- Hydroelectric Facilities

Maryland hydroelectric facilities are listed in Table VII-3. Impoundments created by their dams (though most of the dams were not built specifically for hydropower) have displaced terrestrial habitats. The largest impoundment, formed by the Conowingo Dam, lies primarily in Pennsylvania. If that impoundment is excluded from the total, the area inundated by impoundments in Maryland created for or with hydroelectric power totals 8,957 acres, representing 0.1% of Maryland's total acreage. None of the impoundments are located in urban areas, and the habitats inundated were generally riparian corridors, which are known to support diverse and valuable flora and fauna. Additional riparian habitat becomes established along the new water line of the impoundment, and the impoundment itself provides open water habitat suitable for a variety of wildlife, including waterfowl. It may also provide new recreational areas.

None of the hydroelectric sites is known to have been constructed in a critical or unique habitat, and the existing facilities cannot be considered to have eliminated a significant portion of Maryland's total riparian habitat. However, unaltered rivers are increasing in recreational value due to the popularity of canoeing and whitewater sports. Variable flow downstream from a dam can adversely impact the riparian corridor by washing away streambank vegetation during high flow periods, which can be almost as severe as, but more frequent than, natural floods on unimpeded streams and rivers.

- Transmission Corridors

Transmission corridors are distributed throughout the state, connecting sources of power, distribution centers and users. The ecological impacts of power lines can be either positive or negative. Clearings must be created to establish transmission line corridors, and the corridors must be maintained as grass or brush. When such corridors are created in forested areas considerable edge habitat is created, and new types of ecosystems (e.g., grass, shrubs) are also created, sometimes resulting in temporary increases in species diversity of both flora and fauna (MD-PPRP 1978; Thibodeau and Nickerson 1986). With proper construction techniques, even sensitive wetlands can recover from the disturbance within two years (Grigal 1985). On the other hand, construction of

Table VII-3

Hydroelectric facilities in Maryland, with size of drainage area and impoundment

Site	Drainage Area (square miles)	Impoundment Area (acres)
Deep Creek	65	4500
Brighton	77	800
Savage River [(a)]	105	360
Rocky Gorge	132	773
Bloomington [(a)]	287	952
Potomac #4	5900	675
Parker Pond	9	41
Conowingo	27000	8960
Gilpin Falls	23	3
Potomac #3	6236	325
Potomac #5	5100	490
Union	290	34
Gores Mill	11	1
Wilson Mill	180	3
Total	45415	17917 (28 square miles)

Source: Weisberg et al. 1985

(a) Not yet constructed.

transmission corridors may cause wildlife to emigrate in response to noise, and can disrupt forage, breeding and migration areas.

Long-term impacts of the presence of a transmission corridor can be minimized if proper corridor maintenance procedures are followed. Improper use of chemical herbicides to control plant growth could result in runoff into non-corridor areas and consequently cause damage to non-targeted vegetation, and wildlife may be injured or killed due to improper maintenance procedures (MD-PPRP 1978; FWS 1979). In general, however, as long as transmission corridors are sited to avoid sensitive or unique ecosystem types, and proper erosion control measures are taken during and following construction, it is unlikely that impacts of transmission lines on terrestrial ecosystems in Maryland can be considered to be significant.

- Combustion By-product Landfills

Another source of direct impact on terrestrial ecosystems is the establishment of landfills for combustion by-products, some of which may be reusable in the future. Such sites displace a certain amount of habitat and otherwise alter locations to make them unsuitable for wildlife. The land area required by conventional pulverized coal-fired power plants depends on both the type and amount of coal used. The land area required for fly and bottom ash for various sizes of power plants is presented in Table VII-4. At the present time, there are six active power plant ash sites in Maryland, occupying approximately 1,200 acres, and over 30 inactive or insignificant ash sites (MD-PPRP 1984). Coal-fired plants in Maryland, whose capacity totals 5,680 MW, will require approximately 1,140 acres for landfilling over a 40-year span. Thus, the active sites will probably be adequate for future use (This estimate does not include the potentially large volumes of flue gas desulfurization sludges that could be generated if acid rain controls were implemented).

Air Emissions Impacts

Coal-fired power plants can also affect terrestrial ecosystems through emissions of gaseous and particulate matter to the air, from their stacks or from coal handling activities. Much of their impact is covered in Chapter III, which discusses air emissions primarily in terms of ambient air quality standards.

Table VII-4

Forty-year land requirements for solid waste combustion by-product landfills (including ponds) from coal-fired power plants

Plant Size (MWe)	Land Area Required, Acres (ha) Northern Appalachian Coal		Eastern Interior Coal	
100	20	(8)	40	(16)
350	70	(28)	140	(57)
700	140	(57)	280	(113)

Source: FWS 1978

Some plant species are sensitive to pollutant concentrations lower than the national air quality standards. However, no long-term studies in Maryland currently monitor the health of plant communities near power plants, so no data are available on actual damage to plants from existing emissions. This section therefore focuses on the types of emissions that can affect terrestrial ecosystems, and the potential impacts that those emissions can have.

- Particulate Emissions

Particulate matter may be introduced into the atmosphere in a variety of ways by the operation of fuel-burning power plants, primarily those using coal. Primary modes include fugitive emission of coal dust during loading, transport, unloading and storage on site, and the emission of particulate material from the stacks of the plant. Particulate emissions from stacks of power plants are generally controlled very effectively by existing emission control technology, particularly precipitators. The overall level of control, however, is more effective (95-97%) on large particles (> 5 um diameter) than on small particles (72% for < 5 um diameter). Power plant emission rates and total emissions are discussed in detail in Chapter III.

No studies have been conducted in Maryland to assess the impacts of particulate emissions from power plants, direct or indirect (e.g., coal dust emitted during coal transportation), on terrestrial biota, and so no evidence of impacts is available. In the extensive background discussions provided by the U.S. EPA to support revisions to national ambient air quality standards for particulate matter (EPA 1987), the only impacts for which concern was expressed dealt with human health, soiling and nuisance effects, and effects on visibility.

Particles in the air, particularly at high concentrations, can impact vegetation and animals in a number of different ways. Plant stomata (openings in the leaves) may be clogged, interfering with gas exchange and enhancing penetration of healthy tissues by pathogens. Radiation reflectance and absorption properties of vegetation can be altered, affecting heat exchange and photosynthesis. Germination may be reduced; and uptake of harmful substances may be increased. Terrestrial invertebrates may be affected by direct deposition of fine particulates on soft integumental tissues, causing abrasion damage. Vertebrates may inhale particulates, which interfere with oxygen transfer across mucous membranes and cause physical irritation of soft tissues (FWS 1978).

Dust loading in excess of 1 g/m^2/day causes damage to leaves (FWS 1978). Such loading would require the settling of 6,700 m^3 of air with a 150 ug/m^3 concentration of total suspended particulates (TSP). The particulate concentrations measured or modeled in Maryland have not reached this level, with the exception of one instance in the Baltimore area (see Chapter III, Section B). The only real potential for damage by particulates appears to be as dry deposition of toxic materials, which is described more fully below.

