

# ACID RAIN

CE 326 Principles of Environmental  
Engineering

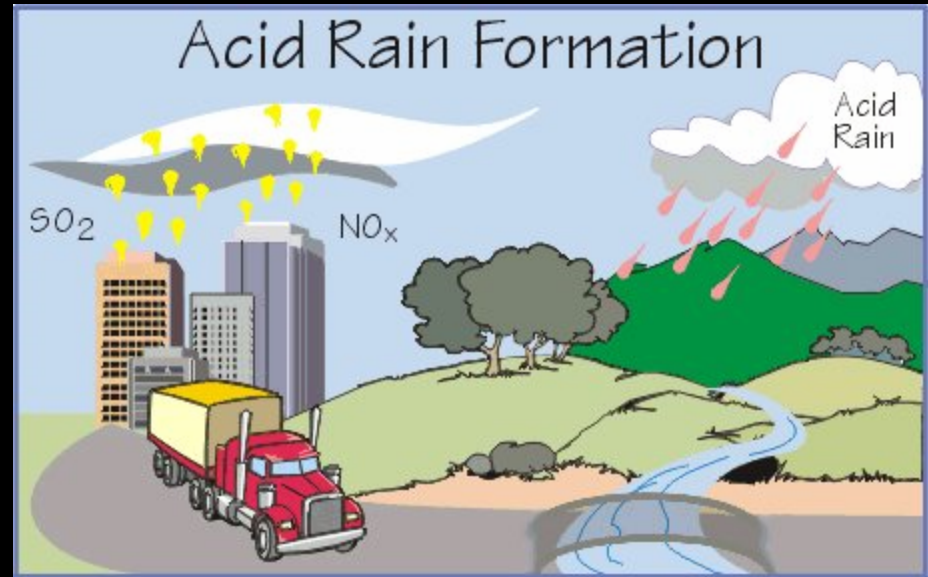
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# What is acid rain?

- More accurate term may be acid deposition
- Occurs in two forms
  - wet deposition (acidic rain, fog, and snow)
  - dry deposition (acidic gases and particles)
- Principal components are  $\text{SO}_x$  and  $\text{NO}_x$
- About 2/3 of  $\text{SO}_x$  and 1/4 of  $\text{NO}_x$  comes from power plants (most are coal burning)



# How do we measure?

- pH of “natural” rain water is 5.6 ( $pK_{a1}$  of carbonic acid is 6.35)
- are monitored by two networks, both supported by EPA
  - The National Atmospheric Deposition Program measures wet deposition, and its Web site (<http://nadp.sws.uiuc.edu/>) features maps of rainfall pH
  - The Clean Air Status and Trends Network (CASTNET) measures dry deposition. Its features information about the data it collects, the measuring sites, and the kinds of equipment it uses - <http://www.epa.gov/castnet/>

# Effects of acid rain

- damage to forests and soils, fish and other living things, materials, and human health.
- acidification of lakes and streams
- In a National Surface Water Survey (NSWS)
  - effects of acidic deposition in over 1,000 lakes larger than 10 acres and in thousands of miles of streams believed to be sensitive to acidification was studied.
  - acid rain caused acidity in 75 percent of the acidic lakes
  - acid rain caused acidity in about 50 percent of the acidic streams

# Effects of acid rain

- regions in the U.S. identified as containing many of the surface waters sensitive to acidification include:
  - the Adirondacks and Catskill Mountains in New York state,
  - the mid-Appalachian highlands along the east coast,
  - the upper Midwest, and mountainous areas of the Western United States.
  - In areas like the Northeastern United States, where soil buffering capacity is poor, some lakes now have a pH value of less than 5.
  - One of the most acidic lakes reported is Little Echo Pond in Franklin, New York. Little Echo Pond has a pH of 4.2.
  - also a problem in lakes smaller than 10 acres that were not included in the NSWIS (may increase the number up to four-fold).

