Environmental Chemistry

Environmental Chemistry, vanLoon & Duffy – Chapter 1

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Early Earth History

The history of the Earth begun more than 4.6 billion years ago.

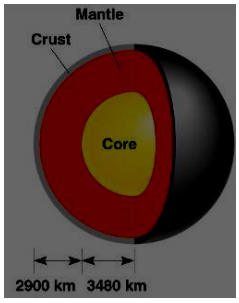
In the earliest period of Earth's life, the solid materials present in its core consisted of iron and alloys of iron.

The mantle and crust of the Earth were in large part made up of oxides and silicates of metals.

The major gases in the primeval atmosphere were H_2, N_2, CO and CO_2.

With time volcanism brought new gases to the surface where they reacted to form other new gas species.

Oxygen was abundant but there was no free dioxygen gas. It was associated with metals or in the atmosphere as CO_2.



Early Earth History

Early in the Earth's history, water was formed

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$

$$H_2 + CO_2 \rightarrow CO + H_2O$$

These reactions require catalysts: they were available as metal oxides.

The early seas were acidic (dissolved CO_2, HCl, sulfur species).

↓

pH = 2

↓ + warm temperatures

dissolution of components in the associated rocks (Calcium)

↓

pH ~ 8

The beginnings of Life

Because there was no free oxygen in the atmosphere, no ozone could be formed.

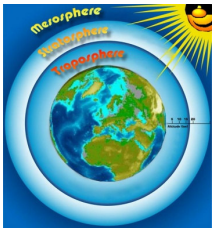
↓

The atmosphere was transparent to UV light

↓

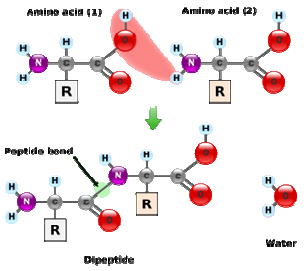
$CO + 2H_2 \rightarrow CH_3OH$ (Methanol)

$CO + H_2 \rightarrow HCHO$ (Formaldehyde)



Very early in the Earth's history, these molecules were formed in addition to other species (HCN, NH_3, H_2S, …).

Some of small molecules reacted to produce larger molecules (amino acids and simple peptides).



The beginnings of Life

The first cells used inorganic molecules as starting materials for their synthesis.

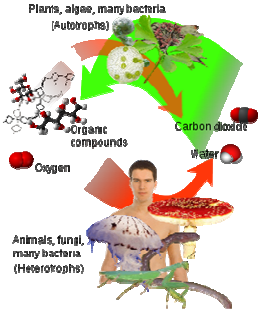
With increasing complexity, some cells developed an ability to carry out photosynthesis (a reaction increasing oxygen in the atmosphere).

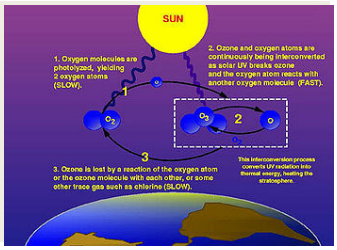
$$CO_2 + H_2O \rightarrow \{CH_2O\} + O_2$$

Carbon dioxide gradually became a minor gas in the atmosphere.

