The Various Aspects of Treatment by the Soil in Onsite Wastewater Systems

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Role of Soil in an On-Site Wastewater System

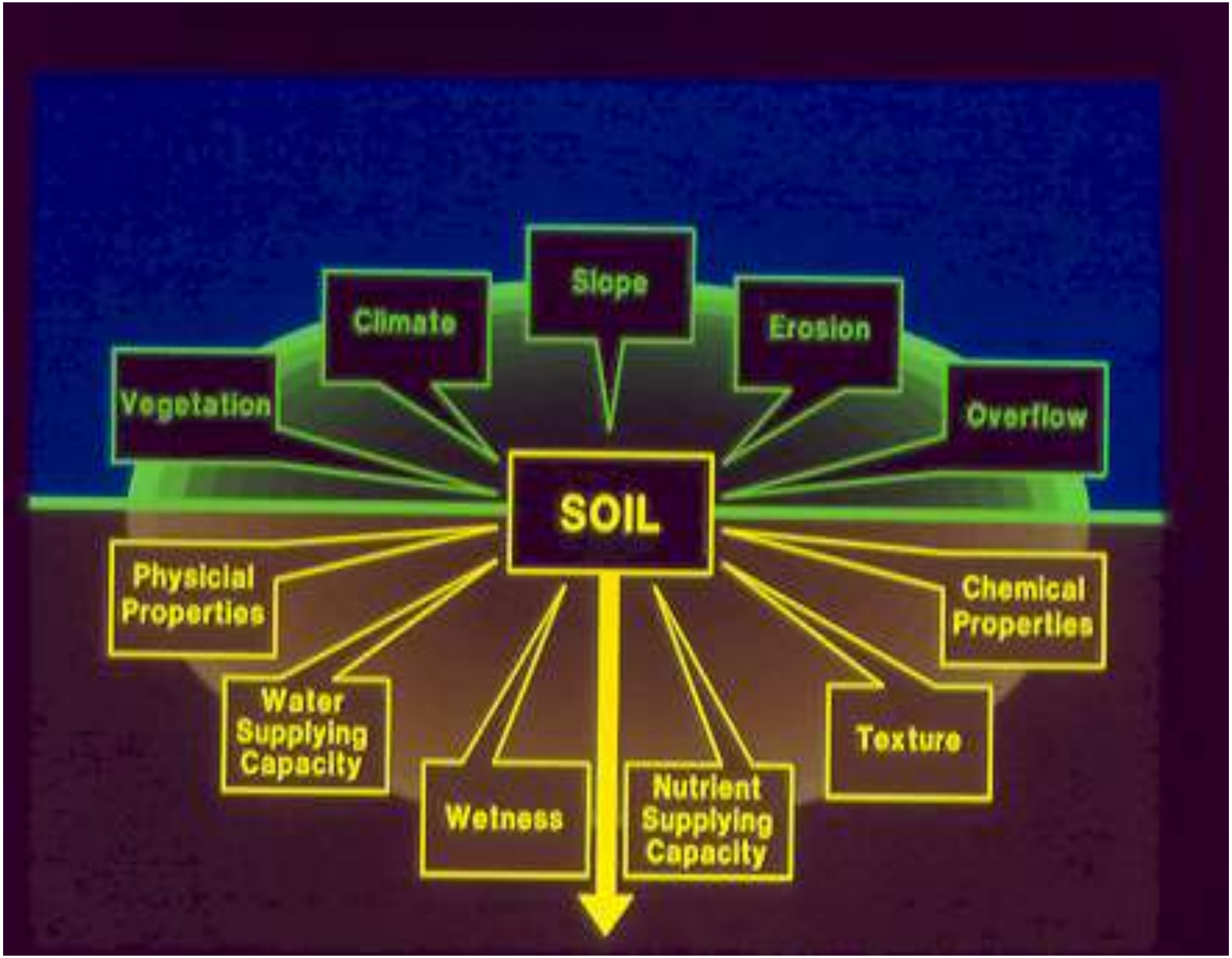
- Provide Treatment for Public Health and Environment

- Successfully Handle Large Volumes of Water on a Continuous Basis

- Repository for Recycling/Reuse of Water

Soil/Site Evaluations

- Most Important Phase of Designing the System
- Soil is a Physical, Biological, and Chemical Treatment System.
- Need for Standard Procedures and Reporting Methods

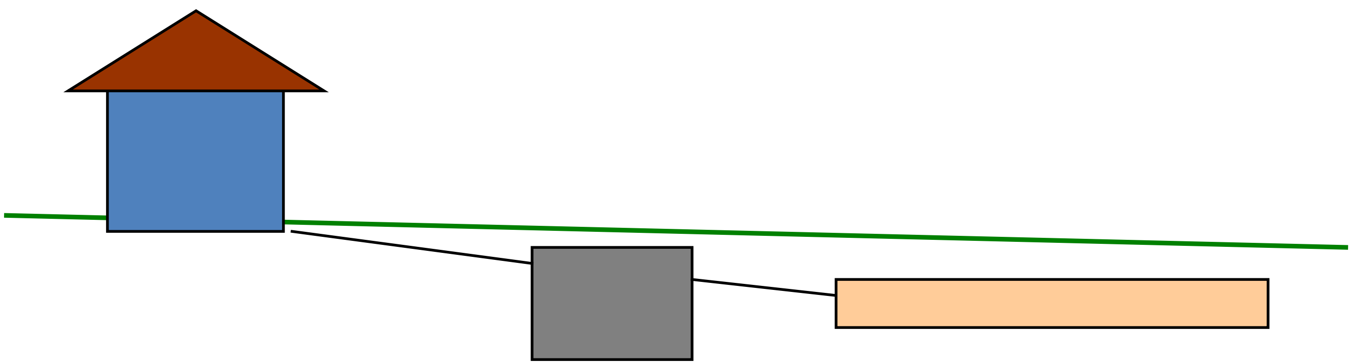

Slope
Climate
Erosion
Vegetation
Overflow
SOIL
Physicial Properties
Chemical Properties
Water Supplying Capacity
Texture
Wetness
Nutrient Supplying Capacity

Soil Assessment for Onsite Wastewater Systems

- Uses Soil Science terms
- Uses few, if any, soil mechanics terms
- Considers a balance of physical, chemical, and biological properties
- Soil is a layered system: anisotropic
- Assesses landscape parameters to predict water movement

Onsite Soil Evaluation

Source → System Pretreatment/distribution → Soil dispersal/ Final treatment



Flow → System design ← Soil evaluation

Accurately describe the site/soil and report limitations

Influent characteristics

Effluent characteristics

What do we need to know?

For design, the ***effluent*** quality depends upon the ***influent*** characteristics

Influence of wastewater source on waste stream characteristics

- **Residential**
- **Municipal**
- **Commercial**
- **Industrial**
- **Agricultural**

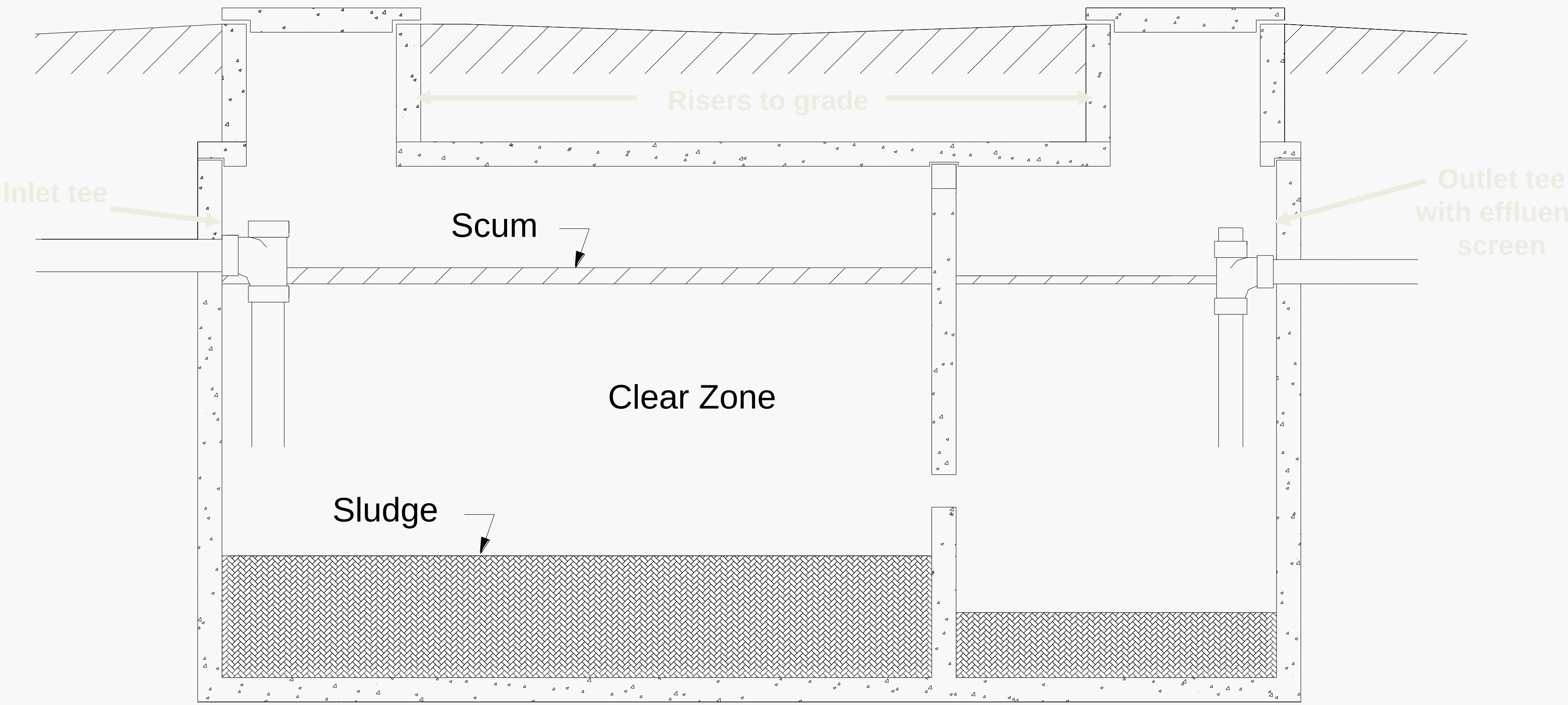
Raw Sewage Characteristics

Component	Range of Concentrations	Typical Concentration
Total Suspended Solids, TSS	155 – 330 mg/L	250 mg/L
BOD_5	155 – 286 mg/L	250 mg/L
pH	6 -9 s.u.	6.5 s.u.
Total Coliform Bacteria	10^8 – 10^{10} CFU/100mL	10^9 CFU/100mL
Fecal Coliform Bacteria	10^6 – 10^8 CFU/100mL	10^7 CFU/100mL
Ammonium-Nitrogen, NH_4-N	4 - 13 mg/L	10 mg/L
Nitrate-Nitrogen, NO_3-N	Less than 1 mg/L	Less than 1 mg/L
Total Nitrogen	26 – 75 mg/L	60 mg/L
Total Phosphorus	6 - 12 mg/L	10 mg/L

mg/L = milligrams per liter
s.u. = standard units
CFU/100 mL = Colony-Forming Units per 100 milliliters

Adapted From: US EPA *Onsite Wastewater Treatment Systems Manual*, EPA/625/R-00/008, US EPA Office of Water, 2002

Dual Chamber Septic Tank

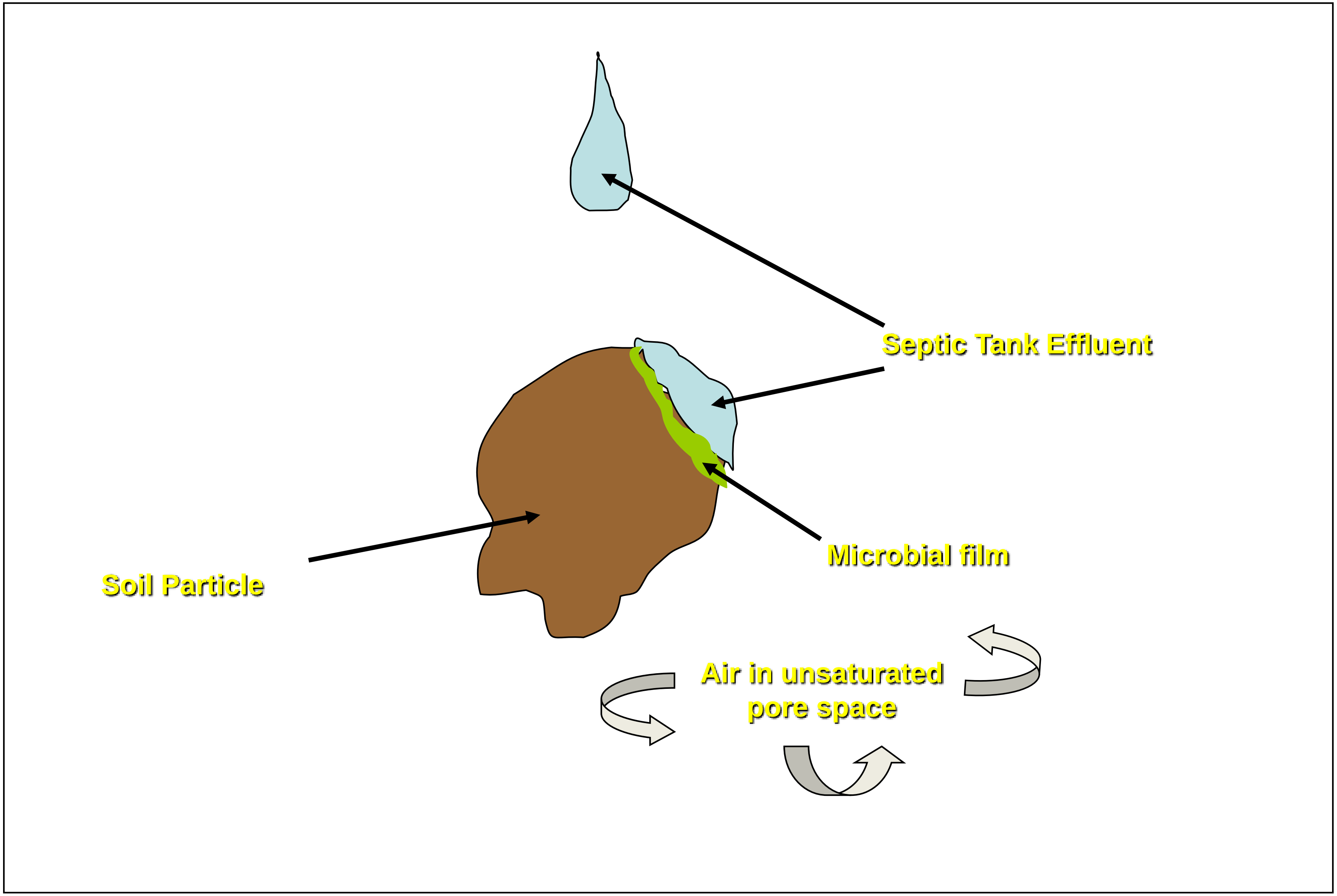


Typical Domestic Septic Tank Effluent Characteristics

Component	Concentration Range	Typical Concentration
Total Suspended Solids, TSS	36 - 85 mg/L	60 mg/L
5-Day Biochemical Oxygen Demand, BOD_5	118 - 189 mg/L	120 mg/L
pH	6.4 – 7.8 s.u.	6.5 s.u.
Fecal Coliform Bacteria	10^6 – 10^7 CFU/100mL	10^6 CFU/100mL
Ammonium-Nitrogen, NH_4-N	30 – 50 mg/L	40 mg/L
Nitrate-Nitrogen, NO_3-N	0 – 10 mg/L	0 mg/L
Total Nitrogen	29.5 – 63.4 mg/L	60 mg/L
Total Phosphorus	8.1 – 8.2 mg/L	8.1 mg/L

