RE: Agenda, call-in information, and materials for SAB INC Public Teleconferences, July 8 12-3 pm Eastern Time

Mosier, Arvin R to: Angela Nugent 07/05/2009 09:19 PM

Cc: "Russell Dickerson [russ@atmos.umd.edu]", "jng@Virginia.EDU", "theist@uic.edu"

Angela, I was scanning through the June 21 INC report draft and it appears that my revisions of section 2.3.1.2. fell through the cracks. There aren't a huge number of changes needed, but a number of things that were requested are included in the attached file that did not make it into the last version of the report.

Best regards, Arvin

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From: Nugent.Angela@epamail.epa.gov [Nugent.Angela@epamail.epa.gov]
Sent: Saturday, July 04, 2009 3:34 PM
Subject: Agenda, call-in information, and materials for SAB INC Public Teleconferences, July 8 12-3 pm Eastern Time

Note to Members of the SAB Integrated Nitrogen Committee

Happy 4th of July! Jim has given me the go-ahead to send out the agenda for the July 8th teleconference; the July 9th agenda will be posted later next week.

The call in number is:866-299-3188, access code 343-9981 and press the # sign.

Attached are files with the:

1.draft agenda for the teleconference call. (See attached file: Agenda-INC- 07-08-09.pdf)
2.draft list of action Items from the May 2009 INC meeting not addressed by June INC Draft report (See attached file: May action item gaps.pdf)

3.comments received from Don Hey on a working draft of the Executive Summary; comments received too late to be addressed in the June draft (See attached file: Hey comments-06-19-09.pdf)

4. as FYI - response received this week from EPA Staff member Andy Manale to answer questions about EPA Nitrogen Backgrounder posed by INC members at the May 2009 INC meeting(See attached file: sab response - cd.pdf)

Please note that the size of the current draft INC report (which will be the focus of the teleconference) in pdf form is 3 gigabytes, a size too large to send through many of your email systems. The draft report is posted on the SAB Web site below.

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All the material for the teleconference, plus the latest INC draft

report, are posted on the SAB Web site (www.epa.gov/sab) on the Web page dedicated to the July 8th teleconference. That page can be accessed by using the "Calendar" link on the blue navigation bar to access the teleconference dates for July 8th h, or by accessing the direct link below:

http://yosemite.epa.gov/sab/sabproduct.nsf/a84bfee16cc358ad85256ccd006b0b4b/8a44c6d355a01c9f852575be004c45cb!OpenDocument&Date=2009-07-08

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Email: nugent.angela@epa.gov Revision of Section 2_3__1_2_Mosier.doc

2.3.1.2 Input and recycling of Nr within terrestrial systems in the US

This section builds upon Section 2.2 by integrating the information in that section on Nr introduction into the US and its loss to environmental systems by energy and food production into the overall picture of Nr cycling within terrestrial systems.

Annual input of newly created Nr onto terrestrial ecosystems comes from atmospheric deposition, synthetic fertilizer and BNF in managed and unmanaged ecosystems (Table 1.). Although Nr from atmospheric deposition is formed inadvertently during fossil fuel combustion and from volatilization of NH_3 from agricultural activities it serves to provide nutrients, along with biological N fixation and synthetic fertilizer, for food, feed and fiber production in the agricultural sector. Forests and grasslands use Nr for growth and home gardens, parks and recreational areas utilize Nr within the urban landscape. Approximately 32 Tg of new Nr reached the land of the 48 contiguous states in 2002 (Table 1). An additional ~0.2 Tg of N was imported mainly as food and drink products (FAO, 2008). An additional ~12 Tg of Nr was recycled back to terrestrial and aquatic systems in livestock (~6 Tg N) excreta, human (~2 Tg N) excreta, and crop residue from the previous year's production (~4 Tg N; USEPA, 2007). Of this N ~ 1.3 Tg (~1.2 from livestock manure and <0.1 from sewage sludge) was used as fertilizer for crop production (USEPA, 2007).

