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Nitrogen and Co-Pollutants

RESEARCH ROADMAP

Office of Research and Development
Research Roadmap: Nitrogen and Co-Pollutants

EPA
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Agency

EPA 601/R-15/002

Nitrogen and Co-Pollutants Research Roadmap

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT

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Executive Summary

Historically, Environmental Protection Agency (EPA), state, and local governments, and numerous stakeholders have made progress to reduce the reactive nitrogen (Nr) and co-pollutant loadings that contribute to tropospheric ozone and acid rain, and can cause the adverse impacts of aquatic ecosystem collapse (via harmful algal blooms, hypoxia, and fish kills), terrestrial biodiversity changes, and degradation of drinking source waters that result in costly water treatment. However, despite such efforts these pollutants continue to be released and discharged at concentrations that cause significant adverse impacts on human health and well-being and aquatic and terrestrial ecosystems. These impacts will likely be exacerbated in coming years by the pressures of land use change, climate change, and the resource needs of an increasing human population (Millennium Assessment, 2005).

As a part of the "One EPA" concept, EPA's research and program offices (Office of Research and Development (ORD), Office of Water (OW), Office of Air and Radiation (OAR)) and regional offices are collaborating on the design of a cross-media, integrated, multidisciplinary approach to sustainably manage Nr and co-pollutants (in particular phosphorus, but also sulfur and sediments) loadings to air, surface and ground water to reduce adverse impacts on the environment and human health. The goal of the Nitrogen and Co-pollutant Research Roadmap (henceforth "Roadmap") is to develop a common understanding of the Agency's nitrogen and co-pollutant management goals; the research program portfolios developed by the ORD National Program Directors (NPDs) in relation to the OW and OAR program offices' priority research needs; and to identify major focus areas and opportunities for integration across the Agency, research gaps, and future research directions. As such, the Roadmap is not a research program in and of itself. Rather, the results of the Roadmap's analyses will be used by program offices and ORD Research Programs to inform the design of integrated research portfolios and policy mechanisms.

This Roadmap was developed jointly by representatives from ORD (including four national research programs), OW, OAR, and the regional offices. The impetus for the Roadmap is the 2011 EPA Science Advisory Board's (SAB) Integrated Nitrogen Committee report, *Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options*. The SAB made several research and management recommendations based on their analysis, including taking an integrated approach to the management of Nr, forming an intra-Agency task force to build on the existing research and management capabilities within EPA, and working with other agencies and departments through an interagency working group to manage reactive nitrogen more effectively and efficiently.

This Roadmap is structured around a series of ordered Science Challenges that evolved from the 2011 memo from the OW Assistant Administrator to Regional Administrators (U.S. EPA, 2011, or the "Stoner Memo"), describing the steps that could be taken to reduce nutrient pollution using existing programs and authorities. The Science Challenge descriptions were expanded to include air pathways and direct effects. To make the task of research collaboration and cooperation more manageable, the goal of nitrogen and co-pollutant reduction has been broken down into six major research topics or "Science Challenges."

The Science Challenges are summarized by the following questions:

1. *Where should we be targeting to reduce nitrogen and co-pollutant loads?*
2. *What information do we need to set nitrogen and co-pollutant reduction goals for priority areas?*
3. *What's in our toolbox to manage and reduce nitrogen and co-pollutant loads and does it work?*
4. *What are some new, innovative approaches we haven't tried before?*
5. *Are we getting the reductions and ecosystem and human health benefits we expect?*
6. *How do we best maintain inter-office accountability, assess progress, and communicate results to the public?*

These Science Challenges form a pathway to achieve the overall goal. The general roles of ORD, regional offices and program offices along this pathway are shown in Figure 1.

Each of these six Science Challenges is broken down into the subset of key research activities needed to achieve a solution to that Challenge. The Science Challenges and their sub-components (research steps) translate a management goal to a science objective and general research path. The Science Challenges are composed of a **Sub-outcome** that addresses program office, regional office, state and stakeholder needs by defining management goals and objectives; a **Sub-output** that defines the relevant scientific objectives; and a **Generalized Research Path** that defines the steps required to achieve a sub-outcome (management goal) from a sub-output (science objective) (see Appendix E). The generalized research path broadly describes the essential steps needed to accomplish a sub-output related to air and water quality goals generally, and although the research priorities of the regulatory programs are embedded, it is not directly intended for a specific decision such as air quality standards or numeric nutrient criteria.

Using this Roadmap framework, current EPA-ORD, OW, and OAR research activities were mapped onto each Science Challenge, which allowed identification of key areas of existing integration, areas where further integration is needed or would be useful, and where critical gaps and opportunities exist. Key areas of integration included research in common places (Gulf of Mexico, Chesapeake Bay), common topics (ecosystem services and economic research) and common regulatory objectives (air and water quality standards).

The key research areas that have been identified are:

- Develop empirical data and models that better tie nitrogen- and co-pollutant-related water quality and terrestrial ecosystem impairments to quantitative loads, and better predict how impairments vary with changes in load, concentration, and biogeochemical conditions.
- Determine how the magnitude, frequency, and duration of nitrogen and co-pollutant loading affect expression of impairment for aquatic and terrestrial endpoints.
- Develop better tools to determine nitrogen and co-pollutant source apportionment in watersheds at a range of scales.

- Incorporate climate change (temperature, storms) into models predicting environmental impacts of future nitrogen and co-pollutant loads.
- Better integrate pollution-response models across air, land, and all water body types.
- Develop and integrate ecosystem service metrics and accountability measures for social and economic endpoints of concern that are integrated into exposure-response models for nitrogen and co-pollutants. Assess the ability to expand and adapt existing models such as BenMap versus novel model development.
- Continue efforts to introduce new technological applications to nitrogen and co-pollutant management problems, such as genomic indictors of sources and effects, satellite monitoring of conditions, and improved sensor technologies.
- Support and enhance monitoring programs that provide the information needed to assess system-level, long-term responses to policies and management.

Identifying mitigation pathways and practices that will lead to a reduction of Nr loading in the United States, as recommended by the Scientific Advisory Board (SAB), requires cross-agency co-operation between EPA, United States Department of Agriculture (USDA), United States Geological Survey (USGS), Department of the Interior (DOI) and other agencies, as well as cross-office coordination within EPA, i.e., across ORD, OW, OAR, and regional offices. This perspective is supported by the National Research Council report, *Science for Environmental Protection: The Road Ahea*d (NRC, 2012), which recommends that EPA use a systems approach to improve integration and coordination of science across agency programs and regional offices. A lack of systems-level understanding will contribute to continued degradation of the environment and increased public health risks due to Nr and co-pollutants -- with population pressures only exacerbating the problem (Nutrient Innovations Task Group 2009, SAB 2011). Significant, sustained reductions in Nr and co-pollutants must be economically efficient; socially acceptable; environmentally sound; adaptable to climate, land-use and demographic changes; and permanent. These requirements can be met only through integrated research that informs the systematic, collective, and adaptive management of air, land, and water at multiple scales.

Introduction

Background

Nitrogen (along with phosphorus) addition in agriculture has enabled the United States to significantly increase its food and fuel stock-per-acre production. Other uses, such as gardens and landscaping from home to community scales, have provided aesthetic and economic appeal to businesses and properties. It is also a waste product from water treatment, air emissions from combustion, and other sources. As with all good things, too much can result in unintended negative impacts on non-target systems. The challenge has been to manage the additions, removals, treatments, and alternatives across the contributing sources to provide the benefits without the unintended costs.

In August 2011, the EPA Science Advisory Board's Integrated Nitrogen Committee (SAB INC) released *Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options* (SAB, 2011). This report provides a comprehensive summary of the current science related to natural and anthropogenic contributions to reactive nitrogen ("Nr"; all biologically active, chemically reactive and photochemically active nitrogen compounds) sources, uses, and cycling, and related impacts on human health and the Nation's ecosystems, as well as the regulatory and non-regulatory approaches currently used to manage Nr. The SAB report clearly recognizes the impact of human activities on the N cycle, and the associated degradation of air and water quality, noting that humans in the conterminous United States introduce five times more Nr into the environment than do natural processes.

Reactive nitrogen management poses many challenges to traditional regulatory systems because: effects are across traditional media-specific regulatory boundaries, effects are not due primarily to direct toxicity but rather to changes in ecosystem structure and function, the pollutant can be converted among chemical forms with different effects, and ecological sensitivity to pollutants may vary spatially depending upon ecosystem characteristics (Compton et al., 2011). A substantial portion of the pollutants may come from non-point sources which are not explicitly regulated by EPA under the Clean Water Act (CWA). A variety of scales are addressed, including national, regional, and local ecosystems as well as multiple media (air, land, water), policies, sources, impacts, and decisions.

Significant reductions in Nr and co-pollutant loadings are necessary to meet EPA's air, water quality, and drinking water standards, criteria, and goals. To successfully achieve this end, EPA decided to develop a research roadmap using a cross-Agency team to identify research for incorporation into the ORD Research Program portfolios that inform the development of effective regulatory and voluntary policies crafted by EPA, states, and tribes for successful implementation of an integrated and sustainable Nr and co-pollutant management program. Understanding nitrogen pollution for this range of scales and moving between them will provide to these entities the science needed to construct flexible policies that can meet multiple needs.

Purpose

The vision underlying the Roadmap is that EPA will conduct nitrogen and co-pollutant research that informs the policy choices and decision-making of EPA and its partners and stakeholders as they strive to reduce pollution from nitrogen and co-pollutants in the United States. The Roadmap does not replace program office priority research needed to inform regulatory decisions, but looks for efficiencies between offices and agencies to meet multiple needs. The objectives of this effort are to develop a common understanding of the Agency research program portfolios developed by the ORD research programs, OW, OAR, and regional offices and compare them with the OW and OAR program offices' priority research needs to identify major focus areas, opportunities for integration across the Agency, research gaps, and future research directions. This Roadmap creates a path for unifying and integrating EPA nitrogen research efforts across multiple media and various temporal and spatial scales as displayed in the Nitrogen Cascade (Figure 2). ORD research programs and OW and OAR science and policy related to reactive N are operating at a variety of scales from local and state to regional and national.

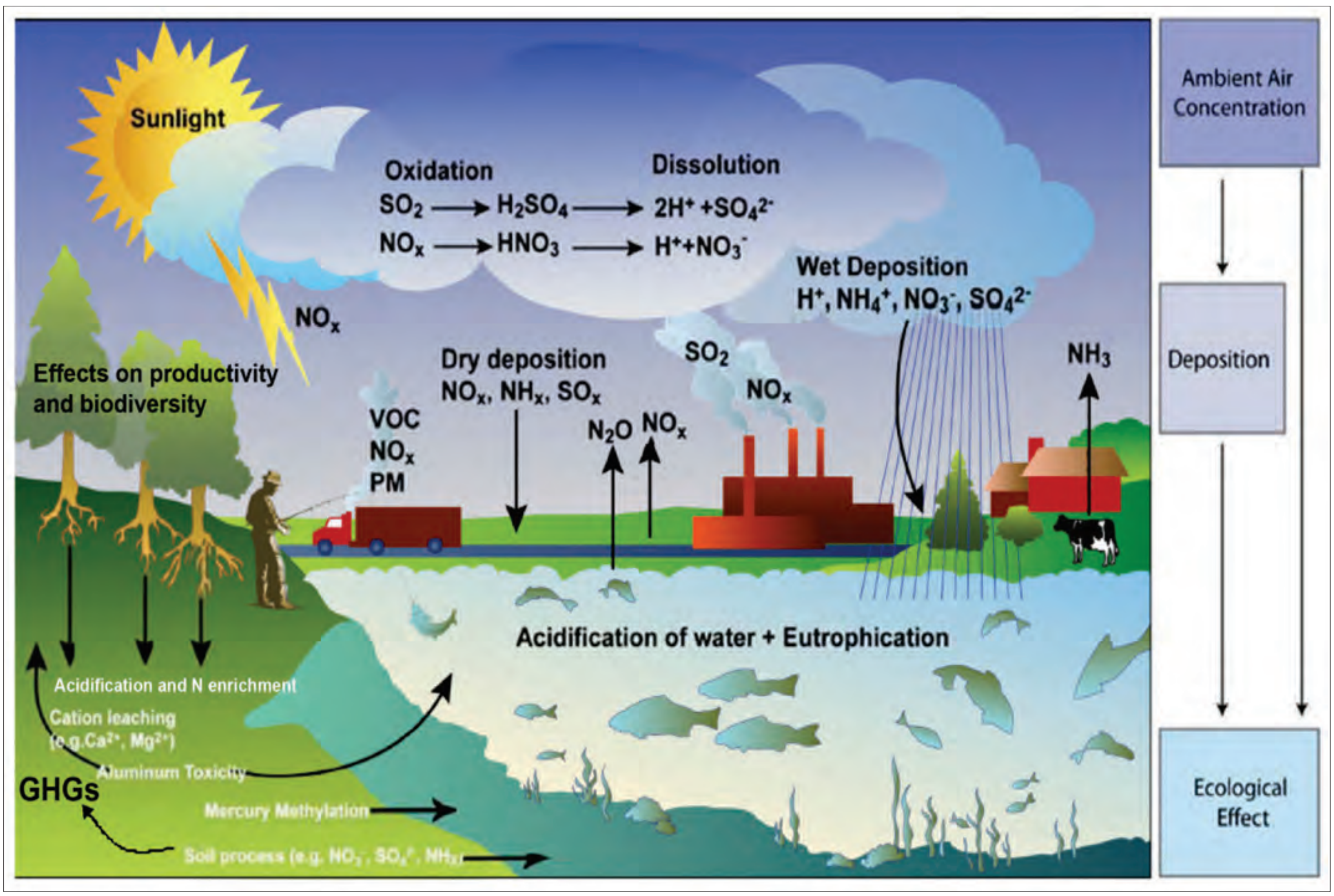

Figure 2. Simplified diagram of the ecological effects caused by nitrogen and sulfur air pollution (Greaver et al., 2013).

The Roadmap has been developed to address the SAB recommendations for integrated science and integrated management to include both atmospheric and aquatic sources and controls. For example, based on the SAB recommendations, it will be important to focus on efficient, effective, and equitable solutions to achieve reduction targets for nitrogen and co-pollutants, while recognizing that the optimal levels of control will likely vary by location and scale. In response to the SAB report, we have developed a table of ORD's current research projects that address many of the SAB recommendations fully or in part (see Appendix D).

The Roadmap consists of six Science Challenges (described below in the section "Research Scope"), developed based on program and regional office input. The relevant on-going nitrogen and co-pollutant related research in the ORD Research Programs (ACE, HHRA, SHC, and SSWR), OW, OAR, and regional offices were compiled and summarized as to how well this ongoing work addresses the steps in each Science Challenge (see Supplementary Document 1). Where possible, research addressing these areas in other Federal agencies was also included, but is recognized as incomplete as of this date and in need of expanded effort. The gap assessment aids in identifying research areas, which research programs or other areas (i.e. program offices, regions, other Federal agencies) this work is best suited for, prioritizing these areas and making recommendations for research projects to be included in the 2016-2020 ORD Strategic Research Action Plans.

The Roadmap is not a standalone research program, but is a framework for integrating research related to Nr and co-pollutants across the ORD research programs, OW, OAR and the regional offices. As such, the roadmap focuses on organizing research in a way that individual research program or program office efforts cannot so that innovative approaches and sustainable solutions which are central to addressing nitrogen can be developed. The result of organizing research in this manner is the ability of integrated research programs to complete their investigations and then prepare synthesis documents that inform decisions on endpoints, thresholds, exposure, sources, and services from a holistic and integrated perspective. Synthesis can also enable integration across disciplines to identify research gaps as well as generate scientific evidence that informs decisions.

One of the benefits of this Roadmap is highlighting where the connections are (or should be), not only across research projects and research programs, but also between people. Achieving the expected outcomes will involve improved communication and improved integration of effort across Federal agencies and within EPA. As indicated by the diversity of EPA Offices, regional offices and ORD laboratories and centers, the Roadmap effort has brought together researchers across these organizations and research programs to develop a path forward toward a common goal. The development of the Roadmap has been highly dependent on connecting people across Offices and maintaining communication across disciplines, program boundaries, and decisions. The value of making these connections and maintaining this dialogue will be a long-term benefit to the Agency.

Nitrogen & Co-Pollutant Roadmap Goal:

To protect human health and public welfare and ecosystem health through the restoration of air and water quality by integrating Agency research that supports the management of Nr and co-pollutants.

Research Scope

Expanded Problem Statement

Over the past 40 years, EPA has used its regulatory and voluntary programs within the statute-driven offices (Clean Water Act (CWA) – Office of Water (OW), Clean Air Act (CAA) – Office of Air and Radiation (OAR), Safe Drinking Water Act (SDWA) – (OW)) to address water and air nitrogen deposition/volatilization pollution problems. EPA and stakeholders have made progress to reduce the Nr and co-pollutant (e.g., P, S, C) loadings that cause the adverse impacts of tropospheric ozone, acid rain, aquatic ecosystem collapse (seen via harmful algal blooms, hypoxia, and fish kills), terrestrial biodiversity changes, degradation of drinking source waters, and costly water treatment. However, these pollutants are still released and discharged at concentrations that are having significant adverse impacts on human health and well-being, and aquatic and terrestrial ecosystems. These impacts will likely be exacerbated in coming years by the pressures of land use change, climate change, and the resource needs of an increasing human population (MA, 2005).

The EPA Science Advisory Board's Integrated Nitrogen Committee report (SAB, 2011), provides a comprehensive summary of the current science related to natural and anthropogenic contributions to Nr sources, uses, and cycling, and related impacts on human health and the nation's ecosystems, as well as the regulatory and non-regulatory approaches currently used to manage reactive nitrogen. The report clearly recognizes the impact of human activities on the N cycle, and the associated degradation of air and water quality, noting that humans introduce five times more Nr into the environment than do natural processes. The SAB made several research and management recommendations based on their analysis, including taking an integrated approach to the management of N, forming an intra-Agency task force to build on the existing research and management capabilities within EPA, and working with other agencies and departments outside EPA to manage N more effectively and efficiently. We have used these overarching recommendations as the foundation of the N Roadmap effort. In response to the SAB report, we have compiled an inventory of ORD's current research projects that address many of the SAB recommendations fully or in part (see Appendix D).

Reactive nitrogen pollution poses many challenges to traditional pollution regulatory systems because (1) effects cross traditional media-specific regulatory boundaries (e.g., Nr can cause effects regulated by the CAA, CWA, and SDWA); (2) effects are often not due primarily to direct toxicity but rather to changes in ecosystem structure and function, some of which could be seen as beneficial; (3) the pollutant can be converted from one chemical form to another, each of which has different effects; and (4) ecological sensitivity to pollutants is variable from place to place such that the same air or water quality standard may not be equally protective everywhere depending upon the ecosystem (Compton et al., 2011). A key regulatory challenge is that a substantial portion of the pollutants, both nitrogen and phosphorus, may come from non-point sources which are not explicitly regulated under CWA. While percentages vary widely among watersheds, non-point source contributions in heavily agricultural watersheds may approach 100% for both nitrogen and phosphorus (Puckett, 1994; Woodside and Hoos, 2014).

Identifying mitigation pathways and practices that could lead to a reduction of N loading in the United States, as recommended by the Scientific Advisory Board (SAB), will require cross-agency cooperation between EPA, United States Department of Agriculture (USDA), United States Geological Survey (USGS), Department of the Interior (DOI) and other agencies, as well as cross-office coordination within EPA, i.e., across Office of Research and Development (ORD), Office of Water (OW), Office of Air and Radiation (OAR), and regional offices. This perspective is supported by the National Research Council report, *Science for Environmental Protection: The Road Ahead* (NRC, 2012), which recommends EPA use a systems approach to improve integration and coordination of science across Agency programs and regional offices. While this is a challenging task, without integration of research to inform decisions across EPA and other agencies, there will be an insufficient systems-level understanding. This lack will contribute to continued degradation of the environment due to Nr and co-pollutants -- with population pressures only exacerbating the problem (Nutrient Innovations Task Group, 2009; SAB, 2011). Significant, sustainable reductions in Nr must be economically efficient; socially acceptable; environmentally sound; adaptable to climate, land-use and demographic changes; and permanent. These requirements can be met only through integrated research that informs the systematic collective, adaptive management of air, land, and water.

Solving the Nr problem must be based on the foundation of existing regulations, voluntary approaches, research, and management programs coupled with effective interagency coordination.

Science Challenges

The Roadmap is structured around a series of ordered Science Challenges that evolved from the 2011 memo from the OW Assistant Administrator to Regional Administrators (U.S. EPA, 2011, or "Stoner Memo"), which described the steps that could be taken to reduce nutrient pollution using existing programs and authorities. The Science Challenge descriptions were expanded to include air pathways and direct effects. To make the task of research collaboration and cooperation more manageable, the goal of nitrogen and co-pollutant reduction has been broken down into six major research topics or "Science Challenges".

The Science Challenges are summarized by the following questions:

1. *Where should we be targeting to reduce nitrogen and co-pollutant loads?*
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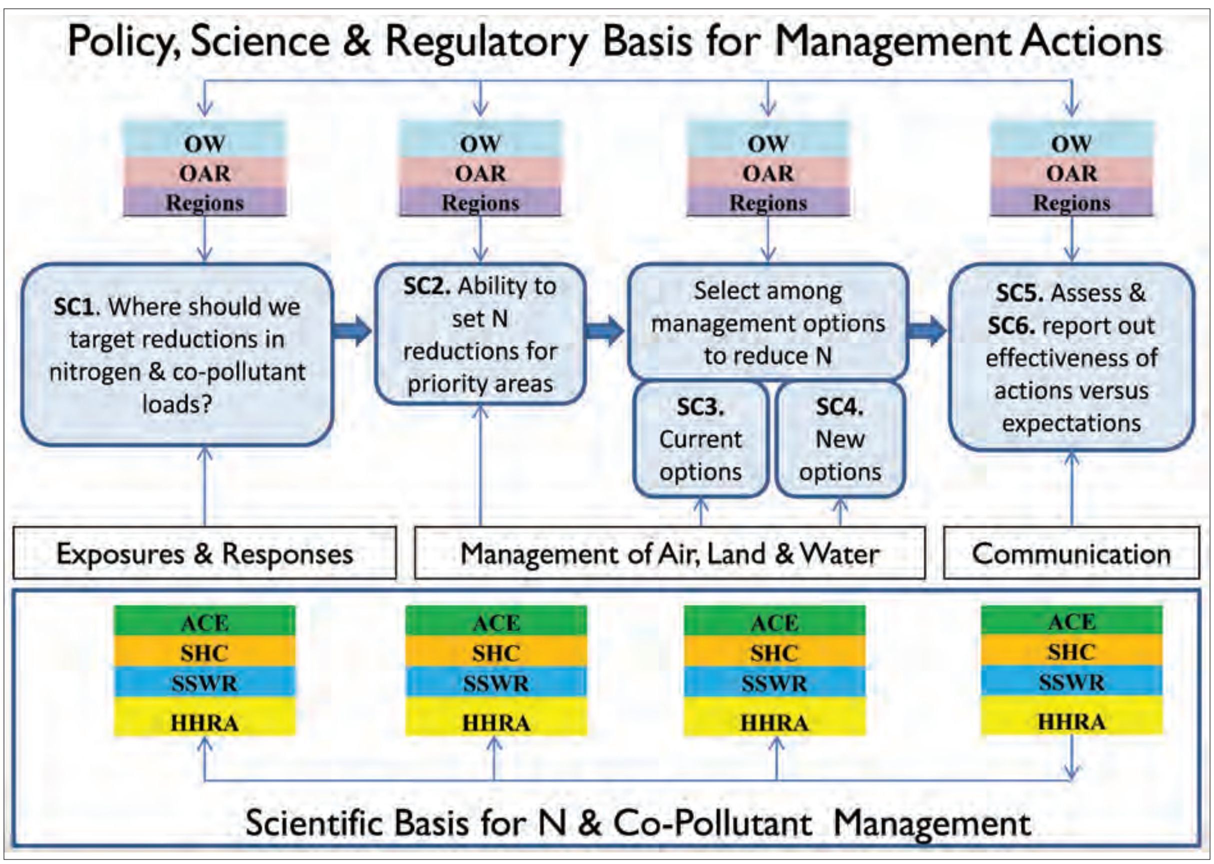

Figure 1. Framework of the nitrogen and co-pollutant research roadmap incorporating the science challenges. Numbers correspond to the Science Challenge question.