Sources: EPA Onsite Wastewater Treatment System Manual, 2002, EPA/625/R-00/08 and Crites and Tchobanoglous, *Small and Decentralized Wastewater Management Systems*, McGraw-Hill, 1998

Septic Tank Effluent is applied to soil and further transformed



Importance

- Largely responsible for reduction of organic material in wastewater
- Use organic matter as a food supply to support the growth of biomass
- By using the organic material, the microbial communities reduce the concentration

Types of Microbial Communities

- Aerobic
- Anaerobic
- Facultative

Aerobic Organisms

- Perform best when waters are well aerated and contain relatively high concentrations of dissolved molecular oxygen

Anaerobic Organisms

- Perform best in conditions with little or no molecular oxygen
- Obtain needed oxygen from molecules that contain oxygen

Facultative Organisms

- Prefer aerobic conditions but easily adapt to low oxygen circumstances

Temperature and Growth

- Growth rates increase with increasing temperature (0 to 55 ºC)
- Growth rates approximately double for a 10 ºC rise in temperature
- Temperature extremes may interfere with metabolic processes or harm the organisms

Toxicity

- Many microbial organisms are able to adapt to changes in their environment—if changes are gradual
- Sudden changes or introduction of toxic materials may be harmful or lethal to the biological community
- Introduction of toxic substances (household bleach) may prove detrimental

Importance of Organic Matter

- Organic material consumes oxygen in water
- Organic material can cause taste and odor problems in recreational and drinking water
- Some material may be hazardous

Dissolved Oxygen

- Dissolved oxygen is oxygen that has been incorporated into water
- Many aquatic animals require it for their survival

Dissolved Oxygen

- There are two important factors that can influence the amount of dissolved oxygen present
  - Water temperature
  - Organic matter

Dissolved Oxygen

- Temperature:
  - Greater temperature → Lower saturated DO
  - Lower temperature → Greater saturated DO

Dissolved Oxygen

- Organic material
  - If oxygen is available, organic material requires oxygen to decompose
  - Organic material may also decompose in the absence of oxygen
  - More organic material requires more DO, and will tend to deplete water of DO

Oxygen Demand

- The oxygen demand is the amount of oxygen required to aerobically oxidize a material

Biochemical Oxygen Demand

- Biochemical oxygen demand, or BOD is the amount of oxygen used by organisms during the breakdown of organic material
- BOD is considered an indirect measure of the organic content of a sample

Total Organic Carbon

- Total organic carbon, or TOC, is the amount of organic carbon bound in a sample.

Solids

Cause many problems:

- Collect in septic tank requiring pump out over time
- May clog distribution areas in poorly-managed systems
- Fill storage areas, clog ditches and channels
- Settle on stream bottoms resulting in death of valuable benthic biota and loss of habitat and dissolved oxygen in the water column

Nutrients

Problems associated with excess nutrients:

- Causes an increase in productivity of aquatic plants, leading to depleted DO levels
- May cause odor problems
- Extra vegetation near surface may inhibit penetration of light into water

pH

- pH is the negative log of the hydrogen ion concentration
- It can have a major impact on biological and chemical reactions

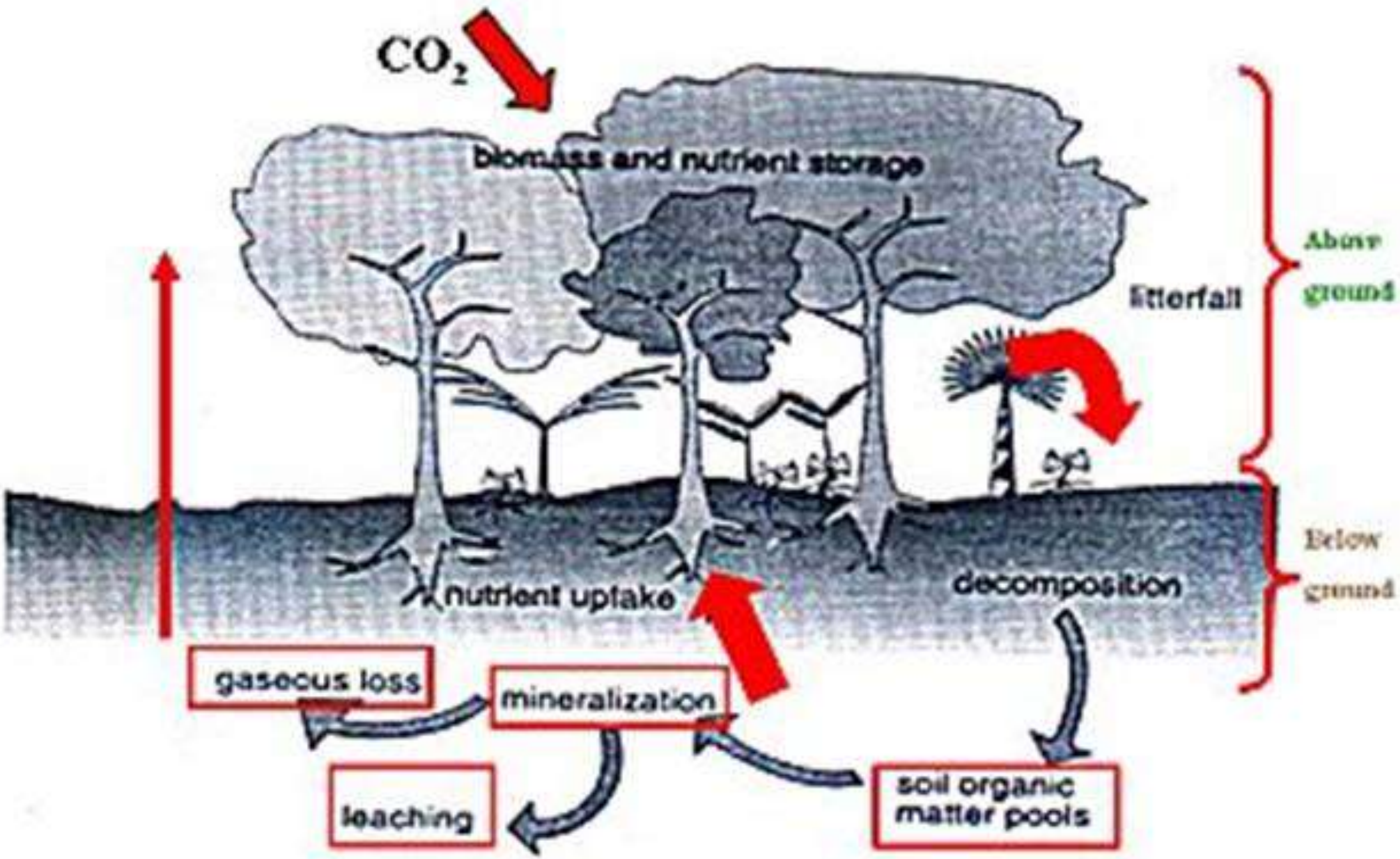
Primary Goal

- Use aerobic microorganisms to provide secondary treatment to domestic wastewater
  - secondary treatment focuses on the removal of biodegradable organics and suspended solids
  - usually accomplished with biological reactors
- Biodegradable organics must be removed from wastewater stream to minimize the impact on the subsequent processes

Organics, Microbes & Oxygen

- Bioavailable organic compounds provide food and energy to microbes
  - naturally-occurring microorganisms consume food, and create more microorganisms
  - the more microorganisms, the more food consumed
  - the more food consumed, more dissolved oxygen is required

Carbon Cycle in Soils



Basic Equation - Carbon

$$\text{Organic Carbon} + O_2 \xrightarrow[\text{microorganisms}]{\text{aerobic}} \text{Energy} + CO_2 + H_2O + \text{Residue}$$

$$+ O_2 \xrightarrow[\text{microorganisms}]{\text{new aerobic}} \text{Energy} + CO_2 + H_2O + \text{Residue}$$

$$+ O_2 \xrightarrow[\text{microorganisms}]{\text{new aerobic}} \text{Energy} + CO_2 + H_2O + \text{Residue}$$

Soil Organic Matter (Organic Carbon)

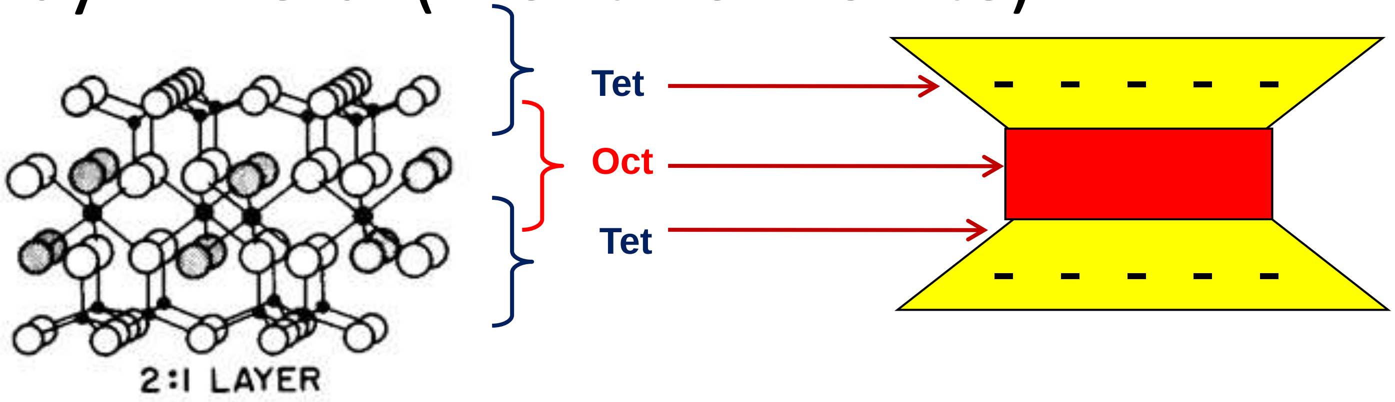
- Degradation by heterotrophic microbes
- Need N for decomposition
- A C/N ratio of 8-10/1 is needed
- Any C/N ratio greater than ~ 25/1 will slow down decomposition of soil organic matter.
- Soil organic matter increase in pores in which effluent is applied will decrease hydraulic conductivity because of solids plugging.
- Decrease organic matter (BOD) by treatment before application to soil.

Cation Exchange Capacity

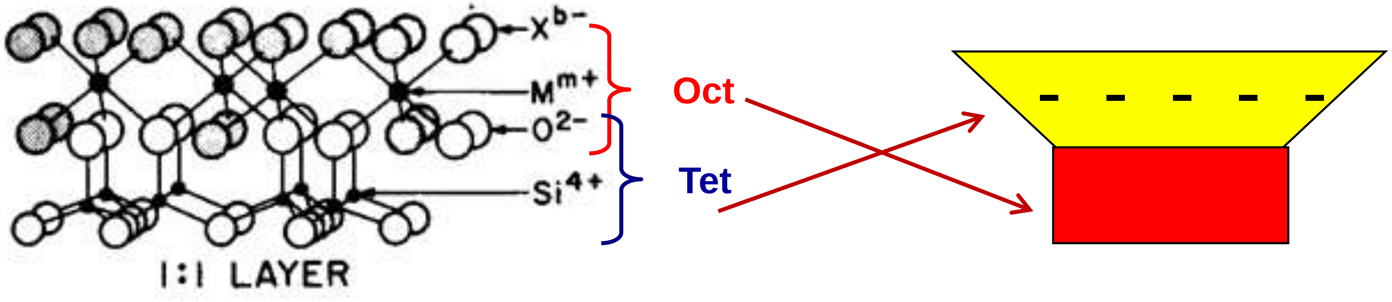
- The soil has a net negative charge arising from clays, organic colloids, and some oxides of Fe and Al.
- The net negative charge attracts positive (cations) ions (opposites attract) such as Ca^{++} Mg^{++} Al^{+++} K^{+} rendering those cations void from being active to leach or react with other ions or substances; this provides treatment!!!
- Microbes are highly associated near the clay and organic surfaces to do their "thing".