- Gaseous and Toxic Atmospheric Emissions Impacts

The gaseous power plant emissions with the greatest terrestrial impacts are sulfur and nitrogen oxides. Acidic deposition impacts associated with these gases will be discussed in Chapter VIII. Only the direct effects of these gases are addressed here. As with particulates, actual evidence of damage is not currently available, and actual concentrations of the pollutants appear to be too low to be likely to cause long-term effects.

Power plants do not emit nitrogen oxides in quantities great enough to cause either acute or chronic injury to vegetation. Nitrogen oxides do contribute to formation of secondary pollutants (e.g., ozone, peroxyacyl nitrates), which can harm many plant and animal species; but power plants' contribution of nitrogen is insignificant relative to other sources such as automobiles and manufacturing (FWS 1978).

Sulfur oxides may have caused damage to some plant communities in Maryland, but direct evidence of damage is unavailable. Sulfur oxides can damage populations of lichens at annual average concentrations of 40 ug/m^3, although episodic higher concentrations may be the actual cause of destruction (FWS 1978). It has been hypothesized that the lichen flora of Maryland may now be depleted due to air pollution (Skorepa and Norden 1984), but no quantitative historical information or detailed correlative studies are available to make such a determination. Sulfur oxides can acutely injure sensitive higher plant species at approximate doses of 1 to 2 ppm (130 to 5,000 ug/m^3) for 3- to 24-hr exposure (FWS 1978). Symptoms of acute sulfur oxide injury include bleaching and necrosis of leaves, reduced production and death (ASA 1976). Chronic injury occurs when plants are exposed to sublethal concentrations for long periods of time. Symptoms of chronic injury include chlorosis, discoloration, bleaching and reduced productivity. Recovery is likely if the source is removed (Bell 1982; Katainen *et al.* 1987). In general, native plant species are less susceptible to sulfur oxide damage than are ornamental and crop species. Tables VII-5 and VII-6 list some representative plants and their relative sensitivity and observed response, respectively, to sulfur oxide toxicity.

Extremely high concentrations of sulfur and nitrogen oxides may affect animals in a variety of ways, including impaired bronchial clearance, increased susceptibility to infection, increased pulmonary resistance, damage to bronchial structures and death (FWS 1978). In Maryland, the only health-effect threshold likely to be exceeded by ground-level concentrations is 500 ug/m^3 of sulfur dioxide, which may be exceeded for a few hours near power plants under inversion or plume fumigation conditions, but is unlikely to occur for the long periods of time necessary to induce chronic symptoms. Thus, the direct effects of sulfur or nitrogen oxides on animals in Maryland are unlikely to be significant at present levels of emission.

- Measured and Predicted Pollutant Concentrations from Power Plants

In the absence of long-term studies to address the terrestrial impacts of power plant-related air pollutants, air quality measurements taken near individual power plants, and air quality modeling, may be used to give some indication of the potential for impact. Here again relevant information is sparse. Comparisons of measured ambient concentrations of SO_2 near PEPCO's Dickerson station with damage thresholds for some sensitive plant species indicate some potential for damage to Kentucky bluegrass, although no air quality standards have been exceeded. Past modeling studies of the same plant indicated that SO_2 concentrations may be higher on Sugarloaf Mountain, to the northeast, over some 3-hour and 24-hour periods (MD-PPRP 1987). Concentrations predicted for Sugarload Mountain indicate potential for damage to some other plant species, including oats, white birch and trembling aspen. Air quality measurements have been made at that location recently, but were not available in time for this study.

Table VII-5

Relative SO_2 sensitivity of woody plants grown in Maryland (native and introduced)

Sensitive Species

red ash (*Fraxinus pennsylvanica)*
European birch *(Betula pendula)*
gray birch *(Betula populifolia)*
white birch *(Betula papyrifera)*
yellow birch (*Betula alleghanensis)*
bitter cherry (*Prunus emarginata)*
Chinese elm (*Ulmus parvifolia)*
larch (tamarack) (*Larix* sp.)
eastern white pine *(Pinus strobus)*
red pine *(Pinus resinosa)*
Lombardy poplar *(Populas nigra)*
staghorn *(Rhus typhina)*
Black willow *(Salix nigra)*

Intermediate Species

basswood *(Tilia americana)*
boxelder *(Acer negundo)*
eastern cottonwood *(Populas deltoides)*
American elm *(Ulmus americana)*
balsam fir *(Abies balsamea)*
red hawthorn *(Crataequs columbiana)*
red maple *(Acer rubrum)*
white oak *(Quercus alba)*
Austrian pine *(Pinus nigra)*

Tolerant Species

Forsythia *(Forsythia Viridissima)*
Ginkgo *(Ginkgo biloba)*
black hawthorn *(Crataequs douglasii)*
common juniper *(Juniperus communis)*
silver maple *(Acer saccharinum)*
suger maple *(Acer saccharum)*
pin oak *(Quercus palustris)*
red oak *(Quercus rubra)*
London plane *(Platanus acerifolia)*
Carolina poplar (*Populas canadensis)*
blue spruce (*Picea pungens*)
smooth sumac *(Rhus glabra)*

Source: Davis and Wilhour 1976

Table VII-6

Effects of sulfur dioxide on vegetation

Concentration (ppm)	Exposure	Plant	Effect
0.4 (1062 $\mu g/m^3$)	3 hr	Oats	Threshold leaf injury
0.35 (929 $\mu g/m^3$)	3 hr	Trembling aspen	2% foliar injury
0.2 (531 $\mu g/m^3$)	2 hr	Kentucky blue grass	Foliar injury
0.01 (27 $\mu g/m^3$)	annual	Oats	Light leaf injury
0.011 (29 $\mu g/m^3$)	annual	White birch	Trace foliar injury
0.0006-0.018 (16-48 $\mu g/m^3$)	annual	Lichens	Decreased growth
0.01 (27 $\mu g/m^3$)	annual	Lichens	Mortality

Source: 40 CFR 52, Subpart V.

- Noncriteria Pollutants

Concentrations of noncriteria pollutants (those for which ambient air quality standards have not been established), potentially toxic substances associated with Maryland power plant emissions, have not been measured or modeled to date. However, it is reasonable to assume that deposition patterns for criteria pollutants, as illustrated in Chapter III, are indicative of those for noncriteria pollutants. In the absence of any information or predictions of quantities of pollutants deposited, it is impossible to provide accurate assessment of actual power plant impacts. Overall, however, coal-fired power plants are a minor source of heavy metals compared to smelters and automobiles; and some research (e.g., FWS 1978) suggests that fuel-burning power plants contribute little, if any, measurable quantities of most trace elements to the environment.

Fluorides occur in the highest concentrations of all trace emissions. Gaseous fluorides are potentially more harmful than particulate fluorides (Hill 1969), and may harm several crops of importance in Maryland (including corn, cucumbers and sorghum) and many conifers. They can also eliminate some sensitive species of lichen (Perkins and Millar 1987). Cattle may show symptoms of fluoride toxicity from ingesting forage with concentrations below phytotoxic levels (FWS 1978).

Other potentially toxic materials can be introduced into the atmosphere after being adsorbed onto particulate material (e.g., PAHs and trace metals). Small particles (< 5 um), which can more readily escape control measures, serve as adsorption sites for other materials. They can be carried great distances and have a higher potential for passing into plant tissue openings and into the respiratory systems of terrestrial vertebrates and invertebrates (FWS 1978). Thus, small particulates are the major area of concern in addressing potential impacts of nongaseous toxic power plant emissions.

