7.3 ACID RAIN

College Board Topic 7.7

Related Reading Chapter 17, pages 473 - 475

Learning Objectives and Essential Knowledge

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
STB-2.H Describe acid deposition.	**STB-2.H.1** Acid rain and deposition is due to nitrogen oxides and sulfur oxides from anthropogenic and natural sources in the atmosphere. **STB-2.H.2** Nitric oxides that cause acid deposition come from motor vehicles and coal-burning power plants. Sulfur dioxides that cause acid deposition come from coal-burning power plants.
STB-2.I Describe the effects of acid deposition on the environment.	**STB-2.I.1** Acid deposition mainly affects communities that are downwind from coal-burning power plants. **STB-2.I.2** Acid rain and deposition can lead to the acidification of soils and bodies of water and corrosion of human-made structures. **STB-2.I.3** Regional differences in soils and bedrock affect the impact that acid deposition has on the region—such as limestone bedrock's ability to neutralize the effect of acid rain on lakes and ponds.

SUGGESTED SKILL

Scientific Experiments

4.B

Identify a research method, design, and/or measure used.

Natural precipitation is naturally acidic

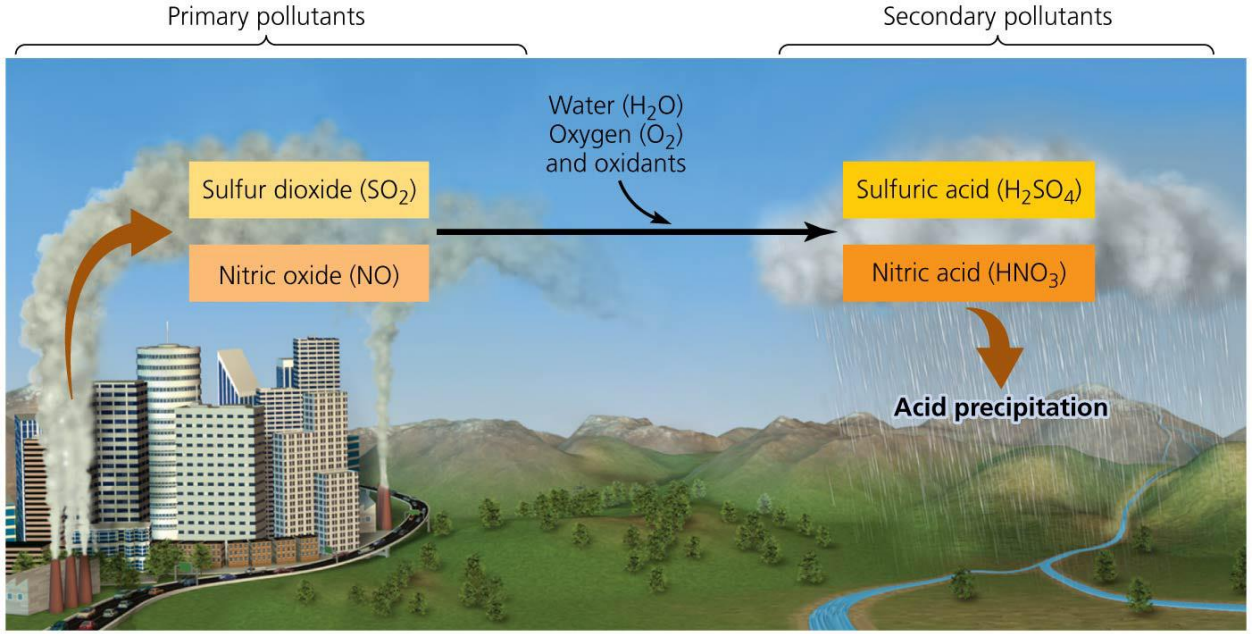
- The average pH of precipitation is naturally 5.6.
  - Respiration and aerobic decomposition naturally release CO_2 into the atmosphere.
  - Lightening strikes produce Nitric oxide (NO).
  - Volcanoes produce Sulfur Dioxide (SO_2).
  - Reactions between water and any of these naturally occurring compounds (NO, SO_2, and CO_2) form acids.
- ***Acid deposition*** is the deposition of acid, or acid-forming pollutants, from the atmosphere onto Earth's surface.
  - Can be wet or dry deposition
    - ***Dry deposition*** is particulate matter containing acid forming compounds or gaseous compounds that bind to surfaces.
    - ***Acid precipitation*** is precipitation (rain, snow, sleet, hail, fog) with a pH below 5.6.