Clay Structural Types

- 2:1 Clay Mineral (Montmorillonite)



- 1:1 Clay Mineral (Kaolinite)

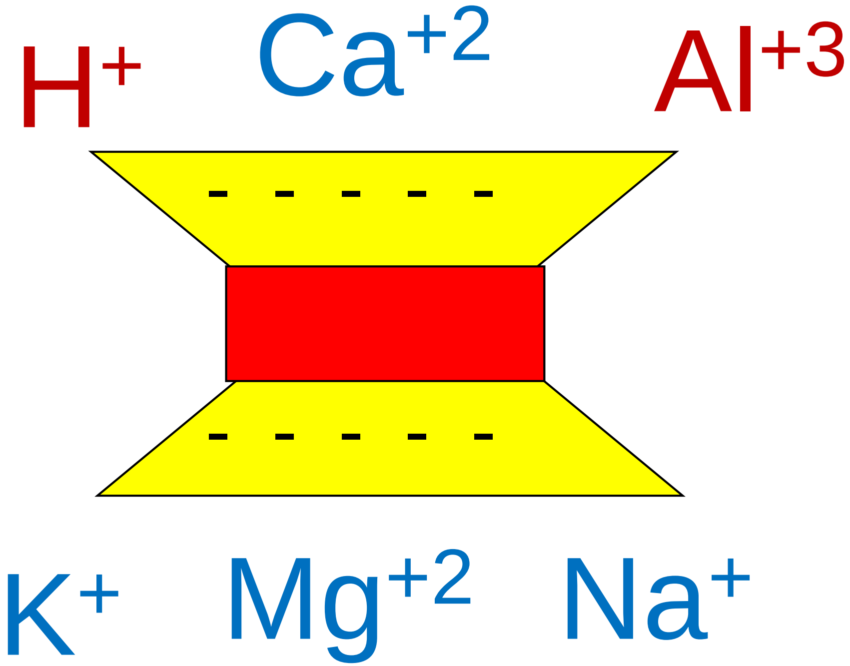


Cation Exchange Capacity (CEC)

- CEC – sum total of the exchangeable cations that a soil can adsorb

Exchangeable acidity

Exchangeable bases



Adsorption by Clay Minerals

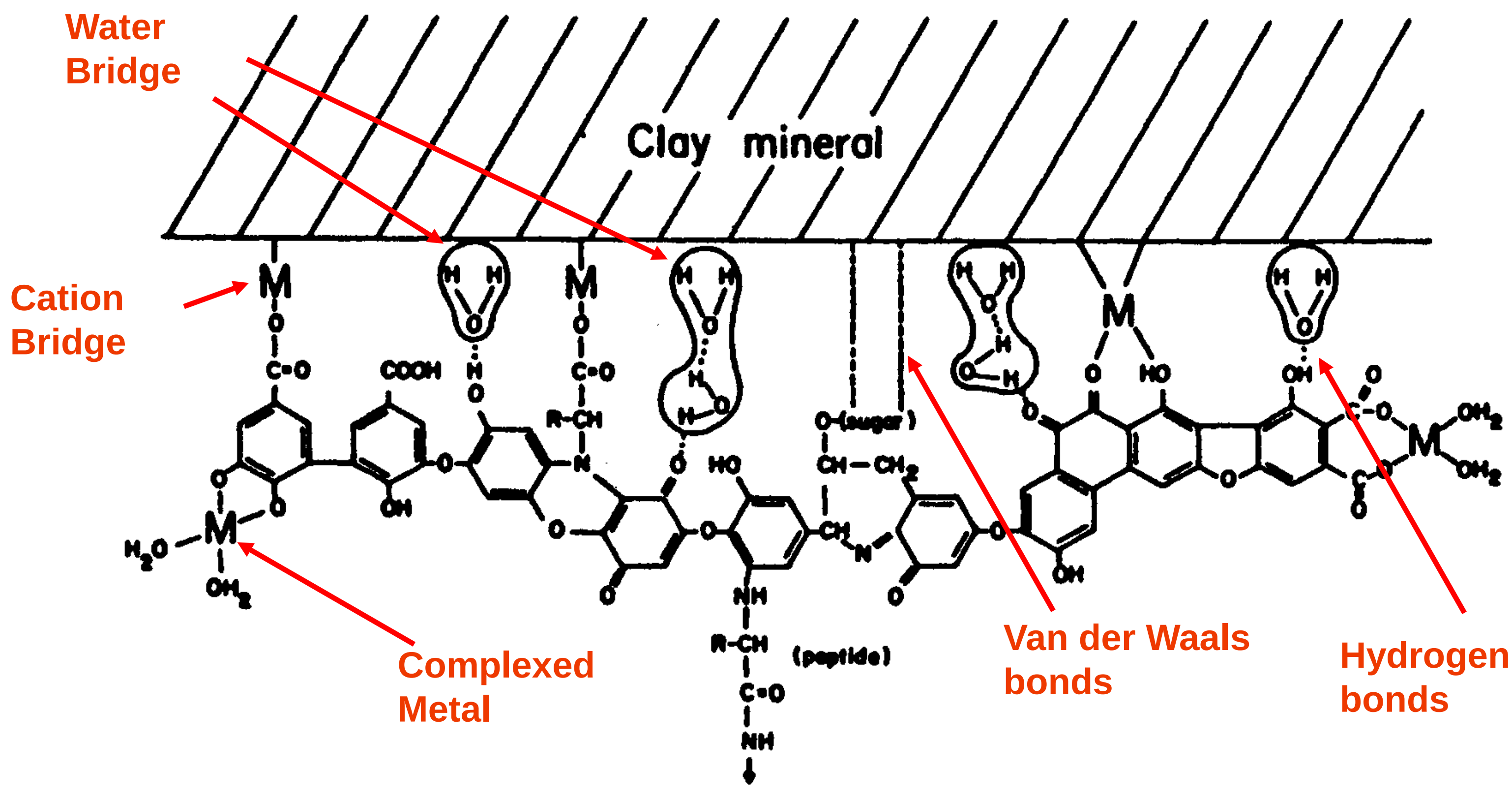
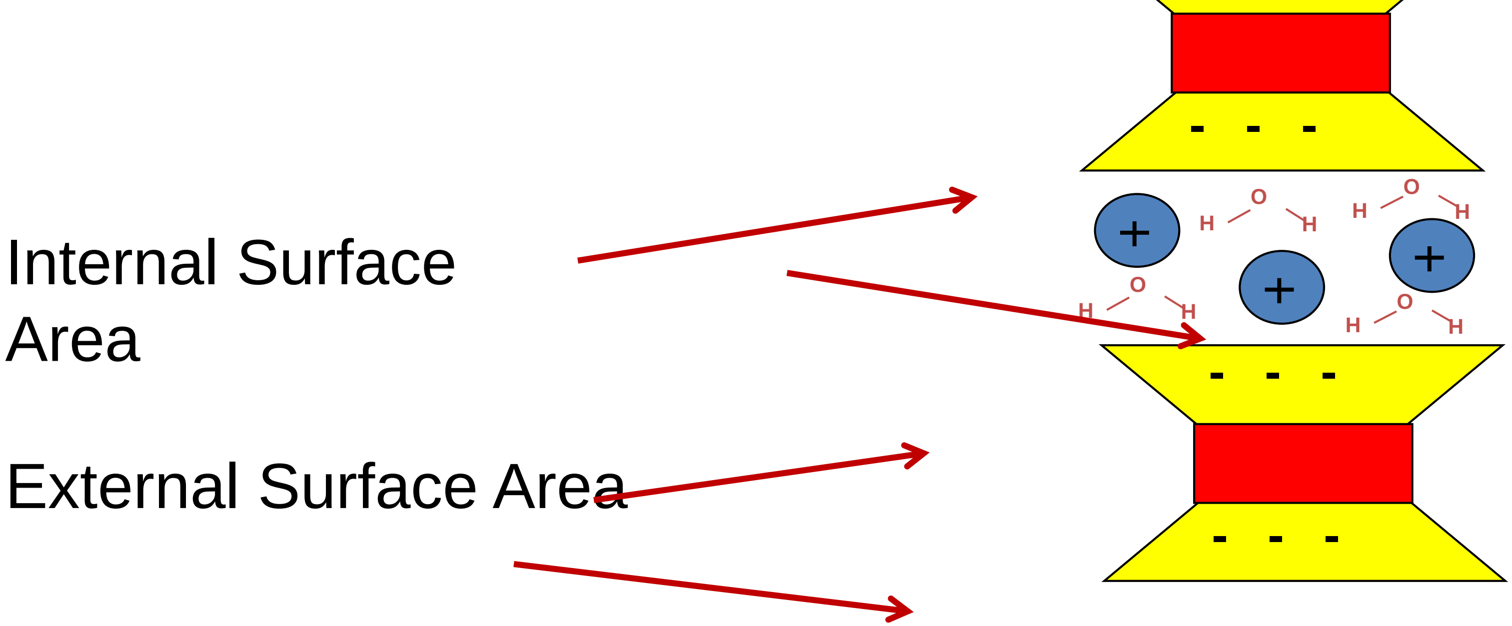


Fig. 18.3 Schematic diagram of clay–humate complex in soil. From Stevenson and Ardakani[20]

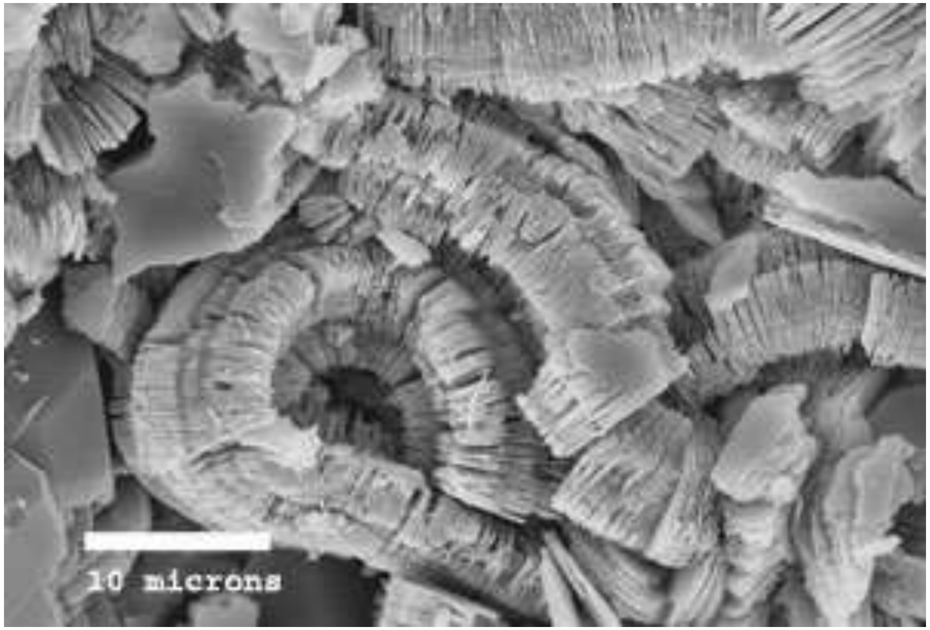
Clay Mineral Surface Area

- Surface Area varies with clay type
  - Kaolinite: 7-30 m^2/g
  - Montmorillonite: 600-800 m^2/g
- Clay interlayers can provide large amounts of surface area

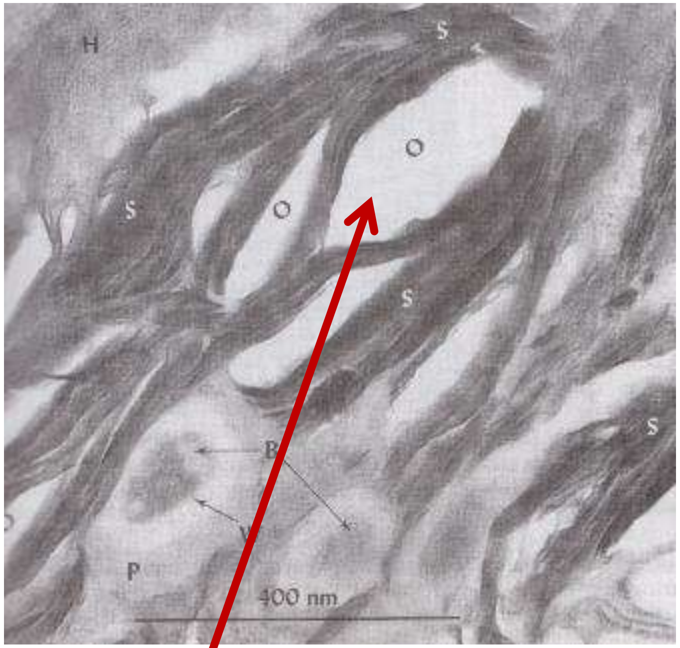


Structural Differences Between Types of Clay

Kaolinite



Montmorillinite



Soil Texture

The Single Most Important Soil Property

- The size distribution of the inorganic primary particles less than 2 mm equivalent spherical diameter.

- Particles greater than 2 mm e.s.d. are called coarse fragments.

Sand vs Clay

Sand

- **Large pores**
- **Water moves fast**
- **Low surface area**
- **Less treatment capacity**

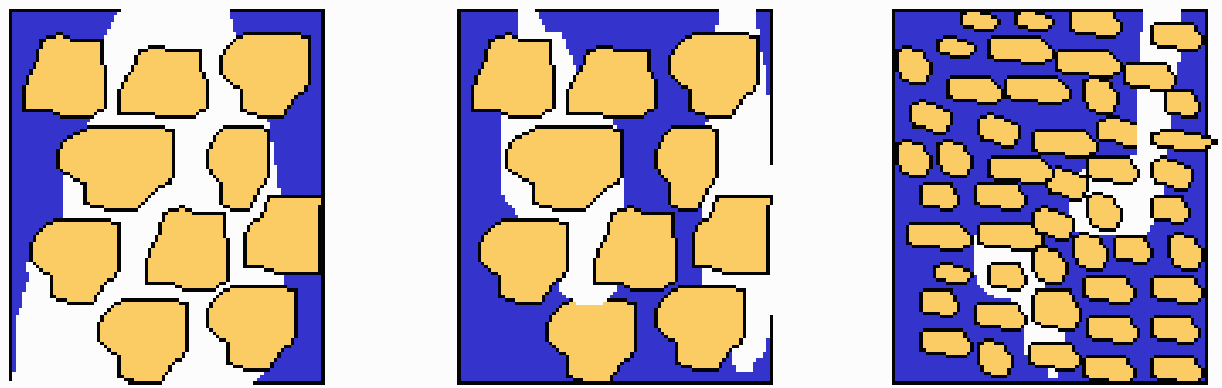
Clay

- **Small pores**
- **Water moves slow**
- **High surface area**
- **More treatment capacity**

Onsite systems need to balance water movement with wastewater treatment

Influence of Texture on Properties

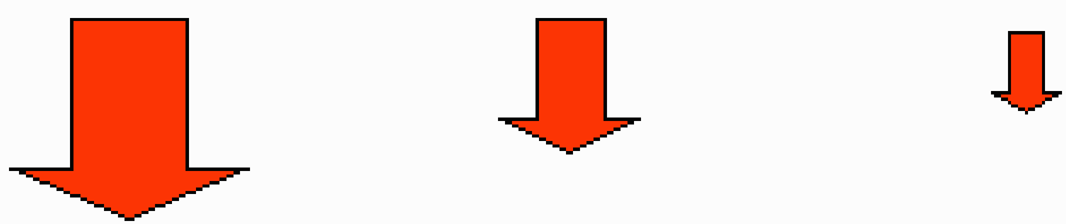
Soil texture:	Sand	Silt	Clay
Size [mm]:	0.05 - 2	0.002 - 0.05	< 0.002



