Texas On-Site Wastewater Treatment Research Council
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The Soil as a Unit Process

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The Soil as a Unit Process

- Ultimate goal
  - To convert wastewater to water
- Intermediate goal
  - To protect environmental and public health
  - Which is accomplished by putting septic tank effluent into the soil
    - Is it disposal
    - Or is it dispersal

What's Wrong with this Technology?

We Add a lot of Water to our Wastes

- If you take out the water used to transport human wastes
  - you will have greater than 95% less mass to deal with
- Water that comes in contact with human or animal wastes becomes wastewater
  - must be treated as wastewater

Unfortunately, Water Transports Wastes Well

- The Romans taught us the benefit of running water
  - They brought water into their cities for
    - drinking
    - hygiene
    - waste removal
  - This allowed cities to grow bigger
    - the people lived longer
    - had more children that survived

So, What Happens to all this Wastewater?

- 75% of the U.S. population is serviced by a sanitary sewer system
  - treated at a centralized WWTP
  - discharged into a surface water body
- 25% use onsite systems
  - some treatment in septic tank
  - most of the treatment is in the soil
  - discharged to the subsurface

And, thus…

- We use the soil to finish getting the wastes out of wastewater
  - we depend on the soil to function as a wastewater treatment plant
    - and most soils are up to the task

In Reality,

- We build WWTP
  - to function like the soil
  - the soil is the original wastewater treatment device
  - the same microorganisms doing the same job

Wastewater Defined

- Wastewater is water that has been used to collect and transport waste
  - Water that has "stuff"*
    - suspended
    - dissolved
    - floating
    - sinking

* "stuff" is a more polite "s" word

So, When using the Soil for Wastewater Treatment

- We have to:
  - Understand the stuff in the wastewater
    - let's call it wastewater strength
  - Understand how much wastewater we are working with
    - wastewater volume
  - Understand how wastes are removed from water
    - wastewater treatment

We Need this Information

- So that we can design a soil-based wastewater renovation system
  - than can remove the wastes from water

Question

- What if your wastewater source was not residential
  - will you get the same quality of effluent?
  - answer - **Not Likely**
- What comes out depends on what went in
  - higher strength influent will product higher strength effluent
  - effluent may require more pretreatment before application to the soil.

Wastewater Sources

- Residential
  - single family homes
  - apartments
  - subdivisions
- Commercial
  - restaurants
  - fuel stations
  - bakeries
  - schools and day care

- These are the most common wastewater sources outside of sewage service areas
  - onsite (or near site) wastewater renovation is the most efficient and economical means of managing the source water

Wastewater Strength

- Typical wastewater constituents
  - Solids
  - Suspended and dissolved organic matter
  - Pathogens
  - Nutrients
  - Personal care products and pharmaceuticals

Wastewater Strength

- Solids
  - Organic and inorganic
    - Fecal solids
    - personal hygiene items
  - Floaters and sinkers
    - fats, oils and grease (FOG)
  - Suspended and dissolved
    - dissolved minerals from source water
    - toilet paper

Wastewater Strength

- Suspended and dissolved organic matter
  - The stuff that bacteria, fungi, and other microbes can breakdown
    - some organic matter is very difficult to breakdown – recalcitrant
    - microbes produce enzymes that breakdown organic matter into bio-available forms
  - One measure of bio-availability is BOD_5
    - Biochemical Oxygen Demand in Five Days
    - aerobic microbes consume dissolved oxygen out of water

Wastewater Strength

- Pathogens
  - Disease causing microorganisms
    - a disease-carrying person sheds pathogens into the wastewater
    - our goal is to minimize the risk of that disease being transmitted
  - Indicators of the potential for pathogens
    - fecal coliforms and *E. coli*
    - found in digestive track of all warm-blooded animals
    - *E. coli O157:H7* is a true pathogen

Wastewater Strength

- Nutrients
  - Chemicals required for growth, when available in excess, too much growth can occur
  - Nitrogen compounds
    - ammonia
    - nitrate
  - Phosphorus

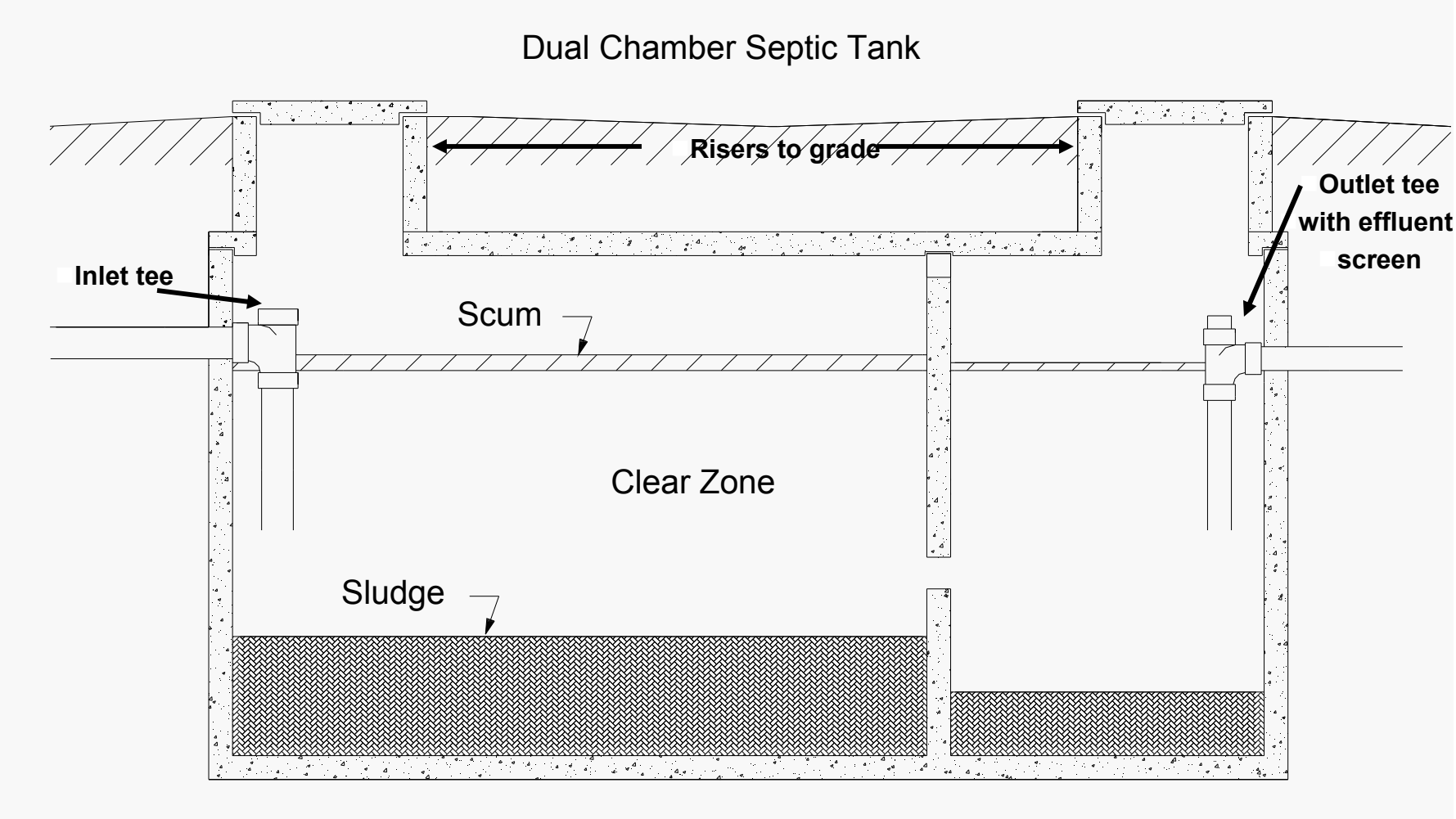
Other Wastewater Sources will have Other Strengths

- Restaurants
  - More FOG
  - Higher temperatures
  - Sanitizers
- Schools
  - Higher nitrogen
  - More trash
- Laundry
  - Lints and detergents

Liquid-Solid Separation

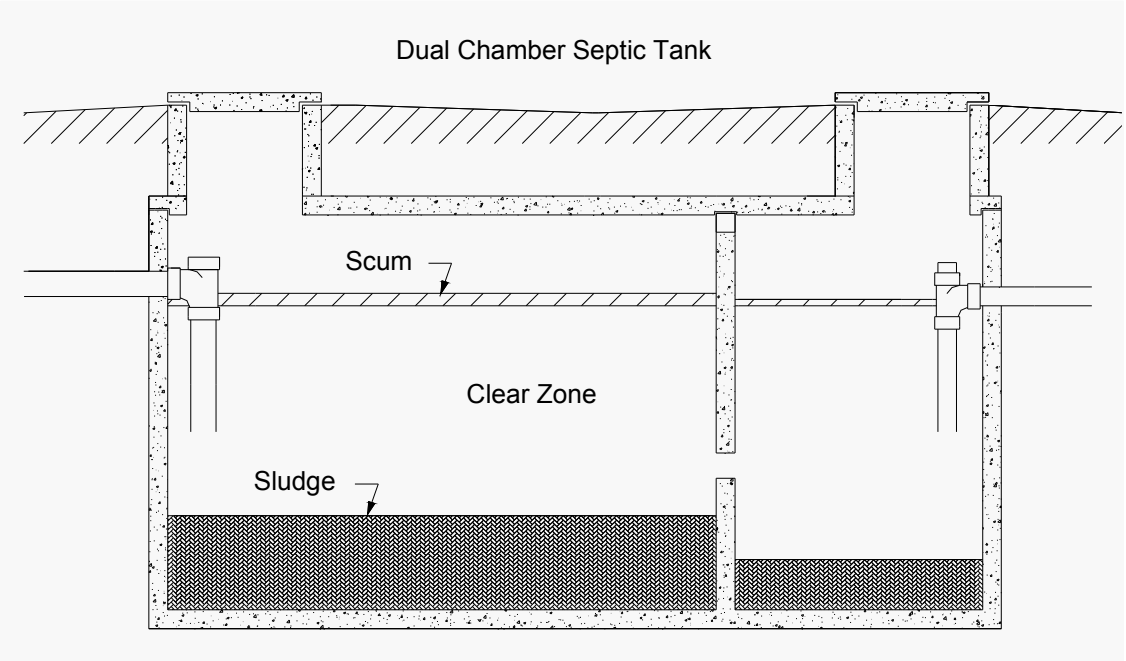
- Primary Treatment
  - Septic tanks
  - Designed to
    - skim off floating material
    - retain sinking material
    - provide a minimum amount of anaerobic digestion
    - have two or three design-flow days volume
    - dampen inflow rate

Typical Cross Section



Goal is Near Zero Velocity in Tank for Optimum Solids Removal

- Maximize distance between inlet and outlet
- Length:Width ratio
  - at least 3:1
- Inlet to outlet drop
  - ~ 2”



Septic Tank Effluent

- Discharge from septic tank
  - Much stuff has been removed from the water
    - still have more to remove
  - Much of the solids have been removed
    - we do not want solids carry-over into the drainfield
    - this material will have to be pumped out of tank
  - Some pathogen reduction
    - cooler temperature than human body
    - different oxygen states
  - Not much conversion of nutrients

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

Case Study:

Septic Tank Effluent and Soil Water Quality

Parameter (units)	Statistics	Septic Tank Effluent Quality	Soil Water Quality at 0.6 m	Soil Water Quality at 1.2 m
BOD (mg/L)	Mean Range #samples	93.5 46 -156 11	<1 <1 6	<1 <1 6
TOC (mg/L)	Mean Range #samples	47.4 31 – 68 11	7.8 3.7 – 17.0 34	8.0 3.1 – 25.0 33
TKN (mg/L)	Mean Range #samples	44.2 19 – 53 11	0.77 0.4 – 1.40 35	0.77 0.25 – 2.10
NO_3-N (mg/L)	Mean Range #samples	0.04 0.01 – 0.16 11	21.6 1.7 – 39.0 35	13.0 2.0 – 29.0 32
TP (mg/L)	Mean Range #samples	8.6 7.2 – 17.0 11	0.40 0.01 – 3.8 35	0.18 0.02 – 1.80 33

