

# **Airsheds and Watersheds III: A Shared Resources Workshop**

**The Significance of Ammonia  
To Coastal and Estuarine Areas**

**November 15-16, 2000**



**The BayCenter at Ruddertowne  
Dewey Beach, Delaware**

**Sponsored by the Chesapeake Bay Program, EPA Great Waters Program,  
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Mid-Atlantic Regional Air Management Association**

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## EXECUTIVE SUMMARY

Emissions of ammonia, the airborne transport of ammonia and its fate were the focus of discussion at the third “Shared Resources” Airsheds and Watersheds workshop, held November 15-16, 2000 in Dewey Beach, Delaware. Two previous workshops addressed the regional impacts of atmospheric nitrogen deposition, but largely from the standpoint of nitrogen oxide (NO<sub>x</sub>) emissions—less attention was given to ammonia emissions. Scientific studies now indicate that ammonia emissions may result in a significant and growing form of nitrogen input to terrestrial and aquatic ecosystems.

Airborne nitrogen compounds in wet and dry deposition, along with nitrogen from fertilizers, sewage, and industrial discharges, are a source of nutrients to receiving waters via surface water runoff, ground water flow and direct inputs. Current estimates are that atmospheric nitrogen deposition can contribute from 10 to over 40% of the “new” nitrogen enrichment of coastal and estuarine waters. Since ammonia is often a preferred form of nitrogen for biological activity, its increasing availability could cause fundamental changes in aquatic algae communities. Additionally, air quality experts recognize that ammonia plays an important role in the formation of fine particulate matter, which can affect human health and degrade visibility. The need for managing ammonia emissions is demonstrated in the Netherlands where the environmental impacts are clearly visible.

According to available assessments, the dominant source of ammonia emissions in the United States is agriculture, primarily livestock operations and commercial fertilizer applications. Other sources include industrial and combustion processes and biological activity in soils. Depending on the source, or spatial concentration of sources, the amount of ammonia released into the air can be substantial. Unlike NO<sub>x</sub>, ammonia is largely unregulated, and partially as a consequence existing ammonia emissions inventories are comparatively poor. In most cases, estimates of ammonia emissions for the various sources have been conducted in different ways, often for different purposes, and usually as an after-thought.

Ammonia and ammonium are undoubtedly critical contributors to US agricultural production. It should be remembered that world food production depends on supplementing plant nutrients obtained from the soil with fertilizers such as ammonia. Currently, there are no feasible alternatives to mineral fertilizers in modern agriculture given the demands of feeding the world population. Without the use of nitrogen and other fertilizers, the agricultural sector would potentially be forced to increase the amount of land used for farming, forcing further invasion of natural ecosystems.

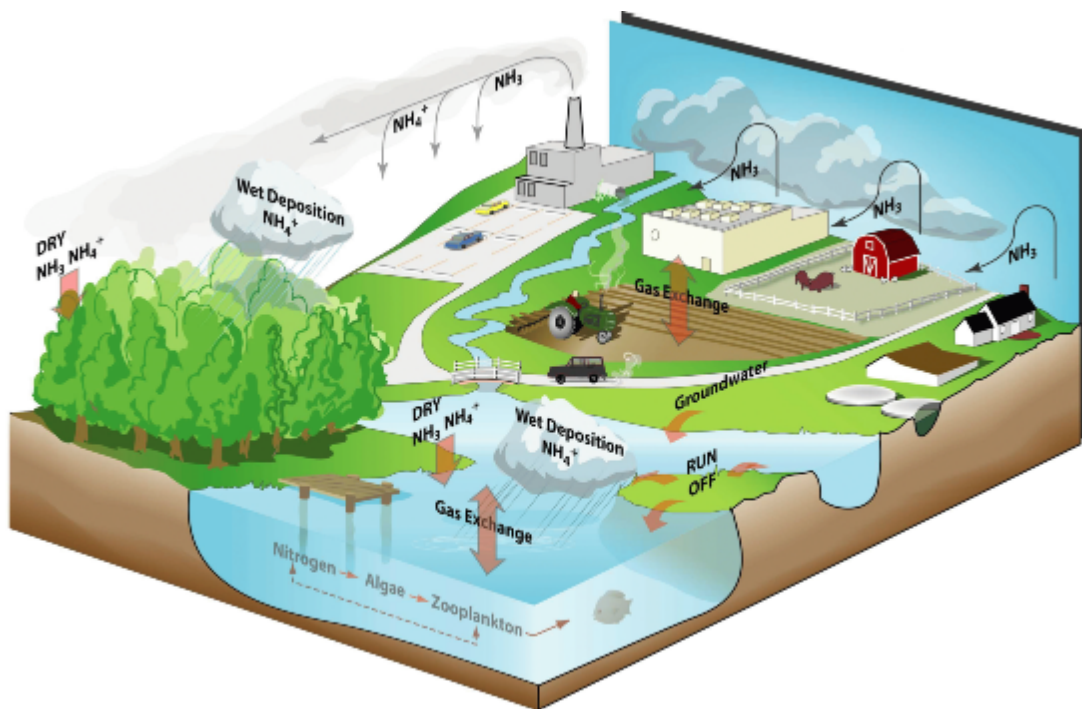
The objectives of this workshop were to generate an awareness of ammonia’s role in impacting our air, land, and water environments and to lay the foundation for understanding the primary emission sources, the magnitude of these emissions, and the atmospheric transport and fate of ammonia on a regional and local scale. The two-day workshop was not designed to consider the importance of ammonia in agriculture and industry. Instead, the workshop was specifically designed to give participants from diverse backgrounds a chance to share information and ideas about ammonia and its potential impacts on the environment.

Five primary conclusions were reached by the workshop participants:

- Ammonia can affect human health and the environment, and more study is needed to establish cause and effect relationships.
- Airborne ammonia can travel short or long distances from its source before depositing to the Earth’s surface. Better emissions data are needed for all of the sources in order to improve ammonia emissions inventories, and deposition data must be collected in emission “hotspots” in order to enhance and refine computer models.

- Ammonia is released into the air from many sources. While the dominant source in the United States and several coastal regions is agriculture, better data must be collected across the agricultural production process to identify how much and when ammonia is released.
- Because of its importance to human health and the environment, it is necessary to manage ammonia emissions. Through education, incentives, and new technologies, non-regulatory actions can be implemented now to reduce or eliminate ammonia releases.
- There was broad agreement on the importance of ammonia and the need for sensitivity to both economic and environmental issues related to it.

While workshop participants represented a broad range of interests including, agriculture, government, universities, industry, and environmental groups, not all invited stakeholder groups were present. Additional meetings are planned to provide educational opportunities and to improve communication, particularly with the agricultural community.



3-Dimensional Schematic developed by Battelle, Inc.

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## INTRODUCTION

Over the past century, human activities to produce food and energy have significantly increased the amount of nitrogen released into the environment. Interestingly, this increased nitrogen can have positive and negative impacts on terrestrial and aquatic ecosystems. One of the most serious negative impacts is the over-enrichment of U.S. estuarine and coastal waters (e.g., eutrophication). Too much nitrogen (as well as other nutrients) can lead to the over-production of algae [including potentially harmful (toxic, food web-altering) bloom species]. These blooms can block sunlight needed for submerged aquatic vegetation to grow. When the algae die they sink to the bottom and decay, potentially using up most of the available oxygen (hypoxia) or all of it (anoxia).

While the most notable human activities that contribute excessive amounts of nitrogen to coastal waters are wastewater treatment discharges, failing septic systems, and over-application of nutrients (including both fertilizers and manure spread as a nutrient source), there has been increased recognition that nitrogen emissions into the atmosphere can be an important source that negatively impacts coastal waters – particularly at a regional scale. However, the extent of this impact is uncertain. This is because there are many factors that influence the dynamics of nitrogen emissions and deposition, including the chemical form of nitrogen emitted, the location of emission sources, the transformation of nitrogen in the atmosphere, the cycling of nitrogen within the watershed, the surface and sub-surface transport of nitrogen from the watershed, and the cycling of nitrogen in coastal waters.

In the mid 1990s, the Chesapeake Bay Program began a series of Shared Resources workshops. The intention of the Shared Resources Initiative was to address ecological issues shared across geographic and political boundaries (migratory birds, migratory fish, the coastal ocean, airsheds, and watersheds). In 1995, the first Airsheds & Watersheds workshop was held at the Airlie House in Warrenton, Virginia (the Airlie Workshop). The main goal of that workshop was to raise awareness of the need for air and water scientists and managers to collaboratively address the issue of atmospheric nitrogen deposition. In 1997, a second Airsheds & Watersheds workshop was held in Raleigh, North Carolina (the Raleigh Workshop) to build upon the momentum generated by the first gathering. Both workshops focused largely on the role of nitrogen

oxides (NO<sub>x</sub>)— far less attention was given to ammonia. There are reasons why the previous workshops did not focus their attention on ammonia emissions. Nitrates, from NO<sub>x</sub> emissions, tend to make up the majority of the nitrogen in wet and dry deposition. In addition, unlike NO<sub>x</sub>, emissions of ammonia are mostly unregulated. As far as the federal Clean Air Act is concerned, ammonia is not one of the six criteria air pollutants nor is it a primary acid rain pollutant. Ammonia is considered a regulated substance under the Prevention of Accidental Releases in the Federal Clean Air Act. This is because at high concentrations ammonia is known to cause, or has the potential to cause, serious adverse effects to humans and the environment. In addition, regulations adopted by the Occupational Safety and Health Administration cover the handling, storage of, and exposure to ammonia in the workplace. Because ambient air concentrations must be extremely high to be considered a human health concern, less emphasis has been placed on collecting data about routine ammonia emissions, sources, and deposition.

In recent years, however, scientific studies conducted in Delaware Bay, Chesapeake Bay, Albermarle-Pamlico Sounds, and Tampa Bay, have indicated that ammonia emissions may represent a significant and growing source of nitrogen impacting terrestrial and aquatic ecosystems. Air quality experts also have begun to recognize that ammonia plays an important role in the formation of fine particulate matter and regional haze. This heightened focus on ammonia is timely, because the Nation's coastal populations of humans and animals have been growing rapidly over the last several decades, leading to increases in ammonia emissions and deposition in coastal areas.

As a result of the increased focus on ammonia, its significance to coastal and estuarine areas became the focus of the third Airsheds & Watersheds workshop. The report that follows is a product of this third workshop held November 15-16, 2000 in Dewey Beach, Delaware (the Dewey Beach Workshop). The workshop was sponsored by the Chesapeake Bay Program, EPA Great Waters Program, the NOAA Air Resources Laboratory, and the Mid-Atlantic Regional Air Management Association. The objectives were to generate an awareness of the impacts of ammonia emissions to our air, land, and water environments and to lay the foundation for understanding the primary

emission sources, the magnitude of these emissions, and the atmospheric transport and fate of the nitrogen on a regional and local scale.

The material presented in this report draws from the workshop presentations and deliberations. Topics covered are the effects of ammonia; atmospheric transport and deposition; ammonia sources and emissions; and managing ammonia emissions. The information captured in the discussion sessions are incorporated into the conclusions and future directions section. Workshop participants represented a broad range of interests including, agriculture, government, universities, industry, and environmental groups. The Workshop's agenda and a list of participants are provided in the appendices. This report, in its entirety, as well as posters presented during the workshop and related illustrations may be viewed at: <http://www.chesapeakebay.net/ammoniaworkshop.htm>.



## EFFECTS OF AMMONIA EMISSIONS

Ammonia ( $\text{NH}_3$ ) is a gas that is readily released into the air from a variety of biological sources (e.g., human and animal wastes, soils, and commercial fertilizers), as well as from a variety of industrial and combustion processes. Depending on the source or the spatial concentration of sources, the amount of ammonia released into the air can be substantial.

While ammonia has many beneficial uses in society, environmental managers should be aware that ammonia emissions can affect the quality of our environment. The consequences of emissions into the air were the focus of this workshop.

### Effects on Air Quality

Cliff Davidson is Professor of Civil and Environmental Engineering, and of Engineering and Public Policy at Carnegie Mellon University. He is also the Director of the Environmental Institute at CMU. Dr. Davidson has authored several books and many journal papers dealing with air quality issues. He has just completed a term as President of the American Association for Aerosol Research. Dr. Davidson addressed the effects of ammonia on air quality.

In recent years it has become apparent that ammonia plays a key role in the formation of fine particulate matter (particles less than  $2.5\ \mu\text{m}$  in diameter or  $\text{PM}_{2.5}$ ). Once ammonia is in the air, it can react quickly with oxidized sulfur and nitrogen (e.g.,  $\text{SO}_4$ ,  $\text{HNO}_3$ ) and form fine particles, primarily of ammonium sulfate and ammonium nitrate. According to the EPA, ammonium compounds are a major component of fine particulate matter in the Eastern U.S. About half is ammonium sulfate; much of the  $\text{PM}_{2.5}$  is particles of diameter  $0.5 - 1.0\ \mu\text{m}$ . Air quality and health experts believe that a significant fraction of the  $\text{PM}_{2.5}$  can be inhaled by humans and deposited in the bronchioles and alveolar sacs in the respiratory system, possibly leading to adverse health effects (Figure 1). This is consistent with results of epidemiological studies that suggest mortality rates correlate with fine sulfate particles, which are typically  $0.1$  to  $0.5\ \mu\text{m}$  diameter.

Other effects include visibility degradation (Figures 2 & 3). Studies have shown that visibility is most affected by particles with diameters between  $0.4$  and  $0.7\ \mu\text{m}$ , – the wavelength range of visible light. Airborne ammonium sulfate particles fall mainly in this

Three Compartments of the Human Respiratory System (Ray, 1995)

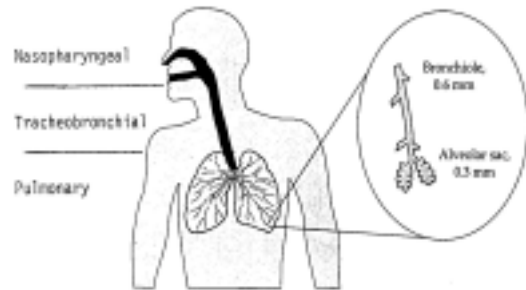


Figure 1 as Presented by Cliff Davidson

size range. While people often associate poor visibility with urban areas, such as Los Angeles, California, it also is a serious problem in the Appalachian Mountain ranges and in coastal regions. Poor visibility over a large area is referred to as regional haze, because it is so pervasive and caused by many air pollution sources dispersed over large areas (rather than by a single source).



Figures 2& 3 Effects of Regional Haze at Newark, NJ  
Clear Day Above; Hazy Day Below  
<http://www.hazecam.net/newark.html>



## Effects on Terrestrial Landscapes

Jim Galloway is Professor and Chair of the Dept. of Environmental Sciences at the University of Virginia. His research is in the area of biogeochemistry and includes works on the natural and anthropogenic controls on chemical cycles at the watershed, regional and global scales. Dr. Galloway is internationally recognized for his work on acid deposition effects on soils, waters and forests and watershed biogeochemistry. Dr. Galloway discussed the effects of ammonia on terrestrial ecosystems.

On a global scale, about 60% of the nitrogen (oxidized and reduced) produced through human activities (food and energy production), is released into the air; over half of this nitrogen is ammonia. When airborne nitrogen (e.g. nitrate and ammonium) deposits onto terrestrial ecosystems, a substantial portion remains within the local ecosystem due to retention of the nitrogen by the soil or by plant uptake. What is not kept in the terrestrial system is either discharged to groundwater, streams and rivers, or released back to the atmosphere. The proportion of nitrogen derived from wet or dry deposition that is transported to local waterways from the land depends on the nature of the landscape in question, especially soil type and vegetation. Scientists believe that on the average less than 25% of the atmospheric nitrogen deposited to terrestrial ecosystems is transported to coastal estuaries.

The total amount of nitrogen mobilized by humans through energy and food production is about 150 Tg N/yr. This is greater than the natural terrestrial rate.

-Dr. James Galloway, University of VA

The cycling of nitrogen in the soil is complex but important in understanding the effects of ammonia on terrestrial ecosystems (Figure 4). Nitrogen occurs as a nutrient in the soil and is vital for plant growth. The addition of nitrogen from ammonia/ammonium deposition can increase plant productivity during the growing season. However, at the wrong time of year (the winter months), nitrogen inputs can decrease a plant's resistance to frost. This is because there is little microbial activity taking place. Enhanced ammonium deposition also can cause the acidification of soils.

The acidification begins in the atmosphere where ammonia ( $\text{NH}_3$ ) reacts with a  $\text{H}^+$  ion, producing ammonium ( $\text{NH}_4^+$ ). When ammonium deposits (or is applied) to the soil, it is generally oxidized relatively rapidly by soil bacteria to form nitric acid. Nitric acid dissociates readily in the soil solution releasing  $\text{H}^+$  ions. In addition, when the ammonium is directly taken up by a plant, the surrounding soil can become more acid due to the release of  $\text{H}^+$  from the plant to balance the positive charge of the ammonium removed from the soil solution. Under normal conditions, the internal chemical reactions within the soil maintain a balance between acid-producing processes and acid consuming processes, resulting in little change in soil acidity. With continued, substantial inputs of ammonium, the original internal balance within the soil can no longer be maintained resulting in soil acidification; and the potential loss of nutrient base cations like calcium and

## The Terrestrial N Cycle

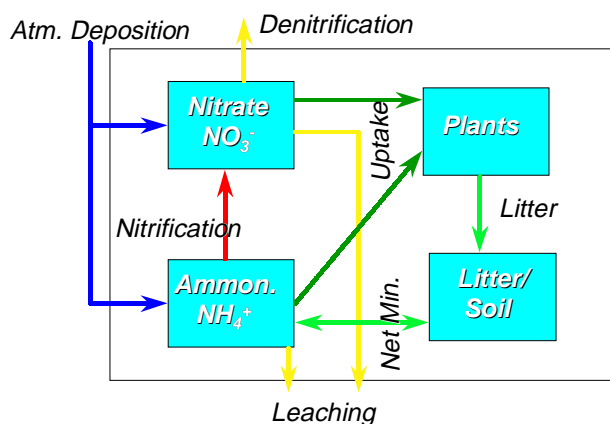


Figure 4 as Presented by Jim Galloway

magnesium, and an increase in the bioavailability of potentially toxic cations like aluminum. This induced change in soil acidity will most likely alter forest productivity and also bring about a change in plant community structure with a possible decrease in soil biodiversity.