Metals such as arsenic, beryllium, cadmium, selenium and lead are generally emitted as fine particulates and can be 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.

Contamination from Non-point Sources: Coal Piles and Combustion By-products

Several aspects of coal-fired power plant operations can lead to surface and ground water contamination in addition to regulated effluent discharges. Non-point source water contamination can result from leaching and runoff from beneath coal storage piles and ash landfill sites. For a more complete description of these processes in ground water contamination, see Chapter VI.

Leachate from coal piles and ash landfills is qualitatively similar to acid mine drainage and, if untreated, can have similar impacts on streams receiving the effluent. In Maryland, a study of the effects of PEPCO's Faulkner ash landfill, which takes ash from the Morgantown plant, found elevated levels of total dissolved solids, sulfate and several major cations as well as depressed pH in surface and ground water immediately around and downslope of the landfill (Simek *et al.* 1983). The biological effects of these impacts in the nutrient-poor Zekiah Swamp appear to be insignificant (Klose and Potera 1984). Trees immediately adjacent to the ash site had elevated tissue content of arsenic and manganese compared to trees from control sites, but the concentrations were still within the natural ranges for these elements (Klose and Potera 1984). Tree tissue data do not provide any strong indication that the metals in ash site leachate have accumulated in nearby trees.

Cooling Tower Aerosols

Cooling towers operate by passing a continuous shallow flow of heated water over a large surface exposed to the air. When evaporation occurs, the rising water vapor carries with it solids dissolved in the liquid water. Residual liquid flowing from the cooling surfaces ("blowdown") is mixed with additional water and recirculated. Concentration and vaporization cause a plume of water vapor carrying salts and other solids to leave the cooling tower and pass over the landscape. These solids may have an impact on terrestrial ecosystems. In general, those impacts are believed to occur within 1,800 m of the tower (Weil *et al.* 1985). In some field studies, elevated levels of chlorides possibly associated with cooling tower drift have been found in foliage of sensitive species located 1,600 m from working natural draft cooling towers (Curtis *et al.* 1976). However, no evidence of damage from Maryland power plants has been found.

At present, only three power plants in Maryland (Chalk Point, Vienna and Brandon Shores) operate with cooling towers. Chalk Point's towers were studied for their impact because the drift consists of concentrated estuarine water with an initial salinity of between 3 and 15 ppt. Studies summarized in Mulchi *et al.* (1977) indicate that the Chalk Point cooling tower drift has measurable effects on tissue and possibly soil chloride concentrations, but that immediate impacts to vegetation are unlikely. It is possible that long-term effects could occur due to accumulation of elevated salts in soils, but no current information is available. No studies have been done to assess the potential impacts of other constituents of drift, such as biocides and descaling compounds.

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CHAPTER VIII

ACID DEPOSITION

The deposition of acidic materials, commonly termed "acid rain," and its potential ecological and economic effects have been vigorously discussed at the international, national, state, and local levels of government. Acidic precipitation may adversely effect physical, terrestrial, and aquatic resources. In terrestrial and aquatic ecosystems heightened acidity has been observed to result in chemical (e.g., increased metals concentrations) or biological alterations (e.g., reduced fish populations or growth). In addition, acid deposition has also been reported to accelerate damage to some construction materials. As discussed in Chapter III, the precursors of acid deposition, SO_2 and NO_x, are abundant in fossil fuel power plant emissions They are therefore of concern when discussing 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. A more detailed discussion of the effects of acid deposition on Maryland resources can be found in the annual acid deposition reports submitted to the Governor and the General Assembly (MD-PPRP 1987, 1988).

A. The Acid Deposition Process

Acid deposition is defined as the combination of acidic precipitation (rain, snow, fog) and acidic dry deposition (gases, aerosols, particulates). Understanding its potential effects on physical, terrestrial, and aquatic resources requires an understanding of precipitation chemistry, the hydrologic cycle, and the chemical evolution of precipitation in a watershed.

Precipitation Chemistry

Atmospheric deposition becomes acidic through complex interactions with acid precursors such as nitrogen and sulfur oxides. These compounds originate largely in man-made sources such as power plants, automobiles, factories, and to a lesser degree in natural sources such as fires, volcanoes, and marshes. As these oxides are transported in the upper atmosphere they 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 result in the elevated concentrations of free hydrogen ion (H^+) associated with acid deposition.

The acidity of aqueous solutions, including precipitation. is normally measured on the pH scale, which ranges from one to fourteen. A pH of seven 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 not affected 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 rainfall is reportedly between 4.0 and 4.2, or roughly ten times as acidic as natural rainfall (Maryland Office of Environmental Programs 1984).

The Hydrologic Cycle

The degree of damage or alteration potentially caused by acid deposition is largely a function of the hydrologic pathways of precipitation. Rainwater follows several pathways in the hydrologic cycle (Figure VIII-1). Some of the water returns to the atmosphere through evaporation, while some is transpired or taken up by plant roots and evaporated through leaves. (Evaporation and transpiration are often collectively referred to as evapotranspiration.) When the precipitation rate exceeds the infiltration capacity of soils, water will flow as a thin sheet across the land surface as overland flow and discharge directly to surface waters. If the unsaturated zone (the soil above the water table) is uniformly permeable, most of the water infiltrates and moves vertically (percolates) through the soil. However, if less permeable layers of soil occur beneath the surface, percolating water may move horizontally in the unsaturated zone, perhaps even reappearing later as overland flow. This lateral movement of water through soil layers, termed interflow, may be substantial and may contribute significantly to total stream flow in some watersheds.

