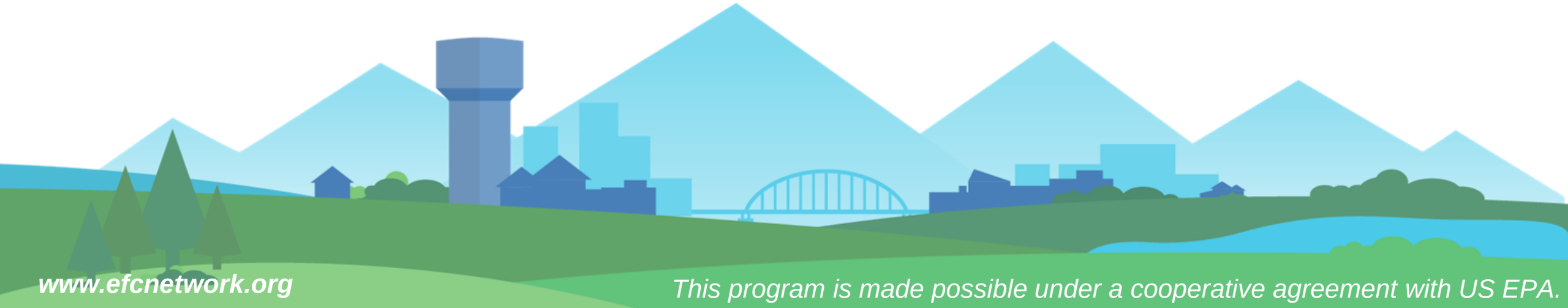
Activated Sludge Process Control Calculations

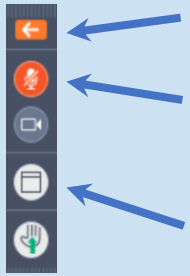
Tuesday, May 14, 2024



This program is made possible under a cooperative agreement with US EPA.

Logistics

Opening the control panel



Show your control panel

All phones/microphones are muted for the duration of the webinar

Toggle between full screen/window screen view

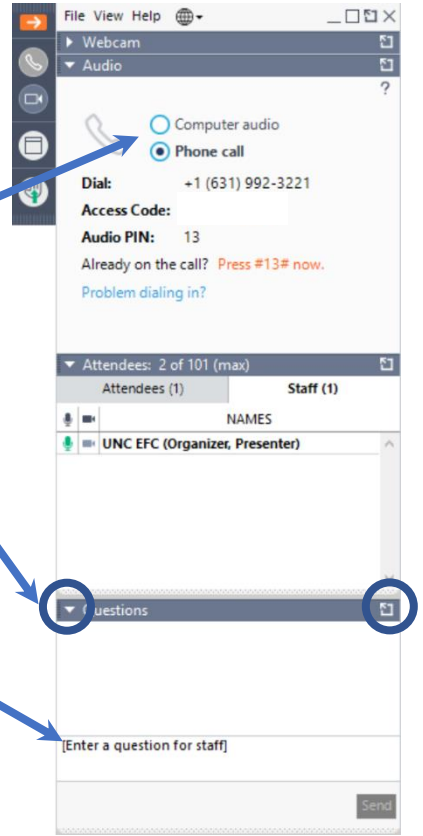
Using the control panel

Audio: please choose between computer audio or phone call

If you do not hear audio right now, please check your speaker volume or enter #[your Audio PIN]# if using phone

Click to open in Control Panel

Submit **questions** in the Questions box at any time, and press [Send]



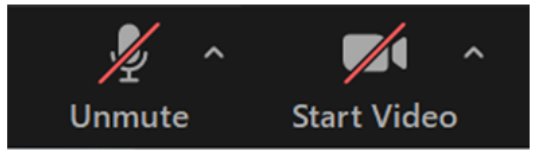
Click to open in separate box and resize

Zoom Logistics

Audio/Webcam Settings

Mute, Unmute, select your audio source, or test audio settings.

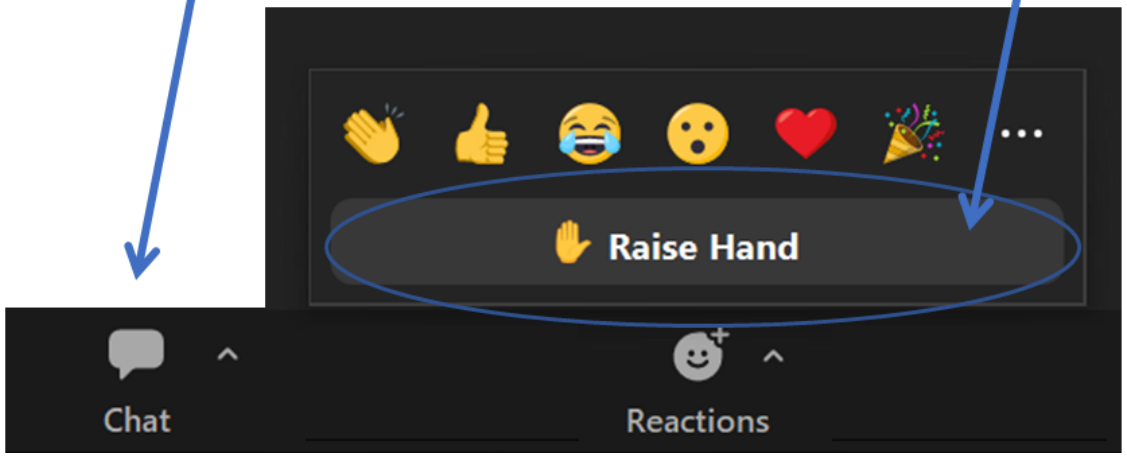
Turn webcam on or off



Asking a Question

Type questions into the chat box any time throughout the session

If you would like to unmute to ask a question, please **raise your hand** under the **Reactions** tab.



Certificate of Completion

This session has NOT been submitted for pre-approval of Continuing Education Credits, but eligible attendees will receive a certificate of attendance for their personal record.

To receive a certificate:

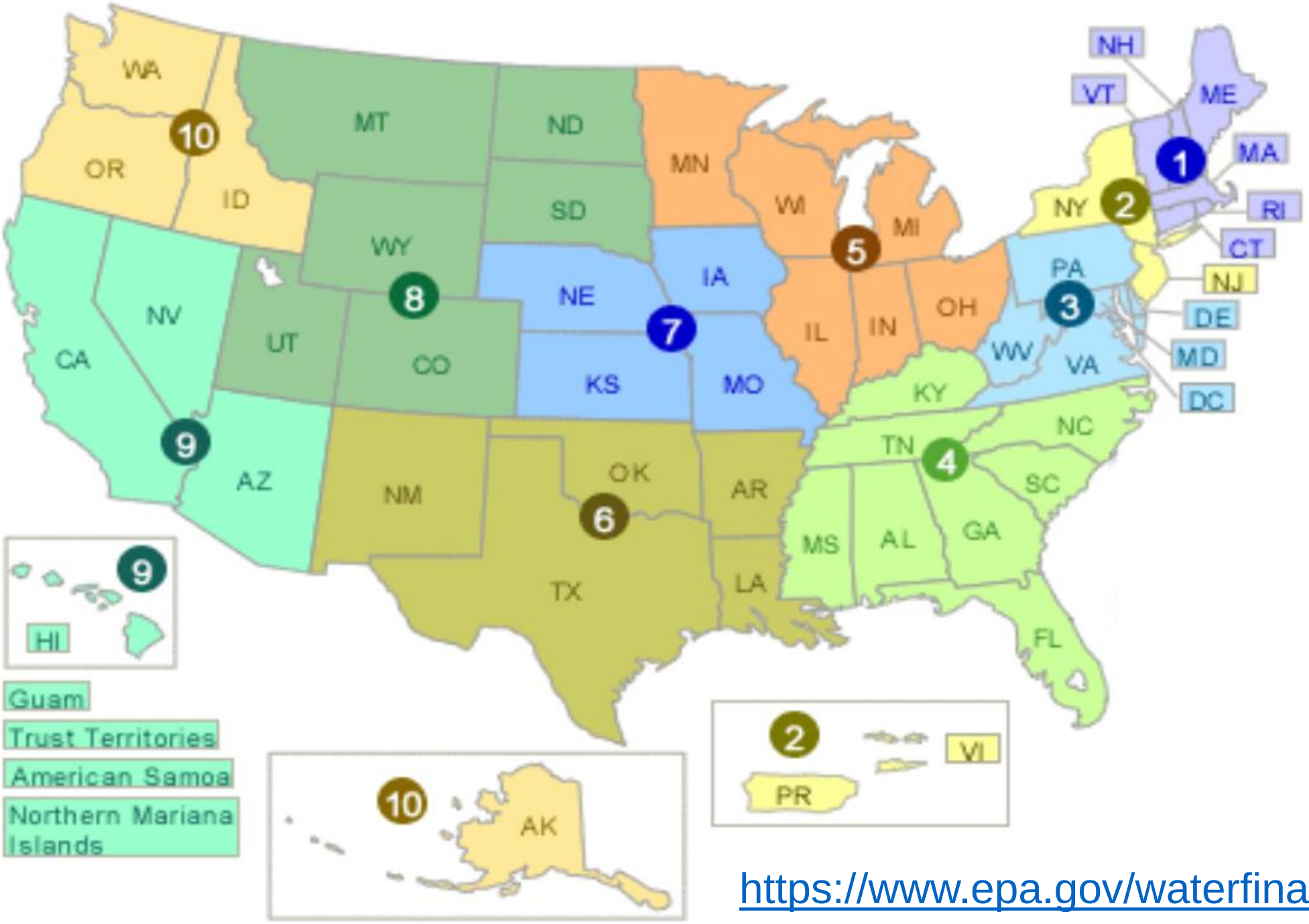
- You must attend the entire session
- You must register and attend using your real name and unique email address - group viewing credit will not be acceptable
- You must participate in polls
- Certificates will be sent via email within 30 days

If you have questions or need assistance, please contact smallsystems@syr.edu.

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.



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 5

Mission: Help communities increase technical, managerial, and financial capacity of utilities through technical assistance, training, access to resources, research, and technology.

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. **Activated Sludge Overview**

2. **Mean Cell Residence Time (MCRT)**

$$\text{Days} = \frac{\text{Pounds of MLSS under aeration}}{\text{Lbs/day solids leaving system}}$$

3. **Food to Microorganism Ratio (F:M)**

$$\text{F:M} = \frac{\text{Lbs/day of BOD entering treatment}}{\text{Lbs MLVSS in aeration tank}}$$

EFCN
environmental finance center network

Poll #1: Which statement best describes your learning goal today?

a) An experienced operator refreshing my understanding of AS process control

b) A new operator seeking an introduction to AS process control

c) I am preparing for an upcoming certification exam

d) A board member seeking insights for a future infrastructure project

e) Something else (make a comment).

Why are we gathered here today?

The Big Idea:

Learn how to use the F:M ratio and MCRT formulas as part of activated sludge process control.

Essential Questions:

- What do the results of these calculations mean?
- What data is needed and how is it obtained?
- How is the activated sludge process adjusted?

How to take an active role

- Work the sample problems
- Enter questions and respond to poll questions.

