Updated: 15 October 2019

Print version

CEE 370 Environmental Engineering Principles

Lecture #16

Ecosystems I: Major Biogeochemical Cycles, Energy & Human Influence

Reading: Mihelcic & Zimmerman, Chapter 5
Davis & Masten, Chapter 5

David Reckhow CEE 370 L#16 1

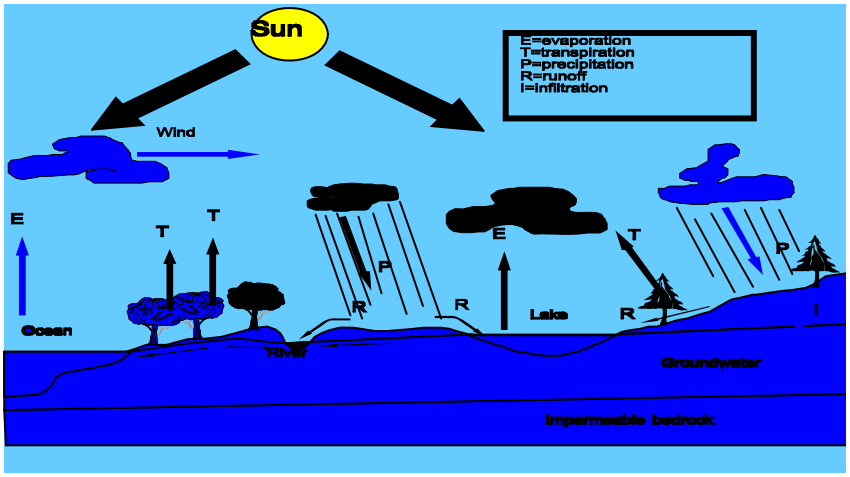
Global Water Balance

Water source	Mass, Kg
Oceans	$13{,}700 \times 10^{17}$
Groundwater	$3{,}200 \times 10^{17}$
Water locked in ice	165×10^{17}
Water in lakes, rivers	0.34×10^{17}
Water in atmosphere	0.105×10^{17}
Total yearly stream discharge	0.32×10^{17}

Ray, Table 3.4, pg. 42

David Reckhow CEE 370 L#14 2

Hydrologic Cycle



Ray, Figure 3.12, pg. 41

Quantitative Balance

- Showing global mass fluxes
  - In 10^{12} m^3/yr

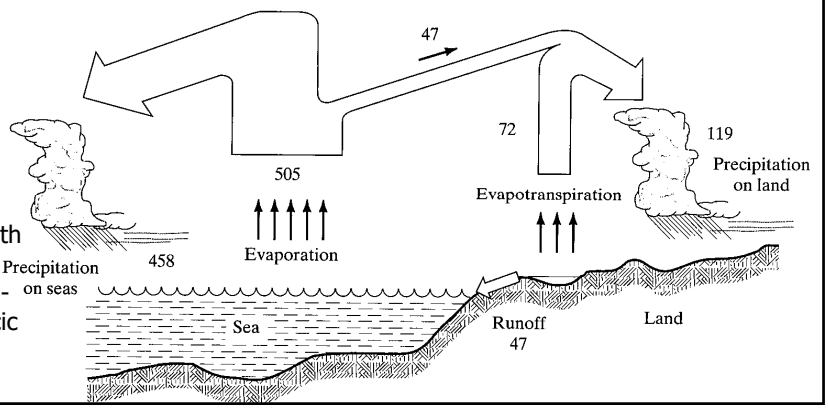
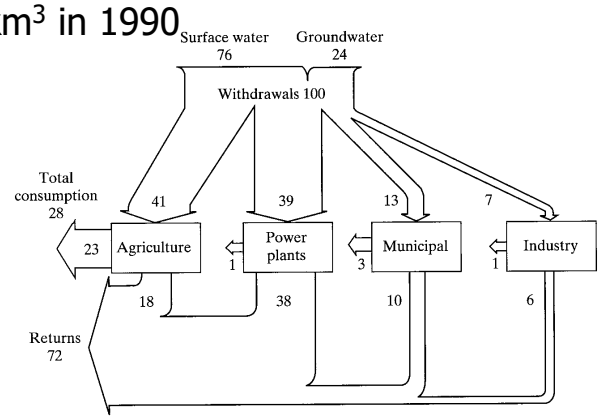


Fig. 5.3 in Masters, Compare with Fig. 6.1 in D&M; Fig. 5-27 in Mihelcic

Freshwater withdrawals

- Values shown are percent of total annual US withdrawals of fresh water
  - About 500 km^3 in 1990



David Reckhow

Local Water Balance

- Change in storage = inputs – outputs

$$\frac{dS}{dt} = P - R - E - I$$

  - Where:
    - S = storage
    - P = precipitation rate
    - E = evapotranspiration rate
      - Includes transpiration from plants and direct evaporation from water bodies, soil, etc.
    - R = runoff rate
    - I = infiltration rate (or leachate for a landfill)

David Reckhow CEE 370 L#14 6

Determining a Water Balance

$$\sum Inputs = \sum Outputs$$

For a unit period of time, we can express this in depth of water, spread out over the entire land area

$$P = E + R + I + S$$

where,

P	=	precipitation, [cm or in]
E	=	evapotranspiration or evaporation plus transpiration, [cm or in]
R	=	runoff, [cm or in]
I	=	infiltration, [cm or in]
S	=	storage, [cm or in]

Example: Evapotranspiration

A 1 km^2 watershed has been monitored recently in order to estimate the summer evapotranspiration. During the month of August the rainfall was 4 cm. The runoff from the area was 5000 m^3. Infiltration for the area was estimated to be 0.7 cm. Storage can be assumed to be negligible, and therefore changes in storage negligible.

- What was the total evapotranspiration?
- What was the evapotranspiration on an average daily basis?

Solution to example

We know the input to the system and two of the three outputs. We must first convert the runoff volume into depth over the 1 km^2 area.

$$R = \left(\frac{5000\ m^3}{1\ km^2}\right) x \left(\frac{km}{1000\ m}\right)^2 x \left(\frac{100\ cm}{1\ m}\right)$$

$$R = 0.5\ cm$$

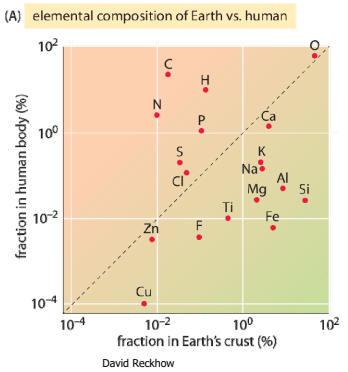
$$E = P - (I + R + \frac{dS}{dt}) = 4\ cm - (0.7\ cm + 0.5\ cm + 0\ cm)$$

$$E = 2.8\ cm$$

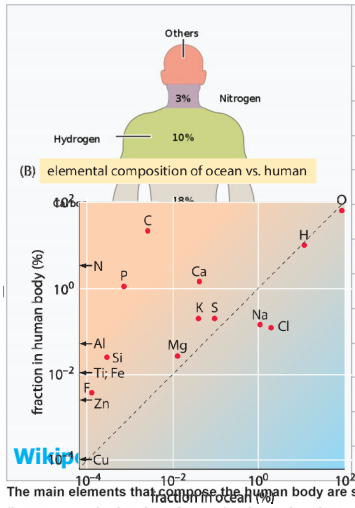
David Reckhow CEE 370 L#14 9

What are you made of?

