II. Atmospheric Deposition 101

Pollutants released into the atmosphere do not "go away." Some stay in their original form in the atmosphere, the others are transformed into other chemicals (which may or may not be considered pollutants). Some stay in the atmosphere, the remainder are removed from the atmosphere—are deposited—to the land or water. Pollutants can travel anywhere from a few yards to a few thousand miles before depositing as a part of the pollutant load to our land and water.

The pollutants that are often identified as having significant atmospheric contributions in waterbodies are **sulfur compounds, nitrogen compounds, mercury compounds,** other **heavy metals,** and a handful of **anthropogenic** (of human origin) **pesticides** and **industrial by-products,** including **current-use pesticides** and **herbicides** such as **atrazine.** For a list of the pollutants that are most commonly studied, see the box below.

Pollutants Identified as Significant for Atmospheric Deposition in at Least One Location

*Sulfur compounds
Nitrogen compounds
Mercury compounds
Lead compounds
Cadmium compounds
Chlorpyrifos
*Copper
*Zinc
Polychlorinated biphenols (PCBs)
Diazinon
Dioxins/furans
Dieldrin
DDT/DDE
Hexachlorobenzene (HCB)
a-hexachlorocyclohexane (a-HCH)
Lindane
Toxaphene
Polycyclic organic matter (POM), including polycyclic aromatic hydrocarbons (PAHs)
*Atrazine

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*Indicates pollutants that are not identified as Great Waters Pollutants of Concern.

Nitrogen inputs have been studied in several east and Gulf Coast estuaries due to concerns about eutrophication. Nitrogen from atmospheric deposition is estimated to be as high as 10 to 40% of the total input of nitrogen to many of these estuaries and perhaps higher in a few cases. Deposition of toxic pollutants is being studied in the Great Lakes and several estuaries on the Atlantic, Gulf, and Pacific coasts. For example, copper deposition is known to contribute to the ongoing total copper load to San Francisco Bay. Roughly 80% of the mercury input to Lake Michigan is estimated to be due to atmospheric deposition. The contribution of pollutants from deposition compared with other sources varies both by waterbody and pollutant.

Not only is the type of pollutant important in understanding air deposition, but the chemical form of the pollutant is critically important as well. Mercury, for example, is emitted in both the elemental (Hg^{o}) and divalent (Hg^{2+}) form in the case of coal-fired utilities. Elemental mercury can be transported in the atmosphere for long distances (e.g., thousands of miles). It can be oxidized in the atmosphere and is deposited as divalent mercury in complexes in precipitation or as particles. The divalent form of mercury in the gas phase may be removed from the atmosphere within a short distance of its emission source (e.g., tens to hundreds of miles). Solubility, reactivity, and physical state are often different for each form of a pollutant. Important chemical species of concern in air deposition to waterbodies are shown on the following page by physical state (solid, liquid, or gas).

Physical State for Pollutants of Concern:

Present in Precipitation

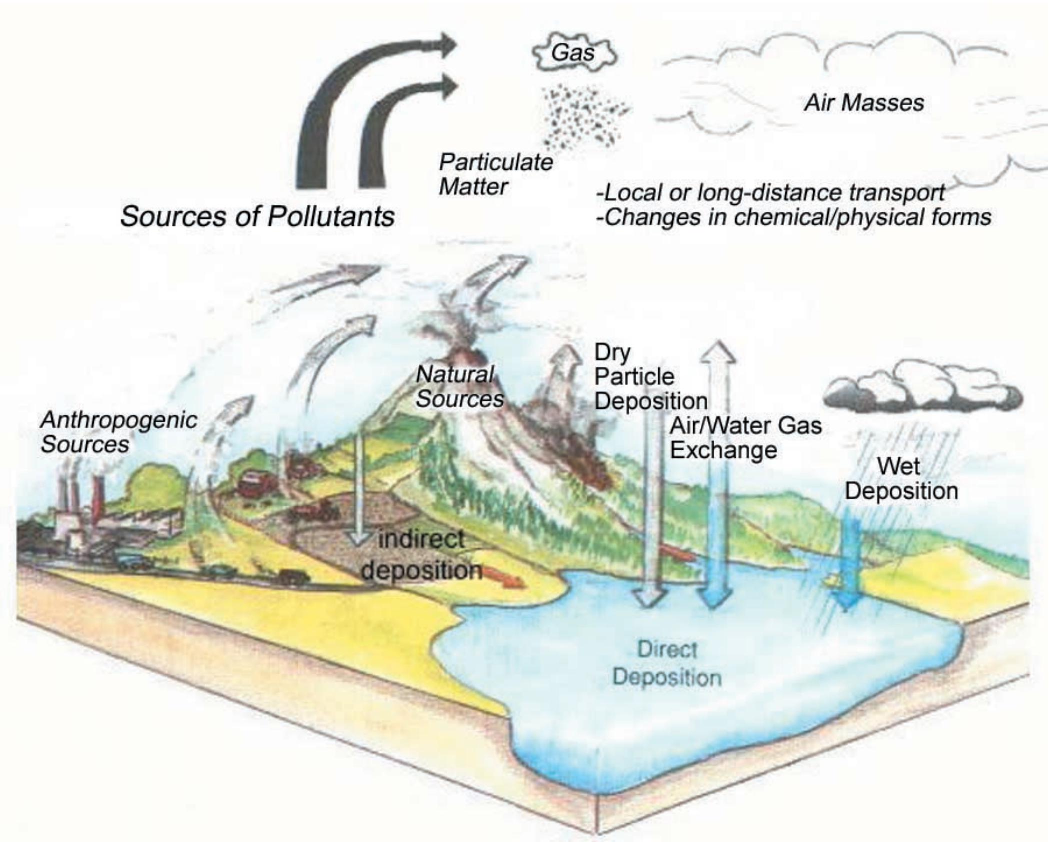
NO_3^-	nitrate
NH_4^+	ammonium ion
Organic nitrogen compounds	
SO_4^{2-}	sulfate
HSO_3^-	bisulfite
SO_3^{2-}	sulfite
Atrazine, alachlor, cyanazine (herbicides) and degradation products	
PCBs	polychlorinated biphenyls

Present in Gaseous Phase

NO	nitric oxide
NO_2	nitrogen dioxide
NH_3	ammonia
N_2O_5	dinitrogen pentoxide
HNO_3	nitric acid (vapor)
SO_2	sulfur dioxide
POM	polycyclic organic matter
PAH	polycyclic aromatic hydrocarbons
Hg^{2+}	mercuric ion
Hg^o	elemental mercury
PCBs	polychlorinated biphenyls
D/F	dioxins/furans
POM	polycyclic organic matter

Present in/on Particles

NH_4^+	ammonium ion
NO_3^-	nitrate
Organic nitrogen compounds	
H_2SO_4	sulfuric acid
SO_4^{2-}	sulfate
Hg^{2+}	mercuric ion
$HgCl_2$	mercuric chloride
HgO	mercuric oxide
Hg^o	elemental mercury
Pb	lead
Cd	cadmium
PCBs	polychlorinated biphenyls
D/F	dioxins/furans
POM	polycyclic organic matter



For most pollutants, deposition has been studied in a limited number of geographic areas. However, that does not mean that deposition is not a problem in other geographic areas; rather, it is unknown. The deposition monitoring networks that cover the broadest geographic areas are for sulfur and nitrogen compounds. As you begin to consider deposition in your area, it may be difficult to find existing data about deposition rates. This handbook provides tips on where you could look for existing information in the **Summary of Data Sources** on page 14. For more information on air deposition monitoring, see the section on **What You Need to Know about Air Deposition Monitoring** on page 31.