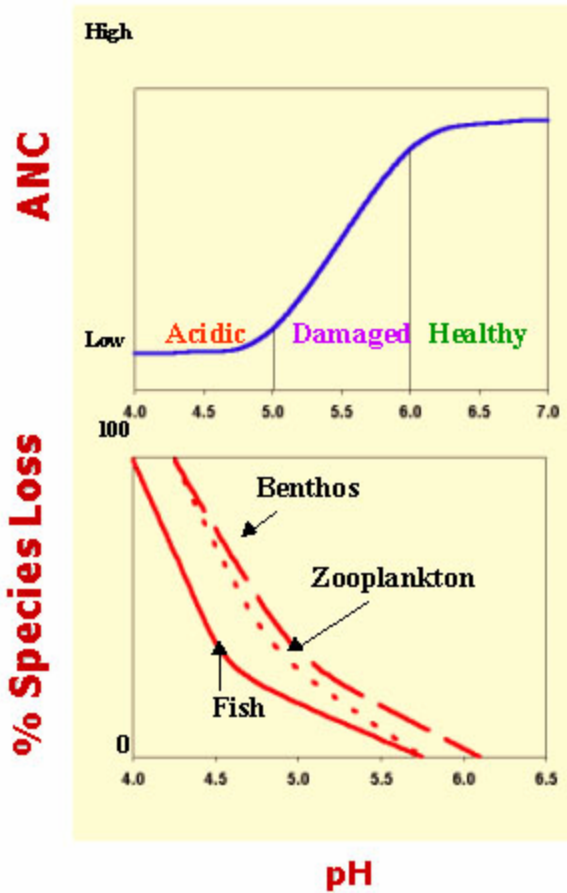
# Effects of acid rain

- approximately 70 percent of sensitive lakes in the Adirondacks are at risk of episodic acidification (brief periods of low pH)
- low buffered streams:
  - 580 of the streams in the Mid-Atlantic Coastal Plain are acidic,
  - in the New Jersey Pine Barrens, over 90 percent of the streams are acidic (highest rate of acidic streams in the nation), and
  - over 1,350 of the streams in the Mid-Atlantic Highlands (mid-Appalachia) are acidic, primarily due to acidic deposition.
- Canadian government has estimated that 14,000 lakes in eastern Canada are acidic.

# Affects Fish and Aquatic Species

- acid rain causes a cascade of effects that harm or kill individual fish, reduce fish population numbers, completely eliminate fish species from a waterbody, and decrease biodiversity.
- increased aluminum levels cause chronic stress that may not kill individual fish, but leads to lower body weight and smaller size and makes fish less able to compete for food and habitat.
- generally, the young of most species are more sensitive to environmental conditions than adults. At pH 5, most fish eggs cannot hatch. At lower pH levels, some adult fish die.

# Acid Rain and Ecological Effects



<http://www.on.ec.gc.ca/wildlife/acidrain/images/ac-slide7.jpg>

	pH 6.5	pH 6.0	pH 5.5	pH 5.0	pH 4.5	pH 4.0
TROUT	Survives	Survives	Survives	Survives	Does not survive	Does not survive
BASS	Survives	Survives	Survives	Does not survive	Does not survive	Does not survive
PERCH	Survives	Survives	Survives	Survives	Survives	Does not survive
FROGS	Survives	Survives	Survives	Survives	Survives	Survives
SALAMANDERS	Survives	Survives	Survives	Survives	Does not survive	Does not survive
CLAMS	Survives	Survives	Does not survive	Does not survive	Does not survive	Does not survive
CRAYFISH	Survives	Survives	Survives	Does not survive	Does not survive	Does not survive
SNAILS	Survives	Survives	Does not survive	Does not survive	Does not survive	Does not survive
MAYFLY	Survives	Survives	Survives	Does not survive	Does not survive	Does not survive

[http://ncaswcd.org/Programs/Education/High%20School%20Envirothon/Current%20Environmental%20Issues\\_files/image018.gif](http://ncaswcd.org/Programs/Education/High%20School%20Envirothon/Current%20Environmental%20Issues_files/image018.gif)

# Tree and Forest Damage

- damage of trees at high elevations (for example, red spruce trees above 2,000 feet) and many sensitive forest soils.

