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2 The Honorable Lisa P. Jackson  
3 Administrator  
4 U.S. Environmental Protection Agency  
5 1200 Pennsylvania Avenue, N.W.  
6 Washington, D.C. 20460

7

8 Subject: Reactive Nitrogen in the United States; An Analysis of Inputs, Flows, Consequences,  
9 and Management Options: A Report of the EPA Science Advisory Board

10

11 Dear Administrator Jackson:

12

13 We are pleased to submit the accompanying SAB report, *Reactive Nitrogen in the*  
14 *United States—An Analysis of Inputs, Flows, Consequences, and Management Options*. This  
15 study was undertaken to review the impacts of excess reactive nitrogen on human health and  
16 the environment and to describe sources and flows of reactive nitrogen. In the context of this  
17 information, the study suggests risk management options to decrease the amount of reactive  
18 nitrogen in the environment while increasing benefits, and recommends new research to  
19 improve the understanding of reactive nitrogen sources, flows, impacts, and risk reduction  
20 options.

21 EPA and other federal agencies have implemented programs to reduce the risks posed  
22 by excess reactive nitrogen, but a more comprehensive and integrated approach is needed to  
23 manage and optimize the use of reactive nitrogen. The nature of reactive nitrogen demands an  
24 integrated approach within EPA and across other relevant federal agencies, as reactive nitrogen  
25 cycles through the environment in different forms, once it is introduced. The current media-  
26 specific, pollutant-specific, and problem-specific approach has achieved notable improvements  
27 in air and water quality over the past 40 years but does not take advantage of the adaptive,  
28 knowledge-based approach needed for effective control of current loadings of reactive nitrogen  
29 to the environment. Such an approach requires accounting for the different chemical forms of  
30 reactive nitrogen and targeting the most effective intervention points.

31 In this regard, our overarching recommendations urge formation of intra-EPA and  
32 inter-agency reactive nitrogen Management Task Forces that will encourage reactive nitrogen  
33 management policies that build on existing reactive nitrogen research and management  
34 capabilities within the Agency and across federal and state governments.

35 Additional key findings include:

36

- 37 • In the United States, human activities associated with multiple sources currently  
38 introduce more than five times more reactive nitrogen into the environment than natural

1 processes. The largest sources of newly created reactive nitrogen entering the U.S.  
2 environment include: 1) creation and use of inorganic fertilizers; 2) cultivation of  
3 agricultural legume crops; and 3) combustion of fossil fuels.

- 4 • The creation of reactive nitrogen ensures a plentiful supply of food, fiber, and fuel,  
5 however, much of the reactive nitrogen used for this purpose is lost to the environment,  
6 as is all the reactive nitrogen formed during fossil fuel combustion.
- 7 • The introduction of anthropogenically created reactive nitrogen to the environment is  
8 the cause of problems such as degradation of air and water quality, harmful algae  
9 blooms, hypoxia, fish kills, loss of drinking water supplies, loss of biodiversity, forest  
10 declines, and human health problems. At a minimum, the financial cost of these losses  
11 are in the multi-billions of dollars per year. Thus new strategies to minimize inputs of  
12 reactive nitrogen to the environment and maximize nitrogen use efficiency are likely to  
13 be cost effective.

14  
15 The Integrated Nitrogen Committee recommends the following actions to address the  
16 problem of reactive nitrogen.

- 17 • Use available technology to decrease by 25% the total amount of reactive nitrogen  
18 entering the U.S. environment. Specific actions include increased controls on oxides of  
19 nitrogen emissions, improved reactive nitrogen uptake by agricultural crops, decreased  
20 losses of reactive nitrogen from agricultural lands and animal feeding operations, and  
21 decreased discharge of reactive nitrogen from point sources and developed lands.
- 22 • Further examine ways to expand the national ambient air quality standard for nitrogen,  
23 which regulates “oxides of nitrogen” as a criteria pollutant and which uses NO<sub>2</sub> as the  
24 indicator, to the use of “total oxidized nitrogen,” using NO<sub>y</sub> as the indicator. This is  
25 more inclusive of the oxidized, reactive nitrogen compounds that contribute to impacts  
26 on human and ecosystem health. In addition, expand the category of reactive nitrogen  
27 criteria pollutants to include chemically reduced forms of nitrogen and establish new  
28 thresholds that will likely be required to adequately manage them.
- 29 • Develop a long-term strategy for data collection on reactive nitrogen use that provides  
30 adequate information about where and how it is used. Expand monitoring networks to  
31 quantify reactive nitrogen in air and water (in urban, agricultural, and rural settings) and  
32 link them to critical threshold loadings for determining the negative impacts of reactive  
33 nitrogen on the environment and human health.
- 34 • Develop an integrated, multiple-metrics, multi-media approach (utilizing the ecosystem  
35 services concept) to set priorities and to manage reactive nitrogen that recognizes the  
36 associated complexities and tradeoffs as it moves through the environment. This is  
37 contrary to the current approach in which air, land and water pollution are managed  
38 separately. Management efforts aimed at key points in the nitrogen cycle may be more  
39 technologically efficient and economically cost effective than control or intervention  
40 elsewhere. Thus regulatory policies must be matched to the nature and dynamics of  
41 reactive nitrogen as it cascades damage throughout the environment and to human  
42 health.

**8-27-09 Science Advisory Board (SAB) Integrated Nitrogen Committee Draft Advisory Report**  
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1           In closing, we appreciate the opportunity to provide advice on this very important topic,  
2 and we look forward to receiving your response. The SAB would be pleased to assist EPA in  
3 implementing the report's recommendations, if the Agency would find the support valuable.

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Sincerely yours,

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10

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11

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

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## Executive Summary

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### 2 Introduction

3 Human activities currently produce five times more reactive nitrogen<sup>1</sup> per year than natural processes. The  
4 four largest sources of new anthropogenically created reactive nitrogen entering the U.S. environment are:  
5 1) use of synthetic fertilizer resulting in the introduction of 15.2 Tg N per year to terrestrial landscapes; 2)  
6 cultivation of agricultural legume crops that such as soybeans and alfalfa that convert atmospheric  
7 nitrogen into 7.7 Tg of reactive nitrogen reactive nitrogen per year; 3) fossil fuel combustion resulting in  
8 emission of 5.7 Tg of reactive nitrogen into the atmosphere per year; and 4) importation of 0.15 Tg  
9 nitrogen per year into the United States in grain and meat. Together, these sources represent  
10 approximately 70% of the total reactive nitrogen input into the United States environment per year. Once  
11 introduced in the United States, most reactive N is lost to the environment, where it is distributed by  
12 hydrologic and atmospheric transport.

13

14 In this report, the Science Advisory Board (SAB) has undertaken an assessment of reactive nitrogen in the  
15 United States because human activities have significantly increased the amount of reactive nitrogen that is  
16 being introduced into the U.S. environment that have resulted in significant negative impacts on  
17 ecosystems and people.

18

19 Release of anthropogenically created reactive nitrogen has resulted in excess nitrogen in the air, water  
20 and land environments of the United States. This has caused problems such as harmful algae blooms,  
21 hypoxia, fish kills, contamination of drinking water supplies, acid deposition, loss of biodiversity, forest  
22 declines, and human health problems associated with atmospheric pollution. These problems are both  
23 extensive and expensive.

24

25 Management of Nr requires an integrated, multiple-metrics, multi-media approach to set priorities and to  
26 manage reactive nitrogen that recognizes the complexities and tradeoffs associated with reactive nitrogen  
27 in the environment. Management efforts aimed at key points in the nitrogen cascade may be more  
28 technologically efficient and economically cost effective than control or intervention elsewhere.

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30 This report recommends several actions to address the problem of excess reactive nitrogen. An  
31 overarching recommendation urges formation of Intra-EPA agency and Inter-agency reactive nitrogen  
32 Management Task Forces that will shift to reactive nitrogen management policies that build on existing  
33 reactive nitrogen research and management capabilities within the Agency and across Federal and State  
34 governments.

35

36 In addition, this report recommends:

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<sup>1</sup> The term reactive nitrogen (Nr) is used in this paper to include all biologically active, chemically reactive, and radiatively active nitrogen (N) compounds in the atmosphere and biosphere of Earth. Thus, Nr includes inorganic chemically reduced forms of N (NH<sub>x</sub>) [e.g., ammonia (NH<sub>3</sub>) and ammonium ion (NH<sub>4</sub><sup>+</sup>)], inorganic chemically oxidized forms of N [e.g., nitrogen oxides (NO<sub>x</sub>), nitric acid (HNO<sub>3</sub>), nitrous oxide (N<sub>2</sub>O), N<sub>2</sub>O<sub>5</sub>, HONO, peroxy acetyl compounds such as PAN, and nitrate ion (NO<sub>3</sub><sup>-</sup>)], as well as organic compounds (e.g., urea, amines, amino acids, and proteins), in contrast to non-reactive gaseous N<sub>2</sub>.

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- 1 • Use of available technology and management methods to decrease by 25% the total amount of  
2 reactive N entering the U.S. environment. Specific actions include increased controls on NO<sub>x</sub>  
3 emissions, improved reactive nitrogen uptake by agricultural crops, decreased loss of reactive  
4 nitrogen from agricultural lands and animal feeding operations, and decreased discharge of  
5 reactive nitrogen from point sources and developed lands. Specifically:
  - 6 ○ Expansion of EPA's NO<sub>x</sub> control efforts to achieve a 2.0 Tg N/year decrease in generation  
7 of reactive nitrogen from mobile and stationary sources.
  - 8 ○ Reduction of the discharge and emission of reactive nitrogen from agricultural lands by 1  
9 Tg/year and improvement of crop N-uptake efficiencies and reduction of the application of  
10 synthetic fertilizers by 2.4 Tg/yr.
  - 11 ○ Decreased emissions of livestock-derived NH<sub>3</sub> by 0.5 Tg/yr.
  - 12 ○ Decreased discharge of reactive nitrogen from point sources and developed lands, by 0.5-  
13 0.8 Tg/yr.

14  
15 The INC also recommends that EPA:

- 16  
17 • Change the NO<sub>2</sub> criteria pollutant to include all forms of nitrogen oxides (i.e., NO<sub>y</sub>), which is more  
18 inclusive of the oxidized nitrogen compounds that contribute to impacts on human and ecosystem  
19 health.
- 20 • Expand the category of reactive nitrogen criteria pollutants to include chemically reduced and  
21 organic forms of nitrogen and establish new thresholds that will likely be required to adequately  
22 manage it.
- 23 • Develop a long term strategy for data collection on the use of reactive nitrogen that provides  
24 adequate information about where and how it is used, and for monitoring of reactive nitrogen in air  
25 and water (both urban and rural) and link it to critical threshold loadings for determining the  
26 negative impacts of reactive N on the environment and human health.
- 27 • Develop an integrated, multiple-metrics, multi-media approach (utilizing the ecosystem services  
28 concept) to set priorities and to manage reactive nitrogen by means that recognize the complexities  
29 and tradeoffs associated with reactive nitrogen in the environment. Well-designed management  
30 efforts aimed at key points in the nitrogen cascade will be more technologically efficient and  
31 economically cost effective than control or intervention elsewhere. This is why regulatory policies  
32 must be matched to the nature and dynamics of reactive nitrogen as it cascades damage throughout  
33 the environment and to human health.

34  
35 The remaining portions of the Executive Summary expand on these points and provide background on Nr  
36 in the United States, an assessment of our knowledge on Nr creations and transfers among systems, and  
37 gives details on the impacts and metrics and more complete information on management strategies.

### 38 **Background**

39 Reactive nitrogen (Nr) encompasses biologically and radiatively active, and chemically reactive nitrogen  
40 compounds. Excess reactive nitrogen releases to the environment are a major cause of air and water  
41 quality degradation linked to major impacts to human and ecosystem health. Some sources and forms of

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1 reactive nitrogen have been regulated through the Clean Air and Clean Water Acts. Specific regulations  
2 have been introduced to decrease primary air pollutants such as nitrogen oxides (NO<sub>x</sub>), eutrophication of  
3 waterways by nitrate ions (NO<sub>3</sub><sup>-</sup>) and acid rain. While notable progress has been made, the fragmentation  
4 of this approach has proven a barrier to achieving additional improvements. This report has been  
5 developed to identify a more comprehensive analytical framework and alternative means to manage  
6 reactive nitrogen and to advise EPA on strategies that might prove more effective. This framework  
7 requires an integrated systems approach that identifies the stocks and follows the flows and chemical  
8 transformations of reactive nitrogen through air, land and water. A more comprehensive integrated  
9 approach will also help to establish priorities for action.

10 At the global scale, human activities now create approximately twice as much Nr as natural continental  
11 ecosystems. In the United States (US), Nr creation by human activity is about five-times larger than  
12 natural processes. Human activities create Nr by: (1) the Haber-Bosch process to generate ammonia  
13 (NH<sub>3</sub>) for synthetic nitrogen fertilizer and industrial feedstocks, (2) the enhancement of biological  
14 nitrogen fixation (BNF) in crop cultivation (e.g., legumes), and (3) the combustion of fossil fuels<sup>2</sup> and  
15 industrial process emissions. The first two anthropogenic activities form Nr on purpose; all three result in  
16 unwanted pollutants.

17 Anthropogenic creation of Nr provides essential benefits for humans--first and foremost in meeting human  
18 dietary needs. In fact, a large fraction of the human population of the earth could not be sustained if  
19 synthetic nitrogen fertilizers did not augment food production significantly all over the world. Essentially  
20 all of the Nr created by human activities, however, is released to the environment, often with unintended  
21 negative consequences. It circulates between, and accumulates within, the atmospheric, aquatic, and  
22 terrestrial ecosystems. As summarized in Table A, it contributes to a number of adverse public health and  
23 environmental effects, including photochemical smog, nitrogen-containing trace gases and aerosols,  
24 decreased atmospheric visibility, acidification of terrestrial and aquatic ecosystems, eutrophication of  
25 coastal waters (i.e., harmful algal blooms, hypoxia), drinking water concerns, freshwater Nr imbalances,  
26 greenhouse gas emissions and subsequent climate change, and stratospheric ozone depletion.

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<sup>2</sup> Burning of biomass such as in forest fires or wood-burning stoves releases Nr into the atmosphere, but this is generally from fuel N; it represents an exchange of Nr between media and not the generation of new Nr. Burning of biofuels in high-temperature internal combustion engines such as ethanol from corn or biodiesel used to power vehicles does generate new Nr, and EPA emissions inventories account for these under transportation or "Highway Vehicles." In this report, emissions of new Nr from biofuels is grouped with Nr from fossil fuels.

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1 **Table A: Examples of Impacts of Excess Reactive Nitrogen on Human Health and Environment**

Impact	Cause	Location	Metric	Source	Reference
Acidification of surface waters; loss of biodiversity	Acidification of soils, streams and lakes is caused by atmospheric deposition of sulfur, HNO <sub>3</sub> , NH <sub>3</sub> and ammonium compounds.	Primarily mountainous regions of the United States	Out of 1,000 lakes and thousands of miles of streams in the Eastern United States surveyed, 75% of the lakes and 50% of the streams were acidified by acid deposition	Fossil fuel combustion and agriculture	<a href="http://www.epa.gov/acidrain">http://www.epa.gov/acidrain</a>
Biodiversity loss	Nitrogen deposition	Grasslands and forests in the United States receiving N deposition in excess of critical load	Decrease in species richness of grasslands and forests	Utilities, traffic, and animal agriculture	Bobbink et al., 2009; Fenn et al., 2003.
Forest decline	Ozone and acid deposition	Eastern and Western United States	Decreased timber growth; increased susceptibility to disease and pests	Utilities, traffic, and animal agriculture	Johnson & Siccama, 1983; MacKenzie & El-Ashry, 1990
Crop yield loss	Ozone	Eastern and Western United States	\$ 2-5 billion/year	Utilities & traffic	Heck et al, 1984
Hypoxia of coastal waters	Excess nutrient loading, eutrophication, variable freshwater runoff	Gulf of Mexico, other estuarine and coastal waters	Benthic finfish/shellfish habitat loss, fish kills, sulfide toxicity, costs >\$50 million annually	N, P from energy and food production	Bricker et al. 1999, Verity et al. 2006; U.S. EPA SAB 2008; Rabalais et al., 1999; Mitsch et al., 2001
Harmful Algal Blooms	Excessive nutrient loading, climatic variability	Inland and coastal waters	Fish kills, losses of drinking and recreational waters costs >\$100 million annually	Excess nutrient (N & P) loading	Paerl 1988; ECOHAB 1995; NRC 2000
Visibility decrease	Fine particulate matter	National Parks and wilderness areas	visibility impairment	NO <sub>y</sub> and NH <sub>x</sub> from fossil fuels and agriculture	Malm et al., 2004 EPA-CASAC-09-010
Human mortality	PM <sub>2.5</sub> , O <sub>3</sub> and related toxins.	US urban and nearby areas.	Pollution related deaths estimated at 28,000-55,000 per year.	NO <sub>y</sub> and NH <sub>x</sub> from fossil fuels and agriculture	Mokdad et al., 2004] Ezzati et al., 2004.

Impact	Cause	Location	Metric	Source	Reference
Total damage to public health and environment	NO <sub>x</sub> into air	Chesapeake Bay Watershed	\$3.4 Billion; 200,000 Mt	Mobile sources	Moomaw and Birch, 2005
Total damage to public health and environment	NH <sub>x</sub> and nitrate into air and water	Chesapeake Bay Watershed	\$1.5 Billion; 400,000 Mt	Agriculture	Moomaw and Birch, 2005

1

2 Nr effects are manifest as declines in both human health (e.g., respiratory and cardiac diseases) and  
 3 ecosystem health (e.g., coastal eutrophication and loss in biodiversity). The effects are often magnified  
 4 because any one atom of nitrogen in the environment can contribute to both beneficial and detrimental  
 5 effects in sequence, as excess Nr moves through various environmental reservoirs. This feature of Nr is  
 6 the conceptual foundation for the nitrogen cascade.

7 The nitrogen cascade provides a conceptual framework to assess and quantify the effects of Nr as it  
 8 originates, flows, and transitions through the atmosphere, land and water. The framework helps organize  
 9 Nr sources within each environmental system, its transfer among the systems, and the benefits and impacts  
 10 along the way. It further highlights potential decreases in emissions or management intervention within  
 11 each system that integrate those actions among sources and media (air, land, water) to provide an efficient  
 12 mechanism for regulation.

13 To assist EPA in its understanding and management of nitrogen-related air-, water-, and soil-pollution  
 14 issues, this Integrated Nitrogen Committee (INC) was formed and charged by the Science Advisory Board  
 15 (SAB) of the U.S. Environmental Protection Agency to address the following objectives:

- 16 1. Identify and analyze, from a scientific perspective, the problems nitrogen presents in the  
 17 environment and the links among them;
- 18 2. Evaluate the contribution an integrated nitrogen management strategy<sup>3</sup> could make to  
 19 environmental protection;
- 20 3. Identify additional risk management options for EPA's consideration; and
- 21 4. Make recommendations to EPA concerning improvements in nitrogen research to support risk  
 22 reduction.

23

24 This Executive Summary contains an overview of the analyses made by the INC to fulfill the four charges.  
 25 The detailed analyses that support the conclusions and recommendations follow in the main body of the  
 26 report. It summarizes the Nr inputs to the United States, the fate of the Nr in the United States and  
 27 addresses how both public health and environmental impacts are and could be assessed. The

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<sup>3</sup> An integrated nitrogen management strategy takes a holistic approach for managing Nr. In the context of the nitrogen cascade, all Nr anthropogenic creation and destruction mechanisms and all Nr uses are recognized. The strategy should take account of synergies and trade-offs, to ensure that decreasing one problem related to nitrogen does not result in other unintended adverse environmental, economic and societal consequences. By identifying relative priorities, assessing cost effectiveness and risks, the strategy should seek to maximize the benefits of Nr, while limiting overall adverse effects.

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1 recommendations are organized within three tiers. The first tier contains “overarching” recommendations  
2 for both research and management that the INC believes will help the EPA develop an integrated nitrogen  
3 management strategy. The second tier consists of four recommendations (“Target Goals”) that are  
4 suggested for management actions that could achieve an initial 25% decrease in the amount of Nr lost to  
5 the U.S. environment using existing technologies. The third tier offers more specific recommendations  
6 that support and clarify the intent of the three overarching and four “Target Goal” recommendations.

7 In recent years, other studies have examined some aspects of the biogeochemical flows of Nr in the U.S.  
8 nitrogen cycle, the impacts of alterations in those flows, and suggested policies for addressing some  
9 specific consequences of those alterations. By contrast, this report of the INC committee seeks to provide  
10 an integrated and holistic approach to all aspects of the current Nr-management problems and challenges  
11 in our country. The INC is convinced that the EPA has a potentially powerful lead role to play -- together  
12 with other federal, state, and local organizations -- in developing integrated strategies to maximize  
13 beneficial impacts and decrease detrimental impacts of Nr management in this country.

#### 14 **Overview**

15 The INC addressed the four objectives in the following manner.

16 ***Objective 1: Identify and analyze, from a scientific perspective, the problems Nr presents in the***  
17 ***environment and the links among them.***

18 To address this objective, the INC used the nitrogen cascade framework to determine the major sources of  
19 newly created Nr in the United States (see Figure 1). The flows of Nr within the food, fiber, feed and  
20 bioenergy production systems for the U.S. were examined, paying special attention to the locations in each  
21 of these systems where Nr is lost to the environment. The same process was employed for energy  
22 production but, since all the Nr formed during energy production is lost to the environment, the committee  
23 identified the important energy producing sectors that contribute to Nr formation.

24 The committee next examined the fate of the Nr lost to the environment, estimated the amount stored in  
25 different systems (e.g., forest soils) and tracked Nr as it is transferred from one environmental system  
26 (e.g., the atmosphere) to another (e.g., terrestrial and aquatic ecosystems).

27 The introduction of Nr to the U.S. environment, its flows between reservoirs, transfers of Nr out of the  
28 U.S. environment and losses of Nr due to conversion to N<sub>2</sub> are summarized in Figure 2.

29 These two activities set the stage for addressing the environmental and human health problems Nr  
30 presents, and the links among them. Using the nitrogen cascade, the committee identified the impacts Nr  
31 has on people and ecosystem functions as it moves through different systems. The committee also  
32 addressed the alternative metrics that could be used, including tons of specific forms of Nr, human health  
33 indicators and the economic damage cost, to assess incommensurable impacts due to environmental  
34 changes (e.g., acid deposition), vs. impacts due to losses of ecosystem services (e.g., loss of biodiversity),  
35 and trade-offs among Nr Impacts.

36 ***Objective #2: Evaluate the contribution an integrated N management strategy could make to***  
37 ***environmental protection.***

38 An integrated management strategy should take into account the contributions of all Nr sources, and all

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1 chemical species of Nr that adversely impact both human health and environmental systems. Further, an  
2 integrated strategy should ensure that solving one problem related to Nr does not exacerbate another  
3 problem or diminish necessary ecosystem services to produce food, feed, fiber, or bioenergy. In short, the  
4 strategy should seek to achieve desirable benefits of Nr, while limiting adverse effects.

5 To address this challenge, the committee identified several actions that could be taken to better manage Nr  
6 in one environmental system that have caused unintended consequences in another. Examples of  
7 management actions that could be taken that would be ‘integrative’ in nature are highlighted.

8 ***Objective #3: Identify additional risk management options for EPA’s consideration.***

9 The INC has identified four major Target Goals for actions that collectively will decrease Nr losses to the  
10 environment by about 25%, recognizing that decreasing Nr emissions by these actions will result in  
11 further decreases in Nr-related impacts throughout the nitrogen cascade. INC has suggested several ways  
12 in which each of these Target Goals could be attained including conservation measures, additional  
13 regulatory steps, application of modern technologies, and end-of-pipe approaches. These are initial  
14 actions; others should be taken once the recommended actions are completed. Thus the last sections of  
15 this report focus on a better understanding of N dynamics and impacts in the United States.

16 ***Objective #4: Make recommendations to EPA concerning improvements in Nr research to support risk***  
17 ***reduction.***

18 Throughout the report, there are summary statements, labeled “Findings.” Attached to these findings are  
19 one or more specific “Recommendation” for actions that could be taken by EPA or other management  
20 authorities. In each case, the intent is to provide the scientific foundation regarding a specific Nr-relevant  
21 environmental issue and one or more recommendations by which EPA acting alone or in cooperation with  
22 other organizations could use currently available technology to decrease the amount of Nr lost to the U.S.  
23 environment.

24 The remaining sections of this Executive Summary cover the points made above in greater detail. A full  
25 list of findings and recommendations for technical and policy actions are to be found in Appendix 3 of the  
26 full report.

27 **Nr Sources and Transfers**

28 *Sources of Nr*

29  
30 At the global scale, human activities produce approximately twice as much reactive nitrogen as do natural  
31 processes; in the United States, however, the amount of Nr produced by human activities is approximately  
32 five-times larger than natural processes. As shown in Figure 1, natural ecosystems in the United States  
33 introduce about 6.4 teragrams (Tg) of reactive nitrogen per year (Tg N/yr). In contrast, human activities  
34 introduce about 28.5 Tg N/yr.

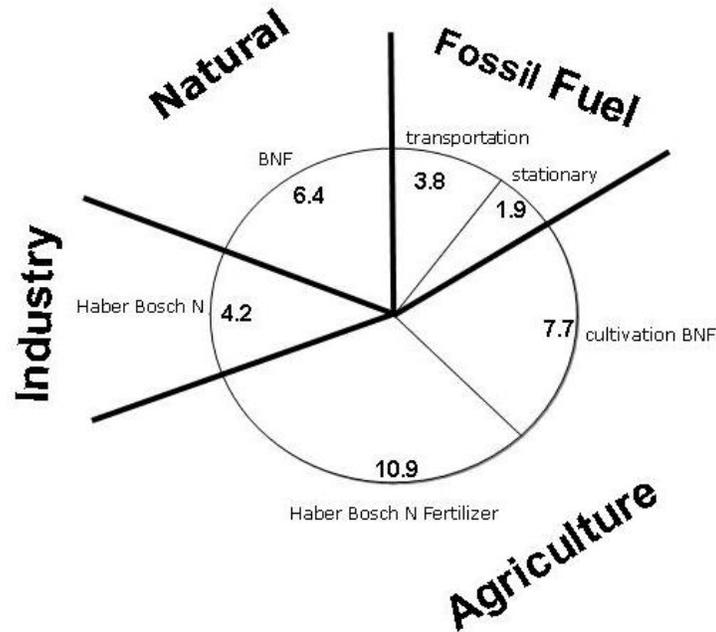
35  
36 The largest single source of Nr in the United States is the Haber-Bosch process, which introduces about  
37 15.2 Tg N/yr -- 9.4 Tg N/yr from domestic U.S. Nr production and 5.8 Tg N/yr from imports of synthetic  
38 Nr fertilizers, feed grains and food. This total amount is used in three ways -- 9.9 Tg N/yr is used to  
39 produce agricultural crops; 1.1 Tg N/yr is applied to turf grasses; and 4.2 Tg N/yr is used as industrial feed

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1 stocks for production of nylon, refrigerants, explosives and other commercial products. N fixation in  
2 cultivated croplands introduces 7.7 Tg N/yr into Agroecosystems.

3  
4 Fossil fuel combustion is the second largest source of Nr. It introduces approximately 5.7 Tg N/yr into the  
5 environment (almost entirely as NO<sub>x</sub>) -- 3.8 Tg N/yr from transportation sources and 1.9 Tg N/yr from  
6 stationary sources such as electric utilities, industrial boilers and from certain industrial processes.

7  
8 **Figure 1: Sources of reactive nitrogen (Nr) introduced into the United States in 2002 (Tg N/yr)**



- 9  
10  
11 Explanatory notes:
- 12 • Numerical units = teragram of reactive nitrogen (Nr) per year (Tg N/yr)
  - 13 • Natural BNF = biological nitrogen fixation in natural grasslands, rangelands, and forests,
  - 14 • Fossil Fuel-Transportation = combustion in vehicles, trains, airplanes, ships and off-road construction  
15 equipment.
  - 16 • Fossil Fuel-Stationary = combustion of fossil fuels in power plants and industrial boilers.
  - 17 • Agriculture-cultivation BNF = agricultural augmentation of biological nitrogen fixation -- for example by  
18 planting of nitrogen fixing legumes.
  - 19 • Agriculture-Haber Bosch N fertilizer = agricultural use of synthetic nitrogen fertilizers produced by the Haber  
20 Bosch process for converting gaseous N<sub>2</sub> to Nr.
  - 21 • Industry-Haber Bosch N = Industrial sources of Nr produced by the Haber-Bosch process.
  - 22 • Figure 1 documents only the introduction of new Nr in the United States, and not the transfers of existing Nr  
23 among systems (e.g., Nr in manure).
- 24  
25

26 The third largest source of Nr introduced into the United States is enhancement of biological nitrogen  
27 fixation (BNF) by cultivation of legumes like soybeans and alfalfa that have nitrogen-fixing symbionts, or  
28 by crops like rice that have nitrogen-fixing bacteria in their rhizosphere. These Nr fixing crops introduce

1 about 7.7 Tg N/yr. A small amount of additional Nr is also imported in grain and meat products; in 2002  
2 this source of added Nr was approximately 0.2 Tg N/yr (not shown in Figure 1).

3  
4 In summary, agricultural production of food, feed, fiber, and bioenergy and combustion of fossil fuels are  
5 the largest sources of Nr released into the environment in the United States. The percentage distribution of  
6 Nr released to the U.S. environment from human activities in 2002 was: about 65% from agricultural  
7 sources, about 20% from fossil fuel sources, and about 15% from industrial sources (Figure 1).

8  
9 *Transfers of Nr among environmental systems*

10  
11 There are several possible fates for the approximately 35 Tg N/yr introduced into the U.S. environment  
12 each year from natural sources and human activities. Figure 2 illustrates these fates by showing the  
13 cascading flow of reactive nitrogen once it enters the atmospheric, terrestrial, and aquatic environments.  
14 The different environments have special characteristics. Nr in terrestrial and aquatic environments can be  
15 converted to non-reactive N<sub>2</sub> while much of the human morbidity and mortality attributed to Nr relates to  
16 the atmospheric environment. Given the flows of Nr and changes in its form within and between the  
17 different environments, decisions about where one intervenes to control or limit the impact of Nr become  
18 critical to both cost effectiveness and the extent of negative impact. For example, insofar as Nr's entry into  
19 terrestrial systems can be limited, its flow and transfer into aquatic and atmospheric systems may be  
20 mitigated and potential negative impacts avoided.

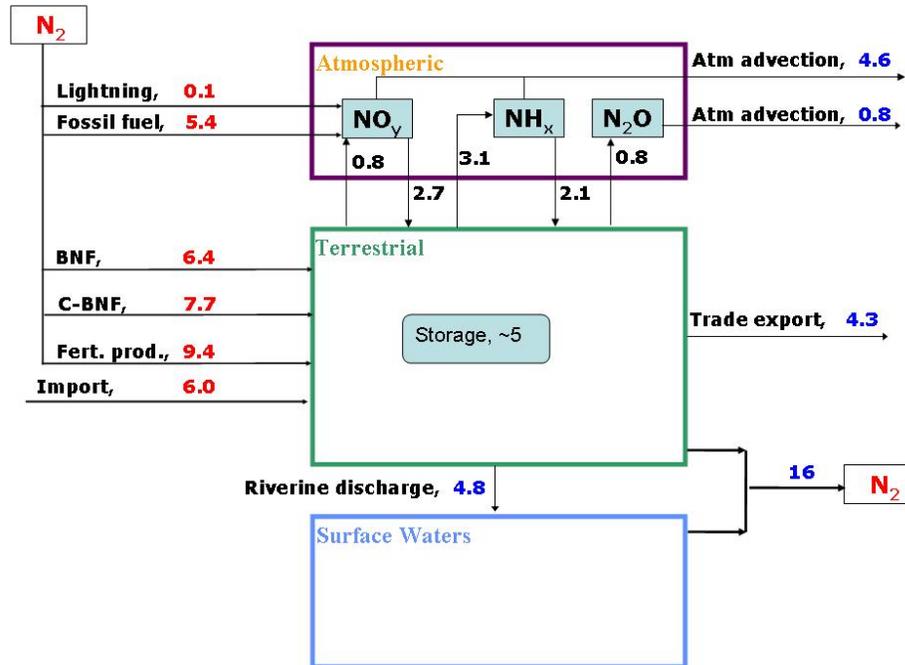
21  
22 Emissions of N<sub>2</sub>O discharge about 0.8 Tg N/yr into the global atmosphere. Of the 6.3 Tg N/yr of U.S. NO<sub>x</sub>  
23 emissions, 2.7 Tg N/yr are deposited back onto the land and surface waters of the United States. Thus, by  
24 difference we estimate that as much as 3.6 Tg N/yr per year of the NO<sub>x</sub> emissions are advected out of the  
25 U.S. atmosphere. Similarly, of the 3.1 Tg N/yr of NH<sub>3</sub> that are emitted into the U.S. atmosphere each year,  
26 about 2.1 Tg N/yr are deposited onto the land and surface waters of the United States, and about 1 Tg N/yr  
27 is advected out of the United States via the atmosphere. In sum, 5.4 Tg N are advected out of the United  
28 States from all sources each year either to other nations or to the global atmospheric or ocean commons.

29  
30 Riverine discharges of Nr to the coastal zone account for 4.8 Tg N/yr, while export of N-containing  
31 commodities (e.g., grain) removes another 4.3 Tg N/yr from the United States. Altogether, along with 5.4  
32 Tg N/yr of atmospheric advection, these total Nr outputs out of the U.S. continental environment add up  
33 to about 14 Tg N/yr, leaving about 21 Tg N/yr unaccounted for. Of this amount, we estimate that 5 Tg  
34 N/yr year are stored in soils, vegetation, and groundwater (as shown by the 'Storage' box in Figure 2),  
35 and, by difference, we estimate that about 16 Tg N/yr are denitrified to N<sub>2</sub> (Figure 2). Denitrification, a  
36 process that microbially converts Nr to N<sub>2</sub> (as well as forming some N<sub>2</sub>O) requires both a carbon source  
37 and anaerobic conditions, a situation that is found in wetlands and oxygen-depleted streams, rivers, soils,  
38 and other engineered denitrification systems. There are substantial uncertainties (+/- 50%) for some of  
39 these estimates -- especially those that involve NH<sub>x</sub> emission and deposition and terms that are arrived at  
40 by difference (e.g., atmospheric advection and denitrification). These significant uncertainties are  
41 important factors in the three "Overarching Recommendations" of this report.

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**Figure 2: Nr inputs and outputs for the United States in 2002 (Tg N/yr)**



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6  
7  
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9

Explanatory notes:

- The left side of this figure shows the inputs into the U.S. atmosphere from lightning and fossil fuel combustion and into the U.S. terrestrial system from biological nitrogen fixation in unmanaged landscapes (BNF), biological nitrogen fixation in cultivated landscapes (C-BNF), fertilizer production within the United States (Fert prod), and imports of nitrogen-containing commodities. Not shown because the number is so small, is 0.2 Tg N/yr of NH<sub>3</sub> of Nr that is formed during fossil fuel combustion.
- The middle and right-hand parts of this figure show emissions of NO<sub>y</sub>, NH<sub>x</sub> and N<sub>2</sub>O, and deposition of NO<sub>y</sub> and NH<sub>x</sub> to the U.S. landscape. Transfers out of the United States are shown as atmospheric advection of NO<sub>y</sub> and NH<sub>x</sub> (by difference), and of N<sub>2</sub>O. The best estimate of advection of NO<sub>y</sub> plus NH<sub>x</sub> from the continent (export) are smaller than shown here. Nevertheless, these values are used for internal consistency among all media. See Section 2.3.
- NO<sub>y</sub>, NH<sub>x</sub> and N<sub>2</sub>O are all components of Nr, but a fundamental difference is that the NO<sub>y</sub> and NH<sub>x</sub> are rapidly transferred from the atmosphere to receiving ecosystems due to a short atmospheric residence time (≤ 10 days) where they continue to contribute to the N cascade. Because of its longer residence time (~100 years), however, N<sub>2</sub>O remains in the troposphere where it contributes to climate change, until it is transferred to the stratosphere, where it contributes to ozone depletion.
- The sum of the inputs is 35 Tg N/yr, the sum of the outputs is 14 Tg N/yr. The difference (missing Nr) is 21 Tg N/yr. As discussed in the text, we estimate that storage in soils, vegetation and groundwater is ~5 Tg N/yr. By difference, we estimate that formation of N<sub>2</sub> by denitrification is ~16 Tg N/yr.
- In this figure, freshwater wetlands, lakes, and rivers are included in the terrestrial box while coastal wetlands, lagoons, and other similar ecosystems are included in the surface waters box.

20  
21  
22  
23  
24  
25

1 **Consequences, impacts, and metrics for Nr Use**

2 Because nitrogen is both a critically important natural resource and also a contributor to a number of  
3 environmental problems, it is imperative to understand how to decrease the risks to society while also  
4 providing the food, energy, and materials required by society. And, because N fertilizer supports high  
5 levels of productivity on existing farmland, which reduces the need to expand agriculture at the expense of  
6 rain forests and wetlands, efforts to mitigate the negative consequences of Nr cycling in crop and livestock  
7 systems must also consider potential tradeoffs on food production and land use. Fortunately there are  
8 opportunities for reducing the negative environmental impact from Nr use in agriculture while also  
9 sustaining the capacity to increase food production to meet increased demand expected from a larger and  
10 wealthier human population.

11  
12 The most important beneficial consequence of Nr use in the United States (and other parts of the world) is  
13 providing adequate supplies of food, feed, fiber, and fuel crops to meet dietary and other needs of people  
14 in this country and abroad – an issue of global food security. In many ecosystems, the supply of  
15 biologically available Nr is a key factor controlling adequacy of food, feed, and fiber supplies, the  
16 profitability of crop and animal agricultural, the nature and diversity of plant life, and vital ecological  
17 processes such as the cycling of carbon and soil minerals.

18  
19 In addition to these important human-beneficial consequences, there are also numerous and important  
20 negative consequences from anthropogenic Nr. These negative consequences include formation of  
21 photochemical smog, exposure to toxic gases and aerosols in the air, acidification and eutrophication of  
22 terrestrial and aquatic ecosystems, climate change and other greenhouse effects, as well as stratospheric  
23 ozone depletion. Human activities have not only increased the supply but enhanced the global movement  
24 of various forms of Nr through air and water. Mitigating risk from these factors is difficult because one  
25 molecule containing Nr can contribute to all of these effects as a consequence of the nitrogen cascade.  
26 Nitrogen is a dynamic element easily transformed from one chemical form to another and is transported  
27 rapidly through and among ecosystem reservoirs. These characteristics make nitrogen an especially  
28 challenging element to manage.

29  
30 Reactive nitrogen plays a major role in climate forcing, but weather and climate also exert a profound  
31 influence on the public health and public welfare effects of Nr. Some climate predictions call for higher  
32 ambient temperatures and increased intensity of rainstorms over North America – riverine discharge of  
33 nitrate increases with storm runoff and amounts of annual precipitation. Increasing the maximum summer  
34 temperatures can increase photochemical smog. Nitrogen deposition and carbon sequestration are linked,  
35 but the interactions are nonlinear and difficult to predict. This report calls for further investigation of the  
36 impact of climate on Nr, because it is probable that climate change will accentuate the need to control  
37 excess nitrogen.

38 *Current Risk Reduction Strategies*

39  
40 Various approaches can be used to prevent, eliminate, decrease, or otherwise manage Nr risks.  
41 Understanding the environmental impacts of Nr can inform decisions on how best to manage nitrogen  
42 risks. There are two main approaches to characterizing the adverse public health and environmental  
43 impacts of Nr: traditional damage estimates and decreases in ecosystem services. Historically, EPA's

1 environmental protection programs have addressed the adverse public health and public welfare impacts  
2 of Nr through use of such common metrics as National Ambient Air Quality Standards (NAAQS) and, in  
3 the case of water resources, Total Maximum Daily Loads (TMDLs) built upon attainment of water quality  
4 standards and criteria. These common metrics have had the considerable advantage of providing  
5 frameworks within which air and water quality standards could be derived that are protective of specific  
6 human health and environmental risks – the principal missions of EPA. The ecosystem services approach  
7 complements these traditionally used common metrics by considering how specific ecosystem services are  
8 impaired by excess Nr. The ecosystem services approach can also recognize the important functions that  
9 wetlands and similar ecosystems can and do provide in decreasing Nr losses to the environment. The  
10 attractiveness of this approach is its recognition that the health of humans and the health of ecosystems are  
11 inextricably linked. Less clear, in some cases, however, are practical ways in which to measure and  
12 monitor these adverse impacts.

13  
14 Ecosystem-service-based measurements provide a richer context for the complex connections among Nr  
15 inputs and transformations. Furthermore, impacts on human well-being can help identify those adverse  
16 effects of Nr that impose the greatest damage costs to society.

17  
18 The INC finds that traditional metrics of Nr used in combination with economic damage costs, human  
19 health metrics and the loss of ecosystem services will:

- 20 • Provide a clearer picture of priorities for action,
- 21 • Help identify effective control points for decreasing Nr impacts, and
- 22 • Provide insights into more efficient and cost-effective regulatory and non-regulatory strategies for  
23 decreasing Nr negative impacts.

#### 24 25 *Tradeoffs Among Nr Risk Management Options*

26  
27 Once the foreseeable impacts are understood and the suite of benefits associated with various risk  
28 reduction options is described, then managers can consider trade-offs. Risk reduction integration provides  
29 an intellectual framework that allows managers to make informed decisions about which benefits may  
30 need to be relinquished for other benefits when not all the desired benefits can be achieved. For example,  
31 limiting nitrogen fertilizer application to decrease risk from Nr applied to agro-ecosystems may decrease  
32 crop yields and increase food and feed commodity prices, which in turn may result in expansion of crop  
33 production area at the expense of natural wetlands, grasslands, and forests—a process called indirect land-  
34 use change.

#### 35 36 *Measurement of Reactive Nitrogen in the Environment*

37  
38 What air and water quality managers measure determines not only what they focus on but also how they  
39 gauge the success or failure of their environmental management strategies and tactics. Most regulations set  
40 limits or specify control technologies for specific forms of Nr without regard to the ways in which Nr may  
41 be transformed once it is introduced into the environment. Normally, regulations also require some form  
42 of monitoring to document compliance. However, monitoring of the specific chemical forms of Nr is not  
43 enough. There is a need to measure, compute, and report the total amount of Nr present in impacted  
44 systems in appropriate units because one chemical form of Nr can be quickly converted to other more or  
45 less damaging forms.

1

2 The impacts of reactive nitrogen often can be expressed as the economic costs of damages, the cost of  
3 remediation or substitution, or the cost/ton of remediation for each form of reactive nitrogen. Damage  
4 costs do not always scale as tons of Nr released into the environment. If damage costs rather than tons of  
5 Nr were utilized as a metric, the full implications of the cascade, and the setting of priorities for  
6 intervention might differ. Similarly, if human mortality and morbidity are the metrics used, priorities for  
7 decreases in Nr emissions could be very different.

8

9 To determine the extent of damage caused by excess nitrogen in environmental reservoirs, one needs to  
10 know both the present Nr concentration or loading within a reservoir and the threshold at which negative  
11 impacts are manifested. This threshold then provides a target load that can be used to guide strategies to  
12 decrease the amount of Nr in the reservoir. The thresholds for impacts are better known for some adverse  
13 impacts than others. For example, the impacts of ozone on human health are known well enough so that  
14 EPA has set standards for both ozone and for NO<sub>2</sub>, an ozone precursor. The same can be said for the  
15 impacts of Nr discharge to coastal waters. Total Maximum Daily Loads (TMDLs) are used to link Nr  
16 loading to impact. On the other hand, the impact of Nr deposition on ecosystems is less well known. There  
17 is strong scientific evidence to show that Nr deposition rates of 10 – 20 kg N per hectare per year can  
18 cause negative impacts on a variety of ecosystems (Bobbink et al., 2009). Since a large part of the land  
19 surface in the northern hemisphere receives Nr deposition in that range, it is necessary to better define the  
20 link between Nr deposition and ecosystem response. Further, and related to the previous section, our  
21 knowledge of Nr deposition is uncertain, especially for the chemically reduced inorganic and organic  
22 forms of Nr. Our knowledge needs to be improved to better link total reactive nitrogen deposition to  
23 ecosystem response and critical thresholds.

24

## 25 **Integrated Risk Reduction Strategies for Nr**

26 Typically, quantitative risk assessment, technical feasibility, economic, social and legal factors, and  
27 additional benefits of various air and water management strategies contribute to the development of a suite  
28 of risk-reduction strategies from which managers can select an optimal approach.

29

### 30 *Management Strategies for Nr*

31

32 There are several ways in which the release and control of Nr in the environment can be approached. In  
33 general these can be classified as follows:

34

35 1. Improved practices and conservation—in which the flux of Nr that creates a detrimental impact  
36 is decreased through better management practices (e.g. on-field agricultural practices, control of  
37 urban runoff, controlled combustion conditions)

38

39 2. Product substitution—in which a product is developed or promoted which has a smaller  
40 dependency on Nr (e.g. use of switchgrass instead of corn grain as a feedstock for biofuel ethanol  
41 production).

42

43 3. Transformation—in which one form of nitrogen is converted to another less damaging form of  
44 nitrogen (e.g. nitrification of municipal wastewaters, denitrification of Nr by converting it back to

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1 non-reactive gaseous N<sub>2</sub> with created and restored wetlands).

2  
3 4. Source limitation—in which the amount of Nr introduced into the environment is decreased  
4 (e.g., lower fertilizer application rates, use of catalytic converters in vehicles and low-NO<sub>x</sub> burners  
5 in power plants).

6  
7 5. Removal—in which particulate forms of Nr are captured in a more readily managed physical  
8 form such as sewage sludge which can be disposed of by land application or incineration.

9  
10 6. Improved use or reuse efficiency—in which the efficiency of production that is dependent on Nr  
11 is improved (e.g. increased grain yields per unit of Nr fertilizer applied, decreased NO<sub>x</sub> emissions  
12 from improved diesel engines in trucks and off-road construction equipment, reuse of Nr-laden  
13 runoff to grow algae for other uses, such as bioenergy or animal feeds).

14  
15 Efficient and cost-effective management of Nr often requires combinations of these six Nr management  
16 strategies; no one approach is a perfect alternative for decreasing excess Nr in the environment.

17  
18 *Policy Mechanisms for Management of Nr in the Environment*

19  
20 Generally speaking, U.S. environmental policies employ one or more of the following four mechanisms  
21 for management of pollutants in the environment:

22  
23 1. Command-and-Control—in which permitted limitations on pollutant or chemical-precursor  
24 emissions are issued under various regulatory statutes. Violations may result in the  
25 assessment of penalties.

26  
27 2. Government-based programs affecting the desirability of an environmental management  
28 mechanism, such as directed taxes, price supports for a given commodity, subsidies to  
29 bring about a particular end-result, and grants for capital expansion or improvement of  
30 pollution-abatement technologies.

31  
32 3. Market-based instruments for pollution control in which cap and trade markets are used to  
33 bring about a desired policy end-result -- often at decreased overall cost to society.

34  
35 4. Voluntary programs in which desired environmental outcomes are achieved using private  
36 or government-initiated agreements or through targeted outreach and education programs.

37  
38  
39 **Major Findings and Recommendations**

40  
41 The ultimate goal of this report is to aid EPA in the development of an integrated N management strategy.  
42 To accomplish this, the committee recommends that EPA and other research organizations strengthen the  
43 science related to flows and impacts of Nr, that EPA use current knowledge to identify management  
44 actions that can be taken now, and that EPA join with other organizations to implement management

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1 actions within a framework that does not exacerbate one Nr problem when addressing another.

2 **Recommendation A**

3 *An integrated approach to the management of Nr will likely use a combination of these four*  
4 *implementation mechanisms. Each mechanism must be appropriate to the nature of the problem at*  
5 *hand, supported by critical research on decreasing the risks of excess Nr, and reflect an integrated*  
6 *policy that recognizes the complexities and tradeoffs associated with the nitrogen cascade.*  
7 *Management efforts at one point in the cascade may be more efficient and cost effective than*  
8 *control or intervention at another point. This is why understanding the nature and dynamics of the*  
9 *N cascade is critically important.*

10 **Recommendation B**

11 *EPA should form an Intra-agency Nr Management Task Force that will build on existing Nr*  
12 *research and management capabilities within the Agency. This Intra-Agency Task Force should be*  
13 *aimed at increasing scientific understanding of: 1) Nr impacts on terrestrial and aquatic*  
14 *ecosystems, human health, the atmosphere, and climate, 2) Nr-relevant monitoring requirements,*  
15 *and 3) the most efficient and cost-effective means by which to decrease various adverse impacts of*  
16 *Nr loads as they cascade through the environment.*

17 **Recommendation C**

18 *EPA should join with other agencies within the U.S. government in establishing an Inter-agency*  
19 *Nr Management Task Force. The members of this Inter-Agency Task Force should include at least*  
20 *the following federal agencies: U.S. Department of Agriculture (USDA), U.S. Department of*  
21 *Energy (DOE), U.S. Department of Transportation (DOT), National Oceanic and Atmospheric*  
22 *Administration (NOAA), U.S. Geological Survey (USGS), U.S. Forest Service (USFS,) and Federal*  
23 *Emergency Management Agency (FEMA)). This Task Force should coordinate federal programs*  
24 *that address Nr concerns and help ensure clear responsibilities for monitoring, modeling,*  
25 *researching, and managing Nr in the environment. The International Office of EPA should work*  
26 *closely with the Department of State to ensure that EPA is aware of international efforts to control*  
27 *Nr and is developing national strategies that are compatible with international initiatives.*

28 These intra- and inter-agency Nr-Management Task Forces should take a systems approach to  
29 research, monitoring, and evaluation to inform public policy related to Nr management. The INC  
30 proposes that this be done by 1) developing the methods for the systems approach; 2) enhancing  
31 ecosystem services; 3) identifying and implementing best management practices; 4) assessing tools  
32 and metrics; and 5) developing improved education and training opportunities.

- 33
- 34 • Development of methods to help implement a systems approach
    - 35 ○ developing and evaluating proposed Nr budgets
    - 36 ○ developing appropriate life cycle accounting methods
    - 37 ○ developing monitoring as the basis for informed policies, regulations, and incentive
    - 38 frameworks for addressing excess Nr loads

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- 1       ○     evaluating the critical loads approach to air and water quality management
- 2       ○     developing Nr indicators for excess Nr effects on economic damage, human health and
- 3       environment
- 4       ○     developing new systems-based approaches for controlling Nr releases to the environment
- 5       ●     Enhancing ecosystem services that lead to the denitrification of Nr in the landscape including
- 6       reconnecting rivers and streams to their floodplain, creating and restoring wetlands in agricultural
- 7       landscapes, and enlarging the surface area of streams and ditches to enhance their potential
- 8       denitrification.
- 9       ●     Best management practices (BMPs)
- 10      ○     developing the scientific understanding required for identifying best management practices
- 11      (BMPs) for specific application, including:
- 12      ○     Nr applications in agriculture to ensure adequate food, feed, fiber, and bioenergy
- 13      feedstock supply while also avoiding negative impacts on the environment and
- 14      human health;
- 15      ○     Nr applications for developed (e.g., residential and commercial) runoff mitigation and
- 16      landscape maintenance;
- 17      ○     planning and pollution prevention including low impact development and natural
- 18      ecosystem service preservation;
- 19      ○     enhancing the appropriate matching of crops, cropping systems, and land types and
- 20      capabilities for the most productive use of Nr and the reduction of excess Nr
- 21      ○     development and natural ecosystem service preservation;
- 22      ○     primary use of natural land features and attributes, such as wetland preservation and
- 23      enhancement, natural soil profiles and buffer strips;
- 24      ○     improved removal of Nr from sewage waste streams at both large-scale wastewater
- 25      treatment facilities and individual subsurface (septic) systems
- 26      ○     establishing proactive extension and technology transfer approaches to facilitate adoption
- 27      of BMPs
- 28      ●     Assessment activities
- 29      ○     assessing combined carbon (C) and Nr effects on terrestrial and aquatic ecosystems
- 30      ○     assessing indicators/endpoints, costs, benefits and risks associated with impairment of
- 31      human health and decline and restoration of ecosystem services
- 32      ○     reviewing existing and proposed legislation for purposes of extending Nr regulatory

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- 1 authority or streamlining procedures for enacting Nr risk reduction strategies
- 2 ○ evaluating economic incentives, particularly those that integrate air, aquatic, and land
- 3 sources of excess Nr
- 4 ● Developing new education, outreach, and communication initiatives

5 In addition, INC makes four recommendations that set near-term targets for the decrease of Nr entering  
6 the environment from various sources.

- 7  
8 (1) INC recommends that the EPA expand its NO<sub>x</sub> control efforts from the current decreases of  
9 emissions of light duty vehicles (including passenger cars) and power plants to include other  
10 important unregulated mobile and stationary sources sufficient to achieve a **2.0 Tg N/yr** decrease  
11 in the generation of reactive nitrogen. Such changes can be effected by applying existing, proven  
12 technology. Emissions from many point sources are controlled with low-NO<sub>x</sub> burners or NO<sub>x</sub>  
13 reduction – such equipment should also be installed on industrial boilers and the remaining,  
14 uncontrolled power plants. NO<sub>x</sub> controls for modern, on-road vehicles are effective and these  
15 technologies should be applied to off-road vehicles, locomotives, ships and other devices with  
16 internal combustion engines.
- 17 (2) INC recommends a goal of decreasing livestock-derived NH<sub>3</sub> emissions by 30% (a decrease of **0.5**  
18 **Tg N/yr**) by a combination of BMPs and engineered solutions. This is expected to decrease PM<sub>2.5</sub>  
19 by ~0.3 µg/m<sup>3</sup> (2.5%), and improve health of ecosystems by achieving progress towards critical  
20 load recommendations. Additionally we recommend decreasing NH<sub>3</sub> emissions derived from  
21 fertilizer applications by 20% (decrease by ~**0.2 Tg N/yr**), through the use of NH<sub>3</sub> treatment  
22 systems and BMPs
- 23 (3) INC recommends that excess flows of Nr into streams, rivers, and coastal systems be decreased by  
24 approximately 20% (~**1 Tg N/yr**) through improved landscape management and without undue  
25 disruption to agricultural production. This would include activities such as using large-scale wetland  
26 creation and restoration to provide needed ecosystem services of Nr retention and conversion as well as  
27 matching cropping systems and intensity of Nr use to land characteristics. Improved tile-drainage  
28 systems and riparian buffers on cropland, and implementing storm water and non-point source  
29 management practices (e.g., EPA permitting and funding programs) are other alternatives that are  
30 less proven. In addition, the committee recommends that crop N-uptake efficiencies be increased  
31 by up to 25% over current practices through a combination of knowledge-based practices and  
32 advances in fertilizer technology (such as controlled release and inhibition of nitrification). Crop  
33 output can be increased while decreasing total Nr by up to 20% of applied artificial Nr, amounting  
34 to ~**2.4 Tg N/yr** below current amounts of Nr additions to the environment. These are appropriate  
35 targets with today's available technologies and further progress is possible.
- 36 (4) INC recommends that a high priority be assigned to nutrient management through a targeted  
37 construction grants program under the CWA. This will decrease Nr emissions by between **0.5 and**  
38 **0.8 Tg N/yr**.

39  
40 INC is confident that implementing these recommendations will decrease the amount of Nr introduced

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1 into the United States by about 25%, which will similarly decrease the amount of Nr lost to the  
2 atmosphere, soils and waters.

3 **Epilogue**

4 Human activities have significantly increased the introduction of Nr loads into the U.S. environment.  
5 While there have been significant benefits resulting from increased food production, there also have been,  
6 and will continue to be, major risks to the health of both ecosystems and people due to the introduction of  
7 Nr into the nitrogen cascade. Regulations to set limits, require monitoring, and specify control  
8 technologies for nitrogen compounds should give careful consideration to the ways in which Nr may be  
9 transformed once it is introduced into the environment. To maintain the benefits and limit the negative  
10 impacts of excess of Nr, EPA should join with other federal agencies, States, universities, and private  
11 sector organizations in developing both an integrated total Nr management strategy, and a strong Nr  
12 public outreach and education program. There are real economic costs to the recommendations contained  
13 in this report. For each recommendation there will of necessity be tradeoffs derived from the varying cost-  
14 effectiveness of different strategies. It is vitally important that the recommendations, and the analysis of  
15 the associated trade-offs, be implemented and addressed in an integrated manner.

## Chapter 1: Introduction

### 1.1 General background about the Nitrogen Cascade: N exposures, cycles, and loadings

*Water, water everywhere, and all the boards did shrink;*

*Water, water everywhere, nor any drop to drink.*

This couplet from the *Rime of the Ancient Mariner* (Samuel Taylor Coleridge, 1772–1834) is an observation that, although sailors were surrounded by water, they were dying of thirst because of its form. Just as water is a critical substance for life, so is nitrogen (N). And just as most of the water on the planet is not useable by most organisms, most of the N is also unavailable.

Approximately 78% of the atmosphere is diatomic nitrogen (N<sub>2</sub>), which is unavailable to most organisms because of the strength of the triple bond that holds the two N atoms together. Over evolutionary history, only a limited number of species of bacteria and archaea have evolved the ability to convert N<sub>2</sub> to Nr via biological N fixation. However, even with adaptations to use N efficiently, many ecosystems of the world are limited by N.

This limitation has driven humans to use increasingly sophisticated and energy-intensive measures to obtain Nr to sustain food production and to produce other commodities (e.g., nylon, explosives). In the beginning, hunters and gatherers harvested food from natural stocks. With the advent of agriculture, local sources of Nr were used (soil stocks, crop residue, manures) to increase productivity of landscapes. In the 19<sup>th</sup> century, long range transport of Nr to sustain food production increased by shipping bird guano from the Pacific Islands and nitrates from South America to Europe and other locations. By the beginning of the 20<sup>th</sup> century, these sources were not sufficient to sustain the growing global population requirements for food.

This deficiency led to what has been called one of the world's most important discoveries—how to extract N<sub>2</sub> from the atmosphere and convert it to NH<sub>3</sub>—the Haber-Bosch process (Smil, 2001; Erisman et al., 2008). Today this process and cultivation-induced biological N fixation (C-BNF) introduce over 140 teragrams (Tg) of N per year (hereafter expressed as Tg N/yr) into the global environment to increase food production. Another 23 Tg N/yr are introduced by the Haber-Bosch process for the chemical industry, and 25 Tg N/yr are introduced via the combustion of fossil fuels.

The total global anthropogenic Nr creation rate is ~190 Tg N/yr (2005), substantially larger than the median of estimates for Nr creation by natural terrestrial processes (~100 Tg N/yr) (Galloway et al., 2008). The fact that humans are more effective than nature in Nr creation means that on average, humans are less reliant on natural sources of Nr. However, with global commodity stocks running at a 58-day supply and food prices increasing dramatically, the challenge is to increase the nutrient use efficiency of Nr in agricultural systems while maintaining or increasing yields (USDA ERS/World Agricultural Outlook Board, July 11, 2008. World Agricultural Supply and Demand Estimates).

There are large regional disparities in Nr creation rates on both absolute and per capita bases. Total Nr creation is larger in Asia than in any other region. Per capita Nr creation is largest in North

1 America and Europe. Humans also redistribute large amounts of Nr among countries or regions of  
2 the world through exports of fertilizers, feed grains, and fossil fuels. Nevertheless, there are large  
3 regions of the world with populations approaching one billion, where there is malnutrition in part  
4 due to a lack of available Nr to sustain crop production.

5 The introduction of Nr into most regions of the United States by humans has greatly increased food  
6 availability. However, since essentially all the Nr created for food production and by fossil fuel  
7 combustion is lost to the environment, it has also greatly increased Nr's contribution to a wide  
8 variety of environmental problems. Most plants, animals, and microorganisms are adapted to  
9 efficiently use and retain small increments of additional Nr. Addition of Nr to most ecosystems may  
10 first lead to increased uptake, growth, storage, and hence to increased biomass, including food or  
11 fiber production. However, further addition of Nr in excessive amounts often leads to imbalances in  
12 the movement of Nr among reservoirs and potential losses<sup>4</sup> to the environment in the form of air  
13 emission or water discharges into other ecosystems where Nr may disrupt ecosystem functions and  
14 have a negative impact on resources. In essence, the assimilative capacity of the ecosystem may be  
15 insufficient to benefit from increases in Nr without disruptive change. While there will always be Nr  
16 losses to the environment during food production, the challenge is how to minimize those losses  
17 while meeting the demand for food production.

18 Negative consequences of Nr flux in the U.S. environment include increases in photochemical smog  
19 and PM<sub>2.5</sub>, decreases in atmospheric visibility, both increases and decrease in productivity of  
20 grasslands and forests, acidification of soils and freshwaters, accelerating estuarine and coastal  
21 eutrophication, increases in the emission of greenhouse gases to the atmosphere, and decreases in  
22 stratospheric ozone concentrations. Most of these changes in environmental conditions lead to a  
23 variety of negative impacts on both ecosystem and human health. These changes, which impact air,  
24 land, water and the balance of life in an interrelated fashion, are often referred to as a cascade of  
25 effects from excess Nr<sup>5</sup> or the "nitrogen cascade" (Figure 3). Unlike other element-based pollution  
26 problems, the N cascade links the negative impacts, where one N-containing molecule can in  
27 sequence contribute to all the environmental issues mentioned above.

---

<sup>4</sup> In the context of this report, "losses" refers to transfers among systems and not the conversion of Nr to N<sub>2</sub>. Whenever N<sub>2</sub> formation is discussed, it is explicitly stated.

<sup>5</sup> Excess reactive nitrogen (Nr) is defined as the amount of Nr that is present in, or introduced into, an environmental system (e.g., Nr inputs to the atmosphere, Nr inputs to grasslands and forests, Nr inputs to estuaries) from anthropogenic sources that is not incorporated into agricultural and other biological products (e.g., food, feed, fuel and fiber), or stored in long-term storage pools (e.g., cropland soils).

Thresholds are used to determine at what amount excess Nr causes negative effects on ecosystem services and functions, and human health. Thresholds vary by metric (e.g., concentration, loading, etc) and depend on the environmental system (e.g., atmosphere, forest). Examples for specific thresholds are given later in the report in relevant sections.

1 The nitrogen cascade has three dimensions:

- 2 • biogeochemical,
- 3 • alterations in the environment, and
- 4 • human and ecosystem consequences.

5 The “biogeochemical” dimension of the nitrogen cascade involves Nr creation from N<sub>2</sub> as a  
6 consequence of chemical, food and energy production, Nr use in food and chemical production, Nr  
7 losses to the environment, changes in Nr species residence times in environmental reservoirs, Nr  
8 transfers among reservoirs and Nr conversion back to N<sub>2</sub>. Alterations to the environment then result  
9 from increased Nr levels in the environment. These alterations have negative consequences for  
10 ecosystem and human health at local, regional, national and global scales. Because nitrogen is a  
11 critical resource and also a contributor to many of the environmental concerns facing the United  
12 States today, it is imperative to understand how human action has altered N cycling in the United  
13 States, and the consequences of those alterations on people and ecosystems. The over-arching  
14 question is how do we protect and sustain an ecosystem that provides multiple benefits to society  
15 while also providing the interconnected material, food and energy required by society.