Activated Sludge Process

Impacts of activated sludge

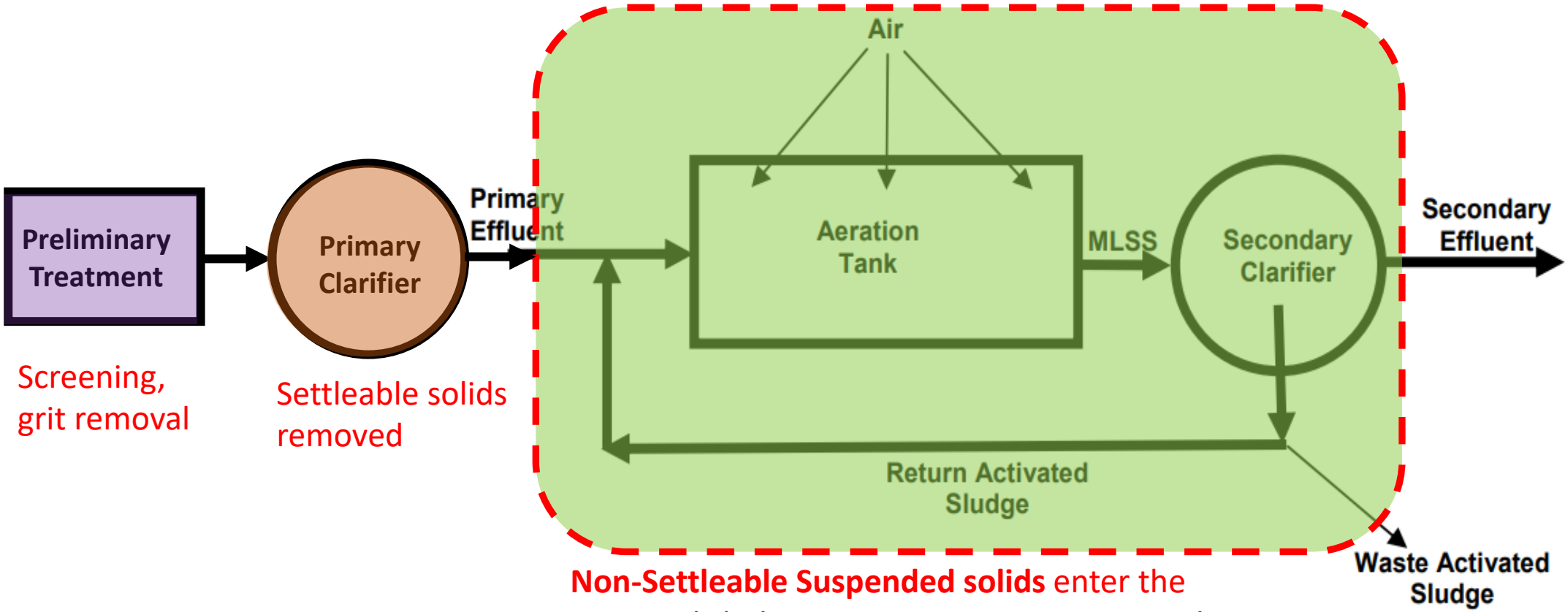
In the past, untreated waste was disposed of into receiving waters and near areas of habitation

Activated sludge developed in the early 1900s

Reduced disease transmission and improved quality of receiving waters.

Chamber pot being emptied out a window. Ancient Origins (2018). https://www.ancient-origins.net/history-ancient-traditions/medieval-sanitation-0010886

Basic activated sludge layout



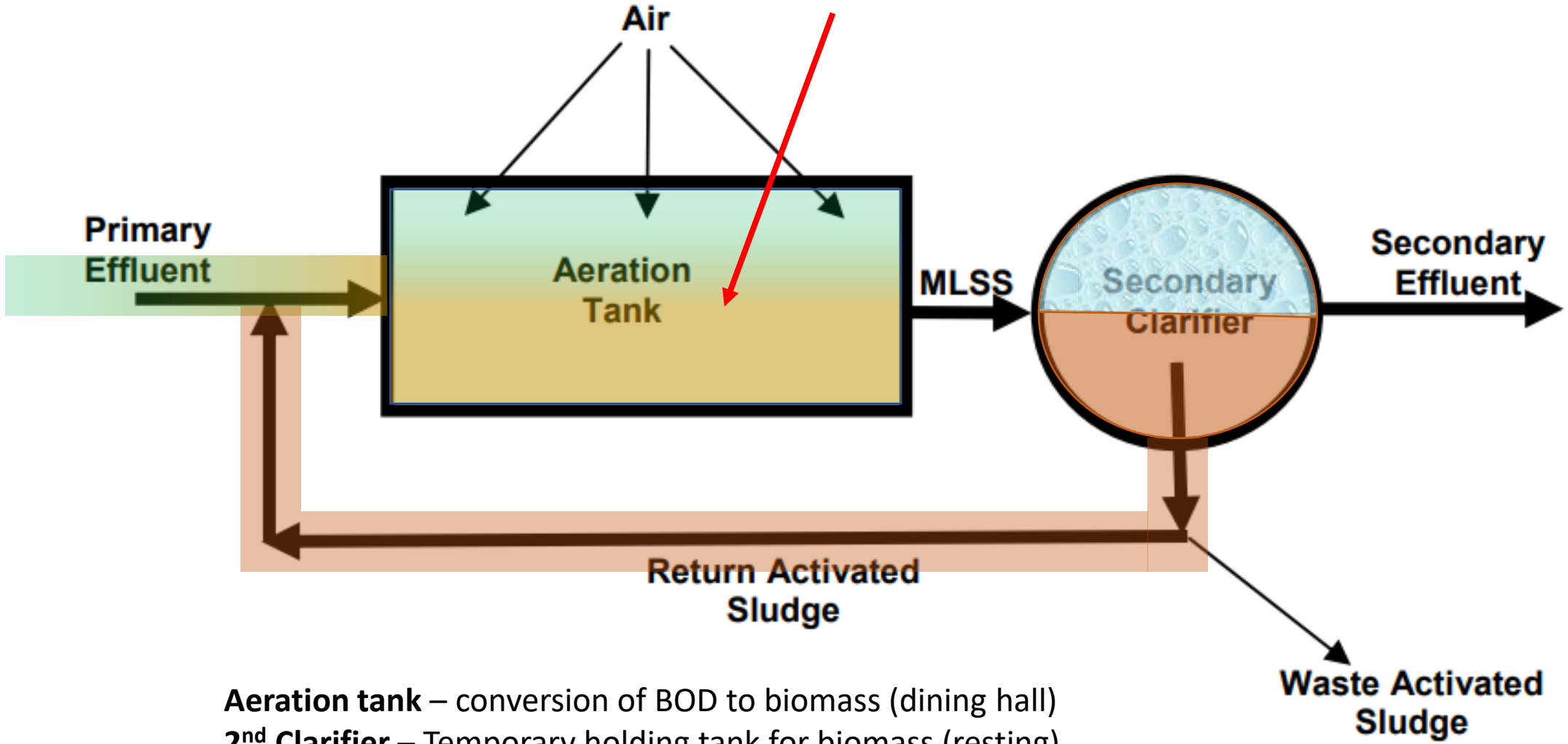
Screening, grit removal

Settleable solids removed

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

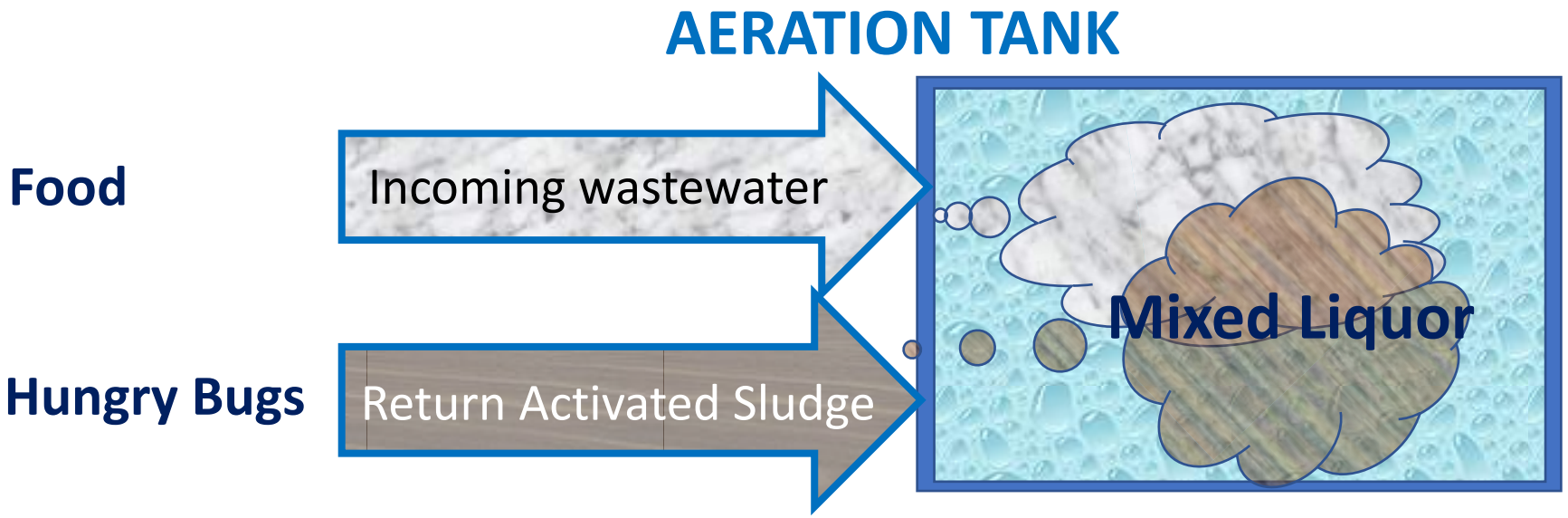
The activated sludge process

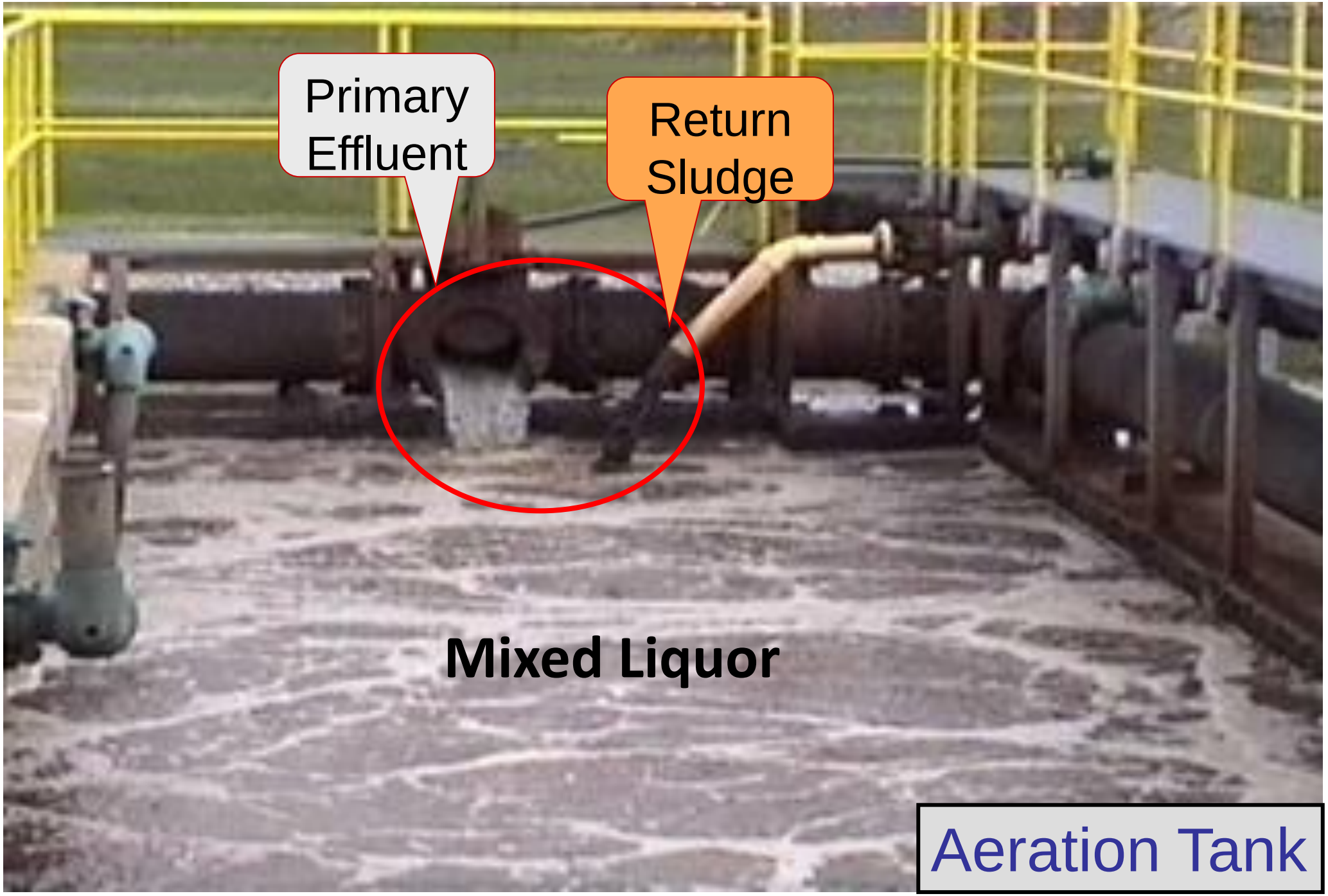
Mixed Liquor: Incoming wastewater is combined with return activated sludge from the secondary clarifier.