Monitoring extensively enough to answer all your questions about deposition may be prohibitively expensive. Therefore, models are often used to complement or replace monitoring to help answer these questions. For example, modeling can fill spatial or temporal gaps in the data. Models also can address questions that monitoring alone may be unable to address. One example is predicting the effect of various management options or future emission reductions on deposition rates. Another is figuring out what types of sources are responsible for the deposition in your area. The pollutants for which modeling has been used to estimate deposition rates include nitrate, ammonia, ammonium, sulfate, total mercury, cadmium, dioxins, atrazine, and particulate matter. While models are extremely useful, they are, by definition, simplifications of reality. It is important to understand what assumptions and simplifications a model includes and their implications for the answers you are seeking. Furthermore, even the best models are only as reliable as the data input to them. To the extent possible, models should be calibrated against actual deposition measurements. For more information on modeling, see **What You Need To Know About Air Deposition Modeling** on page 45.

Where Does Atmospheric Deposition Come From?

Atmospheric deposition comes from emissions of air pollutants from natural and human-made (anthropogenic) sources. Some pollutants in the atmosphere occur naturally, including nitrogen, sulfur, mercury, lead, cadmium, copper, and zinc. These pollutants also have significant anthropogenic sources, which can rival or exceed emissions from natural sources.

Primary anthropogenic sources of nitrogen include burning fossil fuels (e.g., in power plants, industries, and vehicles) and agricultural activities (including fertilizer application and animal feedlots and waste lagoons). Natural sources of nitrogen emissions include lightning, natural burns (e.g., forest fires), and microbial activity. Sulfur oxides are formed when fuel containing sulfur (mainly coal and oil) is burned and during metal smelting and other industrial processes.

Generally, the primary anthropogenic sources of mercury emissions are from combustion of material containing mercury, such as coal-burning utilities and boilers, and waste incinerators. There are also emissions from industrial processes, such as chlor-alkali plants and gold mining operations.

Definitions of Common Terms

The grasshopper effect: Some pollutants (especially PCBs, pesticides, toxaphene, and some forms of mercury) do not stay deposited. Instead, depending on a host of variables that are not easy to quantify, they can be re-emitted from contaminated soil or water. This leads to a pattern where a pollutant is emitted from an original source, transported some distance, and deposited. Then a portion is re-emitted, transported further, and redeposited. The pattern is repeated indefinitely. There is evidence that these pollutants tend to sorp/desorp until they reach northern climates or high elevations. The latter phenomenon is sometimes called the "cold condensation effect." It is due to the physical and chemical properties of the pollutants. However, substantial amounts of these pollutants are still found at lower latitudes.

Anthropogenic mercury emissions are a component of a global mercury cycle. Because elemental mercury can travel great distances in the atmosphere, and mercury compounds have their own natural cycle between the atmosphere, the earth, and the oceans, a background level of mercury is present in the atmosphere. This background reservoir is continuously refreshed from natural and anthropogenic sources around the world. Other heavy metals have somewhat different sources; they come primarily from smelting, metals production or plating, and mining, as well as combustion of material containing the metals. Some pollutants are mainly emitted as combustion by-products. Dioxins/furans are by-products of combustion of organic material containing chlorine. Typically, POM, including PAHs, also are by-products of incomplete combustion of fossil fuels and plant biomass.

Many atmospherically deposited compounds are not naturally occurring in the environment. For example, PCBs are a group of synthetic organic compounds that were used widely in electrical equipment. Pesticides and herbicides are typically manufactured chemicals. The use of some of these pollutants has been banned or restricted in the United States. In those cases, emissions are mainly from volatilization from contaminated soils, use from existing stocks (if still allowed), and long-range transport from other countries.

Common atmospherically deposited pollutants in waterbodies are listed in Appendix 1 with their major sources and uses. The discussion of inventories (page 47) in the chapter **What You Need to Know About Air Deposition Modeling** also contains citations for additional information on emission sources.

What is the Link Between Emissions, Atmospheric Deposition, and Ecological Impacts of Pollutants?

It is often difficult to make a direct connection between emissions of any pollutant at one location and deposition at another. Emissions from a particular source may spread over a wide area and deposit in several watersheds. In addition, deposition rates in any watershed are probably due to a large number of sources and a variety of meteorological patterns. There are situations, however, where reducing emissions in a specific area leads directly to reducing atmospheric deposition rates. For example, when large reductions in sulfur dioxide emissions were implemented in the Ohio River Valley, a significant drop in sulfate deposition was measured downwind in the highly sensitive Adirondacks and New England.

Several studies suggest links between atmospheric deposition and environmental impacts, including one showing that rainwater containing typical levels of nitrogen increased the rate of algal growth when added to seawater. However, it is difficult to actually trace most atmospheric pollutants into the food web because pollutants that have been

Definitions of Common Terms:

Direct deposition: The process of deposition of air pollution directly into a body of water (usually thought of in terms of a large body of water like an estuary or large lake). The amount of pollution reaching the water in this way is called the **direct load** from atmospheric deposition.

Indirect deposition: The process of deposition of air pollution to the rest of the watershed (both the land and the water). Once pollutants are deposited in the watershed, some portion of them are transported through runoff, rivers, streams, and groundwater to the waterbody of concern. The portion that reaches the waterbody by passing through the watershed is called the **indirect load** from atmospheric deposition.

Wet deposition: Pollutants deposited in rain, snow, clouds or fog. Acid rain, which has been recognized as a problem in Europe, eastern Canada, Asia, and areas of the United States, is an example of wet deposition of sulfur and nitrogen compounds.

Dry deposition: Pollutants deposited when it is not raining or snowing. This is a complicated process that happens in different ways depending on the size and chemical nature of the particle or gas being deposited and the "stickiness" of the surface. Dry deposition of particles can basically be thought of as similar to dust collecting on a table.

deposited through air deposition are difficult to distinguish from those that entered the food chain through other pathways. So, modeling is typically used to make these links. For example, for mercury, fate and transport modeling and exposure assessments predict that the anthropogenic contribution to the total amount of methylmercury in fish is, in part, the result of mercury emissions from industrial and combustion sources increasing mercury body burdens (i.e., concentrations) in fish. Furthermore, the consumption of fish is the dominant pathway of exposure to methylmercury for fish-consuming humans and wildlife. If a pollutant is known to cause a particular environmental problem and atmospheric deposition of that pollutant is known to be a significant part of the total load, it is plausible that atmospheric deposition is responsible for a portion of the environmental problem.

III. How Do I Know If Air Deposition is a Problem for My Watershed?

Several signs suggest that atmospheric deposition may be a problem:

- Known water sources of pollution do not explain the amount or location of contaminants found in the waterbody.
- National or regional deposition modeling or monitoring maps indicate a large amount of deposition in the area. For a list of places to find these maps see page 14.
- Atmospheric deposition has been identified as a significant source of pollution in a nearby or similar waterbody.
- There is broad-scale (often low-level) water or sediment contamination with toxic pollutants but no hot spots or known discharges.
- Large sources of atmospheric pollutants are upwind.

PAHs Deposition Found in Casco Bay, ME

A comprehensive analysis of sediments in Casco Bay revealed widespread distribution of organic contaminants, such as PAHs, in sediments throughout the Bay, including in areas away from population centers, current discharges, or known historical water discharges. This pattern suggested that atmospheric sources could be responsible for contaminants. The Casco Bay National Estuary Program Comprehensive Conservation and Management Plan directed EPA, the Maine Department of Environmental Protection, and the Casco Bay Estuary Project to determine how atmospheric deposition contributes to the problem of sediment contamination. In response, the partners initiated a three-year deposition monitoring program for PAHs, among other pollutants. The PAHs monitoring site is one of only a handful in the country and not part of any coordinated network. Wet and dry deposition of PAHs to Casco Bay, as measured at the Wolfe's Neck monitoring site, appear to represent a significant source of PAHs to the Casco Bay Estuary. A caveat must be added to this statement, however, because loading of PAHs to the Bay is not well characterized for all sources in the watershed.