- Compare with Redfield ratio



David Reckhow



Element	Symbol	% in body
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.2
Calcium	Ca	1.5
Phosphorus	P	1.0
Potassium	K	0.4
Sulfur	S	0.3
Sodium	Na	0.2
Chlorine	Cl	0.2
Magnesium	Mg	0.2
Others		< 1.0

The main elements that compose the human body are shown from most abundant (by mass, not by fraction of atoms) to least abundant.

Major Forms of Carbon on Earth

Source	Mass, 10^{15} Kg	Percent
Geologic inorganic minerals	60,000	83%
Geologic organic minerals[a]	12,000	17%
Oceanic inorganics	40	0.056
Atmosphere	0.7	0.00097
All life on earth	0.6	0.00083

Ray, Table 3.3, pg. 37

Carbon Forms: Definitions

Inorganic Carbon

CO_2 = carbon dioxide (dissolved and gas)
H_2CO_3 = carbonic acid (dissolved)
HCO_3^- = bicarbonate (dissolved)
CO_3^{-2} = carbonate (dissolved)
$CaCO_3$ = calcium carbonate (mineral)

Organic Carbon

$C_6H_{12}O_6$ = glucose (a sugar)
CH_3COOH = acetic acid (a carboxylic acid)

The Carbonate System

$$CO_2(aq) + H_2O \leftrightarrow H_2CO_3$$

- Major buffer ions
- volatile: interaction with atmosphere
- biologically active

- Definitions:

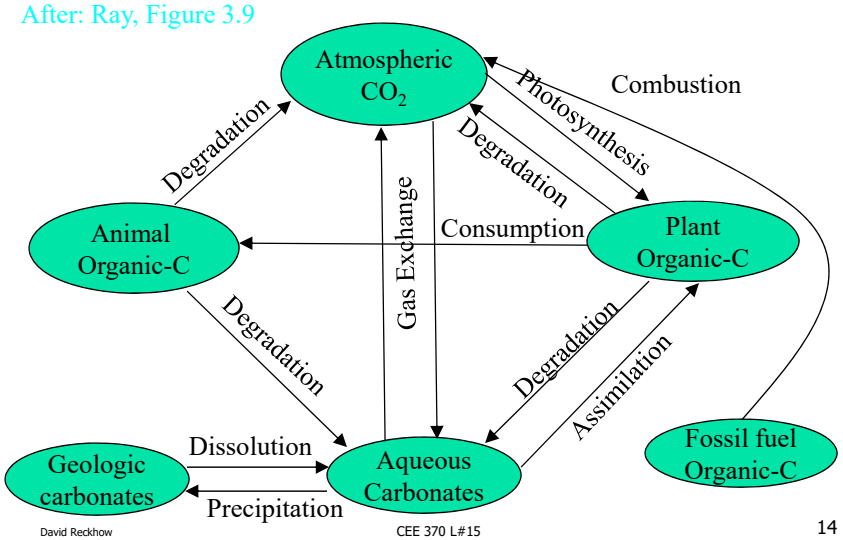
$$[CO_2(aq)] + [H_2CO_3] = [H_2CO_3^*]$$

