Activated Sludge Process Control Calculations

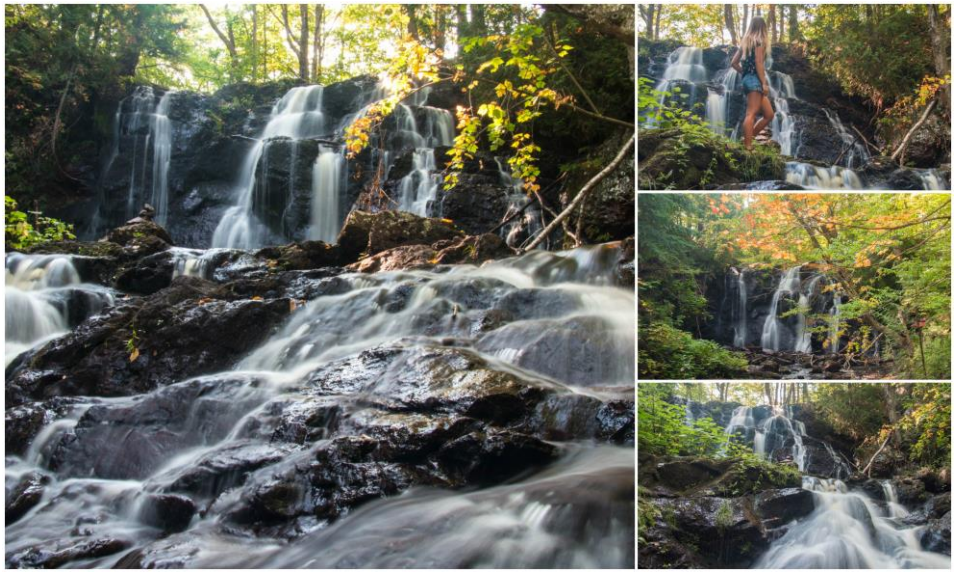
Thursday, June 23, 2022
1- 2 pm EST

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

Today's presenter:

Gregory Pearson, Water and Wastewater Systems Trainer – Great Lakes Environmental Finance Center at Michigan Technological University

- Certified WT, WD, WWT Operator
- Trainer and Technical Assistance Provider
- Experience in operations and utility management



Michigan.org: Scenic places in the upper peninsula

Michigan Technological University

Great Lakes Environmental Infrastructure Center

Environmental Finance Center for EPA Region 5

Process Control

F:M Ratio: The ratio of food coming into the activated sludge system, to the microorganisms available to consume them.

- **MCRT**: The average time in days that microorganisms remain in the activated sludge system.

The societal impacts of activated sludge

1. **Health**: Reduced disease transmission and mortality.

2. **Population Density**: Large, densely populated cities made possible.

3. **Environment:** Aquatic life in receiving waters is protected.

4. **Sustainability**: Reuse of water made possible (recycled water flows)

5. **Resources**: Creates potential sources of energy and nutrients (methane, compost).

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

NYC: 1400 tons or 2,800,000 pounds of biosolids daily

Poll #1: How does your city or township currently treat domestic wastewater?

a) Septic systems
b) Wastewater Lagoon system
c) Rotating biological contactor or trickling filter.
d) Activated Sludge Process
e) Other

Main components of activated sludge

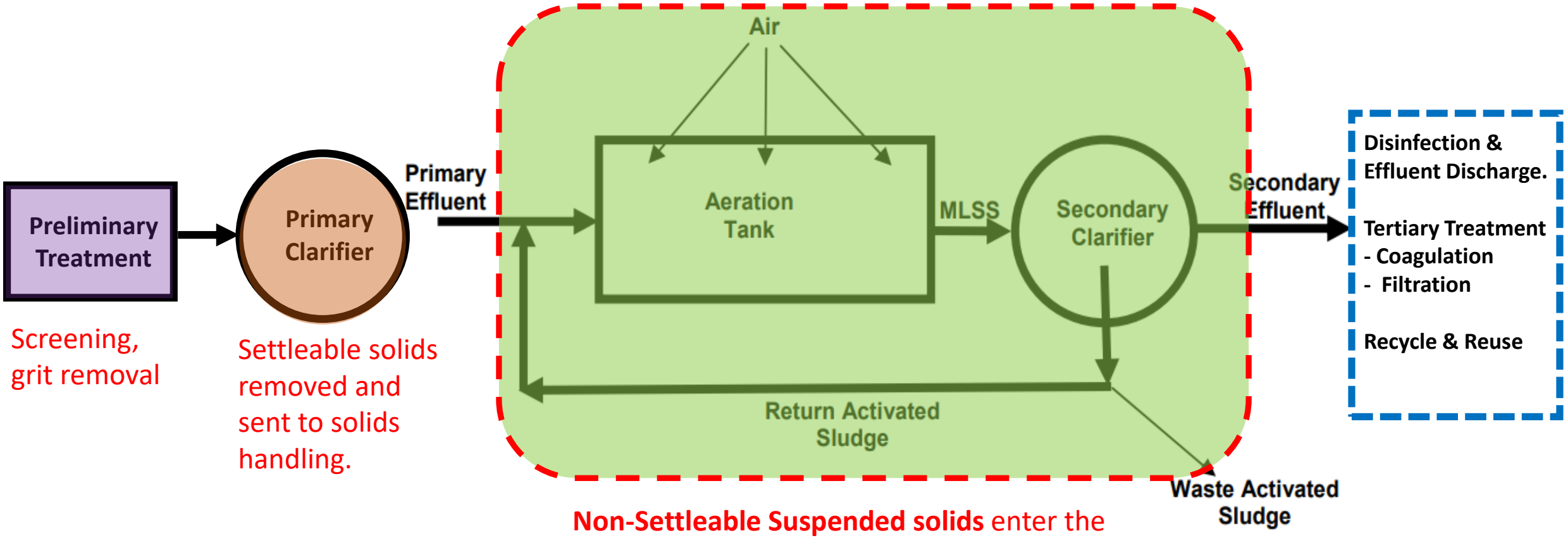
1. **Aeration Tank**: Incoming waste is combined with concentrated microorganisms to create a mixed liquor which is aerated and suspended.

2. **Secondary Clarifier**: The biomass created in the aeration tank settles as sludge to the bottom of the clarifier. Clarified water is the final effluent.

3. **Return Activated Sludge Flow (RAS):** A portion of the secondary clarifier sludge is returned to the aeration tank.

4. **Waste Activated Sludge Flow (WAS):** A portion of the secondary clarifier sludge is removed from the activated sludge system.

The activated sludge process



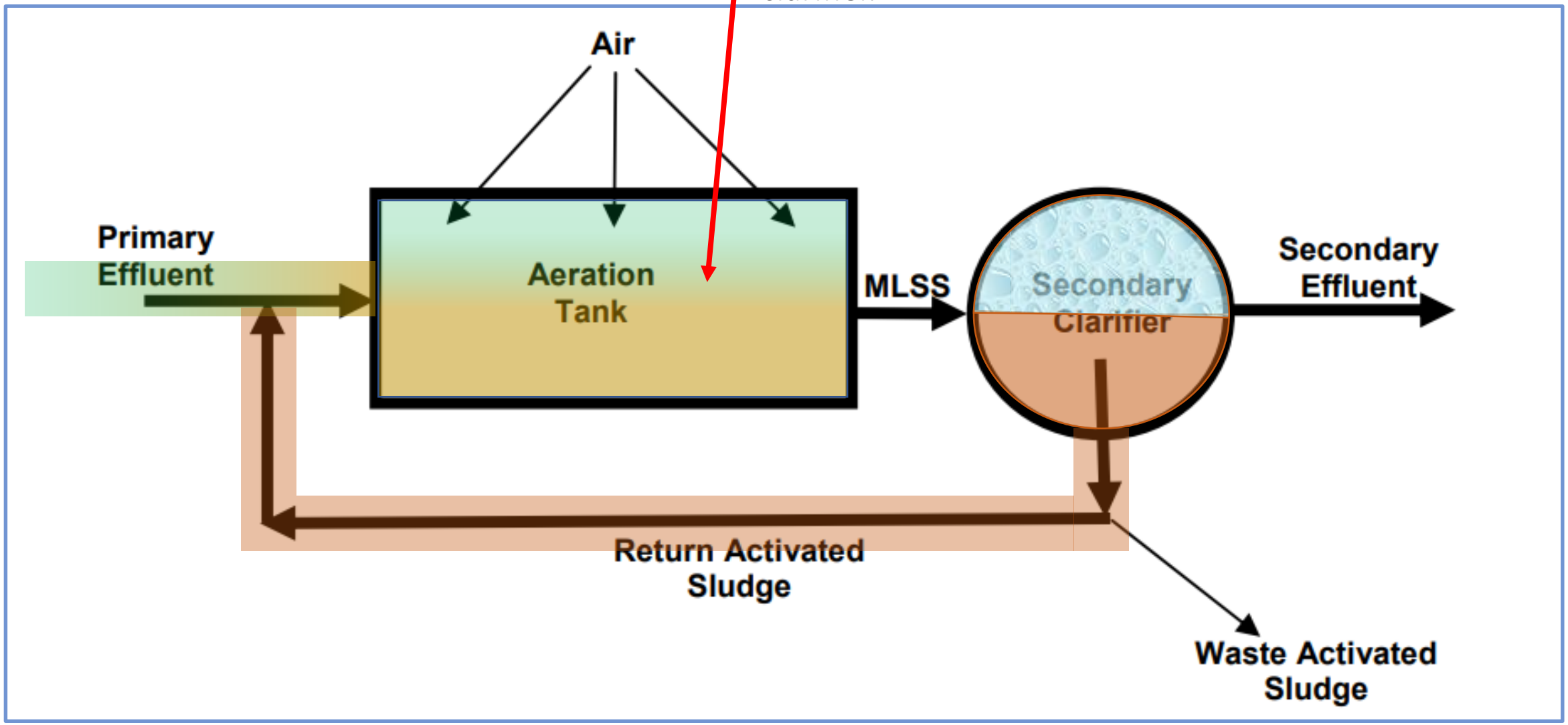
Screening, grit removal

Settleable solids removed and sent to solids handling.

