# *Basic Concepts of Wastewater Treatment*

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## Basic Concepts of Wastewater Treatment

7 Contact hours
9 CC10 hours

Recently hired apprentices and trainees who are new to the wastewater treatment field will be introduced to the various pollutants contained in domestic wastewater, how these pollutants affect public health and the water environment, and methods by which pollutant levels are reduced in treatment plants. Basic physical, chemical, and biological principles will be covered as they pertain to a typical wastewater treatment plant.

1. Recognize various pollutants contained in domestic wastewater;
2. Review basic physcial, chemical and biological principals of wastewater;
3. Implement methods to reduce pollutants in wastewater treatment plants.

8:30 – 9:00: Intro / Objectives

9:00 – 10:00: Pollutants contained in domestic wastewater & their affects on public health and the environment.

10:00 – 10:10: BREAK

10:10 – 10:40: NPDES Program – Organization & Basic Requirements

10:40 – 11:30: Physical / Chemical / Biological Treatment Overview

11:30 – 12:30: LUNCH

12:30 – 1:00 Preliminary & Primary Treatment Processes

1:00 – 1:50: Secondary Treatment Processes / Activated Sludge

1:50 - 2:00: BREAK

2:00 – 2:40: Advanced Treatment Processes / Chemical Precipitation & Filtration

2:40 – 3:10 pH / Alkalinity Adjustment

3:10 – 4:00: Disinfection / Dechlorination

4:00 – 4:20: Post Test

4:20 - 4:30 Evaluation / Closing

MCET
environmental, health, and safety training

CSM college of southern maryland
La Plata · Leonardtown · Prince Frederick · Waldorf

# Basic Concepts of Wastewater Treatment

## Agenda

- Introductions / Objectives
- Pollutants Contained in Domestic Wastewater & Their Affect on Public Health & The Environment
- Physical / Chemical / Biological Treatment Overview
- Preliminary & Primary Treatment
- Secondary & Advanced Treatment / Activated Sludge
- Filtration
- Disinfection / Dechlorination
- Effluent Monitoring
- Post Test
- Evaluation & Closing

## Questions

# Anytime

## Purpose of This Training

- Provide an overview of the reasons we treat wastewater.
- Describe the basic processes at wastewater treatment facilities
- Introduce operational considerations for WWTFs

## Pollutants Contained in Domestic Wastewater & Their Affect on Public Health & The Environment

## Why do we treat wastewater ?

- ✓ Protection of Public Health
  - Removal of Pathogenic Organisms
- ✓ Protection of the Water Environment
  - Removal of Pollutants that will….
    1. Deplete Dissolved Oxygen
    2. Promote Algae Growth
    3. Inhibit Growth of Submerged Aquatic Vegetation

## Pollutants That Compromise Public Health

- Pathogenic (Disease Causing) Organisms
  - Bacteria
  - Viruses
  - Intestinal Parasites
- Toxic Substances

## How do we determine if pathogens are present?

- Sampling / Analysis for Presence of "Indicator Organisms"
  - Total Coliform
  - Fecal Coliform
  - E.Coli

## Pollutants that Affect the Water Environment

- Organic Solids
  - Dissolved
  - Particulate
- Inorganic Solids
- Low Dissolved Oxygen
- High or Low pH
- Nutrients
  - Nitrogen
  - Phosphorus
- Toxic Compounds

## Solids

- TSS (Total Suspended Solids)
  - Settlable
  - Colloidal

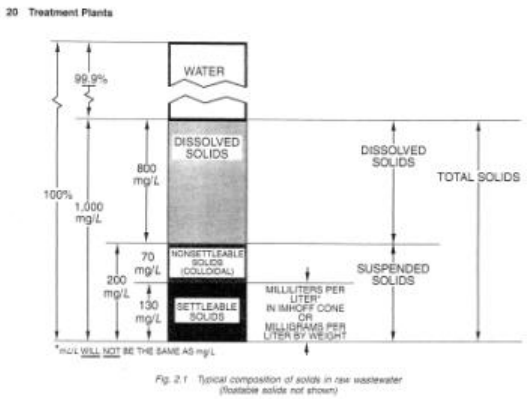


Fig. 2.1 Typical composition of solids in raw wastewater (floatable solids not shown)

## Organic Compounds

- BOD ( Bio-Chemical Oxygen Demand )
  - Test used to determine the strength of the wastewater. This also provides a gauge of the amount of food available to the microorganisms.
  - Soluble (Dissolved in the wastewater)
  - Particulate ( Particles free floating in the wastewater. A portion can be settled out.

## pH and DO

- pH scale

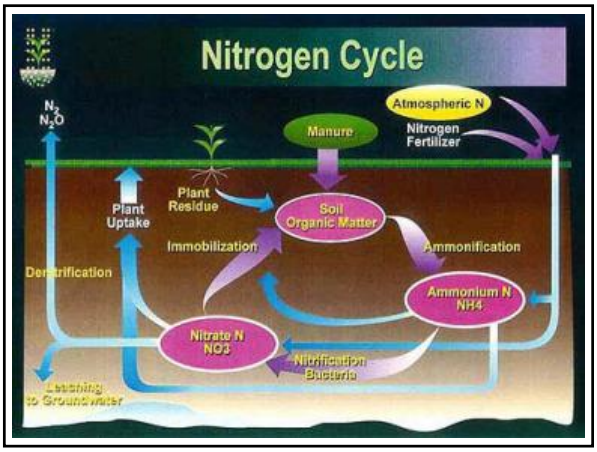
  0 ---------- 7 ---------- 14

  (Acid) (Alkaline)

- Dissolved Oxygen (DO)
  - Importance
  - What affects DO?

## Nutrients

- Nitrogen
  - Ammonia ($NH_3$)
  - Organic Nitrogen
  - Nitrite ($NO_2$)
  - Nitrate ($NO_3$)
- Phosphorus
  - Soluble
  - Particulate



## Toxic Compounds

- Ammonia
- Chlorine
- Metals
- Other

## NPDES Program Organization And Basic Requirements

## Clean Water Act

- Federal Law Established in 1972
- Includes the "NPDES" Program
  - National Pollutant Discharge Elimination System
- Responsibility for Enforcement
  - Federal: US Environmental Protection Agency
  - State: Maryland Department of Environment

## NPDES Program

- The State of Maryland received delegation from EPA in 1974 to operate the NPDES program.
- This includes:
  - Issuing NPDES or "Discharge" Permits
  - Enforcing the provisions of those discharge permits
  - Managing construction grants / loan projects

## Responsibilities of NPDES Permit Holders

- Comply with ALL provisions of the permit
- Operate and maintain the collection system and treatment plant
- Meet effluent quality and loading requirements
- Perform "self-monitoring" in accordance with 40 CFR 136
- Report monitoring results and violations to regulatory agencies
- Other

## Physical / Chemical / Biological Treatment Overview

## Physical Treatment

- Screening
  - Removal of paper, plastics, rags, rocks, etc
  - Process uses “bar screens”
- Sedimentation
  - Removal of settleable solids by gravity
  - Grit tanks
  - Large settling tanks called “clarifiers”

## Physical Treatment

- Floatation
  - Skimming of floating material
  - Oil & Grease
  - Also occurs in clarifiers
- Filtration
  - Removal of fine particles
  - Sand filters
  - Membranes

## Physical Treatment

- Disinfection by Ultra-Violet Light
  - Inactivates Pathogens

## Chemical Treatment

- pH Adjustment
  - UP: Lime, Soda Ash, Caustic Soda
  - DOWN: Acid
- Coagulation / Precipitation
  - Removal of fine solids and/or phosphorus
- Disinfection
  - Inactivates Pathogens
  - Chlorine or Chlorine Based Compound

## Chemical Treatment

- Sludge Conditioning / Dewatering
  - Polymer
- Carbon Addition
  - Methanol, Glycerin, etc.
- Odor Control
  - Caustic Scrubbers
- Other
  - Hypo

## Biological Treatment

- Uses specific types of microorganisms to ..
  - Convert Organics to $CO_2$ and $H_2O$
    - BOD / TSS Removal
  - Convert Ammonia to Nitrate
    - Nitrification
  - Convert Nitrate to $N_2$
    - Denitrification
  - Uptake Phosphorus

## Biological Treatment

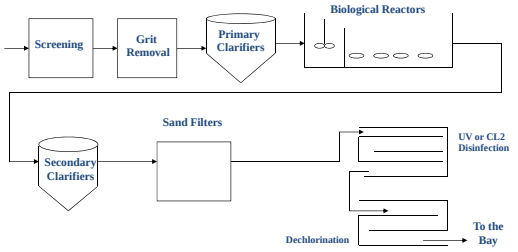
- Types of Biological Treatment
  - Dispersed Growth
    - Lagoons
    - Activated Sludge
  - Attached Growth
    - Trickling Filters
    - Rotating Biological Contactors (RBC's)
  - Combination of Dispersed & Attached Growth
    - Integrated Fixed-Film / Activated Sludge (IFAS)
    - Membrane Bioreactor (MBR)

## Biological Treatment

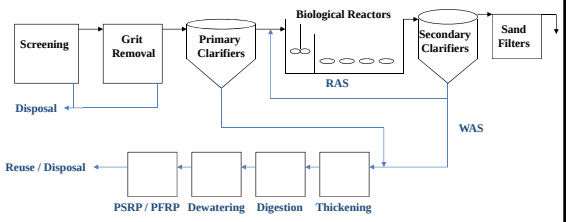
- Duplicates reactions that occur naturally in the water body, except….
  - Controlled Conditions
    - Enclosed tanks
    - Controlled dissolved oxygen levels (air addition)
    - Controlled Food / Microorganism Ratio
  - Reduced degradation of water body