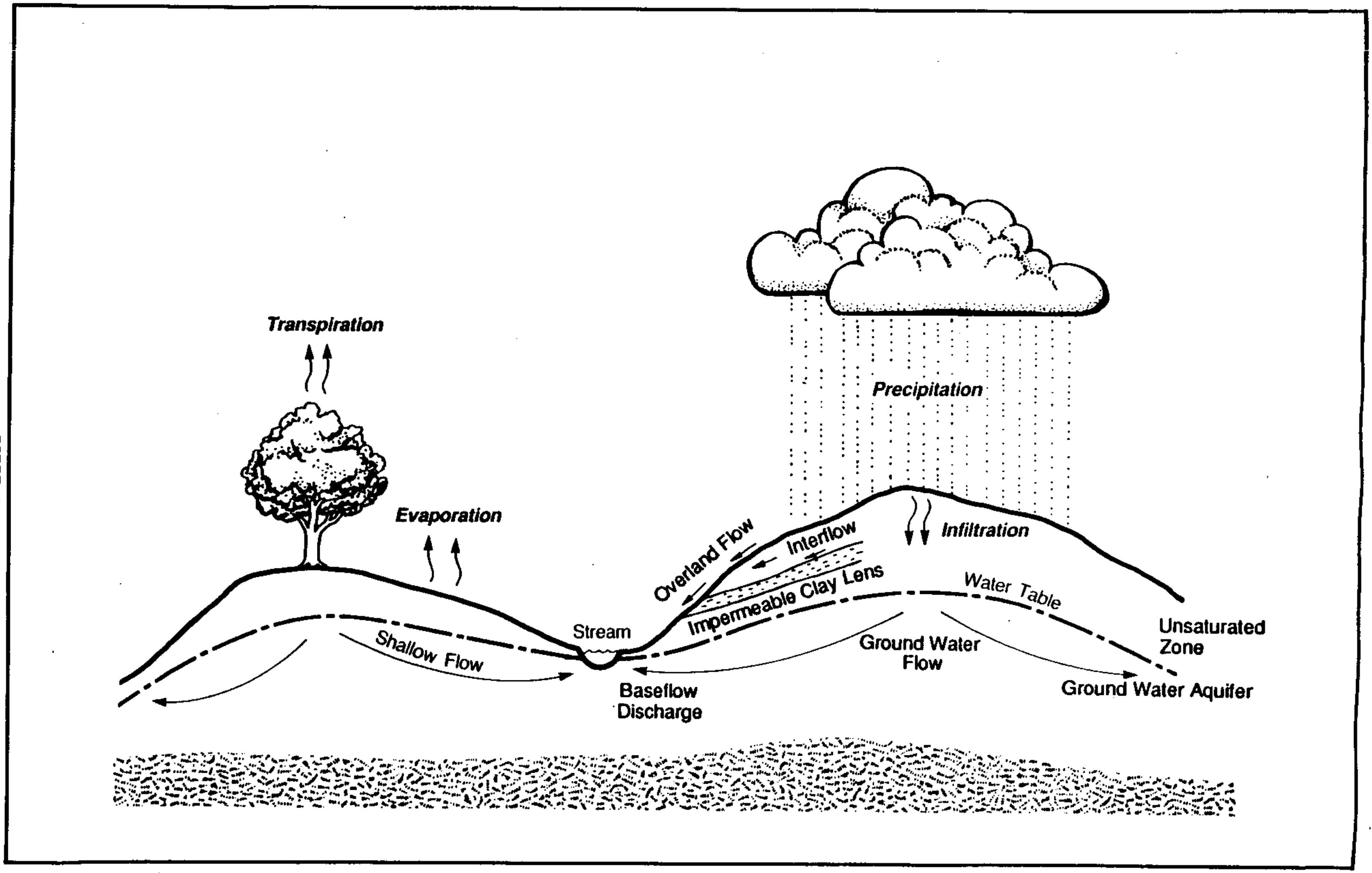

Figure VIII-1. Schematic representation of the hydrologic cycle

Percolating water that reaches the saturated soil or bedrock unit is stored in a ground water aquifer. When ground water discharges to a stream or lake, it is termed baseflow. The annual contribution of baseflow to surface waters by volume is significantly greater than that of storm water.

Chemical Evolution of Precipitation in a Watershed

The vegetation of a watershed can significantly alter precipitation chemistry (Bockheim 1984; Lovett 1983). For example, rain may dissolve or absorb alkaline compounds from the needles of conifers or the leaves of deciduous trees, thereby neutralizing much of its acidity. Evapotranspiration, which removes essentially pure water from the soil, may increase the concentrations of ionic compounds (whether brought in by rain or dissolved from soil) in percolating water.

The interaction of percolating acidic water (interflow) with alkaline soil and geologic materials may also neutralize the water. However, in areas where this does not happen, acidic waters may percolate to ground water and subsequently discharge to surface waters. Overland flow, if it occurs, has little contact time with any potential neutralizing geologic material. The chemical characteristics of overland flow are therefore principally a function of the type and quantities of surface materials suspended in it. Thus its effect on the chemistry of the surface water cannot be readily determined.

B. Impacts of Acid Deposition

The impacts of acid deposition are discussed in previous CEIR's (MD-PPRP 1986) and in the annual acid deposition reports to the Governor and General Assembly (MD-PPRP 1987, 1988). The following section summarizes those effects.

Atmospheric Effects

Under programs such as the National Acid Precipitation Assessment Program (NAPAP), a continuing effort is underway to provide long-term monitoring of both wet and dry deposition over the United States. Measurements of dry deposition are not routinely made, because no simple and accurate method exists for making the measurements (Joyner and Hood 1985). Consequently, the dry deposition contribution to total deposition is still poorly quantified. Because the measurement of dry deposition has become such a critical information need, NAPAP is currently developing a dry deposition monitoring program with plans to begin a 100-site network.

Although the dry deposition monitoring program is just starting, the wet deposition monitoring program has been established for several years. Several state and federal programs have been established to collect and analyze rainwater in and around Maryland. Most of these monitoring programs conducted to date (Table VIII-1) show that the annual volume-weighted mean pH of precipitation in the state is generally less than 4.4 and typically in the range of 4.0 to 4.2, a value that is generally consistent with measurements in the northeastern United States (MD-PPRP 1988).

The results of a recently completed project to examine the statewide concentration and deposition patterns of hydrogen ions (pH), sulfate, and nitrate (Maxwell and Mahn 1987) are summarized in Figures VIII-2 to VIII-5. These results indicate that total sulfate and nitrate deposition increased from the southern to the northern portions of the state. These increases correspond to a decreasing pH (Maxwell and Mahn 1987).

<u>Ground Water</u>

Acid deposition may alter ground water quality and affect potable water supplies through two primary chemical mechanisms (Hultberg and Johansson 1981; Lord and Kish 1985):

- the acidification of water through an increase in the concentration of hydrogen ions; and
- the accelerated leaching and mobilization of ionic components into drinking water supplies from mineral surfaces or from the piping that supplies drinking water.

Table VIII-1. Recent acid deposition monitoring programs in Maryland

Deposition Monitoring Program	Operator	Dates of Operation	Type of Sampling
Catoctin Mountain Studies	USGS	1982-Present	Originally event now weekly
Maryland Air Management Administration (MAMA) Sites	MAMA	Oct 1984-Present	Weekly
Smithsonian Site	Smithsonian	1974-Present	Event
White Rock Substation	NADP/BG&E	Oct 1984-Present	Event and Weekly
Wye Institute	NADP/MD Ag	Mar 1983-Present	Weekly