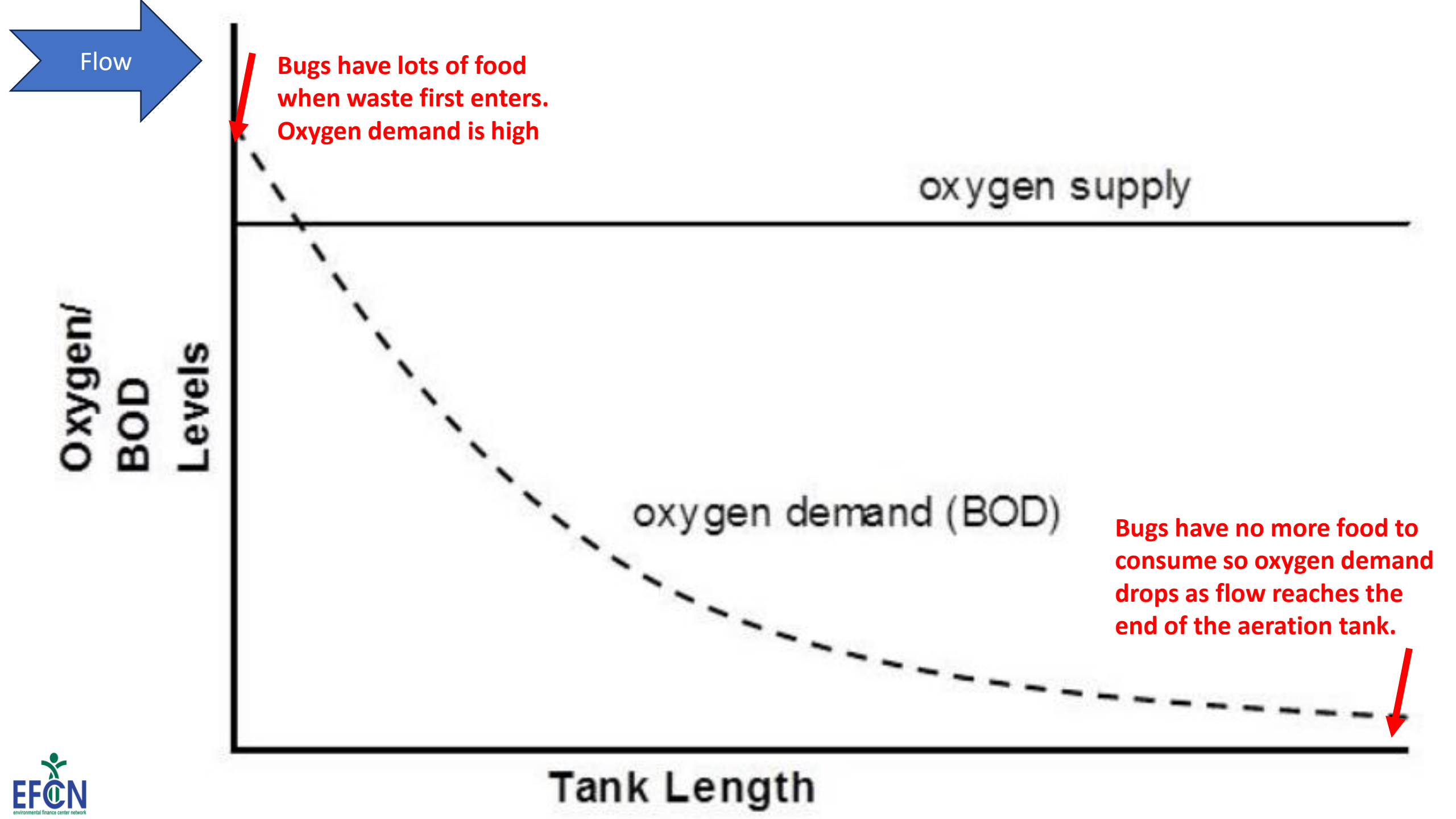


Aeration tank – conversion of BOD to biomass (dining hall)
2nd Clarifier – Temporary holding tank for biomass (resting)

Activated Sludge System (Aeration Tank)

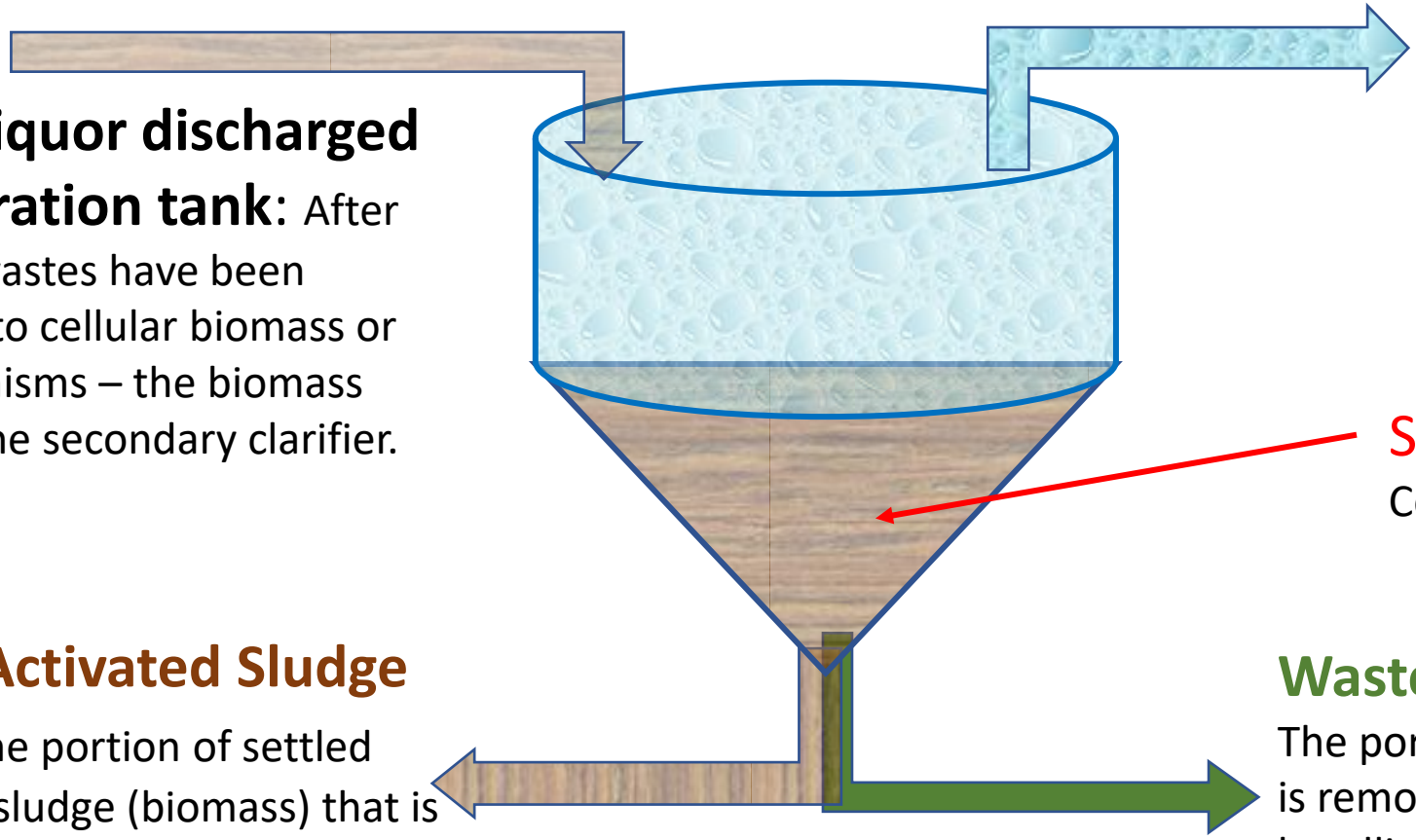



Primary Effluent
Return Sludge
Mixed Liquor
Aeration Tank


Flow
Bugs have lots of food when waste first enters. Oxygen demand is high
oxygen supply
Oxygen/ BOD Levels
oxygen demand (BOD)
Bugs have no more food to consume so oxygen demand drops as flow reaches the end of the aeration tank.
Tank Length

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

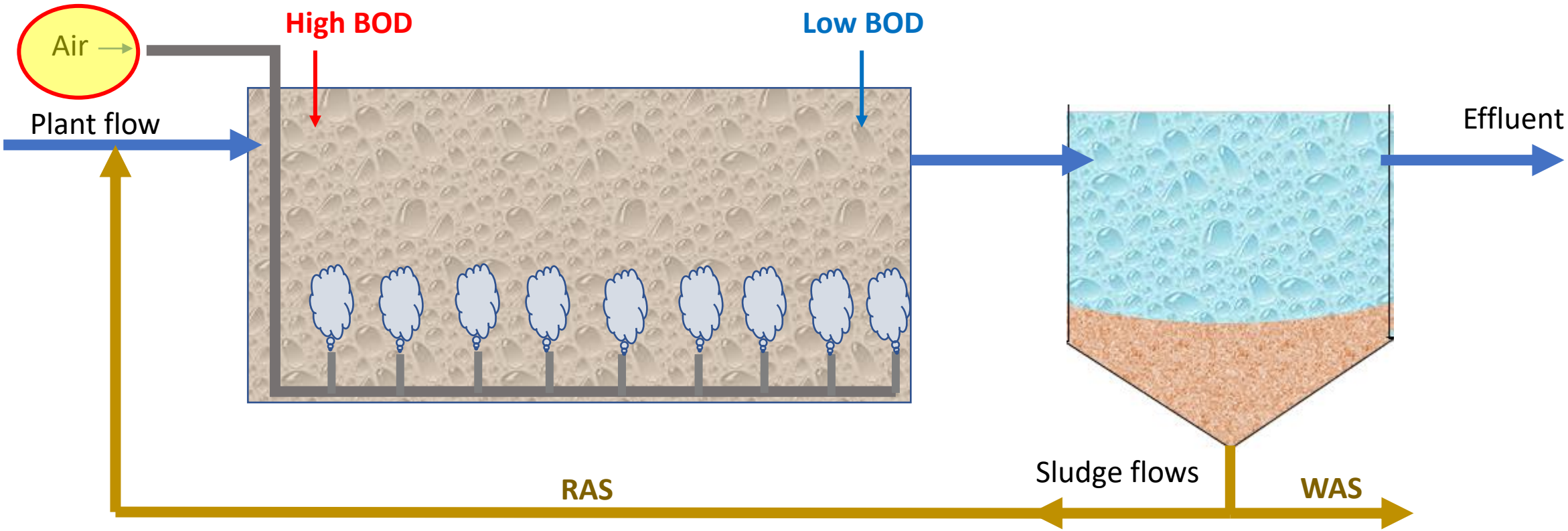
Return Activated Sludge (RAS): The portion of settled secondary sludge (biomass) that is returned to the aeration tank.

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

EFCN environmental finance center network

Conventional activated sludge layout



Aeration Time is 2 to 5 hours but solids can remain in the system from 3 to 15 days.

Diagram created by G. Pearson

Poll #2:

What is the most important next step for the wastewater system in your community?

a) Replace or rehab collection system components
b) Upgrade the wastewater treatment plant
c) Assess the condition of wastewater pipes
d) Extend service to unsewered residents
e) Conduct a rate study and develop a CIP

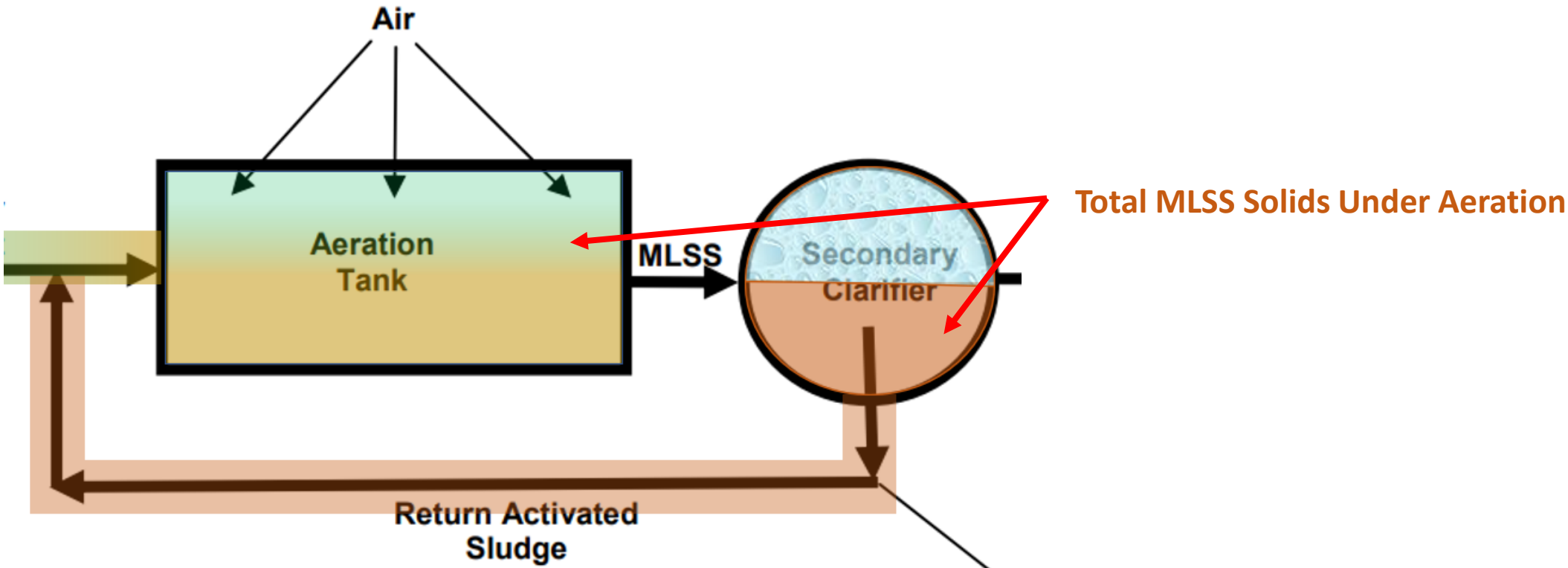
Select the closest answer

EFCN
environmental finance center network

Mean Cell Residence Time (MCRT)