Research Alignment and Coordination

This Roadmap envisions a cross-Agency team to identify research that informs the development of effective policies needed for successful implementation of an integrated and sustainable Nr and co-pollutant management program, in addition to well-defined regulatory programs under the CAA, CWA, and SDWA. It represents the collaborative product of discussions across ORD, OW, OAR, and the regional offices. The overarching goal is to protect human health, public welfare, and ecosystem health through the restoration of air, land, and water quality by integrating Agency research that supports the management of Nr and co-pollutants.

Contributions from ORD, OAR, OW and the regional offices in terms of research, science, and policy expertise are essential to designing the goals, research paths, research tasks, and workplans as well as conducting and using the research, science, and tools proposed in each of the Science Challenges to achieve the sub-outcomes. OAR, OW, ORD and regional researchers and scientists will collaborate on the design of investigations, synthesis of data and information, tools, and their implementation in both existing and innovative management actions and policy design. Simultaneously, OW, OAR and the regional offices will be encouraged to collaborate to find innovative policy and management approaches, in addition to current regulatory programs, to optimize nitrogen and co-pollutant reductions by developing voluntary initiatives and exploring improved ways to link CAA, SDWA, and CWA authorities. One possible example is determining how best to align CAA secondary National Ambient Air Quality Standards (NAAQS) implementation with CWA Total Maximum Daily Loads (TMDLs) to achieve needed nitrogen reductions that will lead to ecological and human health benefits.

The value of communication across disciplines and offices should not be overlooked. Continued discussions with a cross-office Roadmap steering committee, annual engagement with the National Program Directors during their planning cycles, and annual face-to-face meetings with scientists and decision-makers across the Agency will be important. In the longer term, this type of effort can and should be extended to the other Federal partners and states as well.

Cross-Cutting ORD Research

Current and Planned ORD Research

To move from the Roadmap to research implementation across the Agency, the program and regional offices must identify the gaps between the ongoing research and what is needed to achieve the Outcomes of the Science Challenges. Other organizations, agencies, states and stakeholders that are conducting research relevant to achieving the Science Challenges must be identified to avoid duplicative efforts and then engaged in information exchange and collaboration. Finally the cross-cutting research agenda must be agreed on, resources identified, priorities set, and the work started.

Some of these transformative steps are already underway. Supplementary Document 1 provides an inventory of the relevant ongoing research in each ORD research program, OW, OAR and the regional offices that is associated with each Science Challenge and step. This information is being used to conduct a gap analysis to (1) identify current EPA actions to address each step of the generalized research path, (2) identify the key gaps/limitations to attainment of major client needs, (3) make recommendations for future research, and (4) identify external collaborators (USDA, USGS, NOAA, states, etc) for research needs. OW and OAR staffs have exchanged information on existing authorities, processes, and policies to initiate a process of finding innovative cross-office solutions to management of nitrogen and co-pollutants. The general roles of each of the programs in the current research are shown in Table 1, with the full detailed table given in Supplementary Document 1.

As ORD proceeds through the development of its Strategic Research Action Plans (StRAPs) for FY16 – 19, the National Program Directors will use the Roadmap to identify the areas of nitrogen and co-pollutant investigation that must be taken up in the individual StRAPs in order to deliver integrated research products that can be used to fulfill the reactive nitrogen and co-pollutant science challenges. The Roadmap is the first conceptual crafting of EPA's research response to managing nitrogen. A complete map of the multi-program, multi-office, integrated science plan will be complete in September 2015. For example: within the SSWR StRAP, attention is being given to the collaboration that must occur between those conducting research into new technologies for nitrogen removal/reuse from wastewater and those conducting research to quantify the environmental and human health outcomes of using the new technology. Both of these are science challenges identified by the Roadmap that are in need of integrated research as there are many new technologies and approaches coming on-line and under investigation.

Table 1. Research and management efforts for Nr and co-pollutant Science Challenges (SCs) and Research Steps. Major efforts are indicated by black, contributing programs in gray, and white indicates minor or no effort. Research on human health impacts from air quality is well documented elsewhere and not covered in detail in this Roadmap. See Appendix E for descriptions of the Science Challenges and Detailed Research Steps.

Generalized Research Pathway	ACE	SSWR	SHC	HHRA	OW	OAR	OEI
SC 1 – Identify priority areas							
Step 1.1 Synthesis	Gray	Gray	Gray	Black	Black	Black	Gray
Step 1.2 Endpoints and Thresholds	Gray	Black	Gray	Gray	Black	Black	
Step 1.3 Exposure	Gray	Black	Gray	Gray	Gray	Black	
Step 1.4 Services		Gray	Black		Gray	Black	
Step 1.5 Climate Change	Black	Black	Gray			Gray	
Step 1.6 Exceedance	Gray	Black	Gray	Gray	Gray	Black	
Step 1.7 Tools	Gray	Black	Gray	Gray	Gray	Gray	
SC 2 – Set reduction goals for priority areas							
Step 2.1 Synthesis	Gray	Gray		Black	Black	Black	
Step 2.2 Sources	Gray	Black	Gray	Gray	Gray	Black	
Step 2.3 Exposure Response	Gray	Black	Gray	Gray	Black	Black	
Step 2.4 Endpoint Response	Gray	Black	Gray	Gray	Black	Black	
Step 2.5 Services	Gray	Gray	Black			Black	
Step 2.6 Climate Change	Black	Gray	Gray			Gray	
Step 2.7 Tools	Gray	Black	Gray		Black	Gray	
SC 3 – Current management options							
Step 3.1 Synthesis	Gray	Black	Black		Gray	Gray	
Step 3.2 Technologies	Gray	Black				Gray	
Step 3.3 Data	Gray	Black	Gray		Gray	Gray	
Step 3.4 Cost impacts	Gray	Black	Gray		Black	Black	
SC 4 – New management options							
Step 4.1 Synthesis		Black			Black	Gray	
Step 4.2 Innovative Strategies	Gray	Black	Gray		Black	Gray	
Step 4.3 Future factors	Gray	Black	Gray			Gray	
Step 4.4 Analysis of Strategy Effectiveness	Gray	Black	Gray		Black	Gray	
SC 5 – Assess effectiveness							
Step 5.1 Synthesis	Gray		Black		Black	Black	
Step 5.2 Models	Gray	Black	Gray			Gray	
Step 5.3 Metrics	Black	Black			Gray	Gray	
Step 5.4 Verification procedures	Black	Black			Black	Black	
Step 5.5 Monitoring systems	Gray	Black			Black	Black	
SC 6 – Report on effectiveness							
Step 6.1 Inter-office Accountability	Gray	Gray	Gray	Gray	Black	Black	
Step 6.2 Inter-office Points of Contact	Gray	Gray	Gray	Gray	Black	Black	
Step 6.3 Synthesis	Gray	Gray	Gray	Gray	Black	Black	Gray
Step 6.4 Communication Strategy	Gray	Gray	Gray	Gray	Black	Black	Gray
Step 6.5 Communications Eval. & Meas.	Gray	Gray	Gray	Gray	Black	Black	Gray

Summary of Current Research Efforts by Science Challenge

Brief summaries of current EPA research activities within each of the six Science Challenges are provided below, while a more complete inventory of pertinent research is provided in Supplementary Document 1.

Science Challenge 1 – *Where should we be targeting to reduce nitrogen and co-pollutant loads?*

EPA research is contributing to identifying priority areas for Nr reductions. Current ORD research syntheses address atmospheric deposition and terrestrial impacts (CMAQ, ISA) as well as aquatic impacts of acidification due to nitrogen and sulfur deposition. Several OW efforts compile information related to the effects of N on freshwater, wetland, and estuarine ecosystems, including the Nitrogen and Phosphorus Pollution Data Access Tool (NPDAT), Nutrient Indicators Dataset (NID), National Rivers and Streams Assessment (NARS), and Wadeable Streams Assessment (WSA). This provides a good overview of at-risk systems. Endpoints and thresholds research focuses on estuarine, freshwater, and terrestrial systems, but a number of specific research gaps were identified (Appendix E). Current Exposure research includes ACE, SSWR, and SHC development of data layers for the EnviroAtlas. The ACE MDST-3 project provides a modeling framework that should be broadly applicable to the prediction of deposition fields that would allow estimation of exposure. The work by both ORD and OW connecting nitrogen criteria and the social and economic impacts of Nr is relatively new and there are a large number of gaps for understanding and quantifying the relationships and the cost and benefits of action or inaction. However, the emerging work on ecosystem goods and services, and ecosystem service production functions (SHC) should provide a good framework within which to evaluate the response of social and economic systems to nitrogen loads and concentrations in both air and water. Current ORD research on climate change impacts on nutrient issues is limited, and there is a need for developing an ensemble of potential future scenarios and associated analyses of system response to better understand how climate change will affect exposure and thresholds. Combining the ACE MDST-3 project's estimates of deposition exposure with the body of work on thresholds and end points provides a national set of exceedance values. It would be helpful to know the range of scales at which the models are predictive. Both ORD and OW have a variety of tools either completed or in development, and information transfer for tool sets to end users (e.g. states and tribes) is via websites with general menus that include various options that might be useful for an assessment. Guidance is needed from program offices to determine if this approach is adequate or if a more structured approach is needed. A few ACE projects provide structured tool transfer and training as well as user support at a central website.

Science Challenge 2 – *What information do we need to set nitrogen and co-pollutant reduction goals for priority areas?*

Current research across EPA is examining how to set nitrogen and co-pollutant reduction goals for priority areas. Through Integrated Science Assessments (ISA) and Integrated Risk Information System (IRIS), the synthesis needed for air deposition impacts are relatively adequate. Ongoing work under ACE appears to generally cover needs with regard to air sources, and because terrestrial systems are primarily exposed via air sources, source apportionment for terrestrial systems is similarly covered. ORD in combination with OAR has good programs for tracking and monitoring air loads and sources that are well centralized and operate at relevant temporal scales but there is nothing similar for water. There is little current work identified for water on source attribution and load quantification. ORD has developed and continues a limited amount of stable N isotope research on source identification, and the approach has wide external (academic, USGS) research efforts. Ongoing work in ACE addresses exposure response of air pathways. For exposure response in water, the ORD VELMA model is supported under ACE, SHC, and SSWR, and has the potential to model source reductions under land use change scenarios at small watershed scale. There are few ORD studies examining stress-response for terrestrial systems. While there is a broad spectrum of relevant research on ecosystem services work within SHC that is potentially relevant, it is not explicitly focused on defining the linkage between changes in N-exposure and the derivation of ecosystem services. Present ORD research on climate impacts on nitrogen are limited, but includes the regional scale study on the MARB-GOM, a multimedia modeling study of stream flow and nitrogen, and estuarine nutrient stress-response work which incorporates hydrologic flow and water temperature variation in assessing nutrient impacts. A critical gap that crosses all SC2 steps appears to be the level of effort focused on integrated decision-support tools which will provide insights in environmental, social, and economic components specifically related to N issues. There is some work with human health effects of nutrients, particularly on drinking water and nitrates, yet this aspect of the social dimension is limited to published response and valuation data. SSWR task 2.3C is addressing the distribution, causation, and mitigation of cyanobacterial blooms and their impacts on ecosystems and on human health.

Science Challenge 3 – *What's in our toolbox to manage and reduce nitrogen and co-pollutant loads and does it work?*

A variety of research across EPA is focused on tools to manage and reduce N and co-pollutant loads, and to determine if tools actually work. EPA and ORD are keenly aware of and routinely conduct sensitivity and uncertainty analyses using various methods on a wide range of models. Ongoing research within ACE in collaboration with OAR appears to generally cover management options for air sources, including human health-related benefits analyses, and supporting data collection. ACE modeling tools provide integral support for air analyses of management options. Climate effects of nitrogen emissions are also being addressed in ACE. OW, through collaboration with USGS on the NPDAT tool, can determine the relative importance of different N sources to air, land, freshwater and coastal systems. Collaboration with USDA NRCS and local Soil and Water Conservation Districts on local projects within SHC and SSWR will ensure a stronger connection and credibility in the agricultural community. Information on the social and economic factors is currently lacking, but SSWR and SHC are conducting modeling and economic studies to allow for inclusion of economic factors and tradeoffs in an N reduction strategy, and also to model future loading scenarios and impacts. Recently within EPA, there has been an increased effort to look at the costs associated with reactive nitrogen, in terms of the damage, mitigation, restoration, and replacement costs. OW has an effort documenting nutrients in the economy, ORD SHC has completed a national damage cost assessment of N and other work on ecosystem services, and ORD SSWR also has initiated a program and accompanying STAR grant to examine the benefits of water quality improvements, which should include nutrients. SHC is also developing a decision tool called N-Sink that could assist states in planning their reduction strategies because it illustrates the spatial arrangement of agricultural or urban N sources and soil and wetland N-sinks. SSWR research on green infrastructure (GI) includes examination of what works and what doesn't in N removal, and the economic costs and benefits of GI. The NARS program (OW) conducts unbiased probabilistic surveys of conditions in rivers and streams, lakes and reservoirs, estuarine and coastal waters, and wetlands at regional and national scales. SSWR Project 1 is developing methods to predict watershed integrity using spatially explicit modeling. SSWR tasks 2.3 B and C have developed satellite remote sensing techniques for use in compliance monitoring of state water quality standards.

Science Challenge 4 – *What are some new, innovative approaches we haven't tried before?*

While more work is clearly needed, some current research seeks to find new, innovative approaches to nutrient management that EPA has not tried before. The STAR program has recently funded four research centers that will contribute to addressing this need. The centers are funded for a four-year period at a total of approximately $12 million including EPA and matching funds. A second RFA for additional centers is proposed in 2014, to be funded at a total level of approximately $5 million including EPA and matching funds. The Centers are: Project 1: Center for Integrated Multi-scale Nutrient Pollution Solutions, Pennsylvania State University; Project 2: Center for Reinventing Aging Infrastructure for Nutrient Management (RAINmgt), University of South Florida; Project 3: Center for Comprehensive, Optimal, and Effective Abatement of Nutrients, Colorado State University; Project 4: National Center for Resource Recovery and Nutrient Management, Water Environment Research Foundation. SSWR 6.2 is exploring novel approaches to nitrogen reduction at the source and through restoration of ecosystem services. One research task is comparing the impact of oyster reef restoration and oyster aquaculture on key ecosystem services of nitrogen removal, water quality and the benthic and finfish communities. A second research task is exploring novel waste water technology options in southeastern New England that could provide cost effective decentralized technology. A third research task is exploring the potential for social enterprise organizations (SEO) to develop innovative business opportunities/models to provide cost effective and sustainable solutions to nitrogen pollution. There are a significant number of new technologies and approaches coming on-line and in development for treating, removing, and recovering nitrogen and co-pollutants from wastewater at scales ranging from households to large wastewater treatment plants. ORD's StRAPs will outline research to evaluate and advance these technologies and approaches to inform states, tribes, and localities as they make infrastructure decisions.

Science Challenge 5 – *Are we getting the reductions and ecosystem and human health benefits we expect?*

Some research efforts are ongoing within EPA to address whether we are getting the reductions and the ecosystem and human health benefits expected from management actions. The report "An Optimization Approach to Evaluate the Role of Ecosystem Services in Chesapeake Bay Restoration Strategies" includes quantification and valuation of "bonus biological services" based on various scenarios for achieving the nitrogen, phosphorus, and sediment TMDL for the Chesapeake watershed. Currently, ORD and partners are working to (1) make the optimization model available for use by the Chesapeake Bay Program Office and modeling community, and (2) to communicate the co-benefits, such as improved hunting and fishing opportunities, of BMP implementation to managers and stakeholders. The GOM/MARB modeling effort (SSWR, ACE, SHC) includes an atmospheric deposition component and provides an approach to many assessment needs, but does not currently include a component to derive economic and social endpoints, other than the endpoints important to air pollution through the availability of BenMAP. Some research to determine the stress-response relations of biotic endpoints to nitrogen is conducted under SSWR 2.3A, but is not designed to be used by any specific modeling framework. Verification procedures and monitoring system improvements are addressed to a modest degree in ACE relative to atmospheric pathways of nitrogen and co-pollutant delivery. This work is conducted in collaboration with OAR to address accountability.

Science Challenge 6 – *How do we best maintain inter-office accountability, assess progress, and communicate results to the public?*

A particular challenge for the EPA Nr and co-pollutant research is how to best maintain inter-office accountability communications, assessment of joint progress in terms of achieving Nr reductions, and in optimizing communications with the public. Some of this communication will rely on collaboration with other entities on common issues, for example USGS and water quality, and USDA and soil health and food security issues, and a variety of agencies on sustainability. There is little or no current EPA research in this research area, but we recognize the importance of internal and external communication, and new research in SSWR and SHC will focus on communicating our science and also working more closely with stakeholders to understand how to best inform decisions. This effort will need to draw upon researchers outside of EPA with this expertise, potentially working with the Nutrient Centers through EPA's STAR grants program and with other agencies.

Examples of ORD Integration

While much greater integration across the EPA research portfolio is clearly needed, several research efforts exemplify integrative research approaches to nitrogen and co-pollutants. Such research projects are housed within most of the StRAPs that currently include nitrogen-related research in their portfolio. Here we describe four ORD research projects or tasks that promote integration in nitrogen and co-pollutant research:

NO_xSO_x Integrated Science Assessment (HHRA 2.2.1)

The Integrated Science Assessment (ISA) of the ecological effects of nitrogen oxides (NO_x) and sulfur oxides (SO_x) is part of the periodic review of the National Ambient Air Quality Standards (NAAQS) required by the Clean Air Act. It serves as the scientific foundation for OAR risk and policy assessments that guide the EPA to determine whether or not to set, revise, or retain the NO_x and SO_x NAAQS. This assessment draws upon research from across the ACE, SSWR, and SHC programs, program offices, regional offices and external research.

The ISA is a synthesis of all relevant scientific information with specific focus on atmospheric chemistry and ecological effects related to gas-phase and deposition of NO_x and SO_x (Figure 2). The assessment considers multiple environmental media and therefore follows the path and consequences of the nitrogen and sulfur pollutants as they are emitted to the air, deposit, and cascade from terrestrial to aquatic environments. This national-scale assessment draws upon information that is generated from across the ORD RAPs, partner agencies and the greater scientific community, including peer-reviewed literature as well as technical documents and datasets.

The atmospheric chemistry of oxidized nitrogen compounds included are gases such as nitrogen dioxide (NO_2), nitric oxide (NO), nitric acid, particulate nitrate, sulfur dioxide (SO_2), and particulate sulfate. Ecological effects include acidification, nitrogen enrichment, eutrophication, and sulfur-induced mercury methylation of terrestrial, freshwater, wetland, and estuary ecosystems in the United States.

Integrated Multimedia Modeling for Nitrogen Case Study

ACE MDST-3: Integrated Multimedia Systems Modeling for Sustainability

SSWR Task 2.3.D: Modeling the Linkage between Discharge and Nutrients from the Mississippi River Basin to Gulf of Mexico Hypoxia

SHC 3.3.1.1: Integrated Management of Reactive Nitrogen

Hypoxia in the Gulf of Mexico is a critically important environmental issue affecting vitality in the northern Gulf. A signature case study was developed between the ACE MDST-3 project and the SSWR Task 2.3D, with participation by SHC Task 3.3.1.1, to address the hypoxia issue. The joint project is developing multimedia models of the linkage between discharge and nutrients from the Mississippi River Basin (MARB) and the resultant Gulf of Mexico (GOM) hypoxia. The goal is to predict how nutrient management decisions and future climate change will impact the size, frequency and duration of the hypoxic area that forms every summer. The integrated, multimedia modeling will be used to predict a broad set of consequences in the MARB and the GOM associated with nitrogen management decisions. Without such a multimedia framework, the interrelated actions of excess nitrogen can lead to unintended or unidentified consequences for particular decisions. The modeling framework shown in Figure 3 includes a northern GOM model set (SSWR 2.3D) and a MARB model set (ACE MDST-3; SHC 3.3.1).

The ocean model set consists of state-of-the-art linked hydrodynamic (NCOM), eutrophication (GEM and GoMDOM), and nutrient air deposition (CMAQ) models. Collaborators within ORD under the SSWR project include multiple divisions (GED, MED, AMAD) across multiple National laboratories (Figure 3) including the OEI Environmental Modeling and Visualization Laboratory. Interagency collaborators include the Naval Research Laboratory, which provides the 3-D hydrodynamic model for the Gulf of Mexico to which EPA models are linked. Academic collaborators include faculty at Dalhousie University, Louisiana State University, and Texas A&M University.

The MARB model set includes atmospheric models (WRF meteorology and CMAQ air quality) coupled to an agricultural management/BMP model (USDA's EPIC) and watershed hydrology (VIC) and watershed models (NEWS and SWAT). Climate downscaling drives a coupled WRF-VIC model to in turn drive watershed models. Collaborators within ORD under the ACE Project include SHC: NHEERL, WED (NEWS); SSWR: GED (GEM); SSWR: MED, NERL, ERD (SWAT); NERL, ESD (Riparian Buffers); NRMRL, APPCD (N_2O Fluxes); and ACE MDST-4 (climate down-scaling). Interagency collaborators include PNNL (VIC) and USDA (EPIC). Academic collaborators include faculty at UW (VIC and water temperature), WSU (collaborating with SHC) (NEWS), Texas A&M (EPIC and SWAT), Univ. of Maryland (N_2O biogeochemistry), and Rice University (Soil NO).