USGS: United States Geological Survey

NADP: National Atmospheric Deposition Program

BG&E: Baltimore Gas & Electric Company

MD Ag: Maryland Agricultural Extension Service

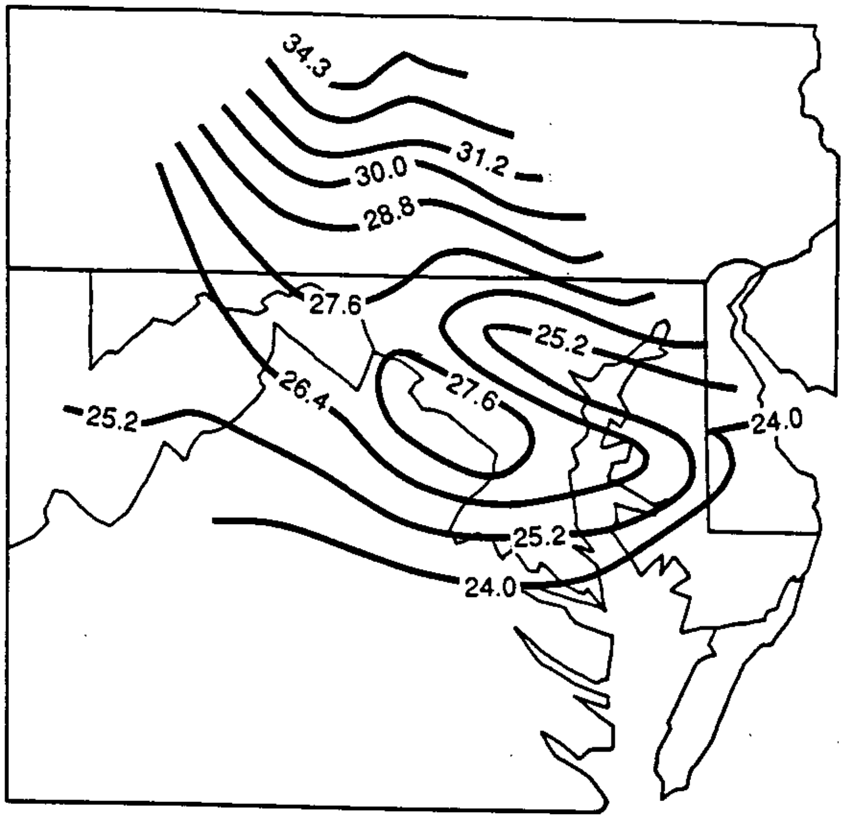

Figure VIII-2. **Annual average sulfate concentration (µmol/L) for 1984**

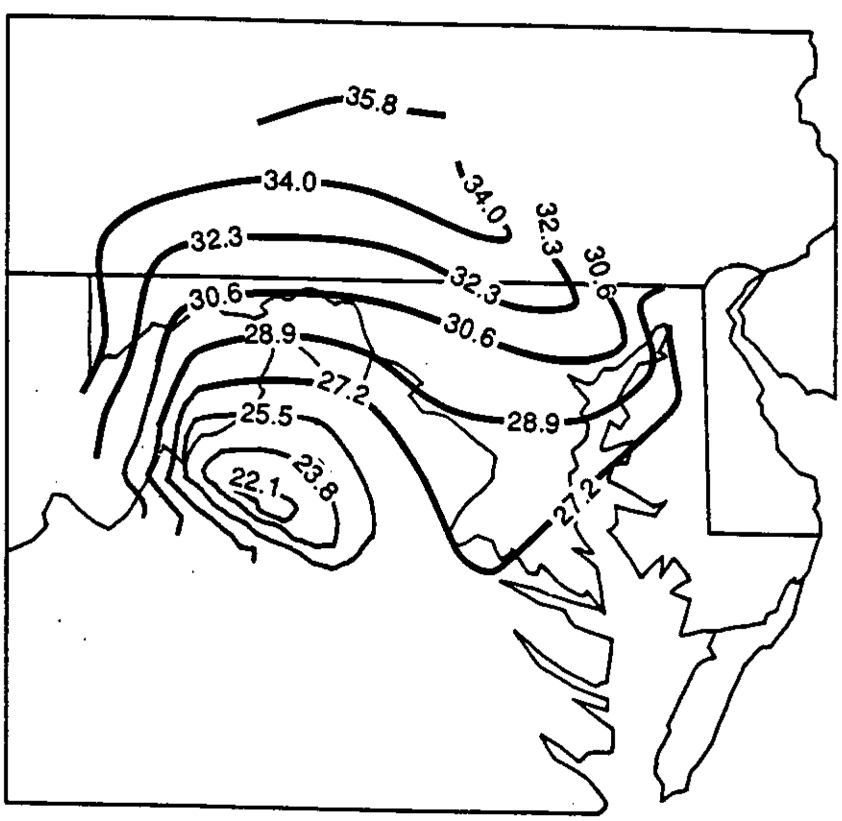

Figure VIII-3. **Annual total sulfate deposition (kg/(ha·yr)) for 1984**

Source: Maxwell & Mahn 1987

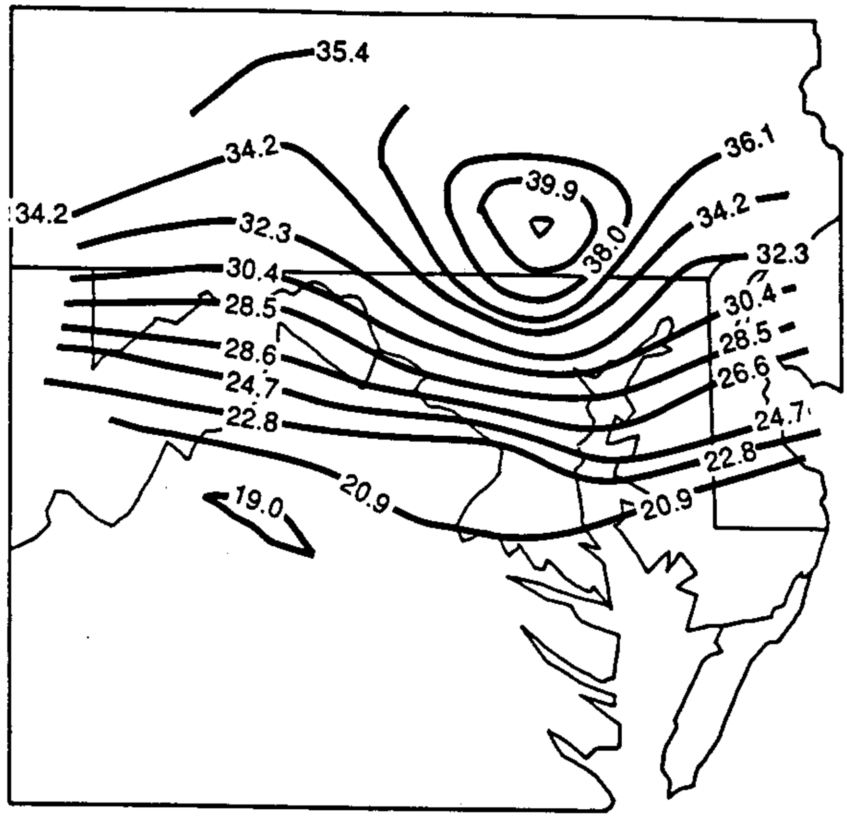

Figure VIII-4 Annual average nitrate concentration (μmol/L) for 1984

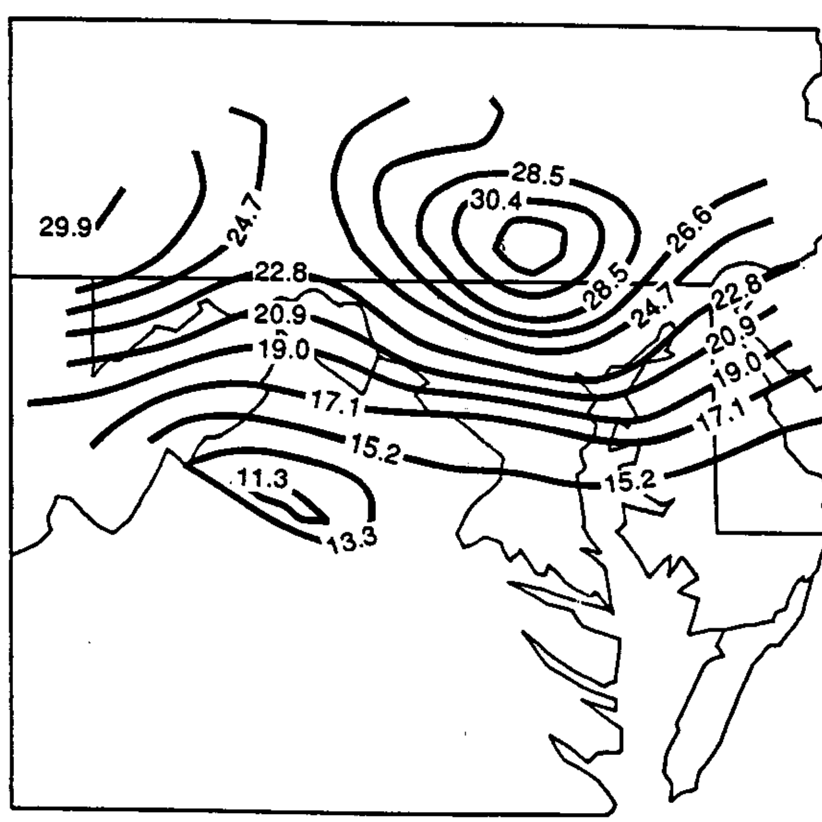

Figure VIII-5 Annual total nitrate deposition (kg/ha·yr)) for 1984

Source: Maxwell & Mahn 1987

A detailed study on the effects of acid deposition on ground water in Maryland (Bachman and Katz 1986) investigated the relationship between precipitation quality and shallow ground water quality of the Columbia aquifer, which covers the majority of Maryland's Eastern Shore. The study revealed that concentrations of chemical species in the ground water of the Columbia aquifer were significantly different from concentrations of these same species in the precipitation. In general, hydrogen and sulfate were the dominant ions in the precipitation, whereas sodium and chloride dominated in ground water. Also, compared to precipitation, groundwater was depleted in hydrogen ions by a factor of seven to eight while being enriched in silica, potassium, and bicarbonate. The study reached the following conclusions (Bachman and Katz 1986):

- the weathering of aluminosilicate minerals to clay in the saturated zone reduced the hydrogen ion concentration of acid deposition by adsorbing the hydrogen ions onto the newly formed clay minerals, and
- any dissolved aluminum that may have become mobilized during initial reactions with acid deposition would be retained in the late-stage clay mineral weathering products.

However, the authors noted that if the ground water discharges to surface water (via baseflow) before the aluminum is immobilized by mineral weathering, the lower pH of the stream water in the study area would keep potentially toxic forms of aluminum in solution. This conclusion is supported by the field data, which indicated that stream water contained dissolved aluminum concentrations that approached or exceeded 1 mg/l, whereas ground water samples contained much lower concentrations of approximately 0.01 mg/l.

Conkwright (1984) reported that a review of U.S. Geological Survey well-water records in Maryland did not reveal any obvious trends related to acid deposition and water quality degradation. His data indicated that the chemical quality of ground water in Maryland is controlled by the geologic materials existing over recharge areas and by conditions within the aquifer, rather than by atmospheric contributions. He noted that, in Maryland, geologic materials can remove hydrogen ions introduced to the ground surface by precipitation. However, the effect of long-term, continued loading of hydrogen ions in the unsaturated and saturated zones in Maryland is not known.

Aquatic Resources