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

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



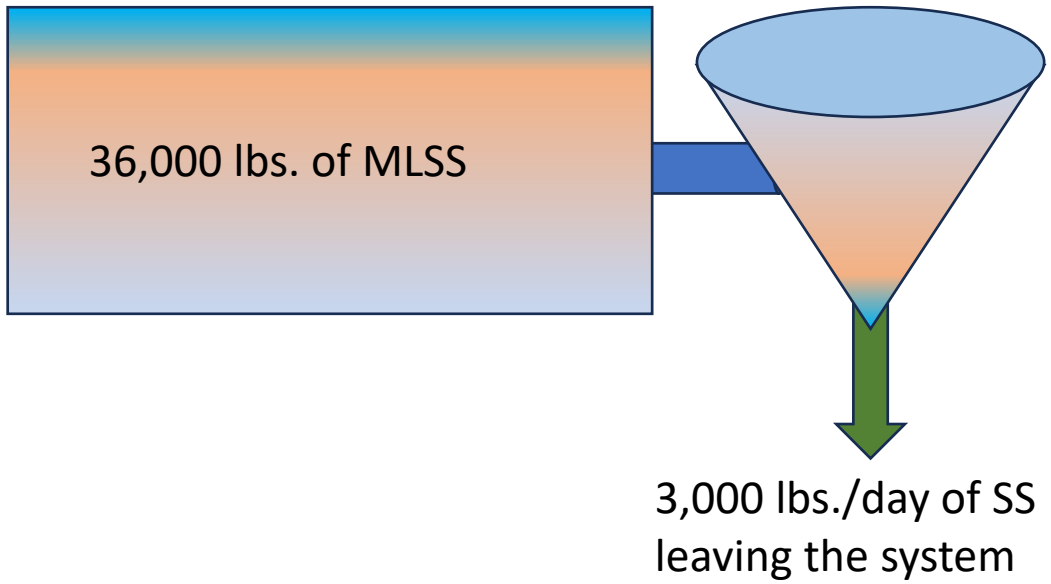
Example 1: Basic

A wastewater treatment plant has a total of 36,000 lbs. of MLSS under aeration, and there are 3,000 lbs./day of suspended solids leaving the system. What is the MCRT in days?

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

$$\text{MCRT} = \frac{\text{36,000 pounds}}{\text{3,000 lbs./day}} =$$

36,000 lbs. ÷ 3,000 lbs./day = **12 days**



The pounds formula

Pounds = MG x mg/L x 8.34 lbs./gal

This formula is used to convert between concentration in mg/L and weight of solids in pounds.

- Units of volume are MG (or MGD for volume)
- Concentration unit is mg/L
- 8.34 lbs./gal is the weight of 1 gallon of water
- Pounds or Pounds per Day

Example:

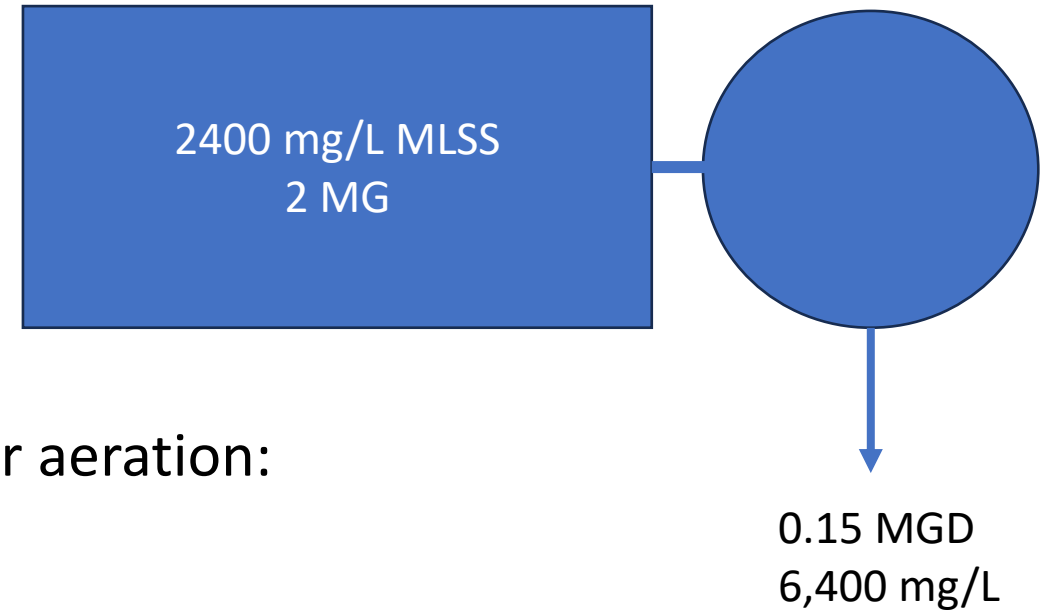
How many pounds of suspended solids are in an activated sludge aeration basin if the volume is 800,000 gallons and the MLSS concentration is 2,000 mg/L?

0.8 MG x 2,000 mg/L x 8.34 lbs./gal = 13,344 pounds

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**

Process control with MCRT

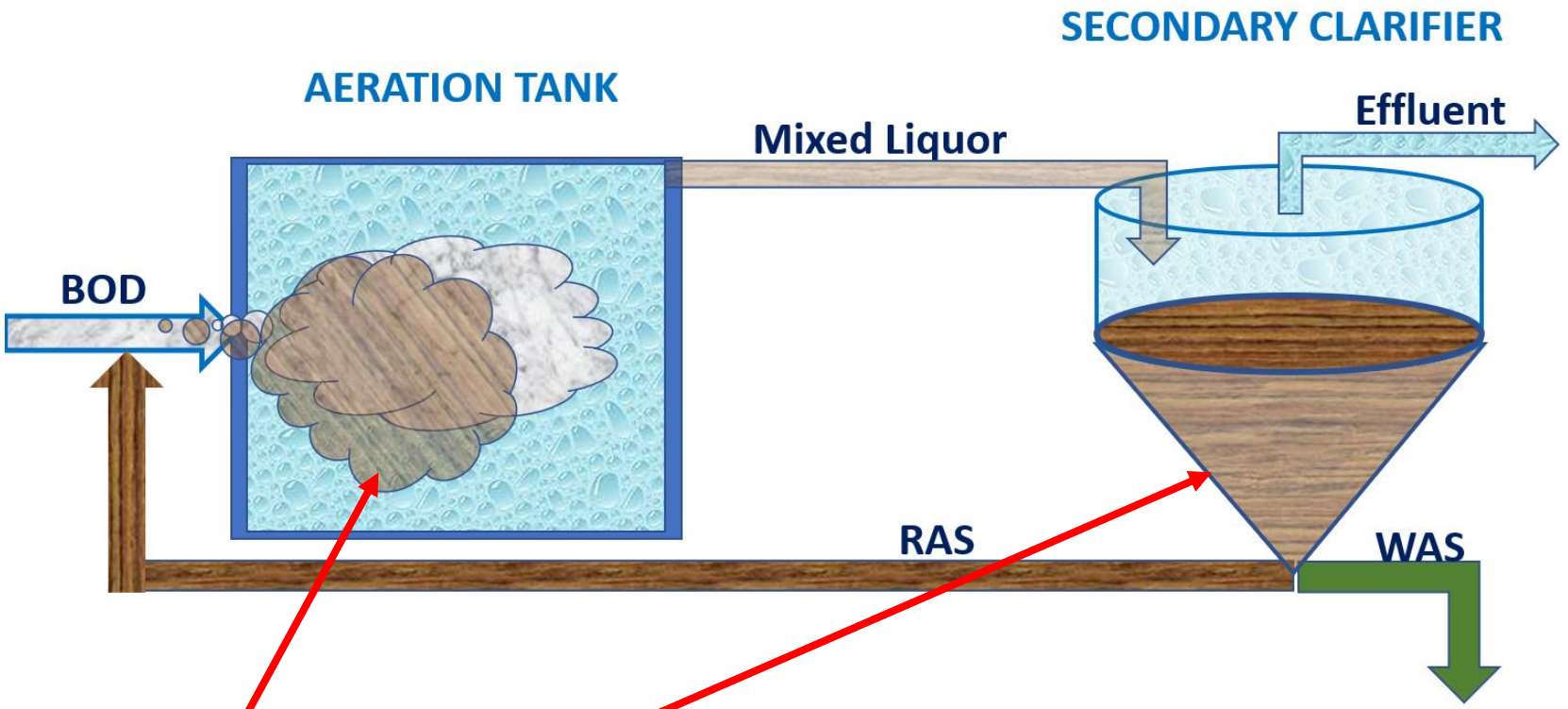
$$\text{MCRT} = \frac{\text{MLSS in the aeration system (pounds)}}{\textbf{WAS (lbs./day)}}$$

20,000 pounds = **5 days**
4,000 lbs./day

Increase WAS ➔
➔ Decrease WAS

20,000 pounds = **4 days**
5,000 lbs./day

Mean Cell Residence Time (MCRT)



Solids leaving system in effluent

Solids leaving system as WAS

Pounds of solids under aeration (Aeration + Clarifier)

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

$$\text{MCRT} = \frac{(\text{Aeration MG} + \text{Clarifier MG}) \times (\text{MLSS mg/L}) \times 8.34 \text{ lb/gal}}{\text{Lbs/day SS in WAS} + \text{Lbs/day SS in Eff}} = \text{Days}$$

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:

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

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

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

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

Poll #3

An activated sludge plant has 30,000 pounds of MLSS under aeration and a wasting rate that eliminates of 6,000 lbs./day of suspended solids from the system. What is the MCRT?