The products of the multimedia modeling for the Gulf hypoxia relative to the ocean models are scenario analyses of nitrogen and phosphorus load reduction impacts on the hypoxic area under present and future climate conditions defined by changes in precipitation and river freshwater discharge, nitrogen and phosphorus loads, air temperature, resultant water temperature, and wind. The products of the multimedia modeling for the MARB that provide inputs to the ocean models are scenarios designed to illuminate an array of consequences and identify win-win situations as well as unintended consequences. While traditional, single media approaches, including addition of riparian buffers, can reduce nutrients entering streams and rivers, side benefits/harm may be missed, but these can be illuminated using a multimedia perspective. For example, modifying corn nitrogen use efficiency can reduce the amount of fertilizer needed, thereby reducing ammonia emissions, and in turn reducing fine particle levels (improving human health), reducing nitrate entering ground water (improving human health), and reducing N_2O emissions (reduced greenhouse gas emissions) as well as reducing nutrients entering streams and rivers. No till agricultural management reduces surface runoff into streams, but it can increase percolation of nitrate into ground water. Only considering air emission reductions on air end points misses the side benefits

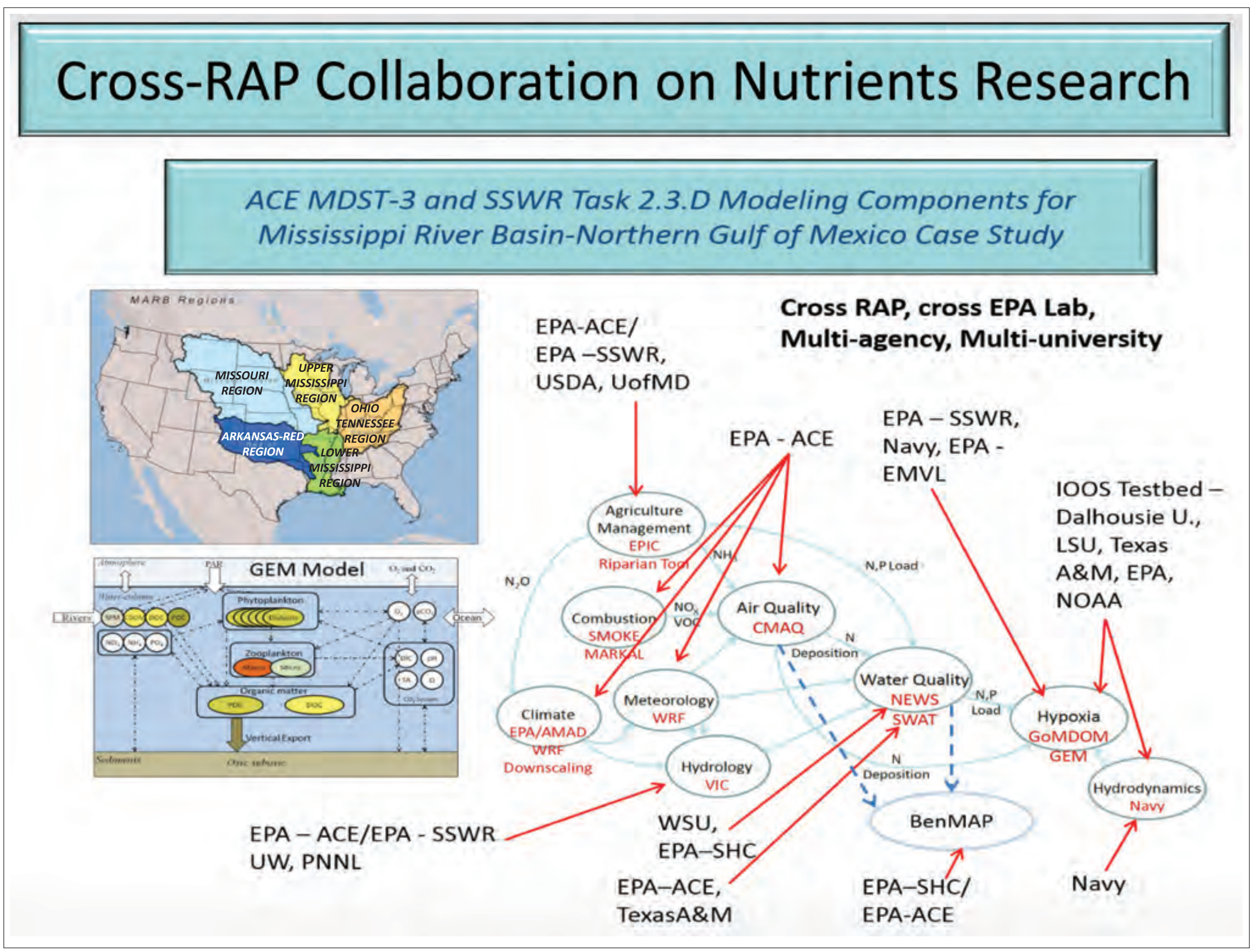

Figure 3. Schematic diagram of the linked modeling components in the MARB – GOM hypoxia case study.

of improved water quality and reduced eutrophication in coastal estuaries. The goal is a more holistic intra-Agency analysis capability to inform the Gulf Hypoxia Task Force decision process with a more complete accounting of side benefits in the watershed.

Linkage and integration among the ORD Programs and across Federal agencies and academia is critical to address the issue of nutrients in the MARB and nutrient driven hypoxia in the GOM, given the physical scale and complexity of the linked physical, geochemical, and biological models required.

Informing Sustainable Nitrogen Decisions using an Ecosystem Services Framework (SHC 3.3.1)

This effort combines nutrient input mapping, modeling, decision tools, and economic damage information to apply to decisions about nutrient management and policy. Input layers (HUC12 scale, year 2006) for background N fixation, crop N fixation, manure N and synthetic fertilizer N were included in the EnviroAtlas and the Estuary Data Mapper. Building upon this data, the Nutrient Export from Watersheds (NEWS) is used to predict future nitrogen inputs to the coastal zone based on scenarios of "business as usual" and "ambitious" approaches to nutrient management scenarios of biofuel use in collaboration with ACE and SSWR projects on coastal N loading and impacts are also in development. The balance of agricultural N costs and benefits related to nutrient impacts is the most important driver of inputs to many coastal areas. This effort identifies areas where other N sources are projected to increase, and provides region-specific guidance on which sources are most important to manage sustainably. This research explores the possibilities for the 25% reduction in N inputs to the U.S. landscape recommended by the EPA Science Advisory Board's Integrated Nitrogen Committee.

In order to develop a framework for assessing the damages associated with N release to the environment from human activities, SHC is assembling data on the economic damages of N release on human health, climate regulation, ecosystems and agriculture. Damages are associated with specific nitrogen sources, so that source-specific costs can be generated. Each impact is linked to the ecosystem class and beneficiary defined by the SHC Final Ecosystem Goods and Services Classification System (FEGS-CS). Values are compared with the recent European Union assessment of the costs and benefits of nitrogen for Europe; many of the values are quite similar, or within the range found by the E.U. assessment team. The highest costs per unit nitrogen are associated with human respiratory health, although some of the impacts on coastal ecosystems are quite large as well. A number of gaps were identified in the assessment, including lack of data on harmful algal blooms, terrestrial impacts, and drinking water treatment or replacement costs. Current efforts are connecting with ACE and OW-OST to improve and extend these cost estimates. These data will be combined with existing data on nitrogen flow to the environment in order to assess the national and regional damages and future projected damages on ecosystem services.

Narragansett Bay and Watershed Sustainability – Demonstration Project (SSWR 6.1)

The goal of the Narragansett Bay Demonstration Project is to determine whether systems-based approaches (Figure 4) can be used to identify and manage causes of degraded water resources to promote ecosystem protection and recovery. This project is designed to: (1) Provide a better understanding of the historical context of environmental change and diverse environmental management policy responses, leading up to the present condition; (2) Address contemporary environmental stress-response relationships including consideration of multiple stressors affected by nutrient loading to surface water resources; and (3) Better inform future governance decisions that contribute to more sustainable solutions in the future.

EPA researchers are documenting disturbances and enhancements in this watershed and estuary that relate to nutrient effects on key ecosystem structures and functions. The conceptual research and management framework for long-term environmental governance is scalable, and can be adapted for use in southern New England and other parts of the country.

Contributing research from other SSWR projects includes work on national indicators of watershed integrity (SSWR 1.1b), work on modeling in support of numeric nutrient criteria development for estuarine and coastal systems (SSWR 2.3A), research related to assessment of cyanobacteria risks in lakes and reservoirs (SSWR 2.3C). Environmental data from EPA's National Aquatic Resource Surveys (NARS) are being supplemented with additional data collected in the Narragansett Bay watershed (SSWR 1.1b for streams, SSWR 2.3C for lakes).

The research draws on emerging science from the ACE program to access results from the CMAQ model relating to the magnitude and sources of NO_x emissions from fixed and mobile sources to spatial variations in atmospheric nitrogen deposition. SSWR 6.1 research integrates emerging

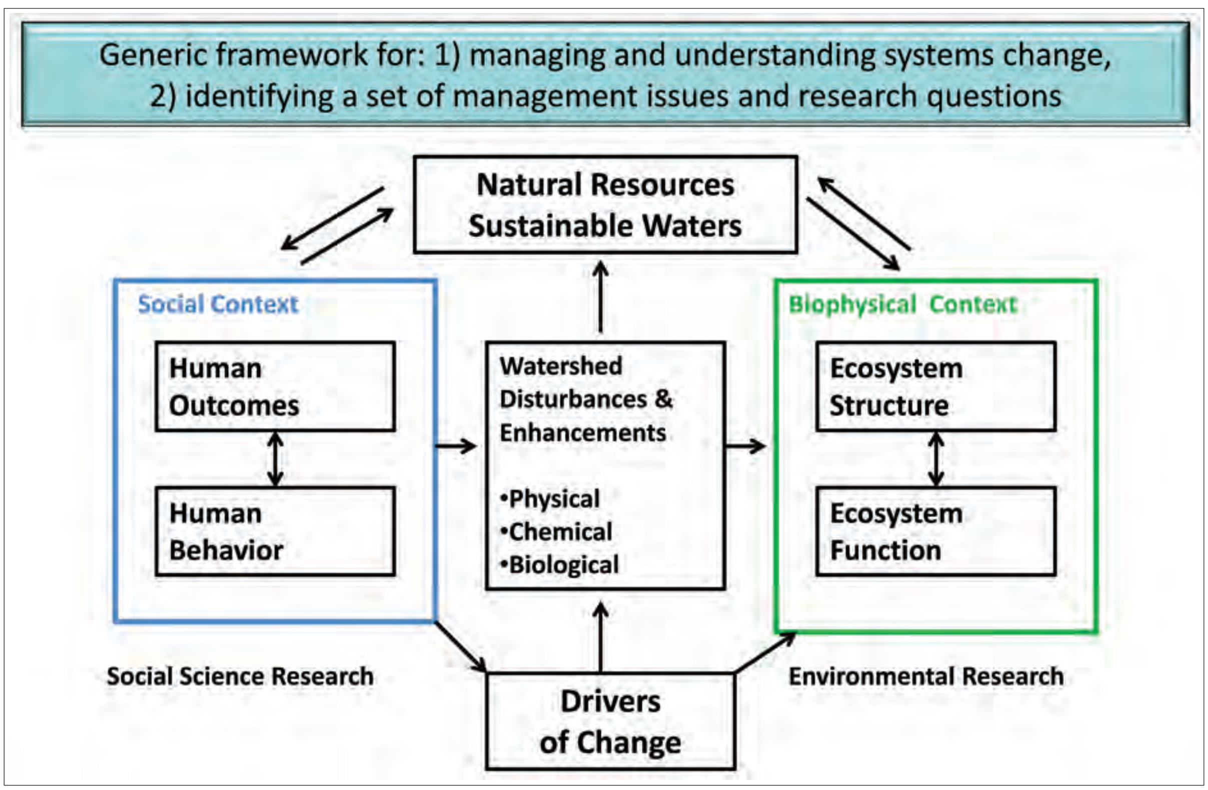

Figure 4. A conceptual framework for integrated management of Nr in the context of ecosystem based management. SSWR Project 6.1 (Based on Collins et al., 2011).

scientific understanding related to multimedia sources and consequences of nutrient fluxes through air, to watersheds, and to associated estuaries. Interagency collaboration with USGS in the watershed involves testing and refinement of methods, indicators and models, for more effective decision support.

The estuarine research component of the project effort involves collaboration with a number of academic investigators funded by the NOAA Coastal Hypoxia Research Program (CHRP). We will learn whether EPA regulatory water quality and ecological models for Narragansett Bay do better or worse than the finer scale hydrodynamic and more simplified ecology models developed by CHRP. Both EPA and NOAA funded research contributes to decisions about: (1) The need for additional point source waste water treatment facility permitting adjustments going forward, and (2) Needed monitoring and modeling to inform restoration and spatial planning efforts that could be adapted for use in other watersheds and estuaries.

Opportunities for Further Integration

Where could we better collaborate and leverage across programs?

As indicated by the diversity of EPA offices, regional offices, and ORD laboratories and centers, the N Roadmap effort has brought together researchers across these organizations to develop a path forward towards a common goal. The Roadmap gap analysis should form a key element informing the development of the next iterations of the ORD Strategic Research Action Plans (StRAPs). A significant organizational challenge will be to operationally coordinate research planning and implementation among the StRAPs on a continuing basis. Climate change issues are identified as critical to effective future management of N and copollutants, and more interaction with the climate change roadmap effort could be beneficial. At this time, the Roadmap team has not yet consulted with the EPA Office of Enforcement and Compliance Assurance (OECA) or the Office of Policy (OP) to determine if there are any initiatives which might contribute to new management approaches for N and co-pollutants.

Where could we better collaborate and leverage other stakeholders?

A number of ongoing efforts tied to the Nitrogen Roadmap work to better collaborate with and leverage resources from other stakeholders. Many of these efforts were directly initiated or enhanced through the Cross-ORD Nitrogen & Co-pollutant Roadmap team.

- A joint EPA-USDA-USGS research collaboration workshop was held June 24-26, 2014, to identify common and complementary research and outreach activities in support of joint decision-making on N and co-pollutant management.
- The US Global Climate Research Program - Nitrogen Cluster workgroup seeks to improve interagency coordination of nitrogen cycle research and to identify opportunities for interagency collaboration. (EPA and NOAA co-chair; DOE, NASA, NSF, USDA, USGS).
- The EPA Office of Water Innovative Technology Blueprint Initiative focuses on partnering with and leveraging the actions of a full array of external partners and stakeholders, including the Water Environment Federation (WEF), the Water Environment Research Foundation (WERF),

the National Association of Clean Water Agencies (NACWA), the American Water Works Association (AWWA), and the U.S. Water Alliance, for the purpose of advancing innovative water and wastewater management technology.

- Nutrients prize challenges will explore innovative ideas that would fundamentally change management or recovery of nutrients. Participants will include Federal agencies, state water and agricultural agencies, academia, industry, and the general public.
- Means to leverage other agency national monitoring networks could be developed to determine changes in ecosystem condition resulting from management choices (e.g. US Forest Service Forest Inventory and Analysis database, the National Parks Service Inventory and Mapping database).
- There is ongoing collaboration with USDA to improve nutrient trading, as well as the National Water Quality Initiative, the White House nutrient challenges, and the joint USDA-USGS-EPA workshop on nitrogen and co-pollutant management.
- The development of the proposed national monitoring network (http://acwi.gov/monitoring/network/) involving primarily USGS, EPA, NOAA.
- EPA's STAR (Science to Achieve Results) program has funded four nutrient research centers to develop scalable, transferable, sustainable, and innovative management approaches. There is potential to develop cooperative research agreements with these centers.
- New Memorandum of Agreement between EPA and land grant universities from 12 Hypoxia Task Force states; including the extension and research side of each university.
- Support the new Southeast New England Program (SNEP), designed to employ innovative and sustainable solutions to restore coastal watersheds and estuaries of southeastern New England, which includes support from EPA-ORD, EPA Region 1, and the National Estuary Programs.
- Potential expansion of the BenMAP model could include economic and social costs and benefits associated with nitrogen and co-pollutant reductions, but would also require appropriate exposure-response functions.
- Collaboration with USDA could be improved on analyses of air, surface, and ground water quality changes associated with land management.
- External collaboration could be developed to leverage and extend current research to acidification of forest soils and to develop the required concentration-response functions.
- Through collaboration with other agencies, expand work on the impact of nitrogen on biodiversity from the northeastern United States to the western United States and include grasslands and rangelands, encompassing research on acidification of forest soils.
- A STAR research center has been awarded at Pennsylvania State University, with a focus on the Chesapeake Bay that proposes to develop an integrated, holistic approach to understanding drivers and pressures related to nitrogen and phosphorus, valuation of ecosystem services and alternative decision scenarios.

- Investigation of cross agency efforts is particularly needed. The USDA led interagency Mississippi River Basin Healthy Watersheds (MRBI) should be assessed to determine whether its methods and results are transferable to other regions of the country. The USFS-FIA and NPS-I&M programs should be similarly assessed for relevant information.
- Three other national networks address and report on regional trends connected to nonurban and ecosystem exposure: The National Atmospheric Deposition Program (NADP), the Clean Air Status and Trends Network (CASTNET) and the Interagency Monitoring of Protected Visual Environments (IMPROVE).

Process to Stimulate this Integration

The gap identification process focused not only on research gaps but on the revisions to organizational process that would be needed to achieve and maintain an integrated Nr and co-pollutants research and management effort. Agreement will be needed on goals, roles, responsibilities, and resources commitments. Key needs in terms of building a more integrated approach are to:

- Develop a process to ensure integrative success of nitrogen and co-pollutant research housed in multiple tasks, projects, ORD RAPs, and program office and regional efforts.
- Develop a process to identify relevant external (academic, Federal, state, NGO) research efforts that address key nitrogen and co-pollutant management steps identified.
- Develop a formal, collaborative process between ORD, the program offices, and regional offices to discuss how best to provide tools for the program offices to make national decisions (e.g., National Ambient Air Quality Standards or NAAQS) and for the regional offices and states to use in developing prioritized load reductions.
- Develop a formal, collaborative process between ORD and OAR to understand the data and modeling needs required to inform exposure and risk assessments for ecosystem impacts, including characterization of changes in ecosystem services, to support the reviews of the secondary NAAQS.
- Develop an ongoing process for identifying additional research gaps that were missed in this analysis.
- Ensure that results of case studies (e.g. GOM, Chesapeake Bay, Narragansett Bay) are mutually informative and can start to address research scaling issues.

Research Gaps & Priority Research Needs

Synthesis of Existing Gaps

To conduct the gap analysis, the writing team examined the "needs" expressed by the explicit statement of a Research Step within a Science Challenge, and referred to a detailed spreadsheet inventory of current research products to determine if the products identified in the inventory were adequate to cover the Research Step needs, i.e. that the Step could be accomplished with existing research products. Missing needs were then enumerated by the individual doing the Research Step gap review, merged with those of the other Research Step level reviews, and evaluated and synthesized by the entire core writing team to determine what needs were missing to accomplish both the individual Research Steps and the overall Science Challenge. The process was repeated for each Science Challenge. The complete list of research gaps identified is listed in Appendix E.

An overarching research need is for development of integrated models and tools that include environmental, social, and economic components for management approaches that go beyond current regulatory programs. An important discussion with stakeholders is to define just what may be needed for more integrated decision-support tools which will provide insights in all three areas, specifically related to nitrogen and co-pollutant issues. There has been relatively little research concerning human health effects of nitrogen, particularly in drinking water nitrate contamination, and thus research applications to address this aspect of the social dimension are very limited. It may be necessary to interact more with the EPA-ORD Chemical Safety for Sustainability research program to determine whether current efforts were missed in the inventory process, or whether this constitutes a major gap. Research on human health impacts from air quality is well documented elsewhere and was not explicitly covered in this Roadmap. Research on nitrogen and terrestrial systems was much more limited in the inventory than on aquatic systems, and requirements may need to be filled from external collaborators. A major gap for NAAQS is the lack of availability of information on exposure response functions for many nitrogen related impacts, which prevents the assessment of the impacts of changes in nitrogen loadings that would result from alternative NO_x standards.

There are relatively few EPA projects identified which examine climate impacts on nitrogen sensitivity. Given the degree to which climate change effects are likely to be regionally specific, there may be insufficient spatial coverage to allow adequate extrapolation across all water body types and ecoregions of the United States. It may be critical to rely on additional external research in this area to extend the inference space, and these efforts need to be explicitly identified.

While there are a range of both Agency and external models for nitrogen and co-pollutant source apportionment in water at varying spatial scales, it should be determined whether these models, augmented by site specific modeling tools used in TMDL development, are adequate at intermediate (small watershed) spatial scales. A comparative assessment of the utility of current modeling tools to meet needs of the states would be generally useful, in conjunction with efforts by OW, states and other agencies. This would include the Recovery Potential Screening tool in development by OW that can help inform decisions for particular watersheds for nutrient issues (http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/index.cfm).

Prioritized Research Needs for ORD

Key science gaps were identified through our examination of the Science Challenges and the current EPA research portfolio. A total of some 95 research needs were identified (see Appendix E), and a summary list of broad, significant research needs was identified based on this assessment:

- Develop empirical data and models that better tie nitrogen and co-pollutant related water quality and terrestrial ecosystem impairments to quantitative loads, and better predict how impairments vary with changes in load, concentration and biogeochemical conditions.
- Determine how the magnitude, frequency, and duration of nitrogen and co-pollutant loading affect expression of impairment for aquatic and terrestrial endpoints.
- Develop better tools to determine nitrogen and co-pollutant source apportionment in watersheds at a range of scales.
- Incorporate climate change (temperature, storms) into models predicting environmental impacts of future nitrogen and co-pollutant loads.
    - e.g. changing hydrological cycle impacts on water quality impairments
    - e.g. interactions of temperature, drought and nitrogen and co-pollutants in generating impairments
    - e.g. interactions between nitrogen and co-pollutants and coastal acidification
- Better integrate pollution-response models across air, land, and all water body types.
- Develop and integrate ecosystem service metrics and accountability measures for social and economic endpoints of concern that are integrated into exposure-response models for nitrogen and co-pollutants. Assess the ability to expand and adapt existing models such as BenMap versus novel model development.
- Continue efforts to introduce new technological applications to nitrogen and co-pollutant management problems, such as genomic indictors of sources and effects, satellite monitoring of conditions, and improved sensor technologies.
- Support and enhance monitoring programs that provide the information needed to assess system-level, long-term responses to policies and management.

Leadership of the N Roadmap team was established to ensure that policy perspectives and needs of the program offices were central. The Research Framework of the N Roadmap was structured to address science needs for decision making, using a policy document that described the steps that could be taken to reduce nutrient pollution using existing programs and authorities (U.S. EPA, 2011, or "Stoner Memo"). Language in the Framework was expanded to include air pathways and direct effects. All research gaps that were identified were vetted against the detailed Research Framework steps to ensure that results would inform a decision-making need. This Roadmap effort is led by ORD, but the effort represents a strong cross-EPA team. The team worked across RAPs and regional and program offices to synthesize information across the existing research program and identify opportunities for integration and areas to strengthen.

Informing 2016 – 2019 ORD Research Planning

Upon completion of the N Roadmap, a first step will be to hold a webinar to introduce the research gaps and needs to interested parties in ORD (e.g. the NPDs, MIs, those scientists already doing some type of N and co-pollutant research or assessment). The objective will be to convey an overview of the current EPA Nr program, presenting a succinct and well-formulated list of priorities and the client needs supported.

