ORD Research Integration:

Nitrogen

Introduction

Nitrogen is an essential nutrient that is used in agriculture and energy production, but excess nitrogen leads to air and water quality degradation. EPA and stakeholders have made significant strides in reducing the nitrogen and co-pollutant (e.g., phosphorus, sulfur) loadings that cause the adverse impacts of ozone, acid rain, harmful algal blooms, hypoxia, drinking water impacts, and fish kills, yet nitrogen and co-pollutant issues remain pervasive, costly, and a high priority for Agency actions (http://www.epa.gov/waters/ir/index.html). These impacts will likely be exacerbated in coming years from pressures of land use change, climate change, and the resource needs of an increasing human population.

In August 2011, the EPA Science Advisory Board's (SAB) Integrated Nitrogen Committee released the report "*Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options.*" This report provides a comprehensive summary of the current science related to natural and anthropogenic contributions to nitrogen 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 nitrogen. The SAB report clearly recognizes the impact of human activities on the nitrogen cycle, and the associated degradation of air and water quality, noting that humans introduce more than five times the reactive nitrogen 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 reactive nitrogen, forming an intra-Agency task force to build on the existing research and management capabilities in the Agency, and working with other Agencies and departments outside the Agency to manage reactive nitrogen more effectively and efficiently.

Integration

Sustainable nitrogen and co-pollutant management will require integration across Offices within EPA and with other federal and state agencies. By capitalizing on the strengths inherent in our research and regulatory capacities and non-regulatory efforts through partnerships with states, NGOs, and industry, we anticipate that integration will allow us to provide the most cost effective, efficient, and economically sustainable management solutions, including development of complementary regulatory authorities that reduce the unintended consequences of our actions and address currently unresolved nitrogen and co-pollutant impacts. Currently, the Safe and Sustainable Water Resources (SSWR), Sustainable and Healthy Communities (SHC), Air, Climate and Energy (ACE), and Human Health Risk Assessment (HHRA) research programs have active research projects related to understanding and reducing nitrogen and co-pollutant loadings. EPA's regulatory offices, Office of Air and Radiation and Office of Water , also have science programs focused on these objectives as well as how to use science to inform policy and decision making. All of these collaborative efforts will contribute outputs critical to the design and implementation of integrated nitrogen and co-pollutant management approaches, including:

SSWR:

- support for development of numeric nutrient criteria for inland and coastal waters,
- water quality simulation modeling for nitrogen and phosphorus,
- improved assessment approaches and biological indicators to asses responses to nitrogen and phosphorus, sustainable nitrogen and co-pollutant removal technologies,

- holistic and practical nitrogen and co-pollutant management solutions and strategies using a systems view approach (STAR),
- model simulations predicting a shift in hydrology, resulting in acidification of soil and stream water and deterioration of water quality in forested watersheds (STAR),
- identification of global water security threats to both human society and biodiversity (STAR), and
- improved models of the geographic distribution of atmospheric nitrogen deposition (STAR).

SHC:

- refined information on nitrogen inputs for use at varying scales across the U.S.,
- synthesis of spatial and other information on nitrogen impacts on ecosystem services for air and water that identifies opportunities within the nitrogen cascade where management actions could yield the greatest benefits, and
- life cycle assessment of nitrogen reduction options for the U.S.

ACE:

- linked modeling system connecting key elements of the nitrogen cascade that can predict impacts of emissions, deposition, land use change and climate change on air and water quality endpoints,
- maps of nitrogen-induced herbaceous species losses using empirically derived response functions for Level 1 ecoregions across the U.S.,
- assessment of changes in carbon sequestration and nitrogen fluxes associated with changes in climate and hydrology, and
- modeling framework and decision support tools for evaluating sensitivity of ecosystems to nitrogen deposition under changing climate conditions.

HHRA:

- Integrated Risk Information System (IRIS) toxicological review of ammonia, and
- Integrated Science Assessment (ISA) synthesizing and evaluating the most policy-relevant science for oxides of nitrogen (NOx) and sulfur oxides (SOx) to help form the scientific foundation for the review of the secondary (welfare-based) National Ambient Air Quality Standards (NAAQS).

STAR:

- RFA soliciting proposals to establish holistic and practical nutrient reduction management strategies including: source water nutrient reduction; innovative water treatment technologies for drinking, waste, reuse, and industry; reduced levels of nutrient-associated disinfection and other by-products; reduced nutrient inputs from agriculture and urban land use; reduced total treated water volumes, and reduced algal blooms to improve human and ecosystem health (to be awarded in 2013).

Nitrogen and co-pollutant research across the new research programs will require integration with OW and OAR to optimize the utility of results and products. We have committed to developing a Nitrogen Roadmap that identifies how we will foster research, program implementation, and policy integration for nitrogen and co-pollutant issues across the Agency over time, and have initiated discussions with external stakeholders.