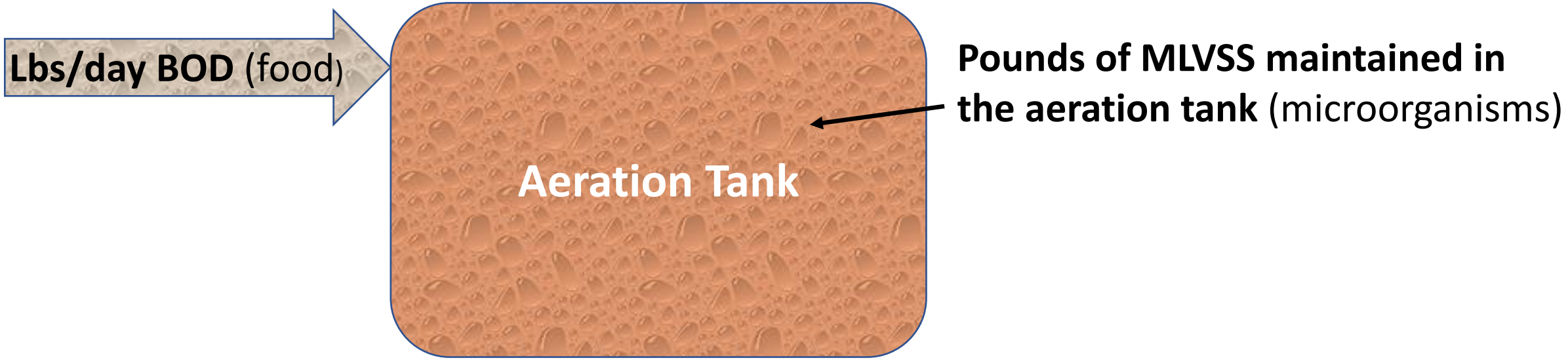
a. **18 days**
b. **9 days**
c. **6 days**
d. **5 days**

Section 3
F:M

Food To Microorganism Ratio

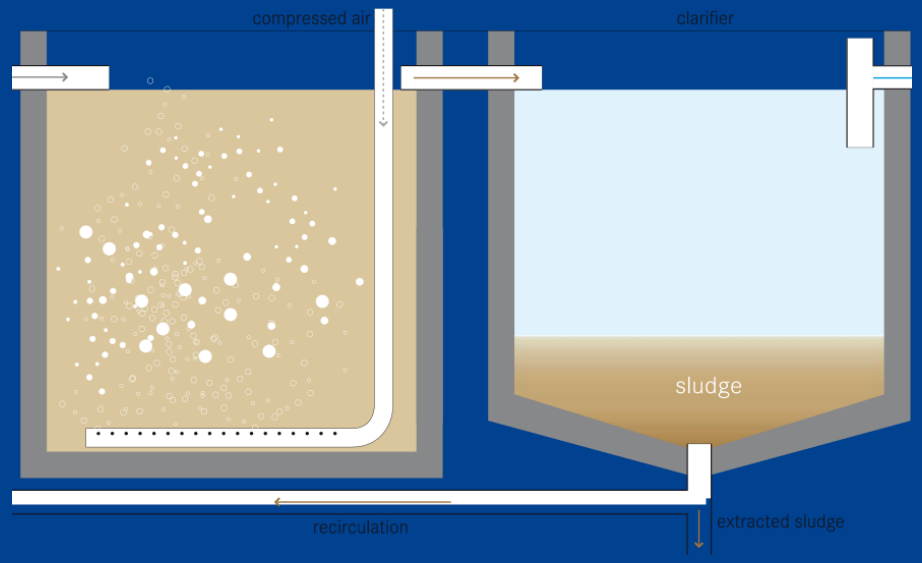
Food to microorganism ratio (F:M)

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



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

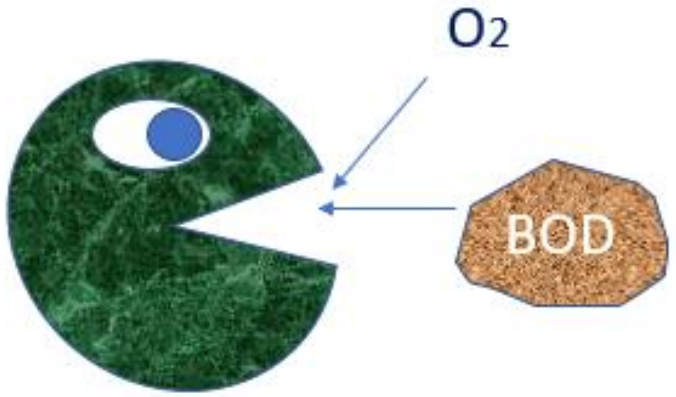
F:M Ratio



1. **BOD** (Biochemical Oxygen Demand)
2. **MLVSS** (Mixed Liquor Volatile Suspended Solids.)

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 (bacteria) to metabolize wastes. [Initial DO – Final DO.]



Microorganisms require oxygen to metabolize waste.

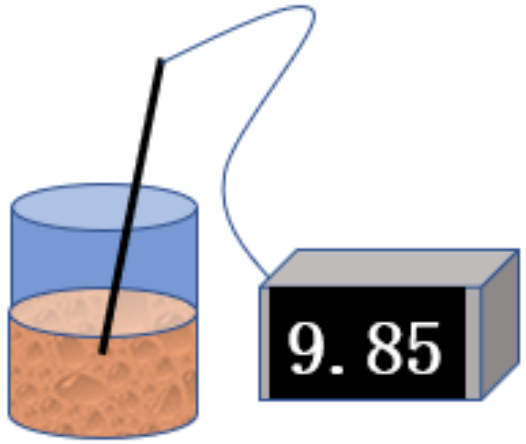
BOD Test

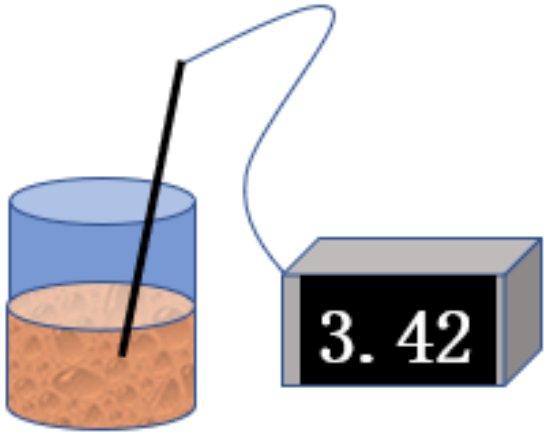
1. **A sample of wastewater is added to the test bottle** (i.e. 10 ml of sample added to the 300 ml test bottle ➔ P = 10/300 or 0.033)
2. **The D.O. concentration is measured at the start and completion**

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

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

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





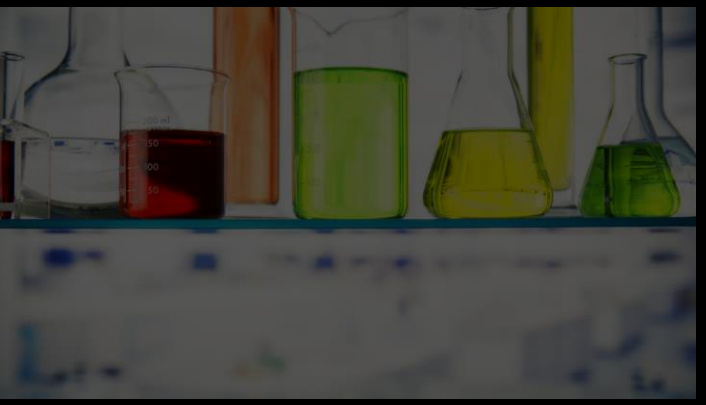
P = decimal volumetric fraction

BOD or COD

COD = Chemical Oxygen Demand

Uses a chemical oxidizer and is a faster test, but provides a reading higher than BOD. Includes oxidation of non-biodegradable substances

Classification	BOD (mg/l)	COD (mg/l)
Weak	<200	<400
Medium	350	700
Strong	500	1000
Very Strong	>750	>1500



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 volatile portion of Mixed Liquor Suspended Solids.
- Typically, around 70% of MLSS
- Indicates the microorganisms available to consume wastes. Used in F/M Ratio.

MLSS Concentration Measurement

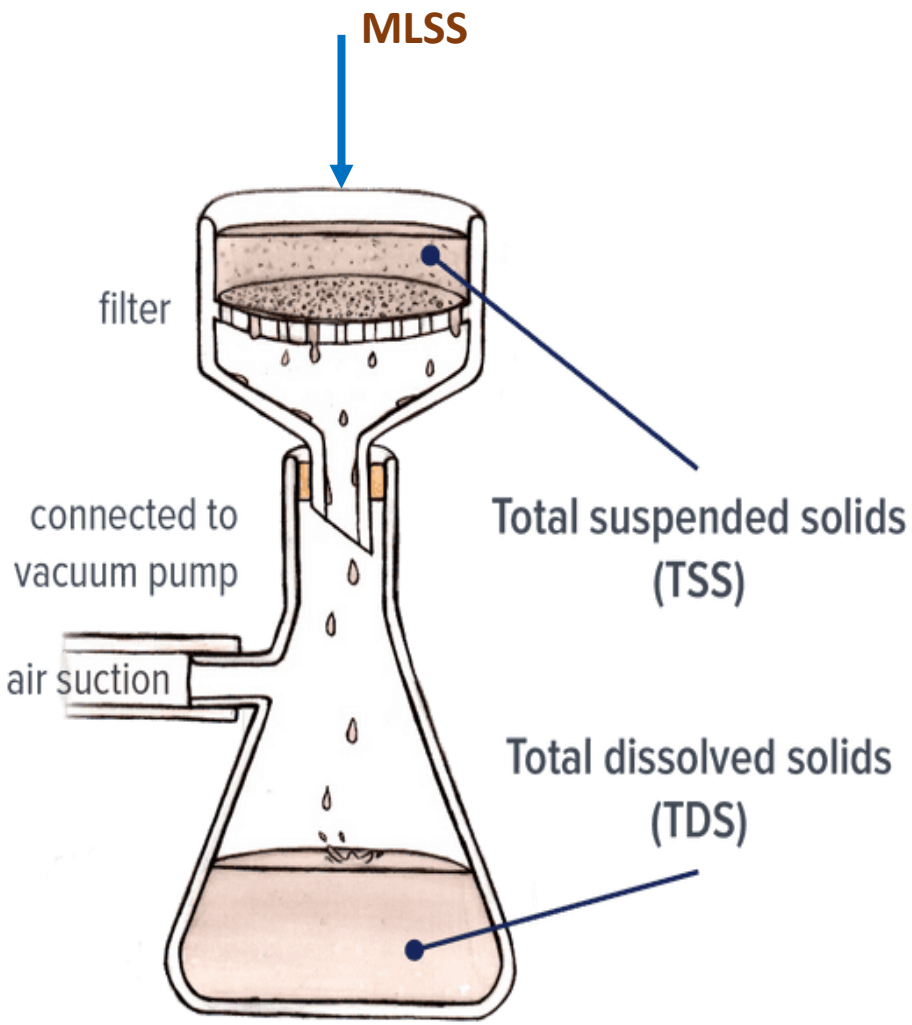
1. Sample is collected from the aeration basin.
2. A 0.45-micron filter captures suspended solids from a known sample volume
3. Solids are dried and weighed
4. Calculate MLSS concentration

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.

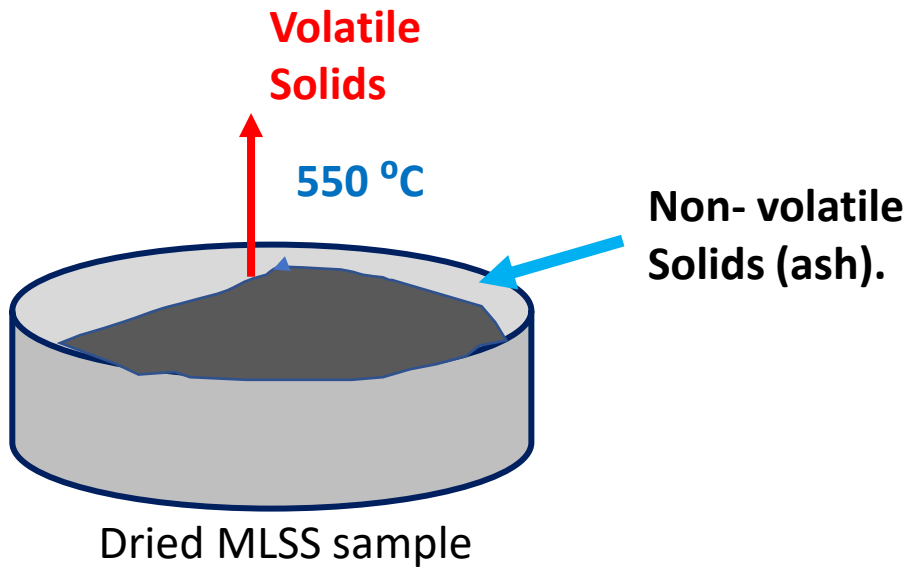
$$\text{MLSS, mg/L} = \left(\frac{\text{Net dry weight, mg}}{\text{Sample volume, mL}}\right) \times 1000 \text{ mL/L}$$

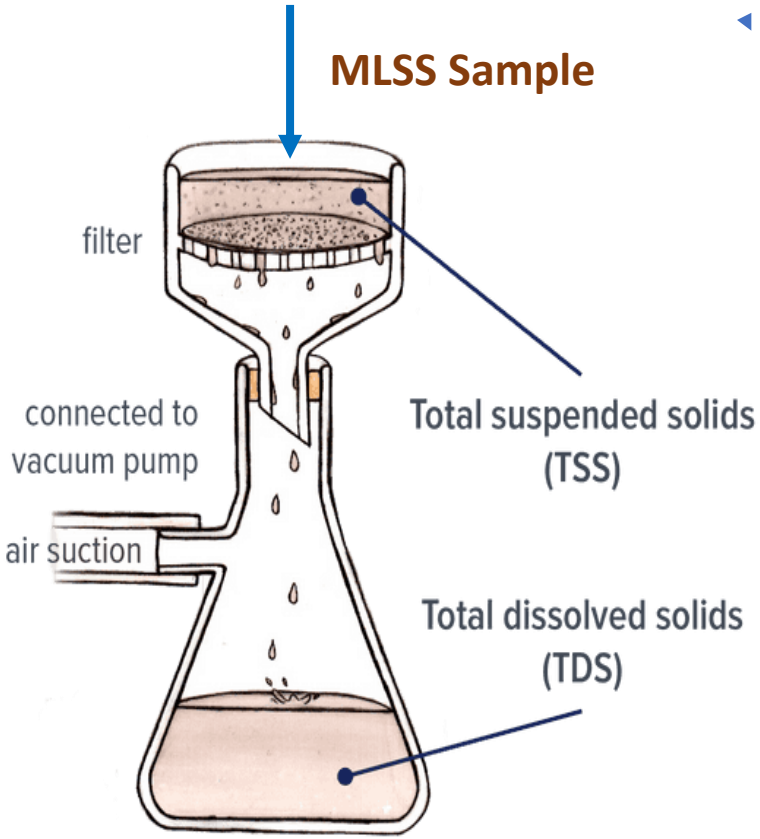
$$\text{MLSS, mg/L} = \frac{75 \text{ milligrams}}{25 \text{ mL}} \times 1000 \text{ mL/L} = 3{,}000 \text{ mg/L}$$



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 ^{o}C
4. Then the sample is weighed again and MLVSS determined





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

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

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.

