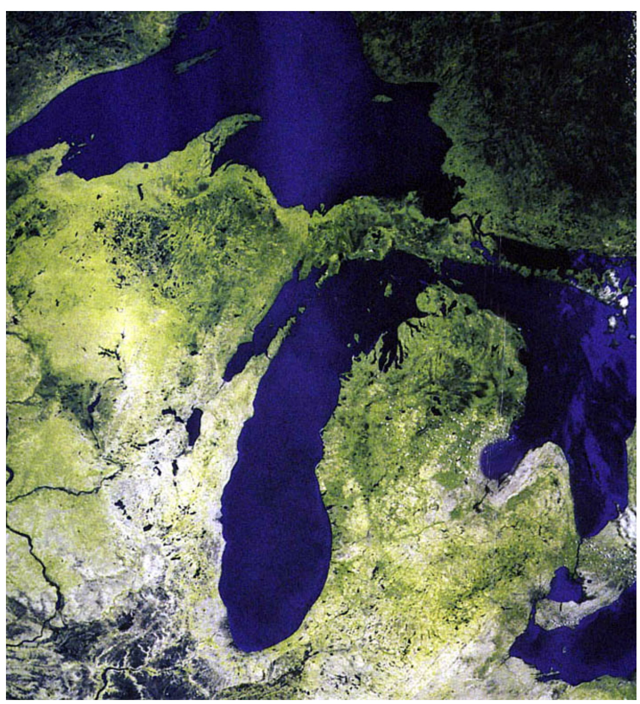
The Global Water Cycle

Accounting, Cycling, and Controls

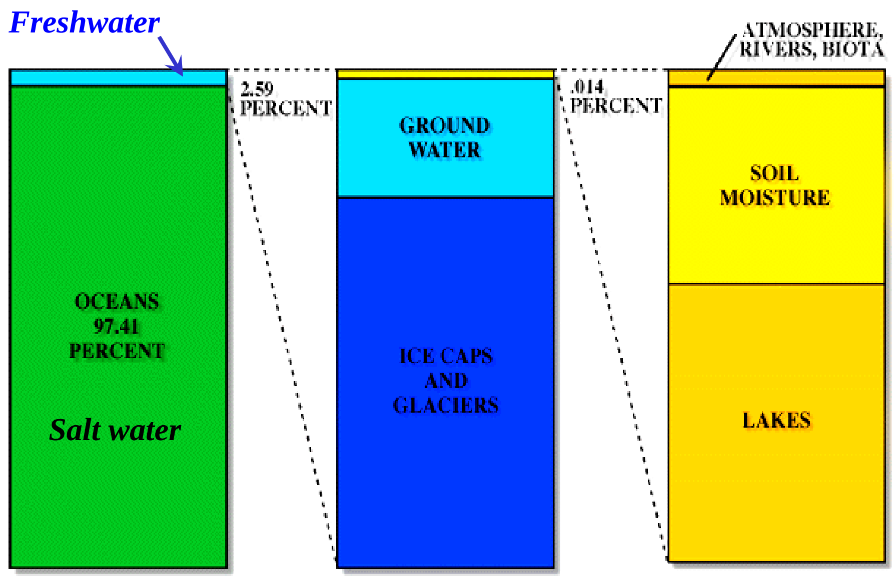
(1) Accounting:

Location	Amount ($km^3 \times 10^6$)
Rocks (unavailable)	150
Oceans	1,350
Ice	27.5
Groundwater	15.3
Lakes and Rivers	0.025
Atmosphere (vapor)	0.013