The potential for acid precipitation to acidify surface waters is a function of the extent of nuetralization provided by passage of the precipitation through soil and geologic materials as well as the ability of the water body to provide neutralization. Surface waters that are sensitive to acidification characteristically exhibit low to moderate pH and acid neutralization capacities and reduced concentrations of basic cations such as calcium and magnesium.

Acidified surface waters typically exhibit elevated concentrations of aluminum, zinc, and nickel, which can be potentially toxic to aquatic biota. Of these elements dissolved aluminum is typically most toxic, and reportedly is often more critical for fish mortality than the direct effects of low pH (Haines and Schofield 1980). Most of the dissolved aluminum in surface water is present as organic complexes (Driscoll 1980). The inorganic fractions consist of ionic aluminum (Al^{+3}) and aluminum fluoride, hydroxide, and sulfate complexes, which are more toxic to fish than the organic complexes of aluminum. Lowering the pH in natural water bodies to approximately 5.2 to 5.4 increases the labile (inorganic) monomeric aluminum and thereby increases potential toxicity to fish. (Baker 1981; Baker and Schofield 1981).

Aquatic organisms at all trophic levels have displayed varying degrees of tolerance to the chemical alterations commonly found in acidified surface waters (Mierle *et al.* 1986). Their responses depend primarily on both pH and the presence and/or absence of calcium and trace metals. In general, benthic macroinvertebrates, particularly mysids, amphibians, and crayfish, appear to be acid-sensitive; plankton, reptiles and amphibians are also relatively intolerant of low pH. Studies have indicated, however, that there is a relationship between acidification and both plankton species decline and amphibian (salamander) egg development (Stokes 1986; Mierle *et al.* 1986).

Most of the existing knowledge of the sensitivity of fish to acidic surface waters concerns species commonly found in inland lakes and streams. Figure VIII-2 presents the combined results of numerous laboratory and field studies. Three anadromous species -- striped bass, blueback herring, and American shad -- are among the most sensitive species yet studied. 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.

The direct effects of acidification on fish can be summarized as follows:

- acute mortality
- reproductive failure
- avoidance of the acidified area
- reduced growth rates
- other chronic effects

The most important direct effects relative to 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 commonly regarded as the major cause of fish population extinction in acidified waters. Waters of low pH have been reported to promote 1) failure of gametes to develop or function properly; 2) failure of fertilized eggs to develop or hatch; and 3) hatching of larvae that are deformed or otherwise unfit (Haines and Schofield 1980). Fritz (1980) hypothesized that some population declines may also be related to the inhibition of spawning behavior (due to pH-induced changes that affect courtship behavior), or to the inability of adult fish to locate spawning sites (due to effects on visual perception or olfactory tissues).

Exposure to sublethal reductions in pH may also ultimately increase fish mortality and population decline, but supporting data for this hypothesis do not currently exist. Fish mortality from these reductions in pH may result from