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

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

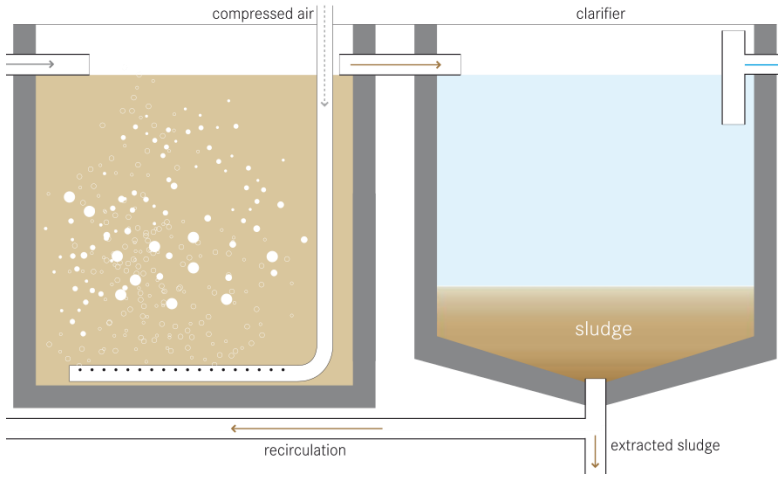
$$\textbf{F:M} = \frac{\textbf{3.0 MGD x 275 mg/L x 8.34 lbs./gal}}{\textbf{1.0 MG x 2,200 mg/L x 8.34 lbs./gal}} =$$

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

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

Step 3: Compare the F:M ratio to the target ratio.

Typical F:M Ratios



Conventional activated sludge

- F:M 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.

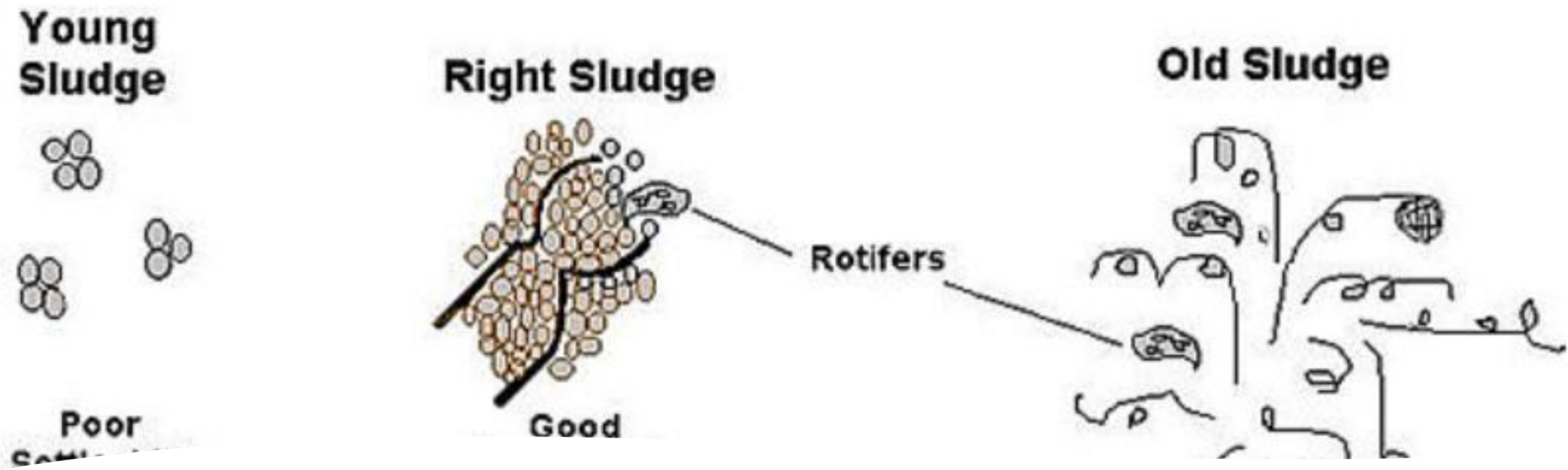
F:M Ratio Considerations

Too High: Too much food for microorganisms to process

- Insufficient BOD removal
- Poor settling

Too Low: Not enough food for microorganism growth and reproduction.

- Promotes growth of filamentous bacteria
- Poor settling



What is the goal of using F:M and MCRT

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

Sludge Settleability (the volume of settled sludge)

1. A 1,000 mL sample is collected from the outlet of the aeration basin.
2. Sludge settles for 30 minutes.
3. Settleability is the wet volume of settled sludge in mL after 30 minutes of settling time.

Sludge Volume Index (SVI)

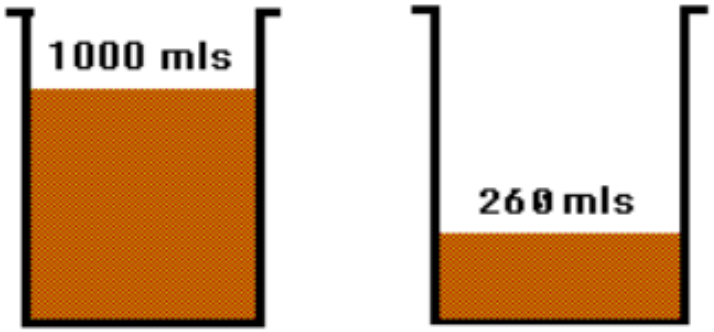
Indicates how well sludge is settling compared to solids.

SVI = $\frac{\text{mls Settled in 30 min}}{\text{MLSS, mg/L/1000}}$

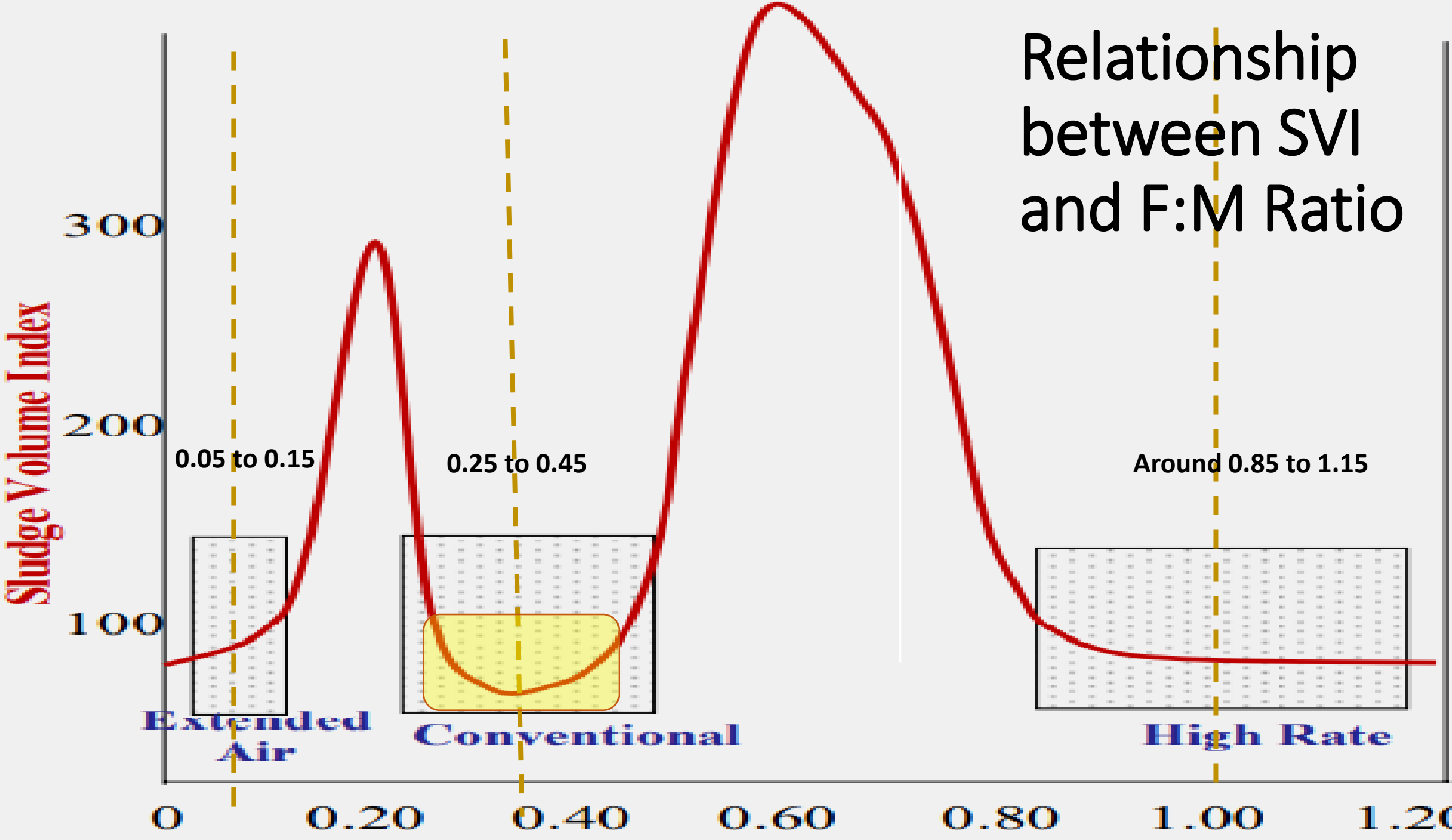
- An SVI between 80 and 120 is considered to produce good settling. 150 is considered a maximum value.

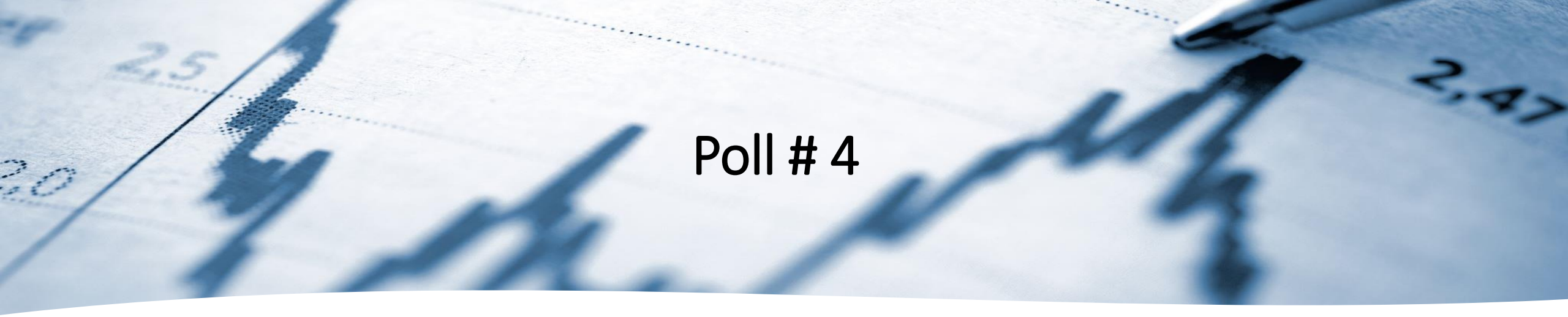
A 1,000 ml settleometer is filled with a mixed liquor that has a concentration of 2,400 mg/L. After 30 minutes the settled sludge volume is 260 ml. Calculate the SVI.

$$\frac{260 \text{ ml}}{2{,}400 \text{ mg/L} / 1000} = \textbf{108}$$



Relationship between SVI and F:M Ratio





Poll # 4

The wastewater coming into an activated sludge plant has a dramatic and sudden increase in BOD. Which of the following would best help the operators ensure there is sufficient biomass to provide optimal treatment?

