# Wastewater Treatment Process Control: Concepts and Calculations

Thursday, May 29, 2025: 1:00 – 2:00 pm EST

environmental finance center network

Great Lakes Environmental Infrastructure Center
Environmental Finance Center for EPA Region 5

www.efcnetwork.org

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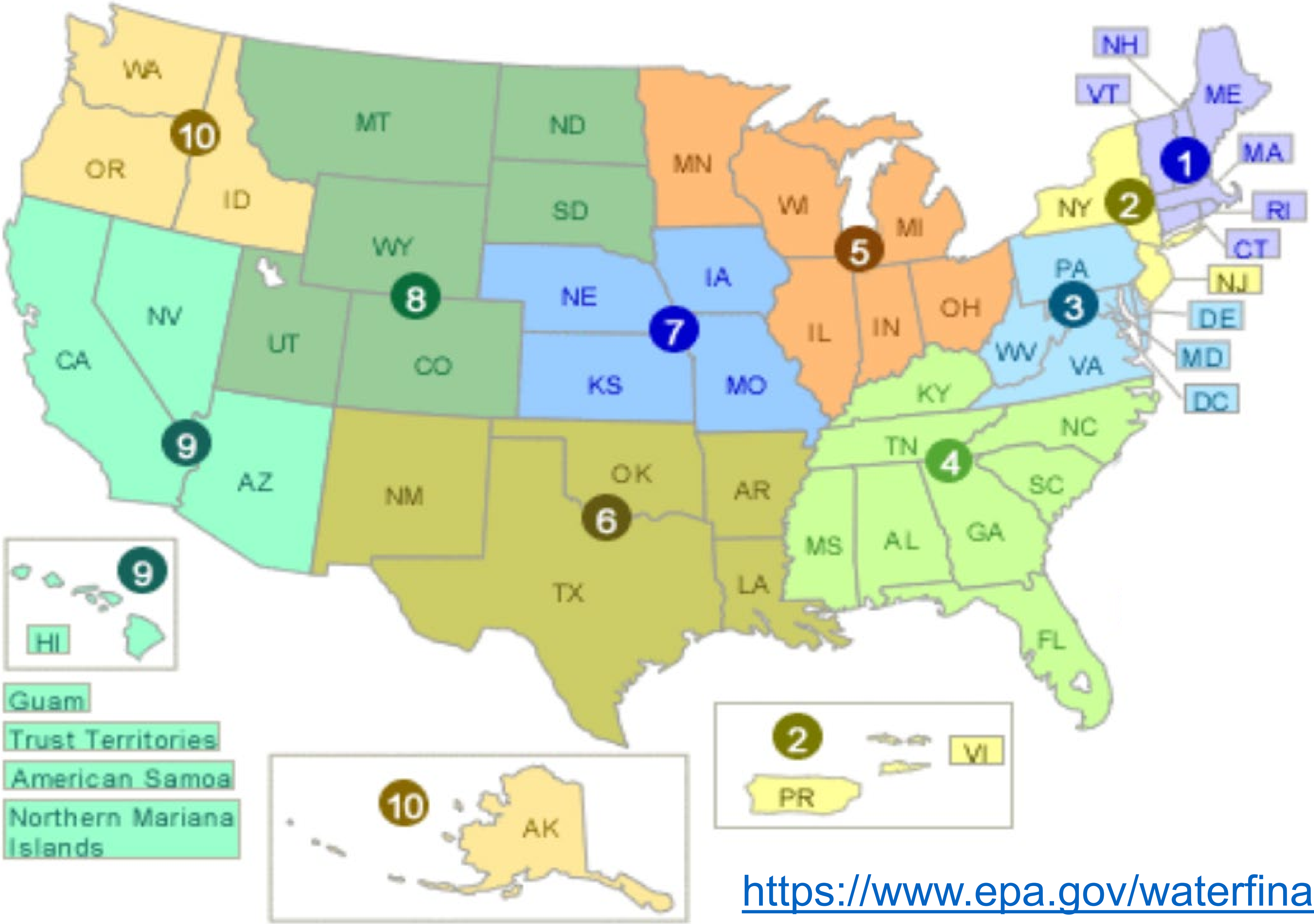
# About Us

**The Environmental Finance Center Network (EFCN)** is a university- and non-profit-based organization creating innovative solutions to the difficult how-to-pay issues of environmental protection and environmental infrastructure.

The EFCN works collectively and as individual centers to address these issues across the entire U.S, including the 5 territories and the Navajo Nation. The EFCN aims to assist public and private sectors through training, direct professional assistance, production of durable resources, and innovative policy ideas.

EFCN
environmental finance center network




https://www.epa.gov/waterfinancecenter/efcn

# Great Lakes Environmental Infrastructure Center

*Environmental Finance Center for EPA Region 5*


**Serves** small communities (population of less than 10,000) throughout EPA Region to build technical, managerial, and financial capacity through technical assistance and training.

**Located**: Michigan Technological University (MTU) Center for Technology & Training CTT).

**Gregory Pearson** – Water and Wastewater Systems Trainer and TA Provider

# What we will cover today

1. **Secondary wastewater treatment concepts**
   a) Biochemical Oxygen Demand (BOD)

2. **Activated sludge process control**
   a) Food to microorganism ratio (F/M)
   b) Mean cell residence time (MCRT)

3. **Lagoon system process control**
   a) retention time

4. **Trickling Filter process control**
   a) Organic loading
   b) Hydraulic loading

Poll 1

# Poll 1

**Which of the following statements best defines “secondary wastewater treatment”?**

a) A process that uses microorganisms to consume organic wastes.

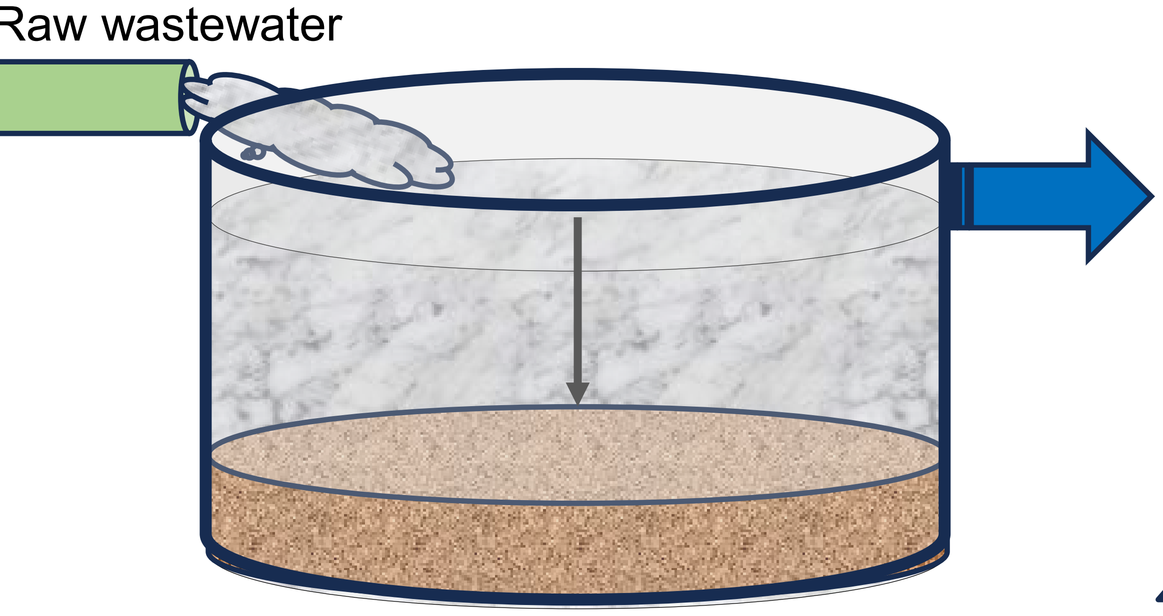
b) The second step of any wastewater treatment process.

c) A side effect of treatment that removes ammonia

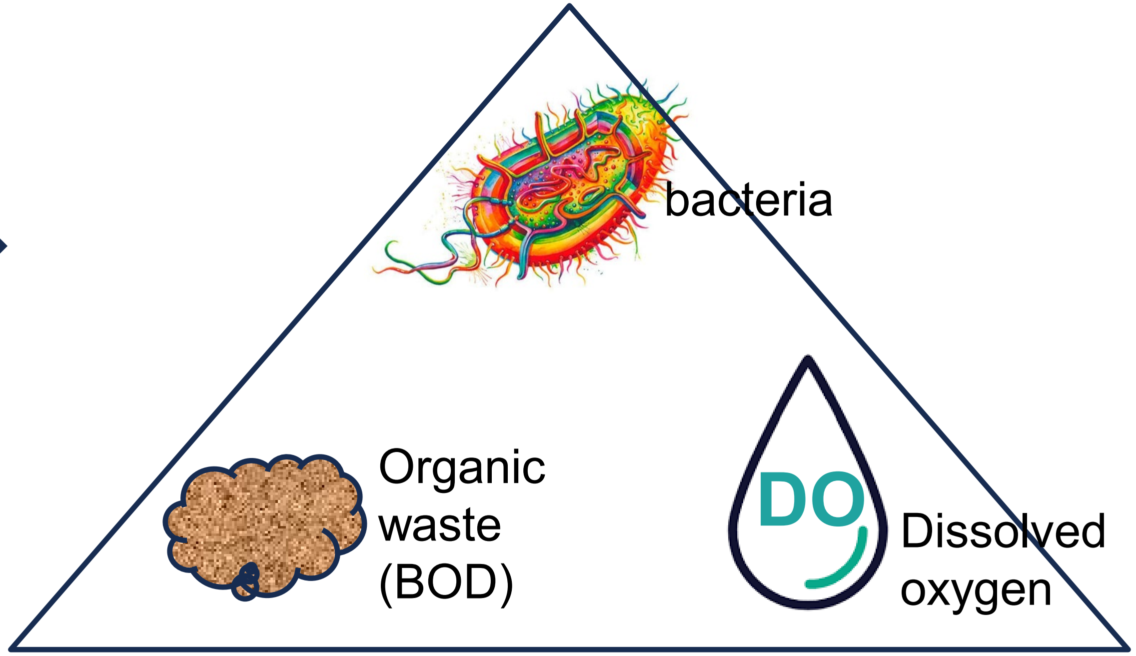
d) A process that uses coagulation and filtration.

# Secondary Wastewater Treatment Processes

- **Uses naturally occurring microorganisms to consume waste**
- Called "secondary" because it follows primary treatment (settling)
- Designed to remove BOD to protect receiving waters



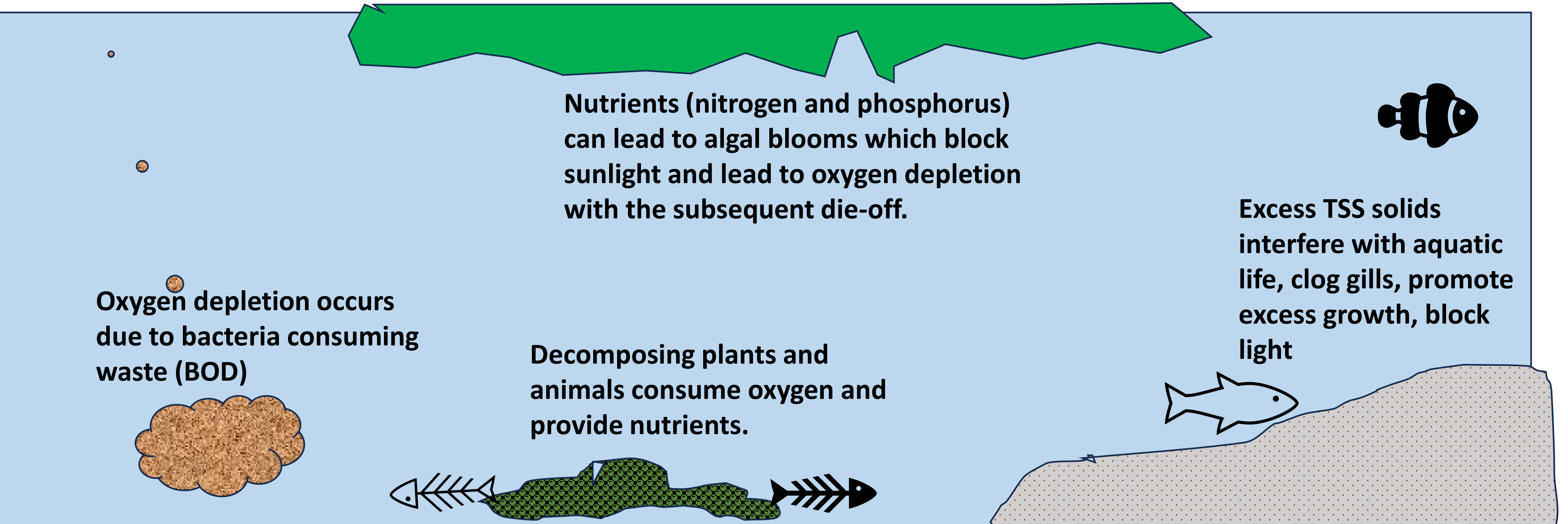

Primary treatment




Secondary treatment

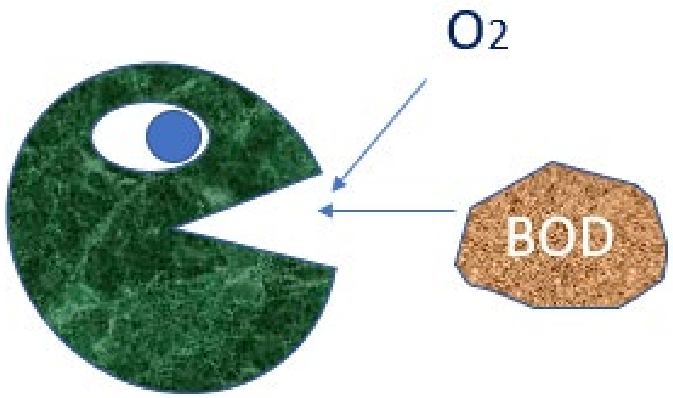
# Impacts of waste on receiving waters

Oxygen is depleted due to bacterial decomposition of wastes (BOD)



# Biochemical Oxygen Demand (BOD)

- Indicates the strength of the waste stream in mg/L of BOD
- Determined in a 5-day test that measures how much oxygen is required by microorganisms to metabolize wastes.




Microorganisms require oxygen to metabolize waste.

