

Metals such as arsenic, beryllium, cadmium, mercury, selenium, and lead are generally emitted as fine particulates and are adsorbed by the soil, depending on the soil's ion-exchange capacity. A worst-case model study assessed the impacts of these metals from a 1,000 MW plant (FWS 1978) and concluded that power plant emissions of these elements are generally not harmful, but that cadmium and selenium emissions are potentially of concern on soils with a naturally high concentration of the two metals.

In Maryland, acid, sandy soils of the Coastal Plain, and acid soils derived from crystalline rock in the Piedmont and Appalachian provinces, are potentially at risk from cadmium and selenium emissions over the long term because of their reduced cation exchange capacity. In addition, trace metals and some hydrocarbons can be incorporated into food chains (see below).

Impacts on Terrestrial Food Chains

Chemicals of greatest concern in food chains are those with a tendency to accumulate at higher levels in the chain. Nonthreatening concentrations in vegetation or herbivores may build up, by repeated exposure and storage in tissues, to toxic levels in predators (including humans). Bioaccumulating metals include cadmium and mercury. An even greater tendency to concentrate is exhibited by complex substances like dioxins and polychlorinated biphenyls (PCBs), which are metabolized extremely slowly and accumulate in fatty tissue.

Toxic contaminants emitted by combustion of fossil fuels are dominated by trace elements in the mineral matrix of coal, especially arsenic and mercury. Although arsenic is thought to be emitted in greater quantities than mercury, it is of less concern because it is not bioaccumulated to the same degree. Dioxins and PCBs are relatively rare due to high combustion temperatures and low concentrations of chlorine in coal.

The fate and impact of power plant contaminants once they enter the food chain can be estimated by a formal risk assessment. Although such assessments are usually conducted to evaluate human hazard, they identify contaminant concentration points in the terrestrial ecosystem and the results also apply to other top-level receptors in the system. PPER conducted such a risk assessment in connection with the certification process for the proposed Station H facility at Dickerson (PPER 1989).

The risk assessment included emissions from the proposed Station H, the proposed Montgomery County municipal waste incinerator, and the existing Dickerson steam generating station. Ambient ground level concentrations projected by an air quality dispersion model were used to estimate inhalation exposure. A terrestrial food chain model simulated the exposure pathways through soil, vegetation, domestic animals, and fish (see Figure 7-4). The total ingestion risk (summed for all three facilities) for a hypothetical most-exposed individual was less than 1 in 100,000. Only three constituents contributed significantly to the total ingestion risk: arsenic (65 percent), dioxins (25 percent), and PCBs (10 percent). This study is also discussed in Chapter 3, Section F.

Each pollutant accumulates in the food chain by different mechanisms, and hence follows different pathways to a top-level receptor such as humans. The predicted contribution of each pathway is shown for each pollutant in Table 7-8. Over 50 percent of arsenic (and most other metals) ingestion is from fruits and vegetables. The exception to this is mercury, which in its methylated form is readily absorbed and concentrated by fish. Over 90 percent of dioxins and PCBs is transmitted through herbivores (e.g., beef and dairy products), which acquire the contaminants by direct soil ingestion during feeding or from the surfaces or tissues of plants. Numerous factors including pollutant lifetime in and on soil, plant affinity for the pollutant, and animal behavior (or management) will determine the actual amounts that enter the food chain and are subject to bioaccumulation.

The overall ecosystem impact of the large number of toxic compounds emitted from fuel-burning power plants is unknown. Many of the compounds, including mercury, arsenic, dioxins, and PCBs, are accumulated at various points in the food chain. The Station H risk assessment, although subject to considerable uncertainty in its estimations, showed that most of these contaminants were likely to be emitted at such low levels that they would not result in significant health risks to humans. While this is indicative of the risks to other top-level receptors in Maryland's terrestrial ecosystems, wildlife will have a different mix of food sources, may accumulate toxic materials more efficiently, and may be exposed to additional non-power plant sources of contaminants.

Climate Impacts

Many power plant impacts are local in nature. However, emissions of gases to the atmosphere may have long-range or even global ecological impacts. The mechanism involved is the so-called "greenhouse" effect, whereby the accumulation of carbon dioxide and other radiatively active trace gases (water vapor, methane, nitrous oxide, ozone, and chlorofluorocarbons) in the atmosphere raises the temperature at the Earth's surface. Seemingly small average annual temperature changes can have profound impacts on terrestrial ecosystems through associated changes in precipitation amounts and patterns, growth rates, and seasonal maximum and minimum temperatures. This phenomenon is discussed in detail in Chapter 3, Section H.

Responses of ecological systems to possible global climate changes triggered by increased CO₂ concentrations in the atmosphere would be difficult to predict even if the exact pattern of the changes were known. Ecological systems are inherently complex and often interact with their physical environment in nonlinear ways. Both the rate of change and the degree of variability are important in determining whether a species will adapt to the changes or cross an extinction threshold (Strebel 1980, 1985). Similarly, history is important in determining what species are in an area or available to colonize it if conditions change.

Some recent estimates suggest that global average surface temperatures could ultimately rise by between 1.5 and 5.5°C (see Chapter 3, Section H). The actual

Table 7-8
Predicted contribution of exposure pathway to pollutant ingestion
associated with existing and proposed sources at the Dickerson site
(percent)

Pollutant	Exposure Pathway			
	Soil-human (direct ingestion)	Plant-human	Soil-animal- human	Plant-animal- human
Arsenic	34	59	5	2
Beryllium	14	86	<1	<1
Cadmium	2	85	2	11
Chromium	32	65	2	<1
Lead	27	48	19	6
Mercury	4	24	40	32
Nickel	1	82	3	13
Dioxin	<1	12	59	29
Formaldehyde	<1	99	0	<1
Polynuclear aromatic hydrocarbons	6	58	14	22
PCB	1	3	48	48
Source: PPER 1989.				

increases will be greatest in midcontinental areas; Maryland's climate could be moderated by coastal waters. Nonetheless, changes of this magnitude would cause many species ranges to move northward by several hundred kilometers, within the next 100 years. For example, beech could be expected to retreat to New England and Canada, disappearing from Maryland's ecosystems (Roberts 1989). Records of previous climate changes preserved in fossils show clearly that ecological communities may be disassembled and new combinations of species assembled in response to the new climatic conditions (Davis 1981).

Thus the projected warming could reconfigure Maryland's ecosystems. In general, a more southerly set of species would be expected. As a first approximation, since elevation can compensate for latitude, a shift of Coastal Plain species to the Piedmont, Piedmont species to the Appalachian Province, and disappearance of many current Appalachian Province species could be expected. Crop species that can tolerate the new conditions may actually be more productive, since higher levels of carbon dioxide generally increase yield for a single species. The response of natural ecosystems, however, is much more complex due to the multiple species interactions with each other and with precipitation and soil nutrients (CGC 1988).

An additional consideration is change in the sea level as the warming causes glacial ice to melt. Projections are that sea level may rise by as much as 1 cm/year during the next century (CGC 1988). This will cause major dislocations in estuarine, marsh, and nearshore ecosystems. The information currently available suggests that intertidal wetlands have a maximum rate of growth along a gradient in the same 1 cm/year range (Boamann *et al.* 1984). Freshwater wetlands may also be affected as salt wedges penetrate further upstream. These impacts would be of major concern to Maryland.

Overall, there is general scientific agreement that the global climate is likely to change, possibly rapidly, in the next 100 years, if the rate of global warming and mean temperature rise continues. There are no conclusive measurements to indicate that this change has started, or how rapid it will be. One common hypothesis is that the change will be caused primarily by CO₂ emissions from combustion, including burning fossil fuels by power plants. To date, it appears that Maryland's power plants contribute, and have contributed, a small but measurable fraction to the CO₂ problem. The climate change and ecological effects of increased atmospheric CO₂ are currently unpredictable except in very broad outline. They could, however, include dramatic alterations of Maryland's terrestrial systems over the next 100 years.

D. Summary

The construction and operation of power plants may affect terrestrial ecosystems by direct habitat alterations, air emissions that are later deposited on the land or water surface, or emissions that alter the balance of atmospheric gases and initiate changes in climate. Direct alterations of habitat due to existing power plants are generally localized in extent and without impact on critical or unique

habitats. The impact of emissions of gaseous or particulate contaminants on terrestrial ecosystems has not been subject to long-term studies in Maryland. While there appears to be the potential for damage to some ecosystems, there is no evidence that such damage has actually occurred.