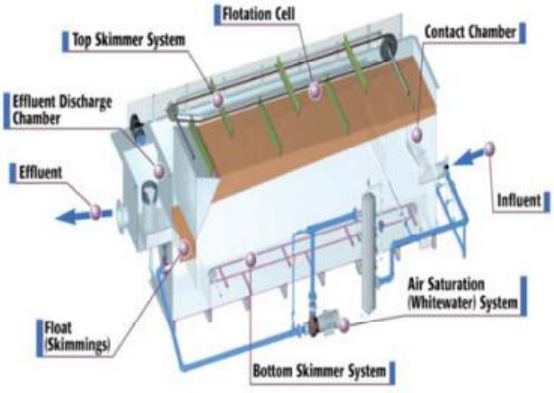
## General Treatment Plant Configuration

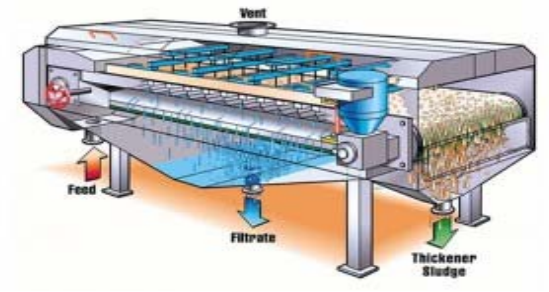
## General Plant Configuration
## "Liquid" Processes




## General Plant Configuration
## "Solids" Processes



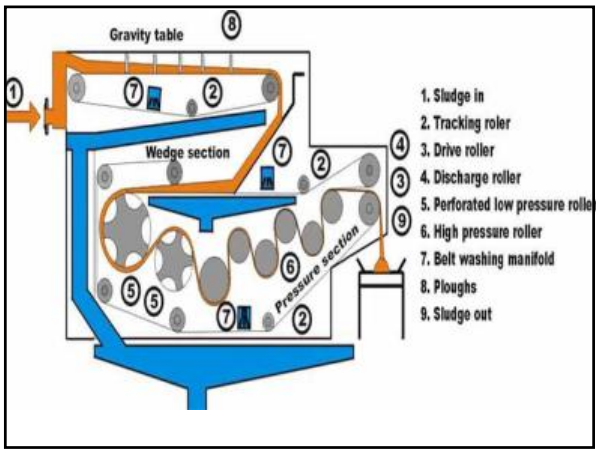


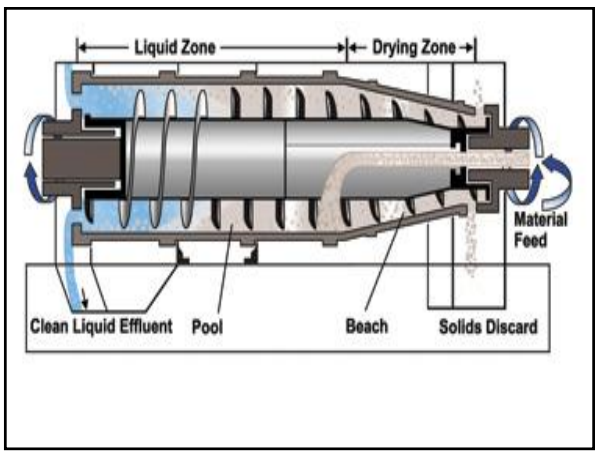

## Aerobic Digestion

- Advantages
  - Easy to control and start up
  - Low ammonia and BOD in return stream
  - Few odor issues
  - Explosive gases not produced
- Disadvantages
  - Energy intensive
  - Does not produce energy
  - Not usually used for primary sludge
  - Temperature variability issues

## Anaerobic Digestion

- Advantages
  - Renewable energy
  - Destroys pathogens
  - Reduces volatile content
  - Much less waste than aerobic
- Disadvantages
  - Slow start up
  - Sealed tank harder to maintain
  - Production of explosive gas
  - Greater operational oversight required



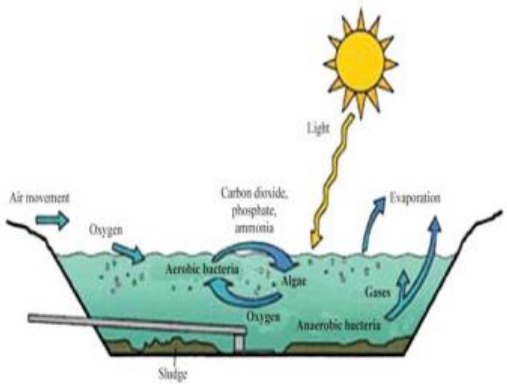

## PSRP

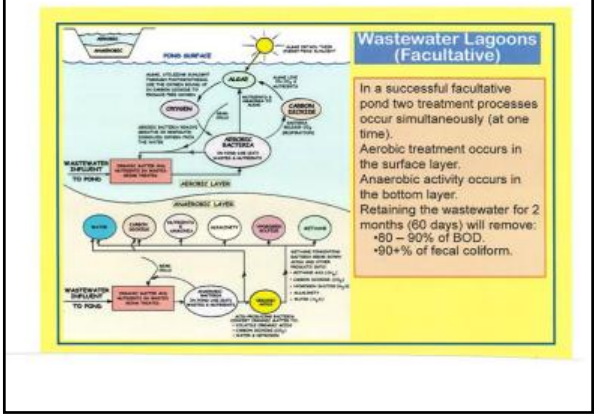
- Aerobic Digestion
- Air Drying
- Anaerobic Digestion
- Composting
- Lime Stabilization

## PFRP

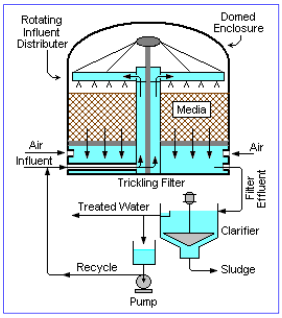
- Composting
- Heat Drying
- Heat Treatment
- Thermophilic Aerobic Digestion
- Beta Ray Irradiation
- Gamma Ray Irradiation
- Pasteurization

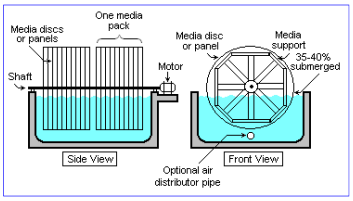
## Lagoons




## Trickling Filters




## Rotating Biological Contactors (RBC)

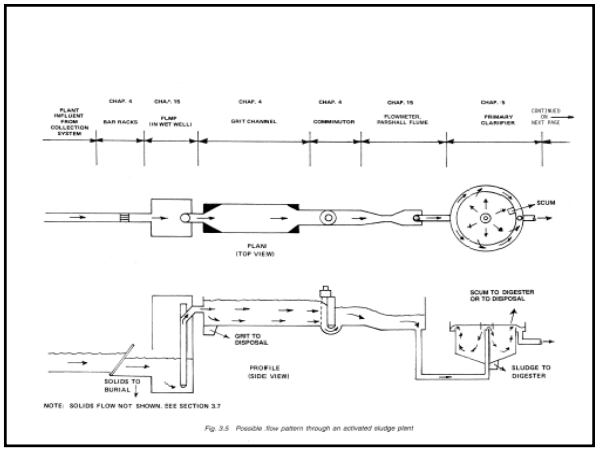




Fig. 3.5 Possible flow pattern through an activated sludge plant

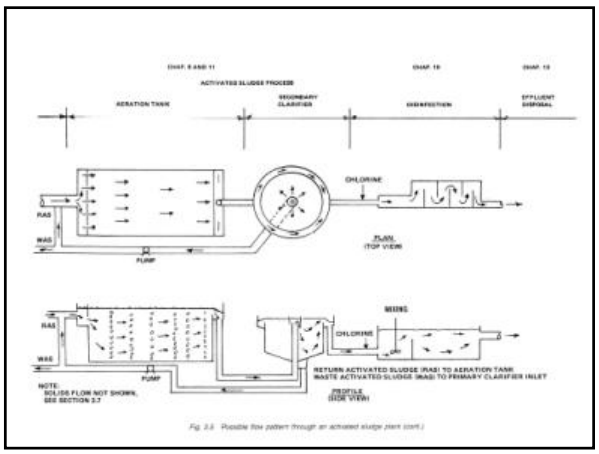
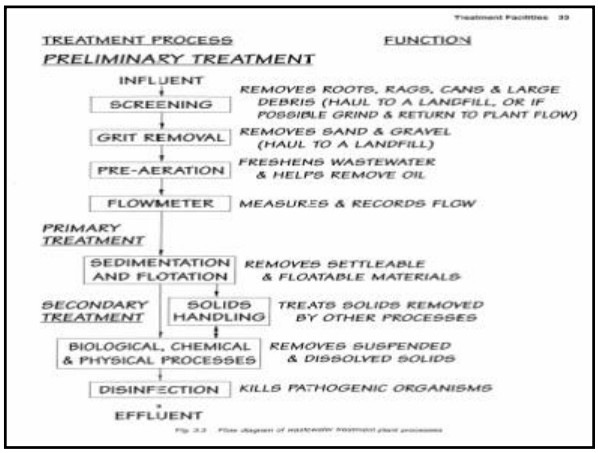
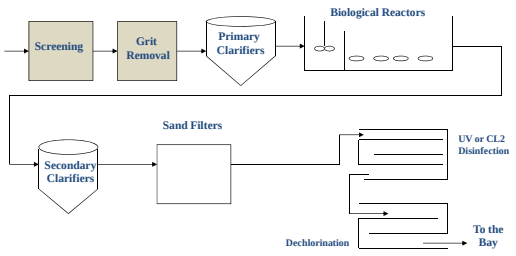



Fig. 3.6 Possible flow pattern through an activated sludge plant (cont.)