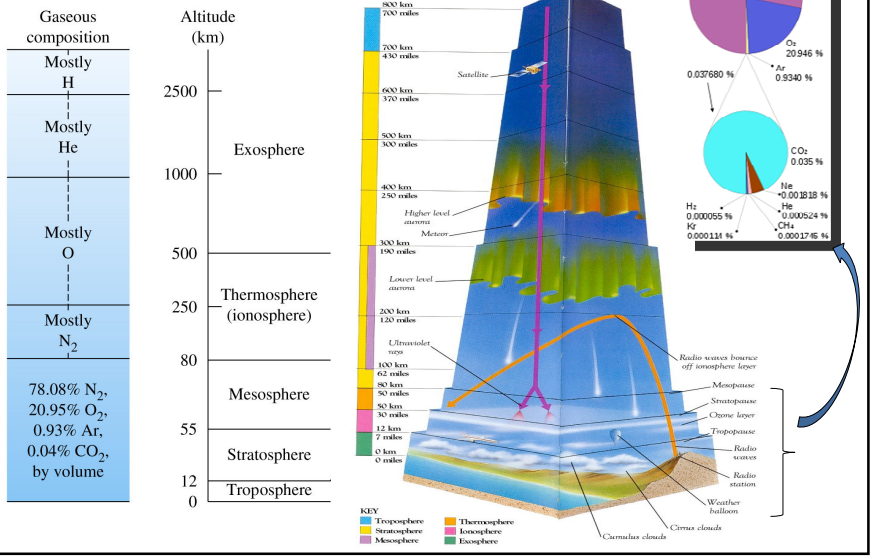
The presence of free oxygen led to the synthesis of ozone, playing the role of a shield for the high energy components of the solar radiation.

This opened the possibility for terrestrial life to emerge.