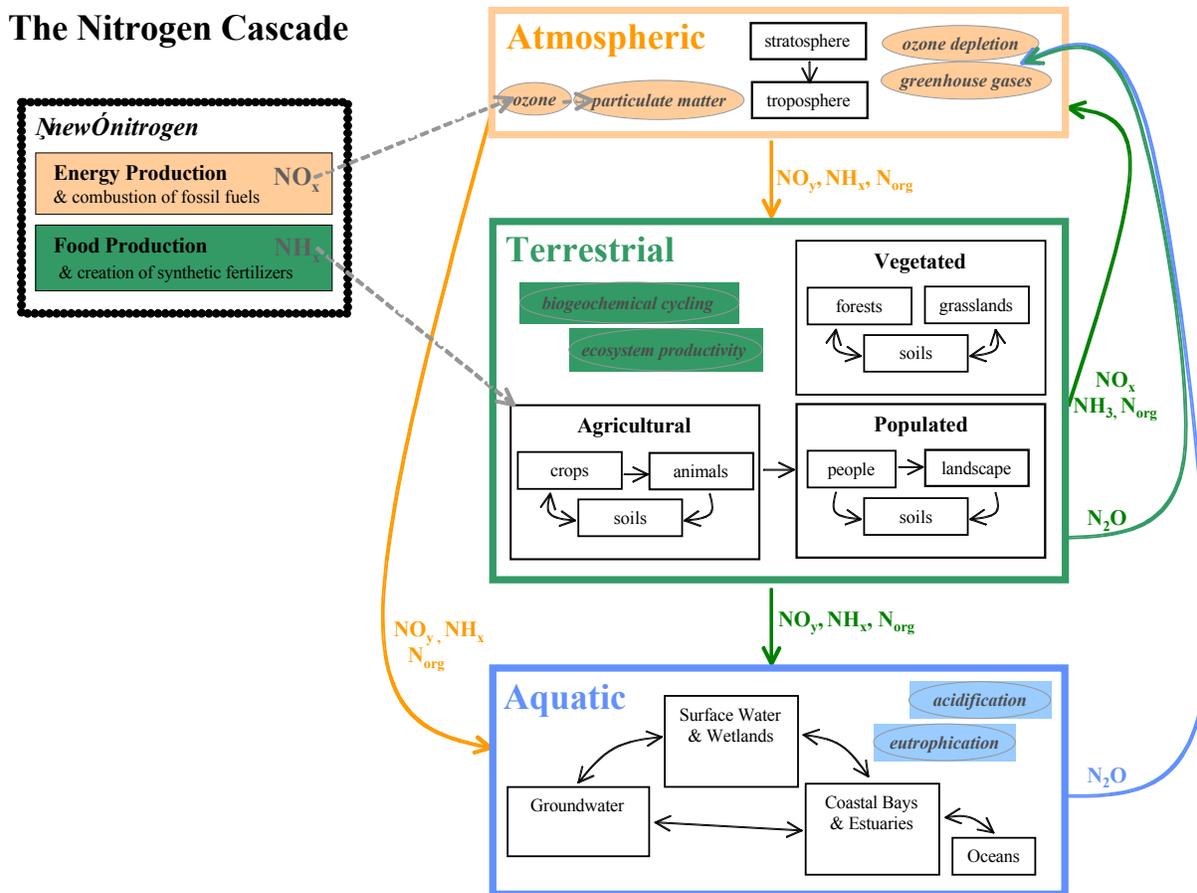
16 In summary, Nr inputs to the nation and the world have been increasing, largely due to human  
17 activities associated with food production and fossil fuel combustion. Despite the obvious benefits  
18 of a plentiful supply of food and energy, the adverse consequences associated with the accumulation  
19 of Nr in the environment are large, with implications for human health and the environment.

20 The greater the inputs of Nr to the landscape, the greater the potential for negative effects, caused by  
21 greenhouse gas production, ground level ozone, acid deposition, and Nr overload that can contribute  
22 to climate change, degradation of soils and vegetation, acidification of streams, lakes and rivers,  
23 estuarine and coastal eutrophication, hypoxia and habitat loss.

24 The growing nature of the Nr problem, and the adverse and intertwined consequences associated  
25 with Nr inputs to air, land, and water as exhibited in the N cascade underscore the need for  
26 researchers and managers to explore integrated strategies that minimize N inputs, maximize its use  
27 efficiency, promote Nr removal processes and protect humans and natural resources.

1  
2

**Figure 3: The Nitrogen Cascade**



3  
4

5 *The concept of the nitrogen cascade highlights that once a new Nr molecule is created, it can, in*  
 6 *sequence, travel throughout the environment contributing to major environmental problems*  
 7 *(Galloway et al., 2003). This adaptation of the cascade was developed by the Integrated Nitrogen*  
 8 *Committee to provide a context for considering nitrogen-related issues and ecosystem effects in the*  
 9 *United States. To consider the cascading effects of Nr in the United States, we examine the various*  
 10 *atmospheric, terrestrial, and aquatic environmental systems where Nr is stored, and the magnitudes*  
 11 *of the various flows of N to, from, and within them. The nitrogen cascade concept implies the*  
 12 *cycling of Nr among these systems. The process of denitrification is the only mechanism by which*  
 13 *Nr is converted to chemically inert  $\text{N}_2$ , ‘closing’ the continuous cycle. Denitrification can occur in*  
 14 *any of the indicated reservoirs except the atmosphere.*

15 *The “new” N box depicts the two primary anthropogenic sources by which Nr originates, energy*  
 16 *production and food production, and where they enter ecosystems. Energy production includes both*  
 17 *fossil fuel and biofuel combustion. Food production includes N fertilizer produced in the United*

1 *States, cultivation-induced biological N (C-BNF) in the United States, production of animals and*  
2 *crops in the United States for human consumption, and imports of N-containing fertilizer, grain and*  
3 *meat to the United States.*

4 *The atmospheric system indicates that tropospheric concentrations of both ozone and particulate*  
5 *matter are increased due to NO<sub>x</sub> emissions to the atmosphere. The ovals illustrate that the increase*  
6 *in N<sub>2</sub>O concentrations, in turn, contribute to the greenhouse effect in the troposphere and to ozone*  
7 *depletion in the stratosphere. Except for N<sub>2</sub>O, there is limited Nr storage in the atmosphere. Losses*  
8 *of Nr from the atmospheric system include NO<sub>y</sub>, NH<sub>x</sub>, and organic nitrogen (N<sub>org</sub>) deposition to*  
9 *terrestrial and aquatic ecosystems of the earth's surface. There is little potential for conversion of*  
10 *Nr to N<sub>2</sub> via denitrification in air. However, once airborne deposition of Nr occurs it will be subject*  
11 *to denitrification pathways via soil and water.*

12 *The terrestrial system depicts that Nr enters agricultural lands via food production and is introduced*  
13 *to the entire terrestrial landscape via atmospheric deposition. Within agricultural regions there is*  
14 *cycling among soils, crops and animals, and then a transfer of Nr as food to populated regions, from*  
15 *which there are Nr losses to the environment (e.g, sewage, landfills). The ovals showing ecosystem*  
16 *productivity and biogeochemical cycling reflect that Nr is actively transported and transformed*  
17 *within the terrestrial system, and that as a consequence there are significant impacts on ecosystem*  
18 *productivity due to fertilization and acidification, often with resulting losses of biodiversity. There is*  
19 *ample opportunity for Nr storage in both biomass and soils. Losses of Nr from this system occur by*  
20 *leaching and runoff of NO<sub>y</sub>, NH<sub>x</sub> and N<sub>org</sub> to Aquatic ecosystems and by emissions to Atmospheric*  
21 *system as NO<sub>x</sub>, NH<sub>3</sub>, N<sub>org</sub>, and N<sub>2</sub>O. There is potential for conversion of Nr to N<sub>2</sub> via denitrification*  
22 *in the terrestrial system.*

23 *The aquatic system shows that Nr is introduced via leaching and runoff from terrestrial ecosystems*  
24 *and via deposition from atmospheric ecosystems. Connected with the hydrological cycle, there are*  
25 *Nr fluxes downstream with ultimate transport to coastal systems. Within the aquatic system, the*  
26 *ovals highlight two significant impacts of waterborne Nr—acidification of freshwaters and*  
27 *eutrophication of coastal waters. Except for Nr accumulation in groundwater reservoirs, there is*  
28 *limited Nr storage within the hydrosphere. Losses of Nr from the aquatic system are primarily via*  
29 *N<sub>2</sub>O emissions to the atmospheric system. There is a very large potential for conversion of Nr to N<sub>2</sub>*  
30 *via denitrification in water and wetlands.*

31 *NO<sub>y</sub>, NH<sub>x</sub> and N<sub>2</sub>O are all components of Nr, but a fundamental difference is that the NO<sub>y</sub> and NH<sub>x</sub>*  
32 *are rapidly transferred from the atmosphere to receiving ecosystems due to a short atmospheric*  
33 *residence time (≤ 10 days) where they continue to contribute to the N cascade. Because of its longer*  
34 *residence time (~100 years) however, N<sub>2</sub>O remains in the troposphere where it contributes to*  
35 *climate change, until it is transferred to the stratosphere, where it contributes to ozone depletion.*

36 **1.2 Overview of historical and current EPA research and risk management programs related**  
37 **to Nr**

38 The mission of the Environmental Protection Agency is to protect human health and the  
39 environment. In achieving this mission, EPA is accountable for addressing five goals given in

1 the 2006 – 2011 EPA Strategic Plan:

- 2 1. Clean air and global climate change,
- 3 2. Clean and safe water,
- 4 3. Land preservation and restoration,
- 5 4. Healthy communities and ecosystems, and
- 6 5. Compliance and environmental stewardship.

7 The *Strategic Plan* includes targets for reducing risk from N. EPA's *Report on the Environment*  
8 (ROE), provides "data on environmental trends," to determine whether or not EPA is on track to  
9 meet its targets and goals. EPA is responsible and accountable for reducing at least some risks  
10 from reactive N.

11 The principal mechanisms for Nr removal from circulation in the environment are complete  
12 denitrification (re-conversion of Nr back to non-reactive gaseous N<sub>2</sub>), and storage in long-term  
13 reservoirs (e.g., soils, sediments, and woody biomass). In some cases, it may be possible to  
14 capture Nr emissions or discharges and deliver them to food or fiber production areas where  
15 there are nitrogen deficiencies. However, major challenges in the management of the N cycle  
16 are how to decrease creation of Nr while still meeting societal needs, promote denitrification of  
17 excess Nr (without producing N<sub>2</sub>O), and improve the efficiency of use and reuse of excess Nr in  
18 a cost-effective manner. Solving both these challenges will result in less Nr accumulation

19 The parts of EPA most directly concerned are the Office of Air and Radiation, the Office of  
20 Water, and the Office of Research and Development. Programs designed to save energy, such as  
21 Energy Star, tend to reduce emissions of Nr as well.

22 EPA's Office of Air and Radiation reduces risk from Nr in over a dozen programs including  
23 National Ambient Air Quality Standards (NAAQS) standard setting and implementation;  
24 emission standards for industrial stationary sources and area sources; the Acid Rain Program; the  
25 Clean Air Interstate Rule; and programs that focus on mobile source emissions. EPA's Office of  
26 Water addresses Nr under both the Clean Water Act and the Safe Drinking Water Act with  
27 activities such as; criteria development and standard setting; NPDES permits; watershed  
28 planning; wetlands preservation; and regulation of Concentrated Animal Feeding Operations  
29 (CAFOs).

30 EPA's Office of Research and Development's mission is to conduct leading-edge research and  
31 foster the sound use of science and technology in support of EPA's mission. ORD is well  
32 recognized for providing a scientific basis for the development of the NAAQS standards for NO<sub>x</sub>  
33 and particulate matter (PM). ORD's revised Multi-Year Plan for Ecological Research will  
34 identify and quantify the positive and negative impacts on ecosystem services resulting from  
35 changes in nitrogen loadings from major source categories to support policy and management  
36 decisions in EPA's Offices of Air Resources and Water.

37 EPA has brought a great variety of risk reduction tools to bear on reactive N: conventional  
38 regulation and enforcement; cap and trade approaches; measurement, monitoring and place-  
39 based approaches; control technology development and verification; communication and

1 education; intergovernmental and international cooperation, and voluntary approaches. The  
2 variety and breadth of EPA programs addressing Nr reflect the ubiquity of Nr in the  
3 environment, the historical single medium regulatory approach, and the lack of a silver bullet for  
4 reducing risks from N.

### 5 **1.3. The need for integration**

6  
7 Some impacts of N on ecosystems and people have been known for centuries (e.g., impacts of  
8 atmospheric deposition on agricultural crops); others for only a few decades (e.g., impact of N<sub>2</sub>O on  
9 stratospheric ozone). Notwithstanding current uncertainties, EPA and its predecessor organizations  
10 have been active in the management of Nr through efforts to decrease the Nr amount in sewage,  
11 control of NO<sub>x</sub> to decrease photochemical smog and acid rain, control of Nr inputs to coastal  
12 systems, controls on fine particulates in the atmosphere and decrease in Nr leaching and runoff from  
13 crop and animal production systems. As beneficial as those efforts have been, they have focussed on  
14 the specific problem without consideration of the interaction of their particular system with other  
15 systems downstream or downwind. Given the reality of the nitrogen cascade, this approach may  
16 result in short-term benefits for a particular system but will also likely only temporarily delay larger-  
17 scale impacts on other systems. Thus there is a need to integrate N management programs, to ensure  
18 that efforts to lessen the problems caused by N in one area of the environment do not result in  
19 unintended problems in other areas.

### 20 **1.4 Charge and scope of this report**

21 In 1973 the Science Advisory Board issued its first report, the 200-page *Nitrogenous Compounds*  
22 *in the Environment*. The report addressed sources and effects of nitrogenous compounds,  
23 including those from air emissions, animal wastes, crop agriculture, industrial processes, and  
24 solid wastes. After concluding that, “At present, all known trends appear to be ones that can be  
25 managed and kept within control, if appropriate steps are taken now,” the SAB provided  
26 recommendations relating to Nr research on and control. Later, the SAB would consider the  
27 1970s to be the first step in environmental protection, characterized by broad agreement on  
28 environmental problems and their sources. The second step emerged in the 1980s when the risk  
29 assessment/risk management paradigm proposed by the National Research Council in 1983  
30 achieved wide acceptance.

31 In *Toward Integrated Environmental Decision-Making*, published in 2000, the SAB articulated a  
32 third step in environmental protection -- the framework for integrated environmental decision-  
33 making. In this 2000 report, the SAB noted that the three-phase structure outlined in the risk  
34 assessment/risk management paradigm (problem formulation, analysis & decision-making,  
35 followed by implementation and evaluation), “belies the complexities involved in putting the  
36 concept of integrated decision-making into practice.”

37 The SAB’s interests in N science and integrated environmental protection converged in 2003,  
38 when the SAB identified integrated N research and control strategies as an important issue facing  
39 the Agency and formed the Integrated Nitrogen Committee to undertake a study of this issue.  
40 The charge to the committee was to:

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- 1 1. Identify and analyze, from a scientific perspective, the problems N presents in the
- 2 environment and the links among them;
- 3 2. Evaluate the contribution an integrated N management strategy could make to
- 4 environmental protection;
- 5 3. Identify additional risk management options for EPA's consideration; and
- 6 4. Make recommendations to EPA concerning improvements in N research to support risk
- 7 reduction.
- 8

9 In the course of its study, the INC held four public face-to-face meetings at which it invited  
10 briefings from EPA's Office of Air and Radiation, Office of International Affairs, Office of  
11 Research and Development, and Office of Research and Development; from the Department of  
12 Agriculture's Agricultural Research Service, Cooperative State Research, Extension and  
13 Education Service, and the Economic Research Service; and from external organizations such as  
14 the Energy Research Centre of the Netherlands, Environmental Defense Fund, International  
15 Plant Nutrition Institute, Iowa State University, LiveFuels, and the Soil and Water Conservation  
16 Society.

17 Additionally, the INC invited scientists and managers from EPA, other federal agencies, states  
18 and localities, academia, non-governmental organizations and the private sector to participate in  
19 a October 20-22, 2008 Workshop Meeting on Nitrogen Risk Management Integration. The  
20 purpose of the meeting was to take public input on the committee's preliminary assessment of Nr  
21 problems, consequences, and remedies, with emphasis on risk reduction; to react to the  
22 committee's quantitative suggestions for Nr reduction targets; and to suggest mechanisms  
23 whereby the Nr strategy might be enacted. The committee took this public input into  
24 consideration as it developed the first draft of this report.

1 **Chapter 2: Behavior of reactive nitrogen in the environment**

2 This chapter identifies and analyzes, from a scientific perspective, the problems Nr presents in the  
3 environment and the links among them.

4 **2.1 Introduction**

5 Although N is a major required nutrient that governs growth and reproduction of living organisms, Nr  
6 losses from human sources have a profound effect on air, water and soil quality. Human consumption of  
7 energy to sustain economic development results in emissions of NO<sub>x</sub> to the atmosphere via fossil fuel  
8 combustion. Consumption of food to meet nutritional requirements of a growing population results in  
9 agricultural emissions of NH<sub>3</sub>, urban and industrial emissions of NO<sub>x</sub>, and N<sub>2</sub>O as well as losses of NO<sub>3</sub><sup>-</sup>  
10 and other N compounds to water bodies due to leaching and runoff. Once released into the atmosphere  
11 by either human or natural processes, these Nr compounds undergo transformation through atmospheric  
12 reactions (e.g. gas-to-particle conversion), transport associated with wind, and finally wet and dry  
13 deposition. Reactive nitrogen lost from agricultural and peopled systems can enter groundwater,  
14 streams, lakes, estuaries, and coastal waters where the Nr can also undergo transformation mediated by a  
15 wide range of biotic and abiotic processes. The introduction of Nr into agroecosystems provides much of  
16 the world's food. The losses of Nr to the environment throughout the food production process and  
17 during fossil fuel combustion contribute to many of the major environmental problems of today.

18 This chapter of the report addresses three aspects of the committee's work. The first two are the  
19 introduction of Nr into U.S. systems from fossil fuel combustion and from food production (Section 2.2)  
20 and the fate of Nr after it is emitted to the atmosphere by fossil fuel combustion or lost to the air, water  
21 and soils from agricultural production systems (Section 2.3). The third aspect is the impacts of Nr on  
22 humans and ecosystems (Section 2.4) from both a traditional view (i.e., specific effects such as impacts  
23 of smog on people and plants) and a more integrated view (i.e., the consequences of Nr on ecosystem  
24 services).

25 The issues of Nr in the U.S. environment revolve around the introduction of new Nr by imports,  
26 fertilizer production, C-BNF, and fossil fuel combustion and around its distribution within agricultural  
27 system and populated systems and redistribution through losses from those systems to the environment  
28 (Figure 3). National-level values for Nr fluxes are displayed in Table 1. Those fluxes that represent the  
29 introduction of new Nr into the United States are marked with an asterisk. Specific sections of the  
30 report will use these values to more clearly determine the flux and fate of Nr in the United States.

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**Table 1: Nr fluxes for the United States, Tg N in 2002<sup>a</sup>**

<b>Nr inputs to the <i>Atmospheric</i> environmental system</b>		<b><u>Tg N/yr</u></b>	<b><u>%</u></b>
	N <sub>2</sub> O-N emissions <sup>1</sup>	0.8	8
	Agriculture - livestock (manure) N <sub>2</sub> O-N	0.03	
	Agriculture - soil management N <sub>2</sub> O-N	0.5	
	Agriculture - field burning agricultural residues	0.001	
	Fossil fuel combustion - transportation*	0.1	
	Miscellaneous	0.1	
	NH <sub>x</sub> -N emissions <sup>2</sup>	3.1	31
	Agriculture: livestock NH <sub>3</sub> -N	1.6	
	Agriculture: fertilizer NH <sub>3</sub> -N	0.9	
	Agriculture: other NH <sub>3</sub> -N	0.1	
	Fossil fuel combustion – transportation *	0.2	
	Fossil fuel combustion - utility & industry *	0.03	
	Other combustion	0.2	
	Miscellaneous	0.1	
	NO <sub>x</sub> -N emissions <sup>2</sup>	6.2	61
	Biogenic from soils	0.3	
	Fossil fuel combustion – transportation *	3.5	
	Fossil fuel combustion - utility & industry *	1.9	
	Other combustion	0.4	
	Miscellaneous	0.2	
	Total <i>Atmospheric</i> inputs	10.0	100
<b>Nr inputs to the <i>Terrestrial</i> environmental system</b>			
	Atmospheric N deposition <sup>b</sup>	6.9	19
	Organic N <sup>3</sup>	2.1	
	Inorganic NO <sub>y</sub> -N <sup>4</sup>	2.7	
	Inorganic-NH <sub>x</sub> -N <sup>4</sup>	2.1	

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	*N fixation in cultivated croplands <sup>b</sup>	7.7	21
	Soybeans*	3.3	
	Alfalfa*	2.1	
	Other leguminous hay *	1.8	
	Pasture*	0.5	
	Dry beans, peas, lentils *	0.1	
	N fixation in non-cultivated vegetation * <sup>b</sup>	6.4	15
	N import in commodities * <sup>f</sup>	0.2	0.3
	Synthetic N * <sup>g</sup>	15.1	41
	Fertilizer use on farms & non-farms	10.9	
	Non-fertilizer uses	4.2	
	Manure N production <sup>g</sup>	6.0	16
	Human waste N <sup>10</sup>	1.3	3
	Total <i>Terrestrial</i> inputs	43.5	100
<b>Nr inputs to the <i>Aquatic</i> environmental system</b>			
	Surface water N flux <sup>11</sup>	4.8	

1

2 Table 1 Notes

- 3 a. The Nr estimates in this table are shown with two significant digits or 0.1 million metric tons N per  
4 year (or Tg N/yr) to reflect their uncertainty; occasionally this report will show data to more significant  
5 digits, strictly for numerical accuracy. Obtaining quantitative estimates of each of the Nr terms and the  
6 associated uncertainties remains a major scientific challenge.
- 7 b. Reducing the uncertainty in total deposition of atmospheric Nr to the surface of the 48 contiguous  
8 United States remains a scientific and policy priority. Based on observations and models, we estimate  
9 5.9 (range 4 – 9) Tg N/yr total anthropogenic Nr deposition to the entire 48 States (Section 2.3.1.10).  
10 The EPA sponsored Community Multiscale Air Quality (CMAQ) Model run yielded a value of 4.8 Tg  
11 N/yr. The value shown for the total (6.9 Tg N/yr) reflects the assumption that organo-nitrogen species  
12 should be added to the model estimate as 30% of the total.
- 13 c. The synthetic N total includes 5.8 Tg N of fertilizer net imports to the United States (8.25 Tg N  
14 imported - 2.41 Tg N exported) plus 9.4 Tg N of fertilizer produced in the United States in 2002.
- 15 \* Terms with an asterisk indicate Nr that is created, highlighting where reactive nitrogen is introduced to the  
16 environment.

17 Table 1 Data Sources (all data reflect N fluxes in the United States in 2002):

- 18 • <sup>1</sup> Emissions, N<sub>2</sub>O-N (USEPA Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2006)  
19 • <sup>2</sup> Emissions, NH<sub>x</sub>-N (USEPA National Emissions Inventory, release version October 2007)

- 1 • <sup>2</sup> Emissions, NO<sub>x</sub>-N (USEPA National Emissions Inventory, release version October 2007)
- 2 • <sup>3</sup> Atmospheric deposition, organic N (30% of total atmospheric N deposition, Neff et al. 2002)
- 3 • <sup>4</sup> Atmospheric deposition, inorganic NO<sub>y</sub>-N & NH<sub>x</sub>-N (USEPA CMAQ model)
- 4 • <sup>5</sup> N<sub>2</sub> fixation in cultivated croplands (USDA census of agriculture 2002, literature coefficients)
- 5 • <sup>6</sup> N<sub>2</sub> fixation in non-cultivated vegetation (unpublished data estimate after Cleveland and Asner 1990)
- 6 • <sup>7</sup> Net N imports in commodities and fertilizer trade (FAOSTAT)
- 7 • <sup>8</sup> Synthetic N fertilizer use (FAOSTAT & AAPFCO)
- 8 • <sup>9</sup> Manure N production (USDA census of agriculture, literature coefficients)
- 9 • <sup>10</sup> Human waste N (US Census Bureau population census, literature coefficients)
- 10 • <sup>11</sup> Surface water N flux (USGS SPARROW model, after Alexander et al. 2008)

11

## 12 **2.2 Sources of Nr new to the environment**

### 13 **2.2.1 Introduction**

14 Creation of “new” Nr in the environment refers to Nr that is either newly fixed within or  
15 transported into the United States. This “new” Nr highlights where Nr is introduced into  
16 ecosystems. New Nr arises from fossil fuel combustion, food production and materials  
17 production (Table 1).

18 Fossil fuel combustion emits Nr (mostly NO<sub>x</sub>) to the atmosphere. Fossil fuel combustion  
19 introduces 3.5 Tg N/yr and 1.9 Tg N/yr of NO<sub>x</sub>-N to the atmosphere from transportation, and  
20 utility/other industry sources, respectively (Table 1). Another 0.2 Tg N/yr of NH<sub>3</sub>-N and 0.1 Tg  
21 N/yr of N<sub>2</sub>O-N is emitted from the same sources (Table 1). Thus the total amount of Nr created  
22 by fossil fuel combustion is 5.7 Tg N/yr, of which > 90% is in the form of NO<sub>x</sub>-N.

23 Synthetic Nr fertilizers are typically produced by the Haber-Bosch process and used primarily in  
24 agriculture to support food production. Production of fertilizers within the United States  
25 introduces Nr into U.S. terrestrial landscapes at the rate of 9.4 Tg N/yr, and net imports of  
26 fertilizer via world trade introduce 5.8 Tg N/yr. Of this total (15.2 Tg N/yr), 9.8 Tg N/yr is used  
27 as fertilizer on farms and 1.1 Tg N/yr is used on non-farms (i.e., residential and recreational turf-  
28 grass and gardens, and in explosives used by the mining industry), and 4.2 Tg N/yr is introduced  
29 for non-fertilizer uses, such as for production of plastics, fibers, resins, and for additives to  
30 animal feed (Table 1).

31 Additional Nr is introduced into the United States from cultivation-induced biological nitrogen  
32 fixation (BNF) by agricultural legume crops such as soybean and alfalfa (7.7 Tg N/yr), and from  
33 imports of N contained in grain and meat (0.15 Tg N/yr) (Table 1).

34 Thus in 2002, anthropogenic activities introduced a total of 29 Tg N into the United States,  
35 mostly in support of food production, although turf production, industrial uses and fossil fuel  
36 combustion were also important sources. Natural sources of Nr in the United States are BNF in  
37 unmanaged landscapes, and lightning. The former contributes 6.4 Tg N/yr (Table 1) and the  
38 latter 0.1 Tg N/yr. Clearly, anthropogenic activities dominate the introduction of Nr into the  
39 United States.

40 Losses of Nr to the environment in the United States occur during fossil fuel combustion and

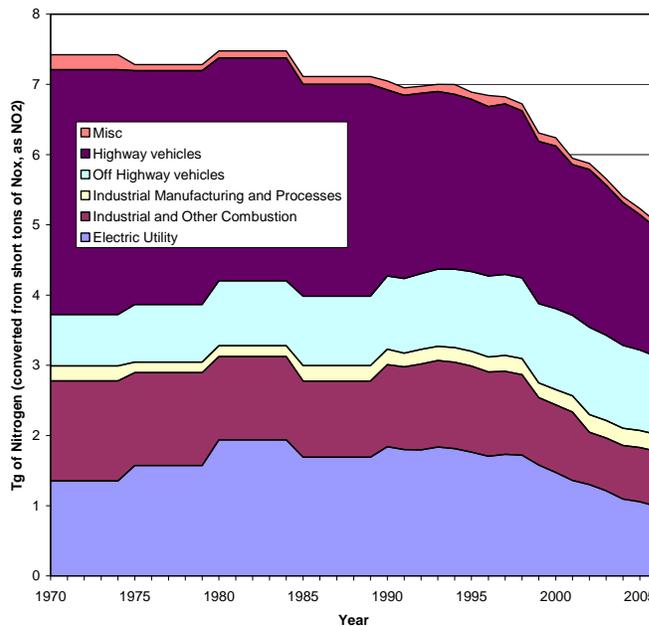
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1 food production. The former occurs immediately, as  $N_r$  formation during combustion is  
2 inadvertent and the  $N_r$ , primarily as  $NO_x$ , is emitted directly into the atmosphere. The latter  
3 occurs through all stages of food production and consumption. The remaining sections of  
4 Section 3.2 document the magnitude of the losses to the environment from the various  
5 components of both energy and food production.

### 6 2.2.2 $N_r$ formation and losses to the environment from fossil fuel combustion

7 Fossil fuels such as coal, petroleum, and natural gas provide about 80% of all energy production  
8 (based on year 2000). When these fuels are burned at high temperatures,  $NO_x$  is formed. The  
9 source of N is either the N contained in the fossil fuel or the  $N_2$  that comprises about 80% of  
10 atmosphere. Fuel-derived N is important in the case of burning coal (which contains N), while  
11 atmospheric-derived  $N_2$  is formed during higher temperature processes that occur when gasoline  
12 or diesel fuel is burned in motor vehicles (Table 1). In the United States, highway motor  
13 vehicles account for the largest anthropogenic source of  $NO_x$  at 36% (Figure 4), while off-  
14 highway vehicles, electric utilities and industrial processes account for 22%, and 20%,  
15 respectively.

16 **Figure 4: U.S.  $NO_x$  emission trends, 1970-2006. Data are reported as thousand of metric**  
17 **tons of N converted from  $NO_x$  as  $NO_2$**

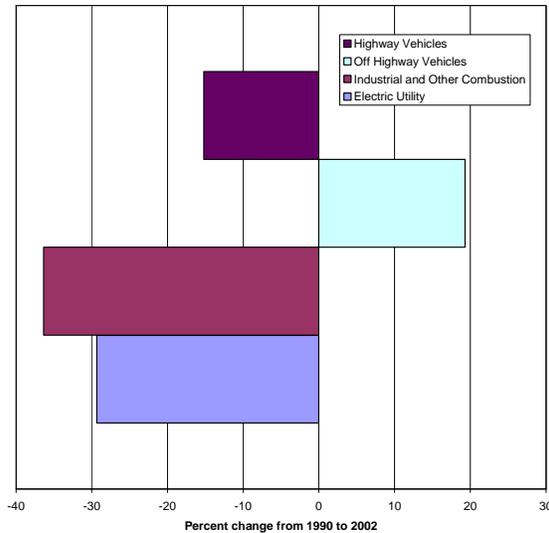


40 (Source: <http://www.epa.gov/ttn/chief/trends/index.html>)

41 Figure 4 also illustrates that the amount of  $NO_x$  (reported as metric tons of N) released from  
42 various fossil fuel sources has decreased dramatically from 1970. Total emissions were on the  
43 order of 7,400 metric tons in 1970, decreased to 5900 in 2002, with further decreases in 2006 to  
44 5,030 metric tons. Overall this represents a decrease of over 30%. The top sources (highway  
45 vehicles, off-highway vehicles, electric utilities, and other industrial and combustion systems)  
46 show decreases between 15-30% from 1990 to 2002 (Figure 5). Reductions were the highest for

1 “other” systems followed by electric utilities. These decreases are most likely the result of  
 2 changes in regulations and control technologies for these stationary systems. To a lesser extent,  
 3 changes in highway vehicle regulations and the removal of older fleets from the road has resulted  
 4 in a decrease of approximately 15%. This decrease however, is accompanied by an increase in  
 5 miles traveled, which suggests that the actual decrease in a single vehicle is larger. Off highway  
 6 vehicles showed an increase in emissions, potentially due to better quantification of these  
 7 sources. Sources here include locomotives, marine engines, etc. While some regulations are in  
 8 place for some of these sources, such as locomotives, further control of these and other sources  
 9 could decrease emissions. In fact, technological development in the locomotive industry shows  
 10 that decreases of approximately 70% are possible. Further decreases would require more  
 11 innovative, expensive methods such as Selective Catalytic Reduction (SCR) with urea injection.  
 12 Engine manufacturers are also investigating using SCR systems for diesels. However, it must be  
 13 noted that these systems emit small amounts of NH<sub>3</sub> and must be operated properly to avoid  
 14 trading off NO<sub>x</sub> emissions for NH<sub>3</sub>.

15 **Figure 5. Percent reductions in NO<sub>x</sub> emissions, 1990-2002, from different sources (off-road,**  
 16 **on-road vehicles, power generation, etc.)**



17

18 It should be noted that it is difficult to control nitrogen emissions with regulations on one source  
 19 solely. As seen in Table 2 (data taken from 2001 for illustrative purposes), Texas’ fuel  
 20 combustion sources are on the same order as highway vehicles; this is in comparison to  
 21 California, where vehicles, highway and off-highway are the dominant source (over 75%) for  
 22 this state. These results are attributed to industries and coal-fired power plants located in Texas.  
 23 Almost 40% of the power generation in Texas is due to coal-fired plants. On the other hand,  
 24 California imports most of its coal-fired power and generates its own power predominantly from  
 25 other sources, such as natural gas (50%), hydro and nuclear (33%). Florida, Ohio, and Illinois  
 26 are also shown. The emission of NO<sub>x</sub> from highway vehicles is likely related to population. For  
 27 example, the estimated population of California for 2006 is 36.4 million people versus Ohio and  
 28 Illinois which are on the order of 11-12 million.

**Table 2: Examples of multiple sources from states with high NO<sub>x</sub> emissions**  
**(based on 2001 data; and tons of NO<sub>x</sub> as NO<sub>2</sub>)**

(Source: These data were derived from the 2001 information obtained at:  
<http://www.epa.gov/air/data/geosel.html>)

	<b>TX</b>	<b>CA</b>	<b>FL</b>	<b>OH</b>	<b>IL</b>
<b>Fuel Combustion-Electric Util.</b>	91,441	8,441	87,489	93,792	59,124
<b>Fuel Combustion - Industrial</b>	98,978	31,237	11,792	17,300	26,481
<b>Fuel Combustion - Other</b>	9,222	21,407	5,707	12,974	10,894
<b>Industrial Processes</b>	25,584	13,786	5,933	8,123	7,122
<b>Highway Vehicles</b>	164,937	182,471	116,889	83,593	78,278
<b>Off-Highway Vehicles</b>	106,162	85,064	38,475	46,239	52,797
<b>Miscellaneous Sources</b>	4,807	7,882	13,110	1,526	999
<b>TOTAL, metric tons</b>	<b>501,151</b>	<b>350,301</b>	<b>279,778</b>	<b>263,561</b>	<b>235,817</b>

### 2.2.3 Nr inputs and losses to the environment from crop agriculture

Agriculture uses more Nr and accounts for more Nr losses to the environment than any other economic sector. Synthetic fertilizers are the largest sources of Nr input to agricultural systems. The next largest source is N fixation in cultivated croplands (Table 1). The major pathways by which Nr is lost from these systems include NO<sub>3</sub> losses from leaching, runoff and erosion and gaseous emissions via volatilization of NH<sub>3</sub> and NO<sub>x</sub> and nitrification/denitrification. Similar loss pathways occur for Nr that cycles through livestock systems, which also account for a large portion of Nr flux (predominantly as NH<sub>3</sub>) in animal agricultural systems (Aneja et al. 2006). Therefore, assessment of Nr impacts on the environment and development of strategies to minimize negative impact should be based on a thorough understanding and accurate accounting of Nr fluxes in both crop and livestock systems, and the trends in management practices that have greatest influence on Nr loss to the environment from these systems (Aneja et al, 2008a,c).

In the past 60 years, N fertilizers have had a beneficial effect on agriculture both nationally and globally by increasing crop yields. However, the high loading of Nr from agricultural nutrient sources has lead to deleterious effects on the environment, such as decreased visibility from increased aerosol production and elevated N concentration in the atmosphere, ground, and

1 surface waters (Galloway et al. 2003).

2 *2.2.3.1 Nitrogen fertilizer use*

3 Obtaining accurate data on fertilizer use is a critical first step in understanding N<sub>r</sub> cycles in  
4 agriculture. There are several sources of data reporting fertilizer usage but it is not clear whether  
5 data quality is sufficient for assessing environmental impact. Although the Uniform Fertilizer  
6 Tonnage Reporting System (UFTRS) was developed to collect fees to fund the consumer  
7 protection mission of State Chemists and fertilizer regulatory control officials, it also provides  
8 data on fertilizer sales in many states, which in turn are used by many agencies and  
9 environmental scientists to estimate consumption and use of nitrogenous fertilizers in the United  
10 States. The Association of American Plant Food Control Officials (AAPFCO) tallies and  
11 publishes the statewide fertilizer sales data annually (Terry et al. 2006), which is one of the most  
12 widely used sources of data on fertilizer use. It is typically assumed that fertilizers are used in the  
13 same region in which they were sold. The annual state-level data published by AAPFCO, which  
14 are based on commercial fertilizer sales and often taxed at the state level (but not in all states),  
15 are the only data source available. This state-level data source includes fertilizer sales for both  
16 agricultural and non-agricultural purposes. These state-level data must then be allocated to  
17 counties, regions, or watersheds in the states, and the algorithms used for this process are based  
18 on a number of assumptions that address dealer/farmer storage, inventories, and cross-state sales  
19 issues (personal communication, Stan Daberkow, USDA-ERS).

20 The USDA National Agricultural Statistics Service Information (NASS) fertilizer usage data  
21 represents another source of information derived from farmer “agricultural chemical use”  
22 surveys that provide information in six categories: field crops, fruits and vegetables,  
23 nurseries/floriculture, livestock use, and post-harvest application. For each group, NASS  
24 collects fertilizer, pesticide, and pest management data every year on a stratified random sample  
25 of farmers at the field level  
26 ([http://usda.mannlib.cornell.edu/usda/current/AgriChemUsFC/AgriChemUsFC-05-16-](http://usda.mannlib.cornell.edu/usda/current/AgriChemUsFC/AgriChemUsFC-05-16-2007_revision.pdf)  
27 [2007\\_revision.pdf](http://usda.mannlib.cornell.edu/usda/current/AgriChemUsFC/AgriChemUsFC-05-16-2007_revision.pdf)). The NASS report represents another useful data source but also would  
28 require extrapolation across reported crop acreage to represent a complete sample of application  
29 rates.

30 The UFTRS was not designed to track the source of inorganic nutrients applied to agricultural  
31 land on the geographic scale needed for watershed modeling. The system only tracks sales of  
32 synthetic fertilizers and not manure or biosolids applied to farmland. In addition, geographical  
33 data associated with each sale may or may not be near the actual point of application. However,  
34 given either regulatory or legislative changes (data reporting is mandated through each state’s  
35 fertilizer law), it could be possible to refine the current system used by each state Department of  
36 Agriculture to generate more precise data for improved modeling of watershed-scale nutrient  
37 mass balances. Those changes would help target interventions and extension programs to  
38 improve nutrient management and reduce nutrient losses. The lack of potential funding and the  
39 necessity to coordinate all the states involved limit the practicality of such an approach.

40 The state Departments of Agriculture have already made recommendations to improve the

1 reporting system. These include:

- 2 1. An assessment to determine the needs for fertilizer usage data, the accuracy of the current
- 3 data collection methods, and whether methods require revision to meet highest priority
- 4 needs,
- 5 2. Improvements in the database format and web-based access,
- 6 3. The identification of funding sources to support development of a more accurate,
- 7 accessible, and comprehensive database system, and
- 8 4. Education and outreach to improve precision of reported fertilizer tonnage including a
- 9 clear distinction between nutrients used in crop, livestock, and non-agricultural
- 10 operations.
- 11

12 In addition, the information could be refined to reflect site-specific data layers, although that  
13 would require development of a geospatial framework (and legal authority) to encourage  
14 reporting at the retail level where it is possible to collect geographic information.

15 The Chesapeake Bay watershed provides a good example of the fertilizer data dilemma. While  
16 the fertilizer tonnage that is currently being utilized to calibrate the Chesapeake Bay Program  
17 Watershed Model is relatively accurate, the county-specific tonnage may have an accuracy of  
18 only  $\pm 20$  to 50% (Chesapeake Bay Scientific Technical Advisory Committee. 2007). For  
19 example, in a recent year, 17% of the reported tonnage had been reported without an identified  
20 use and there are indications some tonnage may have been reported more than once through the  
21 distribution chain (Chesapeake Bay Scientific Technical Advisory Committee report, Oct. 2007).  
22 It is also possible that fertilizer reported for crop agriculture may actually have been used for  
23 lawn and turf, forestry, or other non-agriculture applications.

24 Nitrogen fertilizer application data on a specific crop-by-crop basis that can be associated with  
25 crop yields and location are essential for assessing both use patterns and efficiency. The USDA-  
26 NASS maintains a database on N fertilizer rates applied to the major crops (corn, wheat, cotton,  
27 soybeans, and occasionally other crops) based on farmer surveys conducted every other year.  
28 These data represent another source of information ("Protocols for Farming Reporting" Mark R.  
29 Miller, USDA, NASS).

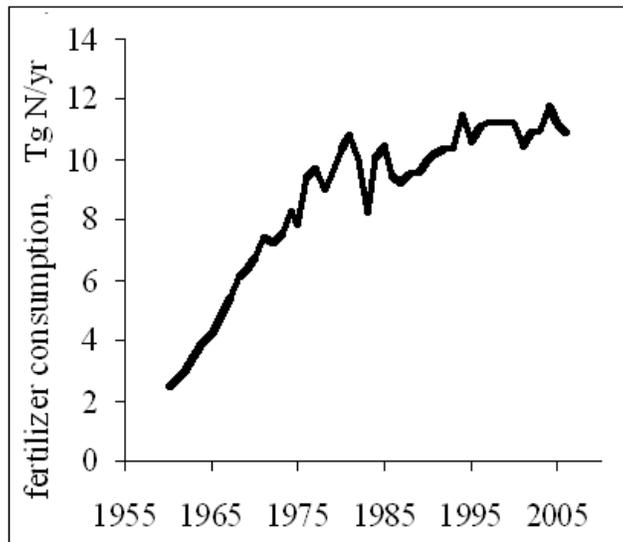
30 Data derived from NASS farmer surveys include six categories: field crops, fruits and  
31 vegetables, nurseries/floriculture, livestock use and post-harvest application. For each group,  
32 NASS collects fertilizer, pesticide, and pest management data every year on a stratified random  
33 sample of farmers at the field level. One field represents an entire farm for each sample in the  
34 field crops survey. Fruit and vegetable information are collected for the entire farm. If the field  
35 chosen for sampling has had manure applied in conjunction with inorganic fertilizer, only the  
36 inorganic portion will be reported because the survey does not ask about manure. Core crops are  
37 surveyed every other year on an even/odd basis for different crops and surveyed states are  
38 selected to cover at least 80% of planted acres. NASS is not currently scheduled to resume  
39 coverage of corn and other commodity crops until 2010, which is a five year gap. NASS will try  
40 to resume its coverage of corn management survey in 2008. This is a critical data gap and it is a  
41 problem given the large changes in corn price and production area during this period. Those data

1 have to be available if there is to be progress in assessing fertilizer use and efficiency for major  
2 crops in the United States. USDA NASS must resume their yearly data collection for commodity  
3 crops (Chemical Use Survey). Potential environmental impacts of increased N inputs associated  
4 with expanded corn acreage for biofuel production cannot be properly evaluated in the absence  
5 of such critical nutrient management data.

6 Based on the NASS survey data, USDA has recently released an updated report on fertilizer use  
7 that provides data on fertilizer consumption and type of fertilizer used from 1960-2006 (Figure  
8 6) and types of fertilizers used (Table 3). (U.S. Fertilizer Use and Price; Released Friday,  
9 October 5, 2007). Share of crop area receiving fertilizer and fertilizer use per receiving acre, by  
10 nutrient, are presented for the major producing states for corn, cotton, soybeans, and wheat.  
11 Additional data include fertilizer farm prices and indices of wholesale fertilizer price. See  
12 <http://www.ers.usda.gov/Data/FertilizerUse/>

13 **Figure 6: Fertilizer consumption in the United States 1960 to 2006**

14 (Source: AAPFCO; 1960 - 2006. [www.aapfco.org](http://www.aapfco.org))



15

**Table 3: Types and amount of nitrogen fertilizers used in the United States in 2002.**

(Data from Terry et al. (2006))

Synthetic Nitrogen Fertilizers	Tg N/year	% of total
Other	0.21	2
Urea	2.21	20
N Solutions	2.55	23
Anhydrous NH <sub>3</sub>	2.88	26
DAP, MAP, and NPK blends	2.28	32
NH <sub>4</sub> <sup>+</sup> SO <sub>4</sub> <sup>2-</sup> , NH <sub>4</sub> <sup>+</sup> , Thiosulfate, and Aqua NH <sub>3</sub> and NH <sub>4</sub> <sup>+</sup> Nitrate	0.76	7
<b>Total</b>	<b>10.89</b>	<b>100</b>

**Finding 1**

Crop agriculture receives 63% of U.S. annual new Nr inputs from anthropogenic sources (9.8 Tg from N fertilizer, 7.7 from crop BNF versus 29 Tg total) and accounts for 58% (7.6 Tg, see Table 1) of total U.S. Nr losses from terrestrial systems to air and aquatic ecosystems, yet current monitoring of fertilizer use statistics by federal agencies is inadequate to accurately track trends in quantities and fate of N applied to major crops and the geospatial pattern by major watersheds.

**Recommendation 1:** *Increase the specificity and regularity of data acquisition for fertilizer application to major agricultural crops in terms of timing and at a sufficiently small application scale (and also for urban residential and recreational turf) by county (or watershed) to better inform decision-making about policies and mitigation options for reducing Nr load in these systems and to facilitate monitoring and evaluation of impact from implemented policies and mitigation efforts.*

**2.2.3.2 Nitrogen fertilizer use efficiency**

Nitrogen fertilizer use efficiency (NFUE) is critical because higher use efficiency leaves less N remaining to create potential environmental problems. Here and throughout this report we define NFUE as the grain yield per unit of applied N, which is the product of two parameters: (i) the proportion of applied N fertilizer that is taken up by the crop, or N fertilizer recovery efficiency [(RE) in kg N uptake per kg N applied], and (ii) the physiological efficiency with which the N taken up by the crop is used to produce economic yield such as grain or fruit [(PE), kg yield per

1 kg N uptake](Cassman et al., 2002)<sup>6</sup> All else equal, when higher NFUE is achieved without yield  
2 reduction, the crop takes up more of the applied N and incorporates it into its biomass, which  
3 leaves less of the applied N at risk for losses via leaching, volatilization, or denitrification. Fixen  
4 (2005) reports that there is substantial opportunity for increasing NFUE through development  
5 and adoption of more sophisticated nutrient management decision aids.

6 In most cropping systems, RE is the most important determinant of NFUE. A recent review of  
7 RE for cereals based on field studies around the world, mostly conducted on “small-plot”  
8 experiments at research stations, reported mean single year RE values for maize, wheat and rice  
9 of 65%, 57% and 46%, respectively (Ladha et al., 2005). However, crop RE values based on  
10 actual measurements in production-scale fields are seldom greater than 50% and often less than  
11 33%. For example, a review of RE in different cropping systems, estimated average recoveries  
12 of 37% for maize in the north central United States (Cassman et al., 2002). It is also important to  
13 note that soil N provides the majority of the N taken up by most crops grown on soils with  
14 moderate to good soil fertility. For maize in the U.S. corn belt, for example, 45-77% of total N  
15 uptake was estimated to come from soil N reserves based on experiments from research stations  
16 (Sawyer J, Nafziger E, Randall G, Bundy L, Rehm G, and Joern B. 2006. Concepts and  
17 Rationale for Regional Nitrogen Rate Guidelines for Corn. Iowa State Extension PM 2015,  
18 [www.extension.iastate.edu/Publications/2015.pdf](http://www.extension.iastate.edu/Publications/2015.pdf)). Therefore highest N efficiency and economic  
19 return on N inputs are achieved when the amount and timing of applied N is synchronized with  
20 the availability of soil N throughout the growing season to minimize both the quantity of N input  
21 required and the N losses from soil and applied N sources.

22 However, there are relatively few data that provide direct measurement of N fertilizer recoveries  
23 by our major field crops under production-scale conditions. Reducing the uncertainty in  
24 estimates of N fertilizer RE is fundamental for prioritization of research and education  
25 investments, both in the public and private sectors. While management can substantially improve  
26 RE on average, in any given year weather will always be an uncontrolled factor that can  
27 significantly influence system efficiency. Weather can influence system efficiency through  
28 effects on crop growth vigor and ability to acquire applied nutrients and through losses of  
29 nutrients due to runoff, denitrification, and leaching that can occur in periods of excessive  
30 rainfall.

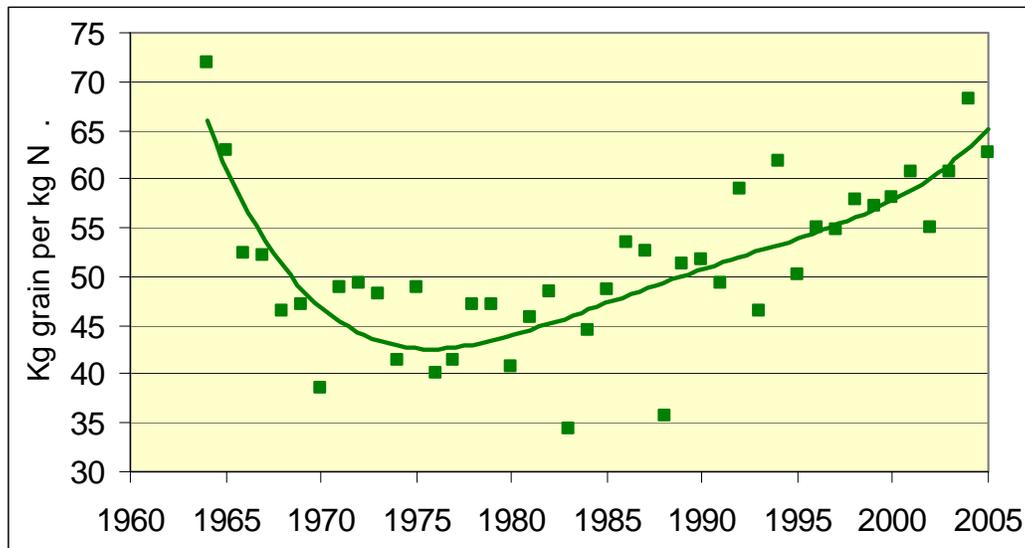
31 Although total N fertilizer use in the United States has leveled off in the past two decades  
32 (Figure 6), yields of all major crops have continued to increase. Because crop yields are closely  
33 related to N uptake (Cassman et al., 2002), these trends imply a steady increase in NFUE and  
34 reduced N losses to the environment because more of the applied N is held in crop biomass and  
35 harvested grain. Greater NFUE has resulted from two factors. The first factor is a steady  
36 improvement in the stress tolerance of corn hybrids (Duvick and Cassman, 1999) that increase  
37 crop growth rates and allows sowing at higher plant densities, which together accelerate the  
38 establishment of a vigorous root system to intercept and acquire available N in the soil profile.

---

<sup>6</sup> N fertilizer use efficiency (NFUE) is calculated as the ratio of grain yield to the quantity of applied N fertilizer (kg grain/kg applied N).

1 The second factor is the development and adoption of technologies that may improve the  
 2 congruence between crop N demand and the N supply for indigenous soil resources and applied  
 3 N. Examples of such technologies include soil testing for residual nitrate and adjusting N  
 4 fertilizer rates accordingly, split N fertilizer applications, fertigation (the application of nutrients  
 5 through irrigation systems), site-specific management, and new fertilizer formulations (e.g.  
 6 controlled release, nitrification inhibitors). For maize, which receives the largest share of total N  
 7 fertilizer in the United States (44%, 2005), NFUE has increased by more than 50% from 1974-76  
 8 to 2002-05 (Figure 7). Similar improvements have been documented for rice production in Japan  
 9 and for overall crop production in Canada.

10 **Figure 7: Trends in Corn Grain Produced per Unit of Applied Fertilizer-N (NFUE) in the**  
 11 **United States (USDA data)**



12

13 Despite these steady improvements, current levels of N fertilizer uptake efficiency appear to be  
 14 relatively low (Cassman et al., 2002), although data from production-scale studies are few  
 15 (Cassman et al., 2002). Most farmers do not use best management practices (BMPs) with regard  
 16 to nitrogen fertilizer management. For example, a recent USDA-ERS AREI report indicates that  
 17 a majority of farmers still apply N in the fall, which gives the lowest fertilizer uptake efficiency  
 18 and highest N<sub>r</sub> losses compared to application in spring or during the crop growth period  
 19 (USDA, ERS, 2006). This situation suggests substantial potential for improvement in NFUE and  
 20 an associated reduction in N<sub>r</sub> losses from crop agriculture, especially for maize in the warmer  
 21 portions of the Corn Belt and other southern and southeast areas where maize is grown. One  
 22 potential development is the use of controlled release fertilizers that emit N in congruence with  
 23 crop demand during the growing season. Although such fertilizers are already in use on high  
 24 value horticultural crops, they are currently too expensive for lower value commodity grains  
 25 such as corn, rice, or wheat. Such enhanced efficiency fertilizers can increase NFUE where there  
 26 is high risk for N losses in cereal systems that receive the total amount of applied N in one or two  
 27 large doses.

1 As producers have increased yields in commodity crops significantly over the past 25 years, the  
2 question arises whether university recommendations for nutrient applications are still current.  
3 Many university recommendations are now 20 to 25 years old. As a corollary to this problem,  
4 numerous environmental models of nutrient pollution are still utilizing older yield estimates,  
5 which often underestimate crop nutrient uptake and overestimate nutrient losses (Robert  
6 Burgholzer, cited in Understanding Fertilizer Sales and Reporting Information, *Workshop*  
7 *Report, Oct. 2007*).

8 A systematic effort needs to be made to update those data. The concept of NFUE should be  
9 emphasized as a way to address the need to balance economic *and* environmental goals. In fact,  
10 the development and adoption of technologies that improve nitrogen fertilizer efficiency can  
11 contribute to more profitable cropping systems through a reduction in fertilizer costs. For  
12 example, average NFUE in the United States required 1.0 kg of applied N to produce 43 kg of  
13 grain yield in the 1974-76 period, whereas that same amount of N produced 65 kg of grain in  
14 2003-05 period (data taken from Figure 7). This gain in efficiency means that it is possible to  
15 achieve the 2004 U.S. average corn yield of about 150 bushels per acre with 144 lbs of applied N  
16 fertilizer based on the most recent NFUE achieved by U.S. corn producers, versus about 200 lbs  
17 of N fertilizer at the 1980 efficiency level. At a cost of \$0.40 per pound of applied N, this  
18 reduction in N fertilizer input requirements represents a saving of about \$22 per acre.

19 Nitrogen costs have become extremely volatile, mirroring natural gas prices. In late 2008,  
20 Nitrogen fertilizer prices were more than double 2006/7 Nitrogen prices. More recently, nitrogen  
21 fertilizer prices have fallen back to two thirds of the high following the decline of natural gas  
22 prices. If corn brings \$4.00 per bushel (25.5 kg) and nitrogen costs \$0.40 a pound (0.45 kg), this  
23 is a 10 to 1 price ratio – not different from the \$2.00 corn and \$0.20 nitrogen ratio that was  
24 typical from 2000-2005. There are also other critical factors in the farmer's nitrogen application  
25 decisions such as yield at the margin and weather. In the corn belt, one or two years in five may  
26 provide extremely favorable weather for corn production. A producer may view applying some  
27 extra nitrogen, hoping for good weather, as a reasonable economic gamble. If the yield response  
28 is more than half a bushel (12.7 kg) of corn per pound (0.45 kg) of N at the margin or if there is  
29 more than one extremely good year in five, the farmer comes out ahead.

30  
31 Realistically, few farmers calculate their marginal returns from additional N in good years versus  
32 average, but the high corn-to-fertilizer price ratio encourages some farmers to plan for a good  
33 year and consider a larger N application than might otherwise be appropriate for the N utilization  
34 in the four years of lower yield. This presents a real dilemma if the policy goal is to reduce N  
35 transfers to the environment, especially in the four years of average or lower yields. Meeting this  
36 challenge will require approaches such as the development of real-time, in-season, decision-  
37 making tools that allow crop producers to use N fertilizer rates for average yields at planting and  
38 during early vegetative growth and a final top-dressing as required to meet any additional N  
39 demand above this amount due to favorable climate and soil conditions that support higher than  
40 average yields (Cassman, 1999; Cassman et al, 2002). Robust crop simulation models using real-  
41 time climate data at a relatively localized geographic scale will be required to develop such tools.

42 Another option is to develop new, alternative crop production systems that require less N  
43 fertilizer. Such systems may employ legume cover crops, more diverse crop rotations, and

1 tighter integration between crop and livestock production to achieve greater reliance on N inputs  
2 from legume N fixation and recycling of N in manure and compost. At issue, however, is  
3 whether such systems actually reduce Nr losses to the environment because the same loss  
4 mechanisms and pathways operate on N from both commercial fertilizer and organic sources.  
5 Also at issue is the indirect land use change impact from widespread adoption of these more  
6 diverse cropping systems because they have reduced crop yields per unit land area compared to  
7 more simplified crop rotations such as corn-soybeans that receive N fertilizer. Lower yields  
8 would require more land in production to meet food demand. Therefore, a key issue is whether  
9 the tradeoff in reduced N fertilizer inputs to more diverse crop rotations with organic N inputs  
10 would actually result in less Nr losses to the environment compared to conventional cropping  
11 systems that require less land to produce the same amount of crop output.

## 12 **Finding 2**

13 Nr inputs to crop systems are critical to sustain crop productivity and soil quality. Moreover,  
14 given limited land and water resources, global population growth and rapid economic  
15 development in the world's most populous countries, the challenge is to accelerate increases in  
16 crop yields on existing farm land while also achieving a substantial increase in N fertilizer  
17 uptake efficiency. This process is called "ecological intensification" because it recognizes the  
18 need to meet future food, feed, fiber and energy demand of a growing human population while  
19 also protecting environmental quality and ecosystem services for future generations (Cassman,  
20 1999). More diverse cropping systems with decreased Nr fertilizer input may also provide an  
21 option on a large scale if the decrease in Nr losses per unit of crop production in these diverse  
22 systems can be achieved without a decrease in total food production, which would trigger  
23 indirect land use change to replace the lost production and negate the benefits.

## 24 **Recommendation 2:**

- 25 a) *Data on NFUE and N mass balance, based on direct measurements from production-*  
26 *scale fields, are required for the major crops to identify which cropping systems and*  
27 *regions are of greatest concern with regard to mitigation of Nr load and to better focus*  
28 *research investments, policy development, and prioritization of risk mitigation strategies.*  
29 b) *Promote efforts at USDA and land grant universities to: (i) investigate means to increase*  
30 *the rate of gain in crop yields on existing farm land while increasing N fertilizer uptake*  
31 *efficiency and (ii) explore the potential for more diverse cropping systems with lower N*  
32 *fertilizer input requirements so long as large-scale adoption of such systems would not*  
33 *cause indirect land use change.*  
34 c) *EPA should work closely with the U.S. Department of Agriculture (USDA), Department*  
35 *of Energy (DOE), and the National Science Foundation (NSF), and land grant*  
36 *universities to help identify research and education priorities efficient use and mitigation*  
37 *of Nr applied to agricultural systems.*  
38

1 *2.2.3.3. Biological fixation in cultivated croplands.*

2 Reactive nitrogen is also introduced to the landscape in significant quantities via BNF in  
 3 cultivated crop lands. Management of biologically fixed N, insofar as it is possible, is  
 4 proportionally as critical a task as the management of synthetic N because Nr from BNF is prone  
 5 to the same loss pathways as Nr from commercial fertilizers. To quantify BNF due to human  
 6 cultivation of crops, the committee calculated the annual agricultural fixation for 2002 using crop  
 7 areas and yields reported by the Census of Agriculture (2002). The committee multiplied the  
 8 area planted in leguminous crop species by the rate of N fixation specific to each crop type,  
 9 assigning rates based on a literature review, as summarized in Table 4 below and shown relative  
 10 to other inputs in Table 1. Annual nitrogen inputs to cropping system from BNF by legume  
 11 crops was 7.7 Tg N/yr in 2002, accounting for ~15% of the overall Nr inputs to the terrestrial  
 12 landscape from all sources and 20% of the agricultural sources (Table 1). Soybean and alfalfa  
 13 contributions are the most important agricultural legumes in terms of nitrogen input and  
 14 contribute 69% of total BNF inputs in U.S. agriculture.

15 **Table 4: Estimates of nitrogen input from biological nitrogen fixation (from major legume**  
 16 **crops, hay, and pasture)**

<b>Nr fixation in cultivated croplands</b>				
	<b>production area, Mha</b>	<b>rate, kg/ha/yr</b>	<b>Tg N/yr</b>	<b>% of total</b>
<b>Soybeans</b>	29.3	111	3.25	42
<b>Alfalfa</b>	9.16	224	2.05	27
<b>Other leguminous hay</b>	15.4	117	1.80	23
<b>Western pasture</b>	161	1	0.16	2
<b>Eastern pasture</b>	22.0	15	0.33	4
<b>Dry beans, peas, lentils</b>	0.88	90	0.08	1
<b>Total</b>			<b>7.67</b>	<b>100</b>

17 \*Updated estimate for soybean based on a generalized relationship between soybean yield and the  
 18 quantity of N fixation (Salvagiotti et al., 2008). Other values are from Boyer et al. (2002).

19 *2.2.3.4. Emissions factors and losses to the environment from fertilizers and organic nitrogen*  
 20 *sources.*

21 Agriculture is a significant contributor of Nr inputs into the atmosphere. Nitrogen fertilizer losses  
 22 vary greatly due to differences in soil properties, climate, and the method, form, amount, timing

1 and placement of applied nitrogen (Cassman et al., 2002). In addition, any factor that affects crop  
2 growth vigor and root system function also affects the ability of the plant to recover applied N  
3 efficiently. For example, denitrification can range from 0-70% of applied N (Aulakh et. al,  
4 1992). This process is mediated by heterotrophic, facultative anaerobic soil bacteria that are  
5 most active under warm, wet soil conditions; they have low activity in dry sandy soils.

6 Despite this variation, watershed, regional and national assessments of carbon and N cycling  
7 often rely on average values for losses from each pathway. For example, the Intergovernmental  
8 Panel on Climate Change (IPCC) assumes that 1% of applied N fertilizer (uncertainty range of  
9 0.3-3.0%) is lost from direct emissions of N<sub>2</sub>O at the field level due to denitrification, based on  
10 analysis of all appropriate scientific publications that report these losses for specific crops and  
11 cropping systems (IPCC, 2007). The same 1% default emission factor for field-level N<sub>2</sub>O  
12 emission is applied to other N inputs from crop residues, organic amendments such as manure,  
13 and from mineralization of native soil organic matter. Data from scores of field studies were  
14 used to obtain this average value. A number of recent studies confirm that N<sub>2</sub>O losses to the  
15 environment during the growing season at the field level represent <1% of the applied nitrogen—  
16 even in intensive, high-yield cropping systems (Adviento-Borbe et al., 2006). Despite these  
17 average values, it is also clear that N<sub>2</sub>O losses can vary widely even within the same field and  
18 from year to year due to normal variation in climate and crop management (Parkin and Kaspar,  
19 2006; Snyder, 2007). Moreover, the loss of nitrogen from agricultural watersheds is strongly  
20 dependent on climate change (e.g. rainfall changes). Predicted increases and decreases in rainfall  
21 will likely have a dramatic impact on nitrogen export from agricultural fields. For example,  
22 precipitation is predicted to increase in the upper Mississippi watershed, and other factors being  
23 equal, N export should increase (e.g., Justic et al., 1995b).