In addition to plant fertilization and soil acidification, there are other effects of ammonium deposition including nitrogen saturation. All terrestrial (and aquatic) ecosystems cycle nitrogen through

various chemical forms because it is a vital nutrient necessary to support life. Nitrogen saturation occurs when inputs of nitrogen essentially overwhelm the internal nitrogen-cycling processes of an ecosystem. In a sense, the ecosystem begins to leak nitrogen because excess amounts occur at certain critical points in the nitrogen cycle. This excess nitrogen can be lost via transformation into gaseous nitrogen species, or by leaching of the soil solution below the active rooting zone of the soil where it can enter the groundwater, with eventual discharge to surface water bodies. The presence of excess nitrogen in groundwater and surface waters can lead to algal blooms in receiving waters, and/or can also promote acidification of surface waters. Excessive amounts of nitrogen (usually nitrates) in groundwater leaving forest soils are often associated with cations like  $H^+$  or aluminum, both of which can be detrimental to aquatic life. The changes in a terrestrial ecosystem approaching nitrogen saturation are often subtle, being reflected in gradual changes in plant community structure, and the release of nitrogen either in the gas phase or in groundwater and surfaces waters draining the ecosystem.

In summary, enhanced ammonium deposition onto a terrestrial ecosystem can, in sequence: increase soil acidity and either increase or decrease forest productivity. Once it has left the terrestrial ecosystem, the nitrogen (which is largely in the form of nitrate) can in sequence: decrease stream/lake biodiversity, decrease the quality of drinking water, increase coastal eutrophication, and alter coastal biodiversity. These sequential effects are referred to as the nitrogen cascade. The ultimate fate of nitrogen from the air to the soils with eventual nitrogen saturation, particularly of upland forest systems, depends on many factors including how much nitrogen is depositing, how long the deposition has been occurring, how it is being accumulated, and most importantly the land use history. Older, mature forest will be less likely to utilize enhanced amounts of nitrogen deposition, and will be more likely to undergo nitrogen saturation. Younger forests (<60 or 70 years old) that are rapidly aggrading and incorporating nitrogen into the forest biomass could take decades before becoming susceptible to nitrogen saturation.

## **Effects on Coastal and Estuarine Waters**

Hans Paerl is Kenan Professor of Marine and Environmental Sciences, at the University of North Carolina-Chapel Hill, Institute of Marine Sciences. His research includes nutrient cycling and production dynamics of aquatic ecosystems, environmental controls of algal production, and assessing the causes and consequences of eutrophication. Dr. Paerl's recent studies have identified the importance and ecological impacts of atmospheric nitrogen deposition in estuarine and coastal environments. His work plays a central role in coastal water quality and fisheries issues facing the nation. Dr. Paerl addressed the effects of ammonia on coastal and estuarine aquatic ecosystems.

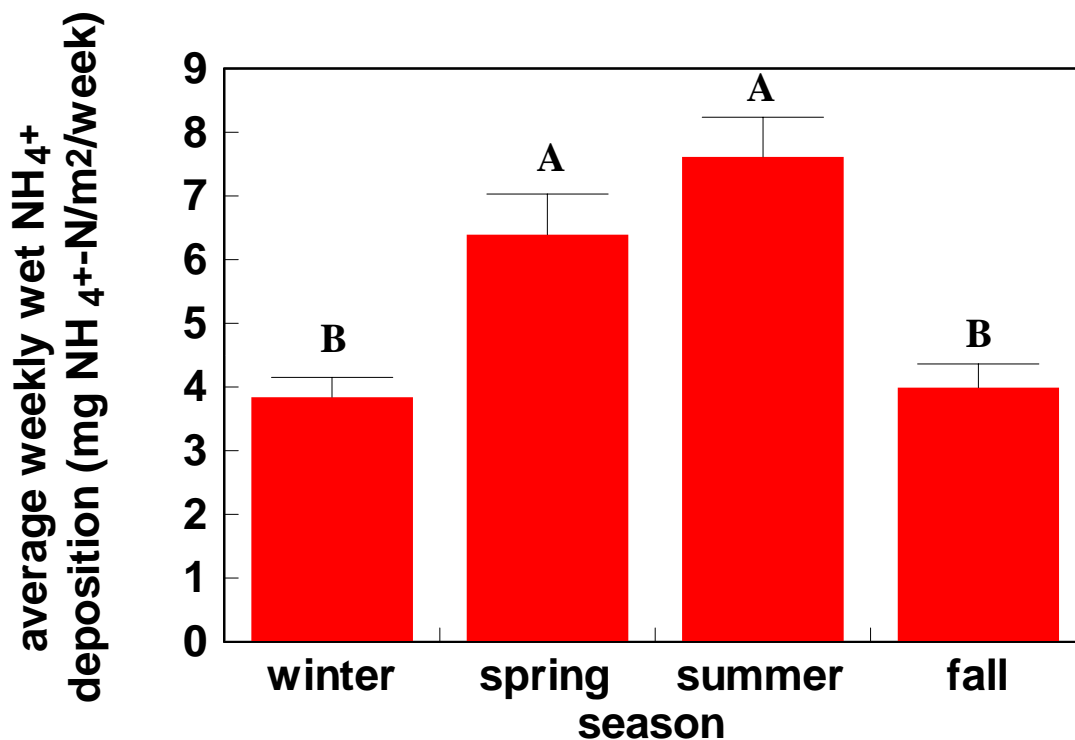
As previously discussed, some of the airborne nitrogen that is not utilized by the terrestrial ecosystem can make its way into receiving waters (called indirect load). Airborne nitrogen deposition also can by-pass the terrestrial landscape by directly falling onto the water surface (called direct load). Regardless of whether the airborne nitrogen is indirectly or directly loaded into the water, too much of it can have (or contribute to) a number of ecological effects, including the acceleration of a natural process called eutrophication. Eutrophication is the process by which a water body becomes enriched with organic material (e.g., algae). This organic material can be stimulated to harmful levels by large inputs of nutrients, such as nitrogen and phosphorus. The growth rate of this organic material can be increased if the nitrogen deposited is in the form of ammonia/ammonium.

In coastal and estuarine waters, nitrogen is the nutrient most often controlling primary production, and too much of it can lead to an over-production of algae, including harmful, toxic, food web-altering, algal blooms (e.g., red and brown tides). The algal blooms also can block sunlight needed for important habitat, such as submerged aquatic vegetation and corals. When the algae die, they sink to the bottom and are decomposed by bacteria. During this process, most of the water's oxygen (hypoxia) or all of the water's oxygen (anoxia) needed for aquatic life can be depleted. These problems can cause a decline in fisheries and recreational activities, which ultimately cost coastal regions millions of dollars in lost tourism and fisheries revenues.

It has been estimated that atmospheric nitrogen deposition can contribute from 10% to over 40% of the “new” nitrogen enrichment of coastal and estuarine waters. Along the Coastal Atlantic Ocean, there is greater nitrogen stimulation of primary production occurring in the near shore region than farther out in the Gulf Stream. Studies conducted in North Carolina, for example, show that both ammonium and nitrate have strong stimulating effects. It appears that the presence of iron and a complexing agent for metal ions called EDTA play an additionally important role for nitrate stimulation. This is not the case for ammonium. In studies where algae are treated with similar amounts of ammonium and nitrate, there is greater production from the ammonium. In essence, it is a preferred “flavor” of nitrogen for many types of algae. This is because, unlike nitrate, ammonium is in a ready-to-use form of nitrogen for most biological activity. It does not need to be biochemically converted or reduced, a process which requires energy. As a result, the

increasing availability of ammonium could cause a fundamental change in the algae community.

The different chemical forms and amounts of nitrogen depositing from the air appear to influence the type and amount of algae present in the system. Growth rates of those algae able to use the nitrogen the fastest will be enhanced, enabling them to most effectively compete with other types of algae. For example, ammonium deposited directly onto the surface waters in the summer could trigger a bloom of “bad” algae. There is a difference between bad algae and just too much algae. For example, “bad” algae can produce toxins, are inedible, or can trigger low oxygen conditions. Monitoring data collected in North Carolina indicate that the highest average ammonium deposition in rain occurs during the spring and summer (Figure 5) – the primary growing seasons for plants (including algae). Presently, diurnal (day/night) effects and differential growth of organisms on a seasonal basis have yet to be fully addressed.



**Figure 5** Seasonal Comparison of Wet Deposition as Presented by Hans Paerl

## TRANSPORT AND DEPOSITION OF AMMONIA

Bruce Hicks is the Director of the Air Resources Laboratory (ARL) of NOAA's Office of Oceanic and Atmospheric Research. His research focuses have been on issues such as the exchange of materials (e.g., ammonia) between the atmosphere and the land and water surfaces.

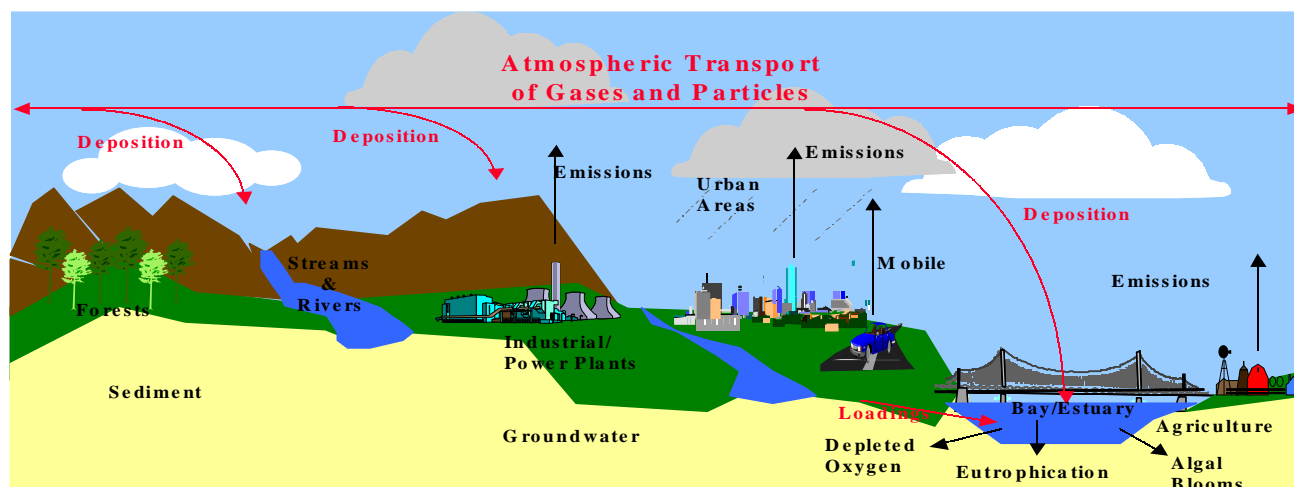
Robin Dennis is a NOAA, ARL scientist who serves as Senior Program Manager with the Atmospheric Modeling Division at EPA's National Exposure Research Laboratory. Dr. Dennis was involved in setting the vision and conceptual development for EPA's Models-3 and in the conceptual development of EPA's new Multi-media Integrated Modeling System. He is currently performing diagnostic evaluations of regional models for ozone, particulate matter, acidic and nutrient deposition, particularly linking air and water for coastal and estuarine assessments.

Bruce Hicks and Robin Dennis jointly presented information on the atmospheric transport and deposition of ammonia/ammonium.

Once nitrogen compounds are released into the air, there are many physical and chemical factors that influence their transport and deposition. First, there is need to consider "reactive" nitrogen compounds in two distinct groups – Reduced, which is dominated by ammonia gas, and Oxidized which is dominated by nitric acid gas and particulate nitrate. Oxidized nitrogen compounds tend to reside in the air longer than reduced nitrogen. Both can react with each other and with other air pollutants, particularly sulfates, and form fine particulate matter, and both are highly soluble in water.

Some of the factors that determine whether these airborne gases and particles travel a short or long distance from their source before depositing include the source type and height of emission (e.g., industrial smokestack, automobile exhaust pipe, animal housing unit), and weather conditions (e.g., wind, temperature, humidity). The presence of sulfates and nitric acid gases in the air, for example, is an important modifying factor for ammonia because they will take up ammonia gas to form particles, which can then reside in the atmosphere for several days. Generally, smaller particles will travel farther than larger ones, although very tiny particles with high diffusiveness may deposit quickly onto the Earth's surface. Small particles also can coagulate to form larger particles.

Once nitrogen (reduced or oxidized) is released into the air, it can deposit to the Earth's surface in the form of a particle, as a gas, or in precipitation (typically rainfall). The forms of nitrogen that are a concern to coastal watersheds, when the nitrogen deposits, are particulate nitrate ( $\text{pNO}_3^-$ ), nitric acid gas ( $\text{HNO}_3$ ) and nitrate in precipitation, which all originate from  $\text{NO}_x$  emissions; particulate ammonium ( $\text{NH}_4^+$ ), ammonia gas ( $\text{NH}_3$ ), and ammonium in precipitation, which all originate from ammonia emissions; and dissolved organic nitrogen (DON). Although the sources of DON are not well identified, it is believed at the moment to be a small fraction of the total nitrogen deposition. Therefore, this section focuses primarily on reduced and oxidized nitrogen.



For the East Coast, it is believed that about 66% of the nitrogen emitted into the air is from NO<sub>x</sub> emissions and 34% is from ammonia emissions. However, in Eastern North Carolina 57% of the nitrogen emitted into the air is from NO<sub>x</sub> emissions and 43% is from ammonia emissions. This larger fraction of ammonia emissions in Eastern North Carolina is evident in the National Atmospheric Deposition Program (NADP: site NC35 in Sampson County) data, where, on the average, 52% of the nitrogen in wet deposition is nitrate (from nitrogen oxide emissions); 48% is ammonium (from ammonia emissions). These data are indicative of the large number of confined animal operations in that portion of the state, and they demonstrate that both forms of nitrogen are important.

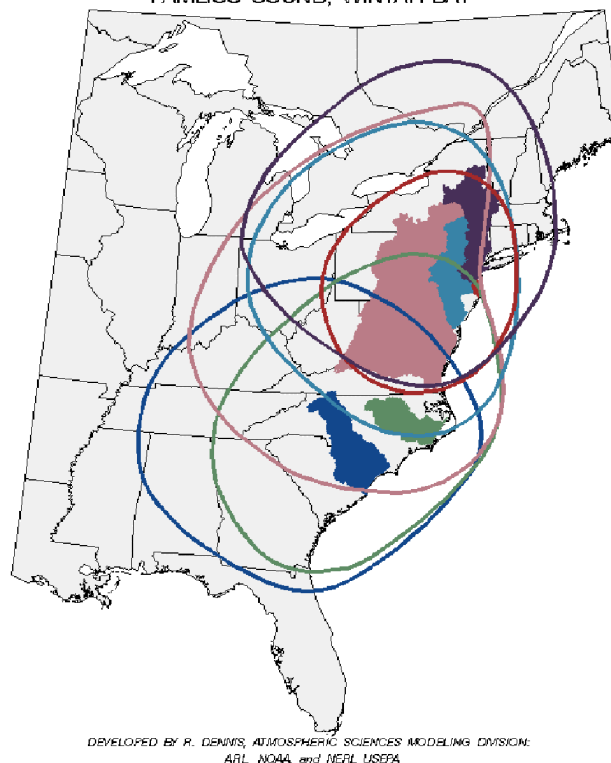
In recent years, the EPA's Regional Acid Deposition Model (RADM) has been used to estimate the area where nitrogen emission sources have the greatest potential in depositing nitrogen (wet and dry) to a watershed. The area encompassing these sources is referred to as the "principal airshed." The airshed is not as firmly defined as the watershed; there are not clear boundaries to the flow of chemicals in the atmosphere as there are for the flow of surface and ground waters in watersheds. The absolute influence that an emission source has on deposition to an area continuously diminishes with distance. In other words, the airshed represents the area that encompasses emissions that would contribute most to the deposition across a watershed should all emission sources be equal.

RADM was first used in the mid 1990s to develop the NO<sub>x</sub> airshed for the Chesapeake Bay watershed. Since that time, NO<sub>x</sub> airsheds have been delineated for other east and gulf coast water bodies, including Delaware Bay, Pamlico Sound, and Narragansett Bay (Figure 6). More recently, RADM was used to describe the ammonia/ammonium airshed for the Chesapeake Bay and Pamlico Sound (Figure 7). The Chesapeake Bay's ammonia airshed is about 688,000 km<sup>2</sup> in size. This is four times larger than the Bay's watershed; slightly smaller than the NO<sub>x</sub> airshed – which is 1,081,600 km<sup>2</sup> in size (Figure 8). The ammonia airshed for the Pamlico Sound is roughly 406,400 km<sup>2</sup> in size or 15 times larger than the watershed drainage area.

It is important to understand the concept of airsheds because the relationships between emissions and deposition, and subsequently atmospheric loadings into a water body, are not equal. For example, if 100 kg of nitrogen were released into the air from a source, it

will not all be deposited at once nor in one area. The annual deposition will be distributed over space and will be unevenly distributed in time. Just as emissions and deposition are not in a 1 : 1 ratio, neither are deposition and loadings to a water body. The terrestrial landscape will retain much of the deposited nitrogen. For example, the current belief is that approximately 10% of the deposited nitrogen to a typical forest ecosystem will be transported into receiving waters.