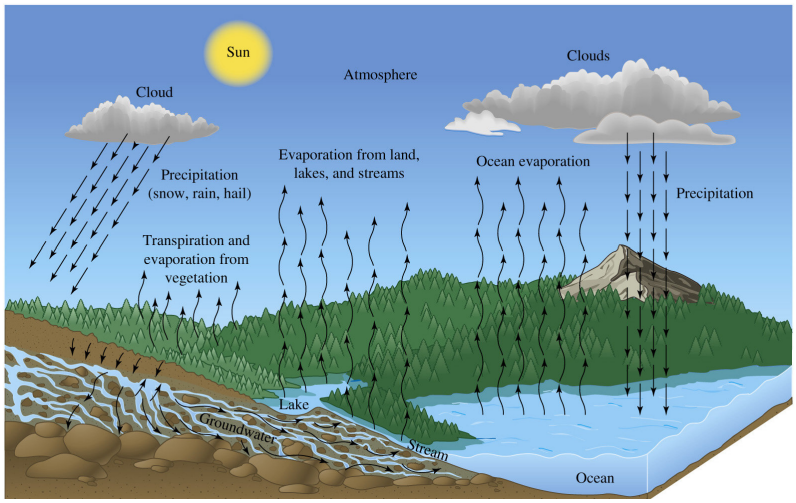




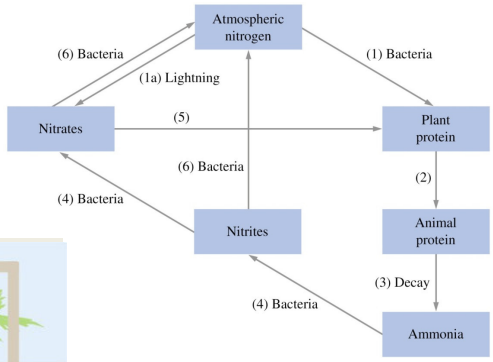
Layers of the Atmosphere

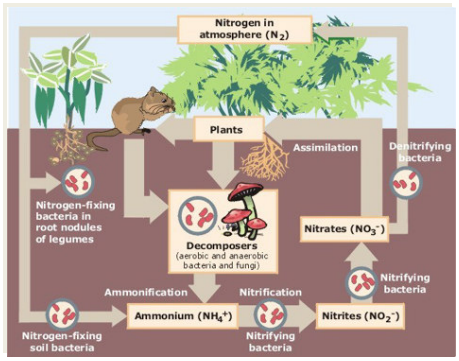


The Hydrologic Cycle



The Nitrogen Cycle



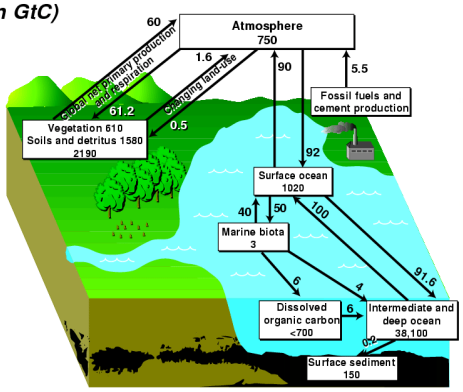


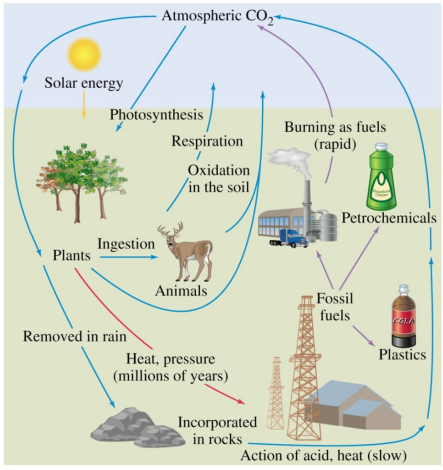
Plants use the inorganic nitrogen-containing ions nitrate (NO_3^-) and ammonium (NH_4^+).

Animals can only use organic nitrogen i.e. nitrogen already incorporated into organic molecules.

The Carbon Cycle

Global Carbon Cycle
(in GtC)





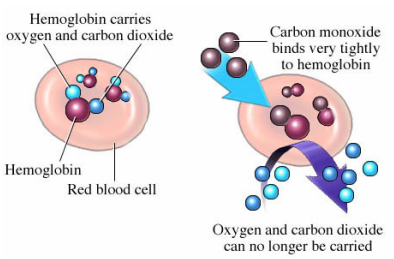
Main cycle
Fossilization tributary
Disruption by human activities

Air Pollution

An air *pollutant* is a substance found in air in *greater abundance than normally occurs naturally*, and having one or more harmful effects on human health or the environment.

Carbon monoxide (CO) and carbon dioxide (CO_2) are formed in varying quantities when fossil fuels are burned.

Carbon monoxide replaces O_2 molecules normally bonded to Fe^{2+} ions in hemoglobin in blood.

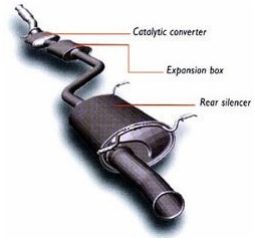


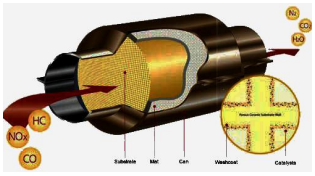
Photochemical Smog

When sunlight falls on air containing a mix of *nitrogen oxides, hydrocarbons, and other substances*, it produces a mix of pollutants called photochemical smog.

Automobile exhaust is a significant contributor to the production of photochemical smog.

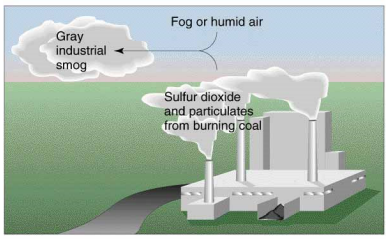
Automobiles are now equipped with *catalytic converters.*





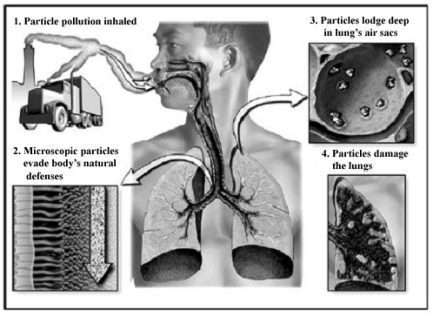
Industrial Smog

Industrial smog occurs mainly in cool, damp weather and is usually *characterized by high levels of sulfur oxides (SO_x)* and of particulate matter (dust, smoke, aerosols, etc.).

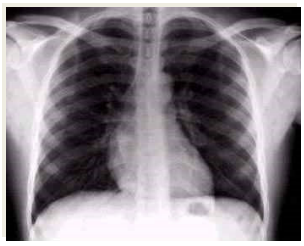


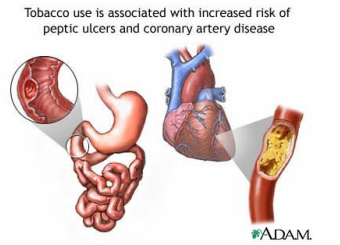
Particulate matter consists of solid and liquid particles of greater than molecular size.