Case Study:

Septic Tank Effluent and Soil Water Quality

TDS (mg/L)	**Mean Range #samples**	**497 354 – 610 11**	**448 184 – 620 34**	**355 200 – 592 32**
Cl (mg/L)	**Mean Range #samples**	**70 37 – 110 11**	**41 9 – 65 34**	**29 9 – 49 31**
F. Coli (log # per 100 mL)	**Mean Range #samples**	**4.57 3.6 – 5.5 11**	**nd[c] <1 24**	**nd <1 21**
F. strep. (log # per 100 mL)	**Mean Range #samples**	**3.60 1.9 – 5.3 11**	**nd <1 23**	**nd <1 20**

[a]The soil matrix consisted of a fine sand; the wastewater loading rate was 3.1 cm per day over 9 months. TOC = Total organic carbon; TKN = Total Kjeldahl nitrogen; TDS = Total dissolved solids; Cl = Chlorides; F. Coli = Fecal Coliform; F. strep = Fecal Streptococci

[b]Soil water quality measured in pan lysimeters at unsaturated soil depths of 2 feet (0.6 meters) and 4 feet (1.2 meters)

[c]nd = none detected

Source: Adapted from Anderson, 1994

When the Effluent is too Strong for the Soil System

- Additional treatment options
  - Larger primary tanks
    - more separation and more anaerobic digestion
  - Grease traps
    - Cool and separate FOG before mixing with black water
  - Aerobic treatment
    - More BOD_5 removal and nitrogen conversion
      - aerobic treatment units
      - packed-bed media filters

The Soil as Final Treatment

- Soil is a tremendous wastewater treatment media
  - Biological properties
  - Chemical properties
  - Physical properties
- However, the soil has its limits
  - Pretreatment must bring the strength down to a level the soil can assimilate

What is Soil?

- Particles
  - Minerals, Nutrients & Organic Matter
- Pores
  - Air & Water
- Particle surface area
- Soil organisms
  - Single cell
  - Multi-cellular
  - Insects
  - Small animals

It's not dirt unless it's

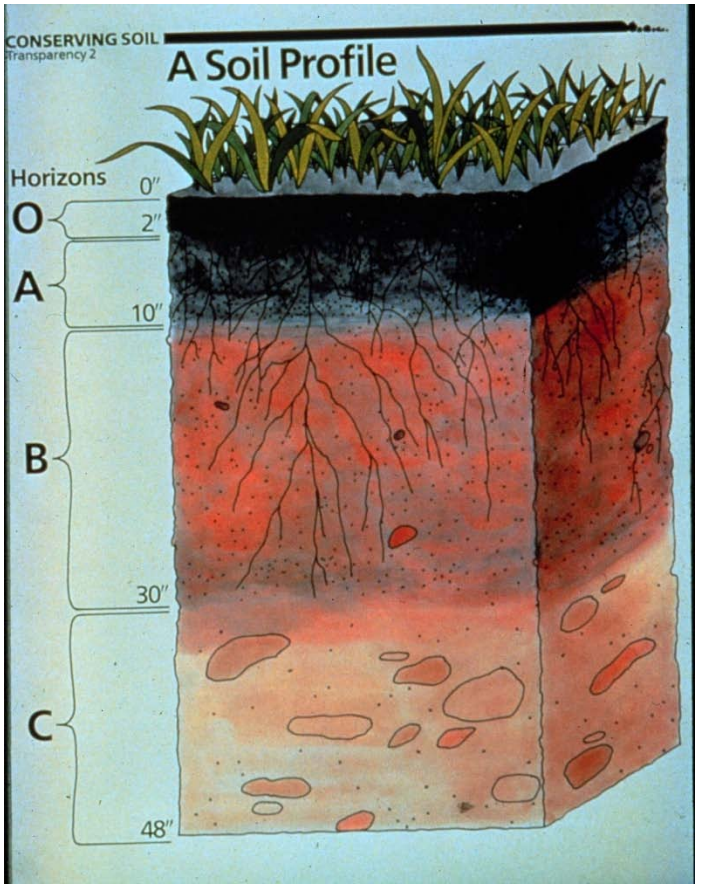
under your fingernails

Soil Properties that Influence Wastewater Treatment

- Wetness conditions
- Water movement
- Gas movement
- Restrictive zones or horizons
- Landscape

Soil Terms

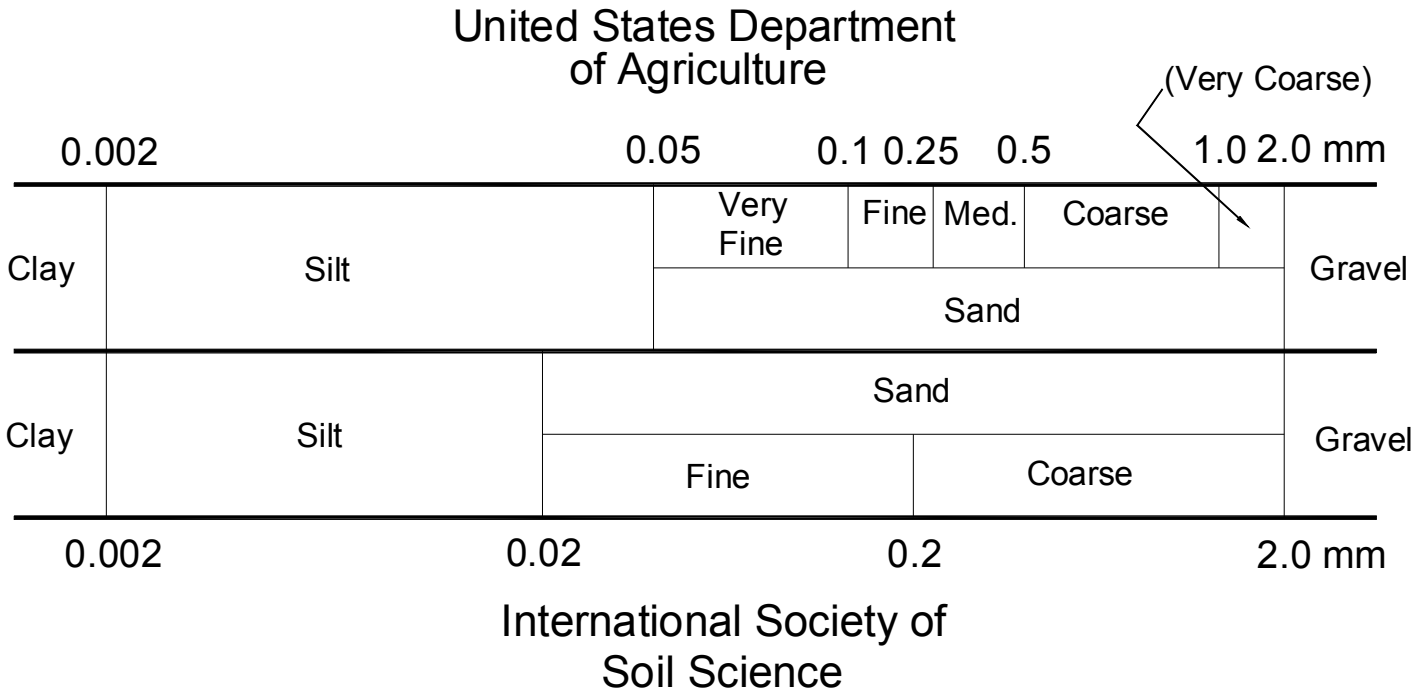
- Soil Horizon
  - Layers
  - Texture, Structure, Color
- Soil Profile
  - Groups of Horizons
  - Soil type



Characteristics of Soils

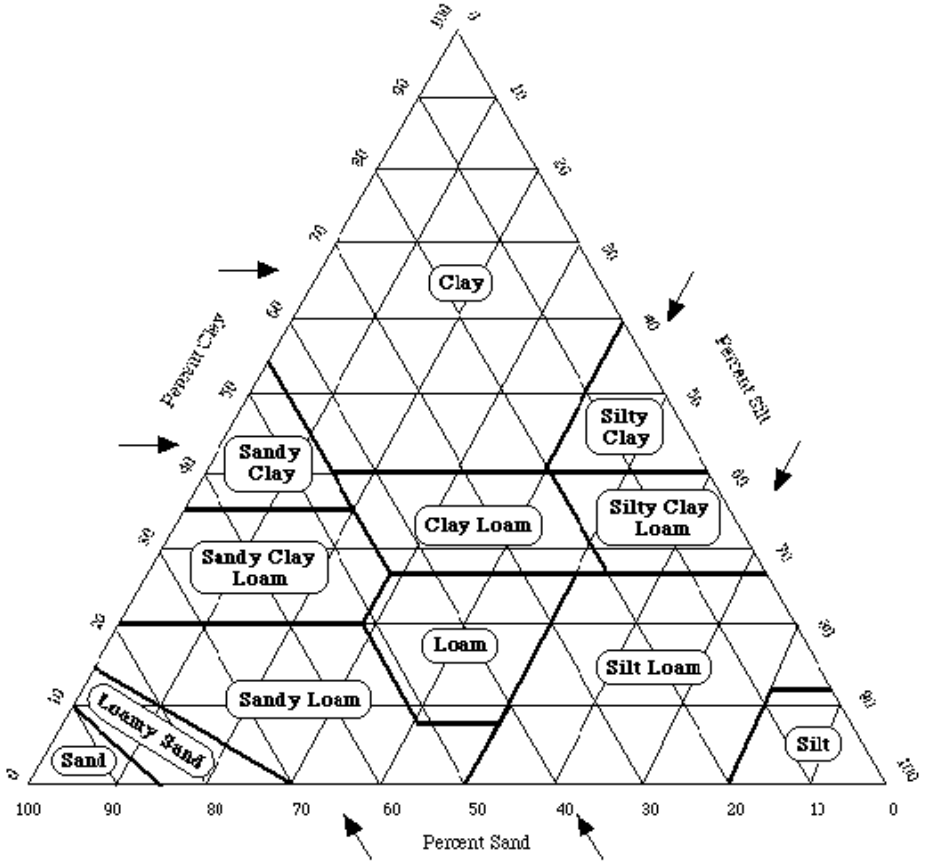
- Texture
  - Distribution of sand, silt and clay particles
    - relative percentages of sand, silt, and clay

Textural Classification



Textural Triangle

- Graphical Method
  - % sand entered on bottom parallel to silt axis
  - % clay entered on left side and is parallel to sand axis
  - % silt entered on right side and is parallel to clay axis



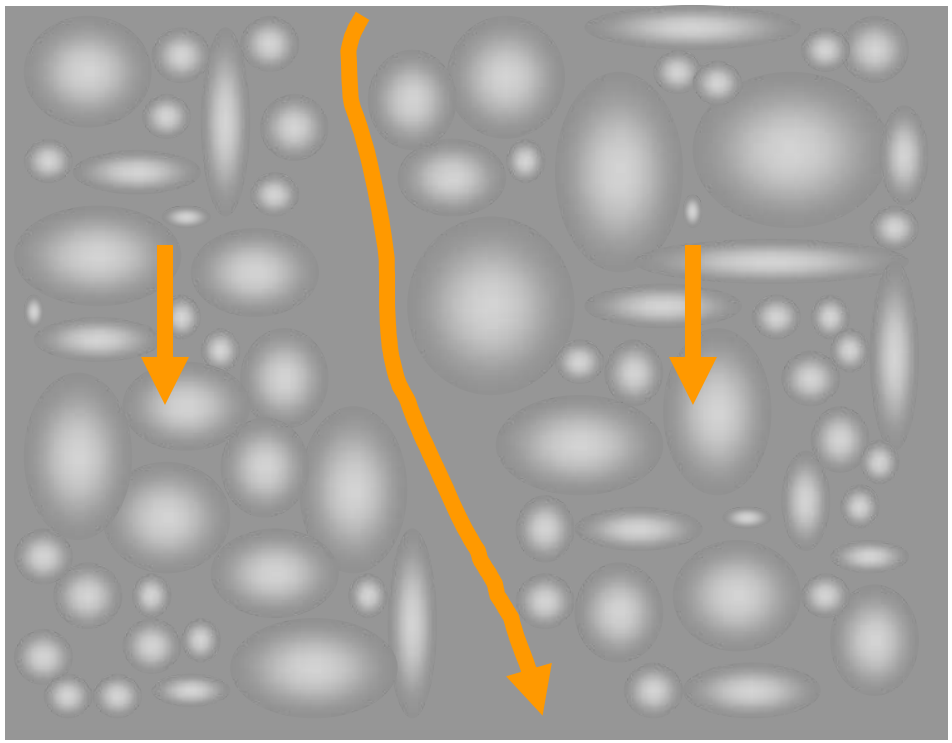
Natural Soil Structure

- Description of how soil particles are aggregated or clustered
  - Granular
  - Angular Blocky
  - Subangular Blocky
  - Platy
  - Wedge
  - Prismatic
  - Columnar