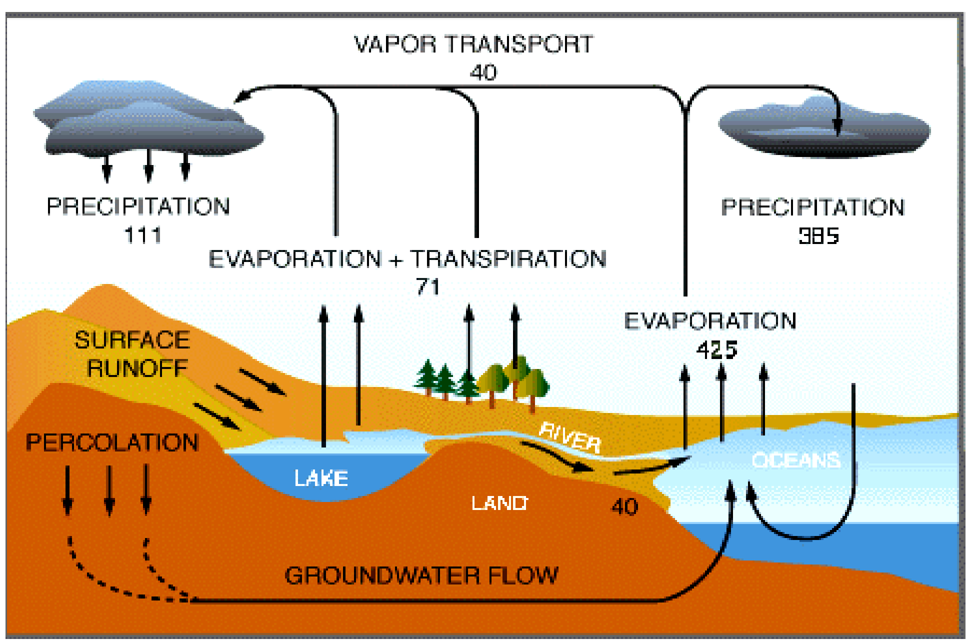
The Laurentian Great Lakes contain ~20% of all the world's freshwater



Freshwater is SCARCE!



The Global Water Cycle



(2) Cycling:

Pathways:

Precipitation, Evaporation, Vapor transport, Runoff

Residence Times:

(A) Ocean R_T = (total in ocean) / (evaporation)

= $(1{,}350 \times 10^6\ km^3) / (0.425 \times 10^6\ km^3/yr)$

= 3,176 years

(B) Calculate the atmospheric residence time = ?

(3) Controls:

(A) Human Consumption

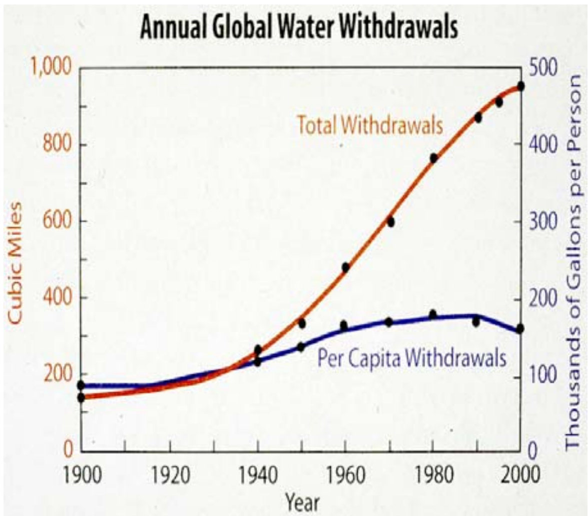
(B) Temperature

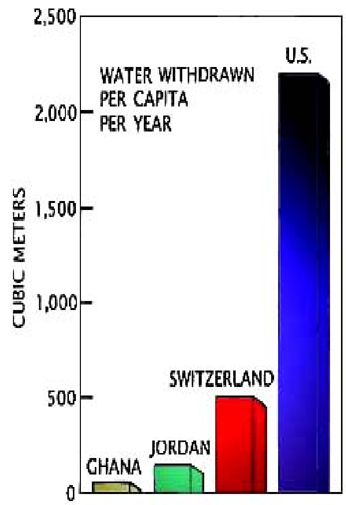
1. **Glacier melting**
2. **Sea level rise**
3. **Changes in deep-water formation**