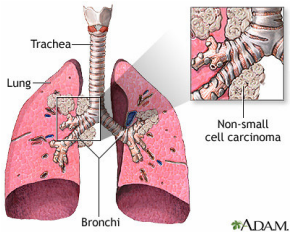
When inhaled deeply into the lungs, these pollutants *break down the cells of the tiny air sacs, called alveoli, where oxygen and carbon dioxide exchange normally occurs.*



Effect of Tobacco







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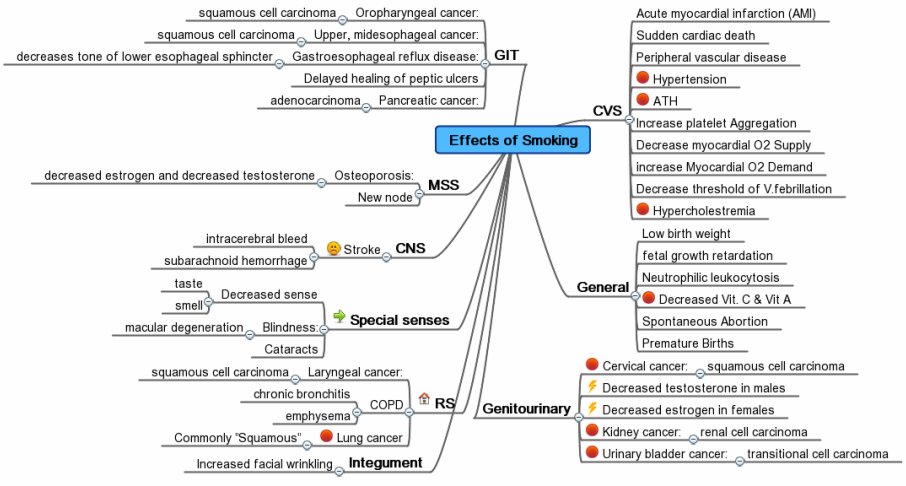


Effect of Tobacco

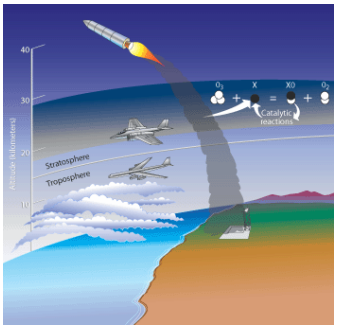
The Ozone Layer

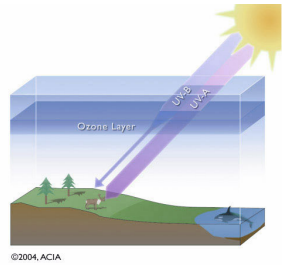
The ozone layer is a band of the stratosphere about 20 km thick, centered at an altitude of about 25 to 30 km

Ozone absorbs ultraviolet (UV) radiation, and the ozone layer thus protects life on Earth

Ozone is produced in the upper atmosphere in a *sequence of two reactions involving free radical oxygen atoms*

Of all the *human* activities that affect the ozone layer, release of chlorofluorocarbons (CFCs) is *thought to be* the most significant





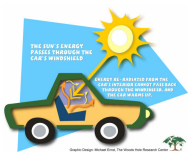
CO_2 and the Greenhouse Effect

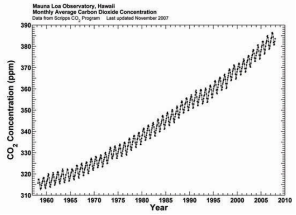
The greenhouse effect occurs when radiant energy is retained in the atmosphere and warms it

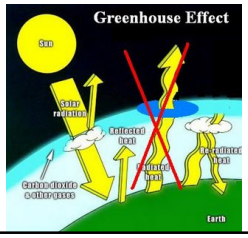
Some atmospheric scientists think that global warming is already under way