PRINCIPAL OXIDIZED NITROGEN AIRSHEDS FOR:  
HUDSON/RARITAN BAY, BARNEGAT BAY,  
DELAWARE BAY, CHESAPEAKE BAY,  
PAMLICO SOUND, WINYAH BAY



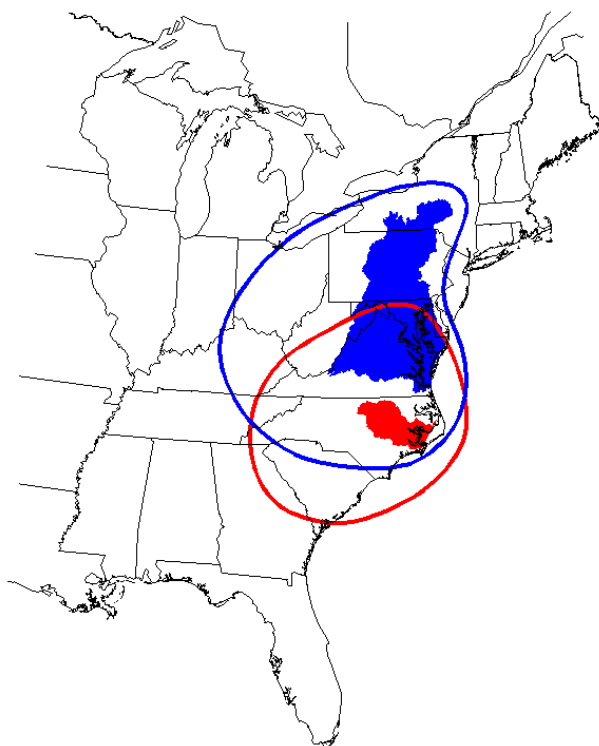
**Figure 6** Overlapping Oxidized Nitrogen Airsheds  
as Presented by Robin Dennis

### *Spatial Variability of Deposition*

Once in the air, nitrogen can travel short or long distances before being removed by precipitation (rain or snow), called *wet deposition*, or by the gravitational settling of particles (not associated with precipitation) and turbulent exchange of small particles and gases, called *dry deposition*. Wet deposition is highly variable with time and space on an event basis (e.g., some areas can receive large inputs while neighboring areas receive little to no input), but this variability is largely random. However, yearly averaging of wet deposition data from



PRINCIPAL REDUCED NITROGEN AIRSHEDS FOR:  
CHESAPEAKE BAY, PAMLICO SOUND



DEVELOPED BY R. DENNIS, ATMOSPHERIC SCIENCES MODELING DIVISION:  
ARL, NOAA, and NERL USEPA

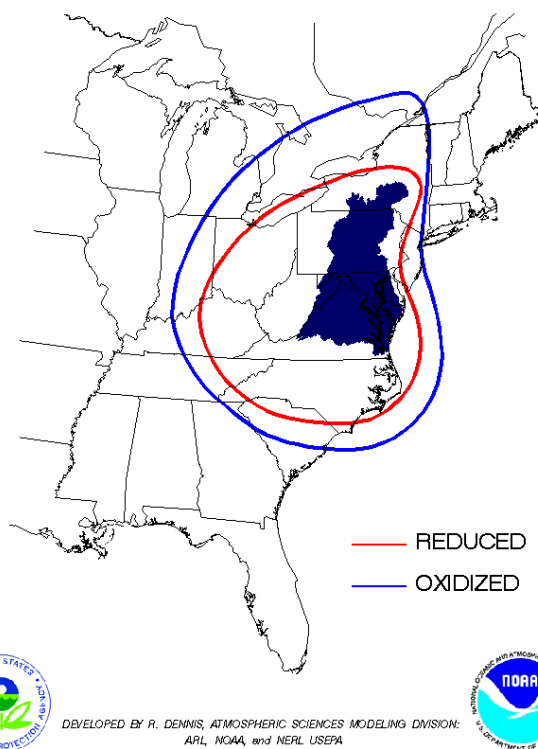
**Figure 7** Overlapping Reduced Nitrogen Airsheds  
as Presented by Robin Dennis

one location will yield a total deposition amount that is much the same as that computed for a neighboring location, except in extremely complex topography (e.g., mountains). Thus, from this yearly averaging, spatial patterns of accumulated wet deposition appear to be relatively smooth ( Figure 9).

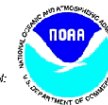
The factors that determine wet deposition are the amount of airborne material (e.g., nitrogen) to be scavenged by clouds (termed “washout”) and the efficiency of the precipitation scavenging process below the clouds (termed “rainout”). The efficiency of the scavenging process varies with location and season. The amount of material in wet deposition also depends on the solubility of the chemical. Nitric acid and ammonia are comparable in solubility, so there is little difference in the removal efficiency by wet deposition for oxidized and reduced nitrogen.

This is not the case for dry deposition – the net consequence of gravitational settling, turbulent

PRINCIPAL NITROGEN AIRSHEDS FOR:  
CHESAPEAKE BAY



DEVELOPED BY R. DENNIS, ATMOSPHERIC SCIENCES MODELING DIVISION:  
ARL, NOAA, and NERL USEPA



**Figure 8** Chesapeake Bay Nitrogen Airsheds  
as Discussed by Robin Dennis

exchange, and surface absorption. Dry deposition is controlled by meteorological factors (e.g., wind and temperature), as well as by the nature of the underlying surface, and occurs largely to landscapes where the efficiency of transfer is the greatest. For example, dry deposition to a forest is likely to be far more efficient than dry deposition to grassland in the same general area. Thus, the spatial variability of dry deposition is not random but is more organized according to the characteristics of the underlying topography and vegetation.

### *Diurnal Considerations*

During the night, the land surface cools and becomes colder than the air. The air stratifies — it forms layers that tend to slide over each other, although all moving according to the prevailing wind. Trace gases that are injected into the lowest air layers will tend to be trapped there. If the nitrogen is emitted by a source located in a valley, then it is possible that it will

## Estimated ammonium ion deposition, 1999

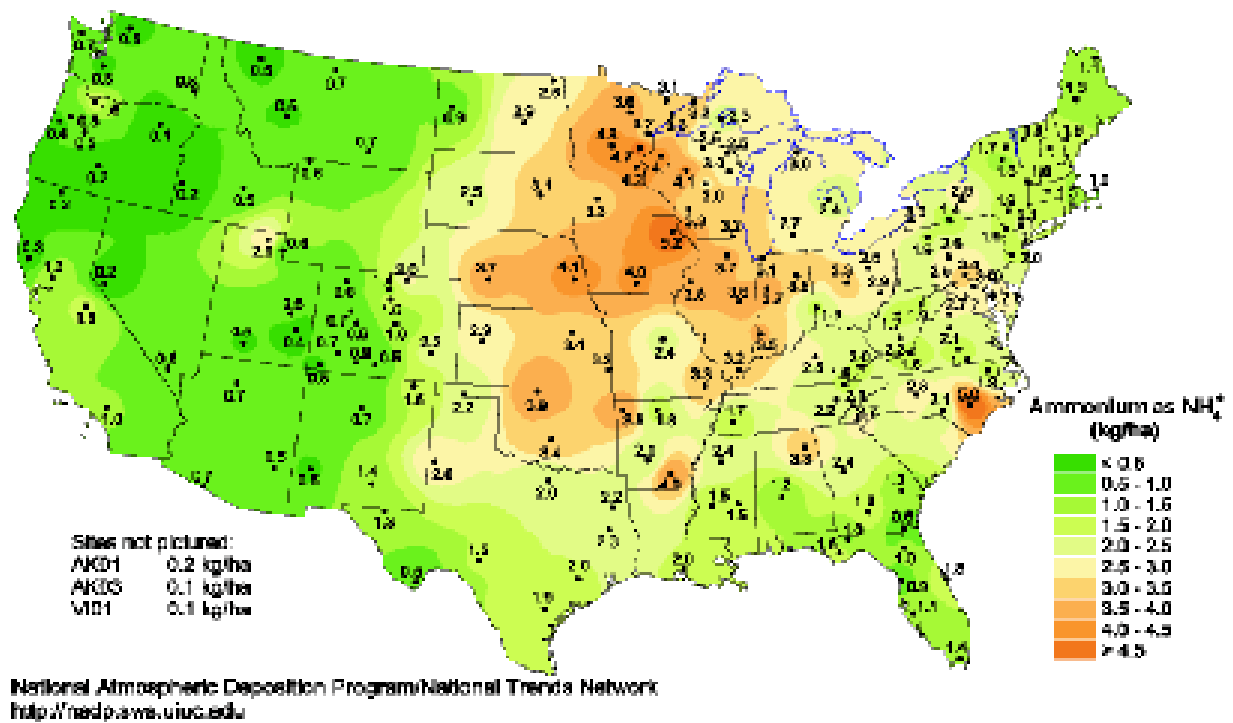


Figure 9 Ammonium ion Deposition across USA, 1999

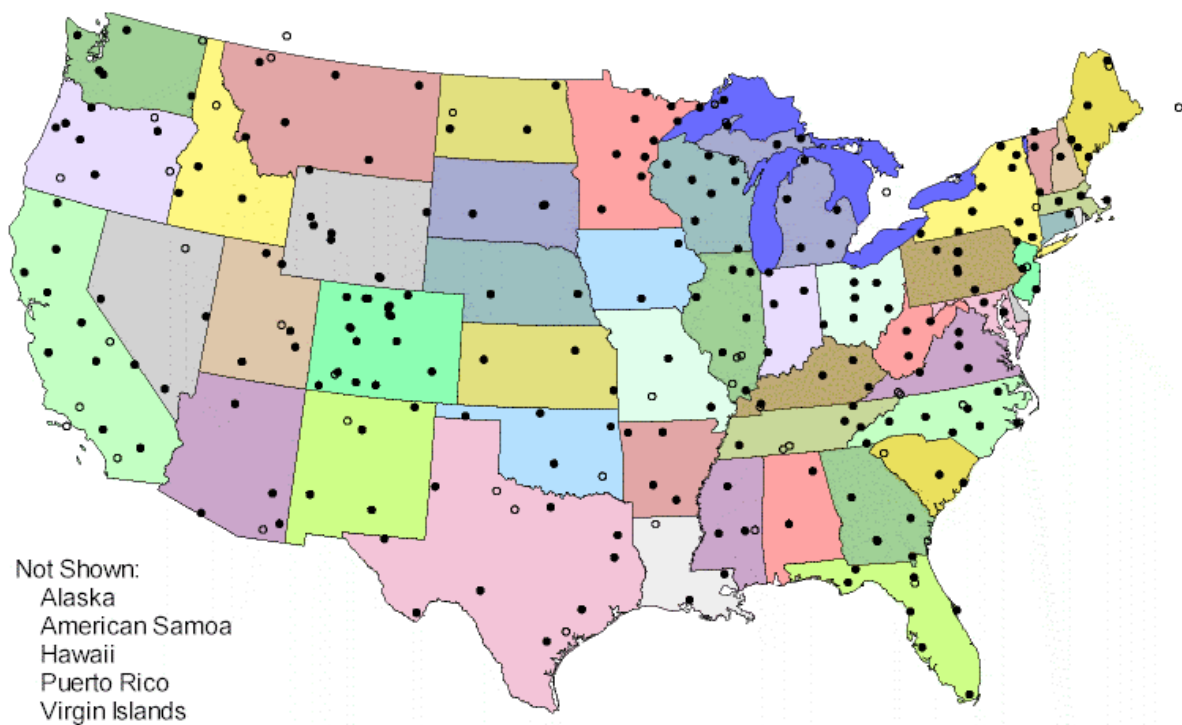


Figure 10 National Atmospheric Deposition Program (NRSP-3)/  
 National Trends Network Sites



be trapped there, until the sun rises and convection sets in, unless the wind is strong enough to overcome the stratification. Shortly after sunrise, the land surface becomes warmer than the air and convection starts – “hot air rises.” Turbulent mixing is enhanced in daytime, by this convection. Trace gases injected into the lower atmosphere during the daytime will then be mixed vertically, as high as the convection reaches – the top of the so-called mixed layer.

Because of this daytime mixing, ambient air concentration levels experienced by people are reduced, relative to nighttime situations. During the transition periods (from night to day and from day to night), conditions are often highly variable. Convection during daytime and the lack of it at night are controlling considerations. It is sometimes postulated that convection will be augmented because ammonia is lighter than air. However, this fact is not very important because ammonia is present in concentrations too small (even when it is close to the emission source) to modify the buoyancy characteristics of the air in which it is mixed. Regardless of its initial concentration, further dilution will occur more rapidly in daytime than at night.

As discussed earlier, gaseous ammonia can react quickly with oxidized sulfur and nitrogen in the air and form fine particles of ammonium compounds. This conversion to particulate ammonium occurs at a rate that depends on the presence of these other pollutants, temperature, and the presence of water. In daytime, this conversion can be quite rapid – a time constant of a few hours. At night, this conversion is much slower. Thus, much of the ammonia emitted into the air at night will survive as a gas until the early daylight hours (less dry deposition occurs at night), but most likely will be converted to particulate ammonium (sulfate or nitrate) during the daytime.

### ***Evaluating Wet and Dry Deposition***

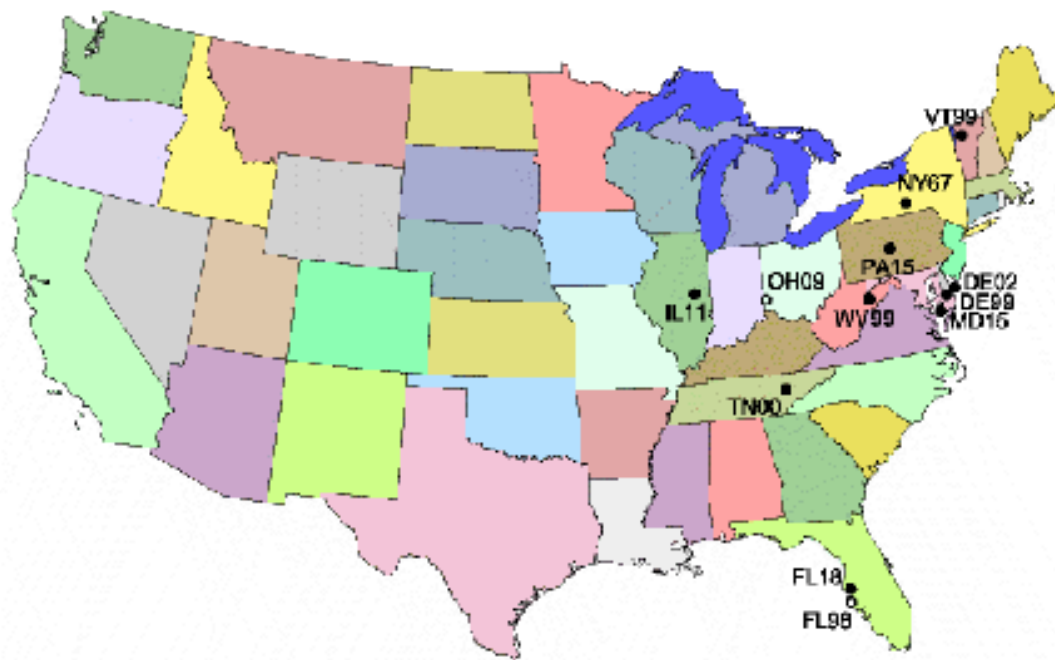
When collecting and analyzing deposition data, it is necessary to consider wet and dry deposition separately. In order to measure wet deposition, a relatively simple apparatus can be used, involving samplers that open only when it rains or snows. At present, there is one national monitoring network operating in the U.S.— the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) (Figure 10). NADP/NTN uses a weekly sampling protocol with the goal to assess time trends

and spatial patterns of wet deposition. However, NADP/NTN’s operating procedures impose some limitations when assessing ammonium deposition to sensitive coastal areas. For instance, NADP/NTN site locations have historically been rural by design in order to assess the relationship between regional pollution and changes in regional deposition patterns. Consequently, NADP/NTN site requirements have historically ruled out operation in areas affected by local emissions sources (e.g., urbanized areas) and coastal sea salt.

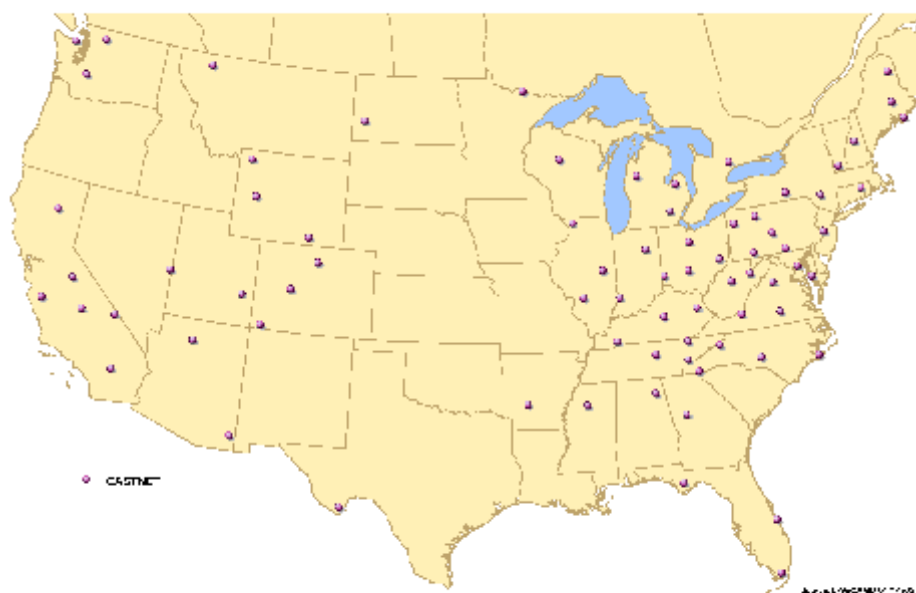
In recent years the NADP has become open to the establishment of coastal sites, as more estuary programs have expressed need for atmospheric nitrogen deposition data. Another limitation is that weekly data are of limited use in coupling with meteorological models and process-oriented studies. The weekly sampling also hinders the determination of ammonium deposition because nitrogen compounds are chemically unstable, and some of the ammonium, being a preferred form of nitrogen for biological activity, may not survive in the collected sample.

