services were described using survey and contingent valuation studies. Quantification of effects on services caused by nutrient enrichment was not possible at this time.

The ecosystem services associated with the mixed conifer forest case study focused on visual and recreational aesthetics provided by the community As with Coastal Sage Scrub communities ecsosytem services were qualitatively described using surveys and contingent valuation studies.

7.4 Appendix 4. Background Information on Critical Loads

In the United States, the critical loads approach is not an officially-accepted approach to ecosystem protection. For example, language does not exist in the Clean Air Act and its subsequent amendments that specifically require the use of a critical loads approach. Nevertheless, the critical loads approach is being explored as an ecosystem assessment tool with great potential to simplify complex scientific information and effectively communicate with the policy community and the public. The critical loads approach can provide a useful lens through which to assess the results of current policies and programs and to evaluate the potential ecosystem-protection value of proposed policy options.

Recent activities within federal and state agencies, as well as the research community, in the United States indicate that critical loads may be emerging as a useful ecosystem protection and program assessment tool. In 2004, the National Research Council recommended that the U.S. Environmental Protection Agency (EPA) consider using critical loads for ecosystem protection. In 2005, the EPA included a provision in its Nitrogen Dioxide Increment Rule that individual states may propose the use of critical loads information as part of their air-quality management approach, in order to satisfy requirements under Clean Air Act provisions regarding “prevention of significant deterioration”. Between 2002 and 2006, several federal agencies convened conferences and workshops to review critical loads experience in other countries, discuss critical loads science and modeling efforts, and to explore the possible future role of a critical loads approach in air-pollution control policy in the U.S.

As a result of these developments, agencies such as the National Park Service (NPS) and U.S. Forest Service developed specific recommendations for using the critical loads approach as a tool to assist in managing federal lands. Several federal agencies are now employing critical loads approaches to protect and manage sensitive ecosystems. For example, in Rocky Mountain National Park, Colorado, the NPS has entered into a Memorandum of Understanding (MOU) with the Colorado Department of Public Health and Environment (CDPHE) and the EPA to address harmful impacts to air quality and other natural resources occurring in the Park and to reverse a trend of increasing nitrogen deposition. The MOU requires NPS to develop a resource management goal to protect Park resources and requires the CDPHE to develop an air management strategy that will help to meet Park goals. Based on research results that indicate deleterious effects on natural resources from current levels of atmospheric nitrogen deposition, NPS has established a resource-management goal linked to a critical load for wet nitrogen deposition of 1.5 kg N ha^{-1} yr^{-1} for high elevation aquatic ecosystems. The Colorado Air Quality Control Commission has also established a “Rocky Mountain National Park Initiative Sub-committee” to involve stakeholders, review the research, identify information needs, and discuss options for improving conditions in the Park. This multi-agency effort has fostered a series of critical load research projects being carried out across the US. These current research projects provide an excellent opportunity for the ESRP to work within and build onto their efforts.