What is Acid Rain?

- Acid deposition originates from emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x).
- These compounds react with water, water vapor, oxygen, and oxidants to form sulfuric (H_2SO_4) and nitric acids (HNO_3)
  - $3NO_2 + H_2O \rightarrow 2\mathbf{HNO_3} + NO$
  - $2SO_2 + O_2 \rightarrow 2SO_3$

    $SO_3 + H_2O \rightarrow \mathbf{H_2SO_4}$
- Remember, ***acids*** are substances that release H^+ into solutions.
  - In water, $HNO_3 \rightarrow \mathbf{H^+} + NO_3^-$
  - In water, $H_2SO_4 \rightarrow \mathbf{H^+} + HSO_4^-$

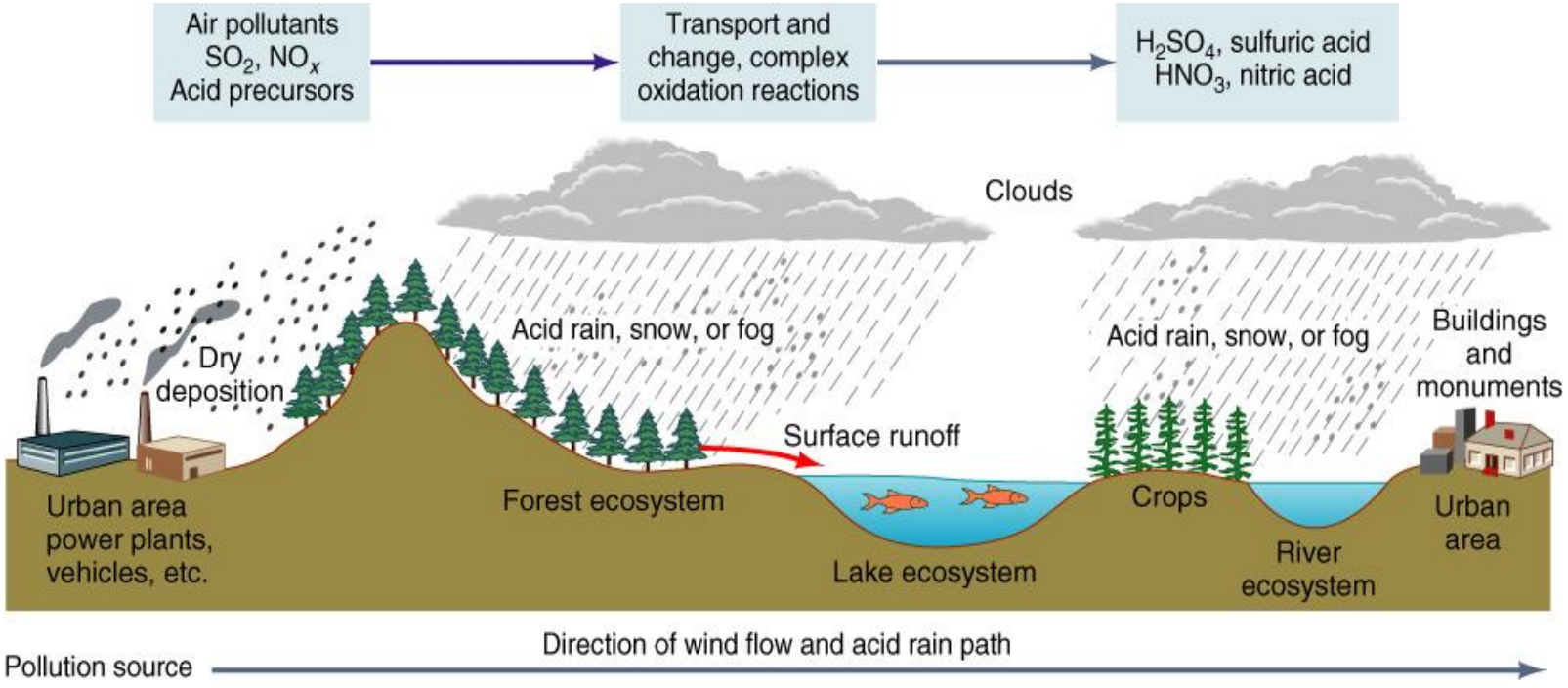
    $HSO_4^- \rightarrow \mathbf{H^+} + SO_4^{2-}$
  - The addition of H^+ lowers the pH of a solution (makes it more acidic).
  - The ***pH scale*** is logarithmic, so a decrease of one pH unit (ex: 5 → 4) is equal to a 10x increase in H^+.