Most of the new Nr (~17 Tg total with 9 Tg from synthetic fertilizer and ~8 Tg from biological N fixation; Table 13) was used to produce food for human consumption and forage and feed for livestock and poultry. In addition to new Nr and Nr that was recycled from livestock and human excreta, crop production releases Nr that is stored in soil organic matter (see section 2.3.2). The N in cereal crops is typically derived from added fertilizer (synthetic or manures) and from mineralization of soil organic matter (conversion of complex organic molecules to ammonium) in about equal amounts. As discussed in Sections 2.2 and 3.3.4, crop production is not efficient in using Nr so only 30-70% (a global average of 40%) of all of the N mobilized for crop production is harvested in the crop. The remainder is in crop residue (roots and above ground stover) stored in the soil, leached to aquatic systems as NO_3^-, volatilized to the atmosphere as NH_3 or NO_x or denitrified (see Section. 2.4) to produce NO_x, N_2O and N_2. An additional ~1.1 Tg of synthetic fertilizer N is used to maintain turfgrass in the urban environment (see Section 2.2.4) and another 0.1-0.2 Tg N is used to enhance forest production.

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Table 1: Sources of reactive N input into terrestrial systems in the US in 2002 (from Table 1; in Tg N).

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Source	Environmental System				
	Agricultural	Vegetated		Populated	Total
		Forest	Grassland		
Atmospheric	1.3	1.4	1.9	0.4	6.9*
N fixation	7.7	--	6.4	--	14.1
Synthetic N	9.7	0.1	**	1.1	10.9
Animal manure##	1.2	--	3.8#	--	6.0#
Human sewage##	0.1	--	--	1.2	1.3

... [1]

*The amount of atmospheric Nr deposition is based on area of each environmental system within the continental US. 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 is assumed to be lost through ammonia volatilization, leaching or denitrification (EPA, 2007).

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##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, while 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) lists the 20 largest agricultural commodities produced, imported and exported in the US 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 US 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 produced in the US in 2002.

Of this 24.3 Tg N approximately 2.5 Tg was used to grow feed used for milk, egg and meat production. This estimate is made assuming that 4 units of N are required to produce a unit of milk, eggs or meat (see section 3.3.4.1.). This estimate also assumes that 1/3 of N required for livestock production comes from commodities in the FAO top 20 list and the remaining 2/3 comes from alfalfa, silage and grass over the course of a year (Oitjen and Beckett, 1996) Approximately 4.3 Tg of N in agricultural commodities (2.8 Tg in soybeans, corn and wheat) were exported, while ~0.15 Tg N was imported in various food and drink commodities. The US human populace consumed ~1.96 Tg of N in 2002 (292 million people, consume 114.7 g protein person^{-1} day^{-1}, 0.16 g N g^{-1} protein^{-1}, 365 days) (approximately 1.2 Tg from animal protein-N and 0.7 from vegetative protein).

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

In forests and grasslands (vegetated system) N input in 2002 was ~3.5 Tg of anthropogenically introduced N, with the remaining ~10.1 Tg derived from BNF and livestock manure deposition. Of this anthropogenic N, ~21% was retained in soil and tree biomass while the remainder was removed in tree harvest (~0.2 Tg, see section 2.3.2.3) or lost to other parts of the environment through NH_3 volatilization and NO_3^- leaching and runoff (Table 14). Total N input into agricultural systems was ~20 Tg with

~ 11 Tg being removed as products which includes the transfer of ~2 Tg N as food to the human population. Almost 40% of the N input into agricultural systems is lost through NH_3 volatilization, nitrification/denitrification and NO_3^- runoff. The 4.2 Tg of Nr of Haber-Bosch N that is used for industrial feedstock is not included in this assessment. Of the input of ~3.3 Tg of N into the populated system ~80% is lost through human excreta processed in sewage treatment plants, denitrification in soils and leaching and runoff of NO_3^- (Table 14).

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

Table 2: Nr input and flows (Tg N/yr) in the terrestrial portion of the Nitrogen Cascade (Figure 3) within the continental US in 2002

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Environmental System*	N Input to System	N Storage in System**	Agricultural & Forest Products	Transfer to Aquatic or Atmospheric Systems
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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*The Environmental Systems are those noted in the Terrestrial portion of the N Cascade shown in Figure 3, data from Table 1 are manipulated in Table 13 . **Estimates are from pages 87-91 of this report.

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Finding 1

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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.

