Ascertaining Sources of Nitrogen Entry to the Chesapeake Bay with Emphasis on Atmospheric Inputs

STAC Task Group Final Report

October 16, 1996

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atmospheric N and Bay N. These steps should include the commissioning of critical literature reviews, supported by a STAC workshop, possibly culminating in a STAC "white paper" if necessary. STAC should develop a task group or team to oversee and coordinate the whole effort with emphasis on terrestrial and watershed, but including atmospheric and aquatic scientists.

4. Throughout all its discussions, it was apparent to the Task Group that N monitoring and modeling deficiencies were so serious as to compromise our knowledge of N balance, transport and fate computations in much of the terrestrial and watershed systems. Major N species are not being measured, and N measurements too often are not being made at the critical places or times. We recommend STAC ask that these sampling, monitoring, and modeling issues be addressed with the goal of proposing corrective actions soon.

II. Mission and Objectives

This STAC Task Group was established by STAC at their March 8, 1996, meeting to objectively and technically evaluate claims made that atmospheric nitrogen was the source of two-thirds of the nitrogen entering Chesapeake Bay. This claim greatly exceeded published values and was presented orally without written background to the STAC Executive Committee at their March 7, 1996, meeting.

In response to this charge, the Task Group developed the following objectives, which were accepted by STAC:

1. Technically evaluate Jaworski's report that N entry into the Chesapeake Bay is mostly from atmospheric origin.

2. Outline a technical framework needed to define and quantify the sources, processes, and pathways that control N flows through the Basin and into the Bay. Identify the key technical questions, issues, and unknowns that must be addressed.

3. Develop a basis and agenda for a subsequent Task Group to develop a "white paper" that expands the framework, including the existing literature and data and modeling procedures needed to assess the significance of both terrestrial and atmospheric inputs and identifies research gaps, needs, and management opportunities.

   The Task Group added the last two objectives because they felt that Jaworski's or other claims regarding the impact of specific N sources to the Chesapeake Bay would be best addressed by developing a unified technological and scientific basis to assess N sources and their importance.

III. Membership

H.B. Pionke, Chair, Soil Chemist/Watershed Scientist, Agricultural Research Service
G.M. Gross, Liaison, Oceanographer, Chesapeake Bay Research Consortium
A.W. Taylor, Environmental/Soil Chemist, Chesapeake Bay Research Consortium
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D.W. DeWalle, Professor, Forest Hydrology, Penn State University
J.A. Lynch, Professor, Forest Hydrology, Penn State University
J. Bachman, Geologist/Watershed Scientist, U.S. Geological Survey
B. Hicks, Atmospheric Scientist, NOAA
J.E. Baker, Professor, CEES, University of Maryland

(C.W. Randall, Chair, STAC, Chesapeake Bay Research Consortium; attended August 8-9 meeting.)

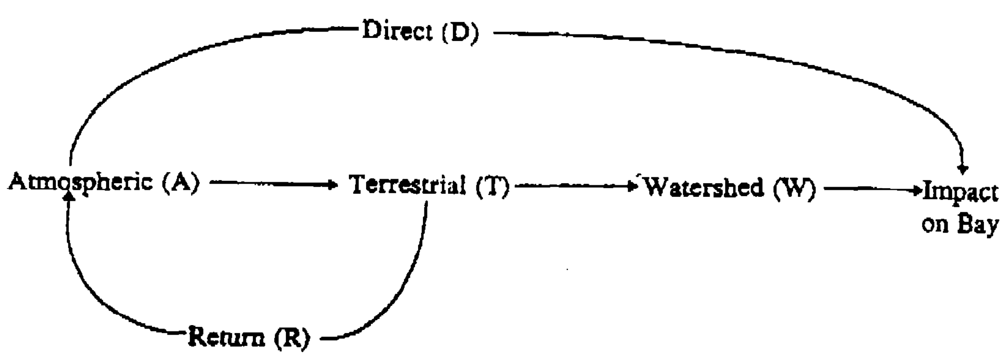
IV. Implementation

The basic strategy was to communicate by mail, FAX, and phone until a meeting was needed for direct discussion and completion of the assignment. This meeting was held August 8-9, 1996, at the Air Resources Laboratory, NOAA Bldg., Silver Springs, MD (see enclosed agenda, VII). Because no written Jaworski report was available, we deleted Objective 1 and concentrated our efforts on Objectives 2 and 3.