If the answer to all the questions is no, it is unlikely that significant atmospheric deposition is taking place in your watershed or it is masked by high loads from other sources. These signs are "warning flags." If the answer to any of the statements is "yes," it does not necessarily mean air deposition is a large source of pollution or that it must be controlled. It simply suggests that it would be a good idea to take a closer look at what amount of deposition might be occurring directly in the waterbody or in the larger watershed and affecting water quality through indirect deposition.

The following examples show some ways that watershed management programs discovered that atmospheric deposition was a significant source of pollution in their watersheds.

During the late 1970s and early 1980s, studies in the Great Lakes area were finding elevated levels of PCBs, mercury, toxaphene, and other pesticides in fish, water, and sediments of remote lakes with no direct water discharge of these contaminants.

Atmospheric deposition was suggested as a cause, and subsequent monitoring confirmed that significant amounts of mercury were being deposited with rainwater. Further studies showed that sources in the area could account for some of these contaminant loadings; but, in some cases, contaminants were being transported long distances through the air. From there, suspicion arose that mercury was probably being deposited in other locations and from other sources as well. Furthermore, other pollutants could also be deposited in the same way. Atmospheric deposition is now recognized as a significant source of a large number of toxic pollutants in the Great Lakes area, as well as several other places around the country. It is also now known that long-range transport of these pollutants from sources in lower latitudes are causing substantial contamination of otherwise pristine Arctic and high elevation ecosystems.

The Delaware Inland Bays National Estuary Program began an air deposition monitoring study to help Delaware develop a TMDL. Atmospheric deposition was suspected, in part due to studies from North Carolina showing a large amount of ammonia deposition downwind of industrial hog farms on the Carolina coastal plain. The peninsula on which Delaware sits, known as the Delmarva Peninsula, is also home to large numbers of concentrated animal feeding operations, although on Delmarva they are mostly chicken farms. Also, data from the Atmospheric Integrated Research Monitoring Network (AIRMoN) site near the Bays were used to gauge wet nitrogen deposition. Researchers have indeed found a significant amount of ammonia deposition into the Delaware Inland Bays and the coastal Atlantic ocean. These data were combined with data from other sources to develop a TMDL for nitrogen for the Delaware Inland Bays. The TMDL does not include any reductions in nitrogen loads from atmospheric sources other than those that are predicted from existing federal laws, but it does identify atmospheric deposition of nitrogen as a significant source of pollution to the fragile ecosystems of the Bays.

Does No Local Source = No Air Deposition Problem?

Not necessarily. Since some air pollutants can be transported long distances, local sources may or may not be the most important contributor to an atmospheric deposition problem. For example, the Chesapeake Bay Program estimates that local emissions from automobiles contribute about a third of the nitrate deposition to the Chesapeake Bay. Emissions from power plants, some of which are local but many of which are hundreds of miles away, also contribute a third of the total nitrate deposition.

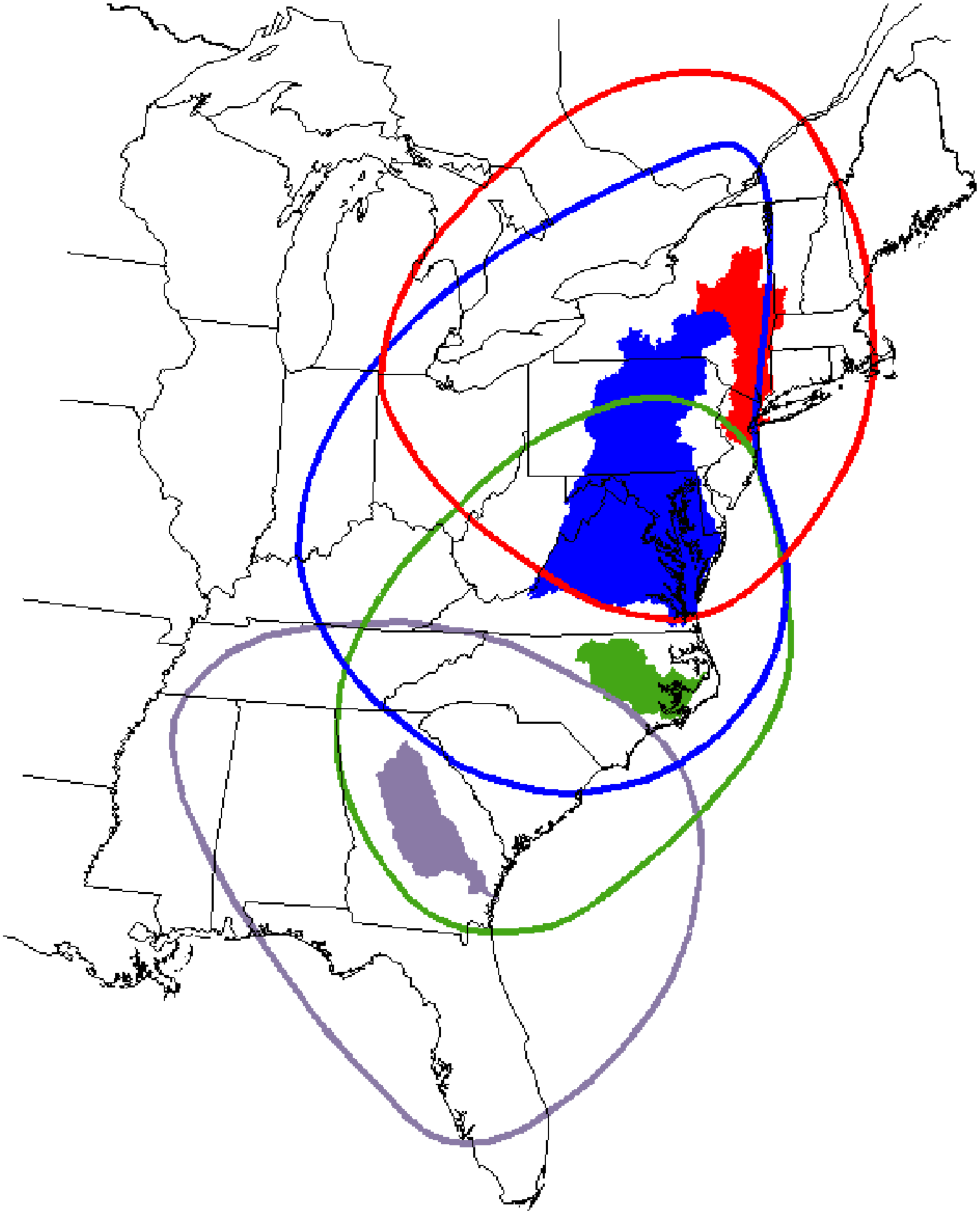
How far pollutants travel depends on their characteristics. For example, ammonia is generally transported relatively short distances (within a few hundred miles), while elemental mercury and pollutants such as DDT appear to be transported globally. Therefore, a lack of local air sources, especially for long-lived toxic pollutants such as elemental mercury and pesticides, does not rule out atmospheric deposition as a significant pathway.

The Tampa Bay Estuary Program used data from a nearby National Atmospheric Deposition Program (NADP) site and local rainfall data to estimate how nitrogen was being deposited directly into Tampa Bay. That loading was compared to nitrogen loads

What Is An Airshed?

An airshed is different than a watershed. In a watershed, everything that falls in that area flows into a single body of water. An airshed, in contrast, is a theoretical idea. It defines the source area that contains the emissions that contribute a certain percentage (usually 75%) to the deposition in a particular watershed or waterbody. In other words, the area containing sources shown by a model to be responsible for some percentage of the atmospheric deposition reaching an estuary is defined as the airshed. Airsheds are determined from models and differ for each form of every pollutant (e.g., the ammonia and nitrogen oxides airsheds are different for the same waterbody). Airsheds can be useful tools to explain atmospheric transport and the need to control sources far from the ecosystem of concern. Nitrogen oxides airsheds have been developed for every east coast estuary; they can be found on EPA's Air-Water Coordination group's homepage at http://www.epa.gov/owow/oceans/airdep. Examples of airsheds are on the next page.