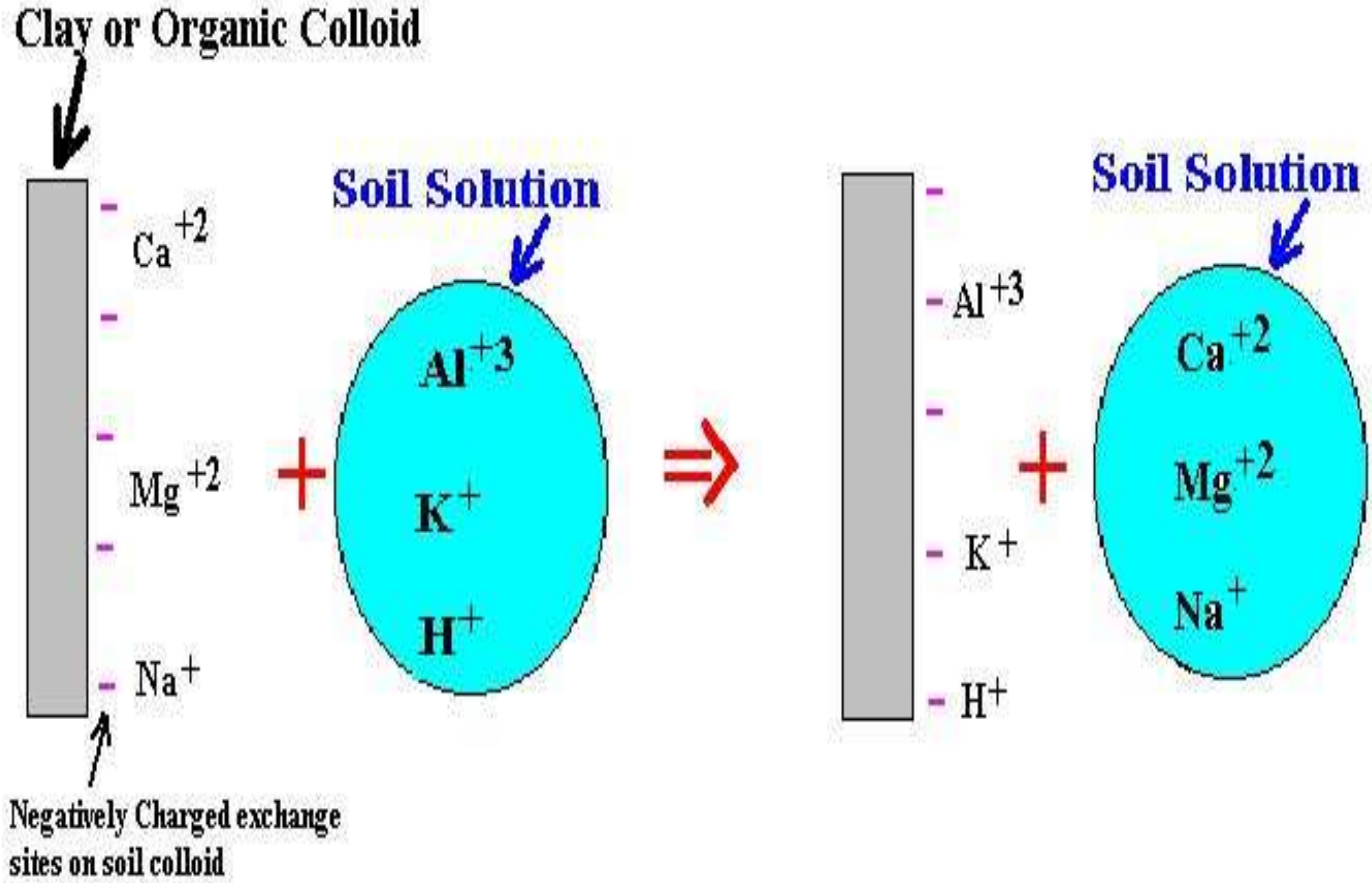
	Sand	Silt	Clay
Macropores	+++	++	(+)
Medium-sized p.	++	++	++
Micropores	(+)	++	+++

Percolation:

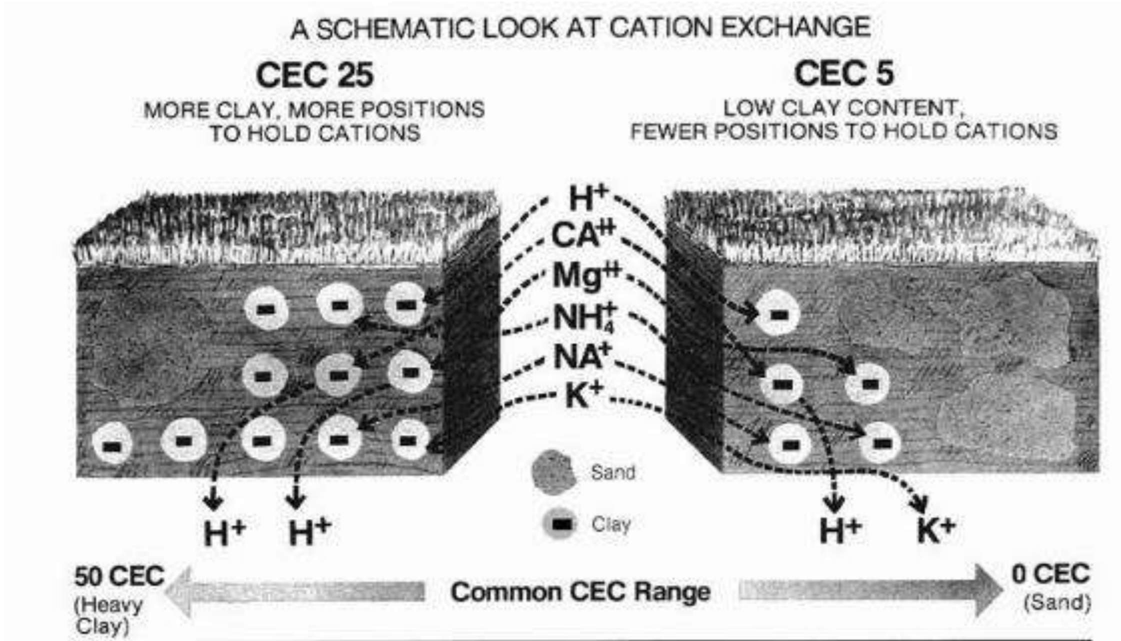
Leaching:



Cation Exchange Illustrated



Importance of Cation Exchange Capacity

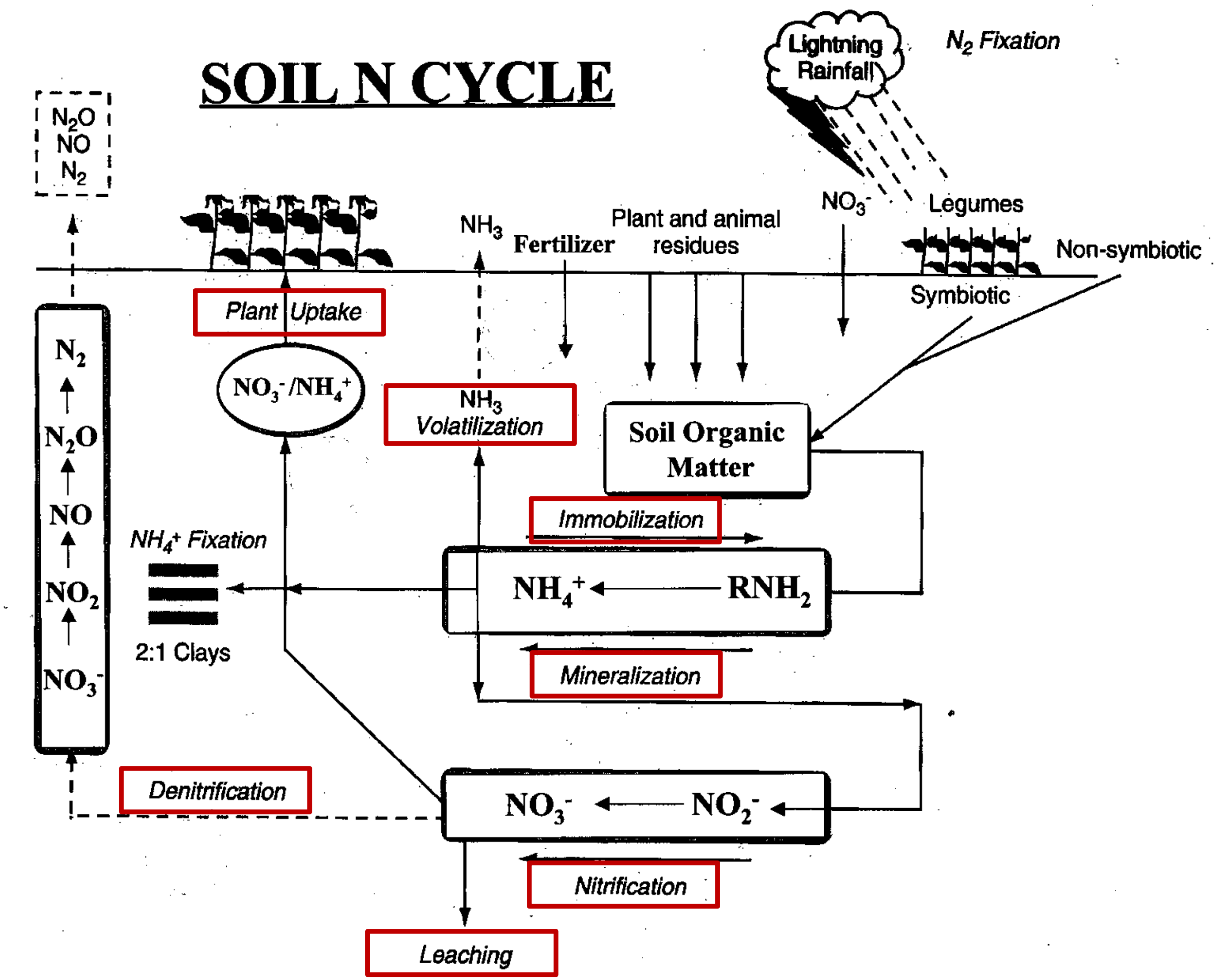


SOME PRACTICAL APPLICATIONS	
Soils with CEC 11-50 Range	Soils with CEC 1-10 Range
• High clay content • More lime required to correct a given pH • Greater capacity to hold nutrients in a given soil depth • Physical ramifications of a soil with a high clay content • High water-holding capacity	• High sand content • Nitrogen and potassium leaching more likely • Less lime required to correct a given pH • Physical ramifications of a soil with a high sand content • Low water-holding capacity

Soil Nitrogen

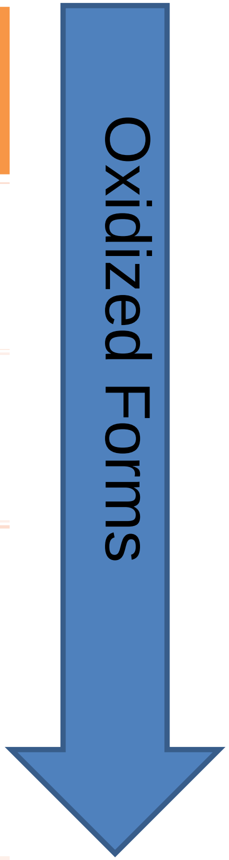
Important for amino acids and proteins in living organisms

Nitrogen Cycle

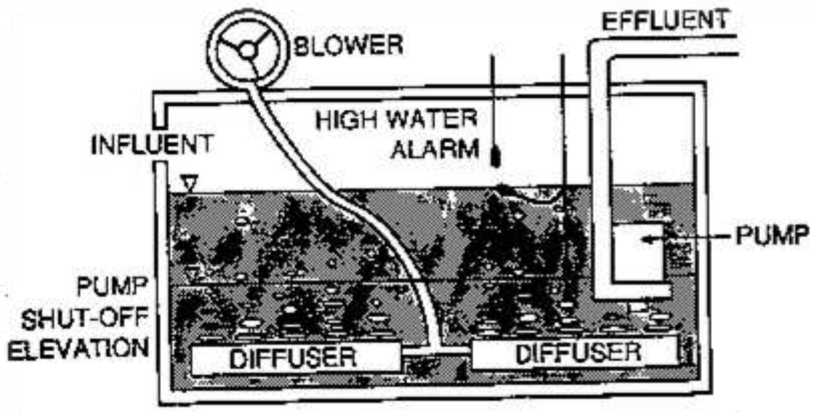


Nitrogen Species and Oxidation States

Species	Species Valence	H/O Valence	Oxidation State of N
NH_4^+	+1		
NH_3	0		
N_2	0		
N_2O	0		

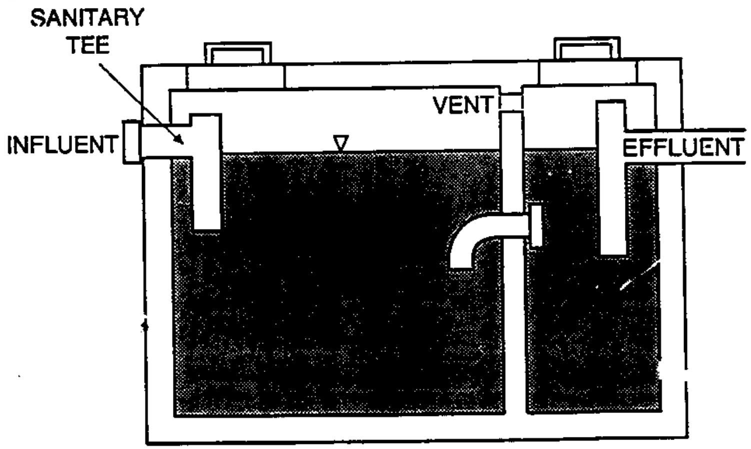


Septic System Treatment



(a)