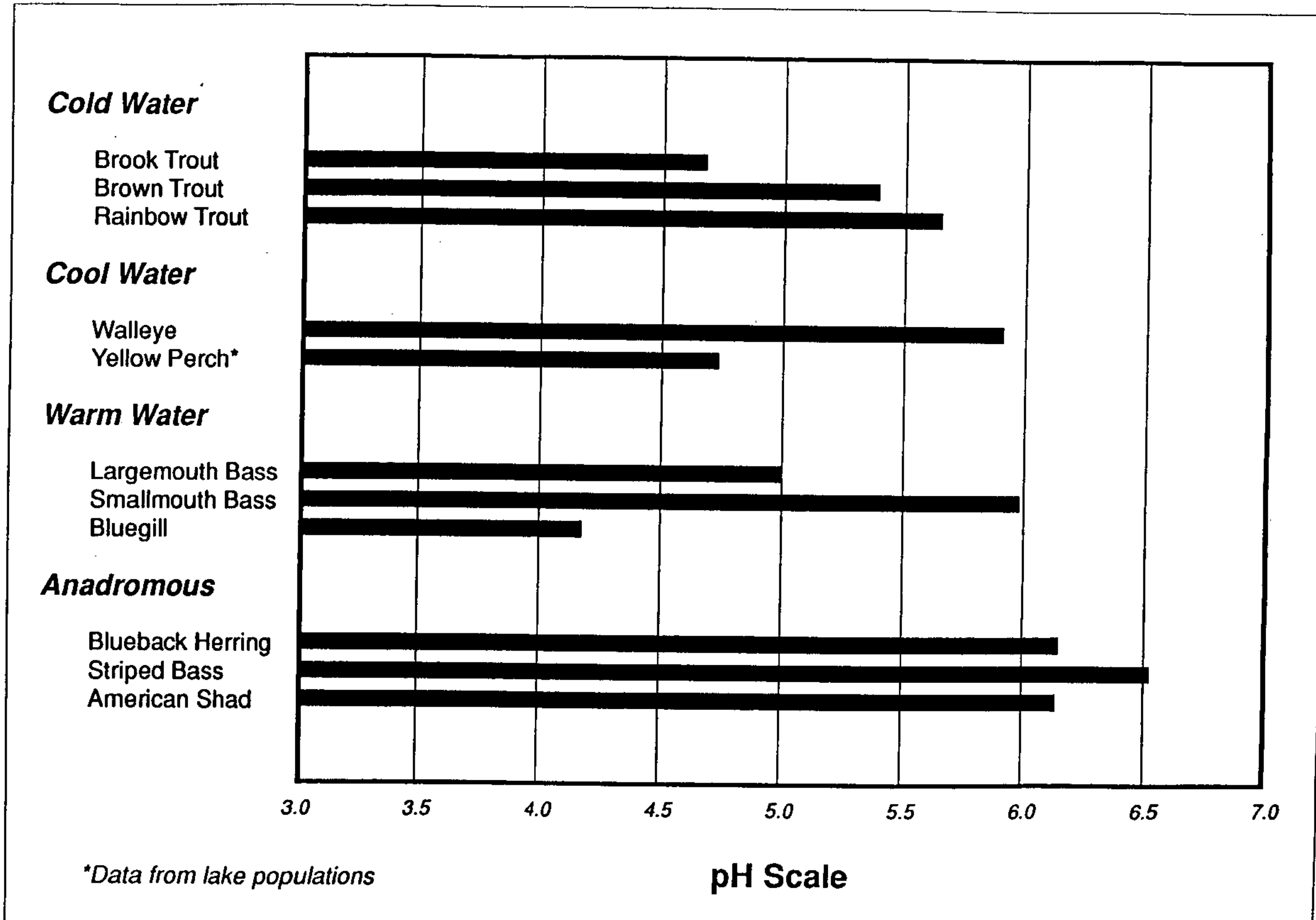

Figure VIII-6. Critical pH values,(i.e. those causing mortality in some part of the life cycle), for some common Maryland game fishes

Sources: Haines 1981; Baker 1982; Wood & McDonald 1982; Klauda & Palmer 1986; Mehrle et al. 1984; 1985; Hall et al. 1986.

decreased resistance to diseases, habitat degradation, changes in predator-prey relationships, increased bioavailability of toxic substances, and synergistic and additive effects of environmental stresses concomitant with sublethal physiologic impairment (Fraser and Britt 1982).

Nationwide Surface Water Effects

Much information that can be used in conjunction with information from studies being conducted in Maryland to address the potential impact of acid deposition on Maryland's surface water resources is presently being gathered by research programs funded by the federal government and private sector. Among these programs are four major research efforts being conducted by EPA: 1) the National Surface Water Survey (NSWS), 2) the Direct/Delayed Response Program (DDRP), 3) the Watershed Process/Manipulation Program and 4) the Temporally Integrated Monitoring of Ecosystem (TIME) Program. The majority of these studies have not yet been completed. Preliminary results of these studies, however, indicate that the response of a water body to acidic deposition is dependent on the soils, bedrock, hydrogeology, and to some extent the vegetation of the surrounding watershed.

Maryland Surface Water Effects

A series of studies have been conducted to specifically address the effects of acid deposition on Maryland's water resources. The following is a description of these studies and their results.

The Coastal Streams Pilot Survey was conducted in the spring of 1983 to provide an overview of the potential impact of stream acidification on the water quality of spawning areas for fish such as American shad, blueback herring, alewife, white perch, and yellow perch and to determine if further investigation of this issue was warranted. The results of this study (Ecological Analysts 1983) showed that each of the 23 streams sampled weekly during March and April exhibited pulses of lowered pH (< 6.0), potentially toxic to certain populations, at least once during periods of high rainfall (Janicki and Cummins 1983).

The Coastal Streams Acidification Study of the possible effects of stream acidification on anadromous fish was planned and initiated in 1984, designed to examine the potential contribution of acid deposition to acidic pulses that were observed in 1983. Results indicated that the responses of these streams to precipitation events are highly variable and likely to depend on the meteorological and chemical characteristics of the precipitation events (Campbell *et al.* 1987). Use of conventional agricultural soil amendments such as limestone in the watershed was also thought to be an important determinant of the responses observed in these streams.

A summary and qualitative analysis to characterize the sensitivity of surface waters in Maryland to acidification was conducted in 1986 (Janicki and Greening 1987). Overall, 19 percent of the streams sampled exhibited mean alkalinity values of less than 200 ueq/l, an alkalinity value commonly used by researchers as a stream sensitivity criterion (Norton *et al.* 1982). Acidic conditions (mean pH values less than 6.0), which are potentially detrimental to aquatic biota (Harman 1984), have been observed in about 9 percent of the streams for which data were collected. For the most part, streams located in the Appalachian Plateau and Coastal Plain physiographic provinces of Maryland (refer to Figure VII-2) are most likely to exhibit lower alkalinity and pH values. Conversely, those streams of the Valley and Ridge, and Piedmont provinces generally show relative insensitivity to acidification.

The Maryland Synoptic Stream Chemistry Survey, conducted in 1987, was designed to provide statewide estimates of the number and extent of stream resources presently affected by or at risk from acidification. This study included the sampling of 630 stream reaches in the various physiographic regions of the state. Water samples from each stream were analyzed for acid neutralizing capacity (ANC), pH, conductivity, dissolved organic carbon, and dissolved inorganic carbon. Results (Table VIII-2) of this study indicated that approximately one-third of the stream reaches sampled are potentially sensitive to acidification or already acidified. Sensitive streams are present in all physiographic provinces in Maryland, the highest proportion being found in the Southern Coastal Plain and Appalachian Plateau.

Table VIII-2

Summary of Maryland Synoptic Stream Chemistry Survey Results

Physiographic Province	Number of Streams Sampled	MEAN pH	MEAN ANC µeg/L	MEAN DOC (1) mg/L	MEAN DIC (2) mg/L	MEAN Conductivity µS/cm
Appalachian Plateau	134	6.90	471	1.27	5.67	123
Valley & Ridge	46	7.87	3456	1.44	43.39	479
Blue Ridge	47	7.31	423	1.59	5.29	127
Piedmont	118	7.40	586	3.56	7.02	153
North Coastal Plain	92	6.88	506	8.44	6.69	206
South Coastal Plain	98	6.22	171	5.70	3.40	118

(1) DOC = Dissolved organic carbon.
(2) DIC = Dissolved inorganic carbon.