V. Analysis and Conclusions

1. The Task Group established some guidelines and concepts in order to best focus on this task.

   We looked at fate and transport of atmospheric N and their effect on N impact in the Bay as a sequence through components and across boundaries. Diagrammatically, this appears as follows.



   We focused on the terrestrial component because we felt this knowledge was least developed and unified compared to atmospheric and Bay components. This is not to imply that we have all the answers for these two components, but we know least about atmospheric N transport through terrain to the Bay and its importance relative to other terrestrial N sources. For example, STAC has issued three publications on atmospheric N issues since 1994, and most money and attention since the Bay's program inception has logically focused on the aquatic biology and estuarine processes. In contrast, the terrestrial component is a mixture of agricultural, forestry, and urban research and monitoring at a multiplicity of scales and objectives, mostly not focused directly on the Bay.

We defined our system in terms of boundaries and components, with the focus on the terrestrial component and its impact on the Bay (see above diagram). Thus, atmospheric N and Bay processes were recast in terms of atmospheric input to the terrestrial component (A), terrestrial output (T) to the watershed, and watershed output (W) to the Bay, which greatly simplified our task. The connection between terrestrial output (T) and watershed output (W) is the flow system at the watershed scale - streams, rivers, impoundments, aquifers, wetlands, etc. The atmosphere also delivers N directly to the Bay (D) and the terrestrial can be a local source (R) of atmospheric N. We wanted to avoid addressing N cycling, transport, and fate in the atmosphere or Bay component *per se* except as it directly affected our assessment of the atmospheric input (A) or terrestrial output (T). For example, knowing the N uptake patterns by phytoplankton as controlled by N species, season, and their position in the Bay would give us insight on which N species need to be monitored and when at the terrestrial output boundary (T). Although we did discuss N cycling, transport, and fate in the terrestrial component, we emphasized the dominant or controlling processes and parameters and avoided those we believe to be of lesser importance.

The August 8-9 meeting agenda (VII) was set up as in the diagram to establish the relevant atmospheric input and Bay impact issues, to examine the terrestrial effect of forest and agriculture, and to place the terrestrial into a watershed context that included flow connections to the Bay. Each session was initiated by our Task Group expert to identify the key issues. The rest of the Analysis and Conclusions section follows this agenda.

2. Atmospheric-N Input

Atmospheric N can impact the Bay directly by deposition on the Bay surface (D) or indirectly through the terrestrial (T) and watershed components as inflow (W) to the Bay. In either case, the atmospheric N input data must provide good and defensible N input assessments at both the terrestrial input (A) and Bay deposition (D) scales. The committee felt there were some serious deficiencies that should be addressed and opportunities to improve the assessment. Because the terrestrial component accounts for at least 95% of the basin surface, we focused mostly at the terrestrial input (A) boundary.

Good data on atmospheric input N is sparse or lacking. Most data being collected does not provide adequate measures of total N input nor defensible surrogate relationships for approximating total N input. The problem is multifaceted, dealing with poor information on N fractions and species input, totally, seasonally, and areally. Also, we have a poor concept of input variabilities and thus the significance of inputs. Typically NO_3 and NH_4 are measured in wet deposition. However, neither dry deposition nor organic N deposition are routinely measured. Often dry deposition is assumed to be some constant proportion of wet deposition, which is not warranted based on available data. We know dry deposition occurs continually, whereas wet deposition occurs episodically with precipitation.

Variation of N input with season and extreme episodic events may control atmospheric transfers to and impacts in the Bay. We know, for example, about 60% of the NO_3 and NH_4 in wet fall occurs during the growing season when N uptake by plants is greatest. Conversely, the remaining 40% falls when hydrologic processes may accelerate and enhance N transfer to the Bay. We have limited information on how episodic events (hurricane, snow melt, drought) affect N atmospheric input even though we know episodic events can dominate the Bay hydrologically.