There is a potential for impacts from new construction of dams, plants, or landfills. In most cases, adverse effects of such activities could be avoided by careful site location and planning. Of significant concern would be any need to modify or disrupt water flow patterns in a way that would impact regulated wetlands areas. Also of concern would be the impact of gaseous and particulate emissions, which would add to the cumulative effect of such contaminants from other sources.

Large-scale impacts are possible if the current build-up of carbon dioxide in the atmosphere, to which Maryland's power plants contribute, causes rapid shifts in climate. Such shifts, which are currently thought to be probable, would most likely replace many of the components of Maryland's ecosystems with more southerly species. Control of carbon dioxide emissions is only possible over an extended period and would have no immediate impact on the problem.

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F. Glossary

Bioaccumulation. The processes by which a chemical is taken in by a living organism faster than the chemical can be released, resulting in increasing concentrations of the chemical in the tissues of the organism.

Criteria pollutant. Pollutant for which the U.S. EPA has established a National Ambient Air Quality Standard. There are currently six criteria pollutants: particulate matter, sulfur dioxide, nitrogen dioxide, ozone, carbon monoxide, and lead.

Ecosystem. The interacting system of a biological community and its nonliving surroundings.

Noncriteria pollutant. Pollutant for which EPA has not established a National Ambient Air Quality Standard.

Nontidal wetland. Wetland in which the water regime is not affected by the tides; instead, water level varies with changes in the local water table, rainfall, season, and water levels in nearby streams or rivers.

Physiographic province. A region characterized by similar geologic structure and climate.

Riparian. Related to or located in or along the bank of a stream or river.

Saprolite. Soils formed from the disintegration of rock.

Stomata. Openings in plant leaves through which gases are exchanged with the atmosphere.

Tidal wetland. Wetland, for example a tidal marsh or river floodplain, in which the water regime is affected by the rise and fall of the tides.

Wetland. Area covered with or saturated by water for a sufficient period of time during the growing season each year to support certain types of "water-loving" or hydrophytic vegetation.

CHAPTER 8

ACID DEPOSITION

A. Introduction

The deposition of acidic materials, commonly termed "acid rain," and its potential ecological and economic effects have been vigorously discussed at all levels of government from international to local. Acid deposition may adversely affect physical, terrestrial, and aquatic resources. In certain terrestrial and aquatic ecosystems, heightened acidity has been observed to cause chemical (e.g., increased metals concentrations) or biological alterations (e.g., reduced fish populations or growth). In addition, acid deposition has been reported to accelerate damage to some construction materials. Because the precursors of acid deposition are abundant in fossil fuel power plant emissions (see Chapter 3), they are of concern when discussing the environmental impacts of electrical power generation in Maryland.

The following section summarizes the major technical issues and scientific findings concerning the formation and potential effects of acid deposition on environmental and economic resources in Maryland. Measures for controlling acid deposition, and the recommendations of the Governor's Work Group on Acid Deposition, are also discussed. A more detailed discussion of acid deposition can be found in the annual acid deposition reports submitted to the Governor and the General Assembly (PPRP 1987, 1988; CBRM 1989a, 1990).

B. The Acid Deposition Process

Acid deposition is defined as acidic precipitation (rain, snow, fog) and/or acidic dry deposition (gases, aerosols, particulates). The acid deposition process is illustrated in Figure 8-1. Deposition and precipitation become acidic through interactions with acid precursors such as nitrogen and sulfur oxides and, to a lesser extent, volatile organic compounds. These compounds originate largely in man-made sources such as power plants, automobiles, and factories, and also from natural sources such as fires, volcanos, and marshes. Sulfur and nitrogen oxides, as they are transported through the upper atmosphere, react with water vapor, sunlight, and other atmospheric pollutants (particularly ozone) to produce sulfates (SO_4) and nitrates (NO_3). These oxidized forms of sulfur and nitrogen are acidic and cause the elevated concentrations of free hydrogen ions (H^+) associated with acid deposition. Volatile organic compounds can act as organic acids contributing to deposition acidity but can also influence the production of ozone.

The acidity of aqueous solutions, including precipitation, is normally measured on the pH scale, which ranges from 1 (acidic) to 14 (basic). A pH of 7 is neutral (neither acidic or basic), and a change of one pH unit represents a tenfold change in acidity (H^+ concentration). Studies in remote areas suggest that the pH of rain unaffected by man-made emissions is not neutral but is approximately 5.0 as a result of natural emissions (NAS 1983). In Maryland, the mean annual pH of

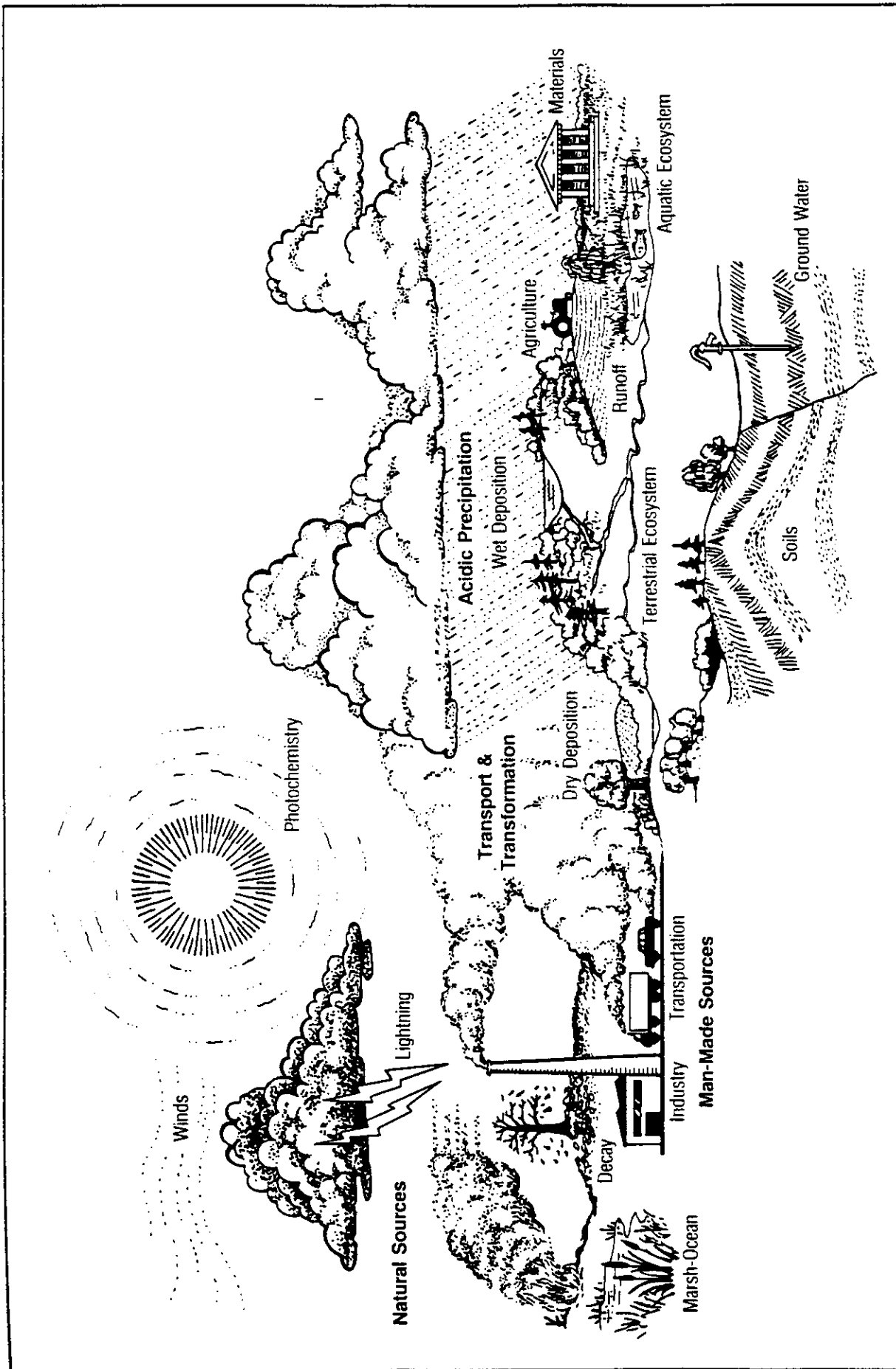


Figure 8-1. The acid deposition process

rainfall is between 4.2 and 4.3, or roughly ten times as acidic as natural rainfall (NADP 1989).

