EPA
United States
Environmental Protection
Agency

SAB

Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options

A REPORT OF THE EPA SCIENCE ADVISORY BOARD



Science Advisory Board
Office of the Administrator

An SAB Original Study

- Undertaken to provide advice to EPA, from a scientific perspective, on managing problems caused by excess reactive nitrogen (Nr) in the environment.
- Analyzes the inputs and flows of reactive nitrogen in the U.S.
- Recommends new risk reduction strategies to improve upon traditional media-specific regulatory and nonregulatory approaches.
- Recommends using the movement of nitrogen among environmental reservoirs in multiple ecosystems and media (the Nitrogen Cascade) as a framework for understanding and more effectively managing reactive nitrogen.

The Problem of Reactive Nitrogen

- Excess Nr, which includes biologically active and chemically reactive forms of nitrogen, is associated with many large-scale environmental concerns.
- Anthropogenic creation of Nr provides essential benefits as a fertilizer for food production.
  - Most U.S. citizens consume food grown with anthropogenic Nr.
  - Most Nr used in food production is lost to the environment.
- The productivity of most of the world's ecosystems is often limited by the availability of Nr.
  - Thus losses to environment have immediate impacts on ecosystems and on people.
- Dealing with the problem of Nr is very complex because it changes form and flows through different media.

Impacts of Excess Reactive Nitrogen

- Environmental Impacts:
  - Hypoxia and eutrophication in surface waters
  - Acid rain
  - Smog
  - Nitrogen saturation of forests
  - Global warming
  - Stratospheric ozone depletion
- Human Health Impacts:
  - Cardiovascular and respiratory system effects of air pollutants
  - Effects associated with nitrate in drinking water
  - Skin cancer
- All of these effects are linked and enhanced by the movement of Nr among environmental reservoirs (the Nitrogen Cascade).

Sources of Reactive Nitrogen

- Human Activities introduce five times more Nr into the U.S. environment than natural sources.
- The largest anthropogenic sources of Nr are: synthetic fertilizer, nitrogen fixing legumes, and fossil fuel combustion.

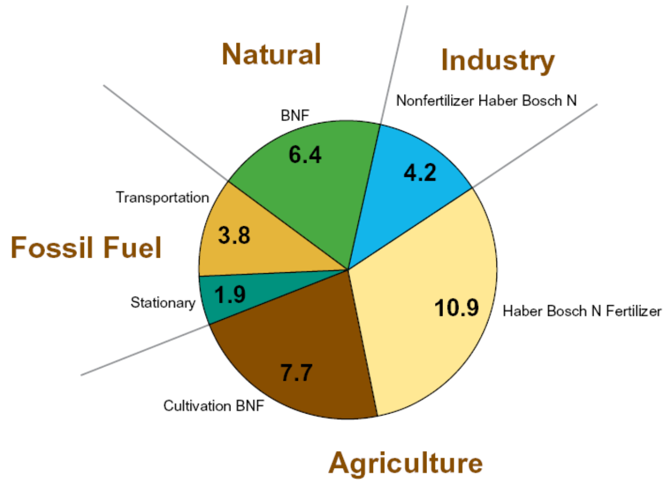


Figure ES-2: Sources of reactive nitrogen (Nr) introduced into the United States in 2002 (Tg N/yr).

Figure ES-2 explanatory notes:
Numerical units: teragram of reactive nitrogen (Nr) per year (Tg N/yr)

The Nitrogen Cascade

- Movement of Nr among environmental reservoirs causes a cascade of effects as it changes form and passes through multiple ecosystems.