# BOD Test

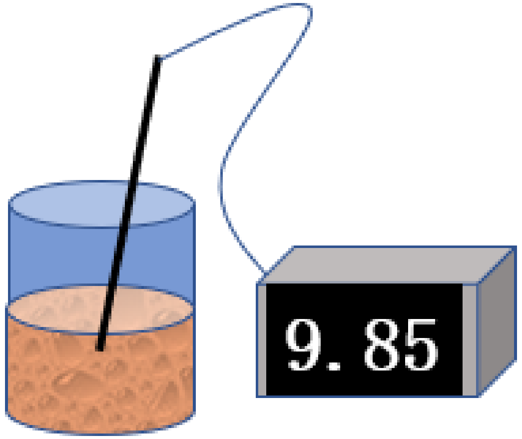
1. **A sample of wastewater is added to the test bottle** (i.e. 10 ml of sample added to the 300 ml test bottle → P = 10/300 or 0.033)

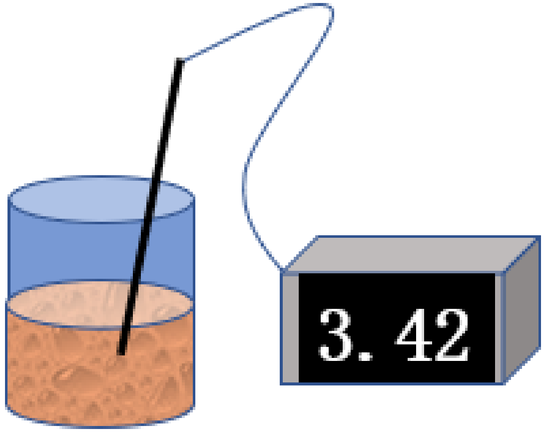
2. **The D.O. concentration is measured at the start and completion**

   9.85 mg/L – 3.42 mg/L = **6.43 mg/L**

3. **The findings are adjusted to the sample size.**

$$BOD5 = \frac{D1 - D2}{P} = \frac{6.43\ mg/L}{\mathbf{0.033}} = \mathbf{194.8\ mg/L}$$




P = decimal volumetric fraction

# Determining pounds per day of BOD

**The inflow to a wastewater plant is 2.0 MGD and the concentration of BOD is 194.8 mg/L. How many pounds/day of BOD are entering the plant?**

Pounds formula:

**Flow (MGD) x Concentration (mg/L) x 8.34 lbs/gal**

Plug in known information and multiply:

**2.0 MGD x 194.8 mg/L x 8.34 lbs/gal = 3,249.3 lbs/day**

# Understanding the pounds formula

**2.0 MGD x 194.8 mg/L x 8.34 lbs/gal = 3,249.3 lbs/day**

**Rewrite**

$$2{,}000{,}000 \text{ gal/day} \times \frac{194.8 \text{ parts}}{1{,}000{,}000 \text{ parts}} \times 8.34 \text{ lbs/gal} = 3{,}249.3$$

**Weight of 2 million gallons of water:**

2,000,000 gal x 8.34 lbs/gal = 16,680,000 lbs.

And

**The weight of the BOD is 194.8 millionths of the water weight**

$$\frac{194.8 \text{ parts}}{1{,}000{,}000} \times 16{,}680{,}000 \text{ lbs} = 3{,}249.3$$

# Activated Sludge Process

EFCN

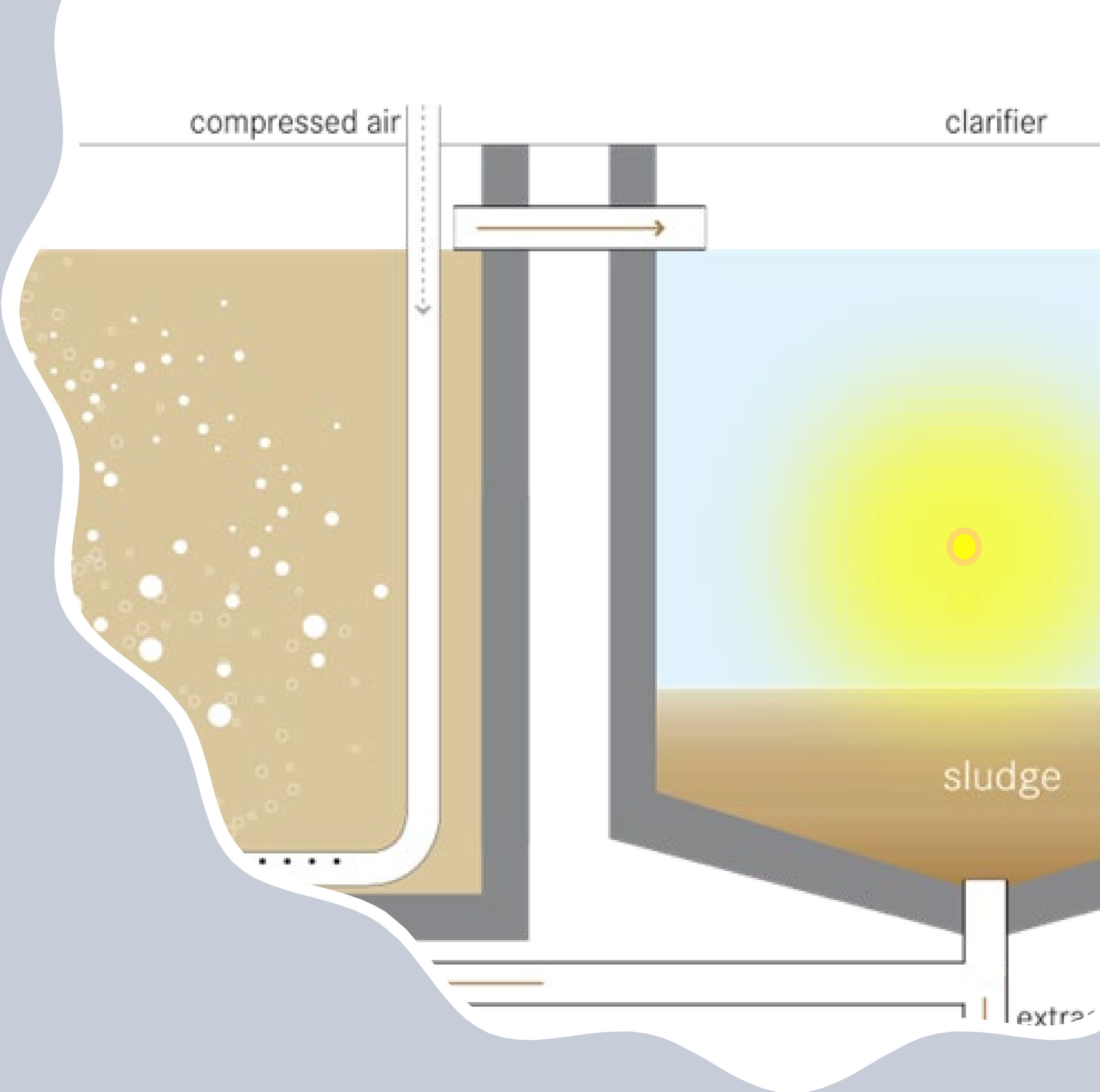
# FM Ratio and MCRT

**FM** = Lbs/day of BOD entering treatment
Lbs MLVSS in aeration tank

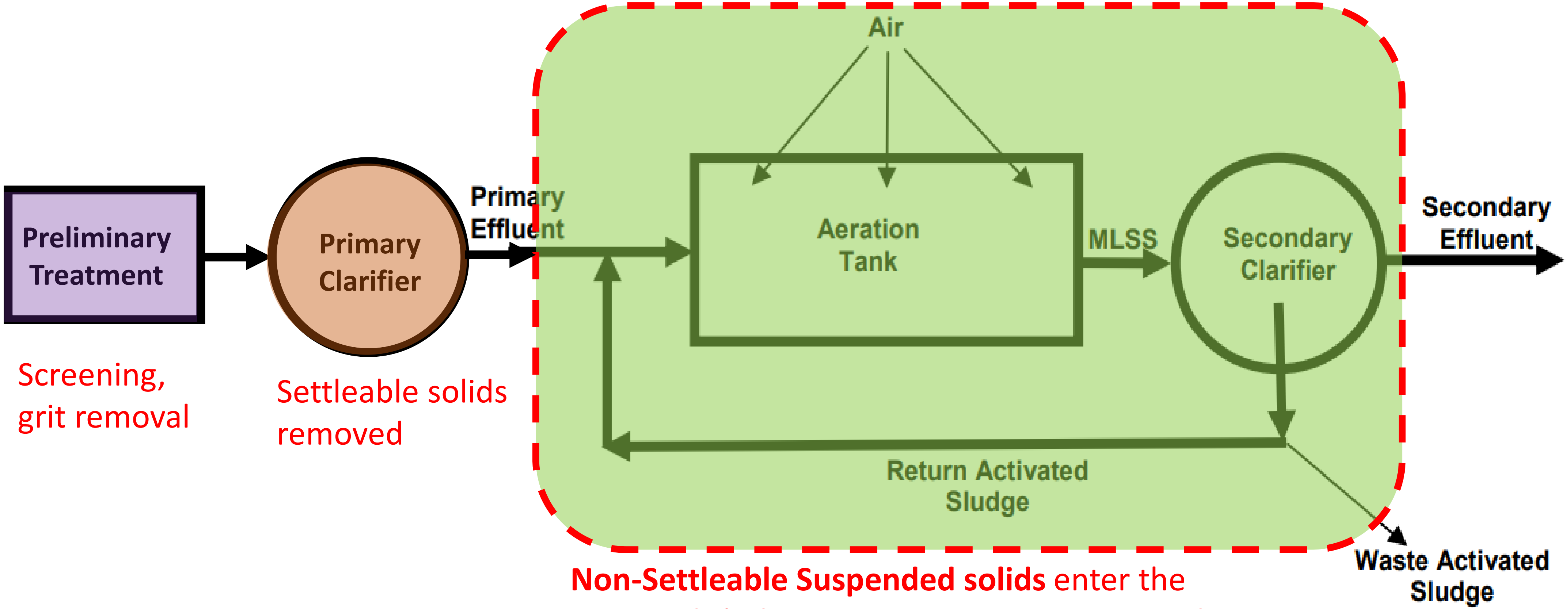
The FM ratio looks at whether there is a correct balance between influent BOD and the population of microorganisms in the aeration tank.

**MCRT** = Pounds of MLSS in the system
Lbs/day of solids leaving system

The MCRT evaluates the average time that solids remain in the activated sludge system. This affects the quantify of total solids and the age of the solids.