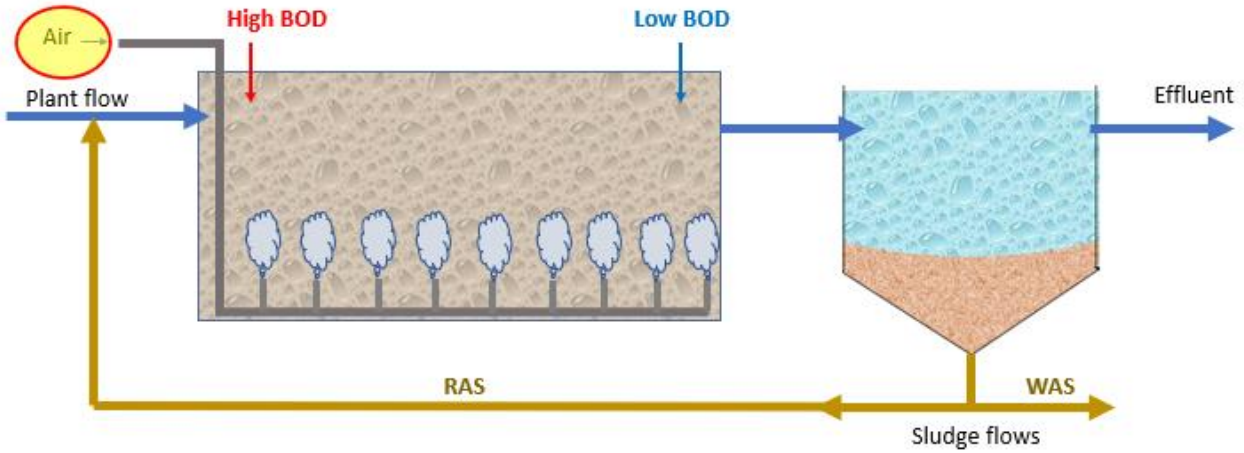
a) Calculate the F:M ratio to determine required MLVSS, then adjust
b) Calculate the SVI to figure out if the settled sludge will fit into the digester.
c) Forget calculations! Set the WAS flows to maximum!
d) Set RAS flow to max and turn off WAS flows, then calculate the new MCRT
e) Do all of the above

General comments about process control

1. **The WAS flow rate effects the time that biosolids are retained in the system** (MCRT).
2. **The RAS flow rate effects the MLSS in the aeration tank and the F:M ratio**. However, the RAS flow setting also involves other considerations and tests such as sludge settleability.
3. **There are times when activated sludge plants need to operate temporarily outside of the normal parameters** (i.e. retain or waste more biosolids than normal)
4. **Often the goal is for RAS and WAS flows to be continuous**.
5. **Knowing how to use the MCRT and FM Ratio formulas is necessary for process control,** but it is only a part.

6. Any adjustment to an activated sludge plant requires sufficient time to take effect

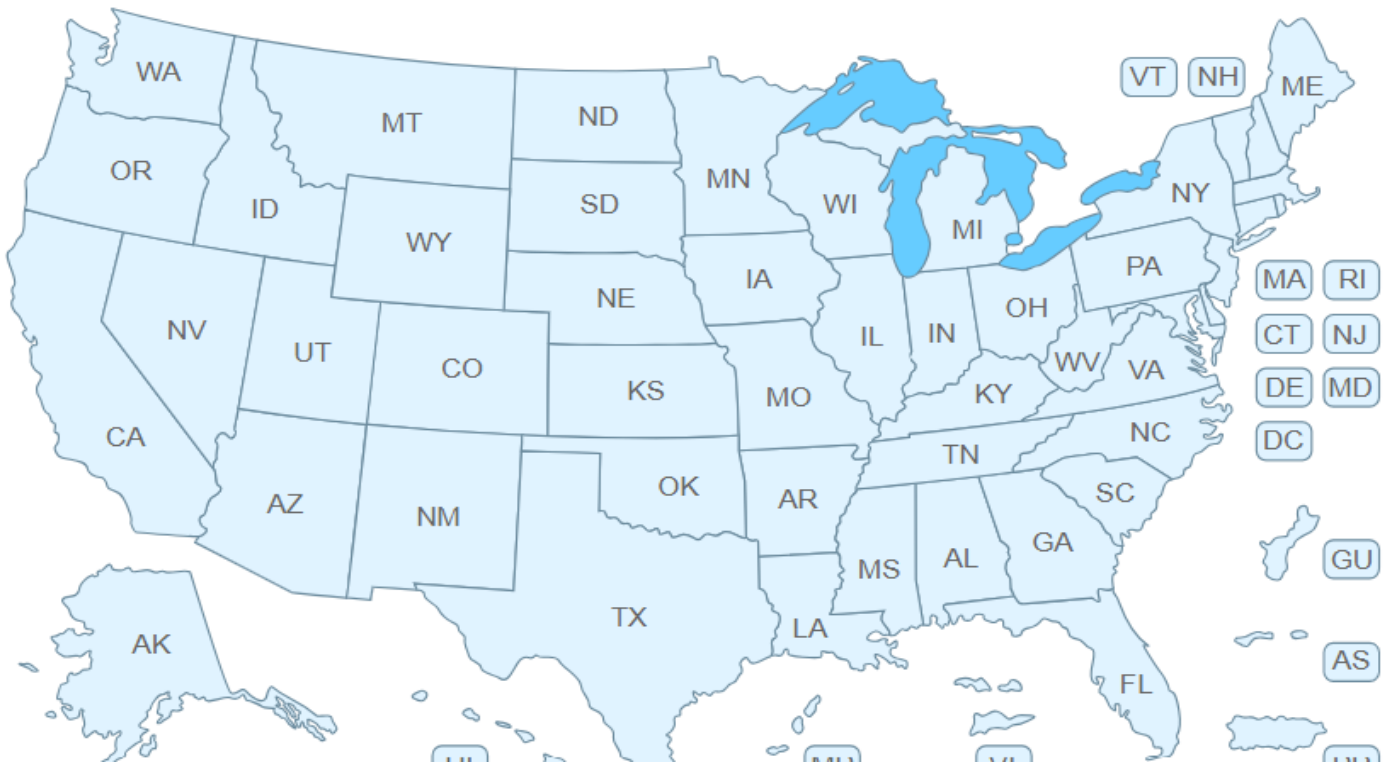
What we covered today



- **Basic Activated Sludge Components and Layouts**
- **FM Ratio** : The ratio of the BOD entering the system to the microorganisms available to consume it.
- **MCRT**: Measures the retention time of the biomass solids or bugs.
- **RAS**: Return activated sludge flows return biomass to the aeration basin.
- **WAS**: Waste activated sludge flows remove solids from the process.

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
- Resources for EPA region 5, technical assistance

  Gregory Pearson, Water and Wastewater Systems Trainer
- Email: gpearson@mtu.edu
- Book a meeting: https://meetings.hubspot.com/gregory-pearson
- Connect: www.linkedin.com/in/gregory-pearson-774757305

Thank you for attending!

Remember to download the slides and references. Contact us if you would like to learn more or request one-on-one technical assistance.

Bonus material

Example problems

EFCN
environmental finance center network

Calculation for RAS flow based on Settleability

$$\textbf{Return Flow Rate (RAS)} = \frac{\text{(Settleable Solids, ml) (flow, MGD)}}{\text{(1,000 ml) - (Settleable Solids, ml)}}$$

Example:

A plant with a flow of **1.2 MGD** had a settleable solids result of **260 mL** after 30 minutes of settling. Estimate the RAS flow rate in gallons per minute.

$$\text{Return flow Rate (RAS)} = \frac{\textbf{260 mL} \times \textbf{1.2 MGD}}{\text{(1,000mL} - \textbf{260 mL)}} = \textbf{0.42 MGD}$$

$$0.42 \text{ MGD} \times \frac{1{,}000{,}000 \text{ gal/MG}}{1{,}440 \text{ min/day}} = \textbf{291.7 GPM}$$

F:M Ratio Calculation Example

What concentration of MLVSS should be maintained in an aeration tank with a volume of 0.105 MG receiving primary effluent BOD of 630 lbs/day? The desired F:M is 0.3.

Step 1: Insert known variables $F:M = \frac{630\ lbs/day}{Lbs\ MLVSS} = 0.3$

Step 2: Rearrange for lbs MLVSS $\frac{630\ lbs/day}{0.3} = lbs\ MLVSS$

630 lbs/day ÷ 0.3 = 2,100 lbs of MLVSS

Step 3: Use the pounds formula

2,100 lbs MLVSS = 0.105 MG x Conc (mg/L) x 8.34 lbs/gal

Step 4: Rearrange to solve for mg/L of MLVSS

$$Conc\ (mg/L) = \frac{2{,}100\ pounds\ MLVSS\ in\ aeration}{0.105MG \times 8.34lbs/gal} = 2{,}398.08\ mg/L$$

Calculating WAS Flow Rate

$$\text{MCRT} = \frac{\text{Lbs of MLSS under aeration}}{\text{Lbs per day WAS}}$$

First, rearrange the general MCRT formula to solve for Lbs per day WAS

$$\text{Lbs per day WAS} = \frac{\text{Lbs of MLSS in system}}{\text{MCRT (days)}}$$

Once we know the required lbs per day of WAS flow, we use the pounds formula to find the required flow.

$$\text{WAS Flow (MGD)} = \frac{\text{Lbs/Day of WAS}}{\text{WAS(mg/L)} \times 8.34 \text{ lbs./day}}$$

WAS Flow Rate Example

A WWTP has 32,000 pounds of solids under aeration and a target MCRT of 5 days. The suspended solids concentration of WAS is 6,800 mg/L. Find the required WAS flow in MGD. *(Disregard solids lost in effluent)*

$$\text{MCRT} = \frac{\text{Lbs of MLSS in System}}{\text{Lbs per day WAS}}$$

Step 1: Rearrange formula and solve for lbs. per day WAS

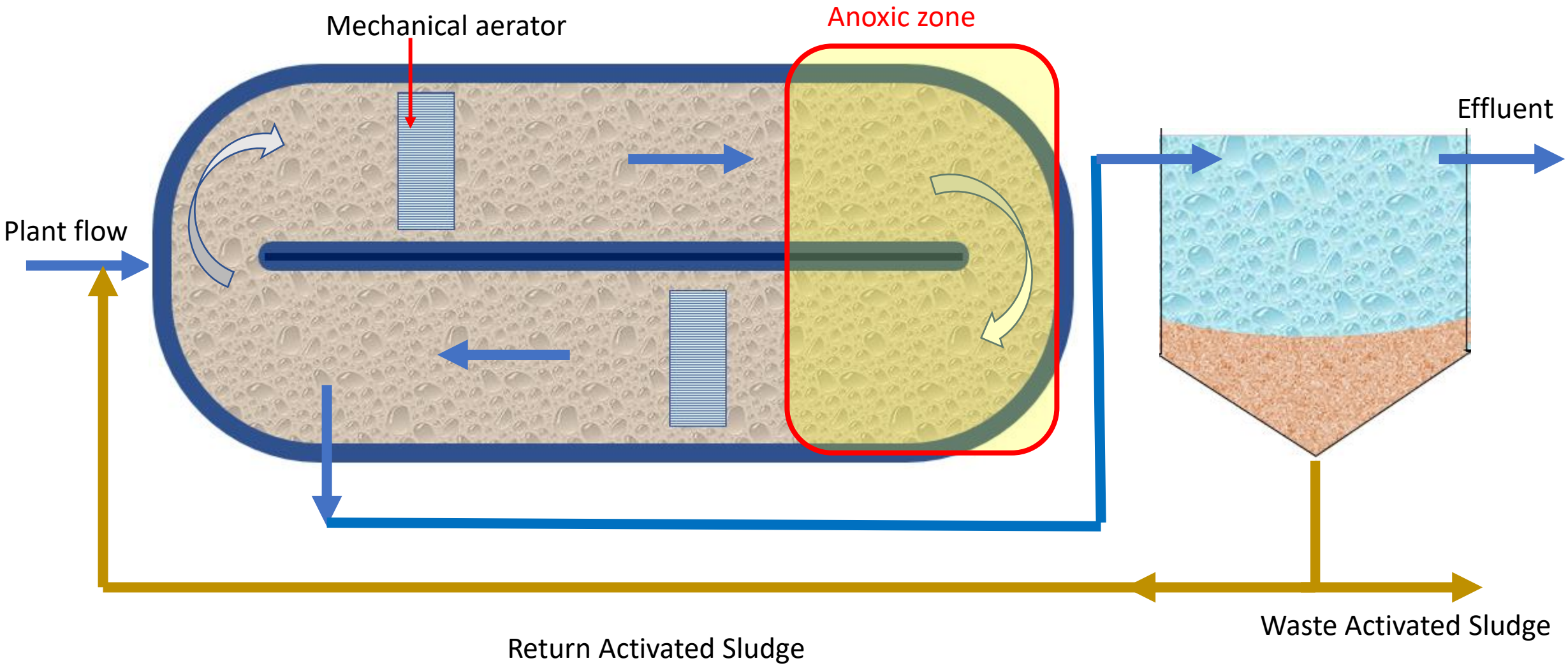
$$\text{Lbs per day WAS} = \frac{\text{Lbs of MLSS in system}}{\text{MCRT (days)}} = \frac{32{,}000 \text{ lbs. MLSS}}{5 \text{ days}} = 6{,}400 \text{ lbs./day}$$