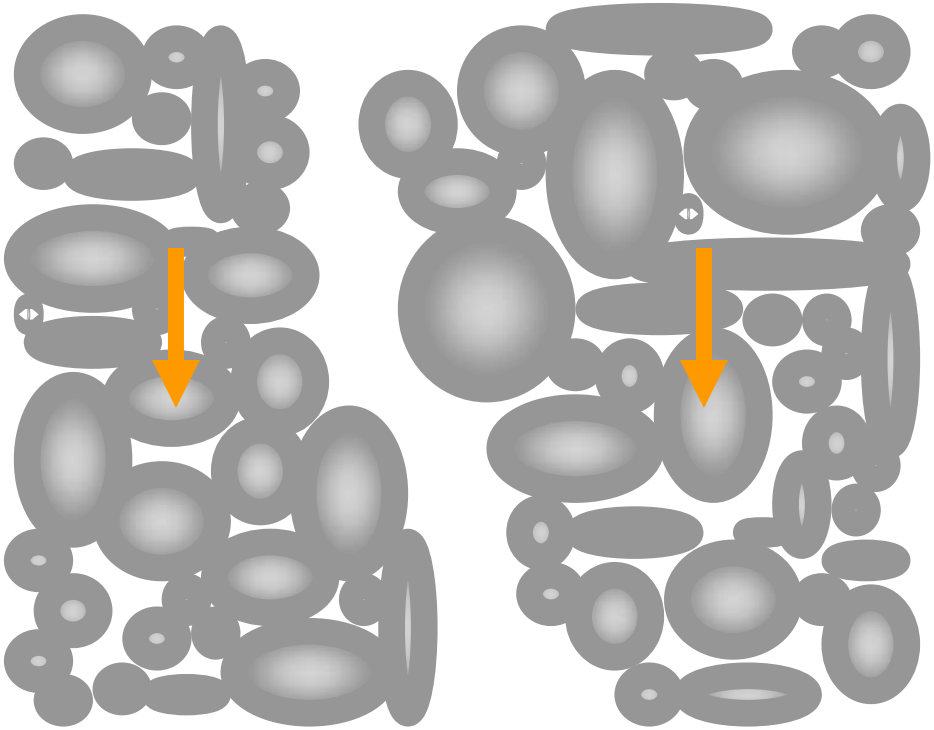
What does Texture and Structure have to do with Wastewater Renovation?

- Texture is related to micropore flow
  - Small pores
  - Exposes wastewater to more soil-particle surface area
  - Attachments site for chemical and biological reactions
- Structure is related to macropore flow
  - Larger pores
  - Key aspect to moving water through soil

Water & Waste Movement



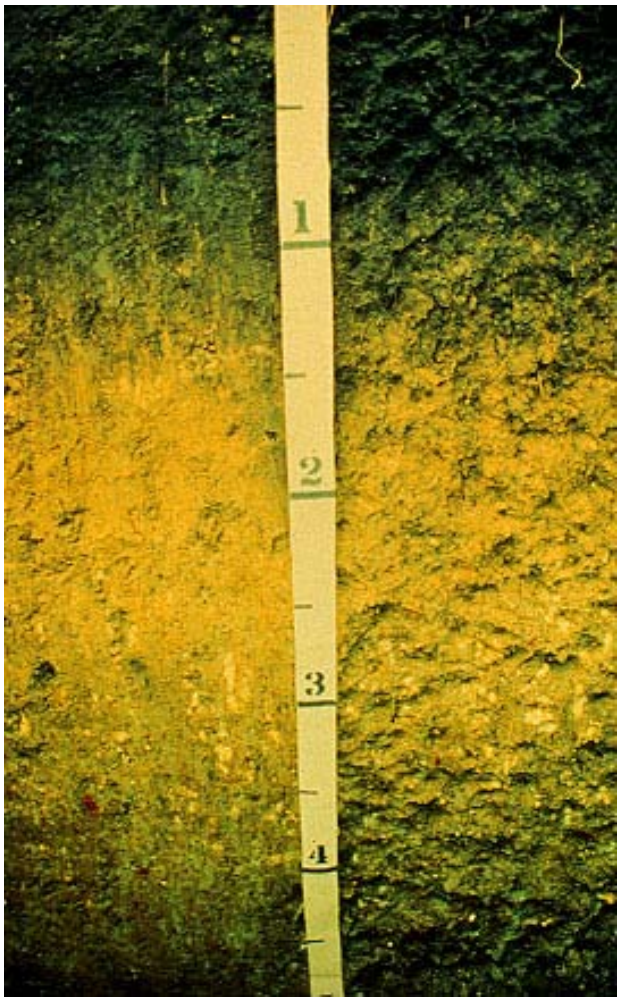
Majority of flow through macropores under saturated conditions



Majority of flow through intrapedal voids under unsaturated conditions

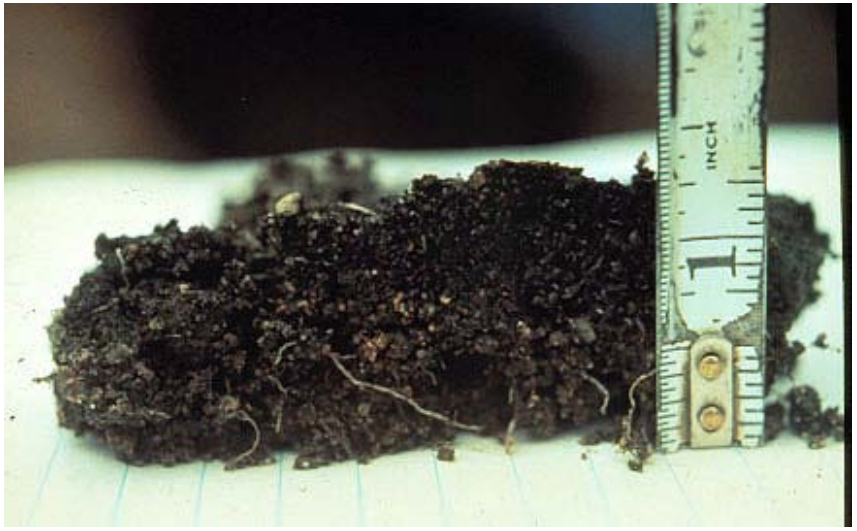
Texture and Treatment

- Surface area for attachment sites
  - 1 lb of sandy soil has 3 acres of surface area
  - 1 lb of loamy soil has 15-acres of surface area



Wastewater, Soils and Conventional Systems

- Biomat forms at soil interface
  - Restricts flow
  - Creating unsaturated flow below infiltrative surface
- This means:
  - More contact with the soil particles
  - Gas exchange can occur with atmosphere
  - Aerobic organisms treat the wastewater



Importance of Soil to Onsite Wastewater Treatment

- Biological treatment
  - Soil-borne microbes use wastewater as food source
  - Predate on microbes in wastewater
- Chemical treatment
  - Reactions bind many constituents to soil particles
- Physical treatment
  - Filter and strain larger wastewater particles in pores
- Dispersal
  - Disperses treated water back into the hydrologic cycle

Limiting Factors

- Permeability
  - if water is applied at a rate greater than it can move through profile, then effluent will pond in the trenches
- Water holding capacity
  - if too more water is added than the soil can hold, then saturated conditions and deep drainage occurs
  - or in sandy soils, the water will move through too quickly

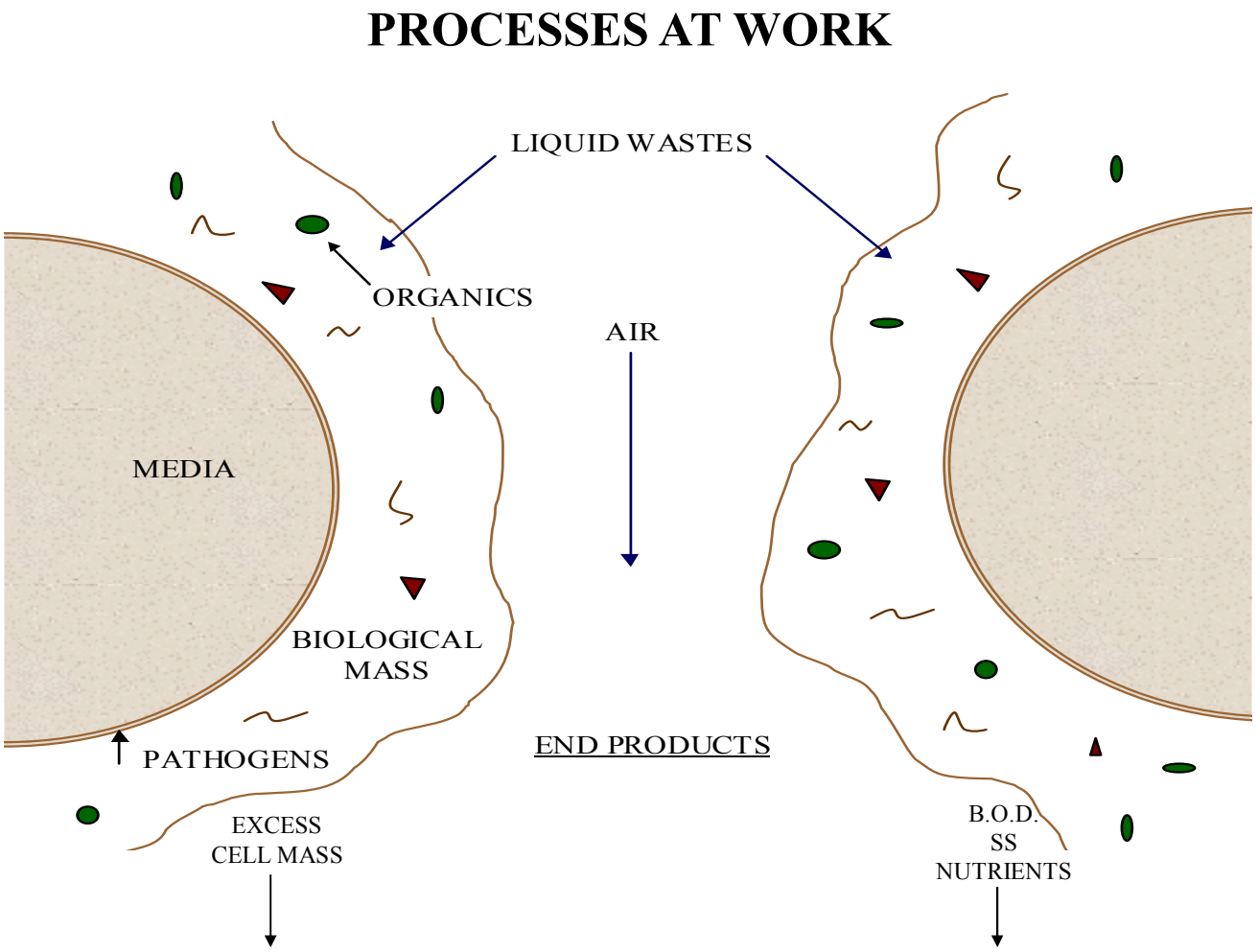
Adding Water to Soil

- Soil particles are wetted
  - particle holds water by surface tension
  - more surface area means more water held
  - small soil particles have more surface area