Spatially, we know that N deposition varies. However, sampling networks are not sufficient to define this spatial variability nor link it to local sources or geographic position. We know terrestrial activities (urban areas, vehicles, local agricultural activity) provide local sources of NO_x and NH_3 to the atmosphere N (see R in diagram), which may become deposited elsewhere in the basin. For forests, where atmospheric input can be the largest N source, knowing this spatial variability is important. We need the capability to spatially weight N deposition over the basin.

Related to the above, we lack information on how much of the N deposition measured at a site originates locally or within the basin compared to that entering the air shed from outside the basin. Monitoring and/or methodology is needed to subtract out the effects of local sources for computing atmospheric N input at the basin scale. Otherwise, we may be doing a double accounting, depending on the nature of the N source.

We are unable to compare the impact of direct (D) with indirect (W) source of atmospheric N on the phytoplankton in the Bay, because the appropriate sampling and research has not been done. Although very little of the total atmospheric deposition to the Basin and the Bay falls directly on the Bay, this portion may have an outsized impact relative to the mass contributed. One reason may be that the timing and location of entry is optimal for phytoplankton production. We need defensible measures of the transfer coefficients in terms of amount and impact by both direct (D) and indirect (W) pathways.

Although we do not know how much atmospheric N is entering the Bay mouth from coastal waters, the amount may be significant and increasing. We need to know how much N enters the Bay by this pathway, because the lower Bay is N limited.

3. Bay-N Input

The lower boundary (T) defines export from the terrestrial system, which becomes input (W) to the Bay through the connecting surface and groundwater systems. The impact of N input to the Bay is based on two aspects of entry - the amount of N that enters and its use efficiency as determined by entry conditions. The probabilities of getting the right N form in the right place at the right time is key to producing phytoplankton in the N-limited portions of the Bay. Thus, the need to know when, where, and what N form as well as amount of N input to the Bay helps define the information and measurements we need on terrestrial N output (T), Bay N input (W), and direct atmospheric N input (D). Currently, we do not sufficiently consider N dynamics in the Bay when selecting or designing data collection and monitoring of N input from the terrestrial or atmosphere.

Once in the Bay, N uptake efficiency by phytoplankton depends on the N form: NH_3 > NO_3 > Dissolved Organic N (DON). Atmospheric N input as wet deposition approximately distributes as 20% NH_3, 60% NO_3, and 20% DON. Terrestrial N outflow approximately is 0% NH_3, 90% NO_3, and 10% DON, showing that for the same total N loading this N distribution, and thus impact, could vary by source. This N form distribution can also vary by season. The timing of input can effect impact so that seasonal and episodic events need to be sampled. N input in mid summer-early fall, when inflows and rainfall are lowest, has most impact whereas the largest N input is in spring, especially during snow melt.

Major episodic events can disrupt the Bay, causing a short-term, intense as well as a longer-term, chronic response in terms of N dynamics. We did not address how this translates into sampling and data needs regarding atmospheric and terrestrial N inputs, but recognized its importance.

Clearly, how the Bay responds to N inputs should provide the parameters for N sampling and analysis of input waters. Because of the makeup of this Task

Group, we did not pursue this further other than to identify this as an issue to be addressed.

4. Terrestrial

The terrestrial component consists of basically three land uses--forest, agriculture, and urban-suburban. The dominant land use is forest (58.5%, 60%), followed by agriculture (32.6%, 29%), and then by urban-suburban (6.7%, 10%). The parenthesis refer to the percent land use determined from EMAP, followed by those used in the NPS modelling effort.

The terrestrial component controls N gains, losses, and transfers from input (A) to output (T) boundary. The terrestrial component is best viewed in terms of N sources, sinks, and storages linked by the terrestrial flow system. Over the long term or under steady state where stored N does not change, the terrestrial control on N export simplifies to knowing the major N sources (atmospheric and terrestrial N input) and sinks (denitrification, volatilization, harvest, outputs) operating in that terrestrial component whether it be forest, agricultural, or urban/suburban. A terrestrial-based N mass balance is the first, and in many ways, the most critical step for assessing the fate and importance of atmospheric N to the Bay.