$$[H_2CO_3^*] + [HCO_3^-] + [CO_3^{-2}] = C_T$$

David Reckhow CEE 370 L#14 13

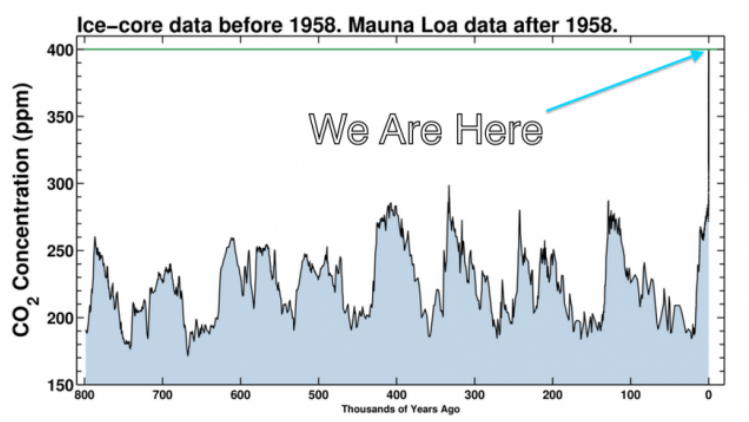
The Carbon Cycle

After: Ray, Figure 3.9



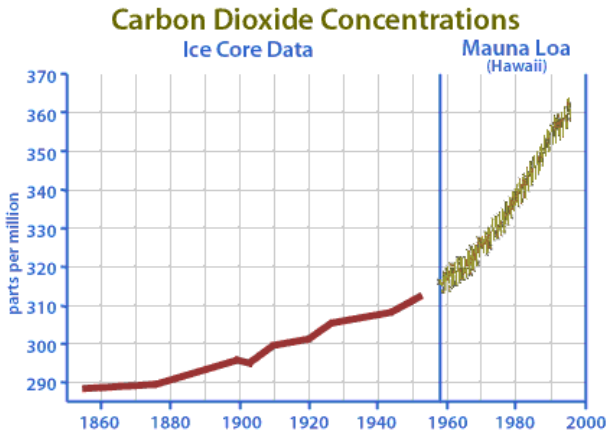
David Reckhow CEE 370 L#15 14

CO_2: Long-term View



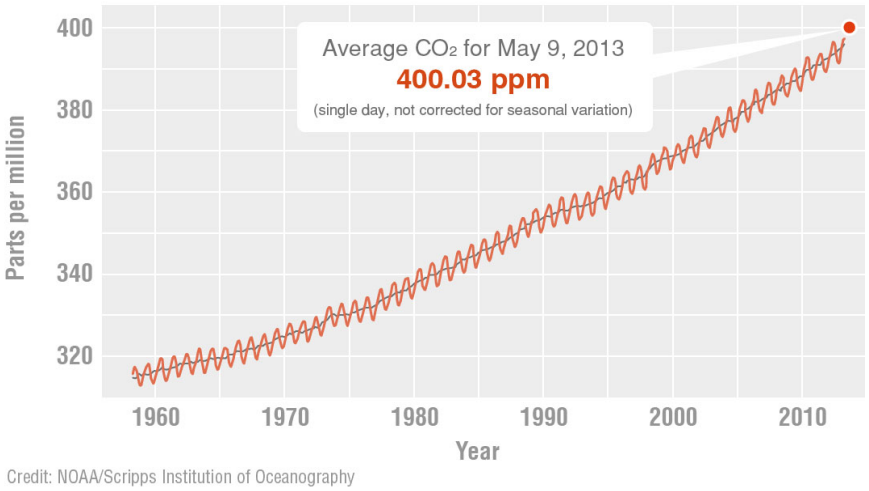
David Reckhow CEE 370 L#16 15

CO_2: Mid-term View



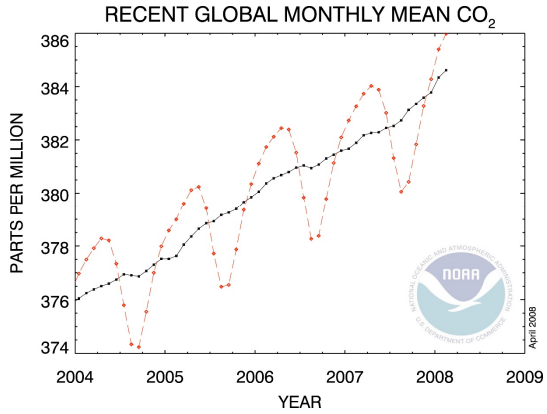
David Reckhow CEE 370 L#16 16

CO_2: Mid-term View



Credit: NOAA/Scripps Institution of Oceanography

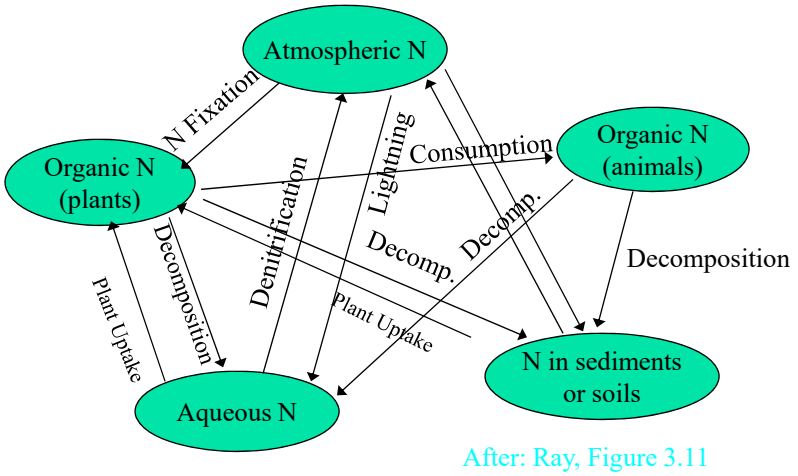
CO_2: Short-term View



NOAA website: http://www.noaanews.noaa.gov/stories2008/20080423_methane.html

Nitrogen Cycle

- Process Based view

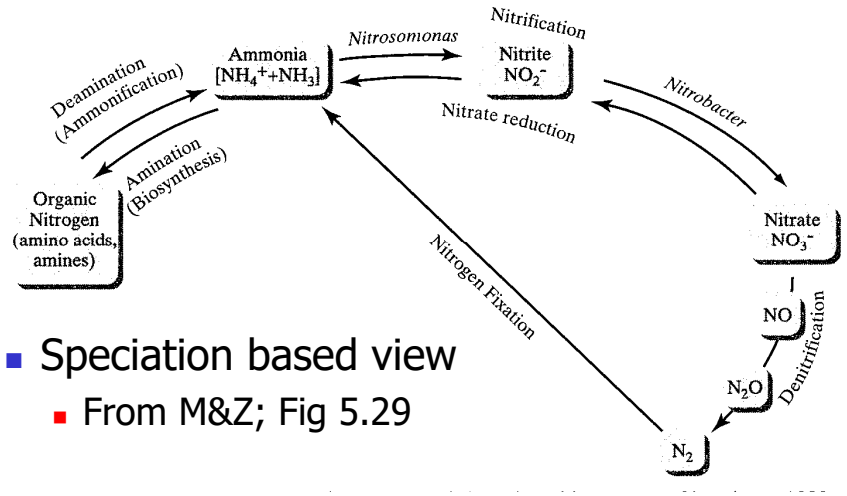


After: Ray, Figure 3.11
compare with Fig 4.7 in D&M

Nitrogen

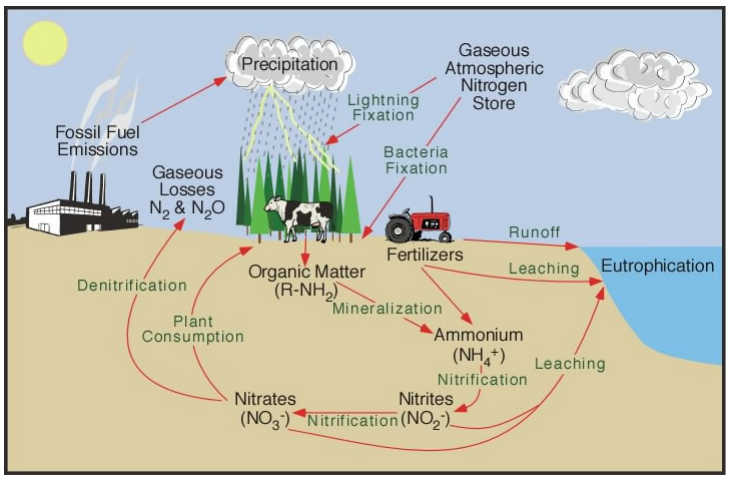
- Pollutant discharges often carry N
  - Nitrate (NO_3^-)
  - Ammonia (NH_4^+)
    - more heavily contaminated waters
- Both forms can be utilized by algae leading to "cultural eutrophication"

Nitrogen Cycle



- Speciation based view
  - From M&Z; Fig 5.29

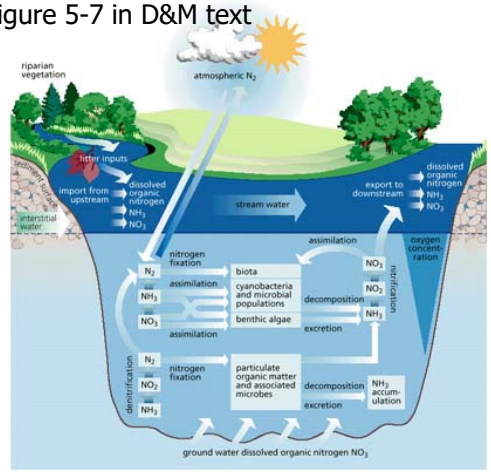
N Cycling: land focus



http://www.physicalgeography.net/fundamentals/images/nitrogencycle.jpg

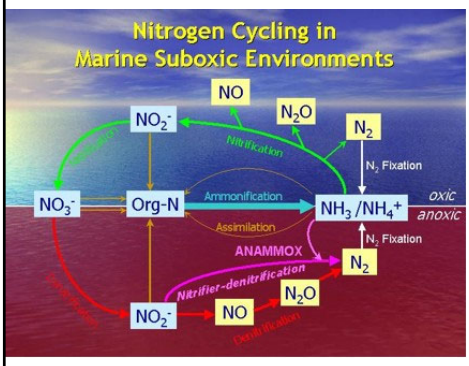
N Cycling: Aquatic View

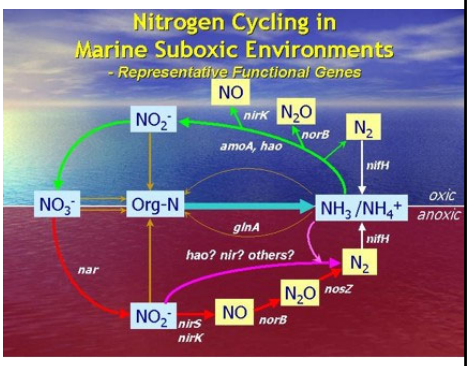
- http://www.epa.gov/watertrain/ecology/s33.jpg
  - Similar to Figure 5-7 in D&M text