To improve upon NADP methods, the Atmospheric Integrated Research Monitoring Network (AIRMoN, Figure 11), a sub-network of NADP managed by the National Oceanic and Atmospheric Administration (NOAA), uses a daily sampling protocol, with a special focus on urban and coastal regimes. At this stage, however, there are few wet deposition stations in areas where data are required for studies of nitrogen deposition to coastal environments. Yet, it is in such areas that effects of ammonia emissions are likely to be the greatest due to increasing human and animal populations.

Conversely, there is no simple method for measuring dry deposition. Artificial collection surfaces (plates, buckets, etc.) do not yield the same answers as are relevant for natural surfaces, because the properties controlling dry deposition rates are usually surface-specific. This is especially the case for dry deposition of trace gases onto vegetation, where the leaf structure, function, and surface area are controlling factors. In general, scientists agree that there are some good methods for measuring dry deposition, mostly based on micrometeorological principles. Unfortunately, these are too complex to be used routinely, except in unusual circumstances where highly qualified technical assistance is available.



**Figure 11** NOAA's Atmospheric Integrated Research Monitoring (AIRMoN) Sites  
(solid circles are active sites, open circles are inactive sites)



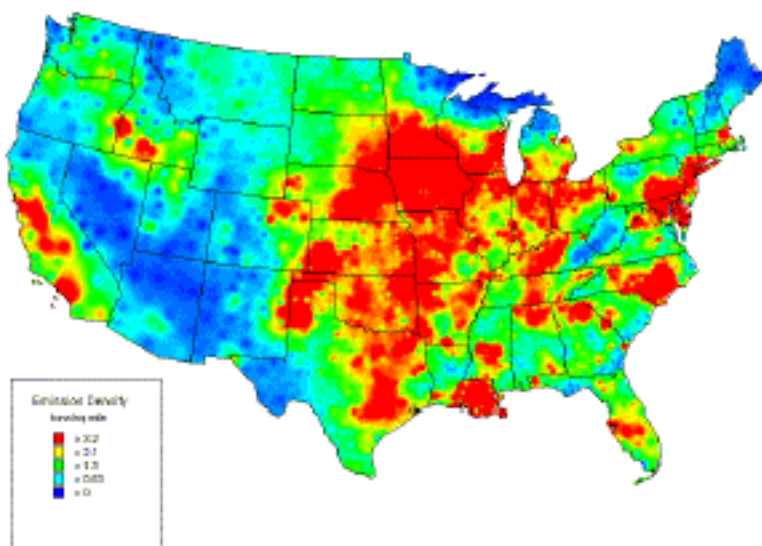
**Figure 12** Clean Air Status and Trends Network (CASTNet) sites  
<http://www.epa.gov/castnet/maps/>

A more widely used technique for estimating dry deposition rates is the inferential method. This method combines estimates of the average deposition velocity (based on a number of observed quantities) with measurements of weekly average air concentrations of the chemical species under consideration. Some of the chemicals being measured exist as gases, others as particles. However, great care must be taken to ensure the integrity of the collected chemical samples. There are two national networks applying the inferential method—EPA's Clean Air Status and Trends Network (CASTNet, Figure 12) and the NOAA's AIRMoN-dry. The latter is a research network aimed at further developing the methods that can be used routinely in CASTNet and similar operations. Neither of these networks measure ammonia in ambient air or in deposition. They only measure ammonium. Currently, there are only a few dry deposition stations located near coastal areas. The primary reason for this is that the presence of sea salt in the air is known to confound the measurement technique (a multi-filter system) that is used. Consequently, intensive studies are sorely needed to accelerate the development of the technologies to address this issue.

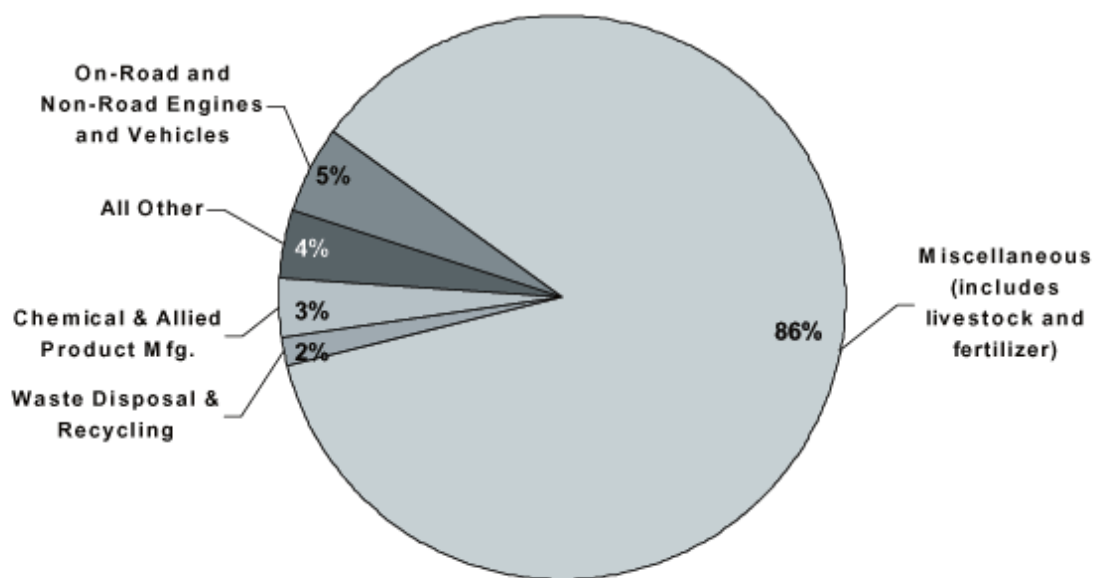
### ***Nitrogen in Wet vs. Dry Deposition***

As previously mentioned, nitric acid and ammonia are comparable in solubility, so there is little differentiation of the nitrogen (e.g., nitrate and ammonium) in terms of the rate of deposition of rain water. However, there are differences with nitrogen in dry deposition. Using computer models and available deposition data, scientists have found that along the East Coast dry deposition of nitrate is mostly in the gaseous form (nitric acid), rather than in the particulate form. On the other hand, dry deposition of ammonia is mostly in the particulate form (e.g., ammonium sulfate), rather than the gaseous form (except close to the ammonia emission sources). In short, dry deposition is dominated by nitric acid gas and particulate ammonium. However, what is known about dry ammonia deposition will likely change as improved measurements and modeling of localized ammonia emissions in “hotspots” (e.g., confined animal operations) are established.

**Density Map of 1998 Ammonia Emissions by County**  
**EPA's National Air Pollutant Emissions Trends, 1900-1998**



**1998 National Ammonia Emissions by Principle Source Category**  
**EPA's National Air Pollutant Emissions Trends, 1900-1998**



## AMMONIA SOURCES AND EMISSIONS

Bill Battye is founder of EC/R Incorporated and currently serves as one of EC/R's managing partners. He was a co-author of the infamous "Battye" report and has worked for over 20 years in the fields of air pollution control and modeling. He has extensive experience in preparing emissions inputs for regional models, in assessing regional haze and PM formation. Mr. Battye presented the most recent information on the known substantial sources of ammonia emissions and the uncertainties associated with emission estimates.

While it is important to understand how ammonia is transported through the air, and when and where it deposits onto the Earth's surface, it is also important to understand where ammonia emissions originate. Ammonia is released into the air from *biological sources*, whereby it volatilizes from animal wastes and soils; *industrial sources*, whereby it is released during the making of ammonia-based products and other products or during the use of ammonia-based products; and *combustion sources*, whereby it is released in association with combustion processes. Important questions associated with each of these are How much ammonia is released from these sources? When and where is ammonia released? and, How will emissions change over time?

A management tool often used to help understand pollutant emissions is an inventory. An emissions inventory is a comprehensive listing, by source, of air pollutant emissions. An inventory represents a specific geographic area, for a specific time period. A source can be categorized as a point source, an area source, a mobile source (on or off-road), or a biogenic source. Emissions inventories are used for several purposes, including air quality modeling and analysis, control strategy development, screening sources, and to estimate the effectiveness of regulatory controls.

Since ammonia is not one of the six criteria air pollutants, nor a primary acid rain pollutant, the quality of existing ammonia emissions inventories is not as good. In most cases, estimates of ammonia emissions have been conducted in different ways for different sources, often for different purposes, and usually as an after-thought. Although, efforts are underway to improve emissions inventories for ammonia.

### Source Category Descriptions

**Point Sources:** individual large stationary sources that emit hazardous air pollutants or pollutants above a given emission threshold.

**Area Sources:** represents numerous smaller facilities or activities that emit small amounts of a given pollutant.

**Mobile Sources:** portable on-road vehicles that are certified for highway use; portable non-road vehicles or equipment that are not certified for highway use.

**Biogenic Sources:** living organisms that produce air pollutants.

### Background

The initial development of an ammonia emissions inventory began around 1985 for the purposes of the National Acid Precipitation and Assessment Program (NAPAP). At that time, NAPAP was interested in ammonia's role in acid precipitation. While the methods used to develop the inventory are considered sound, the data for establishing emission factors and activity levels were crude. In the early 1990s, the EPA became interested in improving this inventory because of concerns with aerosols and the formation of fine particulate matter (PM<sub>2.5</sub>).

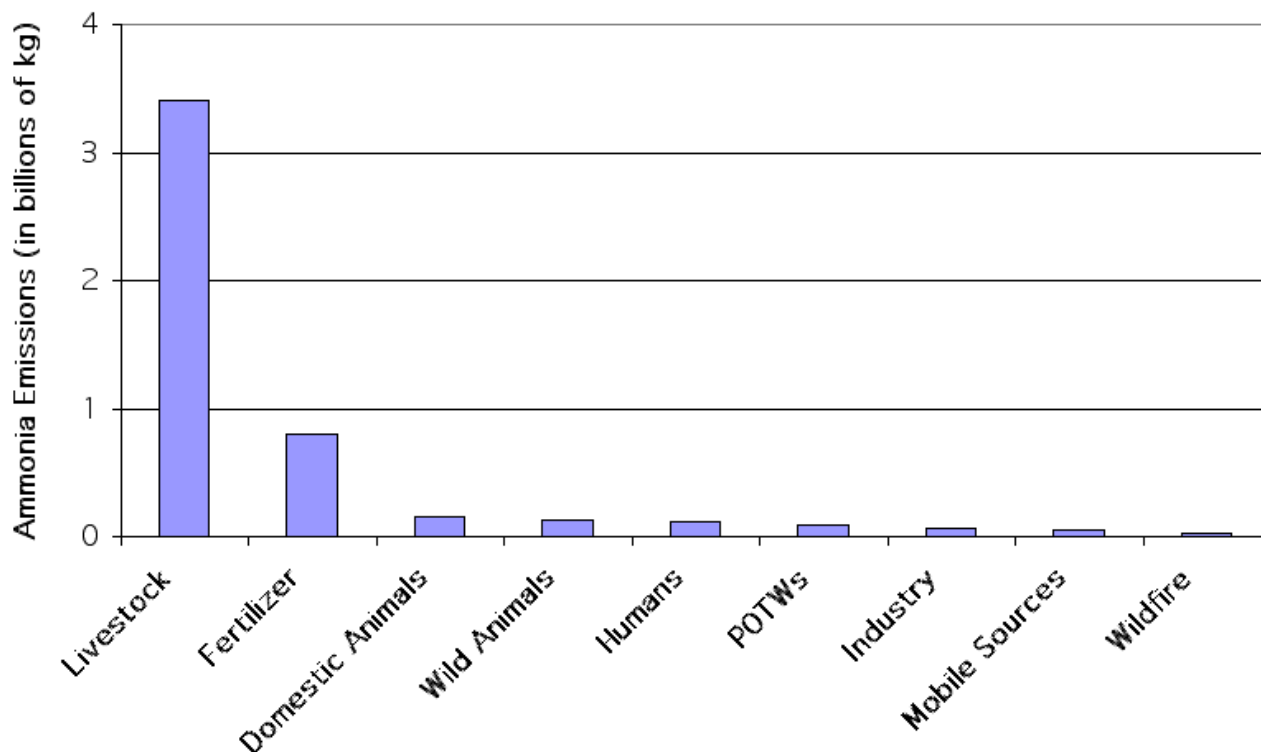
EPA prepared an ammonia emissions inventory for the National Particulate Matter Study by artificially "growing" the 1985 NAPAP inventory to 1990, using Bureau of Economic Activity data. To estimate emissions for a given year, economic estimates are often used instead of real data, even when data exist. This is primarily because current inventories are not flexible enough to incorporate new data as they become available. However, a research group at Carnegie Mellon University has constructed a software application that generates an ammonia emission inventory for the U.S. based on user-defined input, whereby emission factors and activity levels can be easily modified. This structure makes it easy to perform sensitivity analyses and to

update the inventory when new data become available. This inventory is now available using updated activity levels and high resolution spatial and temporal information. The inventory can be found at <http://www.envinst.cmu.edu/nh3/>. Figure 13 is a summary of the categories of the inventory with total amounts of emissions in each category.

The primary data source for ammonia emissions estimates has been the 1994 report from EC/R Incorporated – Development and Selection of Ammonia Emission Factors by R. Battye, et.al. (herein referred to as the 1994 Battye Report). Although over the last several years some of the details of this report have been questioned, it still remains a useful source. A related report recently has been written by W. Battye (EC/R, Inc.) and V. Aneja (North Carolina State University)—Evaluation & Improvement of Ammonia Emissions Inventories. The Evaluation Report was prepared for modeling particulate matter for the Coordinating Research Council in Atlanta, Georgia.

The 1994 Battye Report was prepared for EPA's Office of Research and Development as a compilation of the literature published after 1985 on ammonia sources and emission factors. The report presents a review of the research obtained at that time, provides a basis for understanding the uncertainties with emission factors, and identifies data gaps for future emission factor development. The report demonstrated that there is considerable variability and uncertainty in ammonia emissions estimates. For example, emission factors developed by the European community (who are well advanced on this issue) are used for certain U.S. sources. This is because there has been little to no data collected in the U.S. At this time, it is not clear whether the use of European emission factors for U.S. sources is appropriate. Uncertainties also exist because, in many cases, short-term measurement studies were used to derive emission factors. A case in point is soils and vegetation, which may be a major source of ammonia, but only short-term measurement studies were used to develop the inventory. To improve the inventory, long-term measurements are needed because soils and

### 1995 National Ammonia Emissions



**Figure 13** Source Categories in the Carnegie Mellon Ammonia Emissions Inventory  
Provided by Cliff Davidson

vegetation can be a source of ammonia (in areas where there is no other source and ambient air ammonia concentrations are low), as well as a sink of ammonia (in areas where there are other sources and ambient air concentrations are high).

Another data source used is the National Emissions Trends (NET) Inventory, which is prepared annually by the EPA and is based on periodic updates of inventories submitted by the States. After 1996, this inventory has been known as the National Emissions Inventory (NEI). The EPA uses the inventory for analyses of trends in emissions. The NET is a repository of data on emissions for priority air pollutants for modeling regional transport. Ammonia was added as an after-thought because it was needed for modeling the formation of particulate matter. EPA has generated new ammonia emissions data for the NET by using methodologies recommended in the 1994 Battye Report.

Table 1 shows the percentage of ammonia emissions for farm animals, fertilizer, and mobile sources on a national basis (using the NET inventory), a regional basis (using the NET inventory), and a state basis (using the Battye and Aneja analysis).

**Table 1**

**Comparative NH<sub>3</sub> emissions (Bill Battye, EC/R)**

	Farm Animals	Fertilizer	Mobile
National (NET)	75%	12%	~5%
Chesapeake Bay Region (NET)	58%	13%	18%
North Carolina (Battye & Aneja)	85%	6%	6.4%

The 1996 NET Inventory shows that the major source of ammonia emissions is agriculture, primarily from livestock (Figure 14). This is consistent with all of the other data sources used thus far. However, depending on the area of interest, the percentage contribution from sources can vary. For example, ammonia emissions in the state of North Carolina are dominated by livestock, estimated at about 11 kg/hectare. In Charlotte, North Carolina, however, where there are not many livestock operations, motor vehicles appear to be the dominant source of ammonia emissions, estimated at about 7 kg/hectare. When taking all emissions from the city of Charlotte and comparing them

to emissions in the State, the city's emissions are about equal to the State's livestock emissions (Figure 15). Furthermore, depending on the source, there may be seasonal variations in ammonia emissions (e.g., agricultural emissions are greatest during the Spring and Summer).

### **Inventory Uncertainties**

As stated earlier, the 1994 Battye Report demonstrated that there is considerable variability and uncertainty in ammonia emissions estimates. However, because of air quality concerns, efforts are now underway at both the state and federal levels to improve ammonia emissions estimates.

The uncertainties associated with ammonia inventories lie both in the lack of quality data to establish emission factors and in inadequate information about activity levels for each source and for categories within each source. For example, under the livestock source, there are different emissions (and therefore different emission factors) associated with each type of animal (e.g., cattle, hogs, and poultry) and with the class of animal under each type (e.g., beef cows, milk cows, fattening pigs, breeding sows, broilers, laying hens). Emission factors also vary depending on whether the animal is housed in a barn or grazes in the field.