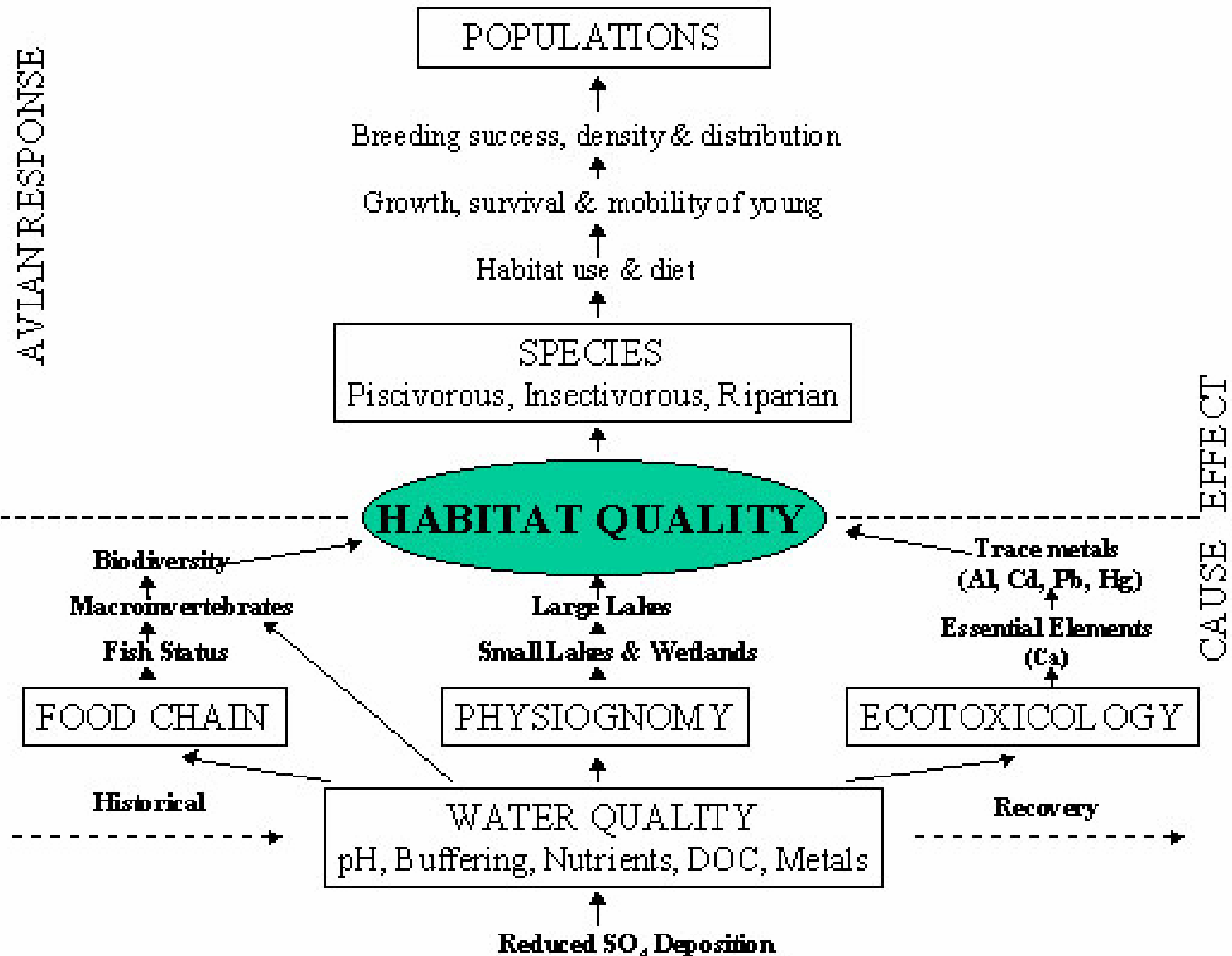


# Water Quality Impacts

- nitrogen impacts on water quality due to eutrophication (oxygen depletion, blooms of algae, declines in the health of fish and shellfish, loss of seagrass beds and coral reefs, and ecological changes in food webs):
  - 10-45 percent of the nitrogen produced by various human activities that reaches estuaries and coastal ecosystems is transported and deposited via the atmosphere.
  - For example, about 30 percent of the nitrogen in the Chesapeake Bay comes from atmospheric deposition.