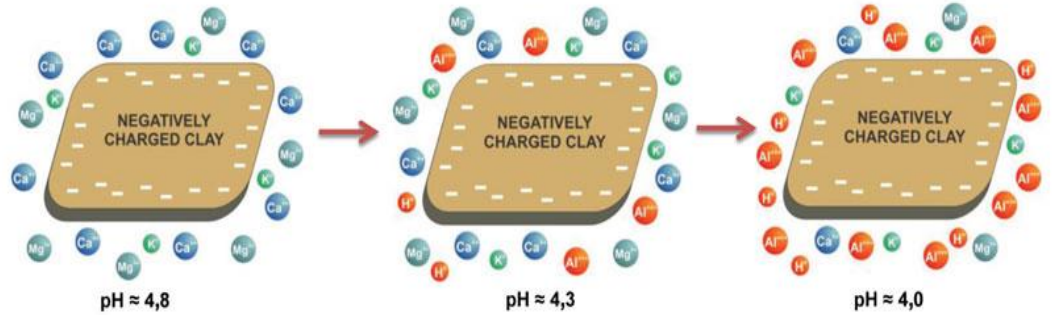
- Combustion of coal in power plants to produce electricity is the major source of SO_2 in the atmosphere.
  - Production of metals and diesel combustion are other sources of SO_2.
- Vehicle emissions and coal and/or gas power plants are the major sources of nitrogen oxides (NO_x).