An emission factor is a representative value that attempts to relate the quantity of a pollutant released

#### **Emissions Inventories & Emissions Factors**

Emission inventories and emission factors are fundamental tools for air quality management. An emission inventory is a comprehensive listing, by source, of air pollutant emissions. An inventory represents a specific geographic area, for a specific time period. An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the air with an activity associated with the release of that pollutant. Emission factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e. g., kilograms of ammonia emitted per megagram of nitrogen in the fertilizer). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i. e., a population average).

The above text was developed using information from the EPA web site: <http://www.epa.gov/oar/oaqps/efactors.html> which used information from the introduction to the Fifth Edition of the Compilation Of Air Pollutant Emission Factors (AP-42).



# Sources of Ammonia National (1996 NET)

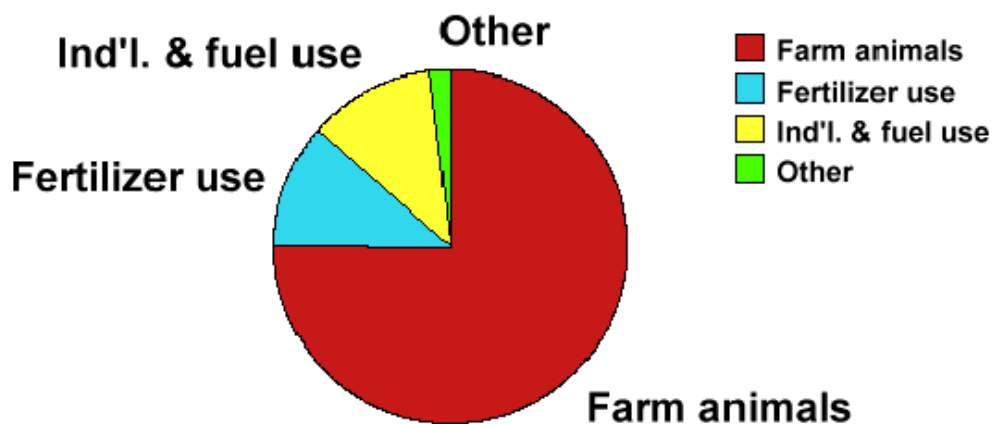


Figure 14 as presented by Bill Battye

## North Carolina Urban & Rural Source Contributions

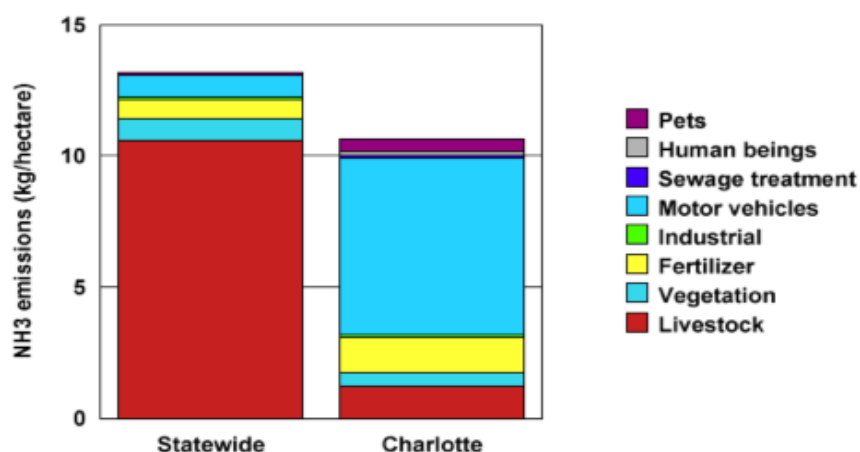


Figure 15 as presented by Bill Battye

into the air with an activity associated with the release of that pollutant. In the present context, an emission factor would be represented as kg NH<sub>3</sub>/animal/year. Emission factors are simply averages of all available data of acceptable quality. These data can come from various sources, including research studies and measurement programs, which can differ greatly from one another. Too often there are not enough quality data available to develop a valid emission factor.

From the extensive list of ammonia source categories (see sidebar), five sources were selected for discussion during the workshop: *agricultural emissions*, since they dominate all other sources; *motor vehicle emissions*, since emissions of ammonia may increase in the near future as a result of improvements to motor vehicles and fuels, and growth in vehicle miles traveled; *electric utility emissions*, since this also may be a growing source of ammonia due to NO<sub>x</sub> controls; and *refrigeration*, since ammonia is extensively and increasingly being used as a refrigerant in large commercial and industrial systems.

### Agricultural Emissions

Larry Jacobson is a Professor and Extension Engineer and Livestock Housing Specialist in the Department of Biosystems and Agricultural Engineering at the University of Minnesota. His research and extension emphasis areas are in indoor and outdoor air quality for both animal and human health concerns, environmentally safe manure management systems, and economical facilities for livestock and poultry in Minnesota. Dr. Jacobson presented information on ammonia loss from livestock production systems, including housing, manure handling and storage.

Jack Meisinger is a Research Soil Scientist with the U.S. Dept. of Agriculture and a Adjunct Assoc. Prof. at the Univ. of Maryland College Park. He has studied many aspects of the agricultural nitrogen cycle including use of soil nitrate tests to estimate N sufficiency, methods to estimate N<sub>2</sub> fixation, use of cover crops to protect water quality, effects of no-tillage on the soil N cycle, and the use of N<sup>15</sup> in agricultural research. Dr. Meisinger's most recent research is related to nutrient utilization in animal agriculture. He is currently involved in large interdisciplinary dairy manure and poultry litter projects studying methods to conserve N and P in manure and methods to manage ammonia losses from manures. Dr. Meisinger presented information on ammonia loss from land-applied manure and commercial fertilizers.

The factors that affect how much ammonia is released from animal agriculture include the form and

### LIST OF AMMONIA SOURCES

- Agriculture
  - livestock
  - commercial fertilizers
- Industry
- Refrigeration
- Electric Utilities
- Motor Vehicles
- Biomass Burning
- Non-Agricultural Soils
- Publically-Owned Treatment Works
- Human Breath/Perspiration



Photo obtained from <http://www.beltie.org/photo.html>

The farm community does not see ammonia loss as an environmental problem. The current priority regarding airborne emissions from animal production systems in the U.S. is odor.

-Dr. Larry Jacobson, University of MN

amount of nitrogen in the waste (which will vary depending on the animal type, age, size, and animal feed),

and the handling of the waste. The handling of the waste depends on the amount of time the waste is in the animal house, in storage, or in the field; the methods used to collect and store the waste; and the methods used to treat and use the waste. The amount of ammonia released from the building varies depending on the type and size of animals, the animal's diet, the building ventilation (climate), and the housing system. The amount of ammonia released from the storage unit will vary depending on the type of storage used (e.g., open or closed tank, pile), the form of waste being stored (liquid or dry litter), and weather conditions. Table 2 demonstrates the most recent published emission factors for livestock across a variety of data sources.

The factors that affect how much ammonia volatilizes into the air from the waste following land application include the nitrogen content in the waste; the form of the waste (liquid or dry litter); the chemical form of nitrogen; the timing of the application relative to crop demand; the method of application; the nitrogen demand of the crop/vegetation; soil properties (e.g.,

moisture, alkalinity, and calcium), and weather conditions (e.g., temperature). In the United States, over 90% of the animal waste is distributed on crop land. In the past, much of this waste was surface broadcast and not incorporated into the soil. Today, a majority of the land-applied waste is either directly injected (usually liquid form) or tilled into the soil almost immediately after spreading. This reduces the amount of animal waste exposed to the air, thereby reducing the amount of ammonia that can volatilize. Conservation tillage, which is used to reduce soil erosion, does not cause increased ammonia volatilization since it is possible to develop methods to get solid manure into soils with limited disturbance. This method has been shown to be effective in preventing ammonia loss to the atmosphere. In short, the application method and tillage practices used by the farmer dictates the amount of ammonia volatilized. However, there is little documentation on what methods are used, when they are used, and whether the manure is spread on crop land or other types of land. In some situations, such as with North Carolina swine farms, a certified nutrient management plan is needed for

**Table 2**

**Recent Published Emission Factors for Livestock  
(kg-NH<sub>3</sub>/animal-year)**

Source	EPA 1994 report	ECETOC (1994)	EMEP (1996)	Bouwman (1997)	UNECE (Van Der Hoek, 1998)	Missel- brook (2000)	Others	Estimate from MWPS
Dairy Cow	39.7	39.5	29.1	24.8	28.5	26.5	23 <sup>a</sup>	11 - 40
Beef Cow	23.1	27.8	14.6	9.5	14.3	6.8		9 - 18
Swine	9.2	4.25	-	4.9	-	-		
Sows	16	-	16.6	-	16.4	5.2	5.9 - 12 <sup>b</sup>	14 - 17
Pigs	7	-	6.46	-	6.4	4.8		5 - 10
Lagoons only							2.2 <sup>c</sup> 2.3 <sup>d</sup>	
Poultry	0.24	0.19	-	0.24	0.37	-		
Layers	-	-	0.38	-	-	0.45		0.2 - 0.4
Broilers	-	-	0.27	-	0.28	0.23		0.1 - 0.2
Sheep	1.7	1.8	1.46	0.77	1.34	0.73		
Horses	12.1	11.9	-	9.2	8.0	-		

**a** Schmidt and Winegar (1996)

**b** McCulloch *et al* (1998), summer only for finishing pigs

**c** Aneja (2000)

**d** Harper (2000)

spreading the animal manure, thereby providing some documentation.

Dairy farms can be viewed as a biological protein factory, with about 20-30 percent of the nitrogen converted to product and 70-80 percent to waste.

-Dr. Jack Meisinger, USDA

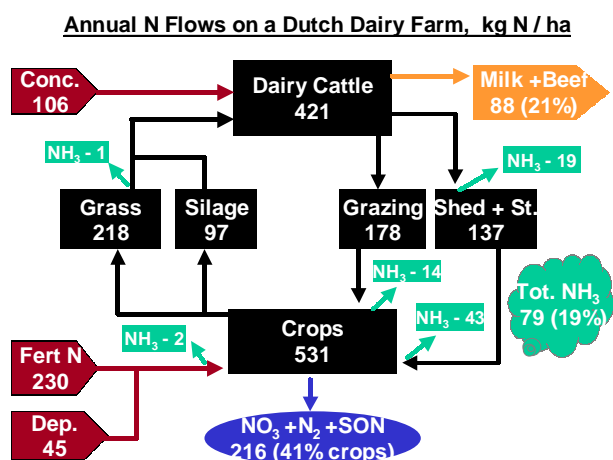
Many of the same factors that affect the release of ammonia from land-applied animal waste also apply to urea-containing fertilizers and anhydrous ammonia. Currently, to estimate ammonia emissions from commercial fertilizers only county-level total sales data are used. This is not an accurate method for estimating ammonia emissions since emissions will depend on the type of fertilizer, the application method, and the local soil properties. Furthermore, where the fertilizer is sold may not be the same as the county where it is applied. However, in the absence of more refined fertilizer application data and improved fertilizer emission factors, this is the only method available.

While ammonia emissions can be estimated using a simple mass balance approach (a comparison between what goes into a system versus what comes out), nothing will be learned about when and how ammonia is released across the agricultural production process. In order to prepare an ammonia emissions inventory for livestock, for example, the number of animals first must be determined. Then, an appropriate emission factor must be identified for each animal type, each waste handling system, and each land application method. Once emission factors are completed, county level emissions must be computed. These emissions are then apportioned to smaller geographic areas. Finally, seasonal, daily, and hourly allocation factors are applied.

The nitrogen flow diagram for a typical dairy farm (Figure 16) offers a good opportunity for an overview of nitrogen and ammonia cycling in a livestock operation. Figure 16 summarizes the data of Bussink & Oenema (1998), which illustrate several important points: 1) the dairy can be viewed as a biological protein factory which converts about 21% of nitrogen input into milk and meat (upper right); 2) the major ammonia escape points are housing and manure storage, grazing, and land application of manure; and 3) the total estimated ammonia loss is 19% of the nitrogen input (middle right), which is comparable to the nitrogen removed in milk and meat. Figure 16 also illustrates that managing ammonia emissions will require a whole-farm approach with careful attention to: management of building and manure storage facilities, grazing management, and management of land application of manures.

**Figure 16**

N Flow Diagram as presented by Jack Meisinger



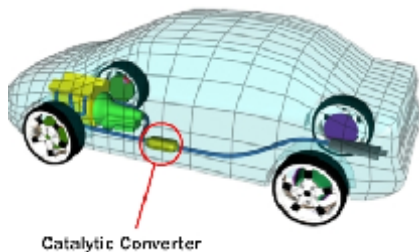
Bussink & Oenema, 1998

Ammonia released from urea containing fertilizers used by homeowners also will contribute to the total ammonia emissions. Urea based fertilizers on home turf can be especially vulnerable to ammonia loss because they are not incorporated into the soil, homeowners are more likely to over-fertilize, and most homeowners apply fertilizer during the warm months of the year when losses will be largest. However, compared to the acreage of farms, the home turf use should be a much smaller source. Analyses of commercial fertilizer sales data show the non-farm use is small, although it is likely under-reported.

## Motor Vehicle Emissions

Dr. Michael Rodgers is the Director of the Air Quality Laboratory, a Principal Research Scientist in the Schools of Civil and Environmental Engineering and Earth and Atmospheric Sciences, and an Adjunct Professor in the School of Public Policy at the Georgia Institute of Technology. He also serves as chief scientist for atmospheric chemical and meteorological measurements of the Southern Oxidants Study. In the transportation area, Dr. Rodgers directs a number of projects that are quantifying emissions from motor vehicles, under sponsorship of the U.S. EPA, the state of Georgia, and other agencies. His primary research interests include regional and global atmospheric chemistry, air quality related public policy, atmospheric emissions modeling, and satellite remote sensing. Dr. Rodgers presented information on the emission of ammonia from motor vehicles.

Ammonia is emitted by motor vehicles under certain conditions. The potential for ammonia to be emitted exists with vehicles equipped with three-way catalysts, operating under certain fuel-rich or fuel-lean conditions, and when the catalyst is operating in some kind of failure mode. The main purpose of the three-way catalyst is to reduce emissions of unburned hydrocarbons, carbon monoxide and NO<sub>x</sub>. A fuel-rich condition means that in the air to fuel ratio, there is more fuel than there is oxygen in the mix. When conditions are fuel-rich, there will be excess volatile organic compounds (hydrocarbons) and a small amount of NO<sub>x</sub> generated after the combustion process.



<http://www.howstuffworks.com/catalytic-converter.htm>

Conversely, if more oxygen is present during the combustion process (a fuel-lean condition), there will be more NO<sub>x</sub> generated and a small amount of VOCs left. The requirements for ammonia to be produced are that there must be a fair amount of nitrogen (usually NO<sub>x</sub>), a fair amount of hydrogen (usually from the VOCs, but can be from the water vapor), and a reduction catalyst present simultaneously. Newer cars are designed and built to achieve pure stoichiometry in the combustion process, with the exact mixture of fuel and air to result

in very low concentrations of both VOCs and NO<sub>x</sub>. Therefore, high ammonia emissions from these vehicles are believed to be unlikely. However, ammonia can be produced if the catalyst is operating in hyper-efficient mode (it should be good, but not too good) or is faulty.

The most plausible scenarios for generating ammonia are when the vehicle's engine is not calibrated correctly or when equipment fails, causing the engine to operate slightly fuel-rich or slightly lean. Other conditions include short-term transients (increases or decreases in fuel or air) in normally operating vehicles due to sudden changes in fuel flow (accelerations), coupled with an imperfectly operating catalyst. In reality, transients are too brief to constitute as a major emission source and most equipment failures preclude simultaneous high VOC and NO<sub>x</sub> emissions. Thus, high ammonia emissions are thought to be associated with a relatively small fraction of vehicles. However, cold starts and quick acceleration will create some NH<sub>3</sub> emissions from most vehicles. It is believed that roughly 10% of the vehicles emit 90% of the ammonia.

In spite of the uncertainties associated with the ammonia emissions from vehicles, there are a large number of vehicles operating in the United States. This, coupled with increased vehicle-miles-traveled, makes it possible that motor vehicles are a significant, although probably not dominant, source of ammonia emissions.



An additional uncertainty is that three-way catalysts are present on a large and increasing portion of the motor vehicle fleet, yet it is unknown how much ammonia is produced from them. Just because NO<sub>x</sub> emissions are found to be reduced by the catalyst does not mean that the nitrogen was converted to an inert form (N<sub>2</sub>). Some portion may have been converted to ammonia. Measurements of ammonia are not typically included in studies of vehicle emissions. Those tests that are conducted are based on new or artificially-aged catalysts, and the applicability of those results to the entire motor vehicle fleet is uncertain, at best.



Consideration should be given to upcoming improvements to motor vehicles and fuels in how the changes may affect ammonia emissions. These improvements include: new catalyst design, high efficiency materials for low emission vehicles, new types of fuels, and new emissions regulations. Another consideration is that existing catalysts will continue to age. All of these changes could cause a shift in the contribution of ammonia emissions from motor vehicles over the next several years.

### **Electric Utility Emissions**

Tom Feeley is the Environmental and Water Resources Product Manager for the U.S. Department of Energy's National Energy Technology Laboratory (DOE/NETL). He is responsible for strategic planning, policy, budgeting, program development, and outreach related to DOE/NETL's fossil energy environmental research programs. Mr. Feeley has over 20 years experience in managing the research and development of flue-gas-cleanup, carbon-sequestration, coal-preparation, and coal-conversion technology for coal-based power systems, with particular focus on fine particulates, mercury, ozone, and air-water interface issues. Mr. Feeley presented information on the loss of ammonia from the electric utility sector.