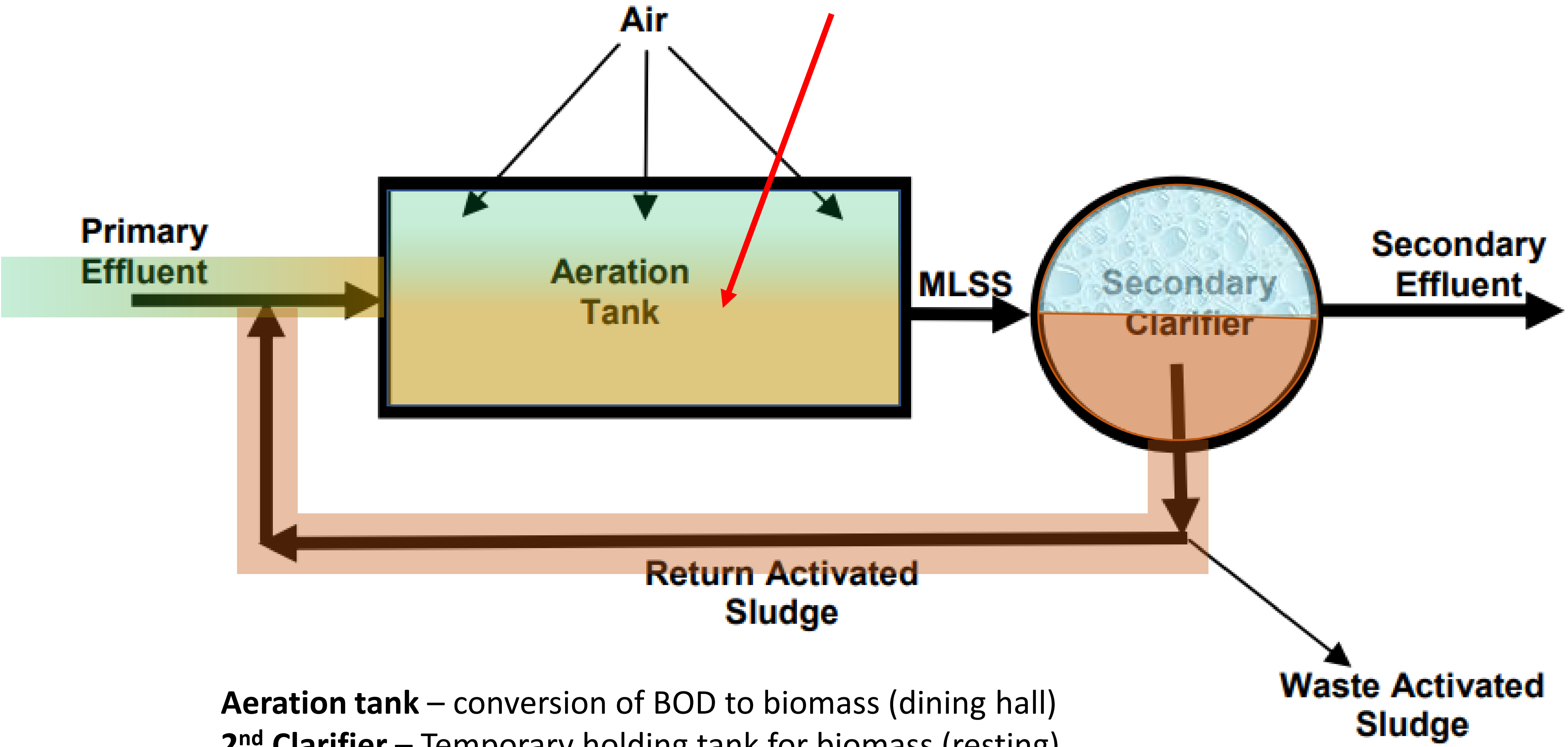
# Basic activated sludge layout




**Non-Settleable Suspended solids** enter the activated sludge process. Waste is converted to cellular biomass.

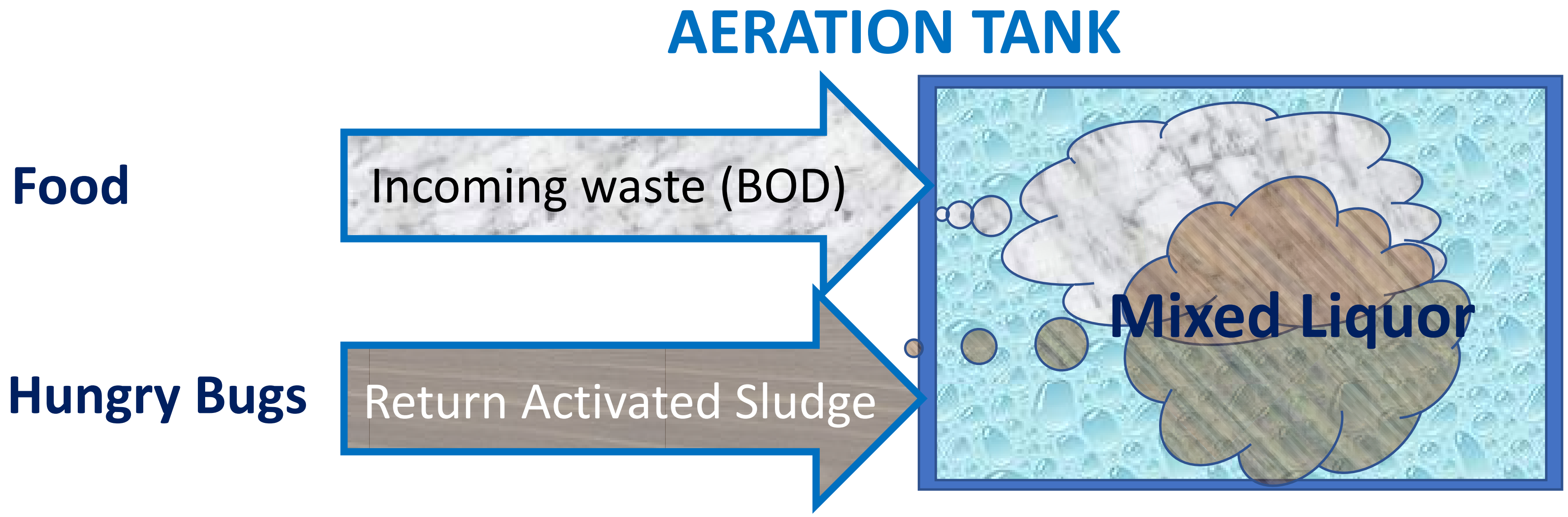
# The activated sludge process

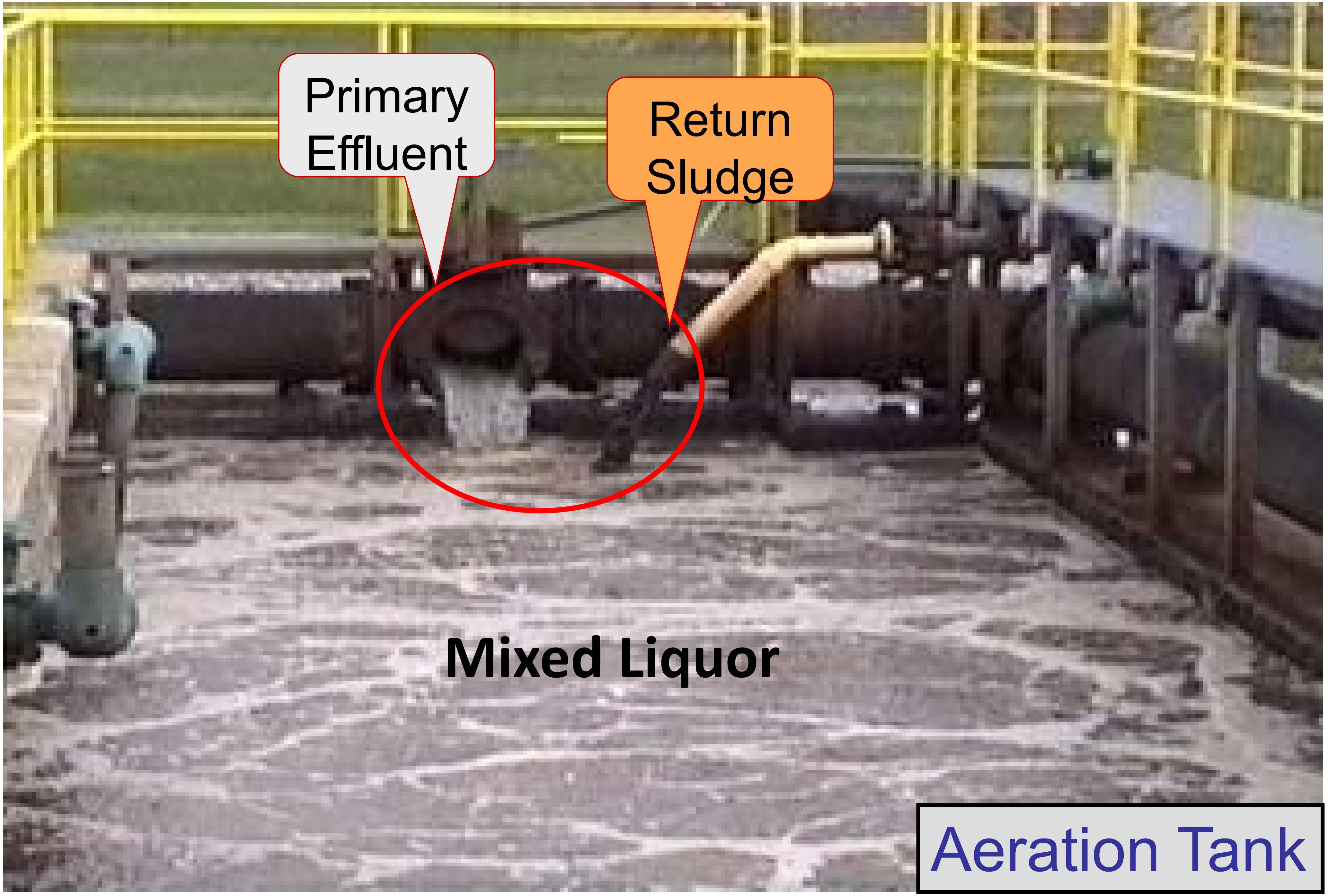
**Mixed Liquor**: Incoming wastewater is combined with return activated sludge from the secondary clarifier.

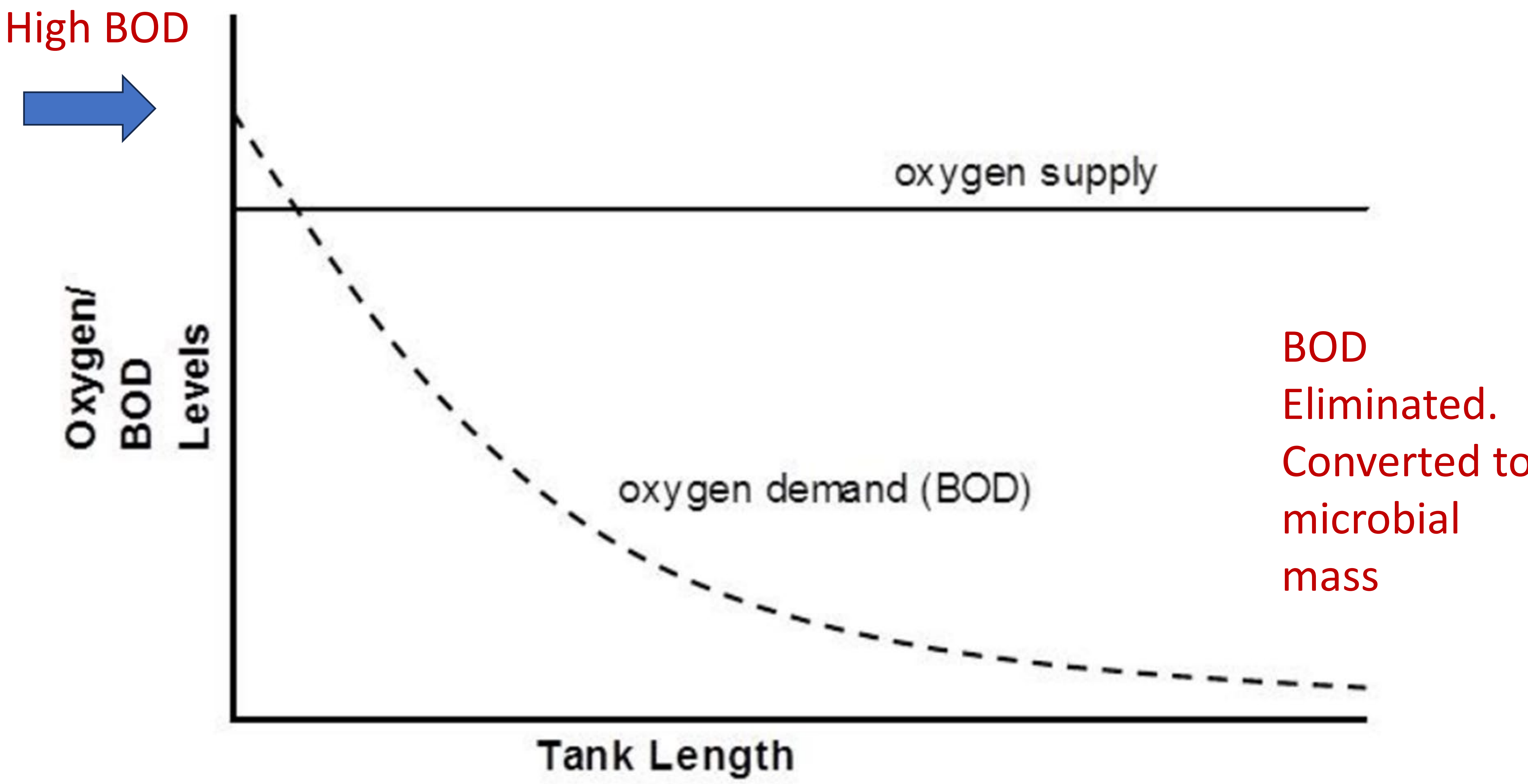



**Aeration tank** – conversion of BOD to biomass (dining hall)
**2nd Clarifier** – Temporary holding tank for biomass (resting)

# Activated Sludge System (Aeration Tank)

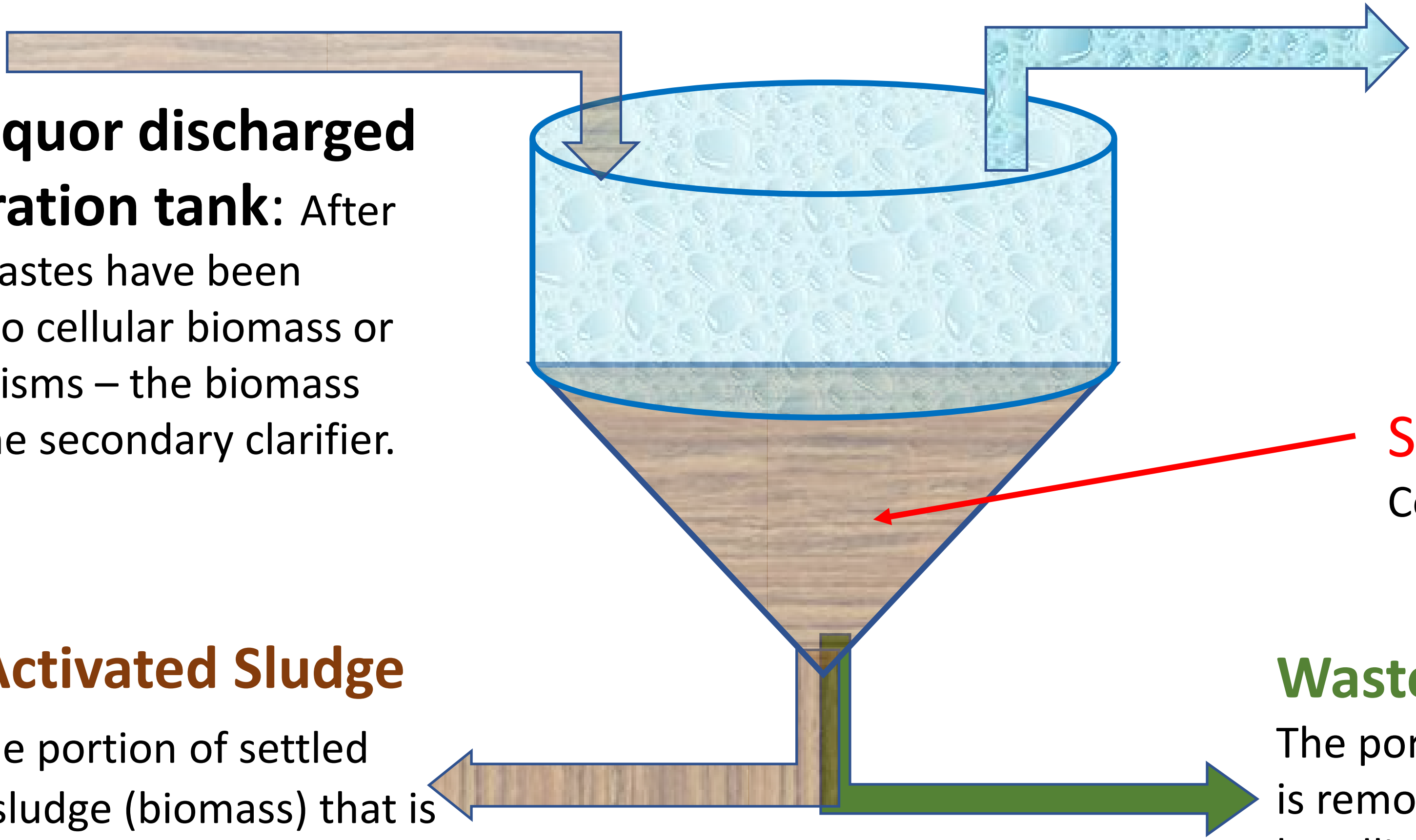



Primary Effluent
Return Sludge
Mixed Liquor
Aeration Tank


High BOD
oxygen supply
Oxygen/
BOD
Levels
oxygen demand (BOD)
Tank Length
BOD
Eliminated.
Converted to
microbial
mass

# Secondary Clarifier

# SECONDARY CLARIFIER



**Mixed Liquor discharged from aeration tank:** After aeration, wastes have been converted to cellular biomass or microorganisms – the biomass settles in the secondary clarifier.