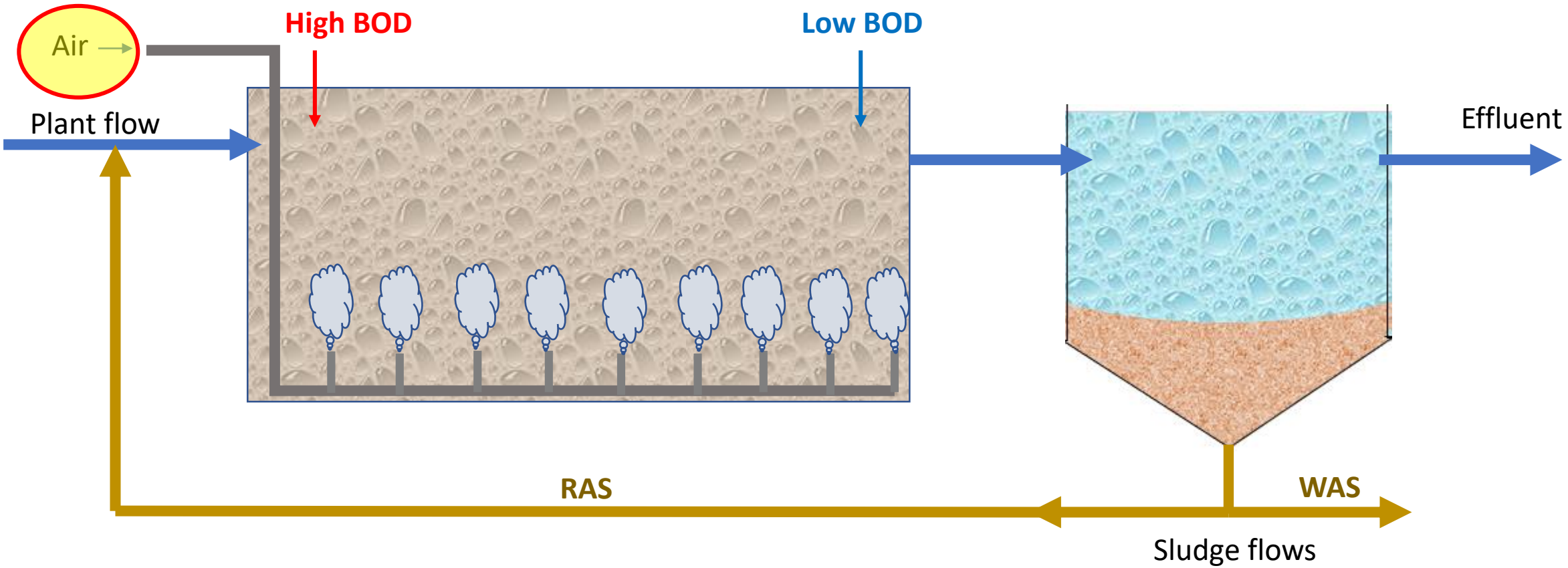
Non-Settleable Suspended solids enter the activated sludge process. Waste is converted to cellular biomass.

The activated sludge process

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



Conventional activated sludge layout

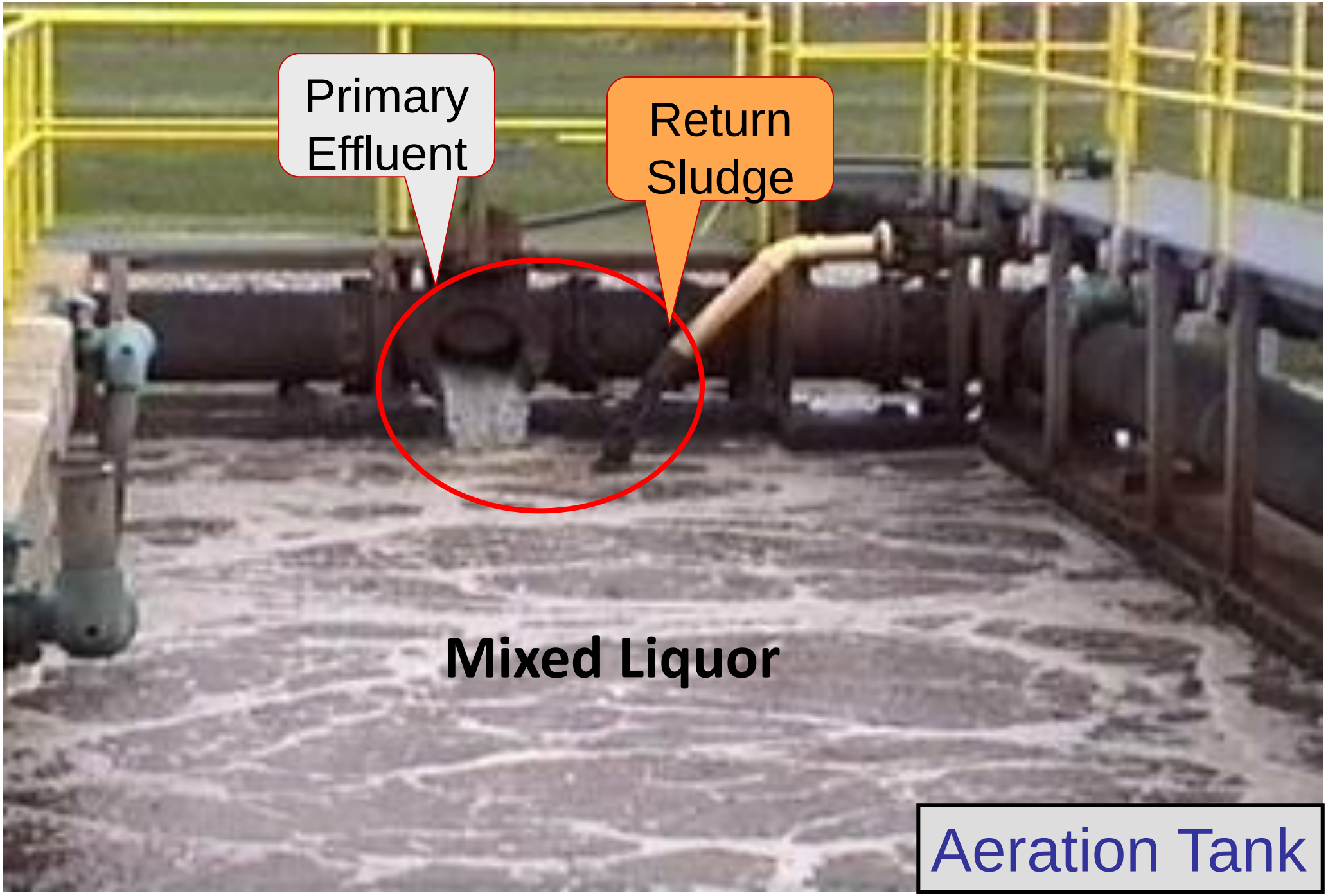


Main points to notice:

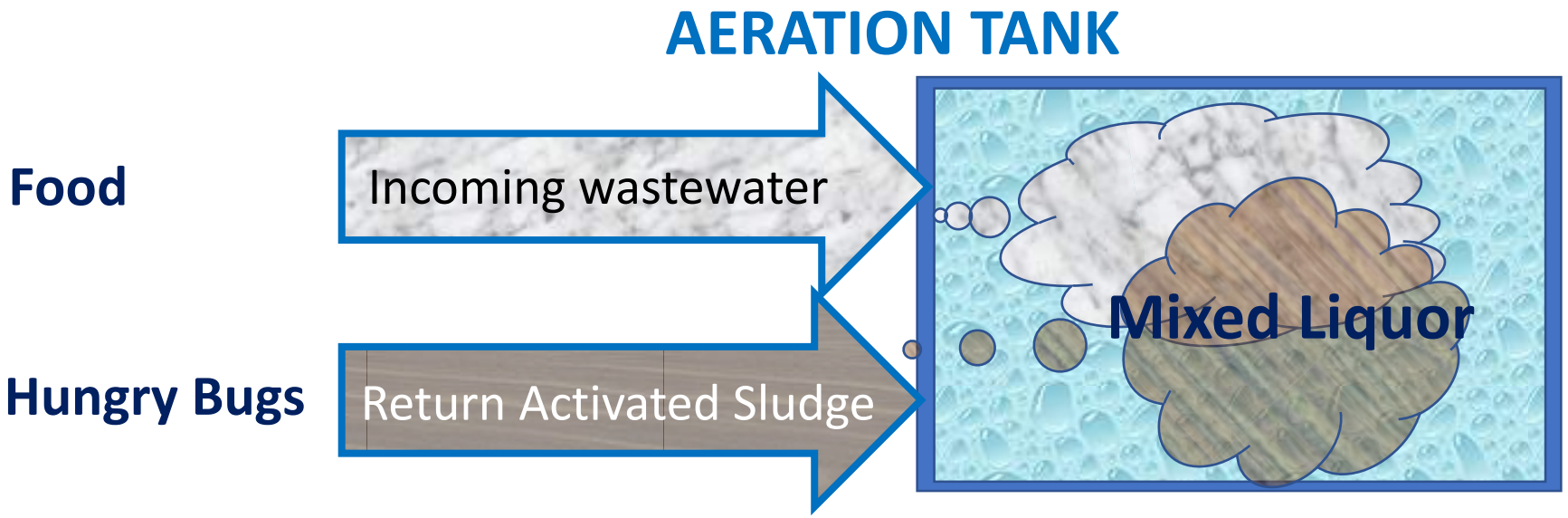
1) Continuous process. 2) Treatment progresses through the aeration basin. 3) Solids remain in system longer than the water.

Mixed Liquor
Under Aeration

Aeration Tank


Primary Effluent
Return Sludge
Mixed Liquor
Aeration Tank

Activated Sludge System (Aeration Tank)

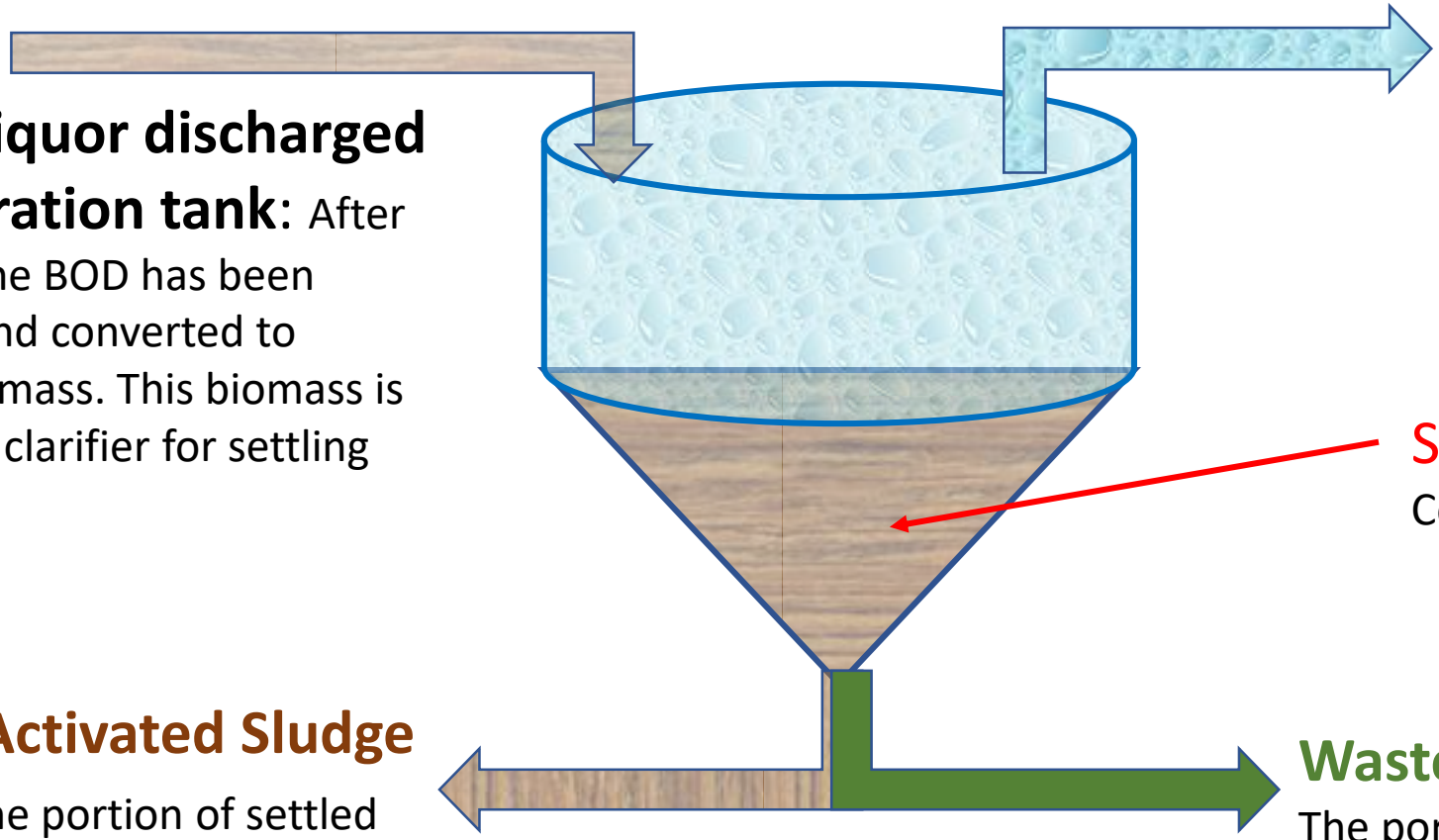


1. **Mixed Liquor**: Incoming raw wastewater is mixed with return activated sludge to create a mixed liquor.
2. **Aeration** is applied to the mixed liquor to promote rapid metabolism of wastes.
3. **Biomass**: BOD is consumed by bacteria and converted into biomass.

Secondary Clarifier

Activated Sludge System (CLARIFIER)

SECONDARY CLARIFIER



Mixed Liquor discharged from aeration tank: After aeration, the BOD has been removed and converted to cellular biomass. This biomass is sent to the clarifier for settling

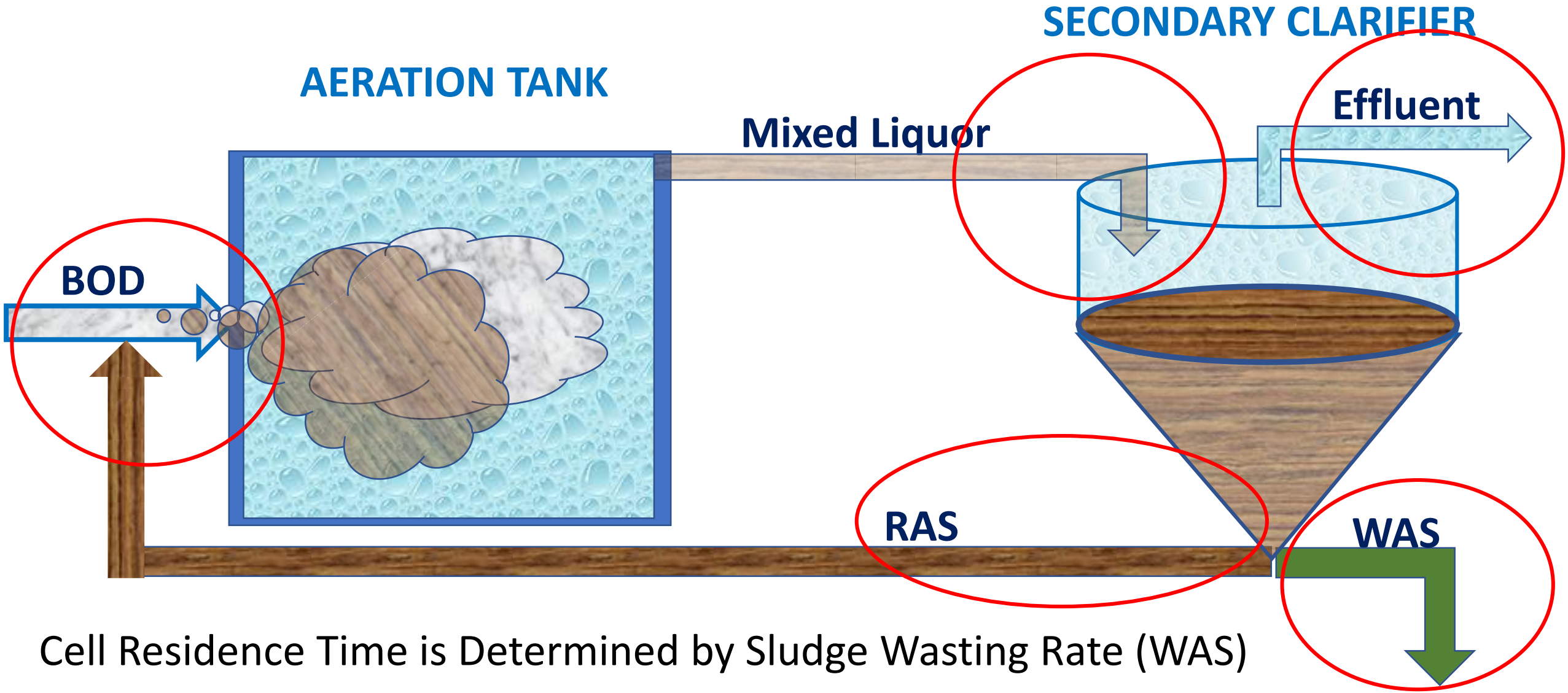
Final Effluent:
The clarified water is the final effluent of the activated sludge process.