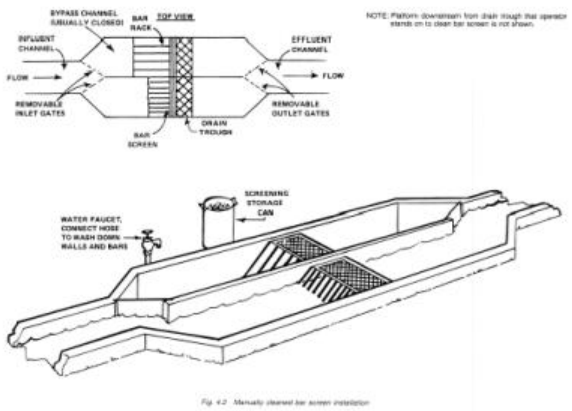

## Preliminary Treatment

## Preliminary Treatment



## Preliminary Treatment
## Screening & Grit Removal

- Screening
  - Remove Rags and Other Large Debris
  - Odors
  - Hazards - Hydrogen Sulfide and Methane
  - What is the common method of disposal?
- Grit Removal
  - What is grit
  - Why do we remove it?
  - What is the common method of disposal?



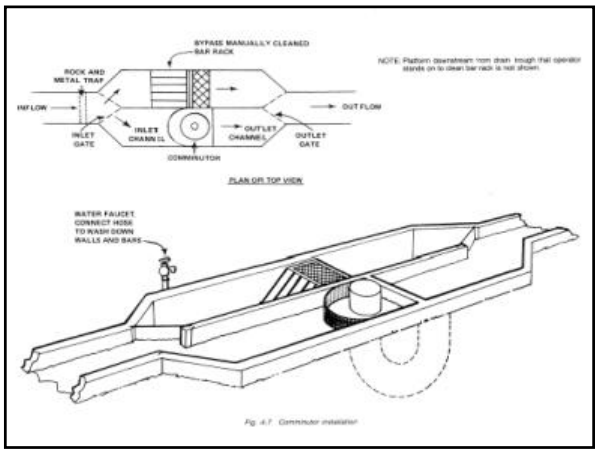




Fig. 4.7 Comminutor installation

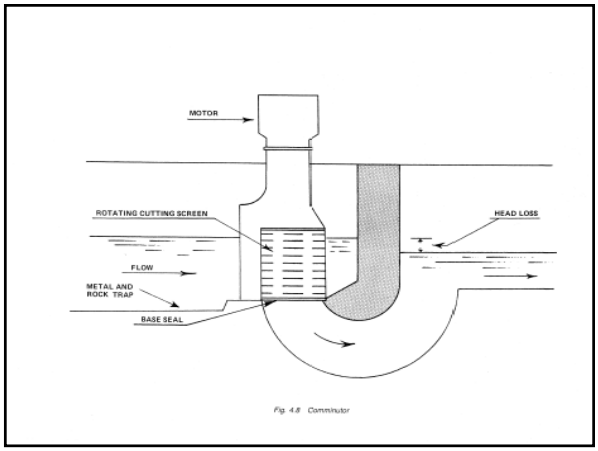



Fig. 4.8 Comminutor

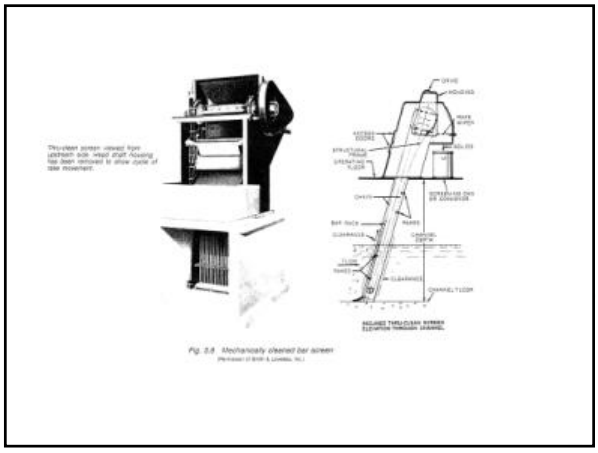
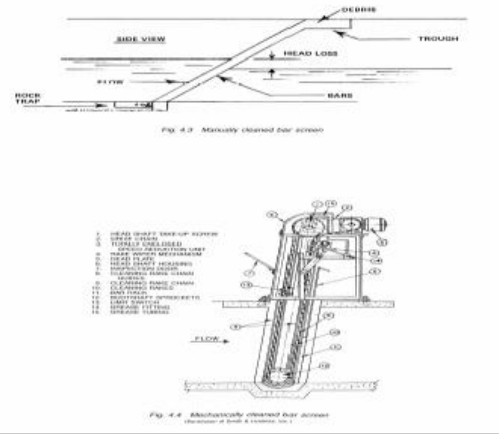
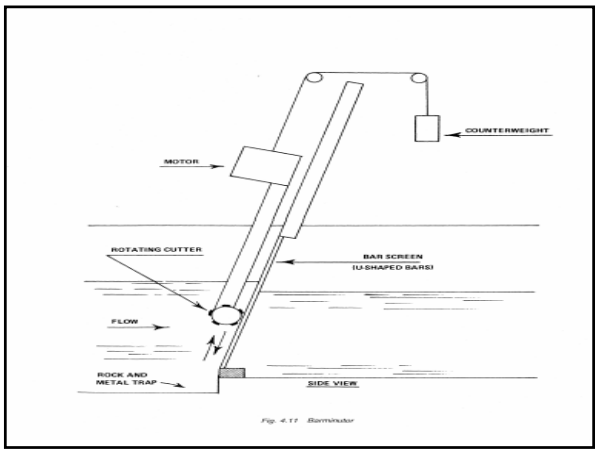
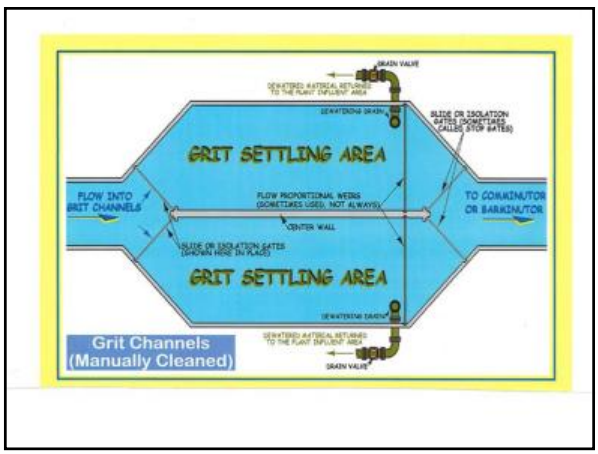
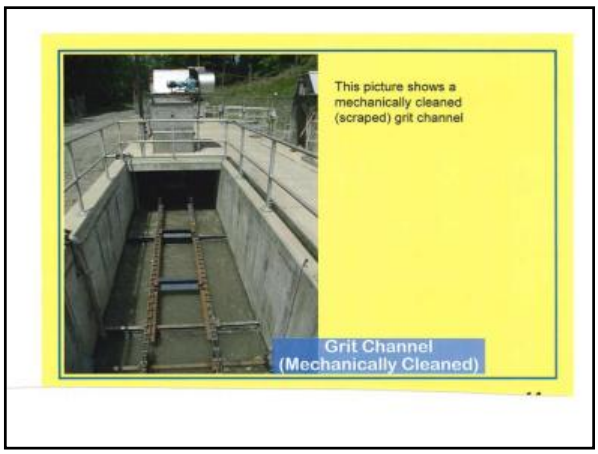


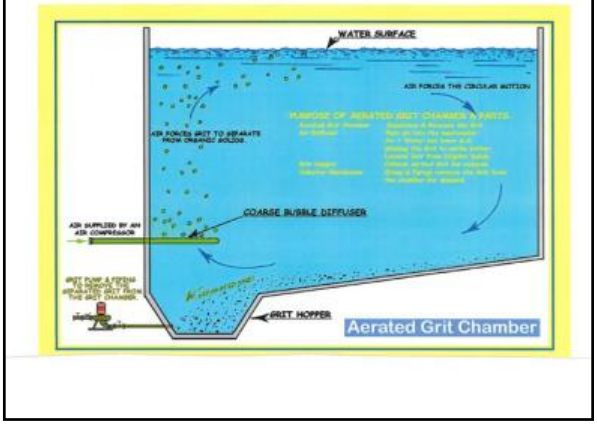
Fig. 3.8 Mechanically cleaned bar screen