Principal Nitrogen Oxide Airsheds and Corresponding Watersheds for Hudson/Raritan Bay, Chesapeake Bay, Pamlico Sound, and Altamaha Sound (listed from north to south)



Airsheds developed by R. Dennis, Atmospheric Sciences Modeling Division: NOAA Air Resources Laboratory and USEPA National Exposure Research Laboratory from other sources, including wastewater treatment plants and stormwater runoff. Because the amount of nitrogen calculated as coming from the atmosphere was comparable to the amount coming from the other sources (about 27% of the total load), the estuary program decided to set up an atmospheric deposition monitoring program to measure the deposition load more carefully. Local monitoring in Tampa Bay Estuary Program confirmed that 25 to 30% of the nitrogen entering the Bay comes from atmospheric deposition. The program has begun working with local sources to reduce that load.

IV. I Think Air Deposition is a Problem. Now What?

So you think air deposition may be a problem in your watershed. Now what? The first step is to take a closer look without actually spending money on equipment or data collection. This section describes the desk or paper studies that experts recommend conducting before you collect new data.

This also is a good time to start thinking about what expert assistance you may need and asking for suggestions of people who can help. However, consider waiting until after you have started or completed the paper studies recommended in this chapter to get experts on board. The paper studies will help you figure out what your next steps will be and the kind of expertise you will need. Also, the experts will appreciate starting with the information you will have already pulled together.

This section contains information on

- Paper studies
- Data sources.

Paper Studies

The watershed problems that you are trying to address point you to the pollutants for which you think air deposition may be a problem. Now would be the time to identify specifically the pollutants you need to focus on, if you haven't already. Doing a paper study for those pollutants means taking a survey of information already available and putting it in the context of the watershed. This would include available information about potential sources that could influence deposition and estimates of their magnitude. Information about sources can be found in Appendix 1 and through emission inventories (discussed on page 47). For toxic pollutants that tend to persist in the environment, also think about what sources may have contributed in the past, but are not current contributors. For example, a waste incinerator that closed two years ago may have contributed significantly to the total load of mercury and dioxins/furans cycling in your waterbody.

You also want to get a rough "back-of-the-envelope" estimate of the contribution from air deposition compared with other inputs. If it is difficult to come up with actual numerical deposition estimates, you can still look at pieces of the puzzle conceptually to help develop hypotheses about what is happening. For example, information about air pollution sources, prevailing winds, and non-air sources of pollution will provide clues.

The results of the paper study will provide guidance for your next steps. Let us say you have estimated that the input of air deposition is very small relative to other inputs or you have very little information about another potentially important pathway of pollutant to your waterbody. You may decide to expend resources on studying or reducing other inputs before proceeding with additional study of the air inputs. Should you decide that your next step is additional air deposition analysis, the paper study should shed more light on the questions that you still need to answer and the kind of data you need to gather.

There are several places to find information on deposition rates. Air deposition and air quality monitoring networks and individual research sites already in place around the United States are good places to start. The air quality monitoring networks alone will not provide deposition rates; rather they provide information about the concentration of pollutants in the ambient air. However, as discussed later in this section, air concentrations can be used in estimating dry deposition rates. They can also be used alone as evidence of where the highest deposition is anticipated to occur if you don't have enough information to estimate deposition rates. You would expect more deposition in the general areas where ambient air concentrations are highest. You can also look for results of air quality or deposition modeling studies.

For suggestions on places to start looking for estimated deposition loading rates, see **Summary of Data Sources** on page 14. Also look in the Great Waters Reports to Congress (available on the Web at www.epa.gov/oar/oaqps/gr8water/) or search scientific paper databases for publications, especially for more uncommon pollutants (those not listed on page 3).

Dry Deposition Rates vs. Velocities

Dry deposition rate: The amount of pollutant that lands in a particular place over a certain period of time, for example, 50 kilograms/hectare/year (kg/ha/yr.) This is the number to know for management purposes.
Dry deposition velocity: A term in the equation below that explains how much of a particle or a gas falls to the ground. The entire equation is:

dry deposition rate (D) = C x Vd for some period of time

where

Vd = dry deposition velocity
C = pollutant concentration in air at a reference height

Dry deposition monitoring methods either measure deposition rate directly (rarely—due to limitations) or measure the pollutant concentration in air and use a modeled velocity to calculate the load or flux.

Definitions of Common Terms

Receptor: A place that receives a pollutant. Receptor generally refers to a location in the transport process that is relevant to the question needing to be answered. Examples of receptors are the deposition monitoring site, the landscape the pollutant deposits on, an estuary or lake where its ecological effects are in question, or any place in the ecological web where it might be found (such as algae or fish tissue). Scientists sometimes refer to "measuring the form of pollutant present at the receptor site." This really means they want to know how much of the pollutant in what form is showing up at the place(s) where they are monitoring for it.

Deposition rates are often reported as pounds/hectare/year (lb/ha/yr), grams/square meter/day (gm/m^2/day), or kilograms/year (kg/yr) for a specific waterbody. They may be reported as wet deposition rates, dry deposition rates (not deposition velocities, as described below), and total deposition rates. If the total deposition rate is reported, check with the author to find out if it includes wet and dry deposition of all forms of the pollutant. For example, total nitrogen deposition sometimes means wet and dry deposition of nitric acid; sometimes wet and dry deposition of nitric acid and ammonium; sometimes wet and dry deposition of nitric acid, ammonium, and ammonia; and sometimes wet and dry deposition of nitric acid, ammonium, ammonia, and organic nitrogen.

If you cannot find data on dry deposition rates, you may be able to estimate them with dry deposition velocities and concentrations of the pollutants in ambient air, as noted in the Dry Deposition box at the left. Velocity measurements describe how fast a particle or gas falls to a particular type of surface, such as the outside surface of a leaf, but they do not indicate how many particles or how much gas falls. They are sometimes reported in the scientific literature as centimeters/second. A table showing some of the dry deposition velocities from the literature is in Appendix 2.

Deposition rates reported in the literature are very sensitive to the landscape and meteorological conditions. They are good enough for a paper study first estimate, but they should be used with caution to calculate more exact dry deposition loads. Generally the more the conditions under which the reported value was collected resemble your conditions (surface, meteorology, and nearby sources), the more accurate the deposition rate is likely to be. For example, if the watershed is just downwind of a large oil refinery complex, borrow a deposition rate from another area that has similar emissions upwind rather than the watershed next door with no emissions from that industry. The key to picking a good deposition rate or rates is to have a general knowledge of what industries emit which pollutants and where they are located. If the reported values are relatively close together (within one order of magnitude), it is easiest to average them and use the average deposition rate for back-of-the-envelope calculations. If there is a large difference between them (or if you're not sure if the difference is large), pick a high one and a low one to do the back-of-the-envelope calculations of loadings with each.

To do a **back-of-the-envelope calculation** of the direct atmospheric load to the body of water, multiply the deposition load by the area of the waterbody. For example, if the low reported deposition rate for total mercury deposition is 0.1 micrograms per square meter per year (µg/m^2/yr), and the waterbody is 5,193 m^2, the direct mercury load is 519 µg/yr. If the high reported deposition rate is 15 µg/m^2/yr, the total load to the waterbody is 77,895 µg/yr. Therefore, the direct atmospheric mercury load probably falls between 500 and 80,000 µg/yr. This translates into 0.0005 grams per year (g/yr) and 0.08 g/yr. This may not sound like a lot, but it can be, depending on how much comes from other loads and how sensitive the ecosystem is.