There are many natural sources that contribute significantly to "greenhouse" gas production that cannot be controlled by humans

The main strategy for countering human contributions to possible global warming is to curtail the use of fossil fuels







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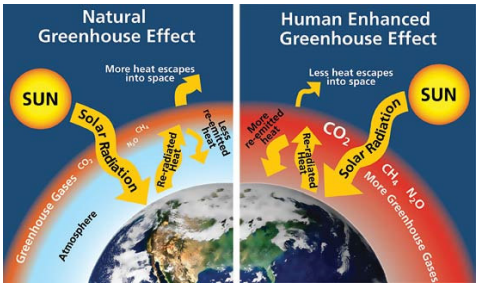
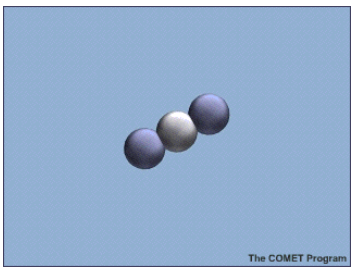
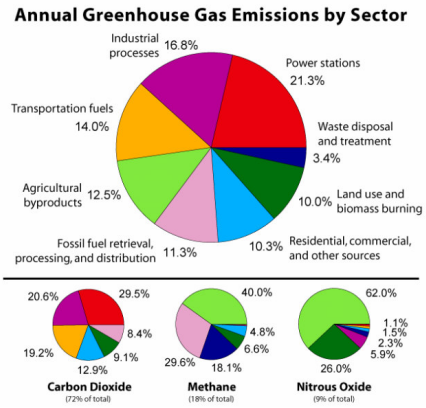
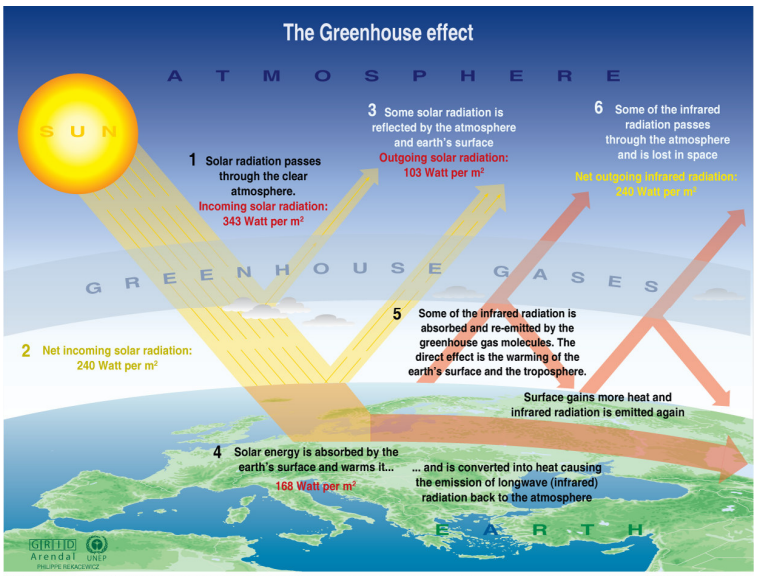






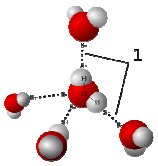
The Greenhouse Effect



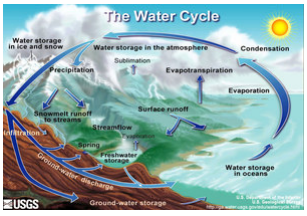
Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

Earth's Natural Waters

Water commonly occurs as a liquid, the only prevalent naturally occurring liquid on Earth's surface.



Ice is *less dense* than the liquid; it *expands when it freezes.*



Water has a higher density than most other familiar liquids; hydrocarbons and other organic compounds that are insoluble in water and less dense than water float on its surface.

Water has a high heat capacity and a high heat of vaporization.