24 Additional indirect N<sub>2</sub>O emissions result from denitrification of volatilized NH<sub>3</sub> deposited  
25 elsewhere or from NO<sub>3</sub> lost to leaching and runoff as the Nr cascades through other ecosystems  
26 after leaving the field to which it was applied. Here the IPCC assessment protocol assumes that  
27 volatilization losses represent 10% of applied N, and that N<sub>2</sub>O emissions for these losses are 1%  
28 of this amount; leaching losses are assumed to be 30% of applied nitrogen and N<sub>2</sub>O emissions  
29 are 0.75% of that amount (IPCC, 2007). Therefore, the IPCC default value for total direct and  
30 indirect N<sub>2</sub>O emissions represents about 1.4% of the applied N from fertilizer. By the same  
31 calculations, 1.4% of the N in applied organic matter, either as manure or compost, or in recycled  
32 crop residues, is also assumed to be emitted as N<sub>2</sub>O.

33 Others have estimated higher average N<sub>2</sub>O losses of 3-5% of applied nitrogen fertilizer based on  
34 global estimates of N<sub>2</sub>O emissions from recycling of Nr (Crutzen et al., 2008), as opposed to the  
35 field-based estimates that form the basis of IPCC estimates. Because N<sub>2</sub>O is such a potent  
36 greenhouse gas, and given the more than 2-fold difference in estimates of N<sub>2</sub>O losses, there is a  
37 critical need to improve understanding and prediction of N<sub>2</sub>O losses from agricultural systems.  
38 N<sub>2</sub>O emissions in the United States are estimated to be 0.78 Tg N/yr (Table 5) (EPA, 2005).

1

**Table 5: N<sub>2</sub>O emissions in the United States, 2002**

	<b><u>Tg N/yr</u></b>	<b><u>%</u></b>
<b>Agricultural Soil Management</b>	0.54	69
<b>Manure Management</b>	0.03	4
<b>Mobile Combustion</b>	0.09	12
<b>Stationary Combustion</b>	0.03	4
<b>Nitric &amp; Adipic Acid Production</b>	0.05	6
<b>Wastewater Treatment</b>	0.02	2
<b>Other</b>	0.02	2
<b>Total</b>	<b>0.78</b>	<b>100</b>

2

3 Biogenic NO<sub>x</sub> emissions from croplands are on the order of 0.5% of fertilizer input—much more  
 4 than this in sandy soils and less as clay content increases (Aneja et al. 1996; Sullivan et al. 1996;  
 5 Veldkamp and Keller. 1997; Civerolo and Dickerson, 1998). However, NO<sub>x</sub> emissions by  
 6 agricultural burning are relatively unimportant. Ammonia volatilization of N from applied  
 7 fertilizer can be the dominant pathway of N loss in rice soils and can account for 0->50% of the  
 8 applied N depending on water management, soil properties and method of application (citations  
 9 within Peoples et al. 1995). Ammonia volatilization can be of the same range in upland cropping  
 10 systems, with largest losses occurring typically on alkaline soils (Peoples et al. 1995). The IPCC  
 11 (2007) uses a value of 10% of synthetic fertilizer N application and 20% of manure N as  
 12 estimates of average NH<sub>3</sub> volatilization.

13 Taken together, N losses from all forms of direct gaseous emissions forms from crop production  
 14 systems can represent a substantial portion of applied N fertilizer when soil conditions favor such  
 15 emissions and there is a lack of synchrony between the amount of N applied and the immediate  
 16 crop demand (Goulding, K., 2004). Therefore, achieving greater congruence between crop  
 17 demand and the N supply from fertilizer is a key management tactic to reduce N losses from all  
 18 sources. Success in reducing N losses and emissions from agriculture will depend on increased  
 19 efforts in research and extension to close gaps in our understanding of N cycling and  
 20 management in crop production, especially as systems further intensify to meet rapidly  
 21 expanding demand for food, feed, fiber, and biofuel.

22 **Finding 3**

23 Nitrous oxide emissions from the Nr inputs to cropland from fertilizer, manure, and legume

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1 fixation represent a large proportion of agriculture's contribution to greenhouse gas emissions,  
2 and the importance of this source of anthropogenic greenhouse gas will likely increase unless  
3 NFUE is markedly improved in crop production systems. Despite its importance, there is  
4 considerable uncertainty in the estimates of nitrous oxide emissions from fertilizer and research  
5 should focus on reducing this uncertainty.

6 **Recommendation 3:** *The committee recommends that EPA ensure that the uncertainty in*  
7 *estimates of nitrous oxide emissions from crop agriculture be greatly reduced through the*  
8 *conduct of EPA research and through coordination of research efforts more generally with other*  
9 *agencies such as USDA, DOE, NSF and with research conducted at universities.*

#### 10 2.2.3.5. *Impact of biofuel production capacity on Nr flux in agriculture*

11 The enormous use of liquid fuels in the United States, the rising demand for petroleum based  
12 liquid fuels from countries like China and India, and the decline in petroleum discovery all  
13 contributed to the recent record high petroleum prices. In addition most of the world's petroleum  
14 reserves are located in politically unstable areas. This has provided strong motivation for policies  
15 promoting investment in biofuels made from corn, oil crops, and ultimately from cellulosic  
16 materials. In the United States, ethanol production capacity from corn in 2006 has more than  
17 doubled to over 47 billion liters/year (January 2009). The renewable fuels standard in the 2007  
18 Energy Independence and Security Act (EISA) will support another 9.5 billion liters/year of corn  
19 based ethanol by 2015. An additional 79.5 billion liters is to come from cellulosic ethanol by  
20 2022. Biodiesel from vegetable oils also is encouraged in EISA, but expansion has been slowed  
21 by the high food value of such oils. Brazil is rapidly expanding its production of relatively low  
22 cost sugarcane ethanol and U.S. policies continue to be aimed at bringing about increased future  
23 biofuel production in the United States.

24  
25 In 2007 and 2008 petroleum prices pushed ethanol prices high enough to draw corn from food  
26 and feed uses into ethanol production and contribute to the increased price of corn. Because of  
27 the increase in petroleum/ethanol prices and the government subsidy for ethanol production, 30%  
28 of the corn crop ended up going to ethanol in 2008 (Abbott, et. al. 2008). With the subsequent  
29 collapse in petroleum and ethanol prices, followed by corn prices, we have had unused capacity  
30 in the U.S. ethanol industry as the corn/ethanol price ratio made ethanol production uneconomic  
31 for some firms. However, EISA is likely to lead to the production of cellulosic materials and  
32 even some expanded corn production for biofuels once the United States gets beyond the current  
33 blending limit for ethanol (Doering & Tyner, 2008). The higher corn prices of 2007 and 2008  
34 resulted in more land being planted to corn and higher N fertilizer requirements. Corn area went  
35 from 31.73 million hectares in 2006/7 to 37.88 million hectares in 2007/8. 4.86 million hectares  
36 of the expansion were from a reduction in soybeans, and the remaining new acres came primarily  
37 from reduced cotton acres and from hayland and pasture. This strong response to high demand  
38 for biofuel feedstock has led to concern about increased pressure on the environment from  
39 biofuels One important factor is the increased N necessary for growing corn and cellulosic  
40 materials (Robertson, et. al. 2008). Expansion of corn or cellulosic materials production into  
41 marginal lands can be even more problematic with respect to nutrient leaching and soil erosion.  
42 Changes in N fertilizer prices add uncertainty to the additional amounts of N that may ultimately  
43 be used in biofuel feedstock production. Production of large amounts of distillers grains co-

1 product is also changing the way that livestock feed rations are formulated, which in turn could  
2 have an influence on the cycling of N in cattle manure (Klopfenstein et al., 2008).

3

4 **Finding 4**

5 Rapid expansion of biofuel production has the potential to increase N fertilizer use through  
6 expanding corn production and its associated N fertilizer inputs and extending cultivation for  
7 cellulosic materials that will also need N. Distillers grains are changing animal diets and  
8 affecting N recycling in livestock. Both have important consequences for the effective future  
9 management of Nr.

10

11 **Recommendation 4:** *EPA should work with USDA and universities to improve understanding*  
12 *and prediction of how expansion of biofuel production, as mandated by the 2007 EISA, will*  
13 *affect Nr inputs and outputs from agriculture and livestock systems. Rapid expansion of biofuel*  
14 *production has the potential to increase N fertilizer use through expansion of corn production*  
15 *area and associated N fertilizer inputs, and from extending cultivation of cellulosic materials*  
16 *that will also need N inputs.*

17

18 **2.2.4. Nr inputs and losses from animal agriculture**

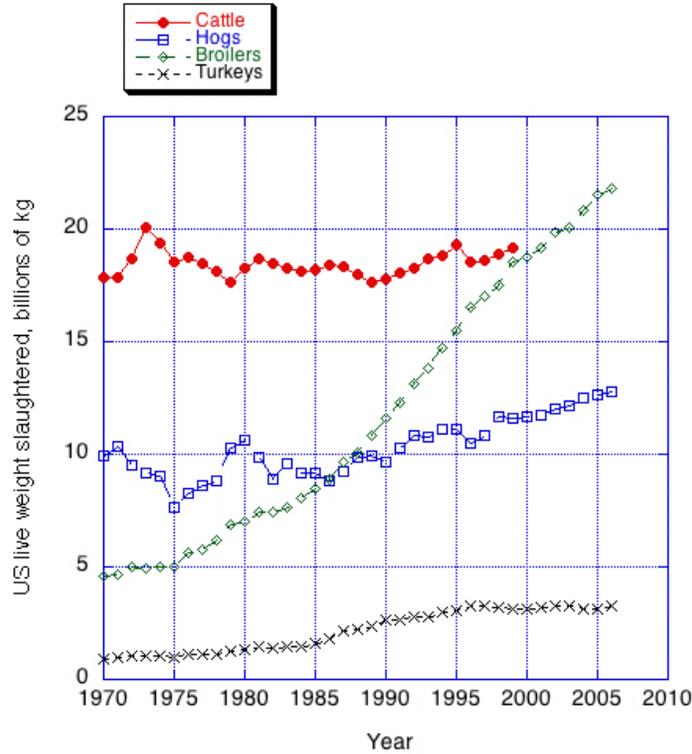
19 In the United States, domestic animals produce 6.0 Tg N/yr in manure and are the largest source  
20 of atmospheric NH<sub>3</sub>-N (1.6 Tg N/yr) (Table 1). Livestock also contribute to N<sub>2</sub>O-N emissions,  
21 though in much smaller proportions (~4% of total U.S. N<sub>2</sub>O-N emissions).

22 *2.2.4.1 Trends in Animal Agriculture*

23 While animal production has been increasing since World War II, this report will emphasize the  
24 period from 1970 to 2006. The production of chicken broilers increased by more than four fold  
25 from 1970 to 2006 (Figure 8) and milk production increased by nearly 60% in this time period  
26 (Figure 9). Turkey production doubled and pork production increased about 25%, while meat  
27 from cattle (beef and dairy) remained constant (Figure 8).

1 **Figure 8: Meat production from 1970 to 2006. Source: USDA-NASS, Census Reports**

2 (Data on cattle not taken after 1999)

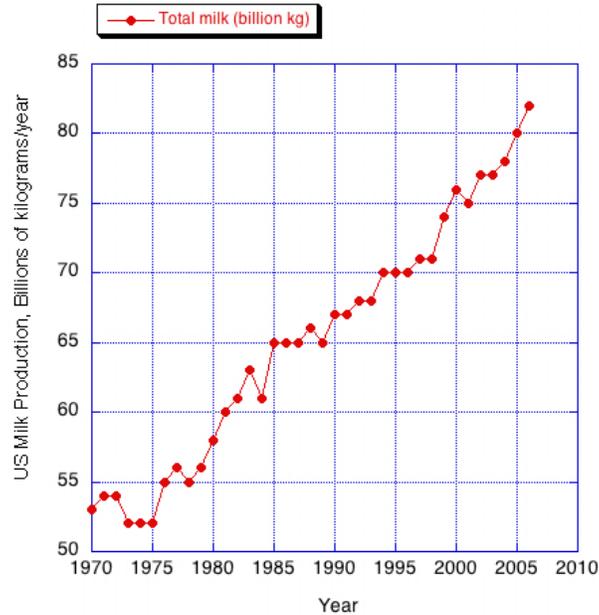


3

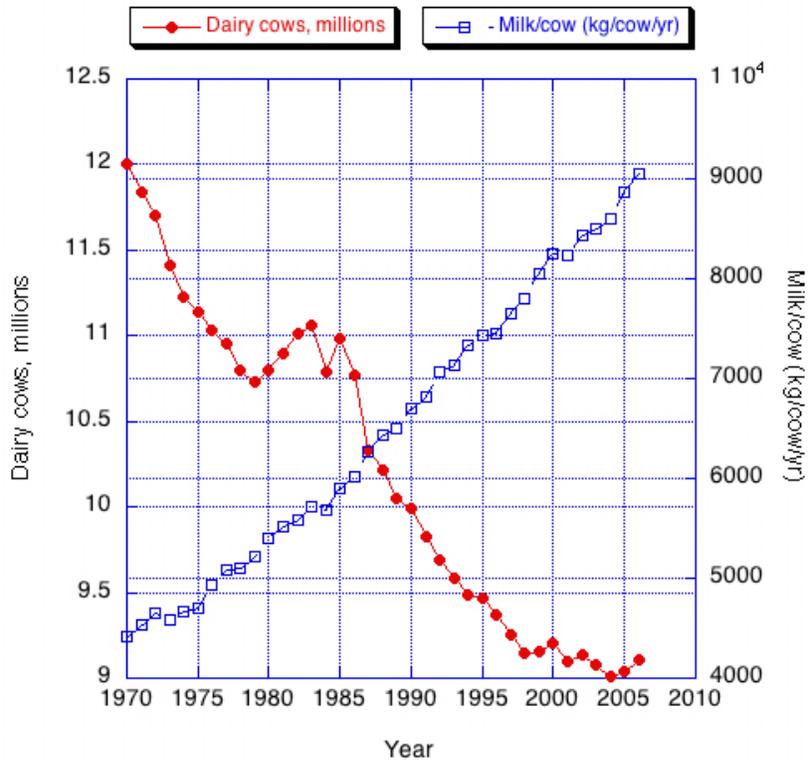
4 Another trend in animal production has been for fewer animals to produce more animal products.  
 5 For example, the 60% greater amount of milk produced in 2006 compared to 1970 required 25%  
 6 fewer cows (Figures 9 and 10). Animal inventories declined by 10% for beef brood cows from  
 7 36 million head in 1970 to 33 million head in 2006, and the inventory of breeder pigs and market  
 8 hogs declined 8% from 673 million head to 625 million head in the same period, even with  
 9 similar or greater annual meat production. This trend resulted from greater growth rates of  
 10 animals producing more meat in a shorter amount of time. In 1970, broilers were slaughtered  
 11 after 80 days on feed at 1.7 kg live weight, but by 2006 the average weight was 2.5 kg after only  
 12 44 days on feed (NASS-USDA, 2007).

This Draft is made available for review and approval by the chartered Science Advisory Board. This Draft does not represent EPA policy.

1 **Figure 9: Milk production from 1970 to 2006. Source: USDA-NASS, Census Reports.**



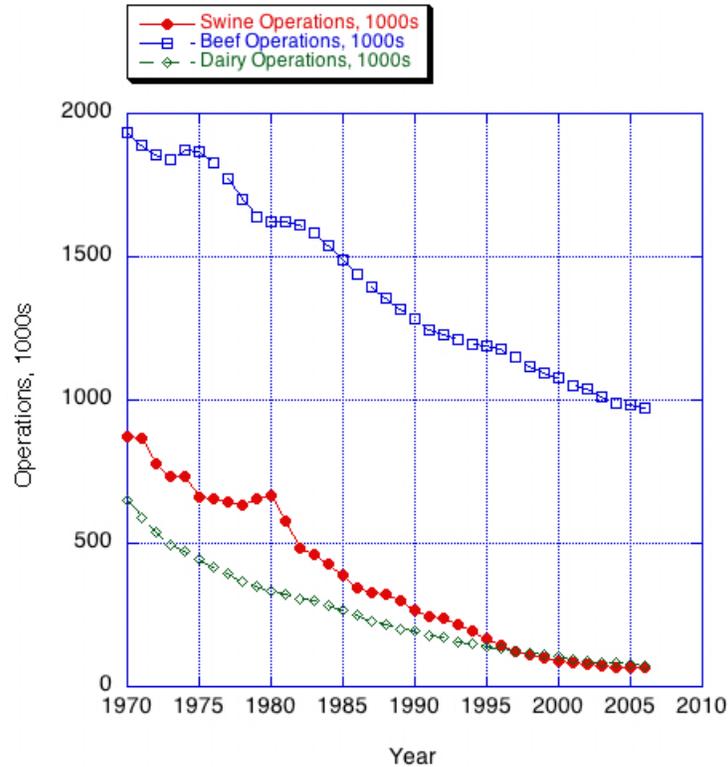
2  
3 **Figure 10: U.S. Inventory of mature dairy cows and milk production per cow from 1970 to**  
4 **2006. Source: USDA-NASS, Census Reports.**



5  
6 Another trend in animal agriculture has been the increased size and smaller number of animal

1 operations, which results from the mechanization of agricultural practices and increased  
 2 specialization. There were only 7% as many swine operations and 11% as many dairy operations  
 3 in 2006 as there were in 1970 (Figure 11). There were half as many beef operations in 2006 as  
 4 in 1970, but beef operations also expanded in size while smaller producers held jobs off the farm.

5 **Figure 11: Number of animal operations in the United States from 1970 to 2006. Source:**  
 6 **USDA-NASS, Census Reports.**



7

8 All of these trends show an increase in management and labor efficiency to produce a similar or  
 9 greater amount of animal products. Also, because animal production is more concentrated on  
 10 fewer farms with greater specialization, fewer crops are produced on those farms. As a result, it  
 11 is increasingly common to have more manure nutrients produced on a livestock farm than can be  
 12 used efficiently as fertilizer for crops on that farm. Therefore, unless the manure is applied over a  
 13 larger crop area, the resulting over-application of manure on the livestock farm can reduce the  
 14 subsequent efficiency of its utilization and result in greater nutrient losses.

#### 15 2.2.4.2. Impact of livestock production trends on nitrogen use efficiency

16 The trends have both positive and negative environmental impacts. One of the significant  
 17 positive impacts is that with smaller animal inventories producing greater quantities of animal  
 18 products, there is an improved efficiency of nitrogen utilization per product produced. This  
 19 effect is partly the result of effectively reducing maintenance requirements during production.  
 20 The requirements for feeding animals can be divided into two components: maintenance and  
 21 production. The maintenance component is that feed which is used to keep the animal alive and

1 healthy so that production is possible. The production component includes feed that is converted  
2 to animal protein and waste due to the inefficiencies of these conversions. The maintenance  
3 component depends upon the number of animals, each animal's mass, and the time the animal is  
4 on feed. Thus, the maintenance requirement is diluted by faster growth rates and greater body  
5 weight at slaughter. The increases in production rates over time have lead to greater efficiencies  
6 in N and P utilization for animal production and lower amounts of nutrients excreted per unit of  
7 animal protein produced.

8 Public concerns about the potential environmental and health effect of air emissions from  
9 CAFOs expand the impacts of food production beyond those associated with traditional  
10 agricultural practices (NRC, 2001, Aneja et al., 2009). Increased emissions of N compounds  
11 from animal agriculture into the atmosphere may lead to increased odor and interact in  
12 atmospheric reactions (e.g. gas-to-particle conversion) (Baek et al. 2004a; Baek and Aneja  
13 2004b). These are then transported by wind and returned to the surface by wet and dry deposition  
14 processes, which may have adverse effects on human health and the environment (McMurry et.  
15 al, 2004; Aneja et. al, 2006, 2008a, b, c; Galloway et. al, 2008).

16 Adverse effects include eutrophication, soil acidification, loss of biodiversity, and reactions that  
17 increase the mass concentration of atmospheric aerosols ( $PM_{2.5}$ ). Aerosol formation occurs when  
18  $HNO_3$  reacts with basic compounds, and  $NH_3$  reacts with acidic compounds. Ecosystem  
19 acidification can occur when  $HNO_3$  is deposited from the atmosphere. In addition, acidification  
20 can also occur when  $NH_x$  is deposited due to the production of  $HNO_3$  from nitrification via soil  
21 microbes. Soil acidification occurs when  $HNO_3$  or  $NH_4^+$  deposits on soils with low buffering  
22 capacity, which can cause growth limitations to sensitive plant species. Deposition of  $NO_3^-$  or  
23  $NH_4^+$  also causes eutrophication (i.e. an over-abundance of nutrients), which can promote  
24 harmful algal growth leading to the decline of aquatic species. In fact, volatilized  $NO_3^-$  can travel  
25 hundreds of miles from its source affecting local and regional biodiversity far from its origin  
26 (Aneja et al. 2008b; James, 2008).

27 The potential for reduced environmental impact from Nr in livestock systems depends on the  
28 proportion of the total intake attributable to maintenance costs. The commonly used tables for  
29 diet formulation published periodically by the National Research Council (NRC) for various  
30 animal commodities can be used to track diet formulation practices and assumptions regarding  
31 maintenance and production requirements. About one third of the energy intake recommended  
32 for growing broilers was assumed to be needed for maintenance (NRC, 1994) but protein  
33 requirements were not divided between maintenance and production. For example, a dairy cow  
34 producing 40 kg milk per annum would divert about 25% of its energy and 12% of its protein to  
35 maintenance (NRC, 1989).

36 In terms of nutritional efficiency of a herd or flock, maintenance of a productive phase (e.g.  
37 growth, lactation) also requires maintenance of a reproductive phase of the animals' life cycle.  
38 In other words, the actual nutritional maintenance cost of a herd or flock is greater than it is for  
39 productive individuals only. For example, milk production requires non-lactating cows and  
40 heifers in the herd which do not produce milk but which consume nutrients. These additional  
41 maintenance costs are lower for broiler flocks than for cattle.

1 **Finding 5**

2 There are no nationwide monitoring networks in the United States to quantify agricultural  
3 emissions of greenhouse gases, NO, N<sub>2</sub>O, reduced sulfur compounds, VOCs, and NH<sub>3</sub>. In  
4 contrast there is a large network in place to assess the changes in the chemical climate of the  
5 United States associated with fossil fuel energy production, ie the National Atmospheric  
6 Deposition Program/National Trends Network (NADP/NTN), which has been monitoring the  
7 wet deposition of sulfate (SO<sub>4</sub><sup>2-</sup>), NO<sub>3</sub><sup>-</sup>, and NH<sub>4</sub><sup>+</sup> since 1978.

8 **Recommendation 5:** *The status and trends of gases and particulate matter emitted from*  
9 *agricultural emissions, e.g., NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> should be monitored and assessed utilizing a*  
10 *nationwide network of monitoring stations. EPA should coordinate and inform its regulatory*  
11 *monitoring and management of reactive nitrogen with the multiple efforts of all agencies*  
12 *including those of the U.S. Department of Agriculture and NSF supported efforts such as the*  
13 *National Ecological Observatory Network (NEON) and the Long Term Ecological Research*  
14 *Network (LTER).*

15 *2.2.4.3. Changes in feeding practices*

16 From 1970 to 2006, several feeding practices were changed for diets fed to livestock. In 1989  
17 and 1996, the NRC introduced the idea of dividing the form of protein fed ruminants into that  
18 which is degraded by rumen microorganisms and that which passes through the rumen to be  
19 digested directly in the stomach and small intestine. Feeding ruminants with attention to rumen  
20 degraded and rumen undegraded protein decreases the amount of protein fed by 10 to 15% for a  
21 given protein requirement. For poultry and swine, manufactured amino acids were added to  
22 diets, decreasing the need for protein by 30%. Today, two amino acids (lysine and methionine),  
23 coated in a way to prevent degradation in the rumen, are sometimes added to dairy cattle diets  
24 thereby decreasing protein intake by another 15% (NRC, 2001). Phytase added to swine and  
25 poultry diets in the past decade has decreased phosphorus feeding by 20 to 50% with some of the  
26 decrease attributed to simply better understanding phosphorus requirements

27 It is difficult to estimate the combined effects of changes in feeding practices, but for  
28 calculations on changes in manure N, we assume improvements in both production rates and  
29 ration formulation. In the case of beef cattle diet formulation, the changes in feeding practices  
30 were determined by comparing the NRC 1976 recommendations with the NRC 2006  
31 recommendations. Surprisingly, NRC 1996 recommended greater total crude protein compared  
32 to NRC 1976 despite formulating for rumen degraded and un-degraded protein and considering  
33 amino acid content. Therefore, improved diet formulation did not decrease N intake for beef in  
34 this time range but the effect of reduced maintenance did improve efficiency of N utilization.

35 *2.2.4.4. Reduced nitrogen excretion from increased efficiency*

36  
37 Nitrogen excretion as fraction of animal production decreased from 1970 to 2006 (Table 6).  
38 However, in cases where the total amount of animal production in the United States increased  
39 substantially (e.g. broilers), total N excretion increased. The decrease in N excretion per unit of  
40 animal productivity was estimated by calculating the effects of changes in feeding practices and

1 reduction of maintenance as described previously. The data on Table 6 indicate that there has  
 2 been an increase in N utilization efficiency for livestock products.  
 3

4 **Table 6: Livestock N excretion per kg production (g/kg) and per total United States (Tg**  
 5 **/yr)**

Commodity*	1970		2006	
	g/kg product	Total United States	g/kg product	Total United States
<b>Milk</b>	17	0.89	11	0.92
<b>Pork, live weight</b>	57	0.56	42	0.54
<b>Broilers, live weight</b>	56	0.26	46	1.00
<b>Beef, live weight</b>	123	1.2	110	1.3

6 \*Does not include manure produced for reproduction of stock (e.g. growing dairy heifers, breeder  
 7 pigs).

8 For broilers, data are available to more accurately estimate the effect of changes in feeding and  
 9 genetics on N excretion over time. However, these data do not represent the time period of  
 10 interest in this report. Havenstein et al. (1994) compared a 1957 strain of broiler fed a 1957 diet  
 11 to a 1991 strain fed a 1991 diet. Based on the reported N intake and production data, there was a  
 12 51% reduction in N excreted between these diets (Kohn, 2004).

13 Similarly, Kohn (2004) compared N excreted by U.S. dairy cows in 1944 and 2001. In 1944, the  
 14 historically largest herd of dairy cattle in the United States (25 million cows) produced an  
 15 average of 7 kg milk per cow per day (NASS-USDA, 2007). In 2001, nine million cows  
 16 produced an average of 27 kg milk per cow per day. Assuming the cows in 1944 and 2001 were  
 17 fed according to popular feeding recommendations of the time, the N intakes were 360 and 490  
 18 g/d per cow, and N excretion rates (N intake minus N in milk) were 326 and 364 g/d per cow.  
 19 Multiplying by the number of cows in the United States, shows that total milk production  
 20 increased 40% from 52 billion kg to 73 billion kg, while N excretion decreased 60% from 3.0 Tg  
 21 N to 1.2 Tg N, respectively.

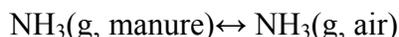
22 For Table 7, manure N was calculated for all U.S. animal agriculture using data on animal  
 23 production from the 2002 Census of Agriculture (USDA 2002). For data on livestock production  
 24 (cattle, calves, poultry, hogs, and pigs), manure was calculated by the methods of Moffit and  
 25 Lander (1999), following the exact methods they had used to compute manure from the 1997  
 26 Census of Agriculture, but using the updated information from the 2002 Census of Agriculture.  
 27 For data on production of manure from other animals (horses, goats, and sheep), the table uses  
 28 coefficients for manure excretion as a function of average animal weights and animal inventory,  
 29 taken from Battye et al. (1994).

**Table 7: Manure production from animal husbandry in the continental United States, Tg N per year 2002**

	<u>Tg N/yr</u>	<u>%</u>
<b>Cattle &amp; Calves</b>	4.35	72
<b>Poultry</b>	0.94	16
<b>Hogs &amp; Pigs</b>	0.53	9
<b>Horses, Goats &amp; Sheep</b>	0.19	3
<b>Continental United States</b>	6.02	100

#### 2.2.4.5. Volatilization of animal waste

Ammonia volatilization is highly variable and is influenced by the amount of total ammoniacal nitrogen (TAN), temperature, wind speed, pH, chemical and microbiological activities, diffusive and convective transport in the manure, and gas phase resistance in the boundary layer above the source (Arogo et al., 2006). For example, greater TAN concentrations, wind speeds, temperatures, and pH levels increase NH<sub>3</sub> volatilization. Ammonia increases linearly with TAN concentration. Higher temperatures increase NH<sub>3</sub> volatilization rates due to decreased solubility in turn affecting NH<sub>3</sub>/NH<sub>4</sub><sup>+</sup> equilibrium which follows Henry's law for dilute systems:



Ammonia-ammonium equilibrium [NH<sub>4</sub><sup>+</sup>(l) ↔ NH<sub>3</sub>(l) + H<sup>+</sup>] is affected by temperature influencing the dissociation constant K<sub>a</sub> [K<sub>a</sub> = (NH<sub>3</sub>)(H<sub>3</sub>O<sup>+</sup>)/(NH<sub>4</sub><sup>+</sup>)] and pH (Arogo et al., 2006; James, 2008). At pH 9.2 a solution contains approximately equal amounts of solution NH<sub>4</sub><sup>+</sup> and solution NH<sub>3</sub>. At pH 7.2 the solution contains approximately 99% solution NH<sub>4</sub><sup>+</sup> and 1% NH<sub>3</sub>. Thus NH<sub>3</sub> emissions are typically higher in more basic soils. Chemical equilibria dictate that an aqueous solution will hold less NH<sub>3</sub> with increasing temperature so, temperature affects solution-atmosphere NH<sub>3</sub> exchange as well (Freney et al. 1983).

EPA estimates annual manure N excreted in livestock production in the United States for the "Inventory of U.S. Greenhouse Gas Emissions and Sinks" (EPA, 2007). For the year 2002, these estimates (Appendix 3, Table A-174; EPA, 2007) indicate that a total of 6.8 Tg of N was excreted in livestock manure. Only a fraction of this N, ~1.24 Tg was recovered and applied directly as a nutrient source for crop production. Approximately 1.8 Tg N was transferred from the manure management systems, most likely by ammonia volatilization. Other loss vectors

1 include leaching and runoff during treatment, and storage and transport before soil application.  
 2 The remainder of the N was deposited in pastures and rangeland or in paddocks. This N is also  
 3 susceptible to movement into the atmosphere and aquatic systems or incorporation into soil  
 4 organic matter. By a combination of BMPs and engineered solutions it may be possible to reduce  
 5 the emissions and discharge of odors, pathogens, and nitrogen compounds from agricultural  
 6 operations (Aneja et al. 2008b,d).

7 Total manure reported in Table 7 in the contiguous United States was estimated using USDA's  
 8 method and yields an estimate of 6.0 Tg N/yr; while EPA's greenhouse gas inventory method in  
 9 Table 8 yields a total for the United States of 6.8 Tg N/yr in 2002. The 'greenhouse gas' method  
 10 suggests 13% higher manure N production. This difference highlights uncertainty in the  
 11 calculations. The values in Table 8 include Alaska and Hawaii whereas the values in Table 7 do  
 12 not; though given the small relative amount of livestock production in those states that doesn't  
 13 contribute substantially to the difference.

14 **Table 8: Fate of Livestock Manure Nitrogen (Tg N) (EPA, 2007)**

Activity	1990	1992	1994	1996	1998	2000	2002	2004
<b>Managed manure N applied to major crops</b>	1.1	1.2	1.2	1.2	1.2	1.3	1.2	1.3
<b>Manure N transferred from management systems</b>	1.5	1.6	1.6	1.6	1.7	1.7	1.8	1.7
<b>Pasture, range, &amp; paddock manure N</b>	3.0	4.0	4.1	4.2	3.9	3.8	3.8	3.7
<b>Total</b>	<b>6.6</b>	<b>6.7</b>	<b>6.9</b>	<b>7.0</b>	<b>6.9</b>	<b>6.8</b>	<b>6.8</b>	<b>6.7</b>

15

16 **Finding 6**

17 Farm-level improvements in manure management can substantially reduce Nr load and transfer.  
 18 There are currently no incentives or regulations to decrease these transfer and loads despite the  
 19 existence of management options to mitigate.

20 **Recommendation 6:** *Policy, regulatory, and incentive framework is needed to improve manure*  
 21 *management to reduce Nr load and ammonia transfer, taking into account phosphorus load*  
 22 *issues.*

23 **2.2.5 Nr inputs to residential and recreational turf systems**

24 Turf grasses cover 12.6-16.2 million ha across the continental United States (Milesi et al. 2005).  
 25 The area under turf grass is roughly the size of the New England states and occupies an area up

1 to three times larger than that of *irrigated* corn (The Lawn Institute, 2007). The majority of this  
2 turf area (approximately 75%) is in residential lawns. About 80% of all U.S. households have  
3 private lawns (Templeton et al. 1998) that average 0.08 ha in size (Vinlove and Torla, 1995).  
4 Another approximately 15 % of total turf grass area is in low maintenance parks and  
5 approximately 10% is in athletic fields and golf courses, which often receive higher levels of N  
6 application due to hard use conditions.

7 Supplemental N fertilization is often necessary to maintain healthy and aesthetically pleasing turf  
8 color, high shoot density and the ability to resist and recover from stress and damage. Nitrogen  
9 also may be derived from atmospheric deposition or recycled decomposition of soil and grass  
10 clipping organic matter. Whether these inputs are sufficient to maintain lawns of adequate  
11 quality depends on many factors including age of the turf, uses, and expectations or goals of the  
12 homeowner or field manager. Also, turf grasses are used to stabilize soil, often with an erosion  
13 prevention matrix such as organic mats or with hydroseeding. Depending on circumstances,  
14 these turf uses may be temporary until natural vegetation succeeds the turf, or may be low  
15 maintenance turfs that are seldom fertilized such as highway medians and shoulders, grassy  
16 swales and buffers.

17 Turf grass is maintained under a variety of conditions. Approximately 50% of all turf grass is  
18 not fertilized, while the remainder is fertilized at varied intensities (Petrovic, personal  
19 communication—June 5 2007). The committee has arrayed the different turf managements into  
20 three groups according to the estimated amount of N-fertilizer applied annually (Table 9),  
21 residential lawns maintained by homeowners (0.73 kg/100 m<sup>2</sup>), residential lawns cared for by  
22 professional lawn care companies (2.92 (range, 1.95-7.3) kg/100 m<sup>2</sup>), and athletic fields and golf  
23 courses (3.89 (range, 2.64-6.64) kg/100 m<sup>2</sup>). The estimate of total N-fertilizer used on turf grass  
24 in the United States is 1.1 Tg N/year, or 9% of the total average annual N-fertilizer used between  
25 1999 and 2005. Depending on land use patterns, certain areas of the country, particularly coastal  
26 areas where residential and urban properties prevail, turf fertilizer can be an important or even  
27 dominant source of nitrogen to surface waters.

28 Turf fertilizer N is susceptible to losses to the atmosphere, and surface and ground water when it  
29 is not properly managed. Research on lawns has shown that leaching of NO<sub>3</sub> can range between  
30 0 and 50% of N applied (Petrovic, 1990). Nitrogen leaching losses can be greatly decreased by  
31 irrigating lightly and frequently, using multiple and light applications of fertilizers, fertilizing at  
32 the appropriate times, especially not too late in the growing season, and using soil tests to ensure  
33 proper balance of non-N soil condition and pH. In a soil column experiment with turf coverage,  
34 the percentage of N leached (as percentage of nitrogen applied) varied from 8 to 14% using light  
35 irrigation and from 2 to 37% with heavy irrigation.

36 Applying fertilizer in appropriate amounts, avoiding periods when grass is dormant, and not  
37 fertilizing too soon before irrigation or large rainfall events can all help ensure leaching and  
38 runoff will be minimal without affecting turfgrass color and growth (Mangiafico and Guillard,  
39 2006).

40 Nitrogen runoff losses are poorly quantified but a range similar to leaching is probable (Petrovic,  
41 personnel communication). The chemical form of fertilizer N does not impact leaching/runoff

1 unless it is applied in late autumn (Petrovic, 2004), although use of slow release or organic  
 2 fertilizers can help reduce runoff and leaching. Shuman (2002) notes that runoff can be limited  
 3 by applying minimum amounts of irrigation following fertilizer application and avoiding  
 4 application before intense rain or when soil is wet. Losses of Nr to the atmosphere can be  
 5 significant when urea is applied. Measured denitrification losses are usually small, but depend  
 6 upon timing of N application relative to soil water status, irrigation and temperature. Typically  
 7 25% of N applied is not accounted for in runoff, leaching, and uptake/removal, or soil  
 8 sequestration (Petrovic, personnel communication), which suggests that volatilization and  
 9 denitrification are important loss vectors. Nitrogen volatilization (Kenna, 2008, CAST Book)  
 10 rates ranged from 0.9% under light irrigation to 2.3% under heavy irrigation.

11 While under-fertilization can lead to reduced grass stand and weed encroachment which results  
 12 in more leaching and runoff N losses than from well managed lawns (Petrovic, 2004; Petrovic  
 13 and Larsson-Kovach, 1996), Guillard (2006) recommends not fertilizing lawns of acceptable  
 14 appearance. Further, prudent fertilization practices may include using one-third to one-half (or  
 15 less) of the recommended application rate, i.e., application rates below 0.5 kg/100m<sup>2</sup>, and  
 16 monitoring response (Guillard, 2006). Less or no fertilizer may produce acceptable lawns,  
 17 especially once the lawn has matured, provided clippings are returned and mowing length is left  
 18 high.

19 As noted above, according to Petrovic (personal communication) half the lawns may not receive  
 20 any fertilizer. Those lawns are presumably satisfactory to their owners. Further N reductions can  
 21 be made if white clover is incorporated into turf and grasses such as fescues are selected for  
 22 amenable parts of the country, which require little or no N supplements once mature. These  
 23 practices can potentially reduce N fertilization (and subsequent leaching risk) on turf by one third  
 24 or more, saving 0.4 or more Tg N/year. When properly managed, turf grass provides a variety of  
 25 services that include decreasing runoff, sequestering carbon dioxide, and providing a  
 26 comfortable environment in which to live (Beard and Green, 1994).

27 **Table 9: Estimate of Fertilizer N used on turf grass in the United States in the year 2000,**  
 28 **based on a total area of 12.6 million ha.**

Type of Turf Fertilized	Area (Million ha)	N rate (kg/ha/yr)*	Total N Used (Tg/yr)
Nominal Fertilization	4.7	73	0.35
Professional Lawn Care	0.93	296 (195-488)	0.27
High Maintenance Areas (golf/sports)	1.26	390	0.49
<b>Total</b>	<b>6.89</b>	--	<b>1.11</b>

29 \*1000 m<sup>2</sup>/ha, used values of 0.73, 2.92 and 3.89 kg N/100 m<sup>2</sup>

30 In recent years, about 11Tg of fertilizer N /year was used in the United States. The above

1 numbers convert to 1.1 Tg/year of N being used on turf (roughly 10% of U.S. Total)

## 2 **Finding 7**

3 Synthetic N fertilizer application to urban gardens and lawns amounts to approximately 10% of  
4 the total annual synthetic N fertilizer used in the United States. Even though this N represents a  
5 substantial portion of total N fertilizer use, the efficiency with which it is used receives relatively  
6 little attention.

7 **Recommendation 7a:** *To ensure that urban fertilizer is used as efficiently as possible, the*  
8 *committee recommends that EPA work with other agencies such as USDA as well as state and*  
9 *local extension organizations to coordinate research and promote awareness of the issue.*

10 **Recommendation 7b:** *Through outreach and education, supported by research, improved turf*  
11 *management practices should be promoted, including improved fertilizer application and*  
12 *formulation technologies and maintenance techniques that minimize supplemental Nr needs and*  
13 *losses, use of alternative turf varieties that require less fertilization, alternative ground covers in*  
14 *place of turf, and use of naturalistic landscaping that focuses on native species.*

15

## 16 **2.3. Nr transfer and transformations in and between environmental systems**

17 This chapter discusses the transfers and flows of Nr within and between environmental systems  
18 (ES) which include atmosphere, terrestrial, and aquatic environments. The first section (2.3.1)  
19 contains information on Nr deposition from the atmosphere to terrestrial and aquatic systems,  
20 presents estimates of input and recycling of Nr within terrestrial systems, and discusses  
21 movement of Nr from the terrestrial to the aquatic system. The second section (2.3.2) presents  
22 an estimate of storage of Nr within the terrestrial system. The input and transfers of Nr within 16  
23 northeast U.S. watersheds is discussed in Section 2.3.3. Within the nitrogen cascade there are a  
24 number of places where the flow of Nr is constrained or regulated. In the final section (2.3.4) a  
25 list of critical information needs is presented.

### 26 **2.3.1 Input and transfers of Nr in the United States**

27 This section contains discussions on inputs and transfers between and within environmental  
28 systems. First Nr deposition from the atmosphere to earth's surface is considered. Second is  
29 input and transfer of Nr within terrestrial systems, and finally the transfer of Nr into aquatic  
30 systems is discussed.

#### 31 *2.3.1.1 Nitrogen deposition from the atmosphere to the earth's surface*

32 *Introduction.* Atmospheric input contributes substantially to the Nr content of terrestrial and  
33 aquatic ecosystems for the United States, but the magnitude and mechanisms of Nr deposition to  
34 the Earth's surface remain major unanswered environmental questions. "Along the eastern U.S.  
35 coast and eastern Gulf of Mexico, atmospheric deposition of N currently accounts for 10% to  
36 over 40% of new N loading to estuaries" (Paerl et al., 2002). Other watershed contribution  
37 estimates range widely throughout the United States, depending on size of the watershed related  
38 to the size of the estuary, and the magnitude of contributing sources of atmospheric N

1 enrichment. Valigura et al. (2001) identified a median atmospheric nitrogen contribution of about  
2 15% for 42 watershed located throughout the United States, although the maximum estimate was  
3 60%.

4  $\text{NO}_x$ ,  $\text{NH}_3$  and their reaction products not deposited onto the continent are generally lofted into  
5 the free troposphere where they can have a wide range of influence and, in the case of  $\text{NO}_x$ ,  
6 because of nonlinearities in the photochemistry, generate substantial amounts of tropospheric  
7 ozone (EPA, 2006). Total N deposition involves both gases and particles, and both dry and wet  
8 (in precipitation) processes. Rates of deposition for a given species (in units of mass of N per  
9 unit area per unit time) can be measured directly, inferred from mass balance of the atmospheric  
10 budget, or modeled numerically, but substantial uncertainties remain with each of these  
11 techniques when applied to deposition of any Nr species. A portion of the Nr deposited to the  
12 earth's surface is re-emitted as  $\text{NH}_3$ , NO, or  $\text{N}_2\text{O}$  (Civerolo and Dickerson, 1998; Crutzen et al.,  
13 2008; Galbally and Roy, 1978; IPCC, 2007; Kim et al., 1994). Although naturally-produced Nr  
14 is involved, anthropogenic Nr dominates over most of the United States. In this section we  
15 review the state of the science concerning the total annual Nr deposition and trends in that  
16 deposition to the contiguous 48 states.

17 Deposition involves both oxidized and reduced N species. Of the oxidized forms of atmospheric  
18 N, all the members of the  $\text{NO}_y$  family ( $\text{NO}$ ,  $\text{NO}_2$ ,  $\text{NO}_3$ ,  $\text{N}_2\text{O}_5$ , HONO,  $\text{HNO}_3$ ,  $\text{NO}_3^-$ , PAN and  
19 other organo-nitrates,  $\text{RONO}_2$ ) can be transferred from the troposphere to the surface, and some  
20 undergo bidirectional flux, e.g., NO. Note that volatile amines are also detected as  $\text{NO}_y$   
21 compounds (Kashihira et al., 1982; Wyers et al., 1993). Although a potent greenhouse gas,  $\text{N}_2\text{O}$   
22 is only emitted, not deposited and therefore will not be considered here. Of the reduced forms of  
23 atmospheric nitrogen,  $\text{NH}_3$  and  $\text{NH}_4^+$  play a major role. There is also evidence of deposition of  
24 organic N such as amino acids and isoprene nitrates, and recent observations suggest that these  
25 can account for ~10% (possibly as much as 30%) of the U.S.  $\text{NO}_x$  budget, especially in summer  
26 (Duce et al., 2008; Horowitz et al., 2007; Keene et al., 2002; Sommariva, 2008). While this is a  
27 worthy research topic, measurements are still limited and deposition of organic N compounds  
28 will not be reviewed here. The wide array of relevant atmospheric compounds makes direct  
29 measurement, and accurate load quantification challenging.

30 The six principal (or *criteria*) pollutants for which EPA has established national ambient air  
31 quality standards (NAAQS) includes "oxides of nitrogen" or  $\text{NO}_x$ . The specific chemical  
32 compound nitrogen dioxide ( $\text{NO}_2$ ) has been selected as the indicator for compliance with the  
33 NAAQS for  $\text{NO}_x$ . The levels of primary and secondary standards for  $\text{NO}_2$  are identical at 0.053  
34 ppm (approximately  $100 \mu\text{g}/\text{m}^3$ ) in annual arithmetic average, calculated from the 1-h  $\text{NO}_2$   
35 concentrations. A recent ISA ) evaluated the scientific foundation for the review of the  
36 secondary (welfare-based) NAAQS for oxides of nitrogen and concluded that:

37  
38 The instrumentation deployed at present in the routine monitoring networks  
39 for determination of gas-phase  $\text{NO}_2$  and  $\text{SO}_2$  concentrations is likely adequate  
40 for determining compliance with the current NAAQS. But in application for  
41 determining environmental effects, all these methods have important  
42 limitations, which make them inadequate for fully characterizing the state of  
43 the atmosphere at present, correctly representing the complex heterogeneity of

1 N and S deposition across the landscape, and for realistically apportioning the  
 2 contributions of reduced and oxidized forms of atmospheric N and S in  
 3 driving observed biological effects at a national scale.  
 4

5 In terms of forming an integrated policy for protecting the environment from adverse effects of  
 6 reactive nitrogen, is appropriate to consider whether the existing criteria pollutants are  
 7 sufficiently inclusive of Nr species.

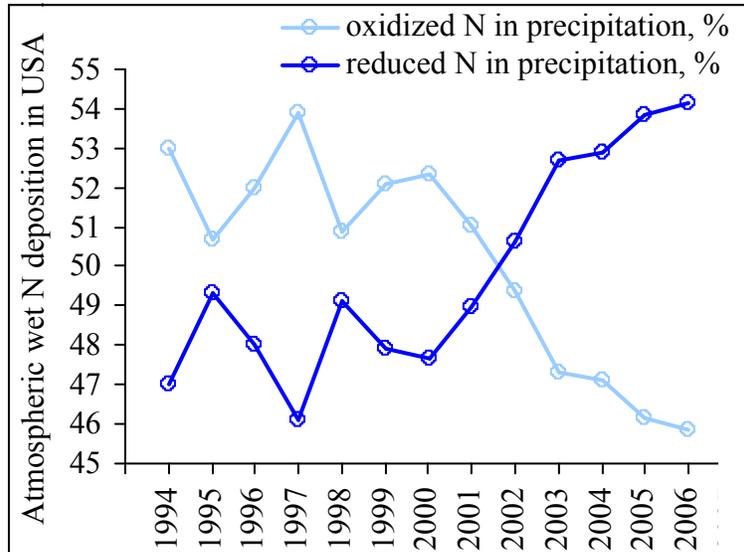
8 *Review of Nr wet deposition.* Substantial progress has been made in monitoring wet deposition,  
 9 as is summarized by the National Atmospheric Deposition Program/National Trends Network  
 10 (NADP), established in 1979, which monitors precipitation composition at over 250 sites in the  
 11 United States and its territories (<http://nadp.sws.uiuc.edu>). Precipitation at each station is  
 12 collected weekly according to well established and uniform procedures from which it is sent to  
 13 the Central Analytical Laboratory for analysis of acidity,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ , chloride, as well as the  
 14 base cations calcium, magnesium, potassium and sodium. For greater temporal resolution, the  
 15 Atmospheric Integrated Research Monitoring Network AIRMON, comprised of seven sites, was  
 16 formed in 1992 as part of the NADP program to study wet deposition composition and trends  
 17 using samples collected daily. The same species are measured as in NADP. By interpolating  
 18 among sites, NADP is able to estimate the wet deposition of  $\text{NH}_4^+$  (reduced N), and  $\text{NO}_3^-$   
 19 (oxidized N) for the 48 contiguous states (Table 10 and Figure 12).

20 **Table 10: Annual wet deposition of reduced ( $\text{NH}_4^+$ ), oxidized ( $\text{NO}_3^-$ ), and total N to the 48**  
 21 **contiguous states, from the NADP/National Trends Network (NTN)**

22 <http://nadp.sws.uiuc.edu>

<b>NADP/NTN deposition estimates</b>			
	reduced N in precipitation, kg/ha/yr	oxidized N in precipitation, kg/ha/yr	total wet N deposition, kg/ha/yr
1994	1.49	1.68	3.17
1995	1.63	1.67	3.30
1996	1.66	1.80	3.45
1997	1.49	1.74	3.24
1998	1.72	1.78	3.49
1999	1.46	1.58	3.04
2000	1.48	1.62	3.10
2001	1.50	1.57	3.07
2002	1.59	1.55	3.14
2003	1.72	1.55	3.27
2004	1.70	1.52	3.22
2005	1.65	1.41	3.06
2006	1.65	1.40	3.05

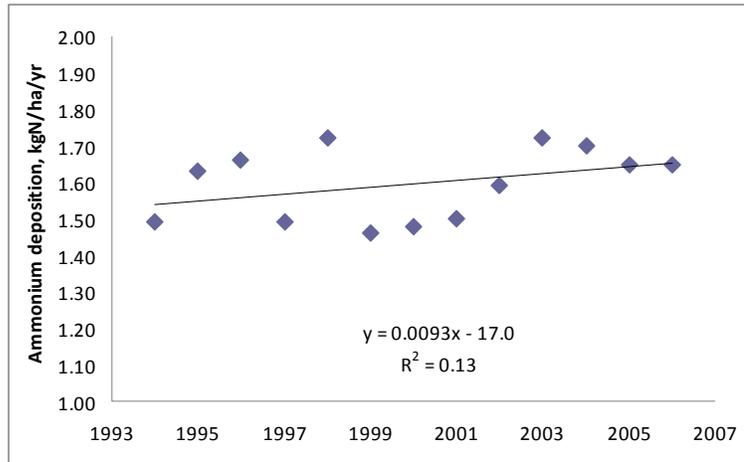
1 **Figure 12: Percent change in relative contribution of oxidized ( $\text{NO}_3^-$ ) and reduced ( $\text{NH}_4^+$ )**  
 2 **nitrogen wet deposition from 1994 to 2006. As emissions of  $\text{NO}_x$  have decreased, the**  
 3 **relative importance of  $\text{NH}_x$  has increased.**



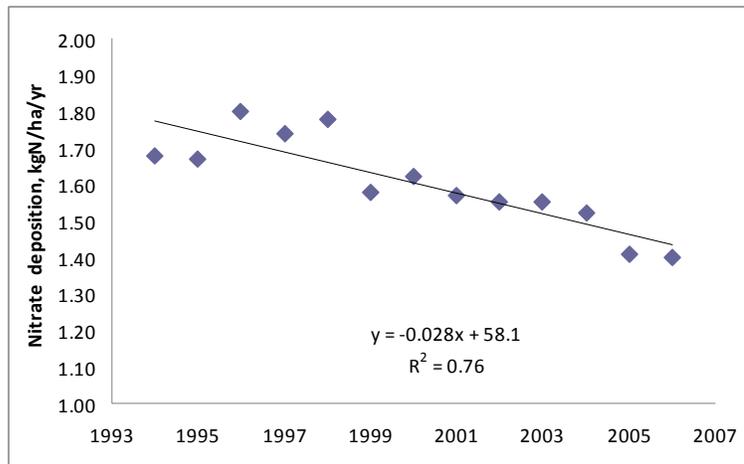
4  
5  
6 Although individual regions vary, the NADP data for the entire 48 states indicate an apparent  
 7 decrease in  $\text{NO}_3^-$  wet deposition, but not in  $\text{NH}_4^+$  deposition (Table 10 and Figure 13).  
 8 Ammonium wet deposition shows a weak increase, although the correlation coefficient is small.  
 9 As  $\text{NO}_x$  controls have become more effective, the role of reduced N appears to have grown in  
 10 relative importance. The nitrate data appear to show a statistically significant trend and  
 11 quantifying the response of deposition to a change in emissions would be useful to both the  
 12 scientific and policy communities. A notable reduction in power plant  $\text{NO}_x$  emissions occurred  
 13 as the result of the  $\text{NO}_x$  State Implementation Plan (SIP) call (Bloemer et al., 2009; Gilliland et  
 14 al., 2008; McClenny et al., 2002). EPA should pursue a rigorous analysis of the emissions and  
 15 deposition data, including identifying monitors and methods that are consistent from the  
 16 beginning to the end of the record, as indicated in Recommendation 8.

1 **Figure 13: Trend in reported wet deposition of  $\text{NH}_4^+$  and  $\text{NO}_3^-$  for the 48 contiguous**  
 2 **states; data were taken from NADP.**

3 Note the sampling methods and locations have not been tested for temporal or spatial bias.



4



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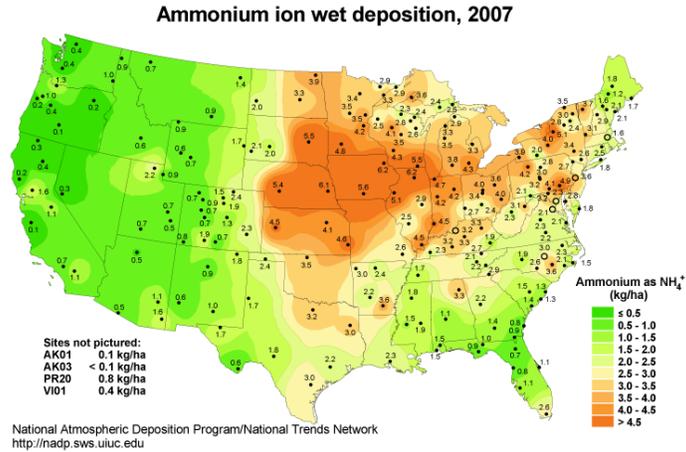
7 *How is  $N_r$  deposition related to emissions?* The relationship between emissions of  $N_r$  and  
 8 observed deposition is critical for understanding the efficacy of abatement strategies as well as  
 9 for partitioning local and large-scale effects of emissions. Only a few studies covering several  
 10 individual sites have sufficient monitoring consistency and duration to determine rigorously  
 11 long-term trends in  $\text{NO}_3^-$  and  $\text{NH}_4^+$  and their relationship to emissions, and here we consider  
 12 several examples (Butler et al., 2005; Kelly et al., 2002; Likens et al., 2005). These sites tend to  
 13 be in the eastern United States where monitoring is more concentrated and has a longer history  
 14 and where upwind sources and downwind receptors are relatively well known. Examination of  
 15 these studies reveals that concentrations of gaseous and particulate N species in the atmosphere,  
 16 as well as the  $N_r$  content of precipitation over the eastern United States shows significant  
 17 decreases. Correlation with regional emissions is stronger than with local emissions, in keeping

1 with the secondary nature of the major compounds –  $\text{NO}_3^-$  and  $\text{NH}_4^+$ . Decreases in  $\text{NH}_4^+$   
2 concentration and wet deposition are attributed to decreases in  $\text{SO}_4^{2-}$  concentrations meaning that  
3 more of the reduced Nr remains in the gas phase. For the period 1965 to 2000,  $\text{NO}_3^-$  levels in  
4 bulk deposition correlate well with reported  $\text{NO}_x$  emissions. For shorter and earlier time periods  
5 the correlation is weaker, and the authors attribute this to changes in the EPA's methods of  
6 measuring and reporting emissions; they find evidence of continued errors in emissions from  
7 vehicles. Decreases in deposition will probably not be linearly proportional to decreases in  
8 emissions; for example a 50% reduction in  $\text{NO}_x$  emissions is likely to produce a reduction of  
9 about 35% in concentration and deposition of nitrate.

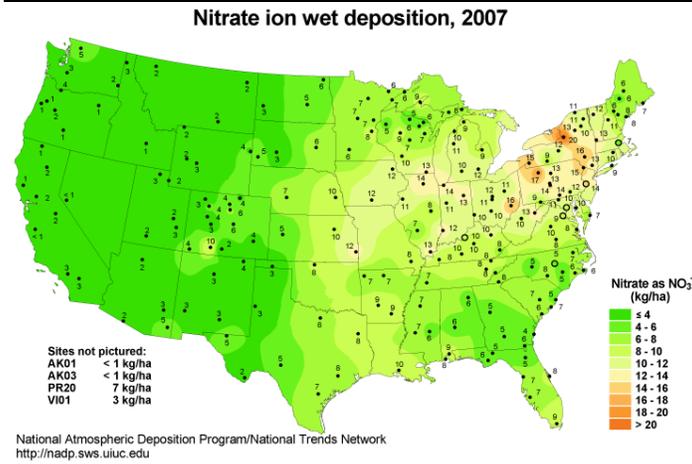
10 The relationship between chemically reduced N emissions and deposition is more complex. The  
11 maps of ammonium deposition (Figure 14) show that maxima occur near or downwind of major  
12 agricultural centers where emissions should be high. The full extent of the deposition record (see  
13 <http://nadp.sws.uiuc.edu/amaps2/>) show the large intensification of  $\text{NH}_4^+$  wet deposition in  
14 selected areas. The southeastern United States, particularly North Carolina, has seen a long-term  
15 rise (Aneja et al., 2000; Aneja et al., 2003; Stephen and Aneja, 2008). The increase in deposition  
16 coincides with the increase in livestock production, but a swine population moratorium appears  
17 to have helped abate emissions (Stephen and Aneja, 2008). Concentrations of aerosol  $\text{NH}_4^+$  have  
18 decreased in many parts of the country, and this may appear to contradict the trend in wet  
19 deposition, but a decrease in condensed phase  $\text{NH}_4^+$  will be accompanied by an increase in vapor  
20 phase  $\text{NH}_3$  if  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  concentrations decrease; see <http://vista.cira.colostate.edu/improve/>.  
21 This potentially misleading information highlights the need for measurements of speciated  $\text{NH}_x$   
22 (Sutton et al., 2003).

1

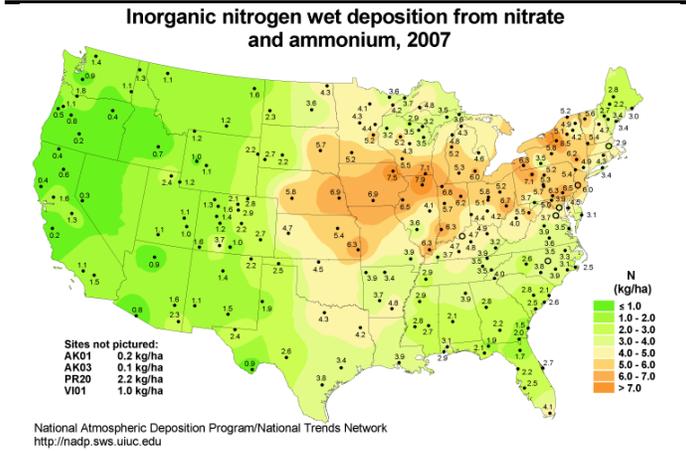
2 **Figure 14: Annual  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ , and total inorganic N deposition for the year 2007 showing**  
 3 **spatial patterns of deposition. <http://nadp.sws.uiuc.edu/amaps2/>**



4



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1

2 *Review of dry deposition observations for the eastern United States.* Monitoring dry deposition  
 3 presents a greater challenge than monitoring wet deposition. The Clean Air Standards and  
 4 Trends Network (CASTNET) and Atmospheric and Integrated Research Monitoring Network  
 5 (AIRMON) were established to monitor chemical and meteorological variables to infer dry  
 6 deposition in order to study the processes leading from emissions to atmospheric concentrations  
 7 and through deposition to ecosystem effects. AIRMON dry deposition monitoring was  
 8 discontinued in 2003. See <http://www.epa.gov/castnet/>,  
 9 <http://www.arl.noaa.gov/reserach/programs/airmon.html>, and <http://nadp.sws.uiuc.edu>.

10 Recent reviews (Sickles and Shadwick, 2007a; Sickles and Shadwick, 2007b) analyze the  
 11 seasonal and regional behavior of concentration and deposition of a variety of primary and  
 12 secondary pollutants including reactive N and investigated trends from 1990 to 2004 for the  
 13 United States east of the Mississippi River. The investigators evaluated observations from more  
 14 than 50 sites in the eastern States and concluded that for 2000-2004, the mean annual total  
 15 measured N deposition for this area was 7.75 kg N per hectare per year (expressed as kg  
 16 N/ha/yr); see Table 11. This value includes vapor phase HNO<sub>3</sub>, particulate NO<sub>3</sub><sup>-</sup>, and NH<sub>4</sub><sup>+</sup>; it  
 17 does not include deposition of other oxidized species such as NO<sub>x</sub> and PAN, nor gas-phase  
 18 reduced N species most notably NH<sub>3</sub>. The measured deposition rates peak in spring and  
 19 summer, but unaccounted for ammonia deposition is probably a substantial fraction of the total,  
 20 and the true annual cycle remains uncertain.

21 **Table 11: Deposition of N to the eastern United States in units of kg N/ha/yr\***

	Annual deposition kg N/ha/yr
Dry NH <sub>4</sub> <sup>+</sup>	0.41
Wet NH <sub>4</sub> <sup>+</sup>	2.54
Dry HNO <sub>3</sub> + NO <sub>3</sub> <sup>-</sup>	1.88
Wet NO <sub>3</sub> <sup>-</sup>	2.92
<b>Total measured N Dep.</b>	<b>7.75</b>
Est. dry other NO <sub>y</sub>	0.94
Est. dry NH <sub>3</sub>	1.90
Est. total NO <sub>y</sub>	5.74
Est. total NH <sub>3</sub> + NH <sub>4</sub> <sup>+</sup>	4.85
<b>Est. Grand Total</b>	<b>10.59</b>

22

1 \*Data are from the U.S. CASTNET program for the period of 2000-2004. Monitored species for  
2 34 sites east of the Mississippi include vapor-phase  $\text{HNO}_3$ , particulate  $\text{NO}_3^-$ , and  $\text{NH}_4^+$ ;  
3 unmonitored are other oxidized species such as  $\text{NO}_x$  and PAN and gas-phase reduced N species  
4 most notably  $\text{NH}_3$  (Sickles and Shadwick, 2007a). For an explanation of how deposition of  
5 unmeasured species was estimated see text.

6 *Estimated total N deposition to the eastern United States.* CASTNET monitors  $\text{HNO}_3$  and  $\text{NO}_3^-$ ,  
7 but not other members of the  $\text{NO}_y$  family – notably  $\text{NO}_x$ . Dennis (EPA, 2007) estimated that the  
8 unmeasured  $\text{NO}_y$  species account for about 50% of the dry deposition of nitrates. Half of 1.88  
9 (see Table 11) is 0.94 kg N /ha/yr. Ammonia is also unmeasured by CASTNET, and model  
10 estimates (Mathur and Dennis, 2003) of  $\text{NH}_3$  indicate that dry deposition should account for  
11 75% of wet  $\text{NH}_4^+$  deposition; 75% of 2.54 is 1.9 kg N /ha/yr. Adding these two values to the  
12 total from Table 11 yields a reasonable estimate, within about  $\pm 50\%$  absolute accuracy, of total  
13 deposition of about 10.6 kg N /ha/yr for the eastern United States.