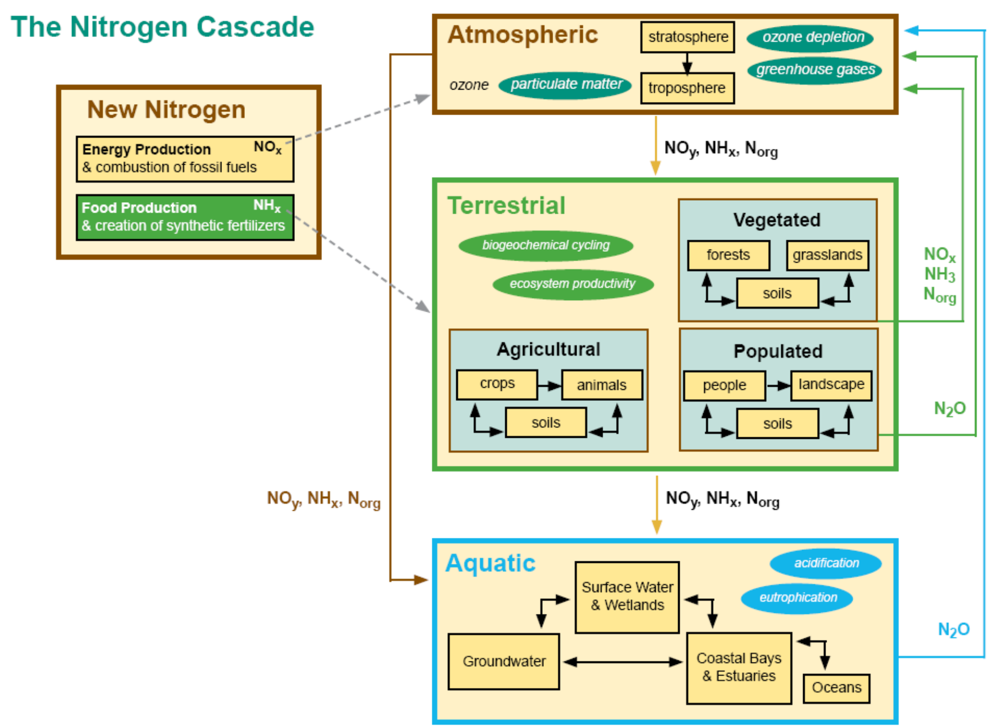
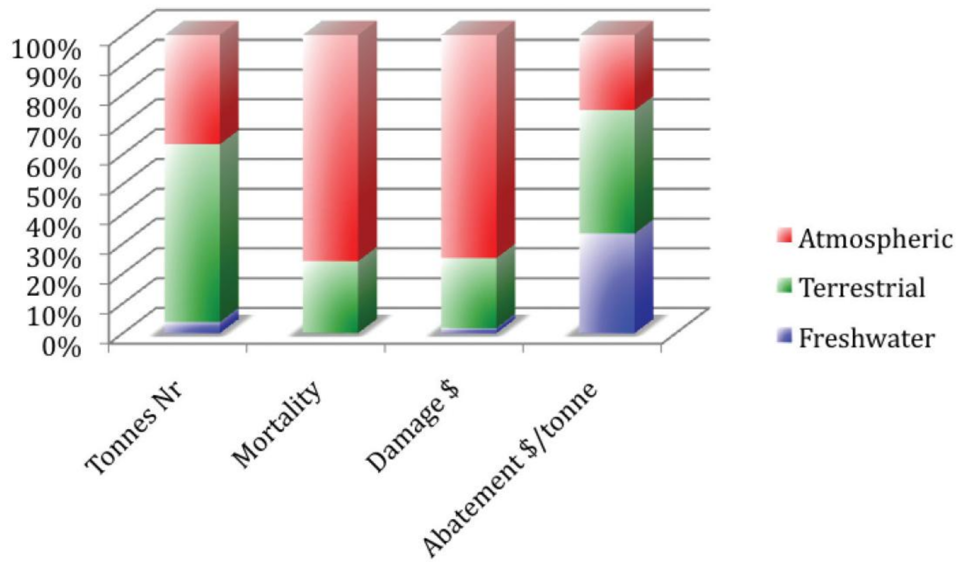


Figure ES-1: The nitrogen cascade

The Nitrogen Cascade in Chesapeake Bay – Implications for Nr Management

- Damage costs and marginal abatement costs per metric ton of Nr by source (atmospheric, terrestrial, freshwater) indicate that the least costly abatement and greatest gain come from atmospheric emission controls.



Relative importance of all reactive nitrogen sources released into atmospheric, terrestrial, and freshwater media within the Chesapeake Bay Watershed (Birch et al., 2011)

Overarching SAB Recommendations

- The nitrogen cascade should be used as a framework to understand the environmental impacts of reactive nitrogen as it moves through multiple ecosystems and media.
- Integrated cross-media management approaches and regulatory structures are needed to recognize tradeoffs and focus management efforts at points of the nitrogen cascade where they are most efficient and cost effective.
- EPA should form an intra-Agency Nr management task force to build on the existing breadth of Nr research and management capabilities within the Agency.
- EPA should convene an inter-Agency Nr management task force to coordinate federal programs that address Nr monitoring, modeling, research, and management.

Specific Recommendations

- EPA should consider a range of Nr risk management options including:
  - An evaluation of the full suite of regulatory and non-regulatory tools used to manage Nr to determine the most effective mechanisms to apply to each source.
  - Reexamination of the criteria air pollutant "oxides of nitrogen" to consider whether it should be supplemented with other indicators of chemically reactive nitrogen.
  - A policy, regulatory, and incentive framework to further limit the transport of applied nutrients off farms.
- EPA should undertake education, communication, and outreach to build public support for addressing the widespread problem of Nr.
- Additional Nr research and monitoring is essential to:
  - Reduce the margins of error in our current understanding of environmental Nr concentrations or flows.
  - Target actions to reduce excess Nr and understand the efficacy of management actions that have been taken.
  - Improve our understanding of the indirect impacts of Nr and the indirect impacts of measures to control Nr.