(C) Land-use changes

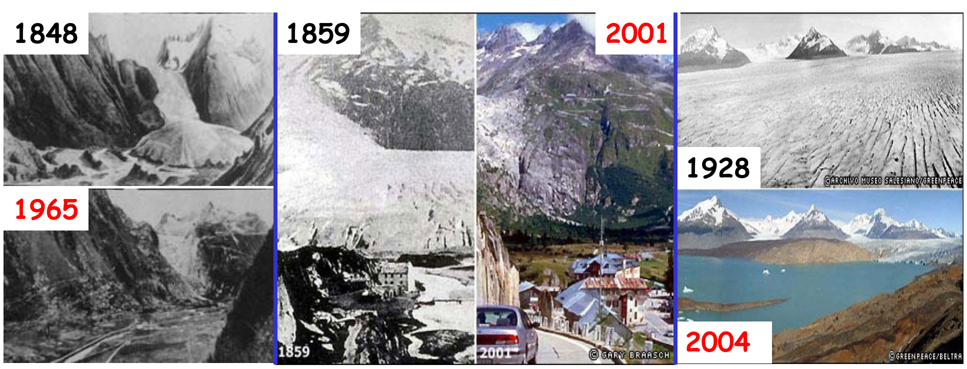
A. Human Consumption of Freshwater

Local problems, soon to become regional problems





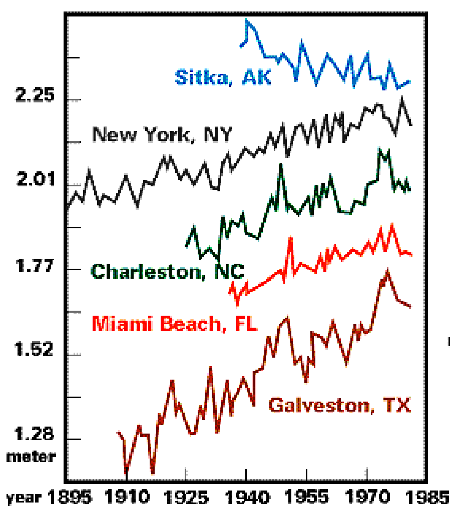
B. Increasing Temperature is Melting Glaciers

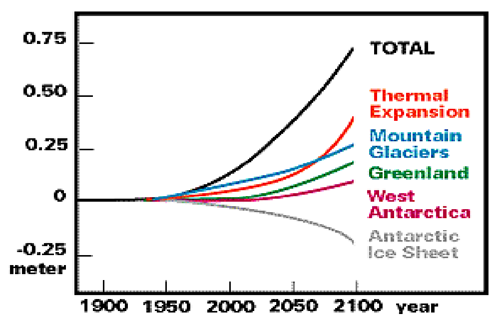


Switzerland *Andes*

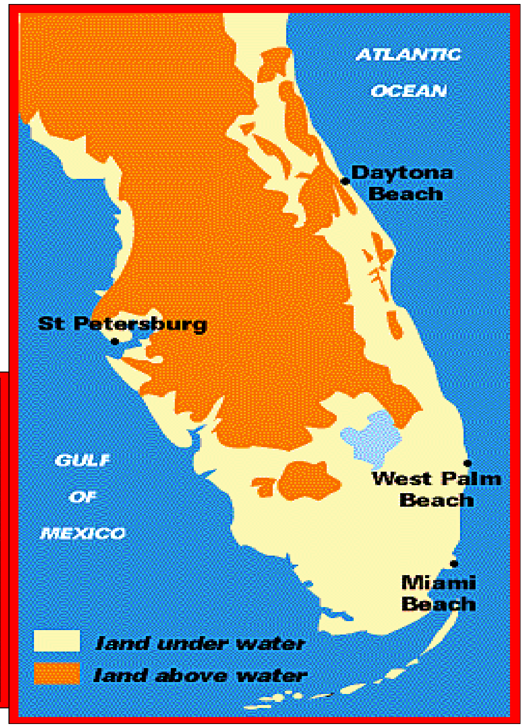
Mountain and coastal glaciers in Alaska have melted substantially in the last 50 years