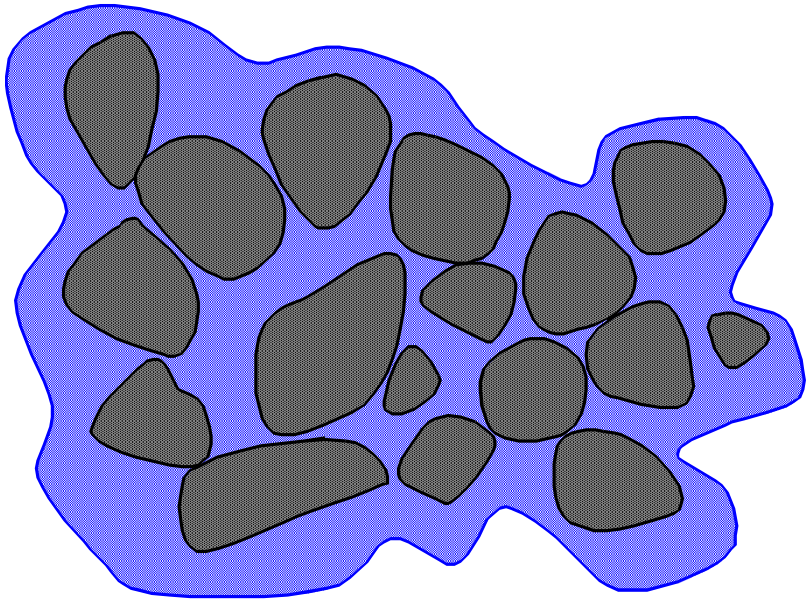
Moisture Holding Capacity

- Water is held by the soil particles
  - Water and soil particles are attracted to each other
  - This layer of water is where the microorganisms that renovate wastewater live and work.

The Soil is a Treatment Media

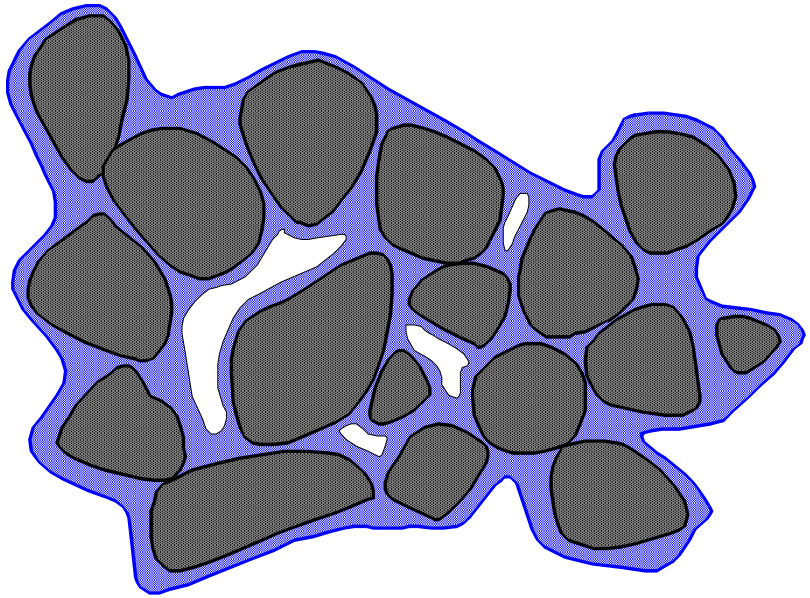


Saturated Media/Soil



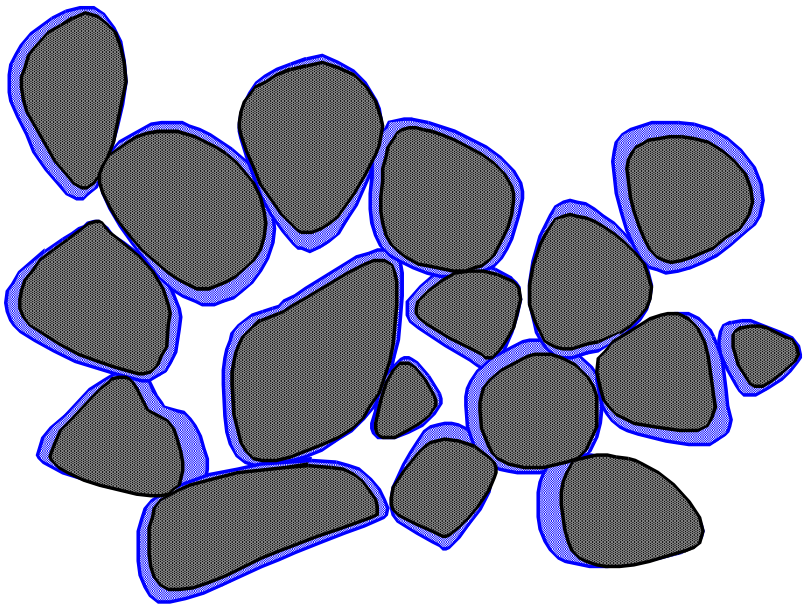
- All the pore space is filled with water
- Very little oxygen is available for microorganisms
- Water will drain by gravity

Field Condition



- The amount of moisture when drainage no longer occurs
- Non-saturated flow
- Aerobic conditions for microorganisms

Wilting Point



- Particles hold moisture with greater tension
- Roots cannot pull moisture from particles
- Wasted opportunity to renovate wastewater

Soil-Water Volume

- Difference between wilting point and field condition
  - is a volume of water that is aerobic and can provide excellent renovation of wastewater

From a Design Perspective

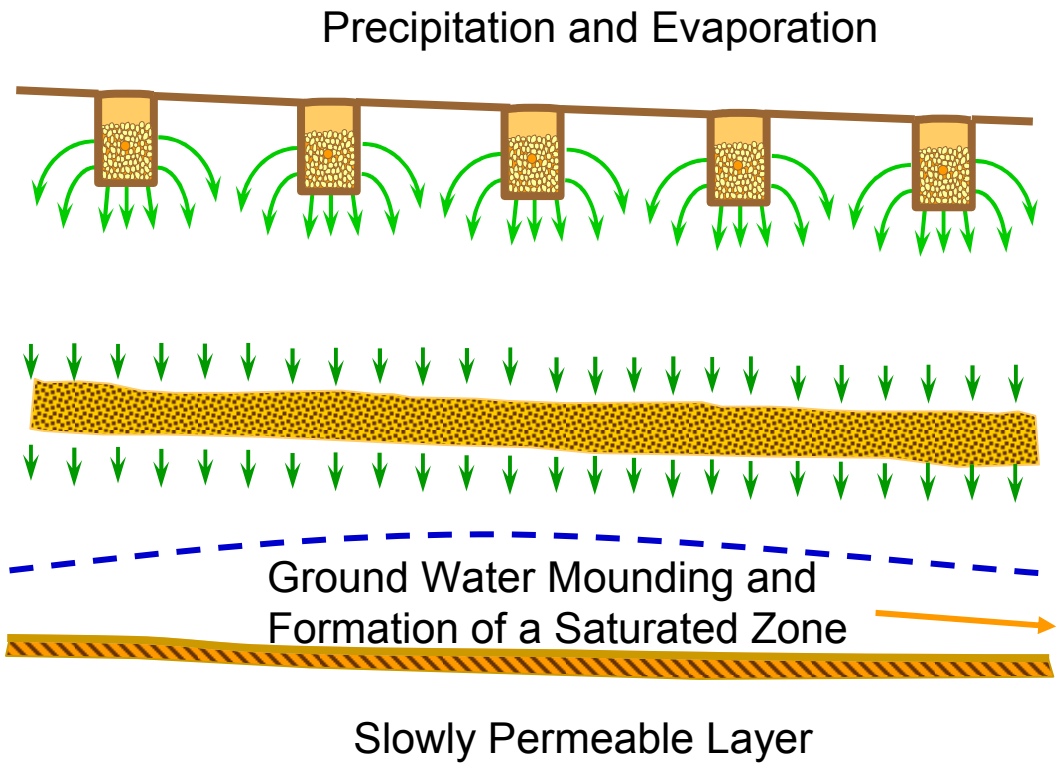
- We have to distribute the effluent to the soil interface such to maximum the soil's ability to renovate wastewater

Hydrology of a Conventional Septic System

Infiltration from Trenches

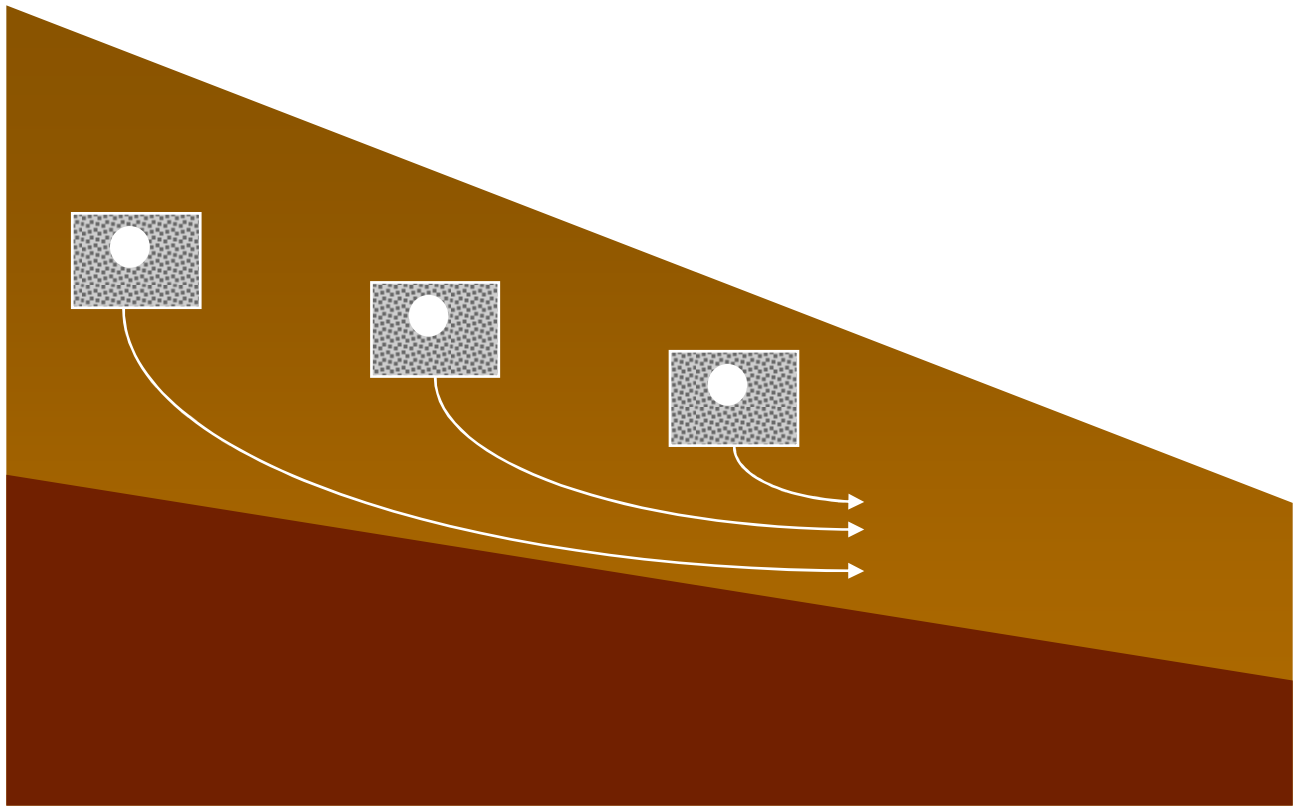
Water is pulled in all directions as soil becomes wetted