This mass balance approach is presented in the attached table (VIII) to provide insights on the dominant N controls for the different terrestrial systems. The range of values provided are approximations based on a variety of data and experience. For any given site, measured values may differ from the tabulated ranges, which provide typical ranges for the various components.

5. Terrestrial--Forest

This largest land use (60%) represents a biological system that cycles the least N among the terrestrial systems (see table) and is usually N limited. Outside of the soil supply-return cycle (60-80 kg/ha/yr), the forested system operates on a small N input of which atmospheric N is a major N source. This is the primary reason that the magnitude, trends, variability, and monitoring of atmospheric N input has become an issue.

There are major concerns with accurately estimating the N mass balances for forests. This is a critical issue.

Some of these concerns relate to errors in the input-output datasets. The atmospheric N inputs (A) as currently measured, are probably underestimated for the reasons discussed in Section V.2. In addition, N export (T) may be underestimated because DON losses are not being measured even though they may be substantial. Moreover, N export for a given site can vary by more than twofold, depending on the quality and frequency of the flow record.

Some of these concerns relate to poor measures of some mass balance components (see table). For example, biologically fixed N inputs can be substantial for N-fixing trees, such as black locusts. Microbial-based N fixation, which is not considered important in the N-rich agricultural system, may be a substantial contributor in forest systems. N-fixation input is likely to be variable, depending on the species present, their composition within the stand, and stand maturity. Relatedly, estimates of volatilization and denitrification N losses do not have to be in error by much to cause serious errors in computing N export in outflow . Many people assume that N outflow from forests comes only from atmospheric N input. There is no data to support this assumption or that a direct linkage exists between them. Instead, the atmospheric N input most likely becomes part of the soil and biomass N pools and is subject to the full, not a short circuited, N cycle.

Considerable data exists to compare atmospheric N input to outflow for forested systems throughout the basin. Mostly, N export is a small perçent (5-20%) of atmospheric N input, but can be much higher and is variable across the basin. This variability may be related to land use history, species composition and stand maturity, location, soils, management, etc. For example, we know that as a forest matures it exports more N to the stream--all else being equal. These input-output comparisons are misleading, not only for the measurement reasons already stated, but because they are used to promote the concept of "N saturation." The "N saturation" concept presumes that forests have a finite N capacity that can be filled. Analogous to a newly built impoundment, there will be no outflow until storage is filled, after which the outflow will rapidly approach or equal input. This concept ignores what we already know about N cycles and terrestrial systems. It ignores N sinks and views the forest system only as hydrologically or chemically based N storages that eventually will fill. It ignores forest management impacts on N removal and cycling. It assumes a threshold function rather than a continuous relationship in terms of N outflow response over time. It is inconsistent with the well-founded concept that the N cycle is dynamic, provides the basic control on N export, and includes all N sources, storages, and sinks.

It is our opinion that major episodes may greatly impact N export and need to be considered, especially when they are operational at the basin scale. These include droughts, hurricanes, major snow melts, forest fires, defoliations, and harvesting.

Considering that most of the forests in the basin are even aged and are approaching maturity, considerable timber harvesting will likely occur in the next several decades. The impact of this harvesting on altering the N cycle may be important with respect to N export to the Bay.

Finally, the role of forest management and BMPs will be very important from this more unified and systems perspective. As summarized by one Task Group member, "If output is determined by internal nutrient dynamics, there is no direct input/output connection, and atmospheric input to the forest is not significant in controlling output, outputs will be controlled by management. Thus, forest BMPs will be of major importance."

6. Terrestrial--Agriculture

The second largest land use (29%) is agricultural, which mostly cycles large amounts of N and is usually not N limited. By design, the primary control on N status and cycling is management of N sources, crops, soils, and livestock. Land use *per se* (agriculture vs. forest vs. urban) does not exert the primary control on N status. Agricultural land uses range from heavily N fertilized and manured horticultural and row crops to pastures. Pastures, in turn, may range from N intensive to unimproved, the latter approaching the N status typical of forests.