Increasing temperatures are raising the mean sea level



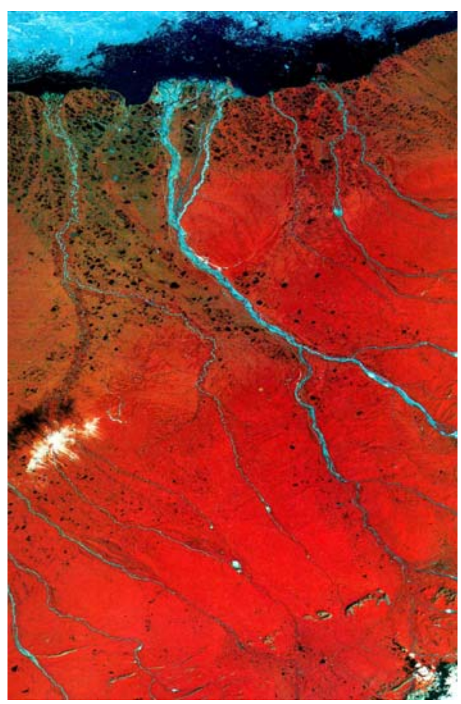


A rise in sea level of ~4.7 m would flood almost half of southern Florida

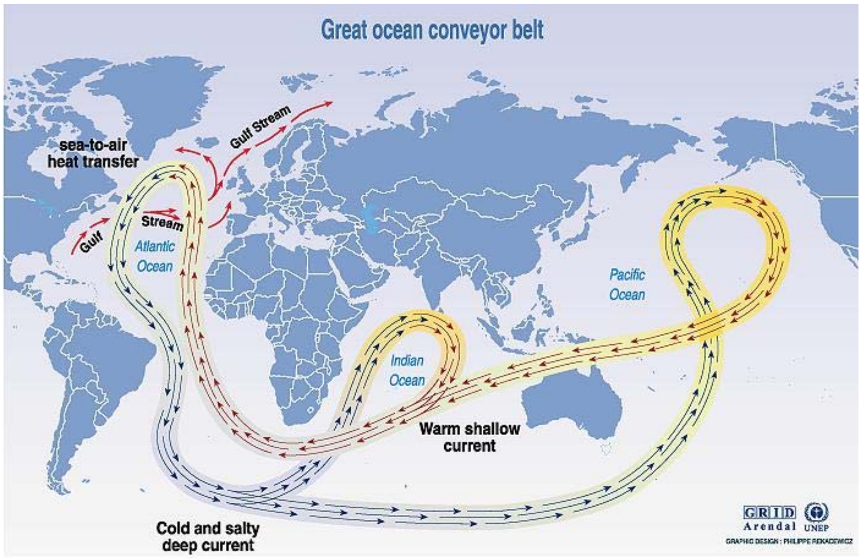


The flow of freshwater in rivers to the Arctic Ocean will likely increase as the temperature warms and glaciers melt.

This could place a "cap" on the sea and prevent deep-water from forming.



Increased freshwater input to the Arctic Ocean may prevent "deep-water formation"



Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

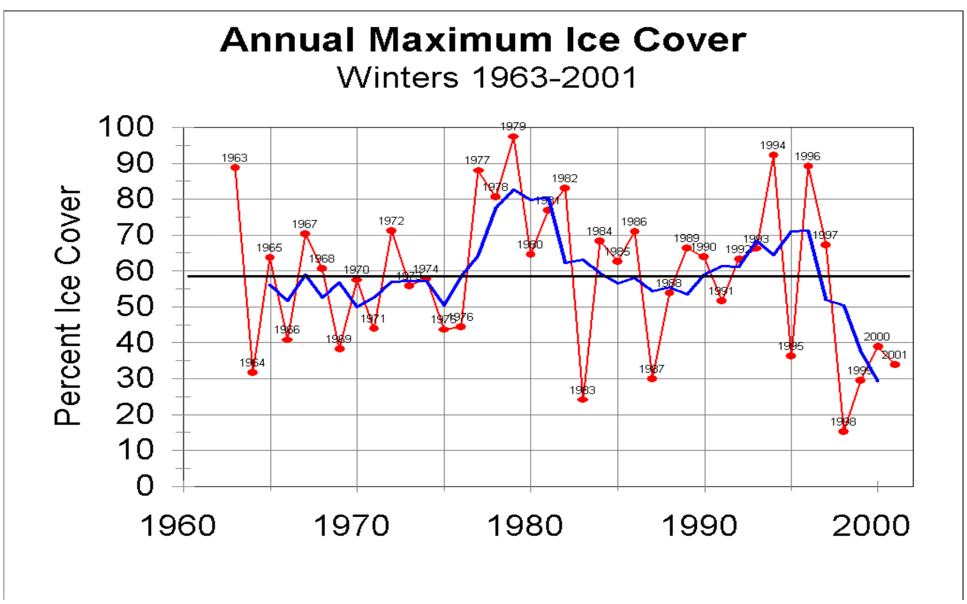
Interactions in the Hydrological Cycle

Low water levels on Lake Michigan in 2000

Why were lake levels so low in 2000?

Precipitation was normal for that year!

Reduced ice cover increased the amount of time for evaporation to lower the lake levels.