Compare the estimated load(s) to loads from other sources. Are they roughly similar, or does one dwarf the others? It helps to calculate the estimated percent load of atmospheric sources. For example, if the other known source is a waterborne point source on the lake that discharges 0.1 g/yr and a tributary that carries approximately 0.05 g/yr, the percentage of atmospheric load ranges from <0.3% to 53%. In this case, since it is possible that air deposition is a significant source, it is probably worth spending time and/or money refining the estimated loading. In general, if air deposition is more than 10 to 15% of the total load, it is probably worth spending additional resources to refine the estimates by measuring atmospheric deposition directly in the watershed. This does not mean you have to control air sources, just that it is worth knowing more accurately how important they are.

Summary of Data Sources

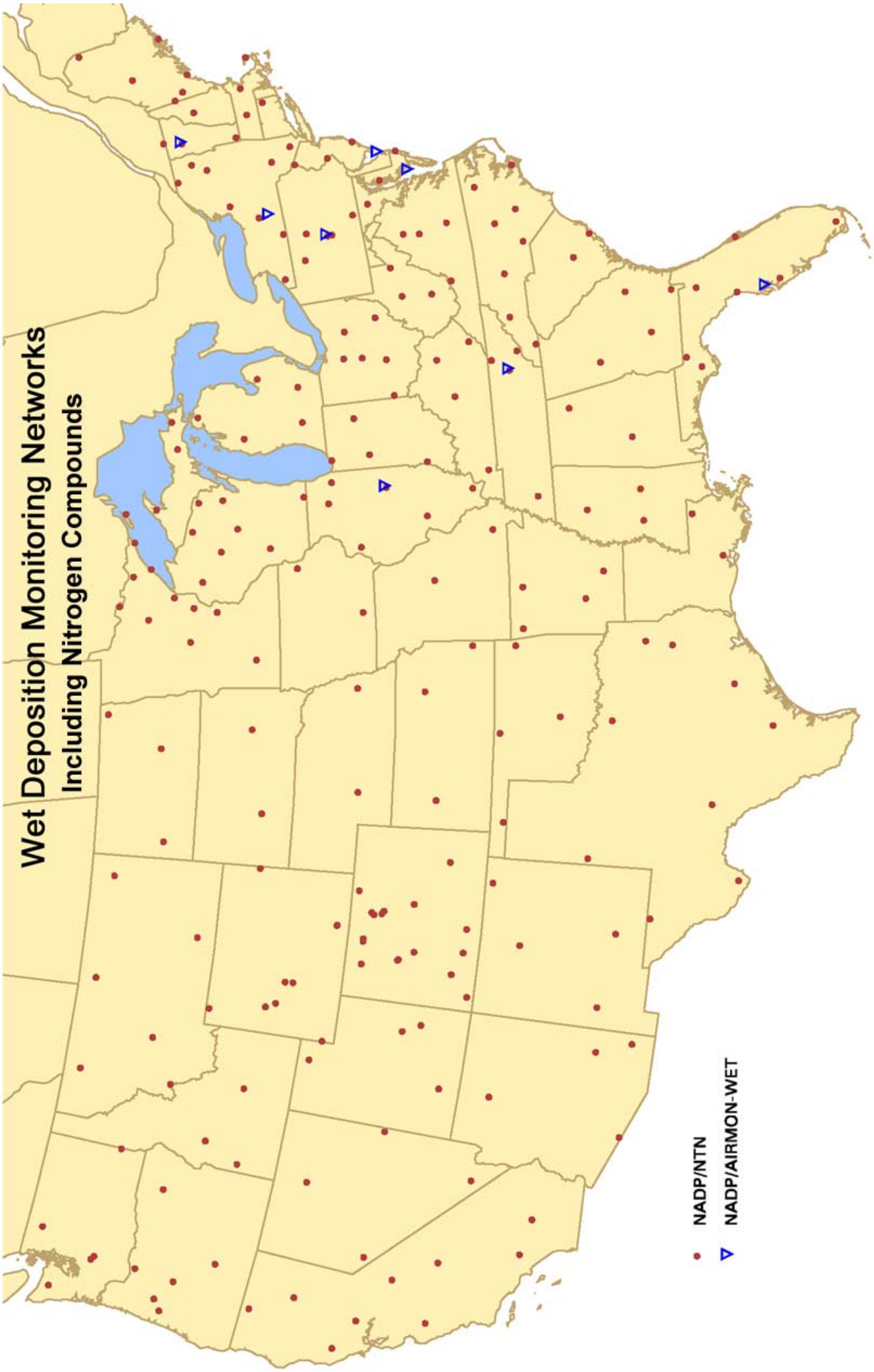
This section describes a variety of sources of information for your paper study. The national deposition and air monitoring networks are an important place to look. The majority of this section is devoted to describing these networks. Other sources are air deposition research or local studies and results from runs of air quality or deposition models.

Monitoring Networks

Some monitoring sites measure only wet deposition of a few pollutants and some measure only dry deposition; some measure deposition daily and some measure it weekly. The following paragraphs summarize some of the monitoring networks and individual studies that may have useful information to help with the paper study. Contact each of these programs directly for the latest information on where sites are located, details on specific constituents measured, and the latest measured deposition rates at each site.

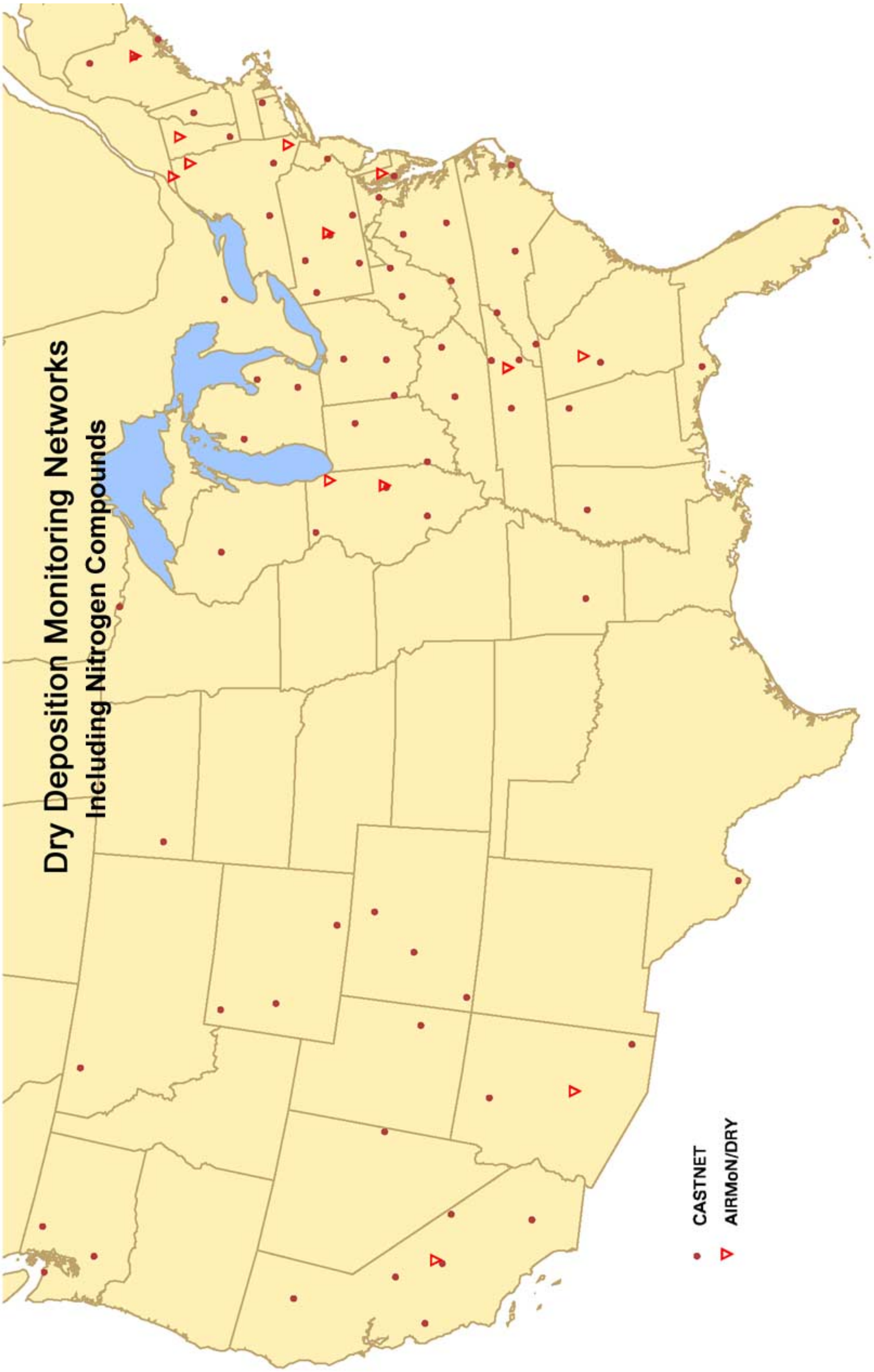
NADP-National Trends Network (NTN). The NADP was originally set up in 1978 to measure deposition of pollutants that cause acid rain. (The NTN was once a separate network, but has now completely merged into the NADP umbrella.) NADP-NTN is considered the standard for wet deposition measurements of sulfate, nitrate, ammonium, and orthophosphate. Samples are collected on a weekly basis. The network consists of over 200 sites, many of which are located in relatively rural or remote areas. These sites are also predominantly inland. The sites were (and still primarily are) set up far away from sources to measure regional deposition rates and not the