N Cycling: Biochemical Focus

- Representative functional gene markers for various nitrogen cycling pathways

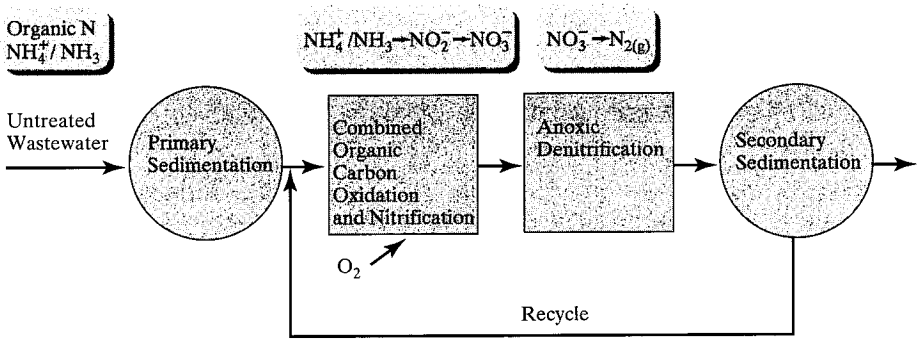




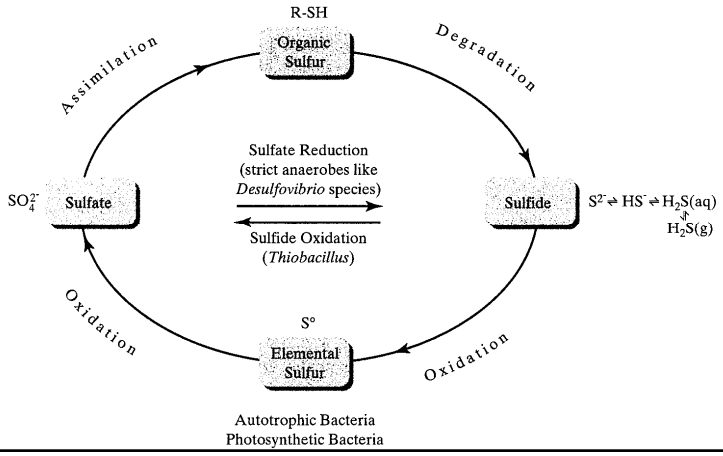
www.mpi-bremen.de/Binaries/Binary2363/ncycle2.jpg

Nitrogen Cycle

- As applied to nitrogen control in wastewater treatment



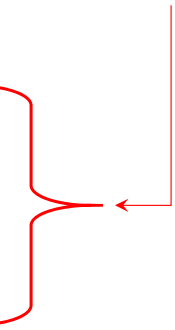
Sulfur Cycle



David Reckhow

Ecology

- Definition
  - Study of structure and function in nature: interactions between living things and the abiotic environment
- Great Spheres
  - Abiotic
    - Atmosphere (air)
    - Hydrosphere (water)
    - Lithosphere (soil)
  - Biotic
    - Biosphere



Ecology and the Environment

- Ecology
  - Ecosystems
  - Energy and Trophic Levels
- Limnology
- Population & Habitat
- Biogeochemical Cycles
  - Carbon
  - Nitrogen
  - Water (Hydrologic Cycle)

Some Definitions

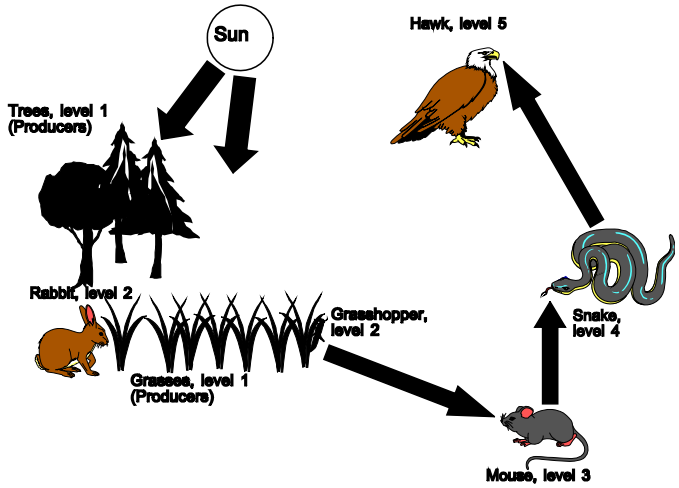
- Ecosystem - an organism or group of organisms and their environment. It includes:
  - Abiotic environment
  - producers (autotrophs)
  - consumers
  - decomposers
- Trophic Level - position in the food chain

Primary Productivity

Ecosystem	Net Primary Production, $g/m^2/yr$	Area, $10^6 km^2$
Tropical rain forests	2000	17
Tropical seasonal forests	1500	7.5
Temperate evergreen forests	1300	5
Temperate deciduous forests	1200	7
Cultivated lands	644	14
Temperate grasslands	500	9
Tundra and alpine meadows	144	8
Desert shrubs	71	18
Lakes and streams	500	2.5
Swamps and marshes	2500	2
Algal beds and reefs	2000	0.6
Estuaries	1800	1.4
Total continental	720	149
Total marine	153	361
Total world	320	510

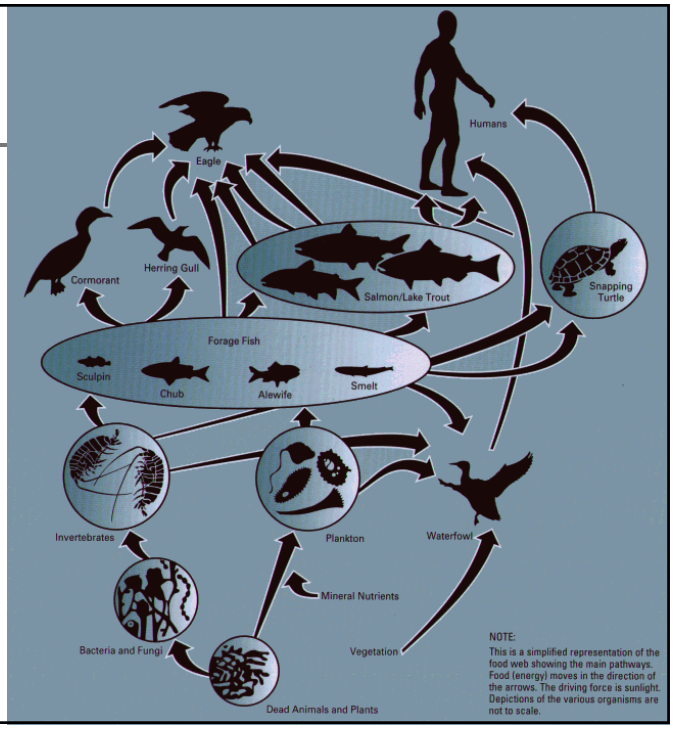
Table 3.1 in Ray (pg 23)