N management and losses from agricultural systems have long been viewed from the context of managing N pools and cycles on site. As a result, agricultural scientists link N inputs to N outputs through supply, interactions, and depletion of soil N pools rather than by directly linking outputs to specific inputs. This approach much better represents the N system and provides a technically defensible basis for assessing and trading off N inputs as they affect pool size, transfers, and export.

The major N inputs into agricultural systems are manure, fertilizers, and legumes, depending on the agricultural management system selected (see table). Moreover, large N additions accumulate in different pools over the short term, such as the plant residue and soil organic matter pools listed under Returns. Over the long term, these two N pools reach a steady or stable state, whereby N additions would redistribute among the outputs rather than continue to accumulate in storage. The atmospheric N input is not only very small relative to the major agricultural N sources, but also is small relative to the variabilities in measuring and estimating manure N, soil organic N buildup, plant residue returns, etc. One result is that atmospheric N input is ignored because it is too small a contributor to the N pools and can be mostly compensated by better managing the more easily managed anthropogenic N inputs. For example, the

N fertilizer application (e.g. 150 kg/ha/yr) could be reduced by the 60% of the atmospheric N deposited on land during the growing season (e.g. 6 kg/ha/yr). To control N loss from agricultural systems, much more will be gained by advancing the sampling, measuring, and managing of the major N pools and their variabilities, than to control atmospheric N input.

The N outflow from agricultural watersheds tends to be about 5-20 times higher than from forest watersheds, with nearly all the dissolved N lost as nitrate. Thus, agricultural lands are the source of most N mass exported to the Bay, which has been recognized in several STAC publications. However, we don't know how this N mass translates to impact in the Bay due to N transformations in streams and groundwater, the timing of N inputs relative to N demand in the Bay, and the whole internal N cycling within the Bay itself.

Agriculture may be a substantial local source of atmospheric N (see R in diagram). Confined animal operations and certain agricultural practices can be an important NH_3 source. Up to 50% of the N in animal wastes can be volatilized as NH_3 from barns and waste pits. Fertilizer (UAN), manures, and urine can be major sources of NH_3 volatilization when surface applied instead of being incorporated (see table). We do not know at what spatial scale this NH_3 loss will impact the Bay. This will be very difficult to measure and assess, but needs to be addressed.

Similar to forest input-output N data sets, the analogous agricultural data have many deficiencies as well. Regarding inputs, manurial and legume N inputs are approximate, at best. The manure issue is further aggravated in that many animal-based farms in the basin import N as feed. The typical N flow or mass balance computations for such farms are often imprecise, but typically show a large N surplus, i.e., N inputs exceed N outputs. The soil organic matter and plant residue N pools are usually computed and difficult to determine objectively. The N outputs, mostly as NO_3 in ground water, are difficult to sample representatively at the larger watershed scales or valleys where agricultural land uses tend to dominate.

7. Terrestrial--Urban/Suburban

The urban/suburban areas constitute the smallest (10%) and perhaps the most variable land use. Our Task Group was not sufficiently knowledgeable to pursue this in detail, but there were several points we wanted to make. Mostly, urban areas are hydrologically and physically close to source streams and the Bay, which means rapid and direct entry of their runoff into the Bay. Thus, we would expect a higher transmission per unit N input (A) from these areas compared to the more remote areas.

Urban areas represent very mixed land uses, such as paved roads, roofs, lawns, septic systems, parks, and forest-type environments. Generally, surface runoff is more important than in forest or agricultural systems. Also, urban areas tend to be zones of higher N deposition, because they can also be atmospheric N sources (NO_x, NH_3). Much N comes from vehicles and is tied to human activities, typically exhibiting an exponential decay relationship for deposition with distance from the center of human activity. This combination of sources, high deposition and runoff may well deliver relatively large impacts to the Bay, especially as related to episodic events.

Similar to the agricultural activities that promote local NH_3 volatilization, these urban areas may also be very important sources of local atmospheric N that may impact lands or waters located downwind.

8. Watersheds

Watersheds range from relatively small (few ha's) to large (1000's km^2) and as such may be practically all terrestrial or may include streams, rivers, regional aquifers, and impoundments as major components. Because watersheds can incorporate scale-dependent and aquatic-based controls on N export as well as mixed forest, agricultural, and urban/suburban terrestrial components with all the associated variabilities, we chose to break out watersheds as a separate category.