**Final Effluent:**
The clarified water is the final effluent of the activated sludge process.

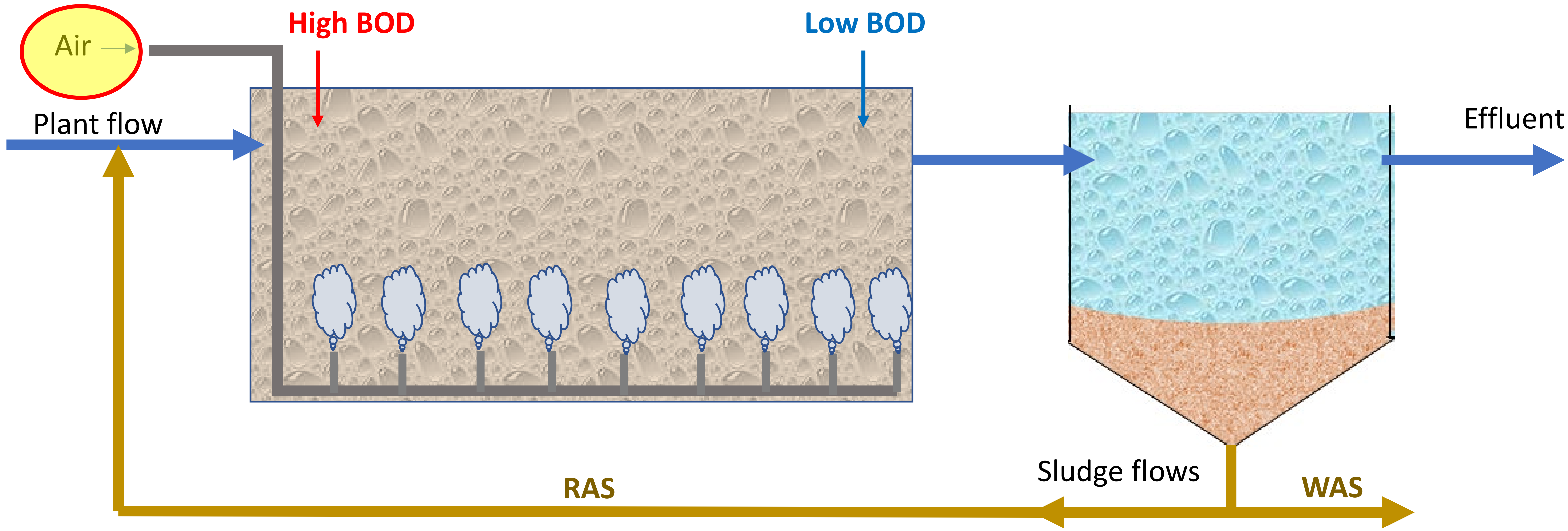
**Settled Sludge:**
Consists of hungry microorganisms

**Return Activated Sludge (RAS):** The portion of settled secondary sludge (biomass) that is returned to the aeration tank.

**Waste Activated Sludge (WAS):**
The portion of settled secondary sludge that is removed from the system. Sent to solids handling (digesters).

Diagram created by G. Pearson

# Conventional activated sludge layout

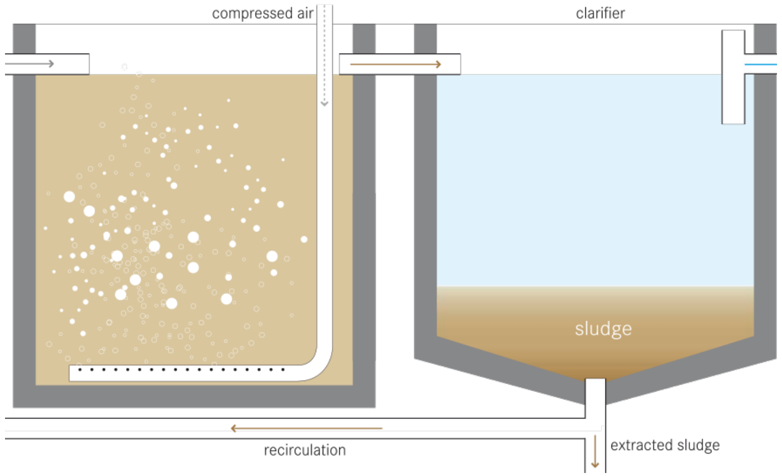



Aeration Time: Around 2 to 5 hours but solids remain in the system longer (3 to 15 days).

Poll 2

Diagram created by G. Pearson

# Typical F:M Ratios




## Conventional activated sludge

- F:M target ratio from 0.25 to 0.45
- Higher loading with food and more air

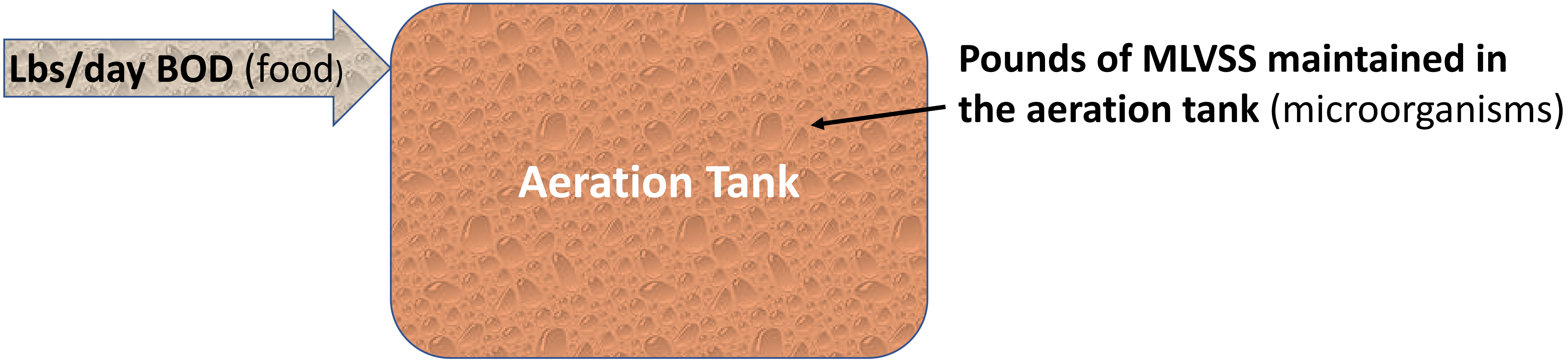
## Extended Aeration

- F:M ratio from 0.05 to 0.15
- Less food and more microorganisms

An F:M ratio of 0.25 could be thought of conceptually as 1 meal for 4 diners; and an F:M ratio of 0.05 as 1 meal for 20 diners.

# Food to microorganism ratio (F:M)

Ratio of incoming BOD (food) to MLVSS (microorganism) in the Aeration Tank.




**F:M Ratio** → $$\frac{\text{Incoming BOD}}{\text{MLVSS in tank}} = \frac{\text{Flow (MGD)} \times \text{BOD (mg/L)} \times 8.34\ \text{lbs/gal}}{\text{Volume (MG)} \times \text{MLVSS (mg/L)} \times 8.34\ \text{lbs/gal}}$$

# Poll 2

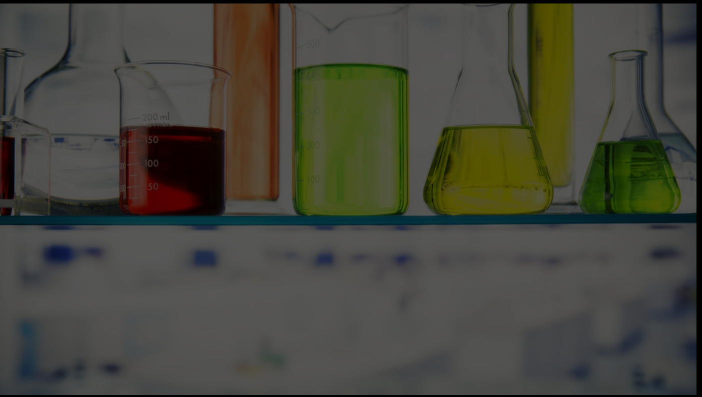
**Which of the following would help ensure sufficient biomass if influent BOD increases?**

a) Use target F:M ratio to determine required MLVSS, then adjust

b) Do nothing, MLVSS will naturally increase in proportion to BOD

c) Increase WAS flow to maximum as a precaution

d) Do all of the above



# MLSS and MLVSS

## Mixed Liquor Suspended Solids (MLSS)

- MLSS is the total concentration of all solids in the aeration tank measured in mg/L.
- Used in MCRT.

## Mixed Liquor Volatile Suspended Solids (MLVSS)

- The organic portion of Mixed Liquor Suspended Solids; typically, around 70% of MLSS
- Used as a measure of microorganisms available to consume wastes.
- Used in F:M ratio calculation

# MLSS Concentration Measurement

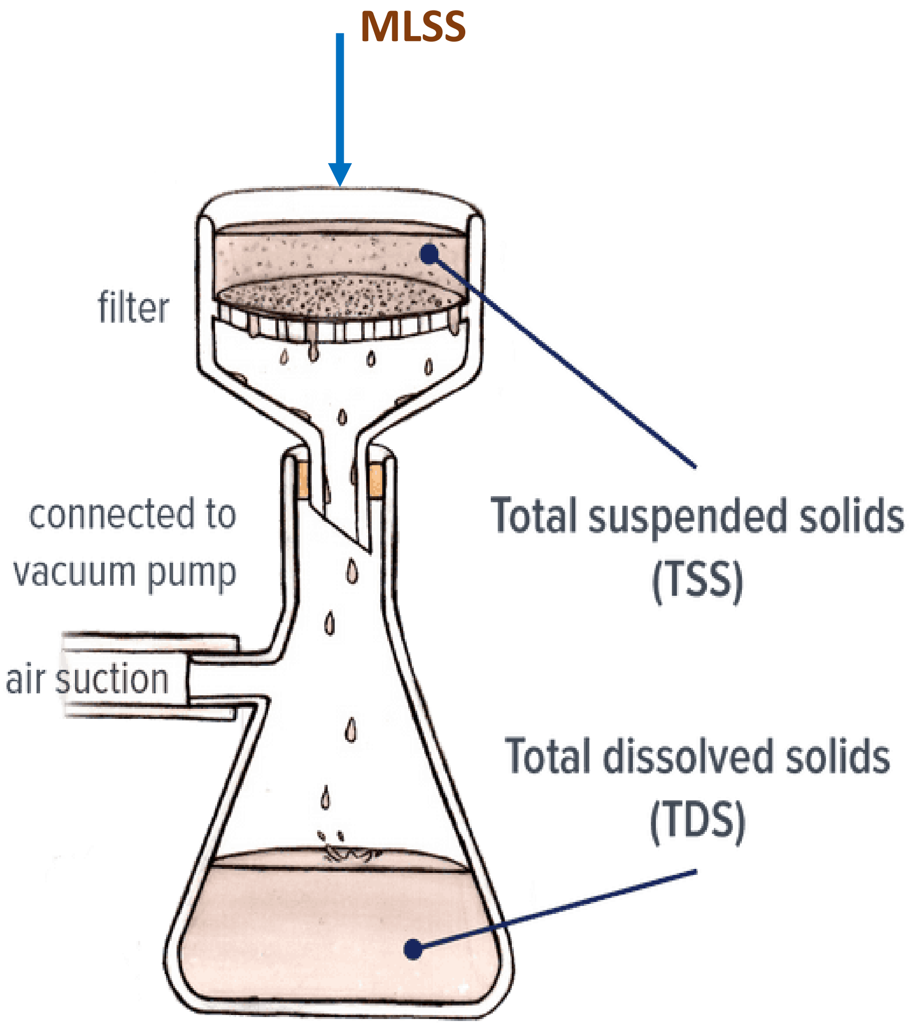
1. Sample is collected from the aeration basin.
2. A 0.45-micron filter captures suspended solids from a known sample volume
3. Solids are dried and weighed
4. Calculate MLSS concentration

**Example:**

**A 25 mL sample from the aeration tank is filtered and dried. The net dry weight of the filtered suspended solids is found to be 75 mg.**

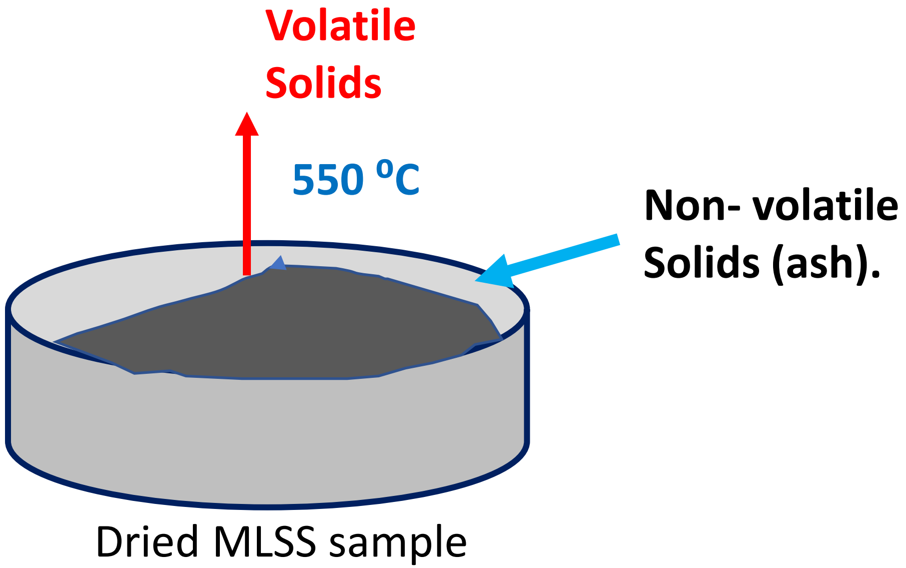
$$\text{MLSS, mg/L} = \left(\frac{\text{Net dry weight, mg}}{\text{Sample volume, mL}}\right) \times 1000\ \text{mL/L}$$

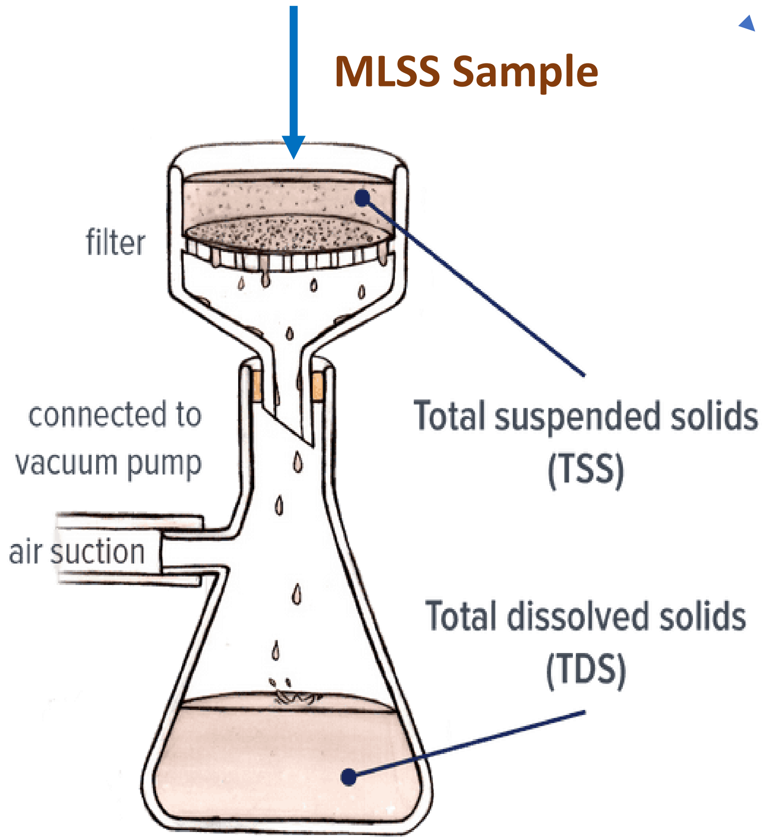
$$\text{MLSS, mg/L} = \frac{75\ \text{milligrams}}{25\ \text{mL}} \times 1000\ \text{mL/L} = 3{,}000\ \text{mg/L}$$