Once soil is saturated, predominate direction is by gravity



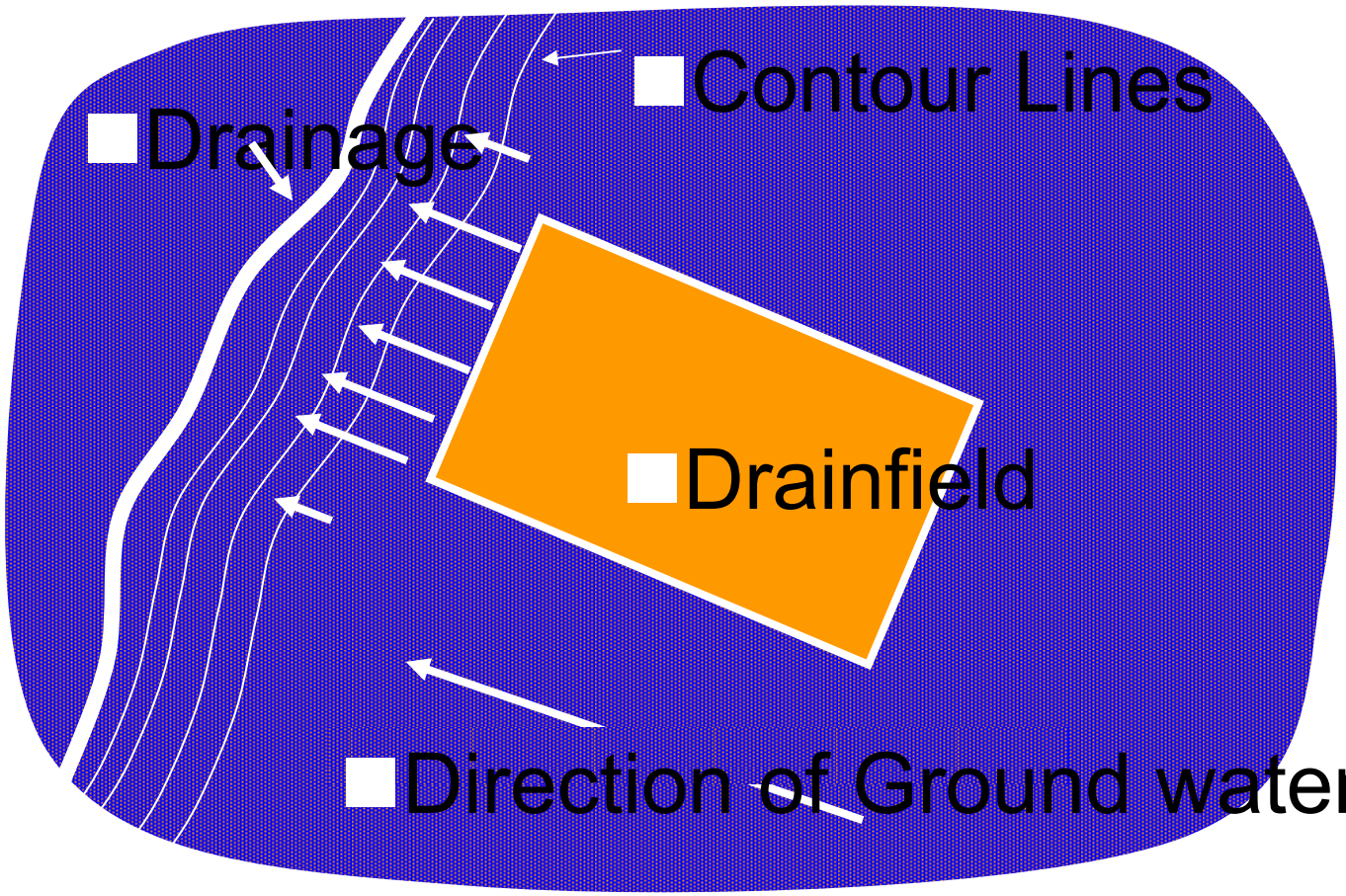
During the Layout

- Consider the Linear Loading
- Water will flow along the restrictive surface
  - Effluent may surface down gradient



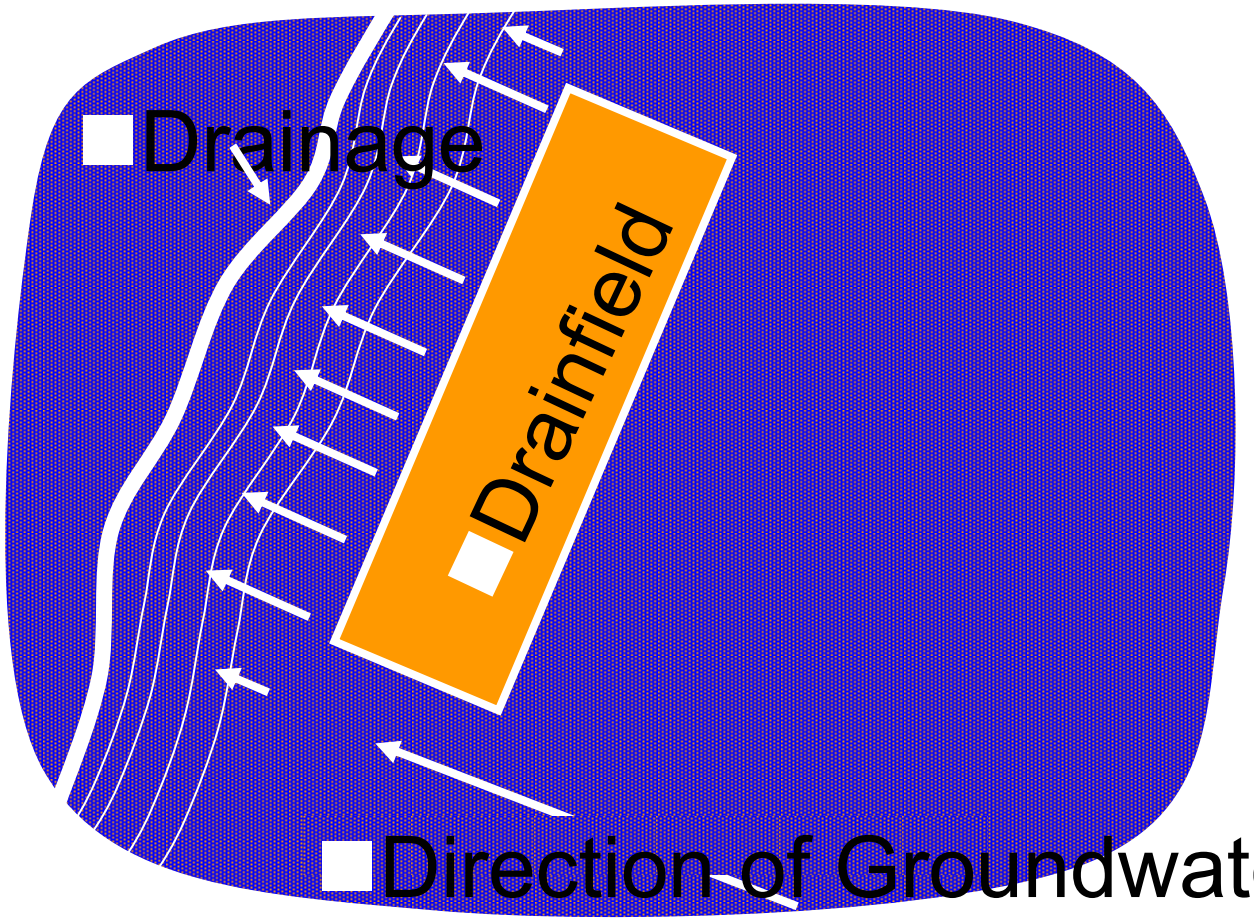
Poor Linear Loading

- Many short trenches on same slope



Longer Linear Loading

- Few long trenches on same slope



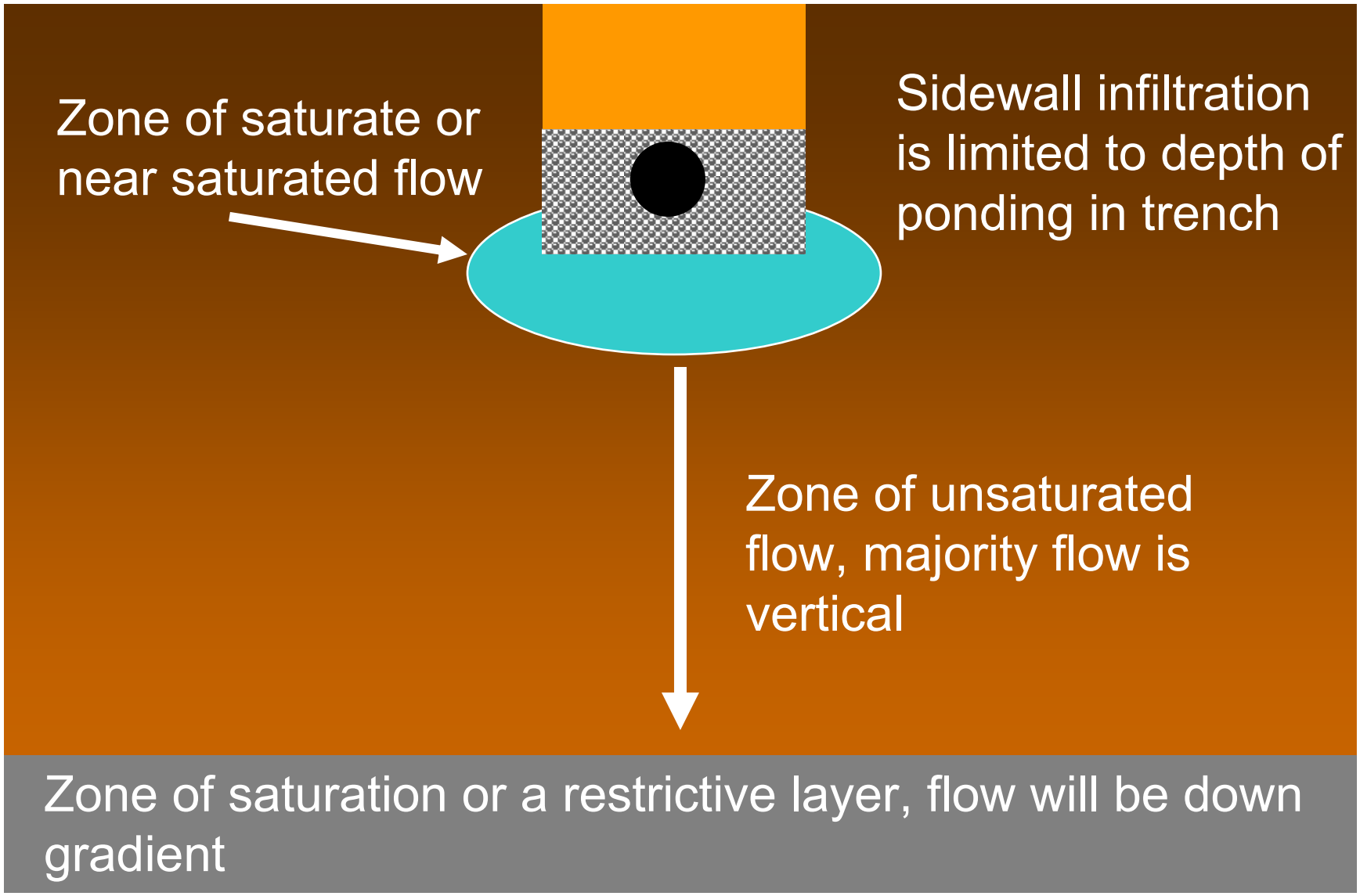
Soil Treatment Area Sizing

- Sewage effluent characteristics
- Soil properties
  - texture
  - structure
  - consistence/mineralogy
- The biomat
- Hydraulic conductivity
- And, of course – the regulations

Soil Absorption Systems

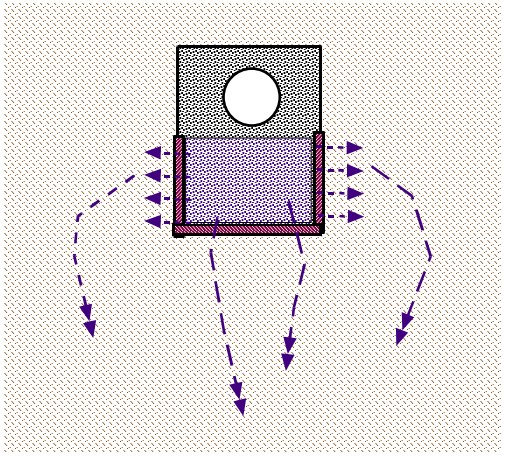
- Where the majority of the wastewater treatment takes place