The degree of damage or alteration to terrestrial, physical, and aquatic resources potentially caused by acid deposition depends on the atmospheric concentration of acidic precursors, the hydrologic pathways of precipitation, and the interaction of precipitation with the vegetation, soils, or geologic components of a watershed. The remainder of this chapter discusses the interaction of acid deposition with watershed components; measures taken to reduce the emissions of acid deposition precursors; and recent findings of acid deposition monitoring programs, as well as studies of the effects of acid deposition in terrestrial, aquatic, and physical resources.

C. Emissions and Transformation of Acid Precursors

Emissions

Sulfate and nitrate concentrations in precipitation have been shown to have the greatest influence in determining its acidity (Endlich *et al.* 1986; Maxwell and Mahn 1987). The primary sources for sulfates and nitrates in the atmosphere are sulfur dioxide (SO₂) and nitrogen oxides (NO_x). In 1987, power plants accounted for approximately 85 percent of the total annual stationary source sulfur dioxide emissions in Maryland; industrial sources were responsible for most of the rest. The change in total annual SO₂ emissions in Maryland over the 12-year period 1975 through 1987 is illustrated in Figure 8-2. While this time period saw a slight decrease in total annual SO₂ emissions, annual power plant emissions actually increased slightly.

The 1987 SO₂ emissions for the major power plants in Maryland are shown in Table 8-1. The bulk of the power plant emissions in Maryland comes from older facilities, built between 1950 and 1975. The older facilities were expected to operate for 30 to 40 years, implying retirement dates in the mid-1990s to early 2000s (ERM 1987). Because of the cost of building new plants, and operational concerns such as reliability, availability, and new plant siting, utilities such as PEPCO and BG&E are considering the development of programs that will probably extend the operational life of base load plants to about 60 years. Unless the emissions characteristics of these plants are changed by use of low-sulfur fuel or emission controls, annual SO₂ emissions in Maryland are likely to rise due to increased electricity consumption until these plants are retired.

Automobiles and other mobile sources account for approximately 45 percent of the approximately 209,000 tons of NO_x emitted annually in Maryland (MAMA 1989). Power plants contributed about 40 percent of statewide NO_x emissions, while industrial sources accounted for the remainder. Figure 8-3 shows the annual total nitrogen oxides emissions in Maryland over the 12-year period 1975 through 1987. Nitrogen oxides emissions decreased over this period, although the last three years' emissions remained relatively constant.

Table 8-1
1987 SO₂ and NO_x emissions by plant for utility power plants in Maryland

	SO ₂		NO _x	
	Tons	lbs/MMBtu	Tons	lbs/MMBtu
BG&E				
Gould	853	1.06	560	0.44
Riverside	1,633	1.09	1,396	0.45
Westport	595	1.06	553	0.44
Wagner (2&3)	13,679	--	9,032	--
Brandon Shores	19,994	1.06	9,740	0.45
Crane	25,313	2.69	12,646	1.45
Total	62,067		33,927	
PEPCO				
Morgantown	83,000	2.66	16,446	0.6*
Dickerson	38,774	2.19	11,029	0.6
Chalk Point	57,277	--	17,076	--
Total	179,051		44,551	
APS				
R.P. Smith	4,540	1.49	2,494	0.87
Total	4,540		2,494	
DP&L				
Vienna	4,483	1.64	624	0.32
Crisfield	3	0.19	34	0.49
Total	4,486	1.83	658	0.81
EASTON				
Easton	78	--	915	--
Total	78	--	915	--
TOTAL UTILITY EMISSIONS	250,222		82,545	

Source: MAMA 1987 emissions inventory

* Estimates for NO_x provided by PEPCO are the following (Cline 1990):

Morgantown 1 and 2	0.9 lbs/MMBtu
Dickerson 1,2,3	0.7
Chalk Point 1 and 2	1.4
Chalk Point 3	0.4 (oil)
Chalk Point 3	0.2 (gas)
Chalk Point 4	0.3 (oil)
Chalk Point 4	0.2 (gas)