14 *Characteristics of N deposition to the eastern United States.* A more complete analysis of the  
15 seasonality, oxidation pathways, thermodynamics, phase partitioning, relative roles of wet and  
16 dry deposition, spatial distribution, is provided in Appendix 4.C and will be only briefly reviewed  
17 here. Warmer temperatures are conducive to release of  $\text{NH}_3$  from soils and manure as well as  
18 from atmospheric particles, thus ammonia concentrations are typically highest in summer.  
19 Diffusion of gases is faster than diffusion of particles, and dry deposition of vapor-phase N is  
20 faster as well; for example the mean CASTNET reported  $\text{HNO}_3$  deposition velocity is 1.24 cm/s  
21 while that for particulate  $\text{NO}_3^-$  is 0.10 cm/s. In 2003 and 2004 substantial reductions in  
22 emissions from electric generating units (power plants) were implemented under the  $\text{NO}_x$  State  
23 Implementation Plan (SIP) call. Many of these power plants are located along the Ohio River  
24 generally upwind of the measurement area. Significant reductions ( $p = 0.05$ ) were found  
25 between the 1990-1994 and 2000-2004 periods (Sickles and Shadwick, 2007a).

26 *Uncertainty in measured deposition.* Analysis of uncertainties in the deposition of N is  
27 challenging. The coefficient of variation for total, regional N deposition for 2000-2004 is 23%,  
28 representing a minimal value of uncertainty. Concentrations of some of the  $\text{NO}_y$  species are  
29 monitored, as is the wet deposition of major oxidized and reduced N species, but concentrations  
30 of ammonia and other N species are not monitored. The network for monitoring dry deposition  
31 is sparse and has not been evaluated for spatial bias. The monitors are located in flat areas with  
32 uniform surfaces – advective deposition into for example the edges of forests are estimated to  
33 contribute substantially to the uncertainty (Hicks, 2006). Other sources of error include the  
34 model used to convert weekly average concentrations and micrometeorological measurements  
35 into depositions. Precision can be determined from collocated sites and is estimated at 5% for  
36 nitrate and 15% for ammonium in precipitation (Nilles et al., 1994). The uncertainty in  
37 estimated dry deposition arises primarily from uncertainty in deposition velocities (Brook et al.,  
38 1997; Hicks et al., 1991) and can be as high as 40% for  $\text{HNO}_3$ . Total uncertainty for deposition  
39 of N based on measurements is at least 25% and may be as high as 50%.

40 *Deposition estimates from numerical models.* The EPA Community Multiscale Air Quality  
41 model (CMAQ) was run for North America at 36 km resolution (R. Dennis et al., personal  
42 communication January 2008)\*. Simulation of N deposition is hampered by the lack of

1 emissions information (especially for NH<sub>3</sub>) by the need to parameterize PBL dynamics and deep  
 2 convection, as well as by simplified multiphase chemistry. This run of CMAQ did not account  
 3 for NO<sub>x</sub> emissions from marine vessels, and these amount to about 4% of the total NO<sub>x</sub>  
 4 emissions in 2000. Calculated nitrogen deposition for the 48 contiguous states (Table 12) was  
 5 broadly consistent with direct measurements (Table 11). CMAQ NO<sub>x</sub> emissions were 5.84 Tg N  
 6 for the year 2002; of that 2.74 Tg N were deposited. This suggests that ~50% was exported – a  
 7 number somewhat higher than has been reported in the literature; this discrepancy is discussed  
 8 below.

9 **Table 12: Results from CMAQ\* for total deposition in 2002 to the 48 contiguous states of**  
 10 **oxidized and reduced N.**

	kg N/ha/yr	Tg N/yr
<b>Oxidized N</b>	3.51	2.74
<b>Reduced N</b>	2.66	2.07
<b>Total N Depos.</b>	6.17	4.81

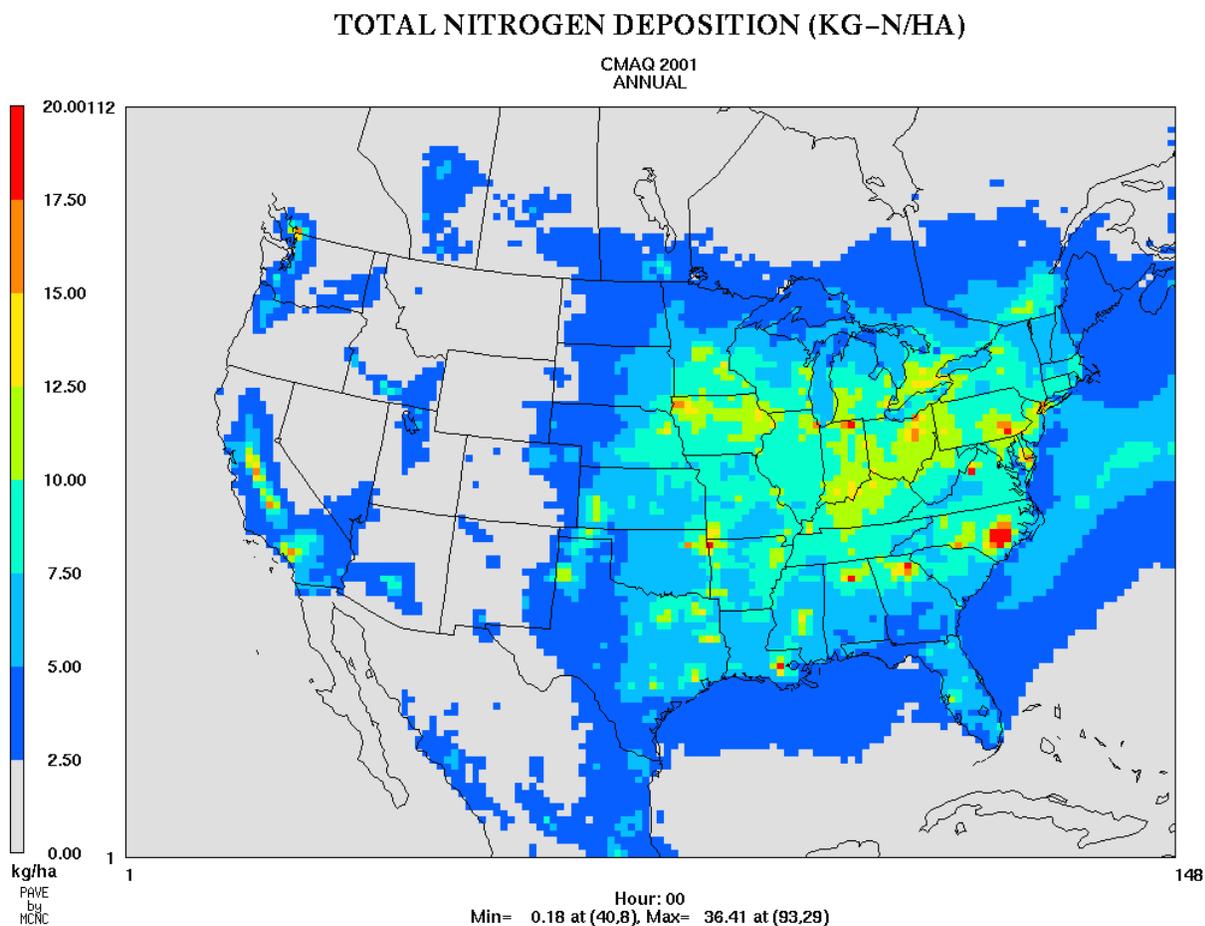
11

12 \*The CMAQ results were adapted from: Schwede, D., R. Dennis, M. Bitz. (in review). The  
 13 Watershed Deposition Tool: A tool for incorporating atmospheric deposition in water-quality  
 14 analyses, submitted to *Journal of the American Water Resources Association* 2009.  
 15 (<http://www.epa.gov/amad/EcoExposure/depositionMapping.html>)

16 Ammonia emissions and ambient concentrations can be measured, but are not routinely  
 17 monitored. For Nr, the CMAQ numerical simulation employed inverse modeling techniques –  
 18 that is NH<sub>3</sub> emissions were derived from observed NH<sub>4</sub><sup>+</sup> wet deposition (Gilliland et al., 2006;  
 19 Gilliland et al., 2003; Mathur and Dennis, 2003). Model determinations therefore do not provide  
 20 an independent source of information on NH<sub>4</sub><sup>+</sup> deposition.

21 The three-year CMAQ run gives an indication of the spatial pattern of deposition (Figures 15).  
 22 For NH<sub>x</sub>, wet and dry are equally important, but for NO<sub>y</sub>, dry deposition accounts for about 2/3  
 23 of the total deposition while wet deposition accounts for about 1/3. For NH<sub>x</sub>, wet and dry are  
 24 equally important, but for NO<sub>y</sub>, dry deposition is greater than wet. While this is not true for the  
 25 eastern United States it is true for the United States as a whole; in arid southern California, for  
 26 example, dry deposition of Nr dominates. Based on CMAQ, total NO<sub>y</sub> deposition is 2.79 times  
 27 the wet deposition and total NH<sub>x</sub> deposition is 1.98 times the wet deposition. Using the data  
 28 from Table 10 for the average wet deposition for the period 2000- 2004, total deposition of  
 29 oxidized N is 4.36 kg N /ha/yr (2.79 \* 1.56 = 4.36). The total deposition for reduced N is 3.17  
 30 kg N /ha /yr (1.98 \* 1.60). The grand total (wet and dry oxidized and reduced) is then about 7.5  
 31 kg N /ha /yr.

**Figure 15: CMAQ annual average (wet plus dry and oxidized plus reduced) nitrogen deposition (in kg-N /ha/yr) across the United States based on 3 years of differing meteorology - one dry, one wet, and one average precipitation year - across the Eastern United States (Source: EPA, 2007).**



The model has highly simplified organic N deposition. Note these values reflect emissions before the NO<sub>x</sub> SIP-call which resulted in substantial reductions in NO<sub>x</sub> emissions from point sources over the eastern United States.

For comparison purposes, a collection of Chemical Transport Models (CTM's) (Dentener et al., 2006) yielded total (wet plus dry) deposition to the whole United States of about 3.9 Tg N /yr oxidized N<sub>r</sub> and 3.0 Tg N /yr ammoniacal N for current emissions. The fate of NO<sub>x</sub> is assumed to be primarily HNO<sub>3</sub> or aerosol NO<sub>3</sub> ; organic N species are generally not modeled in detail. Because this analysis includes Alaska, a better estimate for NO<sub>x</sub> for the 48 contiguous states is 4.6 Tg N /yr. The variance among models was about 30% (one σ) for deposition fluxes in regions dominated by anthropogenic emissions. Globally, the calculations from the ensemble of 23 CTM's estimated 36-51% of all NO<sub>y</sub> and NH<sub>x</sub> emissions are deposited over the ocean. This

1 load could be important to estuarine N loading estimates as offshore N is carried inshore by  
2 currents or through advective processes.

3 *Deposition estimates from mass balance.* From estimated total emissions of Nr compounds and  
4 observed or simulated export a reasonable estimate of rate of deposition can be obtained by mass  
5 balance – deposition equals emissions minus export. A more complete analysis is presented in  
6 Appendix 4.C. Although substantial uncertainty (about a factor of two) exists for the emissions  
7 of NH<sub>3</sub>, NO<sub>x</sub> release is reasonably well known. In general, advection in the boundary layer and  
8 lofting through convection followed by export at higher altitudes are the two main mechanisms  
9 that prevent removal of NO<sub>y</sub> and NH<sub>x</sub> by deposition to the surface of North America (Li et al.,  
10 2004; Luke et al., 1992).

11 Experimental observations have been conducted over the eastern United States for more than two  
12 decades (Galloway et al., 1988; Galloway and Whelpdale, 1987; Galloway et al., 1984; Luke and  
13 Dickerson, 1987). Most recent estimates (Dickerson et al., 1995; Li et al., 2004; Parrish et al.,  
14 2004b) (Hudman et al., 2007), agree that annually 7 - 15% of the emitted NO<sub>x</sub> is exported in the  
15 lower to mid-troposphere.

16 CTM's derived small export values – on the order of 30% of the total NO<sub>x</sub> emitted into the lower  
17 atmosphere (Doney et al., 2007; Galloway et al., 2004; Holland et al., 1997; Holland et al., 2005;  
18 Horowitz et al., 1998; Kasibhatla et al., 1993; Liang et al., 1998; Park et al., 2004; Penner et al.,  
19 1991). Reviewed publications using the mass balance approach have substantial uncertainty but  
20 indicate with some consistency that 25-35% of the NO<sub>y</sub> emitted over the United States is  
21 exported.

22 *Comparison of models and measurements of oxidized N deposition.* Both ambient measurements  
23 and numerical models of NO<sub>y</sub> have reached a level development to allow reasonable estimates of  
24 deposition. For reduced nitrogen, neither ambient concentrations nor emissions are known well  
25 enough to constrain models. Appendix 4.C. summarizes published research on NO<sub>y</sub> export and  
26 deposition. Recent model estimates of the U.S. N budget are reasonably uniform in finding that  
27 about 25-35% of total NO<sub>x</sub> emissions are exported.

28 Results from CMAQ runs, described above, indicate that of the NO<sub>x</sub> emitted over the continental  
29 United States, 50% is deposited and 50% is exported. This is within the combined error bars of  
30 other studies, but well under the best estimate of 70% deposition. One possible source of this  
31 discrepancy is underestimate of deposition of organo-nitrogen compounds. The chemical  
32 mechanism used in CMAQ was highly simplified – only about 2-3% of the total Nr deposition  
33 can be attributed to organo-nitrogen compounds (R. Dennis personal communication, 2008).  
34 Ammonia from fossil fuel combustion while important locally, is probably a small component of  
35 national Nr deposition (see Appendix 4.C.)

36 Major sources of uncertainty in modeled and observed values include missing deposition terms  
37 and poorly constrained convective mass flux. As indicated above, convective mass flux (rapid  
38 vertical transport) is uncertain because most convective clouds are smaller than a grid box in a  
39 global model. There is evidence for nonlinearities in NO<sub>2</sub> deposition velocities with greater  
40 transfer from the atmosphere to the surface at higher concentrations (Horii et al., 2004; 2006).

1 Emissions from Canada and Mexico can have a substantive impact on atmospheric Nr over the  
2 United States. near major sources such as downwind of industrial Ontario and major cities of  
3 Mexico, such as Tijuana and San Diego, CA (Wang et al., 2009). While Nr is imported into the  
4 United States from these boarder countries, there is also export. The emissions from Canada and  
5 Mexico are each 10-15% of those of the United States and the bulk of the Mexican population is  
6 distant from the United States. We expect the overall impact of neighboring countries to add  
7 about 10% uncertainty to the estimated Nr budget for the 48 contiguous states.

8 *Conclusions on atmospheric deposition of Nr.* Downward transport from the atmosphere is a  
9 major source of Nr to the Earth's surface, but there are uncertainties in the characteristics and  
10 absolute magnitude of the flux. Pollutants not deposited are exported from the continent and  
11 alter the composition and radiative balance of the atmosphere on a large scale. A review of the  
12 literature revealed the following major points concerning the present state of the science:

- 13 1. Measurements from the National Atmospheric Deposition Program (NADP) indicate  
14 that *wet* deposition of ammonium plus nitrate for the period 2000 – 2006 averaged 3.1  
15 kg N/ha/yr over the 48 contiguous States.
- 16 2. The reduced ( $\text{NH}_4^+$ ) and oxidized ( $\text{NO}_3^-$ ) forms of reactive N contributed about  
17 equally to the flux, but input to the eastern United States was greater (and less  
18 uncertain) than to the western United States.
- 19 3. For the United States east of the Mississippi River, dry deposition data have also been  
20 analyzed – the Clean Air Standards and Trends Network (CASTNET) monitors vapor  
21 phase  $\text{HNO}_3$ , as well as particulate  $\text{NO}_3^-$  and  $\text{NH}_4^+$ . These measurements indicate  
22 7.75 kg N/ha/yr total deposition (5.46 wet 2.29 dry) over the East. Conspicuous by its  
23 absence from this number is dry deposition of ammonia.
- 24 4. Decreases in  $\text{NO}_x$  emissions appear to have led to decreases in  $\text{NO}_3^-$  deposition.  
25 NADP data show a national decreasing trend in the wet nitrate deposition and some  
26 individual sites show statistically significant decreases in deposition and correlations  
27 with emissions.
- 28 5. A thorough review of all published studies of the U.S.  $\text{NO}_y$  budget indicates that  
29 about 70 % of the  $\text{NO}_x$  emitted by the United States is deposited onto the continent  
30 with the remainder exported, although substantial uncertainty remains. Major sources  
31 of error include dry deposition of unmonitored members of the  $\text{NO}_y$  family,  
32 uncertainties in the chemistry of organic N, and poorly constrained estimates of  
33 convective venting of the planetary boundary layer.
- 34 6. Based on observations and model estimates of the relative deposition of unmeasured  
35 quantities, total estimated deposition of all forms of Nr for the period 2000-2004 is  
36 ~11 kg N /ha /yr for the eastern United States, and for the 48 States ~7.5 kg N /ha /yr  
37 with a range of 5.5 to 9.5 kg N /ha /yr.

38

### 39 **Finding 8**

40 Scientific uncertainty about the origins, transport, chemistry, sinks, and export of Nr remains  
41 high, but evidence is strong that atmospheric deposition of Nr to the Earth's surface as well as  
42 emissions from the surface to the atmosphere contribute substantially to environmental and

1 health problems. Nitrogen dioxide,  $\text{NO}_2$ , is often a small component of  $\text{NO}_y$ , the total of  
2 oxidized nitrogen in the atmosphere. The current NAAQS for  $\text{NO}_2$ , as an indicator of the criteria  
3 pollutant “oxides of nitrogen,” is inadequate to protect health and welfare.  $\text{NO}_y$  should be  
4 considered seriously as a supplement or replacement for the  $\text{NO}_2$  standard and in monitoring.  
5 Atmospheric emissions and concentrations of Nr from agricultural practices (primarily in the  
6 form of  $\text{NH}_3$ ) have not been well monitored, but  $\text{NH}_4^+$  ion concentration and wet deposition (as  
7 determined by NADP and NTN) appear to be increasing, suggesting that  $\text{NH}_3$  emissions are  
8 increasing. Both wet and dry deposition contribute substantially to  $\text{NH}_x$  removal, but only wet  
9 deposition is known with much scientific certainty. Thus consideration should be given to  
10 adding these chemically reduced and organic forms of Nr to the list of Criteria Pollutants.

11 **Recommendation 8a.** *EPA should re-examine the Criteria Pollutant “oxides of nitrogen” and*  
12 *the indicator species,  $\text{NO}_2$ , and consider using chemically reactive nitrogen (Nr without  $\text{N}_2\text{O}$ ) as*  
13 *the criteria pollutant and  $\text{NH}_x$  and  $\text{NO}_y$  as the indicators.*

14 **Recommendation 8b.** *Begin monitoring of  $\text{NH}_x$  and  $\text{NO}_y$  as soon as possible to supplement the*  
15 *existing network of  $\text{NO}_2$  compliance monitors.*

16 **Recommendation 8c.** *Pursue the longer term goal of monitoring individual components of Nr,*  
17 *such as  $\text{NO}_2$  (with specificity), NO, and PAN, and  $\text{HNO}_3$ , as well as support the development of*  
18 *new measurement and monitoring methods.*

19 **Recommendation 8d.** *Increase the scope and spatial coverage of the Nr concentration and flux*  
20 *monitoring networks (such as the National Atmospheric Deposition Program and the Clean Air*  
21 *Status and Trends Network) and appoint an oversight review panel for these two networks.*

22 **Recommendation 8e.** *EPA in coordination with other federal agencies should pursue research*  
23 *goals including:*

- 24 • *Measurements of deposition directly both at the CASTNET sites and in nearby locations*  
25 *with non-uniform surfaces such as forest edges.*
- 26 • *Improved measurements and models of convective venting of the planetary boundary layer*  
27 *and of long range transport.*
- 28 • *Improved analytical techniques and observations of atmospheric organic N compounds in*  
29 *vapor, particulate, and aqueous phases.*
- 30 • *Increased quality and spatial coverage of measurements of the  $\text{NH}_3$  flux to the atmosphere*  
31 *from major sources especially agricultural practices.*
- 32 • *Improved measurement techniques for, and numerical models of  $\text{NO}_y$  and  $\text{NH}_x$  species*  
33 *especially with regard to chemical transformations, surface deposition, and off shore*  
34 *export; develop linked ocean-land-atmosphere models of Nr.*

35 **2.3.1.2 Input and recycling of Nr within terrestrial systems in the United States**

36 This section builds upon Section 2.2 by integrating the information in that section on Nr

1 introduction into the United States and its loss to environmental systems by energy and food  
2 production into the overall picture of Nr cycling within terrestrial systems.

3 Annual input of newly created Nr onto terrestrial ecosystems comes primarily from atmospheric  
4 deposition, synthetic fertilizer and BNF in managed and unmanaged ecosystems (Table 1).  
5 Although Nr from atmospheric deposition is formed inadvertently during fossil fuel combustion  
6 and from volatilization of NH<sub>3</sub> from agricultural activities, it serves to provide nutrients, along  
7 with biological N fixation and synthetic fertilizer, for food, feed and fiber production in the  
8 agricultural sector. Forests and grasslands use Nr for growth. Home gardens, parks and  
9 recreational areas utilize Nr within the urban landscape. Approximately 32 Tg of new Nr  
10 reached the land of the 48 contiguous states in 2002 (Table 1). An additional ~0.2 Tg of N was  
11 imported mainly as food and drink products (FAO, 2008). An additional ~12 Tg of Nr was  
12 recycled back to terrestrial and aquatic systems in livestock (~6 Tg N) excreta, human (~2 Tg N)  
13 excreta, and crop residue from the previous year's production (~4 Tg N; U.S. EPA, 2007). Of  
14 this N ~ 1.3 Tg (~1.2 from livestock manure and <0.1 from sewage sludge) was used as fertilizer  
15 for crop production (U.S. EPA, 2007).

16 Most of the new Nr was used to produce food for human consumption and forage and feed for  
17 livestock and poultry Nr (~17 Tg total with 9.7 Tg from synthetic fertilizer and ~8 Tg from  
18 biological N fixation; Table 13). In addition to new Nr and Nr that was recycled from livestock  
19 and human excreta, crop production releases Nr that was stored in soil organic matter (see  
20 section 2.3.2). The N in cereal crops is typically derived from added fertilizer (synthetic or  
21 manures) and from mineralization of soil organic matter (conversion of complex organic  
22 molecules to ammonium) in about equal amounts. As discussed in Sections 2.2 and 3.3.4., crop  
23 production is not efficient in using Nr so only 30-70% (a global average of 40%) of all of the N  
24 mobilized for crop production is harvested in the crop. The remainder is in crop residue (roots  
25 and above ground stover) stored in the soil, leached to aquatic systems as NO<sub>3</sub><sup>-</sup>, volatilized to the  
26 atmosphere as NH<sub>3</sub> or NO<sub>x</sub> or denitrified (see Section. 2.4.7.3, Fig. 23) to produce NO<sub>x</sub>, N<sub>2</sub>O and  
27 N<sub>2</sub>. An additional ~1.1 Tg of synthetic fertilizer N is used to maintain turfgrass in the urban  
28 environment (see Section 2.2.5) and another 0.1-0.2 Tg N is used to enhance forest production.

29 **Table 13: Sources of reactive N input into terrestrial systems in the United States in 2002**  
30 **(from Table 1; in Tg N/yr).**

Source	Environmental System				Total
	Agricultural	Vegetated		Populated	
		Forest	Grassland		
Atmospheric	1.3	1.4	1.9	0.4	6.9*
N fixation	7.7	--	6.4	--	14.1

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<b>Synthetic N</b>	9.7	0.1	**	1.1	10.9
<b>Animal manure##</b>	1.2	--	3.8#	--	6.0#
<b>Human sewage##</b>	0.1	--	--	1.2	1.3

\*The amount of atmospheric Nr deposition is based on area of each environmental system within the continental United States. The total area does not sum to 100% because non arable lands are not included in this table.

\*\*Synthetic fertilizer N used for managed pasture fertilization is included in the agricultural land classification.

#Unrecoverable livestock manure deposited on grasslands, the unaccounted for ~ one Tg of N/r is assumed to be lost through ammonia volatilization, leaching or denitrification (EPA, 2007).

##Note that livestock manure and human sewage used as fertilizer are recycled N components of the nitrogen Cascade and not new Nr inputs.

Within the nitrogen cascade (Figure 3), the interactions between the agricultural and populated portions of the terrestrial system dictate the production and flow of Nr. Although occupying the largest area, forest and grassland portions of terrestrial ecosystems serve mainly to absorb atmospheric deposition and provide a source of forest products and forage for livestock production. Reactive nitrogen input into these systems is from biological N fixation in unmanaged lands, atmospheric deposition and Nr from livestock manure that is deposited. The livestock is grazing within grasslands (Table 13) may lead to the N saturation of unmanaged forest and grassland ecosystems (Galloway et al. 2004; Bobbink et al., 2009).

This report uses the Nr input numbers from Table 13 and food production numbers to estimate the flow of Nr through agricultural and populated parts of the terrestrial system (Table 14). The FAO (2008; [www.fao.org/statistics/toptrade/trade.asp](http://www.fao.org/statistics/toptrade/trade.asp)) lists the 20 largest agricultural commodities produced, imported and exported in the United States in 2002. Of these commodities, corn (229 Tg), soybeans (75 Tg), wheat (44 Tg) and cow's milk (77 Tg) were produced in the greatest amount. Using commodity N content data (derived from data used to calculate crop residue N in the EPA (2007g) inventory of U.S. greenhouse gas emissions and sinks, an estimated 9 Tg of N was marketed in three crops, soybeans (4.4 Tg N; from EPA, 2007g), corn (3.2 Tg N), and wheat (0.9 Tg N). Whole milk contained ~ 0.5 Tg of N while other meat and egg produce contained ~1.4 Tg of N, totaling ~ 1.9 Tg N. Grain, fruits, nuts and vegetables contained ~9.3 Tg of N. If the total N input use efficiency is 40% then ~23 Tg of N from all sources is required to produce 9.3 Tg of vegetative commodities. Table 14 lists the estimated Nr input into agricultural systems (~ 20 Tg) and additional N input from crop residue that was returned to the field the previous year (4.4 Tg) and from mineralization of soil organic matter (4.7 Tg). All of this N input totals ~29 Tg of N that is actually involved in the production of the 9.3 Tg of crop commodity N. If one assumes that return of crop residue to the field is directly proportional to crop production, then 24.3 Tg of N was required to produce the 9.3 Tg of crop commodity N. These estimates indicate that ~38% of the total annual input of N that went into the agricultural crop production system was contained in the main crop commodities

1 produced in the United States in 2002.

2 Of this 24.3 Tg N approximately 2.5 Tg was used to grow feed used for milk, egg and meat  
3 production. This estimate is made assuming that 4 units of N are required to produce a unit of  
4 milk, eggs or meat (see section 3.2.4.1.). This estimate also assumes that 1/3 of N required for  
5 livestock production comes from commodities in the FAO top 20 list and the remaining 2/3  
6 comes from alfalfa, silage and grass over the course of a year (Oitjen and Beckett, 1996)  
7 Approximately 4.3 Tg of N in agricultural commodities (2.8 Tg in soybeans, corn and wheat)  
8 were exported, while ~0.15 Tg N was imported in various food and drink commodities. The  
9 U.S. human populace consumed ~1.96 Tg of N in 2002 (292 million people, consume 114.7 g  
10 protein/person/day, 0.16 g N/g protein, 365 days) (approximately 1.2 Tg from animal protein-N  
11 and 0.7 from vegetative protein).

12 These three consumption areas, internal consumption of vegetable N for livestock production,  
13 human consumption, and export account for 77% of the commodities produced. The  
14 unaccounted for commodity N is likely partly in annual storage. Some smaller fraction of annual  
15 production is used for pet food and a small fraction is returned to the terrestrial environment  
16 because of spoilage and handling losses.

17 In forests and grasslands (vegetated system) N input in 2002 was ~3.5 Tg of anthropogenically  
18 introduced N, with the remaining ~10.1 Tg derived from BNF and livestock manure deposition.  
19 Of this anthropogenic N, ~21% was retained in soil and tree biomass while the remainder was  
20 removed in tree harvest (~0.2 Tg, see section 2.3.2.3) or lost to other parts of the environment  
21 through NH<sub>3</sub> volatilization and NO<sub>3</sub><sup>-</sup> leaching and runoff (Table 14). Total N input into  
22 agricultural systems was ~20 Tg with ~ 11 Tg being removed as products which includes the  
23 transfer of ~2 Tg N as food to the human population. Almost 40% of the N input into  
24 agricultural systems is lost through NH<sub>3</sub> volatilization, nitrification/denitrification and NO<sub>3</sub><sup>-</sup>  
25 runoff. The 4.2 Tg of Nr of Haber-Bosch N that is used for industrial feedstock is not included  
26 in this assessment. Of the input of ~3.3 Tg of N into the populated system ~80% is lost through  
27 human excreta processed in sewage treatment plants, denitrification in soils and leaching and  
28 runoff of NO<sub>3</sub><sup>-</sup> (Table 14).

29 Table 14 summarizes the input and flow of Nr in the main terrestrial systems within the  
30 continental United States. Anthropogenic input of Nr into forests and grasslands totaled ~3.5 Tg  
31 in 2002 with an estimated 6.4 Tg of Nr being introduced through natural biological N fixation.  
32 Of this Nr ~ 0.7 Tg was stored in vegetation and soils (see section 3.3.2) and ~2 Tg removed as  
33 livestock forage, while the remainder was lost to the atmosphere and aquatic systems, or  
34 removed as forest products and livestock forage. The largest anthropogenic Nr input (~20 Tg)  
35 was into agricultural production where ~11.2 Tg was removed as agricultural product, ~ 2 Tg  
36 transferred as edible product to the “populated” portion of the terrestrial system, ~0.8 Tg was  
37 stored in agricultural lands, and ~7.6 Tg N was lost to the atmosphere and aquatic systems. New  
38 N input into the “Populated” portion totaled ~3.3 Tg, which came from N transfer in food and  
39 use of fertilizer N in lawns, gardens and recreational areas. Within these areas an estimated 0.12  
40 Tg was stored in urban forests.

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**Table 14: Nr input and flows (Tg N/yr) in the terrestrial portion of the Nitrogen Cascade**

3

**(Figure 3) within the continental United States in 2002**

Environmental System*	N Input to System	N Storage in System**	Agricultural & Forest Products	Transfers to Aquatic or Atmospheric
Vegetated	13.6	0.7	2.2	10.7
Agricultural	19.6	0.8	11.2	7.6
Populated	3.3	0.1	0	3.2

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\*

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\*The Environmental Systems are those noted in the Terrestrial portion of the N Cascade shown in Figure 3. Data from Table 13, derived from regrouping data from Table 1, are shown in Table 14.

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\*\*Estimates are from section 2.3.2. of this report.

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**Finding 9**

10

Although total N budgets within all terrestrial systems are highly uncertain, Nr losses from grasslands and forests (vegetated) and urban (populated) portions of the N Cascade appear to be higher, on a per cent of input basis, than from agricultural lands. The relative amount of these losses ascribed to leaching, runoff and denitrification, are as uncertain as the N budgets themselves.

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**Recommendation 9:** EPA should join with USDA, DOE, and universities should work together in efforts to ensure that the N budgets of terrestrial systems are properly quantified and that the magnitudes of at least the major loss vectors are known.

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*2.3.1.3 Transfer of Nr to aquatic systems*

19

Within the nitrogen cascade, Nr flows from the atmosphere and terrestrial systems into aquatic systems. Aquatic systems include groundwater, wetlands, streams and rivers, lakes and the coastal marine environment. Nr is deposited directly into surface aquatic systems from the atmosphere (direct deposition) and Nr that is not either stored or removed as products on terrestrial systems eventually moves into aquatic systems (indirect deposition).

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The area of an airshed generally greatly exceeds that of a watershed for a specific estuary or coastal region. For example, the airshed of the Baltic Sea includes much of western and central Europe (Asman 1994, Hov et al., 1994), while the airsheds of the United States' two largest estuarine ecosystems, the Chesapeake Bay and Albemarle-Pamlico Sound, are 15 to over 30 times the size of their watersheds (Dennis 1997). Thus, the airshed of one region may impact the watershed and receiving waters of another, making eutrophication a regional-scale management issue (Paerl et al. 2002, Galloway and Cowling 2002). Furthermore, atmospheric N inputs do not stop at coastal margins. Along the North American Atlantic continental shelf, atmospheric N inputs more than match riverine inputs (Jaworski et al., 1997, Paerl et al., 2002), underscoring

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1 the fact that N-driven marine eutrophication may require regional or even global solutions. Even  
2 in truly oceanic locations (e.g. Bermuda), North American continental atmospheric N emissions  
3 (reduced and oxidized N) are commonly detected and significant (Luke and Dickerson 1987,  
4 Prospero et al. 1996). Likewise, islands in the North Pacific receive N deposition originating in  
5 Asia (Prospero et al., 1989).

6 Riverine and atmospheric “new” Nr inputs in the North Atlantic Ocean basin are at least equal  
7 and may exceed “new” Nr inputs by biological N<sub>2</sub> fixation (Howarth et al. 1996, Paerl and  
8 Whittall 1999, Paerl et al. 2002). Duce et al. (2008) estimate that up to a third of ocean’s external  
9 Nr supply enters through atmospheric deposition. This deposition leads to an estimated ~ 3% of  
10 new marine biological production and increased oceanic N<sub>2</sub>O production. Schlesinger (2009)  
11 estimated that global atmospheric transport of Nr from land to sea accounts for the movement  
12 almost one third of the annual terrestrial Nr formation. Therefore, our understanding of marine  
13 eutrophication dynamics, and their management, needs to consider a range of scales reflecting  
14 these inputs, including ecosystem, watershed, regional and global levels.

15 One example of shifting N inputs is the proliferation of intensive livestock operations in coastal  
16 watersheds, which has led to large increases and changes in chemical composition of nitrogenous  
17 compounds discharged to estuarine and coastal waters via runoff, groundwater and atmospheric  
18 deposition (Paerl, 1997; Howarth, 1998; Galloway & Cowling, 2002). In general, coastal waters  
19 under the influence of these operations are experiencing increases in total N loading as well as a  
20 shift toward more reduced N (NH<sub>4</sub><sup>+</sup>, organic N) relative to oxidized N (NO<sub>3</sub><sup>-</sup>) (Howarth et al.,  
21 2002; Galloway & Cowling, 2002). These increases, combined with increases in hypoxia and  
22 anoxia in receiving waters, are leading to more NH<sub>4</sub><sup>+</sup>-rich conditions, which will favor algal  
23 groups able to best exploit this N form, including some harmful algal bloom (HAB) taxa (Paerl  
24 and Whittall 1999; Paerl et al. 2007). Similarly, conversion of forest and agricultural lands to  
25 urban lands can alter landscapes and promote N loading to estuaries by increasing impervious  
26 pathways and removing natural landscape filters for Nr. Development also destroys wetlands,  
27 leading to more NO<sub>3</sub><sup>-</sup>-enriched conditions, potentially favoring plant taxa best able to exploit this  
28 N form.

29 A recent evaluation of decadal-scale changes of NO<sub>3</sub><sup>-</sup> concentrations in ground water supplies  
30 indicates that there is a significant increase in nitrate concentrations in well water across the  
31 United States (Rupert, 2008). This study compared the nitrate content of 495 wells during 1988-  
32 1995 with nitrate content found during 2000-2004 as a part of the United States Geological  
33 Survey, National Water-Quality Assessment Program. From a subset of wells that had data on  
34 ground water recharge so that correlations with historic fertilizer use could be made, the study  
35 concluded that nitrate concentrations in ground water increased in response to the increase of N  
36 fertilizer use.

### 37 **Text Box 1: Hypoxia in the Gulf of Mexico**

38 An example of a problem of excess Nr that moves from one part of the United States to another  
39 is the movement of Nr from the states that make up the Mississippi River drainage to the Gulf of  
40 Mexico. A hypoxic zone covers a significant area of the receiving bottom waters of the  
41 continental shelf of the northern Gulf of Mexico (details may be gleaned from SAB, 2007). This

1 is a seasonally severe problem that has persisted there for at least the past 20 years. Between  
2 1993 and 1999 the hypoxia zone ranged in extent from 13,000 to 20,000 km<sup>2</sup> (Rabalais et al.  
3 1996, 1999, Rabalais and Turner 2001). The hypoxia is most widespread, persistent, and severe  
4 in June, July, and August, although its extent and timing can vary, in part because of the  
5 amplitude and timing of flow and subsequent nutrient loading from the Mississippi River Basin.  
6 The waters that discharge to the Gulf of Mexico originate in the watersheds of the Mississippi,  
7 Ohio, and Missouri Rivers (collectively described here as the Mississippi River Basin). With a  
8 total watershed of 3 million km<sup>2</sup>, this basin encompasses about 40% of the territory of the lower  
9 48 states and accounts for 90% of the freshwater inflow to the Gulf of Mexico (Rabalais et al.  
10 1996; Mitsch et al. 2001; EPA, 2007b).

11 The report, *Hypoxia in the Northern Gulf of Mexico. An update by the EPA Science Advisory*  
12 *Board*. December, 2007 (SAB, 2007) determined that “To reduce the size of the hypoxic zone  
13 and improve water quality in the Basin, the SAB Panel recommends a dual nutrient strategy  
14 targeting at least a 45% reduction in riverine total nitrogen flux (to approximately 870,000 metric  
15 tons/yr) and at least a 45% reduction in riverine total phosphorus flux (to approximately 75,000  
16 metric tons/yr). Both of these reductions refer to changes measured against average flux over the  
17 1980 - 1996 time period. For both nutrients, incremental annual reductions will be needed to  
18 achieve the 45% reduction goals over the long run. For nitrogen, the greatest emphasis should be  
19 placed on reducing spring flux, the time period most correlated with the size of the hypoxic  
20 zone.”

### 21 **2.3.2. Storage of Nr within terrestrial environmental systems**

22 According to the nitrogen cascade conceptualization, terrestrial environmental systems are  
23 compartmentalized into agriculture, populated, and vegetated systems. Annual input of Nr is  
24 greatest in agricultural ecosystems (farmland, cropland, and grazed pastureland) including Nr  
25 inputs, using 2002 as the base year, of 9.8 Tg from synthetic fertilizer, 7.7 Tg from biological N  
26 fixation in crops (mainly soybeans), and 1.3 Tg from atmospheric deposition. Nr input into  
27 vegetated systems (mostly forested, but including non-cropland grasslands and other natural  
28 vegetation types as well) comes mostly from atmospheric deposition (3.2 Tg). Annual input of  
29 Nr into populated systems includes synthetic fertilizer application to urban turfgrass and  
30 recreational areas (~1.1 Tg), and atmospheric deposition 0.2 Tg (Table 13).

31 Much of the annual Nr input into these terrestrial systems passes through, and is transferred  
32 within, terrestrial systems or atmosphere via NH<sub>3</sub>, NO<sub>x</sub> or N<sub>2</sub>O, or aquatic environmental  
33 systems via NO<sub>3</sub><sup>-</sup> and organic N leaching and runoff or NH<sub>x</sub> and NO<sub>y</sub> deposition.

34 The largest single reservoir of total N in the terrestrial environmental system is soil organic  
35 matter (SOM). Approximately 52,000 Tg C and 4,300 Tg N are contained in the upper 100 cm  
36 of soil in the 48 contiguous states (N is estimated from assumed C/N ratio of 12) (Lal et al.  
37 1998). For comparison, the total above ground biomass of U.S. forests of these states contains ~  
38 15,300 Tg of C and ~ 59 Tg N (estimated using a C/N ratio of 261, and 15,500 Tg of SOM-C,  
39 1290Tg total N (estimated using a C/N ratio of 12) (EPA, 2007g). Most of this SOM-N is bound  
40 within complex organic molecules that remain in the soil for tens to thousands of years. A small  
41 fraction of this SOM is mineralized, converted to carbon dioxide and Nr annually. The total N

1 contained within above and below ground compartments isn't really of concern. What is of  
2 interest in addressing issues of Nr, is the change in N stored within the compartments of  
3 terrestrial systems. The pertinent question is whether N is being retained or released from long-  
4 term storage. The committee evaluated estimates of annual change of N storage within  
5 important components of terrestrial systems. The EPA Inventory of U.S. Greenhouse Gas  
6 Emissions and Sinks 1990-2005 (USEPA 2007g) carbon stock information obtained from  
7 chapter 7 of the report provided information used by the committee to estimate N storage in U.S.  
8 terrestrial systems. Nitrogen stock change was determined by simply assigning a C/N ratio of 12  
9 for soils and 261 for trees and making the appropriate conversions from C to N.

### 10 2.3.2.1. *Agricultural*

11 Croplands within the contiguous 48 states occupy ~149 million ha (19%) of the 785 million ha of  
12 land area, of which 126 million ha were cultivated in 2002 (NRCS, 2007;  
13 [www.nrcs.usda.gov/technical/land/nrio3/national\\_landuse.html](http://www.nrcs.usda.gov/technical/land/nrio3/national_landuse.html)). Croplands are generally found  
14 on well drained mineral soils (organic C content 1-6% in the top 30 cm). Small areas of drained  
15 organic soils are cultivated (organic C content of 10-20%) in mainly Florida, Michigan and  
16 Minnesota (EPA, 2007g). Organic soils lost ~0.69 Tg of Nr in 2002 while mineral soils  
17 accumulated ~1.5 Tg of Nr (Table 15). Much of the accumulation of SOC was due to the use of  
18 conservation tillage and high yielding crop varieties (EPA, 2007g). Losses of Nr from organic  
19 soils are due to mineralization of SOM and release of Nr input. In cultivated soils annual input  
20 of new Nr is approximately 9.7 Tg from fertilizer N, 1.1 Tg from livestock manure (recycled N),  
21 ~7.7 Tg from biological N fixation and 1.2 Tg from atmospheric deposition. Assuming that loss  
22 of fertilizer N from the small area of organic soils is a minor fraction of the total, then ~17% of  
23 N input from synthetic fertilizer, ~12% of total N input, is stored in cropland mineral soils  
24 annually.

25 According to the U.S. EPA National Greenhouse Inventory (EPA 2007b) the net increase in soil  
26 C stocks over the period from 1990 through 2005 was largely due to an increase in annual  
27 cropland enrolled in the Conservation Reserve Program, intensification of crop production by  
28 limiting the use of bare-summer fallow in semi-arid regions, increased hay production, and  
29 adoption of conservation tillage (i.e., reduced- and no-till practices). The EPA estimates shown  
30 in Table 15 assume that no-till crop production results in net carbon sequestration. Recent  
31 publications indicate, however, that no-till cropping practices do not result in net carbon  
32 sequestration (Baker et al. 2007; Blanco-Canqui, H. and R. Lal. 2008; Verma et al., 2005), which  
33 means the estimates of soil C and N storage in mineral soils in Table 15 that were derived from  
34 EPA, (2007b) need to be reconsidered. These new studies and that of David et al. (2009)  
35 suggest that organic C conservation by reduced tillage practices has been overestimated because  
36 soil sampling and analysis has been confined to the top 30 cm of soil when the top meter of soil  
37 needs to be considered. Baker et al. and Verma et al. also show that long-term, continuous gas  
38 exchange measurements have not detected C gain due to no-till. They concluded that although  
39 there are other good reasons to use no-till, evidence that it promotes C sequestration is not  
40 compelling. These findings highlight the need for appropriate assessment of ecosystem N  
41 storage so that this committee's conclusion that only a small part of annual Nr input is stored in  
42 agricultural lands, forests, and grasslands can be confirmed or disproven.

1 2.3.2.2. *Populated systems—urban lands*

2 Populated or “developed land” (developed land is the terminology used by NRCS) occupied  
3 ~42.9 million ha of the U.S. land area in 2002. This equates to approximately 5.5% of the U.S.  
4 land area (NRCS, 2007). The EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks  
5 (EPA, 2008) indicates that urban areas cover over 4.4% of the land area with tree canopy  
6 covering 27.1% of the urban area. The tree-covered area constitutes approximately 3% of total  
7 tree cover in the continental United States. If the NRCS value of 42.9 million ha is used, then  
8 trees cover ~11.3 million ha of urban land in the contiguous 48 states. Another ~ 14.2 million ha  
9 of land is covered by turf grass in parks, golf courses, and lawns. In both urban forests and turf  
10 grass, N<sub>r</sub> storage is dependent upon the age of the trees or turf. In young, pre-steady state,  
11 systems N is being accumulated while at steady state no net change occurs. Some areas may be  
12 degrading and actually losing biomass and returning N to the environment. EPA (2007g) does  
13 not estimate carbon changes in turf grass, but does estimate changes in carbon storage in urban  
14 forests. Urban trees sequestered an estimated net 22 Tg of carbon and 0.12 Tg of N in 2002  
15 (using the hardwood C/N ratio of 186) (EPA, 2007g). Annual fertilizer N input into the urban  
16 landscape is approximately 10% of total fertilizer N consumption in the United States. (EPA,  
17 2007g), or ~1 Tg of N in 2002. Another 0.2-1.0 Tg N is deposited from atmospheric deposition,  
18 which can be disproportionately high due to locally high NO<sub>y</sub> concentrations. Storage of ~0.12  
19 Tg N in urban forests constituted approximately 3% of N<sub>r</sub> input annually.

20 2.3.2.3. *Vegetated systems—forests and grasslands*

21 *Forests.* Forests cover approximately 164 million ha, ~21% of the land area of the contiguous 48  
22 states (NRCS, 2007). The forest carbon stocks analysis by EPA (2007g) is based on state  
23 surveys that are conducted every 1 to 10 years. Annual averages are applied to years between  
24 surveys. Changes in C related to the rate of tree growth, Birdsey (1992) estimated that 52,500  
25 Tg of C in above and below ground in U.S. forests; soil contains 59% of total C, 9% in litter and  
26 5% in tree roots. The EPA estimate for 2002 is 43,600 Tg of C. For the following N storage  
27 estimate, based on EPA (2007g) data, we have assumed that forests are 85% softwood and 15%  
28 hardwood with an average C/N ratio = 261. These estimates indicate that forests and forest  
29 products stored ~0.43 Tg of N in 2002 (Table 15)

30 *Grasslands.* Grasslands, including rangelands and pasturelands, occupy approximately 213  
31 million ha (27.1%) of the contiguous 48 state land area. The NRCS divides these grasslands into  
32 pastureland (48.2 million ha) and rangeland (164 million ha). Pastureland is managed, may be  
33 fertilized and mown, and rangeland is managed only to the extent that livestock grazing intensity  
34 on the land used for livestock grazing is regulated. Changes in the N status of grasslands are  
35 dependent upon changes in soil organic matter as the above ground biomass produced annually is  
36 either consumed by livestock or decomposed in the field. Soil organic C stocks were estimated  
37 using the Century biogeochemical model and data used were based upon the NRCS/National  
38 Resources Inventory (NRI) survey (EPA, 2007g). Changes in soil N content were estimated  
39 using a C/N ratio = 12. Nitrogen input into rangelands is generally only from atmospheric  
40 deposition, which contributes 1.9 Tg N each year to range production (Table 15). Rangeland  
41 tends to be in relatively remote areas where atmospheric N<sub>r</sub> deposition is low

1 Collectively, forests and grasslands stored ~0.74 Tg of N in 2002. Much of the soil N storage in  
2 grasslands is a result of conversion of croplands to grasslands, mainly due to the conservation  
3 reserve program. Forest soils appear to be losing N while overall N storage is from  
4 accumulation in above ground biomass and that that remains in forest products that are stored for  
5 long periods.

6 *2.3.2.4. Summary of estimates of Nr stored in terrestrial systems in 2002*

7 An estimated 1.7 Tg of N was stored in the terrestrial systems of the contiguous 48 states in 2002  
8 (Table 15). Soils were the largest reservoir with croplands (0.82) and grasslands (0.31)  
9 sequestering most of the N. Estimated total Nr input from synthetic fertilizer, biological N  
10 fixation and atmospheric deposition into terrestrial systems within the contiguous 48 states in  
11 2002 was ~32 Tg . Although uncertainty of the storage estimate needs to be assessed, it is  
12 probably at least +/-50%. Annual storage in agricultural, grassland and forest soil and in forest  
13 biomass is approximately 6 to 10 % of annual Nr input. All of the input and outflow numbers  
14 are highly uncertain, but N loss through denitrification appears to be the major loss mechanism.  
15 As with the 16 northeastern U.S. watershed example, discussed in section 2.3.3, and, as  
16 concluded in a recent global Nr review by Schlesinger (2009), storage in soils and trees accounts  
17 for only a small portion of the annual N input while apparent loss through denitrification  
18 dominates the budget. Some small fraction is re-volatilized and exported from the continent.

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**Table 15: Net Annual Change in Continental U.S. Croplands soil C and N, Forest C and N, and Grassland Soil C and N in 2002**

Measurements in Tg. Negative sign indicates a decrease in storage: positive number indicates increase in storage, soil C/N ratio = 12; wood C/N = 261 (C storage numbers were obtained from EPA, 2007g).

	C	N
<b><i>Cropland</i></b>		
<b>Cropland remaining cropland</b>		
Mineral soil	17	1.4*
Organic soil	-8.3	-0.69
<b>Land converted to cropland</b>	0.8	0.067
<b>Total</b>	9.6	0.80
<b><i>Forests</i></b>		
<b>Forests and harvested wood products</b>		
Above ground biomass	85	0.32
Belowground biomass	16	0.063
Dead wood	9.1	0.035
Litter	7.2	0.028
Soil organic matter	-2.8	-0.23
Harvested Wood	59	0.22
<b>Total</b>	173	0.43
<b><i>Grasslands</i></b>		
<b>Grasslands remaining grasslands</b>		
Mineral soil	-0.8	-0.067
Organic soil	-1.3	-0.11
<b>Lands Converted to Grasslands</b>	5.8	0.48
<b>Total</b>	3.7	0.31
<b>US Total C &amp; N Storage in 2002</b>	186	1.7

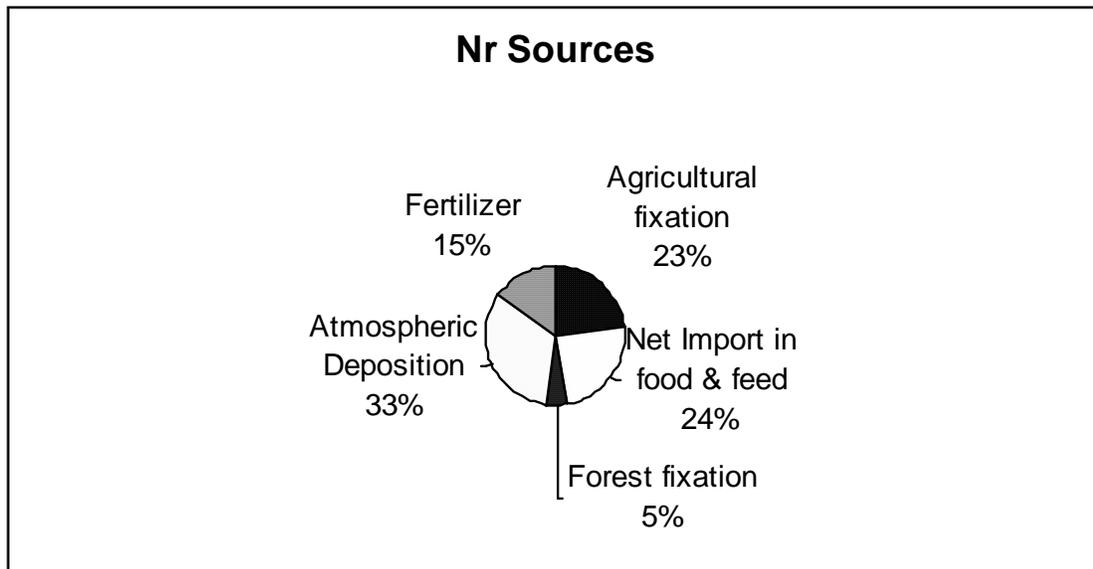
1                   \* See section 2.3.2.1 for discussion of soil organic matter accumulation in crop lands.

2   **2.3.3 Input and fate of Nr in 16 watersheds in the northeast United States**

3   There are no comprehensive data available to assess the transfer and transformations in and  
4   between the atmosphere, terrestrial systems (agriculture, populated and vegetated systems) and  
5   aquatic systems nationally. Determining a national N budget is a priority research area. As there  
6   are no national data available, an example analysis of Nr input and fate in 16 watersheds in the  
7   northeast United States, for which data are available, is used to show an evaluation of the inputs  
8   and fate of Nr for a large watershed (Van Breemen et al. 2002).

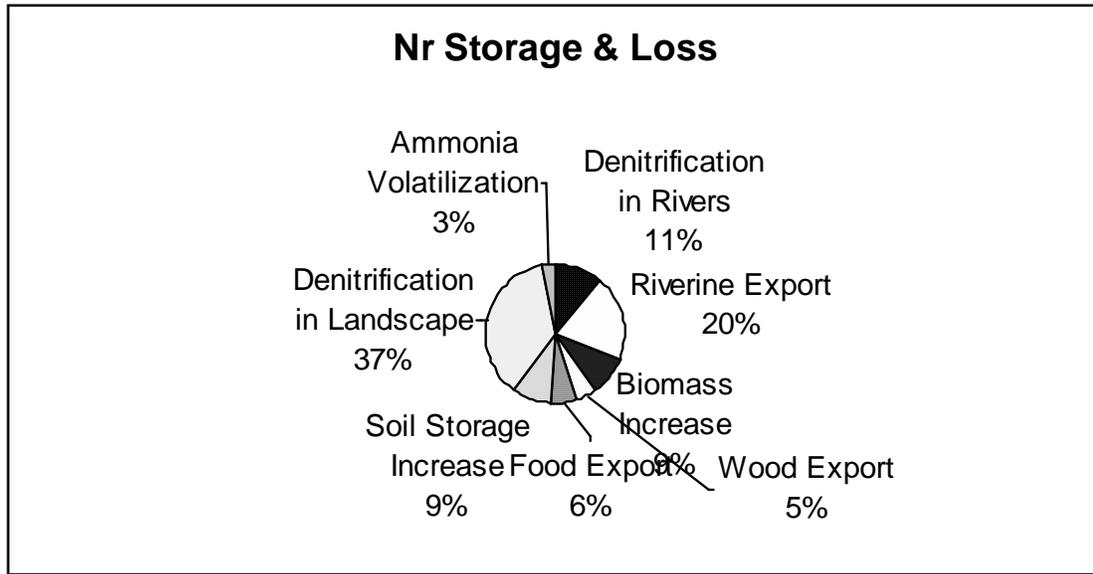
9   The watersheds in this study encompass a range of climatic variability, Maine to Virginia. The  
10   watersheds are a major drainage to the coast of the North Atlantic Ocean. Using data from the  
11   early 1990s, Boyer et al. (2002) reported the quantification of N inputs to each watershed from  
12   atmospheric deposition, N fertilizers, biological N fixation, and import of N in agricultural  
13   products (food and feed). They compared inputs with N losses from the system in riverine  
14   export. As a part of the same study, Van Breemen et al. (2002) analyzed the fate of N inputs to  
15   these watersheds and developed budgets for each watershed. The total area of the watersheds  
16   was 32,666 km<sup>2</sup> with land use categories of forest (72%), agricultural (19%), urban (3%),  
17   wetlands (5%), and 1% other uses. The Nr input into the watersheds (using weighted averages  
18   for all 16 watersheds) was 3,420 kg per square km per year (hereafter expressed as kg /km<sup>2</sup> /yr).  
19   Figure 16 shows the Nr sources and the estimated fate of this Nr as a per cent of the weighted  
20   average Nr input.

21   **Figure 16: Nr input and loss from 16 watersheds in the northeast United States**



22

23



1

2 Van Breemen et al. (2002) indicate that Nr inputs and storages and losses were well correlated  
 3 ( $R^2 = 0.98$ ). Denitrification in landscape soils is the most uncertain estimate, because rates are  
 4 calculated by difference between total inputs and outputs, so they accumulate errors from all  
 5 estimates. They suggest that the denitrification loss term may also reflect the change in N  
 6 storage in groundwater. The net storage of N in the soil (18% of total storage and losses)  
 7 indicates that there is a non-steady state condition in the soil. Increasing storage of Nr on land  
 8 implies that drainage and denitrification exports of Nr are likely to increase when a new steady  
 9 state condition is reached.

10 These data suggest that Nr research need to focus on understanding the “denitrification” loss  
 11 term in this analysis. The losses occur in the terrestrial landscape, before Nr enters the river.  
 12 Where do these losses occur, within the agricultural field, in drains and ditches near the  
 13 agricultural field, in riparian areas, or wetlands? Understanding this term may help in the  
 14 management of Nr in watersheds to decrease nitrate movement into aquatic systems as well as to  
 15 limit  $N_2O$  emissions to the atmosphere.

16 The Van Breemen et al. (2002) study also estimated that approximately 30% of N input was  
 17 exported to the rivers and about two thirds (20% of total N input) of this N was exported to  
 18 coastal waters by rivers. The remaining one third (11% of total N input) was considered to have  
 19 been denitrified in the rivers. These examples also demonstrate that Nr in the atmosphere,  
 20 terrestrial systems and aquatic systems are not separate and must be considered collectively.  
 21 Atmospheric deposition is a variable, but important input into aquatic systems that contributes to  
 22 Nr enrichment problems. Aquatic and terrestrial systems process this Nr and return other Nr  
 23 gases ( $NH_3$ ,  $NO_x$  and  $N_2O$  to the atmosphere). Nr from terrestrial systems impacts both the  
 24 atmosphere and aquatic systems through emission of  $NH_3$ ,  $NO_x$ ,  $N_2O$  and leaching and runoff of  
 25  $NO_3^-$ .

1 **Finding 10**

2 Denitrification of Nr in terrestrial and aquatic systems is one of the most uncertain parts of the  
3 nitrogen cycle. Denitrification is generally considered to be a dominant N loss pathway in both  
4 terrestrial and aquatic systems, but it is poorly quantified

5 **Recommendation 10:** *EPA, USDA, DOE, and universities should work together to ensure that*  
6 *denitrification in soils and aquatic systems is properly quantified, by funding appropriate*  
7 *research.*

8 **2.3.4. Areas of great uncertainty in Nr transfer and transformations.**

9 In developing the discussion of Nr transfers and transformations in and between the  
10 environmental systems of the nitrogen cascade, the committee has encountered a number of areas  
11 where quantities or flows of Nr are highly uncertain. All of these areas need attention from EPA  
12 in conjunction with other federal and state agencies and universities. Although most of the  
13 following points have been highlighted in various "Findings" and "Recommendations," within  
14 chapter three of this report we feel the need to highlight the following areas:

- 15 • Total denitrification in animal feeding operations, in soils, and in aquatic systems needs  
16 to be quantified along with all gaseous products produced and released to the atmosphere  
17 during nitrification/denitrification. These gases include NO<sub>x</sub>, N<sub>2</sub>O and N<sub>2</sub>.
- 18 • The amount of Nr transferred to each environmental system as dry deposition needs to be  
19 quantified and monitored.
- 20 • The fraction of NO<sub>y</sub> in the form of organo-nitrates and other organic nitrogen species is  
21 poorly quantified, but may play a major role in air quality and Nr cycling.
- 22 • Rates and amounts of ammonia emissions from fertilized soils and animal feeding  
23 operations need to be quantified and the fate of this ammonia determined.
- 24 • The annual change in N storage in soils (agricultural, forest , grassland and urban areas)  
25 needs to be quantified in conjunction with the change in carbon

26 These areas of high uncertainty are highlighted because very little information exists in some of  
27 the areas while in other areas, such as denitrification and the relative release of N<sub>2</sub>O from soils  
28 and aquatic systems, the sparse data are highly variable which makes developing meaningful  
29 guidelines for control difficult.

30 **2.4 Impacts, metrics, and current risk reduction strategies for Nr**

31 **2.4.1 Measurement of Nr in the environment**

32 Although N is among the most abundant elements on earth, only a small fraction, Nr is  
33 responsible for impacts on the environment. Most regulations focus narrowly on specific  
34 chemical forms of nitrogen as they affect media- or site-specific problems, setting limits or  
35 specifying control technologies without regard to the ways in which N is transformed once

1 introduced into the environment. Measurement methods are typically expressed in terms of mass  
2 loadings or concentrations of a particular form of N, e.g. ppm NO<sub>x</sub>, mg/l total NH<sub>x</sub>, or kg/ha of  
3 NO<sub>3</sub><sup>-</sup>.

#### 4 **Finding 11**

5 The committee finds that there is a need to measure, compute, and report the total amount of Nr  
6 present in impacted systems in appropriate units. Since what is measured influences what we are  
7 able to perceive and respond to; in the case of Nr, it is especially critical to measure total  
8 amounts and different chemical forms, at regular intervals over time.

9 **Recommendation 11.** *The committee recommends that EPA routinely and consistently account*  
10 *for the presence of Nr in the environment in forms appropriate to the medium in which they*  
11 *occur (air, land, and water) and that accounting documents be produced and published*  
12 *periodically (for example, in a fashion similar to National Atmospheric Deposition Program*  
13 *(NADP) summary reports). The committee understands that such an undertaking will require*  
14 *substantial resource, and encourages the Agency to develop and strengthen partnerships with*  
15 *appropriate federal and state agencies, and private sector organizations, with parallel interests*  
16 *in advancing the necessary underlying science of Nr creation, transport and transformation,*  
17 *impacts, and management.*

#### 18 **2.4.2 General considerations for Nr impacts**

##### 19 *2.4.2.1 Historical measurement and impact categories*

20 The types of impacts of Nr in the environment are dependent on three general factors: the  
21 sources of Nr, the types of media impacted, and Nr chemical forms. The magnitude of effects  
22 depends on loading and the nature of the system impacted. As illustrated in Figure 3, the impacts  
23 of a given source of Nr can be multiple as N is transformed in the environment and transported  
24 among ecosystem components. The nitrogen cascade provides a comprehensive framework for  
25 understanding the role of Nr in the earth's ecosystems and establishes a framework for  
26 developing and implementing management methods through which beneficial effects can be  
27 enhanced while minimizing detrimental impacts.

28 A risk management paradigm in which various approaches are used to limit environmental  
29 impacts to "acceptable" levels of risk is a useful concept for understanding the environmental  
30 impacts that Nr can have. For this purpose, impacts are divided into several general categories  
31 within which various contaminants have a direct correlation with damage. Risk "end points" are  
32 typically established through reference to supporting scientific studies, location-specific  
33 conditions, and economic, safety, and social factors.

34 Historically, EPA environmental protection programs have addressed impacts of Nr such as  
35 climate change, eutrophication, ecotoxicity, human health (cancer and non-cancer), acidification,  
36 smog formation, and stratospheric ozone depletion, among others (Bare et al 2003). Within these  
37 categories it is sometimes possible to express end points in terms of collective metrics, such as is  
38 done with greenhouse gases in the form of carbon dioxide equivalents, or acidification as H<sup>+</sup>  
39 equivalents. This approach has the considerable advantage of defining a straightforward

1 framework within which environmental standards can be derived that are protective of human  
 2 health and the environment, EPA's principal mission. This approach also encourages evaluation  
 3 of damage from multiple sources as long as the characterization metric used is genuinely  
 4 representative of the impact of a given contaminant. Thus, for example, the total impact of acidic  
 5 gases such as SO<sub>2</sub> and NO<sub>x</sub> on the acidification of watersheds can be expressed as a common  
 6 metric. However, metrics for human health are generally not as simple to characterize nor are the  
 7 appropriate end points; thus, the mechanism of toxicity, number of individuals affected, value of  
 8 lost workdays, medical treatment costs, and value of human lives lost may all be used.