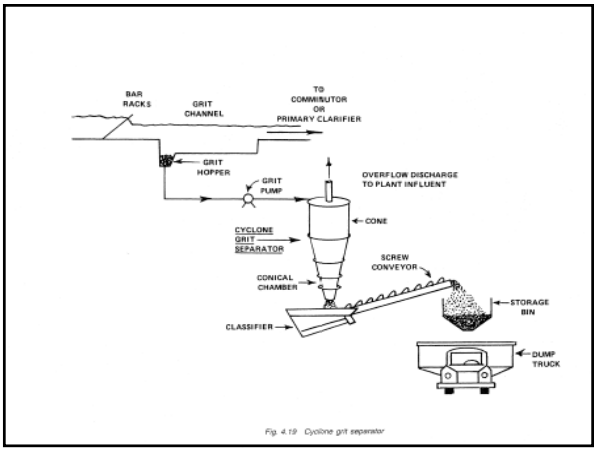




Fig. 4.19 Cyclone grit separator

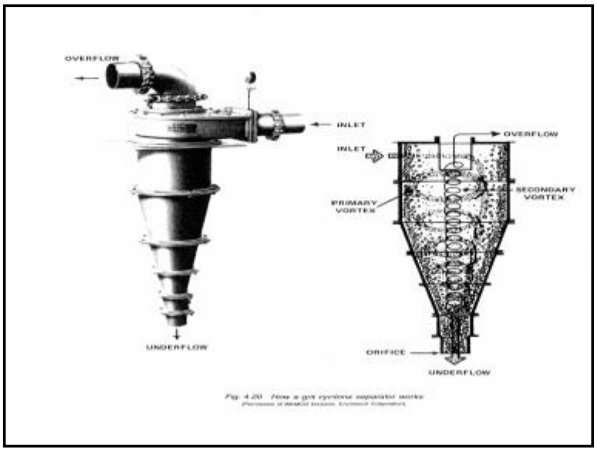
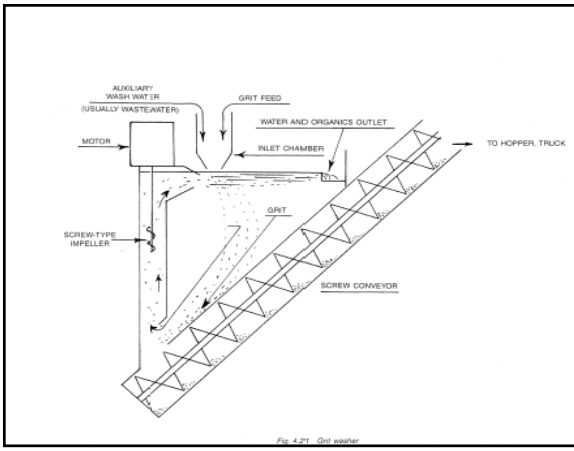
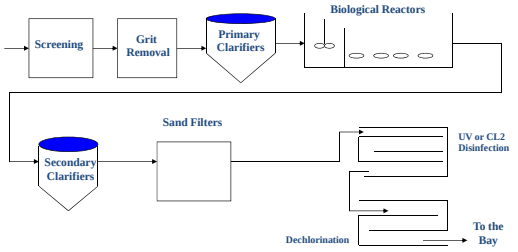



Fig. 4.20 How a grit cyclone separator works

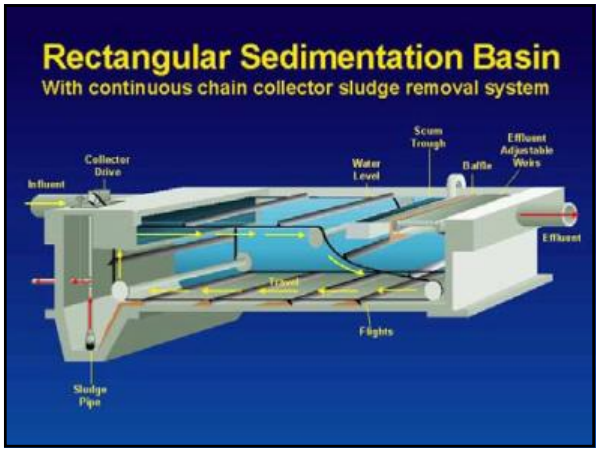

## Primary Treatment

## Sedimentation / Floatation




## Primary Clarifiers

- Remove settleable solids and floatables
- Reduce BOD / TSS
- Factors that affect efficiency
- Bulking & gasification
- Sludge blankets
- Short circuiting



## Circular Clarifier

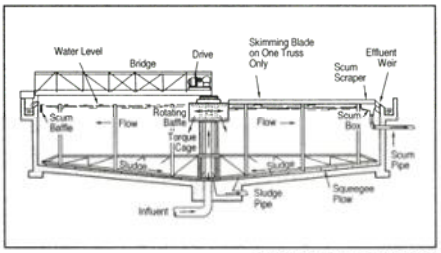
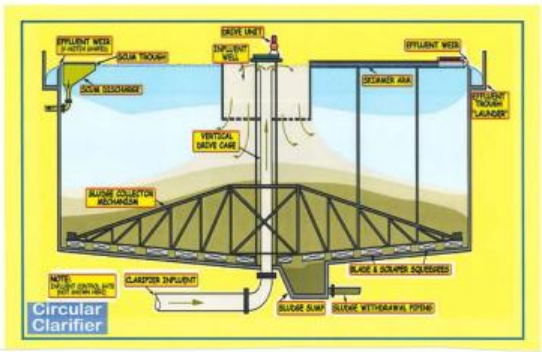



FIGURE 5-5 A typical circular sedimentation basin

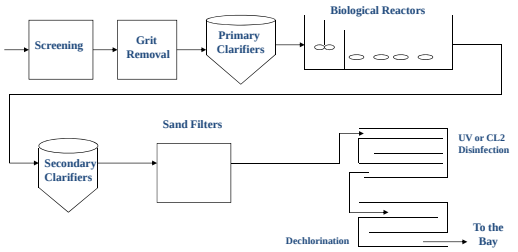
Courtesy of FMC Corporation, MHS Division

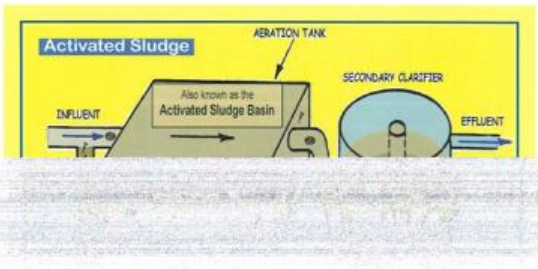
## Circular Sedimentation Basin

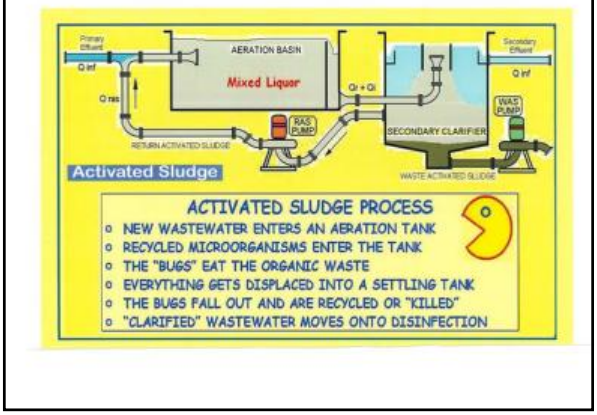


## Secondary & Advanced Treatment – Activated Sludge

## Biological Treatment / Activated Sludge




## Biological Reactors

- Remove BOD
- Convert / Remove Nutrients
  - Nitrogen & Phosphorus
- What is activated sludge
  - Bacteria
  - Protozoa
  - Animals

## Mixed Liquor

- Mixed Liquor Suspended Solids (MLSS)
  - Suspended Solids in the Biological Reactor
- Mixed Liquor Volatile Suspended Solids (MLVSS)
  - Volatile (active) Suspended Solids in the Biological Reactor
- Expressed as concentration (mg/L) or quantity (lbs)

## RAS / WAS

- Return Activated Sludge (RAS)
  - Biomass recyled from the secondary clarifier to the Biological Reactor
  - Thicker in concentration than MLSS
- Waste Activated Sludge (WAS)
  - Biomass removed from the Biological Reactor
  - Sent to Solids Processing

## F/M & MCRT

- Food to Microorganisms Ratio (F:M)
  - Ratio of BOD (food) to MLSS (microorganisms)
- Mean Cell Residence Time (MCRT)
  - How many days a microorganism is “in the system”

## Other Important Data

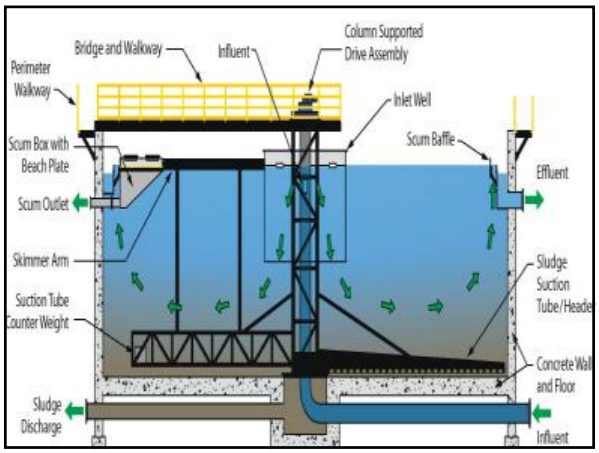
- Mixed Liquor Dissolved Oxygen (MLDO)
  - Oxygen in Aerobic portion of Biological Reactor
- Depth of Blanket (DOB)
  - Depth of settled sludge in secondary clarifiers
- Mixed Liquor pH and Alkalinity
  - Affects the type & growth rate of microorganisms
  - Alkalinity is the capacity of liquid to neutralize acid