Management Approach

Our approach to integrating nitrogen and co-pollutant research involves establishing a cross-EPA workgroup to develop a shared vision for a cross EPA Nitrogen Roadmap by November 2012. This group meets regularly to share information about planned research in each of the relevant programs and in so

doing, seeks opportunities for collaboration that could improve the outcomes of the research, meet our goals, and save resources. Within the new ORD research programs, the nitrogen and co-pollutant integration effort is led by the SSWR research program. It is the responsibility of the Nitrogen Lead to follow-up with Laboratory managers, NPDs, and Program Leads to facilitate these opportunities and remove hurdles that would prevent such efficiencies. Through continued interaction among ORD and Program scientists from different programs, integration on existing projects will occur and joint understanding of knowledge gaps will lead to coordinated future efforts.

To date, ORD, OW, and OAR have agreed to work towards developing an integrated, systems based approach to reactive nitrogen and co-pollutant management in both the short-term (< 5yrs) and long-term. The goal of this effort is to develop a one-EPA perspective on sustainable nitrogen and co-pollutant management across the regulatory landscape to inform risk assessments, policy analyses, and benefits assessments. A successful approach to integrated nitrogen and co-pollutant management is expected to:

- Engage & benefit Program Offices, Regions, and external stakeholders
- Address OW, OAR, and Regional needs, as well as SAB recommendations
- Inform decisions and recognize impacts on other decisions
- Account for interactions between nitrogen and co-pollutants (P, S, C, sediments)
- Connect nitrogen and co-pollutant impacts to social and economic responses that are successfully communicated to the public
- Describe the effects of management strategies on nitrogen and co-pollutant sources
- Produce interoperable tools that can inform nitrogen and co-pollutant reduction approaches across multiple scales and multiple media, and minimize adverse human health and ecological impacts
- Reduce excessive loadings and yield the greatest water and air quality benefits (e.g., protecting drinking water quality, reducing hypoxia, restoring nitrogen and co-pollutant impaired watersheds, supporting individual state nutrient strategies, etc.)
- Couple source reductions with comprehensive efforts to attenuate excess nitrogen in the environment through land and watershed management (e.g., wetlands creation and restoration)
- Inform the prioritization of watersheds and development of nitrogen and co-pollutant reduction targets (criteria) in States that will result in real reductions through time
- Improve how we manage nitrogen and co-pollutants in the air, land, and water, thereby fostering a demonstrable reduction in nitrogen impaired source waters, aquatic and terrestrial systems, and air-related health impacts while maintaining our food production capacity

Challenges

Although EPA has talent and expertise in addressing environmental problems related to nitrogen and co-pollutants, addressing the social and economic aspects of this issue has not traditionally been considered within ORD, and some statutory authorities do not directly allow for consideration of costs when setting water quality criteria or air standards (e.g., the establishment of 304a Water Quality Criteria for the protection of aquatic life and National Ambient Air Quality Standards). Challenging ourselves to step outside of our traditional research and regulatory paradigms and think about sustainable solutions will require creative solutions from both our research and regulatory perspectives, such as options that can be voluntarily implemented because of their multiple benefits (e.g., recovering N and P from waste streams, using green infrastructure and constructed wetlands to recycle nutrients near their discharge points, combining fish farms with agricultural production to create closed loop

systems with regard to wastes, managing waste loads for better denitrification). Sustainably managing the nitrogen and co-pollutant problem will require integration across the research, policy, and regulatory capabilities of EPA and other federal agencies as well as states, academia, and stakeholders.

Strengths

This integration effort capitalizes on one of EPA's biggest strengths: the commitment of its workforce to fulfill the Agency's mission to protect human health and the environment. The Nitrogen Roadmap represents transdisciplinary contributions of research and program scientists with varied expertise, as well as the contributions of policy analysts, economists, social scientists, program managers, and various stakeholders. Much of this effort has been built on longstanding collaborative relationships within ORD and between ORD and EPA's regulatory Program Offices, and Regional Offices. An integrated approach to address aspects of known nitrogen and co-pollutant impacts that are currently difficult to resolve will build collaborative solutions among the science, policy, and regulations, improve transparency, and reduce the unintended consequences of our nitrogen and co-pollutant reduction actions.

Table 1. Inventory of current ORD nitrogen and co-pollutant research projects that address SAB recommendations

No.	SAB Recommendation	ORD Research Projects	Expected Outcomes
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 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** National Atlas of Ecosystem Services	**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.		
2c	Identify research and education priorities to support more efficient use and better mitigation of Nr applied to agricultural systems.	**SHC 1.2.3** National Atlas of Ecosystem Services	**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.	**ACE EB-2** Managing the impacts 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	**ACE EB-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 EB-2)** Ecosystem goods and services production and benefit functions (and conclusion of Future	**SHC 2.1.2.1 (ACE EB-2)** Enhanced CMAQ modeling capability with respect to biofuels, feedstock production and N_2O fluxes