Recommendation 8: *EPA should join with USDA, DOE, and universities to work together in efforts to ensure that the N budgets of terrestrial systems are properly quantified and that the magnitude of at least the major loss vectors are known.*

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2.3.1.3 Transfer of Nr to aquatic systems

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). What is the concern about too much Nr in aquatic systems? EPA's Office of Water (EPA, 2007d) notes the following reasons for implementing numerical water quality standards:

- *Excessive nutrients (nitrogen and phosphorus) can cause negative ecological impacts to water bodies on a national scale by stimulating harmful algal blooms.*
  - *Algal blooms block sunlight and result in the destruction of submerged aquatic vegetation which serves as critically important habitat and food for many organisms.*
  - *Algal blooms eventually die off and consume dissolved oxygen from the water column which can lead to die off of aquatic organisms.*
  - *One result of algal blooms is decreased biological diversity and populations, including smaller populations of game and commercial fish.*
  - *Some blooms, considered "harmful algal blooms" or "HABs", have a toxic effect on living organisms and are disruptive of ecosystem structure and transfer of energy to higher trophic levels.*

- *Excessive nutrients also pose public health risks.*
  - *Algal blooms can cause taste and odor problems in drinking water.*
  - *Hazardous algal blooms can cause respiratory distress and neurological problems in swimmers.*
  - *Excessive nitrates can cause blue baby syndrome.*

- *Nutrient pollution is occurring at a national scale and has not been completely addressed .*
  - *49 states and 4 territories have 303(d) listings due to nutrients, and about 50% of thestates have greater than 100 water quality impairments due to nutrients .*

- *Over 10,000 impairments are a result of nutrient pollution .*

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

Finding 2

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

Recommendation 9: *The committee recommends that EPA develop a uniform assessment and management framework that considers the effects of Nr loading over a range of scales reflecting ecosystem, watershed, and regional levels. The framework should include all inputs. related to atmospheric and riverine delivery of Nr to estuaries, their comprehensive effects on marine eutrophication dynamics and their potential for management.*

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

For at least 50 years, researchers have recognized this growing imbalance, especially in estuarine and coastal waters where anthropogenically-derived N over-enrichment has fueled accelerated primary production, or "cultural" eutrophication (Vollenweider et al. 1992, Nixon 1995). Eutrophication is a condition where nutrient-enhanced primary

production exceeds the ability consumers and organic matter-degrading microbes to consume and process it. D'Elia (1987) characterized this condition as "too much of good thing" or over-fertilization of N-limited marine ecosystems with "new" N, a bulk of it being anthropogenic (Howarth et al. 1986, Vitousek et al. 1997, Galloway and Cowling 2002). Symptoms of N-driven eutrophication vary from subtle increases in plant production to changes in primary producer community composition, to rapidly accelerating algal growth, visible discoloration or blooms, losses in water clarity, increased consumption of oxygen, dissolved oxygen depletion (hypoxia), which is stressful to resident fauna and flora, or in the case of total dissolved oxygen depletion (anoxia), elimination of habitats (Paerl 1988, 1997, Diaz and Rosenberg 1995, Rabalais and Turner 2001). Other effects include submerged aquatic vegetation (SAV) losses, possible impacts on tidal wetland health, and disruption of estuarine food chain dynamics that may favor an imbalance towards lower trophic levels (e.g., jellyfish).

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

The area of an airshed generally greatly exceeds that of a watershed for a specific estuary or coastal regions. 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 US's 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 the fact that N-driven marine eutrophication may require regional or even global solutions. Even in truly oceanic locations (e.g. Bermuda), North American continental atmospheric N emissions (reduced and oxidized N) are commonly detected and significant (Luke and Dickerson 1987, Prospero et al. 1996). Likewise, islands in the North Pacific receive N deposition originating in Asia (Prospero et al., 1989).

Riverine and atmospheric "new" Nr inputs in the North Atlantic Ocean basin are at least equal and may exceed "new" Nr inputs by biological N_2 fixation (Howarth et al. 1996,

Paerl and Whitall 1999, Paerl et al. 2002). Duce et al. (2008) estimate that up to a third of ocean's external Nr supply enters through atmospheric deposition that Schlesinger (2009) noted were derived from terrestrial sources. This deposition leads to an estimated ~ 3% of new marine biological production and increased oceanic N_2O production. Therefore, our understanding of marine eutrophication dynamics, and their management, needs to consider a range of scales reflecting these inputs, including ecosystem, watershed, regional and global levels.