#### 9 2.4.2.2 *Ecosystem functions and services*

10 A complementary approach to classical impact characterizations is the use of ecosystem  
 11 "service" and "function" categories, in which the impairment of a specific service provided by  
 12 one or more ecosystems or impairment of an ecological function by causative contaminant  
 13 emissions is assessed (Costanza 1997; Millennium Ecosystem Assessment 2003). Such an  
 14 approach is inherently attractive because of its basis in scientific reality, i.e. the health of humans  
 15 is inextricably linked to the health of the environment. Less clear, in some cases, are ways in  
 16 which to measure and monitor such impacts and account for the effects of a complex array of  
 17 factors and stressors that contribute to or damage ecosystem service, function and health. Table  
 18 16 provides examples of ecosystem services and corresponding functions.

19 The use of ecosystem services in a regulatory context would be a different approach for the EPA,  
 20 one with considerable potential, but one for which experience is currently lacking. In this context  
 21 INC supports plans by the EPA to incorporate research on the services concept, focusing on Nr  
 22 as the suite of contaminants of interest, into its future ecological research plans (USEPA, 2009a).  
 23 Recently, the Science Advisory Board completed a self-initiated study on "Valuing the  
 24 Protection of Ecological Systems and Services" (EPA 2009b). This report explores the concept  
 25 of ecosystem services as a basis for regulatory action and presents a roadmap for implementing  
 26 this approach.

27 **Table 16: Ecosystem service and corresponding function categories (Costanza et al. 1997)**

Ecosystem Service	Ecosystem Function
Gas regulation	Regulation of atmospheric chemical composition
Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global, regional, and local levels
Disturbance regulation	Capacitance, damping, and integrity of ecosystem response to environmental fluctuations
Water regulation	Regulation of hydrologic flows
Water supply	Storage and retention of water
Erosion control and sediment retention	Retention of soil within an ecosystem

Soil formation	Soil formation processes
Nutrient cycling	Storage, internal cycling, processing, and acquisition of nutrients
Waste treatment	Recovery of mobile nutrients, and removal or breakdown of toxic compounds
Pollination	Movement of floral gametes
Biological control	Trophic dynamic regulation of populations
Refugia	Habitat for resident and transient populations
Food production	That portion of gross primary production extractable as food
Raw materials	That portion of gross primary production extractable as raw materials
Genetic resources	Sources of unique biological materials and products
Recreation	Providing opportunities for recreational activities
Cultural	Providing opportunities for noncommercial uses

1

2 *2.4.2.3 Economic measures and impacts*

3 It is also possible to translate the effects of Nr into economic terms. Two economic measures that  
 4 are often used are the dollar costs of damages and the cost of remediation or substitution.  
 5 Another important economic metric is the cost/ton of remediation for each form of Nr. Damage  
 6 costs do not always scale as tons of Nr released into the environment. If damage costs rather than  
 7 tons of nitrogen were utilized as a metric, the full implications of the cascade and the setting of  
 8 priorities for intervention might differ.

9 It is important to note that the choice of metric used in assessing impacts may play an influential  
 10 role in what and how one manages. Air and water protection laws state that the goal is “to protect  
 11 human health and the environment.” Yet, there is no generally agreed-upon common metric for  
 12 measuring the full range of effects (which are complex and often unknown) or for setting  
 13 priorities in the establishment or implementation of policies.

14 As noted above, there are multiple metrics for measuring Nr or any other agent in the  
 15 environment. The most common metric utilizes quantitative measures of the total amount of Nr  
 16 (and any of its specific chemical forms) in different environmental reservoirs and the mass flux  
 17 between them. But while providing common units, typically mass or concentration, these  
 18 measures do not distinguish the relative societal costs of health or environmental consequences  
 19 of reactive nitrogen of different forms or places in the cascade. While not all damages can be  
 20 turned into economic costs (see Chesapeake Bay box), and the costs of some damages have not  
 21 been quantified, enough of the major damages can be quantified economically to provide a  
 22 useful complementary metric for decision-making.

23 The advantage of monetizing damages is that it reflects an integrated value that human society

1 places on lost ecosystem goods and services in common currency and illustrates the cascading  
2 costs of damages as Nr changes form and moves between different parts of the ecosystem. In  
3 addition, human health implications can also be included as the cost of health care treatment, lost  
4 work days and other aspects of morbidity and mortality (e.g., economic value of lives lost). A  
5 third metric is to look at morbidity and/or mortality separately and not monetize them with a cost  
6 value. Of course a concern, particularly with respect to the economic metric, is that there are a  
7 number of ecosystem services that arguably cannot be easily monetized, for example the loss of  
8 biodiversity and those ecosystem functions that are affected by climate change or other stressors.

9 Ecosystem services considered to be regulating and supporting ecosystem services are  
10 particularly difficult to fit into an economic metric. It is thus essential that a variety of  
11 complementary metrics be used to assess the impact of anthropogenic Nr on the environment and  
12 human well being.

13 There is value in each of the ways that N metrics are expressed. Traditional categories provide a  
14 readily adaptable framework for regulation, while ecosystem service and function-based  
15 categories provide a richer context for stating the complex connections among Nr inputs and  
16 transformations and their impacts on ecosystem health and human well-being. Dollar-based  
17 metrics provide a means of identifying those effects that have the greatest impacts and costs to  
18 society.

### 19 **Finding 12**

20 The committee finds that reliance on only one approach for categorizing the measurement of Nr  
21 is unlikely to result in the desired outcome of translating N-induced degradation into the level of  
22 understanding needed to develop support for implementing effective Nr management strategies.

23 **Recommendation 12.** *It is, therefore, recommended that the EPA examine the full range of*  
24 *traditional and ecosystem response categories, including economic and ecosystem services, as a*  
25 *basis for expressing Nr impacts in the environment, and for building better understanding and*  
26 *support for integrated management efforts.*

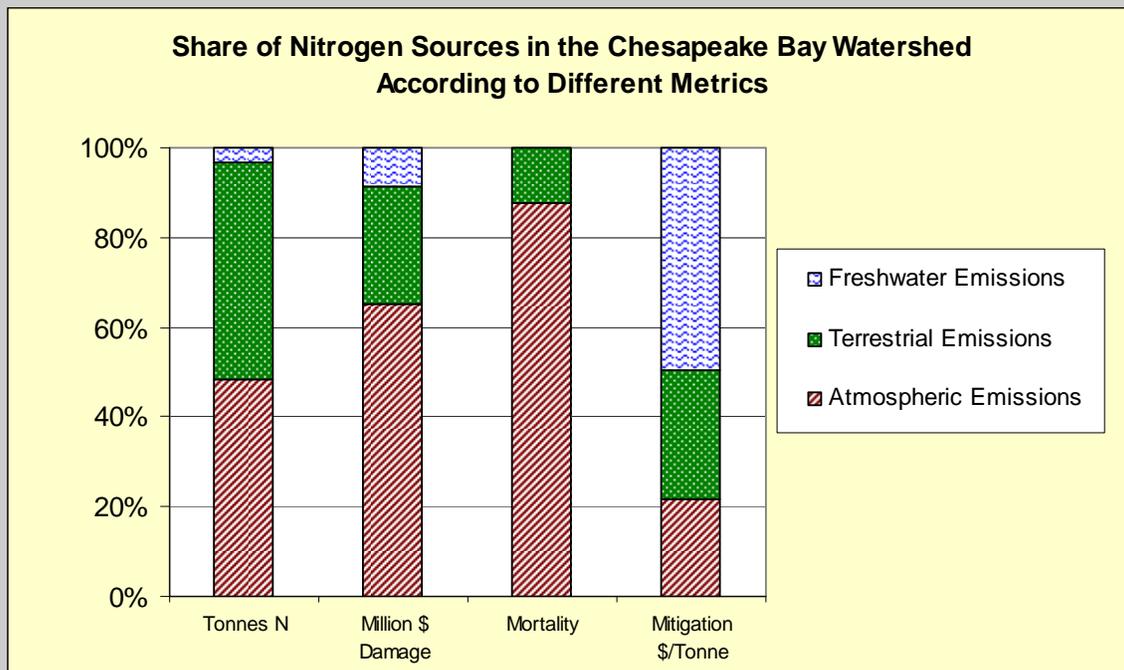
### 27 **Text Box 2: Economic Impacts and Metrics for Chesapeake Bay**

28 Recently, the N cycle and the implications of the reactive nitrogen cascade were translated into  
29 economic terms for the case of Chesapeake Bay (Moomaw and Birch 2005). As an illustration,  
30 each of these metrics is shown as a percentage of Nr fluxes in the Chesapeake Bay water and air  
31 shed in Figure 17 below. Note that approximately 48% of N entering the watershed is coming  
32 through emissions to the atmosphere, but they are causing 65% of the dollar damages and 88%  
33 of the human mortality. A nearly equal percentage, 49%, of the Nr involves runoff from the land,  
34 but it accounts for only 26% of the damage costs and 12% of the mortality. Fresh water releases  
35 of Nr account for only 3% of the Nr and 9% of the cost damages and contribute nothing to  
36 mortality losses. Hence freshwater releases in the Chesapeake Bay ecosystem cause the smallest  
37 damage but account for the largest cost per MT to mitigate. Costs of reactive N mitigation  
38 provide an additional economic measure of the cost effectiveness of actions to reduce a ton of N.

### 39 **Figure 17: Relative importance of all reactive nitrogen sources in the Chesapeake Bay**

1

**Watershed according to four different metrics.**



2

3 The metrics are broken down further by the specific source of NO<sub>x</sub> and NO<sub>y</sub> emissions into each  
 4 of the three media in Table 17

5 **Table 17: Alternative metrics for different atmospheric emissions and for terrestrial and**  
 6 **freshwater releases of reactive NO<sub>x</sub> and NO by source**

	Nr (mt)	\$ Damage (millions)	Mortality	Mitigation (\$/mt)
<b>Atmospheric - Utility Emissions</b>	150,000	510	309	\$6,500
<b>Atmospheric - Mobile Source Emissions</b>	190,000	642	389	\$15,000
<b>Atmospheric - Point Source Emissions</b>	48,000	162	98	\$23,000
<b>Atmospheric - Area Source Emissions</b>	98,000	334	203	\$5,100
<b>Terrestrial Emissions</b>	490,000	668	141	\$11,000
<b>Freshwater Emissions</b>	32,000	223	0	\$19,000

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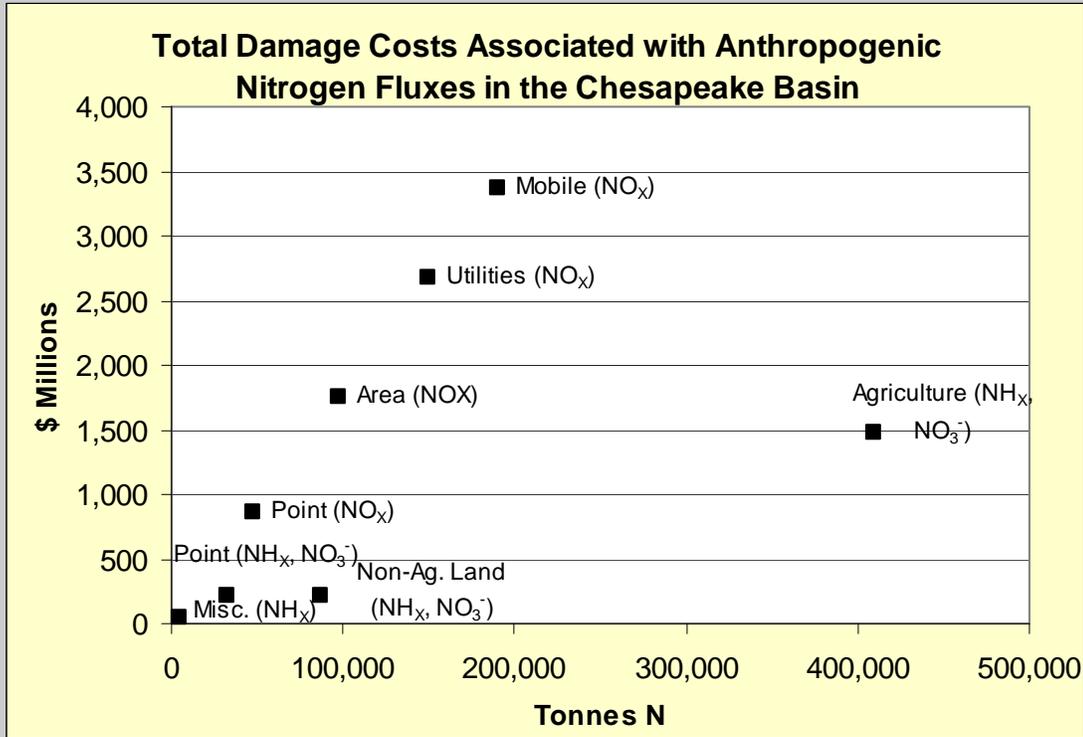
1 The metrics of damage cost and mortality (morbidity shows a similar pattern to mortality, but is  
2 only one-tenth the damage cost) indicate that controlling emissions of NO<sub>x</sub> from combustion and  
3 industrial processes produces greater gains in protecting human health and the environment, than  
4 does reducing Nr releases from the land even though the two sources are comparable in scale in  
5 terms of reactive forms of N released to the watershed. This difference occurs because emissions  
6 to the air cascade through more parts of the watershed ecosystem than do releases directly to the  
7 Bay. If human health effects are monetized, then the economic gains are even greater from  
8 reducing atmospheric emissions. See Figure 18.

9 Looking at the remediation cost of controlling releases to the environment, the least costly per  
10 ton of Nr or per dollar saved also comes from atmospheric emission controls. While most  
11 legislation constrains how cost for remediation can be considered, it is useful to know where the  
12 lowest cost options lie in setting priorities. These metrics provide several ways of looking at the  
13 nitrogen cascade and its impact on human health and the environment. However, there are many  
14 impacts that remain unaccounted for in any of these metrics. Some impacts could be quantified,  
15 but the necessary data have yet to be collected. Economic losses due to damage to recreational  
16 and commercial fisheries in the Bay and in freshwater are examples that are likely to be  
17 significant but have not yet been quantified.

18 And, finally, Nr is not the only stressor that can affect both human and environmental health.  
19 Researchers are challenged to comprehensively understand cause-and-effect relationships in a  
20 complex environment and to balance management actions and costs to ensure that management  
21 strategies are effectively minimizing risks and implemented.

1  
2

**Figure 18: Total damage costs associated with anthropogenic nitrogen fluxes in the Chesapeake Basin**



3

*Scatter plot of all quantifiable damage costs (including health impacts) relative to tons of Nr showing the significant difference in emphasis of the two different metrics*

4  
5

6 Similarly, economic losses due to climate change and ozone depletion from N<sub>2</sub>O emissions have  
7 not been evaluated, as have a variety of other environmental and health effects. Other parts of the  
8 country such as the Mississippi Valley would show a very different pattern of cost damages with  
9 terrestrial and freshwater emissions causing proportionally higher damage costs, and emissions  
10 to the atmosphere causing a lower percentage of damages. But those very differences would  
11 assist EPA and the generators of those emissions in setting priorities for mitigation.

12 As these multiple metrics indicate, decisions about which fluxes of Nr to mitigate depend upon  
13 which metric is utilized. The cascading economic costs of damage highlight the importance of  
14 regulating air emissions because of their impacts on human health as well as their large  
15 contribution to the degradation of Chesapeake Bay water quality. Hence, if one is interested in  
16 reducing water impacts of Nr, the total reduction of damage may rely nearly as much on stricter  
17 enforcement of the CAA as the CWA. This challenges our traditional approach to regulation, but  
18 that is a consequence of comprehensively examining Nr guided by the nitrogen cascade.

1 **2.4.3 Reactive nitrogen and aquatic ecosystems**

2 *2.4.3.1 Impacts of Nr on aquatic systems*

3 What is the concern about too much Nr in aquatic systems? EPA's Office of Water (EPA,  
4 2007d) notes the following impacts:

- 5 • *Excessive nutrients (nitrogen and phosphorus) can cause negative ecological impacts to*  
6 *water bodies on a national scale by stimulating harmful algal blooms.*
- 7 • *Algal blooms block sunlight and result in the destruction of submerged aquatic*  
8 *vegetation which serves as critically important habitat and food for many organisms.*
- 9 • *Algal blooms eventually die off and consume dissolved oxygen from the water column*  
10 *which can lead to die off of aquatic organisms.*
- 11 • *One result of algal blooms is decreased biological diversity and populations,*  
12 *including smaller populations of game and commercial fish.*
- 13 • *Some blooms, considered "harmful algal blooms" or "HABs", have a toxic effect on*  
14 *living organisms and are disruptive of ecosystem structure and transfer of energy to*  
15 *higher trophic levels.*
- 16 • *Excessive nutrients also pose public health risks.*
  - 17 • *Algal blooms can cause taste and odor problems in drinking water.*
  - 18 • *Hazardous algal blooms can cause respiratory distress and neurological problems in*  
19 *swimmers.*
  - 20 • *Excessive nitrates can cause blue baby syndrome.*
- 21 • *Nutrient pollution is occurring at a national scale and has not been completely*  
22 *addressed.*
  - 23 • *49 states and 4 territories have 303(d) listings due to nutrients, and about 50% of the*  
24 *states have greater than 100 water quality impairments due to nutrients.*
  - 25 • *Over 10,000 impairments are a result of nutrient pollution.*  
26

27 Mitsch et al. (2001) suggest that streams and rivers themselves are not always as much affected  
28 by nutrient loading as are lakes, wetlands, coastal areas and other lentic bodies of water.  
29 However, in most cases, these nutrient-enriched waterways flow to the sea, with eutrophication  
30 of coastal waters the unfortunate result. This problem now occurs regularly throughout the world  
31 (WRI, 2007), in locations such as the Gulf of Mexico (Rabalais et al. 1996), the Baltic Sea  
32 (Larson et al. 1985), and the Black Sea (Tolmazin 1985).

33 During the past century, following large-scale use of synthetic N fertilizers in agriculture, rapid  
34 expansion of industrial and transportation-related fossil fuel combustion and coastal  
35 urbanization, humans have significantly altered the balance between "new" N inputs and N  
36 losses in the marine environment (Codispoti et al. 2001, Galloway and Cowling 2002). During  
37 this time frame, terrestrial discharge and atmospheric N emissions have increased by 10 fold  
38 (Howarth et al. 1996, Holland et al., 1999). This number keeps growing as human development  
39 continues to expand in coastal watersheds (Vitousek et al. 1997).

40 Researchers have long recognized this growing imbalance, especially in estuarine and coastal

1 waters where anthropogenically-derived N over-enrichment has fueled accelerated primary  
2 production, or “cultural” eutrophication (Vollenweider et al. 1992, Nixon 1995). Eutrophication  
3 is a condition where nutrient-enhanced primary production exceeds the ability of higher ranked  
4 consumers and organic matter-degrading microbes to consume and process it. D’Elia (1987)  
5 characterized this condition as “too much of good thing” or over-fertilization of N-limited  
6 marine ecosystems with “new” N, a bulk of it being anthropogenic (Howarth et al. 1986,  
7 Vitousek et al. 1997, Galloway and Cowling 2002). Symptoms of N-driven eutrophication vary  
8 from subtle increases in plant production to changes in primary producer community  
9 composition, to rapidly accelerating algal growth, visible discoloration or blooms, losses in water  
10 clarity, increased consumption of oxygen, dissolved oxygen depletion (hypoxia), which is  
11 stressful to resident fauna and flora, or in the case of total dissolved oxygen depletion (anoxia),  
12 elimination of habitats (Paerl 1988, 1997, Diaz and Rosenberg 1995, Rabalais and Turner 2001).  
13 Other effects include submerged aquatic vegetation (SAV) losses, possible impacts on tidal  
14 wetland health, and disruption of estuarine food chain dynamics that may favor an imbalance  
15 towards lower trophic levels (e.g., jellyfish).

16 Anthropogenic or cultural eutrophication has been closely linked to population densities in  
17 coastal watersheds (Peierls et al., 1991, Nixon 1995, Vitousek et al. 1997). Primary sources of N  
18 enrichment include urban and agricultural land uses as well as wastewater treatment plants, most  
19 of which have not been designed to remove nutrients. A significant, and in many instances  
20 increasing, proportion of “new” N input can also be attributed to remote sources residing in  
21 airsheds. Delivery routes can also be complex, especially when via subsurface aquifers outside  
22 the immediate watershed, which can confound source definition and create long delays in  
23 delivery and management response (Paerl 1997, Jaworski et al., 1997, Galloway and Cowling  
24 2002, Paerl et al. 2002).

25 The availability of N controls primary production in much of the world’s estuarine, near-shore  
26 coastal and open ocean waters (Dugdale 1967, Ryther and Dunstan 1971, Nixon 1995, Paerl  
27 1997; Boesch et al. 2001). Nitrogen can also play a role as either a primary or secondary limiting  
28 nutrient in freshwater environments, especially large lakes (e.g. L. Tahoe, L. Superior). As such,  
29 the fertility of these waters is often closely controlled by N inputs, which are provided either  
30 internally by regeneration of pre-existing N and biologically-fixed atmospheric N<sub>2</sub>, or supplied  
31 externally (i.e. “new” N) as combined N sources delivered via surface runoff, sub-surface  
32 groundwater or atmospheric deposition.

33 The extent to which accelerated N loading promotes eutrophication and its symptoms varies  
34 greatly among marine ecosystems. Receiving waters exhibit variable sensitivities to N and other  
35 nutrient [phosphorus (P), iron (Fe), and silica (Si)] loads that are controlled by their size,  
36 hydrologic properties (e.g. flushing rates and residence times), morphologies (depth, volume),  
37 vertical mixing characteristics, geographic and climatic regimes and conditions. In addition, the  
38 magnitude and distribution of N in relation to other nutrient loads can vary substantially. In  
39 waters receiving very high N loads relative to requirements for sustaining primary and secondary  
40 production, other nutrient limitations may develop. This appears to be the case in coastal waters  
41 downstream of rivers draining agricultural regions that are enriched in N.

42 On the ecosystem level, estuarine and coastal waters exhibit individualistic responses to N loads

1 over seasonal and longer (multi-annual, decadal) time scales. The degree to which these systems  
2 are exposed to freshwater discharge, tidal exchange and vertical mixing is critical for  
3 determining how they respond to specific N loads (Vollenweider et al., 1992, Nixon 1995,  
4 Cloern 1999, 2001; Valdes-Weaver et al. 2006; Paerl et al. 2007). Another variable is the  
5 manner in which N loading takes place, which may range from acute pulsed events such as  
6 storms and associated flooding, to longer-term gradual (chronic) increases in N loading  
7 associated with more predictive seasonal, annual and inter-annual hydrologic cycles. There are  
8 striking contrasts in ecosystem response to N inputs that reflect a range in physical  
9 (hydrodynamic, optical) and climatic conditions (Cloern 1999, 2001). Examples include  
10 contrasts between strong tidally-driven estuarine systems, such as Delaware Bay and San  
11 Francisco Bay, and non-tidal, lagoonal systems, such as North Carolina's Pamlico Sound and  
12 Texas's Laguna Madre, or semi enclosed coastal systems, such as Florida Bay and the Long  
13 Island Sound (Bricker et al., 1999; Valdes-Weaver et al. 2006; Paerl et al. 2007).

14 Externally-supplied N comes in various forms, including organic N and inorganic reduced ( $\text{NH}_3$   
15 and  $\text{NH}_4^+$  ion) and oxidized ( $\text{NO}_3^-$ ) N, all of which are potentially available to support new  
16 production and eutrophication. Laboratory experiments on phytoplankton isolates and bioassays  
17 with natural phytoplankton communities have indicated that these contrasting forms may be  
18 differentially and preferentially utilized, indicating that, depending on composition of the  
19 affected phytoplankton community, some forms are more reactive than others (Collos, 1989;  
20 Stolte et al., 1994; Riegman, 1998). Phytoplankton community composition can also be altered  
21 by varying proportions and supply rates of different forms of N (Dortch, 1990; Stolte et al.,  
22 1994; Harrington, 1999; Pinckney et al., 1999; Pehler et al., 2002). Monitoring and research on  
23 dissolved organic N inputs and their effects should be conducted in receiving streams, rivers,  
24 lakes, estuarine and coastal waters, since there is evidence that these compounds can be utilized  
25 by phytoplankton, including harmful bloom species (Paerl 1988, Antia et al. 1991, Carlsson and  
26 Granéli 1998, Gilbert et al. 2006). In addition, specific N compounds may interact with light  
27 availability, hydrodynamics and other nutrients, most notably P, Si, Fe, and trace metals, to  
28 influence phytoplankton community growth rates and composition (Harrison & Turpin, 1982;  
29 Smith, 1990, Dortch & Whitley, 1992).

30 *Scope of the Problem in the United States.* Over the past 25 years, there has been a growing  
31 recognition of cultural eutrophication as a serious problem in coastal estuaries (NRC, 2000).  
32 Globally, Selman et al. (2008) have reported "Of the 415 areas around the world identified as  
33 experiencing some form of eutrophication, 169 are hypoxic and only 13 systems are classified as  
34 'systems in recovery'". Comprehensive surveys of U.S. estuaries have been conducted by  
35 NOAA as part of the National Estuarine Eutrophication Assessments (NEEA) in 1999 and 2004  
36 (Bricker et al. 1999; 2007). The most recent report, released in 2007 (Bricker et al., 2007)  
37 focused on nutrient enrichment and its manifestations in the estuarine environment and relies on  
38 participation and interviews of local experts to provide data for the assessment. Among the key  
39 findings for nearly 100 assessed U.S. estuaries were that eutrophication is a widespread problem,  
40 with the majority of assessed estuaries showing signs of eutrophication—65% of the assessed  
41 systems, representing 78% of assessed estuarine area, had moderate to high overall eutrophic  
42 conditions. The most common symptoms of eutrophication were high spatial coverage and  
43 frequency of elevated chlorophyll *a* (phytoplankton)—50% of the assessed estuaries,

1 representing 72% of assessed area, had a high chlorophyll *a* rating.

2 Further field evaluations by EPA and state and university collaborators under the National  
3 Coastal Assessment (NCA) using probabilistic monitoring techniques The NCA National Coastal  
4 Condition Reports (EPA, 2001, 2004 and 2006) are more closely related to nutrient enrichment  
5 assessments, especially for manifestations of nutrient enrichment such as hypoxia, nuisance algal  
6 blooms, and general habitat degradation. The last comprehensive national NCCR was published  
7 in 2004 (EPA, 2004) with a more recent assessment focused on 28 National Estuary Program  
8 estuaries published in 2007 (EPA, 2006). The 2004 NCCR included an overall rating of “fair”  
9 for estuaries, including the Great Lakes, based on evaluation of over 2000 sites. The water  
10 quality index, which incorporates nutrient effects primarily as chlorophyll-a and dissolved  
11 oxygen impacts, was also rated “fair” nationally. Forty percent of the sites were rated “good” for  
12 overall water quality, while 11% were “poor” and 49% “fair”.

### 13 **Finding 13**

14 Over the past 25 years, there has been a growing recognition of eutrophication as a serious  
15 problem in coastal estuaries (NRC, 2000). The last comprehensive national NCCR was  
16 published in 2004 (EPA, 2004) included an overall rating of “fair” for estuaries, including the  
17 Great Lakes, based on evaluation of over 2000 sites. The water quality index, which incorporates  
18 nutrient effects primarily as chlorophyll-a and dissolved oxygen impacts, was also rated “fair”  
19 nationally. Forty percent of the sites were rated “good” for overall water quality, while 11% were  
20 “poor” and 49% “fair”.

21 **Recommendation 13:** *The committee recommends that EPA develop a uniform assessment and*  
22 *management framework that considers the effects of Nr loading over a range of scales reflecting*  
23 *ecosystem, watershed, and regional levels. The framework should include all inputs. related to*  
24 *atmospheric and riverine delivery of Nr to estuaries, their comprehensive effects on marine*  
25 *eutrophication dynamics and their potential for management.*

#### 26 2.4.3.2 Aquatic thresholds for Nr

27 In aquatic ecosystems, thresholds at which excess Nr becomes a problem can be expressed as a  
28 management goal such as a total maximum daily load (TMDL) or as a critical load (CL). Under  
29 the authority of the CWA, EPA has developed guidance for establishing numeric nutrient criteria  
30 on an eco-regional basis for lakes and reservoirs, streams and rivers, estuaries and coastal waters,  
31 and wetlands. EPA has proposed specific numbers for lakes and reservoirs and rivers and  
32 streams and protocols for developing criteria for estuaries and wetlands. Each state is advised to  
33 go through an assessment to determine the best methodology for implementing numeric criteria  
34 (EPA 2000b; 2000c; 2001c; and 2007e). These criteria will identify impaired waterbodies for  
35 which TMDLs may be required.

36 The second type of threshold available for aquatic ecosystems is the critical load (CL). Unlike  
37 the TMDL, the CL (in the United States) has no regulatory framework but rather sets the  
38 threshold of Nr loading at which negative impacts have been documented. Based extensively on  
39 European work CLs for aquatic ecosystems are Nr inputs on the order of 2-15 kg N/ha/yr

1 (Bobbink et al., 2009). There are numerous locations within the United States where deposition  
2 to surface waters falls within this range.

### 3 *2.4.3.3 Water quality regulation and management*

4 Section 303 of the CWA requires states to adopt water quality standards and criteria that meet  
5 the state-identified designated uses (e.g., uses related to “fishable”, “swimmable”) for each  
6 waterbody. Specifically, “A water quality standard defines the water quality goals of a water  
7 body, or portion thereof, by designating the use or uses to be made of the water and by setting  
8 criteria necessary to protect the uses.” (40 CFR Sec. 131.2). Further, “Such standards serve the  
9 dual purposes of establishing the water quality goals for a specific water body and serve as the  
10 regulatory basis for the establishment of water-quality-based treatment controls and strategies  
11 beyond the technology-based levels of treatment required by sections 301(b) and 306 of the  
12 Act.” (40 CFR Sec. 131.2).

13 The EPA sets minimum requirements for approvable standards and criteria including: use  
14 designations; water quality criteria sufficient to protect the designated uses; and an  
15 antidegradation policy (40 CFR Sec. 131.6). Traditionally, N<sub>r</sub> and other land, air and water  
16 pollutants are measured in terms of quantity (mass) released per unit time (e.g., kg/day) or as a  
17 concentration (e.g., milligrams per liter, hereafter ml/L). Therefore, regulations often specify  
18 mass loading limits or maximum concentrations in permits.

19 In the mid-to-late 1990s, EPA began to emphasize the development of numeric nutrient criteria  
20 for both P and N through the state standards-setting process because, according to the 1996  
21 Water Quality Report to Congress (EPA 1997), 40% of the rivers, 51% of the lakes and ponds,  
22 and 57% of the estuaries assessed for the report were exhibiting a nutrient-related impairment.  
23 Few states had adopted numeric nutrient criteria for all affected waterbodies, especially for N,  
24 often relying on narrative criteria or secondary effects such as chlorophyll-a concentration,  
25 dissolved O<sub>2</sub>, or water clarity. EPA’s strategy, driven by President Clinton’s Clean Water Action  
26 Plan (EPA, 1998) mandated numeric nutrient criteria to begin to address the problem (EPA  
27 1999). To move the objectives of the Clean Water Action Plan forward, EPA published national  
28 nutrient criteria guidance for lakes and reservoirs (EPA 2000b), rivers and streams (EPA 2000c),  
29 estuaries and coastal waters (EPA 2001c), and wetlands (EPA 2007e), based upon ecoregional  
30 guidance for lakes and reservoirs and rivers and streams. To date, relatively few states have  
31 adopted new numeric criteria into their water quality standards. While some successes are  
32 evident in promulgating P criteria for freshwater systems, which has a richer history of numeric  
33 criteria incorporation into state water quality standards, development of numeric nitrogen criteria  
34 has been elusive for a variety of reasons.

35 Multimedia and multijurisdictional N management can be complicated because the CWA has  
36 little authority over atmospheric sources, and individual states explicitly lack authority to control  
37 upstream sources. Quite often in estuaries such as the Gulf of Mexico or Chesapeake Bay,  
38 management goals that meet water quality standards cannot be attained without interstate  
39 compacts or a strong federal role that may be resisted by upstream states that may have to bear  
40 the cost but do not necessarily reap the benefits of the water quality improvement. Such a

1 dilemma underscores the need for an integrated approach to Nr management.

2 Populated (urban/suburban/developed) land areas provide significant loads of Nr to the  
3 environment, both by generation (e.g., deposition of NO<sub>x</sub> emissions) and by transfer (e.g.,  
4 domestic sewage from imported food). Categorical sources include sewage treatment plants  
5 (STPs), industries, subsurface (septic) systems, atmospheric deposition, domestic animal and  
6 wildlife waste, and fertilizers used on lawns, gardens and landscapes. Infrastructure (e.g., storm  
7 sewers) and landscape conditions (e.g., increased impervious cover) more efficiently move Nr  
8 associated with surface runoff to receiving waters and may also inject or infiltrate Nr into ground  
9 water. Landscape changes, primarily increases in impervious cover, soil disturbance and  
10 compaction, and wetland/hydric soil losses, have also reduced the capacity for natural systems to  
11 treat Nr inputs by recycling or denitrification. Other disruptions in chemical condition (e.g.,  
12 acidification), biology (e.g., vegetative cover), and physical character (e.g., temperature increase)  
13 alter the nitrogen cascade, which may have both negative and positive consequences for Nr  
14 amelioration on the populated landscape and in air and water. Populated lands are estimated to  
15 export as much as 10 times the total nitrogen that was exported under pre-development  
16 conditions.

17 **Finding 14**

18 Intervention to control Nr under most water management programs generally occurs in three  
19 ways:

- 20
- 21 • Prevention or source controls
  - 22 • Physical, chemical or biological “dead ending” or storage within landscape compartments  
23 where it is rendered less harmful (e.g., long-term storage in soils or vegetation;  
24 denitrification, primarily in wetlands; reuse)
  - 25 • Treatment using engineered systems such as wastewater treatment plants or BMPs for  
26 stormwater and nonpoint source runoff.

27 While most management programs focus on the third (treatment) approach, there are opportunities  
28 for combining the three that can be more effective and cost less.

29 **Recommendation 14.** *To better address Nr runoff and discharges from the peopled landscape the  
30 committee recommends that EPA:*

31 **14a.** *Evaluate the suite of regulatory and non regulatory tools used to manage Nr in  
32 populated areas from nonpoint sources, stormwater and domestic sewage and industrial  
33 wastewater treatment facilities, including goal-setting through water quality standards and  
34 criteria. Determine the most effective regulatory and voluntary mechanisms to apply to each  
35 source type with special attention to the need to regulate nonpoint source and related land  
use practices.*

36 **14b.** *Review current regulatory practices for point sources, including both wastewater  
37 treatment plants and stormwater, to determine adequacy and capacity towards meeting  
38 national Nr management goals. Consider technology limitations, multiple pollutant benefits,  
39 and funding mechanisms as well as potential impacts on climate change from energy use and*

1 *greenhouse gas emissions, including nitrous oxide.*

2 **14c.** *Set Nr management goals on a regional/local basis, as appropriate, to ensure most*  
 3 *effective use of limited management dollars. Fully consider “green” management practices*  
 4 *such as low impact development and conservation measures that preserve or re-establish Nr*  
 5 *removing features to the landscape as part of an integrated management strategy along with*  
 6 *traditional engineered best management practices.*

7 **14d.** *Research best management practices that are effective in controlling Nr, especially for*  
 8 *nonpoint and stormwater sources, including land and landscape feature preservation and set*  
 9 *Nr management targets that realistically reflect these management and preservation*  
 10 *capacities. Construct a decision framework to assess and determine implementation actions*  
 11 *consistent with management goals.*

12 **14e.** *Use ecosystem-based management approaches that balance natural and anthropogenic*  
 13 *needs and presence in the landscape.*

14 **2.4.3.4 Attainment of water quality management goals and standards**

15 Estuarine systems, where bio-available Nr is more likely to be the limiting nutrient, are most  
 16 often susceptible to Nr enrichment (Paerl 1997; Boesch et al. 2001). Defining single number  
 17 criteria for nutrients or related indicators representative of undesirable levels of productivity  
 18 (e.g., chlorophyll *a*) is difficult, even using the ecoregional approach recommended by EPA.  
 19 State managers more often use the formal TMDL process or collaborative estuarine management  
 20 plans to set site- or estuary- specific N management targets to meet existing, related water quality  
 21 criteria (e.g., dissolved O<sub>2</sub> or chlorophyll *a*). Some of the more prominent efforts and targets for  
 22 nitrogen control are summarized in Table 18.

23 **Table 18: Estuaries with nitrogen management plans or TMDLs and percent nitrogen load**  
 24 **reduction targets**

Estuary	Nitrogen Load Reduction Target	TMDL or Plan
Casco Bay, Maine	45%	Plan
Chesapeake Bay	>40%	Plan
Northern Gulf of Mexico Mississippi Plume Region	45%	Plan
Long Island Sound	60% for CT & NY sources	TMDL
Neuse River Estuary, NC	30%	TMDL
Tampa Bay, FL	Maintain TN load at 1992-1994 levels	TMDL & Plan

25

1 These targets all exceed the national estimates for nitrogen load reductions the INC has identified  
2 in this report, which are generally less than 25% from specific source categories. Since not all  
3 sources offer management opportunities, the expectation is that reductions in Nr loadings to  
4 estuaries would cumulatively be less than 25%, which is below the targets identified in Table 18.  
5 Many of the management actions the committee has proposed would also require substantive  
6 changes in national programs, regulatory authority, management technologies and societal  
7 demands to be accomplished. This is a nutrient management concern state managers are well  
8 aware of as they develop TMDLs and management plans that range above attainment potential,  
9 not only for Nr but more frequently for other pollutants that are predominately nonpoint source  
10 and stormwater loaded (including atmospheric source contributions).

11 The Chesapeake Bay Program, for example, is a model for Nr and P management in many ways.  
12 Considerable resources were committed, and many BMPs implemented, with disappointing  
13 results. Despite regional efforts and commitments from all watershed states, and more funding  
14 than any other estuary program is likely to see, management targets have not been met, and  
15 recent data (2007) reveal the occurrence of a severe hypoxic episode. Concerns over the slow  
16 progress in restoring the Chesapeake Bay led to the issuance of an Executive Order on May 15,  
17 2009, establishing a Federal Leadership Committee led by the EPA to develop and implement a  
18 plan to restore the Bay in collaboration with state agencies (Federal Register: 74(93): 23097-  
19 23104). Similarly, the adoption of the Long Island Sound TMDL, which was driven by the  
20 presence of reactive nitrogen (see text box 3), sets an implementation plan that could attain  
21 Connecticut and New York dissolved oxygen criteria, but only if “alternative technologies” such  
22 as mechanical aeration of the Sound or biological harvesting of nutrients, are used.

### 23 **Finding 15**

24 Meeting Nr management goals for estuaries, when a balance should be struck between economic,  
25 societal and environmental needs, under current federal law seems unlikely. Enforceable  
26 authorities over nonpoint source, stormwater, air (in terms of critical loads), and land use are not  
27 adequate to support necessary Nr controls. Funding programs are presently inadequate to meet  
28 existing pollution control needs. Furthermore, new technologies and management approaches are  
29 required to meet ambitious Nr control needs aimed at restoring national water quality.

30 **Recommendation 15.** *INC recommends that EPA reevaluate water quality management*  
31 *approaches to ensure Nr management goals are attainable, enforceable, and affordable and that*  
32 *monitoring and research are adequate to problem definition and resolution, particularly in the*  
33 *development of nitrogen removal technologies.*

### 34 **Text Box 3: Long Island Sound Total Maximum DailyLoad: Focus on Reactive Nitrogen**

35 A TMDL sets a goal for reducing the load of a specific pollutant that is causing impairment to a  
36 waterbody. In the case of Long Island Sound, the impairment constitutes low concentrations of  
37 dissolved O<sub>2</sub> that violate both Connecticut’s and New York’s water quality standards. Nitrogen  
38 has been identified as the pollutant that causes substandard levels of dissolved oxygen in Long  
39 Island Sound and, accordingly, Connecticut’s and New York’s environmental agencies have  
40 developed a TMDL that assigns nitrogen reductions from both point sources (the wasteload

1 allocation or WLA) and nonpoint sources (the load allocation or LA) in their respective states to  
2 meet the established 58.5% reduction of anthropogenic sources.

3 The Long Island Sound TMDL is set at 23,966 tons of N/year, which represents a 23,834  
4 ton/year reduction from the total baseline (anthropogenic + natural sources considered) of 47,788  
5 tons/year from Connecticut and New York only. Most of that N load comes from point sources –  
6 POTWs (publicly owned treatment works) and CSOs (combined sewer overflows) – accounting  
7 for 38,899 tons/yr of the total N load from the two states, or 81% of the load. For that reason, the  
8 focus has been on managing point sources, although attainment of water quality standards will  
9 require more widespread reductions from atmospheric deposition, stormwater and nonpoint  
10 sources, and from other watershed states north of Connecticut.

11 Connecticut and New York have some flexibility in the apportionment of those reductions  
12 between the WLA and the LA, but must have completed 40% of the required reductions by 2004,  
13 75% by 2009 and 100% by 2014 when the final TMDL will be met. However, the TMDL is  
14 presently undergoing revision to incorporate findings from a new model of Long Island Sound,  
15 and to reflect changes in dissolved O<sub>2</sub> criteria in both states. The revised TMDL will likely  
16 require more aggressive reductions of nitrogen to meet dissolved O<sub>2</sub> criteria and may formalize  
17 targets for upstream state contributions and atmospheric deposition.

#### 18 *2.4.3.6 Water quality monitoring and assessment*

19 Under Sec. 106 of the CWA, the EPA provides funds to assist state and interstate agencies and  
20 tribes to conduct monitoring of the nation's waters to ensure adopted water quality criteria and  
21 designated uses are met. Further, primarily under Sec. 305(b) of the CWA, those entities are  
22 required to report, on a biennial basis, on the health and status of their jurisdictional waters.  
23 These assessments are presented by the states to the EPA to categorize attainment of designated  
24 uses. EPA has published these reports up until 1998 (EPA 2000a), after which it transitioned  
25 into a Water Quality Report in 2000 (EPA 2002) and a National Assessment Database in 2002  
26 (<http://www.epa.gov/waters/305b/index.html>). States also prepare a list of "impaired" waters  
27 under Sec. 303(d) of the CWA (EPA, 1999). Subsequent reports will provide a synthesis of  
28 CWA Sec. 305(b) and 303(d) reporting under a Consolidated Assessment and Listing  
29 Methodology or "CALM" approach.

30 The EPA compiles the approved state 303(d) lists into a national listing  
31 ([http://iaspub.epa.gov/waters/national\\_rept.control](http://iaspub.epa.gov/waters/national_rept.control)). The list provides information by state as  
32 well as by impairment cause, and identifies the TMDLs completed to date. The most current data  
33 available on the EPA Web site includes reporting from most entities through 2004. The report  
34 identifies 5,617 impairments related to "nutrients" (almost 9% of all identified impairments),  
35 although other impairments may ultimately have a nutrient enrichment cause. For example,  
36 oxygen depletion (4,540), turbidity (2,050), algal growth (510), ammonia (generally toxicity –  
37 416), and HABS (4) can all have a common cause such as N or P enrichment. It should also be  
38 clear that impairments may have multiple causes so, for example, waters identified as impaired  
39 by O<sub>2</sub> depletion may also be impaired by nutrients.

40 There are other initiatives promoted by EPA to monitor and assess the nation's waters, generally

1 implemented in collaboration with, or by, the state and interstate agencies and tribes having  
2 jurisdiction over the waters. These include the Wadeable Stream Assessment (WSA) (EPA  
3 2006a), the National Coastal Assessment (NCA) and its National Coastal Condition Reports  
4 (EPA 2001a, 2004, and 2006b), the Survey of the Nation's Lakes and Survey of the Nation's  
5 Rivers and Streams, and, more recently, probabilistic monitoring efforts in lakes, streams and  
6 estuaries (<http://www.epa.gov/owow/monitoring/reporting.html>). Many of these are aimed at  
7 including a biological assessment component that is often lacking in water pollutant and  
8 chemistry efforts described above.

9 The National Oceanic and Atmospheric Administration has periodically produced estuarine  
10 assessments under the National Estuarine Eutrophication Assessment (NEEA) program. The  
11 most recent report was released in 2007 (Bricker et al., 2007). The report has a focus on nutrient  
12 enrichment and its manifestations in the estuarine environment and relies on participation and  
13 interviews of local experts to provide data for the assessment. Among the key findings were:

- 14 • Eutrophication is a widespread problem, with the majority of assessed estuaries  
15 showing signs of eutrophication—65% of the assessed systems, representing 78%  
16 of assessed estuarine area, had moderate to high overall eutrophic conditions.
- 17 • The most common symptoms of eutrophication were high spatial coverage and  
18 frequency of elevated chlorophyll *a* (phytoplankton)—50% of the assessed  
19 estuaries, representing 72% of assessed area, had excessive chlorophyll *a* ratings.  
20

## 21 **2.4.4 Reactive nitrogen and air quality**

### 22 *2.4.4.1 Impacts of Nr on atmospheric systems*

23 The atmosphere is 78% N, mostly N<sub>2</sub>, with just trace amount of Nr. The former has a long  
24 residence time (millions of years) and has no negative impact on ecosystems or humans. With  
25 one exception, the N species that constitute Nr (see footnote in the Executive Summary and  
26 Chapter 2) have residence times of less than a year (many on the order of days), and contribute to  
27 all the negative impacts associated with excess Nr in the atmosphere. In addition, the exception  
28 (N<sub>2</sub>O), with a residence time of over a century, also contributes to negative impacts on  
29 ecosystems and humans.

30 The atmosphere receives Nr mainly as air emissions of NO<sub>x</sub>, NH<sub>3</sub>, and N<sub>2</sub>O from aquatic and  
31 terrestrial ecosystems and of NO<sub>x</sub> from combustion of biomass or fossil fuels. Once emitted NO<sub>x</sub>  
32 can be transformed into a variety of oxidized N species. Ultimately much of the NO<sub>x</sub> is  
33 converted to HNO<sub>3</sub>, which is either converted to an aerosol (e.g., ammonium nitrate) or  
34 deposited on land, surface waters, or other surfaces. NH<sub>3</sub> emitted to the atmosphere is either  
35 deposited or transformed into an ammonium aerosol (e.g., ammonium bisulfate or ammonium  
36 sulfate). Before deposition, NH<sub>4</sub><sup>+</sup> aerosols contribute to fine particulate matter and regional haze  
37 concentrations in the atmosphere. Due to the short residence time of NO<sub>x</sub>, NH<sub>3</sub> and their  
38 reaction products, can only accumulate in the troposphere on a regional scale. Almost all Nr  
39 emitted as NO<sub>x</sub> and NH<sub>3</sub> is transferred back to Earth's surface within hours to days.

40 Six major atmospheric effects are associated with increased NO<sub>x</sub> and NH<sub>3</sub> emissions, and two

1 with N<sub>2</sub>O emissions (Galloway et al., 2003). For NO<sub>x</sub> and NH<sub>3</sub> emissions they are: (1) fine PM  
2 decreases atmospheric visibility; (2) elevated ozone concentrations enhance the greenhouse  
3 potential of the atmosphere; (3) ozone and fine particulate matter have serious impacts on human  
4 health (Brunekreef et al. 2005, Brook et al. 2003, Pope 2000a, 2000b Pope et al. 1995, Pope  
5 2009); (4) NH<sub>3</sub> plays an important role in the direct and indirect effects of aerosols on radiative  
6 forcing and thus on global climate change (Seinfeld and Pandis 1998, Penner et al. 2001;  
7 Lelieveld et al. 2001; Myhre, 2009); (5) ozone deposition can decrease productivity of crops,  
8 forests, and natural ecosystems; and (6) atmospheric deposition of NH<sub>3</sub>, NO<sub>y</sub>, and organic  
9 forms of Nr can contribute to ecosystem acidification, fertilization, and eutrophication. For N<sub>2</sub>O  
10 they are: (1) the greenhouse effect in the troposphere and, (2) O<sub>3</sub> depletion in the stratosphere.

#### 11 2.4.4.2 Clean Air Act and air quality regulation and management

12 The modern history of American air pollution control legislation begins with the 1963 Clean Air  
13 Act (CAA) which, along with its amendments, requires the EPA to establish and revise National  
14 Ambient Air Quality Standards (NAAQS's) and to prepare state of the science reviews such as  
15 the Criteria Documents and more recently the Integrated Science Assessments (ISA) (EPA  
16 2004, 2006, 2007). There are six criteria pollutants, carbon monoxide, lead, NO<sub>2</sub>, ozone, SO<sub>2</sub>,  
17 and PM. These have been determined to endanger public health or welfare. The CAA as  
18 currently written requires a review of the scientific criteria for these standards at five-year  
19 intervals. Although NO<sub>2</sub> is the only Nr compound specified as a criteria pollutant, NH<sub>x</sub> and NO<sub>y</sub>  
20 play a major role in formation of the secondary pollutants ozone and particulate matter.

21 The CAA has been amended several times since its inception. In 1970, the CAA was amended  
22 "to provide for a more effective program to improve the quality of the nation's air." The CAA  
23 was again amended again in 1977, primarily to mandate reductions of emissions from  
24 automobiles. Despite evidence that NO<sub>x</sub> is the central pollutant in photochemical smog  
25 formation (Chameides and Walker, 1973; Crutzen, 1973; 1974; Fishman and Crutzen, 1978;  
26 Fishman, et al., 1979) federal regulations did not require automobiles to control NO<sub>x</sub> emissions  
27 to below 1 g/mi (0.14 g N per km<sup>3</sup>) until 1981. Few locales violate the standards for NO<sub>2</sub>, but the  
28 secondary effects of several these gases are also pose health and welfare concerns. If a city had  
29 an annual average NO<sub>2</sub> level anywhere near the NAAQS for NO<sub>2</sub>, it would risk severe  
30 photochemical smog – the summertime efficiency for ozone production ranges from 4 to 10 ppb  
31 O<sub>3</sub> per ppb NO<sub>x</sub>.

32 The focus on compliance monitoring for NO<sub>2</sub> ignores the other, equally important members of  
33 the NO<sub>y</sub> family such as HNO<sub>3</sub> that deposits quickly onto the Earth's surface. It is clear that a  
34 causal relationship between current levels of N and S deposition and numerous biologically  
35 adverse effects on ecosystems across the United States exists (EPA 2008)."Conversion of the  
36 existing network of NO<sub>x</sub> monitors to NO<sub>y</sub> monitors with a detection limit of 0.1 ppb would still  
37 demonstrate compliance with the NO<sub>2</sub> standard but greatly increase the utility of the  
38 measurements for model evaluation as well as for understanding nitrate deposition and formation  
39 of photochemical smog, and haze.

40 Air pollution, especially ozone and PM, continued to be a problem in many American cities and  
41 the CAA was again amended in 1990. The Nr-relevant aspects were aimed at controlling urban

1 smog and acid deposition. States were required to develop emissions inventories for reactive  
2 organic compounds, carbon monoxide, and  $\text{NO}_x$ , but not  $\text{NH}_3$  or  $\text{N}_2\text{O}$ . Over the United States,  
3 sulfate and nitrate are responsible for about 2/3 and 1/3 respectively of the direct deposition of  
4 acids. The CAA Amendment of 1990 required emissions decreases of 10 million tons of  $\text{SO}_2$   
5 and 2 million tons of  $\text{NO}_x$  relative to 1980 levels. Ammonia and ammonium, although they  
6 contribute to acidity after entering terrestrial ecosystems (Galloway, et al., 2003; NRC, 2003)  
7 and are expected to play an increasing role (Pinder et al., 2008) were not regulated by this  
8 legislation.

9 The 1997 revision of the CAA changed the standards for ozone and PM (see Table 3-23). A  
10 sizable fraction of the mass of PM less than 2.5 microns,  $\text{PM}_{2.5}$ , is condensed Nr. As stated  
11 above, these particles have adverse health consequences. PM is also controlled by the Regional  
12 Haze Regulations. By the year 2064, states must restore Class I areas to their natural levels of  
13 atmospheric clarity (EPA 2004).

14 Ozone and PM, the two most recalcitrant of the criteria pollutants, cover large spatial scales.  
15 These secondary pollutants are not released at the tailpipe; rather they form in the atmosphere.  
16 Violations are declared on urban scales, responsibility for their control was assigned to States,  
17 but the physics and chemistry of smog and haze are regional. In the eastern United States, ozone  
18 episodes often cover several states and involve pollutants emitted in upwind states that do not  
19 themselves experience violations (Chen, et al., 2003; Husar, et al., 1977; Logan, 1989; Moy, et  
20 al., 1994; Ryan, et al., 1998). The 1990 amendments to the Clean Air Act established, in part as  
21 a response to this scaling problem, the Ozone Transport Assessment Group (OTAG) and the  
22 Ozone Transport Commission (OTC). These have jurisdiction extending from Washington, DC  
23 to Maine. Progress has been made on regional control of emissions; the  $\text{NO}_x$  SIP call,  
24 implemented in 2003 and 2004, has led to measurable improvements in ambient ozone and  
25 nitrate levels (Gego, et al., 2007; Sickles and Shadwick, 2007). Experiences with ozone and PM  
26 provide a useful demonstration of why it is necessary to develop an integrated approach to  
27 management of Nr.

1 **Table 19: Federal primary ambient air quality standards that involve Nr, effective**  
 2 **January 2008. Secondary standards are currently identical to the primary standards**

Pollutant	Federal Primary Standard (NAAQS)
<b>Ozone (O<sub>3</sub>)</b>	
1-hr average	0.12 ppmv
8-hr average	0.08 ppmv
<b>Nitrogen Dioxide (NO<sub>2</sub>)</b>	
Annual average	0.053 ppmv (100 µg/m <sup>3</sup> )
<b>Particulate Matter, coarse (PM<sub>10</sub>)</b>	
Diameter ≤ 10 µm, 24-hr average	150 µg/m <sup>3</sup>
Annual average	50 µg/m <sup>3</sup>
<b>Particulate Matter, fine (PM<sub>2.5</sub>)</b>	
Diameter ≤ 2.5 µm, 24-hr average	35 µg/m <sup>3</sup>
Annual average	15 µg/m <sup>3</sup>

3  
 4 *2.4.4.3. Atmospheric thresholds for Nr*

5 As shown in Table 19 the metric used for safe, upper limits in the atmospheric  
 6 environment is concentration (in mass per unit volume of air or volume mixing ratios) averaged  
 7 for a given time period, usually 1 hr, 8 hr, 24 hr, or annually. The thresholds for excess Nr in the  
 8 atmosphere remain an area of active research. The only Nr compound for which there is  
 9 currently a NAAQS is NO<sub>2</sub>, which may not exceed 0.053 ppm (100 µg/m<sup>3</sup>) for the annual  
 10 arithmetic mean. This standard, based on the direct health effects, is certainly inadequate  
 11 because NO<sub>2</sub> concentrations well below 0.053 ppm lead to concentrations of secondary  
 12 pollutants well above acceptable levels (i.e., PM<sub>2.5</sub> and O<sub>3</sub>). The NO<sub>2</sub> concentration required to  
 13 achieve the current 75 ppb ozone standard has not been rigorously established, but it must be  
 14 well below 0.053 ppm, because areas currently in violation of the ozone standard typically have  
 15 NO<sub>2</sub> concentrations below 0.020 ppm (<http://www.epa.gov/air/airtrends/nitrogen.html>). The NO<sub>2</sub>  
 16 concentration required to achieve the current 15 µg/m<sup>3</sup> PM<sub>2.5</sub> standard is probably also below the  
 17 100 µg/m<sup>3</sup> standard for NO<sub>2</sub> because of the role of NO<sub>2</sub> in secondary particulate formation.

18 The INC is recommending that NO<sub>x</sub> emissions be decreased by 2 Tg N/yr, relative to the  
 19 baseline level in 2002. Emissions decreases implemented since 2002 have already substantially

1 improved (Gégo, et al., 2007) ozone concentrations. The absolute amount of decrease and the  
2 positive impact it would have on human health is region dependent, but further decreases will  
3 result in further beneficial decreases in PM<sub>2.5</sub> and O<sub>3</sub> concentrations.

4 The threshold for total Nr in the atmosphere are yet to be fixed, but depends on its rate of  
5 deposition to the surface and the sensitivity of the receptor(s). The immediate need for  
6 determining thresholds for atmospheric Nr is monitoring of NO<sub>y</sub> and NH<sub>x</sub>.

## 7 **2.4.5 Reactive Nitrogen and terrestrial ecosystems**

### 8 *2.4.5.1 Impacts of Nr on terrestrial ecosystems*

9 In many terrestrial ecosystems the supply of biologically available Nr is a key factor controlling  
10 the nature and diversity of plant life, and vital ecological processes such as plant productivity and  
11 the cycling of carbon and soil minerals. Human activities have not only increased the supply but  
12 enhanced the global movement of various forms of nitrogen through air and water.

13 The primary source of excess Nr for most unmanaged terrestrial ecosystems is atmospheric  
14 deposition. This additional Nr causes a wide variety of sometimes beneficial effects (increased  
15 growth and productivity of forests, natural grasslands, and crops planted in nutrient deficient  
16 soils) and also sometimes adverse effects on terrestrial and aquatic ecosystems in many parts of  
17 our country. Forests and grasslands exposed to excess Nr can respond in numerous ways.  
18 General effects include the following (Cowling, 1989, Cowling et al. 1990, Cowling et al. 2002,  
19 Garner et al.1989, Woodman and Cowling1987; Vitousek et al., 1997):

- 20 1. Increased productivity of forests soils most of which are Nr-limited throughout  
21 the United States, Nr deficiency of forest soils has been most fully quantified for  
22 pine forests in 14 southeastern states
- 23 2. Acidification of forest soils leading to decreased availability of nutrient cations  
24 including calcium, magnesium, and potassium and aluminum toxicity, established  
25 most clearly in the eastern United States and both central and northern Europe
- 26 3. Nr saturation of forest soils, presently occurring mainly in high-elevation forests  
27 of the eastern United States and southeastern Canada
- 28 4. Ozone-induced predisposition of forest trees to damage by fungal diseases and  
29 insect pests, most clearly established in the case of root disease and bark beetles  
30 in the pine forests of southern California
- 31 5. Ozone-induced inhibition of photosynthesis in both softwood and hardwood tree  
32 species most clearly established in controlled exposure studies in both the United  
33 States and Europe at ambient concentrations of ozone above 60 ppb. Such  
34 concentrations occur frequently throughout the eastern United States and  
35 southeastern Canada
- 36 6. Ozone induced direct injury to foliage, most clearly established in the case of  
37 “emergence tip burn” in eastern white pine
- 38 7. Acidification induced decrease in frost hardiness of high-elevation conifer forests,  
39 most clearly established in the case of red spruce in the northeastern United States
- 40 8. Acidification induced alteration of beneficial symbiotic relationships in forest

- 1 soils, especially mycorrhizae, most clearly established in both northern and  
2 central Europe
- 3 9. Biodiversity losses in natural grasslands and forest areas caused by Nr induced  
4 decreases in abundance of Nr-limited tree and grass species and replacement by  
5 Nr-loving weed species, most clearly established in both Minnesota and  
6 California, and even more vividly in The Netherlands
- 7 10. Decreases in visibility and increased haziness of the atmosphere at scenic vistas in  
8 national and state parks and wilderness areas
- 9 11. More leaching of Nr to aquatic systems via both groundwater and surface runoff –  
10 a cascade effect

11

#### 12 *2.4.5.2 Nr saturation and ecosystem function*

13 There are limits to how much plant growth can be increased by N fertilization. At some point,  
14 when the natural N deficiencies in an ecosystem are fully relieved, plant growth becomes limited  
15 by availability of other resources such as phosphorus, calcium, or water and the vegetation can  
16 no longer respond to further additions of Nr. In theory, when an ecosystem is fully Nr-saturated  
17 and its soils, plants, and microbes cannot use or retain any more, all new Nr deposits will be  
18 dispersed to streams, groundwater, and the atmosphere. Nr saturation has a number of damaging  
19 consequences for the health and functioning of ecosystems. These impacts first became apparent  
20 in Europe almost three decades ago when scientists observed significant increases in nitrate  
21 concentrations in some lakes and streams and also extensive yellowing and loss of needles in  
22 spruce and other conifer forests subjected to heavy Nr deposition. In soils, most notably forest  
23 soils because of their natural low pH, as  $\text{NH}_4^+$  builds up it is converted to nitrate by bacterial  
24 action, a process that releases hydrogen ions and contributes to soil acidification. The buildup of  
25  $\text{NO}_3^-$  enhances emissions of nitrous oxides from the soil and also encourages leaching of highly  
26 water-soluble  $\text{NO}_3^-$  into streams or groundwater. As negatively charged  $\text{NO}_3^-$  seeps away,  
27 positively charged alkaline minerals such as calcium, magnesium, and potassium are carried  
28 along. Thus, soil fertility is decreased by greatly accelerating the loss of calcium and other  
29 nutrients that are vital for plant growth. As calcium is depleted and the soil acidified, aluminum  
30 ions are mobilized, eventually reaching toxic concentrations that can damage tree roots or kill  
31 fish if the aluminum washes into streams (Vitousek et al. 1997).

32 Forests, grasslands, and wetlands vary substantially in their capacity to retain added nitrogen.  
33 Interacting factors that are known to affect this capacity include soil texture, degree of chemical  
34 weathering of soil, fire history, rate at which plant material accumulates, and past human land  
35 use. However, we still lack a fundamental understanding of how and why N-retention processes  
36 vary among ecosystems much less how they have changed and will change with time (Vitousek  
37 et al. 1997).

38 An over-arching impact of excess Nr on unmanaged terrestrial ecosystems is biodiversity loss.  
39 In North America, dramatic reductions in biodiversity have been created by fertilization of  
40 grasslands in Minnesota and California. In England, N fertilizers applied to experimental  
41 grasslands have led to similarly increased dominance by a few N-responsive grasses and loss of  
42 many other plant species. In formerly species-rich heathlands across Western Europe, Nr  
43 deposition has been blamed for great losses of biodiversity in recent decades, with shallow soils

1 containing few alkaline minerals to buffer acidification (Vitousek et al. 1997; Bobbink et al.,  
2 2009).

3 Losses of biodiversity driven by Nr deposition can in turn affect other ecological processes.  
4 Experiments in Minnesota grasslands showed that in ecosystems made species-poor by  
5 fertilization, plant productivity was much less stable in the face of a major drought. Even in non-  
6 drought years, the normal vagaries of climate produced much more year-to-year variation in the  
7 productivity of species-poor grassland plots than in more diverse plots (Vitousek et al. 1997).

#### 8 *2.4.5.3 Thresholds for excess Nr effects on terrestrial ecosystems*

9 In parallel with the original concept of critical loads developed by Nilsson and Grennfelt in 1988  
10 and now widely used for air quality management in Europe, thresholds in general and critical  
11 loads specifically for Nr effects on terrestrial ecosystems in the United States should be  
12 understood to be “quantitative estimates of exposure to air concentrations of Nr compounds  
13 below which harmful effects on specified sensitive elements within ecosystem of concern do not  
14 occur according to present knowledge”(Nilsson and Grennfelt, 1988; Heittelingh et al, 2001).

15  
16 In developing these quantitative estimates of thresholds and/or critical loads for terrestrial  
17 ecosystems in the United States (e.g., Fenn et al., 2002), it is imperative to understand the  
18 extraordinarily wide diversity of types and Nr-sensitivity of various components of terrestrial  
19 ecosystems in various parts of the United States and the huge differences in purposes and  
20 intensity of management and public perceptions of the value of these components to various  
21 sectors of American society. Thus, the critical loads appropriate for maintaining species  
22 diversity in a natural grasslands in northern Minnesota or a wilderness area in the Mediterranean  
23 climate of southern California are likely to be very different from those for direct effects on  
24 similar systems in other regions of the United States. -- or even for beneficial and/or adverse  
25 effects on other components of the same terrestrial ecosystem. For example, the threshold or  
26 critical load for adverse effects of excess Nr on understory vegetation, beneficial mycorrhizae or  
27 lichen communities in a forest ecosystem is likely to be very different from the threshold for  
28 adverse effects on the dominant forest trees in that same ecosystem. Thus, public perceptions of  
29 “specified sensitive elements within the ecosystem” may be important in determining what  
30 specific thresholds or critical loads should be considered in order to minimize or avoid specific  
31 adverse effects of concern.