## Conditions Affected by Dissolved Oxygen

- Aerobic
  - Positive D.O. present
- Anoxic
  - No D.O. present but NO3 present
- Anaerobic
  - No D.O. and No NO3 present

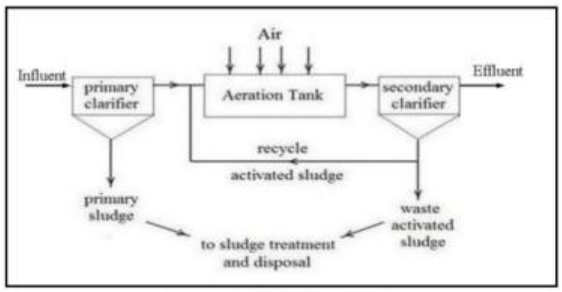
## Secondary Clarifiers

- Remove settleable and floatable solids
- Return Activated Sludge (RAS) to the Reactors
- Waste Activated Sludge (WAS) to Solids Processing
- Factors that affect efficiency
- Bulking & gasification
- Sludge blankets
- Short circuiting



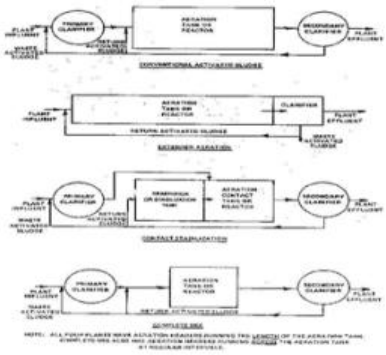

## Activated Sludge - Processes

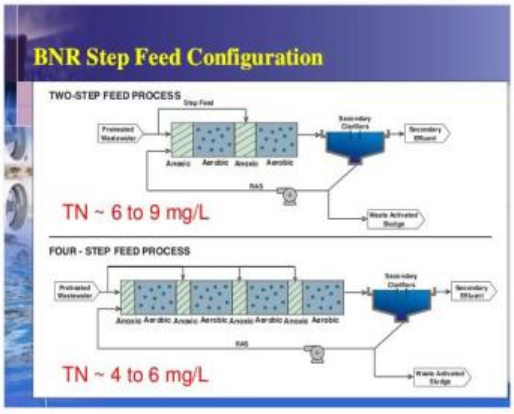
- Conventional
- Step Feed
- Contact Stabilization
- Extended Aeration
  - Oxidation Ditches, Package Plants
- Sequencing Batch Reactor (SBR)
- Membrane Bio-Reactor (MBR)
- Biological Nutrient Removal (BNR) Systems
- Enhanced Nutrient Removal (ENR) Systems




Conventional Activated Sludge

Activated Sludge System Configurations





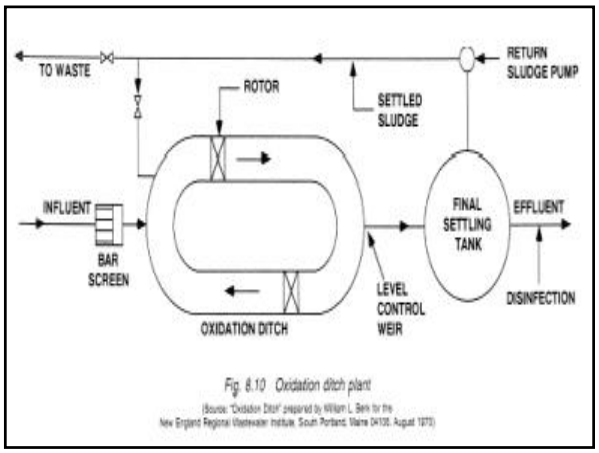



Fig. 8.10 Oxidation ditch plant

(Source: "Oxidation Ditch" prepared by William L. Behr for the New England Regional Wastewater Institute, South Portland, Maine 04106, August 1973)

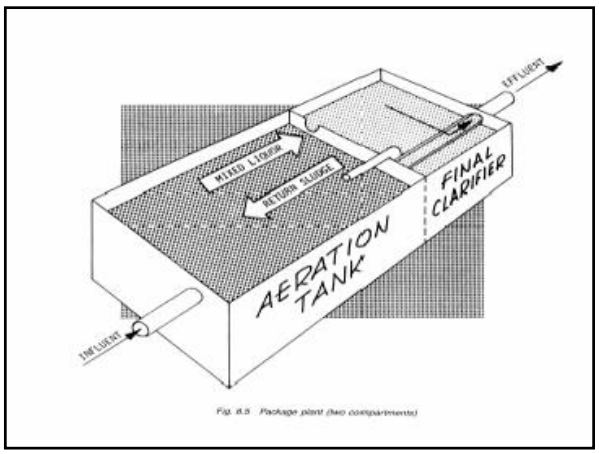
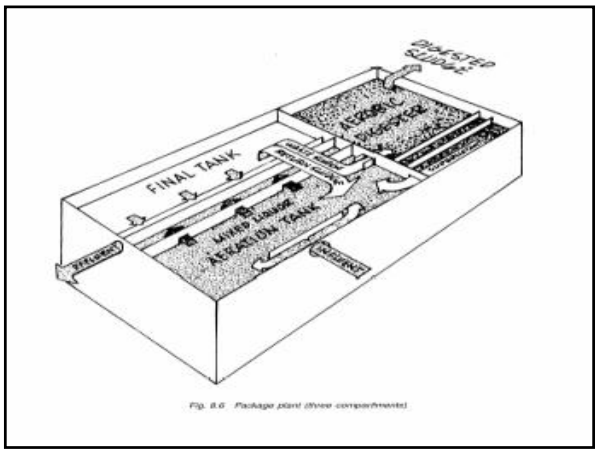
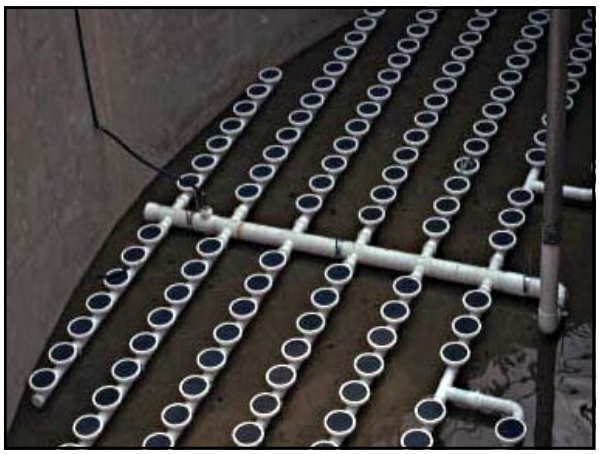
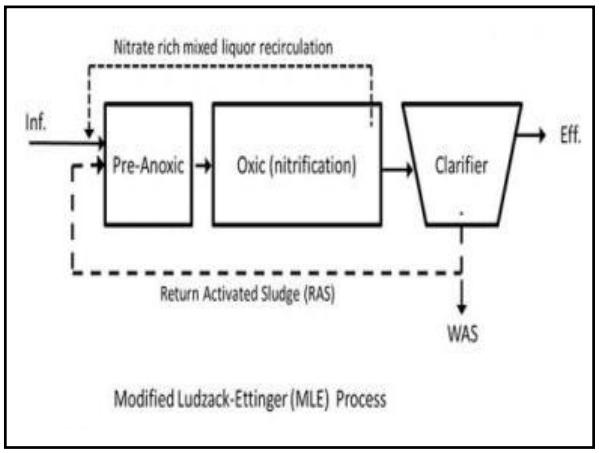


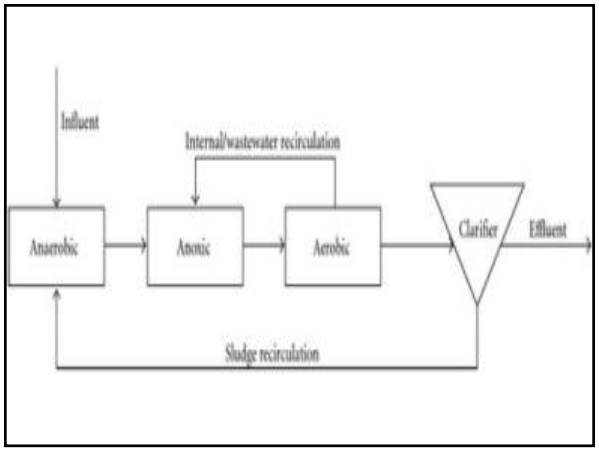

Fig. 8.5 Package plant (two compartments)



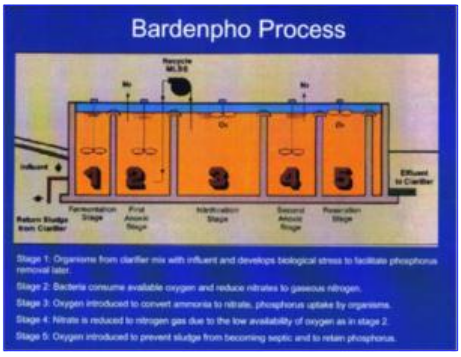





Modified Ludzack-Ettinger (MLE) Process

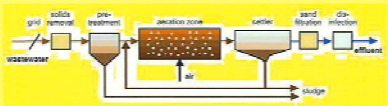



Biological Nitrogen & Phosphorus Removal

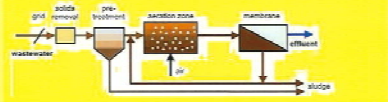


## Membrane BioReactor (MBR)

Conventional Activated Sludge with Sand Filtration

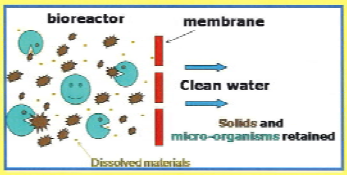



Membrane BioReactor (MBR) Treatment

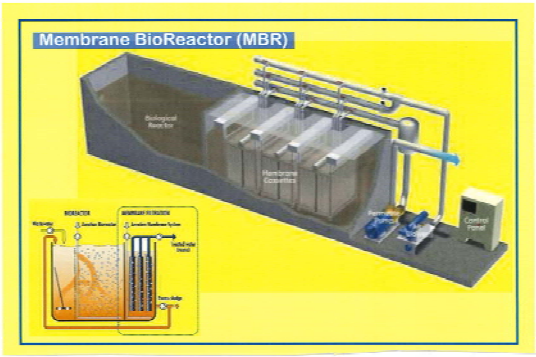



## Membrane BioReactor (MBR)

When used to treat domestic wastewater, MBR processes can produce effluent of high quality enough to be discharged to coastal, surface or brackish waterways or to be reclaimed for urban irrigation. Other advantages of MBRs over conventional processes include small footprint (size), easy retrofit and upgrade to old wastewater treatment plants.