# Mixed Liquor *Volatile* Suspended Solids (MLVSS)

1. 0.45-micron filter captures all the suspended solids from a known sample volume.
2. Solids are dried and weighed to determine MLSS.
3. Volatile solids are burnt off by placing sample in an oven at 550 $^0$C
4. Then the sample is weighed again and MLVSS determined




**Wt of volatile solids = wt. of MLSS – wt. of ash**

**75 mg – 22.5 mg = 52.5 mg**

$$\frac{\text{Wt. of Volatile solids, mg}}{\text{Liquid Sample Volume, L}} = \text{MLVSS (mg/L)}$$

$$\frac{52.5\ \text{mg}}{25\ \text{mL}} \times 1000\ \text{ml/L} = 2{,}100\ \text{mg/L}$$

# F:M Ratio example

**Calculate the F:M Ratio for an activated sludge WWTP with the following data:**
Plant flow is 3.0 MGD. BOD concentration is 275 mg/L. MLVSS concentration is 2,200 mg/L and the aeration basin volume is 1.0 MG.

$$\frac{\text{Food (BOD)}}{\text{Microorganisms}} = \frac{\textbf{Plant Flow (MGD)} \times \textbf{BOD (mg/L)} \times 8.34 \text{ lbs/gal}}{\textbf{Tank Volume (MG)} \times \textbf{MLVSS (mg/L)} \times 8.34 \text{ lbs/gal}}$$

Step 1: Place known data for BOD and MLVSS into the formula

$$\textbf{F:M} = \frac{\textbf{3.0 MGD} \times \textbf{275 mg/L} \times \textbf{8.34 lbs./gal}}{\textbf{1.0 MG} \times \textbf{2,200 mg/L} \times \textbf{8.34 lbs./gal}} =$$

Step 2: Simplify both pounds formulas then divide to find the F:M

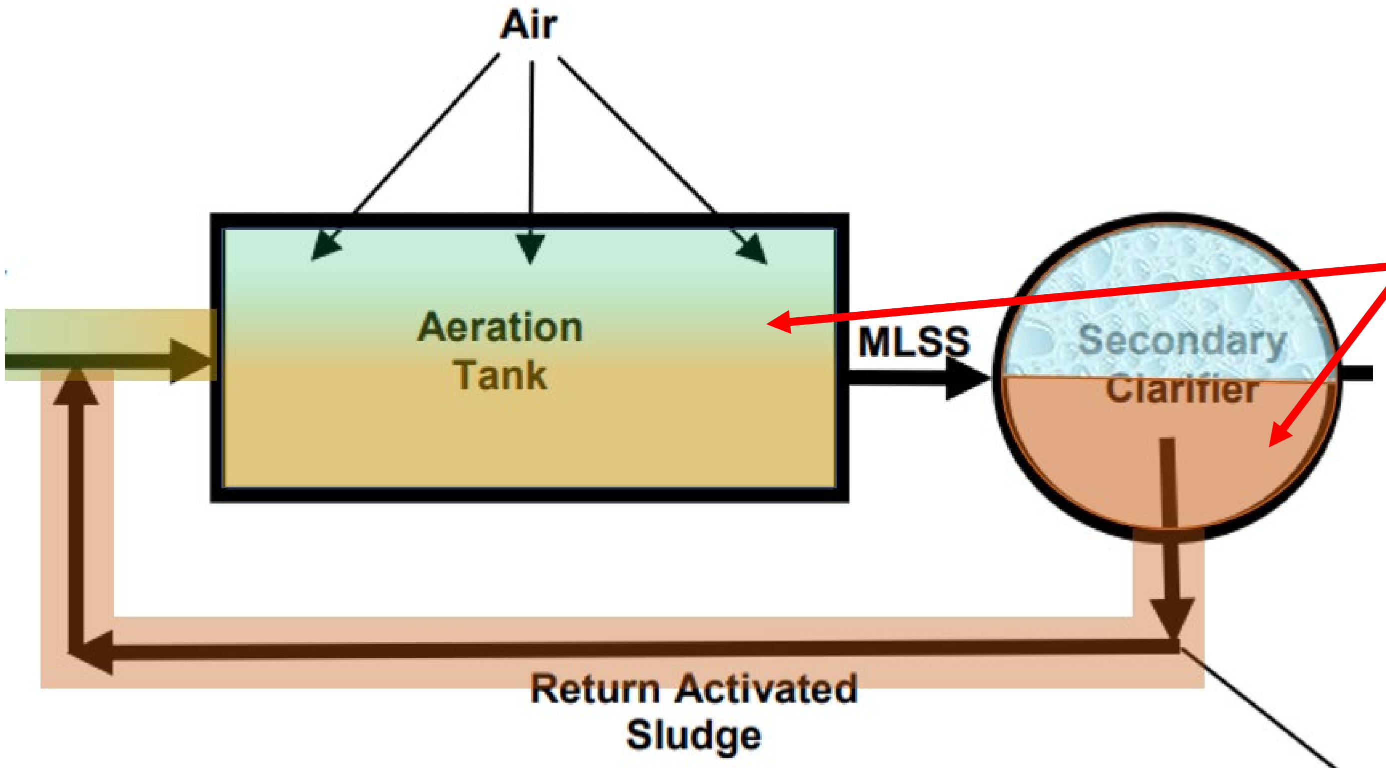
$$\textbf{F:M} = \frac{6880.5 \text{ Lbs BOD/day}}{18{,}348 \text{ Lbs MLVSS}} = \textbf{0.375}$$

Step 3: Compare the F:M ratio to the target ratio range. Is it within 0.25 to 0.45?

# Mean Cell Residence Time (MCRT)

MCRT is the average length of time in days that microorganisms (biosolids) remain in the treatment system.

$$\text{MCRT} = \frac{\text{Lbs MLSS under aeration}}{\text{Lbs/day MLSS leaving system}}$$



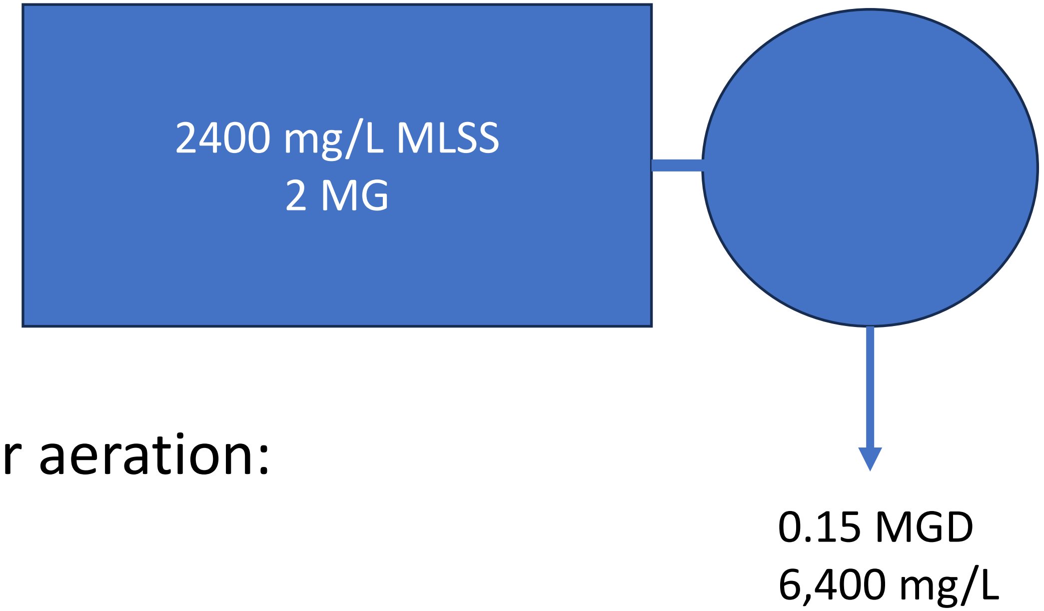

Total MLSS Solids Under Aeration

Suspended solids that are wasted per day (WAS)

**What is the MCRT in days for a wastewater treatment facility with the following parameters?**

- Aeration Volume = 2 MG | MLSS = 2,400 mg/L
- WAS Q = 0.15 MGD | WAS Conc. = 6,400 mg/L

$$\text{MCRT} = \frac{\text{Lbs under aeration}}{\text{Lbs per day wasted}}$$




**Step 1**: Use pounds formula to determine Lbs under aeration:

**2 MG x 2,400 mg/L x 8.34 lbs/gal = 40,032. lbs.**

**Step 2**: Use pounds formula to determine Lbs per day wasted

**0.15 MGD x 6,400 mg/L x 8.34 = 8,006 lbs./day**

**Step 3:** Divide to determine MCRT

40,032 lbs ÷ 8,006 lbs/day = **5.0 days**

# Mean Cell Residence Time (MCRT)

$$\text{MCRT} = \frac{\text{Pounds of Solids Under Aeration}}{\text{Lbs/day solids leaving system}}$$

Pounds of solids in aeration tank and secondary clarifier

$$\text{MCRT} = \frac{\overbrace{(\text{Aeration MG} + \text{Clarifier MG}) \times (\text{MLSS mg/L}) \times 8.34\ \text{lb/gal}}^{\text{Pounds of solids in aeration tank and secondary clarifier}}}{\underbrace{\text{Lbs/day SS in WAS}}_{\text{Pounds of suspended solids leaving as WAS}} + \underbrace{\text{Lbs/day SS in Eff}}_{\text{Pounds of suspended solids leaving in final effluent}}} = \text{Days}$$

Pounds of suspended solids leaving as WAS

Pounds of suspended solids leaving in final effluent

**Determine the MCRT of an activated sludge treatment plant given the following:**

- Aeration tank volume = 1.0 MG | Secondary clarifier operational volume: 0.250 MG
- MLSS conc = 2,050 mg/L | Plant flow: 3.25 MGD. | Effluent suspended solids: 21.2 mg/L.
- WAS flow: 0.0550 MGD. | WAS conc = 7,980 mg/L.

$$\textbf{MCRT} = \frac{(\text{Aeration tank MG} + \text{Clarifier MG}) \times (\text{MLSS mg/L}) \times (8.34\ \text{lbs/gal})}{\text{WAS(MGD)} \times \text{WAS (mg/L)} \times 8.34 + \text{Eff(MGD)} \times \text{SS(mg/L)} \times 8.34}$$

$$\text{MCRT} = \frac{(1.0\ \text{MG} + 0.25\ \text{MG}) \times 2{,}050\ \text{mg/L} \times 8.34\ \text{lbs./gal}}{(0.055\ \text{MGD} \times 7{,}980\ \text{mg/L} \times 8.34\ \text{lbs./gal}) + (3.25\ \text{MGD} \times 21.2\ \text{mg/L} \times 8.34\ \text{lbs./gal})}$$

$$\text{MCRT} = \frac{21{,}371.25\ \text{pounds MLSS in system}}{(3{,}660.4 + 574.6)\ \text{lbs./day leaving}} = \frac{21{,}371\ \text{pounds}}{4{,}235\ \text{lbs./day}} = \textbf{5.05 days}$$

# Poll 3

**An activated sludge plant has 30,000 pounds of MLSS under aeration and a wasting rate that eliminates of 5,000 lbs./day of suspended solids from the system. Estimate the MCRT in days.**

a. 18 days
b. 9 days
c. 6 days
d. 5 days

$$\frac{30{,}000 \text{ pounds MLVSS}}{5{,}000 \text{ lbs/day}} = 6 \text{ days}$$

# Process control with MCRT

$$\text{MCRT} = \frac{\text{MLSS in the aeration system (pounds)}}{\textbf{WAS (lbs./day)}}$$