# Acid Rain and Water Birds

## Pathway of Effects



# Materials and Building Decay

- accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage.
- acid rain can scar automotive coatings
- Acid rain and the dry deposition of acidic particles contribute to the corrosion of metals (such as bronze) and the deterioration of paint and stone (such as marble and limestone).
- some manufacturers use acid-resistant paints, at an average cost of \$5 for each new vehicle (or a total of \$61 million per year for all new cars and trucks sold in the U.S.)



A marble column at the Merchants' Exchange in Philadelphia shows loss of material where the stone is exposed to rain and blackening of the stone surface where the stone is sheltered from rain.



When marble is exposed to acidic rain, sharp edges and carving details gradually become rounded. Antefixes, roof of the Philadelphia Merchants' Exchange (built in 1832).

Formed as a result of air pollution, gypsum alteration crusts have blackened, blistered, and spalled from a marble baluster at the Organization of American States building, Washington, D.C.



Blackened crusts on sheltered portions of the limestone Chicago Tribune Building, Chicago, Illinois.

# Affects visibility

- visibility affected from photochemical smog resulting from  $\text{SO}_x$ , VOC's and  $\text{NO}_x$
- Sulfate particles account for 50 to 70 percent of the visibility reduction in the eastern part of the United States



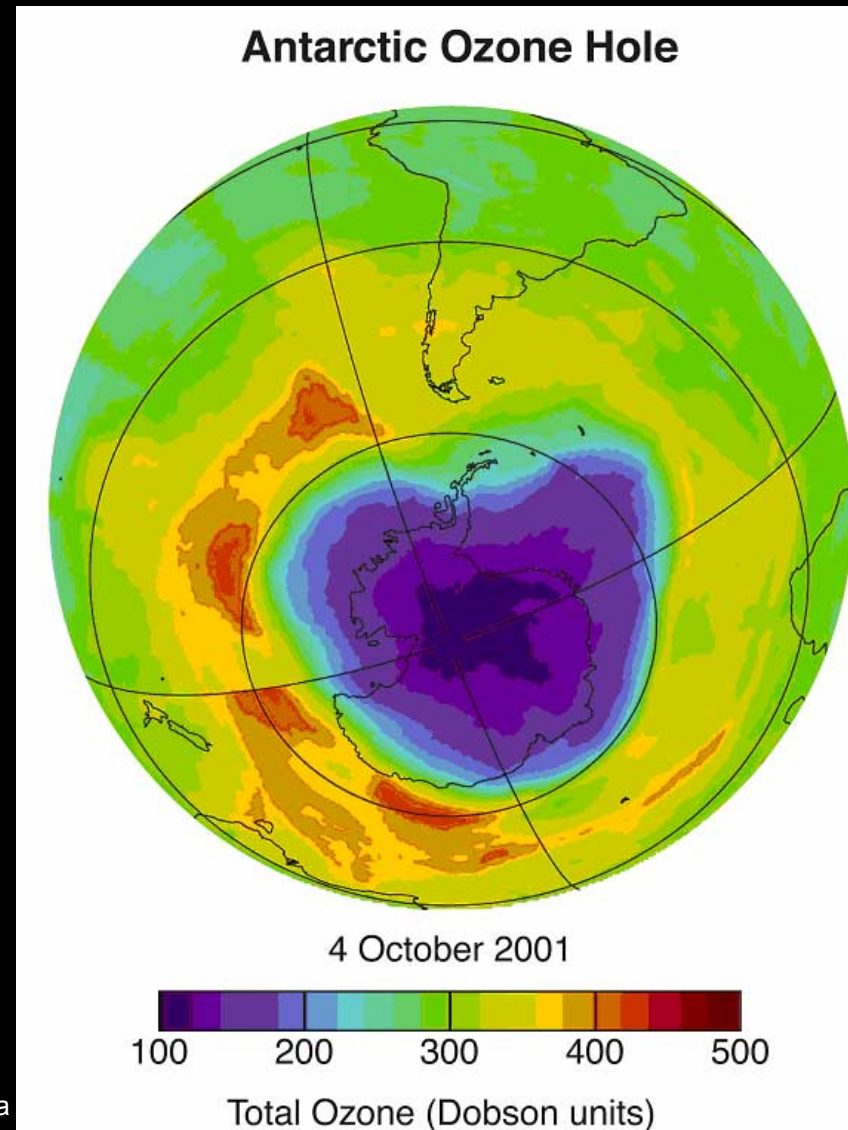
# Acid Rain Reductions

- EPA's Acid Rain Program caps SO<sub>2</sub> emissions from power plants at 8.95 million tons/yr
- 1990 Acid Rain Program under the Clean Air Act set goal to achieve reductions of 10 million tons of sulfur dioxide (SO<sub>2</sub>) and 2 million tons of nitrogen oxides (NO<sub>x</sub>).
- When fully implemented by the year 2010, the public health benefits of the Acid Rain Program are estimated to be valued at \$50 billion annually, due to decreased mortality, hospital admissions, and emergency room visits.

for more details see: <http://www.epa.gov/airmarkets/progress/arpreport/acidrainprogress.pdf>

# Ozone Depletion

- 90% of the planet's ozone is in the ozone layer in the stratosphere (10-50 kilometers above the Earth's surface)
- Stratospheric ozone is a naturally-occurring gas that filters the sun's ultraviolet (UV) radiation
- diminished ozone layer allows more radiation to reach the Earth's surface.



# Ozone Depletion

- overexposure to UV rays can lead to skin cancer, cataracts, and weakened immune systems.