Flow from the Trench



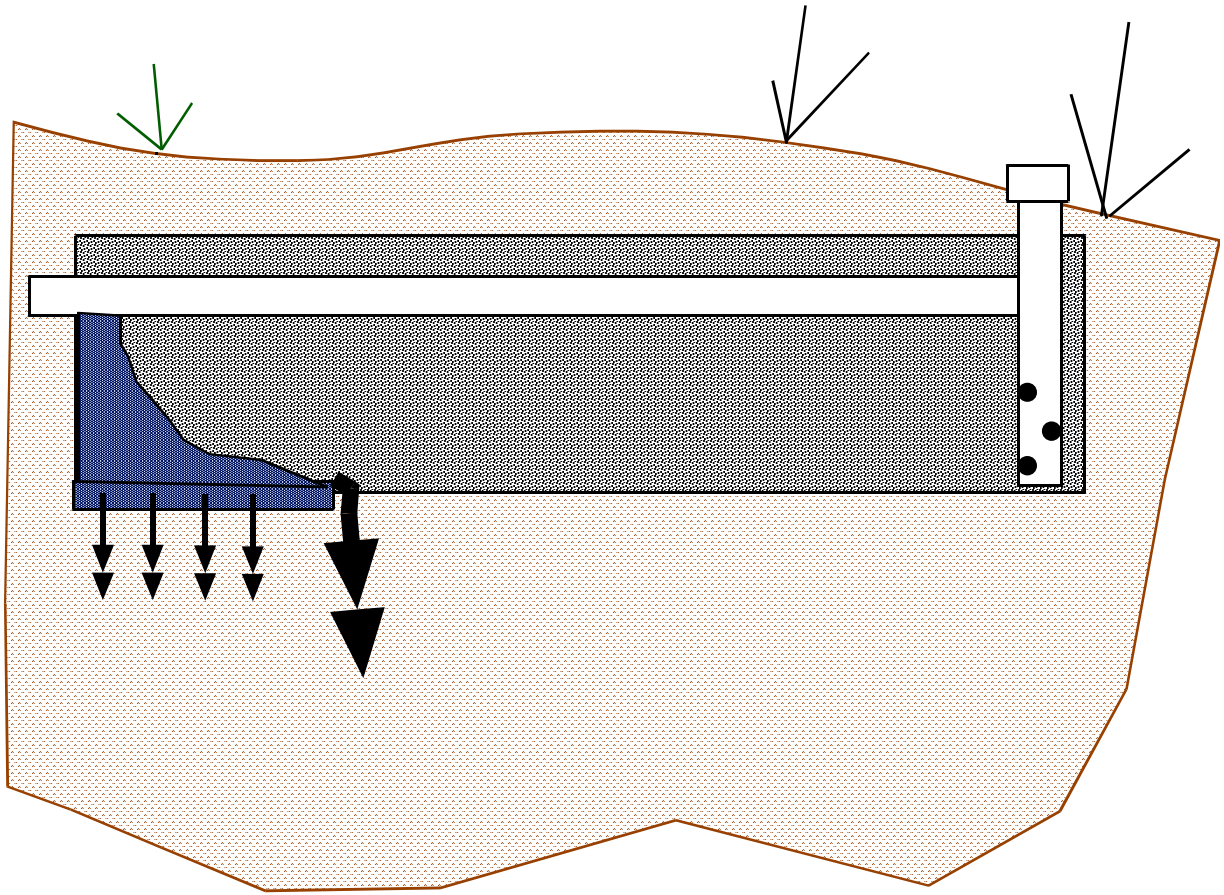
Biomat & Sidewalls

- Biomat develops along the bottom and then around the trench
- Excessive ponding depths may create saturated flow
- Narrower trenches allows more surface area
- Narrower trenches allows better O_2 transfer



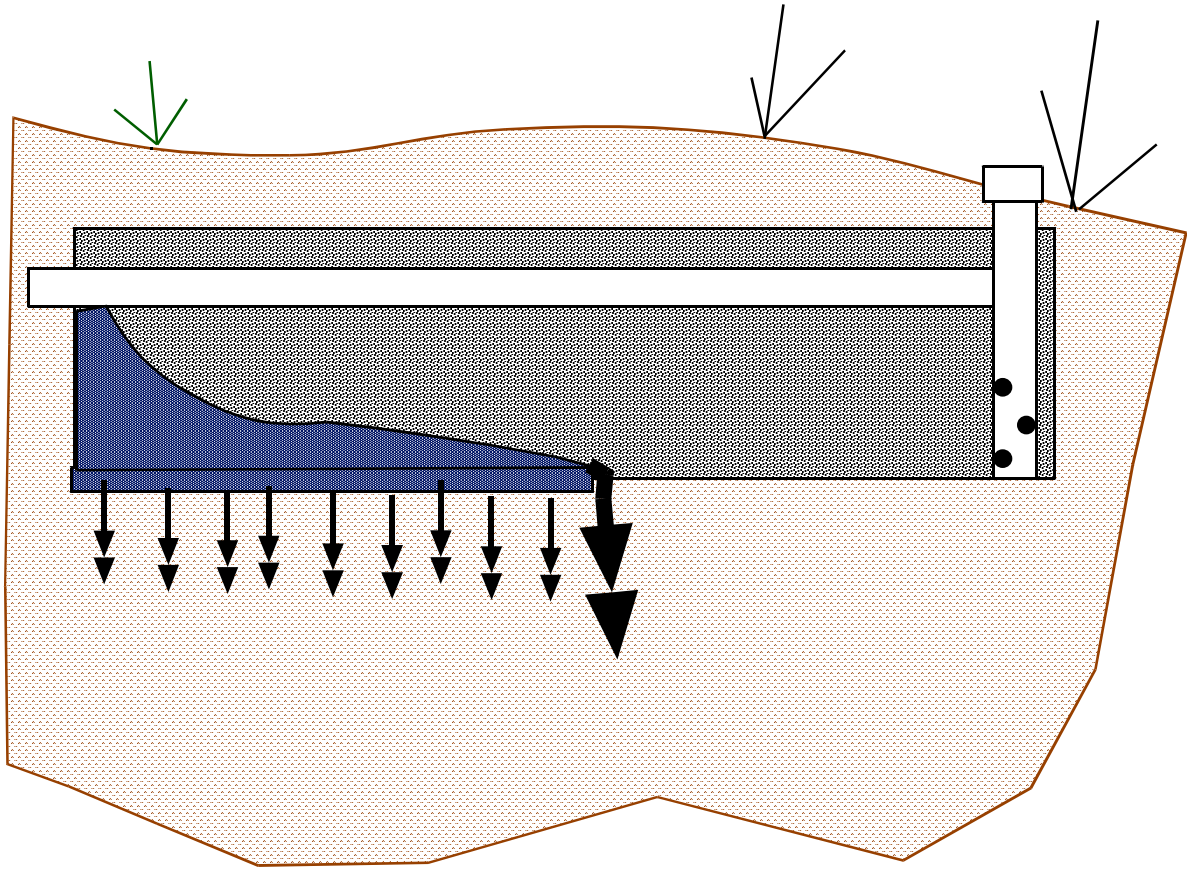
Flow Pattern in a Gravity Trench

- Biomat Growth



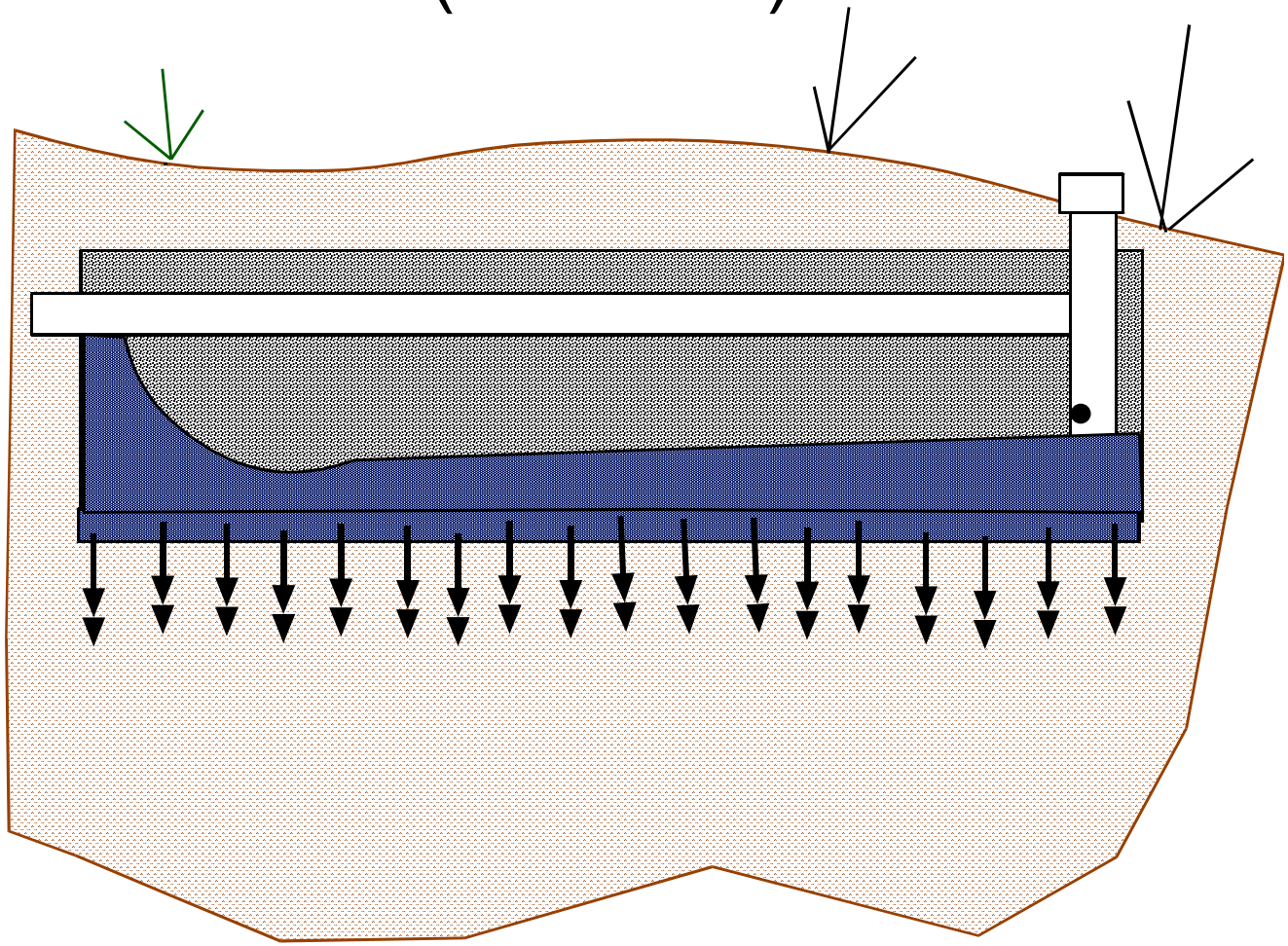
Flow Pattern in a Gravity Trench

- Biomat Growth (t = growth)