$$\frac{\text{30,000 pounds}}{\textbf{5,000 lbs./day}} = \textbf{6 days}$$

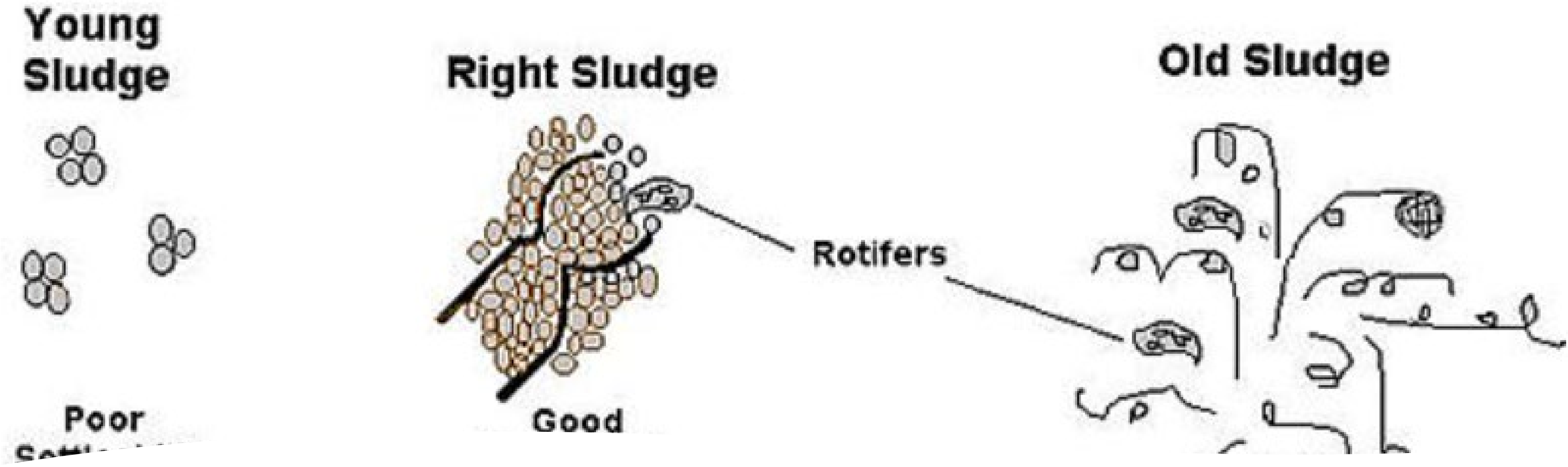
Increase WAS →

← Decrease WAS

$$\frac{\text{30,000 pounds}}{\text{6,000 lbs./day}} = \textbf{5 days}$$

Increase MCRT by decreasing the wasting rate WAS

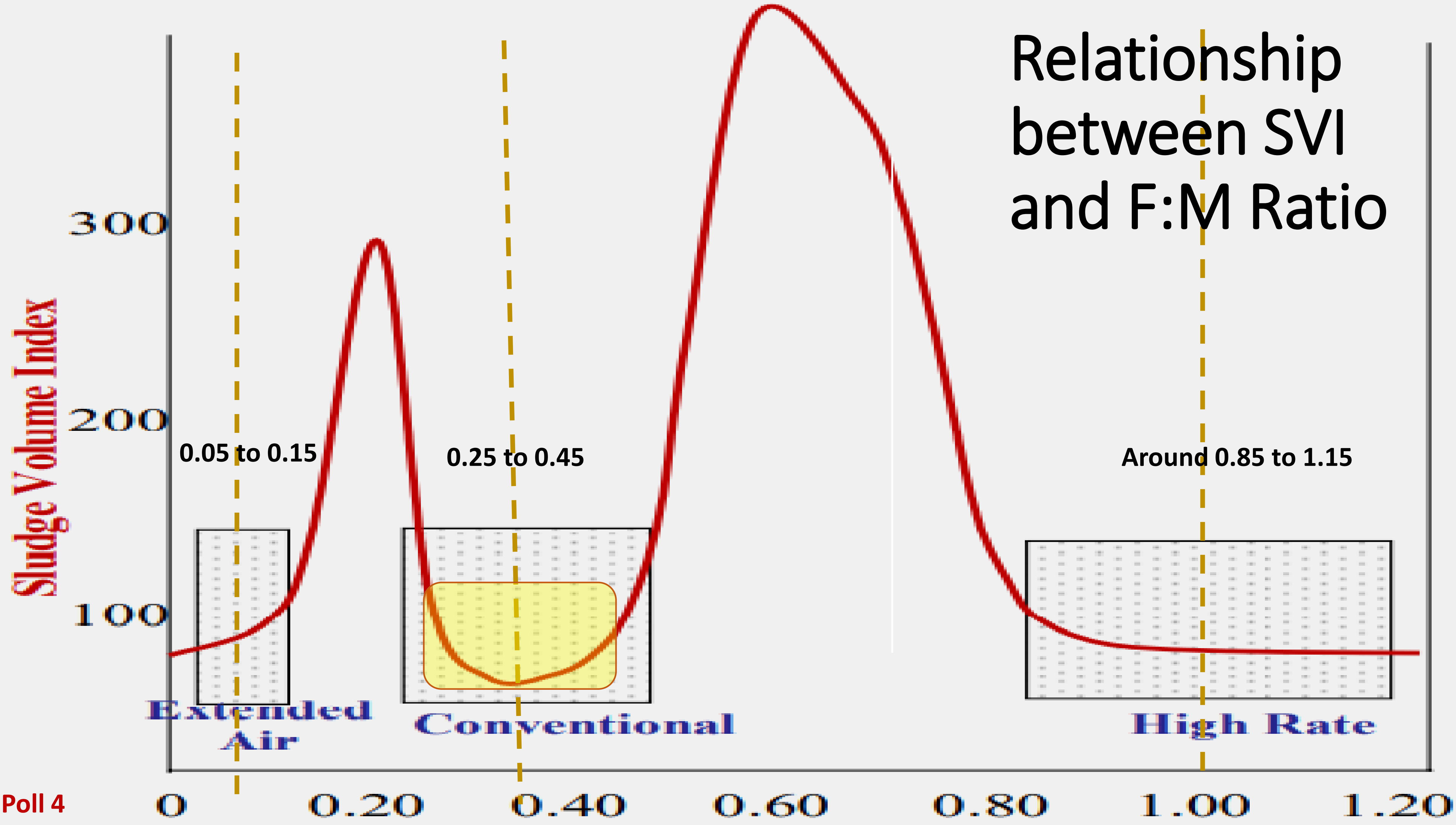
Decrease MCRT by increasing the wasting rate (WAS).




# What is the goal of using F:M and MCRT

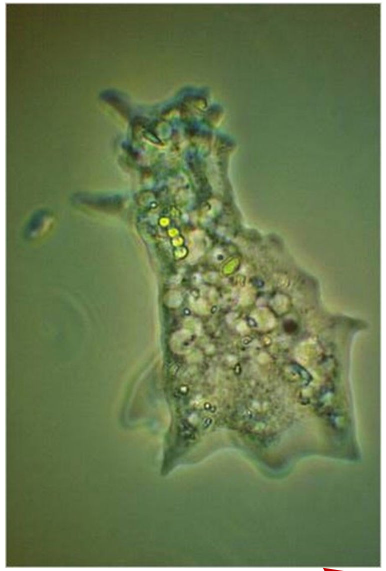
- Ensure sufficient healthy biomass for optimal treatment
- Optimize sludge settling and quality

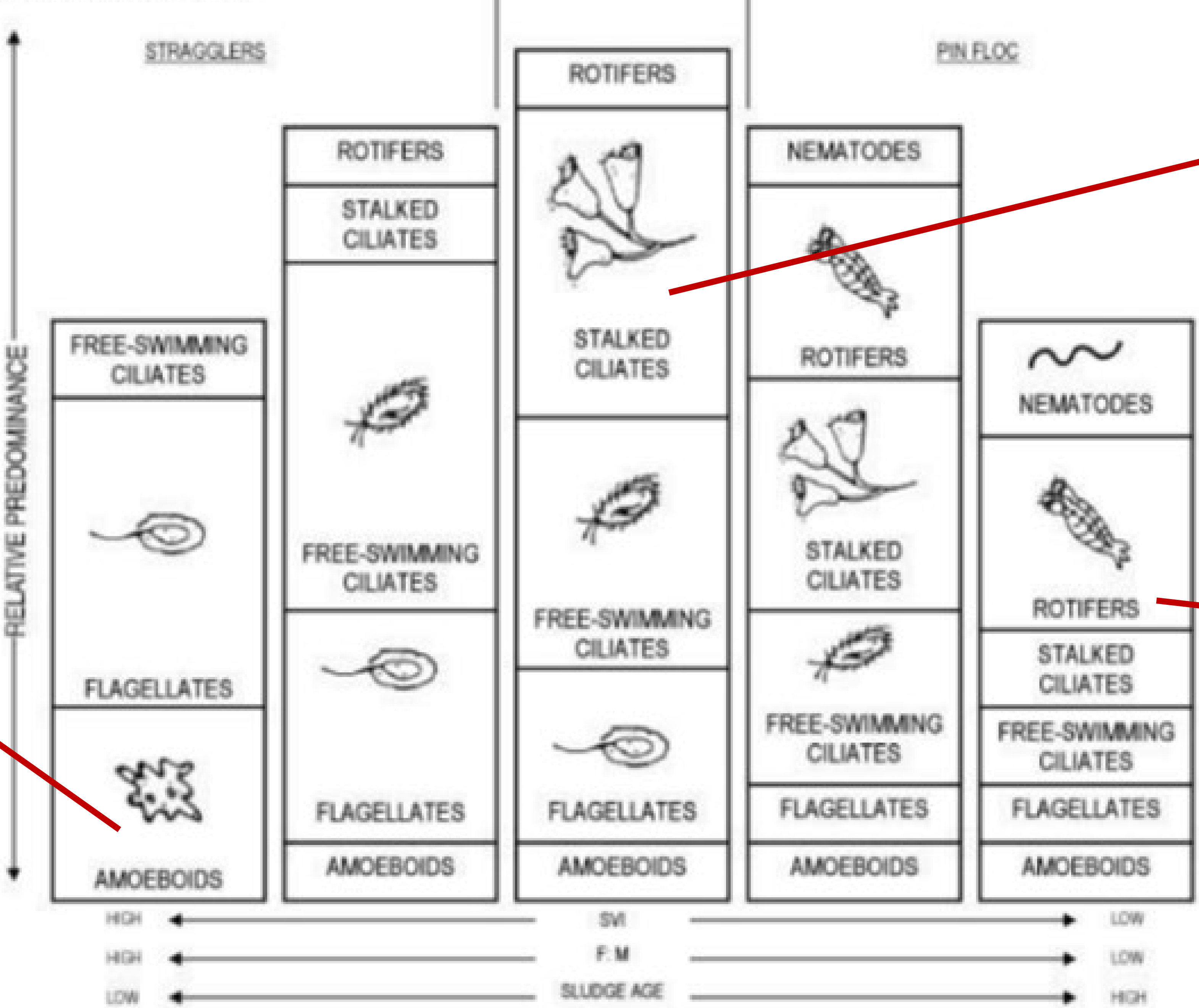
# Relationship between SVI and F:M Ratio

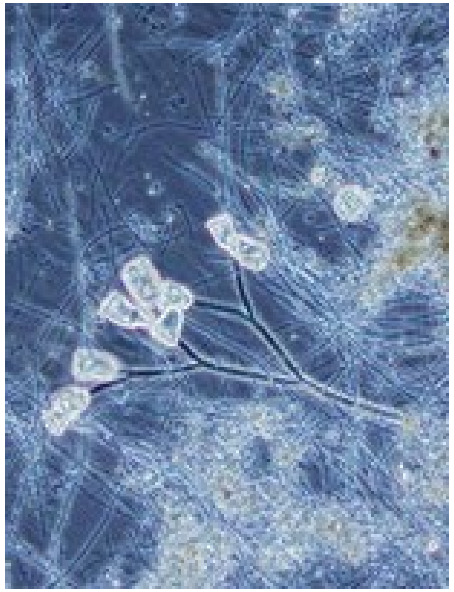



Poll 4

Courtesy of CSU Sacramento, Operation of Wastewater Treatment Plants (Vol II, 6th ed.)





# Ideal lagoon treatment

**Cell #1: Reactor Cell**

High level of aeration and mixing. Should remove 80% of BOD

**Cell #2: Nitrifying Cell**

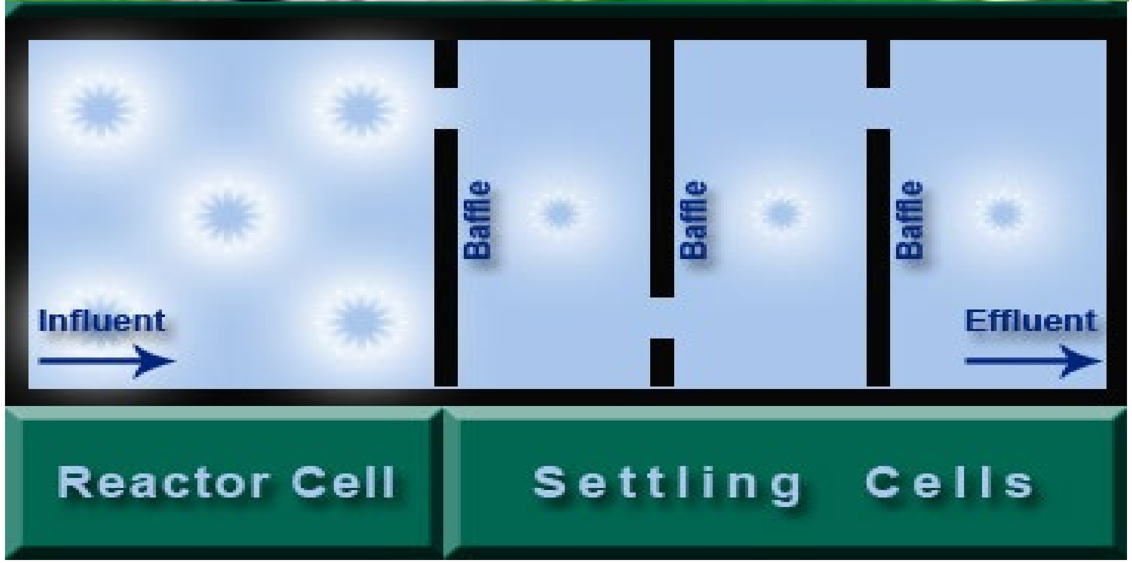
Nitrification of Ammonia

**Cell #3: Final Cell**

Polishing, settling

Requires

- Sufficient retention time
- Adequate DO levels and mixing



# Retention time

**A wastewater lagoon with a 10-ft wastewater depth is 200 ft wide and 300 ft long. The average influent wastewater flow is 0.2 MGD. What is the theoretical retention time for this cell?**

Volume of lagoon:

10ft x 200ft x 300ft x 7.48 gal/cf = 4,488,000 gallons or 4.488 MG

**Retention Time (Days)** $= \dfrac{4.488\ (\text{MG})}{0.2(\text{MGD})} =$ **22.4 days**

**But remember, this is theoretical retention time! Assuming no short-circuiting.**

# Poll 4

**A wastewater lagoon with a 10-ft depth is 200 ft wide and 300 ft long. The average influent wastewater flow is 0.2 MGD. What is the theoretical retention time for this cell with 2 feet of sludge accumulation?**

a) 3 days

b) 18 days

c) 24 days

d) 36 days

# Retention time

**A wastewater lagoon with a 10-ft depth is 200 ft wide and 300 ft long. The average influent wastewater flow is 0.2 MGD. What is the theoretical retention time for this cell with 2 feet of sludge accumulation?**

Volume of lagoon:

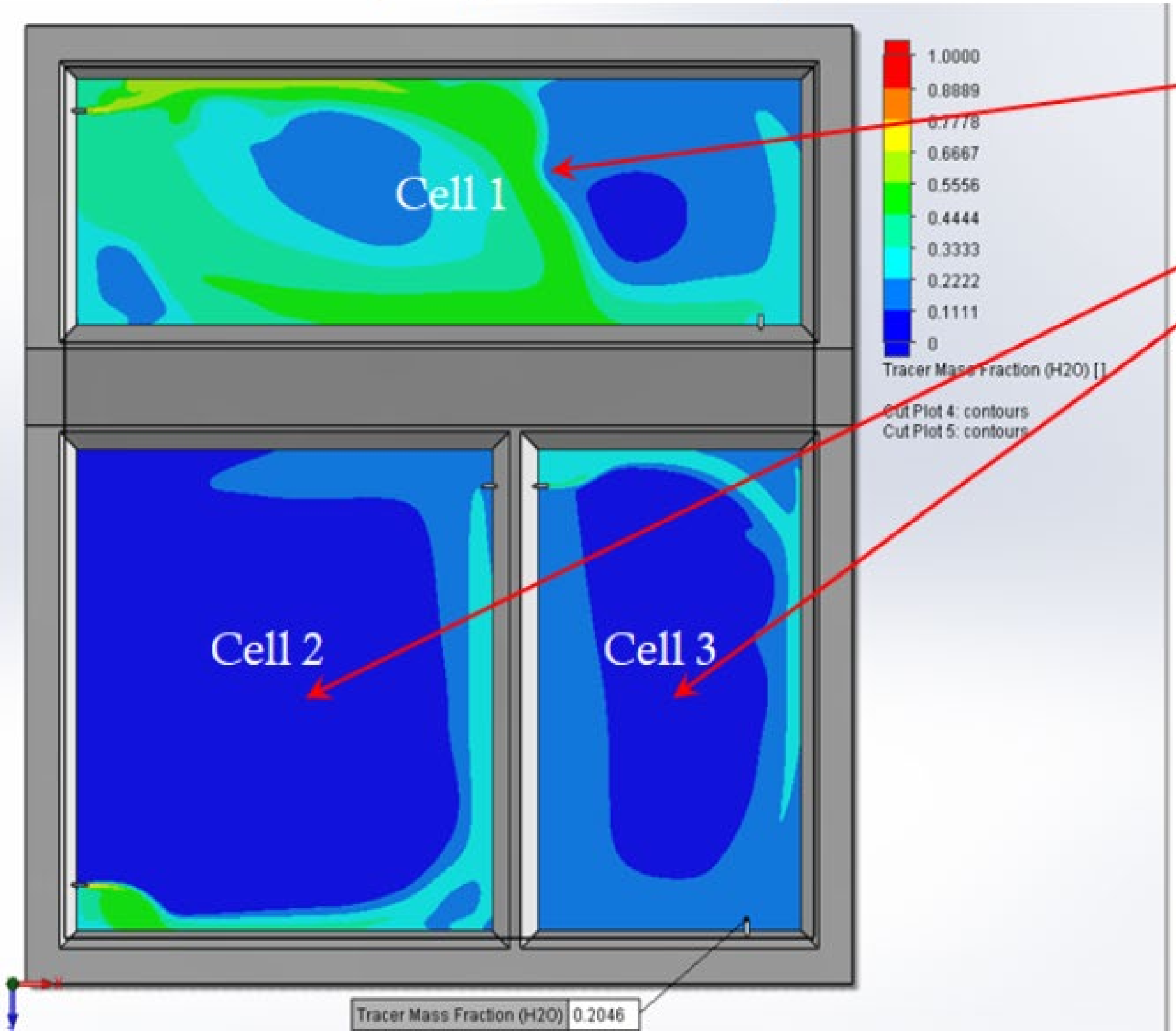
**8 ft** x 200ft x 300ft x 7.48 gal/cf = 3,590,400 gallons or 3.59 MG