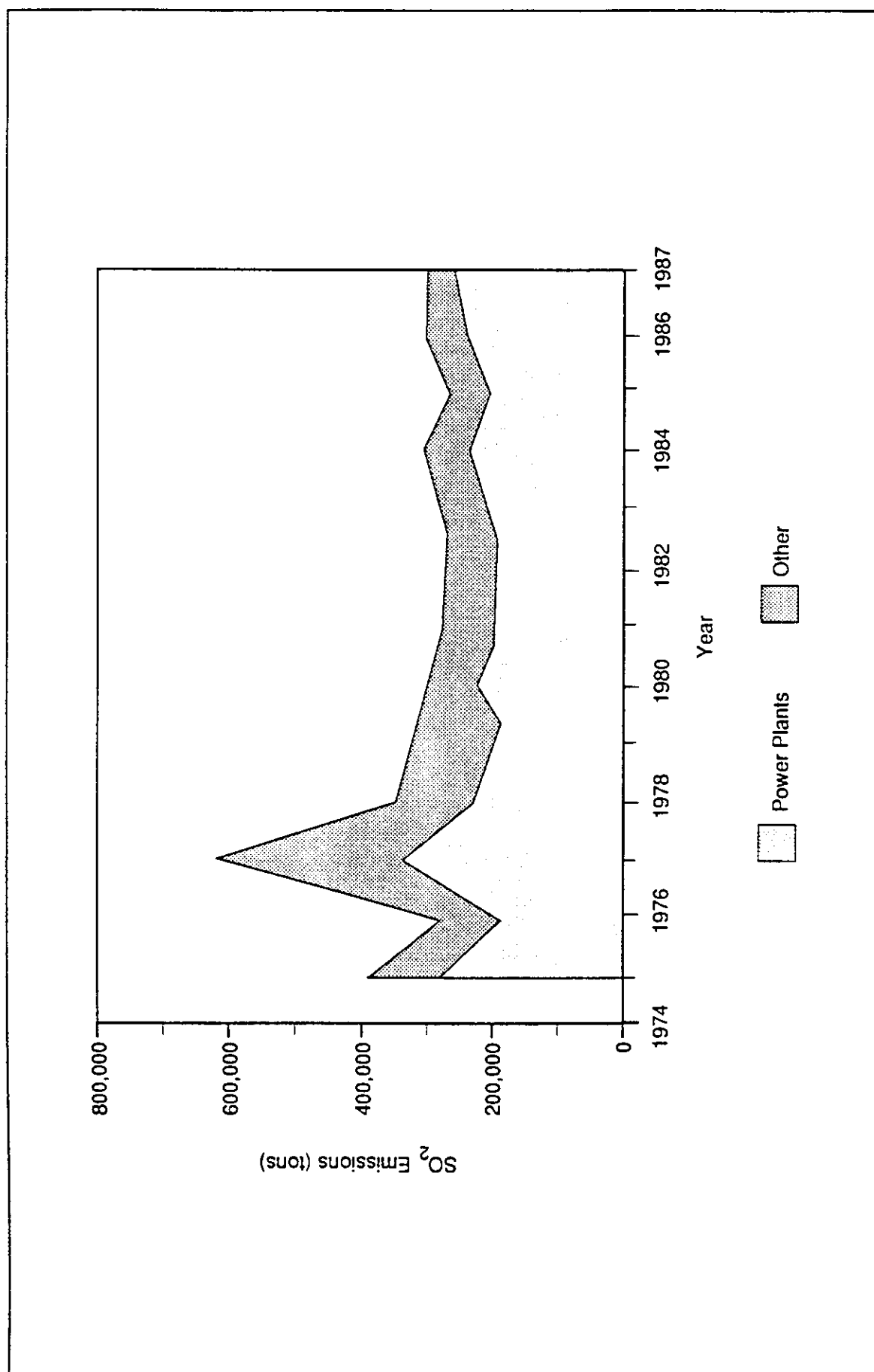


Figure 8-2. Sulfur dioxide emissions for Maryland, 1975 - 1987

Source: Ferri 1986; MAMA 1989

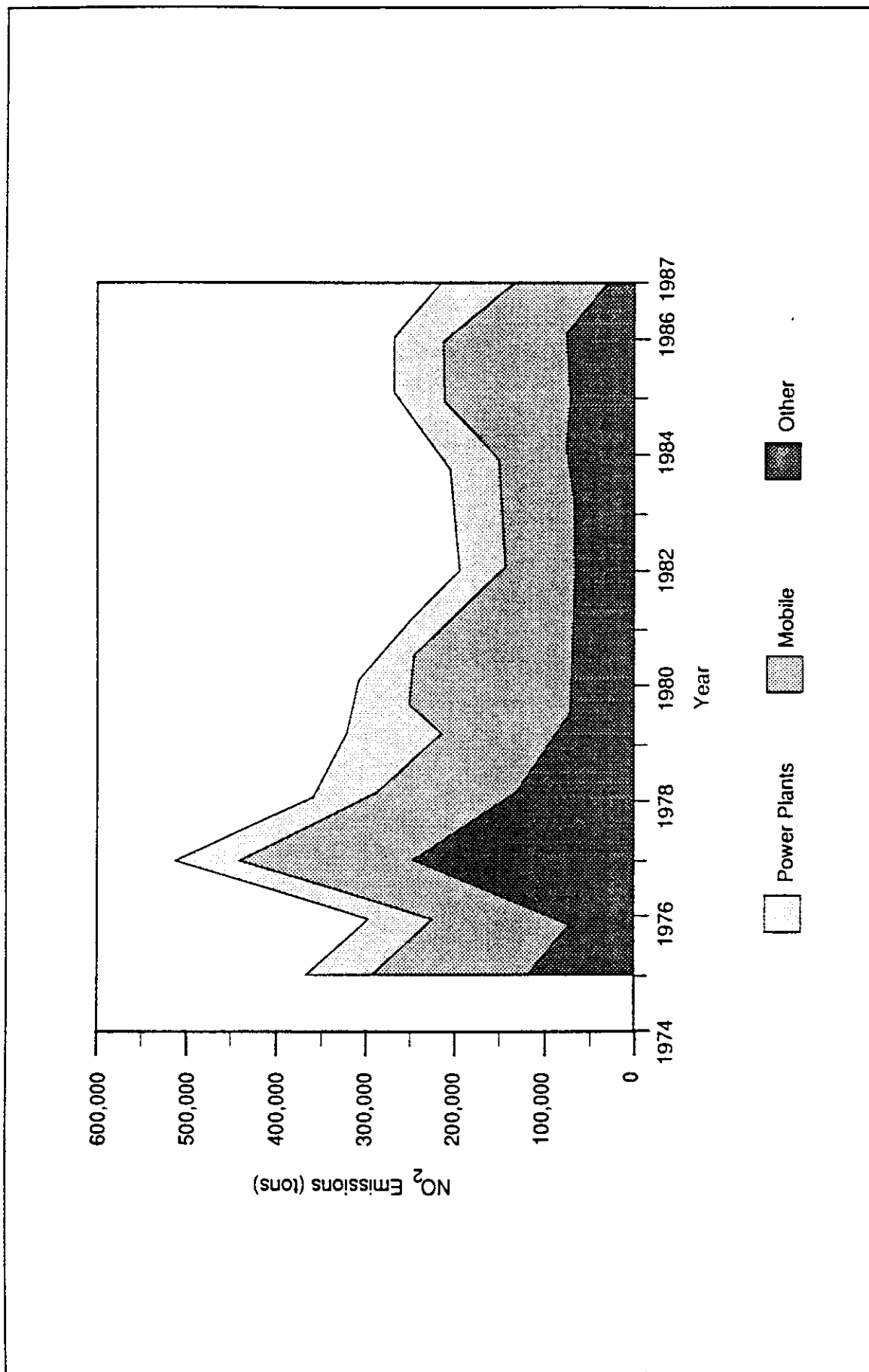


Figure 8-3. Nitrogen oxide emissions for Maryland, 1975 - 1987

Source: Ferren 1986; MAMA 1989

- **Transport and Transformation of Acid Precursors**

Following emission, the precursors of acid deposition may be transported by wind at many levels in the atmosphere. Emissions from some sources are transported within the lowest level of the atmosphere, called the mixed or mixing layer, while others are transported at higher levels. The transport level depends on the height at which the pollutants are released, their temperature at release, ambient air temperature, wind speed, and other factors. Pollutants emitted above the mixed layer have a higher probability of being transported long distances before being deposited. They are also more likely to become embedded in clouds. Pollutants emitted in the mixed layer tend to become well mixed throughout the layer.

The Maryland Department of Natural Resources' Chesapeake Bay Research and Monitoring Division (CBRM) reported that as much as two-thirds of all deposition in Maryland originates from out-of-state sources. Modeling studies have shown that the primary source regions of acid deposition precursors for Maryland are the states to the west and southwest (CBRM 1989a).

Once airborne, the acid precursors may undergo chemical transformation (oxidation) to form acids and acid-producing compounds. The two main pathways of chemical transformation involve reactions in dry air (gas phase) and in liquid water drops (liquid phase) suspended in the air (such as found in clouds and fogs). The chemical reactions depend on many meteorological and atmospheric variables, such as solar radiation intensity, the number and type of clouds, relative humidity, and the presence of other pollutants (e.g., volatile organic compounds) or oxidants (e.g., ozone and hydrogen peroxide). Chemical transformation reactions such as the conversion of SO_2 to sulfate (SO_4) usually occur within days of emission (Pierson *et al.* 1989).

D. Deposition

Deposition may be either dry or wet. Dry deposition consists of gases, particulates, and aerosols (suspensions of fine particles in gases) that are deposited on a surface during periods without precipitation. It varies significantly from location to location because of changes in land use. For example, forests are more efficient than urban areas in removing gases from the air because plants absorb gases through the stomata (pores) on the undersides of leaves. Physical factors such as wind speed, surface wetness, atmospheric stability, and terrain may also affect dry deposition.

Wet deposition occurs in the form of precipitation -- rain, dew, fog, snow, or sleet. It differs from dry deposition in that liquid-phase chemical reactions occur in and below clouds far from emission sources. The principal issues currently being addressed through research into wet deposition concern the variation of deposition chemistry as a function of time, precipitation type, and the life cycles of storms.

Deposition Monitoring

- Dry Deposition Monitoring Programs

The National Dry Deposition Network (NDDN) has been established under the National Acid Precipitation Assessment Program (NAPAP). The NDDN sites are typically located in rural and remote areas throughout the country. They continuously measure wind speed, wind direction, temperature, temperature change, relative humidity, solar radiation, ozone, and precipitation. In addition, the stations measure sulfur dioxide, sulfuric acid, and acidic aerosols to provide weekly daytime and nighttime averages. One NDDN site is located at the Agricultural Research Center in Beltsville, MD.

- Wet Deposition Monitoring Programs

Currently, four wet deposition monitoring sites in Maryland form part of regional or national networks (Figure 8-4). Two sites, Wye and White Rock Stations, are part of the National Acid Deposition Program (NADP) monitoring program; the other two are operated by the Maryland Air Management Administration.

By combining data collected from these four sites with data from others in neighboring states, the spatial distribution and long-term trends in precipitation acidity over a multi-state region can be examined. The two NADP monitoring stations located in Maryland have been operating since 1983 and 1984, respectively. In 1988 (the most recent year with complete data), the annual average pH observed at the Wye and White Rock stations was 4.34 and 4.18, respectively (NADP 1989).

The monitoring results from the Maryland Air Management Administration monitoring stations are similar to NADP results. At Rocky Gap, the annual average pH is 4.1. In comparison, at the Elms station the annual average pH has been between 4.3 and 4.4. These pH measurements have an accuracy of ± 0.01 pH units.