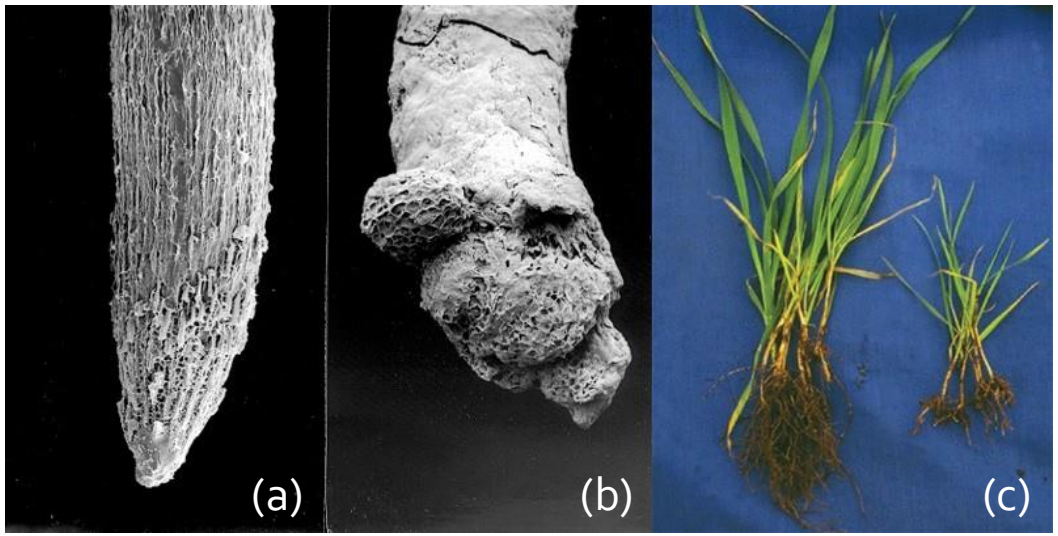
Effects of Acid Rain

- Acid precipitation is rarely directly harmful to human health
- Soil and water acidification
  - Results directly from acid precipitation, or when dry deposited, acidic substances react with water in aquatic systems or with precipitation.
  - Lowers the pH of soils and aquatic ecosystems
- Damage to building and monuments.
- Prevailing winds can transport pollutants (NO_x and SO_2) that cause acid deposition long distances resulting in damages throughout a region.
- The effects of acid deposition are often worst in spring as snow melts and releases large amounts of acidified runoff.