Trophic levels in a grassland ecosystem



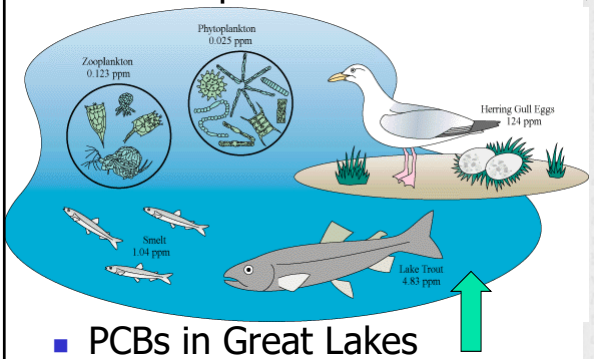
David Reckhow CEE 370 L#15 31

- http://www.epa.gov/glnpo/atlas/images/big05.gif
  - Similar to Figure 4.2 in D&M Text

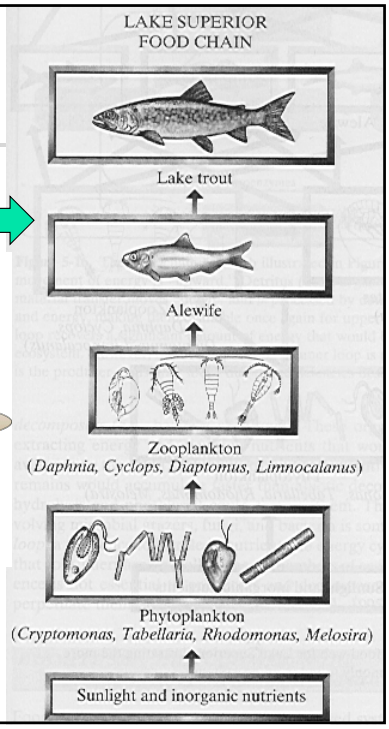


David Reckhow

- Simplified Food Chain in Lake Superior

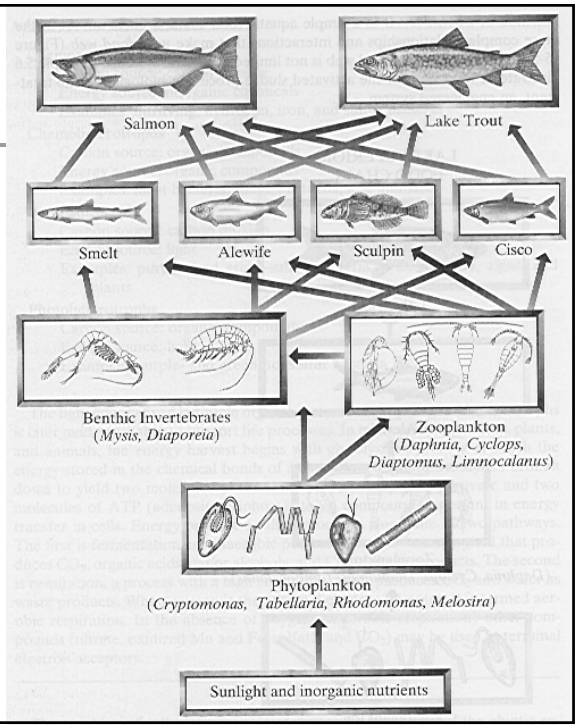


- PCBs in Great Lakes
  - http://www.epa.gov/glnpo/atlas/images/chart403.gif



David Reckhow CEE 370 L#18

- Food Web for Lake Superior

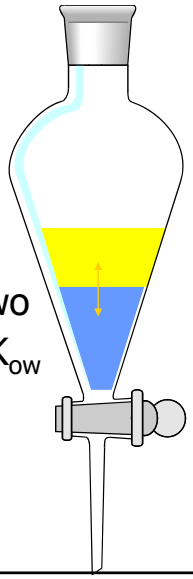


David Reckhow

Octanol:water partitioning

- 2 liquid phases in a separatory funnel that don't mix
  - octanol
  - water
- Add contaminant to flask
- Shake and allow contaminant to reach equilibrium between the two
- Measure concentration in each (K_{ow} is the ratio)
- Correlate to environmental K

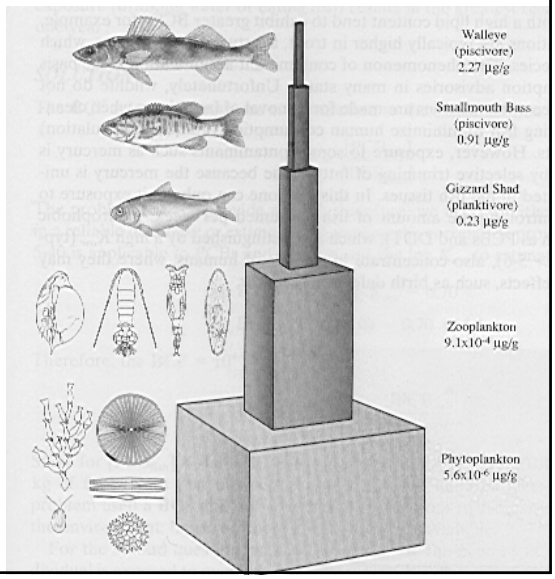
$$K = fn(K_{ow})$$



David Reckhow CEE 370 L#27 35

Bioaccumulation

- Mercury in food chain
  - Data from Onondaga Lake

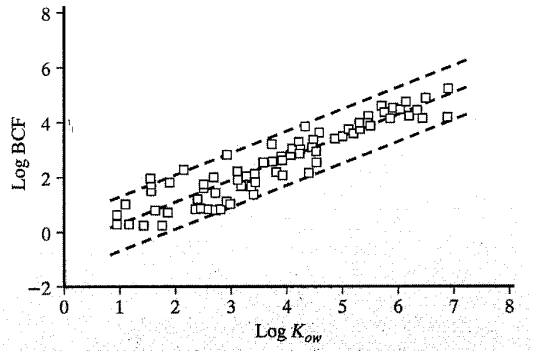


Biomass (box size)

Concentration (Shading)

David Reckhow

- Octanol water partition coefficients and bioconcentration factors



David Reckhow CEE 370 L#27 37

Bioconcentration of DDT

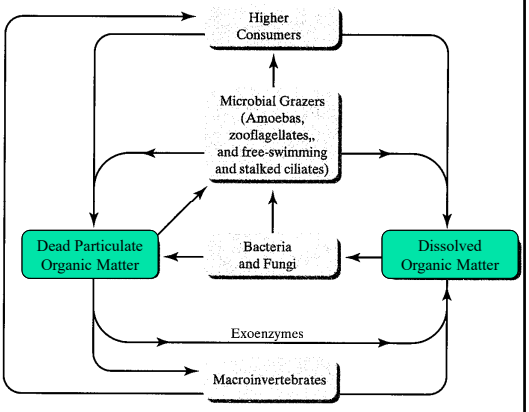
- Conc in organism = (conc in water) x (bioconcentration factor)