## Membrane BioReactor (MBR)



## Activated Sludge Process

- How does it work ?

Organisms + Food + DO = More organism

Or

Bio-Mass + BOD + Air = Need to Waste

**Soluble or Particulate**

## ACTIVATED SLUDGE

- Mechanisms to remove BOD and SS.
- Soluble vs. Particulate BOD.
- BOD removal by ADsorption.
- BOD removal by ABsorption.

## Bacteria

- Remove the BOD
- Primary BOD removers
- Need:
  - Food (BOD)
  - Air
  - Nutrients
  - pH
  - Temperature
  - Life span (MCRT)

## Protozoa

- Indicators organisms
- Food source - Bacteria and BOD
- Microscopic slide to identify

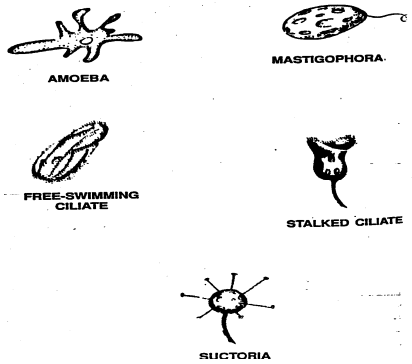
## Protozoa

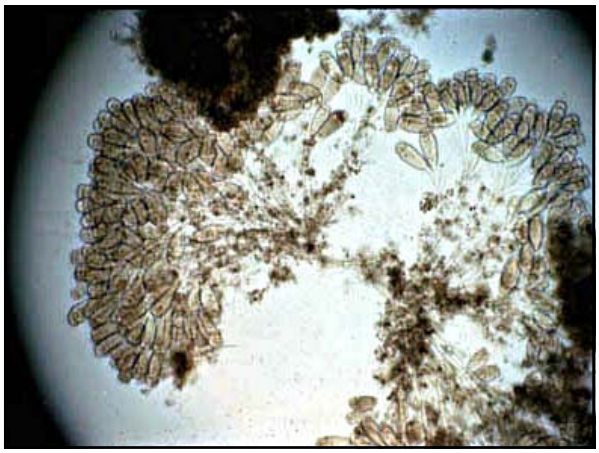
- Amoebas
- Flagellates
- Crawling Ciliates
- Stalk Cilitates

Other Organisms :

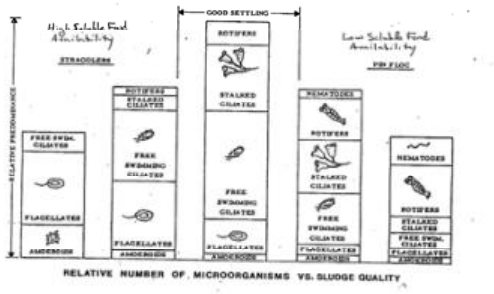
- Rotifers
- Nematodes
- Fungi

## Protozoas





## Microorganisms Table




## BIOMASS – Quality & Quantity

- Impact on effective BOD removal.
- Process control to effect biomass.
- Key process parameter to monitor performance.

» MCRT

## What is MCRT?

MCRT (days) =

$$\frac{\text{Biomass in system (lbs)}}{\text{Biomass wasted (lbs per day)}}$$

= average number of days that Microorganisms remain in the system

## Nitrogen in Domestic Wastewater

TKN = Org. N + Ammonia

| | |
|---|---|
| Organic Nitrogen | |
| Proteins | 15 mg/L |
| Urea | |
| Ammonia Nitrogen | 25 mg/L |
| Nitrate/Nitrite Nitrogen | 0 mg/L |

## Nitrification

**Why Nitrify?**

- **Minimize oxygen depletion in receiving waters**
- **Prevent ammonia toxicity in receiving waters**

## Nitrogen Removal Basics

**What is Nitrification?**

Conversion of Ammonia to Nitrate

$NH_3^+ \rightarrow NO_3^-$

TKN = Ammonia + Organic N

## Nitrification

Nitrosomonas

$NH_3^+ + O_2 \rightarrow NO_2^- + H_2O + H^+$

**Oxygen Required = 3.43 lb / lb N oxidized**

**Alkalinity Required = 7.14 lb as $CaCO_3$ / lb N oxidized**

Nitrobacter

$NO_2^- + O_2 \rightarrow NO_3^-$

**Oxygen Required = 1.14 lb / lb N oxidized**

For both reactions together:

**Total Oxygen Required = 4.57 lb / lb N oxidized**

**Total Alkalinity Required = 7.14 lb as $CaCO_3$ / lb N oxidized**

## DENITRIFICATION

TN = TKN + NOx

Why Denitrify?

Minimize nutrient discharge to stream

Save alkalinity

## DENITRIFICATION

Nitrate + Organic Carbon → Carbon Dioxide + Nitrogen Gas + Water + Hydroxide

$NO_3^-$ + Organic-C → $CO_2$ + $N_2\uparrow$ + $H_2O$ + $OH^-$

**This is equivalent to 2.86 lbs COD utilized per lb nitrate-N denitrified**
**Alkalinity produced = 3.57 lbs as $CaCO_3$ per lb nitrate-N denitrified**

$NO_3^-$ + $H^+$ → $N_2\uparrow$ + $H_2O$ + $O_2$ (Gas)

**Oxygen equivalents recovered = 2.86 lbs per lb nitrate-N denitrified**

## Activated Sludge Process Control

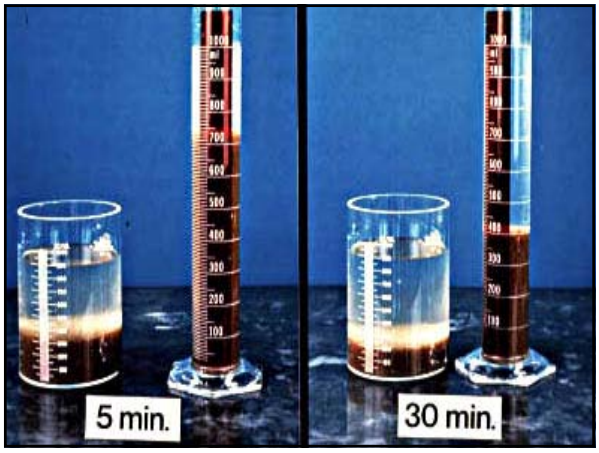
- Concept:
  - To provide the right amount of bio-mass for the BOD in the influent and the water temp.
  - Suspended growth biological process.
  - Maintain proper MCRT for the process being used.
  - To remove as much of the BOD and SS as possible.
  - Input only the amount of DO needed.
  - To produce a good quality / settling bio-mass.
  - Enhanced to achieve nutrient reductions

## PROCESS CONTROL TESTS

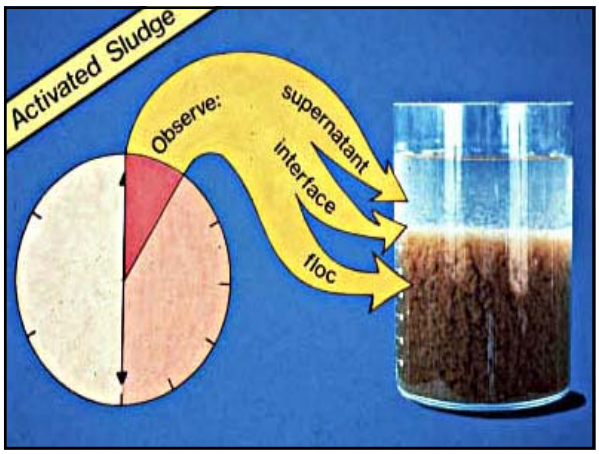
| | |
|---|---|
| MLSS | MLVSS |
| RASss | MLpH |
| MLDO | Microscope |
| SSV | DOB |
| Alkalinity | NH3, NO3, OP |
| ML Temperature | |