**Retention Time (Days)** $= \dfrac{3.59\ (\text{MG})}{0.2(\text{MGD})} =$ **17.95 days**

**Or about 18 days**

# Flow models

Solidworks Analysis by MLC CAD Systems – Tracer Concentration




High velocities due to short circuiting (light blue and green)

Blue areas indicate unused capacity

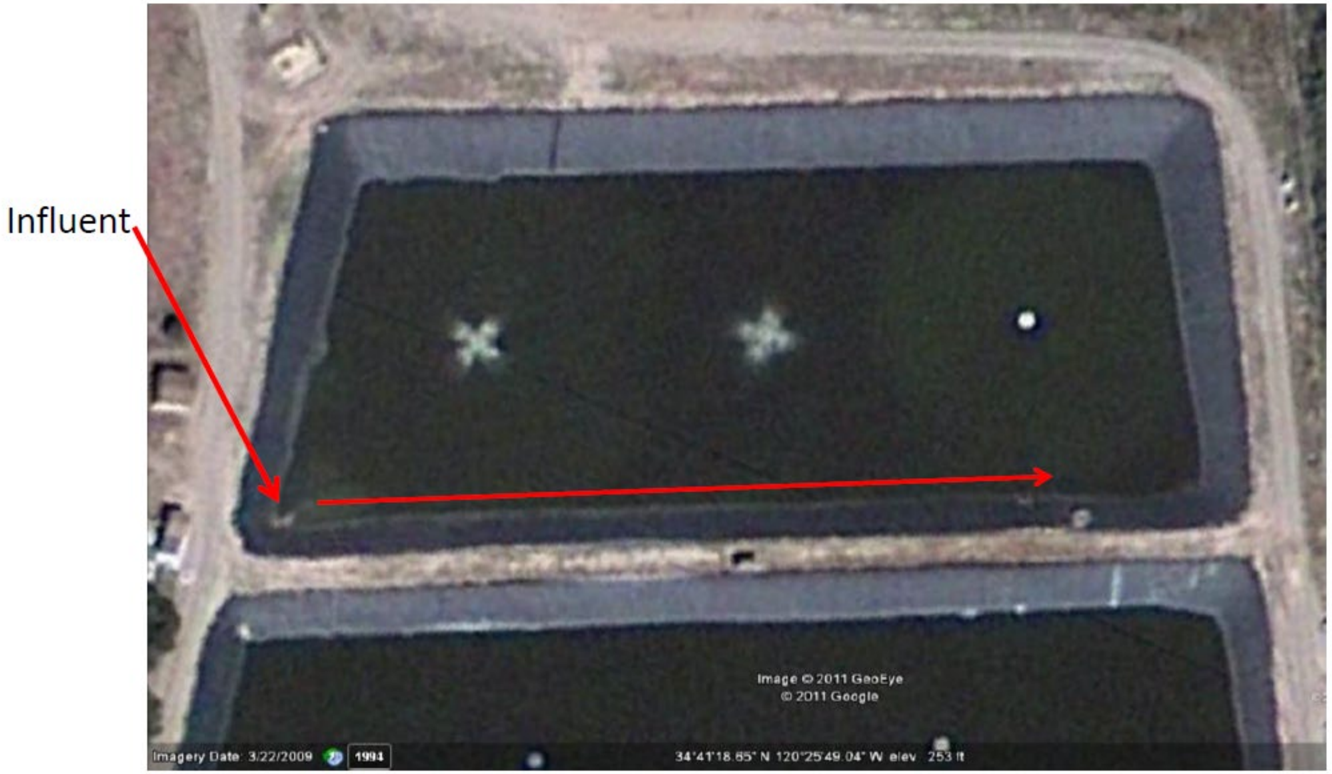
# Dissolved oxygen and temperature measurement

Measure DO and temp at multiple depths and locations throughout the lagoon to assess the degree of short circuiting and if there is sufficient DO and mixing.

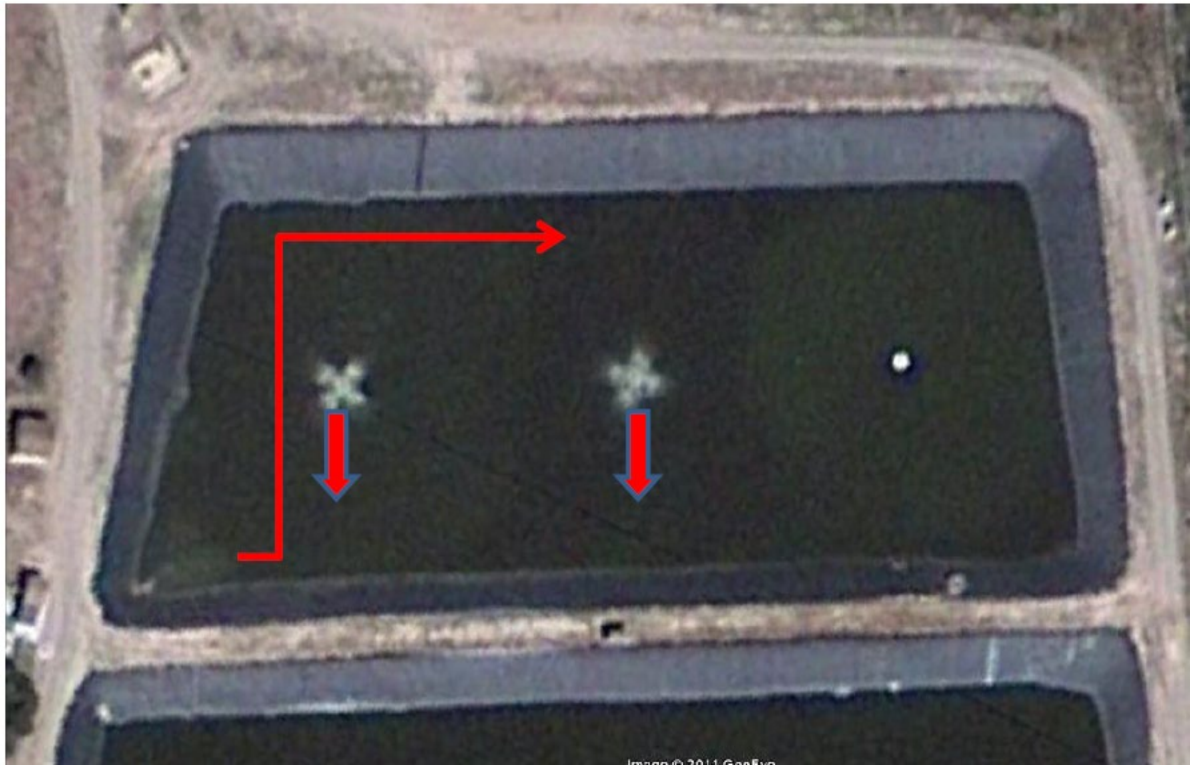

SANITARY
SEWER

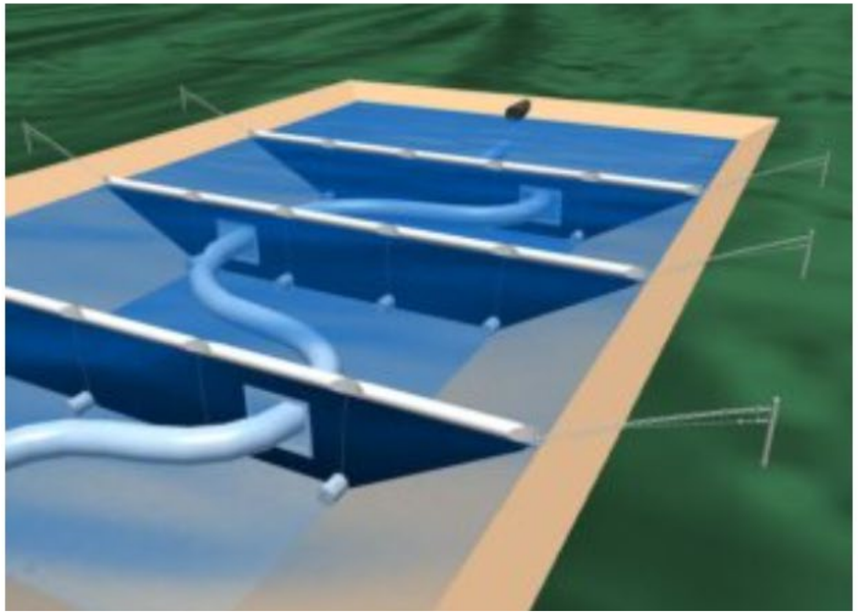

# Repositioning aerators to reduce short-circuiting

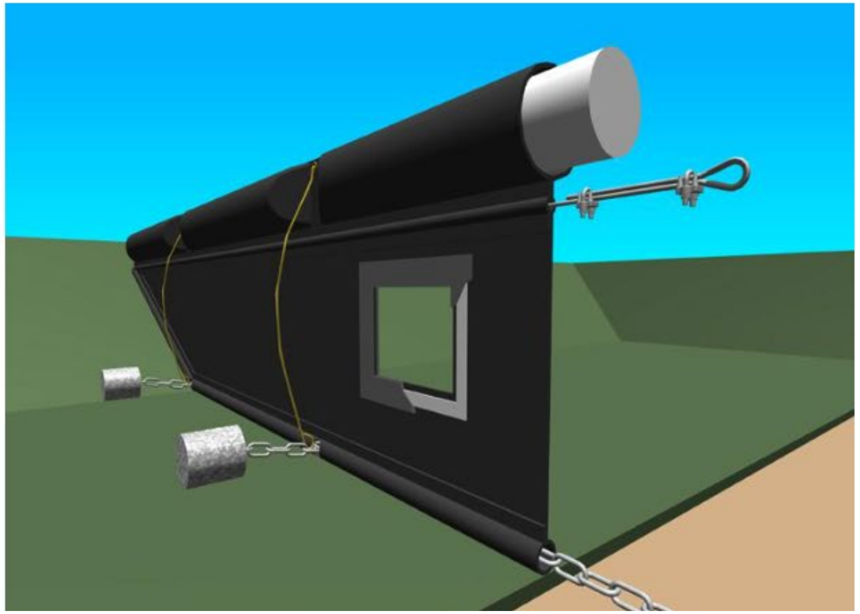
Floating object down bank toward outlet in 6 days




Aerators were repositioned which redirected flow and doubled retention time.





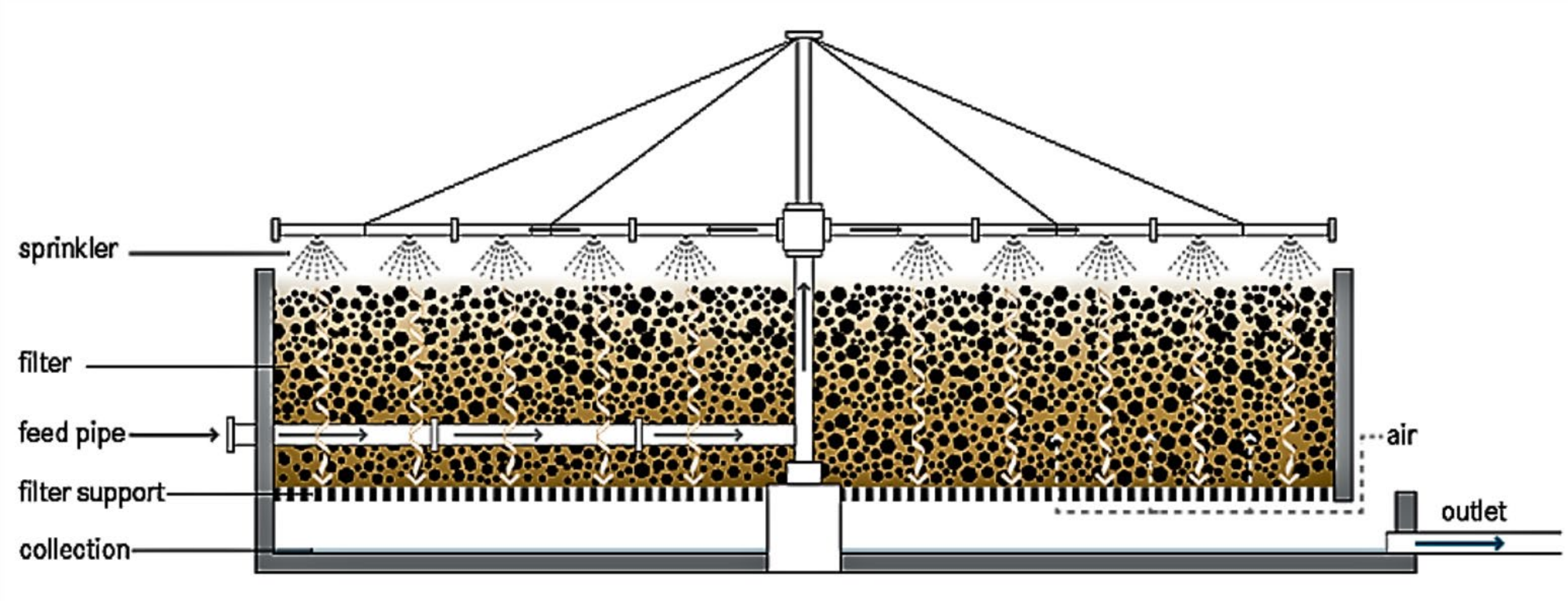


**Installing curtain baffles - Floating and anchored design.**

# Lagoons with installed curtain baffles

# Trickling Filter WWTPs

- Wastewater is sprayed over a media that facilitates attached growth biofilm
- Biofilm has an aerobic layer on the surface. Outer layer will periodically sluff off and enter effluent.
- Organic and hydraulic loading are important factors.