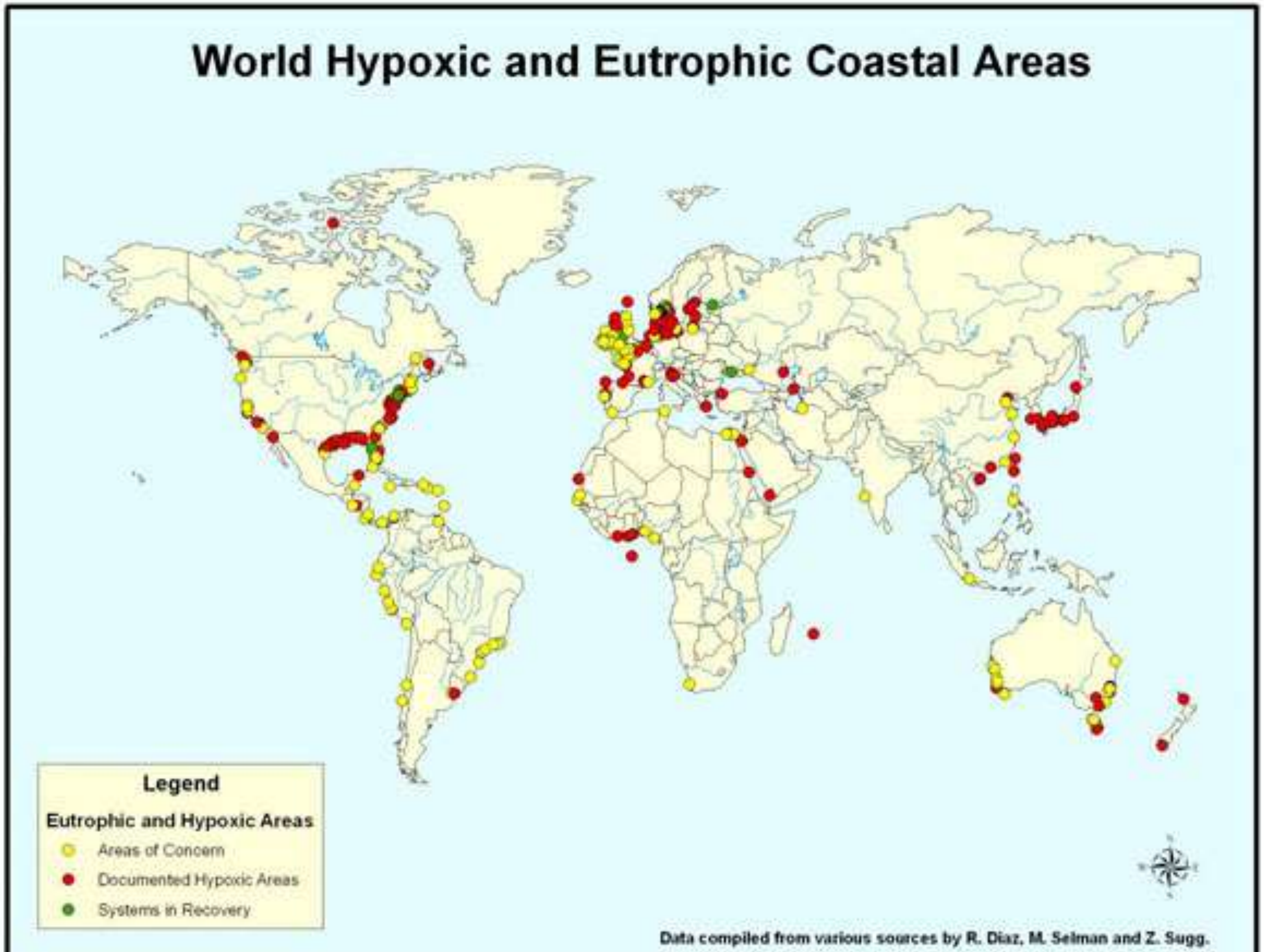
Oxidized Forms of Nitrogen



(b)

Reduced Forms of Nitrogen

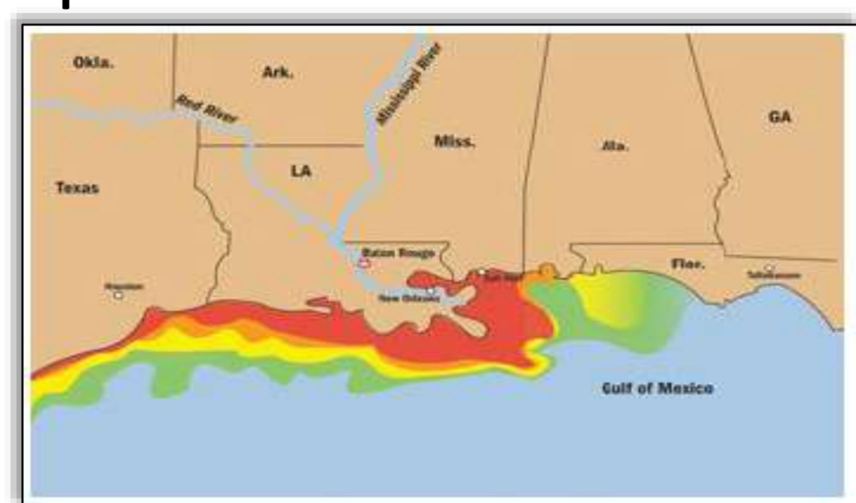
Nutrient Concerns



Gulf of Mexico Hypoxic Zone

- ~10,000 square mile deoxygenated "dead" zone at the mouth of the Mississippi River/Gulf of Mexico
- Unable to sustain bottom-dwelling marine life from April to September

2-3 mg/L
Dissolved
Oxygen



Chemistry of Nitrogen

Nitrogen can exist in nine various forms in the environment due to seven possible oxidation states:

Nitrogen Compound	Formula	Oxidation State
Organic nitrogen	Organic-N	-3
Ammonia	NH_3	-3
Ammonium ion	NH_4^+	-3
Nitrogen gas	N_2	0
Nitrous oxide	N_2O	+1
Nitric oxide	NO	+2
Nitrite ion	NO_2^-	+3
Nitrogen dioxide	NO_2	+4
Nitrate ion	NO_3^-	+5

Chemistry of Nitrogen

- **Because of the various oxidation states that can change in the environment, it is customary to express the forms of nitrogen in terms of nitrogen rather than the specific chemical compound: (eg., Organic-N, NH_3-N, NH_4^+-N, N_2-N, NO_2^--N, and NO_3^--N.)**

- **Thus, for example, 10 mg/L of NO_3^--N is equivalent to 45 mg/L of NO_3^- ion.**

- **To measure total N in soils one must perform a variety of analysis from that one sample. There is no one analysis for assessing total N in soils.**

The Nitrogen Cycle in Soil-Groundwater Systems

- **Transformation of the principal nitrogen compounds in soil-groundwater systems (Organic-N, NH_3-N, NH_4^+-N, N_2-N, NO_2^--N, and NO_3^--N) can occur through five key mechanisms in the environment:**

- **Fixation**
- **Ammonification**
- **Synthesis**
- **Nitrification**
- **Denitrification**

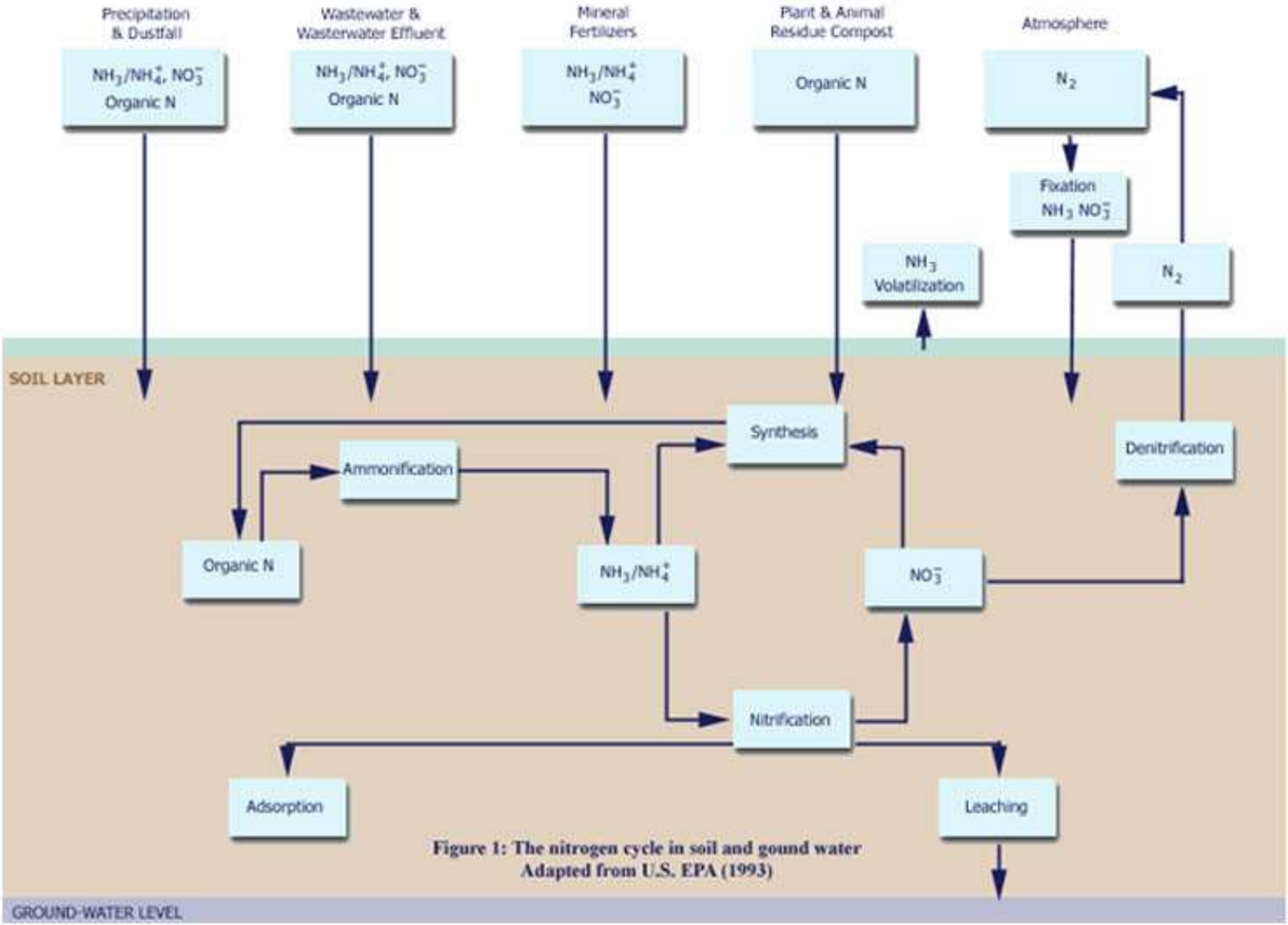


Figure 1: The nitrogen cycle in soil and gound water
Adapted from U.S. EPA (1993)

Biological Nitrification

- Organically bound nitrogen is released when the organic compound is oxidized
  - released as the ammonium cation (NH_4^+)
- Nitrification is a two-step autotrophic process
  - the conversion from ammonium to nitrate

Nitrosomonas

Step 1: $NH_4^+ + 3/2O_2 \rightarrow NO_2^{2-} + 2H^+ + H_2O$

Nitrobacter

Step 2: $NO^{2-} + 1/2O_2 \rightarrow NO^{3-}$

From Academic Curriculum chapter: *Onsite Nitrogen Removal*, By Stewart Oakley

Microbes as Workhorses

- Microorganisms are used
  - to convert colloidal and dissolved carbonaceous organic matter into various gases and into cell tissue
    - gases evolve (CO_2, N_2, and others)
    - new cells can be settled – thus carbon is removed
  - break other nutrients out of organic compounds
    - nitrogenous compounds
    - phosphorus species

Catabolism

- Fermentation
  - first step in biodegradation
    - does not depend on presence of oxygen
  - both aerobic and anaerobic microbes use this step
    - this is why methane and alcohol production must be anaerobic
    - however, anaerobic microbes cannot further oxidize the VFA

$$\underset{\text{organic compounds}}{\text{COHNS}} \xrightarrow[\text{microbes}]{\text{heterotrophic}} \begin{bmatrix} \text{volatile} \\ \text{fatty} \\ \text{acids} \end{bmatrix} + CO_2 + H_2O + CH_4 + \text{energy} + \text{residuals}$$

Catabolism

- Respiration
  - second step for aerobic microbes
    - simple organic compounds can be oxidized to carbon dioxide and water
  - requires the presence of dissolved oxygen

$$\begin{bmatrix} \text{volatile} \\ \text{fatty} \\ \text{acids} \end{bmatrix} + O_2 \xrightarrow[\text{microbes}]{\text{aerobic}} \text{energy} + CO_2 + H_2O + \text{residuals}$$

Environmental Effects

- Microbes need more than organic carbon, dissolved oxygen and water
  - temperature must be life-sustaining
  - need steady supply of food to maintain stable microbial population
  - pH needs to be monitored
    - low alkalinity can cause large changes in pH
  - Be careful with biocides
    - acid drain cleaner
    - antibiotics

Nitrogen Fixation

- **Nitrogen fixation is the conversion of nitrogen gas into nitrogen compounds that can be assimilated by plants. Biological fixation is the most common, but fixation can also occur by lightning, and through industrial processes:**

- **Biological:** $N_2 \rightarrow$ **Organic-N**
- **Lightning:** $N_2 \rightarrow NO_3^-$
- **Industrial:** $N_2 \rightarrow NO_3^-$ **or** NH_3/NH_4^+

Ammonification

- **Ammonification is the biochemical degradation of Organic-N into NH_3 or NH_4^+ by heterotrophic bacteria under aerobic or anaerobic conditions.**

- **Organic-N + Microorganisms $\rightarrow$ NH_3/ NH_4^+**

- **Some Organic-N cannot be degraded and becomes part of the humus in soils.**

Nitrification

- **Nitrification is the biological oxidation of NH_4^+ to NO_3^- through a two-step autotrophic process by the bacteria *Nitrosomonas* and *Nitrobacter*:**

Nitrosomonas

- **Step 1:** $$NH_4^+ + 3/2O_2 \xrightarrow{Nitrosomonas} NO_2^{--} + 2H^+ + H_2O$$

Nitrobacter

- **Step 2:** $$NO_2^- + 1/2O_2 \xrightarrow{Nitrobacter} NO_3^-$$

Nitrification

- **The two-step reactions are usually very rapid and hence it is rare to find nitrite levels higher than 1.0 mg/L in water.**

- **The nitrate formed by nitrification is, in the nitrogen cycle, used by plants as a nitrogen source (synthesis) or reduced to N_2 gas through the process of denitrification.**

- **Nitrate can, however, contaminate groundwater if it is not used for synthesis or reduced through denitrification .**

Denitrification

- **NO_3^- can be reduced, under anoxic conditions, to N_2 gas through heterotrophic biological denitrification as shown in the following unbalanced equation:**

Heterotrophic

Bacteria

- **$NO_3^- + \text{Organic Matter} \rightarrow N_2 + CO_2 + OH^- + H_2O$**

Denitrification

- **The denitrification equation is identical to the equation for the biological oxidation of organic matter with the exception that NO_3^- is used as an electron acceptor instead of O_2:**