32  
33 At present, the sum total of directly measured wet- plus dry-deposited chemically oxidized ( $\text{NO}_y$ )  
34 and chemically reduced ( $\text{NH}_x$ ) inorganic Nr loads in various states within the contiguous states  
35 of United States are of the order of 3 to 15 kg N/ha/year (National Atmospheric Deposition  
36 Program (NADP 2008, CASTNET 2008). As shown in Figure 15, a three-year run of CMAQ  
37 model also provided estimates of the average annual total Nr loads, including organic forms as  
38 well as inorganic  $\text{NO}_y$  and  $\text{NH}_x$  forms of Nr) in the contiguous states of the United States. These  
39 model estimates varied from minimal deposition values of about 3 kg N/ha/year to maximum  
40 estimated values of about 17 kg N/ha/year. This range agrees well with the range of the  
41 measurements.

42  
43 These directly measured and modeled estimates of total (wet-plus-dry) deposition of organic and

1 inorganic forms of Nr indicate that there are several areas, especially in the eastern United States  
2 and a few areas of the western United States, where current total Nr loads are already very close  
3 to- or will very likely soon exceed the recommended threshold and critical load estimates  
4 provided by Bobbink et al (2009) in their excellent review of scientific evidence regarding the  
5 impacts of atmospheric nitrogen deposition on plant diversity in terrestrial ecosystems.

#### 6 7 **2.4.6 Additional comments on Nr critical loads**

8 In recent years, the Acid Rain Action Plan developed by New England governors and eastern  
9 Canadian Premiers has led to evaluations of critical loads to surface waters and forests in that  
10 region. Those studies identified many waters and forest lands that met or exceeded critical load  
11 capacity for combined sulfur and nitrogen deposition both in the New England States, as well as  
12 in the eastern Canadian provinces. The plan set target decreases of 20 to 30% for nitrogen oxide  
13 emissions by 2007 and a 50% decrease in sulfur dioxide emissions by 2010. These targets are  
14 intended to decrease long-range transport of air pollutants, acid deposition, and nutrient  
15 enrichment of marine waters in this region.

16 In May 2006, a Multi-Agency Critical Loads Workshop was held which led to the formation of a  
17 Critical Loads Ad-Hoc Committee (CLAD) within the National Atmospheric Deposition  
18 Program (NADP) to, among other goals, “Provide consistency in development and use of critical  
19 loads in the United States.” One outcome is a project undertaken by the Northeast States for  
20 Coordinated Air Use Management (NESCAUM) to: estimate critical loads of sulfur and nitrogen  
21 in atmospheric deposition for areas where sufficient knowledge, data, and methods exist” and “to  
22 demonstrate the use of critical loads as a tool for assessing environmental policies and programs  
23 and managing natural resources.”

24 A February 2007 Workshop sponsored by EPA on “The Assessment of Health Science for the  
25 Review of the National Ambient Air Quality Standards (NAAQS) for Nitrogen (NO<sub>x</sub>) and Sulfur  
26 Oxides (SO<sub>x</sub>)” expansively reviewed both ecosystem as well as human health effects toward  
27 revision of the NAAQS. In policy discussions at this workshop it was asked if critical loads  
28 assessments were an effective means of improving ecosystem management and if the science  
29 was understood well enough to use critical loads as a management tool. The conclusion was that  
30 although there was a substantial body of accumulated scientific evidence there was only limited  
31 use of critical loads approaches for management of air quality in the United States. The Multi-  
32 Agency Workshop on Critical Loads mentioned above was cited at this workshop as an agenda-  
33 setting effort to resolve some of the science and policy issues that could help advance critical  
34 loads approaches in the United States.

#### 35 **Finding 16**

36 In this connection, the INC strongly commends EPA for its recently increased willingness to  
37 think more holistically – and in more fully integrated ways – about both the policy-relevant  
38 science and the practical arts of air quality management aimed at protection of both aquatic and  
39 terrestrial ecosystems from adverse effects of Nr. These shifts in both emphasis and approach  
40 have included:

- 1) Increased emphasis in the NAAQS review processes on scientific questions that are as directly relevant as possible to well-defined policy questions of concern to EPA;
- 2) More frequent discussion about both public-welfare and public-health impacts of mixtures of air pollutants;
- 3) More frequent discussion about the critical loads concept as an alternative or complement to the more familiar NAAQS Standards;
- 4) Separation of the preparation and review of documentation for a Secondary (public-welfare-based) NAAQS from the (previously always dominating) Primary (public-health-based) NAAQS review processes;
- 5) The decision by the Science Advisory Board of EPA to establish this special Integrated Nitrogen Committee (INC); and
- 6) The unprecedented decision to undertake an integrated (simultaneous) review // of the Secondary NAAQS for two Criteria Pollutants at the same time [Oxides of Nitrogen (NO<sub>x</sub>) and Oxides of Sulfur (SO<sub>x</sub>)].

Especially notable evidence for EPA's "increased willingness to think more holistically – and in more fully integrated ways" is the following statement of Conclusion in the Executive Summary of the December 2008 Integrated Science Assessment for Oxides of Nitrogen and Sulfur (EPA, 2008):

The main effects of N and S pollution assessed in the ISA are acidification, N enrichment, and Hg methylation. Acidification of ecosystems is driven primarily by deposition resulting from SO<sub>x</sub>, NO<sub>x</sub>, and NH<sub>x</sub> pollution. Acidification from the deposition resulting from current emission levels causes a cascade of effects that harm susceptible aquatic and terrestrial ecosystems, including slower growth and injury to forests and localized extinction of fishes and other aquatic species. In addition to acidification, atmospheric deposition of reactive N resulting from current NO<sub>x</sub> and NH<sub>x</sub> emissions along with other non-atmospheric sources (e.g., fertilizers and wastewater), causes a suite of ecological changes within sensitive ecosystems. These include increased primary productivity in most N-limited ecosystems, biodiversity losses, changes in C cycling, and eutrophication and harmful algal blooms in freshwater, estuarine, and ocean ecosystems.

In addition, the committee finds that there have been persistent increases in the amounts of Nr that have been emitted into and retained within various ecosystems, affecting their functioning. Unless this trend is reversed, it will become increasingly difficult for many of these ecosystems to provide the services upon which human well-being is dependent. The committee believes that there is a need to regulate certain forms of Nr to address specific problems related to excess Nr, and we believe that the best approach for an overall management strategy is the concept of defining acceptable total Nr critical loads for a given environmental system.

**Recommendation 16.** *The committee recommends that the Agency work toward adopting the critical loads approach concept in determining thresholds for effects of excess Nr on terrestrial and aquatic ecosystems. In carrying out this recommendation the committee recognizes that it will in many cases be necessary for the Agency to enter into new types of research, policy, and regulatory agreements with other Federal, State, and Tribal units based on cooperative,*

1 *adaptive, and systemic approaches that derive from a common understanding of the nitrogen*  
2 *cascade.*

3 The European Union has undertaken broad measures, based on the critical loads concept, to  
4 manage Nr. Tables 20, 21, and 22 summarize several different environmental impacts, currently  
5 used indicators, and whether there are current limit values set by the United Nations Economic  
6 Commission for Europe (UNECE) or European Union (EU). These tables identify the main  
7 links to the cascade of reactive nitrogen in the environment, the relevance and link to Nr of the  
8 effect/pollutant, and existing agreements in which the effect is currently addressed. In addition,  
9 some impacts are more relevant than others in relation to societal importance and the connection  
10 to the nitrogen cascade. The categorization on a scale of 1 (highest relevance) to 5 (unimportant)  
11 provides a first level prioritization for future mitigation activity. The last column summarizes  
12 existing links to international regulations and conventions.

13 Where there is a limit and the relevance for the nitrogen cascade is high, then this might be the  
14 limiting factor for Nr production and its associated losses to the environment. Some limits might  
15 be more relevant in specific areas and less relevant in others. For example NO<sub>2</sub> concentrations  
16 relevant for human health are limited to 40 ppb in urban areas, limiting industry and traffic, but  
17 are probably not an issue in remote areas with low population densities. In these areas, however,  
18 loss of biodiversity might limit nitrogen deposition and therewith the sources in the region. The  
19 only way to determine the extent that critical thresholds are limiting is by overlaying them for  
20 different regions and determining by monitoring data or by model exercises where and which  
21 sources contribute to exceeding the critical threshold, and then identifying the best methods for  
22 putting caps on relevant sources. A pre-classification of regions might be useful, e.g. urban  
23 regions, remote regions, marine areas, etc.

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1 One aspect of this global view of nitrogen impacts and metrics that is evident is the mix of  
 2 “classical”- and “service”-based categories, consistent with the need for an integrated approach  
 3 to the management of nitrogen.

4 **Table 20: Summary of the effects of excess Nr on human health in relation to metrics,**  
 5 **current international regulations and conventions, and the link to the nitrogen cascade**

	Metrics	Regulated?	Link to Nr cascade	Relevance*	Regulatory or political convention
<b>Respiratory disease in people caused by exposure to high concentrations of:</b>					
<b>Ozone</b>	Sum of ozone over 35 ppb	Y	NO <sub>x</sub> emissions	3	Convention on Long-range Transboundary Air Pollution  Clean Air for Europe
<b>other photochemical oxidants</b>	Org. NO <sub>3</sub> , PAN conc (atm)	N	NO <sub>x</sub> emissions	5	indirectly Convention on Long-range Transboundary Air Pollution et al.
<b>fine particulate aerosol</b>	PM <sub>10</sub> , PM <sub>2.5</sub> conc (atm)	Y	NO <sub>x</sub> , NH <sub>3</sub> em	1	Convention on Long-range Transboundary Air Pollution  Clean Air for Europe
<b>direct toxicity of nitrite NO<sub>2</sub><sup>-</sup></b>	NO <sub>2</sub> <sup>-</sup> conc	Y	NO <sub>x</sub>	2	World Health Organization  Convention on Long-range Transboundary Air Pollution  Clean Air for Europe
<b>Nitrate contamination of drinking water</b>	NO <sub>3</sub> <sup>-</sup> conc (aq.)	Y	NO <sub>3</sub> <sup>-</sup> leaching	2	EU Essential Facilities Doctrine
<b>Depletion of stratospheric ozone</b>	NO <sub>x</sub> , N <sub>2</sub> O conc/flux (atm)	N	NO <sub>x</sub> , N <sub>2</sub> O	3	Montreal Protocol
<b>Increase allergenic pollen production, and several parasitic and infectious human</b>		N		5	None

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<i>Blooms of toxic algae and decreased swimability of in-shore water bodies</i>	Chlorophyll a NO <sub>3</sub> <sup>-</sup> (&P) conc (aq)	N	Runoff, Nr deposition	1	Convention for the Protection of the Marine Environment of the North-East Atlantic  Helsinki Commission  Barcelona Convention
---	--	---	-----------------------	---	---

- 1 \*Relevance and link to nitrogen incorporates societal priority and N contribution: 1) highest relevance, 2) high  
 2 relevance, 3) significant relevance, 4) some relevance, 5) unimportant.

1  
2  
3  
4

**Table 21: Summary of the effects of excess nitrogen on ecosystems related to currently used metrics, the existence of European regulatory values, and the link to the nitrogen cascade**

	<b>Metrics</b>	<b>Regulated?</b>	<b>Link to Nr cascade</b>	<b>Relevance*</b>	<b>Regulatory or political convention</b>
<b>Ozone damage to crops, forests, and natural ecosystems</b>	AFstY (O <sub>3</sub> flux), AOT40	Y	NO <sub>x</sub>	2	Convention on Long-range Transboundary Air Pollution  Clean Air for Europe
<b>Acidification effects on terrestrial ecosystems, ground waters, and aquatic ecosystems</b>	Critical loads	Y	Nr deposition	2	Convention on Long-range Transboundary Air Pollution  Clean Air for Europe WFD
<b>Eutrophication of freshwaters, lakes (incl. biodiversity)</b>	Biological Oxygen Demand, NO <sub>3</sub> <sup>-</sup> conc (aq)  Critical loads	Y  N	Runoff, Nr deposition	3	Water Framework Directive
<b>Eutrophication of coastal ecosystems inducing hypoxia (incl. biodiversity)</b>	BOD, NO <sub>3</sub> <sup>-</sup> conc (aq)  Critical loads	BOD, NO <sub>3</sub> <sup>-</sup> conc (aq)  Critical load	Runoff, Nr deposition	1	Convention for the Protection of the Marine Environment of the North-East Atlantic  Helsinki Commission  Barcelona Convention
<b>Nitrogen saturation of soils (incl. effects on GHG balance)</b>	Critical loads	Y	Nr deposition	1	Convention on Long-range Transboundary Air Pollution  Clean Air for Europe

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<b>Biodiversity impacts on terrestrial ecosystems (incl. pests and diseases)</b>	Critical loads, critical levels (NH <sub>3</sub> , NO <sub>x</sub> )	Y	Nr deposition	1	Convention on Long-range Transboundary Air Pollution  Clean Air for Europe,  Convention on Biological Diversity
--	--	---	---------------	---	---

1 \*Relevance and link to nitrogen incorporates societal priority and N contribution: 1) highest relevance, 2) high  
 2 relevance, 3) significant relevance, 4) some relevance, 5) unimportant.

3

4

1 **Table 22: Summary of the effects of excess N on other societal values in relation to metrics**  
 2 **and regulatory values in current international regulations and conventions and the link to**  
 3 **the nitrogen cascade.**

	Metrics	Regulated?	Link to Nr cascade	Relevance*	Regulatory or political convention
<b>Odor problems associated with animal agriculture</b>	Acidity in prec., prec./T O <sub>3</sub> ,  PM	Y	NO <sub>x</sub> , NH <sub>3</sub>	3	Convention on Long-range Transboundary Air Pollution
<b>Effects on monuments and engineering materials</b>	PM <sub>2.5</sub> conc (atm)	N	NO <sub>x</sub> , NH <sub>3</sub>	4	
<b>Global climate warming induced by excess nitrogen</b>	N <sub>2</sub> O, conc/flux (atm)	N	NO <sub>x</sub> , NH <sub>3</sub>	1	United Nations Framework Convention on Climate Change
<b>Regional climate cooling induced by aerosol)</b>	PM <sub>2.5</sub> conc (atm)	N	NO <sub>x</sub> , NH <sub>3</sub>	1	United Nations Framework Convention on Climate Change

4 \*Relevance and link to nitrogen incorporates societal priority and N contribution: 1) highest relevance, 2) high  
 5 relevance, 3) significant relevance, 4) some relevance, 5) unimportant.

#### 6 **2.4.7 Tradeoffs of Nr impacts**

7 Because N is such an abundant and widespread element, and Nr such a critical component of the  
 8 Earth's biosphere, associated impacts are many and pervasive. In many cases the impacts of Nr  
 9 involve tradeoffs, i.e. mitigating one type of impact may exacerbate others. Given the  
 10 interactions among oxidized and reduced N species, it is important to recognize the potential for  
 11 unintended consequences to occur as a result of strategies aimed at limiting one form of Nr in air  
 12 or water that can lead to the increased production of other forms of Nr, or the formation and  
 13 release of other contaminants of concern. For example stringent control of point sources of Nr  
 14 can be energy intensive, requiring significant energy investments for chemicals, electricity, and  
 15 other support, which may, in turn lead to the production of more reactive nitrogen. Furthermore,  
 16 there may be environmental impacts of these treatment processes, particularly in the production  
 17 of solid wastes that can be significant environmental hazards. This is the main reason why a life  
 18 cycle approach is necessary in evaluating any remediation or treatment scheme.

19 Four categories of tradeoffs examined below are ammonia release from concentrated feed lot  
 20 operations (CAFOs), concerns about human nutrition, nitrification and denitrification, and  
 21 nitrogen-carbon related impacts.

##### 22 *2.4.7.1 Ammonia release from CAFOs*

1 As a result of effluent guidelines for NH<sub>3</sub> in aquatic systems, state and federal regulations and  
2 programs under the CWA were developed to address water quality protection from CAFOs. The  
3 resulting manure management systems utilized NH<sub>3</sub> volatilization as a means to remove N and  
4 decrease the N in the manure when land applied. Only recently has the resulting increase in NH<sub>3</sub>  
5 emission into the air been viewed as a potential problem with respect to air quality concerns and  
6 N deposition.

7 **Finding 17**

8 Current EPA policy (EPA 2007e) discourages states from controlling ammonia emissions as part  
9 of their plan for reducing PM<sub>2.5</sub> concentrations. Ammonia is a substantial component of PM<sub>2.5</sub> in  
10 most polluted areas of the United States. at most times. While it is true that reducing NH<sub>3</sub>  
11 emissions might increase the acidity of aerosols and precipitation, the net effect of NH<sub>3</sub> on  
12 aquatic and terrestrial ecosystems is to increase acidity. After being deposited onto the Earth's  
13 surface, NH<sub>4</sub><sup>+</sup> is under most circumstances quickly nitrified, increasing the acidity of soils and  
14 waters. The committee is unaware of any evidence that NH<sub>3</sub> reduces the toxicity of atmospheric  
15 aerosols or that high concentrations of NH<sub>3</sub> occur naturally over any substantive area of the  
16 United States. Lower NH<sub>3</sub> emissions will lower PM<sub>2.5</sub> concentrations. Such reductions in PM<sub>2.5</sub>  
17 concentrations have been linked to reductions in morbidity and mortality.

18 **Recommendation 17.** *The committee recommends that the EPA presumption that NH<sub>3</sub> is not a*  
19 *PM<sub>2.5</sub> precursor should be reversed and states should be encouraged to address NH<sub>3</sub> as a*  
20 *harmful PM<sub>2.5</sub> precursor.*

21

22 *2.4.7.2 Unintended impacts of lower application rates of nitrogen for crop production*

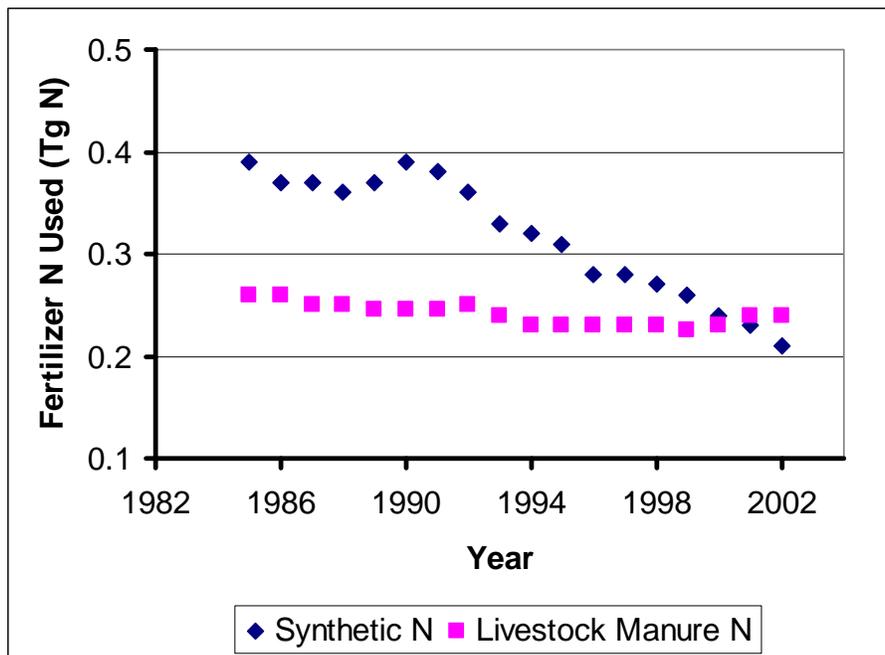
23 Crop production and environmental quality are potentially lost or gained at the expense of each  
24 other. Although leakage of N from crop production systems cannot be eliminated, N losses can  
25 be minimized substantially. One mechanism of decreasing leakage is to apply less N fertilizer to  
26 croplands. For example Hu et al. (2007), using the SWAT model, predict that decreasing N  
27 fertilizer application rates used in the late 1990s by 10 to 50% in the upper Embrarras River  
28 watershed in east central Illinois, would decrease NO<sub>3</sub><sup>-</sup> output to the river by 10 to 43%. This  
29 simple “solution” can cause problems for crop production as yields and crop quality (protein  
30 content) may decrease, causing economic loss to the farmer, decreased food quality for the  
31 consumer, and, at a global scale, a reduction in food security.

32 Cropping systems managed in a consistent manner over time reach a functional equilibrium  
33 between nitrogen inputs and outputs. Because crop yields are closely linked to the quantity of N  
34 accumulation in above ground biomass at maturity (Cassman et al., 2002), there would be a  
35 proportional decrease in crop yields in response to a decrease in the amount of N fertilizer  
36 application. The magnitude of this yield reduction would depend on the magnitude of decrease  
37 in the rate of applied N and the efficiency of N uptake from the applied N, as well as  
38 interrelationships with other nutrients' availability. Hence, yield reductions can be mitigated, or  
39 even eliminated, if methods and fertilizer formulations used in fertilizer-N application increased  
40 the efficiency of nitrogen uptake to offset the reduction in the amount of applied nitrogen. It is  
41 also important to note that reduced or insufficient N rates for crop production risk impairment of

1 long-term soil productivity. Jaynes and Karlen (2005) reported that N rates below the agronomic  
 2 and economic optimum could degrade the soil resource and decrease soil organic matter over  
 3 time. Thus care must be exercised in any N rate adjustments to protect soil productivity and to  
 4 support soil resource sustainability.

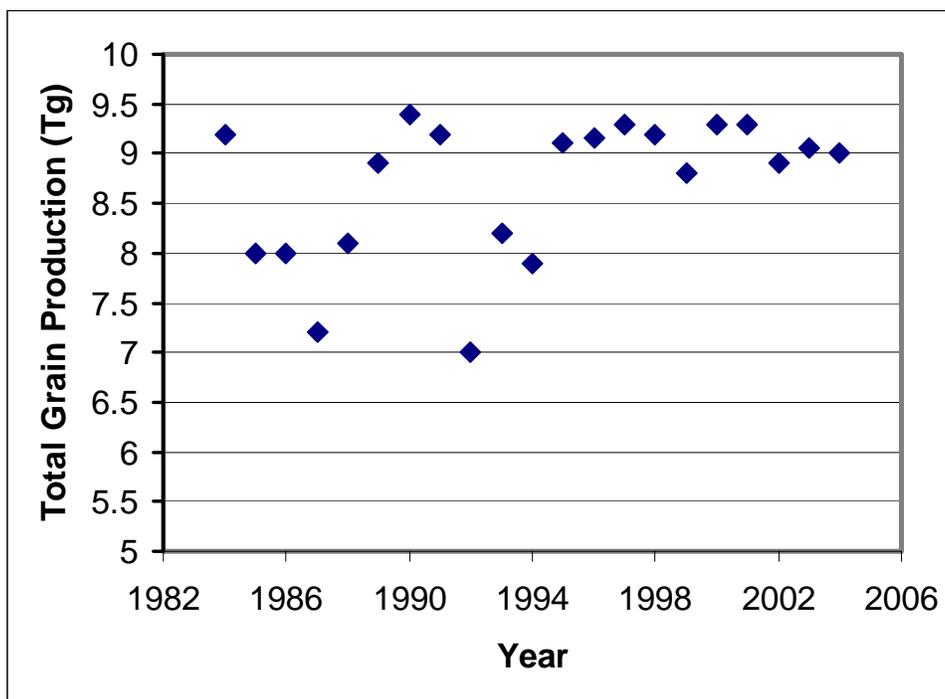
5 An example of the effect of decreasing N fertilizer input to cereal crop production on crop  
 6 production and crop quality as a result of national efforts to decrease Nr losses to the  
 7 environment from crop production is the situation in Denmark. In response to the European  
 8 Union Nitrate Directive synthetic fertilizer nitrogen use in Denmark decreased (Figure 19) from  
 9 approximately 0.4 Tg N in 1991 to 0.2 Tg in 2002. Animal manure N application decreased  
 10 from 0.25 Tg to approximately 0.24 Tg N during this time period. Nevertheless, although N  
 11 input into Danish cereal crop production decreased, cereal crop yield remained relatively  
 12 constant, as shown in Figure 20.

13 **Figure 19: Synthetic fertilizer and livestock manure N used as fertilizer in Denmark 1985-**  
 14 **2003 (IFA 2004).**



15

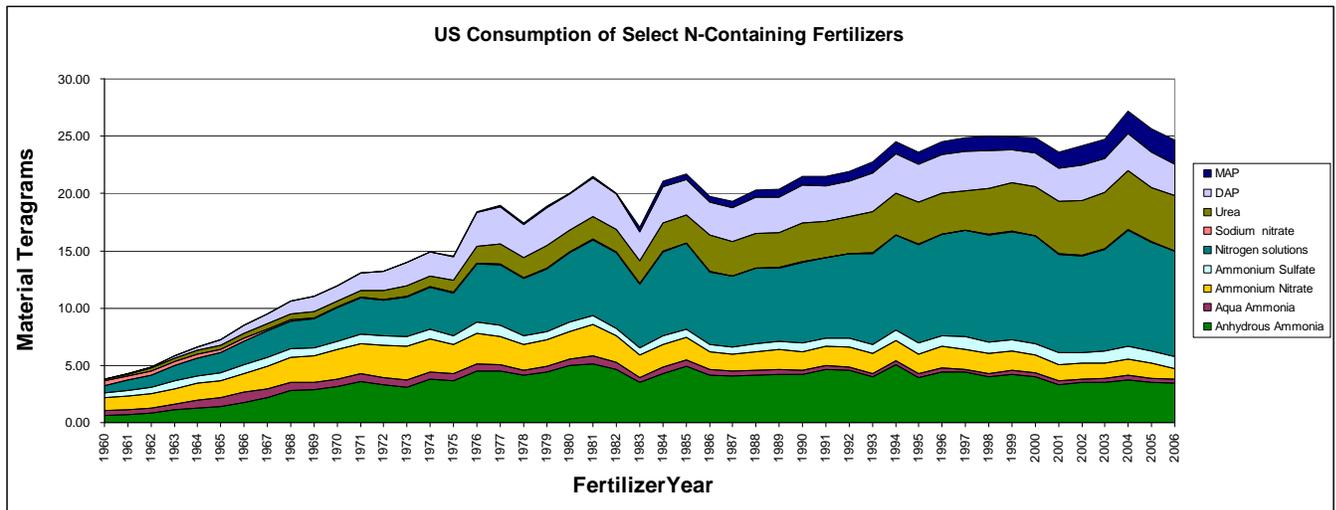
1 **Figure 20: Total cereal grain production in Denmark 1985-2004 (FAOSTAT, 2007)**



2

3 If the methods used to apply N were to be modified to improve its overall efficiency, then it is  
4 possible to reduce N fertilizer inputs and maintain, or even increase crop yields depending on the  
5 magnitude of the improvement in NUE (see section 2.2). Although U.S. fertilizer application has  
6 not declined over time, it has leveled off in recent years, as shown in Figure 21. Even so, yields,  
7 at least for corn grain, have continued to increase, a trend that has been in evidence since the mid  
8 1970s, as shown in Figure 6, section 2.2.3.1.

1 **Figure 21: Consumption of N-containing Fertilizers in the United States (USDA)**

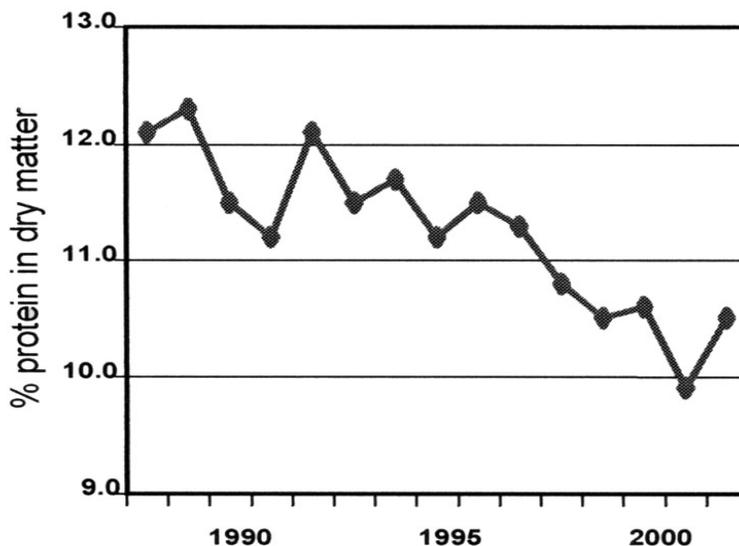


2  
 3 The effect of decreasing N fertilizer input can be estimated based on the current level of PFP for  
 4 applied N (average U.S. grain yield divided by the average N fertilizer application rate). Making  
 5 the assumption that without a concerted effort to improve N fertilizer application methods, yields  
 6 will decrease at 90% of the current PFP for N fertilizer (Cassman et al., 2003; Dobermann and  
 7 Cassman, 2004). With a 10 to 50% decrease in N fertilizer application the calibrated SWAT  
 8 model predicted a 6 to 38% reduction in maize yield in the upper Embrarras River watershed (Hu  
 9 et al. 2007).

10 A negative impact of decreased Nr input into cereal crop production is the potential for a decline  
 11 in grain quality as shown in Figure 22 as a decrease in grain protein content in Denmark. Grain  
 12 protein content in wheat is critical for determining its quality for bread, for example in the  
 13 United States, a grain protein content of 12% is considered the threshold for good quality bread  
 14 wheat, and N fertilizer application rate has a large influence on determining this trait (Cassman et  
 15 al., 1992). As can be seen, grain protein content has declined from 12 to 10% in Denmark over  
 16 the same period of lower fertilizer application rates.

1

**Figure 22: Protein content of cereal grain in Denmark (IFA, 2004).**



2

3 Such trends raise several questions if declines continue or are found to be widespread. What is  
4 the cost to the farmer and in terms of human nutrition and end-use value? Do these costs offset  
5 the environmental benefits created by decreasing N flows from crop production areas? And, what  
6 would be the regional and global impact if similar reductions in nitrogen fertilizer inputs to  
7 agriculture were put in place in developed countries that represent the largest source of grain  
8 exports to international markets?

9 One caveat to this decline in cereal protein content is the fact that grain protein content in maize  
10 hybrids used in the United States declined at a linear rate between 1934 and 1991 (Duvick et al.  
11 2005). Over the time period 1970-1992 hybrid maize grain protein concentration in central Iowa  
12 declined from ~9.7 to 9% (Duvic and Cassman, 1999). Although we do not know the genetic  
13 makeup of the cereal grain shown in Figure 22, it does not seem likely that genetics alone could  
14 account for the large difference in grain protein content between 1990 and 2001.

15 Finally, if protein yields are significantly reduced as a result of lower N fertilization rates, more  
16 land may need to be brought into production. Because nearly all prime agricultural land is  
17 already used for crop production, expansion of crop area will most likely occur on more marginal  
18 land, such as the land currently in the CRP. Such conversion would result in additional N losses  
19 from these acres due to relatively low N fertilizer efficiency that typically occurs on marginal  
20 land that has multiple soil constraints to crop growth and yield.

#### 21 2.4.7.3 Unintended impacts: swapping N between environmental systems

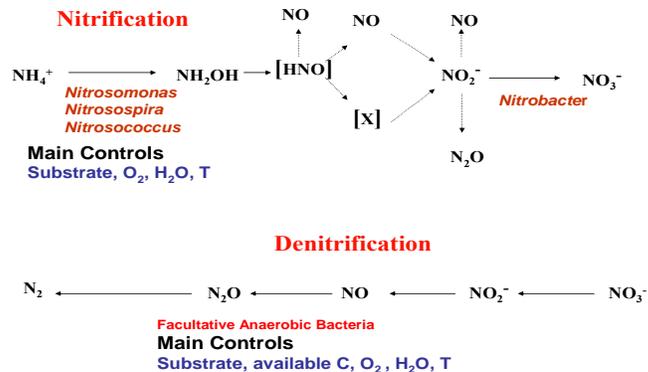
22 Nitrous oxide is produced in “natural” and agricultural soils, and all aquatic systems, almost  
23 exclusively as a result of the microbial processes nitrification and denitrification. As  $\text{NH}_4^+$  ion is  
24 the initial mineral N product formed during organic matter mineralization and most of the  
25 fertilizer used worldwide is  $\text{NH}_4^+$  based (e.g. urea, ammonium sulfate; FAO, 2007), the suite of

1 microbiological reactions that result in the release of gaseous N products need to be considered.

2 Nitrification is the oxidation of  $\text{NH}_4^+$  ion to  $\text{NO}_3^-$  (Figure 23). Most commonly nitrification is a  
3 chemolithotrophic process which consists of the conversion of ammonium to nitrite, which is then  
4 converted to  $\text{NO}_3^-$  by a second group of bacteria. The ammonium oxidizing bacteria (AOB) are  
5 obligate aerobes with some species that are tolerant of low oxygen environments. The most  
6 common genera of autotrophic  $\text{NH}_4^+$  oxidizers are *Nitrosospira* and *Nitrosomonas*, which result  
7 in the formation of nitrite. AOB are found in most aerobic environments where ammonium is  
8 available through the mineralization of organic matter or N compounds are added.

9 Biological denitrification is the dissimilatory reduction of  $\text{NO}_3^-$  and nitrite to produce  $\text{NO}$ ,  $\text{N}_2\text{O}$ ,  
10 and  $\text{N}_2$  by a taxonomically diverse group of bacteria. These bacteria synthesize a series of  
11 reductases that enable them to utilize successively more reduced N oxides as electron acceptors  
12 in the absence of oxygen. The general reductive sequence is shown in Figure 23. In addition to  
13 the free living denitrifiers, symbiotically living Rhizobia in root nodules of legumes are able to  
14 denitrify nitrate and produce nitrous oxide (Mosier and Parkin, 2007).

15 **Figure 23: Diagram of the nitrification and denitrification processes (from Mosier and**  
16 **Parkin 2007)**



17

18 The abundant denitrifiers are heterotrophs, which require sources of electron-reducing  
19 equivalents contained in available organic matter. Factors that most strongly influence  
20 denitrification are oxygen, nitrate concentration, pH, temperature, and organic carbon. The  
21 reductive enzymes are repressed by oxygen but not by  $\text{NH}_4^+$ . Nitrous oxide reductase appears to  
22 be more sensitive to oxygen than either  $\text{NO}_3^-$  or nitrite reductase. Therefore  $\text{N}_2$  production  
23 predominates in more anoxic sites and  $\text{N}_2\text{O}$  production may be greater in more aerobic  
24 conditions. However, the ratio of  $\text{N}_2$  to  $\text{N}_2\text{O}$  emitted may also be affected by high  $\text{NO}_3^-$   
25 concentrations and associated higher levels of electrical conductivity and osmotic stress and soil  
26 pH (low pH favors  $\text{N}_2\text{O}$  production).

27 Given these interactions among oxidized and reduced N species, it is important to recognize the  
28 potential for unintended consequences to occur as a result of strategies aimed at limiting one

1 form of Nr in air or water that can lead to the increased production of other forms of Nr. One  
2 such instance is the potential offsetting of the benefits of  $\text{NO}_3^-$  remediation at the expense of  
3 increasing input of  $\text{N}_2\text{O}$  to the atmosphere.

4 An example of such a situation involves  $\text{NO}_3^-$  leached from agricultural fields, much of which  
5 could be removed from drainage water in natural or reconstructed wetlands. This process is ideal  
6 if the denitrification process goes to completion, i.e. only  $\text{N}_2$  is produced. If, however, the  
7 process is incomplete, and  $\text{NO}$  and  $\text{N}_2\text{O}$  gases are emitted then the end result may create a  
8 compensating risk that could be greater than that posed by the nitrate that is removed. This is  
9 because  $\text{NO}$  continues to be reactive in the atmosphere and is eventually redeposited in aquatic  
10 or terrestrial systems and  $\text{N}_2\text{O}$  is a greenhouse gas that has an atmospheric life time of  
11 approximately 120 years and a radiative forcing of approximately 300 times that of  $\text{CO}_2$  on a  
12 hundred year time frame (IPCC 2001), and is a major source of  $\text{NO}$  in the stratosphere which  
13 depletes stratospheric ozone (Crutzen 1981). If more of the  $\text{NO}_3^-$  denitrified is converted to  $\text{N}_2\text{O}$   
14 in wetlands than upstream or downstream, the environmental cost may be high. Hernandez and  
15 Mitsch (2007) found that permanently flooded wetlands had lower  $\text{N}_2\text{O}/\text{N}_2$  ratios of emissions  
16 than did intermittently flooded wetlands. They also found that the ratio was higher in the cold  
17 months even though the flux rates are much lower then. A full risk assessment needs to be made  
18 to determine how much of such “pollutant swapping” is advisable.

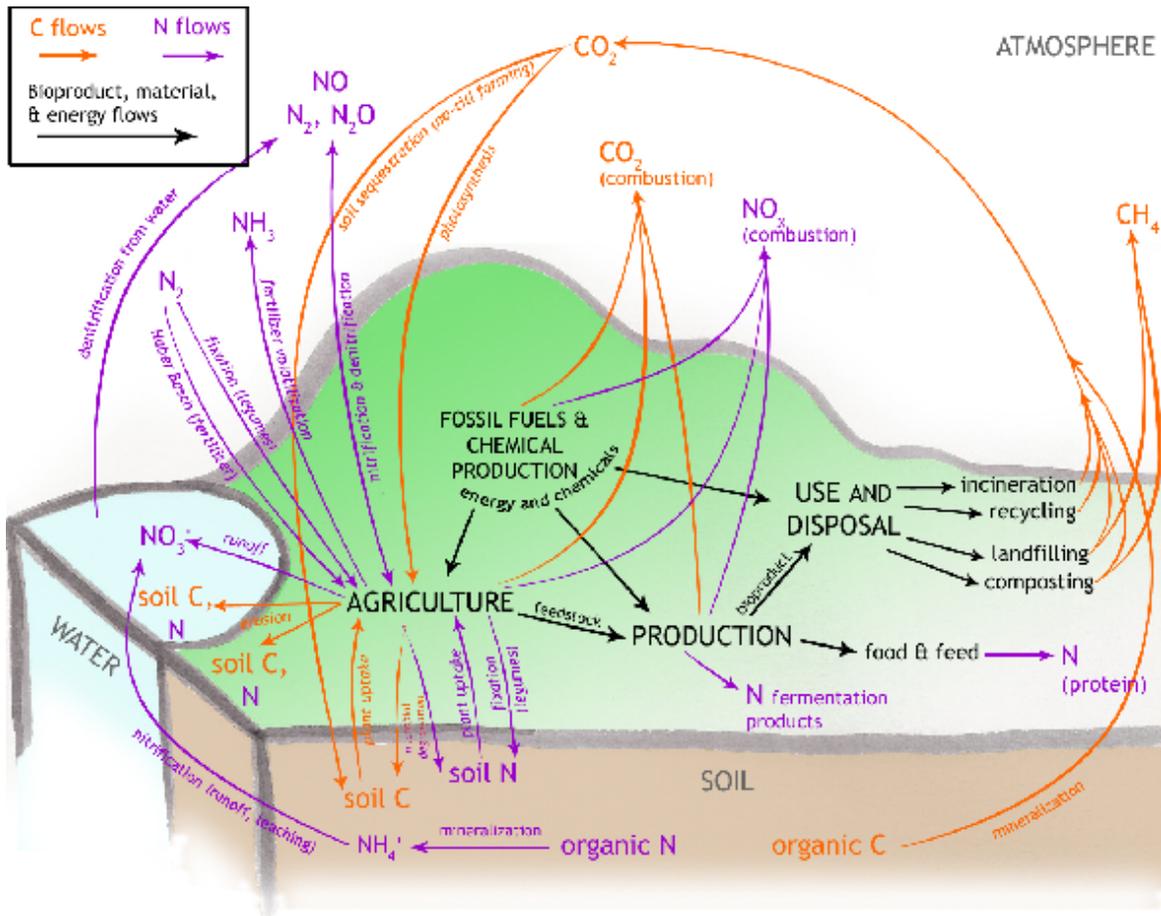
19 A similar potential exists for Nr mediation in sewage treatment, for which current practice is to  
20 convert ammonia/ammonium that mineralizes from excreted organic matter to nitrate through the  
21 nitrification process. As nitrate containing effluent from sewage treatment flows into aquatic  
22 systems the nitrate may be denitrified, resulting in  $\text{N}_2\text{O}$  production if denitrification is not  
23 complete. The protein consumption by the ~301 million humans in the United States results in  
24 the processing of ~ 2 Tg of N annually (~18.4 g N/ person/d), much of which flows through  
25 sewage treatment facilities and ultimately leads to the production of 0.06 – 0.1 Tg of  $\text{N}_2\text{O}$ -N /yr  
26 in aquatic systems or soils to which sewage sludge is applied.

#### 27 *2.4.7.4 Tradeoffs among C and N-driven impacts*

28 Many of the impacts on the environment to which reactive N contributes are also impacted by  
29 other chemical species, notably carbon; there are several points of tangency between the global C  
30 and N cycles, as depicted in Figure 24: combustion, agricultural production, industrial  
31 production, soil and sediment processes, and end-of-life disposition of products. The implication  
32 of these interactions is that, in many instances, the perturbation of one cycle cannot be fully  
33 assessed without including effects on the other. For example, proposals to develop bio-based  
34 products (biofuels, but also other products) as the preferable alternative to fossil-based resources  
35 are not impact-free. Such “trade-offs” may involve a single impact, e.g. global climate change  
36 for which both carbonaceous gases and  $\text{N}_2\text{O}$  contribute, but may also involve trade-offs between  
37 impacts that are not easily compared. Figure 25 shows the latter case in the form of climate  
38 change impacts (for which C is a principal contributor) versus eutrophication impacts (for which  
39 nitrogen is a principal contributor) for several different biofeedstock-product combinations  
40 which are evaluated relative to the substituted commercial product made from fossil C. One  
41 hundred percent would mean that the bio-based alternative is no better than the fossil-based  
42 counter-product, while the negative region of the y-axis in Figure 25 represents net C

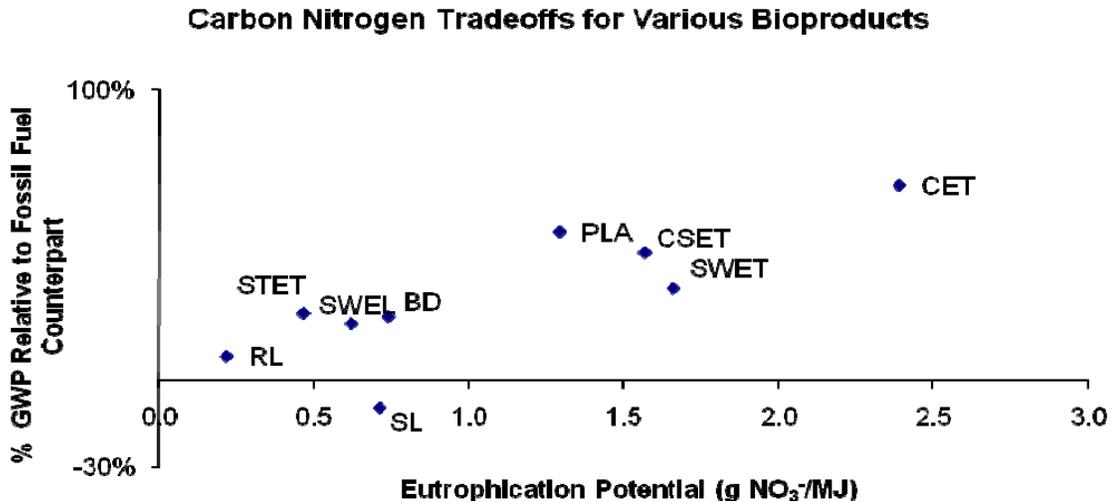
- 1 sequestration. It is difficult to make direct comparisons across disparate impact categories,
- 2 however Figure 25 suggests that, in choosing among alternatives, policies that aim to minimize
- 3 both sets of impacts would be preferred.

4 **Figure 24: Combined carbon and nitrogen global cycles (Miller et al. 2007)**



5

1 **Figure 25: Comparisons Between Climate Change and Eutrophication Impact Categories**  
 2 **for Various Bioproducts (updated from Miller et al. 2007)**



3  
 4 (Abbreviations: BD=Biodiesel; CET=Corn Ethanol; CSET=Corn & Stover Ethanol; PLA=Polylactic Acid (Corn);  
 5 RL=Rapeseed Lubricant; SL=Soybean Lubricant; STET=Stover ethanol; SWEL=Switchgrass Electricity;  
 6 SWET=Switchgrass Ethanol).

7 **Finding 18**

8 The committee notes that the effective management of Nr in the environment must recognize the  
 9 existence of tradeoffs across impact categories involving the cycling of other elements,  
 10 particularly C.

11 **Recommendation 18.** *The committee recommends that the integrated strategies for Nr*  
 12 *management outlined in this report be developed in cognizance of these interrelations and*  
 13 *tradeoffs.*

14 **2.4.8 Interactions of the N cascade and climate**

15 Weather and climate vary substantially on many time scales including the interannual. Long-  
 16 term (decadal or more) change in climate as have been predicted by IPCC (2007) may have  
 17 profound effects on the N cycle; conversely changes in the biogeochemical cycle of Nr can  
 18 induce climate forcing. While it is beyond the scope of this report to fully address how cycles of  
 19 C and N interact (see Figure 24 for a general treatment of the intersection points of C and N  
 20 cycles), there are several ways in which climate impacts the biogeochemical cycle of Nr and vice  
 21 versa, e.g., Holland et al., 1997; Hungate et al., 2003; Hungate et al., 2004; Levy et al., 2008;  
 22 Sokolov et al., 2008; Sutton et al., 2007; Thornton et al., 2007; Yienger and Levy, 1995 . These  
 23 are highly interactive and nonlinear systems, but they include:

- 24 • Increased deposition of Nr into terrestrial and aquatic ecosystems can alter the

1 sequestration of carbon, while increased ambient CO<sub>2</sub> can change the deposition and  
2 uptake of Nr.

- 3 • Nitrate flux from fields to surface waters increases with increasing rainfall (see  
4 accompanying text box 4, The impact of climate change on agricultural discharge of Nr  
5 for Eastern Iowa).
- 6 • Increasing temperature can both increase and decrease atmospheric loading of particulate  
7 matter (PM).
- 8 • Aerosols (PM) have direct and indirect (through cloud microphysics) effects on radiative  
9 forcing of climate and on the hydrological cycle.
- 10 • N<sub>2</sub>O and O<sub>3</sub> are greenhouse gases.
- 11 • Soil Nr chemistry and emissions of N<sub>2</sub>O, NH<sub>3</sub>, and NO depend on environmental  
12 conditions such as temperature and soil moisture.
- 13 • The amount of Nr deposited and exported from the United States depends on  
14 meteorological variables including wind speeds and convection.

15  
16 Numerical models, when verified against past climates, can provide insight into possible future  
17 climates and their impacts on the nitrogen cycle. For example, increasing temperatures increase  
18 the amount of NO<sub>x</sub> control necessary to achieve the same amount of photochemical smog  
19 control (Bloomer et al., 2009; Jacob and Winner, 2009). The EPA program for studying the  
20 impact of climate change on photochemical smog (air pollution ozone) production offers a useful  
21 model; see Jacob and Winner (2009) for an overview.

### 22 23 **Finding 19**

24 The biogeochemical cycle of Nr is linked to climate in profound, but nonlinear ways that are, at  
25 present, difficult to predict. Nevertheless, the potential for significant amplification of Nr-related  
26 impacts is substantial, and should be examined in more complete detail.

27  
28 **Recommendation 19:** *The EPA should support cross-disciplinary and multiagency research on  
29 the interactions of climate and Nr. To determine the interactions of global biogeochemical Nr  
30 cycles and climate, the INC suggests that EPA follow a series of steps such as:*

- 31 1. *Select several likely scenarios for global climate from the IPCC report for the year 2050  
32 or 2100.*
- 33 2. *Down-scale statistics or nest regional climate models within each of these global  
34 scenarios to generate meteorological and chemical fields (e.g., T, RH, winds,  
35 precipitation, CO<sub>2</sub>) for a few years around 2050 and 2100.*
- 36 3. *Run several independent biogeochemical Nr models (Earth System models that include  
37 air/water/land) for N America for these years with current Nr and emissions and  
38 application rates.*
- 39 4. *Rerun models with decreased Nr emissions/application to evaluate strategies for  
40 controlling impacts such as those described in this report.*

**Text Box 4: The impact of climate change on agricultural discharge of reactive nitrogen**

The discharge of reactive nitrogen from intensively managed agroecosystems is characterized by a number of attributes that often exhibit a high degree of variability: fluctuating material flows associated with the degree of nitrogen fixation and the extent of denitrification, the interdependence of crops in rotation, and dependence on geography, weather patterns (particularly rainfall intensity, duration, and frequency), soil type, and agricultural practices.

One way to gauge the impact of climate change on such systems is to examine the ranges exhibited by historical data that collectively encompass the range of impacts that are anticipated. The assumption is that a changing climate will systematically alter governing attributes in plausibly predictable ways, for example increased annual rainfall and temperature over a large geographic region. The IPCC has provided general climate-induced impacts for world regions (IPCC 2007).

The general impact of climate change on the discharge of reactive nitrogen from agroecosystems can be discerned from the information in Figure 26. This figure shows a probability distribution for nitrate discharged from the watersheds of eastern Iowa (approximately 50,000 km<sup>2</sup>), which are dominated by corn-soybean agroecosystems (a general description of the region can be found in Kalkhoff et al. 2000). It is derived from information on the input of synthetic fertilizers in the region during the period 1989-1999, and includes factors that describe the transformation and transfer of Nr once applied. The distribution shown was generated using a Monte Carlo technique, details of which can be found in Miller et al. 2006. Also included in Figure 26 (in green) is a standard log-normal distribution, which the simulation most closely fits, and independently measured nitrate runoff data (an output of the system) over the same time period, as reported by Powers (2007). The inclusion of these data within the simulation distribution (which is based on fertilizer inputs to the system) provides confidence in the descriptive capability of the model.



## Chapter 3: Integrated risk reduction strategies for reactive nitrogen

### 3.1 Introduction

Chapter 2 presented the environmental impacts and metrics associated with the emission of the various forms of Nr and reviewed ways of organizing these into impact “categories.” As noted, Nr has many impacts on the environment, impacts that are interrelated through the nitrogen cascade.

Once the nature and type of impacts are recognized, the risks should be characterized quantitatively, if possible. This information would then be used, along with other considerations such as economic, social and legal factors, to reach decisions regarding risk reduction strategies and the need for and practicability of implementing various risk reduction activities. The regulation of Nr in the environment by EPA follows an impact-by-impact approach which, with few exceptions, examines specific N forms in either aquatic, atmospheric, or terrestrial systems. The principal regulatory authority pertaining to nitrogen is derived from the CWA and the CAA, although other legislation such as the Energy Independence and Security Act (EISA), and the Endangered Species Act (ESA) contain provisions that could result in regulatory actions that affect nitrogen management.

### 3.2 Control strategies for Nr

There are several ways in which the release and control of Nr in the environment can be approached. In general these can be classified as follows:

1. Improved practices and conservation—in which the flux of Nr that creates an impact is lowered through better management practices, including those that preserve or enhance Nr controlling ecosystem services (e.g. on-field agricultural practices, controlled combustion conditions, ecosystem function preservation and management)
2. Product substitution—in which a product is developed or promoted which has a lower dependency on or releases less Nr (e.g. N-bearing wastes instead of corn grain as a feedstock for biofuels, development of alternative power sources such as wind and solar)
3. Transformation—in which one form of nitrogen is converted to another form (e.g. nitrification of wastewater, denitrification in engineered or natural systems),
4. Source limitation—in which the amount of Nr introduced into the environment is lowered through preventive measures (e.g. controls on NO<sub>x</sub> generation)
5. Removal—in which Nr is sequestered from impacting a particular resource (e.g. ion exchange)
6. Improved use or reuse efficiency—in which the efficiency of production that is dependent on Nr is improved (e.g. increased grain yields for lower Nr applied), or Nr wasted from one source is reused in another (e.g. algal farming).

Effective management of Nr requires combinations of these approaches; none is a perfect alternative for controlling Nr in the environment. Table 23 provides a summary of the pros and

1 cons of each of these approaches.

2 **Table 23: Advantages and limitations of various approaches to Nr control**

<b>Control strategy</b>	<b>Advantages</b>	<b>Limitations</b>
<b>Improved practices, conservation</b>	Lessens one or more impacts; utilization of existing ecosystem services	Education cost; availability and cost of preserved lands
<b>Product substitution</b>	Lessens the need for Nr, allows for more targeted uses of Nr	Questions of acceptability, technological issues
<b>Transformation</b>	Reduces one or more impacts to which Nr contributes, for denitrification closes the nitrogen cycle; utilizes natural biogeochemical processes that may be available ecosystem services	May contribute to other impacts; human presence has modified and diminished ecosystem service values
<b>Source limitation</b>	Reduce one or more impacts to which Nr contributes	Decreased crop yields, in some cases few viable alternatives yet developed
<b>Removal</b>	Reduces one or more impacts to which Nr contributes; Natural land features/processes and ecosystem services may be used	Residuals containing Nr must still be managed effectively; availability, location and cost of land for natural or enhanced Nr removal
<b>Improved efficiency</b>	Reduces the need for Nr	Research and education costs

3

4 **3.3 Management of reactive nitrogen in the environment**

5 Four types of management strategies for the control of Nr, and other pollutants, in the  
 6 environment have evolved over the past 40 years:

- 7 1. Command-and-Control—in which an entity’s “right to pollute” is recognized  
 8 through a series of permitted limitations on emissions, violations of which may  
 9 result in penalties being assessed.
- 10 2. Government-based programs for effecting a policy, such as directed taxes, price  
 11 supports for a given commodity, subsidies to bring about a particular end, and  
 12 grants for capital expansion or improvement.
- 13 3. Market-based instruments for pollution control in which market trading schemes  
 14 are used to bring about a desired policy end, often at reduced overall cost.

- 1           4.       Voluntary programs in which desired ends are achieved using private or  
2                   government-initiated agreements or through outreach and education.  
3

4       **3.3.1 Command-and-control**<sup>7</sup>

5       Policy makers have traditionally used command-and-control strategies requiring individuals and  
6       firms to meet mandatory guidelines. Such an approach evolved as the country was gearing up to  
7       meet the requirements first established nationally through the CWA and CAA enabling  
8       legislation in the 1970's. Because U.S. capabilities to monitor contaminant concentrations and  
9       predict environmental impacts was, generally, rudimentary, early emphasis was placed on  
10      “technology-based” approaches for managing emissions, resulting in the promulgation of “best  
11      practicable technology” controls, and eventually “best available technology” controls, the idea  
12      being that mandating some level of control, even with uncertain improvements on impacts,  
13      would be better, and less arbitrary, than other approaches of the time.

14     Nevertheless, both the CWA and the CAA had more specific goals that were aimed at protecting  
15     human health, public welfare, and ecosystem health. For example the CAA required states to  
16     develop implementation plans (SIPs), the approval of which depended on their ability, once  
17     implemented, to meet ambient clean air standards. Likewise, the CWA required greater controls  
18     to be implemented for certain water bodies for which technology-based limits alone were  
19     insufficient to meet standards (this became the TMDL program).

20     Over time, and as our abilities to monitor, predict, and understand impacts improved, it became  
21     possible, or at least plausible, to tailor emission levels on a source-by-source basis, allowing the  
22     firm in question to decide its own technological approach. Thus permits, which place strict limits  
23     on the amount of pollution a firm is allowed to discharge over a specified period of time, have  
24     become the main method for managing the majority of point source contaminants, including the  
25     various forms of Nr, in the environment.

26     **3.3.2 Market based instruments for pollution control**<sup>8</sup>

27     A fundamental shift in environmental management philosophy was initiated with the 1990 Clean  
28     Air Act Amendments, which combined regulatory requirements with market flexibility allowing  
29     lower compliance costs through tradable permits. Most market-based policy instruments operate  
30     on the principle that if the regulatory framework or some other factor sufficiently alters the  
31     relative value of available decision choices for an individual or firm, subsequent decisions they  
32     make will be in alignment with the policy maker's objective.

---

<sup>7</sup> Based on **Models in Environmental Regulatory Decision-Making**, National Research Council, 2007.

<sup>8</sup> Based on Canchi, D., P. Bala and O. Doering, 3/3/2006, Market Based Policy Instruments in Natural Resource Conservation, Report for the Resource Economics and Social Sciences Division, NRCS, USDA, Washington D.C., pp. 4-9.

1 As an example, if a government wants to limit pollution in a river where a number of polluters  
2 discharge, it need not adopt a uniform command and control limit on each firm. Instead, a  
3 regulatory cap on the total permissible pollution can be established at a lower pollution level and  
4 permits to pollute that sum to that overall cap can be issued to all firms. Those firms having low  
5 pollution control costs will have incentive to control more pollution than their permit allowance  
6 and thus have permits they no longer need that can be sold to firms with high costs of pollution  
7 control. Because the supply of permits (and the overall cap on the pollutant) is fixed, the  
8 regulatory goal is achieved. The tradable permit thus brings about the desired reduction in  
9 pollution level at lower cost than if the firms having high costs of pollution control were required  
10 to control their full share and low cost of control firms were limited to their share of control. .  
11 Tradable permits also encourage cost effective pollution control investment by giving each firm  
12 a clear economic signal to invest in new technology to reduce pollution at a level that  
13 corresponds to the market value of the permit."

14 As with control strategies for Nr, there is no one universal market-based strategy that is  
15 applicable to every policy maker's objective. For example, the nature of incentives available to  
16 and effective with producers involved in over-fishing is different from landowners providing  
17 environmental amenities. In the former case, the objective is to restrict the intensity of fishing. In  
18 the latter case the objective is to encourage private landowners to provide environmental goods  
19 and services at the lowest cost possible.

20 Evolution of new market-based strategies is a continuous process. Most strategies have been  
21 customized over time to meet local needs. One can group such market based approaches under  
22 the following conceptual headings:

- 23 1. Water Quality Tradable Permits: Every polluting entity is allowed to discharge  
24 pollutants up to a certain pre-determined limit, defined in concordance with the terms  
25 of the CWA. The entities discharging less than their allocated limit generate credits.  
26 Under this strategy, credits can be traded with other polluting entities that have  
27 exceeded their allocated limit.  
28
- 29 2. Auction Based Contracting: Environmental or conservation contracts are auctioned  
30 where individual landowners place their bids to provide such goods or services from  
31 their land. Two factors jointly determine the selection of the bids; the amount of the  
32 bid and the expected value of the environmental or conservation benefit resulting  
33 from accepting the bid.  
34
- 35 3. Individual Transferable Quotas: An individual transferable quota (ITQ) is an  
36 allocation privilege to extract a specified quantity of a resource among a selected  
37 number of quota holders. The distinctive feature of the ITQ is that the privilege is  
38 transferable or leasable. An ITQ may be a right to produce under favorable  
39 circumstances, such as a tobacco quota when tobacco production would normally be  
40 limited.  
41
- 42 4. Risk Indemnification for Specified Behavior: An example of this is crop insurance  
43 designed to protect farmers from uncertainty in the adoption of best management

1 practices that provide a public good but are inherently riskier.

2

3 5. Easements: Conservation Easements or conservation servitudes refer to the case  
4 where a land owner enters into a legally binding agreement to surrender certain  
5 property rights for a specified period of time either voluntarily or for compensation.  
6 Such arrangements usually provide public goods relative to the environment or  
7 conservation.

8

9 The policy maker's objective, the local conditions, and several other factors determine the  
10 suitability of a particular market based strategy. For example, a tradable permit strategy is well  
11 suited where offsets are possible. In the case of water quality it is not uncommon to find a  
12 spectrum of polluters at different levels of contribution. A policy framework that facilitates the  
13 emergence of multiple options for polluters to buy credits from more efficient controllers of  
14 discharge or to invest in new equipment to achieve further reductions is likely to accomplish the  
15 desired level of water quality at the least possible cost to the economy. Table 24 illustrates the  
16 potential effective application of a number of market based approaches in specific situations.  
17 Accompanying this chapter are two examples of the application of market-based approaches for  
18 the design of water quality trading schemes for Nr in watersheds (text box 5: Water Quality  
19 Trading to Meet the Long Island Sound Wasteload Allocation in Connecticut and text box 6:  
20 Water Quality Trading in the Illinois River Basin).

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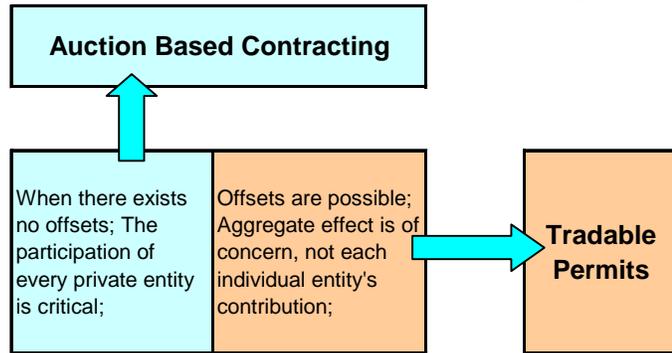
**Table 24: Summary of market-based instruments for pollution control**

Auction Based Contracting		Individual Transferable Quotas		Insurance for the Adoption of BMPs		Easements		
When there exists no offsets; The participation of every private entity is critical;	Offsets are possible; Aggregate effect is of concern, not each individual entity's contribution;	When the depletion is of concern;	When the discharge is of concern;	Homogenous polluters; Offsets not feasible; Excessive pollution is primarily to mitigate uncertain profits; Modest short-term objective;	Not homogenous polluters; Offsets are possible; Pollution is an absolute consequence of the production process;	Unidirectional; When offsets are not possible; One entity retiring more property rights cannot trade with the other retiring less property rights.	Bidirectional; Offsets are possible; Requires specific action on the part of the participant to accomplish the objective;	<b>Tradable Permits</b>
		Aggregate depletion is of concern;	When there exist no offsets; The participation of every private entity is critical;	Tied to a production process; When risk averseness of the entity can be used to motivate participation;	Not tied to any production process; Suited for motivating participants to engage in secondary activities;	Auction based contracting can be seen as a refined and improved cost-efficient alternative to easements;	Designing of auction based contracting requires considerable professional expertise;	<b>Auction Based Contracting</b>
				Discharge of effluents is of concern;	Depletion of a resource is of concern;	Retirement of rights is of concern;	Acquisition of rights is of concern;	<b>Individual Transferable Quotas</b>
						No uncertainty; No action required on the part of the participant;	Tied to a production process;	<b>Insurance for the Adoption of BMPs</b>

2

3

1 Table 24 shows pair-wise comparison between different market-based strategies. The objective  
 2 and the incentive structure of the  
 3 participants determine the suitability of  
 4 one market based strategy over another.  
 5 Each pair of cells briefly lists the most  
 6 relevant set of conditions for which the  
 7 respective strategy may be optimal (left  
 8 cell points to strategy at the top of the  
 9 column and right cell points to the  
 10 strategy at the end of the row). Consider  
 11 the two strategies (illustrated on the  
 12 right): Auction Based Contracting and Tradable Permits. If the participation of every private  
 13 entity is essential, then Auction Based Contracting works best. For example, if the objective is to  
 14 preserve a large tract of privately owned contiguous land. This requires the participation of every  
 15 private land owner to set aside a portion of their land. An auction designed to reveal the  
 16 individual's land owner's reserve price for participation leads to the most efficient solution.  
 17 Compared to this, if the objective is an overall reduction of a pollutant regardless of the  
 18 individual private entity's contribution to the abatement, Tradable Permit strategy with a cap is a  
 19 more appropriate strategy.