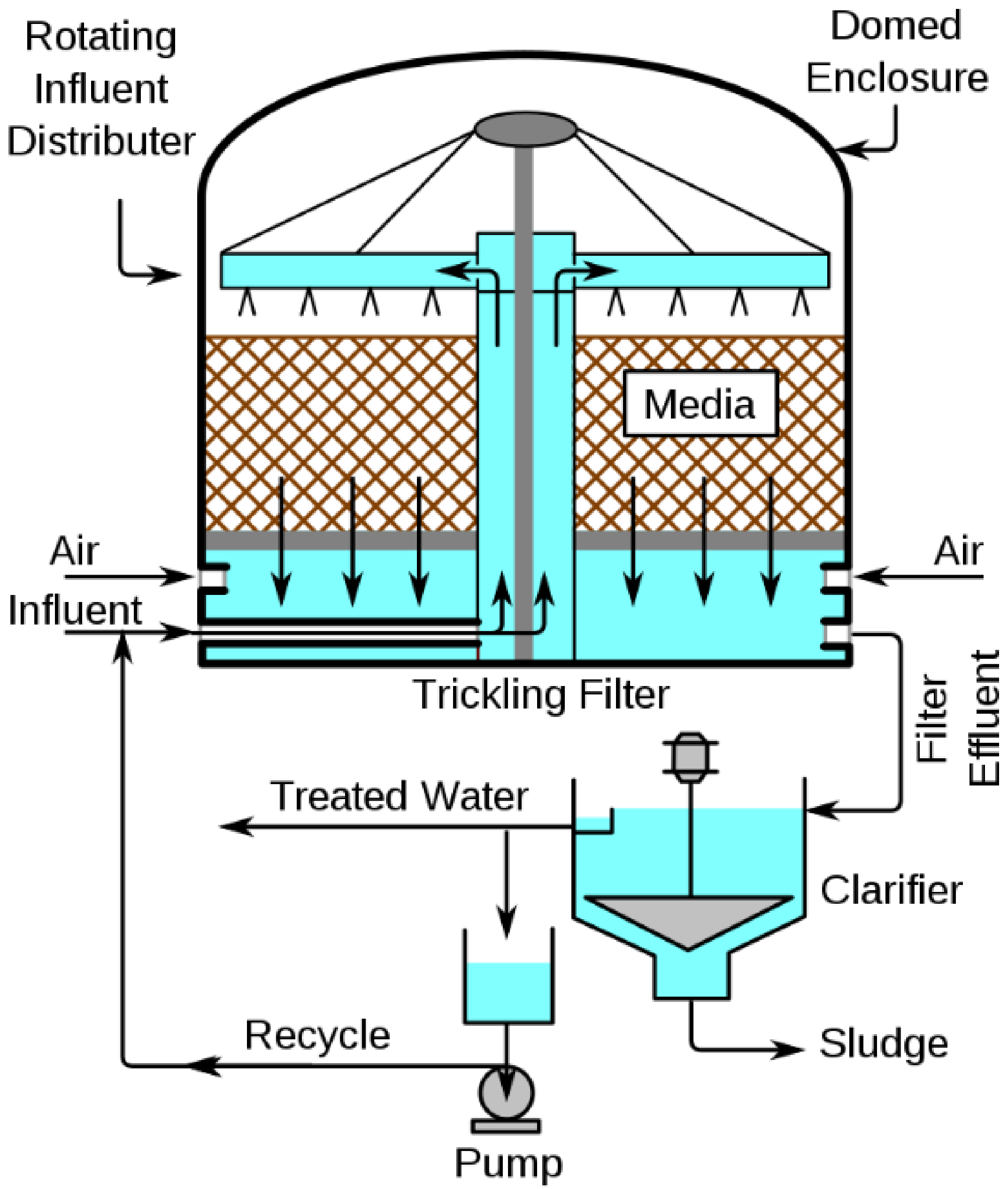


# Recirculation

**Recirculation flows bring filtered and clarified water from the secondary clarifier back to the inlet.**

**Increased recirculation**

- Decreases organic loading
- Increases hydraulic loading



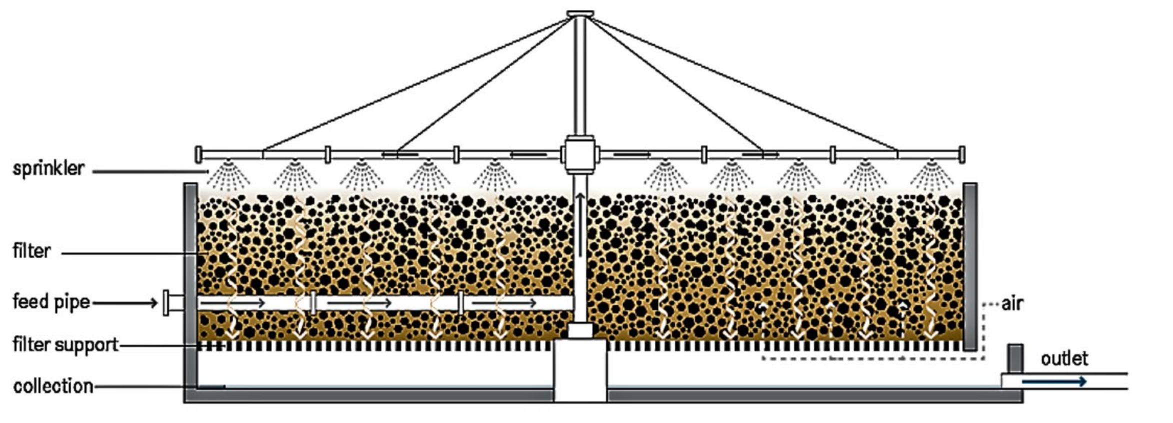
# Organic loading

**Organic Loading** = $\frac{\text{Pounds BOD/day}}{1{,}000\ ft^3}$

**Range**: from 5-25 lbs/day of BOD per 1000 cubic feet of filter media.

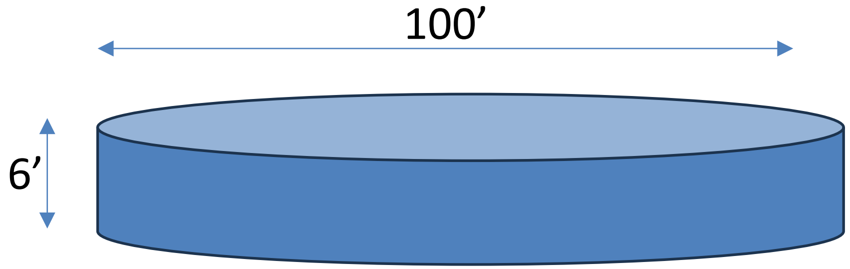
**Too high** – excessive biofilm growth and sloughing, septicity. Increase recirculation.

**Too low** – unhealthy microorganisms. Decrease recirculation



# Organic loading calculations

**A trickling filter receives a total flow of 0.85 MGD with a BOD concentration of 95 mg/L. Calculate the organic loading to this plant, in lb/day/1000 ft³, if the trickling filter has a diameter of 100 ft and a media depth of 6 ft.**




**Step 1: Pounds per day**

0.85 MGD x 95 mg/L x 8.34 lbs/gal = **673.5 lbs/day**

**Step 2: Volume of filter**

100ft x 100ft x 0.785 x 6ft = **47,100 ft³**

**Step 3: Organic loading**

$$\frac{673.5 \text{ lbs/day}}{47.1 \times 1000\text{ft}^3} = \mathbf{14.3\ lbs/day/1{,}000ft^3}$$

# Hydraulic loading rate

Typical hydraulic loading ranges from 25 - 100 gpd/ft2

- **hydraulic loading too low**: impacts to health of biofilm and septicity. Increase recirculation rate.
- **hydraulic loading rate too high**: insufficient treatment; excessive sloughing. Decrease recirculation rate.

$$\textbf{Hydraulic loading} = \frac{\text{plant flow in gallons per day}}{\text{surface area of filter in ft}^2}$$

# Hydraulic loading calculation

**A trickling filter has a diameter of 60 ft in diameter. Influent flow from the primary clarifier is 0.15 MGD and the recirculated effluent flow rate is 0.13 MGD. Calculate the hydraulic loading rate on the filter, in gpd/ft$^2$.**

**Step 1: Determine the total flow applied to the filter**

0.15 MGD + 0.13 MGD = **0.28 MGD**

**Step 2: Convert flow to gpd**

0.28 MGD x 1,000,000 gal/MG = **280,000 gpd**

**Step 3: Determine the surface area of the filter**

60 ft x 60 ft x 0.785 = 2,826 ft$^2$

**Step 4: Hydraulic loading**

280,000 gpd ÷ 2,826 ft$^2$ = **99.07 gpd/ft$^2$**

**Note:** *Hydraulic loading is within the range of 25 to 100 gpd/ft$^2$, but is on the high side*

# Poll 5

**The operator of a trickling filter plant in a resort community detects signs of excessive biofilm growth at the onset of the tourist season. What should be done?**

a) Increase the recirculation rate

b) Decrease the recirculation rate

c) Add additional BOD to stimulate the process

d) Dose the influent stream with a mild chlorine solution

**The operator of a trickling filter plant in a popular resort community detects signs of increased sloughing and ammonia levels in the effluent during the onset of the peak tourist season. What should be done?**

**a) Increase the recirculation rate**

Most likely the organic loading has increased due to more people in the community leading to more BOD. Increasing recirculation will dilute the BOD coming in and reduce organic loading.

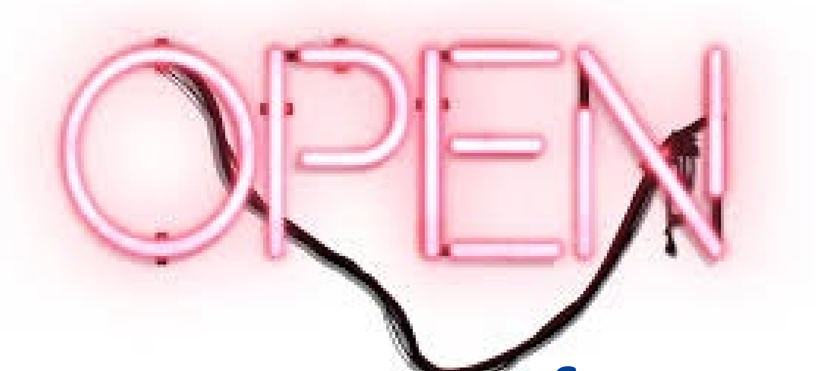
## What we covered today

Essential math calculations necessary for process control of wastewater treatment processes.

- Food to Microorganism Ratio
- Mean Cell Residence Time
- Retention time (lagoons)
- Organic and hydraulic loading of trickling filters

# Thank you for participating!

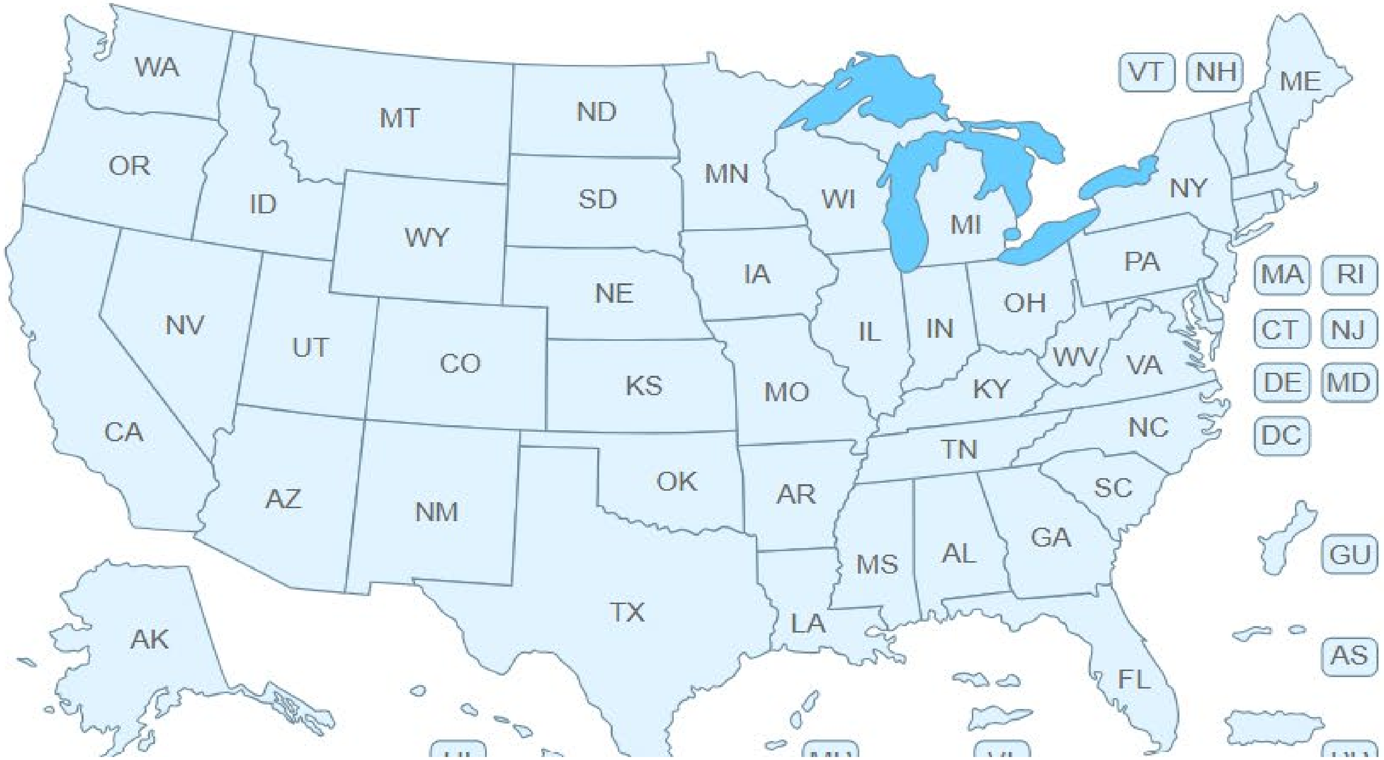
Share 1 thing you enjoyed learning about today in the chat.




We’re now open for questions!

# Funding Sources By State Or Territory

We work with state and federal agencies to make sure that current funding opportunities are consolidated in one place. Click the map below to find water and wastewater infrastru
funding sources for your state or territory.



# Resources and contact info

**Environmental Finance Center Network**

- www.efcnetwork.org
- Events, tools, educational resources, technical assistance

**Great Lakes Environmental Infrastructure Center**

- https://gleic.org
- Email: gpearson@mtu.edu