- Increased UV can also lead to reduced crop yield and disruptions in the marine food chain.
- ozone destruction occurs when the release of chlorofluorocarbons (CFCs) and other ozone-depleting substances (ODS), widely used as refrigerants, insulating foams, and solvents.
- Measurements of CFCs in the stratosphere are made from balloons, aircraft, and satellites.

# Ozone Depletion

- Measurements of CFCs in the stratosphere are made from balloons, aircraft, and satellites.
- When CFCs reach the stratosphere, the ultraviolet radiation from the sun causes them to break apart and release chlorine atoms which react with ozone, starting chemical cycles of ozone destruction that deplete the ozone layer.
- One chlorine atom can break apart more than 100,000 ozone molecules.
- Other chemicals that damage the ozone layer include:
  - methyl bromide (used as a pesticide)
  - halons (used in fire extinguishers), and
  - methyl chloroform (used as a solvent in industrial processes).

# Ozone Depletion

- As methyl bromide and halons are broken apart, they release bromine atoms, which are 40 times more destructive to ozone molecules than chlorine atoms.
- volcanoes and oceans release large amounts of chlorine, the chlorine from these sources is easily dissolved in water and washes out of the atmosphere in rain.
- CFCs are not broken down in the lower atmosphere and do not dissolve in water.
- the increase in stratospheric chlorine since 1985 matches the amount released from CFCs and other ozone-depleting substances produced and released by human activities.
- In 1978, the use of CFC propellants in spray cans was banned in the U.S.
- In the 1980s, the Antarctic "ozone hole" appeared and an international science assessment more strongly linked the release of CFCs and ozone depletion.

# Ozone Depletion

- 1987, the Montreal Protocol was signed and the signatory nations committed themselves to a reduction in the use of CFCs and other ozone-depleting substances.
- Since that time, the treaty has been amended to ban CFC production after 1995 in the developed countries, and later in developing countries.
- Today, over 160 countries have signed the treaty. Beginning January 1, 1996, only recycled and stockpiled CFCs will be available for use in developed countries like the US. This production phaseout is possible because of efforts to ensure that there will be substitute chemicals for all CFC uses.
- but provided that we stop producing ozone-depleting substances, natural ozone production reactions should return the ozone layer to normal levels by about 2050.