Source: Knapp et al. 1988

Based on the results of the MSSCS and other existing data on watershed characteristics, a design for a long-term state stream chemistry monitoring program has been developed to detect future changes in stream chemistry that may indicate either acidification or recovery of acidified streams throughout the state. Additionally, efforts will be made to insure data compatibility between this program and NAPAP's TIME project.

Terrestrial Resources

- Agricultural Resources

The potential impacts of acid deposition on the types of crops that are representative of the major agricultural products in Maryland are summarized in Table VIII-3. No acid precipitation damage to important Maryland crops (corn, soybeans) has been reported under ambient rainfall conditions. However, complications in assessing the sensitivity of a crop to acid deposition often limit the quantification of acid deposition impacts. For example, the effect of acid deposition reportedly varies with the stage of development and the specific cultivar (variety) of the crop. These varying responses have been attributed to physiological differences between cultivars, particularly those relating to the wettability of the leaf surface. Evans *et al* . (1977) and Hutchinson *et al.* (1986) reported that damage is more likely on cultivars with easily wettable leaves, e.g., those lacking pubescence (a hair-like coating) or a thick waxy cuticle, than on cultivars that resist wetting (Evans *et al.* 1977; Hutchinson *et al.* 1986). Regarding development stage, Norby and Luxmoore (1983) found that rain solutions adhere more readily to young, unfolding leaves than to older ones. They subsequently concluded that acid deposition would cause greater damage to younger than to older crop plants. Other research, however, has noted that younger crop leaves often have greater neutralizing ability than older ones (Hutchinson *et al.* 1986).

Differences in experimental methodology, e.g., field versus laboratory studies, also complicate the assessment of the impacts of acid deposition on agricultural crops, since in these studies control crops are different to establish. Research in this area continues.

Table VIII-3
Some potential impacts of acid deposition on agricultural crops

Process	Impact	Reference
Nutritional	Foliar leaching of nutrients, carbohydrates, and growth regulators	Lee et al. 1981 Fairfax and Lepp 1975
Physiological	Disease stimulation or inhibition Accelerated leaf loss Leaf discoloration Lesions Reduced chlorophyll production Reduced nitrogen fixation	Irving and Miller 1981; Irving 1983; Heagle et al. 1983 Forsline et al. 1983 Norby et al. 1986
Yield	Decreased yields Decreased protein contents	Evans et al. 1981

* Most impacts of acid deposition on crops result at a pH lower than that of ambient rainfall.
Source: Lee et al. 1981

Crop research programs under the National Acid Precipitation Assessment Program (NAPAP) include extensive evaluations of the effects of acid deposition on crops, including those common to Maryland. Results available thus far, however, show little impact at current levels of deposition.

Present state-of-the-art field methodology involves the exclusion of ambient rain and the application of simulated acid rain under "real time simulation" (treatment only during periods of actual rain)(Johnston and Shriner 1986). To date, this methodology has only been evaluated with soybeans. Johnston and Shriner (1986), Johnston *et al.* (1987), and Takemoto *et al.* (1987) reported no effect of simulated acid deposition (pH 3.2 to 5.2) on soybeans grown under "real time simulation" rainfall. Research on other plant species is continuing.

Greenhouse experimental methods have focused on the potential impact of gaseous pollutants such as ozone in combination with acid precipitation on crop growth. These studies (Norby *et al.* 1985; Norby and Luxmoore 1983) have either been inconsistent or have found no effect from ozone and simulated acid rain on soybean growth. Johnston *et al.* (1986) reported additive effects of ozone and acid deposition on radish crops, but only with simulated rainfall of pH 3.3. No effects were reported when the pH of the simulated rain approached that of ambient rain (4.0 - 4.2) in Maryland (Norby *et al.* 1985; Johnston *et al.* 1986). As with field studies, greenhouse research in this area is continuing.

- Forest Resources

The role of acid deposition in the decline of forests and forest trees has not been defined, although many hypotheses are being examined. Potential direct effects of acid deposition to forest trees and other vegetation, as determined through laboratory and field studies, include the following:

- leaching of nutrients from foliage,

- increased permeability of leaf surfaces to toxic substances, water, and disease agents,

- altered reproductive process,

- altered root-microorganism relationships,

- erosion of protective wax leaf surfaces, and

- chlorophyll degradation, premature aging, and general physiological alterations.

Only the first of these direct effects, leaching of nutrients from foliage, has been observed under ambient conditions (Fairfax and Lepp 1975; Tukey 1980); but all six have been reported from various experiments using simulated acid rain (Evans *et al.* 1981; Irving 1983; Leben 1954; Shriner and Cowling 1980; Tukey 1980). Potential indirect effects of acid deposition include changes in soil chemical characteristics and resulting changes in plant productivity. That is, soil solutions could become more acidic, resulting in changes in nutrient availability and potentially toxic concentrations of aluminum in solution.

Recent investigations of forest decline have not reached consensus regarding the influence of acid deposition and/or other air pollutants. The combined influences of many natural factors such as climate changes, succession, competition, pathogens, and pests confound the examination of the effect of acid deposition on forest ecosystems. Other factors, including elevated levels of ozone, gaseous sulfur dioxide, and metals, as well as poor forest management practices, may also be responsible for forest decline.

The effect of acid deposition on forests is the subject of extensive research programs sponsored by EPA and EPRI. Current levels of rain acidity in Maryland have not been shown to produce measurable damage to forests. Even in the higher elevations of western Maryland the forests are not exposed to long periods of acid fog, which is suspected of producing forest decline and damage in the high Appalachians in the Northeast and in the southwestern states (Johnson *et al.* 1983). The state has no plans to conduct field studies of acid deposition impacts on forests because the results of programs conducted elsewhere are directly applicable to Maryland.

Human Health

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 quite difficult. In most studies, the results have been confounded by the effects of multiple pollutants. As a result, consensus has not yet been reached as to the appropriate compounds to be measured.

Recent epidemiological studies and related community health studies (Bates and Sizto 1983; Bates 1986; Fine *et al.* 1986) have examined the relationship between acidic airborne pollutants (not necessarily "acid rain") and increased respiratory symptoms. Bates and Sizto (1983) found a positive correlation between summertime hospital admissions for respiratory disease and atmospheric sulfur oxide measurements. Similarly, Koenig *et al.* (1985) noted statistically significant changes in total respiratory resistance in adolescents with asthma when exposed to 0.5 ppm sulfur dioxide or 100 ug/m^3 of sulfuric acid over five separate days. However, other researchers, Linn *et al.* (1986) have reported no physiological or symptomatic changes in study populations following exposure to simulated acidic pollutants.

Interpretation of the results of most human health studies have been confounded by the effects of multiple pollutants. One recent epidemiological study, from the Harvard Six City Study, found a significant relationship between acidic pollutants and increased respiratory problems in certain cases. However, the complexities in measuring exposure and dose-response relationships mentioned above make these results questionable. Additional study is continuing on the subject.

Material Resources

Degradation of some materials commonly used in buildings and statues across the U.S. can be accelerated by acidic pollutants. Serious concern exists over cultural loss resulting from damage to monuments and economic loss from accelerated degradation of building material exposed to the environment. A great