The Global Nitrogen Cycle

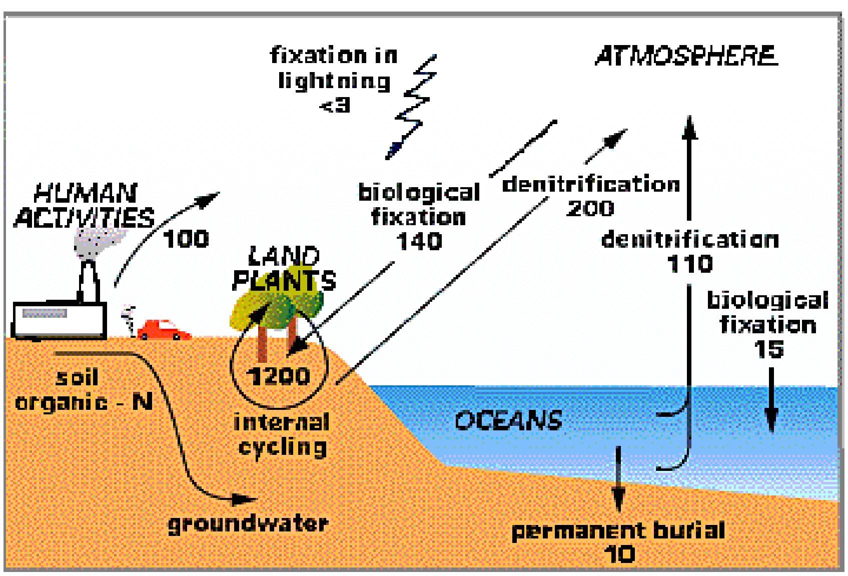
Accounting, Cycling, and Controls

(1) Accounting:

Location	Amount (10^{15} g)
Rocks & Sediments (unavailable)	190,400,120
Atmosphere	3,900,000
Ocean	23,348
Soils	460
Land Plants	14
Land Animals	0.2

In the atmosphere, N_2 = 3,900,000
N_2O = 1.4
NO_x = 0.0006

The Global Nitrogen Cycle – Pathways and Fluxes

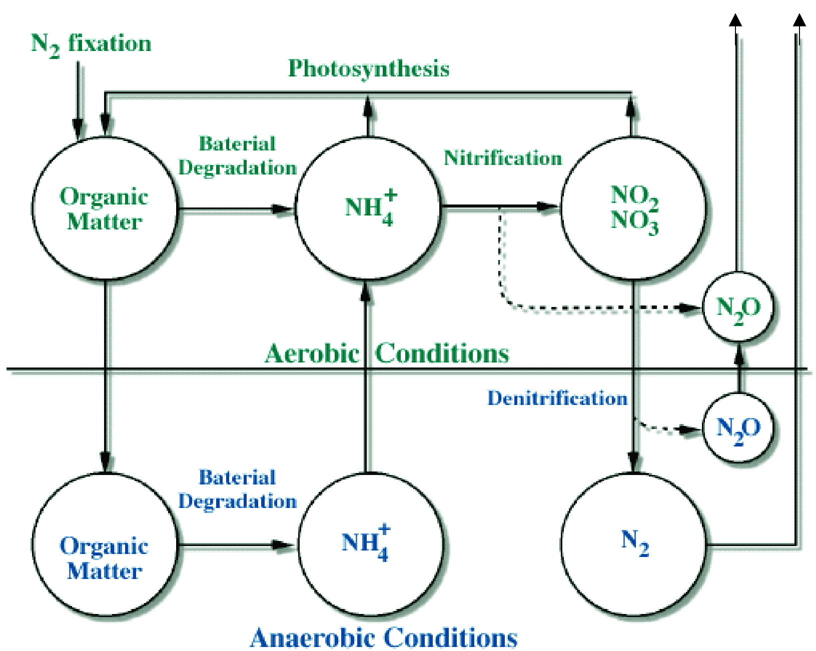


Fluxes in 10^{12} g/yr

(2) Cycling

Pathways and Reactions:

- $N_2 \longrightarrow$ Organic N — ***"N-fixation"***
- Organic N $\longrightarrow NH_4^+$ — ***"Mineralization"***
- $NH_4^+ \longrightarrow NO_3^- + NO + N_2O$ — ***"Nitrification"***
- $NO_3^- \longrightarrow N_2 + N_2O$ — ***"Denitrification"***
- NO_3^- *or* $NH_4^+ \longrightarrow$ Organic N — ***"Plant Assimilation"***



(2) Cycling

Fluxes and Residence Times:

- ***R_T of N_2 in the atmosphere =***

  = (total in atm, 10^{15}g**) / (output,** 10^{15}g/yr**)**

  = (3,900,000) / (0.158)