Settled Sludge:
Consists of hungry microorganisms

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

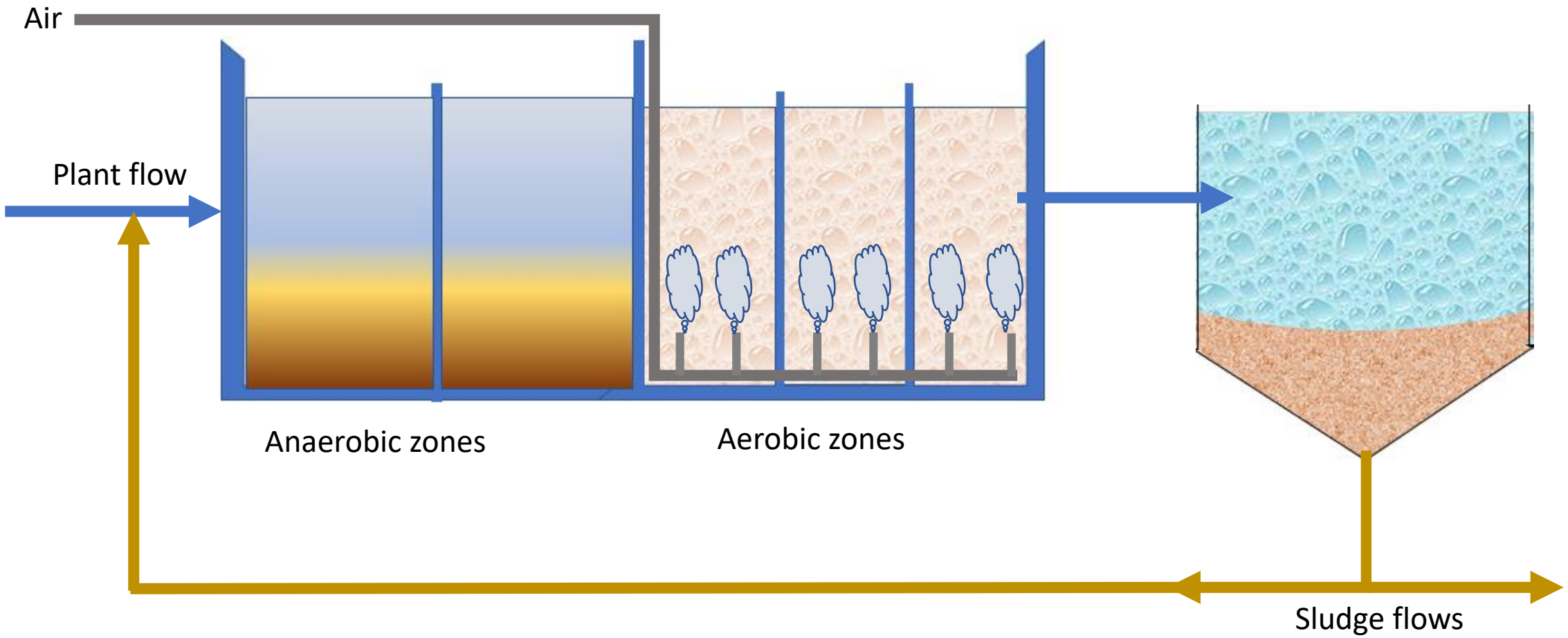
Waste Activated Sludge (WAS):
The portion of settled secondary sludge that is removed from the system. Sent to solids handling (digesters).

Aeration Tank and Clarifier Flows



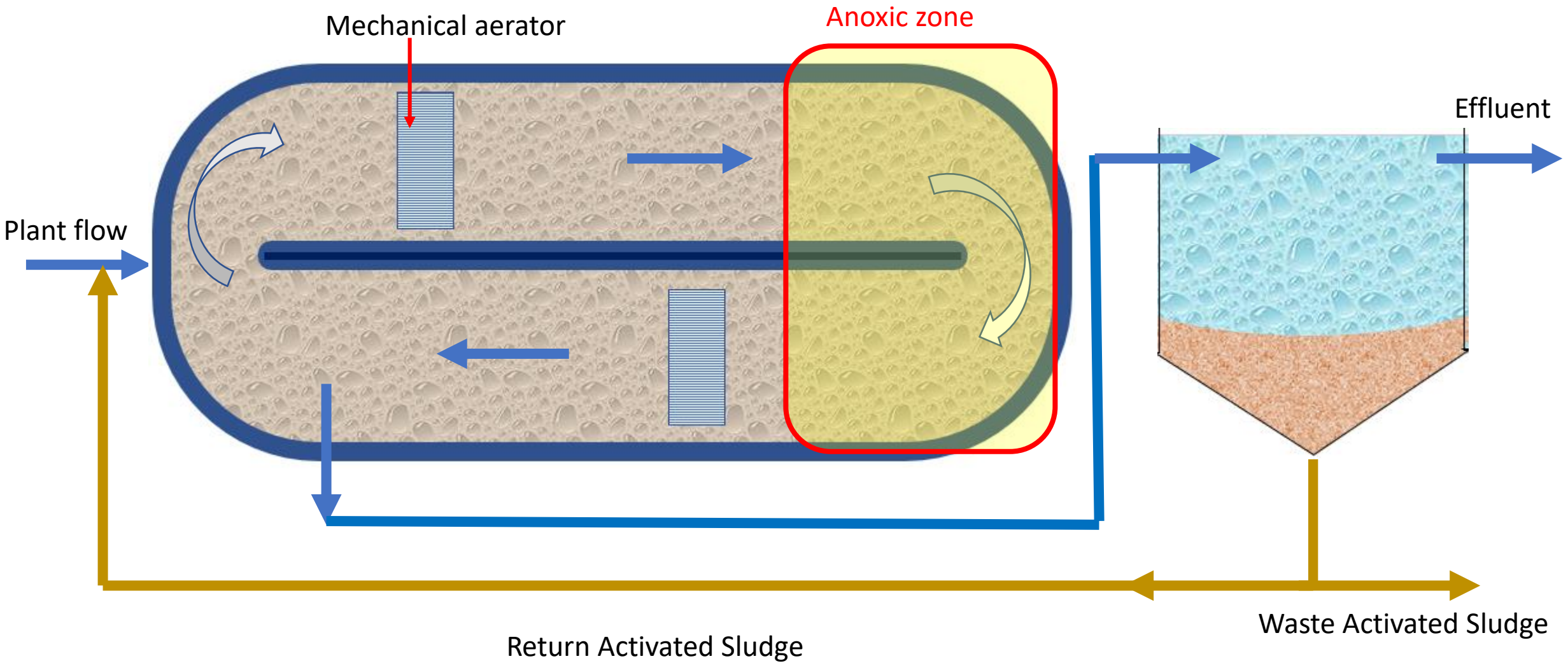
Cell Residence Time is Determined by Sludge Wasting Rate (WAS)

Activated Sludge Anaerobic/Oxic Layout (AO)