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Scope of the Problem in the US. Over the past 25 years, there has been a growing recognition of cultural eutrophication as a serious problem in coastal estuaries (NRC, 2000). Globally, Selman et al. (2008) have reported "Of the 415 areas around the world identified as experiencing some form of eutrophication, 169 are hypoxic and only 13 systems are classified as 'systems in recovery'". Comprehensive surveys of US estuaries have been conducted by NOAA as part of the National Estuarine Eutrophication Assessments (NEEA) in 1999 and 2004 (Bricker et al. 1999; 2007). The most recent report, released in 2007 (Bricker et al., 2007) focused on nutrient enrichment and its manifestations in the estuarine environment and relies on participation and interviews of local experts to provide data for the assessment. Among the key findings for nearly 100 assessed US estuaries were that eutrophication is a widespread problem, with the majority of assessed estuaries showing signs of eutrophication—65% of the assessed systems, representing 78% of assessed estuarine area, had moderate to high overall eutrophic conditions. The most common symptoms of eutrophication were high spatial coverage and frequency of elevated chlorophyll *a* (phytoplankton)—50% of the assessed estuaries, representing 72% of assessed area, had a high chlorophyll *a* rating.

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

A recent evaluation of decadal-scale changes of NO_3^- concentrations in ground water supplies indicates that there is a significant increase in nitrate concentrations in well water across the US (Rupert, 2008). This study compared the nitrate content of 495 wells during 1988-1995 with nitrate content found during 2000-2004 as a part of the United

States Geological Survey, National Water-Quality Assessment Program. From a subset of wells that had data on ground water recharge so that correlations with historic fertilizer use could be made, the study concluded that nitrate concentrations in ground water increased in response to the increase of N fertilizer use.

Text Box 1: Hypoxia in the Gulf of Mexico

An example of a problem of excess Nr that moves from one part of the US to another is the movement of Nr from the states that make up the Mississippi River drainage to the Gulf of Mexico. A hypoxic zone covers a significant area of the receiving bottom waters of the continental shelf of the northern Gulf of Mexico (details may be gleaned from SAB, 2007). This is a seasonally severe problem that has persisted there for at least the past 20 years. Between 1993 and 1999 the hypoxia zone ranged in extent from 13,000 to 20,000 km^2 (Rabalais et al. 1996, 1999, Rabalais and Turner 2001). The hypoxia is most widespread, persistent, and severe in June, July, and August, although its extent and timing can vary, in part because of the amplitude and timing of flow and subsequent nutrient loading from the Mississippi River Basin. The waters that discharge to the Gulf of Mexico originate in the watersheds of the Mississippi, Ohio, and Missouri Rivers (collectively described here as the Mississippi River Basin). With a total watershed of 3 million km2, this basin encompasses about 40% of the territory of the lower 48 states and accounts for 90% of the freshwater inflow to the Gulf of Mexico (Rabalais et al. 1996; Mitsch et al. 2001; EPA, 2007b).

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

Finding 10

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Over the past 25 years, there has been a growing recognition of eutrophication as a serious problem in coastal estuaries (NRC, 2000). The last comprehensive national NCCR was published in 2004 (EPA, 2004) included an overall rating of "fair" for estuaries, including the Great Lakes, based on evaluation of over 2000 sites. The water quality index, which incorporates nutrient effects primarily as chlorophyll-a and

dissolved oxygen impacts, was also rated "fair" nationally. Forty percent of the sites were rated "good" for overall water quality, while 11% were "poor" and 49% "fair".

Recommendation 10: *The committee recommends that EPA consider a range of scales reflecting ecosystem, watershed, and regional levels that include all inputs, e.g. atmospheric and riverine, of marine eutrophication dynamics and management.*

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2.3.2. Storage of Nr within terrestrial Environmental Systems

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

Much of the annual Nr input into these terrestrial systems passes through, and is transferred within, terrestrial systems or atmosphere via NH_3, NO_x or N_2O, or aquatic environmental systems via NO_3^- and organic N leaching and runoff or NH_x and NO_y deposition.