E. Acid Deposition Impacts

Acid deposition can adversely affected terrestrial and aquatic ecosystems, and can contribute to the deterioration of physical resources and the incidence of human health problems, particularly those related to respiratory ailments. Commonly reported effects of acid deposition include the following:

- changes in surface water chemistry such as increased acidity and trace metal concentrations; these changes can be harmful to aquatic biota, most notably fish;
- forest decline and reduced crop yields in areas of the United States and Europe, which may be related to the effects of acid deposition either singly or in combination with ozone;

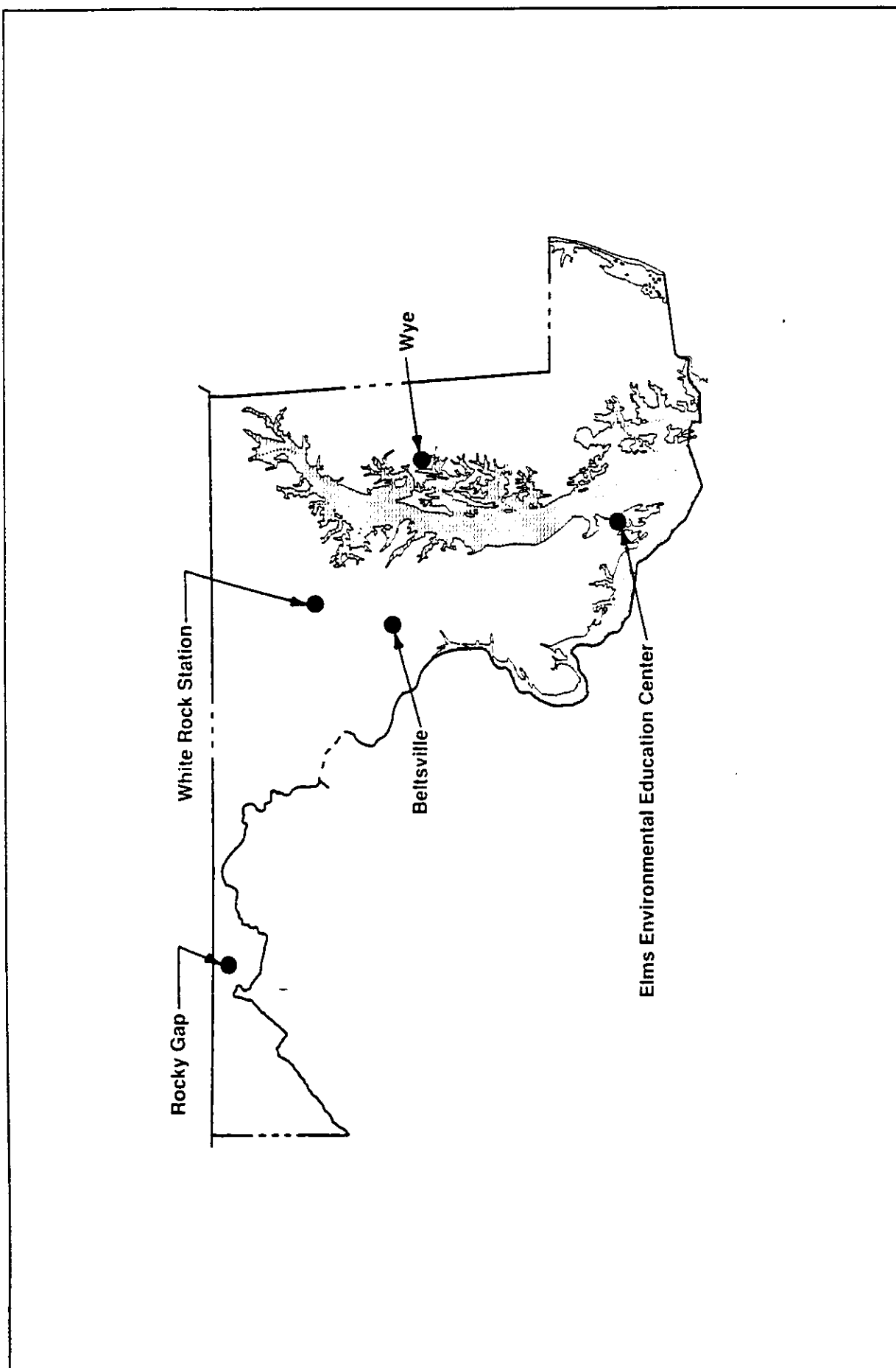


Figure 8-4. Locations of Maryland deposition monitoring sites operating in 1989

- increased eutrophication of waterways resulting from deposition of nitrate;
- potential human health effects; researchers are currently evaluating the effects of acid deposition precursors on respiratory ailments and illnesses and on health effects associated with consumption of acidified water supplies; and
- damage to materials and cultural resources.

The following sections provide an overview of the effects of acid deposition on potential receptors.

Surface Water Effects

The response of surface water systems to acid deposition depends on the relative contribution of baseflow (ground water that flows into the stream), interflow (water within the soil zone that is often perched above the ground water table), and overland flow (run-off from the surface into the stream) to the system, and the ability of watershed components to neutralize acidity. The influence of acidifying compounds can be reduced by buffering interactions with vegetation, mineral weathering reactions, adsorption of the acidifying agents onto soil surfaces, or buffering processes within the stream or lake. Figure 8-5 illustrates the pathways of acid deposition through a watershed.

Surface waters sensitive to acidification characteristically exhibit low-to-moderate pH and acid neutralizing capacity (ANC). The ANC is the capacity for solutes in an aqueous solution to react with and neutralize acid. As such, it provides an index of the sensitivity of streams to acidification (Bricker and Rice 1989). In national and Maryland-only studies, an ANC of 200 microequivalents per liter ($\mu\text{eq/l}$) or less indicates stream sensitivity to chronic acidification and susceptibility to episodic acidification (Kaufmann *et al.* 1988; Knapp *et al.* 1988). Sensitive streams may also exhibit reduced concentrations of basic cations such as calcium and magnesium, which are important in buffering changes in pH, and elevated concentrations of trace metals such as aluminium, zinc, and nickel.

The acidification status of a stream may also be characterized as a function of the sensitivity of fish that might inhabit those streams at low pH conditions. In the North and South Coastal Plain areas of Maryland, where anadromous fish such as blueback herring spawn, a pH below 6.5 indicates streams in which fish populations are potentially affected by acidification (Klauda and Palmer 1987). In upland areas of the state (Piedmont, Blue Ridge and Valley and Ridge Provinces, and the Appalachian Plateau), a pH below 6.0 indicates streams in which anadromous fish populations such as bass, walleye, and trout are potentially affected by acidification.

Assessing the potential effects of acid deposition on surface waters requires identifying areas that exhibit low buffering capacities and elevated metals concentrations. NAPAP's National Surface Water Survey was primarily an effort