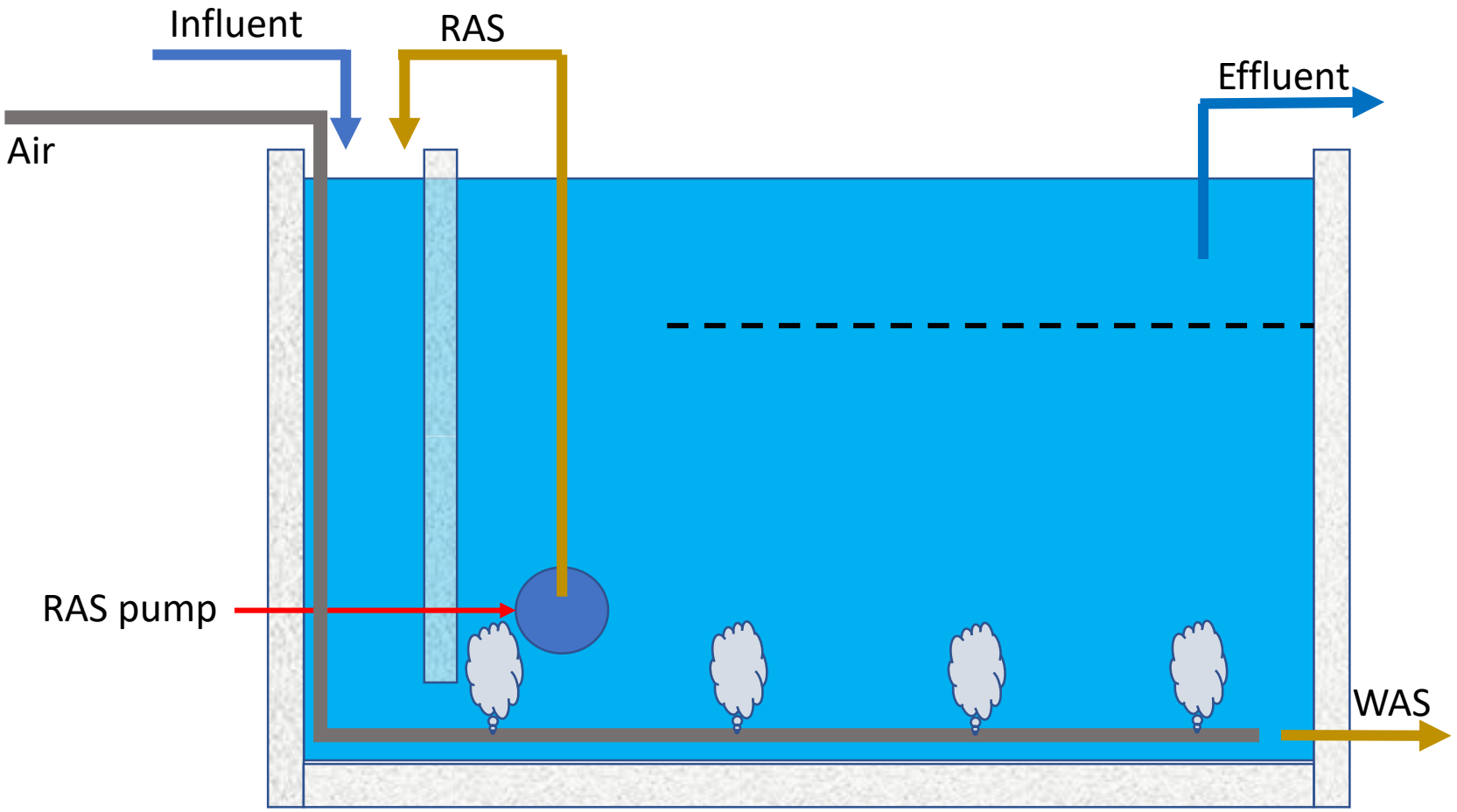
Alternating anaerobic and aerobic zones can help to remove phosphorous from wastewater.

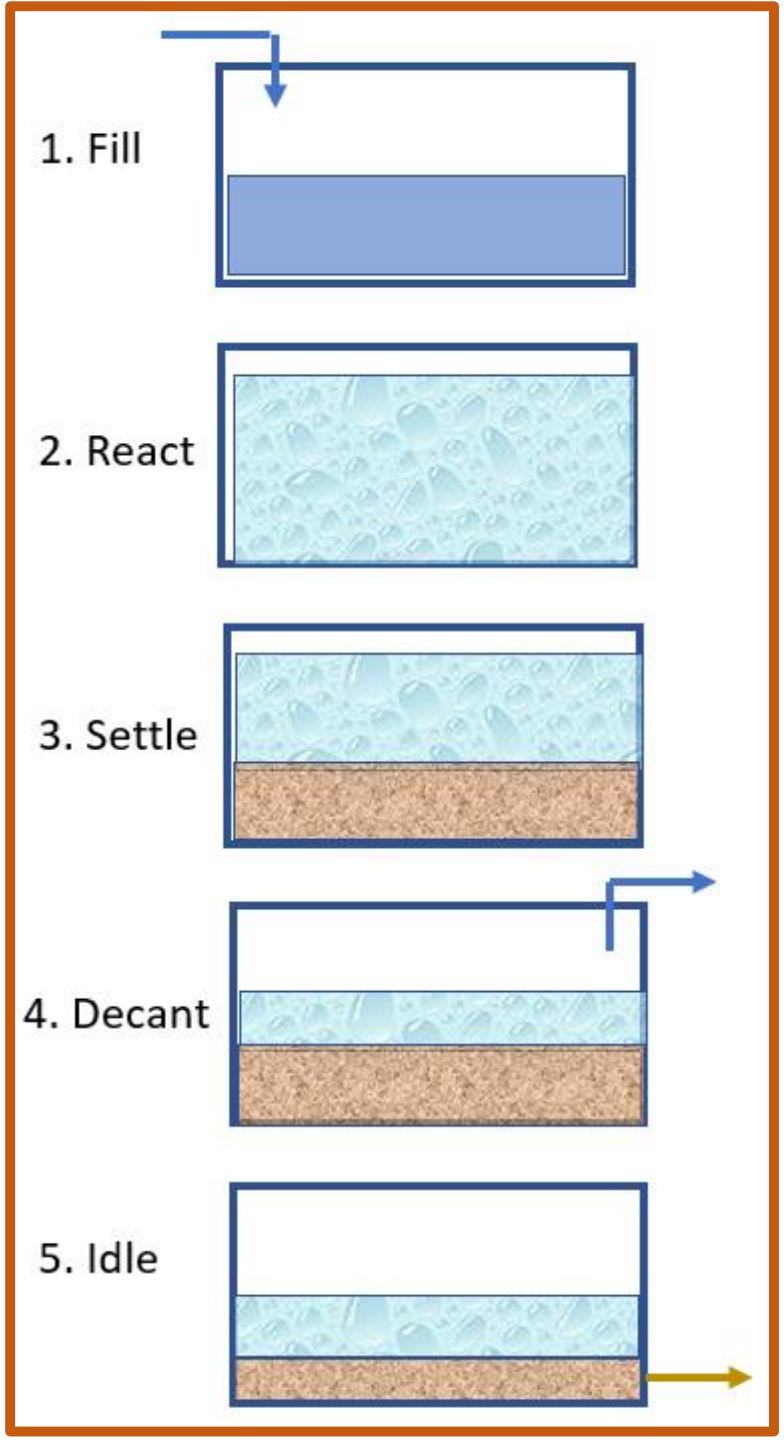
Oxidation Ditch



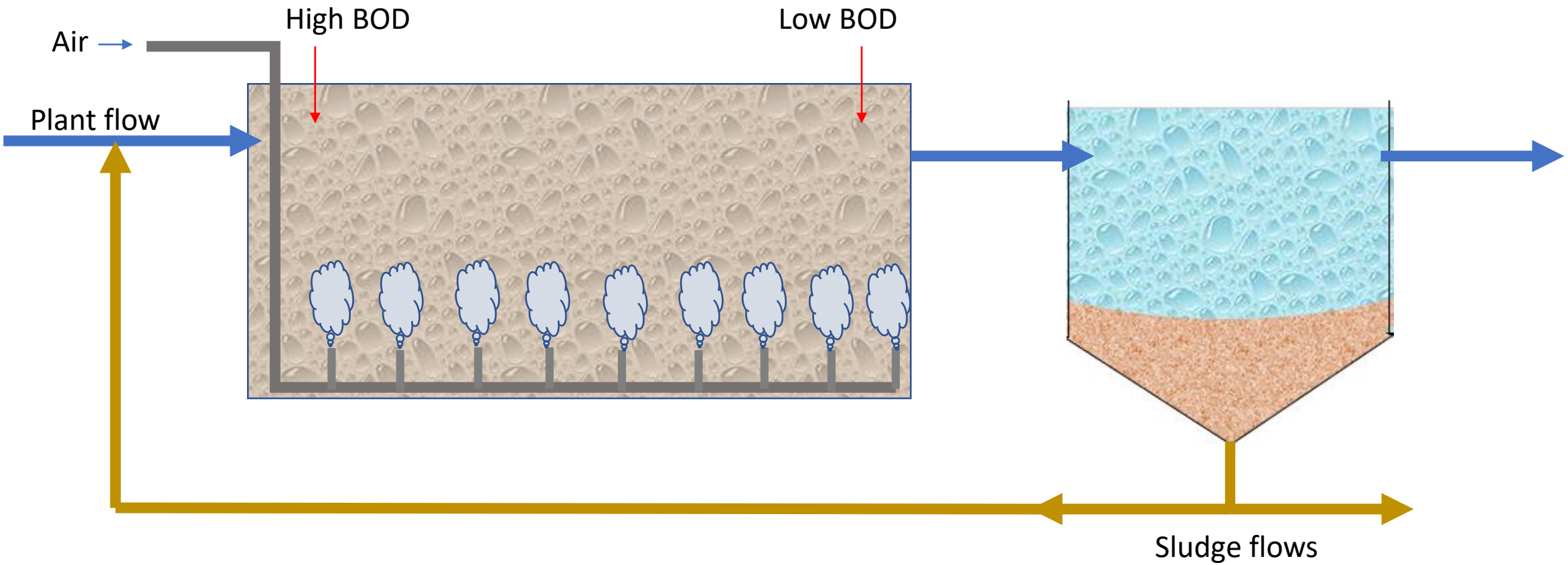
Oxidation ditches have high solids retention times and lower food to microorganism ratios.