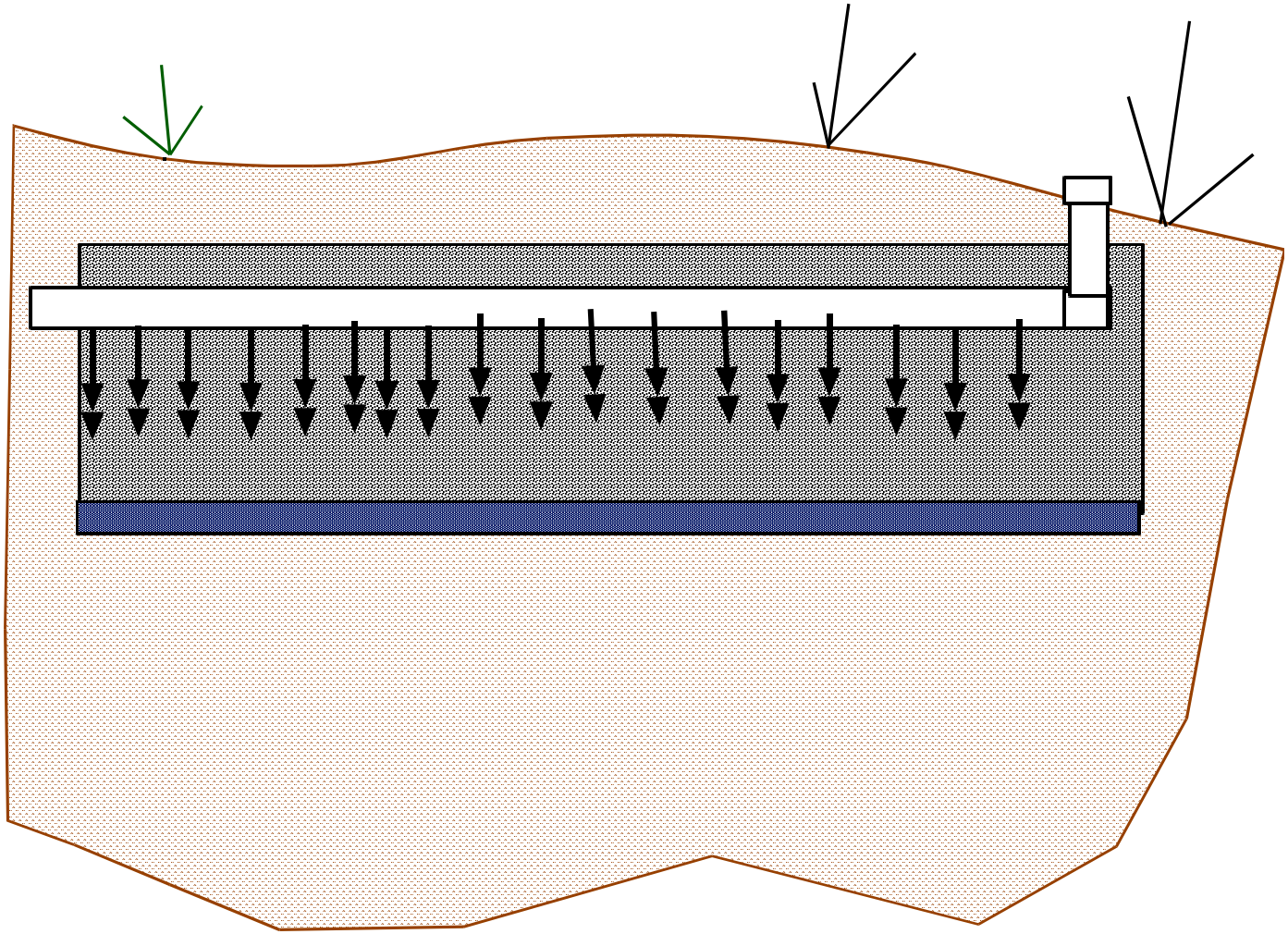


Flow Pattern in a Gravity Trench

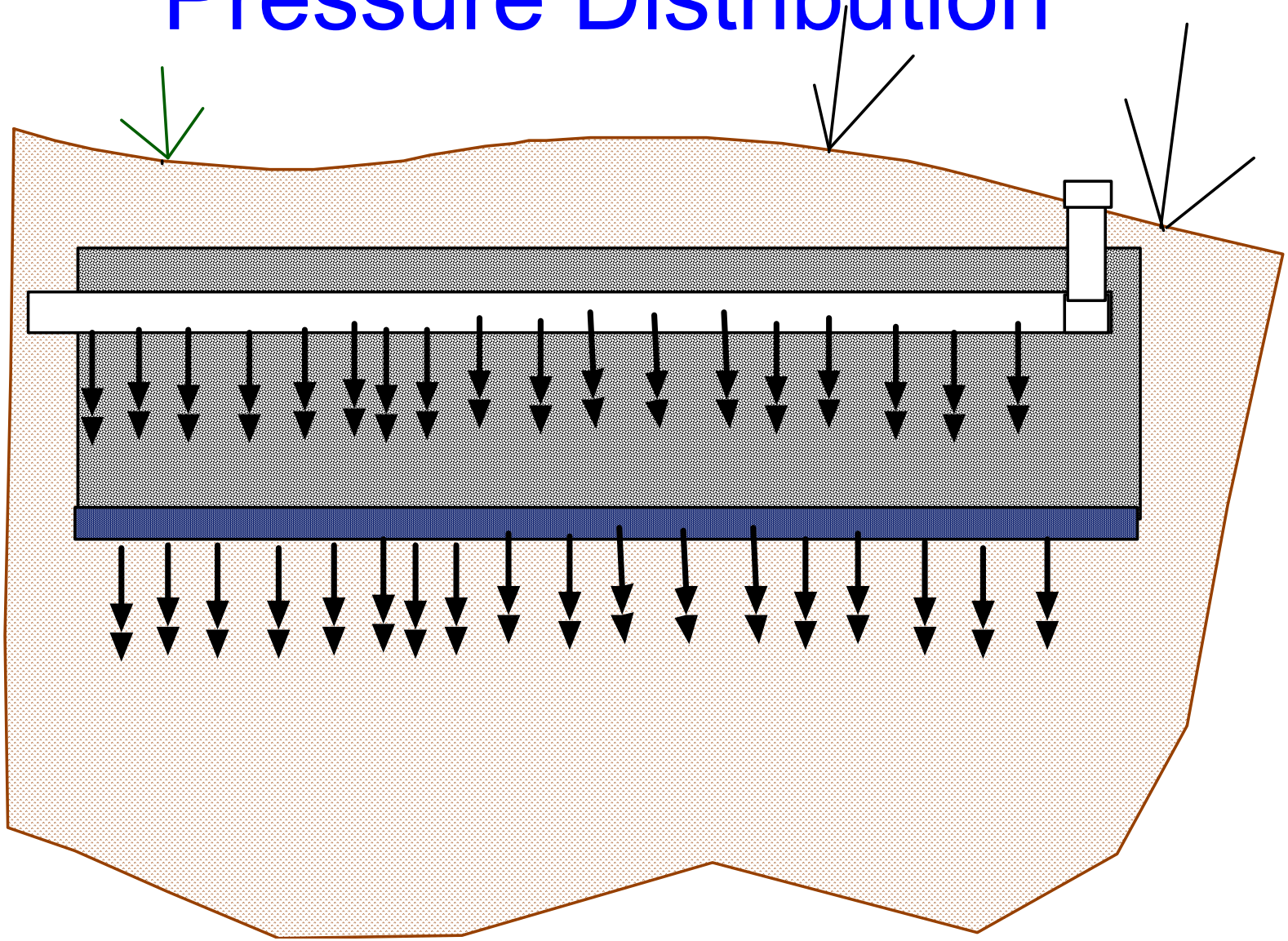
- Biomat Growth (t=mature)



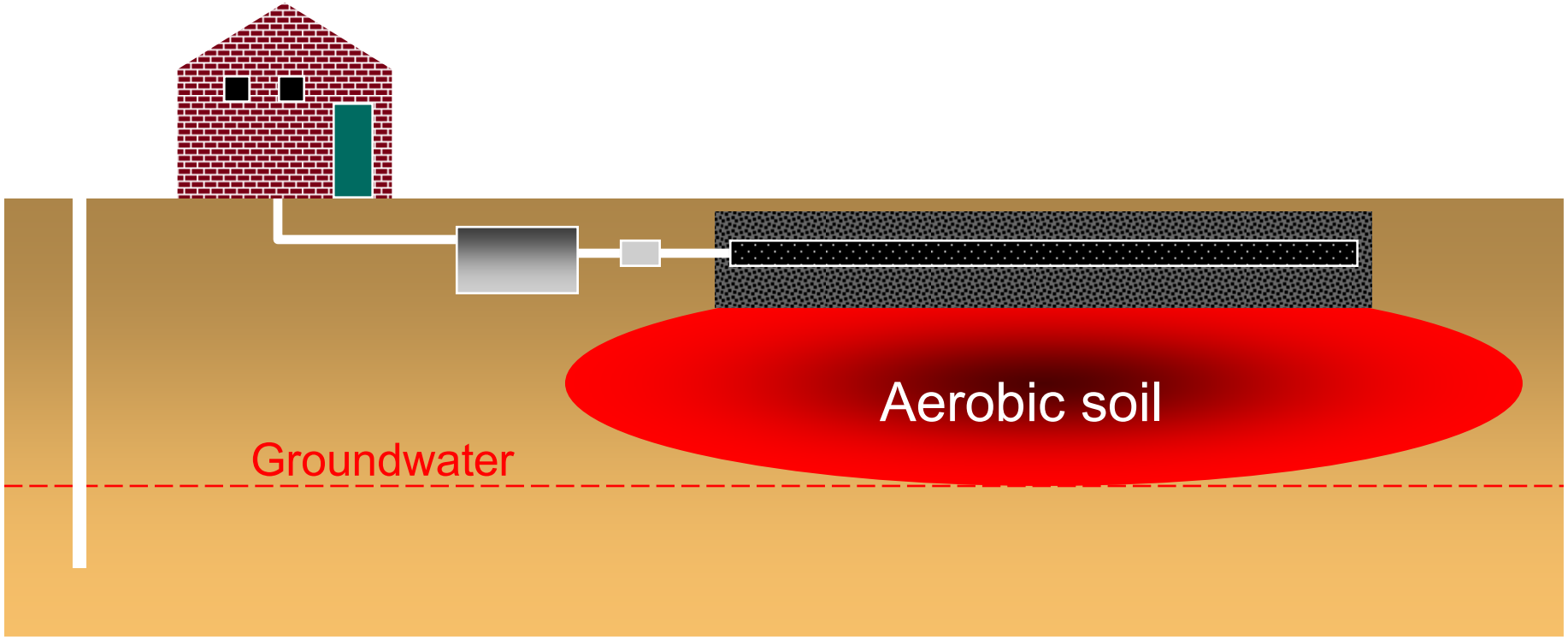
Flow Pattern with Pressure Distribution



Pressure Distribution



Unsaturated flow allows for Aerobic Conditions



Long Term Acceptance Rate
LTAR

- Eventually
  - the biomat controls the ability of the soil to accept effluent
  - this is the LTAR
- Generally, State codes dictate LTARs
  - gallons per day per square foot of trench bottom

Influencing the Biomat

- Good Influence
  - Design
  - Loading
    - Hydraulic
    - Organic
  - Resting
    - dosing
    - multiple drainfields
  - Depth of cover
    - Oxygen availability
- Bad Influence
  - Peroxide
  - Acid drain cleaners