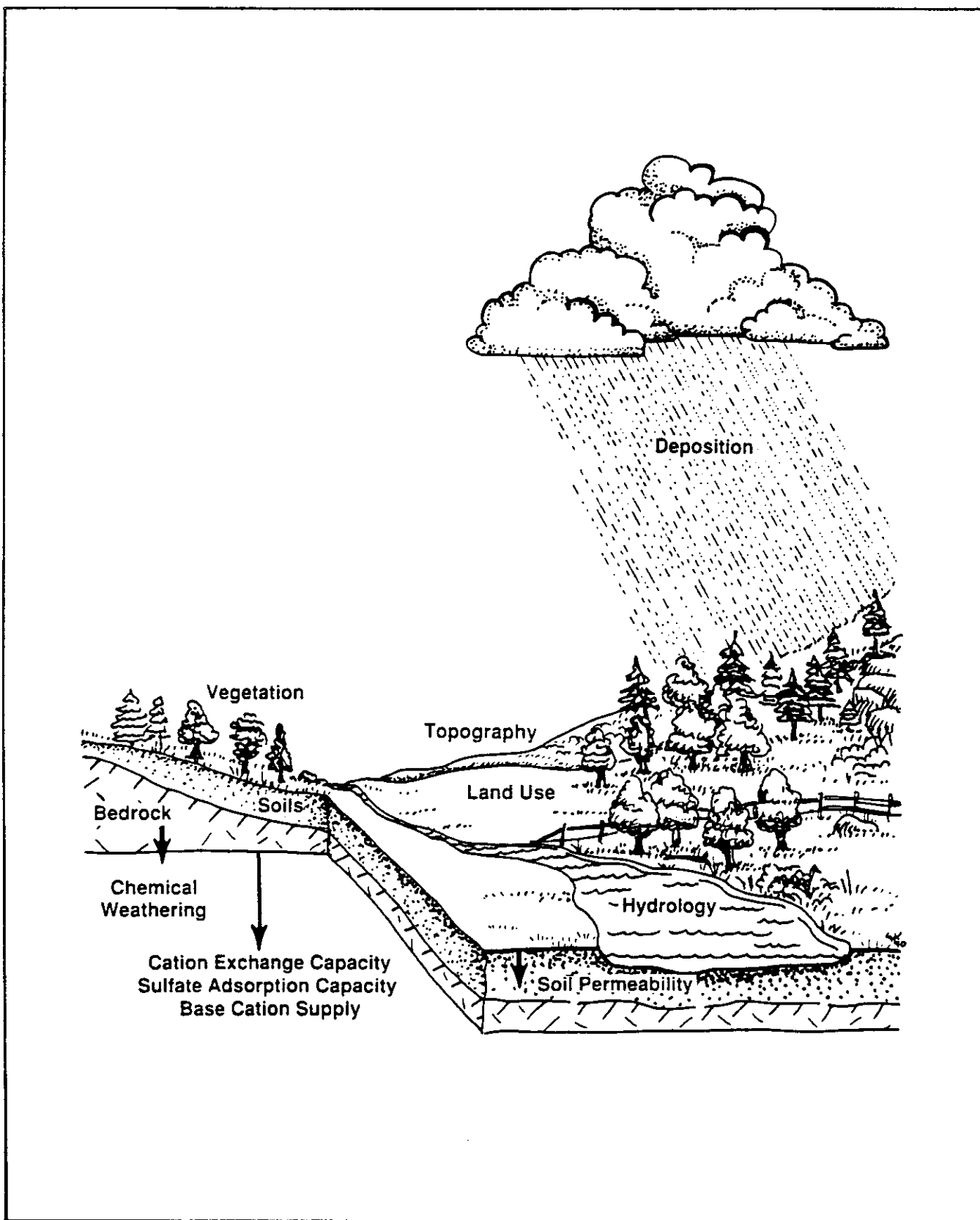


Figure 8-5. Key watershed characteristics that influence the response of surface water to acid deposition

to determine the extent, location, and characteristics of lakes (National Lake Survey) and streams (National Stream Survey) in the United States that either are sensitive to acidification or have already become acidified. This survey found that the greatest percentage of acid-sensitive lakes in the eastern United States were located in Florida and in the Adirondack Mountains region of New York (Linthurst *et al.* 1986). In the western United States, the greatest percentage of sensitive lakes was found in the mountainous regions; the highest proportion of acidic lakes (pH <6.0) in the western United States was found in the Pacific Northwest (Landers *et al.* 1987).

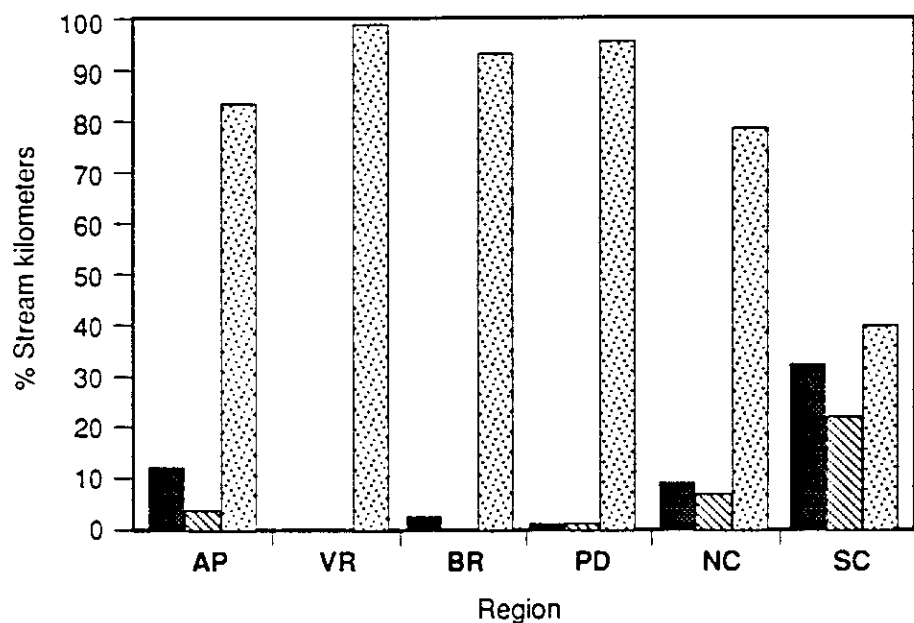
The National Stream Survey found that the highest percentage (60 percent) of acid and acid-sensitive streams in the mid-Atlantic Region of the United States (including Maryland) were in the Northern Appalachian Subregion; 7 percent of the total length of streams surveyed in this region were found to be acidic. In the Mid-Atlantic Coastal Plain, 46 percent of streams surveyed were found to have pH values less than 6.0; 52 percent of the streams in this region had an ANC less than 200 $\mu\text{eq/l}$. Few acidic streams were found in the Valley and Ridge province during the National Stream Survey. Similar studies sponsored by the State of Maryland (Knapp *et al.* 1988) have found that approximately one-third of all streams in Maryland are sensitive to acidification (ANC <200 $\mu\text{eq/l}$) or are already acidified. Statewide an estimated 2,258 km (1,400 miles) of streams were found to have pH levels indicating possible adverse effects on fish populations (Figure 8-6). These streams are present in all physiographic provinces in Maryland; the highest percentages of acid-sensitive and acidified streams are found in the southern Coastal Plain (74 percent) and the Appalachian Region (52 percent).




Episodic Acidification

In Maryland, as in much of the Mid-Atlantic and Southeastern United States, surface waters may experience rapid increases in acidity (episodic acidification) during precipitation events. Episodes of low pH in streams and rivers also occur during spring snowmelt, when several months of accumulated deposition may be released. Spring episodes are a particular concern in Maryland because it is at this time of year that migratory fish such as blueback herring and yellow perch spawn in acid-sensitive Coastal Plain streams.

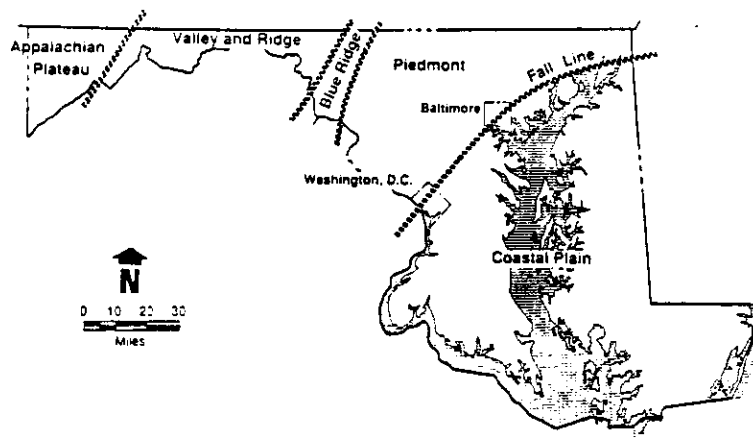
Results obtained by the Maryland Stream Doser Project in 1987 indicated that pronounced changes in stream chemistry may occur during storm events (Janicki and Greening 1988). This multi-year study was designed to evaluate the ability of automated wet calcite slurry dosers to neutralize acidic episodes in two Coastal Plain streams that are used for spawning by several anadromous fish species. In this study, both surface water pH and ANC declined while aluminum concentration increased following precipitation events. With few exceptions, the use of dosers on these streams neutralized pulses of acidity in response to storms.

Adverse effects of acidic episodes are associated primarily with increased hydrogen ion concentrations and elevated levels of dissolved metals. Metals concentrations are increased because of pH-related mobilization or leaching of potentially toxic metals (e.g., aluminum, cadmium, copper, zinc, lead,



 pH < 6.0
 pH 6.0 - 6.5
 pH > 6.5

AP = Appalachian Plateau
 VR = Valley & Ridge
 BR = Blue Ridge
 PD = Piedmont
 NC = North Coastal Plain
 SC = South Coastal Plain



Physiographic provinces of Maryland

Figure 8-6. pH data (percentage of stream kilometers) from the Maryland Synoptic Stream Chemistry Survey

Source: Knapp et al. 1988

manganese) from soils and aquatic sediments (Baker and Schofield 1982; Hutchinson and Sprague 1986).

Effects of Surface Water Acidification on Biological Resources

The negative effects of acidification on fish have been documented in a number of studies (Haines 1981; Baker and Schofield 1982; Hall 1987; Klauda *et al.* 1987). Several researchers (Johnson *et al.* 1987; Hilden and Hirvi 1987) have shown that reduced pH alone is the most important toxic agent and serves as the best indicator of toxic conditions to fish. Hendrey (1987) provided a review of data that has been important in generating hypotheses that link acid deposition and other stresses to a reduction in fish stocks in the Chesapeake Bay and other East Coast estuaries. Buckler *et al.* (1987), in laboratory bioassay experiments with striped bass, found that susceptibility to aluminum toxicity is both age- and pH-dependent. Research on the effects of acidification on other biological resources (amphibians, birds, mammals) has demonstrated that acidification and associated increases in metals concentrations also affect these animals (PPRP 1988; CBRM 1989a).