Source	Conc (ppm)	Bioconcentration Factor
Water	0.00005	1
Plankton	0.04	800
Hard clam	0.42	8,400
Sheephead minnow	0.94	18,800
Chain pickerel (predatory fish)	1.33	26,600
Needlefish (predatory fish)	2.07	41,400
Heron (feeds on small animals)	3.57	71,400
Tern (feeds on small animals)	3.91	78,200
Herring gull (scavenger)	6	120,000
Osprey egg	13.8	276,000
Merganser (fish eating duck)	22.8	456,000
Cormorant (feeds on larger fish)	26.4	528,000
Ring billed gull	75.5	1,510,000

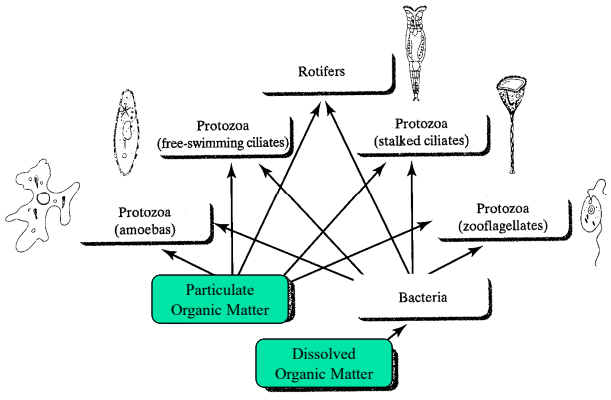
Based on Ray, Table 3.2, pg. 27

David Reckhow CEE 370 L#18 38

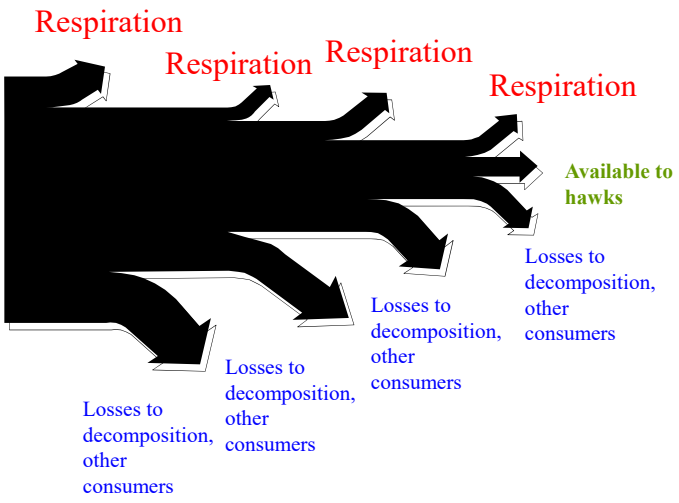
- Consideration of Detritus and detritivores
- Flow is not always upward