Goals for Management Action

- The SAB estimates that a 25% reduction in Nr introduced into the U.S. environment might be achieved with existing technology in the coming 10-20 years through actions that could be taken by EPA and other management authorities.
  - Expanded efforts to control emissions of NO_x from mobile sources and power plants could decrease the generation of Nr by 2.0 Tg/yr.
  - Increased crop uptake efficiencies (through advances in fertilizer technology) could further decrease Nr releases by 2.4.Tg/yr.
  - Livestock-derived NH_3 emissions could be decreased by 0.5 Tg/yr through a combination of BMPs and engineered solutions, and NH_3 emissions from fertilizer application could be decreased by 0.2 Tg/yr through BMPs related to application rate and timing.

Goals for Management Action

- Management actions to reduce Nr by 25% (continued)
  - Excess flows of Nr into streams, rivers and coastal systems could be decreased by 1 Tg/yr through improved landscape management (e.g., wetland creation and improved tile-drainage systems on cropland).
  - Removal of nutrients through sewage treatment infrastructure upgrades and stormwater and nonpoint source control could decrease Nr releases by 0.5 - 0.8 Tg/yr.
- These goals for management action represent realistic and attainable near-term outcomes, but further Nr reductions are needed for many N-sensitive ecosystems and to ensure that health-related standards are maintained.

Key Water Quality Recommendations

- Develop a uniform Nr assessment and management framework that considers loading over a range of scales, and includes all inputs related to atmospheric and riverine delivery to estuaries and their effects on eutrophication dynamics.
- Set Nr management goals on a regional/local basis.
- Address Nr runoff and discharges by reviewing current regulatory and nonregulatory programs and tools to determine adequacy and capacity to meet Nr management goals.
- Determine and apply the most effective regulatory and voluntary mechanisms to each Nr source type, paying special attention to the need to control nonpoint sources.
- Encourage wetland restoration and creation to promote denitrification.

Key Data Acquisition Recommendations

- Obtain more and better data to inform management decision-making
  - In partnership with other agencies, routinely and consistently account for presence of Nr in the environment using an integrated approach to monitoring that includes air, water, and land components.
  - Expand scope and spatial coverage of atmospheric Nr concentration and flux monitoring networks (e.g., National Atmospheric Deposition program, Clean Air Status and Trends Network).
  - Obtain better fertilizer application data for major crops and residential turf.
  - Monitor gas and particulate matter emissions from agriculture.
  - Begin air monitoring of NH_x and NO_y to supplement the existing network of NO_2 compliance monitors.

Key Research Recommendations

- Management Strategies Research
  - Understanding tradeoffs associated with management strategies for carbon, Nr and other contaminants.
  - Understanding the combined impacts of different Nitrogen management strategies on the movement of Nr across environmental media.
  - Understanding the effectiveness of best management practices (particularly for controlling Nr from nonpoint and stormwater sources).
  - Understanding how to manage the impact of Nr on ecosystem services.
- Agricultural Research
  - Understanding and predicting how biofuel production will affect Nr inputs and outputs from agriculture and livestock systems.
  - Increasing gain in crop yields and nitrogen fertilizer use efficiency.
  - Understanding nitrogen mass balance for crop agriculture.
  - Improving fertilizer application and formulation technologies.

Key Research Recommendations (continued)

- Nitrogen Budget Research
  - Quantifying the N budgets of terrestrial systems and the magnitudes of major loss vectors.
  - Quantifying denitrification in soils and aquatic systems.
- Measurement and Modeling Research
  - Improving analytical techniques for measuring atmospheric NO_y and NH_x and modeling the movement of Nr in the environment.
  - Cross-disciplinary research to model interactions of climate and Nr.

Key Air Quality Recommendations

- Expand NO_x control efforts for emissions of mobile sources and power plants.
- Reexamine the criteria air pollutant “oxides of nitrogen” to consider whether it should be supplemented with other indicators of chemically reactive nitrogen.
- Encourage states to address NH_3 as a harmful $PM_{2.5}$ precursor.

Summary

- The SAB has provided findings and recommendations to address the complex problem of reactive nitrogen.
- To build support for Nr management, it is critically important that the problems caused by Nr be recognized by the public.
- The concept of the nitrogen cascade is an essential framework for approaching the problem.
- Integrated cross-media approaches are needed to effectively manage Nr.
- Monitoring and research are needed to support Nr management activities.