Ammonia is released from electricity generating facilities, primarily during the use of ammonia as a reducing agent in Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) systems. Some ammonia also may be released as a by-product of incomplete combustion. The amount of ammonia released from incomplete combustion depends on the type of fuel (e.g., coal, oil, natural gas) used by the power plant.

SCR and SNCR are two important technologies used by the electric utility sector to reduce NOx emissions (see sidebar) at fossil-fuel burning power plants. Both technologies use ammonia to reduce NOx to elemental nitrogen ( $N_2$ ) and water. When these technologies are used, some of the ammonia remains after the NOx has been converted. This excess ammonia gets emitted into the flue gas, termed "ammonia slip." The ammonia slip then can react with other flue gas constituents, such as sulfate, to form compounds that can coat the preheater surfaces or adhere to fly ash. The ammonia slip also may enter the smokestack and be released into the atmosphere. In both technologies, using more ammonia can produce greater NOx

### **NOx Emissions & Ground-Level Ozone**

Nitrogen oxides (NOx) are a precursor to the formation of ground-level ozone ( $O_3$ ), a major component of urban smog. The formation and accumulation of  $O_3$  involves complex non-linear processes. Therefore, the following is a simplified description:

Nitric oxide (NO) is produced during combustion. The NO is converted to nitrogen dioxide ( $NO_2$ ) by reacting with either inorganic or organic radicals formed from oxidized VOCs (volatile organic compounds) or by reacting with  $O_3$ . In the presence of sunlight, the  $NO_2$  then forms  $O_3$  and NO. When  $NO_2$  is formed without reacting with  $O_3$ , the ground-level  $O_3$  accumulates.

An abundance of ground-level  $O_3$  can result in detrimental effects on human health, agricultural crops, forests, and other plants.

reductions, but at a cost of producing more ammonia slip.

SCR involves the injection of ammonia into the flue gas downstream of the furnace as it passes over a catalyst bed, usually vanadium pentoxide/titanium oxide. This results in a greater than 80%  $NO_x$  emission reduction. In the SNCR system, urea (an ammonia derivative) is directly injected into the furnace; no catalyst is used. SNCR typically results in a 25-40%  $NO_x$  emission reduction.

Recently, the U.S. Department of Energy (DOE) prepared an analysis to estimate the amount of ammonia

### **NOx SIP Call**

22 States and the District of Columbia are required to revise their State Implementation Plan (SIP) measures under EPA's NOx SIP Call to ensure that emissions reductions are achieved to mitigate the regional transport of  $O_3$  across State boundaries in the eastern half of the U.S. Reducing the formation and regional transport of  $O_3$  is necessary to help certain States attain the human health standards for ground-level  $O_3$ .

A portion of the electric-utility industry, in the states affected by the NOx SIP Call will be required to install SCR, and to a lesser extent, SNCR, technology to reduce their NOx emissions during the ozone season—May through September.

that could be released to the atmosphere as a result of increasing installation of SCR and SNCR technologies. The increased installations are in response to the NO<sub>x</sub> SIP call (see sidebar). As a part of this analysis, DOE established a relative, rather than an absolute, estimate of future ammonia emissions from fossil fuel-fired boilers. In their approach, DOE created a matrix (with limited field data) of possible internal ammonia slip vs. the percent of slip that could be emitted into the stack (Table 3).

DOE then applied the matrix to the anticipated installation of SCR/SNCR technologies under three possible scenarios: a best-case scenario, a mid-case scenario, and a worst-case scenario to estimate annual emissions of ammonia (Tables 4,5,6). In the best case scenario of 2 ppmv (parts per million by volume) ammonia slip, if 1% of the slip made it into the stack, the resulting ammonia emission into the air would be about 33 tons/year. Under the worst case scenario of 10 ppmv, if 25% of the slip made it into the stack, the resulting ammonia emission into the air would be about 4,174 tons/year. Based on this preliminary analysis, DOE concluded that the potential NH<sub>3</sub> emissions from fossil-fuel-fired boilers equipped with SCR/SNCR in the NO<sub>x</sub> SIP Call region could range from 33 to 4,174

tons/year. Although, even under the worst-case scenario, future ammonia emissions from utility boilers would be dwarfed by emissions from other sources, such as livestock.

It is important to note that DOE made several important assumptions in carrying out the analysis. First, they assumed that there is actually ammonia escaping up the stack in a well-performing SCR or SNCR system. Secondly, they assumed that the amount of ammonia released from the stack was independent of the coal sulfur content. Both of these assumptions would result in potentially higher NH<sub>3</sub> emissions.



Coal-fired Electric Power Plant (Courtesy of NREL)

### Ammonia Slip Matrix

Internal NH <sub>3</sub> Slip, ppmv	% Internal NH <sub>3</sub> Slip to Stack		
2	1	10	25
5	1	10	25
10	1	10	25

Table 3

### Best Case Results - 2 ppmv NH<sub>3</sub> Slip

% Slip to Stack	NH <sub>3</sub> emitted from stack, tons/year
1	33
10	334
25	835

Table 4

### Worst Case Results - 10 ppmv NH<sub>3</sub> Slip

% Slip to Stack	NH <sub>3</sub> emitted from stack, tons/year
1	167
10	1670
25	4174

Table 6

### Mid-Case Results - 5 ppmv NH<sub>3</sub> Slip

% Slip to Stack	NH <sub>3</sub> emitted from stack, tons/year
1	84
10	835
25	2087

Table 5



Vendors of SCR and SNCR technologies and the electric utility industry are striving to minimize ammonia slip from the standpoint of equipment performance guarantees, balance-of-plant issues, and potential environmental impacts. Vendors and utilities agree that actual field data will need to be collected before a definitive answer can be given to the question of how much ammonia is emitted from fossil-fueled power plants. Currently, limited data exists on the performance of these technologies, particularly on plants using high-sulfur and low-rank coals. Data also will need to be collected on the ultimate fate of the ammonia slip—that is, the distribution of the ammonia between the fly ash, the atmosphere, and that which deposits on air preheater.

DOE estimates that the electric utility industry will be installing SCR on 495 boilers with a total capacity of 175.5 Gigawatts of energy, and SNCR on 208 boilers with a total capacity of 12.8 Gigawatts of energy through the year 2007. Thus, it is predicted that ammonia emissions will increase as a result of increased use of SCR and SNCR. How much it will increase is unknown at this time.

### **Large Refrigeration Systems**

Kent Anderson is President of the International Institute of Ammonia Refrigeration (IIAR), a foundation whose membership includes contractors, manufacturer's representatives, end users, engineers, wholesalers and manufacturers of ammonia refrigeration products. IIAR is the only organization dedicated specifically to the use of ammonia as a refrigerant. Through its membership, IIAR promotes the safe and efficient use of ammonia by the refrigeration industry. Mr. Anderson presented information on the loss of ammonia from large commercial and industrial refrigeration systems.

Ammonia is used extensively as a refrigerant in large commercial and industrial systems, as a replacement for banned chlorofluorocarbons (CFCs), and for the phasing-out of hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). Ammonia has been a favorable replacement because it is a natural compound with a short lifetime in the air. CFCs, on the other hand, are man-made and have a lifetime of 40-100 years in the atmosphere.

A commercial refrigeration unit is similar to a home air conditioning system, but about 1000 times larger. The system works by removing heat from one place (the cooler) and exhausting it in another (generally outside air). The premise of refrigeration is simple: a liquid

expands into a gas, thereby absorbing heat; when compressed back into a liquid the heat is released. A good refrigeration fluid should have a low enough boiling point (35°F – 60°F) to cycle at ambient temperatures. Since this is a closed loop system, there should be no releases. However, these systems are not perfect and there are fugitive emissions, accidental spills, and leakages that can occur. The key issues and concerns surrounding the loss of ammonia from refrigeration systems are employee exposure, off-site vapor clouds, contamination of surface water, fish kills, vegetation



Industrial Refrigeration Unit

damage, loss of cooling capabilities, and product contamination. At ambient air concentrations of 25 parts per million, ammonia can be detected by its odor—although it is not harmful to humans at that level.

Refrigeration systems use about 12 kg of ammonia per ton of cooling. For an average-size system, there could be 22,000 kg of ammonia stored at a plant for use. A well-operating plant may lose about 5% (~1,200 pounds) of ammonia per year. A moderately-operated plant may lose between 5% and 20%, and a poorly-operated plant may lose 100% (or ~22,000 kg) of ammonia per year.

At this time, there are no good sources of data on the total usage of ammonia as a refrigerant or on releases of ammonia from refrigerant processes. Therefore, there are large uncertainties with ammonia emissions estimates from this source. The 1994 Battye Report estimates that ammonia emissions from refrigeration are probably high ~250 million kg per year. Other data sources estimate emissions at approximately 25 million kg per year, but these numbers are questionable as well. The EPA estimates, also with high uncertainties, that ammonia emissions are about 90 million kg per year. Another source of information that can be used is ammonia purchases. Refrigeration plants purchase annually between 2,200 and 22,000 kg per year. Compared to other sources, potential ammonia losses from the refrigeration industry are not large.

## MANAGING AMMONIA

This next section highlights two different experiences of governments that have taken action to address the issue of ammonia emissions. The first describes the environmental situation in the Netherlands and the actions that have been taken by the Netherlands' government to manage agricultural ammonia. The second describes the environmental problems occurring in the coastal region of North Carolina and the actions currently being pursued by the State to reduce nutrient pollution from large-scale swine operations, including ammonia emissions. The final part of this section raises the idea of using environmental assessments as the link between science and policy development.

### Lessons Learned from the Netherlands

Dr. Jan Willem Erisman is Program Manager for Environmental Research, Head of the Department of Integrated Assessment, Energy Research Center of the Netherlands, ECN. He has been involved with a variety of environmental issues, including air quality, acid rain, and eutrophication. Dr. Erisman presented the actions that had been taken in the Netherlands to control ammonia emissions.

Biologically available nitrogen is an important environmental threat in the Netherlands. Today, there are approximately 16 million people, 15 million pigs, 100 million chickens, and five million cows, all in an area approximately 16,000 square miles in size, and all generating nitrogen through their waste products. The Netherlands (Figure 17 below) is slightly less than twice the size of New Jersey.



**Figure 17** Map of The Netherlands

Two centuries ago, there was equilibrium between nutrients in the soil and the crops grown. As the human population grew and farmland became scarce, people began to convert natural, wilderness areas into farmland; this land was poorer in nitrogen. At that time, animals were used primarily for their manure to fertilize crops, not as much for food. As the demand for crop foods increased, more nutrients were required and this drove the need to produce and use commercial fertilizers.

After World War II, however, food became scarce, and urgent efforts were taken by the Netherlands' government to produce more food. Livestock then became viewed as an important food source. Animals were imported into the country, fed, and then processed into meat products. Only about 20-30% of the nutrients fed to livestock are converted into meat; the rest ends up in animal waste. While much of the meat products is exported, the animal waste stays in the Netherlands. These intensive livestock operations, which are the dominant source of ammonia, are located adjacent to the remaining valuable, natural wilderness areas in the Netherlands. The four main areas for ammonia emissions from animal waste in the Netherlands are the animal housing units, unconfined animals in the field, storage facilities, and land-application.

Studies show that wet deposition of ammonia has increased by a factor of five over the last 100 years. The deposition data reflect the ammonia emissions data. The annual average atmospheric concentration of ammonia is  $5 \mu\text{g}/\text{m}^3$ , with hot spots of  $20\text{-}25 \mu\text{g}/\text{m}^3$ . The deposition rate is about  $30 \text{ kg NH}_3/\text{hectare}$ , with a maximum deposition rate to forests and natural areas of approximately  $90 \text{ kg NH}_3/\text{hectare}$ . This is much higher than for most of the U.S.

The effects of this much ammonia include direct harm to plants (e.g., leaf burning) and threats to human health. The indirect effects include eutrophication, algal blooms, pests and diseases in the forests. But, the most important indirect effect observed in the Netherlands has been a decrease in biodiversity. The Netherlands' government believes that in order to protect biodiversity, a 90% reduction in ammonia emissions is needed. To protect forest growth and groundwater, a 70% reduction is needed. However, these reduction goals are unrealistic.

In the late 1980's, the government established abatement measures focused on covering storage facilities, using slurry injection, and building low emission housing systems. Not long ago, there was great interest in converting the nitrogen in the manure to nitrogen gas ( $N_2$ ). However, this process was found to be expensive and problematic. Today, the Netherlands considers this to be a good option for reducing ammonia emissions and for combating nitrate pollution of ground water and surface water. Other abatement measures for decreasing ammonia emissions include keeping livestock in barns at night, allowing ammonia trading with 25% reductions and requiring farmers to have mineral accounting. The government's requirements intend to optimize the use and generation of nitrogen on the farm. If the farmer exceeds certain limits, he will be fined. Estimates of the abatement measures showed that at least two of them would lead to major ammonia emissions reductions. The first and most important measure is the injection of the manure into the land. This should have reduced emissions by 50% between 1990 and 1997. Several other types of land application were tested in the laboratory showing that up to 90% emission reduction was feasible. The second abatement measure is the use of low emission housing systems, such as flushing systems where the manure is stored under the building or in tunnel dryers where the manure is dried. These should have reduced emissions from the housing units somewhere between 50 and 80%.

From the application of all of these abatement measures, the Netherlands expected a reduction in ammonia emissions to be about 37% between 1990 and 1997. When results of the measures were studied, it was found that the reduction achieved was only about 18% (Figure 18). This gave rise to the idea that there was an "ammonia gap." Possible reasons for this gap include a) the manure was not concentrated over small regions but was transported across the country providing a larger emissions area; b) more animal manure was being land-applied during the warm Spring and Summer months because Winter applications were stopped; c) practical application is different from laboratory studies; d) the regulations had not been fulfilled; e) there might be long-term ammonia emissions, not just over some short periods of time; f) sulfur emissions had been reduced in Europe, thereby decreasing the sink for ammonia. Perhaps the most important reason is that basically there is too much nitrogen in the system. It will come out eventually, as

nitrate to ground water and as ammonia, or  $N_2O$  gas to the air.

Today, regulations in the European Union and the Netherlands are mainly for limiting nitrates, "the Nitrate Directive," not for limiting ammonia. A new directive is expected to be implemented which will include a national ammonia emission ceiling with limited targets for the different European countries. In the near future, there will be regulations for low emission housing systems. There also will be an intensification in managing the manure by incorporating it into the soil. Moreover, there will be emission free zones of 250 or 500 meters around nature areas, where animal production will be limited.

Other new abatement measures include optimization of the nitrogen cycle for concentrated animal operations which have land and those which do not have land. Also, there are new control technologies that convert ammonia and other gases into less reactive forms. There are new studies of agro-business parks that concentrate production and storage. These are closed energy and water systems where the production of animal meat is combined with other nutrient production.

It is important to look not only at whether ammonia emissions have been reduced from individual sources, but also whether reactive forms of nitrogen are removed from the system. The question remains, does the effect



Figure 18 as Presented by Jan Willem Erisman

of ammonia emissions abatement lower the total nitrogen in the system? An integrated nitrogen approach is clearly needed. In order to limit the amount of reactive nitrogen in a region, there first must be a determination of the maximum amount of nitrogen produced or imported into a region. This determination would be based on critical limits for all nitrogen-related effects. Once that is determined, there are three options that can be used: 1) the amount of nitrogen that is imported must be decreased; 2) reactive nitrogen must be converted into  $N_2$ , and 3) nitrogen must be exported to poorer nitrogen regions.

Basically, there is too much nitrogen in the system. It will come out eventually as nitrate to ground water or as ammonia or  $N_2O$  gas to air. An integrated approach focused on the decrease of reactive nitrogen is needed.

*-Dr. Jan Willem Erisman, Netherlands Energy Research Foundation*

#### **Actions Currently Being Pursued by the State of North Carolina**

Ms. Robin Smith is currently the Assistant Secretary for Environmental Protection with the North Carolina Department of Environmental and Natural Resources. Ms. Smith supervises all of the Department's environmental divisions, including air quality and water quality. Ms. Smith presented a summary of North Carolina's efforts to reduce ammonia emissions from hog operations.

In recent years, North Carolina has explored several options to reduce the amount of nitrogen lost from hog operations, including an integrated nitrogen approach and best management practices. During the ten-year period, from the late 1980s to late 1990s, there was a significant expansion of the swine industry from about 2 million hogs to nearly 10 million. Like the Netherlands, the State of North Carolina has a greater number of animals than humans. In addition to this rapid growth, the number of small independent farms in the state has decreased while individual operations have become much more concentrated. Most of the these large-scale operations are clustered together in six counties in the central coastal plain (Figure 19),

where the land is flat and the ground water table is high. Around the mid- 1990s, concerns were raised over nutrient loadings to the sensitive Pamlico Sound and Neuse River basins. These basins are home to the greatest concentration of swine operations in the state.