Nutrient Removal

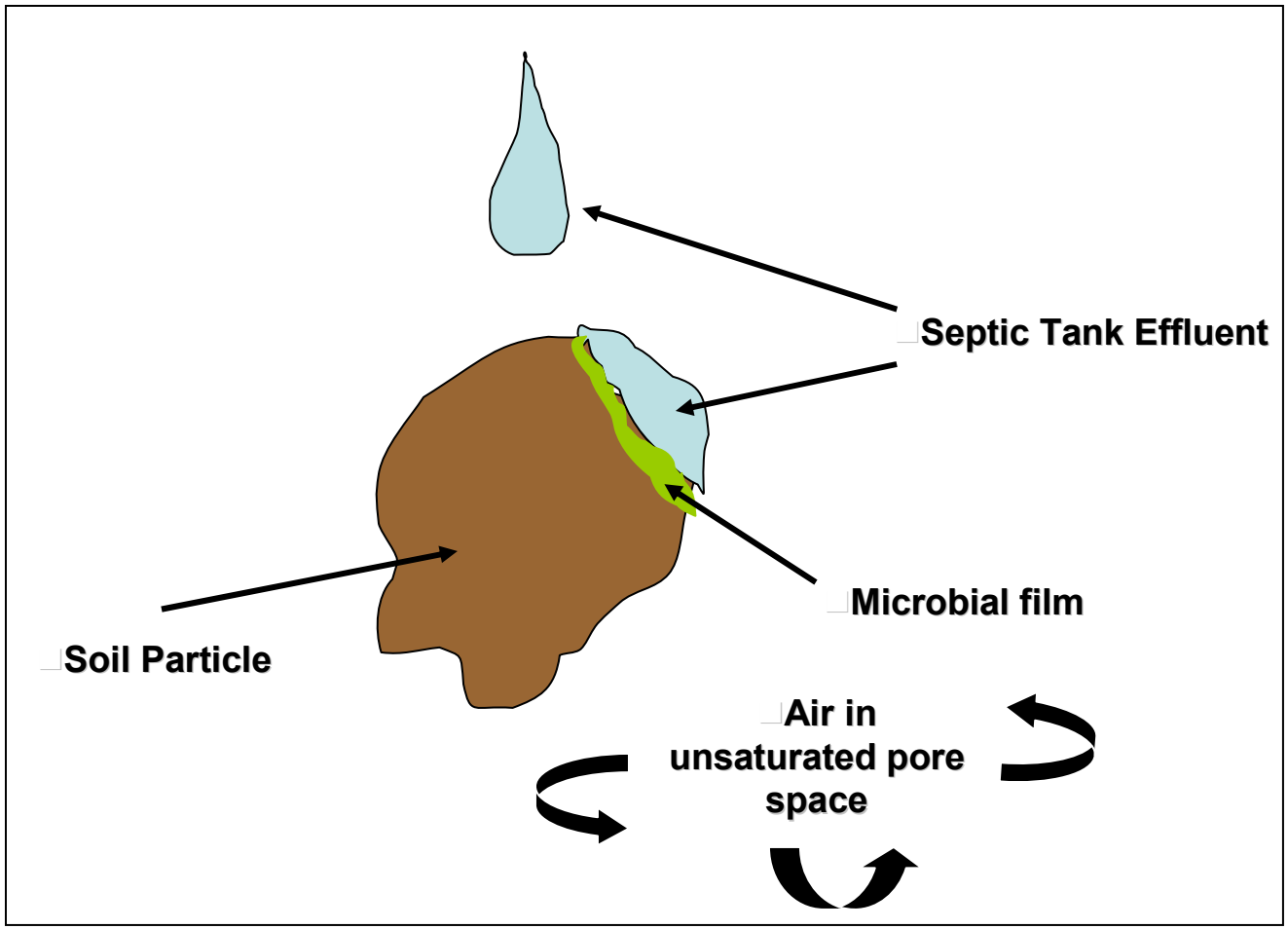
- Dissolved Organic Carbon
  - removal of organic compounds that create an oxygen demand in the receiving stream
    - often measured as BOD or COD
    - high or low strength is function of BOD
    - sometimes called “secondary treatment”
  - treatment processes
    - WWTP use trickling filters, activated sludge plants
    - onsite systems use the soil

How are Nutrients Removed?

- Carbon
  - Becomes food source for soil-borne microorganisms
    - If aerobic conditions, organic carbon can be oxidized to carbon dioxide gas and water
    - If anaerobic conditions, much of the organic matter remains as dead cells and forms the clogging layer

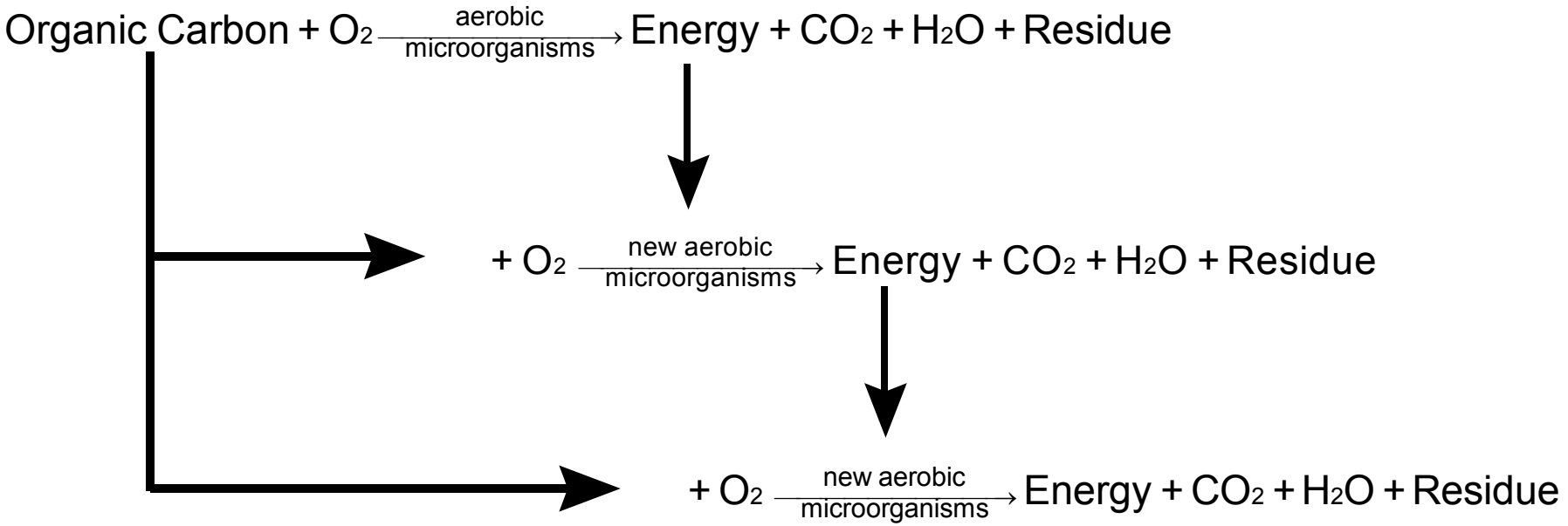
Organic Biodegradation

- Fixed Film treatment on soil particle surfaces



Breakdown of Organics

- Organic carbon is an energy source to most microorganisms



Nutrient Removal

- Nitrogen
  - urea and other nitrogenous compounds in wastewater
  - nitrates and ammonium are plant available
    - can cause eutrophication
  - nitrates in drinking water is toxic to infants
    - blue baby syndrome
  - Treatment Process:
    - WWTP use anaerobic digestion
    - onsite systems use the soil

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

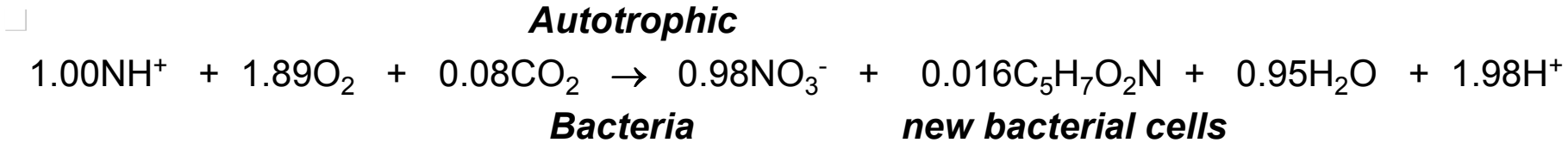
Nitrobacter

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

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

Biological Nitrification

- During this energy yielding reaction
  - some of the NH_4^+ is synthesized into cell tissue giving the following overall oxidation and synthesis reaction:



  - Nitrifiers use CO_2 instead of organic carbon as their carbon source for cell synthesis and for the conversion of NH_4^+ to NO_3^--N.

Biological Denitrification

Heterotrophic Denitrification

Wastewater as the Carbon Source

The following unbalanced equation illustrates the process when wastewater or bacterial cell material is used as the carbon source:

Heterotrophic

$$\underset{\textit{organic matter}}{COHNS} + NO_3^- \xrightarrow{\textit{Bacteria}} N_2 + CO_2 + \underset{\textit{bacterial cells}}{C_5H_7O_2N} + OH^- + H_2O + \text{end products}$$

Nutrient Removal

- Phosphorus
  - We excrete phosphorus compounds
    - bound to organic compounds
  - orthophosphate is the plant available form
    - can be the limiting nutrient in eutrophication
  - treatment process
    - WWTP uses chemical precipitation
    - onsite systems use the soil

Phosphate

- Soil microorganisms release the phosphorus from the organic compounds
  - takes the phosphate form
    - can bind to metal cations in the soil, such as
    - iron
    - aluminum
    - calcium
- Forms a precipitant

If Phosphorus Removal is Required

- If the soil has sufficient
  - iron, aluminum, calcium available,
- then phosphorus removal is assured
- However,
  - in sandy soils
  - phosphorus removal may have to be conducted before effluent is applied to soil

Pathogen Removal

- Disease carrying organisms
  - the original causation for wastewater treatment and disposal
    - separate humans from their wastes
    - minimize the transmission of diseases and illnesses
  - treatment process
    - WWTP use disinfection: chlorine, UV
    - onsite systems use the soil

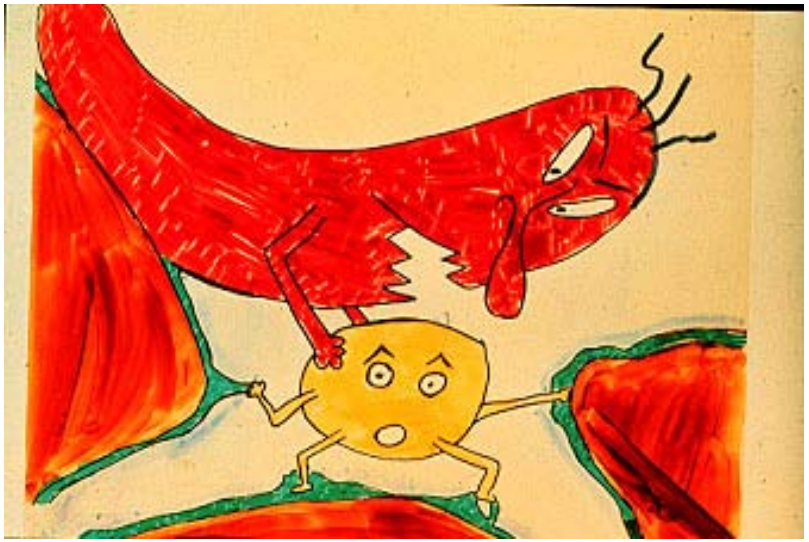
How are Pathogens Removed?

- They are
  - filtered
  - attached to the soil particles
  - killed in the hostile environment
  - attacked by soil organisms

- Given enough time
  - the soil is a very effective treatment media for pathogen removal

Soil Based Pathogen Removal

- Soil can hold some pathogens
  - many soils have a negative charge
  - microbes with a positive charge will bond to the soil
- Predation
  - some pathogens provide a snack to natural soil biota



Soil and Pathogens

- The soil is not sterile
  - Most of the microorganisms in the soil are beneficial
  - we depend on these beneficial microbes for our existence
    - they help grow our crops
  - it is difficult to make measurement of soil microbes and say we killed all the pathogens
    - some of them were already their

Septic System Design Options

- Must allow for aerobic zone beneath field
- Major options include:
  - Depth of trench bottom
    (called the infiltrative surface)
  - Loading rates
    - At infiltrative surface
    - For most restrictive horizon
    - Horizontal flow
  - Distribution system
- Pretreatment options
  - Remove excessive carbon before subsurface application
  - Reduces problems with biomat

Using the Soil as a Wastewater Treatment Plant

- Must think past simple infiltration
  - Will the water be sufficiently renovated before it re-enters the hydrologic cycle?
  - What is “sufficient” treatment?

- Onsite systems must be managed
  - Cannot be installed and forgotten
  - These systems can have a tremendous influence on our environmental quality

The Soil has a Tremendous Capacity to Renovate Wastewater

- We just have to work within the limitations
  - Of the soil resource
  - And the site

Cuss and Discuss Time