Effects of acid deposition on soils



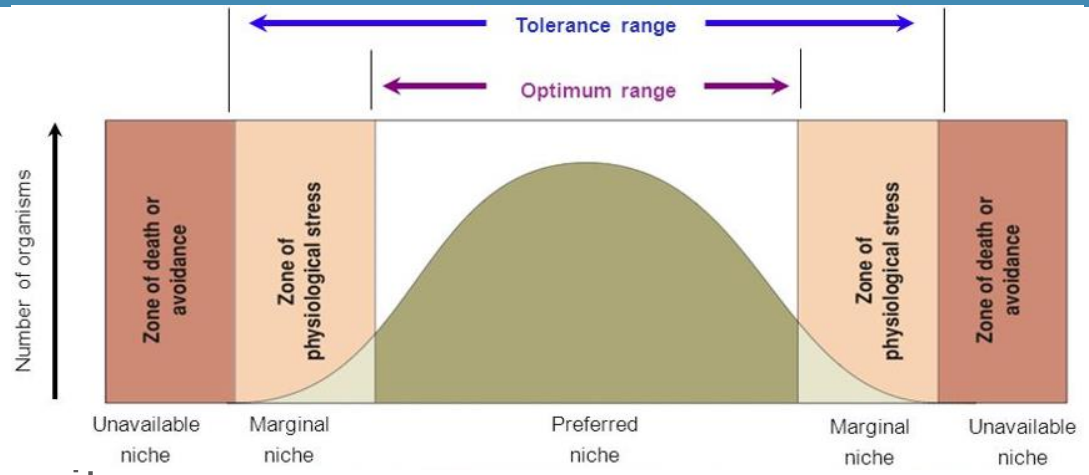


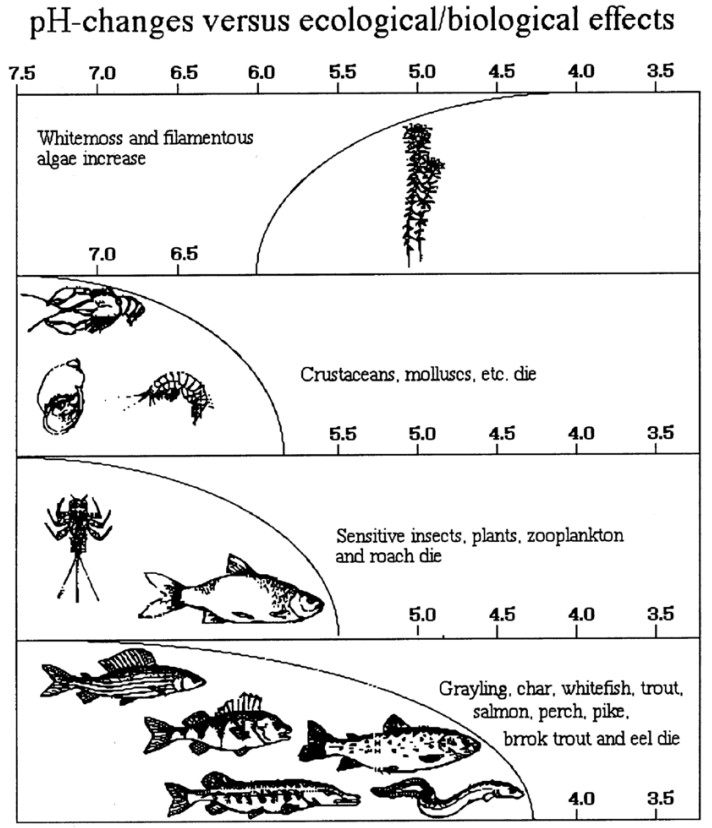
The affects of aluminum toxicity on plant growth. (a) healthy root tip, (b) root tip affected by Al toxicity, (c) stunted plant growth resulting from Al toxicity.

- Soils naturally contain Calcium Carbonate ($CaCO_3$) which acts as a buffer against naturally acidic rainfall.
  - ***Buffers*** help solutions resist changes in pH by reacting with H^+ to reduce the H^+ concentration.
    - $CaCO_3 \leftrightarrow Ca^{2+} + CO_3^{2-} \leftrightarrow HCO_3^-$ *(H^+ from acid)*
  - Some soils contain more $CaCO_3$ and are more resistant to changes in pH.
  - The buffering capacity of any soil can be overwhelmed with enough acid deposition.
  - Humans can add $CaCO_3$ to soil or water to increase buffering and damage caused by acid deposition.
- ***Cation exchange capacity (CEC)*** of soils decrease when pH drops (H^+ increases)
  - H^+ displaces cation nutrients (Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+) from clay particles in the soil, leading to the leaching of nutrients into deeper soil horizons away from plant roots.
- ***Aluminum toxicity*** increases when soil pH drops.
  - Decreasing pH (increasing H^+) dissolves the common soil compound $Al(OH)_3$ producing the ion Al^{3+} which binds tightly to clay particles, further displacing cation nutrients.

Effects of acid deposition on aquatic ecosystems

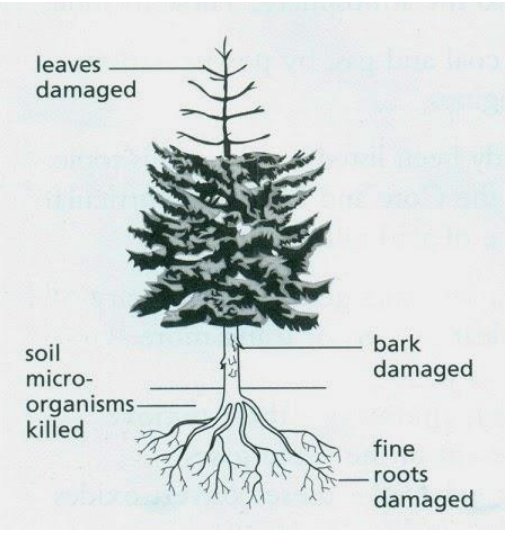
- Acidification of aquatic systems results from acid deposition (wet or dry) directly into aquatic systems or runoff into aquatic systems.
- Aquatic ecosystems exhibit some natural buffering capacity.
- Various species exhibit a specific range of tolerance for various abiotic factors in their environment.
  - pH is an important abiotic factor determining the distribution of aquatic species.
    - Lowered pH causes aluminum toxicity.
    - Blood osmolarity (balance of Na^+ /Cl^-) and water balance is disrupted at lower pH.
  - As pH decreases outside the optimal range for aquatic species, species experience physiological stress, outside of the range of tolerance, all members of a species will be absent.
  - Changes in pH result in changes in species composition of aquatic systems.