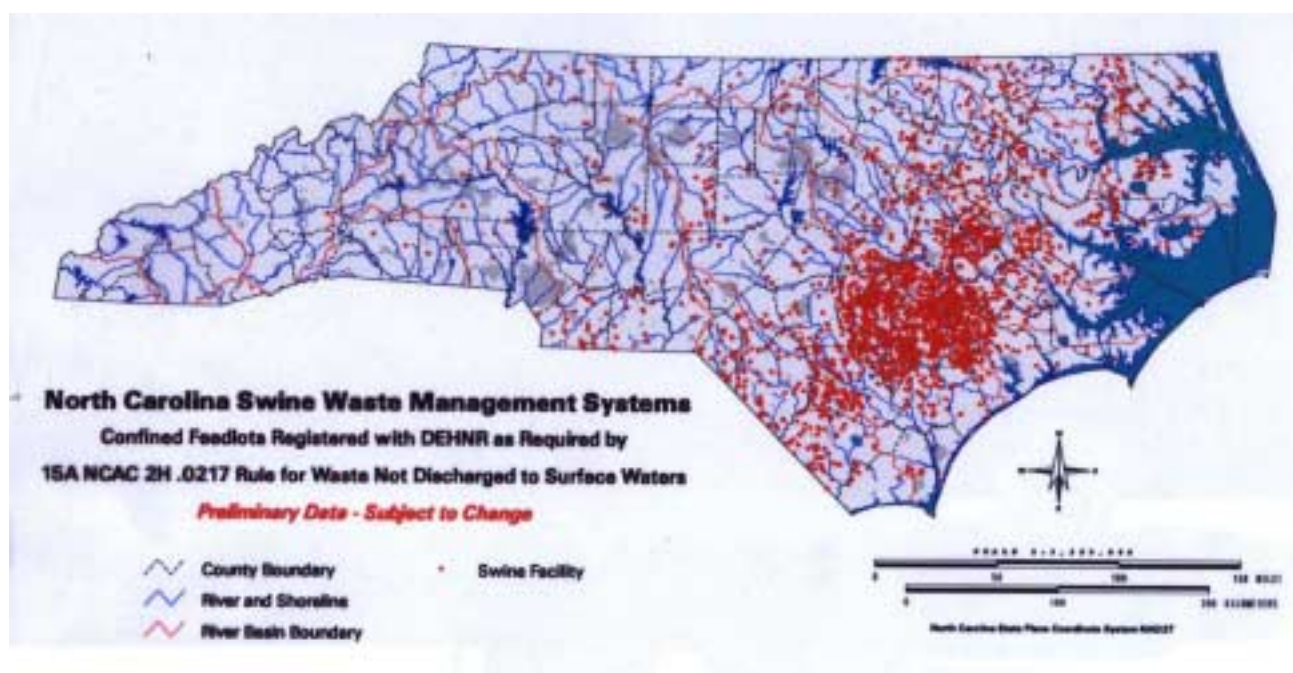
Following a series of environmental problems, including algal blooms and fish kills in the lower rivers and sounds, the North Carolina State Legislature began looking into the causes. While nutrient sources come from several areas, agriculture is believed to be the primary concern in these basins because of nutrient run-off from farm fields, failing waste lagoons, and over-fertilization. There also is concern over the contribution of atmospheric nitrogen deposition. Estimates indicate that up to approximately two-thirds of the nitrogen in the swine excretions is emitted to the air in accordance with the design of a lagoon and sprayfield system. Studies estimate that swine facilities produce approximately 20% of North Carolina's total atmospheric nitrogen compounds, which can react with other constituents in the air and subsequently deposit to soils, vegetation, and water bodies.

In response to the problems in the coastal waters, the North Carolina State Legislature mandated a 30% reduction in nitrogen loading to the Neuse River from 1990 levels. They also mandated funding for research and modeling atmospheric nitrogen impacts in the Neuse Estuary, and they placed a moratorium on new swine operations. In 1995, the state implemented stricter standards for point source discharges and non-point source discharges, including 50-foot buffer requirements on designated water bodies.

In 1998, then Governor Jim Hunt initiated a plan for lagoon conversion. The plan included a 10-year phase-out of open lagoons used in swine operations. The goal was to convert all hog lagoons and sprayfields to new technologies within seven years. This plan provided a framework to begin implementation of environmentally superior animal manure management technologies and to improve existing animal manure management systems, through monitoring, technical assistance and compliance inspections.

In 2000, then Attorney General Mike Easley (now Governor) entered into an agreement with two of the largest integrators in the swine industry. The agreements between the North Carolina Office of the Attorney General and Smithfield Foods, Inc. and Premium Standard Farms, Inc. represent a commitment





**Figure 19** North Carolina Swine Map

by the companies and the state to develop environmentally superior technologies for swine operations. In this agreement, Smithfield, Inc. will provide \$15 million for research on waste management and economic feasibility of new control technologies for lagoons owned by Smithfield. The new technologies will be evaluated based on several criteria, including the control of ammonia emissions. They also agreed to survey their farms to identify those with environmental problems, such as those located in the 100-year flood plains and develop a plan to address those issues.

Today, in addition to the work under the Smithfield and Premium Standard Agreements, North Carolina is working to reduce the excess nitrogen loss from the lagoon/sprayfield system. To date, the Department of Environment and Natural Resources (DENR) has discussed the development of a “Nitrogen Efficiency Rule” to adopt an integrated nitrogen approach to control for loss of nitrogen from the swine facilities, including loss through ammonia emissions. The rule was initiated directly by the Environmental Management Commission, a 17-member Commission appointed by the Governor, the Senate Pro Tempore and the Speaker of the House. The Commission is responsible for adopting rules for the protection,

preservation and enhancement of the State’s air and water resources. It also oversees and adopts rules initiated by several divisions of the DENR, including the Division of Air Quality. The ultimate deposition of ammonia in nutrient sensitive waters was the impetus behind the development of the Nitrogen Efficiency Rule.

The basic concept behind mass balance is very simple, that what goes in must equal what comes out (i.e. no mass is lost or destroyed). For hog production in North Carolina, the nitrogen comes onto the farm as grain and comes out as pork, crops, sludge, and lost nitrogen. Due to the difficulty of measuring ammonia emissions, the concept envisioned measuring the nitrogen utilized by the pork, crops, sludge, and  $N_2$ . Therefore, the mass balance approach would allow lost nitrogen to be accounted for without difficult measurements, and provide a mechanism for those losses to be controlled. Lost nitrogen includes atmospheric loss of ammonia and  $N_2$  as well as land applied nitrogen, which leaches into the groundwater or leaves the site as runoff. Of course, no agricultural system can hope to function without some loss of nitrogen, so the goal of the rule would be to limit the nitrogen loss to an acceptable level. What is acceptable was to be determined by reference to other water quality goals and concerns in the region.

Nitrogen lost to the atmosphere from hog waste has been estimated to equal about 66% of the total nitrogen in the waste, or approximately 50% of the nitrogen imported as grain for feed. The nitrogen lost to the atmosphere is thought to be lost largely as ammonia but some research suggests  $N_2$  loss could also be important. Loss of nitrogen as  $N_2$  is acceptable, as it is benign. Studies are still unclear as to the ratio of ammonia to  $N_2$  emitted from swine operations. Through consideration of the “Nutrient Efficiency Rule,” the department has struggled with the identification of values for nitrogen used by the pork, as  $N_2$ , and other variables that must be accounted for in order to ensure a comprehensive mass balance approach. Due to the uncertainties at this time and until additional information is available, the DENR has begun to explore other options for reducing nitrogen loss, including the development of best management practices aimed at managing nitrogen on the farm.

### **Environmental Assessments as the Link Between Science and Policy Development**

Dr. Alex Farrell is a research faculty member with the Department of Engineering and Public Policy, Center for the Integrated Study of the Human Dimensions of Global Change, at Carnegie Mellon University. His research is mainly in the area of environmental economics and policy, particularly air pollution. For the last several years, Dr. Farrell has been part of a research project based at Harvard University that has been exploring the interface between science and public policy. He is currently editing a book on that topic, called *The Design of Environmental Assessment: Global and Regional Cases*. Dr. Farrell presented examples of how environmental assessments are used as the link between science and policy development.

Important lessons about the role and use of environmental assessments as the link between science and policy development can be derived from two research programs: the Center for Integrated Study of the Human Dimensions of Global Change (HDGC) and the Global Environmental Assessment project (GEA). These two research programs address environmental issues in very different ways, both of which may be beneficial to the current study of ammonia in coastal and estuarine areas.

In the HDGC (<http://hdgc.epp.cmu.edu/>), the social and natural sciences are applied to study problems related to global environmental change, and the focus is on how people understand the world and make decisions, while not ignoring physical phenomena. Then, those decisions and phenomena are modeled to determine potential consequences. A key feature of this approach is the use of Integrated Assessment Models (IAMs), which contains simplified models of complex systems, often specifying parameters as probability distributions (i.e., they are usually stochastic models). It is usually not appropriate to start investigations of a problem with IAMs, since useful examples always rest on detailed (and often disciplinary) research on specific subsystems and phenomena (e.g., the atmospheric transport and fate of ammonia). However, the traditional disciplinary academic approach to addressing problems is often not well suited to developing useful policy advice, since it can be overly narrow, typically treating either physical systems or social systems, but not both. For example, consider the question of whether climate change is important in determining the spread of malaria. Simple physical models have suggested this is the case, but integrated assessments have shown that public health measures dominate the incidence of malaria no matter what climate change occurs. An integrated assessment of this type is only feasible in areas where considerable disciplinary research has already been conducted, so that reduced form equations can be specified and uncertainties quantified. Thus, IAMs can be used to combine various disciplinary approaches coherently, prioritize research, and address policy questions.

One of the largest and most complex IAMs is the Integrated Climate Assessment Model (ICAM), which has been developed by the Center for Integrated Study of the HDGC. Given the importance and substantial complexity of ammonia (or reactive nitrogen) in the economy and in the environment, the impressive existing research basis on the topic, and the significant uncertainties remaining, a stochastic IAM could be very useful in understanding policy issues and opportunities.

The Global Environmental Assessment Project (<http://environment.harvard.edu/gea>) has an entirely different focus. Rather than attempting to develop or apply better assessment tools in specific policy areas, the project seeks to promote better understanding of the actual relationships among the sciences, assessment, policy and management in societies' efforts to grapple

with global environmental change. The project is a multi-year, interdisciplinary effort based at Harvard University. It draws on the faculty and students from the natural sciences and social sciences, as well as practitioners and professional scholars from around the world. Over the last five years, GEA researchers have conducted case studies on issues such as climate change, acidification, genetically modified organisms, and photochemical smog.

Although these case studies each looked at assessments of very different environmental issues, that were conducted by different people using different information, and aimed at different outcomes, it became clear that there were general lessons that could be learned about how to design an environmental assessment. One of the most important lessons is that although an environmental assessment usually entails the creation of discrete products (e.g., models, forecasts, reports), they are best thought of as *social processes* in which the interests of the people conducting the assessment are important, as well as the institutional framework of rules, norms, and expectations surrounding the assessment. The other key findings of the GEA project relate to understanding what an effective environmental assessment is, and why some assessments are effective while others are not.

Effectiveness can be defined by different participants in a variety of ways (which are sometimes contradictory). For example, did the assessment allow for the formulation and evaluation of new policy options? Did it improve scientific knowledge? Did it help win further research funding in the area being assessed? Did it prevent (or delay) action? Did it establish environmental policy or change the negotiating positions of policy-makers? Did it enhance the prestige of particular researchers or institutions?

Three central factors strongly affect the effectiveness of an environmental assessment: saliency, credibility, and legitimacy. Often, these can be in conflict with one another and require balance. Saliency can be defined by whether the assessment addressed an issue that is of interest and relevant to actions that users (i.e., decision makers) can actually take, and whether the assessment process can adapt to changes. Credibility can be defined if the authoritative technical community (or communities) finds the assessment acceptable. Legitimacy can be defined as the belief by the users that the process respects the rules and norms

of relevant institutions, and the users feel their values and interests have been acknowledged and considered. The GEA research shows quite clearly that effective environmental assessments always have reasonably high levels of saliency, credibility, and legitimacy.

The insights of the GEA project may be very useful for those charged with, or simply interested in, future assessments of ammonia policy. A key insight from both of these research projects is that the framing of an issue is crucial to how it will be perceived, what sorts of questions it will touch on, and which organizations will be interested. It will be important to frame the ammonia issue correctly. It may be more useful to think about ammonia within the context of “reactive” nitrogen. It also may be useful to determine whether a single-endpoint view, such as nitrogen-caused eutrophication, should be pursued or whether it is more useful to adopt a multi-pollutant/multi-receptor view.

The ammonia issue is clearly rising in saliency, and it would be worthwhile to have discussions on whether the issue is managing nitrogen or managing the activities that affect nitrogen. That is, should an assessment of the “ammonia issue” consider the possibility of reducing agricultural production as a policy option or not? It may be necessary to consider conducting an Integrated Assessment Modeling for Reduced Nitrogen. When doing so, the focus should be on the process, as well as the content, and it should provide incentives for participation.



## CONCLUSIONS AND FUTURE DIRECTIONS

The conclusions presented in this section are derived primarily from the platform presentations, the question and answer sessions that followed, and the wrap-up session. Future directions (for which there is no order intended) are derived from the platform presentations, the breakout sessions, and the wrap-up session and represent either the collective thinking of the group, or the opinion of one or more of the participants.

### I. Ammonia can effect human health and the environment.

- Through the production of food and energy, humans mobilize twice as much nitrogen as nature produces.
- As a gas, ammonia contributes to air quality problems after it converts to particle form. Particles (dominated by ammonium sulfates in the East) can effect human health and degrade visibility.
- Ammonia/um that deposits to the land can serve as a fertilizer, or it can acidify soils or lead to nitrogen saturation in certain sensitive terrestrial systems. Nitrogen that does not get used by the terrestrial landscape will eventually make its way into downstream ecosystems where waters can become acidified or over-fertilized. The ultimate fate of nitrogen, from the air to the soils to the point it leaves the terrestrial landscape, depends on many factors including how much nitrogen is depositing from the air, how long deposition has been occurring, and the land use history.
- Ammonia/um deposition also can cause (or contribute to) water quality problems, including the over-stimulation of algae growth. Scientists estimate that nitrogen deposition can contribute from 10 to over 40% of the “new” nitrogen enrichment of coastal and estuarine waters.
- For many algae species, ammonia/um is a preferred “flavor” of nitrogen. As a result, the increasing availability of ammonia/um could cause a fundamental change in the algae community.
- The decrease in biodiversity in the Netherlands is believed to be associated with the high concentrations of ammonia emissions and deposition.

Ammonia is a significant source of nitrogen to coastal waters and watersheds.

-Bill Matuszeski, EPA  
Chesapeake Bay Program

### Future Directions:

- More studies are needed on the role of ammonia in the formation of particulate matter, and the effects of ammonia-based particles on human health.
- Further study is needed on the terrestrial and aquatic biological responses to ammonia/um deposition, in order to establish cause and effect relationships.
- Studies are needed to identify the relative magnitude of ammonia verses total nitrogen deposition.
- Further study is needed to better understand at what point nitrogen saturation of soils occurs, the regions where it occurs and to what types of forest systems.

### II. Airborne ammonia compounds can travel short or long distances from their source before depositing in wet or dry forms to the land or water.

- Models used to describe ammonia airsheds indicate that reduced nitrogen does not just deposit locally but may travel long distances through the air before depositing. This means that some of the ammonium depositing to coastal watersheds comes from sources well beyond a jurisdiction’s boundary line. However, models (including the airshed model) are only as good as the information put into them. There is little deposition data for emission “hotspots;” even less information on dry deposition, and no information on how much, and in what forms, airborne nitrogen is entering coastal estuaries via offshore waters.
- NADP data show that ammonium in wet deposition

is increasing in certain parts of the country. In some regions, ammonium deposition is almost as high as nitrate deposition. These data appear to be indicative of the high concentrations of emissions, and they demonstrate that both forms of nitrogen are important.

#### Future Directions:

- More focused, repeatable studies are needed to better understand seasonal and diurnal cycles for emissions, ambient air concentrations and deposition of ammonia, sulfates, and nitrates; the interactions between gas and particle phases; and the influences of coastal sea salt for model development, improvement, and evaluation.
- The density of deposition monitoring stations (wet and dry) must be improved to capture the spatial variability of ammonia emissions and deposition, particularly in areas where there are the greatest concentrations of emissions (e.g., hotspots and coastal).
- Intensive studies are needed to accelerate the development of the technologies that can better quantify dry deposition, in particular better techniques are needed to measure ammonia gas.
- Fixed, monitoring stations, placed in the near-shore coastal shelf (e.g., on an oil drilling platform), are needed to assess the contribution of airborne nitrogen deposition to the coastal ocean.

#### III. Ammonia is released into the air from many sources.

- The dominant source of ammonia emissions in the U.S. is agriculture (livestock wastes and commercial fertilizers). Depending on the area, however, the percentage contribution from sources can vary.
- Ammonia emissions vary greatly across source categories and within a source category.
- The quality of current ammonia emissions inventories is poor for a variety of reasons.
- For many U.S. sources, emission factors were derived from European studies (again, little to no

data has been collected in the U.S.) and from short-term measurement studies.

- The types of animals; the animal waste handling system; the fertilizer application times and methods can each dictate how much ammonia is released into the air.
- Certain techniques, such as covering the animal waste, using bio-filters, and incorporating the waste into the soil, can reduce the amount of ammonia released into the air.
- Ammonia is emitted by motor vehicles under certain conditions, generally when the catalyst is operating in some kind of failure mode.
- The millions of vehicles in the U.S. and increasing vehicle miles traveled make it likely that motor vehicles are a significant source of ammonia in urban/suburban areas, although they are probably not a dominant source of ammonia emissions nationwide.
- It appears that roughly 10% of the vehicles emit 90% of the ammonia attributable to traffic.
- Upcoming improvements to motor vehicles, as well as aging catalysts, may cause ammonia emissions to increase and change the relative contribution of ammonia from motor vehicles.
- SCR and SNCR technologies, used by the electric utility industry, can significantly reduce NOx emissions.
- At this time, there is limited data on how much ammonia slip is generated by SCR and SNCR technologies, particularly on power generating plants using high-sulfur and low-rank coals.
- Ammonia emissions are expected to increase (by an undetermined amount) as a result of increased use of SCR and SNCR technologies.
- There are no good sources of data on the total usage of ammonia as a refrigerant or on releases of ammonia from refrigerant processes. Since ammonia is increasingly being used as a refrigerant, economically the trend is to decrease its release.