The most widely postulated consequence of acid deposition is the reduction or elimination of fish populations in response to surface water acidification (Haines 1981; Dillon *et al.* 1984; NRC 1986). Under acidic conditions (pH 4.5 to 5.5) aluminum has been shown to become an important cation in surface waters (Nordstrom and Ball 1986; Hall 1987). Aluminum concentrations exceeding critical thresholds can have deleterious effects on fish (Baker and Schofield 1982). The dominant mechanisms of acute pH and aluminum toxicity to fish are respiratory distress caused by gill malfunction, failure to maintain acid-base balance in the blood, decreasing blood levels of sodium chloride, and osmotic disturbances (Wood and McDonald 1982; Witters 1986; Jones *et al.* 1987). Recent modeling approaches have suggested that heavily exploited fish stocks at low abundance levels are very susceptible to additional stress such as that caused by increased acidity (Schaaf *et al.* 1987).

The most important direct effects of acidification on the abundance and species diversity of fish in a given surface water body appear to be acute mortality, reproductive failure, and avoidance (Wood and McDonald 1982; Witters 1986; Jones *et al.* 1987). Other chronic effects such as skeletal deformities and reduced growth have also been reported. Reproductive failure is regarded as the major cause of fish population extinction in acidified waters. Also, exposure to sublethal reductions in pH may ultimately increase fish mortality, but as yet there are no supporting data for this hypothesis. Reduced pH may cause fish mortality through decreased resistance to diseases, habitat degradation, changes in predator-prey relationships, increased bioavailability of toxic substances, and synergistic and additive effects of environmental stresses (Fraser and Britt 1982).

Aquatic organisms at all levels display varying degrees of tolerance to the chemical alterations commonly found in acidified surface waters. In general, benthic macroinvertebrates -- particularly mysids, amphibians, and crayfish -- appear to be acid-sensitive. In early life stages, plankton, reptiles, and

amphibians are also relatively intolerant of low pH. Most existing knowledge of the sensitivity of fish to acidic surface waters concerns species commonly found in inland lakes and streams.

Three anadromous species common to Maryland waters -- striped bass, blueback herring, and American shad -- are among the most sensitive fish species yet studied. Using laboratory and field bioassays and water quality and contaminant measurements, Hall (1987) confirmed that Eastern Shore striped bass spawning streams (Choptank, Nanticoke, and Pocomoke Rivers) are susceptible to acidic conditions and that low pH, low hardness, and elevated aluminum levels resulted in high mortality of striped bass larvae. Laboratory studies with blueback herring have shown reduced survival of young embryos (24 hours post-fertilization) at pH 5.0. Shad have been found to be more sensitive to low pH (5.7 to 7.5) when aluminum (50 to 400 $\mu\text{g/l}$) is present (Klauda *et al.* 1987). Other common Maryland freshwater species -- smallmouth bass, walleye, and rainbow trout -- are also affected by water quality conditions (pH <6) that might be expected to occur in sensitive Maryland watersheds. Acidic episodes such as those associated with snowmelt and intense rainstorms can severely stress the early life stages of finfishes and are often more detrimental to fish survival than long-term, gradual habitat acidification processes.

NAPAP released public review drafts of its State of Science and Integrated Assessment reports in 1990. These reports will be reviewed in CBRM's 1990 annual acid deposition report with respect to findings that pertain to Maryland. As an example, the Integrated Assessment report states that, based on the results of stream chemistry surveys and toxicity modeling, the mid-Atlantic Coastal Plain has the highest proportion of streams with chemical conditions stressful for fish of all surveyed regions of the country. An estimated 60 percent of upstream sites have chemical conditions during spring baseflow that in the laboratory would result in 50 percent or greater mortality of acid-sensitive anadromous fish species such as blueback herring (NAPAP 1990).

Terrestrial Resources

No studies of the effects of acid deposition on forests and agricultural crops in Maryland under ambient conditions are available, but the results of programs conducted elsewhere are directly applicable. National studies of forest and crop resources similar to those found in Maryland indicate that, at the levels of deposition now occurring in the state, little if any damage is likely to occur. The types of trees and crops grown in Maryland, and their relatively low elevation, limit the vulnerability of these resources to acid deposition-induced change (PPRP 1987).

- Forests

Acid deposition enters a forest ecosystem along a number of pathways in a variety of forms. When it impinges on the forest system, it may either enter the soil directly or interact with the leaves and branches of the canopy. Interaction with the canopy may either increase or decrease acidity (Reuss and Johnson 1986).

Increased acidity results from a washout of organic acids or dry acid deposition from the canopy; decreased acidity may result from an exchange of H^+ ions in the precipitation for base cations in leaves or other plant tissues in the canopy. It is important to remember that, although acidity resulting from washout and dry deposition does represent a net increase in acid loading over and above the amount in rainfall, washout of organic acids is a naturally occurring process. The low pH in throughfall may therefore be representative of natural acidity and not necessarily acid deposition.

All forests experience natural stresses caused by plant competition, nutrient limitations, adverse weather, insects, disease, and other factors. Stresses created by human activities, such as regional air pollution, can also impair forest health. To date, controlled exposure research shows no direct foliar effects to seedlings from acidic deposition or gaseous sulfur dioxide and nitrogen oxides at regional ambient levels in the United States (NAPAP 1988). Gaseous ozone has, however, been shown to be injurious to tree seedlings at concentrations above 0.05 ppm and is believed to be the leading pollutant stressing high elevation eastern white pine forests (NAPAP 1988). The daily mean concentration of ozone in much of Maryland is between 0.04 and 0.07 ppm but has been reported to be as high as 0.16 ppm (MAMA 1986). Therefore, some high elevation forests in Maryland may be susceptible to ozone stress.

Indirect effects of air pollutants on forest health are less understood. Changes in soil chemistry can cause mineral and nutrient deficiencies that result in reduced growth rates (Tomlinson 1987). Soil-mediated effects of acid deposition on intensively managed plantations will probably be negligible, but the potential for long-term effects is increased at high elevations because of the high levels of atmospheric deposition and the thin soils generally found at higher elevations.

- Agricultural Crops

There is concern that acid deposition and its precursors may cause agricultural losses through decreased crop production. It is more likely, however, that ozone will cause such losses (NAPAP 1989). Research results have established that acidic deposition in the amounts and concentrations that currently occur in the United States has no consistent, demonstrable effect on the yield on agricultural crops (NAPAP 1988).

Studies conducted outside Maryland have suggested minimal yield response of field corn and wheat to acid deposition. However, small but significant reductions in yield have been shown for some corn cultivars under extreme acidic conditions (Abouguendia *et al.* 1988; Banwart *et al.* 1988).

Health Effects

Existing evidence of quantitative relationships between acid deposition and human health remains inconclusive. Because acid deposition involves a complex mixture of substances, measuring exposures and dose-response relationships is difficult. In most studies, the results have been confounded by the effects of

multiple pollutants. Human health effects of acidic deposition precursors may be direct or indirect. Direct human health effects may include changes in lung structure or function or other effects caused by acidic aerosols, sulfur oxides, nitrogen oxides, and ozone. In persons with pre-existing respiratory disabilities, such as asthma, exposure to low levels of sulfate particles, particularly acid sulfate particles (sulfuric acid aerosols), can cause bronchio-constriction and increased airway resistance (Amdur *et al.* 1978). Indirect health effects include changes in human health from exposure to chemicals (principally metals) resulting from acidity-dependent leaching or bioaccumulation in the food chain.

Acid deposition has not been associated with any direct human health effects, but indirect effects on health have been postulated to occur through acidification of drinking water supplies, which leads to corrosion of pipes and mobilization of toxic metals. The corrosiveness of acidic water toward metals found in water supply systems is well known and led to an EPA recommendation that all drinking water supplies be noncorrosive and have a pH above 6.5 (EPA 1979). Mobilization of lead, copper, cadmium, and zinc has been observed in plumbing carrying soft, acidified water (EPA 1979; Lord and Kish 1985). Lead pipes, although no longer used in domestic plumbing, may still be found in older houses. In addition, lead and other metals can be mobilized from solder used to join piping and from some plastic pipes where lead is used as a stabilizer. Acidification of aquifers and lakes could theoretically affect large public water supplies; such acidification has not been reported in Maryland reservoirs and can be easily controlled at the distribution stage.