Substances Found in Natural Waters

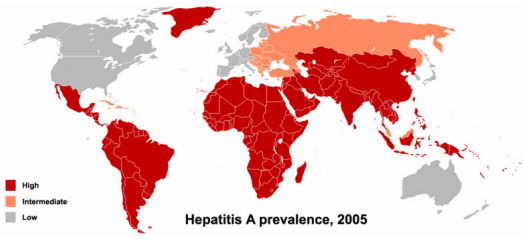
Substance	Formula	Source
Carbon dioxide	CO_2	Atmosphere
Dust	—	Atmosphere
Nitrogen	N_2	Atmosphere
Oxygen	O_2	Atmosphere
Nitric acid (thunderstorms)	HNO_3	Atmosphere
Sand and soil particles	—	Soil and rock
Sodium ions	Na^+	Soil and rock
Potassium ions	K^+	Soil and rock
Calcium ions	Ca^{2+}	Limestone rock
Magnesium ions	Mg^{2+}	Dolomite rock
Iron(II) ions	Fe^{2+}	Soil and rock
Chloride ions	Cl^-	Soil and rock
Sulfate ions	SO_4^{2-}	Soil and rock
Bicarbonate ions	HCO_3^-	Soil and rock

Water Pollution

Contamination of water supplies by microorganisms from human wastes was a severe problem throughout the world until about 100 years ago.

The threat of biological contamination has not been totally eliminated from the developed nations.

Hepatitis A, a viral disease spread through drinking water and contaminated food, at times threatens to reach epidemic proportions, even in developed nations.



Average Daily Per-Person Use of Water in the U.S.

Use	Amount (L)	
Direct use		
Drinking and cooking	7	
Flushing toilets	80	
Supplying swimming pools and watering lawns	85	
Dish washing	14	
Bathing	70	
Laundry	35	
Miscellaneous	90	
Total direct use		**400**
Indirect use		
Industrial	3800	
Irrigation (agriculture)	2150	
Municipal water (nonindustrial)	550	
Total indirect use		**6500**
Total overall use		**6900**

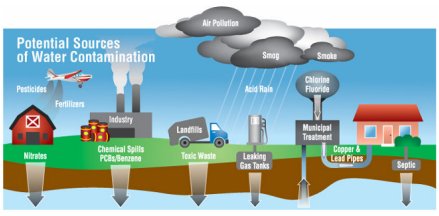
Chemical Contamination

Factories often were built on the banks of streams, and wastes were dumped into the water to be carried away.

Toxic chemicals have been found in both surface water and groundwater.

Industries in the U.S. have eliminated a considerable proportion of the water pollution they once produced.

Many of the food industry wastes are usually treated by regular sewage treatment plants.

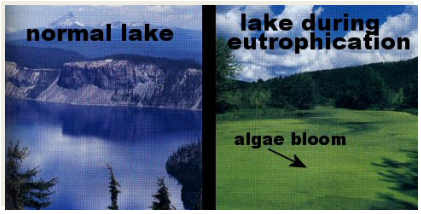


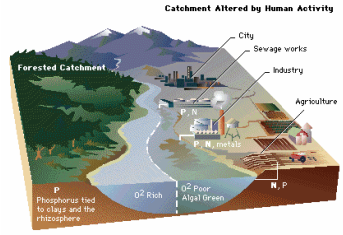
Aerobic oxidation occurs *in the presence of dissolved oxygen* and organic matter is oxidized.

The biochemical oxygen demand (BOD) measures the *quantity of oxygen, in milligrams, needed for the oxidation* of the organic compounds per liter of water.