Sequencing Batch Reactor



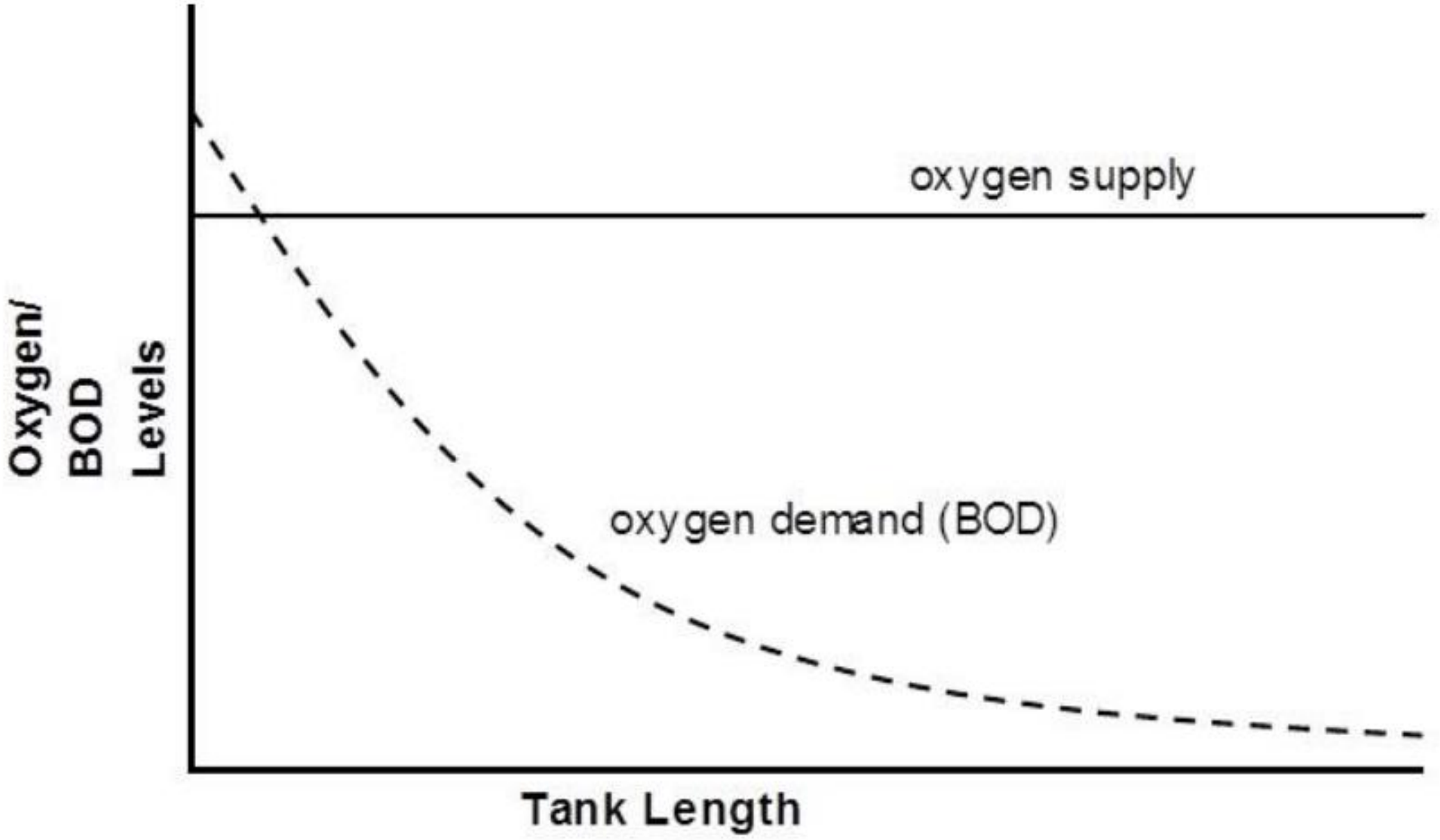


Conventional activated sludge layout



Main points to notice:

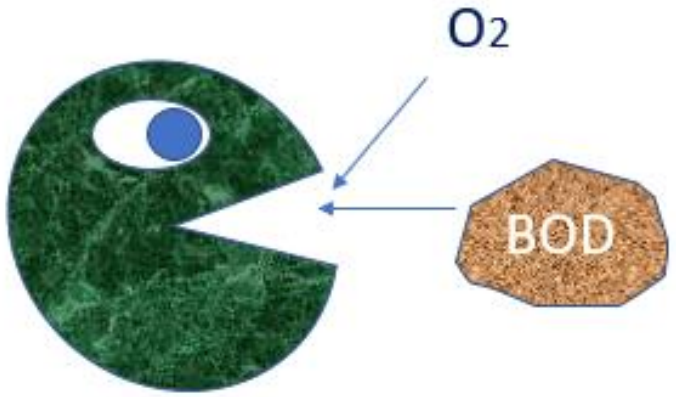
1) Continuous process. 2) Treatment progresses through the aeration basin. 3) Solids remain in system longer than the water.


oxygen supply
oxygen demand (BOD)
Oxygen/
BOD
Levels
Tank Length

Biochemical Oxygen Demand (BOD)

- Indicates the strength of the waste stream in mg/L. BOD is the food that microorganisms consume during the wastewater treatment process.

- Determined in a 5-day test that measures how much oxygen is required by bacteria in order to metabolize wastes.



Microorganisms require oxygen to metabolize waste.

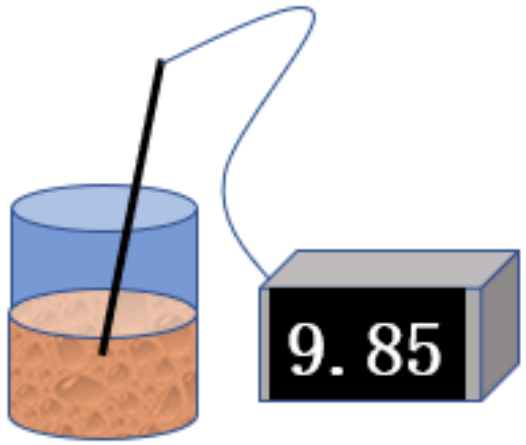
BOD Test

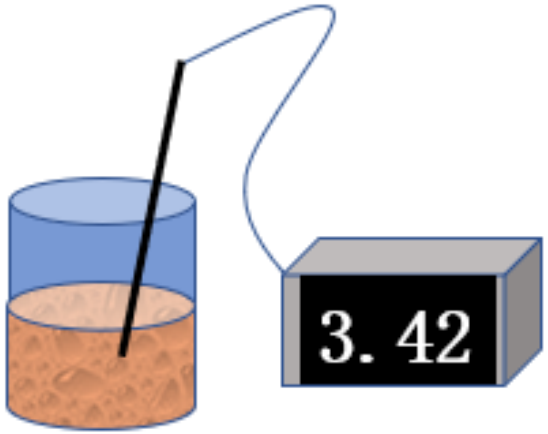
1. **A sample of wastewater is added to the test bottle** (i.e. 10 ml of sample added to the 300 ml test bottle ➔ P = 10/300 or 0.033)
2. **The D.O. concentration is measured at the start and completion**

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

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

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





P = decimal volumetric fraction

Determining Weight & Concentration of Solids

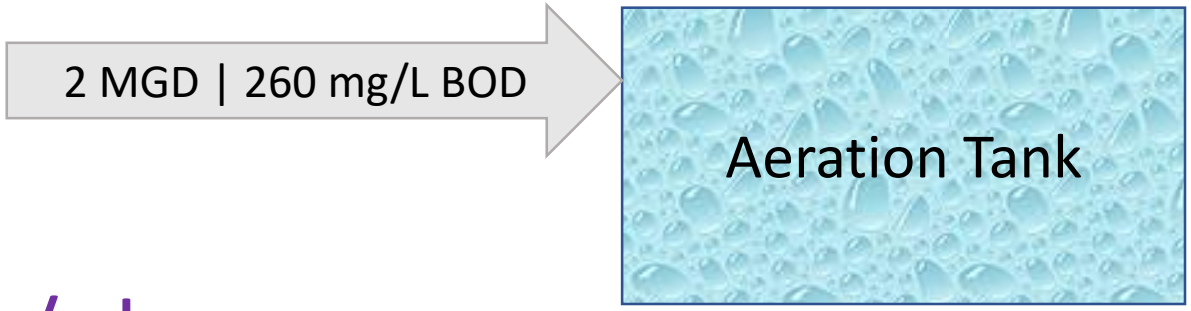
Pounds formula

Flow (MGD) x Conc (mg/L) x 8.34 lbs/gal = Pounds per day

$$\text{Conc (mg/L)} = \frac{\text{Pounds per day}}{(\text{MGD} \times 8.34)}$$

Example BOD Calculation

Calculate the BOD coming into an aeration tank in pounds per day, if the BOD concentration is 260 mg/L and the plant flow is 2 MGD.