Heterotrphic

Bacteria

- **O_2 + Organic Matter $\rightarrow$ CO_2 + OH^- + H_2O**

Denitrification

- **A large variety of heterotrophic bacteria can use nitrate in lieu of oxygen for the degradation of organic matter under anoxic conditions.**
- **If O_2 is present, however, the bacteria will preferentially select it instead of NO_3^-. Thus it is very important that anoxic conditions exist in order that NO_3^- will be used as the electron acceptor.**
- **A carbon source is required as the electron donor for denitrification to occur.**

Environmental Effects of Nitrogen Discharges

- **Health Effects from Groundwater Contamination with Nitrates**
  - **Methemoglobinemia**
  - **Carcinogenesis**
  - **Birth Defects**

- **Surface Water Pollution with Nitrogen**
  - **Eutrophication**
  - **Oxygen Demand through Nitrification**
  - **Ammonia Toxicity to Aquatic Organisms**

Sources of Nitrogen Discharges to Groundwater

Agricultural Activities:

- **A significant source of nitrate in groundwater.**
- **Nitrate can enter groundwater at elevated levels by:**
  - **Excessive or inappropriate use of nitrogen-based nutrient sources:**
    - **Commercial fertilizers**
    - **Animal manures**
    - **Types of crops utilized**
  - **Crop irrigation that leads to nitrate leaching**
  - **Inappropriate livestock manure storage**

Sources of Nitrogen Discharges to Groundwater

Septic Tank-Soil Absorption Systems:

- **Contamination of groundwater with nitrates from septic tank-soil absorption systems is a problem in many parts of the US.**
- **The build-up of nitrate in groundwater is one of the most significant long-term consequences of onsite wastewater disposal.**
- **As an example, the annual nitrogen contribution for a family of four from a septic-tank soil absorption system on a quarter acre lot could be as high as 50 lbs. per year.**

Sources of Nitrogen Discharges to Groundwater

Septic Tank-Soil Absorption Systems:

- **The annual nitrogen requirement for a quarter acre of Bermuda grass is also about 50 lbs. per year, which could also be close to the annual nitrogen production of a family of four.**

- **The nitrogen from the septic tank-soil absorption system, however, is not uniformly distributed throughout a lawn and is typically discharged at a depth below which plants can utilize it.**

- **Nitrogen exists as Organic-N and NH_3-N/NH_4^+-N in septic tank effluent, and is usually transformed into nitrate as the wastewater percolates through the soil column. Also, the nitrogen loading from high housing densities can greatly exceed any potential plant uptake of nitrogen even if the effluent was uniformly distributed for plant uptake.**

Control of Nitrogen Discharges from Onsite Systems

Public health and water pollution control agencies have tried to limit the number of onsite systems in a given area by:

- **Quantifying nitrogen loadings**
- **Examining alternative onsite technologies that provide nitrogen removal**

Nitrogen Dynamics in Septic Tank-Soil Absorption Systems

Wastewater Characteristics:

- **The mass loading of nitrogen in domestic wastewater averages from 4 to 18 lbs. of Total-N per capita per year.**
- **Untreated domestic wastewater typically contains 20 to 85 mg/L Total-N, with the majority occurring as a mixture of NH_3-N/NH_4^+-N (12-50 mg/L) and Organic-N (8-35 mg/L)**

Nitrogen Dynamics in Septic Tank-Soil Absorption Systems

Because the carbon to nitrogen ratio of wastewater is typically on the order of 4:1 to 6:1, there will be excess nitrogen after secondary biological treatment (BOD removal) that cannot be assimilated by microorganisms as shown in the following unbalanced equation:

$$\underset{\text{Organic Matter}}{\text{COHNS}} + O_2 + \text{Nutrients} \xrightarrow{\text{bacteria}} CO_2 + NH_4^+ + \underset{\text{new bacterial cells}}{C_5H_7NO_2} + \text{end products}$$

Nitrogen Dynamics in Septic Tank-Soil Absorption Systems

Septic Tanks:

- **The removal of Total-N within septic tanks is on the order of 10 to 30%, with the majority being removed as particulate matter through sedimentation or flotation processes.**

- **Because of the septic tank's anaerobic environment, nitrogen exists principally as Organic-N and NH_3-N/NH_4^+-N (TKN).**

Nitrogen Dynamics in Septic Tank-Soil Absorption Systems

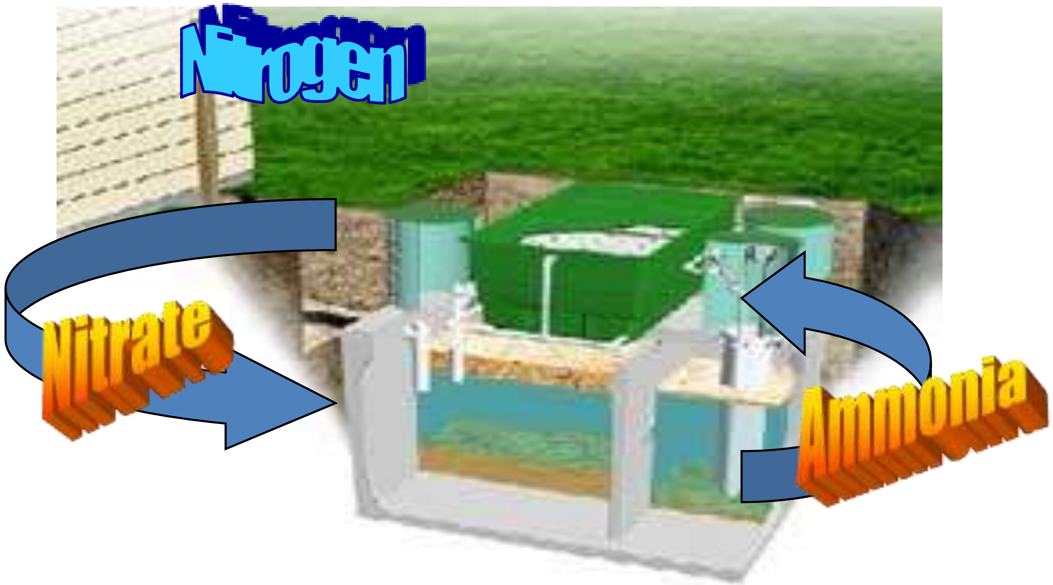
Subsurface Absorption Trenches:

- **Nitrogen can undergo several transformations within and below subsurface absorption trenches:**
  - **Adsorption of NH_4^+-N in the soil**
  - **Volatilization of NH_3-N in alkaline soils at a pH above 8.0**
  - **Nitrification and subsequent movement of NO_3^- -N towards the groundwater**
  - **Biological uptake of both NH_3^-N/NH_4^+-N and NO_3^- -N**
  - **Denitrification if the environmental conditions are appropriate**

Role of Processing Tank and Media Filter for Recirculation

- Anaerobic component of a treatment train
- Aerobically treated effluent is recirculated into the anaerobic tank
- Used in Nitrogen reduction systems
- $NH_4^+ \rightarrow NO_3^- \rightarrow N_2$

Textile filters are typical units that use processing tanks



DO Measurements

Primary tanks - < 0.3 mg/l (ppm)

Recirculation tanks - < 0.5 mg/l is desired

Higher values:

- hinder denitrification
- indicates too much recirculation

Media filters - 2 to 7 + mg/l

Lower values:

- indicates insufficient oxygen (sulfide odor)
- increase recirculation to add more oxygen

High(er) values:

- indicates excessive aeration/recirculation
- low hydraulic retention time; insufficient treatment

Biological Nitrification

Dissolved Oxygen Requirements and Organic Loading Rates:

- **Suspended Growth Systems**
  - **The concentration of DO has a significant effect on nitrification in wastewater treatment.**
  - **Although much research has been performed, practical experience has shown that DO levels must be maintained at approximately 2.0 mg/L in suspended-growth (aerobic) systems, especially when NH_4^+-N loadings are expected to fluctuate widely; this is likely to be the case in domestic onsite wastewater systems.**

Biological Nitrification

Temperature Effects:

- **Temperature has a significant effect on nitrification that must be taken into consideration for design.**

- **In general, colder temperatures require longer cell residence times in suspended-growth systems and lower hydraulic loading rates in attached-growth systems due to slower growth rates of nitrifying bacteria.**

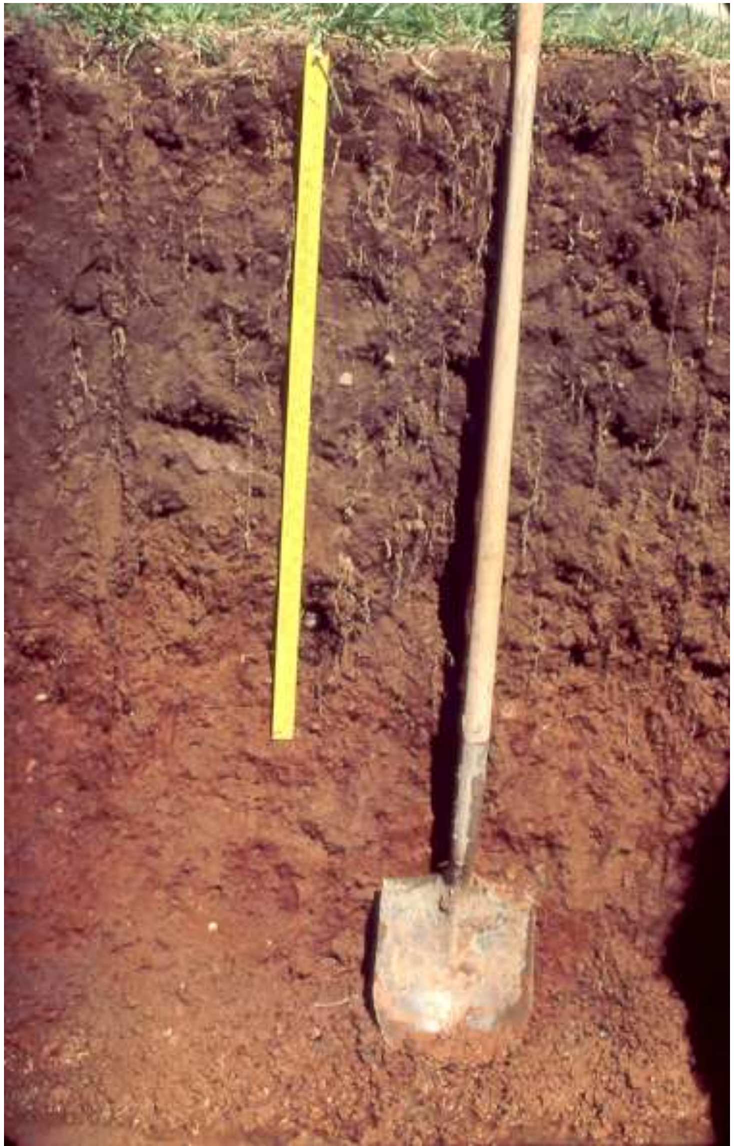
Examples of Onsite Nitrogen Removal Technologies

- **Shallow Trench and Subsurface Drip Irrigation Systems.**
  - **The use of either shallow trench or subsurface drip irrigation (SDI) systems has been proposed as an alternative means to remove Total-N in the soil column. Both systems have the potential to promote nitrogen uptake by plant roots if effluent was discharged directly within the root zone.**
  - **There is also a potential that both systems within the 'A' horizon of the soil could promote denitrification of nitrified effluents if there was sufficient organic matter present, either naturally or added, and if the conditions were conducive for denitrification (ie., anoxic). This type of denitrification has been demonstrated with the use of a reactive porous media barrier using sawdust as a carbon source, which was used to denitrify nitrified septic tank effluents percolating through the soil column.**

Examples of Onsite Nitrogen Removal Technologies

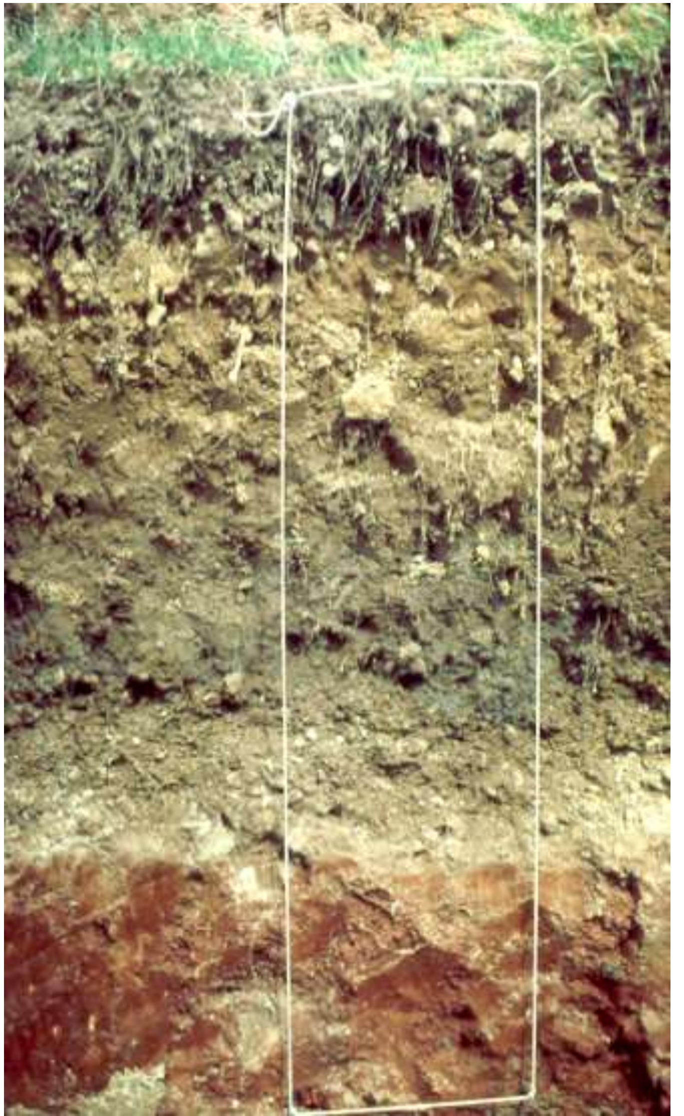
- **Shallow Trench and Subsurface Drip Irrigation Systems.**
  - **To date, the results on the use of shallow trenches or SDI systems for onsite nitrogen removal is mixed at best, with removal efficiencies of Total-N ranging from 0 to 40%.**
  - **Coupling nitrogen loadings with plant uptake requires significant operational monitoring and adjustment.**
  - **Denitrification, if it is desired, cannot be easily controlled within a trench system or the soil column as it can within a treatment reactor above ground.**
  - **Monitoring of nitrogen removal in the soil column is also a significant problem since lysimeter systems have to be used, and they require some degree of sophistication in installation and sample collection.**