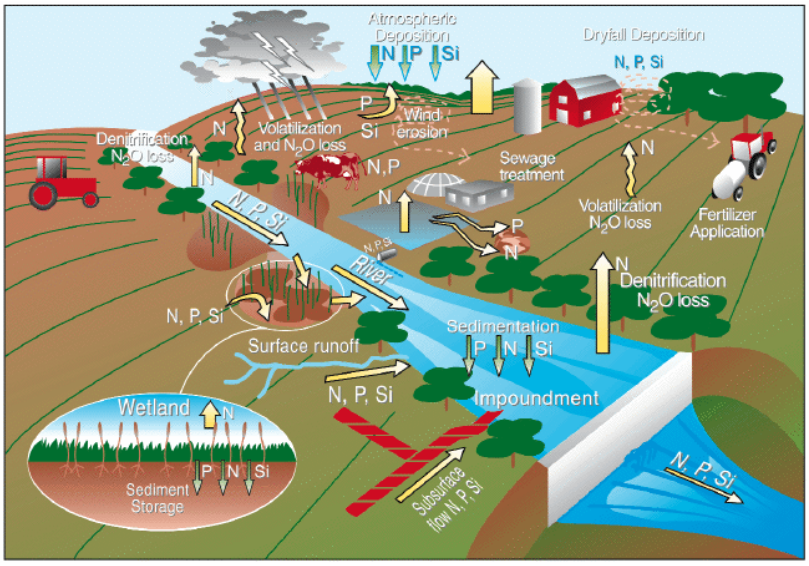
When algae in water die, they become organic waste and increase BOD through eutrophication.

Anaerobic decay is the process by which *bacteria reduce rather than oxidize* organic matter.





AUB Chemistry and Biology of Sewage



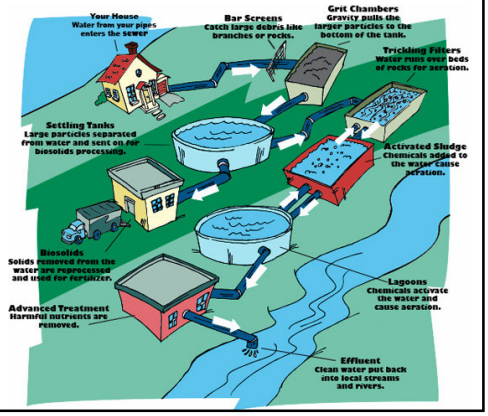
Substance	Formula
Aerobic conditions	
Carbon dioxide	CO_2
Nitrate ions	NO_3^-
Phosphate ions	PO_4^{3-}
Sulfate ions	SO_4^{2-}
Bicarbonate ions	HCO_3^-
Anaerobic conditions	
Methane	CH_4
Ammonia	NH_3
Amines	RNH_2
Hydrogen sulfide	H_2S
Methanethiol	CH_3SH

To make water safe and palatable involves several steps of physical and chemical treatment.

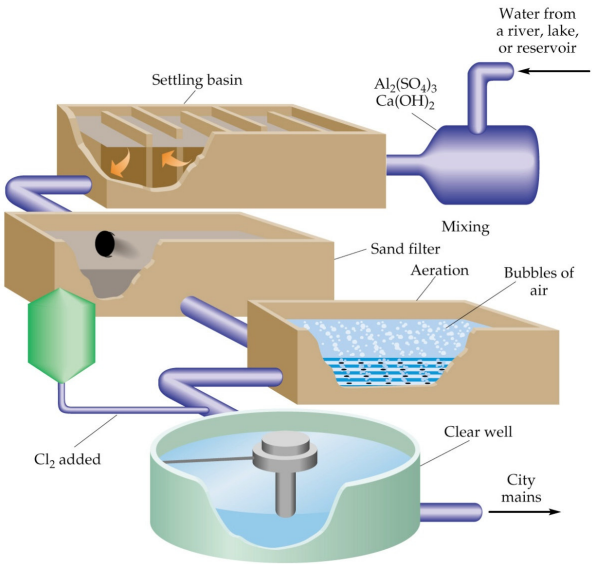
In the first step, *particulate matter is settled* from the water in settling basins where it is treated with *slaked lime (aqueous calcium hydroxide) and a flocculating agent such as aluminum sulfate.*

In the second step, the *water is aerated to remove odorous compounds and to improve its taste.*