20

21 **Text Box 5: Water Quality Trading to Meet the Long Island Sound and Wasteload**  
 22 **Allocation in Connecticut**

23 Pollutant trading is increasingly being promoted as a cost-effective means for attaining water  
 24 quality standards. Connecticut and New York have been working with the EPA Long Island  
 25 Sound Study (LISS) for more than 20 years to address low oxygen conditions (hypoxia) in Long  
 26 Island Sound that have been linked to excessive loadings of nitrogen. A Total Maximum Daily  
 27 Load (TMDL) for nitrogen, drafted by the two states and approved by the EPA in 2001, set a  
 28 58.5% nitrogen reduction target in 2014 from point and nonpoint source/stormwater sources.  
 29 Connecticut has initiated a point source trading program for 79 municipal sewage treatment  
 30 plants (STPs) to facilitate implementation of the TMDL wasteload allocation (WLA) and is  
 31 investigating the potential for incorporating nonpoint source/stormwater into the existing  
 32 Nitrogen Credit Exchange (NCE).

33 Several prerequisite conditions essential to the success of the current point source trading  
 34 program have been met. Briefly, 1) all the STPs contribute to the same water quality problem; 2)  
 35 the technology to remove N and meet the targets exists; 3) there are compelling member benefits  
 36 to participate, especially cost savings; 4) sources can be easily monitored and tracked by end-of-  
 37 pipe monitoring; 5) credit cost calculations are based on established and agreed upon protocols  
 38 founded in state legislation; 6) sources of N are diverse and create viable supply and demand  
 39 conditions while reducing overall cost, with close control by a Nitrogen Credit Advisory Board;  
 40 and 7) transaction costs are low relative to credit prices. In operation since 2002, the NCE has  
 41 proven to be a viable and effective mechanism for meeting the nitrogen WLA.

1 The economic record of the NCE demonstrates the vigor of trading over the first five years of  
 2 completed trades from 2002-2006 (Table 25). In sum, more than 10 million credits have been  
 3 traded on the NCE representing more than \$22 million in economic activity.

4 The use of geographically-based trading ratios is instrumental to the relative cost of meeting N  
 5 reduction limits at the 79 treatment plants, which are scattered throughout the state (Figure 27).  
 6 Because N is reactive as it travels down rivers into the Sound, and the Sound's currents further  
 7 affect relative impacts as they transport N and the resulting algal blooms to the hypoxic areas at  
 8 varying efficiencies, location of each treatment plant makes a difference in relative impact on  
 9 dissolved oxygen per pound of N discharged at end of pipe. Generally, the closer a POTW is to  
 10 the edge of the Sound, and the closer to the hypoxic zone, the higher the trading ratio (Figure  
 11 28). For plants with high trading ratios, economics often favor treatment, while those with lower  
 12 ratios may find the purchase of credits economically advantageous over treatment.

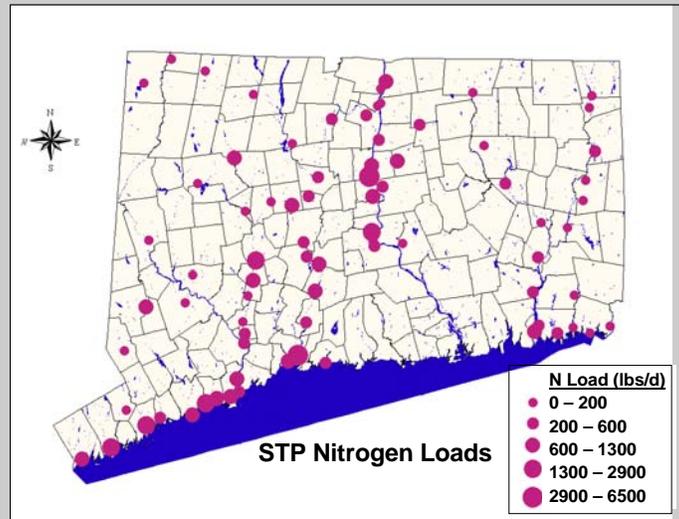
13 **Table 25: Performance of the NCE, 2002-2006**

Trading Year	Credit Price (Dollars)	Purchased (Dollars)	Sold (Dollars)	Purchased (1000 Credits)	Sold (1000 Credits)
2002	\$1.65	\$1,317,223	\$2,357,323	798	1,429
2003	\$2.14	\$2,116,875	\$2,428,636	989	1,135
2004	\$1.90	\$1,786,736	\$2,659,804	940	1,400
2005	\$2.11	\$2,467,757	\$1,315,392	1,170	623
2006	\$3.40	\$3,828,114	\$2,394,956	1,126	704
<b>Total</b>		\$11,516,705	\$11,156,111	5,023	5,291

1

2

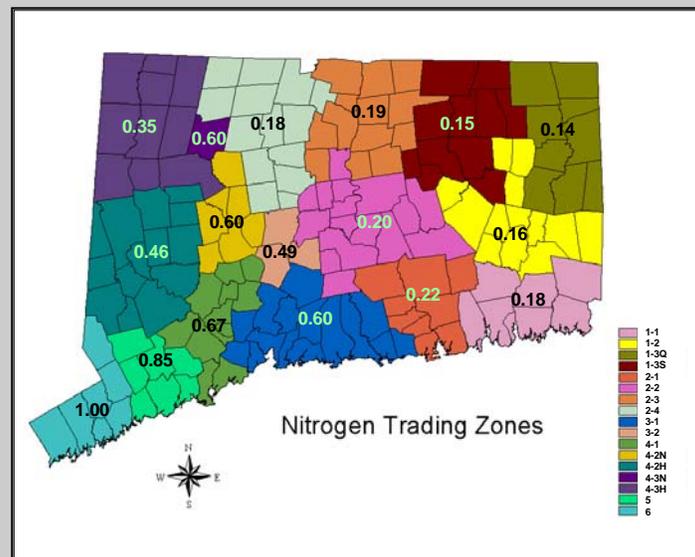
**Figure 27: Relative nitrogen discharge (lbs/day) from 79 POTWs**



3

4

**Figure 28: Trading ratios for municipalities in Connecticut**



5

6 The point source NCE does not reflect a free market approach to trading. Demand is set by the  
 7 annual general permit limit and supply of credits is constrained by the availability of WCF  
 8 dollars and the timing and location of N removal projects. Nevertheless, there is a tendency  
 9 towards implementing cost effective projects as STP authorities decide whether it is less  
 10 expensive to treat or buy credits, and try to predict when that break-even point might occur that  
 11 would warrant application for project funding.

12 Incorporating a NPS/SW component into the existing point source trading program presents  
 13 some difficult challenges. Among the seven prerequisite conditions listed above that are well

1 met by the current point source program, NPS/SW trading does not provide compelling  
2 economic benefits for members; NPS/SW N is difficult to quantify and track; credit cost  
3 estimation does not have a strong foundation in any existing programs; NPS/SW credit costs,  
4 though geographically diverse, may not result in significant implementation savings; and  
5 transaction costs (or time spent negotiating the ground rules for NPS/SW trading) may be  
6 considerably higher than for point source credits. Many of these obstacles can be overcome by  
7 deferring to models and textbook costs and efficiencies for NPS/SW BMPs. Tracking will still  
8 be a challenge because of the sheer number and distribution of BMPs that can be applied  
9 throughout the state that will have to be recorded and quantified.

10 Basic economic principles suggest that a free-market arrangement will not produce many  
11 NPS/SW credits for market. Costs are much higher than for point source credits and a regulatory  
12 approach must therefore be instituted to formalize the load allocation for nitrogen and to  
13 structure participation by municipalities.

14 If a NPS/SW trading component were to be added in the future, it would most likely also be an  
15 incentive-based program rather than a free-market approach. Nitrogen is difficult and costly to  
16 control in Connecticut's urban/suburban setting, and reductions are unlikely to be cost  
17 competitive with POTW credits in a free market system. However, because municipalities are  
18 required to implement the Phase II stormwater permit, and various federal, state and local  
19 programs that require or emphasize NPS/SW management, there may be benefits of an incentive-  
20 based approach to offset some of those costs. For example, payment for NPS/SW reductions at  
21 the same credit prices paid to POTWs under the NCE would help defray costs, and encourage  
22 additional nitrogen reductions from stormwater/NPS sources. Connecticut and the NCAB will  
23 continue to evaluate and explore the viability of these options.

24 Further, the cost for management will be enormous. EPA's Clean Water Needs Survey (EPA  
25 2008) has identified more than \$200 billion in wastewater management infrastructure needs that  
26 does not fully address nutrient control from both traditional point as well as nonpoint/stormwater  
27 sources or consider alternative technologies.

28 Although there are significance differences between water and air quality trading, there are also  
29 several potential barriers to effective trading systems for both media. These are related to  
30 accountability and monitoring; establishing standards and management goals; complexities of  
31 cross media and multiple source trading, including parity of sources; insurance that outcomes  
32 would reduce risk (environmental benefit); economics and marketability of traded credits; and  
33 transparency of the program including public outreach and stakeholder involvement.

### 34 **3.3.3 Government programs, mandates, and policy conflicts**

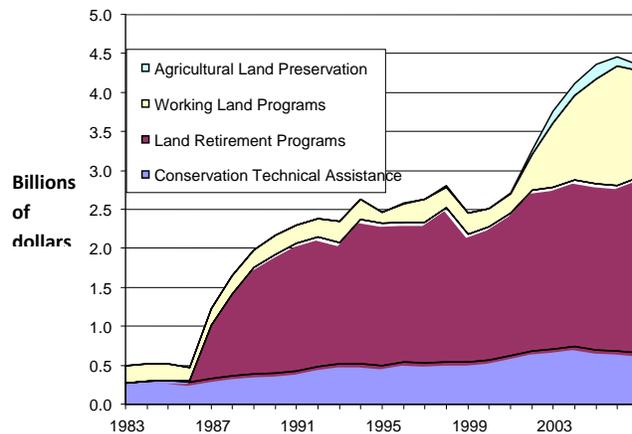
35 The direct allocation of federal funds, and government policies (for various purposes) have  
36 created a variety of results, sometimes in conflict, that directly or indirectly affect Nr generation  
37 and management. Chief among these are those associated with U.S. agricultural and land-use  
38 policies, energy and transportation policies, and both point and non-point mandated controls on  
39 N-bearing aquatic resources including domestic and industrial wastewaters and agricultural  
40 runoff.

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1 The principal agricultural conservation programs in the United States are administered by the  
2 USDA, and consist of the Conservation Reserve and Wetland Reserve Programs (CRP and  
3 WRP, land retirement programs), Environmental Quality Incentives Program (EQIP, a “working  
4 lands” program), various land preservation programs, and technical assistance programs to  
5 agricultural land managers. USDA also manages price support programs and insurance and  
6 disaster programs that, collectively, have relatively little potential for impacting Nr  
7 management). Figure 29 illustrates funding trends for major initiatives showing the slowing of  
8 growth in retirement and assistance programs while preservation and EQIP have increased more  
9 recently. The committee is not able to provide guidance on the appropriate levels of funding for  
10 these programs. Slowing of the CRP may be a result of energy policy initiatives (see below).  
11 Increases in EQIP appear to be associated with greater attention to livestock production, a trend  
12 that reflects growing needs for better management practices in this area (see below and section  
13 2.2.4). Of concern to the committee is the need for more effective approaches aimed at  
14 encouraging farmers and land managers to adopt proven conservation strategies at the field,  
15 farm, and feedlot scale (e.g. more advanced testing methods, geographic position systems-based  
16 variable rate fertilizer application, conservation practices for conserving Nr), and landscape scale  
17 (e.g. riparian buffers and filter strips, wetlands, and stream restoration). It is clear that the extent  
18 of such practices fall far below the technological frontier.

19

**Figure 29: Trends in USDA Conservation Expenditures, 1983-2005**



20

21 The construction and/or restoration of wetlands have received considerable attention in the past  
22 two decades as a conservation method. Such an approach has several positive attributes including  
23 promoting denitrification in watersheds containing or receiving Nr, flood protection, habitat  
24 preservation, and recreational potential (Hey and Philippi, 1995). In the upper Mississippi basin  
25 optimum siting of wetlands could result in as much as 0.4Tg of  $\text{NO}_3^-$  converted to  $\text{N}_2$  (Hey,  
26 2002; Mitsch et al., 1999). Of concern is the potential for the formation of  $\text{N}_2\text{O}$  in such systems

1 if not operated properly, as discussed in section 2.4.7.3.

2 **Finding 20**

3 The restoration of drained wetlands and the creation of new riverine wetlands offer potential  
4 opportunities to transform or sequester reactive nitrogen (Nr) through promotion of the process  
5 of denitrification. These wetlands can be positioned in the landscape to handle the spatial and  
6 temporal demand with minimal impact on food production, while reducing flood damage and  
7 electrical and chemical energy consumption compared to conventional technological solutions.  
8 These wetlands could also replace valuable wetland habitat that has been lost in the United States  
9 to urban and agricultural development over the past 100 years.

10

11 **Recommendation 20:** *In cooperation with the Departments of Agriculture and Army, the Fish  
12 and Wildlife Service and the Federal Emergency Management Agency, the EPA should develop  
13 programs to encourage wetland restoration and creation with strategic placement of these  
14 wetlands where reactive nitrogen is highest in ditches, streams, and rivers. The agency should  
15 also address the means of financing, governance, monitoring and verification. Such programs  
16 might be modeled on the Conservation Reserve Program or extant water quality and  
17 environmental trading programs, but need not be limited to current practices.*

18

19 Further details of wetlands as a management tool are presented as an example in text box 6.

20

**Text Box 6: Water Quality Trading in the Illinois River Basin**

21 For various reasons, wetland restoration has been proposed and the magnitude of needed  
22 restoration estimated. For the Wetland Reserve Program (WRP), the Farm Bill of 1990 set a goal  
23 of restoring approximately 1 million acres. A few years later, the NRC (NRC, 1992) proposed a  
24 national goal of restoring 10 million acres of inland and coastal wetlands by 2010. The council  
25 went on to recommend that 400,000 miles of streams and rivers be restored by 2012 and that 1  
26 million acres of lakes be restored by 2000, both of which would further the control of reactive  
27 nitrogen. While none of these goals has been or is likely to be met by the recommended date,  
28 they articulated a need for wetland restoration addressing the important relationship between  
29 wetlands and water quality.

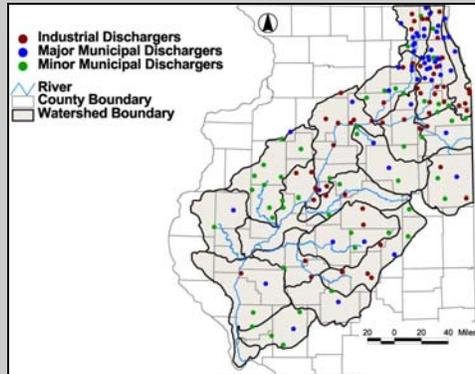
30 Taking into account the economics of using wetlands to manage Nr adds yet another dimension  
31 to site selection. Based on the results of the Water Environment Research Foundation's study  
32 (Hey et al., 2005), The Kinship Foundation sponsored a study (Kostel et al. in preparation) to  
33 define the market for producing and selling Nr (as NO<sub>3</sub><sup>-</sup>) credits. For this analysis, a real,  
34 potential market area was selected: the Illinois River watershed in Illinois—the tributaries  
35 draining Wisconsin, Indiana and Michigan were excluded. The producers of nitrogen credits  
36 were identified as “nutrient farmers” and they became the “sellers” of N credits. The “buyers,”  
37 of nitrogen credits, were restricted to municipal and industrial wastewater treatment facilities,  
38 those facilities that hold an NPDES permit. This restriction, of course, resulted in a considerable  
39 understatement of the market size since the identified buyers emit less than 11% of the total  
40 aquatic N load (David and Gentry, 2000), which finds its way to the Mississippi River—air

1 emission/deposition and agriculture account for the remaining 89%.

2 The watershed was divided into 19 sub-watersheds, spatially locating credit supply and demand.  
3 A linear programming model was developed and used to: 1) examine the potential extent and  
4 distribution of nitrogen credit demand and supply; 2) compare the average seasonal demand  
5 levels to the supply capacity of nutrient farms; and, 3) evaluate the relative effects of seasonality.  
6 Market efficiency was imposed through the objective function: the least costly distribution of  
7 credit production to meet the given monthly demand. Thereby, sellers and buyers were identified  
8 and linked and the spatial characteristics of the market mapped by sub-watershed. At the same  
9 time, the equilibrium price of a credit, or the prevailing price at which buyers and sellers are  
10 willing to trade, was determined. The market, as represented by the model, determined where the  
11 most intensive wetland investment (i.e. wetland restoration) would be, the revenues returned to  
12 these investments, and the costs and savings to the buyers.

13 All 290 permitted dischargers (buyers) are geographically distributed as shown in Figure 30. The  
14 mass loading of the buyers (2,423 tons/month) is reflected in Figure 31. 89% of the demand  
15 comes from the northeastern corner of the basin (Upper Fox, Des Plaines, and Chicago/Calumet  
16 sub-watersheds), the Chicago metropolitan area. As illustrated by Figure 32, 41% of the wetland  
17 restoration area (using the criteria discussed above) were identified in the southwestern corner of  
18 the watershed (Lower Illinois, La Moine, Macoupin, Lower Sangamon, and Middle Illinois sub-  
19 watersheds), where the floodplain is almost entirely leveed. For the market study, the available  
20 load of Nr ( $\text{NO}_3^-$ ) by season and sub-watershed was mapped as illustrated in Figure 33. The N  
21 load was computed using water quality and flow data collected by the U.S. Geological Survey  
22 from 1987-1997. The wetland and wastewater cost functions are described in Hey et al., 2005;  
23 however, the wetland cost functions were modified for the market study to reflect the variability  
24 of land costs across the watershed (i.e., higher land values in urban Chicago vis-à-vis lower land  
25 cost in rural Illinois). This variability is reflected in the spatial distribution marginal costs shown  
26 for the spring marginal costs depicted in Figure 35. As previously noted, wetland treatment costs  
27 vary by time of year because the level of microbial activity, which drives the denitrification  
28 process, varies with water temperature. So, in the winter more wetland area is required than in  
29 the summer to treat an equivalent load of Nr.

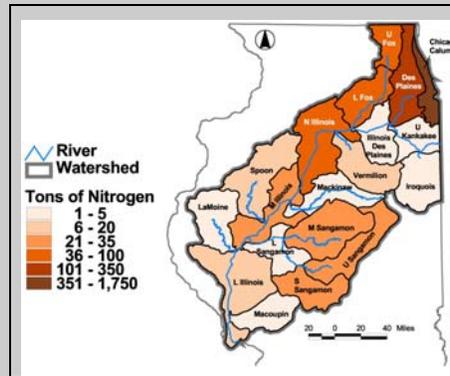
1 **Figure 30: Distribution of municipal (> 1 MGD discharge), and industrial dischargers in**  
2 **the Illinois River Watershed; symbols may represent more than one discharger at that**  
3 **location (Kostel et al., in preparation)**



4

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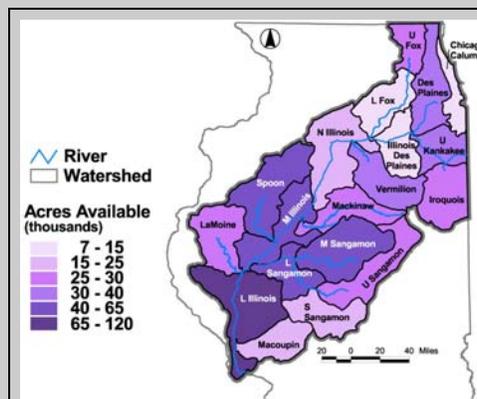
**Figure 31: Distribution of total nitrogen emissions by sub-watershed (Kostel et al., in preparation)**



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**Figure 32: Potential land availability in the 100-year flood zone for nutrient farming in each sub-watershed in the Illinois River Watershed (Kostel et al., in preparation)**

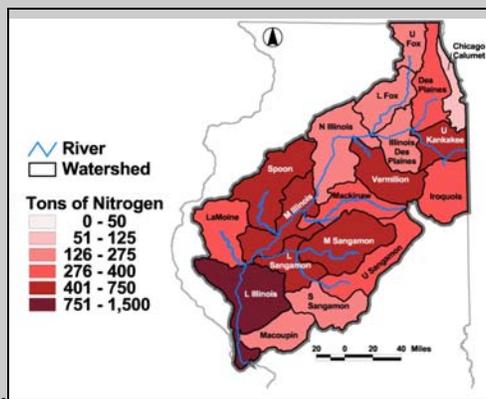
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**Figure 33: Spring available total nitrogen load by sub-watershed (Kostel et al., in preparation)**

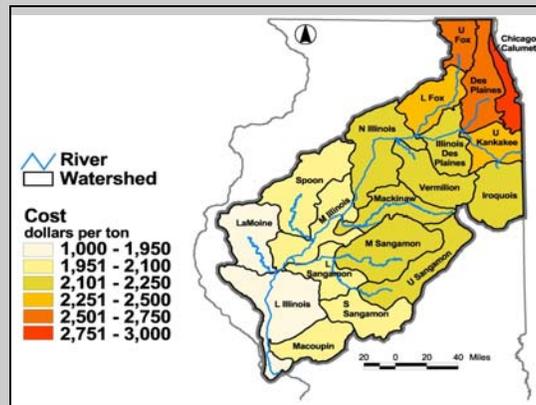
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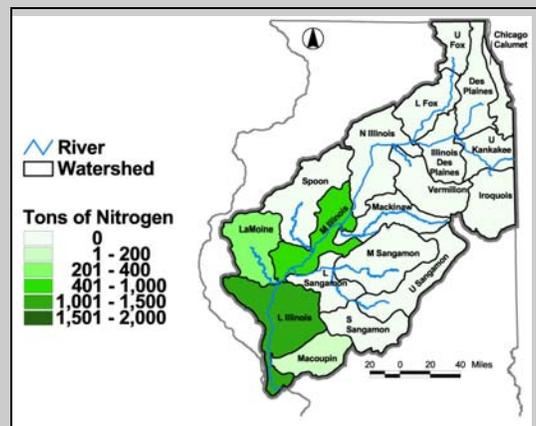
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This Draft is made available for review and approval by the chartered Science Advisory Board. This Draft does not represent EPA policy.

**Figure 34: Spring marginal cost (price) by watershed (Kostel et al., in preparation)**



**Figure 35: Unrestricted spring credit sales (tons/month) by sub-watershed (Kostel et al., in preparation)**



### **Three Regulatory Scenarios**

Regulatory agencies may require that dischargers and nutrient farms be located in proximity to each other and could impose “penalties” when the two are not. Thus, for the sake of analysis, the committee created three regulatory scenarios: 1) unrestricted (buyers can purchase nitrogen credits from nutrient farmers anywhere in the watershed without regard to location (the result of this scenario is given in Figure 36); 2) restricted intra-watershed (buyers must purchase all available credits within its own sub-watershed before buying in other sub-watersheds); 3) Accrued 10% penalty (buyers pay an increasing “tax” on credits purchased in consecutive downstream watersheds). The three regulatory scenarios were analyzed for each of the four seasons. All results can be found in Kostel et al. (in preparation) or Scott et al. (in preparation).

The “unrestricted” scenario is the least expensive because nutrient farms in this scenario are located downstate where land is least expensive. In the other two scenarios, credits were purchased a little more evenly throughout the watershed. Still, most of the credits in the southern

1 corner of the watershed were purchased. The “restricted intra-watershed” and “accrued 10%  
 2 penalty” scenarios resulted in more credits being purchased. This resulted in the sale of N credits  
 3 exceeding the mass of Nr emitted by wastewater treatment, which would benefit the overall  
 4 control of reactive nitrogen. It also would increase the value of the market and the profits of the  
 5 nutrient farmer. The down side of such regulatory controls is that they would drive up the price  
 6 effective price of nitrogen credits. If a buyer had to buy a 1.5 tons for every ton discharged  
 7 because credits are not available in the tributary watershed, the effective price of a credit would  
 8 be 1.5 times the price of the tributary sub-watershed. If prices rise too much, “concrete and steel”  
 9 technologies may become competitive.

10 Considering all of the point source dischargers in the Illinois River watershed, between 29,000  
 11 and 36,000 tons TN/year could be removed through nutrient farming under the studied trading  
 12 schemes (Table 26). The range of removal is a function of the penalties imposed on the market  
 13 by the regulatory agencies. Accordingly, the market revenue would range from \$70 million to  
 14 \$121 million/year. This is a sizeable market that could generate substantial profits, from \$6  
 15 million to \$38 million with the return on investment varying from 5 to 25%. If the savings are  
 16 shared evenly between the seller and buyer, the nutrient farmer could earn between \$200 and  
 17 \$300/acre/year net profit, which in many cases is greater than the profits from corn or soy bean  
 18 production. Further, these profits do not include any earnings from flood control or recreation as  
 19 suggested in the McKnight study report (Hey et al., 2004). With such profits, sufficient land  
 20 should be available for nutrient farming.

21 **Table 26: Nutrient Farm Market Parameters Under Three Trading Scenarios (Kostel et al.**  
 22 **in preparation)**

Parameter	Unrestricted	Restricted Intra-watershed	Accrued 10% Penalty
Total Credits Sold (tons)	29,078	29,078	35,781
Total Revenue <sup>9</sup>	\$69,925,497	\$99,571,889	\$121,457,652
Total Cost to Produce Credits	\$63,258,006	\$66,193,924	\$83,288,747
Profit	\$6,667,491	\$33,377,968	\$38,168,905

23  
 24 This analysis indicates that appropriate lands are available and that wetlands can be effectively  
 25 restored and efficiently used to control Nr. The market, structured as discussed above, could  
 26 generate the capital to accomplish the needed large-scale wetland restoration while saving tax  
 27 payers the cost of upgrading their municipal wastewater treatment plant (TWI, 2007).

<sup>9</sup> Assumes all credits were sold at the cheapest cost within the Illinois River Watershed.

1 **3.3.4. Biophysical and technical controls (control points) on transfer and transformations**  
2 **of Nr in and between environmental systems.**

3 Within the nitrogen cascade there are a number of places where the flow of Nr is constrained or  
4 regulated, either by nature or by human intervention, or a combination of the two. This report  
5 refers to these places in the cascade as “control” points. The control points may restrict the flow  
6 of Nr species within environmental systems (atmospheric, terrestrial, aquatic) or between them.  
7 The control points vary from primary controls where Nr is minimized through conservation  
8 measures or through after-the-fact measures that attempt to convert Nr that is emitted or not fully  
9 used to nonpolluting products, such as to N<sub>2</sub> by denitrification or through long-term storage. The  
10 discussion of choke points is primarily focused on biophysical controls in terrestrial and aquatic  
11 environmental systems. A concluding section on technical controls discusses possibilities for  
12 decreasing NO<sub>x</sub> emissions from combustion.

13 *3.3.4.1. Biophysical controls in terrestrial environmental systems*

14 Approximately 36 Tg of new Nr is introduced into the United States each year (Figure 1). This  
15 new Nr is derived from consumption of ~11 Tg of synthetic N fertilizer, ~8 Tg of N is fixed by  
16 biologically by crops, and ~ 5 Tg is emitted from fossil fuel combustion annually. This N is used  
17 to produce food and fiber (~15 Tg) or is formed during electrical generation, industrial  
18 production or transportation. Efforts to decrease the creation of new Nr should first look to  
19 conservation.

20 Conservation of fossil fuel and resulting decrease in use of fertilizer in food and fiber production  
21 or decreased Nr emission can come through a variety of mechanisms such as more energy  
22 efficient industrial processes, energy efficient homes and vehicles. Further gains are possible  
23 through conservation practices and alternatives to wasteful approaches, such as improving public  
24 transportation to minimize use of personal automobiles, and use of local products that don't  
25 require long-distance shipping.

26 Conservation in food and fiber production and food consumption can also play an important role  
27 in limiting Nr. As agriculture is the largest consumer and producer of Nr, consumption of  
28 fertilizer N could be decreased by changes in diet and increasing fertilizer N use efficiency in  
29 crop and fiber production systems. The control points discussed in this section include: protein  
30 consumption in the human diet, removing croplands that are susceptible to Nr loss from crop  
31 production, decreasing fertilizer N demand by increasing fertilizer use efficiency in crop and  
32 fiber production, turf grass and nitrogen fertilization in the United States, and managing Nr  
33 during recycling through livestock production.

34 *(a) Decreasing the amount of fertilizer N needed through changes in human diet.* Along with  
35 increasing fertilizer N use, continued high intake of protein in developed countries and changes  
36 in the diet of people in developing countries will likely lead to greater N losses from global food  
37 production in the future. The first aspect of changes in food production concerns increasing  
38 protein consumption as global population increases and gets wealthier, which is likely to require  
39 increased N input into food production (Galloway et al. 2007; Naylor et al, 2005).

40 The average protein supply per person in developed countries is presently ~100 g per day, while

1 in the developing countries it is only ~65 g per day [Food and Agricultural Organization  
2 Statistical Database (FAOSTAT), 2003). Protein is used because there is a direct proportionality  
3 between protein and nitrogen composition of food (ca 0.16 g N per 1 g protein). On average in  
4 1995, developed countries consumed ~55% of total protein from animal sources while  
5 developing countries derived ~25% of total protein from animals. Protein consumption was  
6 highest in the United States and western Europe, ~ 70 and ~60 g animal protein per person per  
7 day, respectively. In 2003, total protein consumption in the United States was 115 g person per  
8 person per day (74 derived from animals and 41 from vegetable (FAOSTAT, 2003). In  
9 developing countries, the greatest change in animal protein consumption has occurred in China  
10 where the consumption of meat products has increased 3.2 fold (from ~ 10 to ~32 g per person  
11 per day) since 1980. In Sub-Saharan Africa there has been no increase in either total (~ 50 g per  
12 person per day) or animal protein (~ 10 g per person per day) consumption during the past 30+  
13 years (Mosier et al. 2002).

14 The reason for focusing on the consumption of animal protein is that more N is needed to  
15 produce a unit of animal protein than an equal amount of grain protein. Bleken et al. (2005) note  
16 that the N cost of animal production in Norway and the Netherlands was approximately five  
17 units of N in feeds for each unit of N produced. Approximately 2.5 units of N are required to  
18 produce a unit of wheat protein-N. Bequette et al. (2003) report that dairy cattle consume four  
19 units of N in feeds (including forage and grains) for every unit of N that appears in milk. Using  
20 a range of efficiencies for animal production practices, Kohn et al. (1997) estimated that 4 to 11  
21 units of fertilizer N would be used in a whole farm system to produce a unit of milk protein.  
22 This ratio would be lower when using legume N to feed cattle, as is commonly done. Based  
23 upon the extra N required to produce animal protein compared to grains, continued high protein  
24 consumption in developed countries and changes to higher protein diets in developing countries  
25 will likely increase N input and losses in food production.

26 Moderating this increase by decreasing the average amount of total protein consumed in  
27 developed countries is one mechanism of limiting part of the expected increased N requirement  
28 in food production. One example of a country with a good food supply and moderate  
29 consumption of animal protein is Italy in 1963. At that time food supply was adequate to ensure  
30 sufficient nutrition to all groups of society (Bleken 1997). Total protein consumption was 85 g  
31 per person per day, and consumption of animal protein was 32 g, roughly half of the current  
32 United States diet, and yet much higher than the average of developing countries. Another  
33 example is Japan, where animal protein consumption has traditionally been low, although it has  
34 increased from 25 g in 1963 to 54 g animal protein per person per day in 1995. In the same  
35 period the total protein consumption has increased from 73 g to 96 per person per day.

36 Bleken (1997) analyzed the relation between human diet and global N need for food production.  
37 Her analysis indicates that the total N needed for diets with high animal protein intake  
38 (comparable to many industrialized countries today) are almost twice as high as the N needed for  
39 the average diet in Italy 1963, mentioned above, or for Turkey in 1993. Based on her analysis,  
40 the committee assumes that in the high-N input regions per capita N need for food production  
41 may be reduced by 45%, which would reduce present-day N inputs by 15% worldwide.

42 Switching to a lower protein diet may not, however, reduce N losses if the new diet includes

1 increased quantities of fruits, vegetables, and nuts, in addition to staple grains, beans and pulses.  
2 Vegetables, fruit and nuts are high value crops that typically require large inputs of fertilizers and  
3 pesticides when produced at a large, commercial scale, and N fertilizer losses can be  
4 considerably larger than for grain crops. Having a very diverse diet that includes a wide range of  
5 high value fruits and vegetables that are available 365 days a year whether they are in-season  
6 locally or not, also have consequences for N inputs/outputs from agriculture--both within the  
7 United States and globally. Additional Nr may be conserved by decreasing the amount of food  
8 that is wasted.

9 *(b) Removing croplands that are susceptible to Nr loss from crop production.* Booth and  
10 Campbell (2007) analysis of NO<sub>3</sub> loading in the Mississippi River Basin provides estimates of N  
11 input from agricultural lands to be similar to those estimated by Del Grosso et al. (2006). These  
12 recommendations are essentially the same as those arrived at in the original national hypoxia  
13 assessment which suggested that the most leaky lands be taken out of production (Doering et al.  
14 1999). Booth and Campbell state that,

15 *Nitrogen derived from fertilizer runoff in the Mississippi River Basin (MRB) is*  
16 *acknowledged as a primary cause of hypoxia in the Gulf of Mexico. To identify*  
17 *the location and magnitude of nitrate runoff hotspots, and thus determine where*  
18 *increased conservation efforts may best improve water quality, we modeled the*  
19 *relationship between nitrogen inputs and spring nitrate loading in watersheds of*  
20 *the MRB. Fertilizer runoff was found to account for 59% of loading, atmospheric*  
21 *nitrate deposition for 17%, animal waste for 13%, and municipal waste for 11%.*  
22 *A nonlinear relationship between nitrate flux and fertilizer N inputs leads the*  
23 *model to identify a small but intensively cropped portion of the MRB as*  
24 *responsible for most agricultural nitrate runoff. Watersheds of the MRB with the*  
25 *highest rates of fertilizer runoff had the lowest amount of land enrolled in federal*  
26 *conservation programs. Our analysis suggests that scaling conservation effort in*  
27 *proportion to fertilizer use intensity could reduce agricultural nitrogen inputs to*  
28 *the Gulf of Mexico, and that the cost of doing so would be well within historic*  
29 *levels of federal funding for agriculture. Under this simple scenario, land*  
30 *enrolled in conservation programs would be increased by about 2.71 million*  
31 *hectares, a 29% increase over 2003 enrollments, while land taken out of*  
32 *traditional fertilized agriculture and enrolled in conservation programs would*  
33 *constitute about 3% of 2003 fertilized hectares.*

34 The Booth and Campbell approach places the leakiest intensively cropped lands into government  
35 programs like the Conservation Reserve Program - where they would be put into grass or cover  
36 crops. Doering et al. (1999) had a somewhat different approach. Under their analysis, nitrogen  
37 use or nitrogen loss reductions were imposed on agriculture and the USMP model adjusted crop  
38 rotations, tillage practices and fertilizer inputs within the Mississippi Basin - meeting the given  
39 Nr constraint while maximizing producer and consumer welfare. The model favored those crops  
40 and cropping systems at different points in the landscape having low nitrogen leakage. Where the  
41 model could not find a crop production system having positive returns while meeting the Nr  
42 restrictions, then that land was retired from production. This analysis suggests opportunities for  
43 maintaining land in agricultural production while still reducing Nr losses through better matching

1 of land characteristics with crops and cropping systems.

2

3 *(c) Decreasing fertilizer N demand by increasing fertilizer use efficiency in crop and fiber*  
4 *production.* The largest input of Nr in North America is N) fertilizer used for crop production.  
5 The mean annual N fertilizer input to North America between 1999 and 2003 was 12.5 Tg. Of  
6 this fertilizer N, 66% was used to fertilize cereal crops, mainly corn and wheat (Dobermann and  
7 Cassman, 2005).

8 Corn yield in the United States has increased from an average of 100 bu/ac in 1985 to 136 bu/ac  
9 in 2005 as a result of improved nutrient and pest management, expansion of irrigated area,  
10 conservation tillage, soil testing, and improved crop genetics (yield and pest resistance) [Council  
11 for Agricultural Science and Technology (CAST), 2006]. From 1980 to 2000, N-fertilizer use  
12 efficiency (NFUE, kg grain produced per kg applied N, hereafter expressed as kg grain / kg N)  
13 increased from 42 to 57 kg grain / kg N, a 35% efficiency gain during a period when average  
14 U.S. corn yields increased by 40% (Fixen and West, 2002). Despite this steady increase in  
15 NFUE, the average N fertilizer uptake efficiency for corn in the north-central United States was  
16 37% of applied N in 2000 based on direct field measurements (Cassman et al. 2002). These  
17 results indicate that a large majority of the applied N fertilizer is vulnerable to loss pathways  
18 such as volatilization, denitrification, runoff, and leaching. The results also suggest there is  
19 substantial room for improvement in N efficiency currently achieved by farmers.

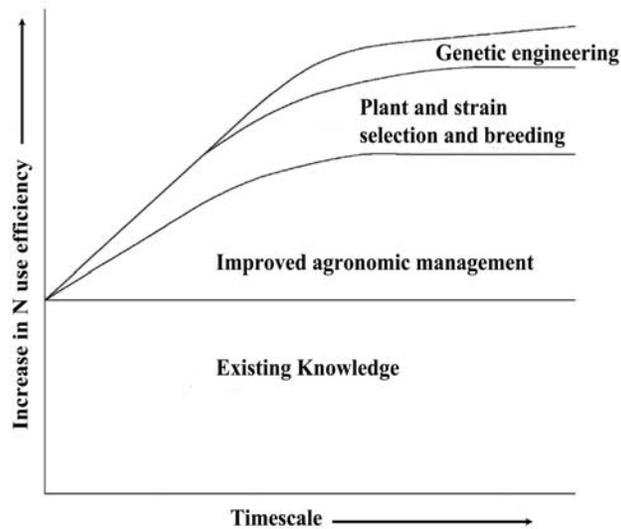
20 Although progress has been made to increase both cereal yield and NFUE, a concerted effort to  
21 further increase NFUE remains a logical control point to reduce production costs, because N  
22 fertilizer represents a significant input cost, and to limit Nr leakage (e.g. NH<sub>3</sub>, NO<sub>x</sub>, N<sub>2</sub>O, NO<sub>3</sub><sup>-</sup>)  
23 from agroecosystems.

24 The goal of reducing Nr while sustaining adequate rates of gain in cereal production to meet  
25 expected food demand will require increases in NFUE, which in turn will require innovative  
26 crop- and soil management practices. This need is exacerbated by the recent increase in demand  
27 for corn to produce ethanol biofuel. The concept of improved N synchrony—practices that better  
28 match the amount, timing, and geospatial location of applied N to crop-N demand and the N  
29 supply from indigenous soil resources-- is generally viewed as the most appropriate approach for  
30 improving NFUE (e.g. Appel, 1994; Cassman et al. 2002). The challenge is for greater  
31 synchrony between crop N demand and the N supply from *all sources* (e.g. soil, fertilizer,  
32 organic inputs such as manure, compost, or green manures, etc) throughout the growing season.  
33 Losses from all N-loss mechanisms increase in proportion to the amount of available N present  
34 in the soil profile at any given time.

35 Several promising technologies and combinations of technologies have emerged in recent years.  
36 Significant increases in NFUE are often achieved through reductions in N fertilizer use by 10 to  
37 30 %, while increases in yield tend to be small (Giller et al. 2004). Figure 36 indicates where  
38 expected greatest gains in NFUE are to be realized in the future from different technology  
39 options. Each of these improvements in management and genetics helps to better match the  
40 amount and timing of applied N to crop-N demand and the N supply from indigenous resources.  
41 However, large investments in research, extension education, and technology transfer will be  
42 required, and significant incentives implemented, to achieve the degree of improved synchrony

1 needed to make substantial improvements in NFUE. The need to accelerate the rate of gain in  
2 crop yields to meet increasing demand for human food, livestock feed, and biofuels represents an  
3 additional new challenge. Crop prices are expected to rise as they more closely track the price of  
4 petroleum (CAST, 2006). Higher crop prices will motivate farmers to achieve higher yields, and  
5 higher crop yields require a greater amount of N uptake to support increased biomass production  
6 (Greenwood et al., 1990). Therefore, an explicit emphasis on developing technologies that  
7 contribute to both increasing yields and NFUE will be needed to ensure that the goals of food  
8 security, biofuel production, and protection of environmental quality are met.

9 **Figure 36: The likely impact of research investment in increasing N fertilizer use efficiency**  
10 **(Giller et al. 2004)**



11

1 (d) *Managing Nr associated with animal waste resulting from livestock production.* Newly fixed  
2 Nr is produced biologically or added as fertilizer to meet the demand for food and fiber  
3 production. Much of the N is used in cereal crop production and cereal crops are then used to  
4 feed livestock. The new Nr is then recycled through the livestock production system and  
5 becomes again susceptible to losses to the atmosphere as ammonia and  $\text{NO}_x$ , is available for  
6 additional  $\text{N}_2\text{O}$  production, and movement into aquatic systems as  $\text{NH}_4^+$  and  $\text{NO}_3^-$ .

7 The bulk of the N fed to livestock ends up in manure, and where this manure (~ one half in urine  
8 and one half in feces) is produced, there is often a much greater supply than can be efficient or  
9 economically used as fertilizer on crops. For large animal feeding operations (AFO's) there is  
10 considerable expense associated with disposal of the manure. Various storage systems have been  
11 developed to deal with this excess manure, the most interesting of which, from the standpoint of  
12 integrated policy on N, convert the urea to  $\text{N}_2$ . The fraction of manure N that can be and is  
13 converted to  $\text{N}_2$  remains a major unanswered scientific or technical question.

14 The NRC (2003) report noted the paucity of credible data on the effects of mitigation technology  
15 on rates and fates of air emissions from AFO's. The report did, however, call for the immediate  
16 implementation of existing atmospheric emission technology.

17 That report also called for a mass balance approach in which the losses of N species such as  
18  $\text{NH}_3$ ,  $\text{NO}$ ,  $\text{N}_2$ , and  $\text{N}_2\text{O}$  are expressed as a fraction of the total N loss. Quoting from the NRC  
19 report:

20 *Storage covers for slurry storage tanks, anaerobic lagoons, and earthen slurry*  
21 *pits are being studied as a method to decrease emissions from those*  
22 *containments. Both permeable and impermeable covers are being studied.*  
23 *Tested covers range from inexpensive material such as chopped straw (on slurry*  
24 *containments only) to more expensive materials such as high density*  
25 *polyethylene. Covers can decrease emissions from storage but their net effect on*  
26 *emissions from the system is conditional on how the effluent is used on the farm.*

27  
28 *Anaerobic digestion in closed containment has been studied for many types of*  
29 *applications. Anaerobic digestion is the process that occurs in an anaerobic*  
30 *lagoon. When conducted in closed vessels, gaseous emissions including methane,*  
31 *carbon dioxide and small amounts of other gasses (possibly ammonia, hydrogen*  
32 *sulfide, and VOCs) are captured and can be burned for electricity generation,*  
33 *water heating, or simply flared. The in-ground digester being tested on a swine*  
34 *farm in North Carolina is an example of the ambient temperature version of this*  
35 *technology (there are also mesophilic and thermophilic designs). The*  
36 *concentration of ammonia remaining in effluent from that digester is higher than*  
37 *the concentration in lagoon effluent and can be volatilized once exposed to air.*  
38

39 Recent research (e.g. Shores et al. 2005; Bicudo et al. 2004; Funk et al. 2004a; Funk et al.  
40 2004b) demonstrates reduction in  $\text{NH}_3$  emissions after a permeable cover was installed. Miner et  
41 al. (2003) reported that a polyethylene cover can reduce  $\text{NH}_3$  emissions by ~80%, but it is not

1 clear what fraction of that N was converted to N<sub>2</sub>. Harper et al. (2000) reported that in a well-  
2 managed swine lagoon denitrification N<sub>2</sub> losses can be equivalent to N lost as NH<sub>3</sub>, in other  
3 words about 50% efficiency. Kermarrec et al. (1998) reported that sawdust litter helps reduce  
4 NH<sub>3</sub> emissions from pig manure with 44-74% of manure N converted to N<sub>2</sub>, but > 10% of the  
5 manure N was released as N<sub>2</sub>O. Sommer (1997) found that NH<sub>3</sub> was emitted from cattle and pig  
6 slurry tanks at the rate of 3.3 kg N m<sup>2</sup>/yr until covered with straw. After straw application NH<sub>3</sub>  
7 emissions were below detection limit. Mahimairaja et al. (1994) reported that NH<sub>3</sub> volatilization  
8 was reduced by 90-95% under anaerobic conditions. Section 2.2.4.5 contains a discussion of  
9 best management practices to minimize NH<sub>3</sub> emissions from livestock waste, and presents  
10 finding and recommendation 6 on the need for a framework for manure management.

11 *(e) Alternatives to current urban landscaping practices.* Section 2.2.5 discussed the use of turf  
12 grasses as a prominent feature in U.S. urban landscapes with over 1 TgN used to fertilize lawns  
13 each year (Table 9). New developments are most amenable to landscaping practices that may  
14 minimize the need to use supplemental fertilizer including preservation of the natural soil profile,  
15 use of turf types that require little or no fertilizer, minimizing turf areas, using organic  
16 maintenance techniques and choosing alternatives to lawns and exotic plant species such as  
17 naturalistic landscaping. Many of these practices are part of a low impact development  
18 philosophy, which can also combine other best management practices to mitigate the effects of  
19 impervious cover and landscape changes. Existing development is also amenable to many of  
20 these practices, especially conversion of typical residential and commercial lawns to natural  
21 landscapes and retrofitting other BMPs that promote infiltration, such as rain gardens.

22 *(f) Structural and non-structural Best Management Practices (BMP) to treat runoff:* There are  
23 probably hundreds, if not thousands, of BMPs that have been designed and manufactured to treat  
24 runoff from both urban and agricultural lands. Whether applied to new development or existing  
25 agricultural or urban land use, most follow basic principles that simulate natural land features  
26 and processes that remove pollutants from runoff. They promote infiltration to take advantage of  
27 the cleansing value of passage through soils and to reduce runoff volumes, and provide for  
28 biological or chemical conditions that help remove pollutants.

29 The most notable of the processes for Nr is providing conditions that are adequate to denitrify Nr  
30 in the waste-stream in a process called biological nitrogen removal, or BNR. BNR simply creates  
31 conditions that convert initial forms of nitrogen to nitrate via oxidation, and convert nitrate to  
32 dinitrogen gas by providing conditions, especially high carbon and low oxygen, where the  
33 denitrification process can occur. These simulate natural conditions such as nitrification that  
34 occurs in oxic soils as water-borne nitrogen infiltrates into the soils and groundwater, and  
35 denitrification that occurs in highly-organic, saturated soils such as in wetlands, where oxygen is  
36 low.

37 Most BMPs are considered structural, and may be highly engineered “package” plants that can  
38 treat sewage or runoff, depending on scale and structure, or simple detention basins that allow  
39 sediments and adhered pollutants to settle out. “Artificial” wetlands are a good example of a  
40 more sophisticated BMP that takes advantage of natural processes, and may be created at the end  
41 of the stormwater pipe, or at edge of field. Non-structural BMPs are often preservation actions,  
42 as discussed earlier, or activities that prevent pollutants from entering the wastestream such as

1 street sweeping or fertilizer limitation.

2 (g) *Wetlands to decrease NO<sub>3</sub><sup>-</sup> loading of aquatic systems.* Much of the nitrate leached from  
3 agricultural fields could be removed from drainage water in wetlands, either natural, created, or  
4 restored. Nitrate removal from the water column in wetlands is performed by plant uptake,  
5 sequestration in the soils, and microbial transformation that include immobilization and  
6 denitrification. Plant uptake and microbiological immobilization result in temporary storages in  
7 the system since most nitrogen will eventually return to the wetland via plant death and  
8 decomposition. In contrast, denitrification constitutes a real nitrogen sink because in this process  
9 bacteria reduce NO<sub>3</sub><sup>-</sup> to nitrogenous gases (N<sub>2</sub>, NO, N<sub>2</sub>O) that are emitted to the atmosphere  
10 (Clement et al., 2002). In general, NO<sub>3</sub><sup>-</sup> removal by wetlands, primarily caused by microbial  
11 denitrification, varies seasonally, with highest rates during summer and lowest rates during the  
12 coldest temperatures (Mitsch et al., 2000; Spieles and Mitsch, 2000; Hernandez and Mitsch,  
13 2007). Hernandez and Mitsch (2007) found that permanently flooded wetlands had lower  
14 N<sub>2</sub>O/N<sub>2</sub> ratios of emissions than did intermittently flooded wetlands. They also found that the  
15 ratio was higher in the cold months even though the flux rates are much lower then. A full risk  
16 assessment needs to be made to determine how much pollutant swapping, i.e., exchanging NO<sub>3</sub><sup>-</sup>  
17 for N<sub>2</sub>O is advisable.

18

19 In addition to preserving existing wetlands there are two basic approaches utilizing wetlands for  
20 reducing the N and other nutrients from reaching rivers and streams and especially vulnerable  
21 downstream coastal systems: 1) creation and restoration of ecosystems, principally wetlands and  
22 riparian forests, between farms and adjacent ditches, streams and rivers; and 2) diversion of  
23 rivers into adjacent constructed and restored wetlands all along the river courses

24 At a series of workshops on restoration of the Mississippi-Ohio-Missouri (MOM) River Basin in  
25 2003-04 (Day et al., 2005; Mitsch and Day, 2006), scientists and managers were asked to focus  
26 on needed research and chokepoint opportunities, especially for managing N in that basin. They  
27 concluded that a major, interdisciplinary research program, as a lead-in to the actual restoration  
28 of wetlands and rivers, needs to take place with sufficient funding, study sites, and time to reduce  
29 remaining uncertainties about the efficacy of wetlands to solve pollution problems related to N.  
30 Twenty to thirty full-scale, existing and new agricultural/wetland demonstration projects should  
31 be located throughout the country and instrumented to study agricultural runoff into wetlands in  
32 a variety of soil conditions. Pilot and full-scale studies are needed of diversions into riparian  
33 systems along river channels to determine their effectiveness for nutrient removal.

34 To give scale to the solution needed, restoration of over 2 million hectares of wetlands is needed  
35 in the MOM basin to reduce the nitrogen load to the Gulf of Mexico sufficiently to ensure a  
36 reduction in the size of the hypoxia (Mitsch et al., 2001; Mitsch and Day, 2006; see Chapter 4).  
37 If wetlands could be economically and effectively restored where croplands now exist on hydric  
38 soils within the 100-year floodplain, returning croplands that are on hydric soils may be an  
39 important NO<sub>3</sub><sup>-</sup> control mechanism. Cropland on hydric soil in the floodplain occupy about 2.8  
40 million hectare, 40% more than is needed for the restoration. If this area and its wetlands were  
41 given back to the Mississippi, over a million tons of NO<sub>3</sub><sup>-</sup>-N would be annually removed or  
42 prevented from reaching the Gulf of Mexico (Hey et al. 2004). A recommendation encouraging  
43 strategic placement of wetland restoration and creation is made in Recommendation 20, section

1 3.3.3.

2

3 3.3.4.2 *Technical controls (control points) on transfer and transformations of atmospheric*  
4 *emissions of Nr in and between environmental systems: NO<sub>x</sub>*

5 A major contributor to Nr in the atmosphere is fossil fuel combustion. During the combustion  
6 process NO<sub>x</sub> (NO<sub>x</sub> = NO + NO<sub>2</sub>) are released to the atmosphere. Globally the production of  
7 NO<sub>x</sub> has accelerated the last few decades through, primarily the increase in fossil fuel  
8 combustion (Galloway et al., 1995; 2008). With this increase in emissions from ~5 Tg N in 1940  
9 to ~ 25 Tg N in 2005, combustion of fossil fuels account for about 50% of the total global NO<sub>x</sub>  
10 emissions for 1990. Of the anthropogenic sources, fossil fuel, aircraft, biomass burning, and part  
11 of the soil emission are most important (Holland et al., 1997). Although global NO<sub>x</sub> emissions  
12 continue to increase, these emissions are declining in the United States. (see section 2.2.2).

13 Nitrogen oxide is formed during combustion by three mechanisms:

- 14 • thermal NO<sub>x</sub> where N and oxygen (O<sub>2</sub>) gas, present normally in combustion air, combine  
15 at high temperatures, usually above 1600 C to form NO through the Zeldovich  
16 mechanism.
- 17 • fuel NO<sub>x</sub> where nitrogen from a fuel, e.g., coal and biofuels, is released as some  
18 intermediate and then combines with O<sub>2</sub> to form NO, and
- 19 • prompt NO<sub>x</sub> where nitrogen gas combines with radical components of the fuel, forming  
20 various compounds including hydrogen cyanide and other cyano radicals. These in turn  
21 form NO<sub>x</sub>. Contributions of prompt NO<sub>x</sub> are usually low as compared to fuel NO<sub>x</sub>.

22

23 There are several ways to control NO<sub>x</sub>. The most common controls are on coal-fired electric  
24 utility generators and those are discussed below. Following electric utility generator controls, or  
25 external combustion systems, there is a discussion on internal combustion controls.

26 Reduction of the temperature limits the kinetics of the N/ O<sub>2</sub> reaction. Temperature can be  
27 controlled by using a fuel-rich mixture versus fuel lean. In this case the reactions to take place at  
28 lower temperatures. Fuel-rich mixtures also reduce the amount of O<sub>2</sub> available for reaction and  
29 there are changes to the chemical mechanisms which limit the oxidation of N<sub>2</sub>. If fuel-lean  
30 mixtures are used for temperature control, while the temperature is lower, there is a significant  
31 amount of O<sub>2</sub> present. Typically in external combustion systems, this is implemented by using  
32 less excess air and using staged combustion. In addition, flue-gas recirculation (FGR) is used to  
33 lower the temperature. Low-NO<sub>x</sub> burners operate under the principle of internally staging the  
34 combustion. To reduce fuel NO<sub>x</sub>, air and fuel staging are used to reduce the peak temperature  
35 where air and fuel are admitted in separate locations.

36 Chemical reduction of NO<sub>x</sub> is also possible. These methods include: selective non-catalytic  
37 reduction (SNCR); SCR; and fuel reburning. SNCR is an add-on technology where urea or NH<sub>3</sub>  
38 is injected in a controlled temperature zone to allow for the reduction of NO<sub>x</sub>. SCR is also an  
39 add-on technology where the flue gas must pass through a catalyst bed to allow for reaction

1 between ammonia and NO<sub>x</sub>. Care must be taken with both technologies to avoid NH<sub>3</sub> slip. Fuel  
2 reburning requires the injection of a fuel to create a zone where NO<sub>x</sub> is reduced to N<sub>2</sub>. Low NO<sub>x</sub>  
3 burners may also use an internal fuel reburning to reduce the NO<sub>x</sub>.

4 For internal combustion engines, the same mechanisms as discussed above are used but in a  
5 variety of different ways, since these systems are using high pressure and predominately have  
6 thermal NO<sub>x</sub> versus fuel NO<sub>x</sub> formation. Most technologies involve the need to reduce the peak  
7 temperature and duration of high temperatures of the combustion zone. For example, gas  
8 turbines utilize low NO<sub>x</sub> burners, while spark ignition engines utilize a three-way catalyst which  
9 requires less than 0.5% O<sub>2</sub>. In this case, additional NO<sub>x</sub> is reduced by utilizing unburned fuel as  
10 a reagent over the catalyst for chemical reduction of NO<sub>x</sub>. It should be noted however, that a  
11 side reaction for the three-way catalyst system produces ammonia. For diesel engines, delaying  
12 the injection of the fuel, and for spark ignited engines retarding the timing can reduce NO<sub>x</sub>  
13 emissions. Engines also use exhaust gas recirculation (EGR) to reduce the peak temperatures.  
14 Recent road side studies have indicated high efficiency (~90%) for NO<sub>x</sub> removal from the  
15 American light-duty fleet (Bishop and Stedman, 2008).

### 16 **3.4 Risk reduction recommendations**

#### 17 **3.4.1 Overarching recommendations**

18 Human activities have significantly increased the introduction of Nr into the U.S. environment  
19 and, through radical alterations of land use, have eliminated many of the natural features that  
20 once may have provided pollutant treatment. While there have been significant benefits resulting  
21 from food production, there have also been, and continue to be, major risks to the health of both  
22 ecosystems and people due to the introduction of Nr into the nitrogen cascade.

23 In its 1990 report, *Reducing Risk*, the Science Advisory Board recommended that the EPA  
24 increase its efforts to integrate environmental considerations into broader aspects of public policy  
25 in as fundamental a manner as are economic concerns. Other Federal agencies often affect the  
26 quality of the environment, e.g., through the implementation of tax, energy, agricultural, and  
27 international policy, and EPA should work to ensure that environmental considerations are  
28 integrated, where appropriate, into the policy deliberations of such agencies. In the current era of  
29 increasing responsibilities without commensurate budgets, intergovernmental cooperation,  
30 partnerships and voluntary programs have become vital tools for agencies needing to stretch their  
31 resources to fulfill their missions.

32  
33 To optimize the benefits of Nr, and to minimize its impacts, will require an integrated nitrogen  
34 management strategy that not only involves EPA, but also coordination with other federal  
35 agencies, the States, the private sector, universities, and a strong public outreach program. The  
36 committee understands that there are real economic costs to the recommendations contained in  
37 this report. For each recommendation there will of necessity be tradeoffs derived from the  
38 varying cost-effectiveness of different strategies.

39 The committee makes three over-arching recommendations:

1 **Recommendation A**

2 *An integrated approach to the management of Nr will likely use a combination of these*  
3 *four implementation mechanisms. Each mechanism must be appropriate to the nature of*  
4 *the problem at hand, supported by critical research on decreasing the risks of excess Nr,*  
5 *and reflect an integrated policy that recognizes the complexities and tradeoffs associated*  
6 *with the nitrogen cascade. Management efforts at one point in the cascade may be more*  
7 *efficient and cost effective than control or intervention at another point. This is why*  
8 *understanding the nature and dynamics of the N cascade is critically important.*

9 **Recommendation B**

10 *EPA should form an Intra-agency Nr Management Task Force that will build on existing*  
11 *Nr research and management capabilities within the Agency. This Intra-Agency Task*  
12 *Force should be aimed at increasing scientific understanding of: 1) Nr impacts on*  
13 *terrestrial and aquatic ecosystems, human health, and climate, 2) Nr-relevant monitoring*  
14 *requirements, and 3) the most efficient and cost-effective means by which to decrease*  
15 *various adverse impacts of Nr loads as they cascade through the environment.*

16 **Recommendation C**

17 *EPA should join with other agencies within the U.S. government in establishing an Inter-*  
18 *agency Nr Management Task Force. The members of this Inter-Agency Task Force*  
19 *should include at least the following federal agencies: U.S. Department of Agriculture*  
20 *(USDA), U.S. Department of Energy (DOE), U.S. Department of Transportation (DOT),*  
21 *National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey*  
22 *(USGS), U.S. Forest Service (USFS,) and Federal Emergency Management Agency*  
23 *(FEMA)). This Task Force should coordinate federal programs that address Nr concerns*  
24 *and help ensure clear responsibilities for monitoring, modeling, researching, and*  
25 *managing Nr in the environment. The International Office of EPA should work closely*  
26 *with the Department of State to ensure that EPA is aware of international efforts to*  
27 *control Nr and is developing national strategies that are compatible with international*  
28 *initiatives.*

29 These intra- and inter-agency Nr-Management Task Forces should take a systems approach to  
30 research, monitoring, and evaluation to inform public policy related to Nr management. The INC  
31 proposes that this be done by 1) developing the methods for the systems approach; 2) enhancing  
32 ecosystem services; 3) identifying and implementing best management practices; 4) assessing  
33 tools and metrics; and 5) developing improved education and training opportunities

- 34
- 35 • Development of methods to help implement a systems approach
- 36 ○ developing and evaluating proposed Nr budgets
- 37 ○ developing appropriate life cycle accounting methods
- 38 ○ developing monitoring as the basis for informed policies, regulations, and
- 39 incentive frameworks for addressing excess Nr loads

- 1       ○     evaluating the critical loads approach to air and water quality management
- 2       ○     developing Nr indicators for excess Nr effects on human health and environment
- 3       ○     developing new systems-based approaches for controlling Nr releases to the
- 4             environment
- 5       ●     Enhancing ecosystem services that lead to the denitrification of Nr in the landscape
- 6             including reconnecting rivers and streams to their floodplain, creation and restoration of
- 7             wetlands in agricultural landscapes, and stream and ditch enhancements that increase the
- 8             surface area of potential denitrification.
- 9       ●     Best management practices (BMPs)
- 10       ○     developing the scientific understanding required for identifying best management
- 11             practices (BMPs) for specific application, including:
  - 12               ■    Nr applications in agriculture to ensure adequate food, feed, fiber, and
  - 13               ■    bioenergy feedstock supply while also avoiding negative impacts on the
  - 14               ■    environment and human health;
  - 15               ■    Nr applications for developed (e.g., residential and commercial) runoff
  - 16               ■    mitigation and landscape maintenance;
  - 17               ■    planning and pollution prevention including low impact development and
  - 18               ■    natural ecosystem service preservation;
  - 19               ■    enhancing the appropriate matching of crops, cropping systems, and land
  - 20               ■    types and capabilities for the most productive use of Nr and the reduction
  - 21               ■    of excess Nr
  - 22               ■    development and natural ecosystem service preservation;
  - 23               ■    primary use of natural land features and attributes, such as wetland
  - 24               ■    preservation and enhancement, natural soil profiles and buffer strips;
  - 25               ■    improved removal of Nr from sewage waste streams at both large-scale
  - 26               ■    wastewater treatment facilities and individual subsurface (septic) systems
- 27       ○     establishing proactive extension and technology transfer approaches to facilitate
- 28             adoption of BMPs
- 29       ●     Assessment activities
- 30       ○     assessing combined carbon (C) and Nr effects on terrestrial and aquatic
- 31             ecosystems
- 32       ○     assessing indicators/endpoints, costs, benefits and risks associated with

- 1           impairment of human health and decline and restoration of ecosystem services
- 2           ○     reviewing existing and proposed legislation for purposes of extending Nr
- 3                   regulatory authority or streamlining procedures for enacting Nr risk reduction
- 4                   strategies
- 5           ○     evaluating economic incentives, particularly those that integrate air, aquatic, and
- 6                   land sources of excess Nr
- 7           •     Developing new education, outreach, and communication initiatives

### 8     **3.4.2 Near-term target recommendations**

9  
10    INC makes four recommendations that set near-term targets for the decrease of Nr entering the  
11    environment from various sources. These, and their rationale, are set forth below.

#### 12    **Target Goal 1. Controls on NO<sub>x</sub> emissions from mobile and stationary sources**

13  
14    The Clean Air Act (1970) and its Amendment (1990) have resulted in NO<sub>x</sub> emissions less than  
15    50 percent of what they would have been without existing controls. While this is an admirable  
16    accomplishment, there is still a need to seek improvements. NO<sub>x</sub> emissions are an order of  
17    magnitude greater than at the beginning of the 20th century. As a consequence there remain  
18    significant negative impacts on both humans and ecosystems. In 2002, coal-fired utilities  
19    generated approximately 1.3 Tg N annually (see Figure 4). If all coal-fired plants used state-of-  
20    the-art NO<sub>x</sub> controls, this number could be reduced by 0.6 Tg N/yr (calculations performed by  
21    Cohen, 2008); in fact by 2008 emissions have been reduced by 0.3 Tg N/yr from 2002 levels (see  
22    Figure 4), so in essence, half the reduction has already been accomplished. The EPA should  
23    continue to reduce NO<sub>x</sub> emissions from major point sources, including electric generating  
24    stations and industrial sources, expanding the use of market mechanisms such as cap and trade.  
25    Under this scenario, it is likely that high efficiency, low emission power plants will be built for  
26    energy needs.