Solution: Use the pounds formula

Lbs/Day = Flow (MGD) x mg/L (BOD) x 8.34lbs/gal

= 2.0 MGD x 260 mg/L x 8.34 lbs/gal

= **4,336.8 lbs/day** (this represents the food entering the system)

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 inorganic substances.

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

Mixed Liquor Suspended Solids (MLSS)

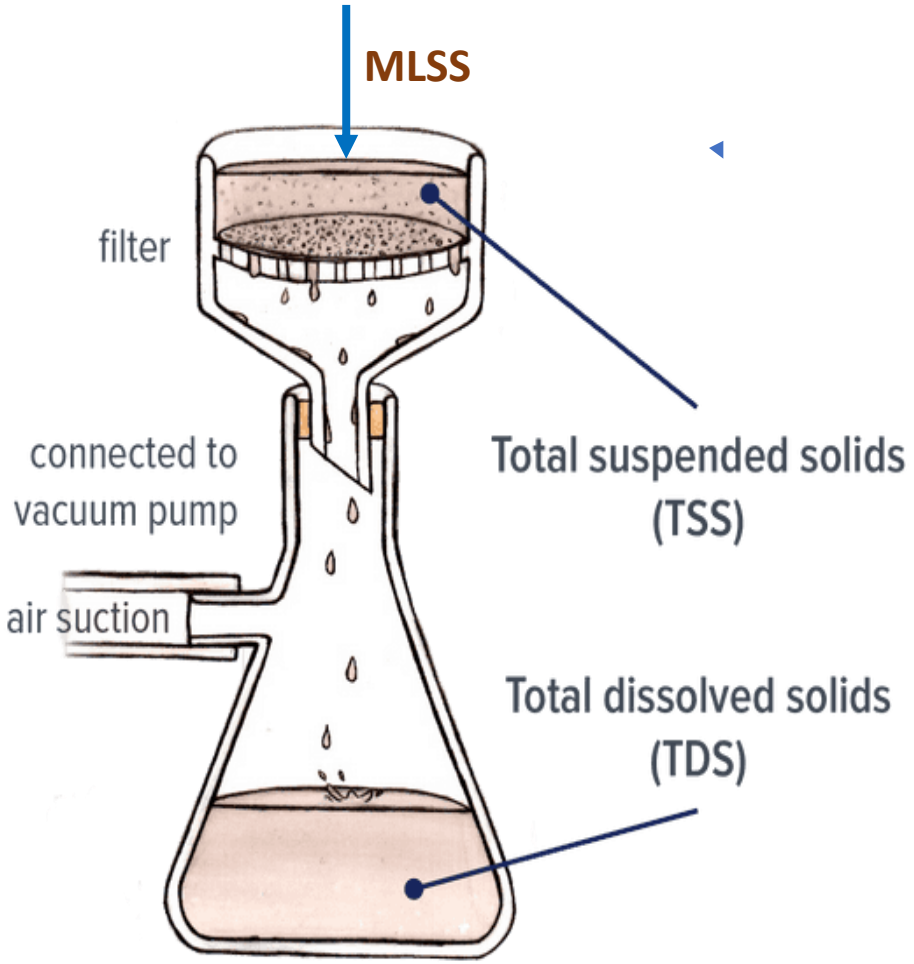
- MLSS is the total concentration of all solids in the aeration tank measured in mg/L
- The mixed liquor consists of the incoming wastewater combined with sludge returned from the secondary clarifier.
- MLSS solids are filtered through a 0.45-micron filter and then dried and weighed.

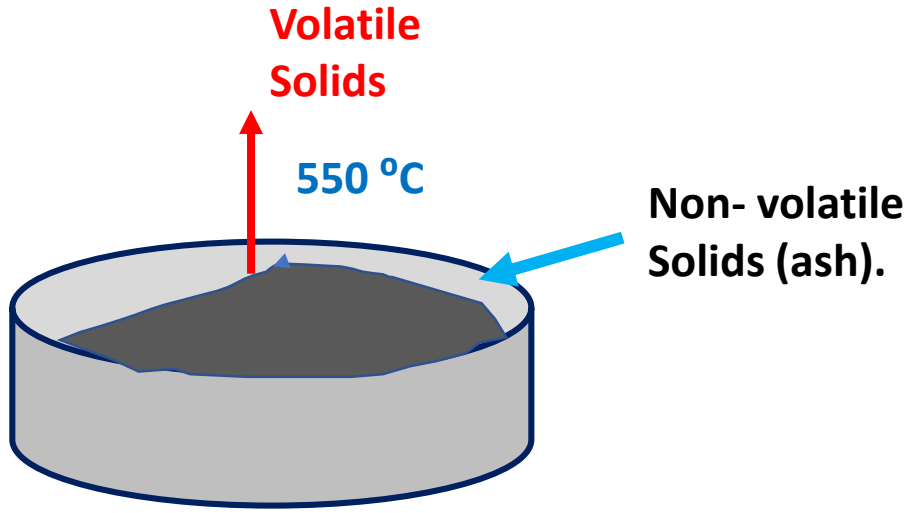
Mixed Liquor Volatile Suspended Solids (MLVSS)

- The volatile portion of Mixed Liquor Suspended Solids. Typically, around 70% of MLSS and indicates the microorganisms available to consume wastes.
- Volatile solids is determined by a test in which sludge solids are filtered through a 0.45-micron filter and then heated in a furnace to 550° C.

MLSS & MLVSS

- 0.45-micron filter captures all the suspended solids from a known sample volume.
- Solids are dried and weighed to determine MLSS.
- MLSS includes non-volatile and volatile suspended solids





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

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

Example MLVSS Calculation

Calculate the pounds of MLVSS in an aeration tank if the MLSS concentration is 2,060 mg/L, the Aeration Tank volume is 1.5 MG, and the percent volatile solids is 70%.

Step 1: Determine MLVSS Concentration

2,060 mg/L x 0.7 = **1,442 mg/L**

Aeration Tank
- **Volume** = 1.5 MG
- **MLSS Conc**. = 2,060 mg/L

Step 2: Use the pounds formula

Lbs MLVSS = Volume (MG) x mg/L (MLVSS) x 8.34lbs/gal

= 1.5 MG x 1,442 mg/L x 8.34 lbs/gal

= **18,039.4 pounds** (This is the pounds of MLVSS under aeration)

Two Core Process Control Concepts

Food to Microorganism Ratio (F:M)

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

Mean Cell Residence Time (MCRT)

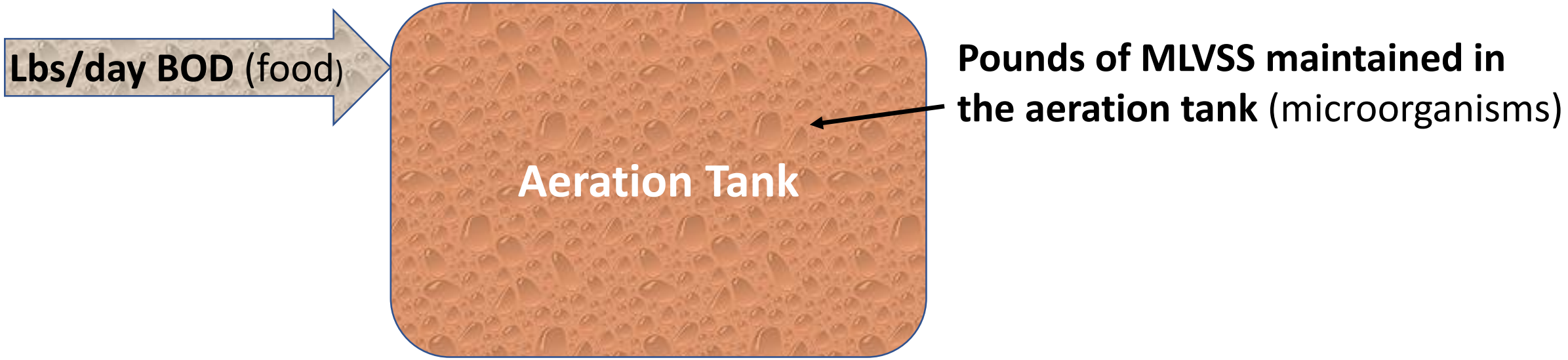
$$\frac{\text{Pounds of MLSS under aeration}}{\text{Lbs/day suspended solids leaving system}}$$

Poll #2: What happens to treated wastewater in your municipality?

a) Discharged to receiving waters
b) Discharged into leach fields
c) Reused for irrigation or industrial applications
d) Used for aquifer recharge
e) Other