Pending approval of the ORD NPDs, a next step could be convening a research integration summit. Representatives of the key research projects, current or planned, under the StRAPs or offices could be convened along with representatives of the program and regional offices and NPD staffs. In preparation for the summit, the identified research gaps from the Roadmap process could be organized around major scientific questions or research priority areas, each clearly tied to client needs. Researchers within the four pertinent ORD research programs and representatives from OAR, OW, and the regional offices could evaluate the gaps in the research priority area, using the gap analysis as the starting point. The summit goals could be to agree on the scientific issues, determine what capacity (FTE, $) exists within the various research partners, and begin to develop a plan for how research might be partitioned among partners. This research planning could be reinforced with annual face-to-face meetings (or webinars) with scientists and decision-makers across the Agency in order to keep this effort on track.

At the same time, a subgroup should discuss how to manage the cross cutting research to ensure that desired research outcomes are achieved. This work group should determine where the critical linkages are that cross the RAPs and determine how they may best be supported. Consideration of cross-rap funding mechanisms should be given. Coordination among RAPs, and laboratories and centers relative to resource decisions within RAPs will be critical in order that priority decisions made in one RAP do not negatively impact the cross-RAP projects. These are discussions and decisions being recommended to the National Program Directors in FY15 so that the FY16-19 StRAPs will be ready for implementation at the start of the new fiscal year.

Summary

This Roadmap is the product of extensive interaction between representatives from ORD's SSWR, SHC, ACE, and HHRA research programs; OW; OAR; and the regional offices. The goal of the Roadmap is to develop a common understanding of the Agency research program portfolios developed by the ORD National Program Directors (NPDs) and compare them with the OW and OAR program offices' priority research needs to identify major focus areas, opportunities for integration across the Agency, research gaps and future research directions.

The effort has allowed for greater collaboration and coordination in Nr research across EPA, identification of gaps and the development of integrated research projects. In an era of declining budgets and FTE, efforts like this that bring together staff across the agency to tackle important problems are needed more than ever. Significant, sustainable reductions in Nr must be economically efficient; socially acceptable; environmentally sound; adaptable to climate, land-use and demographic changes; and permanent. These requirements can be met only through integrated research that informs the systematic collective, adaptive management of air, land, and surface and ground water.

Significant, sustainable reductions in Nr must be economically efficient; socially acceptable; environmentally sound; adaptable to climate, land-use and demographic changes; and permanent. These requirements can only be met through the comprehensive adaptive management of air, land, and water.

Appendix A. Authors and Contributors

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Appendix B. Acronyms and Abbreviations

ACE	Air, Climate and Energy
AMAD	Atmospheric Modeling and Analysis Division/ORD
AWWA	American Water Works Association
BMP	Best Management Practice
CAA	Clean Air Act
CASTNET	Clean Air Status and Trends Network
CHRP	Coastal Hypoxia Research Program
CMAQ	Community Multiscale Air Quality modeling system
CWA	Clean Water Act
DOE	Department of Energy
DOI	Department of Interior
EPA	Environmental Protection Agency
EMVL	Environmental Modeling and Visualization Laboratory
EPIC	Environmental Policy Integrated Climate
FEGS-CS	Final Ecosystem Goods & Services Classification System
GEM	Gulf Ecology Model
GED	Gulf Ecology Division/ORD
GOM	Gulf of Mexico
GoMDOM	Gulf of Mexico Dissolved Oxygen Model
HAB	Harmful Algal Blooms
HAWQS	Hydrologic and Water Quality System
HHRA	Human Health Risk Assessment
HNO_3	Nitric Acid
I/M	Inspection and Maintenance
IOOS	Integrated Ocean Observing System
ISA	Integrated Science Assessment
MARKAL	Market Allocation Model
MCL	Maximum Contaminant Level
MED	Mid-continent Ecology Division/ORD
MI	Matrix Interface
MRB	Mississippi River Basin
N	Nitrogen
N_2O	Nitrous Oxide
NAAQS	National Ambient Air Quality Standards
NACWA	National Association of Clean Water Agencies
NAPAP	National Acid Precipitation Assessment Program
NARS	National Aquatic Resource Surveys
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCOM	Navy Coastal Ocean Model
NEWS	Nutrient Export from Watersheds
NH_3	Ammonia
NH_4^+	Ammonium

NH_x	NH_3, NH_4^+
NO	Nitric oxide
NO_2^-	Nitrite ion
NO_2	Nitrogen dioxide
NO_3^-	Nitrate ion
NO_3	Nitrate radical
NOAA	National Oceanic and Atmospheric Administration
NO_x	Nitrogen oxides (NO + NO_2)
NO_y	Total reactive oxidized nitrogen
NPD	National Program Director
NRC	National Research Council
NRL	Naval Research Laboratory
Nr	Reactive nitrogen
NSF	National Science Foundation
OAQPS	Office of Air Quality Planning and Standards
OAR	Office of Air and Radiation
OECA	Office of Enforcement and Compliance Assurance
OEI	Office of Environmental Information
OP	Office of Policy
ORD	Office of Research and Development
OW	Office of Water
PNNL	Pacific Northwest National Laboratory
RAP	Research Action Plan
SO_2	Sulfur Dioxide
S	Sulfur
SAB INC	Science Advisory Board Integrated Nitrogen Committee
SAB	Science Advisory Board
SDWA	Safe Drinking Water Act
SHC	Safe and Healthy Communities
SO_x	Sulfur oxides
SSWR	Safe and Sustainable Water Resources
StRAP	Strategic Research Action Plan
SWAT	Soil and Water Assessment Tool
TMDL	Total Maximum Daily Load
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UW	University of Washington
VIC	Variable Infiltration Capacity Hydrological Model
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WRF	Weather Research and Forecasting Model
WSU	Washington State University

Appendix C. References

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Appendix D. Inventory of ORD Nr and Co-Pollutant Research Projects (2012) Relevant to SAB Recommendations

ACE: Air, Climate and Energy research program
HHRA: Human Health Risk Assessment research program
SHC: Sustainable and Healthy Communities research program
SSWR: Safe and Sustainable Water Resources research program

NOTE: This Table was developed in 2012 based only on EPA/Office of Research and Development projects and does not reflect Office of Air and Radiation, Office of Water, or regional office research efforts. This is not EPA's formal response to the SAB.

No.	SAB Recommendation	ORD Research Projects	Research Summary
1	Increase the specificity and regularity of data acquisition for fertilizer application to agricultural crops and facilitate monitoring and evaluation of impact from implemented policies and mitigation efforts.	**ACE MDST-3** Modeling air quality impacts on pollutant deposition and water quality **SHC 3.3.1** Informing sustainable decisions about nitrogen	**ACE MDST-3** A fertilizer tool from USDA to allow crop fertilizer management scenarios to be easily incorporated in CMAQ to assess impacts of agricultural management policies **SHC 3.3.1** Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions
2a	Generate data on N fertilizer use efficiency and N mass balance based on measurements from production scale fields for major crops.	**SHC 1.2.3** EnviroAtlas	**SHC 1.2.3** Multiple national data layers developed related to atmospheric deposition, pollutant loading, and N sources and sinks
2b	Promote efforts to: (1) Increase the rate of gain in crop yields on farm land while increasing N fertilizer uptake efficiency and (2) Explore the potential for more diverse cropping systems with lower N fertilizer input requirements.		

No.	SAB Recommendation	ORD Research Projects	Research Summary
2c	Identify research and education priorities to support more efficient use and better mitigation of Nr applied to agricultural systems.	**ACE MDST-3** Modeling air quality impacts on pollutant deposition and water quality **SHC 1.2.3** EnviroAtlas	**ACE MDST-3** A fertilizer tool from USDA to allow generation and evaluation of alternative agriculture management scenarios **SHC 1.2.3** Multiple national data layers developed related to atmospheric deposition, pollutant loading, and N sources and sinks
3	Reduce uncertainty in estimates of nitrous oxide emissions from crop agriculture.	**SEE-2** Energy from Biomass: Managing the Impact of Emerging Bioenergy Pathways **ACE EM-2** Improving emissions inventories **SSWR 1.2** Development and integration of models relating to water resource integrity and sustainability **SSWR 4.3** Green infrastructure modeling tools and data inventories	**SEE**-2 N_2O agricultural emissions data for switchgrass and corn for development of regional N_2O budgets. Enhanced CMAQ modeling capability with respect to biofuels, feedstock production and N_2O fluxes **ACE EM-2** Evaluated EPIC estimates of nitrous oxide emissions from fertilizer application and nitrous oxide emissions incorporated into CMAQ **SSWR 1.2** Improve methods for statistical modeling of individual stressor-response relationships from observational data given the influence of other stressors and spatial relationships **SSWR 4.3** Reliably predict natural infrastructure and engineered green infrastructure water quality impacts at watershed scale
4	Improve understanding and prediction of how expansion of biofuel production will affect Nr inputs and outputs from agriculture and livestock systems.	**SHC 2.1.2.1 (also ACE SEE-2)** Ecosystem goods and services production and benefit functions (and conclusion of Future Midwestern Landscapes Study, including air quality impacts) **ACE EM-2** Improving emissions inventories **SSWR 1.2** Development and integration of models relating to water resource integrity and sustainability **SSWR 4.3** Green infrastructure modeling tools and data inventories	**SHC 2.1.2.1 (also ACE SEE-2)** Enhanced CMAQ modeling capability with respect to biofuels, feedstock production and N_2O fluxes **ACE EM-2** Evaluated EPIC estimates of nitrous oxide emissions from fertilizer application and nitrous oxide emissions incorporated into CMAQ **SSWR 1.2** Improve methods for statistical modeling of individual stressor-response relationships from observational data given the influence of other stressors and spatial relationships **SSWR 4.3** Establish databases on green BMPs performance for stormwater management under regionally-relevant conditions

No.	SAB Recommendation	ORD Research Projects	Research Summary
5	Monitor and assess gases and particulate matter precursors emitted from agricultural emissions (e.g., NO_3^- and NH_4^+ utilizing a nationwide network of monitoring stations.	**ACE NMP-6** Atmospheric deposition tools to inform secondary NAAQS **ACE EM-2** Improving emissions inventories	**ACE NMP-6** Integrated flux measurement platform to measure dry and wet deposition fluxes of ozone, nitrogen and sulfur compounds to provide guidance on monitoring methods **ACE EM-2** Description, development and evaluation of crop residue burning emission estimates
6	Develop a policy, regulatory, and incentive framework to improve manure management to reduce Nr load and ammonia transfer, taking into account phosphorus load issues.		
7a	Coordinate research with other agencies and state extensions to ensure that fertilization recommendations are accurate and promote awareness of the issue.	**SHC 3.3.1** Informing sustainable decisions about nitrogen	**SHC 3.3.1** New regional work centered on groundwater and nutrient trading
7b	Promote improved turf management practices.		
8a	Reexamine the criteria pollutant "oxides of nitrogen" and the indicator species NO_2 and consider adding Nr as a criteria pollutant, and NH_x and NO_y as indicators to supplement the NO_2 National Ambient Air Quality Standard.	**HHRA 2.2.1** Integrated Science Assessment (ISA) of the Ecological Effects of NO_x and SO_x **ACE NMP-6** Atmospheric deposition tools to inform secondary NAAQS	**HHRA 2.2.1** The ISA is a review and integrated synthesis of published literature on the effects of N and S deposition on US ecosystems. It is the scientific foundation for the NAAQS review of NO_x and SO_x **ACE NMP-6** Improved methods for quantifying N and sulfur concentrations and air-surface exchange fluxes with high temporal resolution

No.	SAB Recommendation	ORD Research Projects	Research Summary
8b	Monitor of NH_x and NO_y to supplement the existing network of NO_2 compliance monitors.	**ACE NMP-6** Atmospheric deposition tools to inform secondary NAAQS **ACE EM-1** Methods for measurement to inform policy decisions	**ACE NMP-6** Integrated flux measurement platform to measure dry and wet deposition fluxes of ozone, N and sulfur compounds to provide guidance on monitoring methods **ACE EM-1** FRMs in support of other NAAQS reviews (i.e., NO_2-2014-2015, SO_2 - 2014-2015, CO-2016, PM-2016, NO_x-SO_x Secondary-2016
8c	Monitor and measure individual components of Nr, such as NO_2, NO and PAN, and HNO_3, and other inorganic and reduced forms.	**ACE NMP-6** Atmospheric deposition tools to inform secondary NAAQS **ACE EM-1** Methods for measurement to inform policy decisions **ACE EM-2** Improving emissions inventories	**ACE NMP-6** Improved methods for quantifying N and sulfur concentrations and air-surface exchange fluxes with high temporal resolution **ACE EM-1** FRMs in support of other NAAQS reviews (i.e. NO_2-2014-2015, SO_2 - 2014-2015, CO-2016, PM-2016, NO_x-SO_x Secondary-2016) **ACE EM-2** Revised soil NO emission estimates for the US
8d	Increase scope and spatial coverage of Nr concentration and flux monitoring networks and appoint an oversight review panel for these networks.	**ACE NMP-6** Atmospheric deposition tools to inform secondary NAAQS	**ACE NMP-6** Integrated flux measurement platform to measure dry and wet deposition fluxes of ozone, N and sulfur compounds to provide guidance on monitoring methods
8e	Improve measurements and models for the following: • Deposition directly both at the CASTNET sites and in nearby locations with nonuniform surfaces. • Convective venting of the planetary boundary layer and of long range transport. • Atmospheric organic N compounds in vapor, particulate, and aqueous phases. • NH_3 flux to the atmosphere from major sources especially agricultural practices. • NO_y and NH_x species	**ACE NMP-6** Atmospheric deposition tools to inform secondary NAAQS **ACE MDST-2** Regional to continental scale MP air quality modeling **ACE MDST-3** Modeling air quality impacts on pollutant deposition and water quality	**ACE NMP-6** Integrated flux measurement platform to measure dry and wet deposition fluxes of ozone, N and sulfur compounds to provide guidance on monitoring methods **ACE MDST-2** Improved meteorological modeling fields for CMAQ through refined PBL mixing, land-surface characterization, and data assimilation strategies **ACE MDST-3** CMAQ with bi-directional NH_3 air-surface exchange for improved flux estimations

No.	SAB Recommendation	ORD Research Projects	Research Summary
9	Quantify N budgets of terrestrial systems and define magnitudes of major loss vectors.	**ACE EM-2** Improving emissions inventories **ACE MDST-3** Modeling air quality impacts on pollutant deposition and water quality **SHC 1.2.3** EnviroAtlas **SHC 3.3.1** Informing sustainable decisions about nitrogen	**ACE EM-2** Revised soil NO emission estimates for the United States **ACE MDST-3** Improved sulfur and N deposition estimates, including bi-directional NH_3, from CMAQ for critical loads support regarding acidification and nutrients **SHC 1.2.3** Multiple national data layers developed related to atmospheric deposition, pollutant loading, and nitrogen sources and sinks **SHC 3.3.1** Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions
10	Quantify denitrification in soils and aquatic systems.	**SHC 1.2.3** EnviroAtlas **SHC 3.3.1** Informing sustainable decisions about nitrogen	**SHC 1.2.3** Multiple national data layers developed related to atmospheric deposition, pollutant loading, and N sources and sinks **SHC 3.3.1** Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions
11	Develop a uniform assessment and management framework that considers the effects of Nr loading over a range of scales reflecting ecosystem, watershed, and regional levels.	**ACE MDST-3** Modeling air quality impacts on pollutant deposition and water quality **SHC 3.3.1** Informing sustainable decisions about nitrogen **SSWR 1.2** Development and integration of models relating to water resource integrity and sustainability	**ACE MDST-3** A modeling system to allow the assessment of the effects of Nr loading across air, land and water media at the national scale through connections of the N cascade **ACE MDST-3** Through incorporation of bi-directional exchange of NH_3, improved estimates of the impact of NH_3 on fine particulate formation and lifetimes **SHC 3.3.1** Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions **SSWR 1.2** Improve methods for statistical modeling of individual stressor-response relationships from observational data given the influence of other stressors and spatial relationships

No.	SAB Recommendation	ORD Research Projects	Research Summary
11	(Continued from previous page.) Develop a uniform assessment and management framework that considers the effects of Nr loading over a range of scales reflecting ecosystem, watershed, and regional levels.	**SSWR 2.3** Optimal solutions for sustainable nutrient management **SSWR 4.3** Green infrastructure modeling tools and data inventories **SSWR 6.1** Narragansett Bay and Watershed Sustainability --Demonstration Project	**SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters **SSWR 4.3** Reliably predict natural infrastructure and engineered green infrastructure water quality impacts at watershed scale **SSWR 6.1** (1) Trend analysis of stressors and ecological responses, particularly nutrients, in the Narragansett Bay Watershed; (2) Quantitative models describing current and future nutrient fluxes and associated responses in the Narragansett Bay watershed and estuary ecosystem
12	Reevaluate water quality management approaches, tools, and authorities to ensure Nr management goals are attainable, enforceable, and cost-effective.	**SSWR 2.3** Optimal solutions for sustainable nutrient management **SSWR 6.1** Narragansett Bay and Watershed Sustainability --Demonstration Project	**SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters **SSWR 6.1** Trend analysis of stressors and ecological responses, particularly nutrients, in the Narragansett Bay Watershed
13	Account for the presence of Nr in appropriate forms (air, land, and water) and through periodic accounting documents.	**SHC 3.3.1** Informing sustainable decisions about nitrogen	**SHC 3.3.1** Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions
14	Consider the impact of different metrics and examine the range of traditional and ecosystem response categories as a basis for expressing Nr impacts and supporting integrated management efforts.	**SHC 2.1.2.1 (also ACE SEE-2)** Ecosystem goods and services production and benefit functions (and conclusion of Future Midwestern Landscapes Study, including air quality impacts)	**SHC 2.1.2.1 (also ACE SEE-2)** Synthesis document on use of sustainability metrics to complement life cycle approaches

No.	SAB Recommendation	ORD Research Projects	Research Summary
14	(Continued from previous page.) Consider the impact of different metrics and examine the range of traditional and ecosystem response categories as a basis for expressing Nr impacts and supporting integrated management efforts.	**SHC 3.3.1** Informing sustainable decisions about nitrogen **SSWR 2.3** Optimal solutions for sustainable nutrient management **SSWR 6.1** Narragansett Bay and Watershed Sustainability --Demonstration Project	**SHC 3.3.1** Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions **SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters **SSWR 6.1** SSWR 1.1b contributions to: (1) Trend analysis of stressors and ecological responses, particularly nutrients, in the Narragansett Bay Watershed; and (2) Quantitative models describing current and future nutrient fluxes and associated responses in the Narragansett Bay watershed and estuary ecosystem
15a	1. Evaluate regulatory and non-regulatory tools to manage Nr in populated areas from nonpoint sources, stormwater, domestic sewage, and industrial wastewater treatment facilities. 2. Determine regulatory and voluntary mechanisms to apply to each source type with special attention to the need to regulate nonpoint source and related land use practices.	**SHC 3.3.1** Informing sustainable decisions about nitrogen **SSWR 2.3** Optimal solutions for sustainable nutrient management	**SHC 3.3.1** Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions **SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters

No.	SAB Recommendation	ORD Research Projects	Research Summary
15b	1. Review regulatory practices for point sources, including wastewater treatment plants and stormwater. 2. Consider technology limitations, multiple pollutant benefits, funding mechanisms, and potential impacts on climate change from energy use and greenhouse gas emissions.	**SSWR 4.1** Determine integration of green infrastructure in communities **SSWR 5.2** Innovation for water treatment system efficiency and integration **SSWR 5.3** Water Technology Innovation Cluster **SSWR 5.4** Develop and implement innovative approaches to water infrastructure based on resource recovery **SSWR 5.6** Determine the new and innovative technologies and approaches that can be used to monitor and mitigate aging distribution systems	**SSWR 4.1** Develop effective integrated green and gray approaches at the sewershed/ watershed scale **SSWR 5.2** Develop innovative technologies and approaches for small drinking water and wastewater systems including those that combine pollution prevention, water reuse, resource recovery and potential economic advantages with low capital, operations and maintenance costs **SSWR 5.3** Develop sustainable processes for contaminant (including nutrient) removal below the limits of current technologies that minimizes costs, energy consumption, environmental burden, chemical consumption, and associated greenhouse gases production **SSWR 5.4** Identify and develop and demonstrate technologies that optimize recovery of energy, nutrients, and water within water systems **SSWR 5.6** Improved water conveyance technologies and innovative approaches to assess and replace/rehabilitate aging water infrastructure
15c	1. Set Nr management goals on a regional/ local basis. 2. Consider "green" management practices along with traditional engineered best management practices.	**SSWR 1.2** Development and integration of models relating to water resource integrity and sustainability **SSWR 2.3** Optimal solutions for sustainable nutrient management **SSWR 4.3** Green infrastructure modeling tools and data inventories	**SSWR 1.2** Improve methods for statistical modeling of individual stressor-response relationships from observational data given the influence of other stressors and spatial relationships **SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters **SSWR 4.3** Reliably predict natural infrastructure and engineered green infrastructure water quality impacts at watershed scale

No.	SAB Recommendation	ORD Research Projects	Research Summary
15d	1. Research best management practices that are effective in controlling Nr, especially for nonpoint and stormwater sources, including land and landscape feature preservation and set Nr management targets that reflect management and preservation capacities. 2. Construct a decision framework to assess and determine implementation actions consistent with management goals.	**SSWR 1.2** Development and integration of models relating to water resource integrity and sustainability **SSWR 2.3** Optimal solutions for sustainable nutrient management **SSWR 4.3** Green infrastructure modeling tools and data inventories	**SSWR 1.2** Improve methods for statistical modeling of individual stressor-response relationships from observational data given the influence of other stressors and spatial relationships **SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters **SSWR 4.3** Establish databases on green BMPs performance for stormwater management under regionally-relevant conditions
15e	Develop programs to encourage wetland restoration and creation with strategic placement of wetlands where Nr is highest in ditches, streams, and rivers.	**SSWR 1.3** Decision-support tools to aid development of market based activities that promote watershed integrity **SSWR 2.3** Optimal solutions for sustainable nutrient management **SHC 3.3.1.5** Sustainable nitrogen management tools and case studies	**SSWR 1.3** Decision-support tools to aid development of market-based activities that promote watershed integrity **SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters **SHC 3.3.1.5** Geospatial tool for managers to describe sources and sinks of nitrogen in a watershed for use in conservation and restoration prioritization
16	Adopt the critical loads approach concept in determining thresholds for effects of excess Nr on terrestrial and aquatic ecosystems.	**HHRA 2.2.1** Integrated Science Assessment (ISA) of the Ecological Effects of NO_x and SO_x **ACE MDST-3** Modeling air quality impacts on pollutant deposition and water quality	**HHRA 2.2.1** The ISA is a review and integrated synthesis of published literature on the effects of N and S deposition on US ecosystems. It is the scientific foundation for the review of the secondary NAAQS for NO_x and SO_x **ACE MDST-3** Improved sulfur and N deposition estimates, including bi-directional NH_3, from CMAQ for critical loads support regarding acidification and nutrients

