From emissions to acid deposition

Acid rain is one form of acid deposition. Follow the chain from emitted precursor gases to atmospheric reactions, transport and deposition on land or water.

1. IDENTIFY THE PRECURSORS

Sulfur dioxide (SO_2) comes from burning sulfur-containing coal and other fuels. Motor vehicles and coal-burning power plants release nitrogen oxides (NO_x). Industrial processes also contribute. Natural sources include volcanic emissions; not all acid-deposition precursors are human-made.

2. REACTION AND TRANSPORT

PRECURSORS	→	REACTIONS	→	ACID PRODUCTS
SO_2 and NO_x enter the air.		Water, oxygen and other reactants.		H_2SO_4 and HNO_3 form in the air.

H_2SO_4 = sulfuric acid; HNO_3 = nitric acid. This is a process summary, not a balanced equation. Winds move gases and reaction products, so downwind communities can receive pollution from distant sources.

3. TWO DEPOSITION PATHWAYS

Wet: acidic substances arrive in rain, snow or fog.
Dry: acidic gases and particles settle onto surfaces without precipitation. Later rain can wash deposited material into soils and streams. No rainfall does not mean no acid deposition.

Normal rain is already slightly acidic (about pH 5.6) because dissolved CO_2 forms weak carbonic acid. Pollution-related acid rain involves additional acidity, especially from sulfuric and nitric acids; pH below 7 alone does not identify its cause.

Formation, transport, deposition and normal rain: US EPA, What is Acid Rain?
Source categories and downwind impacts: College Board, STB-2.H and STB-2.I.

Scope: College Board AP Environmental Science CED, Topic 7.7, p. 148.

The same deposition, different damage

The effect of acid deposition depends on both exposure and the receiving environment. Soil thickness, soil chemistry and bedrock help determine how much acidity can be neutralized.

1. COMPARE TWO RECEIVING WATERSHEDS

LIMESTONE-RICH

Carbonate minerals react with acid. More acidity can be neutralized before runoff reaches a lake.

THIN, POORLY BUFFERED

Little reactive carbonate is available. More acidity may reach the lake, allowing a larger pH decline.

Buffering capacity means resistance to pH change, not removal of all pollution. It is finite. These are simplified contrasts: real watersheds differ in flow paths, soil depth and mineral composition.

2. SOILS AND FORESTS

Acidity can leach nutrient ions such as calcium and magnesium from soil and mobilize aluminum into soil water. Nutrient loss and aluminum toxicity can impair roots and growth. Acidic cloud or fog exposure can also damage foliage.

3. LAKES, STREAMS AND FOOD WEBS

Lower pH and dissolved aluminum can harm aquatic organisms and reproduction. Species differ in tolerance; eggs and young stages may be especially sensitive. Losing a prey species can affect predators even when the predators tolerate the water chemistry.

Built environment: acid deposition accelerates metal corrosion and deterioration of carbonate stone, including limestone and marble. The same acid-neutralizing reaction that helps a watershed can dissolve the surface of a monument.

Ecological effects and buffering: US EPA, Effects of Acid Rain.
Bedrock and carbonate-stone deterioration: USGS, Acid Rain and Water.

Scope: College Board AP Environmental Science CED, Topic 7.7, p. 148.

Reduce inputs and test the response

Protecting a lake means looking beyond its shoreline. Reducing upwind emissions addresses the source; monitoring shows whether deposition and ecosystem conditions are improving.

1. CONNECT CONTROLS TO ACID PRECURSORS

Link to Topic 7.6: lower-sulfur fuels and flue-gas desulfurization reduce SO_2; suitable vehicle and power-plant controls reduce NO_x. Conservation and non-combustion electricity can lower both by avoiding fuel burning. The US Acid Rain Program combines an SO_2 cap-and-trade system with NO_x emission limits; its NO_x approach is not the same allowance-trading system.

2. DISTINGUISH SOURCE CONTROL FROM LOCAL TREATMENT

Adding limestone can neutralize acidity in an affected lake or soil, but does not stop upwind emissions. Continued inputs can require further treatment. Monitor chemistry and biological recovery rather than assuming one improved pH reading means the ecosystem is fully restored.

3. EXTENSION: DESIGN A BUFFERING COMPARISON

Question: does limestone reduce the pH change caused by a fixed acid input?
Design: compare equal water volumes with equal masses of similarly sized limestone or quartz chips; include a water-only control.
Keep constant: acid concentration and volume, temperature, stirring and reaction time. Use teacher-approved dilute acid and eye protection.
Measure: initial and final pH with a calibrated probe. Repeat each treatment; compare the pH changes and variation among replicates.

Prediction: limestone should limit the pH drop under these conditions. This small-scale test isolates a mineral effect; it does not reproduce every process in a watershed.

Numeracy link: pH is logarithmic. A sample at pH 4 has $10^2 = 100$ times the hydrogen-ion concentration of one at pH 6 (dilute-water approximation). This is not a claim of 100 times the ecological damage.

Emission policy: US EPA, Acid Rain Program.
Neutralization: USGS, Acid Rain and Water. Experiment: illustrative teaching design.
Logarithmic pH scale: USGS, pH and Water.

Scope: College Board AP Environmental Science CED, Topic 7.7, p. 148.