The largest single reservoir of total N in the terrestrial environmental system is soil organic matter (SOM). Approximately 52,000 Tg C and 4,300 Tg N are contained in the upper 100 cm of soil in the 48 contiguous states (N is estimated from assumed C/N ratio of 12) (Lal et al. 1998). For comparison, the total above ground biomass of US forests of these states contains ~ 15,300 Tg of C and ~ 59 Tg N (estimated using a C/N ratio of 261, and 15,500 Tg of SOM-C, 1290Tg total N (estimated using a C/N ratio of 12) (EPA, 2007g). Most of this SOM-N is bound within complex organic molecules that remain in the soil for tens to thousands of years. A small fraction of this SOM is mineralized, converted to carbon dioxide and Nr, annually. The total N contained within above and below ground compartments isn't really of concern. What is of interest in addressing issues of Nr, is the change in N stored within the compartments of terrestrial systems. The pertinent question is whether N is being retained or released from long-term storage. The committee evaluated estimates of annual change of N storage within important components of terrestrial systems. The EPA Inventory of US Greenhouse Gas Emissions and Sinks 1990-2005 (USEPA 2007g) carbon stock information obtained from chapter 7 of the report provided information used by the committee to estimate N storage in US terrestrial systems. Nitrogen stock change was determined by simply assigning a C/N

ratio of 12 for soils and 261 for trees and making the appropriate conversions from C to N.

2.3.2.1. Agricultural

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

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

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Add the following reference:

David, M.B., G.F. McIsaac, R.G. Darmody and R.A. Omonde. 2009. Long-term changes in mollisol organic carbon and nitrogen. J. Environ. Qual. 38:200-211.

2.3.2.2. Populated systems—urban lands

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

2.3.2.3. Vegetated systems—forests and grasslands

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

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Grasslands. Grasslands, including rangelands and pasturelands, occupy approximately 213 million ha (27.1%) of the contiguous 48 state land area. The NRCS divides these grasslands into pastureland (48.2 million ha) and rangeland (164 million ha). Pastureland is managed, may be fertilized and mown, and rangeland is managed only to the extent that livestock grazing intensity on the land used for livestock grazing is regulated. Changes in the N status of grasslands are dependent upon changes in soil organic matter as the above ground biomass produced annually is either consumed by livestock or decomposed in the field. Soil organic C stocks were estimated using the Century

biogeochemical model and data used were based upon the NRCS/National Resources Inventory (NRI) survey (EPA, 2007g). Changes in soil N content were estimated using a C/N ratio = 12. Nitrogen input into rangelands is generally only from atmospheric deposition, which contributes 1.9 Tg N each year to range production (Table 15). Rangeland tends to be in relatively remote areas where atmospheric Nr deposition is low

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

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

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

Table 3: Net Annual Change in Continental US Croplands soil C and N, Forest C and N, and Grassland Soil C and N in 2002

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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
Cropland		
Cropland remaining cropland		
Mineral soil	17	1.4*
Organic soil	-8.3	-0.69
Land converted to cropland	0.8	0.067
Total	9.6	0.80
Forests		
Forests and harvested wood products		
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
Total	173	0.43
Grasslands		
Grasslands remaining grasslands		
Mineral soil	-0.8	-0.067
Organic soil	-1.3	-0.11
Lands Converted to Grasslands	5.8	0.48
Total	3.7	0.31
US Total C & N Storage in 2002	186	1.7

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

2.3.3 Input and fate of Nr in 16 watersheds in the northeast US.

There are no comprehensive data available to assess the transfer and transformations in and between the atmosphere, terrestrial systems (agriculture, populated and vegetated systems) and aquatic systems nationally. Determining a national N budget is a priority research area. As there are no national data available, an example analysis of Nr input and fate in 16 watersheds in the northeast US, for which data are available, is used to show an evaluation of the inputs and fate of Nr for a large watershed (Fig. 3-14) (Van Breemen et al. 2002).