27  
28    For mobile sources, emissions for highway and off-highway sources are approximately 2.2 Tg  
29    N/yr and 1.2 Tg N/yr, respectively. For on road vehicles, better controls for heavy duty diesel  
30    vehicles are needed. For off-road vehicles, which include locomotives, construction, farm,  
31    landscaping equipment, and marine vehicles, there are currently no controls, but 80-90% NO<sub>x</sub>  
32    removal is technically achievable (deNevers, 1995; Koebel et al., 2004). Assuming a 40%  
33    reduction for these sources, there is a potential reduction of 1.4 Tg. The total reduction for both  
34    mobile and stationary sources is then approximately 2 Tg N/yr. Part of achieving such levels of  
35    compliance will require the implementation of inspection and maintenance programs or road-  
36    side monitoring.

37  
38    INC cautions, however, that achieving such a goal may be inadequate for many areas to meet the  
39    new 60 to 70 ppb ozone standard recommended by the CASAC (EPA, 2008) or even the 75 ppb  
40    currently promulgated. Additional measures such as increasing the role of solar- and wind-  
41    generated electricity, wider use of hybrid and electric cars, and public transit conducive to energy

1 conservation and reduced emissions should be promoted.

2  
3 **Target Recommendation 1.** *INC recommends that the EPA expand its NO<sub>x</sub> control*  
4 *efforts from the current decreases of emissions of light duty vehicles (including passenger*  
5 *cars) and power plants to include other important unregulated mobile and stationary*  
6 *sources (e.g., off road vehicles) sufficient to achieve a 2.0 Tg N/yr decrease in the*  
7 *generation of reactive nitrogen. It is believed that coal-fired utilities could experience a*  
8 *reduction of 0.6 Tg N/yr. Since 2002, emissions have already been reduced by 0.3 Tg*  
9 *N/yr; hence, this represents an additional 0.3 Tg N/yr. Approximately 3.4 Tg N/yr can be*  
10 *attributed to mobile sources (highway, off-highway). Most off road vehicles have no*  
11 *controls on NO<sub>x</sub> emissions. Assuming a conservative 40% reduction, an addition 1.4 Tg*  
12 *N/yr could be reduced.*

13  
14 **Target Goal 2. Nr discharges and emissions from agricultural lands and landscapes**

15 Section 3.3.4.1 (b) reviews the various methods that can be used to improve Nr management in  
16 agricultural systems. The INC expects that crop N-uptake efficiencies can be increased by up to  
17 25% over current levels through a combination of knowledge-based practices and advances in  
18 fertilizer technology (such as controlled release and inhibition of nitrification). Crop output can  
19 be increased while reducing total Nr by up to 20% of applied synthetic fertilizers, approximately  
20 **2.4 Tg N/yr** below current levels of Nr additions to the environment. These are appropriate  
21 targets with today's available technologies. Further progress is possible through expanded  
22 research programs.

23 INC is concerned about current policies and practices governing biofuel development. Acreage  
24 devoted to corn production has increased substantially for corn based ethanol production during  
25 the past several years (with nearly one-third of the crop currently devoted to bioethanol  
26 production), with fertilizer nitrogen use on corn increasing by at least 10% (an additional 0.5 Tg  
27 N/yr), largely to meet biofuel feedstock crop demand. In the absence of Nr controls and a failure  
28 to implement best practices, current biofuels policies will make it extremely difficult to reduce  
29 Nr transfers to soils, water and air (Simpson et al. 2008). Integrated management strategies will  
30 be required.

31 INC also notes with concern the increase of N<sub>2</sub>O in the atmosphere. INC believes that  
32 greenhouse gas (GHG) emissions trading will provide both opportunities and challenges for  
33 mitigating Nr environmental and health impacts. Policies and regulations should consider how to  
34 reward reductions of N-related GHG. Biofuel subsidies that accurately account for Nr  
35 contributions to GHG emissions, certification of individual biofuel plants for GHG impact, and  
36 rewards for farmers who reduce N<sub>2</sub>O emissions are examples of how an integrated strategy can  
37 reduce agricultural GHG impacts. For additional production of liquid biofuels beyond the  
38 grandfathered amount in the Energy Independence and Security Act (EISA), EPA has the power  
39 to exercise some controls on N<sub>2</sub>O emissions through the life cycle greenhouse gas accounting  
40 requirements. In this regard, the committee endorses Section 204 of the EISA calling on the  
41 Agency to adopt a life cycle approach to the assessment of future renewable fuel standards as a

1 positive step toward a comprehensive analysis.

2 Previous sections of the report have reviewed methods of controlling Nr from landscape runoff  
3 through the use of natural or restored wetlands (3.3.3 and 3.4.1 (g)), urban areas (3.4.1 (e)), and  
4 through the use of best management practices (3.4.1 (f)). INC finds that flows of Nr into streams,  
5 rivers, and coastal systems can be reduced by approximately 20% (~1 Tg N/yr) through  
6 improved methods of landscape management and without undue disruption to human  
7 commercial and aesthetic activities.

8 **Target recommendation 2.** *The committee recommends that crop N-uptake efficiencies*  
9 *be increased by up to 25% over current practices through a combination of knowledge-*  
10 *based practices and advances in fertilizer technology amounting to ~2.4 Tg N/yr below*  
11 *current amounts of Nr additions to the environment. INC further recommends that excess*  
12 *flows of Nr into streams, rivers, and coastal systems be decreased by approximately 20%*  
13 *(~1 Tg N/yr) through improved landscape management and without undue disruption to*  
14 *agricultural production.*  
15

16 **Target Goal 3. Ammonia emissions from livestock management and manure handling**

17 In spite of gains made over the last several decades in decreasing the amount of NO<sub>x</sub> emitted  
18 from stationary and mobile combustion sources, the total amount of Nr released into the  
19 atmosphere has remained relatively constant. This is related to the essentially unregulated release  
20 of ammonia from livestock operations. At the present time, fewer livestock are required to  
21 produce more animal products than in the past. For example, since 1975 milk production has  
22 increased linearly at the rate of ~ 180 kg milk per cow /yr while milk cow herd population  
23 decreased at the rate of ~69,000 head per yr, i.e. the 60% greater amount of milk produced in  
24 2006 compared to 1970 required 25% fewer cows. Animal inventories declined by 10% for beef  
25 brood cows from 36 million head in 1970 to 33 million head in 2006, and the inventory of  
26 breeder pigs and market hogs declined 8% from 673 million head to 625 million head in the  
27 same period, even with similar or greater annual meat production. These trends resulted from  
28 greater growth rates of animals producing more meat in a shorter amount of time. In 1970,  
29 broilers were slaughtered after 80 days on feed at 1.7 kg live weight, but by 2006 the average  
30 weight was 2.5 kg after only 44 days on feed. These trends are in requiring fewer animals to  
31 produce more animal food products through improved diet and increased production efficiency  
32 will continue.  
33

34 Implementation of improved methods of livestock management and manure handling and  
35 treatment to decrease NH<sub>3</sub> emissions that have been developed since 1990 and will further  
36 decrease ammonia and other gases and odor emissions. For example, sawdust litter helps  
37 decrease NH<sub>3</sub> emissions from pig manure with 44-74% of manure N converted to N<sub>2</sub>. Storage  
38 covers for slurry storage tanks, anaerobic lagoons, and earthen slurry pits decrease emissions  
39 from those containments. Anaerobic digestion in closed containment has been studied for many  
40 types of applications. Recent research demonstrates reduction in NH<sub>3</sub> emissions after a  
41 permeable cover was installed, e.g a polyethylene cover decreased NH<sub>3</sub> emissions by ~80%. A  
42 well managed swine lagoon can denitrify approximately 50% of the excreted N to N<sub>2</sub>. Recently  
43 engineered developments utilizing closed loop systems (Aneja et al. 2008) substantially reduce

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1 atmospheric emissions of ammonia (> 95%) and odor at hog facilities. Based upon recently  
2 demonstrated reduction of NH<sub>3</sub> emissions from swine and poultry production, a moderate  
3 reduction of 50% from 1990 NH<sub>3</sub> emission estimates for swine and poultry production should be  
4 attainable (Table 27). Because of the larger land area involved in dairy and beef production and  
5 the lack of effort that has been exerted in mitigating NH<sub>3</sub> emissions a more modest and reachable  
6 goal of decreasing NH<sub>3</sub> emissions by 10% through improvements in animal diet and manure  
7 management is proposed (Table 27).

8 **Table 27: Estimates for potential decreases in NH<sub>3</sub> emissions from livestock manure in the**  
9 **United States (estimate is based on livestock emissions of 1.6 Tg from Table 1).**

NH <sub>3</sub> Source	% of Total NH <sub>3</sub>	Tg NH <sub>3</sub> -N/yr emitted	Estimated Decrease of NH <sub>3</sub>	
			%	Tg N/yr
Dairy	23.1	0.37	10	0.040
Beef	27.1	0.44	10	0.040
Poultry	27.5	0.44	50	0.220
Swine	17.5	0.28	50	0.140
Goat/sheep	1.6	0.03	10	0.003
Horse	2.9	0.05	10	0.005
<b>Total</b>	<b>100.0</b>	<b>1.61</b>		<b>0.450</b>

10

11 **Target recommendation 3.** *INC recommends that excess flows of Nr into streams,*  
12 *rivers, and coastal systems be decreased by approximately 20% (~1 Tg N/yr) through*  
13 *improved landscape management and without undue disruption to agricultural*  
14 *production. This would include activities such as using large-scale wetland creation and*  
15 *restoration to provide needed ecosystem services of Nr retention and conversion as well*  
16 *as matching cropping systems and intensity of Nr use to land characteristics. Improved*  
17 *tile-drainage systems and riparian buffers on crop land, and implementing storm water*  
18 *and non-point source management practices (e.g., EPA permitting and funding*  
19 *programs) are other alternatives that are less proven. In addition, the committee*  
20 *recommends that crop N-uptake efficiencies be increased by up to 25% over current*  
21 *practices through a combination of knowledge-based practices and advances in fertilizer*  
22 *technology (such as controlled release and inhibition of nitrification). Crop output can*  
23 *be increased while decreasing total Nr by up to 20% of applied artificial Nr, amounting*  
24 *to ~2.4 Tg N/yr below current amounts of Nr additions to the environment. These are*  
25 *appropriate targets with today's available technologies and further progress is possible.*  
26

27 **Target Goal 4. Discharge of Nr from developed lands and point sources**

28 National loadings of Nr to the environment from public and private wastewater point sources are  
29 relatively modest in comparison with global Nr releases; however, they can be important local  
30 sources with associated impacts, especially in highly-populated coastal watersheds. The  
31 committee has estimated that sewage containing Nr from human waste contributes 1.3 Tg N/yr to

1 the terrestrial inputs of nitrogen (Table 1).

2 The committee has also estimated that turf fertilizer usage contributes 1.1 Tg N/yr to terrestrial  
3 inputs, a load that could potentially be cut by about one third (Section 2.2.5). The INC did not  
4 provide estimates for general stormwater and nonpoint source runoff nitrogen load reductions  
5 specific to developed or urban areas – runoff concentrations and loads are highly variable  
6 reflecting geographic and climatic conditions throughout the United States and equally variable  
7 removal efficiencies from standard treatment BMPs, as shown in a summary of the International  
8 Stormwater Best Management Practices Database (Geosyntec Consultants, Wright Water  
9 Engineers, Inc., 2008). However, most BMPs are effective because they provide the biochemical  
10 conditions of wetlands, providing the biophysical controls described in Section 3.3.4.1 and Text  
11 Box 6. These benefits, and the application of BMPs, are recommended in overarching  
12 recommendation 3, as well as in the preceding Target Recommendation 3 as applied to  
13 agricultural lands. Similar benefits specific to developed lands in managing stormwater and  
14 nonpoint sources should be anticipated with BMP application in those areas.

15 Denitrification processes as applied to human waste at sewage treatment plants are well-studied  
16 and growing in application. Performance of these engineered solutions, collectively referenced as  
17 biological nitrogen removal (BNR), can be more rigorously controlled than for stormwater and  
18 nonpoint source BMPs. Recent publications by the EPA (2007h; 2008b; 2008c) have  
19 summarized the state of and the capability for nitrogen removal, and have reported that  
20 technologies to achieve effluent concentrations of 3 mg total nitrogen per liter (TN/L) or less are  
21 readily available. However, plant capacity and design, wastewater characteristics, and climate  
22 conditions can all affect the ability of a facility to remove nitrogen. EPA's review of 2003-2006  
23 data for 16 facilities that remove nitrogen to varying degrees found a range of final effluent TN  
24 concentrations of 1.0 to 9.7 mg/L, with an average of 5.6 mg/L. In general, very small facilities  
25 (<0.1 MGD) do not perform as well, with a final TN concentration ranging from 6-12 mg/L.  
26 Using data provided by Maryland Department of the Environment (2006) and the Connecticut  
27 Department of Environmental Protection (2007), two states that have promoted nitrogen removal  
28 technologies as solutions to coastal eutrophication, EPA (2007h) has constructed estimates of  
29 treatment cost, which ranges from \$0.99 million to \$1.74 million per MGD treated. Treatment  
30 performance varied and exceeded 5 mg TN/L at some of the facilities. Given these conditions,  
31 and performance uncertainties, it seems reasonable to conclude that removal efficiencies in the  
32 range of 40 – 60% below standard effluent nitrogen loads could be readily attained. Based on the  
33 human waste load of 1.3 Tg N/yr, this would yield a decrease in total nitrogen load of between  
34 0.5 and 0.8 Tg/yr.

35 There are two funding sources of significance authorized in the CWA that are used to fund  
36 projects relevant to the control of Nr. Section 319 establishes state nonpoint source management  
37 programs to plan for and implement management measures that abate sources of nonpoint  
38 pollution from eight source categories, including both urban and agricultural sources; however,  
39 the CWA disallows use of 319 funds for NPDES permit requirements, so urban areas with  
40 stormwater permits do not qualify for Section 319 funding. Over the years section 319 has made  
41 available, through 60% matching funds, over \$1.6 billion in assistance. The much larger source  
42 of funding comes under Title VI of the CWA, which has provided over \$24 billion (federal) for  
43 the construction of treatment facilities for point sources of wastewater over the past twenty years,

1 although only a fraction of this amount has been dedicated to denitrification processes. Title VI  
2 “state revolving” load funds can be used for stormwater management, as well as other water  
3 pollution management activities, but not all states have chosen to use funds beyond traditional  
4 sewage treatment plant infrastructure needs because of the large backlog of demand for those  
5 purposes.

6 **Target Recommendation 4.** *INC recommends that a high priority be assigned to*  
7 *nutrient management of stormwater, nonpoint sources and sewage treatment plant*  
8 *effluent through targeted construction grants programs under the CWA. This will*  
9 *decrease Nr emissions from human sewage by between 0.5 and 0.8 Tg N/yr, with*  
10 *additional decreases likely with increased stormwater and nonpoint source BMP*  
11 *application support.*

12 These recommendations, if implemented, would reduce total Nr loadings to the environment in  
13 the United States by approximately 25% below current levels. The committee believes that these  
14 represent realistic near-term targets based on current technology, however further reductions are  
15 needed for many N-sensitive ecosystems and to ensure that health-related standards are  
16 maintained. Achieving and going beyond these recommended Nr reduction targets are critical  
17 given the growing demand for food- and fiber-production and energy use from population  
18 pressure and economic growth.

### 19 **3.5 The Need for Comprehensive Monitoring for Reactive Nitrogen**

20 In order to meet many of the recommendations in this report, including the target  
21 recommendations above, it will be necessary to establish a comprehensive, multi-media  
22 monitoring network for the many chemical forms of reactive nitrogen. There have been many  
23 reports that comprehensively address monitoring needs for a single medium, issue, or pollutant  
24 but relatively few that meet the diverse monitoring and research demands of a complex,  
25 multimedia monitoring effort that includes observations of and physical, chemical and biological  
26 effects that the nitrogen cascade requires. One such effort, more than a decade old, is the  
27 proposal for a National Environmental Monitoring Framework put forth by the Committee on  
28 Environment and Natural Resources (CENR) from the U.S. Office of Science and Technology  
29 Policy (1997). Among their twenty-four recommendations, the key to success was succinctly  
30 stated in the first, “Make integration of environmental monitoring and research networks and  
31 programs across temporal and spatial scales and among resources the highest priority of the  
32 Framework.” Of course, this speaks generally to the need to have broad coverage, to be able to  
33 effectively understand the relationships between sources and sinks, and to understand the  
34 processes and impacts that occur along that route.

35 In a more recent publication by the General Accounting Office (GAO, 2004), it was concluded  
36 that, for watershed management purposes (which includes multimedia aspects), “Better  
37 coordination of data collection efforts (is) needed to support key decisions.” Four key barriers to  
38 this goal were identified: 1) the significantly different purposes for which groups collect data; 2)  
39 inconsistencies in groups’ data collection protocols; 3) unawareness by data collectors as to  
40 which entities collect what types of data; and 4) low priority for data coordination. Also in 2004,  
41 the Committee on Assessment of Water Resources Research of the National Research Council

1 (National Research Council, 2004) reviewed data collection and monitoring needs to assess  
2 national water quality problems. They concluded:

- 3 • Key legacy monitoring systems have been in substantial decline and in some cases have  
4 been nearly eliminated
- 5 • The consequences will not necessarily remain small
- 6 • There are some positive developments that bear on hydrologic monitoring, specifically  
7 remote sensing techniques
- 8 • Strategic investments for monitoring are necessary to avoid or reduce costs of future  
9 water resource or health crises

10 These concerns are also common to any environmental monitoring whether they pertain to land,  
11 air or water.

12 Perhaps a more comprehensive framework has been developed by the Heinz Center as part of  
13 their “The State of the Nation’s Ecosystems” program. In one of those reports (The Heinz  
14 Center, 2006), five challenges to the nation’s environmental monitoring infrastructure were  
15 identified:

- 16 • Expectations about the performance and products of the nation’s environmental  
17 monitoring infrastructure are changing, with new requirements being imposed on existing  
18 systems
- 19 • There is no overall mechanism to determine the most appropriate and highest priority  
20 investments in monitoring and reporting capacity
- 21 • Important elements in the nation’s ecological data collection and reporting system are  
22 operated by nonfederal entities. In many cases, federal support is ad hoc, relatively small,  
23 and not coordinated across agencies
- 24 • Important elements of the nation’s ecological data collection and reporting system are  
25 operated through ad hoc interagency arrangements
- 26 • Research and development programs are fundamentally different from operational  
27 monitoring programs, and it is important to ensure smooth transitions between the two.  
28

29 In sum, monitoring programs need to be developed that meet the needs of a diverse user base  
30 ranging from research to regulation. A monitoring strategy must consider spatial and temporal  
31 requirements necessary to answer specific questions on source, process, and response that are  
32 essential to an integrated approach. While adaptability of monitoring programs helps meet  
33 changing issues and needs, there is benefit to continuation of legacy efforts to determine trends  
34 and management outcomes that should not be overlooked or abandoned. Finally, success will  
35 likely depend on a strong federal, state, local and academic partnership with adequate and  
36 continuing funding from government sources. This partnership must accommodate all aspects of  
37 monitoring from collection to data management and assessment and provide adequate quality  
38 control assurances.

39 These needs have become apparent in the text and recommendations of this report. Two of the  
40 Overarching Recommendations B and C recognize the need for monitoring to promote both  
41 research and management and the necessity of including a strong partnership among federal

1 agencies to attain that end. More specifically, the committee calls for those agencies, through  
2 their Nr-management related task forces, to develop methods to implement a systems (or  
3 integrated) approach to Nr management. Key features of that approach, all of which are relevant  
4 to an integrated monitoring strategy, are repeated here:

- 5 • Development of methods to help implement a systems approach
- 6 • Development and evaluation of proposed Nr budgets
- 7 • Development of appropriate life cycle accounting methods
- 8 • Development of monitoring as the basis for informed policies, regulations, and incentive  
9 frameworks for addressing excess Nr loads
- 10 • Evaluation the critical loads approach to air and water quality management
- 11 • Development of indicators for excess Nr effects on human health and environment
- 12 • Development of new systems-based approaches for controlling Nr releases to the  
13 environment
- 14

15 There are several findings and recommendations related to data and monitoring needs in this  
16 report: #1 (need for more specific and regular data on fertilizer application to major agricultural  
17 crops, as well as for residential and recreational turf), #5 (the need for a nationwide monitoring  
18 network that quantifies agricultural emissions of greenhouse gases, nitrogen and sulfur  
19 compounds, VOCs and ammonia), #8 (more comprehensive measurements of ambient quantities  
20 and deposition of Nr, including the development of appropriate assessment tools including  
21 numerical models, #14 (the need to better address Nr runoff and discharges from peopled  
22 landscapes), and #15 (the need for adequate monitoring and research in estuaries to identify  
23 problems and solutions consistent with attainable, enforceable and affordable goals).

#### 24 **Finding 21**

25 The committee has determined that an integrated approach to monitoring that includes  
26 multimedia (air, land and water) components and considers a suite of environmental and  
27 human concerns related to reactive nitrogen in the environment (e.g., Nr effects, climate  
28 change, human health) is needed. Some of the phenomena that we present in this report  
29 need more definition and verification but, more importantly, as controls are brought to  
30 bear on Nr, improvements need to be measured to verify and validate successful  
31 management strategies. If the desired improvements are not realized as shown by the  
32 collected data, corrective measures will be required. Such an adaptive approach  
33 acknowledges the likelihood that management programs will be altered as scientific and  
34 management understanding improve.

35  
36 **Recommendation 21.** *The committee recommends that EPA initiate discussions and*  
37 *take action to develop a national, multimedia monitoring program that monitors sources,*  
38 *transport and transition, effects using indicators where possible, and sinks of Nr in*  
39 *keeping with the nitrogen cascade concept. This comprehensive program should build*  
40 *upon existing EPA and state initiatives as well as monitoring networks already underway*  
41 *in other federal agencies such as the U.S. Geological Survey programs and the NADP*  
42 *effort.*

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**Appendix 1: Key to chemical abbreviations**

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- AFO – Animal feeding operations
- C - Carbon
- CFC – Chlorofluorocarbon
- DIN – Dissolved inorganic nitrogen
- DO – Dissolved Oxygen
- Fe - Iron
- HNO<sub>3</sub> – Nitric Acid
- HONO –Nitrous Acid
- N – Nitrogen
- N<sub>2</sub> –Diatomic nitrogen
- N<sub>2</sub>O – Nitrous oxide,
- N<sub>2</sub>O<sub>5</sub> – Dinitrogen Pentoxide
- NH<sub>3</sub> – Ammonia
- NH<sub>4</sub><sup>+</sup> – Ammonium
- NH<sub>x</sub> – NH<sub>3</sub> + NH<sub>4</sub><sup>+</sup>
- NO – Nitric Oxide
- NO<sub>2</sub> – Nitrogen Dioxide
- NO<sub>3</sub><sup>-</sup> – Nitrate ion
- NO<sub>3</sub> – Nitrate radical,
- Norg – Organic Nitrogen
- NO<sub>x</sub> – Nitrogen Oxides (NO + NO<sub>2</sub>)
- NO<sub>y</sub>- (NO, NO<sub>2</sub>, NO<sub>3</sub>, N<sub>2</sub>O<sub>5</sub>, HONO, HNO<sub>3</sub>, NO<sub>3</sub><sup>-</sup>, PAN and other organo-nitrates,  
RONO<sub>2</sub>)
- Nr – Reactive Nitrogen
- O<sub>2</sub> – Oxygen
- OH – Hydroxyl radical
- P – Phosphorus
- PAN– Polyacrylonitrile
- PM – Particulate Matter

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- 1  $PM_{2.5}$  – Particulate Matter less than 2.5 microns in diameter
- 2  $PM_{10}$  – Particulate Matter less than 10 microns in diameter
- 3  $RONO_2$  – Organic Nitrates
- 4 Si – Silicon
- 5  $SO_2$  – Sulfur dioxide
- 6  $SO_4^{2-}$  – Sulfate
- 7 TAN – Total ammonical nitrogen

1 **Appendix 2: Acronyms and abbreviations**

2

3 AAPFCO – Association of American Plant Food Control Officials)

4 AFO – Animal Feeding Operation

5 AIRMON – Atmospheric and Integrated Research Monitoring Network

6 AOB – Ammonia Oxidizing Bacteria

7 BL – Boundary layer

8 BMP – Best Management Practice

9 BNF– Biological Nitrogen Fixation

10 BNR – Biological Nutrient (or Nitrogen) Removal

11 CAA – Clean Air Act

12 CAFO – Concentrated Animal Feeding Operation

13 CAIR – Clean Air Interstate Rule (

14 CALM – Consolidated Assessment and Listing Methodology

15 CAST – Council for Agricultural Science and Technology

16 CASTNET – Clean Air Standards and Trends Network

17 C-BNF – Cultivation-induced biological nitrogen fixation ()

18 CFC – Chlorofluorocarbon

19 CFR – Code of Federal Regulations

20 CL – Critical load. Threshold of Nr loading at which negative impacts have been  
21 documented

22 CLAD – Critical Loads Ad-Hoc Committee

23 CMAQ – Community Multiscale Air Quality

24 DRP – Conservation Reserve Program

25 CSO – Combined sewer overflow

26 CTM – Chemical Transport Models

27 CWA – Clean Water Act

28 DIN – Dissolved Inorganic Nitrogen

29 DO – Dissolved Oxygen

30 DOE – U.S. Department of Energy

31 DOT – U.S. Department of Transportation

- 1 ECU – Electricity generating units
- 2 EFD – Essential Facilities Doctrine
- 3 EGR – Exhaust gas recirculation
- 4 EISA – Energy Independence and Security Act
- 5 EPA – United States Environmental Protection Agency
- 6 EQIP - Environmental Quality Incentives
- 7 EU – European Union
- 8 FAO – Food and Agricultural Organization of the United Nations
- 9 FAOSTAT – Food and Agricultural Organization Statistical Database
- 10 FGR – Flue-gas recirculation (FGR)
- 11 ha – Hectare
- 12 GHG – Greenhouse Gas
- 13 GPS – Geographic Positioning System
- 14 HAB – Harmful Algal Bloom
- 15 IPCC – Intergovernmental Panel on Climate Change
- 16 ISA – Integrated Science Assessments
- 17 ITQ - Individual Transferable Quota
- 18 kg – Kilogram
- 19 L - Liter
- 20 LA – Load Allocation
- 21 LISS – Long Island Sound Study
- 22 mg - Milligrams
- 23 MGD – Million Gallons per Day
- 24 Mmt – Million metric tons
- 25 MT - metric tons
- 26 MOM – Mississippi-Ohio-Missouri
- 27 MRB – Mississippi River Basin
- 28 MS4 – Municipal Separate Storm Sewer System
- 29 NAAQS – National Ambient Air Quality Standards
- 30 NADP – National Atmospheric Deposition Program
- 31 NASS – National Agricultural Statistics Service Information

- 1 NCA – National Coastal Assessment
- 2 NCE – Nitrogen Credit Exchange
- 3 NCCR – National Coastal Condition Report
- 4 NEEA – National Estuarine Eutrophication Assessment
- 5 NESCAUM – Northeast States for Coordinated Air Use Management
- 6 NFUE - Nitrogen Fertilizer Use Efficiency. N fertilizer use efficiency (NFUE) is
- 7 calculated as the ratio of grain yield to the quantity of applied N fertilizer (kg grain/kg
- 8 applied N).
- 9 NMP – Nutrient Management Plan
- 10 NOAA – National Oceanic and Atmospheric Administration
- 11 NPS – Nonpoint Source
- 12 NRC – National Research Council
- 13 NRCS – Natural Resources Conservation Service
- 14 NRD – Natural Resource District
- 15 NRI –National Resources Inventory
- 16 NTN – National Trends Network
- 17 NUE – Nitrogen Use Efficiency. NUE is defined as the kg grain produced per kg of total
- 18 N used by the crop, where total N includes N from fertilizer, biological N fixation and
- 19 soil organic matter mineralization
- 20 OTAG – Ozone Transport Assessment Group
- 21 OTC – Ozone Transport Commission
- 22 PE – Physiological Efficiency with which the N taken up by the crop is used to produce
- 23 economic yield such as grain or fruit
- 24 PFP – Partial Factor Productivity
- 25 POTW – Publicly Owned Treatment Works
- 26 PSD – Prevention of Significant Deterioration
- 27 RE –Recovery Efficiency (kg N uptake per kg N applied)
- 28 SAV – Submerged Aquatic Vegetation
- 29 SNCR – Selective non-catalytic
- 30 SCR – Selective Catalytic Reduction
- 31 SIP – State Implementation Plan
- 32 SOM – Soil organic matter
- 33 SPATIally Referenced Regressions On Watershed Attributes Model – SPARROW

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- 1 STP – Sewage Treatment Plant
- 2 SW – Storm Water
- 3 SWAT – Storm Water Assessment Tool
- 4 SWPPP – Stormwater Pollution Prevention Plan
- 5 T – Temperature
- 6 Tg – Teragram (million metric tons or  $10^{12}$  grams)
- 7 TMDL – Total Maximum Daily Load
- 8 UFTRS – Uniform Fertilizer Tonnage Reporting System
- 9 UNECE – United Nations Economic Commission for Europe
- 10 US – United States of America
- 11 USDA – U.S. Department of Agriculture
- 12 USGS – U.S. Geological Survey
- 13 USEPA – United States Environmental Protection Agency
- 14 WHO – World Health Organization
- 15 WLA – Wasteload Allocation
- 16 WPCA – Water Pollution Control Authorities
- 17 WRI – World Resources Institute
- 18 WRP – Wetland Reserve Program
- 19 WSA – Wadeable Stream Assessment

1 **Appendix 3: Findings and Recommendations of the Integrated Nitrogen Committee**

2 **1. Introduction**

3 This appendix contains a compilation of all the Findings and Recommendations of the  
4 Integrated Nitrogen Committee. Following a listing of the four overarching  
5 recommendations, the more specific recommendations are listed with appropriate section  
6 headings.

7 **2. Overarching Recommendations**

8 **Recommendation A**

9 *An integrated approach to the management of Nr will likely use a combination of*  
10 *these four implementation mechanisms. Each mechanism must be appropriate to*  
11 *the nature of the problem at hand, supported by critical research on decreasing*  
12 *the risks of excess Nr, and reflect an integrated policy that recognizes the*  
13 *complexities and tradeoffs associated with the nitrogen cascade. Management*  
14 *efforts at one point in the cascade may be more efficient and cost effective than*  
15 *control or intervention at another point. This is why understanding the nature*  
16 *and dynamics of the N cascade is critically important.*

17 **Recommendation B**

18 *EPA should form an Intra-agency Nr Management Task Force that will build on*  
19 *existing Nr research and management capabilities within the Agency. This Intra-*  
20 *Agency Task Force should be aimed at increasing scientific understanding of: 1)*  
21 *Nr impacts on terrestrial and aquatic ecosystems, human health, and climate,2)*  
22 *Nr-relevant monitoring requirements, and 3) the most efficient and cost-effective*  
23 *means by which to decrease various adverse impacts of Nr loads as they cascade*  
24 *through the environment.*

25 **Recommendation C**

26 *EPA should join with other agencies within the U.S. government in establishing*  
27 *an Inter-agency Nr Management Task Force. The members of this Inter-Agency*  
28 *Task Force should include at least the following federal agencies: U.S.*  
29 *Department of Agriculture (USDA), U.S. Department of Energy (DOE), U.S.*  
30 *Department of Transportation (DOT), National Oceanic and Atmospheric*  
31 *Administration (NOAA), U.S. Geological Survey (USGS), U.S. Forest Service*  
32 *(USFS,) and Federal Emergency Management Agency (FEMA)). This Task Force*  
33 *should coordinate federal programs that address Nr concerns and help ensure*  
34 *clear responsibilities for monitoring, modeling, researching, and managing Nr in*  
35 *the environment. The International Office of EPA should work closely with the*  
36 *Department of State to ensure that EPA is aware of international efforts to*  
37 *control Nr and is developing national strategies that are compatible with*  
38 *international initiatives.*

39 These intra- and inter-agency Nr-Management Task Forces should take a systems  
40 approach to research, monitoring, and evaluation to inform public policy related to Nr

1 management. The INC proposes that this be done by 1) developing the methods for the  
2 systems approach; 2) enhancing ecosystem services; 3) identifying and implementing  
3 best management practices; 4) assessing tools and metrics; and 5) developing improved  
4 education and training opportunities

- 5
- 6 • Development of methods to help implement a systems approach
  - 7 ○ developing and evaluating proposed Nr budgets
  - 8 ○ developing appropriate life cycle accounting methods
  - 9 ○ developing monitoring as the basis for informed policies, regulations, and  
10 incentive frameworks for addressing excess Nr loads
  - 11 ○ evaluating the critical loads approach to air and water quality management
  - 12 ○ developing Nr indicators for excess Nr effects on human health and  
13 environment
  - 14 ○ developing new systems-based approaches for controlling Nr releases to  
15 the environment
- 16 • Enhancing ecosystem services that lead to the denitrification of Nr in the  
17 landscape including reconnecting rivers and streams to their floodplain, creation  
18 and restoration of wetlands in agricultural landscapes, and stream and ditch  
19 enhancements that increase the surface area of potential denitrification.
- 20 • Best management practices (BMPs)
  - 21 ○ developing the scientific understanding required for identifying best  
22 management practices (BMPs) for specific application, including:
    - 23 ■ Nr applications in agriculture to ensure adequate food, feed, fiber,  
24 and bioenergy feedstock supply while also avoiding negative  
25 impacts on the environment and human health;
    - 26 ■ Nr applications for developed (e.g., residential and commercial)  
27 runoff mitigation and landscape maintenance;
    - 28 ■ planning and pollution prevention including low impact  
29 development and natural ecosystem service preservation;
    - 30 ■ Enhancing the appropriate matching of crops, cropping systems,  
31 and land types and capabilities for the most productive use of Nr  
32 and the reduction of excess Nr
    - 33 ■ development and natural ecosystem service preservation;
    - 34 ■ primary use of natural land features and attributes, such as wetland

- 1 preservation and enhancement, natural soil profiles and buffer  
2 strips;
- 3       ▪ improved removal of Nr from sewage waste streams at both large-  
4 scale wastewater treatment facilities and individual subsurface  
5 (septic) systems
- 6       ○ establishing proactive extension and technology transfer approaches to  
7 facilitate adoption of BMPs
- 8       • Assessment activities
- 9       ○ assessing combined carbon (C) and Nr effects on terrestrial and aquatic  
10 ecosystems
- 11       ○ assessing indicators/endpoints, costs, benefits and risks associated with  
12 impairment of human health and decline and restoration of ecosystem  
13 services
- 14       ○ reviewing existing and proposed legislation for purposes of extending Nr  
15 regulatory authority or streamlining procedures for enacting Nr risk  
16 reduction strategies
- 17       ○ evaluating economic incentives, particularly those that integrate air,  
18 aquatic, and land sources of excess Nr
- 19       • Developing new education, outreach, and communication initiatives

20 **3. Near-term target recommendations**

21 In addition, INC makes four recommendations that set near-term targets for the decrease  
22 of Nr entering the environment from various sources.

- 1 (1) INC recommends that the EPA expand its NO<sub>x</sub> control efforts from the current  
2 decreases of emissions of light duty vehicles (including passenger cars) and  
3 power plants to include other important unregulated mobile and stationary  
4 sources sufficient to achieve a **2.0 Tg N/yr** decrease in the generation of  
5 reactive nitrogen. Such changes can be effected by applying existing, proven  
6 technology. Emissions from many point sources are controlled with low-NO<sub>x</sub>  
7 burners or NO<sub>x</sub> reduction – such equipment should also be installed on  
8 industrial boilers and the remaining, uncontrolled power plants. NO<sub>x</sub> controls  
9 for modern, on-road vehicles are effective and these technologies should be  
10 applied to off-road vehicles, locomotives, ships and other devices with  
11 internal combustion engines.
- 12 (2) INC recommends a goal of decreasing livestock-derived NH<sub>3</sub> emissions by  
13 30% (a decrease of **0.5 Tg N/yr**) by a combination of BMPs and engineered  
14 solutions. This is expected to decrease PM<sub>2.5</sub> by ~0.3 μg/m<sup>3</sup> (2.5%), and  
15 improve health of ecosystems by achieving progress towards critical load  
16 recommendations. Additionally we recommend decreasing NH<sub>3</sub> emissions  
17 derived from fertilizer applications by 20% (decrease by **~0.2 Tg N/yr**),  
18 through the use of NH<sub>3</sub> treatment systems and BMPs
- 19 (3) INC recommends that excess flows of Nr into streams, rivers, and coastal  
20 systems be decreased by approximately 20% (**~1 Tg N/yr**) through improved  
21 landscape management and without undue disruption to agricultural  
22 production. This would include activities such as using large-scale wetland creation  
23 and restoration to provide needed ecosystem services of Nr retention and conversion  
24 as well as matching cropping systems and intensity of Nr use to land characteristics.  
25 Improved tile-drainage systems and riparian buffers on cropland, and  
26 implementing storm water and non-point source management practices (e.g.,  
27 EPA permitting and funding programs) are other alternatives that are less  
28 proven. In addition, the committee recommends that crop N-uptake  
29 efficiencies be increased by up to 25% over current practices through a  
30 combination of knowledge-based practices and advances in fertilizer  
31 technology (such as controlled release and inhibition of nitrification). Crop  
32 output can be increased while decreasing total Nr by up to 20% of applied  
33 artificial Nr, amounting to **~2.4 Tg N/yr** below current amounts of Nr  
34 additions to the environment. These are appropriate targets with today's  
35 available technologies and further progress is possible.
- 36 (4) INC recommends that a high priority be assigned to nutrient management  
37 through a targeted construction grants program under the CWA. This will  
38 decrease Nr emissions by between **0.5 and 0.8 Tg N/yr**.

39  
40 **4. Specific findings and recommendations**

41 **Finding 1:** Crop agriculture receives 63% of U.S. annual new Nr inputs from  
42 anthropogenic sources (9.8 Tg from N fertilizer, 7.7 from crop BNF versus 29 Tg total)

1 and accounts for 58% (7.6 Tg, see Table 1) of total U.S. Nr losses from terrestrial  
2 systems to air and aquatic ecosystems, yet current monitoring of fertilizer use statistics by  
3 federal agencies is inadequate to accurately track trends in quantities and fate of N  
4 applied to major crops and the geospatial pattern by major watersheds.

5 **Recommendation 1:** *Increase the specificity and regularity of data acquisition for*  
6 *fertilizer application to major agricultural crops in terms of timing and at a sufficiently*  
7 *small application scale (and also for urban residential and recreational turf) by county*  
8 *(or watershed) to better inform decision-making about policies and mitigation options for*  
9 *reducing Nr load in these systems and to facilitate monitoring and evaluation of impact*  
10 *from implemented policies and mitigation efforts.*

11 **Finding 2.** Nr inputs to crop systems are critical to sustain crop productivity and soil  
12 quality. Moreover, given limited land and water resources, global population growth and  
13 rapid economic development in the world's most populous countries, the challenge is to  
14 accelerate increases in crop yields on existing farm land while also achieving a  
15 substantial increase in N fertilizer uptake efficiency. This process is called "ecological  
16 intensification" because it recognizes the need to meet future food, feed, fiber and energy  
17 demand of a growing human population while also protecting environmental quality and  
18 ecosystem services for future generations (Cassman, 1999). More diverse cropping  
19 systems with decreased Nr fertilizer input may also provide an option on a large scale if  
20 the decrease in Nr losses per unit of crop production in these diverse systems can be  
21 achieved without a decrease in total food production, which would trigger indirect land  
22 use change to replace the lost production and negate the benefits.

23 **Recommendation 2:**

24 *d) Data on NFUE and N mass balance, based on direct measurements from*  
25 *production-scale fields, are required for the major crops to identify which*  
26 *cropping systems and regions are of greatest concern with regard to mitigation of*  
27 *Nr load and to better focus research investments, policy development, and*  
28 *prioritization of risk mitigation strategies.*

29 *e) Promote efforts at USDA and land grant universities to: (i) investigate means to*  
30 *increase the rate of gain in crop yields on existing farm land while increasing N*  
31 *fertilizer uptake efficiency and (ii) explore the potential for more diverse cropping*  
32 *systems with lower N fertilizer input requirements so long as large-scale adoption*  
33 *of such systems would not cause indirect land use change.*

34 *f) EPA should work closely with the U.S. Department of Agriculture (USDA),*  
35 *Department of Energy (DOE), and the National Science Foundation (NSF), and*  
36 *land grant universities to help identify research and education priorities efficient*  
37 *use and mitigation of Nr applied to agricultural systems.*

38  
39 **Finding 3.** Nitrous oxide emissions from the Nr inputs to cropland from fertilizer,  
40 manure, and legume fixation represent a large proportion of agriculture's contribution to  
41 greenhouse gas emissions, and the importance of this source of anthropogenic greenhouse  
42 gas will likely increase unless NFUE is markedly improved in crop production systems.

1 Despite its importance, there is considerable uncertainty in the estimates of nitrous oxide  
2 emissions from fertilizer and research should focus on reducing this uncertainty.

3 **Recommendation 3:** *The committee recommends that EPA ensure that the uncertainty*  
4 *in estimates of nitrous oxide emissions from crop agriculture be greatly reduced through*  
5 *the conduct of EPA research and through coordination of research efforts more generally*  
6 *with other agencies such as USDA, DOE, NSF and with research conducted at*  
7 *universities.*

8

9 **Finding 4.** Rapid expansion of biofuel production has the potential to increase N  
10 fertilizer use through expanding corn production and its associated N fertilizer inputs and  
11 extending cultivation for cellulosic materials that will also need N. Distillers grains are  
12 changing animal diets and affecting N recycling in livestock. Both have important  
13 consequences for the effective future management of Nr.

14 **Recommendation 4:** EPA should work with USDA and universities to improve  
15 understanding and prediction of how expansion of biofuel production, as mandated by the  
16 2007 EISA, will affect Nr inputs and outputs from agriculture and livestock systems.  
17 Rapid expansion of biofuel production has the potential to increase N fertilizer use  
18 through expansion of corn production area and associated N fertilizer inputs, and from  
19 extending cultivation of cellulosic materials that will also need N inputs.

20

21 **Finding 5.** There are no nationwide monitoring networks in the United States to quantify  
22 agricultural emissions of greenhouse gases, NO, N<sub>2</sub>O, reduced sulfur compounds, VOCs,  
23 and NH<sub>3</sub>. In contrast there is a large network in place to assess the changes in the  
24 chemical climate of the United States associated with fossil fuel energy production, ie the  
25 National Atmospheric Deposition Program/National Trends Network (NADP/NTN),  
26 which has been monitoring the wet deposition of sulfate (SO<sub>4</sub><sup>2-</sup>), NO<sub>3</sub><sup>-</sup>, and NH<sub>4</sub><sup>+</sup> since  
27 1978.

28 **Recommendation 5:** *The status and trends of gases and particulate matter emitted from*  
29 *agricultural emissions, e.g., NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> should be monitored and assessed utilizing a*  
30 *nationwide network of monitoring stations. EPA should coordinate and inform its*  
31 *regulatory monitoring and management of reactive nitrogen with the multiple efforts of*  
32 *all agencies including those of the U.S. Department of Agriculture and NSF supported*  
33 *efforts such as the National Ecological Observatory Network (NEON) and the Long Term*  
34 *Ecological Research Network (LTER).*

35

36 **Finding 6.:** Farm-level improvements in manure management can substantially reduce  
37 Nr load and transfer. There are currently no incentives or regulations to decrease these  
38 transfer and loads despite the existence of management options to mitigate.

1 **Recommendation 6:** *Policy, regulatory, and incentive framework is needed to improve*  
2 *manure management to reduce Nr load and ammonia transfer, taking into account*  
3 *phosphorus load issues.*

4 **Finding 7.** Synthetic N fertilizer application to urban gardens and lawns amounts to  
5 approximately 10% of the total annual synthetic N fertilizer used in the United States.  
6 Even though this N represents a substantial portion of total N fertilizer use, the efficiency  
7 with which it is used receives relatively little attention.

8 **Recommendation 7a:** *To ensure that urban fertilizer is used as efficiently as possible,*  
9 *the committee recommends that EPA work with other agencies such as USDA as well as*  
10 *state and local extension organizations to coordinate research and promote awareness of*  
11 *the issue.*

12 **Recommendation 7b:** *Through outreach and education, supported by research,*  
13 *improved turf management practices should be promoted, including improved fertilizer*  
14 *application and formulation technologies and maintenance techniques that minimize*  
15 *supplemental Nr needs and losses, use of alternative turf varieties that require less*  
16 *fertilization, alternative ground covers in place of turf, and use of naturalistic*  
17 *landscaping that focuses on native species.*

18

19 **Finding 8.** Scientific uncertainty about the origins, transport, chemistry, sinks, and  
20 export of Nr remains high, but evidence is strong that atmospheric deposition of Nr to the  
21 Earth's surface as well as emissions from the surface to the atmosphere contribute  
22 substantially to environmental and health problems. Nitrogen dioxide, NO<sub>2</sub>, is often a  
23 small component of NO<sub>y</sub>, the total of oxidized nitrogen in the atmosphere. The current  
24 NAAQS for NO<sub>2</sub>, as an indicator of the criteria pollutant "oxides of nitrogen," is  
25 inadequate to protect health and welfare. NO<sub>y</sub> should be considered seriously as a  
26 supplement or replacement for the NO<sub>2</sub> standard and in monitoring. Atmospheric  
27 emissions and concentrations of Nr from agricultural practices (primarily in the form of  
28 NH<sub>3</sub>) have not been well monitored, but NH<sub>4</sub><sup>+</sup> ion concentration and wet deposition (as  
29 determined by NADP and NTN) appear to be increasing, suggesting that NH<sub>3</sub> emissions  
30 are increasing. Both wet and dry deposition contribute substantially to NH<sub>x</sub> removal, but  
31 only wet deposition is known with much scientific certainty. Thus consideration should  
32 be given to adding these chemically reduced and organic forms of Nr to the list of  
33 Criteria Pollutants.

34 **Recommendation 8a.** *EPA should re-examine the Criteria Pollutant "oxides of*  
35 *nitrogen" and the indicator species, NO<sub>2</sub>, and consider using chemically reactive*  
36 *nitrogen (Nr without N<sub>2</sub>O) as the criteria pollutant and NH<sub>x</sub> and NO<sub>y</sub> as the indicators.*

37 **Recommendation 8b.** *Begin monitoring of NH<sub>x</sub> and NO<sub>y</sub> as soon as possible to*  
38 *supplement the existing network of NO<sub>2</sub> compliance monitors.*

39 **Recommendation 8c.** *Pursue the longer term goal of monitoring individual components*  
40 *of Nr, such as NO<sub>2</sub> (with specificity), NO, and PAN, and HNO<sub>3</sub>, as well as support the*

1 *development of new measurement and monitoring methods.*

2 **Recommendation 8d.** *Increase the scope and spatial coverage of the Nr concentration*  
3 *and flux monitoring networks (such as the National Atmospheric Deposition Program*  
4 *and the Clean Air Status and Trends Network) and appoint an oversight review panel for*  
5 *these two networks.*

6 **Recommendation 8e.** *EPA in coordination with other federal agencies should pursue*  
7 *research goals including:*

8 • *Measurements of deposition directly both at the CASTNET sites and in nearby*  
9 *locations with non-uniform surfaces such as forest edges.*

10 • *Improved measurements and models of convective venting of the planetary*  
11 *boundary layer and of long range transport.*

12 • *Improved analytical techniques and observations of atmospheric organic N*  
13 *compounds in vapor, particulate, and aqueous phases.*

14 • *Increased quality and spatial coverage of measurements of the NH<sub>3</sub> flux to the*  
15 *atmosphere from major sources especially agricultural practices.*

16 • *Improved measurement techniques for, and numerical models of NO<sub>y</sub> and NH<sub>x</sub>*  
17 *species especially with regard to chemical transformations, surface deposition, and*  
18 *off shore export; develop linked ocean-land-atmosphere models of Nr.*

19 **Finding 9.** *Although total N budgets within all terrestrial systems are highly uncertain,*  
20 *Nr losses from grasslands and forests (vegetated) and urban (populated) portions of the N*  
21 *Cascade appear to be higher, on a per cent of input basis, than from agricultural lands.*  
22 *The relative amount of these losses ascribed to leaching, runoff and denitrification, are as*  
23 *uncertain as the N budgets themselves.*

24 **Recommendation 9:** *EPA should join with USDA, DOE, and universities should work*  
25 *together in efforts to ensure that the N budgets of terrestrial systems are properly*  
26 *quantified and that the magnitudes of at least the major loss vectors are known.*

27 **Finding 10.** *Denitrification of Nr in terrestrial and aquatic systems is one of the most*  
28 *uncertain parts of the nitrogen cycle. Denitrification is generally considered to be a*  
29 *dominant N loss pathway in both terrestrial and aquatic systems, but it is poorly*  
30 *quantified*

31 **Recommendation 10:** *EPA, USDA, DOE, and universities should work together to*  
32 *ensure that denitrification in soils and aquatic systems is properly quantified, by funding*  
33 *appropriate research.*

34 **Finding 11.** *The committee finds that there is a need to measure, compute, and report the*  
35 *total amount of Nr present in impacted systems in appropriate units. Since what is*  
36 *measured influences what we are able to perceive and respond to; in the case of Nr, it is*

1 especially critical to measure total amounts and different chemical forms, at regular  
2 intervals over time.

3 **Recommendation 11.** *The committee recommends that EPA routinely and consistently*  
4 *account for the presence of Nr in the environment in forms appropriate to the medium in*  
5 *which they occur (air, land, and water) and that accounting documents be produced and*  
6 *published periodically (for example, in a fashion similar to National Atmospheric*  
7 *Deposition Program (NADP) summary reports). The committee understands that such an*  
8 *undertaking will require substantial resource, and encourages the Agency to develop and*  
9 *strengthen partnerships with appropriate federal and state agencies, and private sector*  
10 *organizations, with parallel interests in advancing the necessary underlying science of Nr*  
11 *creation, transport and transformation, impacts, and management.*

12 **Finding 12.** The committee finds that reliance on only one approach for categorizing the  
13 measurement of Nr is unlikely to result in the desired outcome of translating N-induced  
14 degradation into the level of understanding needed to develop support for implementing  
15 effective Nr management strategies.

16 **Recommendation 12.** *It is, therefore, recommended that the EPA examine the full range*  
17 *of traditional and ecosystem response categories, including economic and ecosystem*  
18 *services, as a basis for expressing Nr impacts in the environment, and for building better*  
19 *understanding and support for integrated management efforts.*

20 **Finding 13.** Over the past 25 years, there has been a growing recognition of  
21 eutrophication as a serious problem in coastal estuaries (NRC, 2000). The last  
22 comprehensive national NCCR was published in 2004 (EPA, 2004) included an overall  
23 rating of “fair” for estuaries, including the Great Lakes, based on evaluation of over 2000  
24 sites. The water quality index, which incorporates nutrient effects primarily as  
25 chlorophyll-a and dissolved oxygen impacts, was also rated “fair” nationally. Forty  
26 percent of the sites were rated “good” for overall water quality, while 11% were “poor”  
27 and 49% “fair”.

28 **Recommendation 13:** *The committee recommends that EPA develop a uniform*  
29 *assessment and management framework that considers the effects of Nr loading over a*  
30 *range of scales reflecting ecosystem, watershed, and regional levels. The framework*  
31 *should include all inputs. related to atmospheric and riverine delivery of Nr to estuaries,*  
32 *their comprehensive effects on marine eutrophication dynamics and their potential for*  
33 *management.*

34 **Finding 14.** Intervention to control Nr under most water management programs  
35 generally occurs in three ways:

- 36
- 37 • Prevention or source controls
  - 38 • Physical, chemical or biological “dead ending” or storage within landscape
  - 39 compartments where it is rendered less harmful (e.g., long-term storage in soils or  
vegetation; denitrification, primarily in wetlands; reuse)

- 1       • Treatment using engineered systems such as wastewater treatment plants or BMPs for  
2       stormwater and nonpoint source runoff.

3 While most management programs focus on the third (treatment) approach, there are  
4 opportunities for combining the three that can be more effective and cost less.

5 **Recommendation 14.** *To better address Nr runoff and discharges from the peopled*  
6 *landscape the committee recommends that EPA:*

7       **14a.** *Evaluate the suite of regulatory and non regulatory tools used to manage Nr in*  
8 *populated areas from nonpoint sources, stormwater and domestic sewage and*  
9 *industrial wastewater treatment facilities, including goal-setting through water*  
10 *quality standards and criteria. Determine the most effective regulatory and voluntary*  
11 *mechanisms to apply to each source type with special attention to the need to regulate*  
12 *nonpoint source and related land use practices.*

13       **14b.** *Review current regulatory practices for point sources, including both*  
14 *wastewater treatment plants and stormwater, to determine adequacy and capacity*  
15 *towards meeting national Nr management goals. Consider technology limitations,*  
16 *multiple pollutant benefits, and funding mechanisms as well as potential impacts on*  
17 *climate change from energy use and greenhouse gas emissions, including nitrous*  
18 *oxide.*

19       **14c.** *Set Nr management goals on a regional/local basis, as appropriate, to ensure*  
20 *most effective use of limited management dollars. Fully consider “green”*  
21 *management practices such as low impact development and conservation measures*  
22 *that preserve or re-establish Nr removing features to the landscape as part of an*  
23 *integrated management strategy along with traditional engineered best management*  
24 *practices.*

25       **14d.** *Research best management practices that are effective in controlling Nr,*  
26 *especially for nonpoint and stormwater sources, including land and landscape*  
27 *feature preservation and set Nr management targets that realistically reflect these*  
28 *management and preservation capacities. Construct a decision framework to assess*  
29 *and determine implementation actions consistent with management goals.*

30       **14e.** *Use ecosystem-based management approaches that balance natural and*  
31 *anthropogenic needs and presence in the landscape.*

32 **Finding 15.** Meeting Nr management goals for estuaries, when a balance should be  
33 struck between economic, societal and environmental needs, under current federal law  
34 seems unlikely. Enforceable authorities over nonpoint source, stormwater, air (in terms of  
35 critical loads), and land use are not adequate to support necessary Nr controls. Funding  
36 programs are presently inadequate to meet existing pollution control needs. Furthermore,  
37 new technologies and management approaches are required to meet ambitious Nr control  
38 needs aimed at restoring national water quality.

39 **Recommendation 15.** *INC recommends that EPA reevaluate water quality management*

1 *approaches to ensure Nr management goals are attainable, enforceable, and affordable*  
2 *and that monitoring and research are adequate to problem definition and resolution,*  
3 *particularly in the development of nitrogen removal technologies.*

4 **Finding 16.** In this connection, the INC strongly commends EPA for its recently  
5 increased willingness to think more holistically – and in more fully integrated ways –  
6 about both the policy-relevant science and the practical arts of air quality management  
7 aimed at protection of both aquatic and terrestrial ecosystems from adverse effects of Nr.  
8 These shifts in both emphasis and approach have included:

- 9 7) Increased emphasis in the NAAQS review processes on scientific questions that  
10 are as directly relevant as possible to well-defined policy questions of concern to  
11 EPA;
- 12 8) More frequent discussion about both public-welfare and public-health impacts of  
13 mixtures of air pollutants;
- 14 9) More frequent discussion about the critical loads concept as an alternative or  
15 complement to the more familiar NAAQS Standards;
- 16 10) Separation of the preparation and review of documentation for a Secondary  
17 (public-welfare-based) NAAQS from the (previously always dominating) Primary  
18 (public-health-based) NAAQS review processes;
- 19 11) The decision by the Science Advisory Board of EPA to establish this special  
20 Integrated Nitrogen Committee (INC); and
- 21 12) The unprecedented decision to undertake an integrated (simultaneous) review/ /of  
22 the Secondary NAAQS for two Criteria Pollutants at the same time [Oxides of  
23 Nitrogen (NO<sub>x</sub>) and Oxides of Sulfur (SO<sub>x</sub>)].

24  
25 Especially notable evidence for EPA's "increased willingness to think more holistically –  
26 and in more fully integrated ways" is the following statement of Conclusion in the  
27 Executive Summary of the December 2008 Integrated Science Assessment for Oxides of  
28 Nitrogen and Sulfur (EPA, 2008):

29 The main effects of N and S pollution assessed in the ISA are  
30 acidification, N enrichment, and Hg methylation. Acidification of  
31 ecosystems is driven primarily by deposition resulting from SO<sub>x</sub>, NO<sub>x</sub>, and  
32 NH<sub>x</sub> pollution. Acidification from the deposition resulting from current  
33 emission levels causes a cascade of effects that harm susceptible aquatic  
34 and terrestrial ecosystems, including slower growth and injury to forests  
35 and localized extinction of fishes and other aquatic species. In addition to  
36 acidification, atmospheric deposition of reactive N resulting from current  
37 NO<sub>x</sub> and NH<sub>x</sub> emissions along with other non-atmospheric sources (e.g.,  
38 fertilizers and wastewater), causes a suite of ecological changes within  
39 sensitive ecosystems. These include increased primary productivity in  
40 most N-limited ecosystems, biodiversity losses, changes in C cycling, and  
41 eutrophication and harmful algal blooms in freshwater, estuarine, and  
42 ocean ecosystems.

1 In addition, the committee finds that there have been persistent increases in the amounts  
2 of Nr that have been emitted into and retained within various ecosystems, affecting their  
3 functioning. Unless this trend is reversed, it will become increasingly difficult for many  
4 of these ecosystems to provide the services upon which human well-being is dependent.  
5 The committee believes that there is a need to regulate certain forms of Nr to address  
6 specific problems related to excess Nr, and we believe that the best approach for an  
7 overall management strategy is the concept of defining acceptable total Nr critical loads  
8 for a given environmental system.

9 **Recommendation 16.** *The committee recommends that the Agency work toward*  
10 *adopting the critical loads approach concept in determining thresholds for effects of*  
11 *excess Nr on terrestrial and aquatic ecosystems. In carrying out this recommendation*  
12 *the committee recognizes that it will in many cases be necessary for the Agency to enter*  
13 *into new types of research, policy, and regulatory agreements with other Federal, State,*  
14 *and Tribal units based on cooperative, adaptive, and systemic approaches that derive*  
15 *from a common understanding of the nitrogen cascade.*

16 **Finding 17.** Current EPA policy (EPA 2007e) discourages states from controlling  
17 ammonia emissions as part of their plan for reducing PM<sub>2.5</sub> concentrations. Ammonia is a  
18 substantial component of PM<sub>2.5</sub> in most polluted areas of the United States. at most  
19 times. While it is true that reducing NH<sub>3</sub> emissions might increase the acidity of aerosols  
20 and precipitation, the net effect of NH<sub>3</sub> on aquatic and terrestrial ecosystems is to  
21 increase acidity. After being deposited onto the Earth's surface, NH<sub>4</sub><sup>+</sup> is under most  
22 circumstances quickly nitrified, increasing the acidity of soils and waters. The committee  
23 is unaware of any evidence that NH<sub>3</sub> reduces the toxicity of atmospheric aerosols or that  
24 high concentrations of NH<sub>3</sub> occur naturally over any substantive area of the United  
25 States. Lower NH<sub>3</sub> emissions will lower PM<sub>2.5</sub> concentrations. Such reductions in PM<sub>2.5</sub>  
26 concentrations have been linked to reductions in morbidity and mortality.

27 **Recommendation 17.** *The committee recommends that the EPA presumption that NH<sub>3</sub> is*  
28 *not a PM<sub>2.5</sub> precursor should be reversed and states should be encouraged to address*  
29 *NH<sub>3</sub> as a harmful PM<sub>2.5</sub> precursor.*  
30

31 **Finding 18.** The committee notes that the effective management of Nr in the  
32 environment must recognize the existence of tradeoffs across impact categories involving  
33 the cycling of other elements, particularly C.

34 **Recommendation 18.** *The committee recommends that the integrated strategies for Nr*  
35 *management outlined in this report be developed in cognizance of these interrelations*  
36 *and tradeoffs.*

37 **Finding 19.** The biogeochemical cycle of Nr is linked to climate in profound, but  
38 nonlinear ways that are, at present, difficult to predict. Nevertheless, the potential for  
39 significant amplification of Nr-related impacts is substantial, and should be examined in  
40 more complete detail.

1

2 **Recommendation 19:** *The EPA should support cross-disciplinary and multiagency*  
3 *research on the interactions of climate and Nr. To determine the interactions of global*  
4 *biogeochemical Nr cycles and climate, the INC suggests that EPA follow a series of steps*  
5 *such as:*

- 6 5. *Select several likely scenarios for global climate from the IPCC report for the*  
7 *year 2050 or 2100.*
- 8 6. *Down-scale statistics or nest regional climate models within each of these global*  
9 *scenarios to generate meteorological and chemical fields (e.g., T, RH, winds,*  
10 *precipitation, CO<sub>2</sub>) for a few years around 2050 and 2100.*
- 11 7. *Run several independent biogeochemical Nr models (Earth System models that*  
12 *include air/water/land) for N America for these years with current Nr and*  
13 *emissions and application rates.*
- 14 8. *Rerun models with decreased Nr emissions/application to evaluate strategies for*  
15 *controlling impacts such as those described in this report.*
- 16

17 **Finding 20.** The restoration of drained wetlands and the creation of new riverine  
18 wetlands offer potential opportunities to transform or sequester reactive nitrogen (Nr)  
19 through promotion of the process of denitrification. These wetlands can be positioned in  
20 the landscape to handle the spatial and temporal demand with minimal impact on food  
21 production, while reducing flood damage and electrical and chemical energy  
22 consumption compared to conventional technological solutions. These wetlands could  
23 also replace valuable wetland habitat that has been lost in the United States to urban and  
24 agricultural development over the past 100 years.

25

26 **Recommendation 20:** *In cooperation with the Departments of Agriculture and Army,*  
27 *the Fish and Wildlife Service and the Federal Emergency Management Agency, the EPA*  
28 *should develop programs to encourage wetland restoration and creation with strategic*  
29 *placement of these wetlands where reactive nitrogen is highest in ditches, streams, and*  
30 *rivers. The agency should also address the means of financing, governance, monitoring*  
31 *and verification. Such programs might be modeled on the Conservation Reserve*  
32 *Program or extant water quality and environmental trading programs, but need not be*  
33 *limited to current practices.*

34

35 **Finding 20.** The committee has determined that an integrated approach to  
36 monitoring that includes multimedia (air, land and water) components and  
37 considers a suite of environmental and human concerns related to reactive  
38 nitrogen in the environment (e.g., Nr effects, climate change, human health) is  
39 needed. Some of the phenomena that we present in this report need more  
40 definition and verification but, more importantly, as controls are brought to bear  
41 on Nr, improvements need to be measured to verify and validate successful  
42 management strategies. If the desired improvements are not realized as shown by  
43 the collected data, corrective measures will be required. Such an adaptive

1 approach acknowledges the likelihood that management programs will be altered  
2 as scientific and management understanding improve.

3

4 **Recommendation 21.** *The committee recommends that EPA initiate discussions*  
5 *and take action to develop a national, multimedia monitoring program that*  
6 *monitors sources, transport and transition, effects using indicators where*  
7 *possible, and sinks of Nr in keeping with the nitrogen cascade concept. This*  
8 *comprehensive program should build upon existing EPA and state initiatives as*  
9 *well as monitoring networks already underway in other federal agencies such as*  
10 *the U.S. Geological Survey programs and the NADP effort.*

11

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