Increased leaching of toxic metals into surface water or ground water may be caused by acid deposition and may affect drinking water supplies. Cadmium and lead concentrations were found to be higher in tap water from acidified areas in Sweden than non-acidified control areas. In the United States, studies in highly acidic rainfall areas of the Adirondacks showed that about 11 percent of residential wells and about 22 percent of cisterns contained lead at concentrations exceeding EPA standards (Luoma 1988). Bachman and Katz (1985) concluded that acid deposition may accelerate the leaching of aluminum into shallow ground water systems and ultimately surface water systems. The potential for acidification of shallow ground water to affect drinking water in Maryland is uncertain since much of the ground water drinking supplies in Maryland are derived from deep aquifer systems.

Physical Effects

Air pollution, including acid deposition, has been suspected of accelerating the degradation of many types of building materials and cultural artifacts. Degradation of materials may occur in one or several of the following ways:

- loss of surface quality (e.g., loss of color saturation in paints or loss of polish in marble veneers; loss of tensile strength in textiles or paper);
- loss of material (e.g., loss of the zinc coating on carbon steel, loss of carving or inscription detail on marble); or

- chemical transformation (e.g., rusting of painted steel or black crust formation on stone).

Materials sensitive to air pollution include galvanized steel, weathering steel, exterior household paints, maintenance paints, automotive finishes, asphalt roofing shingles, concrete/cement, stone, and mortar (Baer 1987).

Damage to materials is one of the least understood effects of acid deposition, because it results from both natural weathering rates and man-made factors. Because little data exist on the natural weathering rates of common construction materials, it is difficult to assess the incremental effect of pollution-induced changes. Ongoing NAPAP studies are expected to yield additional information on materials damage.

F. Controlling Acid Deposition

Legislative Action

After several years of debate, the Clean Air Act (CAA) Amendments of 1990 were signed into law on November 15. The bill includes provisions for non-attainment areas, permits and air toxics that may affect power plant operations. There are also provisions for acid rain reduction that will directly impact power plant operations in the United States.

The two goals of the acid rain provisions are to: 1) reduce SO₂ emissions in the contiguous U.S. by 10 million tons below 1980 levels by the year 2000, and 2) reduce NO_x emissions by 2 million tons below 1980 levels. As discussed further in Chapter 3, the SO₂ reduction program will be instituted in two phases. In Phase I, beginning in 1995, affected power plants will be required to reduce SO₂ emissions to 2.5 lb/MMBtu based on their average annual fuel consumption rates for the years 1985 to 1987. In Phase II, beginning in 2000, all affected power plants will be required to reduce SO₂ emissions to 1.2 lb/MMBtu times their 1985-1987 average annual fuel consumption rate.

The new SO₂ reduction program takes a market-based approach to air pollution control. The bill sets an overall SO₂ emissions cap, as described above, but allows utilities a number of options for achieving the required levels, including the option of trading emissions "allowances." An allowance is essentially a federal permit to emit one ton of SO₂. Each affected power plant source will receive allowances equal to the amount of SO₂ it is permitted to emit. If a source reduces its SO₂ emissions more than required, it can "bank" the left over allowances for later use, or sell them to other utilities.

Under the market system approach, utilities will have a number of strategies available for compliance with SO₂ reduction goals. Utilities can install emissions control devices, switch to lower sulfur fuels, repower with clean coal technologies, retire older units, purchase allowances or use any combination of these alternatives. With the allowance trading option, the market-based approach will

provide utilities with more flexibility for meeting emissions reductions goals; however, there are still uncertainties surrounding the allowance trading system. Two of the most significant areas of concern center around the cost and availability of allowances. Anticipating some of these issues, the CAA bill calls for the creation of an allowance auction system to be administered by the EPA. The auction is intended to provide an alternative supply of allowances to ensure that allowances will be available to utilities that may not be able to acquire them in the open market. The auction may also serve as a price leveling system, at least in the earlier years of the program.

For the NO_x reduction program, EPA will establish NO_x performance standards by 1993 for tangentially-fired and dry bottom wall-fired boilers. Emissions standards for all other utility boilers will be established by 1997. The NO_x emissions standards will be based on low NO_x burner technology and will be updated as new technologies emerge.

Early economic projections of the costs of acid deposition control measures indicate that as much as \$4.1 billion over the next 10 years may be necessary in capital costs for the equipment required to meet SO₂ and NO_x emissions reductions (EPA 1989). Annual increases in customer utility bills nationwide are expected to average in the range of 1 to 2 percent. Costs to utility customers may, however, be reduced by use of clean coal technologies, emissions trading, and federal subsidy programs. For the impacts of this legislation on specific Maryland power plants, see Chapter 3, Section C.

Emission Controls

Reducing the emissions of acid precursors will likely result in a reduction in the extent of acid deposition. Sulfur oxides (SO_x) are formed when sulfur contaminants in fossil fuels are oxidized during the combustion process. Nitrogen oxides arise not only from the nitrogen in the fuel but also from the nitrogen in the air supplied during the combustion process. The control technologies for SO_x and NO_x are reviewed in Chapter 3, Section C.

Potential Emissions Reductions from Conservation, Load Management, and Alternative Power

A suggested alternative to reducing emissions of SO₂ and NO_x from power plants involves programs to modify or reduce customers' power demands and to increase the generation of power from non-conventional sources. Programs that alter the time pattern of energy use but have little or no effect on total energy consumption ("load management") do not contribute to any meaningful reduction in SO₂ and NO_x. Programs that are directed toward achieving reductions in total energy usage ("conservation") can contribute to an emissions reduction. However, it is important to understand that the reduction in air emission is likely to be proportionately smaller than the reduction in energy consumption arising from conservation. For example, a ten percent reduction in energy consumption may reduce emissions by only three percent. This is because conservation also tends to delay the introduction of new generating capacity which normally has

lower emission rates than those of average existing power plants. Thus conservation, while reducing total emissions, causes the system average emission rates (lb per mWh of various pollutants) to increase. Alternative energy generation sources typically do not provide large savings because they tend to be similar (with respect to emission rates) to the conventional utility plants that they displace. (See also the discussion of small and non-utility generators in Chapter 3).

The estimated reduction in SO₂ emissions from the combined BG&E and PEPCO utility systems from an extremely aggressive conservation and alternative power development program is about 46,000 ton/yr (or about 15 percent of total projected utility SO₂ emissions in the year 2000) (PPRP 1987). The majority of this reduction (30 to 50 percent) would result from residential conservation, including the introduction of high-efficiency appliances.

Maryland utilities participate as full members of integrated interstate power pools in addition to acting as independent inter-regional buyers of capacity and energy. Because the pools operate on the principle of integrated economic dispatch, the extent to which conservation, use of alternative energy, or emission reduction techniques introduced by Maryland utilities would reduce Maryland-generated emissions is unclear. The reductions in power production may occur elsewhere in the power pool region or in adjacent regions. Quantification of this emission exchange is not possible without a knowledge of the emission reduction plans of all utilities operating in the region.

Non-Control Mitigation Programs

Surface water liming is the only common mitigation practice aimed specifically at remediating an acidified receptor. Liming programs have been in effect in northern Europe and Canada for several years and generally report success in maintaining suitable water quality. In the United States, several programs have been initiated within the last five years, primarily as research and demonstration projects. A variety of techniques and materials are currently being used for lake and stream neutralization. A very fine calcium carbonate (calcite) slurry appears to be one of the most effective liming materials and is being used in both lake and stream programs.

An ongoing surface water liming project in Maryland is evaluating the use of stream dosers to ameliorate episodic acid events. This technology controls the release of liming materials as a function of water level or stream chemistry. It is especially important for tributaries of the Chesapeake Bay, where streams serve as spawning grounds for commercially and recreationally important anadromous fish species. Initial results of the doser study show that stream chemistry can be improved by addition of calcite.

A common problem reported in many of the ongoing mitigation programs is that the nearshore or littoral zones of lakes and streams, which are often inhabited by acid-sensitive early life stages of fish and invertebrates, are commonly not mitigated by whole-lake or stream liming. In addition, studies have shown that