Well Drained (Aerated) Soil



Somewhat Poorly Drained Soil

Perched Water Table



Poorly (Aerated) Drained

Poorly Drained Sand

Phosphorus in Soils

- Occurs as PO_4^{-3} form. Loves to "hook up" with many other constituents.
- Little native P in soils initially
- The mineral P is usually very insoluble
- When soluble the mineral P is easy to fix from being biologically available
- Leaching is minimal.
- Efficiency by plants is 10-30%

Importance of Phosphorus

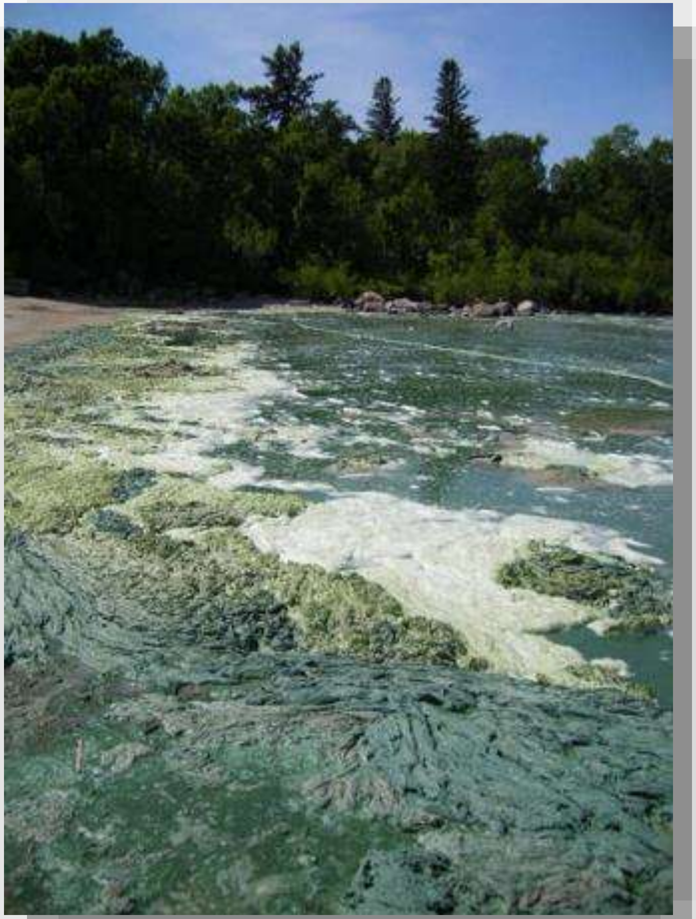
- Component of Adenosine triphosphate (ATP)
- Component of deoxyribonucleic/ ribonucleic acid (DNA/RNA)
- Component of bones and teeth

(Brady and Weil 2008)

P-problems: Eutrophication

- **P-limited algal growth in rivers/lakes**

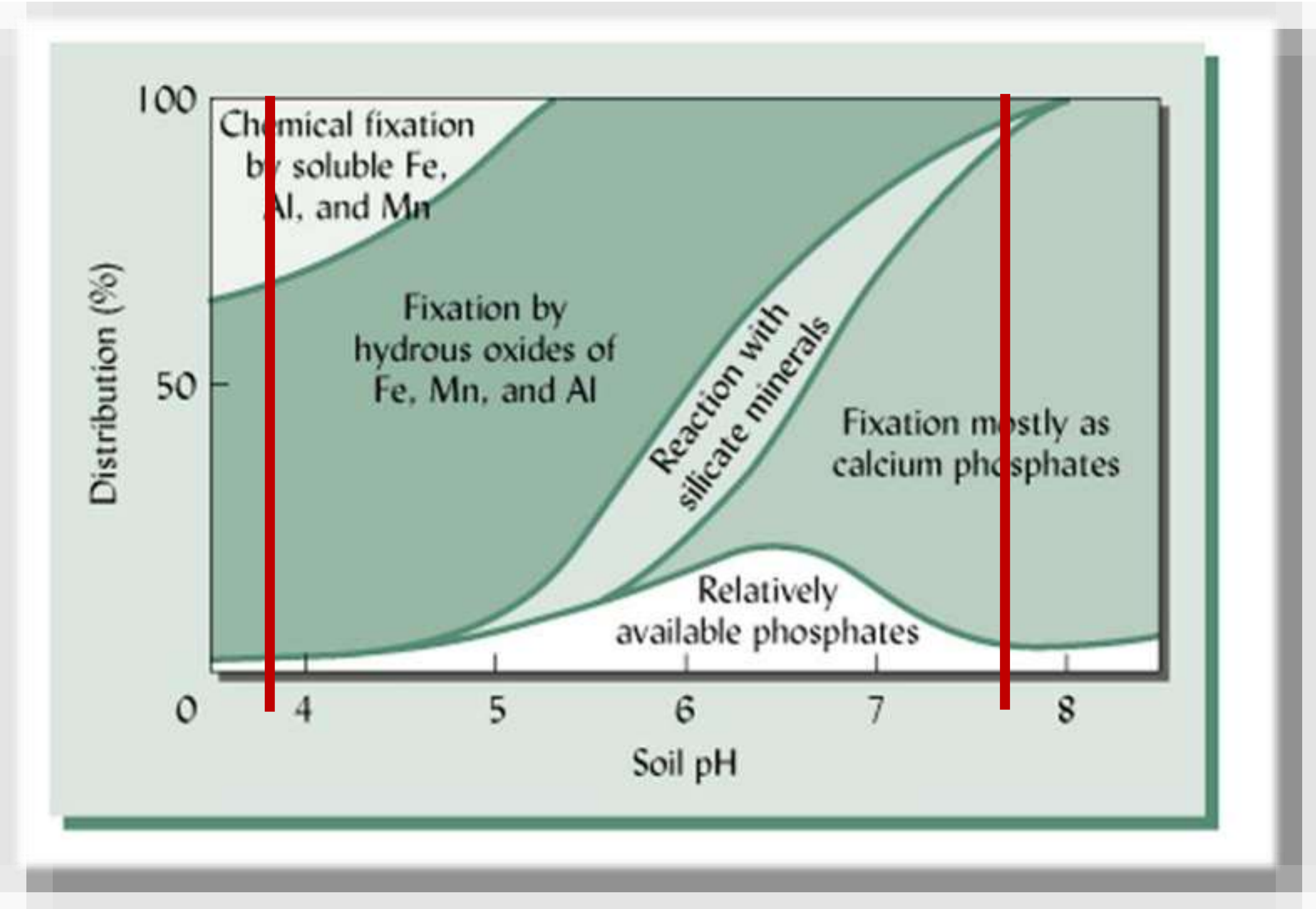
Lake Winnipeg



Schindler et al. 2008

Broiler Production

P-problems: Limited Availability

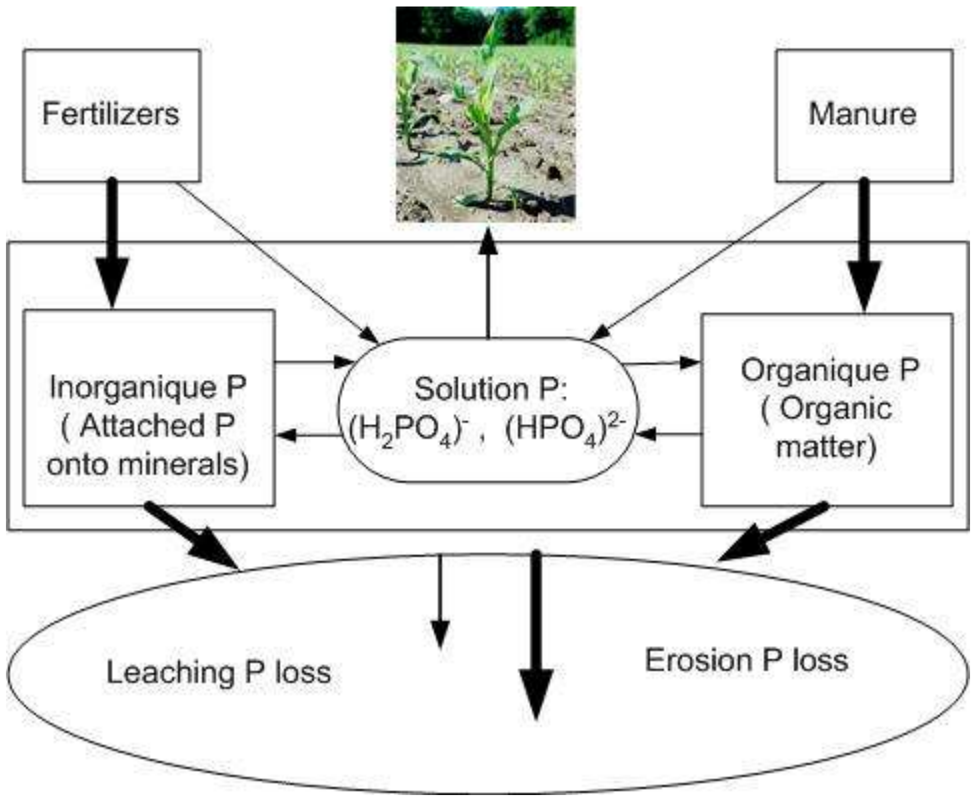


(Brady and Weil 2008)

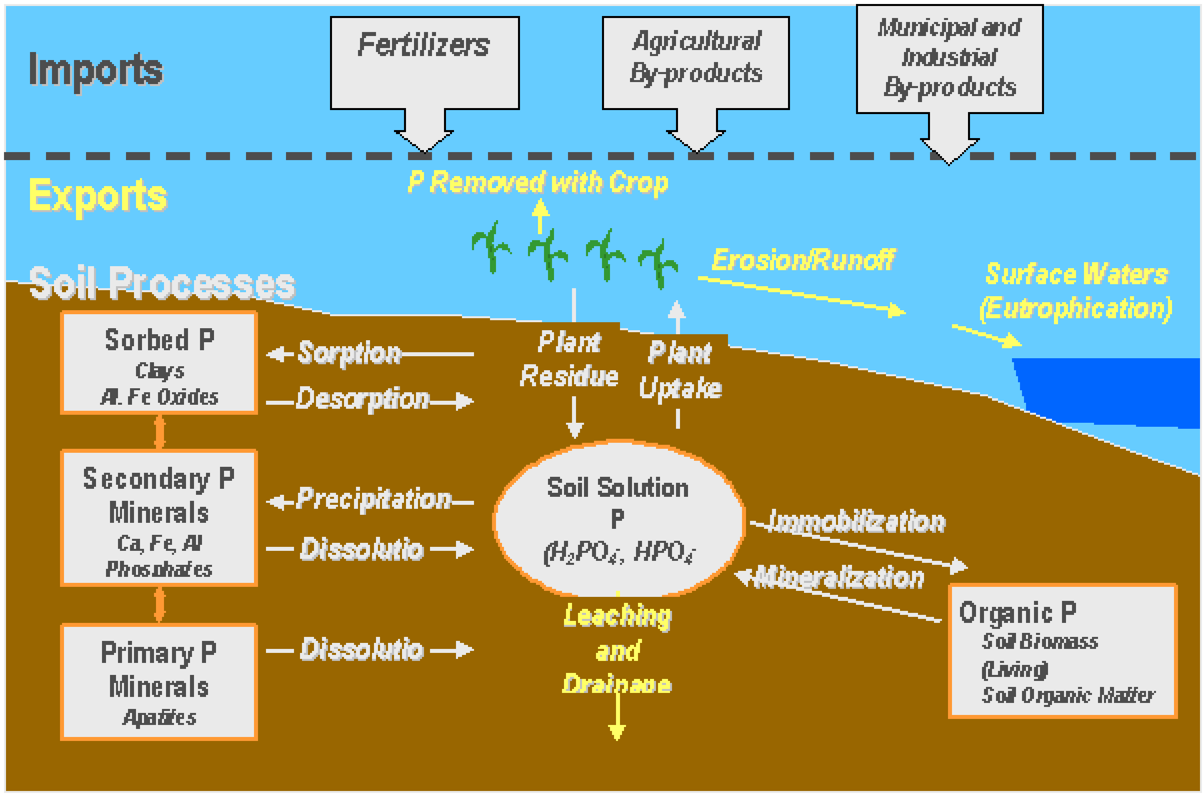
Phosphorus Fixation
(Fixation = tied up with something else)

- Easy to fix with soluble Ca
- Easy to fix with carbonates
- Easy to fix at high pH values
- Easy to fix with soluble Al and Fe
- Easy to fix at acid pH values
- Easy to fix with Fe and Al oxides