Because of the scale and complexity, there may be important N sources and sinks operating at these larger watershed scales. Sources could include municipal sewerage treatment plants with output directly into rivers. Sinks en route from land source to Bay could include wet lands, riparian zones, lakes exhibiting some anoxia, and confined or isolated aquifers. Thus, there is a great risk in assuming that watersheds aggregate land use inputs to some outflow point, when instead they integrate or process these terrestrial outputs (T) en route to becoming inputs to the Bay (W). Another aspect is N storage or detention at the watershed scale, which may be sufficiently large or long to make the short-term input-output N data comparisons suspect or meaningless. Because most of the N exported to the Bay moves as NO_3 through ground water systems, and ground water-based detention can be very long, especially at the larger scales, this must be addressed. Better tools and useful concepts are needed to assess the impacts of these larger scale controls operating on watersheds.

Based on the aforementioned perspective, two related points are made.

Earlier we stated a need to spatially weight atmospheric N input (A) over the basin. We also need the knowledge and tools to spatially weight the terrestrial N outputs (T) to inputs (W) to the Bay. It is well known that surface runoff generated adjacent to a channel delivers more runoff faster to that channel than does surface runoff generated farther upslope. The length, flow rate, and environment of the main flow pathways connecting the terrestrial component to the Bay will affect how quickly and how much of that terrestrial N output reaches the Bay.

The conceptual basis is to establish the critical zones and their position in the flow system. Critical zones are defined as "a bounded area or volume within which one or a set of related processes dominate to provide excessive production (source), permanent removal (sink), detention (storage) or dilution of NO_3."

These ideas are based on the non-uniformity or heterogeneity of the system and the fact that we can capitalize on this feature by focusing our attention, monitoring, modeling, and remediation on the critical zones along major flow pathways or on the highly weighted areas rather than on the whole basin.

The mixed land use watershed, especially those undergoing rapid land use conversions, were of particular concern. We felt better location, rates of change, and trends information is needed on reforestation, urbanization, and agriculture (especially toward intensive N management).

9. Modeling and Monitoring of Atmospheric Deposition

We question the precision of projections based on modeling, even though we agreed modeling can be a useful tool. Broad scale models may be useful for estimating average deposition rates over wide areas, but they do not take into account many local effects. Smaller scale models may exist that will be useful on a smaller and more localized scale. They need to be used and tested. Evaluation and calibration of these will require large amounts of localized data.

In parallel with modeling needs, our sampling and monitoring programs must be improved to get better data than we now have. Without this, it will not be possible to build confidence in model output regardless of scale. The design of sampling networks is a major subject for study. Data collection needs to be diagnostic and include more parameters, measured at more places, more frequently, and less focused on trend analysis.

VI. Recommendations

The following recommendations are general and respond to the charge assigned to the Task Group and the three supporting objectives given under section II, Mission and Objectives.

1. Until a formal written report or reviewable paper is available, no attempt should be made to review Dr. Jaworski's hypothesis. Once available, we recommend STAC initiate a formal critical review by a multidisciplinary team with strong credentials on N in terrestrial and watershed systems.

2. We recommend that STAC submit to the IC the following statement. "The STAC has considered the available information supporting the suggestions by Dr. Jaworski concerning the magnitude of the atmospheric nitrogen inputs to the Bay. We find that this information does not replace existing knowledge and information, much of it peer reviewed and published, and thus does not support the need for any changes in the current nutrient management policies in the Bay program. The STAC is willing to reconsider this conclusion in light of any new written information that may be presented by Dr. Jaworski in the future."

3. STAC should initiate steps to advance and utilize our knowledge of N dynamics, cycling and control in the Chesapeake Basin. Although many questions exist regarding atmospheric N input to the basin and Bay, and the impact of N inputs on the Bay, we know least about the terrestrial component and how it is linked to the atmospheric N and Bay N. These steps should include the commissioning of critical literature reviews, supported by a STAC workshop, possibly culminating in a STAC "white paper" if necessary. STAC should develop a Task Group or team to oversee and coordinate the whole effort with the team emphasis being on terrestrial and watershed, but including atmospheric and aquatic scientists. If such a team is formed, we recommend that section V, Analysis and Conclusions, of this report provide the technical framework for initiating this effort.