No.	SAB Recommendation	ORD Research Projects	Research Summary
16	(Continued from previous page.) Adopt the critical loads approach concept in determining thresholds for effects of excess Nr on terrestrial and aquatic ecosystems.	**ACE MA-1 (also SCH 3.3.1)** Vulnerable people and ecosystems **SHC 3.3.1** Informing sustainable decisions about nitrogen **SSWR 1.2** Development and integration of models relating to water resource integrity and sustainability **SSWR 2.3** Optimal solutions for sustainable nutrient management **SSWR 4.3** Green infrastructure modeling tools and data inventories	**ACE MA-1 (also SHC 3.3.1)** Analysis of terrestrial ecosystem exposure to nitrogen in comparison to critical loads for biodiversity in those ecosystems **SHC 3.3.1** Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions **SSWR 1.2** Improve methods for statistical modeling of individual stressor-response relationships from observational data given the influence of other stressors and spatial relationships **SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters **SSWR 4.3** Establish databases on green BMPs performance for stormwater management under regionally-relevant conditions
17	Address NH_3 as a harmful PM2.5 precursor.	**ACE MDST-2** Regional-to continental-scale multipollutant air quality modeling **ACE MDST-3** Modeling air quality impacts on pollutant deposition and water quality **ACE NMP-6** Atmospheric deposition tools to inform secondary NAAQS	**ACE MDST-2** Advanced aerosol physics in CMAQ to address the interactions of the inorganic system, including the effects of NH_3 in forming fine particulates **ACE MDST-3** Through incorporation of bi-directional exchange of NH_3, improved estimates of the impact of NH_3 on fine particulate formation and lifetimes **ACE NMP-6** Improved methods for quantifying N and sulfur concentrations and air-surface exchange fluxes with high temporal resolution
18	Develop integrated strategies for Nr management to be developed in cognizance of the tradeoffs associated with Nr in the environment.	**ACE MDST-3** Modeling air quality impacts on pollutant deposition and water quality **SSWR 1.2** Development and integration of models relating to water resource integrity and sustainability	**ACE MDST-3** A modeling system to allow the assessment of the effects of Nr loading across air, land and water media at the national scale through connections of the N cascade **SSWR 1.2** Improve methods for statistical modeling of individual stressor-response relationships from observational data given the influence of other stressors and spatial relationships

No.	SAB Recommendation	ORD Research Projects	Research Summary
18	(Continued from previous page.) Develop integrated strategies for Nr management to be developed in cognizance of the tradeoffs associated with Nr in the environment.	**SSWR 2.3** Optimal solutions for sustainable nutrient management **SSWR 4.3** Green infrastructure modeling tools and data inventories	**SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters **SSWR 4.3** Reliably predict natural infrastructure and engineered green infrastructure water quality impacts at watershed scale
19	Support cross-disciplinary and multiagency research on climate and Nr interactions.	**ACE MDST-3** Modeling air quality impacts on pollutant deposition and water quality **ACE MDST-4** Hemispheric- to global-scale multipollutant air quality and climate models **SHC 3.3.1** Informing sustainable decisions about nitrogen **SSWR 1.2** Development and integration of models relating to water resource integrity and sustainability **SSWR 2.3** Optimal solutions for sustainable nutrient management **SSWR 4.3** Green infrastructure modeling tools and data inventories	**ACE MDST-3** With the coupled meteorology and hydrology in dynamically downscaled regional climate simulations, assessments of the impact of climate change on N management in air, land, and water media will be conducted **ACE MDST-4** Methodologies for downscaling NASA/NOAA/NCAR global models using WRF as a regional climate model **SHC 3.3.1** Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions **SSWR 1.2** Improve methods for statistical modeling of individual stressor-response relationships from observational data given the influence of other stressors and spatial relationships **SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters **SSWR 4.3** Reliably predict natural infrastructure and engineered green infrastructure water quality impacts at watershed scale

No.	SAB Recommendation	ORD Research Projects	Research Summary
20	Develop a national, multi-media monitoring program that monitors sources, transport and transition, effects using indicators where possible, and Nr sinks in keeping with the N cascade concept.	**SHC 3.3.1** Informing sustainable decisions about nitrogen **SSWR 2.3** Optimal solutions for sustainable nutrient management	**SHC 3.3.1** Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions **SSWR 2.3** Scientific approaches supporting the development of numeric nutrient criteria and interpretation of narrative standards for inland waters and downstream estuarine and coastal waters

Appendix E. Summary of Research Gap Analysis

Science Challenges

Overarching EPA Nitrogen and Co-pollutant Roadmap Outcome

Reduced and avoided ecological and public health impacts from nitrogen and co-pollutant pollution to air, water, and land.

Overarching EPA Nitrogen and Co-pollutant Roadmap Output

Models, tools and technologies that incorporate scientific, social, economic, and cross media factors to inform regulatory and non-regulatory solutions to nitrogen and co-pollutant issues.

Common gaps across all Science Challenges:

- Develop a process to insure integrative success of nitrogen and co-pollutant research housed in multiple tasks, projects, ORD RAPs and office and regional efforts.
- Develop a process to identify relevant external (academic, Federal, state, NGO) research efforts that address key management steps identified.
- Develop a formal, collaborative process between ORD, the program offices and regional offices to discuss how best to provide tools for the Program Offices to make national decisions and for the regional offices and states to use in developing prioritized load reductions.
- Develop an ongoing process for identifying additional research gaps that were missed in this analysis.
- Ensure results of case studies (e.g. GOM, Chesapeake Bay, Narragansett Bay) are mutually informative and can start to address research scaling issues.

Science Challenge 1 – *Where should we be targeting to reduce nitrogen and co-pollutant loads?*
Nitrogen and co-pollutant loading from atmospheric, aquatic and terrestrial sources is far from uniform, regionally or nationally. Likewise, the effects of nitrogen and co-pollutant pollution vary across receptors; some types of ecosystems, human subpopulations, and water supplies are more vulnerable than others to the risks of exposure to excess nitrogen and co-pollutants. Locating priority areas requires knowledge of the magnitude and sources of the loads, as well as the risks associated with expected ecological and human exposures, both within a particular area, and in other areas to which nitrogen and co-pollutants are exported, such as coastal waters. Societal and economic costs/benefits should be considered, when appropriate and not restricted by law, in determination of optimized nitrogen and co-pollutant reduction strategies. National-scale assessments require information across several finer scales on all relevant populations, ecosystem-types and regions.

Sub-outcome: Programs and stakeholders know where nitrogen and co-pollutant reductions are most needed to prevent harmful ecological and public health impacts.

Sub-output: Effective approaches to evaluate (a) N and co-pollutant occurrence and sources, (b) Exposure to N and co-pollutant pollution by receptor, (c) N and co-pollutant pathways through ecosystems, (d) ecological and human endpoints and thresholds, (e) a range of target levels, and (f) decision-support tools for meeting targets that incorporate social and economic costs and benefits of N and co-pollutant management.

Step 1.1 Synthesis:
Compile and synthesize existing scientific knowledge to inform the identification of geographic areas that are vulnerable to N pollution and identify critical research gaps.

Needs:

- Better integration of ORD,OW, regional, and other Agency efforts, similar to the Integrated Science Assessments (ISA) for NAAQS (See details in Research Inventory Table).
- An assessment of nitrate and nitrites on human health.

Supporting research:

- ISA's for NO_x and SO_x NAAQS (HHRA 2.2.1); Mapping N sources and N-impacted ecosystems at scales for national, regional and local decisions (SHC 3.3.1.1).
- Multi-agency refinement of Critical Loads and impacts database (SHC 3.3.1.3, ACE 145).

Step 1.2 Endpoints and Thresholds:
Determine no-effect (critical concentrations/levels and critical loads, maximum contaminant level goal, water and air quality criteria) exposure levels for nitrogen and co-pollutants in ecological systems or human populations of interest, including an evaluation of impacts of multiple contaminants or other confounding factors (includes dose-response relationships).

Needs:

- Better definition of atmospheric deposition contribution to the total nitrogen load in aquatic systems.
- Determine whether changing climate patterns may threaten endpoints or require reconsideration of threshold values.
- Quantifying the non-point source contribution of nutrients to drinking water contamination, both surface and ground water.
- Better data on human health responses, particularly related to nitrate in drinking water and harmful algal blooms.
- Identify the endpoints and thresholds that can best be used in national assessments, including nitrogen enrichment of terrestrial ecosystems and biodiversity changes.
- Determine ways to aggregate endpoints and thresholds within ecoregions and watersheds.

Supporting research:

- ISA for NO_x and SO_x NAAQS periodically evaluate all published N deposition to ecological response relationships (HHRA 2.2.1). ISA for NO_x evaluates NO_2 relationships to human health response (HHRA 2.1.4).
- Economic and social aspects of nutrient reduction efforts are included in the Narragansett Bay (SSWR6.1) and Chesapeake Bay (SSWR 6.5) watershed studies.
- Critical Loads development (SHC 3.3.1.3, ACE 145, OAR critical loads database).

<u>Step 1.3 Exposure</u>:
Determine the current and projected future levels of nitrogen and co-pollutant exposure in targeted ecological systems and human populations across relevant spatial and temporal scales.

Needs:

- Better data on drinking water and human exposure via nitrosamines and disinfection byproducts, and cyanotoxins.
- Develop low cost and transportable, low energy NO_y and speciated NO_y instruments to characterize ambient nitrogen levels and complete certification process for existing NO_y technology.
- Improve characterization of natural sources of nitrogen (e.g., soils and lightning), organic nitrogen, and cloud and fog deposition in high elevation areas.
- Evaluate dry deposition model performance.
- Improve and expand soil weathering rate estimates nationally.

Supporting research:

- Research on modeling emissions to exposure pathways for N species (ACE MDST-3).
- Research on air monitoring methods with transfer to OAR/OAP and OAQPS (ACE EM-1 and NMP-6).
- ACE, SSWR, and SHC development of data layers for the EnviroAtlas (SHC 1.2.3.3).
- ORD, National Park Service and Forest Service development of total deposition maps (ACE MDST-3).
- ORD/USGS collaboration on SPARROW modeling.
- Assessment of spatial specificity of statistically based condition assessments for program office needs (SSWR 1.1).

<u>Step 1.4 Services</u>:
Establish issue-defined metrics based on environmental, societal, and economic costs and benefits for use in prioritization of locations, exposed populations, or ecological systems for nitrogen loading/exposure reductions.

Needs:

- Coordinate existing work and establish new collaborations with USGS for use of the Nitrogen and Phosphorus Pollution Data Access (NPDAT) tool.
- Develop relationships between thresholds, incremental changes in nitrogen and co-pollutant loads, and effects on ecosystem services.

Supporting research:

- Research on N deposition impacts on biodiversity leading to impacts on recreation, intrinsic value and timber production (SHC 3.3.1.4).
- Determination of economic and social costs and benefits of nutrient reduction (SSWR 1.2; 6.5; SHC 3.3.1.2; SSWR 6.5; OW-OST Nutrients in the Economy).
- Effects of nitrogen and co-pollutant loads on the provision of ecosystem services (SHC 3.3.1; SSWR 6.5; OW).

Step 1.5 Climate Change:
Assess robustness of chosen metrics under scenarios of climate change; e.g., increased water temperature and precipitation changes.

Needs:

- Need to improve downscaled climate models to better predict future air exposures and threshold levels of nitrogen and co-pollutants.
- Need to determine total N exposure to humans and the environment from the emissions of both reduced and organic N, which historically have been less of a focus than oxidized N.
- Need improved data on how climate will alter terrestrial ecosystem sensitivity to N and co-pollutants.
- Need to develop approaches to estimate the anthropogenic contribution to acidification that comes from inputs of nitrogen to coastal/estuarine systems.

Supporting research:

- OW studies on the impact of climate change on N and co-pollutants.

Step 1.6 Exceedance:
Identify ecosystems, human populations, watershed units or areas that are in exceedance of the criteria or critical concentration/level or critical load; or that are reasonably likely to be exposed to critical concentrations/levels.

Needs:

- Determine how magnitude, requency and duration of nutrient loading affect expression of impairment for aquatic endpoints, with coordination of efforts in OW and ORD.
- Determine extent of critical load exceedance on a national scale of multiple endpoints for aquatic and terrestrial acidification and aquatic and terrestrial nitrogen enrichment.

Supporting research:

- Development of a modeling framework for prediction of deposition fields to allow estimation of critical load exceedances (ACE MDST-3).
- OW and ORD model based approaches may address potential vulnerabilities to exceedances of water quality standards (SHC 3.3.1.1).
- Physical condition assessment approaches (e.g. NARS) provide statistically valid, scalable assessments of whether critical levels (e.g. water quality criteria values for nutrients) are being exceeded.
- Satellite based measurements to determine whether TMDL values are being exceeded and for measurement of cyanobacterial blooms (SSWR 2.3B, 2.3C).
- Numeric nutrient criteria development (SSWR 2.3A).
- Development of national critical loads database (OAR).

Step 1.7 Tools:
Develop approaches and tools to support prioritization of locations, systems, etc. for management action to reduce nitrogen loads and exposures based on environmental, social and economic risks.

Needs:

- A formal assessment of existing and proposed decision-support tools, together with some attempt to walk through some scenarios of desired outcomes.
- Tools that can assess human health non-attainment areas, terrestrial effects from deposition, and water quality issues and rank an area in terms of its priority for interventions.
- Compilation in publicly accessible format of existing information on ecological critical loads for terrestrial metrics (e.g. terrestrial biodiversity, soil acidification, aquatic acidification, etc.)
- Develop a process to ensure integrative success of nutrient research housed in multiple tasks, projects, ORD RAPs and Office and Regional efforts. In particular, insure results of case studies (e.g. GOM, Chesapeake Bay, Narragansett Bay) are mutually informative and can start to address research scaling issues.
- Develop and integrate ecosystem service metrics and accountability measures for social and economic endpoints of concern into exposure-response models for nutrients.

Supporting research:

- OW's Recovery Potential Screening tool incorporates a range of indicators and allows the user to examine particular watersheds for potential actions to address N and other stressors (http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/index.cfm).
- Current ecosystem service and economic work being done in Narragansett and the Chesapeake Bay programs (SSWR 6.1, 6.5); national-scale work (SHC 3.3.1.2).

Science Challenge 2 – *How do we set nitrogen and co-pollutant reduction goals for priority areas?* Establishing goals for nitrogen and co-pollutant reduction is a policy matter, but goals must be grounded in the best available science. Research should be applied to estimate effectiveness, feasibility (economic and engineering), and uncertainties of a range of potential reduction goals. Narrative nutrient standards for ambient waters that the majority of states have in place have not consistently proved effective in adequately protecting aquatic life and downstream ecosystems. Similarly, current ambient air quality standards do not fully protect the most sensitive aquatic and terrestrial ecosystems. Ozone, particulate matter and oxides of nitrogen in the ambient air also cause significant human health concerns and must be considered when making decisions about reducing nitrogen and co-pollutants in a geographic area. Appropriately protective and implementable criteria and standards will be important elements of a comprehensive nitrogen and co-pollutant reduction strategy. We should also consider ground water quality goals expressed in state regulations as well as MCLs, and understand the fate and transport of nitrogen from land surface to ground water and then to surface water.

Sub-outcome: Each prioritized area has a range of science-based reduction targets to inform policy and management decisions.

Sub-output: Models, technologies, and decision-support tools that include economic and sustainability approaches to aid with setting reduction goals and optimize implementation approaches.

Step 2.1 Synthesis:
Compile and synthesize existing scientific knowledge to inform setting reduction goals and identify critical research gaps.

Needs:

- A synthesis of N input and effects from sources other than air, specifically designed to help set reduction goals in priority areas.
- An assessment of nitrate and nitrites on human health.
- National database or synthesis of nutrient-related TMDLs and criteria.
- Research providing improved relationships between nutrient source and nutrient-related impairments. Potential syntheses include impaired waters or waters that exceed the proposed criteria with source attribution, and exposure and effects indicators from NARS.

Supporting research:

- HHRA conducts the Integrated Science Assessments (ISA) and Integrated Risk Information System (IRIS) on the ecological and human health effects caused by specific chemical species of N (HHRA 2.2.1, 2.1.4 and 1.1.17).
- OW is creating a database of 5000+ nutrient TMDLs with N and P target values, waterbody type, methods etc. (A Comparison of Nutrient Water Quality Targets and EPA – Recommended Ecoregional Water Quality Criteria).
- OST effort to collate and publish criteria via the Web at the following site http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/progress.cfm

Step 2.2 Sources:
Determine the key assessment endpoints and identify the sources and their relative contribution to nitrogen and co-pollutant loadings, exposure and exceedances affecting priority areas, including downstream effects.

Needs:

- Methods to improve source attribution estimates for nitrogen and co-pollutants at the ecoregion and small watershed scale.
- Formal assessment of strengths and weaknesses of models for use in source apportionment (e.g. CMAQ, SWAT, SPARROW, VELMA, HAWQS) to provide guidance on appropriate use for particular management or regulatory needs.
- Improve methods to estimate ambient air concentration to deposition ratios on a broad scale.

Supporting research:

- Nitrogen source identification research using stable isotopes can provide a tool to estimate relative source importance (SSWR 2.3A).
- The EnviroAtlas (SHC 1.2.3.3) delineates nitrogen sources to terrestrial ecosystems characterized at the 12 digit HUC level.
- SHC 3.3.1.1 provides input source apportionment by HUC 8 and HUC 12 for land and coastal inputs.

- Modeling efforts using NARS data for input will apportion the relative contributions of different sources contributing to the conditions observed (SSWR 1.1).
- Transport and transformation from emissions to exposure, and exposure of terrestrial ecosystems from atmospheric deposition, are dealt with in the EPA air quality tools (ACE MDST-2, MDST-3).
- Source attribution from emitting sectors and/or from geographic regions is available for air concentrations and air deposition, and updates to CMAQ will address ammonia bi-directional exchange (ACE MDST-2).
- Receptor oriented source attribution tools at the local, regional, and national scales are being developed (ACE MA-4).
- Integrated air-water nitrogen budgets and source apportionment to attribute the delivery of nutrients to the Gulf of Mexico (ACE MDST-3).
- N source apportionment to the coastal zone and scenarios of N loading to conterminous US coastal zones (SHC 3.3.1.1.).
- HHRA conducts the Integrated Science Assessments (ISA) and Integrated Risk Information System (IRIS) on the ecological and human health effects caused by specific chemical species of N (HHRA 2.2.1, 2.1.4 and 1.1.17).

Step 2.3 Exposure Response:
Identify source to exposure relationships (how exposure responds to source reduction) and quantify air concentration-to-deposition and terrestrial-to-aquatic relationships.

Needs:

- Research is needed on N transformations in freshwater stream and or lake systems; links to VELMA for soil to stream transformation and CADDIS should be explored.
- Assess how changes in emissions affect nitrogen deposition and transport across terrestrial and aquatic ecosystems.

Supporting research:

- ACE research addresses multiple issues of concentration, deposition, and transport relationships (NMP-6; MDST-3; MDST-2).
- Linked ocean, land atmospheric models of Nr to predict Gulf hypoxia versus source reduction (SSWR 2.3D).
- Developing empirical relationships between land use and nitrogen loads for west coast estuaries (SSWR 2.3A).
- Sources of N associated with land use variation affecting loads to lakes and expression of cyanobacterial blooms (SSWR 2.3C). Determine sources of Nr and expression in Narragansett Bay (SSWR 6.1).
- HHRA conducts the Integrated Science Assessments (ISA) and Integrated Risk Information System (IRIS) on the ecological and human health effects caused by specific chemical species of N (HHRA 2.2.1, 2.1.4 and 1.1.17).

Step 2.4 Endpoint Response:
Develop system-wide ecosystem exposure-response relationships reflecting alternative load reduction scenarios (how ecosystem responds to changes in reduction scenarios), including downstream effects.

Needs:

- Research on exposure-response for terrestrial and aquatic ecosystem components in relation to nitrogen and co-pollutant deposition.
- Improve understanding of how other stressors (e.g. ozone, pests, and drought) may exacerbate nitrogen and co-pollutant impacts.
- Linking freshwater river and stream nutrient response models.
- Inclusion of societal and economic endpoints (in assessments of load reduction scenarios).

Supporting research:

- Meta-analysis on the impacts of nitrogen deposition on herbaceous biodiversity using several existing data sources nationally (SHC 3.3.1.3).
- The ISA for NO_y evaluates all relevant published literature regarding the ecological effects of NO_y deposition as it contributes to effects caused by total N loading. (HHRA 2.2.1).
- Statistical models that relate condition of specific aquatic resources to spatial indicators derived from nationally available datasets (SSWR 1.1B).
- Interlinked exposure-response models which deal with multiple marine aquatic trophic levels (SSWR 2.3D).
- Methods for estuarine source determination of which N inputs are going to biological response endpoints (e.g. macroalgae) (SSWR 2.3.A).
- Human health endpoints related to cyanotoxins (SSWR 2.3C).

Step 2.5 Services:
Determine services of ecosystems and their value and quantify ecosystem service response functions, and metrics, including tools for tradeoff analyses, to assess impacts from nitrogen and co-pollutant sources and loads for ecological systems or human populations of interest.

Needs:

- Nitrogen and co-pollutant impacts on ecosystem services and benefits should be quantified for ecosystem scale metrics such as biodiversity or productivity.
- Ecosystem service metrics should be developed for incremental changes in nitrogen and co-pollutant loadings.
- Public welfare impacts of specific N sources such as ammonia should be quantified.
- Current projects on WQ trading and TMDLs should be connected to nutrient loading and ecosystem services to inform regulatory and management decisions.

Supporting research:

- SHC 3.3.1.2 is synthesizing existing information on connections between nitrogen and social and economic systems.

<u>Step 2.6 Climate Change</u>:
Determine how climate change might affect system-wide ecosystem exposure-response relationships.

Needs:

- Models being developed by ACE, SHC, and SSWR should be extended, where possible, to provide estimates of the effect of climate on nutrient delivery to coastal estuaries nationwide.
- Ecosystem endpoints and thresholds should be evaluated with changing climate parameters, e.g., drought and weather extremes.

Supporting research:

- Regional scale research is bringing together meteorology, hydrology, deposition, and watershed delivery of nutrients to coastal estuaries (MARB/GOM) under climate change conditions (ACE, SHC and SSWR).

<u>Step 2.7 Tools</u>:
Provide tools to conduct integrated environmental, societal and economic analyses to establish nitrogen and co-pollutant reduction goals for the priority locations.

Needs:

- Cross RAP coordination on production of nitrogen and co-pollutant related decision-support tools.
- Increased research effort on human health effects of nitrogen, particularly nitrate in drinking water.
- Development and testing of tools to help develop nitrogen and co-pollutant reduction plans that include tools for source apportionment (e.g. NPDat) together with performance monitoring.

Supporting research:

- Studies of nitrate in drinking water under RESERV and RARE in Yakima River Basin Groundwater Management Area, and Southern Willamette Valley Groundwater Management Area.
- OWOW's Nitrate Epidemiological Data Scoping Study.