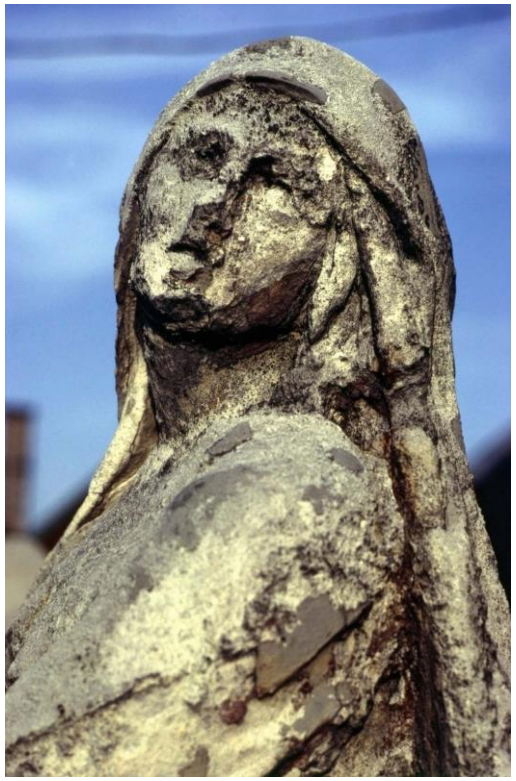




Economic impacts of acid deposition

- Acid deposition:
  - Reduces crop productivity (↓cation exchange and ↑aluminum toxicity).
  - Reduces forest productivity (↓cation exchange and ↑aluminum toxicity).
    - Loss of provisioning (lumber) services.
    - Loss of cultural services (tourism) economic value.
    - Loss of regulating services (dying trees increase erosion which reduces water quality).
    - Loss of supporting services (biodiversity) that underlie the overall functioning of ecosystems.
  - Reduces productivity of freshwater and coastal ecosystems.
    - Similar losses of ecosystem services.
  - Corrodes cars
    - Accelerates metal rust, makes rubber brittle damages paint.
  - Dissolves stone structures:
    - Tombstones, ancient cathedrals and temples, historical monuments and statues.
    - Damages caused by acid deposition cost billions of dollars to prevent or repair annually.





Acid Deposition in the U.S.

TABLE 17.1 Impacts of Acid Deposition

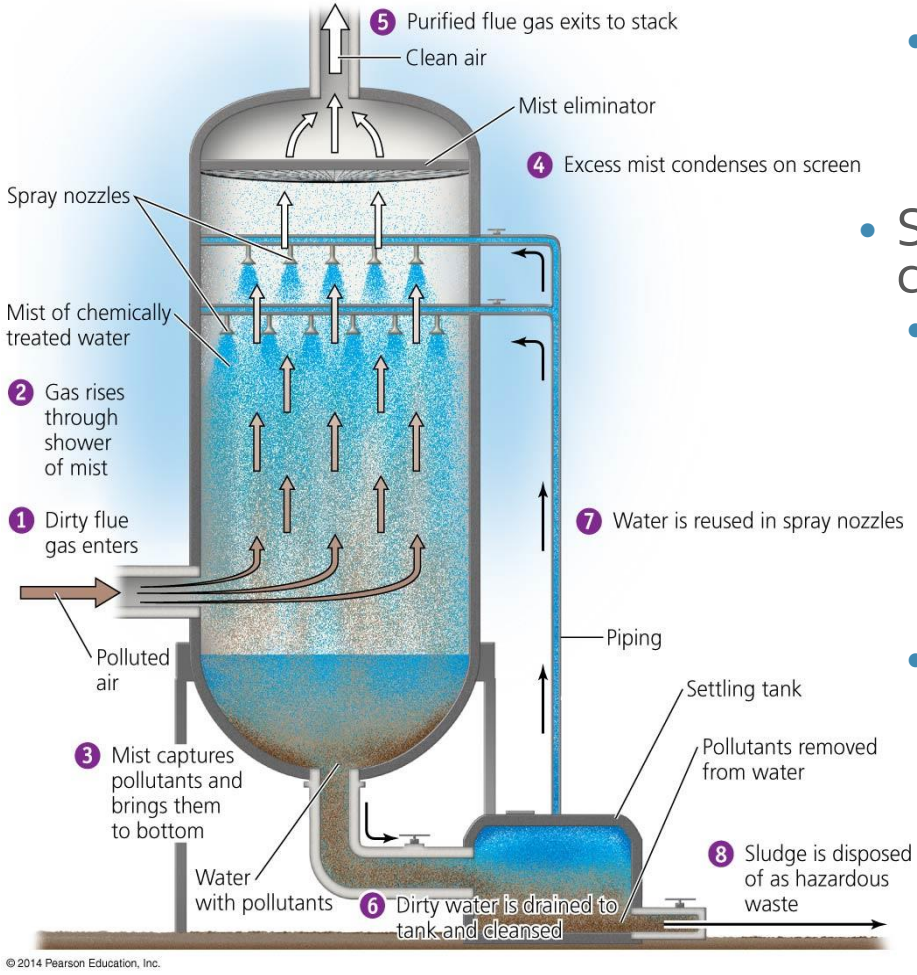
Acid deposition in northeastern forests has . . .