Wet Deposition Monitoring Networks Including Nitrogen Compounds



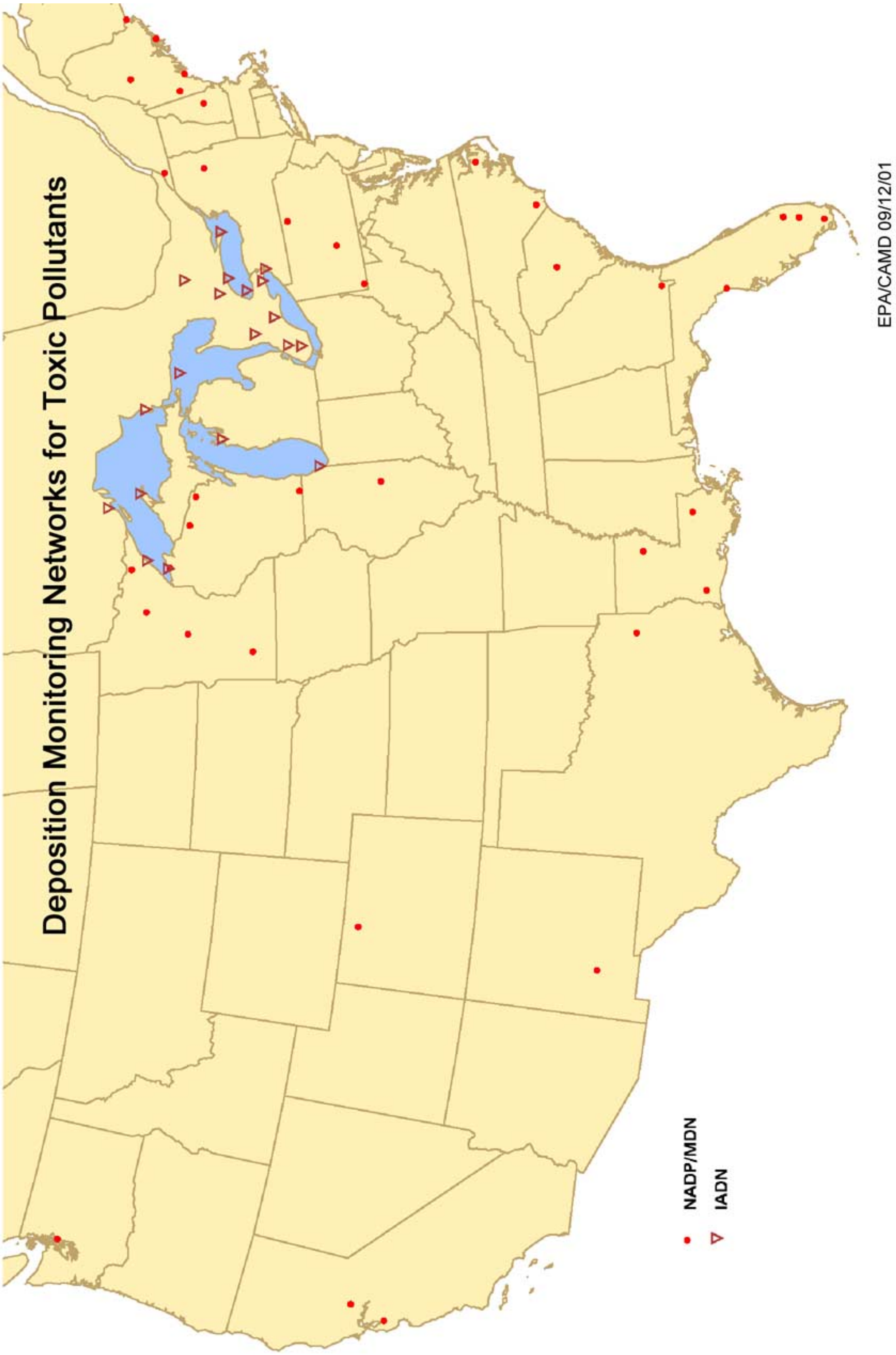
Source: EPA/CAMD 09/12/01

Dry Deposition Monitoring Networks Including Nitrogen Compounds



Source: EPA/CAMD 09/12/01

Deposition Monitoring Networks for Toxic Pollutants



specific impact of a particular source. The sites, therefore, are very valuable in showing trends over space and time, but they cannot be used to identify sources of pollution very well. The sites are almost exclusively inland because sea salt complicates the measurement of sulfate (makes it a little less accurate). This is less of a problem for measuring nitrate and ammonium, and recently NADP added a handful of coastal sites to the two or three that were already operational.

NADP is a multi-agency network run out of the Illinois State Water Survey. It has a technical committee of scientists and agency managers that oversee the network and make sure it continues to provide highly reliable data. All data collected by NADP are available on the Web at no cost through the NADP home page at http://nadp.sws.uiuc.edu. The data are also interpolated using a Kriging model (similar to a statistical least squares fit) to produce maps of nationwide deposition rates. These maps can be accessed on the Web for every year since 1994, as well as the monthly and yearly deposition rates at each monitoring site. These deposition rates are very useful in doing back-of-the envelope calculations for watersheds nationwide.

NADP-Mercury Deposition Network (**MDN**). The MDN is one subnetwork of NADP. The first sites became operational in 1995, and the network became an official part of NADP in 1996. MDN contains approximately 50 mercury deposition monitoring sites nationwide. Most of those sites monitor for total wet mercury deposition; some also monitor for wet methylmercury deposition. Samples are collected on a weekly basis. There is no widely accepted method for measuring dry mercury deposition on a routine basis. The data from MDN can also be accessed on the NADP Web site at http://nadp.sws.uiuc.edu.

Definitions of Common Terms

Aerosol: A technical term for a population of very small solid or liquid particles in the atmosphere. Pollutants that occur as aerosols include nitric acid and sulfuric acid.