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		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	**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
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-7** Atmospheric deposition tools to inform secondary NAAQS **ACE EM-2** Improving emissions inventories	**ACE NMP-7** 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 NO2 National Ambient Air Quality Standard.	**ACE NMP-7** Atmospheric deposition tools to inform secondary NAAQS	**ACE NMP-7** Improved methods for quantifying N and sulfur concentrations and air-surface exchange fluxes with high temporal resolution
8b	Monitor of NH_x and NO_y to supplement the existing network of NO_2 compliance monitors.	**ACE NMP-7** Atmospheric deposition tools to inform secondary NAAQS **ACE EM-1** Methods for measurement to inform policy decisions	**ACE NMP-7** 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 NO2, NO and PAN, and HNO3, and other inorganic and reduced forms.	**ACE NMP-7** Atmospheric deposition tools to inform secondary NAAQS **ACE EM-1** Methods for	**ACE NMP-7** Improved methods for quantifying N and sulfur concentrations and air-surface

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		measurement to inform policy decisions **ACE EM-2** Improving emissions inventories	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-7** Atmospheric deposition tools to inform secondary NAAQS	**ACE NMP-7** 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-7** 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-7** 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
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** National Atlas of Ecosystem Services **SHC 3.3.1** Informing sustainable decisions about Nitrogen	**ACE EM-2** Revised soil NO emission estimates for the US **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** National Atlas of Ecosystem Services **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

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			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 **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	**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 **SSWR 2.3** Improved assessment approaches and biological indicators to assess responses to N&P and compliance **SSWR 4.3** Reliably predict natural infrastructure and engineered green infrastructure water quality impacts at watershed scale. **SSWR 6.1** Develop and demonstrate at the watershed scale approaches for determining condition, resilience, restorability, diagnostics and system level models
12	Reevaluate water quality management approaches, tools, and authorities to ensure Nr management goals are attainable, enforceable, and cost-effective.	**SSWR 2.1** Approaches and predictive tools for sustainable solutions to manage the impacts of land use and climate change on water resources **SSWR 2.3** Optimal Solutions for Sustainable Nutrient Management **SSWR 6.1** Narragansett Bay and Watershed Sustainability --	**SSWR 2.1A** Automated, on-line system for generating screening-level TMDLs for watershed priority-setting. **SSWR 2.3** Development of decisions support systems that integrate and assesses the effects of N and P management practices on nutrient loading, ecosystem

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		Demonstration Project	health, and social and economic outcomes at various scales. **SSWR 6.1** Develop and demonstrate at the watershed scale approaches for determining condition, resilience, restorability, diagnostics and system level models
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 EB-2)** Ecosystem goods and services production and benefit functions (and conclusion of Future Midwestern Landscapes Study, including air quality impacts) **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 2.1.2.1 (also ACE EB-2)** Synthesis document on use of sustainability metrics to complement life cycle approaches **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** Decision support system for sustainably managing nutrients **SSWR 6.1** Develop and demonstrate at the watershed scale approaches for determining condition, resilience, restorability, diagnostics and system level models
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 **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** Development of numeric nutrient criteria and science-based interpretation of narrative standards for inland waters and downstream estuarine and coastal waters **SSWR 6.1** Develop and demonstrate at the watershed scale approaches for determining condition, resilience, restorability, diagnostics and system level models

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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 distribute 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 6.1** Narragansett Bay and Watershed Sustainability -- Demonstration Project	**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** Report on the GEM and GoMDOM predictions of the effects of nutrient load reduction and climate change scenarios on the Gulf of Mexico hypoxia. **SSWR 4.3** Reliably predict natural infrastructure and engineered green infrastructure water quality impacts at watershed scale. **SSWR 6.1** Develop and demonstrate at the watershed scale approaches for determining condition, resilience, restorability, diagnostics and system level models

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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 2.1** Approaches and predictive tools for sustainable solutions to manage the impacts of land use and climate change on water resources **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 2.1** Watershed modeling tools of the effects of agricultural conservation practices/BMPs on subsurface flow, stream hydrology and water quality **SSWR 2.3** Decision support system for sustainably managing nutrients **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 **SSWR 6.1** Narragansett Bay and Watershed Sustainability -- Demonstration Project	**SSWR 1.3** Decision-support tools to aid development of market-based activities that promote watershed integrity **SSWR 2.3** Improved assessment approaches and biological indicators to assess responses to N&P and compliance **SSWR 6.1** Develop and demonstrate at the watershed scale approaches for determining condition, resilience, restorability, diagnostics and system level models
16	Adopt the critical loads approach concept in determining thresholds for effects of excess Nr on terrestrial and aquatic ecosystems.	**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 **SSWR 2.3** Optimal Solutions for Sustainable Nutrient Management **SSWR 4.3** Green infrastructure modeling tools and data inventories	**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 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** Development of numeric nutrient criteria and science-based interpretation of narrative

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			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 $PM_{2.5}$ 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-7** 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-7** 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 **SSWR 2.3** Optimal Solutions for Sustainable Nutrient Management **SSWR 4.3** Green infrastructure modeling tools and data inventories	**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 **SSWR 2.3** Development of numeric nutrient criteria and science-based 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	**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

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		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	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** Decision support system for sustainably managing nutrients **SSWR 4.3** Reliably predict natural infrastructure and engineered green infrastructure water quality impacts at watershed scale.
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** Improved assessment approaches and biological indicators to assess responses to N&P and compliance