Science Challenge 3 – *What's in our toolbox to manage and reduce nitrogen and co-pollutant loads and does it work?* A suite of tools is available for setting standards and then monitoring, managing, and reducing nitrogen and co-pollutant loadings. These include regulatory controls in the form of criteria, standards, and permits to limit the amount of nitrogen and co-pollutant in discharges from wastewater treatment plants, concentrated animal feeding operations, and other point sources to water and limits on atmospheric emissions from stationary and mobile sources. Technologies for nutrient removal are available but additional knowledge is needed in the areas of integrated management, sustainable treatment for small systems, and innovative and sustainable nutrient treatment technologies. A variety of tools are generally lumped under the term "best management practices" (BMPs) and "inspection and maintenance" (I/M) practices particularly for nonpoint sources. These include techniques for monitoring and managing nitrogen and co-pollutants at any point in the life cycle, in inputs such as fuels and industrial feedstocks, in improved industrial and agricultural treatment processes, and in waste streams through sequestration and removal in wetlands, ponds, and vegetated buffers.

Sub-outcome: Effectiveness of existing nitrogen and co-pollutant standards implementation and management tools to reduce nitrogen and co-pollutant loadings is understood and improved.

Sub-output: Improved technologies and management practices to monitor and reduce nitrogen and co-pollutant loadings to achieve regulatory targets for nitrogen.

Step 3.1 Synthesis:
Compile and synthesize existing information to identify critical research gaps.

Needs:

- Develop better data on ammonia emissions and their environmental and human health impacts.
- Improve collaboration with USDA in the areas of technological improvements to reduce losses of nutrients from agricultural fields and terrestrial BMPs to improve both surface and ground water.

Supporting research:

- NPDAT tool efforts to map and determine the relative importance of different N sources to air, land, freshwater, and coastal systems (OW-USGS collaboration), to aid states and regions in prioritizing areas for optimal management action.
- Modeling and economic studies to include economic factors and tradeoffs in an N reduction strategy, and to model future loading scenarios and impacts (SSWR 6.1; SSWR 6.5; SHC 3.3.1).
- Developing of a decision tool (N-sink) to assist states in planning their reduction strategies by illustrating the spatial arrangement of agricultural or urban N sources and soil and wetland N sinks (SHC3.3.1.5).
- Evaluation of the effectiveness, the economic costs and benefits of green infrastructure (GI) (SSWR 4.2A).
- Ongoing collaboration with USDA to improve nutrient trading, the National Water Quality Initiative, the White House nutrient challenges, and the joint USDA-USGS-EPA workshop on nitrogen management.
- A suite of GIS-based tools for siting Low Impact Development in an urban watershed is being developed as one BMP siting tool (SSWR 4.3; SSWR 2.3E).

Step 3.2 Technologies:
Develop new or improved technologies and evaluate their effectiveness to support place-based and problem-based nitrogen pollution reduction decisions.

Needs:

- Development of rapid, cost effective technologies for monitoring of water quality response to management actions is needed to determine which reduction interventions are successful.
- A critical review of strengths, weaknesses and interoperability of the models (available and under development) related to nitrogen and co-pollutant management.

- Conduct an assessment of the impediments (social, economic, environmental) to implementation of nitrogen and co-pollutant management technologies, whether established or novel, at the scales necessary to solve the problem.
- Evaluate and improve mobile source estimates of NO_x.
- Improve emission factors for oil and gas extraction processes.

Supporting research:

- National Center for Sustainable Water Infrastructure Modeling Research. STAR RFA for Center funding, 2014.

Step 3.3 Data:
Develop mechanisms to improve quality and quantity, including non-EPA data, as input into step 3.1 for model input to assess the potential effectiveness of management approaches for nitrogen sources.

Needs:

- Develop methods to distinguish between variations in contributions of surface and ground water inputs, and the organic and inorganic nitrogen species, in settings where non-point source nitrogen and co-pollutants represent the major input.
- Develop a common georeferenced format for data management and data exchange to facilitate evidence based nitrogen and co-pollutant management decisions.
- Develop means to leverage other agency national monitoring networks to determine changes in ecosystem condition resulting from management choices (e.g. US Forest Service Forest Inventory and Analysis database, the National Parks Service Inventory and Mapping database).
- Increase ambient measurements of NO_y and NH_x.
- Increase measurements in the mountainous West of ambient air and water quality.

Supporting research:

- The EPA GeoPlatform has been established to provide a common georeferenced format.
- The development of the proposed national monitoring network (http://acwi.gov/monitoring/network/) involving primarily USGS, EPA, NOAA.
- Nitrogen loading from multiple sources to the atmosphere and to aquatic systems is being modeled at national scales (SHC 3.3.3.1; ACE MDST-3).
- A conceptual approach for research integration designed to inform a variety of management interventions has been developed for Narragansett Bay, and will document some of the estuarine effects of management interventions, and can be transferred to other locations (SSWR 6.1).

Step 3.4 Cost impacts:
Develop scalable and transferable methods to quantify economic costs and benefits of changes in nitrogen load and impact due to control technologies and management practices.

Needs:

- Develop improved data on the relation between green infrastructure approaches, levels of resultant reductions in nitrogen and co-pollutants, particularly in ground water, and the costs per unit reduction.

- Compile and synthesize individual case studies and systems-level approaches that directly relate decisions by a regulator or institution to the total N load reduction and associated suite of costs.
- With collaboration of WERF and other user groups, develop common cost accounting units or currency for decisions at POTWs and drinking water treatment facilities to help make better and more reasonable comparisons in costs.

Supporting research:

- Chesapeake Bay Restoration: ecosystem services and market based aspects of TMDL implementation for nutrients and sediment (SSWR 6.5).

Science Challenge 4 – *What are some new, innovative approaches we haven't tried before?*
Traditional regulatory and non-regulatory measures may not be sufficient to achieve the goals established for a priority area. Innovative approaches that go beyond individual sources may be necessary to be more effective, efficient, socially acceptable and sustainable.

Sub-outcome: Cost effective, innovative, sustainable solutions for large scale, multimedia, nitrogen and co-pollutant management approaches are available to program offices, regional offices, states, tribes, and communities. These solutions include sustainable nitrogen and co-pollutant management of important unregulated sources of nitrogen and co-pollutants in high priority areas.

Sub-output: Provide technical support to design sustainable approaches, beyond current regulatory approaches, to manage nitrogen and co-pollutants that consider multimedia pathways of nitrogen and co-pollutants. Issues may involve: whole farm analysis of Nr and co-pollutant pathways; modeling of nitrogen and co-pollutant emissions generation from alternative energy systems; co-management of animal manure and municipal biosolids in anaerobic digesters; WWTP nutrient recovery from wastewater streams; and calibration of fertilizer application rates for site-specific conditions.

<u>Step 4.1 Synthesis</u>:
Compile and synthesize existing scientific knowledge to inform the development of new strategies to meet reduction goals and identify critical research gaps.

Needs:

- Compilation and synthesis of new approaches to meeting nitrogen and co-pollutant reduction goals.
- Specific plan for funding and staffing information compilation and synthesis on new strategies to meet reduction goals.

Supporting research:

- Evaluation of the effectiveness of new tools and techniques focused at local and regional scales (SSWR 4.2.C - STAR grant focused on Chesapeake Bay).

<u>Step 4.2 Innovative Strategies</u>:
Develop scalable, transferable, sustainable, and innovative management approaches that include unregulated sources of nitrogen (e.g., agriculture, septic systems, urban stormwater and unpermitted air sources).

Needs:

- Increased research on control approaches for unregulated air source.
- Compilation and integration of results from the numerous water-focused research efforts in ORD and the Offices for input into Step 4.4.

Supporting research:

- STAR funded four research centers based on an RFA that is directly related to the goal of this RE (SSWR 2.3F).

Step 4.3 Future Factors:
Determine the robustness of innovative nitrogen management approaches under scenarios of future change (climate, demography, land use).

Needs:

- Further research to connect the management practices to groundwater contamination, particularly in groundwater dependent regions, requires attention. Changes in demography and agricultural practices will shift pressures of nitrogen pollution to different locations and the effect of those changes to nitrogen loading in water may be substantial.
- Develop ability to predict how agricultural land use changes from animal husbandry and crop production will alter future nutrient inputs.

Supporting research:

- One-environment model development to estimate agricultural management and land use change effects on atmospheric and aquatic systems under climate change (ACE MDST-3; SSWR 2.3D).

Step 4.4 Analysis of Strategy Effectiveness:
Determine the effectiveness in terms of environmental, economic and societal metrics of proposed innovative management approaches that include unregulated sources of nitrogen.

Needs:

- Expand the BenMAP model to include economic and social costs and benefits associated with nitrogen and co-pollutant reductions.
- Expand and improve collaboration with USDA on analyses of air and water quality changes associated with land management.
- Develop external collaboration to leverage and extend current research to acidification of forest soils and to develop the required concentration-response functions.
- Through collaboration with other agencies, expand work on impact of nitrogen on biodiversity from the northeastern United States to the western United States and to include grasslands and rangelands, encompassing research on acidification of forest soils.

Supporting research:

- Research on aquatic acidification due to nitrogen and co-pollutant deposition.
- Current research on air deposition impacts on ecosystem services in coastal estuaries, particularly the Chesapeake Bay, is connecting the Hydrologic and Water Quality System

(HAWQS) with CMAQ to address air deposition impacts on nutrients in freshwater systems (OAR/OW/ORD collaboration), with linkage to BenMAP for valuations.

- STAR research center has been awarded at Penn State, with a focus on the Chesapeake Bay, that proposes to develop an integrated, holistic approach to understanding drivers and pressures related to nitrogen and phosphorus, valuation of ecosystem services and alternative decision scenarios.
- OW is working to improve benefits analysis tools, including (1) updating the Water Quality Index tool used to define designated uses, (2) updating the meta-analysis of water quality valuation studies for more robust support of assessments, and (3) developing methods to more consistently include avoided costs in benefit-cost analyses of regulations.

Science Challenge 5 – *Are we getting the reductions and ecosystem and human health benefits we expect?* Integrated nitrogen and co-pollutant management for priority areas will require load reductions from various combinations of atmospheric, terrestrial, and aquatic sources, involving regulatory and non-regulatory actions. Determining overall accountability for the reductions and verifying the expected amelioration of impacts implies the need for novel approaches to monitoring and assessment. This Science Challenge underscores the importance of (1) collecting appropriate baseline data on nitrogen and other pollutants to provide a basis for tracking changes, and (2) collecting information on other factors that are expected to cause changes in nitrogen loadings, such as economic growth or cause changes in effects of nitrogen loadings, such as climate and land use changes.

Sub-outcome: Account for the impact of nitrogen and co-pollutant loading reductions on human health and ecosystems and verify co-benefits of nitrogen and co-pollutant management.

Sub-output: Metrics, monitoring designs, and methods to assess changes in accountability endpoints indicating condition of the ecosystem, human health, and societal benefits resulting from application of management actions.

Step 5.1 Synthesis:
Compile and synthesize existing information to identify critical research gaps.

Needs:

- Research to quantify the relation of nitrogen and co-pollutant reductions and ecosystem and human health benefits. The NAPAP report documents emission reductions under the CAA but was unable to quantify the monetary role of deposition in many cases, and defined the need for an adequate assessment of ecosystem service benefits.
- Establishment of a more comprehensive cross-Agency effort is needed to answer this question for the United States.

Supporting research:

- NARS surveys will assess data from surveys repeating over time to track changes in nutrient levels, but the survey sites are generally not tied to management or policy efforts to achieve nutrient reductions.

- The USGS NAQWA program provides relevant data for specific watersheds and may contribute to this issue.
- OAR's annual Air Trends Report tracks nitrogen reductions in the ambient air.

Step 5.2 Models:
For priority areas identified in RE 1 and 2, develop multimedia models (conceptual or computer-based) of the causal chain from sources to effects, and establish accountability measures for environmental, economic, and social endpoints of concern.

Needs:

- Socio-economic techniques that provide (1) the ability to model the span of ecosystem responses to changes in exposure at numerous locations, and (2) the ability to model the socioeconomic metrics of key ecosystem endpoints of concern.
- Modeling systems for terrestrial effects that integrate biogeochemical and vegetation models and link with ecosystem services that can model biodiversity change as part of an accountability assessment.
- Improved modeling capability that includes accountability measures for social and economic endpoints, and improved ability to tie quantitative biological responses in a rigorous fashion to quantitative loads or concentrations of nutrients in natural water bodies.

Supporting research:

- Efforts to link CMAQ with aquatic acidification models, such as MAGIC, and to link CMAQ with estuarine models, such as the Chesapeake Bay model (ACE MDST-3).
- The secondary NO_x-SO_x standard review could be used to prioritize areas for additional effort to support accountability assessments.
- Demonstration studies in Chesapeake Bay and Narragansett Bay are evaluating changes in nutrient loading from atmospheric deposition, non-point sources from land, and point sources to waterways (SSWR 6.1 and 6.5).
- Watershed and estuarine indicators and metrics are being tested in SSWR 6.1.

Step 5.3 Metrics:
Incorporate methods, models, and metrics developed for RE 1 through RE4 to characterize environmental, economic, and social endpoints of concern and define accountability metrics for key points along the entire causal chain.

Needs:

- Carefully designed longitudinal studies focused on human health impacts at local to regional spatial scales to determine if management interventions are effective.
- Scalable socioeconomic methods, models, and metrics to assess the effectiveness of management interventions, such as terrestrial BMPs.
- Development of methods for quantification of intervention costs, ability and willingness to pay, multiple benefits and co-benefits related to BMPs.
- Improved access to relevant micro-economic data is required to address social and economic metrics to document ecosystem and human health benefits at finer spatial scales.

- Improved methods for collaborative knowledge sharing and problem solving.

Supporting research:

- State level effort focused on tracking and mapping asthma incidence at fine scales, in relation to socioeconomic and environmental co-factors, to determine the effectiveness of local management interventions designed to improve human health outcomes.

Step 5.4 Verification Procedures:
Establish verification and reporting procedures (e.g. management action database) to confirm needed load reduction practices are in place for priority areas.

Needs:

- If a system is currently lacking, program offices should establish a process for acquisition of the needed information and establish a database. This could be accomplished across programs or agencies. For example, the USGS nitrate monitoring program may be one example of supporting research.

Step 5.5 Monitoring Systems:
Develop scalable and transferable monitoring systems to detect changes in both exposure and human and ecosystem responses to changing levels of nitrogen.

Needs:

- Support and enhance monitoring programs that provide the information needed to assess system-level, long-term response to policies and management.
- Investigation of cross-agency efforts is particularly needed. The USDA-led interagency Mississippi River Basin Healthy Watersheds (MRBI) should be assessed to determine whether its methods and results are transferable to other regions of the country. The USFS-FIA and NPS-I&M programs should be similarly assessed for relevant information.

Supporting research:

- Support for ongoing monitoring networks (OAR) including State and Local Air Monitoring Stations (SLAMS). NCore is a new NAAQS-related, multipollutant network that integrates several advanced measurement systems for particles, pollutant gases and meteorology.
- Three other national networks address and report out on regional trends connected to nonurban and ecosystem exposure: The National Atmospheric Deposition Program (NADP), the Clean Air Status and Trends Network (CASTNET) and the Interagency Monitoring of Protected Visual Environments (IMPROVE).
- The development of scalable and transferable monitoring designs for measurement of any of a range of environmental metrics is well advanced within the technical support efforts in ORD (SSWR 1.1) and the NARS within OW.
- Temporally Integrated Monitoring of Ecosystems (TIME) and Long-term Monitoring (LTM) Projects provide some consistent monitoring of lakes and streams for acidity.

Science Challenge 6 – *How do we best maintain inter-office accountability, assess progress, and communicate results to the public?* The program offices, regional offices, and ORD need to hold each other accountable for fully engaging in the research planning process, carrying out the research plan, and reporting on research progress. Also following directly from the accountability established under Science Challenge 5, the public, which has ultimate responsibility for the nitrogen and co-pollutant reduction goals, needs to understand the impacts of nutrient pollution and the impacts of alternative load reduction actions and their efficacy in achieving the reduction goals and the impact on human health, the environment, and co-benefits.

Sub-outcome: The program Offices, regional offices, and ORD stay fully engaged and informed. The public understands (1) baseline nitrogen and co-pollutant loadings and their impacts on human health, ecosystems, and local/national economies; (2) the impact nitrogen and co-pollutant load reductions have on human health, ecosystems, and local/national economics; and (3) actions they can take to reduce loads and recover ecosystem services.

Sub-output: Communication strategies, tools, techniques, and reports to support EPA program offices, regional offices, and the public to assess and interpret trends, changes in accountability metrics, and potential outcomes of implementing alternative load reduction approaches.

Step 6.1 Inter-office Accountability:
Develop efficient processes to insure inter-office accountability.

Needs:

- Annual stakeholder meetings between program offices, regional offices, and ORD to discuss research priorities, progress, and potential collaborations around specific topics of common interest.
- An annual Nitrogen and Co-Pollutant Roadmap meeting to improve communication and review priorities on ongoing research across the ORD, OW, OAR, and the regional offices.

Supporting research:

- ORD research program annual meetings (ACE Jamboree, SHC Communique, SSWR L'eau Down) currently discuss nitrogen and co-pollutant research.

Step 6.2 Inter-office Points of Contact:
Program office points of contact will establish regular interaction and communication on key individual research projects, and inform their management of research status.

Needs:

- OAR, OW and regional contacts should be assigned to track progress of key individual ORD research projects, and may participate in and coordinate with specific projects, as required.

Supporting research:

- ORD research projects currently have points of contact in the offices and regional offices, but interactions tend to be ad hoc and variable among individual research projects.

Step 6.3 Synthesis:
Catalog current EPA efforts to communicate nitrogen and co-pollutant tools and information to the public.

Needs:

- An assessment of the inventory of current OAR, OW, ORD, and regional communications efforts and tools nutrient issues.

Supporting research:

- The EPA Nutrient Pollution website (http://www2.epa.gov/nutrientpollution) has information and links to Communication, Teaching and Technical Resources.
- Various existing reporting tools, (e.g., Report on the Environment, annual Air Trends Report, 305b report, NAPAP report).
- Water Sense and Energy Star websites and staff can provide insight/how to's about empowering the public and stakeholders to take action.
- "Economic Analysis of Nitrogen and Phosphorus Pollution in the U.S.," a report on the costs associated with nutrient pollution (OST-SHPD).
- Developed a mobile phone application for rapid dissemination of satellite data to stakeholders (SSWR 2.3B).
- Exploration of social media communications strategies for cyanobacterial research results, including the Harmful Algal Blog, an Internal EPA Blog (SSWR 2.3C).

Step 6.4 Communication Strategy:
Develop a coordinated One-EPA public education strategy to inform and educate the public about nitrogen and co-pollutant issues.

Needs:

- Develop a coordinated EPA public education campaign to inform the public about the impact of nitrogen and co-pollutant loadings on ecosystems, human health, and the economy, and the actions they can take to reduce their impacts.
- Assess strategies to communicate with differing stakeholders, e.g. individuals, school children, other scientists, key decision makers, homeowners, farmers, municipalities, state or Federal agencies, environmental or recreation organizations.
- Determine what behavioral changes would have the most impact on reducing nitrogen and co-pollutants.
- A clear plan to get the results of research findings into the heads and hands of our non-EPA partners, NGOs, etc.

Supporting research:

- OW offered training "Water Words that Work," which was very helpful identifying how to phrase and meet the target audience at its need.

- SHC (3.3.1) is reaching out to organizations that have developed a nitrogen footprint tool for use by individuals to reduce their N footprint, in order to apply this tool at institutional and community scales.
- The Energy Star program would be a good source of information on developing a public communication strategy.

Step 6.5 Communications Evaluation and Measurement:
Design measures to determine whether public behaviors changed as a result of EPA actions.

Needs:

- Develop metrics for impact of programs and actions; e.g. evaluation of appearance of messages in media, speeches, changes in sales (or marketing) of products or processes that use or reduce Nr and co-pollutants; website visits; number of downloads; social media measurements; research citations; meeting attendance.

Supporting research:

- Many of the NEP programs have developed nutrient reduction programs, nutrient issue communication programs, and may be an important source of information for successful evaluation approaches.