  = 24.68 Million years

- ***R_T of NO_X*** *($NO + NO_2$)* ***in the atmosphere =***

  (0.6) / (60) = 0.01 year = 3.6 days

(3) Controls -- examine the case of Acid Rain

(A) NO_x and Acid Rain

$NO + O_3$ (ozone) $\longrightarrow$ NO_2

$NO_2 + OH$ $\longrightarrow$ HNO_3 (nitric acid)

HNO_3 dissociates in water to form H^+ and NO_3^-

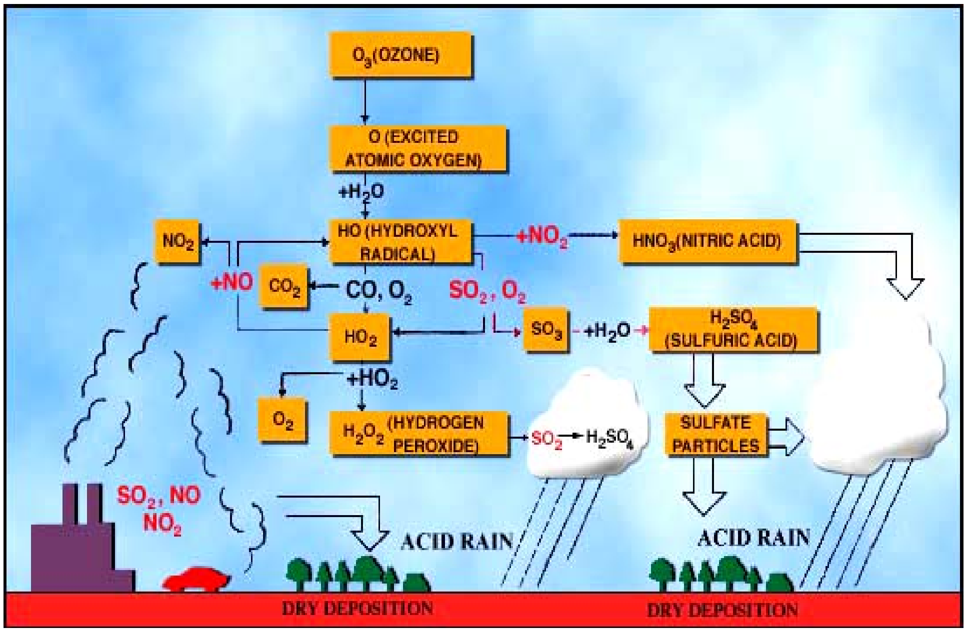
(B) Sulfuric acid formation

$H_2SO_4 \longrightarrow 2\,H^+ + SO_4^-$

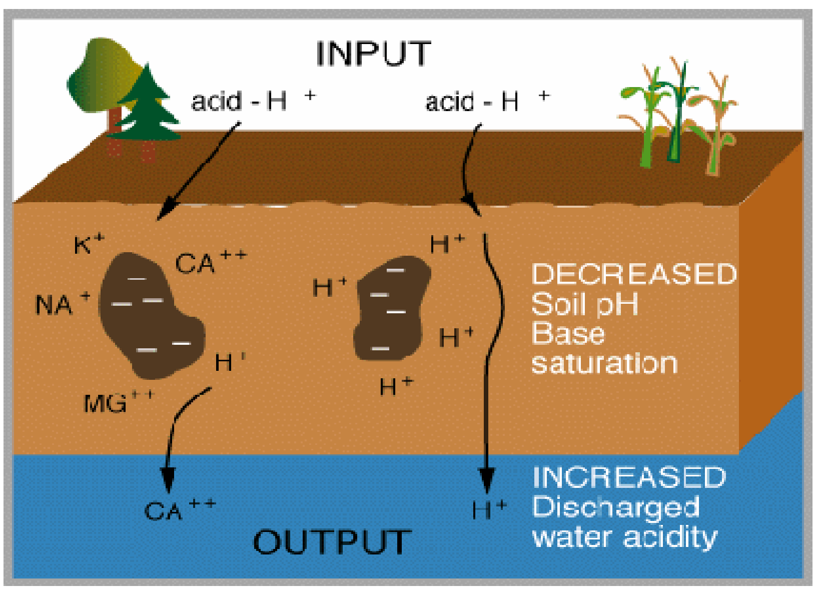
- The H^+ product in both reactions provides the "acidity"