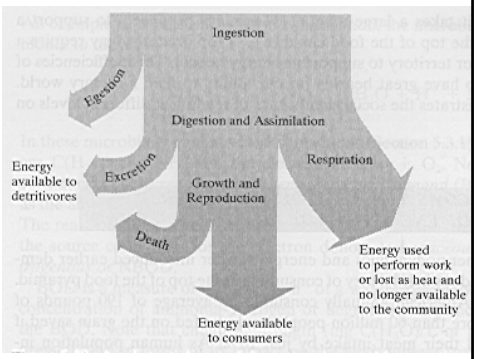
- Food web for activated sludge



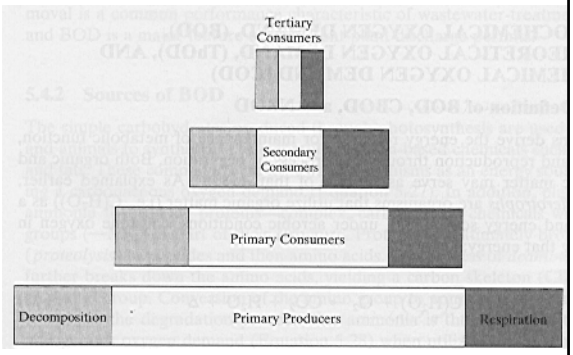
Biomass Energy Flux



- Much energy lost to egestion, excretion, death and respiration



- Loss of energy to detritivory and respiration as you move up the food chain



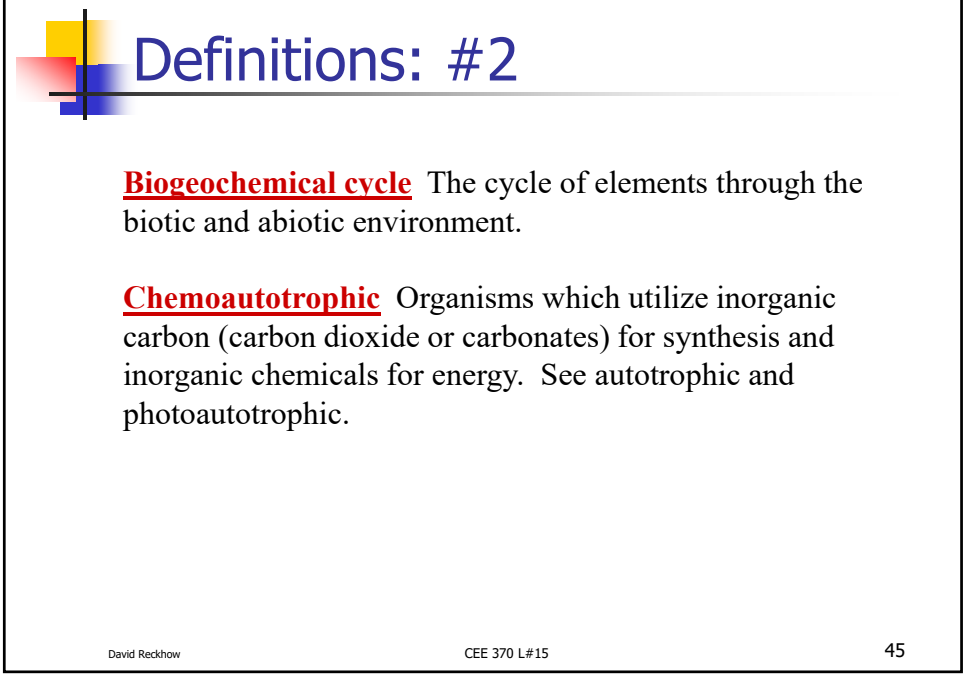
David Reckhow CEE 370 L#18 43

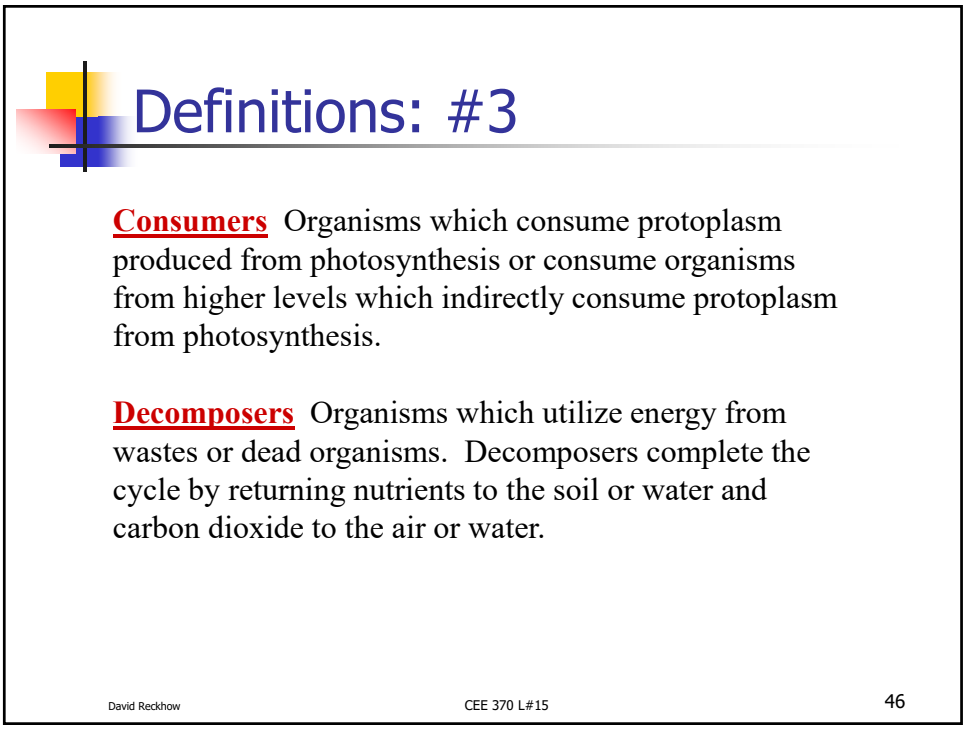
Definitions: #1

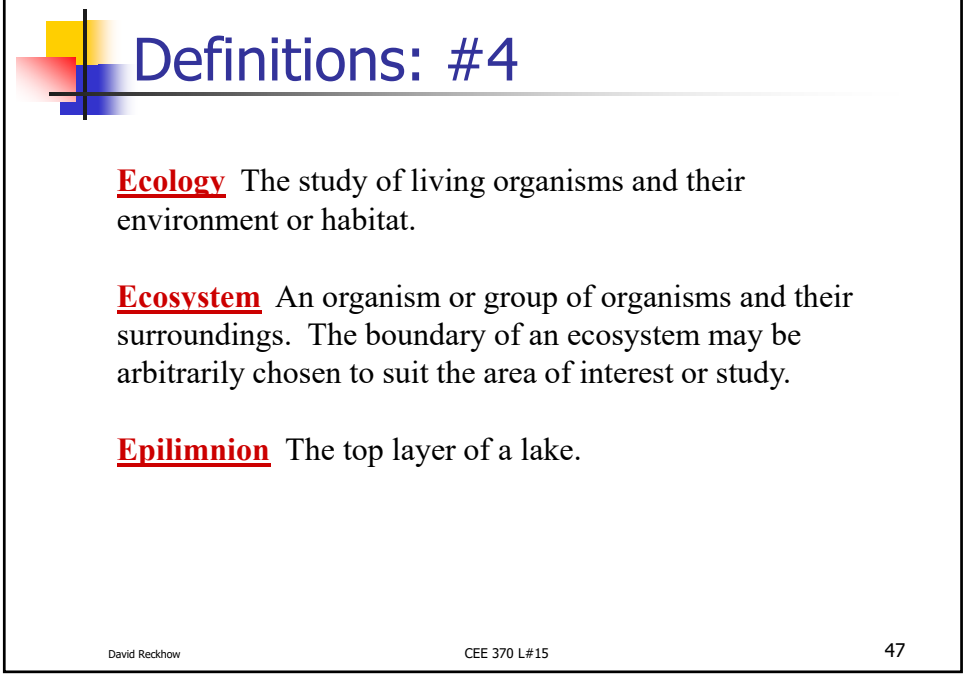
Abiotic environment The part of an ecosystem that includes the nonliving surroundings.

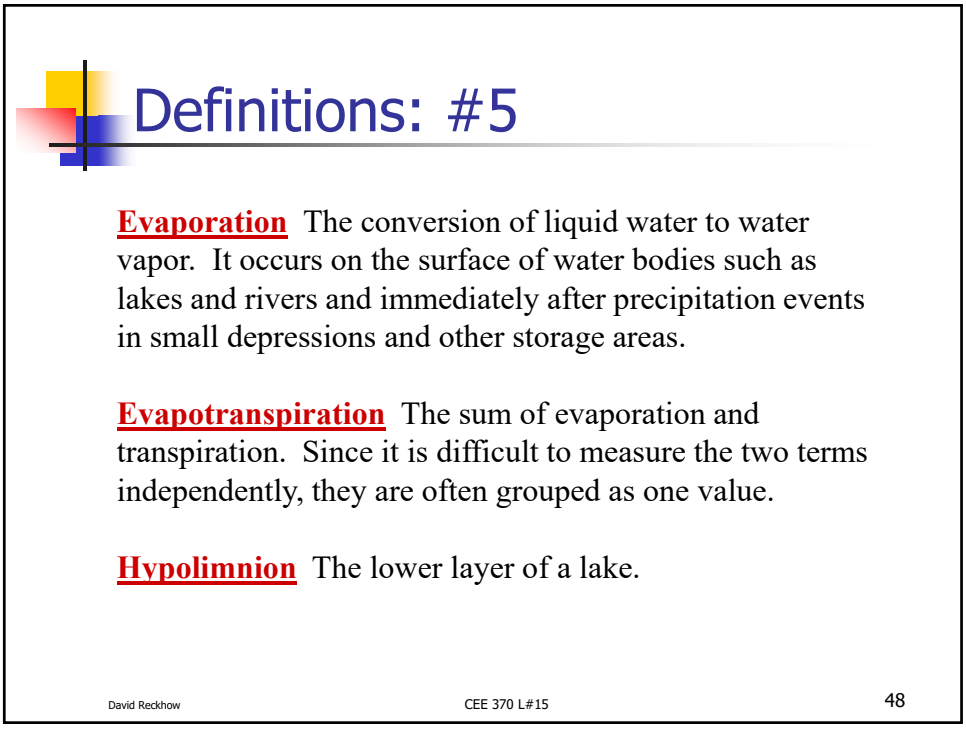
Autotrophic Organisms which utilize inorganic carbon for synthesis of protoplasm. Ecologists narrow the definition further by requiring that autotrophs obtain their energy from the sun. In microbiologist parlance, this would be a photoautotroph. See photoautotrophic and chemoautotrophic.