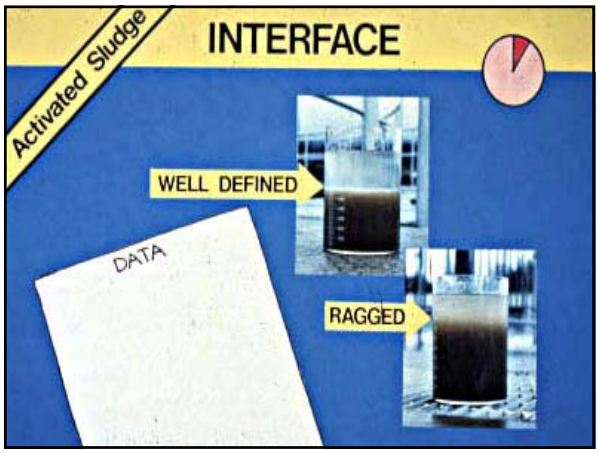
## SSV / SVI

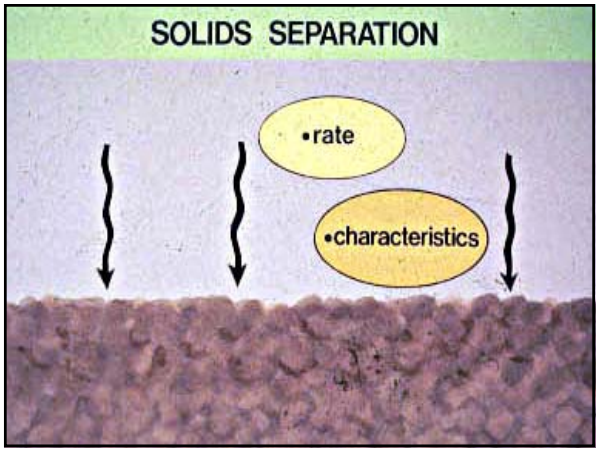
- Settled Sludge Volume (SSV) and
- Sludge Volume Index (SVI)
  - Indicator of the settling in the Secondary Clarifiers
  - SVI Test performed using the MLSS

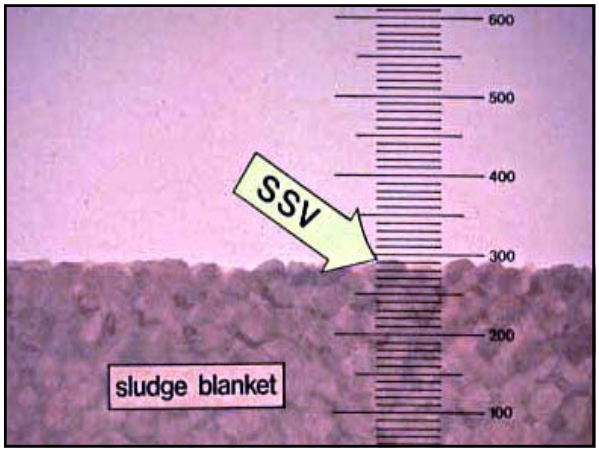









## Causes of Excessive Filamentous Bacteria

- Low MLDO
- High MCRT, low F/M
- Septicity
- Nutrient deficiency
- Low MLpH

## Control of Filaments

- Incorporate selector zone ahead of biological process
- Reduce MCRT
- Add settling agent (polymer) to clarifier influent
- Controlled chlorination
  - Apply to RAS for bulking
  - Spray on surface for foaming

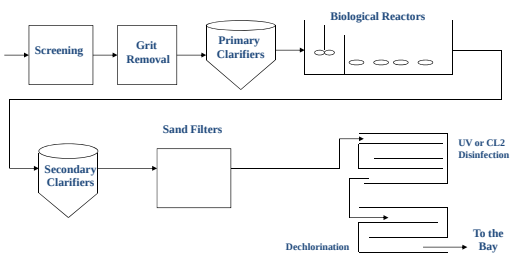
## Basic Process Control Options

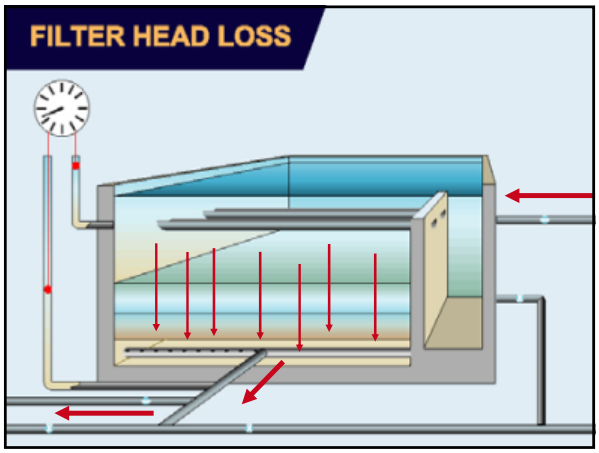
How does each affect performance?

- Regulate MLDO (Mixed Liquor Dissolved Oxygen)
- Regulate pH and Alkalinity
- Regulate RAS flow rate
- Regulate WAS flow rate
- Nutrient Removal
  - ➢ Regulate all above, plus..
    - ✓ Nitrate Recycle Rate
    - ✓Supplemental Carbon Addition

## Filtration

## Filtration






## The Filtration Process

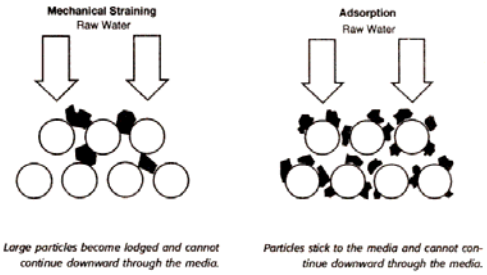
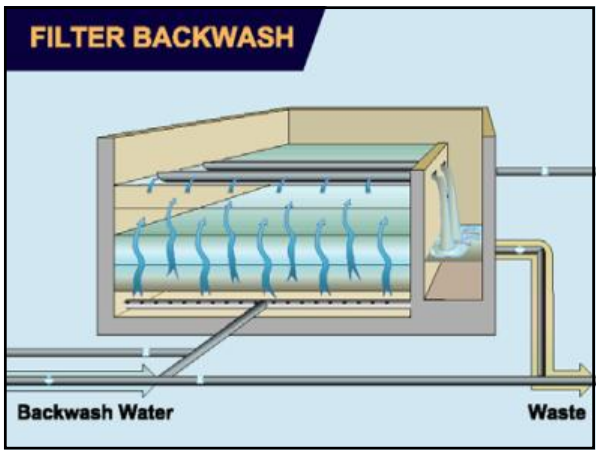
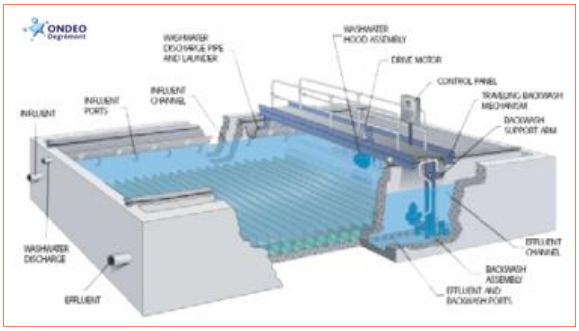
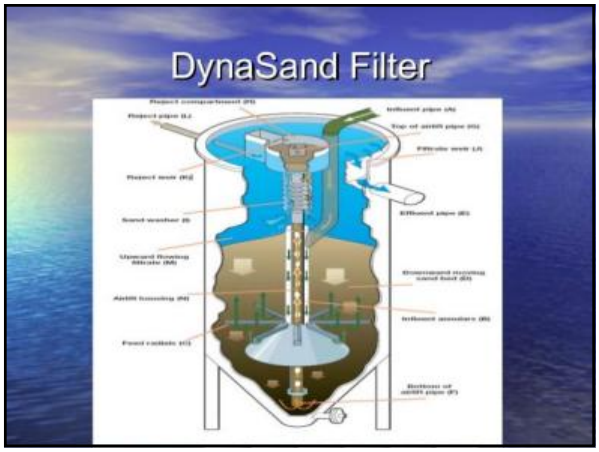



Figure 6-1



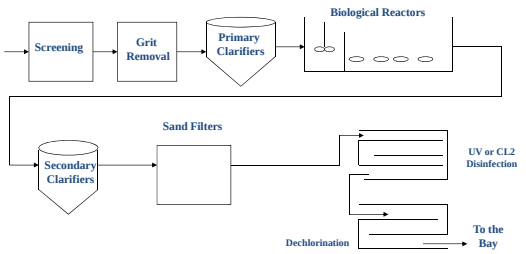
**Automatic (Continuous) Backwash Filter**




# Disinfection

## Disinfection




## Terms to know

- Disinfection
- Pathogens
- Coliform
  - Total Coliform
  - Fecal Coliform
  - E.Coli
- Dechlorination
- UV

## Disinfection

•Why do we disinfect ?

• How do we disinfect ?