In the final step, *water is chlorinated to kill any remaining bacteria.*



Water Treatment

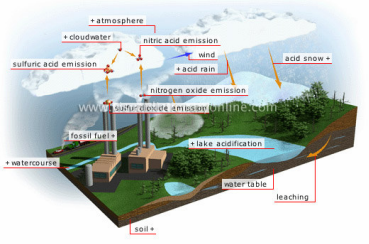


Water Treatment

Method	Cost	Material Removed	Percent Removed
Primary			
Sedimentation	Low	Dissolved organics	25–40
		Suspended solids	40–70
Secondary			
Trickling filters	Moderate	Dissolved organics	80–95
		Suspended solids	70–92
Activated sludge	Moderate	Dissolved organics	85–95
		Suspended solids	85–95
Advanced (tertiary)			
Carbon bed with regeneration	Moderate	Dissolved organics	90–98
Ion exchange	High	Nitrates and phosphates	80–92
Chemical precipitation	Moderate	Phosphates	88–95
Filtration	Low	Suspended solids	50–90
Reverse osmosis	Very high	Dissolved solids	65–95
Electrodialysis	Very high	Dissolved solids	10–40
Distillation	Extremely high	Dissolved solids	90–98

Acid Waters

When rainfall is more acidic than it would be just by dissolving atmospheric CO_2, it is called acid rain

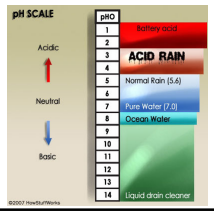


Acid rain corrodes metals, limestone, and marble, and even ruins the finishes on our automobiles

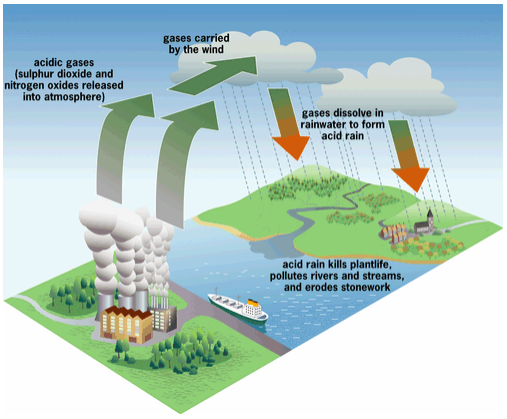
Acid water is detrimental to life in lakes and streams

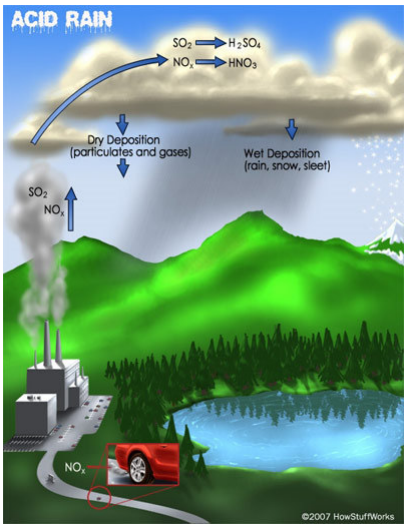
Acid rain has been linked to declining crop and forest yields

Acids are no threat to lakes and streams in areas where the rock is limestone, which can neutralize excess acid

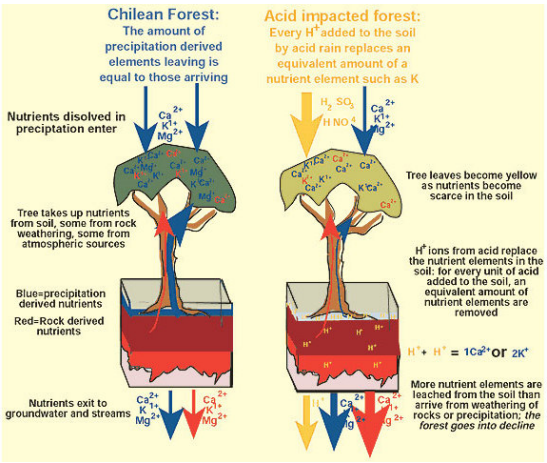


Acid Waters





Acid Waters



Acid Waters