- Accelerated leaching of base cations (ions such as Ca^{2+}, Mg^{2+}, NA^{+}, and K^{+}, which counteract acid deposition) from soil
- Allowed sulfur and nitrogen to accumulate in soil, where excess N can overfertilize native plants and encourage weeds
- Increased dissolved inorganic aluminum in soil, hindering plant uptake of water and nutrients
- Leached calcium from needles of red spruce, causing trees to die from wintertime freezing
- Increased mortality of sugar maples due to leaching of base cations from soil and leaves
- Acidified 41% of Adirondack, New York, lakes and 15% of New England lakes
- Diminished lakes' capacity to neutralize further acids
- Elevated aluminum levels in surface waters
- Reduced species diversity and abundance of aquatic life, affecting entire food webs

- The north eastern U.S. has experienced greater effects from acid deposition than the west.
  - Coal combustion and steel production is more common in the east, especially Ohio, Pennsylvania, Kentucky, and West Virginia.
  - Prevailing winds carry SO_2 from these industries to the northeast (New York, Vermont, Maine, Eastern Canada)
  - Soils in the northeast contain less $CaCO_3$ and are less resistant to pH change.

(a) Acid deposition in 1990

Addressing Acid Precipitation



- Amendments to the Clean Air Act (1990) introduced an emissions trading program (***cap and trade***) for SO_2.
  - Caps pollution at an agreed upon level, then designates each polluters share of allowable pollution.
  - Hefty fines for exceeding a companies share encourage investment in pollution control research and technology.
  - Heavy polluters must buy additional allowances from competitors within their industry who have unused allowances due to their own reduced emissions.

- Scrubbers and electrostatic precipitators reduce air pollution from coal powered industries (electricity and steel).
  - ***Scrubbers***
    - Large column/tube/pipe lined with Lime (CaO) that absorbs or neutralizes oxides (NO_x, SO_x, VOCs) from exhaust streams (emissions).
    - Mist droplets with pollutants and PM trapped in them fall to bottom of scrubber or get trapped at top by mist eliminator
  - ***Electrostatic Precipitators***
    - Power plant/factory emissions passed through device with a neg. charged electrode, giving particles a neg. charge.
    - Neg. charged particles stick to pos. charged collection plates, trapping them.
    - Plates discharged occasionally so particles fall down into collection hopper for disposal in landfills.

Video Resources

- Khan Academy "Buffers the Acid Rain Slayer"
  - https://www.youtube.com/watch?v=77mjvRkfqW4