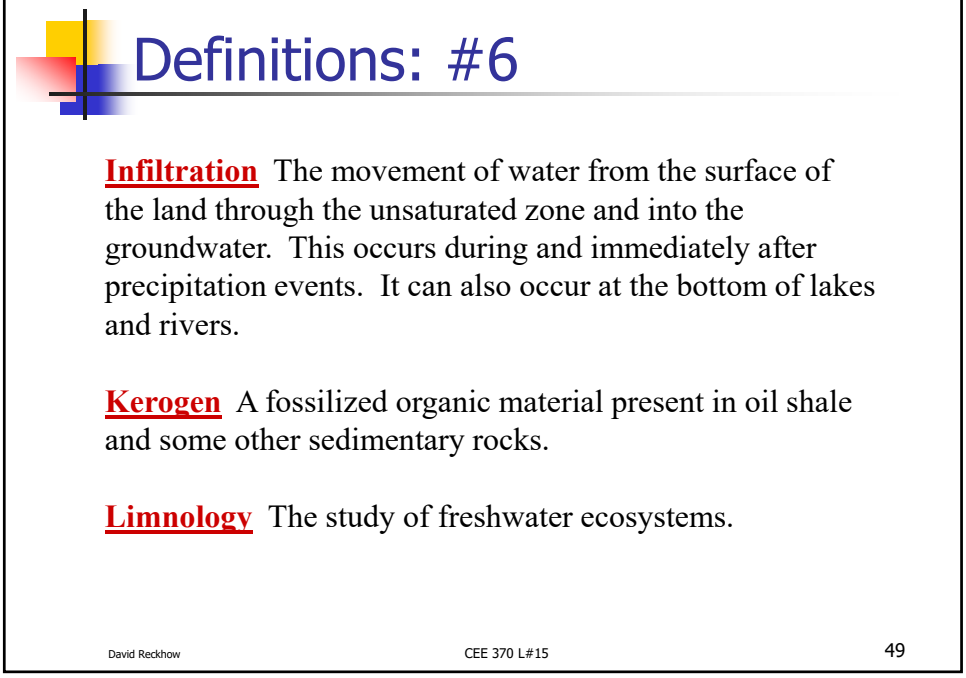
David Reckhow CEE 370 L#15 44

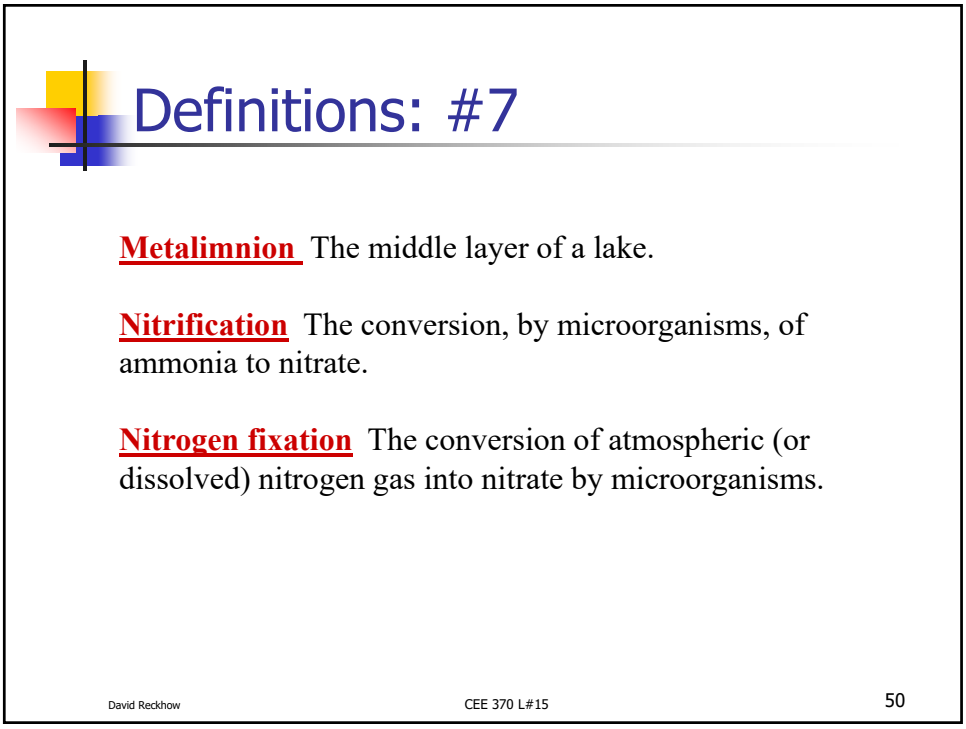

Definitions: #2
Biogeochemical cycle The cycle of elements through the biotic and abiotic environment.
Chemoautotrophic Organisms which utilize inorganic carbon (carbon dioxide or carbonates) for synthesis and inorganic chemicals for energy. See autotrophic and photoautotrophic.
David Reckhow
CEE 370 L#15
45


Definitions: #3
Consumers Organisms which consume protoplasm produced from photosynthesis or consume organisms from higher levels which indirectly consume protoplasm from photosynthesis.
Decomposers Organisms which utilize energy from wastes or dead organisms. Decomposers complete the cycle by returning nutrients to the soil or water and carbon dioxide to the air or water.
David Reckhow
CEE 370 L#15
46


Definitions: #4
Ecology The study of living organisms and their environment or habitat.
Ecosystem An organism or group of organisms and their surroundings. The boundary of an ecosystem may be arbitrarily chosen to suit the area of interest or study.
Epilimnion The top layer of a lake.
David Reckhow
CEE 370 L#15
47


Definitions: #5
Evaporation The conversion of liquid water to water vapor. It occurs on the surface of water bodies such as lakes and rivers and immediately after precipitation events in small depressions and other storage areas.
Evapotranspiration The sum of evaporation and transpiration. Since it is difficult to measure the two terms independently, they are often grouped as one value.
Hypolimnion The lower layer of a lake.
David Reckhow
CEE 370 L#15
48


Definitions: #6
Infiltration The movement of water from the surface of the land through the unsaturated zone and into the groundwater. This occurs during and immediately after precipitation events. It can also occur at the bottom of lakes and rivers.
Kerogen A fossilized organic material present in oil shale and some other sedimentary rocks.
Limnology The study of freshwater ecosystems.
David Reckhow
CEE 370 L#15
49


Definitions: #7
Metalimnion The middle layer of a lake.
Nitrification The conversion, by microorganisms, of ammonia to nitrate.
Nitrogen fixation The conversion of atmospheric (or dissolved) nitrogen gas into nitrate by microorganisms.
David Reckhow
CEE 370 L#15
50

Definitions: #8

Photoautotrophic Organisms which utilize inorganic carbon dioxide for protoplasm synthesis and light for an energy source. See autotrophic and chemoautotrophic.

Precipitation The falling to earth of condensed water vapor in the form of rain, snow, sleet or hail.

Producers Autotrophic organisms which produce protoplasm using inorganic carbon and energy from the sun.

Definitions: #9

Runoff The water that flows overland to lakes or streams during and shortly after a precipitation event.

Saltwater intrusion The gradual replacement of freshwater by saltwater in coastal areas where excessive pumping of groundwater occurs.

Storage The short term retention of water after a precipitation event.

Thermocline The depth at which an inflection point occurs in a lake temperature profile.

Definitions: #10

Transpiration The loss of water from plants through leaves and other parts. This loss can be a significant amount of water during very dry periods.

Trophic level A level in the food chain. The first trophic level consists of the primary producers, autotrophs. The second trophic level is vegetarians which consume autotrophic organisms.

Wetland Semi-aquatic land, that is land that is either inundated or saturated by water for varying periods of time during each year, and that supports aquatic vegetation which is specifically adapted for saturated soil conditions.

- To next lecture