Step 2: Place WAS lbs per day and concentration into the lbs. formula and rearrange to solve for flow

$$6{,}400 \text{ lbs./day} = \text{MGD} \times 6{,}800 \text{ mg/L} \times 8.34 \text{ lbs./gal}$$

$$\text{WAS Flow (MGD)} = \frac{6{,}400 \text{ Lbs./Day of WAS}}{6{,}800 \text{(mg/L)} \times 8.34 \text{ lbs./day}} = 0.113 \text{ MGD}$$

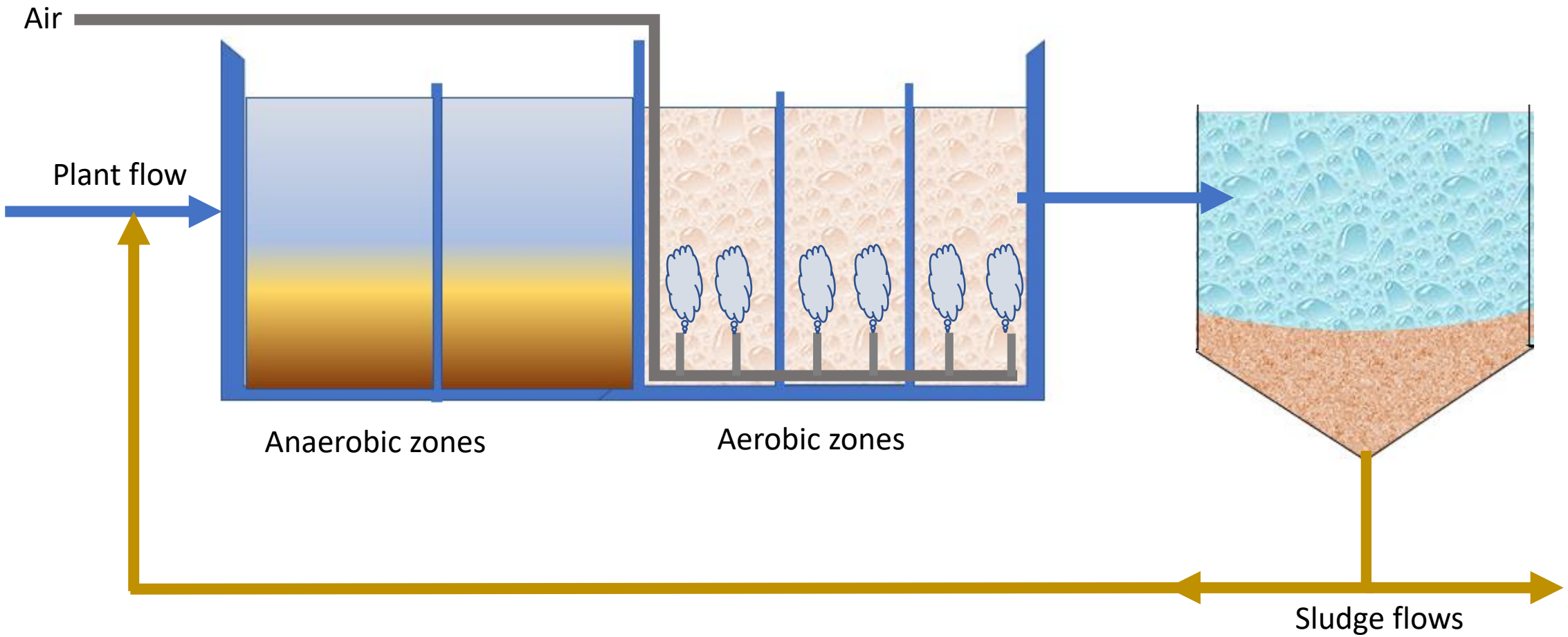
Oxidation Ditch (Extended Aeration)



Oxidation ditches have high solids retention times and lower food to microorganism ratios. Aeration time is 18-36 hrs. but solids can remain from 20 to 30 days.

Diagram created by G. Pearson

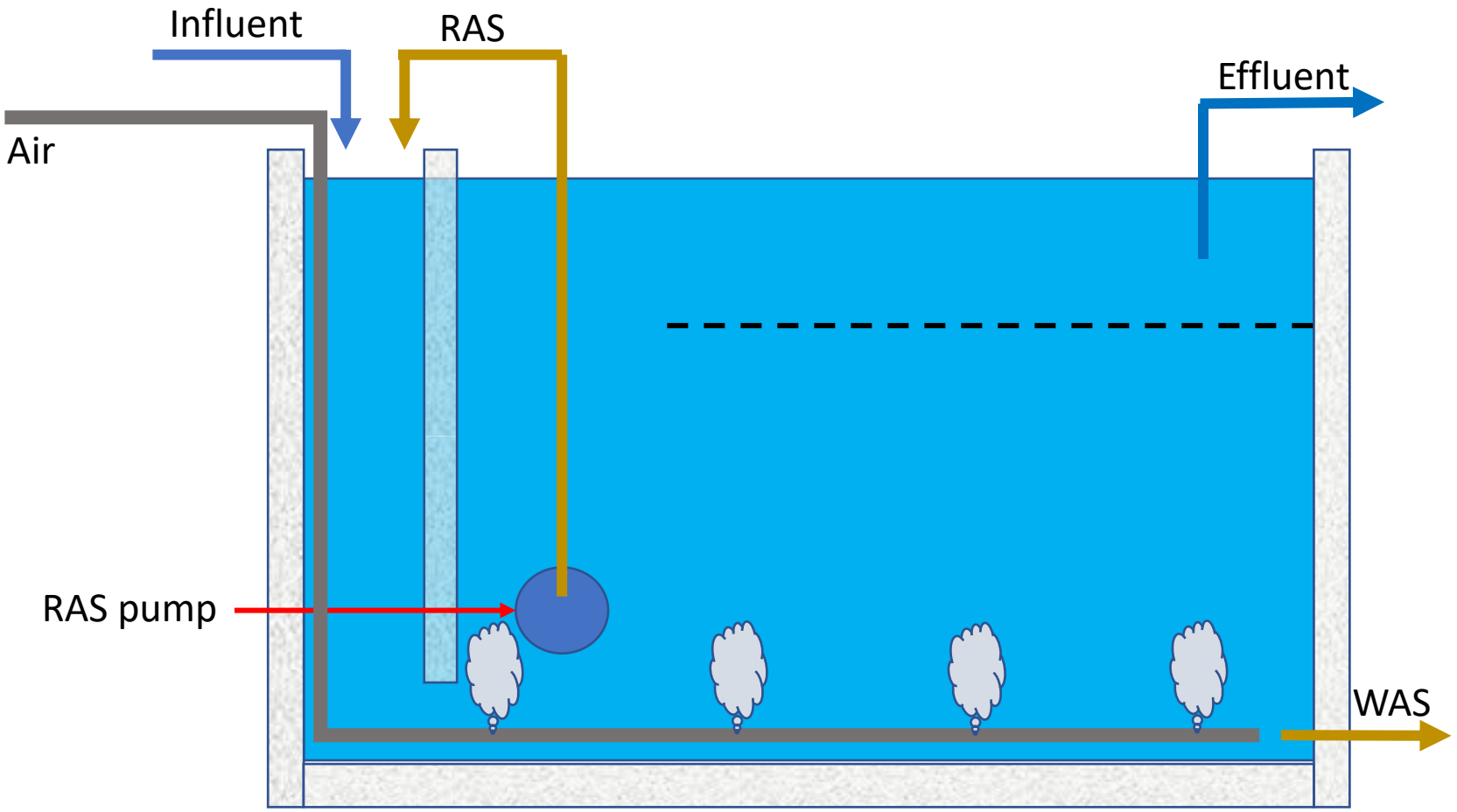
Activated Sludge Anaerobic/Oxic Layout (AO)



Alternating anaerobic and aerobic zones can help to remove nutrients such as nitrogen and phosphorous from wastewater.

Diagram created by G. Pearson

Sequencing Batch Reactor



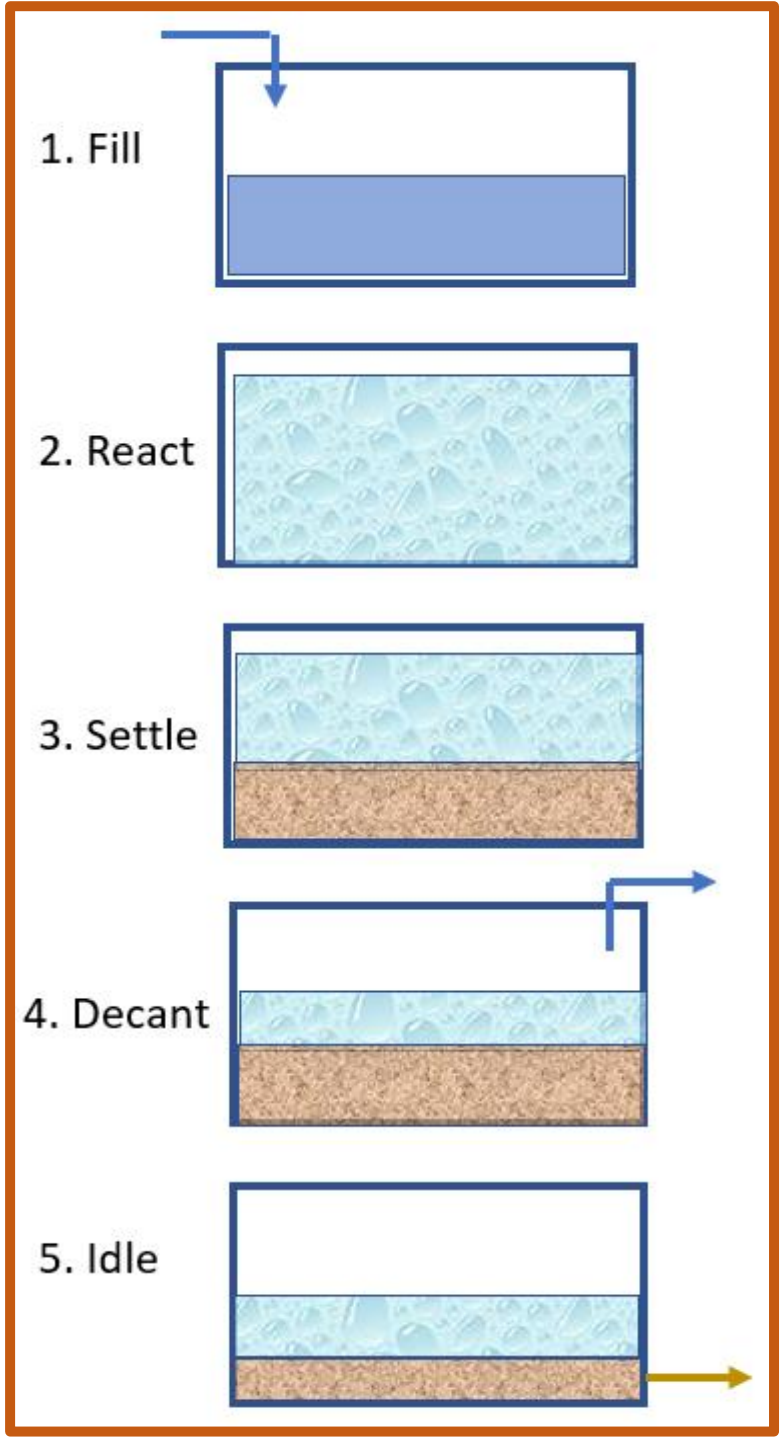


Diagram created by G. Pearson