## Future Directions:

- Ammonia emissions inventories need to be improved and structured in an easily modified format to allow for the incorporation of new data as they are received. More specifically,

-Emission factors across and within source categories should be improved/updated.

-Better quantification of emissions generated by agriculture from the various production processes is needed to identify how much and when ammonia is released.

With ammonia, we have an opportunity to do it right.

-Patricio Silva, Natural Resources Defense Council

-Studies on motor vehicles should be conducted in real-world settings to document and formulate their ammonia contribution.

-More studies should be conducted on SCR and SNCR technologies to quantify their current and future ammonia releases.

-Long-term measurements should be made to improve estimates of ammonia exchange between the air and soils and vegetation since these can serve as either a source or a sink.

-Data should be collected to describe seasonal and diurnal variations in emissions.

-Standardized methods should be used for quantifying ammonia emissions.

- Farm-level fertilizer use (both manure and commercial) and method, place, and timing of application should be documented and made available for updating the inventories.
- Better data (small scale resolution) are needed on land use/land cover.

- Considerations should be given to how future changes with a source category (whether its animal agriculture, motor vehicles, NOx control technologies, or refrigeration) will affect changes in ammonia emissions.

- Ammonia emissions should be considered in the design or testing of new technologies.

## IV. Ammonia needs to be managed.

- Experience in the Netherlands demonstrates that nitrogen emissions pose a serious threat to the environment, particularly through reduction in biodiversity.

- Wet deposition of ammonia has increased in the Netherlands by a factor of five over the last 100 years.

- Various agricultural abatement measures used by the Netherlands did not result in the expected emissions reductions, giving rise to the idea that there is an “ammonia gap”.

- The most likely reason for the gap is that there is too much nitrogen in the system.

- The Netherlands is about 10 years ahead of the U.S. in quantifying ammonia emissions, monitoring deposition, and developing and implementing controls.

- Water quality problems in coastal North Carolina are believed to be associated with the high concentrations of animal operations.

We are ultimately talking about regulation, but not the kind that would be related to the extensive and convoluted process of the CAA or the TMDL process under the CWA. What is needed is something at the state level and not prohibitively intrusive on the farmer.

-Bill Matuszeski, EPA  
Chesapeake Bay Program

- Studies estimate that hog facilities in North Carolina produce approximately 20% of the state's total atmospheric nitrogen compounds.
- North Carolina is in the early stages of drafting air rules for ammonia.
- Managing ammonia should involve both regulatory and voluntary approaches.
- Integrated environmental assessments can be used to link science and policy.
- Reduce the amount of nitrogen that is imported (via feed) to nutrient sensitive areas.
- Establish an ammonia emission standard.
- Encourage the development and use of technologies that convert ammonia to  $N_2$  or reduce the release of ammonia compounds (e.g., enclosed anaerobic digesters, or waste-to-energy).
- Export the animal waste to areas that are poorer in nitrogen.

Non-regulatory actions can be implemented faster through education and innovation. We need to look for pollution prevention opportunities, for these can be implemented tomorrow.

*-David Johnson, VA Dept of Env. Quality*

- Watch the North Carolina rule making process to see if it could serve as a model for a national approach.
- Consider establishing a nitrogen cap or emission trading program on a national, regional, local basis.

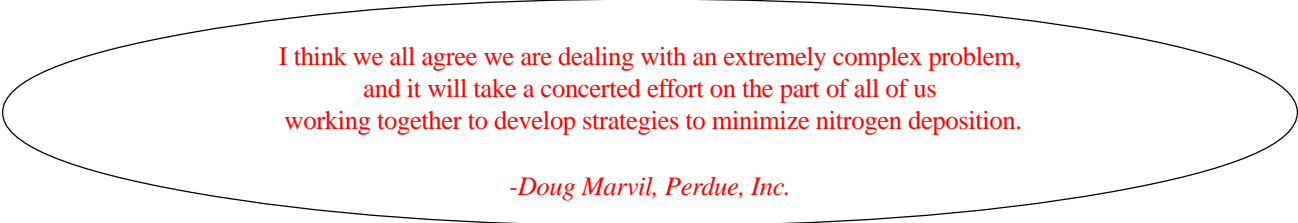
There is, and will be, a need to develop ammonia control technologies for agricultural sources in the near future.

*-Dr. Larry Jacobson, University of MN*

#### Future Directions:

- A nitrogen mass balance should be conducted for farm operations.
- Provide incentives and education for farmers to optimize management of nitrogen on the farm.
- Ensure the continued economic well-being of agricultural communities by adopting alternative nutrient management practices that address air and water quality concerns and are economically feasible.
- Provide education and improve communication, particularly with the agricultural community, on ammonia releases as both an economic issue and a pollution issue.
- Involve all parts of animal agriculture in the process to develop strategies to minimize nitrogen emissions and deposition.
- Encourage development of motor vehicle catalysts that don't emit ammonia.
- Consider conducting Integrated Assessment Modeling for Reduced Nitrogen.
- Correctly frame the ammonia issue.
- Integrate all non-point source pollution issues into the TMDL and NPDES processes.
- Encourage air quality management policies to consider terrestrial and aquatic ecosystem impacts of nitrogen deposition.
- There is a need to educate farmers on the nature of the ammonia problem and the methods that can be used to reduce losses.
- *-Dr. Jack Meisinger, USDA*
- Certain techniques, such as covering the animal waste, using bio-filters, and incorporating the waste into the soil, should be used to reduce the amount of ammonia released into the air.

This Airsheds & Watersheds workshop gave participants from diverse backgrounds a chance to share information and ideas about ammonia and its impacts to the environment. There was broad agreement on the importance of ammonia and the need for sensitivity to both economic and environmental issues related to ammonia. This workshop raised awareness, provided a context to begin discussing future directions, and pointed the way toward developing better tools to understand and manage this multi-disciplinary issue. The organizers encourage all interested parties to continue to develop and share information and to pursue ways to reduce ammonia emissions.



I think we all agree we are dealing with an extremely complex problem,  
and it will take a concerted effort on the part of all of us  
working together to develop strategies to minimize nitrogen deposition.

*-Doug Marvil, Perdue, Inc.*

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## **Appendix B- Commonly-Used Abbreviations & Terms**

A.D.N.	Atmospheric Deposition Nitrogen
AFO	Animal Feeding Operation
AIRMoN	Atmospheric Integrated Research Monitoring Program
ARS	Agricultural Research Service
BACT	Best Available Control Technology
BMP	Best Management Practice
CAA	Clean Air Act (1970)
CAAA	Clean Air Act Amendments (1990)
CAFO	Confined Animal Feeding Operation
CASTNet	Clean Air Status and Trends Network
CBP	Chesapeake Bay Program
CWA	Clean Water Act (1972)
DO	Dissolved Oxygen
DOE	Department of
EPA	Environmental Protection Agency
g	gram
GIS	Geographic Information System
ha	hectare
HNO <sub>3</sub>	Nitric Acid
kg	kilogram
LNB	Low NOx Burners
MACT	Maximum Achievable Control Technology
N <sub>2</sub>	Unreactive Molecular Nitrogen
NAAQS	National Ambient Air Quality Standard
NADP/NTN	National Atmospheric Deposition Program/National Trends Network
NAPAP	National Acid Precipitation Assessment Program
NEP	National Estuary Program
NERRS	National Estuarine Research Reserves System
NH <sub>3</sub>	Ammonia (gas)
NH <sub>4</sub> <sup>+</sup>	Ammonium (aerosol)
NH <sub>x</sub>	ammonia+ammonium
NH <sub>4</sub> -NO <sub>3</sub>	Ammonium nitrate
NH <sub>4</sub> -SO <sub>4</sub>	Ammonium sulfate
N-org.	Organic nitrogen
NO	Nitric oxide
NO <sub>2</sub>	Nitrogen dioxide
NO <sub>3</sub> <sup>-</sup>	Aerosol nitrate
NO <sub>x</sub>	Oxides of nitrogen (NO + NO <sub>2</sub> )
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
O <sub>3</sub>	Ozone
OTAG	Ozone Transport Assessment Group
OTC	Ozone Transport Commission
OTR	Ozone Transport Region
PM	Particulate Matter
POTW	Publically Owned Treatment Works
RADM	Regional Acid Deposition Model
RELMAP	Regional Lagrangian Model of Air Pollution
REMSAD	Regulatory Modeling System for Aerosols and Deposition
SCR	Selective Catalytic Reduction
SIP	State Implementation Plan
SNCR	Selective Non-Catalytic Reduction
SO <sub>2</sub>	Sulphur dioxide

SO <sub>4</sub> <sup>2-</sup>	Sulfate
TMDL	Total Maximum Daily Loads
TRI	Toxics Release Inventory
USDA	United States Department of Agriculture
VOCs	Volatile Organic Compounds

**Acid neutralizing capacity (ANC):** A measure of the ability for water or soil to neutralize added acids. This is done by the reaction of hydrogen ions with inorganic or organic bases such as bicarbonate (HCO<sub>3</sub><sup>-</sup>) or organic ions.

**Acidification:** refers to the loss of ANC or the lowering of pH.

**Adsorb:** To take up and hold (a gas, liquid, or dissolved substance) in a thin layer of molecules on the surface of a solid substance.

**Animal Unit:** a measure that represents the number of animals of different types in a common unit based on live weight; 1 animal unit represents 454 kg (1000 pounds) of live animal weight.

**Anions:** Negatively charged molecule such as sulfate (SO<sub>4</sub><sup>2-</sup>) and nitrate (NO<sub>3</sub><sup>-</sup>). In combination with hydrogen (H<sup>+</sup>), these molecules act as strong acids.

**Anoxia:** Absence of oxygen.

**Atmospheric Deposition:** process whereby pollutants in the air fall on the land or water. Pollution deposited in snow, fog, or rain is called wet deposition, while the deposition of pollutants as dry particles or gases is called dry deposition.

**Atmospheric Transport:** The movement of pollutants through the air. Pollutants can travel short or long distances depending on the emission source, chemical make-up, and weather conditions.

**Buffering capacity:** The resistance of water or soil to changes in pH.

**Cations:** Positively charged ions such as magnesium, sodium, potassium, and calcium that increase pH of water when released to solution through mineral weathering and exchange reactions.

**Critical Loads/Levels:** The concentrations of pollutants above which direct adverse effects on receptors may occur (according to present knowledge).

**Critical Thresholds:** The point at which a system switches to another state as a result of changes in that system.

**Deposition Gradient:** defines the variability in deposition rates from a source.

**Deposition Rate:** the rate at which deposition occurs.

**Discharge:** a release of a pollutant into water.

**Emission:** The flux of material into the air.

**Emission Factor:** an estimate of a pollutant's emission from a particular source type at a particular point in a process.



**Eutrophication:** A process whereby excessive amounts of nutrients over-fertilize a body of water, feeding the growth of algae blooms. When the algae die, they sink to the bottom, where the dead algae decompose in a process that depletes the water of oxygen. These areas of “dead water” are no longer able to support fish and other aquatic life.

**Flux:** The rate of transport of a material across an interface. For example, the flux of nitrogen moving from soils to groundwater may be expressed as kilograms of nitrogen per hectare per year.

**Hypoxia:** A deficiency in the amount of oxygen.

**Leaching:** Process by which water removes chemical solutes from soil through chemical reactions and the downward movement of water.

**Loading:** The total mass of material entering an environmental reservoir (e.g., water body, atmosphere) in a given time. May be expressed as pounds or kilograms per year.

**Nitrogen Fixation:** The process in which bacteria convert biologically unusable nitrogen gas ( $N_2$ ) into biologically usable ammonia ( $NH_3$ ) and nitrates ( $NO_3^-$ ).

**Nitrogen Saturation:** A condition in which a system, such as a forest, contains all the nitrogen it can hold.

**Non-point Source:** A diffuse source of pollution that cannot be attributed to a clearly identifiable, specific physical location or a defined discharge channel.

**Point Source:** A source of pollution that can be attributed to a specific physical location, as in a waste water treatment plant effluent pipe or a smokestack.

**Reactive Nitrogen:** primarily oxides of nitrogen, but includes organic nitrogen.

**Reduced Nitrogen:** ammonia and ammonium.

**Transformation:** The chemical alteration of materials, either completely or partially.

**Volatilization:** re-emission of previously deposited gaseous species into the atmosphere due to many factors, including chemical reactions, vapor pressure, gas-particle partitioning, temperature, and wind speed.

## **Appendix C - Agenda for Shared Resources Workshop**

### **Airsheds and Watersheds– The Significance of Ammonia to Coastal and Estuarine Areas**

**November 15, 2000**

**8:00 am Workshop Check-In Begins**  
*A continental breakfast will be provided*

**9:00 am Welcome**  
**Dr. Bruce Richards**, Director, Delaware Inland Bays Program

**Workshop Moderator:**  
**Susan Wierman**, Executive Director, Mid-Atlantic Regional Air  
Management Association

**9:30 am Keynotes:**  
These three keynote presentations are intended to examine, for the workshop participants, the role and impacts that ammonia emissions and deposition can have on air, land, and water resources. Presenters will address the strengths and weaknesses of the knowledge base that supports the understanding of these roles and impacts.

**Dr. Cliff Davidson**, Carnegie Mellon University  
*Ammonia Effects to Air Quality*

**Dr. James Galloway**, University of Virginia  
*Ammonia/um Deposition Effects to Terrestrial Ecosystems*

**Dr. Hans Paerl**, University of North Carolina, Institute of Marine Science  
*Ammonia/um Deposition Effects to Aquatic Ecosystems*

#### **Plenary– Questions & Answers**

**10:45 am Refreshment Break**

**11:00 am Session I – Atmospheric Transport and Deposition**  
**Moderator: Jim Skillen**, The Fertilizer Institute

**Dr. Robin Dennis**, NOAA/EPA, will examine the physical and chemical processes and the variables that affect and effect the atmospheric transport of ammonia/ ammonium and its subsequent deposition.

**Mr. Bruce Hicks**, Director NOAA Air Resources Laboratory, will examine the variables that influence the shape, size and spatial distribution of deposition gradients, the characteristics of deposition (wet–but mostly dry), and our ability to quantify the magnitude of nitrogen deposition.

**Plenary– Questions & Answers**

**12:30 pm Lunch**

Lunch will be served buffet style in the large banquet hall on the 1<sup>st</sup> level of the Baycenter. Posters will be on display around the lunch area, and poster presenters will be available to allow for informal discussions.

**1:45 pm Session II – Sources and Emissions**

**Moderator: Dr. Wayne Robarge**, North Carolina State University

Mr. William Battye, EC/R will present the most recent information on the known substantial sources of ammonia emissions, the coefficients used to estimate emission losses, and the gaps in identifying and estimating the respective contributions.

**2:30 pm Panel Responses**

Individual panel members will respond from their own perspective within the context of the following areas:

**Dr. Larry Jacobson**, University of Minnesota, will address ammonia loss from livestock production systems, including housing, manure handling and storage.

**Dr. Jack Meisinger**, USDA Agriculture Research Service, will address ammonia loss from land-applied manure and commercial fertilizers.

**Mr. Tom Feeley**, U.S. Dept of Energy, will address the issue of ammonia-slip from selective catalytic and non-catalytic reduction technologies which are used by electric power generating facilities to reduce oxidized nitrogen emissions.

**3:30 pm Refreshment Break**

**3:40 pm Continuation of Panel...**

**Dr. Mike Rodgers**, Georgia Tech, will address ammonia loss from the automobile.

**Mr. Kent Anderson**, International Institute of Ammonia Refrigeration, will address ammonia loss from commercial and industrial refrigeration systems.

**Plenary– Questions & Answers**

**5:30 pm Poster Presentations & Reception**

Light food and a cash bar will be set up on the 1<sup>st</sup> level of the Baycenter. Posters will be on display around the area, and presenters will be available for discussions.

**November 16, 2000**

**8:00 am Continental breakfast**

**8:30 am Summary of Day 1 and Charge to Breakout Groups**

**9:00 am Breakout Session**

Participants will be pre-assigned to one of 7 breakout groups. Each group will identify important gaps in our understanding, identify priorities, and identify opportunities for addressing these gaps.

**10:30 am Refreshment Break**

**10:45 am Session III – Managing Ammonia**

**Moderator: Ann Swanson**, Executive Director, Chesapeake Bay Commission.

Dr. Jan Willem Erisman, Head of the Department of Air Quality and Technology, Netherlands Energy Research Foundation, will present an assessment of the actions taken in the Netherlands to manage ammonia emissions and the lessons learned.

Ms. Robin Smith, Deputy Secretary, North Carolina Dept. of Environment and Natural Resources, will present the course of action currently being pursued by the State of North Carolina to control ammonia emissions.

Dr. Alexander Farrell, Dept. of Engineering and Public Policy, Carnegie Mellon University, will address the role and use of assessments as the link between science and policy development.

**Plenary– Questions & Answers**

**12:15 pm Working Lunch**

Participants will be pre-assigned to one of the round table discussion groups. Each group will address the following questions:

*What management initiatives can or should we take to manage ammonia losses? What, if any, are the barriers to implementing these initiatives?*

**1:30 pm Wrap-up**

A diverse panel will share their perspectives of the salient points of the workshop. One or more of the facilitators will conclude with a summary of the group breakouts and round table discussions.

**Panel:**

**Doug Marvil**, Perdue Inc.

**Bill Matuszeski**, EPA Chesapeake Bay Program

**Patricio Silva**, Natural Resources Defense Council

**David Johnson**, Virginia Dept. of Environmental Quality

**3:15 pm Adjournment - Susan Wierman**

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