4. Throughout all discussions, it was apparent that N monitoring and modeling deficiencies were so serious as to compromise our knowledge of N balance, transport and fate computations in much of the terrestrial and watershed systems. Major N species are not being measured, and N measurements too often are not being made at the critical places or times. We recommend STAC ask that these sampling, monitoring, and modeling issues be addressed with the goal of proposing corrective actions soon.

VII. STAC TASK GROUP MEETING
Room 3404, NOAA Bldg. 3
Silver Springs, MD

Thursday, August 8

1:00-1:20 p.m	Introduction	Harry Pionke
1:20-1:40 p.m.	Atmospheric Input Presentation	Bruce Hicks, Joel Baker
1:40-2:45 p.m.	Discussion	
2:45-3:00 p.m.	Coffee	
3:00-3:10 p.m.	Bay-Estuary Input Presentation	Joel Baker
3:10-4:00 p.m.	Discussion	
4:00-4:20 p.m.	Terrestrial-Forest Presentation	Jim Lynch, Dave DeWalle
4:20-5:30 p.m.	Discussion	

Friday, August 9

8:00-8:20 p.m.	Terrestrial-Agriculture Presentation	Jack Meisinger, Alan Taylor
8:20-9:30 p.m.	Discussion	
9:30-9:50 p.m.	Coffee	
9:50-10:10 p.m.	Terrestrial-Watershed, Overview Presentation	Joel Blomquist, Alan Taylor
10:10-11:00 p.m.	Discussion	
11:00 a.m.-Noon	Closure	Harry Pionke

VIII. Conceptually Based Nitrogen Balance Examples for Different Terrestrial Systems expressed in kg/ha for one year.*

Components	FOREST (60%)**	AGRICULTURE (29%)						
	Mature hardwood	Soybean grain	Alfalfa hay	Grass pasture	Corn Grain, Continuous			
				Grazed	Manure Surface appl.	Manure Injected	Fertilizer (UAN) Surface appl.	Fertilizer (UAN) Injected
INPUTS								
Fertilizer	0	0	0	0	0	0	130-170	130-170
Manure	0	0	0	190-270	250-350	250-350	0	0
Atmosphere	6-9	7-14	7-14	7-14	7-14	7-14	7-14	7-14
Biol. N fixation	8-12	140-180	280-360	--	--	--	--	--
Soil OM	60-80	40-60	50-70	50-70	40-60	40-60	40-60	40-60
Subtotal	75-100	190-250	340-420	250-350	300-400	300-400	180-240	180-240
OUTPUTS								
Harvest (plant storage)	10-20	100-140	200-300	110-140	80-120	80-120	80-120	80-120
Surface runoff	0-2	3-7	1-4	1-4	15-25	7-14	3-7	3-7
Leaching (streamflow)	1-4	5-15	1-5	1-5	15-25	25-35	5-15	30-40
Denitrification	0-2	8-12	12-18	25-35	25-35	50-70	10-20	10-20
NH_4 volat	0-2	2-8	5-15	55-75	50-70	8-12	25-35	2-8
Subtotal	12-30	120-180	250-320	190-250	180-270	170-270	130-190	130-190
RETURNS								
Plant residue (soil returns)	60-80 (?)	50-70	70-90	60-80	120-140	140-160	40-60	40-60
Δ Soil OM	0	+10	+20	+10	+80	+100	0	0

-- Unknown and likely small relative to the other input components.

* These numbers are not to be cited, because they are presented here only as indicators of N component size, distribution, and importance. The goal of this table is to provide a terrestrial systems framework to help identify critical N sources, assumptions, unknowns, and opportunities with respect to controlling N export to the Chesapeake Bay.

** Agricultural land--20%, pasture--9.0%; urban-suburban--10%; water surface--1%; personal communication from L.R. Shuyler on land use in NPS model. Using EMAP results (Gardner et al., CRC Pub. No. 151), land use is forest--58.5%, agriculture--32.6%, urban--6.7%.