Photochemical oxidant: A class of highly reactive chemicals produced in the atmosphere, usually from chemical reactions of NO_x and volatile organic compounds (VOCs) in sunlight. Examples of oxidants include ozone (O_3), hydrogen peroxide (H_2O_2), and organic nitrates. Oxidants react with many of the compounds of interest to atmospheric deposition and alter their behavior. For example, sulfur dioxide (SO_2) is relatively insoluble in water. However, when it reacts with oxidants, the resulting sulfate (SO_4) is much more soluble. Soluble compounds tend to "wash out" in rain much more easily than insoluble ones. In short, oxidants change the chemistry of pollutants in the atmosphere and therefore the processes that control deposition rates.

NADP-AIRMoN. AIRMoN, the smallest subnetwork of the NADP, is sponsored by the Air Resources Laboratory of the National Oceanographic and Atmospheric Administration (NOAA) and run by NADP. The purpose of the network is to provide research-grade monitoring data to the NADP and the data users, especially modelers. The first sites were installed in 1992, and the network actively encourages coastal and urban sites. AIRMoN consists of about 22 sites (13 dry and nine wet) and measures sulfur and nitrogen compounds (dry) and several cations and anions (wet) on a daily (instead of weekly) basis. AIRMoN data can also be accessed on the NADP Web site at http://nadp.sws.uiuc.edu.

Clean Air Status and Trends Network (**CASTNet**). CASTNet is the nation's primary monitoring network for measuring dry acidic deposition. In conjunction with other national monitoring networks, CASTNet is used to determine the effectiveness of national emission control programs. The network was built from an old dry deposition monitoring network started in the mid-1980s and a new commitment in the 1990 CAA to measuring long-term status and trends. There are approximately 80 CASTNet sites nationwide. CASTNet sites use filterpacks to collect ambient air samples, and deposition velocities are calculated using the Multi-Layer Model. The deposition velocity and air concentration are plugged into an equation to get deposition flux or rate. Measurements at each site include weekly average atmospheric concentrations of sulfate, nitrate, ammonium, sulfur dioxide, and nitric acid, and meteorological conditions required for calculating dry deposition rates. Because of the interdependence of wet and dry deposition, NADP wet deposition data are collected at or near all CASTNet sites. CASTNet data can be accessed from EPA's Office of Air and Radiation at http://www.epa.gov/castnet/.

Integrated Atmospheric Deposition Network (IADN). This network has measured deposition of toxic contaminants for the Great Lakes region since 1990 on a master site/satellite plan. IADN is a joint project between the United States and Canada, and monitoring sites are set up on both sides of the border. There is one "master site" near each lake and several "satellite" sites around the lakes that monitor less frequently and often for fewer parameters. This approach attempts to capture both temporal variability (the frequent monitoring at the master site to measure trends) and spatial variability (several sites for each lake to get at source attribution). The sites are rural to measure background or regional deposition and not hot spots from cities. IADN monitors for wet and dry deposition of PCBs, banned pesticides, and some PAHs. IADN measured trace metals historically, and the Canadian sites continue to do so. The U.S. sites do not yet include mercury deposition monitoring. However, both wet divalent and methylmercury will be sampled at Sleeping Bear Dunes, Michigan, beginning in late 2001. Data can be accessed from the Great Lakes National Program Office at http://www.epa.gov/glnpo/monitoring/air.

National Dioxin Air Monitoring Network (NDAMN). NDAMN is a relatively new research network that has only been in operation since 1998. The network has been implemented in stages, with only nine sites initially set out and 11 as of June 2000. The complete network consists of 30 sites that monitor ambient air for a suite of dioxins/furans and dioxin-like PCBs. The sites are located in predominately rural areas to measure background levels of dioxins/furans/PCBs contamination, allow for geographic comparisons of dioxins/furans/PCBs levels, and provide information on long-range transport of dioxins/furans/PCBs. For NDAMN information, contact http://www.epa.gov/ncea/1page.htm.

Interagency Monitoring of Protected Visual Environments (IMPROVE). IMPROVE sites are primarily located in national parks or wilderness areas. They collect ambient air data (not deposition) on aerosols, particulate matter (large and fine), and other visibility-related pollution. The sites are designed to provide data for federal visibility regulations, identify sources of man-made pollution that reduces visibility, and assess whether the goal of no man-made visibility impairment in national parks (Class 1 areas) is being met over the long term.

The IMPROVE Web site provides general public access to the data and information on network sites at http://vista.cira.colostate.edu/improve/Data/IMPROVE/improve_data.htm. Aerosol data for all 101 sampler locations, including carbon, are available in seasonal summaries by year on the University of California, Davis, FTP site at http://improve.cnl.ucdavis.edu.

National Air Monitoring Stations/State and Local Air Monitoring Stations/Special Purpose Monitoring Stations (NAMS/SLAMS/SPMS). NAMS, SLAMS, and SPMS are ambient air quality monitoring networks. NAMS and SLAMS have been maintained for many years, while SPMS

Definitions of Common Terms:

Primary particle: A pollutant that is emitted directly into the atmosphere.
Secondary particle: A pollutant that is formed in the atmosphere from a reaction between other compounds. Examples of secondary particles include most nitrogen compounds that are atmospherically deposited (nitric acid and ammonium nitrate) and sulfate.
Precursor: Compounds that react in the atmosphere to form pollutants. For example, NO_x and VOCs (volatile organic compounds) react to form ozone; they are called "ozone precursors." Since ozone is primarily formed in the atmosphere from these precursors, the precursors themselves are regulated to attain the ozone NAAQS (National Ambient Air Quality Standard).

may be run for intermittent periods of time, ranging from a few months to a few years. The available data usually include the six criteria pollutants: CO, O_3, NO_2, SO_2, lead, and particulate matter (PM_{10}). Some fine particulate matter ($PM_{2.5}$) and air toxics data are also beginning to be made available. Toxics generally have been monitored on the local scale for short periods of time.

EPA has led a major effort to establish a national $PM_{2.5}$ monitoring network to achieve both regulatory and research objectives related to the new ambient standard for respirable particulates. The $PM_{2.5}$ monitoring network consists of three major components: mass monitoring sites (several hundred NAMS/SLAMS sites), routine chemical speciation of the fine particulate sample fraction sites (select NAMS/SLAMS sites and SPMS sites, as part of research efforts), and targeted geographical areas for special research data collection efforts aimed at identifying links between health effects and fine particulates, commonly known as "Supersites." (Eight metro areas have been established: Phase I—Atlanta in 2000, Phase II—Baltimore, Fresno, Houston, Los Angeles, New York, Pittsburgh, and St. Louis in December 2000 through 2001.) For information about $PM_{2.5}$ monitoring efforts, access the EPA TTN Web AMTIC site at http://www.epa.gov/ttn/amtic/.

Estuaries at Which Atmospheric Deposition Data Have Been Collected

Atmospheric deposition studies outside the national monitoring networks have been conducted at these estuaries. You can contact the corresponding National Estuary Program or National Estuarine Research Reserve for additional information.

Albemarle-Pamlico Estuary (nitrogen and trace elements)
Casco Bay (PAHs, Hg, and nitrogen)
Chesapeake Bay (nitrogen and toxic compounds)
Coastal Bend Bay (nitrogen, PAHs, PCBs, some pesticides, trace metals)
Delaware Bay (nitrogen and trace elements including Hg)
Delaware Inland Bays (nitrogen and trace elements)
Galveston Bay (TRIADS [PAHs, PCBs, and pesticides])
Long Island Sound (nitrogen and Hg)
Massachusetts Bay (PAHs and metals)
New York/New Jersey Harbor and State of New Jersey (nitrogen and Pb, Ni, Cu, PCBs, PAHs, and dioxin)
San Francisco Bay (Hg, Cu, PCBs, and PAHs)
Santa Monica Bay (metals and organics)
Sarasota Bay (nitrogen)
Tampa Bay (metals, including Hg; ambient air concentrations of pesticides, PCBs, PAHs)
Waquoit Bay National Estuarine Research Reserve (nitrogen)

While ambient air data do not directly provide deposition rates, they do give a general picture of overall air quality and the potential for deposition. These networks are mostly managed by EPA's Office of Air Quality Planning and Standards and maintained by the various state and local agencies. Check with your state air quality agency and its monitoring group to find out where these sites are located and what they are measuring in your area. Data from all three networks are available from the EPA AIRData Web site at http://www.epa.gov/air/data/monitors.html.