- ***Acid Rain*** **is caused by a** ***combination of element cycles***

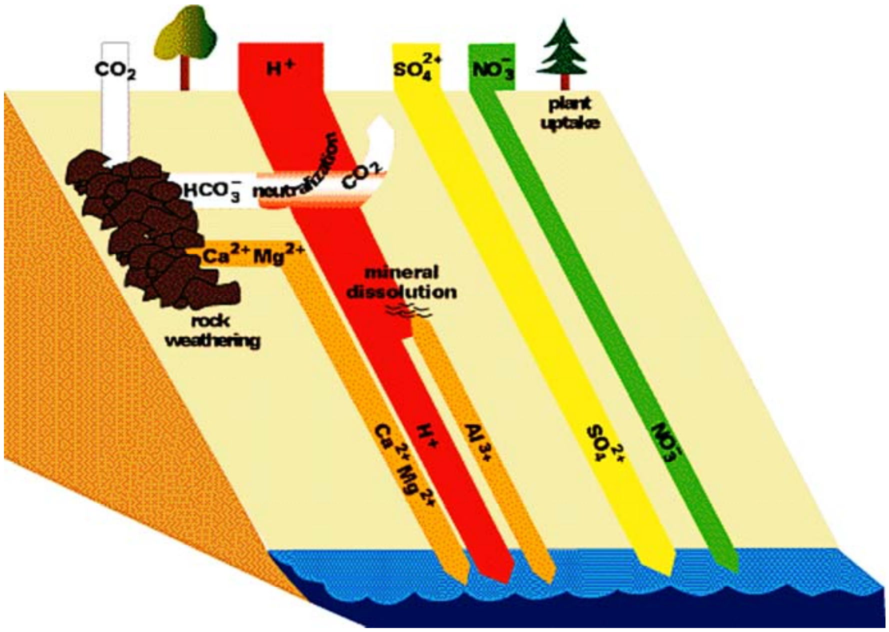
Atmospheric chemical reactions that produce acid rain