Appendix F. Inventory of EPA Research Related to Nitrogen and Co-Pollutants

Color Codes:

Air, Climate, and Energy
Sustainable and Healthy Communities
Safe and Sustainable Water Resources
Human Health Risk Assessment
Office of Water
Office of Air and Radiation
Office of Environmental Information

Project/Task RAP, Title, #	Product	End Date	Point of Contact
EM-1/Task 176	Development of Federal reference methods for NO_2 and SO_2	FY15	Russell Long
EM-2/Task 077	N_2O emissions from nitrification and denitrification using trace gas spectroscopy	FY15	David Williams
EM-3/Task 109	Fusion of data and model outputs for spatial fields across time	FY15	Dave Holland; Val Garcia
EM-3/Tasks 244, 245, 175	Satellite monitoring to track regional NH_3 change with time	FY14, FY17	Jim Sykman; Jesse Bash
EM-3/Tasks 245,175	Satellite top down constraints on NH_3 emissions	FY15	Jim Sykman; Jesse Bash
MA-1/Task 145	Modeling terrestrial individual and interactive effects from climate change and nitrogen deposition change on ecosystem biodiversity in light of critical loads.	FY15	Chris Clark
MA-2/Task 137	Population, land use change and climate change tools	FY17	Britta Bierwagen
MA-2/Task 252	Stream flow and nitrogen flux change under climate change	FY16	Tom Johnson
MA-3/Task 041	Down-scaled regional climate application - drive air and water models	FY15	Chris Nolte
MA-4/Task 110	CMAQ adjoint for receptor-oriented source attribution	FY14/15	Rob Pinder

Project/Task RAP, Title, #	Product	End Date	Point of Contact
MDST-2/Task 174	Modeling regional and urban exposure of air pollutants	FY14, FY17	Jon Pleim
MDST-2/Task 174	Regional air quality with meteorology-air quality feedbacks	FY14	Jon Pleim
MDST-2/Tasks 174, 167	CMAQ DDM-3D for source-oriented source attribution	FY16	Sergey Napelenok
MDST-3	Processed deposition fields for nitrogen deposition exposure and critical load estimates using state of the science modeling	FY14, FY17	Ellen Cooter
MDST-3	Multi-media modeling for GOM Hypoxia in collaboration with SSWR 2.3D	FY16	Ellen Cooter, John Lehrter
MDST-3	Integrated air-water nitrogen budgets	FY16	Ellen Cooter
MDST-3	Modeled air concentration-to-deposition relationships	FY14, FY17	Donna Schwede
MDST-3/Task 008	Simulation of regional deposition and associated air quality	FY14, FY17	Jesse Bash
MDST-3/Task 008	Improvement of CMAQ soil NO flux	FY15	Jesse Bash
MDST-3/Task 008	Multi-media modeling linked to BenMAP benefits model	TBD (unfunded)	Christine Davis
MDST-3/Task 008	Multi-media CMAQ model with crop agriculture management	FY16	Ellen Cooter; Jesse Bash
MDST-3/Task 008	One environment modeling (in collaboration with SSWR 2.3D)	FY16	Ellen Cooter
MDST-3/Task 008	One environment modeling (in collaboration with SHC 3.3.1.2)	FY16	Ellen Cooter; Jana Compton
MDST-3/Task 008	Integrated multi-media modeling of air-driven component	FY14, FY17	Donna Schwede
MDST-3/Task 056	Couple meteorology and hydrology for climate studies	FY15	Tanya Spero
MDST-3/Task 057	Sensitivity of deposition to downscaled climate	FY17	Ellen Cooter
MDST-4/Task 155	Down-scaled regional climate methods - coupling meteorology and hydrology	FY16	Tanya Otte
NMP-1/six tasks	Research to determine human exposure and health effects of air pollutant mixtures as well as single pollutants in a multipollutant context, spanning from in vitro to multi-city studies		Robert Devlin

Project/Task RAP, Title, #	Product	End Date	Point of Contact
NMP-6/Tasks 064, 105	Development of reliable air-surface flux measurements and model parameterizations using empirical measurement		John Walker; Jesse Bash
NMP-6/Tasks 064, 105	Air-surface flux measurements design for monitoring system	FY14, FY17	John Walker, Jesse Bash
NMP-6/Tasks 064, 105	More reliable air-surface flux measurements and model parameterizations	FY14, FY17	John Walker; Jesse Bash
NMP-6/Tasks 105, 064	Air concentration-to-deposition relationships	FY14, FY17	John Walker; Jesse Bash
SEE-1/Task 017	Energy system modeling using MARKAL optimization tool	FY15	William Yelverton
SEE-1/Task 251	Water demand associated with energy production	FY14/15	Rebecca Dodder
SEE-2/Task 027	Biofuels and optimized energy system with MARKAL (in collaboration with MDST-3)	FY14	Rebecca Dodder
SEE-2/Task 178	N_2O emissions from agricultural systems	FY17	Rebecca Dodder; Ellen Cooter
SHC 1.2.3.3	Atlas of modeled hydrologic N loadings under climate scenarios summarized at 12 digit HUC for Nation		Megan Mehaffey
SHC 1.2.3.3	Spatially connected metrics for Ag N source-sink relationships summarized at 12 digit HUC for Nation		Megan Mehaffey
SHC 1.2.3.3	CMAQ N deposition summarized at 12 Digit HUC for Nation	FY13	Robin Dennis
SHC 2.61	Report on the characterization of beneficiaries of FEGS to support incorporation of ecosystem services into community- and national-scale decision making	FY15	Dixon Landers
SHC 2.61	Report on a framework and metrics for assessing the transferability of EGS production functions and estimates	FY16	Ted DeWitt
SHC 2.61	Change in air-quality ecosystem services (Ozone, PM, SO_2 and visibility) and stress-ors (N and S deposition, acid deposition) in the Midwest, associated with a scenario of increased corn production.	FY16	Ellen Cooter

Project/Task RAP, Title, #	Product	End Date	Point of Contact
SHC 2.1.2; SHC 2.1.5	Scaling and transferability of ecosystem services provided by PNW estuaries [co-produced by Project 2.1.2 (Ecological Production Library Task) and Project 2.1.5 (Uncertainty, scalability & transferability EGS Task)]	FY13	Ted DeWitt
SHC 2.1.2.1	Web-ready, searchable database of ecological production functions for multiple scales and multiple geographies.	FY14	Randy Bruins
SHC 3.3.1.1	Report on Sustainability and efficiency in the nitrogen cycle: Interventions to benefit human well-being and ecosystems. (Publication that connects N inputs by region to the impacts of these sources and the management approaches)	FY13	Jana Compton
SHC 3.3.1.1	Quantification of nitrogen loading impacts by source on community-relevant end-points to inform decisions in Mississippi Basin (3.3.1.4) and other sensitive coastal draining watersheds.(Paper published FY14)	FY15	Jana Compton
SHC 3.3.1.1	Publications on current and future N loads with source attribution to watersheds and coastal waters, including information about the potential environmental, social and economic impacts.	FY16	Jana Compton
SHC 3.3.1.1	Quantification of nitrogen loading impacts by source on integrated environmental, social and economic endpoints for conter-minous U.S. to inform decisions in sensitive coastal draining watersheds.	FY16	Jana Compton
SHC 3.3.1.1	Publication on relationships between future coastal N loading and potential community-relevant coastal water quality and eutrophication impacts in the U.S.	FY15	Jana Compton
SHC 3.3.1.1	GIS layer compilations of all N input data at the HUC12 level to identify dominant sources and rates of N inputs to the landscape for watersheds at this scale.	FY13	Jana Compton
SHC 3.3.1.1	Report: Sustainability and efficiency in the nitrogen cycle: Interventions to benefit human well-being and ecosystems	FY15	Jana Compton

Project/Task RAP, Title, #	Product	End Date	Point of Contact
SHC 3.3.1.1	Quantification of nitrogen loading impacts by source on community-relevant water quality endpoints, including NRSA water quality data and other available water quality information.	FY16	Jana Compton
SHC 3.3.1.1	Landscape N sources - what is the current spatial pattern and amount of N input to the landscape, and where are the gaps and largest uncertainties? GIS layer compilations of all N input data at the HUC 8 level (FY12) to identify dominant sources and rates of N inputs to the landscape for watersheds at this scale.	FY12	Jana Compton
SHC 3.3.1.1	Estuary Data Mapper: Geospatial data layers to define N loadings to coastal watersheds and estuaries of the conterminous U.S.	FY13	Naomi Detenbeck
SHC 3.3.1.10	Evaluations of natural and engineered N removing structures as a combination of EPA reports or journal articles.	FY14	Ken Forshay
SHC 3.3.1.11	Technical report on cultural eutrophication effects on belowground structure of northeast salt marshes.	FY14	Cathy Wigand
SHC 3.3.1.11	Model and technical report relating combined eutrophication and climate change effects on New England coastal wetlands will be developed to assist in forecasting combined effects of nutrient loadings, sea level rise, and climate change.	FY14	Cathy Wigand
SHC 3.3.1.2	Integrated scalable framework of response relationships between N loads and the ecosystem goods and service production, human health and well-being, and economic benefits functions.	FY13	Jana Compton
SHC 3.3.1.2	RESERV Project findings: Ecosystem services impacts of reactive N loading in Lower Yakima River Basin.	FY13	Jana Compton
SHC 3.3.1.2	Physical input-output tables for economic commodities and sectors that release reactive N into the environment for use in scenarios and LCA.	FY14	Jana Compton

Project/Task RAP, Title, #	Product	End Date	Point of Contact
SHC 3.3.1.3	Meta-analysis on the impacts of nitrogen deposition on herbaceous biodiversity using several existing data sources nationally.	FY14	Christopher Clark
SHC 3.3.1.3	Analysis on the impacts of nitrogen deposition on herbaceous biodiversity using newly collected data that will cover important gap areas.	FY15	Christopher Clark
SHC 3.3.1.3	Workshop report/journal article on the interactive impacts of nitrogen deposition and climate change on ecosystems and ecosystem services, focusing on water and hydrology, biodiversity, biogeochemical cycling, acidification, and ozone.	FY12	Christopher Clark
SHC 3.3.1.4	New national CMAQ nitrogen and sulfur multi-pollutant scenarios using bi-directional ammonia air-surface exchange based on the latest regulatory rules.	FY13	Robin Dennis
SHC 3.3.1.4	Air-water nitrogen budget scenario(s) for the Mississippi River Basin using the linked EPIC, CMAQ, VIC and NEWS models.	FY14	Robin Dennis
SHC 3.3.1.4	Air-water nitrogen budgets and associated ecosystem services scenarios(s) for the Mississippi River Basin connecting ecosystem service algorithms to the linked EPIC, CMAQ, VIC, NEWS system.	FY15	Ellen Cooter
SHC 3.3.1.4	Scenarios of the impact of climate change on air-water nitrogen budgets and associated ecosystem services for the Mississippi River Basin.	FY16	Ellen Cooter
SHC 3.3.1.5	N-Sink: Simple geospatial tool for managers to describe sources and sinks of nitrogen in a watershed and field test at two case study areas.	FY13	Ken Forshay
SHC 3.3.1.5	Science In Action: Explanation and summary of the use of N-Sink as a nitrogen management tool.	FY14	Ken Forshay
SHC 3.3.1.9	Manuscript on N mass balance and the importance of nitrification/denitrification potential in peatlands of the Upper Mississippi River Basin.	FY14	Brian Hill

Project/Task RAP, Title, #	Product	End Date	Point of Contact
SHC 4.61	3.3.1.2 Institutional footprint tool - Data template and user's manual to calculate and display an institution's nitrogen use.	FY15	Jana Compton
SHC 4.61	Estuary Data Mapper: Report on tools to map/predict potential seagrass habitat zones in estuaries and N loading impacts with pilot application in multiple estuaries with diverse geographic settings.	FY15	Naomi Detenbeck
SHC 4.61	Journal article on the changes in forest tree composition for the Northeast U.S. from N deposition and climate change and the associated changes in key ecosystem services.	FY15	Christopher Clark
SHC 4.61	Report from RESErv project connecting nutrients to aquatic ecosystem services and designated uses in California streams.	FY15	Naomi Detenbeck
SSWR 1.1	1.1A.1 Development of an integrated assessment of large lakes using in situ sensor technologies: linking nearshore conditions with adjacent watersheds.	FY13 Q4	Jack Kelly
SSWR 1.1	1.1A.2 Report on options for combining microbial, algal, macrobenthos, and fish indicators of condition in lakes and streams.	FY15 Q4	Steve Paulsen
SSWR 1.1	1.1A.3 ORD contribution to National Coastal Condition Assessment.	FY13 Q4	Steve Paulsen
SSWR 1.1	1.1A.4 ORD contribution to National Wetlands Condition Assessment.	FY13 Q4	Steve Paulsen
SSWR 1.1	1.1A.5 ORD contribution to National Rivers and Streams Condition Assessment.	FY13 Q4	Steve Paulsen
SSWR 1.1	1.1A.6 ORD contribution to National Lake Condition Assessment.	FY13 Q4	Steve Paulsen
SSWR 1.1	1.1A.7 Develop causal analysis approach to include multiple stressors at multiple scales.	FY14 Q4	Scot Hagerthey
SSWR 1.1	1.1A.8 Integrated assessment designs and indicators for large lakes.	FY15 Q4	Jack Kelly
SSWR 1.1	1.1A.9 Report on the development and use of metagenomic methods for bioassessment of aquatic environments.	FY14 Q4	Erik Pilgrim
SSWR 1.1	1.1B.1: Elements of a watershed classification system for the U.S.	FY14 Q4	Scott Leibowitz

Project/Task RAP, Title, #	Product	End Date	Point of Contact
SSWR 1.1	1.1B.2: Report summarizing results for extensive national study for predicting aquatic condition and watershed integrity nationally	FY16 Q4	Tony Olsen
SSWR 1.1	1.1B.3: Report summarizing results for intensive case studies for predicting aquatic condition and watershed integrity nationally.	FY16 Q4	Scott Leibowitz
SSWR 1.1	1.1B.4: Report synthesizing results from extensive and intensive studies for predicting aquatic condition and watershed integrity nationally.	FY17 Q4	Scott Leibowitz
SSWR 1.1	1.1C.2 Evaluate linked watershed-water body models, including to develop alternative future forecasts.	FY14 Q4	Russ Kreis
SSWR 1.1	1.1C.4 Application of stressor gradient and coral reef condition models to land use and best management options.	FY16 Q4	Pat Bradley; Bill Fisher
SSWR 1.1	1.1C.5 Modeled watershed sources of stress, including climate, for multiple aquatic resources.	FY16 Q4	Jack Kelly
SSWR 1.1	1.1C1 Bayesian decision support system for sediment transport in coastal systems.	FY14 Q4	Bill Fisher
SSWR 1.1	1.1C3 Status of an Integrated Coastal Observing/Modeling System for the U.S. Basin draining into the Great Lakes.	FY14 Q4	Jack Kelly
SSWR 1.1	1.1D1 Peer reviewed journal article on EPA's definition of watershed integrity.	FY14 Q4	John Stoddard
SSWR 1.2	1.2.A.1 Systems modeling approach for linking watershed and water quality conditions for economic-based management.	FY16 Q4	Chris Nietch
SSWR 1.2	1.2.B.1 Translating ecological and economic indicators for WQ trading.	FY16 Q4	Matthew Heberling
SSWR 1.2	1.2.C.1 Report summarizing the derivation of landscape scale metrics for use in understanding ecological thresholds at local to watershed scales and completed analyses identifying various steady-state populations and indicators of tipping points/thresholds for anthropogenic stressors at multiple watershed scales.	FY16 Q4	Charles Lane; Heather Golden

Project/Task RAP, Title, #	Product	End Date	Point of Contact
SSWR 1.3	1.3.A.1. Project Plan for Topic 1 Interoperability with cross-ORD demonstration (SHC Task 1.1.2.2).	FY14 Q4	John Johnston
SSWR 1.3	1.3.A.2. Demonstration Project for Topic 1 Interoperability.	FY15 Q4	John Johnston
SSWR 2.3	2.3.A.1 Report on determining depth of colonization of seagrasses in Florida estuaries for application to numeric nutrient criteria development.	FY12 Q4	Jim Hagy
SSWR 2.3	2.3.A.10 Development of simulation modeling tools to examine the effect of climate change and other drivers on estuarine water quality.	FY14 Q4	Jim Hagy
SSWR 2.3	2.3.A.2 Report on determining the dissolved oxygen requirements of Florida-resident salt water species, with application to development of marine water quality criteria for dissolved oxygen.	FY12	Jim Hagy
SSWR 2.3	2.3.A.5 Report on approaches for developing stream criteria to protect downstream estuaries and coastal waters.	FY15 Q2	Jim Hagy
SSWR 2.3	2.3.A.6 Technical synthesis of approaches for developing numeric nutrient criteria for estuarine and coastal waters: decision support tools for application at site-specific to regional scales.	FY16 Q4	Jim Hagy
SSWR 2.3	2.3.A.8 Evaluation of systems modeling approaches to support nutrient management decision processes that consider nutrient loading, nutrient effects on ecosystem condition and services, as well as social and economic outcomes.	FY16 Q3	Jim Hagy
SSWR 2.3	2.3.A.9 Method evaluation of the use of existing hydrodynamic models for estimating distribution of nutrients, chl a and dissolved oxygen within Narragansett Bay, RI, and potential for their use throughout the Northeast.	FY13 Q4	Jim Hagy
SSWR 2.3	2.3.B.1 Report on satellite (HICO) water quality maps of environmental response variables and feasibility of technology to support compliance monitoring.	FY13	Darryl Keith

Project/Task RAP, Title, #	Product	End Date	Point of Contact
SSWR 2.3	2.3.B.2 An EPA Report to the State of NC DENR and the Albemarle-Pamlico National Estuary Program on effectiveness of Chl a based TMDL.	FY13 Q4	Darryl Keith
SSWR 2.3	2.3.B.3 Prototype smart phone application to report water quality conditions.	FY12	Darryl Keith
SSWR 2.3	2.3.B.4 Database and maps of satellite chlorophyll a for multiple NC estuaries.	FY12	Darryl Keith
SSWR 2.3	2.3.C.1 Report on approaches to predicting cyanobacteria abundance and toxicity based on nutrient inputs and other ecosystem attributes in lakes.	FY15	Brian Milstead
SSWR 2.3	2.3.C.2 Report on models of cyanotoxin effects on mammalian endpoints and the identification of biomarkers of exposure for human health risk assessment.	FY16	Brian Milstead
SSWR 2.3	2.3.C.3 Decision support system to predict the level of human health risk posed by cyanobacteria toxins based on anticipated changes in land use and consequent alteration in nitrogen and phosphorus loads to receiving waters.	FY17	Brian Milstead
SSWR 2.3	2.3.D.1 Report on the Gulf Ecology Model (GEM) and the Gulf of Mexico Dissolved Oxygen Model (GoMDOM), state of the art hypoxia models that will be used to assess the relationship between freshwater discharge and nutrient loads from the Mississippi River Basin and the extent and frequency of hypoxia on the Louisiana continental shelf.	FY13	John Lehrter
SSWR 2.3	2.3.D.2 Report on GEM and GoMDOM predictions of the effects of nutrient load reduction and climate change scenarios on Gulf of Mexico hypoxia.	FY14	John Lehrter
SSWR 2.3	2.3.D.3 Report on multi-media scenarios of air quality and deposition, watershed processing, water quantity and water quality using state of the science models to address sustainability of nutrient management in the face of changes in climate and land use.	FY16	John Lehrter

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SSWR 2.3	2.3.D.4 National maps of edge-of-field water yield and N and P losses under selected climate change scenarios and BMPs.	FY16 Q4	Ellen Cooter
SSWR 2.3	2.3.E.3 Watershed modeling tools of the effects of restoration BMPs on stream hydrology and water quality.	FY16 Q4	Ann Keeley
SSWR 2.3	2.3.E.4 Report on BMP effectiveness for controlling P in watersheds.	FY13 Q4	Ann Keeley
SSWR 2.3	2.3.E.5 Decision support tool and user interface for Best Locator Tool.	FY15 Q4	Ann Keeley
SSWR 2.3	2.3.E.6 Stream daylighting Technical Report.	FY15 Q4	Ann Keeley
SSWR 2.3	2.3.E.7 Watershed modeling tools of the effects of agricultural conservation practices/BMPs on stream hydrology and water quality.	FY15 Q4	Ann Keeley
SSWR 2.3	2.3.E.8 Report describing an automated, online screening-level TMDL modeling system.	FY14 Q4	Ann Keeley
SSWR 2.3	2.3.E.9 Conceptual models illustrating how land use and climate change affect stream flow patterns, stream health and flooding risk, and how BMPs and floodplain strategies can contribute to sustainable solutions.	FY13 Q4	Ann Keeley
SSWR 2.3	2.3.F.1 Center for Integrated Multi-scale Nutrient Pollution Solutions, Pennsylvania State University.	FY19 Q4	Dale Manty
SSWR 2.3	2.3.F.2 Center for Reinventing Aging Infrastructure for Nutrient Management (RAINmgt): University of South Florida.	FY19 Q4	Dale Manty
SSWR 2.3	2.3.F.3 Project 3: Center for Comprehensive, Optimal, and Effective Abatement of Nutrients, Colorado State University	FY19 Q4	Dale Manty
SSWR 2.3	2.3.F.4 Project 4: National Center for Resource Recovery and Nutrient Management, Water Environment Research Foundation (WERF).	FY19 Q4	Dale Manty

Project/Task RAP, Title, #	Product	End Date	Point of Contact
SSWR 4.1	4.1.A.1 Develop a framework for incorporating economic data and stakeholder and citizen preferences into the planning of green infrastructure in neighborhoods and communities.	FY13 Q4	Bill Schuster
SSWR 4.1	4.1.A.2 Guidance for effective use of community assets such as city/county parks, vacant lands and brownfields for green infrastructure BMPs for stormwater discharge permitting and SSO/CSO management.	FY14 Q4	Bill Schuster
SSWR 4.1	4.1.A.3 Guidance on municipal-level best practices to facilitate increased adoption of GI BMPs by community stakeholders (commercial, institutional, private home-owners).	FY14 Q4	Bill Schuster; Marilyn TenBrink
SSWR 4.1	4.1.A.4 Case study report on the green-grey impacts at aggregate sewer shed scale on hydrology, stormwater runoff, and contaminants.	FY15 Q4	Bill Schuster; Tony Tafuri
SSWR 4.1	4.1.A.5 Green Infrastructure and Stormwater Utility Credit Program Design.	FY14	Bill Schuster; Olivia Green
SSWR 4.1	4.1.A.6 Report Catchment-scale effects of distributed and centralized stormwater best management practices and land cover on urban stream hydrology.	FY13 Q4	Bill Schuster
SSWR 4.1	4.1.C.1 Case study report on how adaptive management can be used to monitor and assess GI performance for stormwater management, identify socio-economic and ecosystem service impacts, respond to citizen preferences, and adapt or refine green-gray approach as necessary during implementation.	FY16 Q4	Ahjond Garmestani
SSWR 4.1	4.1.D.1 STAR Grant - Bibliography of grantee publications; Final reports posted on website.	FY17 Q4	Angela Page
SSWR 4.2	4.2.A.1 Identify green infrastructure BMP performance data needs/gaps.	FY12	Michele Simon

Project/Task RAP, Title, #	Product	End Date	Point of Contact
SSWR 4.2	4.2.A.2 Evaluate select GI BMPs for their ability to manage stormwater and reduce contaminant runoff under varying regional environmental conditions.	FY13	Michael Borst
SSWR 4.2	4.2.B.1 Assessment report on the effectiveness of GI BMPs in protecting stream habitat and aquatic communities in multiple climate regions.	FY16 Q4	Naomi Detenbeck
SSWR 4.2	4.2.B.2 Draft publication of a case study on the N uptake and ecosystem function of buried and daylighted streams.	FY13 Q4	Naomi Detenbeck
SSWR 4.2	4.2.B.3 Integrated Watershed Management Decision Support Tool.	FY13 Q4	Naomi Detenbeck
SSWR 4.2	4.2.B.4 Assessment of environmental outcomes of alternative growth scenarios (smart-growth/LID alternatives) to inform Maryland county-level planning in the Chesapeake Bay watershed.	FY14 Q4	Naomi Detenbeck
SSWR 4.2	4.2.B.5 Meta-analysis of green infrastructure performance at the watershed scale.	FY13 Q4	Naomi Detenbeck
SSWR 4.2	4.2.C.1 Highlights on improvements in urban stormwater conditions through the increased adoption of hot spot-specific BMPs via a Community-Based Participatory Research Process.	FY17 Q3	Angela Page
SSWR 4.2	4.2.D.1 Grant. Evaluation of the effectiveness of new tools and techniques focused at local and regional levels to promote sustainable stormwater management in the Chesapeake Bay area, including examining the socio-behavioral reasons why past reduction programs failed.	FY17 Q4	Angela Page
SSWR 4.3	4.3.B.1 HSPF BMP Reference Manual (with HSPF BMP application examples and case studies).	FY15 Q4	Yusuf Mohamoud
SSWR 4.3	4.3.B.2 Updated version of HSPF model with enhanced GI\BMP modeling capabilities needed to support the implementation of complex TMDLs (e.g., pathogens) in urban environments.	FY14 Q4	Yusuf Mohamoud

Project/Task RAP, Title, #	Product	End Date	Point of Contact
SSWR 4.3	4.3.C.1 Enhanced version of the VELMA ecohydrological modeling and decision support framework to address engineered and natural applications of green infrastructure for reducing nonpoint inputs of nutrient , contaminants and sediments.	FY14 Q4	Bob McKane
SSWR 4.3	4.3.C.2 GIS Data Layer: The gradient in natural green infrastructure across different watersheds and watershed segments.	FY16 Q4	Tony Olsen
SSWR 6.1.A	6.1.A.1 Trend analysis of stressors and ecological responses, particularly nutrients, in the Narragansett Bay Watershed. Trend analysis will document changes in nutrient sources over the past century, and environmental consequences (assessment endpoints), that will help in identifying opportunities for targeting reductions for current nutrient sources.	FY15 Q4	Suzanne Ayvazian
SSWR 6.1.B	Quantitative models will relate nutrient loading and sources to environmental responses in the Narragansett Bay and Watershed, to help target nutrient load reductions from both point and non-point sources.Currently nutrient loading reductions are primarily relying on point source permits, and adaptive management, in absence of an established TMDL. Monitoring data and models are used to document current & future Nr loading and ecological effects, and will help determine if additional nutrient controls are needed to restore and protect the aquatic ecosystems.Nr related estuarine acidification could also affect valued resources (e.g. shellfish), and this work can be used with parallel funded efforts focused on environmental finance options and low impact development policies that could contribute to solutions.	FY15 Q4	Brenda Rashleigh