Ambient Air Toxics Monitoring. The EPA is working with state and local air monitoring agencies to develop an air toxics monitoring network with the following objectives: to characterize air toxics problems on a national scale, to provide a means to obtain data on a more localized basis as appropriate and necessary, and to help evaluate air quality models. The goal is to build on monitoring already in place in state, local, and tribal programs, as well as other national networks. As the air toxics network is phased in, the pollutants to be monitored are expected to include several of the compounds of concern for air deposition, such as mercury, POM, and metals. More information can be found at http://www.epa.gov/ttn/amtic/airtoxpg.html.

Applicable Research and Local Studies

Apart from the national networks, other air deposition studies have been or are being conducted at the regional or local level. Information about these results can be found in the scientific literature. You also could contact the state or local environmental agencies or organizations that focus on particular waterbodies (e.g., National Estuary Programs, the Chesapeake Bay Program, the Great Lakes National Program Office) to get leads on research studies. The table below provides the results of monitoring studies on several waterbodies.

This is not an exhaustive list. The Atmospheric Exchange Over Lake and Oceans Study targeted the Lake Michigan and Chesapeake Bay areas for examining the impact of urban plumes from Chicago and Baltimore, respectively, on atmospheric loadings of trace metals, including mercury, and organics (PAHs and PCBs) on the waterbodies. Mass balance studies of individual waterbodies have been performed on Lake Michigan (PCBs, mercury trans-nonachlor, and atrazine) and Green Bay (PCBs, dichlorine, cadmium, lead) in Wisconsin. The Chesapeake Bay Atmospheric Deposition Study was designed to study the loads of a variety of trace metals and organic contaminants in the Chesapeake Bay. The New Jersey Atmospheric Deposition Network was designed to study deposition of PAHs; PCBs; a suite of pesticides, nutrients, and selected trace metals; and mercury to sensitive watersheds in New Jersey.

Modeling Exercises

Other potential sources of information for your paper study are results from deposition or air quality modeling runs that have already been done. Some models provide results on a national or regional scale; others on a more local scale. Descriptions of several models are provided in the chapter **"What You Need to Know About Air Deposition Modeling."** The programs listed in the Resources section in the back of this handbook are a good place to look for modeling that has been done. Another suggestion is to contact your state or local air pollution agency.

Atmospheric Nitrogen Loads Relative to Total Nitrogen Loads in Selected Great Waters*

Waterbody	Total Nitrogen Load (million kg/yr)	Atmospheric Nitrogen Load (million kg/yr)	Percent Load From the Atmosphere
Albemarle-Pamlico Sounds	23	9	38
Chesapeake Bay	170	36	21
Delaware Bay	54	8	15
Long Island Sound	60	12	20
Narragansett Bay	5	0.6	12
New York Bight	164	62	38
Based on ADN loads from the watershed only (excluding direct nitrogen deposition to the bay surface):			
Waquoit Bay, MA	.022	.0065	29
Based on ADN directly to the waterbody (excluding ADN loads from the watershed):			
Delaware Inland Bays	1.3	.28	21
Flanders Bay, NY	.36	.027	7
Guadalupe Estuary, TX	4.2 - 15.9	.31	2 - 8
Massachusetts Bays	22 - 30	1.6 - 6	5 - 27
Narragansett Bay	9	.4	4
Newport River Coastal Waters, NC	.27 - .85	.095 - .68	>35
Potomac River, MD	35.5	1.9	5
Sarasota Bay, FL	.6	.16	26
Tampa Bay, FL	3.8	1.1	28

ADN = atmospheric deposition of nitrogen

*Table from *Deposition of Air Pollutants to the Great Waters—3rd Report to Congress.* EPA-453/R-00-005, June 2000. Original literature references included in the report.

V. Time to Ask for Help!

If you have made it this far, you have a preliminary estimate that says air deposition may be significant. Now it is time to ask for help getting through the rest of the steps. No one can design and carry out an air deposition assessment by themselves; and, unless you are an atmospheric scientist, there will be a steep learning curve. So the most important tool you can find is a group of people who are willing to help and who have done this before.

Managers that have done atmospheric deposition assessments strongly recommend setting up some sort of advisory group to answer the science questions. Consider a variety of research scientists with different perspectives and expertise, such as national experts, scientists doing related work in the region, people with an understanding of how atmospheric deposition fits into the bigger picture of watershed management, and scientists from a local college or university. These experts will be able to advise you on many technical questions. For example, for a monitoring study, questions include site locations, what to monitor, how frequently to sample, methodologies to use, how to develop a quality assurance plan, and how to interpret the data collected. Similarly, for a modeling assessment, there are questions like what model to use, what data inputs to use, and how to interpret results.

You may also want to have local stakeholders involved with the advisory group from the beginning. These include representatives from environmental organizations, scientists and/or officials from different levels of government (e.g., federal, state, tribal, county, municipal), people working on related projects in the area, and representatives from industry. They could bring information and various perspectives that would positively affect the design of the assessment. For example, stakeholders from the governmental sector generally have a better understanding of the management questions than most scientific experts and can assist in framing the scientific dialogue about how to identify data needs and acceptable uncertainty levels. Many times, these kinds of stakeholders are instrumental in identifying opportunities for phasing data collection efforts, beginning with screening-level analysis, that may lead to increasingly sophisticated inquiries. Furthermore, since the local stakeholders may be expected to make decisions, make changes, or spend resources based on the study's findings, getting their buy-in to the study design could smooth the implementation process.

The advisory group should meet in person at least once at the program design stage to map out a data collection strategy they can all agree on. This is especially important in situations where the project is not similar to ones that have been done before, where there is no widely accepted method to answer the question(s) that need to be answered, or where the situation is controversial. If there are conflicting scientific views relating to the study design within your group, you may want to ask the scientists to try to reach consensus among themselves on one or a few approaches they could recommend. In this way, you will not be in the position of trying to reconcile conflicting technical advice. In addition, you will reduce the potential for later disagreements over the validity of the assessment.

After there is consensus on the strategy, most simple questions can be answered by telephone either one-on-one or in small conference calls. However, it is good to hold periodic open meetings or otherwise keep the advisory group involved as the process continues, both to take advantage of new research or other breakthroughs and to keep the "buy-in" that was developed at the beginning.

Colleges and universities are indispensable. Not only do they provide technical expertise and a link to the latest information from the academic world, they can often also help with resources. Some have equipment that can be borrowed, some have laboratories that can run samples for free or at a reduced cost, and they have a large number of low-cost hands available to work. For example, graduate students can collect samples and analyze them as part of their research, and data analysis can be done by classes of statistics students. This is not to say that there is always a wealth of resources waiting to be taken advantage of on local campuses. However, many students and professors look for practical applications for their research, and you need research for a practical application, so—see if you can help each other out!

Several managers who have gone through the process of setting up an air deposition assessment say it is critical to have at least one point-person you always go to first. This person should be part of the team, well-respected by the rest of the group and by you, and available to offer advice regularly. A point-person is indispensable in answering the "stupid" questions (which usually aren't) and generally provide both technical and moral support as you work your way up the learning curve.