• Factors that effect efficiency

## Purpose of Disinfection

- Pathogen Reduction
- Indicators are
  - Fecal Coliform
  - E.Coli

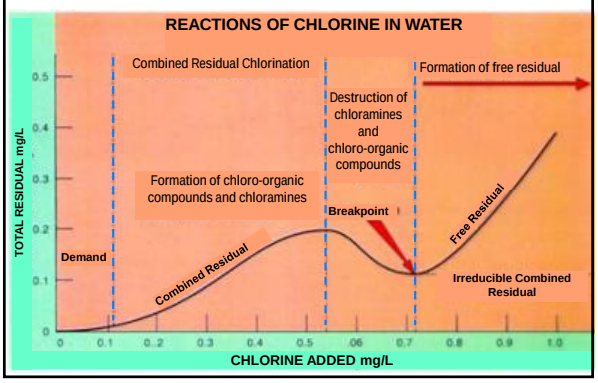
## Methods of Disinfection

- Chlorine Gas
- Calcium Hypochlorite
- Sodium Hypochlorite
- Ozone
- Ultraviolet (UV) light

## Disinfection By Chlorine Key Concepts

- Dose
- Demand
- Residual
  - Free
  - Combined
  - Total
- Contact Time
- Turbidity
- Temperature
- pH

## Breakpoint Chlorination Curve

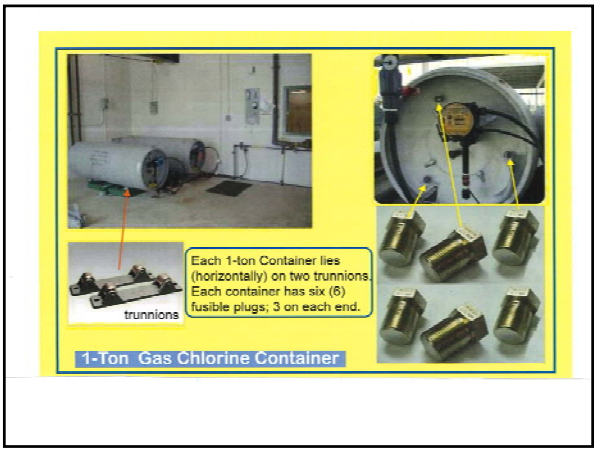



## Chlorine Compounds

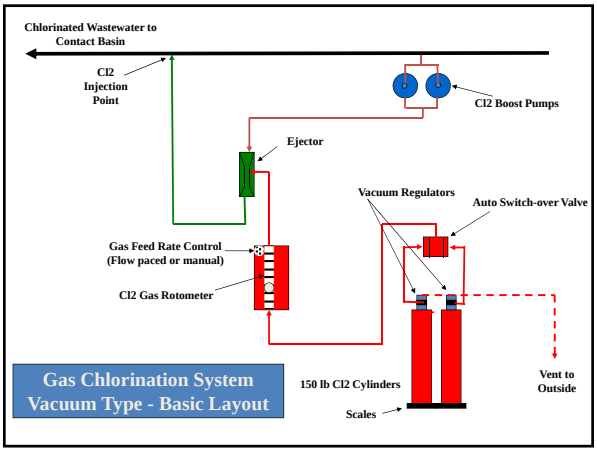
- Chlorine Gas (100%)
- Calcium Hypochlorite (65-70%)
- Sodium Hypochlorite (5–15%)



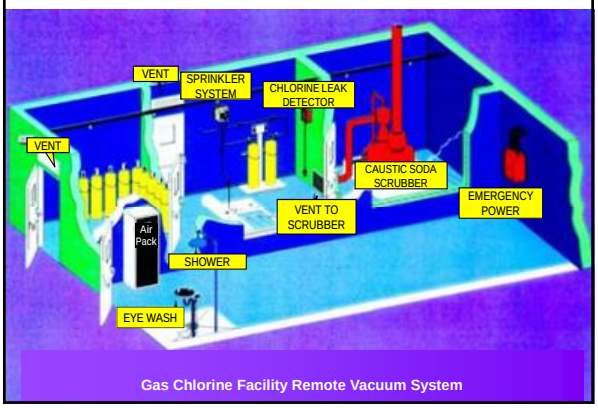
Duplex Vacuum System



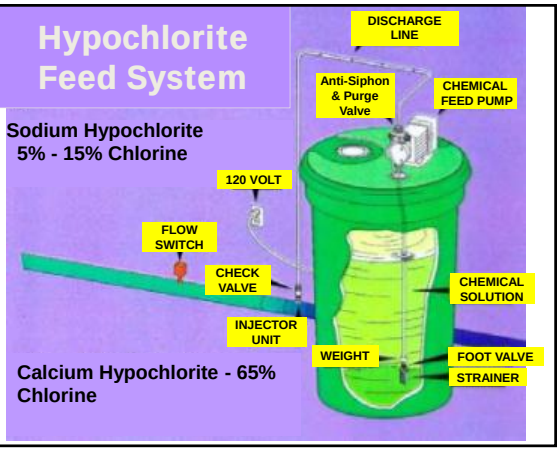




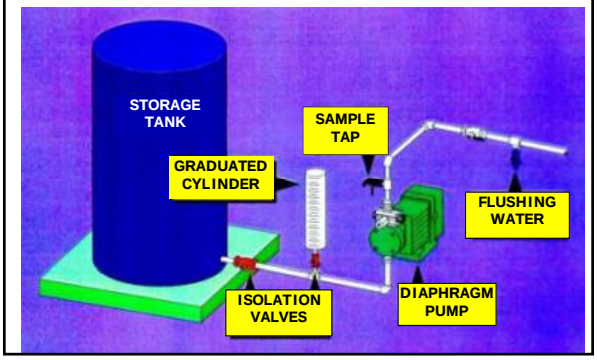
## Gas Chlorine Facilities




## Hypochlorite Feed System




## Hypochlorite Feed System With Calibration Column



## Diaphragm-Type Metering Pump


## Perastaltic Pump


## Calcium Hypochlorite Tablet Feeder

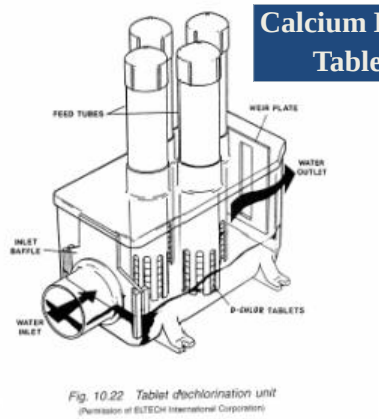


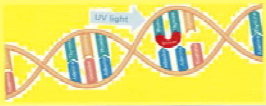

Fig. 10.22 Tablet dechlorination unit
(Permission of ELTECH International Corporation)

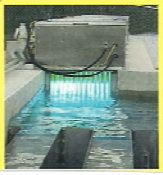
## Ultraviolet Disinfection

An Ultraviolet (UV) disinfection system transfers electromagnetic energy from a mercury arc lamp to an organism's genetic material (DNA and RNA). When the UV radiation penetrates the cell wall of an organism, it destroys (retards) the cell's ability to reproduce. UV process is purely physical.

The effectiveness of a UV disinfection system depends on:

- Characteristics of the Wastewater (particularly the concentration of particulate (i.e. TSS) and colloidal constituents)
- Intensity of UV radiation
- Length of time the microorganisms are exposed to the Radiation
- Reactor Configuration

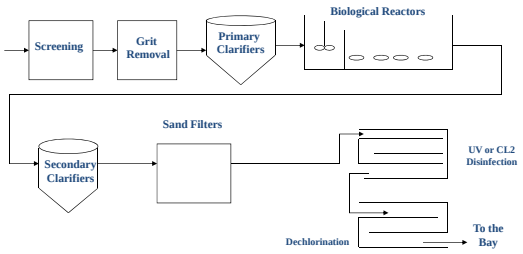


## Ultra-Violet (UV)

## Dechlorination

## Dechlorination




## De-Chlorination

- Why do we de-chlorinate ?
- Most common method
- Sulfur Dioxide (Sodium Bisulfite)
- How does it work?
- What can affect the reaction?
- Side effects of over feeding

## De-Chlorination

- Sulfur Dioxide dissolves rapidly, forming sulfuric acid:

  $SO_2 + H_2O \rightarrow H_2SO_3$

- The sulfite radical formed in this solution reacts with free and combined chlorine:

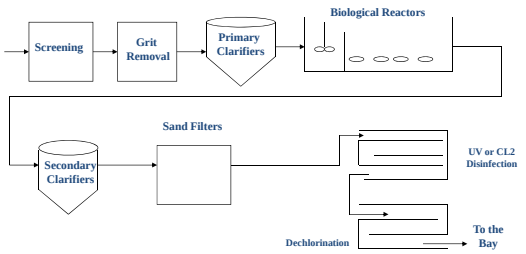
  $H_2SO_3 + HOCl + H_2O \rightarrow H_2SO_4$

  $H_2SO_3 + NH_3Cl + H_2O \rightarrow NH_4HSO_4 + HCl$

- Each reaction is rapid and complete

# Effluent Monitoring

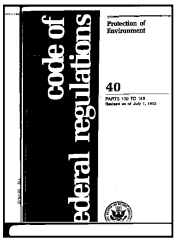
## Effluent Discharge




## NPDES Required Monitoring

Based on the NPDES Permit

- Flow
- pH / DO / Chlorine Residual
- BOD / TSS
- Fecal Coliform / E.Coli
- Nitrogen
  - Ammonia (NH3) + Organic Nitrogen = TKN
  - Nitrite (NO2) & Nitrate (NO3)
  - Total Nitrogen = TKN + NO2 + NO3
- Phosphorus
  - Total Phosphorus
  - Ortho-Phos
- Metals
- Other



## Representative Sampling

- **Grab Sample**
  - an individual sample collected (and analyzed) in less than 15 minutes.
- **Composite Sample**
  - a combination of individual samples obtained at hourly or smaller intervals over a time period. Either the volume of each individual sample is proportional to discharge flow rates or the sampling interval (for constant volume samples) is proportional to the flow rates over the time period used to produce the composite.

## Composite Sampler

## Questions?