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

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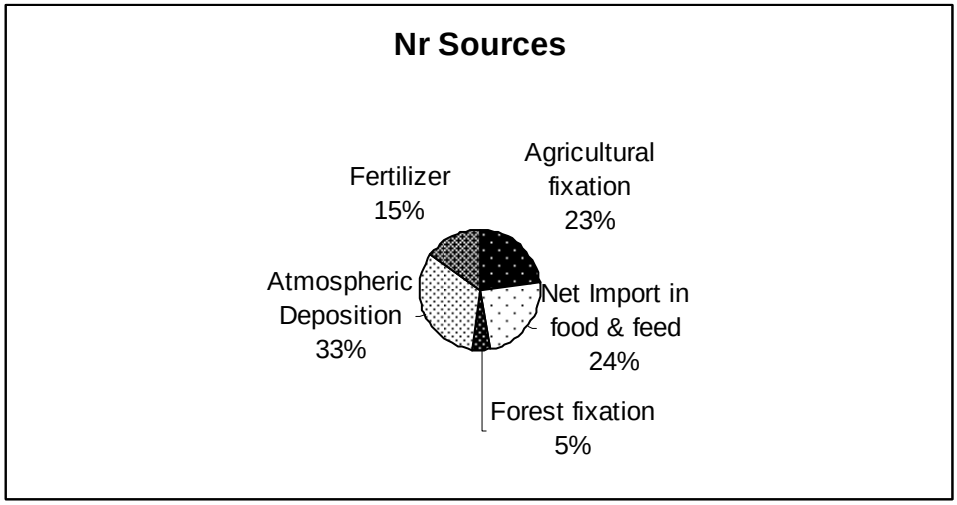
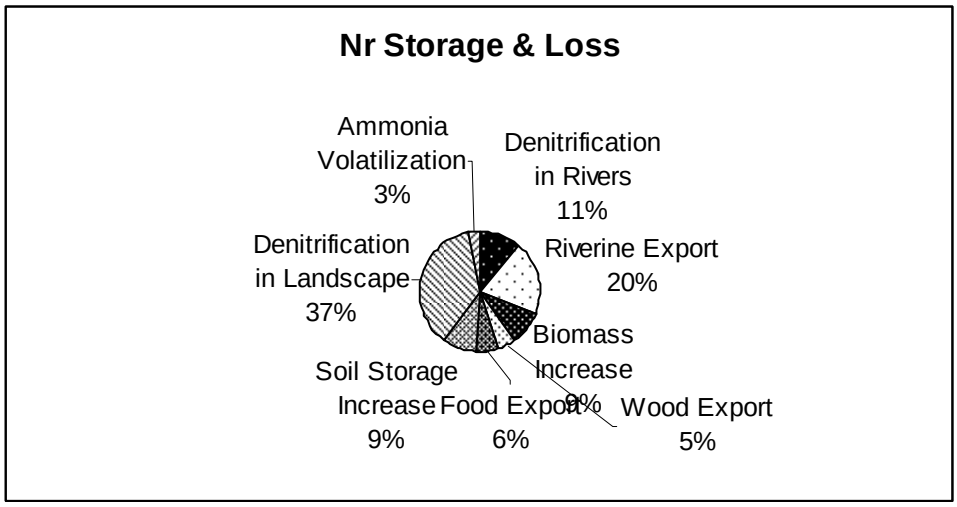
Figure 1: Nr input and loss from 16 watersheds in the northeast US.

The Nr input into the watersheds (using weighted averages for all 16 watersheds) was 3,420 kg /km^2/yr (Van Breemen et al. 2002).





Van Breemen et al. (2002) indicate that Nr inputs and storages and losses were well correlated ($R^2 = 0.98$). Denitrification in landscape soils is the most uncertain estimate, because rates are calculated by difference between total inputs and outputs, so they accumulate errors from all estimates. They suggest that the denitrification loss term may also reflect the change in N storage in groundwater. The net storage of N in the soil

(18% of total storage and losses) indicates that there is a non-steady state condition in the soil. Increasing storage of Nr on land implies that drainage and denitrification exports of Nr are likely to increase when a new steady state condition is reached.

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

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

Finding 3:

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

Recommendation 11: *EPA, USDA, DOE, and universities should work together to ensure that denitrification in soils and aquatic systems is properly quantified, by funding appropriate research.*

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2.3.4. Synopsis of areas of the US nitrogen cascade where the estimates of Nr transfer and transformations in and between environmental systems are highly uncertain.

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

- Total denitrification in animal feeding operations, in soils, and in aquatic systems needs to be quantified along with all gaseous products that are produced and released to the atmosphere during nitrification/denitrification. These gases include NO_x, N_2O and N_2.
- The amount of Nr deposited in each environmental system as dry deposition needs to be quantified and monitored.
- Rates and amount of ammonia emission from fertilized soils and animal feeding operations need to be quantified and the fate of this ammonia determined.
- The annual change in N storage in soils (agricultural, forest , grassland and urban areas) needs to be quantified in conjunction with the change in carbon

These areas of high uncertainty are highlighted because very little information exists in some of the areas while in other areas, such as denitrification and the relative release of N_2O from soils and aquatic systems, the sparse data are highly variable which makes developing meaningful guidelines for control difficult.

Note that section 2.3.4. was listed twice so need to remove one of them and that Figure 18 should be moved to page 182.

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Total Nr input	**20.0**	**1.5**	**12.1**	**2.7**	**39.2**