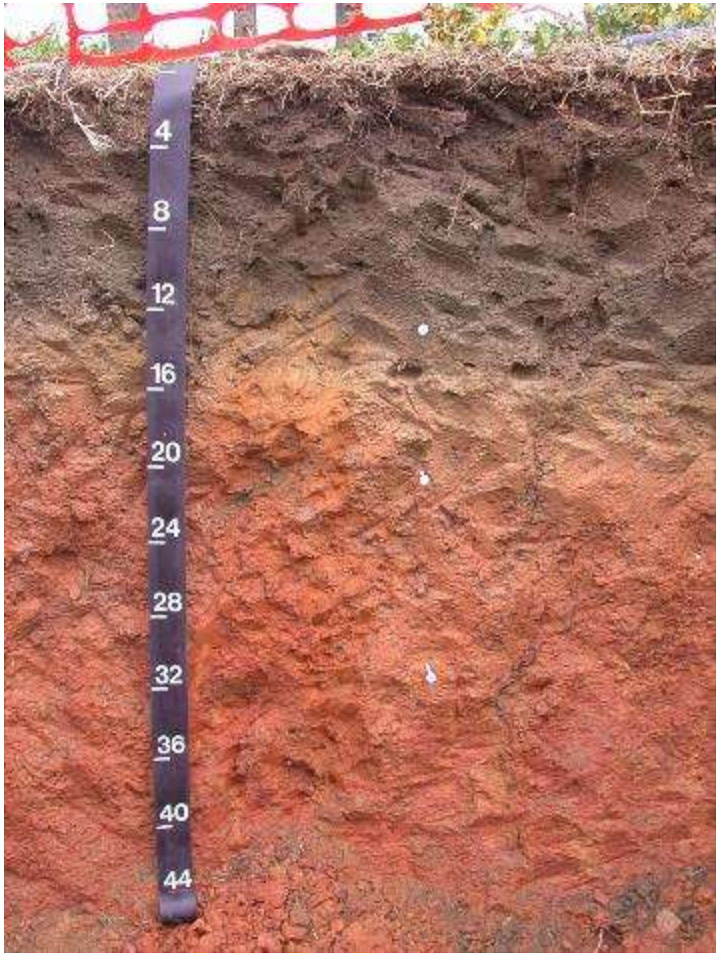
Phosphorus Cycle in Soils

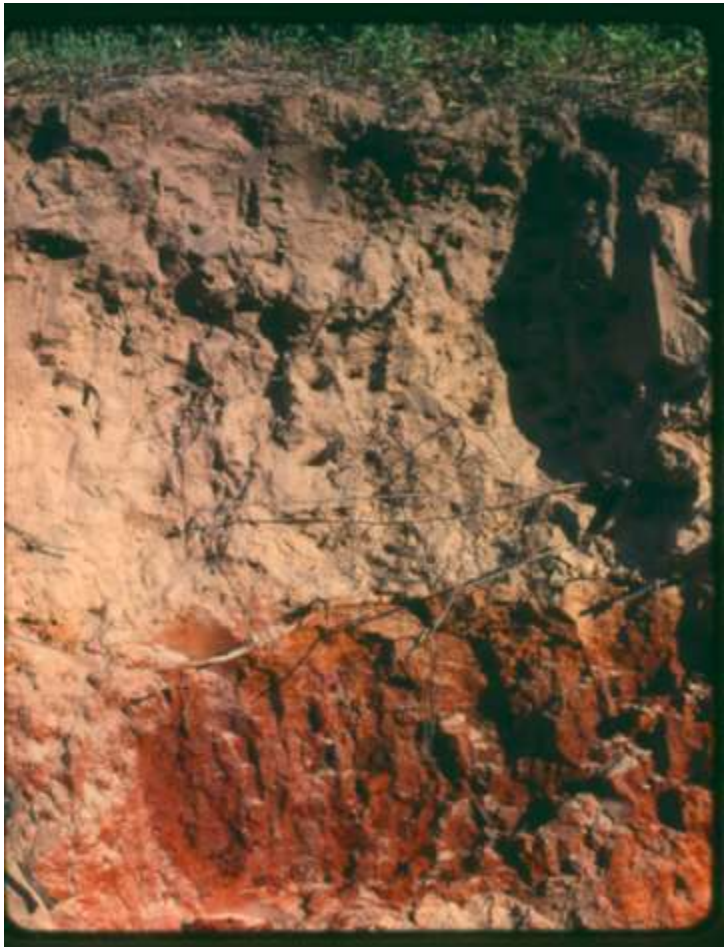


Phosphorus Cycle in Soils



Well drained, clayey soils with large amounts of Fe and Al Oxides: Good P fixation potential

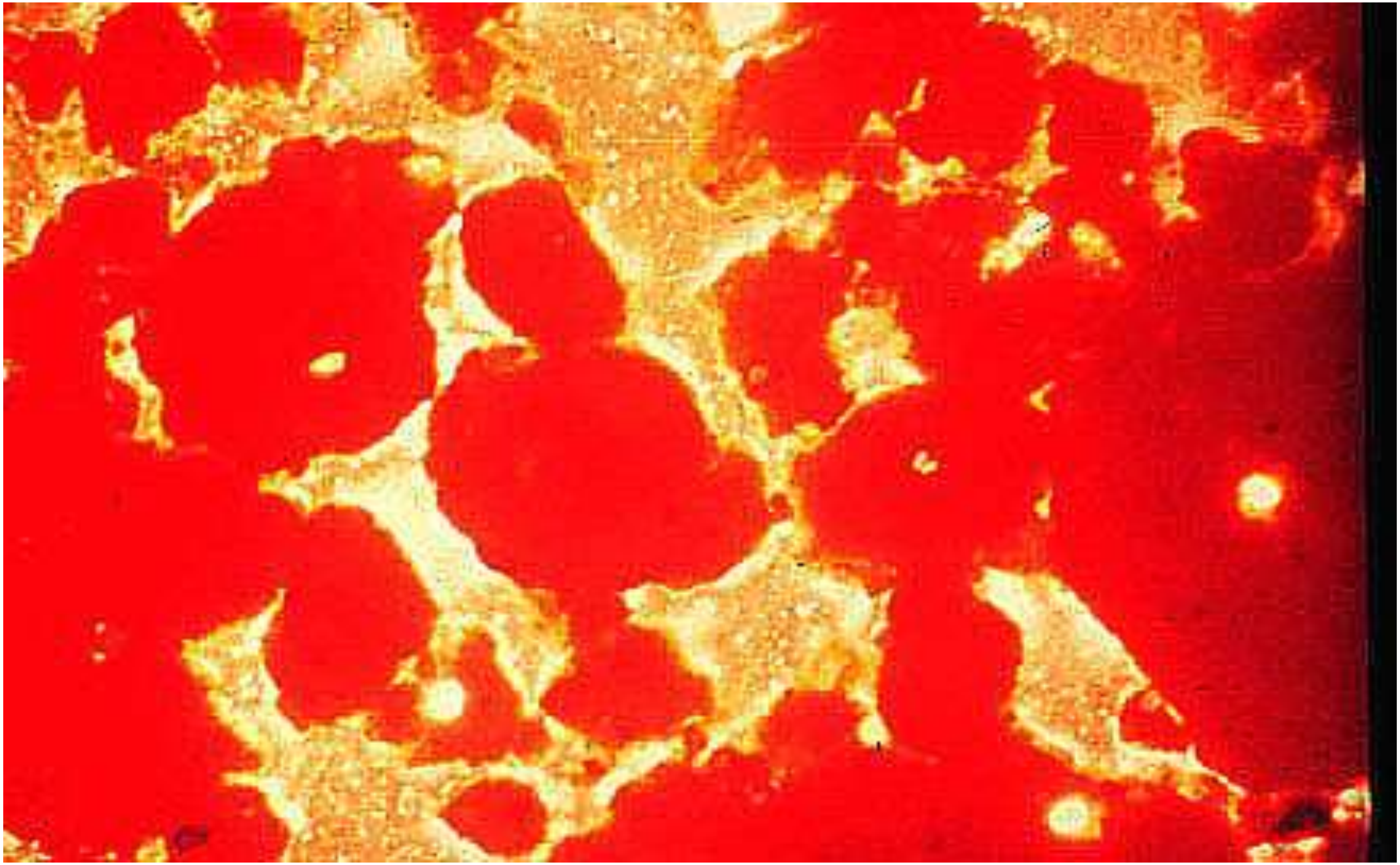


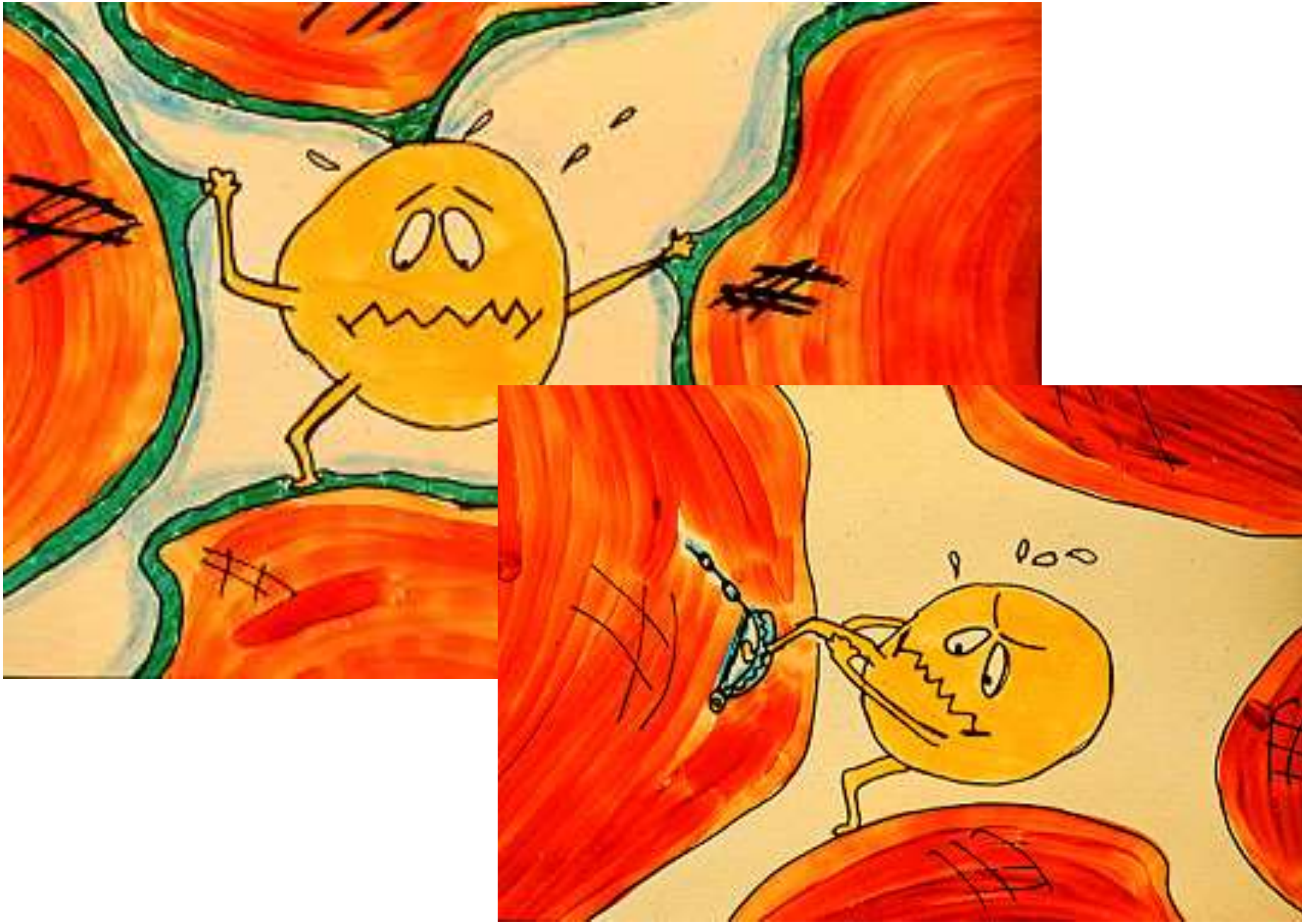


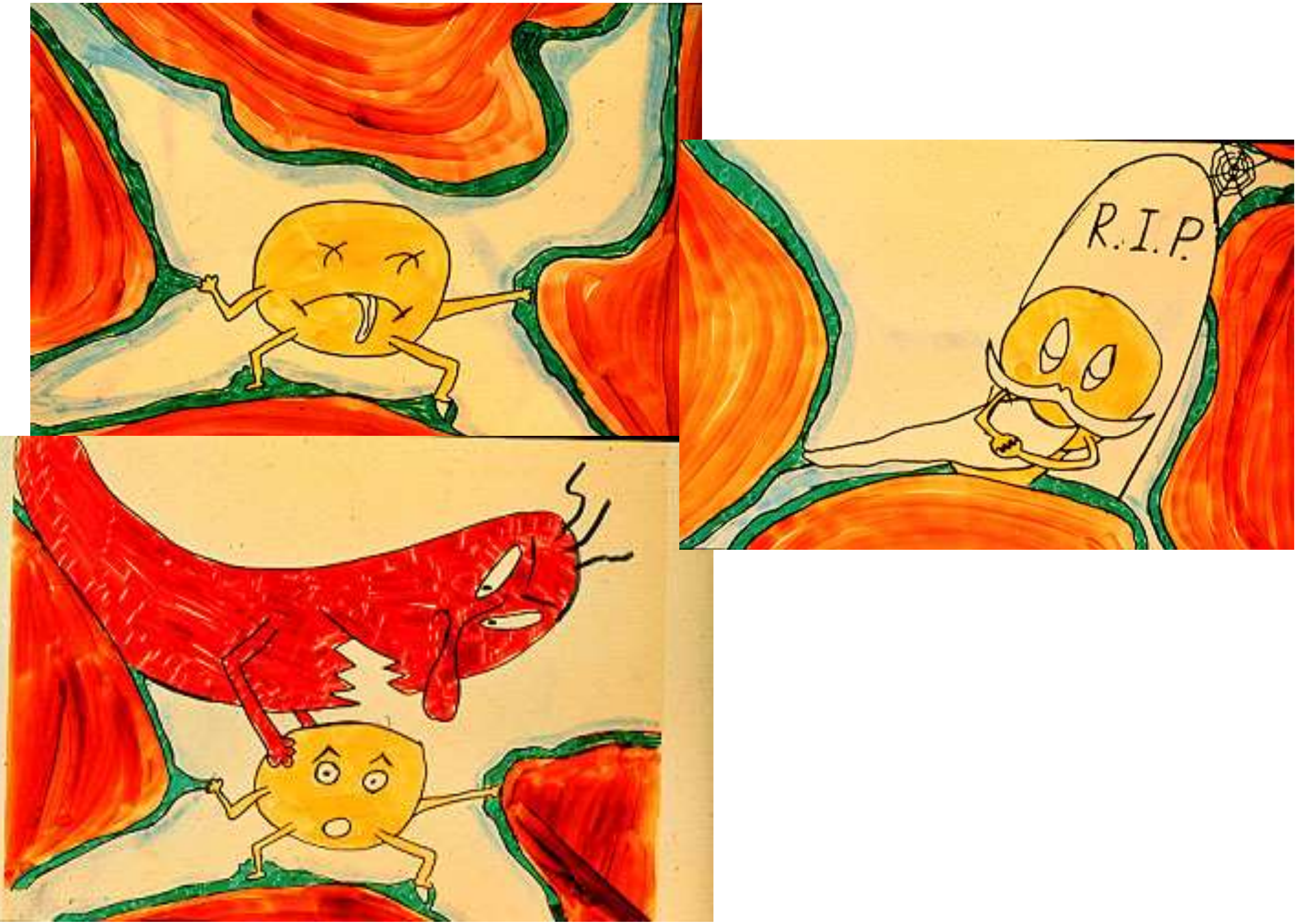
Course Textured Soils: Small P Fixation Potential

How do pathogens get Treated?

- They are attached to the soil particles
- They die from the environment
- They are attacked by soil organisms
- Given time the soil is a very effective treatment media






R.I.P.

How do nutrients get treated?

- Nutrient of concern N & P
- N - groundwater trouble
- P - Surface water trouble
- P complexes with other minerals in the soil and is tied up
- N is transformed & moves with the water unless additional steps are taken

Surfacewater-Groundwater

Soil is a very effective treatment media & treatment is the name of the GAME

Treatment Challenges

- Shallow bedrock
- High watertable
- Slowly permeable soils
- Rapidly permeable soils
- Fill soils

Aerobic zone = Unsaturated flow