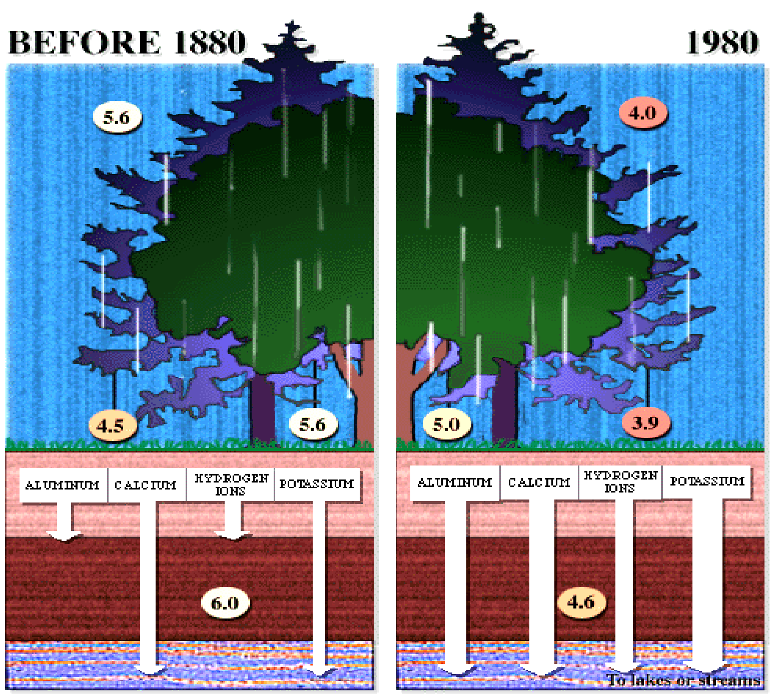


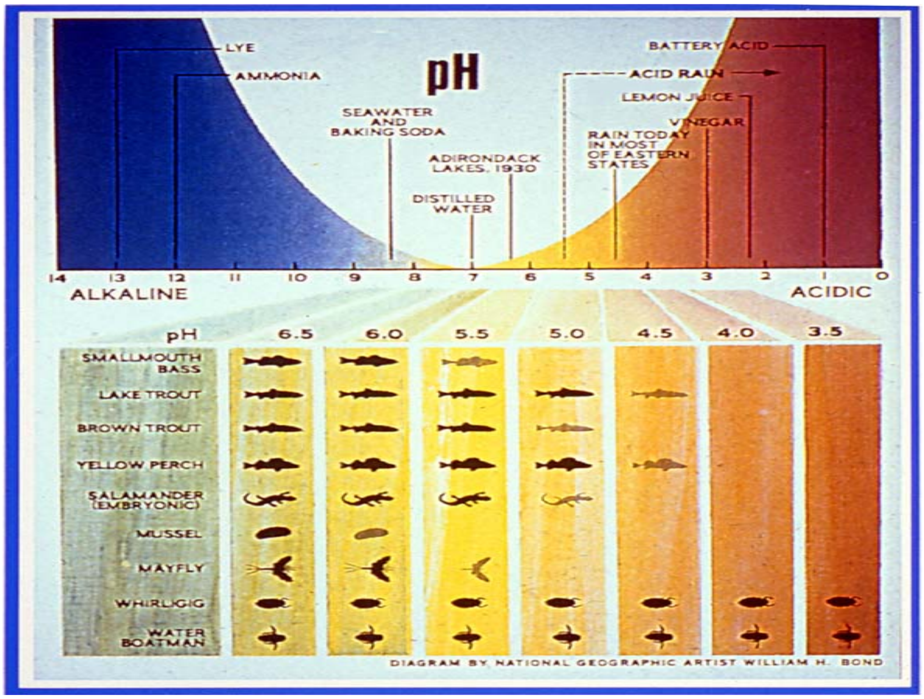
Chemical reactions with H^+ in the soil lead to loss of buffering capacity



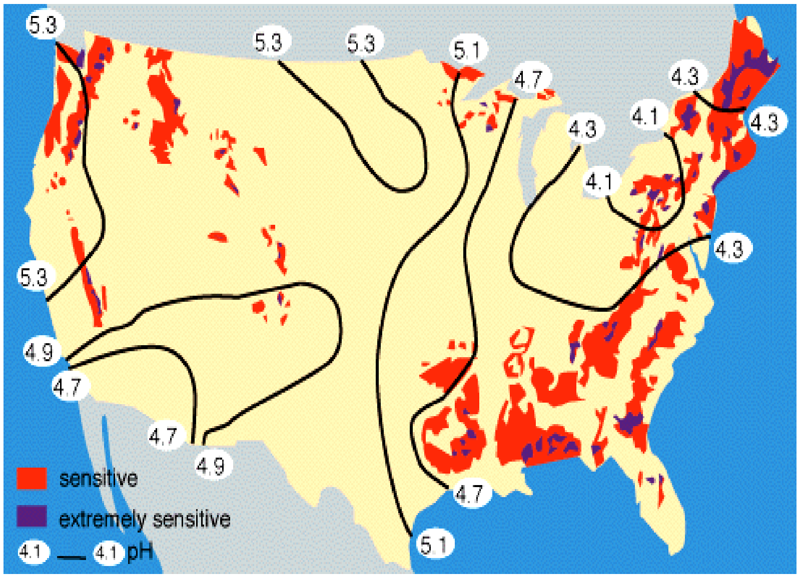
H^+ input increases the output of cations like Aluminum






pH
LYE
AMMONIA
SEAWATER AND BAKING SODA
ADIRONDACK LAKES, 1930
DISTILLED WATER
BATTERY ACID
ACID RAIN
LEMON JUICE
VINEGAR
RAIN TODAY IN MOST OF EASTERN STATES
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
ALKALINE
ACIDIC
pH 6.5 6.0 5.5 5.0 4.5 4.0 3.5
SMALLMOUTH BASS
LAKE TROUT
BROWN TROUT
YELLOW PERCH
SALAMANDER (EMBRYONIC)
MUSSEL
MAYFLY
WHIRLIGIG
WATER BOATMAN
DIAGRAM BY NATIONAL GEOGRAPHIC ARTIST WILLIAM H. BOND

Many areas of the U.S. are sensitive to acid rain



Summary

• The hydrological cycle is influenced or controlled by temperature, land-use changes, and human consumption.

• Acid Rain is an important consequence of the nitrogen and sulfur cycles interacting. Acid rain is produced by the interactions of these and other elements in the atmosphere, and the impacts of acid rain are controlled by other element cycles on land and in the water.

• <u>The main take-home message for today's lecture is:</u>

"ELEMENT CYCLES INTERACT, and they cannot be studied in isolation"