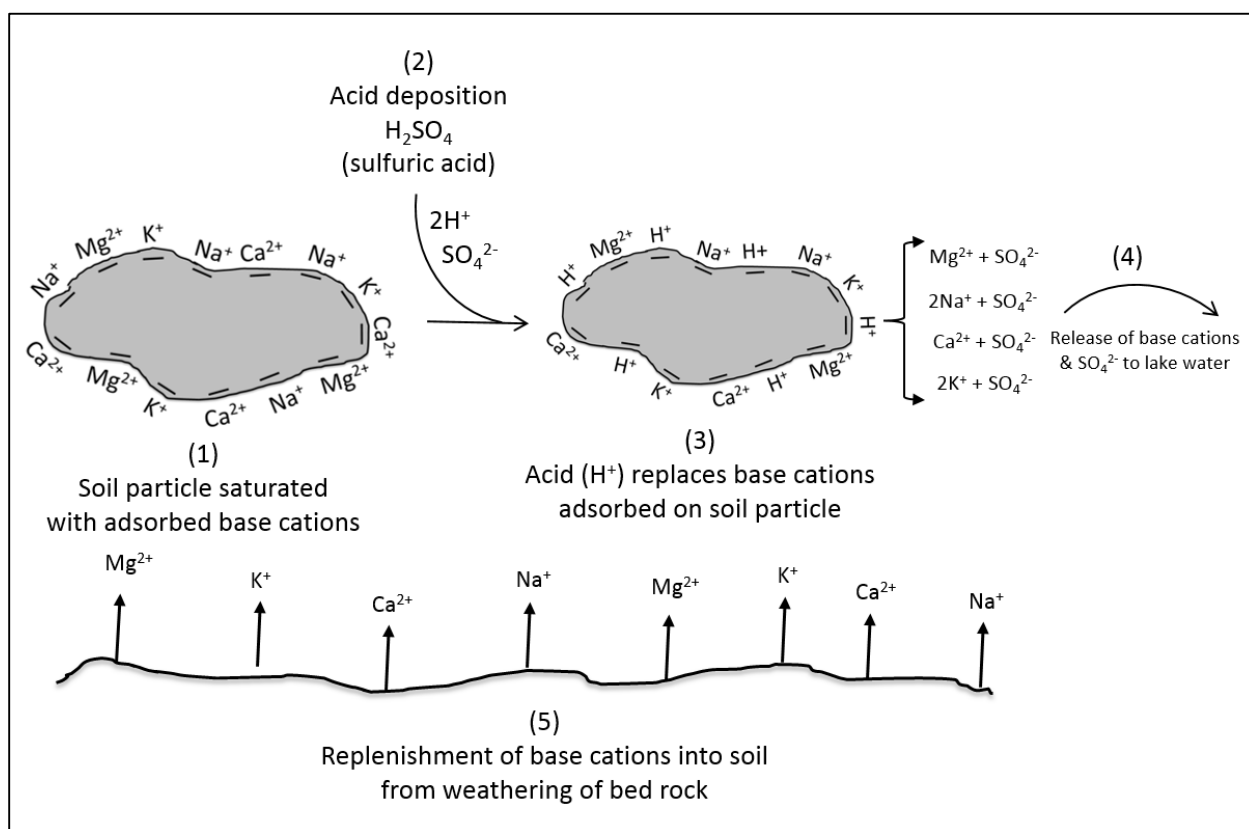


Activity for Lake Acidification by Acid Rain Nature's Alka-Seltzer

Part 2: How a Watershed Protects Its Lake from Acid Rain Example of Big Moose Lake

Background. An analogy can be drawn between the mechanism by which sodium citrate in Alka-Seltzer neutralizes stomach acid (see Activity: Part 1), and the way soils neutralize acid rain. Soil particles possess negative charges on their surfaces that attract positively-charged ions, just as the citrate moiety attracts sodium ions. Some of the more common positively-charged ions in well-buffered soils of temperate climates are calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+). Collectively they are called "base cations."

The numbered sequence in the figure below illustrates the steps in the process of acid neutralization.



Step 1 shows a soil particle with negatively-charged sites on its surface holding positively-charged base cations by electrostatic attraction. All the charged sites on the soil particle are occupied by base cations, signifying that the Cation Exchange Capacity (CEC) is at maximum strength. Step 2 shows the onset of deposition of acid rain caused by sulfur emissions upwind from the lake. In step 3, the soil neutralizes the acid inputs by attracting H^+ to its negatively-charged sites in exchange for release of base cations. H^+ is immobilized while the base cations go into soil solution, pairing with negatively-charged sulfate (SO_4^{2-}) and eventually draining into the lake water. At this point the soil has lost some of its CEC due to the loss of base cations to the lake water. In step 5, weathering of the underlying bedrock releases base cations to the soil. This process replenishes the base cations lost from the soil in the neutralization process. If the rate of replenishment matches or exceeds the rate of acid deposition, the soil will maintain a sufficient

CEC to prevent further lake acidification. If acid deposition exceeds the rate of replenishment, the CEC will eventually dwindle down toward zero. A zero value for the CEC signifies that no base cations remain in the soil, triggering a tipping point and rapid pH decline in which acid inputs drain unimpeded into the lake water.

Activity. We will develop a spreadsheet model for calculating the CEC of the watershed soils, showing how it declines over time. The model will show the negative balance between acid inputs and natural replenishment of base cations, and calculate the year in which the tipping point began to be manifested. In addition, the model traces the impact of the Clean Air Act Amendments of 1990 in reducing acidic inputs. It estimates how the natural replenishment rate serves to overcome the diminishing acid inputs, and estimates the approximate year when the CEC is restored to its full potential.

1880 to 1950: The following are basic facts and assumptions needed for setting up the spreadsheet model for the years of acidification from 1880 to 1950.

General equation for lake acidification:

$$Q_t = Q_o + (t \times R) - (t \times A)$$

where Q_o is the CEC (maximum value in 1880); Q_t is the diminished CEC after “t” years of acidification; R is the natural replenishment rate of base cations; A is the annual rate of acid deposition.

$A = 42.9 \text{ mg H}^+/\text{m}^2/\text{yr}$, the average annual deposition rate over the 70 period of acidification.

R = is the natural replenishment rate per year, a constant assumed to be equivalent to 3% of Q_o , and expressed as $R = 0.03 \times Q_o/\text{yr}$.

Q_t is diminished to near zero by 1950 ($t = 70$), so we can set up the equation:

$$Q_{70} = Q_o + (70 \times R) - (70 \times A) = 0$$

The model will yield values for Q_o and R, which will allow the students to complete their analysis.

1992 to 2040: The following assumptions will be applied for running the model after recovery of the watershed begins in 1992 when the Clean Air Act Amendments of 1990 is implemented.

By 1992, the value of A had decreased to $28.6 \text{ mg H}^+/\text{year}$.

Beginning in 1992, the value of A declines by $0.95 \text{ mg H}^+/\text{year}$.

The model is run just as it did for the period from 1880 to 1950, except that Q_t increases rather than decreases over time. The model is run until $Q_t = Q_o$.