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SSWR 6.1.C	6.1.C.1 Decision Support Tool(s) to inform decisions affecting nutrient flux and possible changes to systems (e.g., ecosystems, communities, and economies) within the Narragansett Bay Watershed. With the input of 1-3 key partners we will develop, as a demonstration, decision support tool(s) which incorporate and integrate data, model output, and maps which promote sustainable management of aquatic resources.	FY16 Q4	Jane Copeland
SSWR 6.5	6.5A.1 Contract report: Ecosystem Services and Environmental Markets in Chesapeake Bay Restoration.	FY14 Q1	Brenda Rashleigh; Naomi Detenbeck
SSWR 6.5	6.5A Contract report: Final Upstream Benefits report, July 31, 2014.	FY14 Q3	Brenda Rashleigh; Naomi Detenbeck
SSWR 6.5	6.5B.1 Contract Report: Other Benefits of the Chesapeake Bay TMDL.	FY15	Brenda Rashleigh; Naomi Detenbeck
HHRA 1.1.17	IRIS assessment of the Human Health Effects of NH3. Literature review and synthesis of effects of ammonia on human health. Dose response metrics are evaluated to determine effects on human health.	FY14 Draft	Audrey Galizia
HHRA 2.2.1	Integrated Science Assessment of the Ecological Effects of NO_x and SO_x. Includes a literature review of deposition response relationships, as a synthesis of published CL for ecosystems in the U.S.	FY16	Tara Greaver
HHRA 2.1.4	Integrated Science Assessment of the Human Health Effects of NO_x. Literature review and synthesis of effects of nitrogen oxides on human health. Dose response metrics are evaluated to determine effects on human health.	FY16	Molini Patel

Project/Task RAP, Title, #	Product	End Date	Point of Contact
Hypoxia Task Force	The Discharge Monitoring Report (DMR) Pollutant Loading Tool is a new tool designed to help you determine who is discharging, what pollutants they are discharging and how much, and where they are discharging. The tool calculates pollutant loadings from permit and DMR data from EPA's Permit Compliance System (PCS) and Integrated Compliance Information System for the National Pollutant Discharge Elimination System (ICIS-NPDES). Data is available for the years 2007-2011. Pollutant loadings are presented as pounds per year and as toxic-weighted pounds per year to account for variations in toxicity among pollutants. The tool ranks dischargers, industries, and watersheds based on pollutant mass and toxicity, and presents 'top ten' lists to help you determine which discharges are important, which facilities and industries are producing these discharges, and which watersheds are impacted.	Completed	Kate Pinkerton (OWOW) http://cfpub.epa.gov/dmr/
Hypoxia Task Force	Coordinated federal agency monitoring in designated MRBI watersheds. Collaboration with USDA, USGS, EPA, states, and other partners to implement a long-term, 3-tiered monitoring strategy to assess the effectiveness of conservation systems.	Ongoing	Katie Flahive (R7)
Hypoxia Task Force	Gather cost benefit analysis information to provide to agricultural communities regarding nutrient pollution best management practices; characterize the socioeconomic barriers towards increased adoption of practices.	Completed	Katie Flahive (R7)
OGWDW	Nutrient Reduction Partnerships with Ag Community: Wisconsin, Wyoming, Pennsylvania.	FY13	
OGWDW	USDA Collaboration – One watershed/ State recommended for FY13 funding and monitoring for water quality impacts.	FY13	OGWDW

Project/Task RAP, Title, #	Product	End Date	Point of Contact
OGWDW	Source Water Workshops (nutrient reduction and CWA-SDWA collaboration).	FY13 depending on funding	OGWDW
OGWDW	Add nitrate MCL violations to the public water system (PWS) layer of the Nitrogen and Phosphorus Data Access Tool (NPDAT) – a GIS tool to identify HUC 12s with high N impacts (pending funding).	TBD	Mike Muse (OGWDW) http://www2.epa.gov/nutrient-policy-data/nitrogen-and-phosphorus-pollution-data-access-tool
OW	Nutrient Indicators Dataset. This Dataset consists of a set of indicators and associated state-level data to serve as a regional compendium of information pertaining to potential or documented nitrogen and phosphorus pollution, impacts of that pollution, and states' efforts to minimize loadings and adopt numeric criteria for nutrients into state water quality standards.	Completed	Corey Buffo (SHPD) http://www2.epa.gov/nutrient-policy-data/nutrient-indicators-dataset
OW	Evaluate ecosystem costs and benefits with nutrient management.	Ongoing	Mario Sengco (OST)
OW	Guiding principles for integrating nutrient causal and response variables-Offer clarity to states about an optional approach for developing a numeric nutrient criterion that integrates causal (nitrogen and phosphorus) and response parameters into one water quality standard (WQS).	Completed	Corey Buffo (SHPD-OST) Dana Thomas (HECD-OST)
OW	Nutrient Adoption Toolkit (including cost). Economic analysis of the costs of nutrient pollution compared to the costs of nutrient mitigation, treatment and water body restoration-2013 - coming soon to the Website - Toolkit of Resources to Provide States with Flexibility in Adopting and Implementing Numeric Nutrient Criteria.	FY15	Corey Buffo (SHPD) http://www2.epa.gov/nutrient-policy-data/toolkit-resources-provide-states-flexibility-adopting-and-implementing-numeric

Project/Task RAP, Title, #	Product	End Date	Point of Contact
OW	Recovery Potential Screening - Tools for Comparing Impaired Waters Restorability. This website provides technical assistance for restoration programs to help states consider where to invest their efforts for greater likelihood of success, based on the traits of their own geographic area's environment and communities. There are three main website components. Step-by-step instructions in recovery potential screening provide watershed managers with a methodology for comparing restorability differences among their waters. The steps in the methodology link to several online tools and resources that are used in recovery potential screening. A library of recovery potential indicators offers technical information on specific recovery-related factors (ecological, stressor, and social), how they influence restorability, and how to measure them.	Ongoing	Doug Norton (OWOW) http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/index.cfm.
OW	Gene expression methods for nitrification inhibition monitoring and management (collaborating with WERF study).	FY14 Q1	Phil Zahreddine (OWM)
OW	Workshop on indicators of nutrient pollution. Progress towards numeric nutrient criteria adoption has been limited in part due to the technical challenge of developing numeric nutrient criteria when multiple factors influence responses and confound nutrient response models. Such conditions can make it difficult to predict nitrogen and phosphorus concentrations that adversely affect aquatic life. States are seeking improved methods to overcome such challenges and to reduce uncertainty when implementing numeric criteria, for example, by integrating biological response indicators into a numeric nutrient criterion decisional framework.	Completed	Dana Thomas (OST)

Project/Task RAP, Title, #	Product	End Date	Point of Contact
OW	Reevaluate eco-region nutrient recommendations for lakes and provide a target for downstream protection.	FY16	Dana Thomas (OST)
OW	Evaluate and synthesize current literature on the need to manage both nitrogen and phosphorus concentrations in water to prevent eutrophication and the proliferation of harmful algal blooms.	FY15	Dana Thomas (OST)
OW	Evaluate the state of the science of potential assessment endpoints for the effects of nitrogen and phosphorus in streams, such as user perception surveys and diatom assemblage indices.	FY16	Dana Thomas (OST)
OW	Improving benefits analysis for OW based on established priorities.		Joel Corona
OW	Analysis of NARS National Lakes Assessment 2012 data to include changes between 2007 and 2012 lakes surveys. Use of NARS National Lakes Assessment 2007 and 2012 for analysis of correlation and predictive discrimination among causal and response variables.	FY16	Amina Pollard; Lester Yuan (OWOW, OST)
OW	Analysis of NARS National Rivers and Streams Assessment 2013/14 to include changes in nutrients since 08/09 for rivers and streams and since 2004 for streams. Analysis conducted for national, regional and major river basin population estimates and change.	FY17	Richard Mitchell (OWOW) and collaborators in ORD, OST
OW, OWOW, WB	Application of Maryland's Assessment and Scenario Tool (MAST) to evaluate alternative management scenarios in order to meet pollutant allocations derived in TMDLs.	Completed	Michael Haire (OW, OWOW, WB)
OW, OWOW, WB	Collection of resources containing BMP information valuable for TMDL development including BMP applicability, cost, and/or pollutant reduction efficiency.	Completed	Menchu Martinez (OW, OWOW, WB)
OWM, OST, OWOW	Case Studies on Implementing Low Cost Modifications to Improve Nutrient Reduction at Wastewater Treatment Plants.	FY15	Tim Connor (OWM); Lisa Larimer (OST); Katharine Dowell (OWOW)

Project/Task RAP, Title, #	Product	End Date	Point of Contact
OWOW	Recovery Potential Screening - Tools for Comparing Impaired Waters Restorability. This website provides technical assistance for restoration programs to help states consider where to invest their efforts for greater likelihood of success, based on the traits of their own geographic area's environment and communities. There are three main website components. Step-by-step instructions in recovery potential screening provide watershed managers with a methodology for comparing restorability differences among their waters. The steps in the methodology link to several online tools and resources that are used in recovery potential screening. A library of recovery potential indicators offers technical information on specific recovery-related factors (ecological, stressor, and social), how they influence restorability, and how to measure them. Recovery Potential Screening Tools are available to implement these methods for a wide range of watershed comparison settings, including nutrients management.	Completed 2012	Doug Norton (OWOW) http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/index.cfm.
OWOW	Recovery Potential Screening – Statewide Watershed Comparison Tools. Based on the approach above, user-friendly watershed comparison tools with over 200 watershed indicators at the HUC12 scale were developed and distributed to state water quality programs throughout the lower 48 states. Each tool contains all statewide data and can calculate watershed condition indices, display data tables, rank order watersheds, plot graphs and maps all within Excel.	Completed 2014	Doug Norton (OWOW)

Project/Task RAP, Title, #	Product	End Date	Point of Contact
OWOW	Recovery Potential Screening State Projects Supporting Watershed Prioritization for Nutrients Management. Using tools and approaches as above, EPA has demonstrated a watershed nutrients prioritization approach that implements the 2011 nutrients policy memorandum appendix. Reports and data will be available for several states who engaged in joint RPS projects with EPA.	4th Q FY2015	Doug Norton (OWOW)
OWM	Evaluation of performance, reliability and cost of full scale innovative nutrient removal technologies (planned, pending availability of funds).	24 months from funding/ startup	Phil Zahreddine (OWM)
OWM	Spokane Regional Phosphorus Bioavailability Study Phase II (collaborating with WERF study).	FY14 Q3	Phil Zahreddine (OWM)
OWM	Pilot the NPDES Permit Writers Training on nutrient WQBELs.	FY15	Phil Zahreddine (OWM)
OWOW	"Infographics" – Outreach to the general public on nutrient pollution education through pictures and graphics.	Ongoing	OWOW
OWOW	Farmer Hero campaign w/ National Association of Conservation Districts, NEPs, and NGO partners.	Ongoing	OWOW
OWOW	Protocol for Developing Nutrient TMDLs, 2nd Edition.	Complete	Carol Peterson (OWOW)
OWOW	MOU w/ Humane Society- Impacts to pets from HABs.	Complete	OWOW
Region 1	Nutrient Permitting Activities - NH @ 3.0 mg/L TN from POTWs to Great Bay Estuary; NH draft MS4 for reduction in phosphorus per TMDLs using BMPs and track stormwater sources to Great Bay Estuary.	FY13	Toby Stover (R1)
Region 1	TMDL Activities – Maine (20 TMDLs w/ load reduction targets for NPS/Agriculture; Vermont (8 TMDLS with load reduction targets for phosphorus from agriculture).	FY13-16	Toby Stover (R1)
Region 2	PR draft numeric nutrient criteria for rivers.		Izabela Wojtenko (R2)

Project/Task RAP, Title, #	Product	End Date	Point of Contact
Region 2	NY draft nutrient criteria for total phosphorus in rivers and lakes.	FY13	Izabela Wojtenko (R2)
Region 2	Conscience Bay Stormwater Treatment & Wetland Enhancement. NY, Village of Old Field w/ EPA-Long Island Sound Study: 35 subsurface infiltration units to treat 194 million gallons of stormwater runoff, vegetation w/ 17,075 upland and wetland plants to reduce N loading to Conscience Bay.	FY13	Izabela Wojtenko (R2)
Region 2	Peconic Estuary Program septic system management for nutrient reduction and N loads to groundwater for determining cost-effective reduction strategies.	FY13	Izabela Wojtenko (R2)
Region 2	Nutrient Bioextraction by Seaweed in the Long Island Sound. University of Connecticut Kelp demonstration project.	FY13	Izabela Wojtenko (R2)
Region 3	Virginia Draft Nutrient Assessment Protocols Pilot studies in priority watersheds.	FY13	Mark Barath (R3)
Region 3	Trend reporting on the Susquehanna River. The USGS, in cooperation with the Maryland Department of Natural Resources and theU.S.EPA's Chesapeake Bay Program, calculates the loads of nutrients and suspended sediments contributed to the Chesapeake Bay from non-tidal areas using data collected at the nine major Bay tributaries through the river input-monitoring (RIM) program. The USGS calculates loads with a statistical model using flow data and nutrient and suspended sediment samples collected at these sites. Calculated loads to the Bay are used to examine trends for effects of management actions, such as the implementation of best management practices and upgrades to wastewater treatment plants, and as input to the Bay watershed model.	Ongoing	Mark Barath (R3) http://www.dnr.state.md.us/bay/monitoring/river/load_flow.html
Region 4	MS draft numeric nutrient criteria.	FY13	Stephen Maurano (R4)

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Region 5	MN proposed nutrient criteria for rivers and streams, nutrient criteria recommendations for the Great Lakes.		Brian Thompson (R5)
Region 5	The Ohio Trophic Index Criterion (TIC) is a composite index that brings together the measures of nutrients, periphyton, dissolved oxygen, and biological assemblages by awarding points to successive ranges of each indicator, where the ranges are defined by benchmarks identified in the nutrient study. Hence, the TIC provides a structured method of aggregating data collected on Ohio's streams and rivers into a nominal scale that is essentially a translator for the condition of a water body relative to nutrient enrichment.	FY13	Brian Thompson (R5)
Region 5	TMDL Activities (50 nutrient TMDLS, 40 in MRB; integrate TMDL-319 for both point and non-point source reductions.)	FY13	Brian Thompson (R5)
Region 6	NM nutrient proof-of-concept for perennial wadeable systems.	Completed	Forrest John (R6)
Region 6	TX chlorophyll a criteria for reservoirs.	Completed	Forrest John (R6)
Region 6	Louisiana Nutrient Reduction Strategy.	Completed	Forrest John (R6) http://deq.state.la.us/portal/Portals/0/permits/lpdes/pdf/LouisianaNutrientReductionStrategy.pdf
Region 6	New Mexico Economic Analysis.	Ongoing	Jack Oliver (OST); Brent Larsen (R6)
Region 6	Louisiana TN-TP criteria development for rivers and streams.	FY15 Q1	Henry Brewer (R6); Forrest John (R6)
Region 6	N-STEPS New Mexico TN-TP Numeric Criteria for Perennial wadeable systems.	FY15 Q1	Jack Oliver (OST); Forrest John (R6)
Region 6	N-STEPS Red River Multijurisdictional Modeling for TN-TM numeric criteria for riverine system (OK, TX, AR, LA, University of AR).	Completed	Jack Oliver (OST); Interagency Agreement; Mike Bira (R6)

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Region 6	Arkansas Watershed Monitoring, L'Anguille, Lake Conway, Little River Ditches Watershed. The project partners will assist agricultural producers in 15 sub-watersheds of the Lake Conway-Point Remove basin to adopt a systems approach with a variety of core and supporting conservation practices to address natural resource concern of water quality pertaining to nutrient runoff and water management. They will focus on avoiding excess application of nutrients and water on fields; controlling the amount of nutrient and water runoff from fields into the watershed; and trapping nutrients before they leave the field. The project area includes 6 adjacent sub-watersheds in the Little River Ditches watershed located in Craighead, Mississippi, and Poinsett Counties. The goal of the conservation partners involved is to reduce the nutrient loss from agricultural land (primarily cropped to cotton) through improved nutrient use efficiency and reduced runoff from agricultural fields.	Ongoing	Brad Lamb http://www.nrcs.usda.gov/wps/portal/nrcs/detail/ar/programs/?cid=nrcs142p2_034806 http://www.nrcs.usda.gov/wps/portal/nrcs/detail/ar/programs/?cid=nrcs142p2_034817
Region 6	Louisiana Watershed Monitoring: Turkey Creek Watershed; Bayou Chene Watershed; Bayou Lacassine Watershed in support of MSRBI. The Mississippi River Basin Initiative (MRBI) Watershed Water Quality Monitoring in Bayou Chene and Lacassine Bayou Project. NRCS has been working with agriculture producers and land owners since 2011 to implement voluntary conservation practices to improve water quality. Three small watersheds in Bayou Lafourche were chosen to implement best management practices to reduce nutrients, total suspended solids, and turbidity. These elements have been identified as suspected sources of impairment to fish and wildlife. In addition, four small watersheds were identified in Turkey Creek as part of the MRBI. The practices implemented through this initiative are designed to reduce organic and sediment loads in the watershed.	Ongoing	Robert Cook (R6)

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Region 6	Nutrient TMDL for Illinois River Basin.	Ongoing	Richard Wooster (R6)
Region 6	DO criteria for Louisiana coastal waters. Decide whether to list coastal waters in Louisiana as impaired for dissolved oxygen (DO). While LDEQ found that three coastal segments were not meeting dissolved oxygen criteria, the state designated the waters as category 4b, a classification for waters that are impaired but for which pollution limits, known as a total maximum daily load (TMDL), is not needed because other controls will lead to meeting water quality standards.	Ongoing	Forrest John (R6)
Region 6	Water Quality Monitoring for the Lake Conway-Point Remove Watershed (Hydrologic Unit Code 11110203) Project 11-600 CWA Section 319(h). Monitoring stations were established in multiple sub-basins (10- and12-digit HUCs) within the Lake Conway-Point Remove watershed in order to estimate pollutant loads as "unit area loads." The environmental data and unit area loads were used as an effort to identify problematic sub-basins (12-digit HUCs) with excessive non-point source pollution.	Completed	Melissa Benfer (R6)
Region 6	FY 15-300 CWA Section 319(h). Water Quality Monitoring for the Lake Conway Point Remove Watershed (Hydrologic Unit Code 11110203). This project aims for monitoring water quality in the Lake Conway Point Remove Hydrologic Unit Code. The primary goal of this project is collecting, analyzing and reporting water quality and discharge data to provide parameter loadings and unit area loadings in assorted 12-digit HUC in the greater Lake Conway Point Remove HUC.	Proposed	Melissa Benfer (R6)

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Region 6	Texas, City of Waco Surface Water Treatment Economic Analysis (drinking water costs due to source water contamination).	Completed	Kim Ngo (R6)
Region 7	Kansas City Urban Stream Monitoring Network utilizes similar protocols and approach as NRSA efforts, but provides data and information at a much finer resolution. 36 sites are sampled for numerous contaminants including TN, TP and microcystins as well as biology (periphyton, phytoplankton, macroinvertabrates, and fish assemblages).	Ongoing	Gary Welker; Laura Webb
Region 7	Kansas City Urban Lakes Monitoring Network is similar to the Urban Streams effort collecting information on ~30 Lakes (including TN, TP, microcystins, and Chl(a)).	Ongoing	Laura Webb; Gary Welker
Region 7	Missouri and Mississippi Big Tributaries Nutrient Monitoring, conducts Spring, Summer, and Fall sampling at ~45 sites including all of the major tributaries to the Missouri and Mississippi River in Region 7 (as well as several sites in Region 5).	Ongoing	Gary Welker; Laura Webb
Region 8	Montana, Utah, Colorado nutrient criteria rules/submittals.	FY13	Tina Laidlaw (R8)
Region 8	Nitrogen reductions associated with septic systems is an area that MT's trading policy focuses on.		Tina Laidlaw (R8)
Region 8	NPS Program engagement with agriculture (NRCS).	FY13	Judy Bloom (R8)
Region 9	CA numeric nutrient endpoint project for streams, bays, and estuaries.	FY13	Terrence Fleming (R9)
Region 9	Air and Water workshop to define nutrient sources and control strategies for loading reduction to Central Valley.	FY13	Terrence Fleming (R9)
Region 10	NPDES permits for phosphorus in Idaho (50 ppb).	FY13	Rochelle Labiosa (R10)
Region 10	Via the NSTEPS HQ funding R10 is working with Idaho DEQ to develop reference site analysis and stressor-response relationships for Idaho streams.	FY14-15	Rochelle Labiosa (R10)

Project/Task RAP, Title, #	Product	End Date	Point of Contact
Region 10	Via the NSTEPS HQ funding, R10 is working with Oregon DEQ to develop ecoregionally based stressor-response relationships for all ecoregions that intersect the state of Oregon.	FY14-15	Rochelle Labiosa (R10)
Region 10	R10 is developing a GIS-based tool that combines USGS Sparrow modeling and land use parameters to determine whether policy actions are corresponding to the areas of the Pacific Northwest with the highest probability of nutrient loading per the available modeling and monitoring data.	FY14-15	Rochelle Labiosa (R10)
Region 10	EPA R10, EPA ORD Newport are working with Oregon State University, to collect data to ascertain the range of temporal variability of ocean acidification parameters in the nearshore in a more agriculturally influenced site as compared to a more ocean-upwelling-influenced site.	FY15	Rochelle Labiosa (R10, ORD)
Region 10	City of Boise permit phosphorus offset on agricultural drain (Dixie Drain). The EPA and IDEQ conducted a technical analysis of the watershed and proposed offset to determine whether, and to what extent the proposed offset would improve conditions in the Boise River compared to the alternative of advanced filtration treatment to achieve the phosphorus goal for the river (70 µg/L) at end-of-pipe. The results are provided in Predicted Effects of Dixie Drain Project on Phosphorus Concentrations in the Boise River, March 2012.	FY13	Rochelle Labiosa (R10) http://www.epa.gov/region10/pdf/permits/npdes/id/west_boise_dixie_mod_fs_id0023981_091312.pdf

Project/Task RAP, Title, #	Product	End Date	Point of Contact
OW - Nutrient Adoption Tool-kit (including cost)	Economic analysis of the costs of nutrient pollution compared to the costs of nutrient mitigation, treatment and water body restoration-2013 - coming soon to the Website - Toolkit of Resources to Provide States with Flexibility in Adopting and Implementing Numeric Nutrient Criteria http://www2.epa.gov/nutrient-policy-data/toolkit-resources-provide-states-flexibility-adopting-and-implementing-numeric.	Operational	http://www2.epa.gov/nutrient-policy-data/toolkit-resources-provide-states-flexibility-adopting-and-implementing-numeric

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