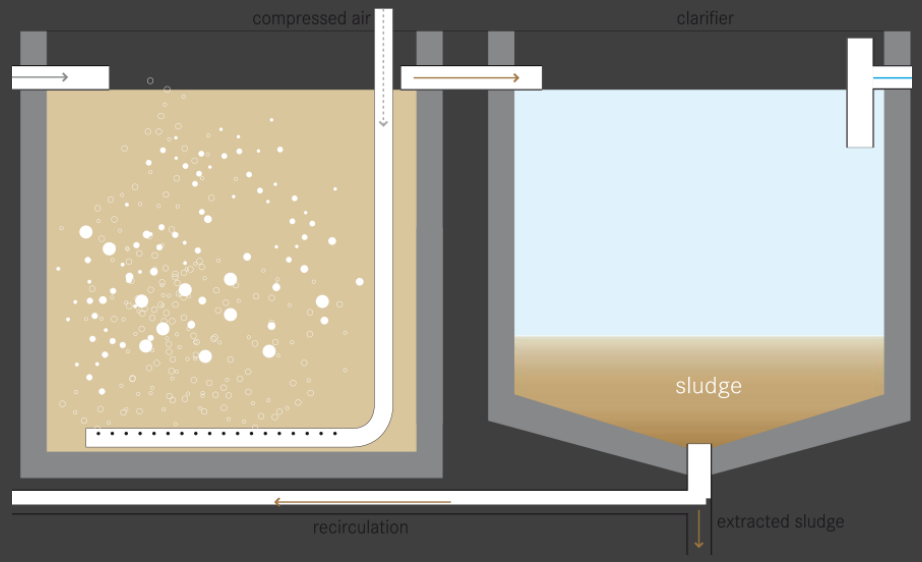
Food to microorganism ratio (F:M)

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



Food to microorganism ratio

- **Food** = Pounds per day of Biochemical Oxygen Demand (BOD) in the influent wastewater.
- **Microorganism**s = Pounds of mixed liquor volatile suspended solids.

Typical F:M Ratios

- **Conventional activated sludge** plants generally operate with an F:M ratio between 0.25 to 0.45.
- **Extended Aeration** plants typically operate with F:M in the 0.05 to 0.15 range.

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

Using F:M Ratio

$$\frac{\text{Food}}{\text{Microorganism}} = \frac{\text{Lbs/Day BOD}}{\text{Lbs MLVSS}}$$

Steps

1. Calculate lbs/day BOD coming into aeration tank
2. Calculate lbs MLVSS in aeration tank
3. Divide and compare to target F:M ratio

$$\frac{\text{Lbs/Day BOD}}{\text{Lbs MLVSS}} = \text{F:M ratio}$$

To calculate pounds of MLVSS, you can rearrange the equation so that you divide the pounds/day of BOD, by the target F:M ratio

$$\frac{\text{Lbs/Day BOD}}{\text{F:M ratio}} = \text{Lbs MLVSS}$$

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 $F:M = \frac{\text{630 lbs/day}}{\text{Lbs MLVSS}} = \mathbf{0.3}$

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

630 lbs/day ÷ 0.3 = 2,100 lbs of MLVSS (you could be done here if determining lbs)

Step 3: Use the pounds formula to determine the concentration of MLVSS (input volume and lbs)

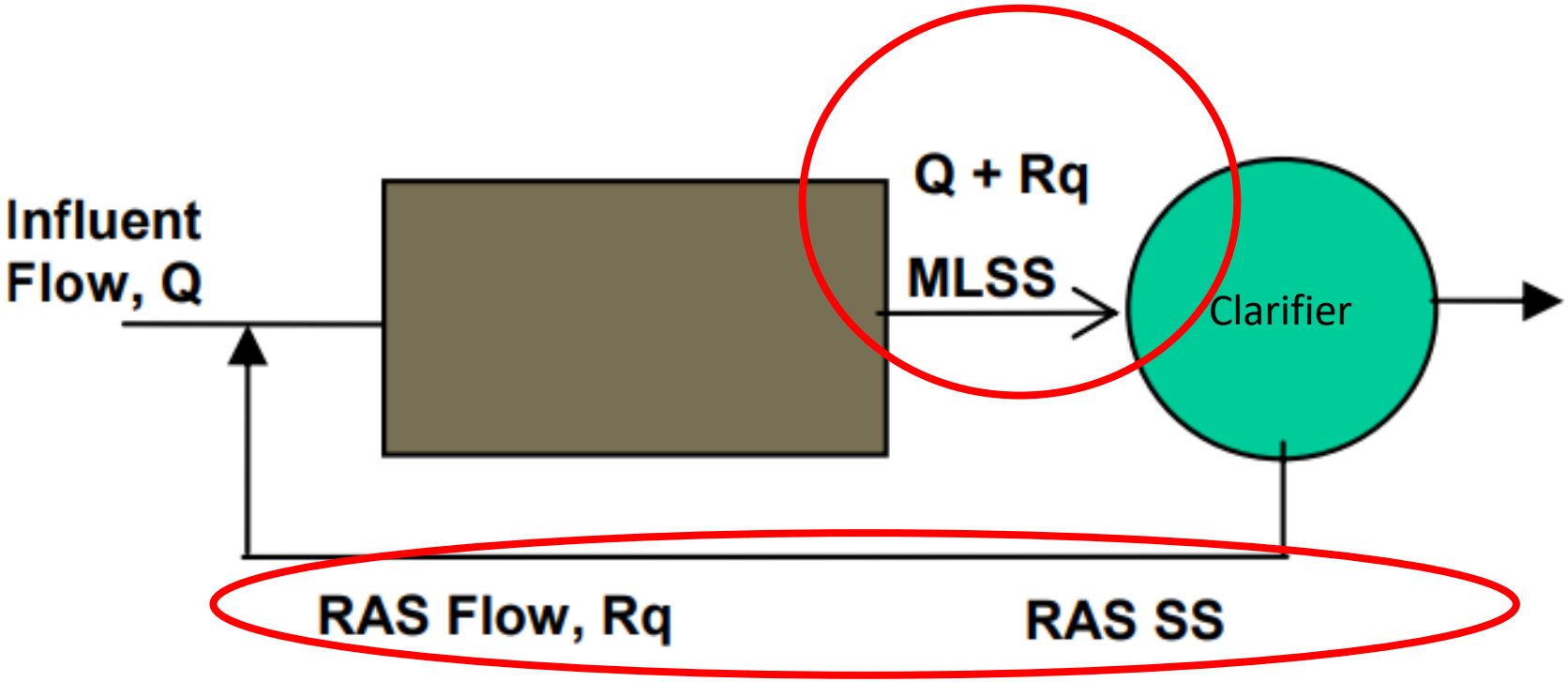
2,100 lbs MLVSS = 0.105 MG x Conc (mg/L) x 8.34 lbs/gal

Step 4: Rearrange to solve for mg/L of MLVSS *(divide both sides by 0.105 MG x 8.34 lbs/gal)*

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

RAS flow based on solids balance

$$Rq = \frac{Q \times MLSS}{RAS\ SS - MLSS}$$



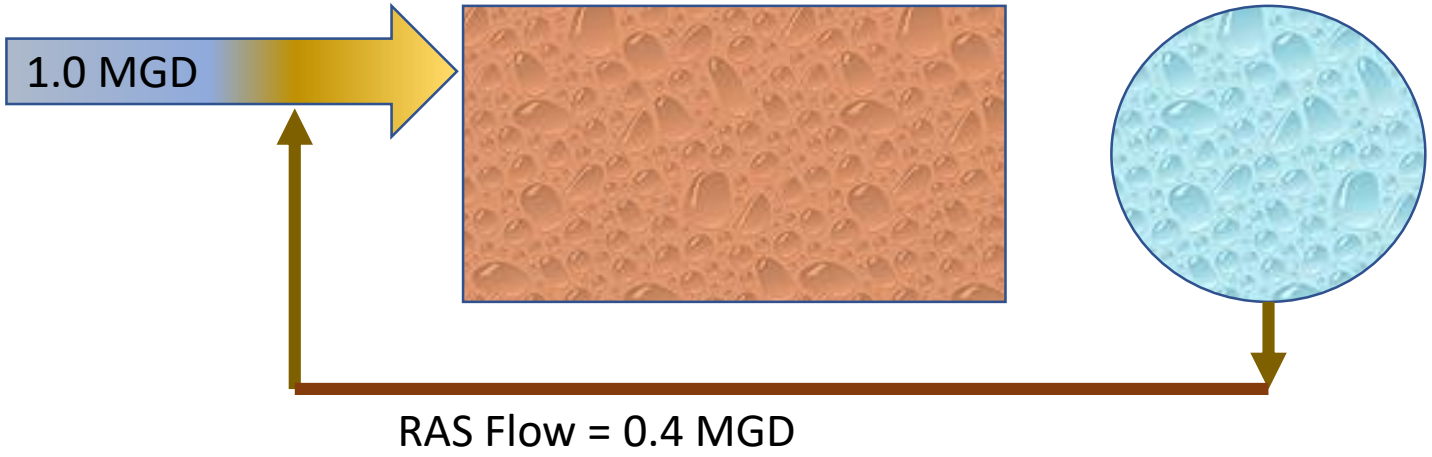
Return Activated Sludge (RAS) brings hungry microorganisms back into the aeration tank

RAS as a % of influent flow

Commonly, RAS flow is set as a percentage of influent flow. This method can help to track RAS with plant flow.

- For example, for a 1 MGD plant, a 40% RAS rate would be 0.4 MGD.

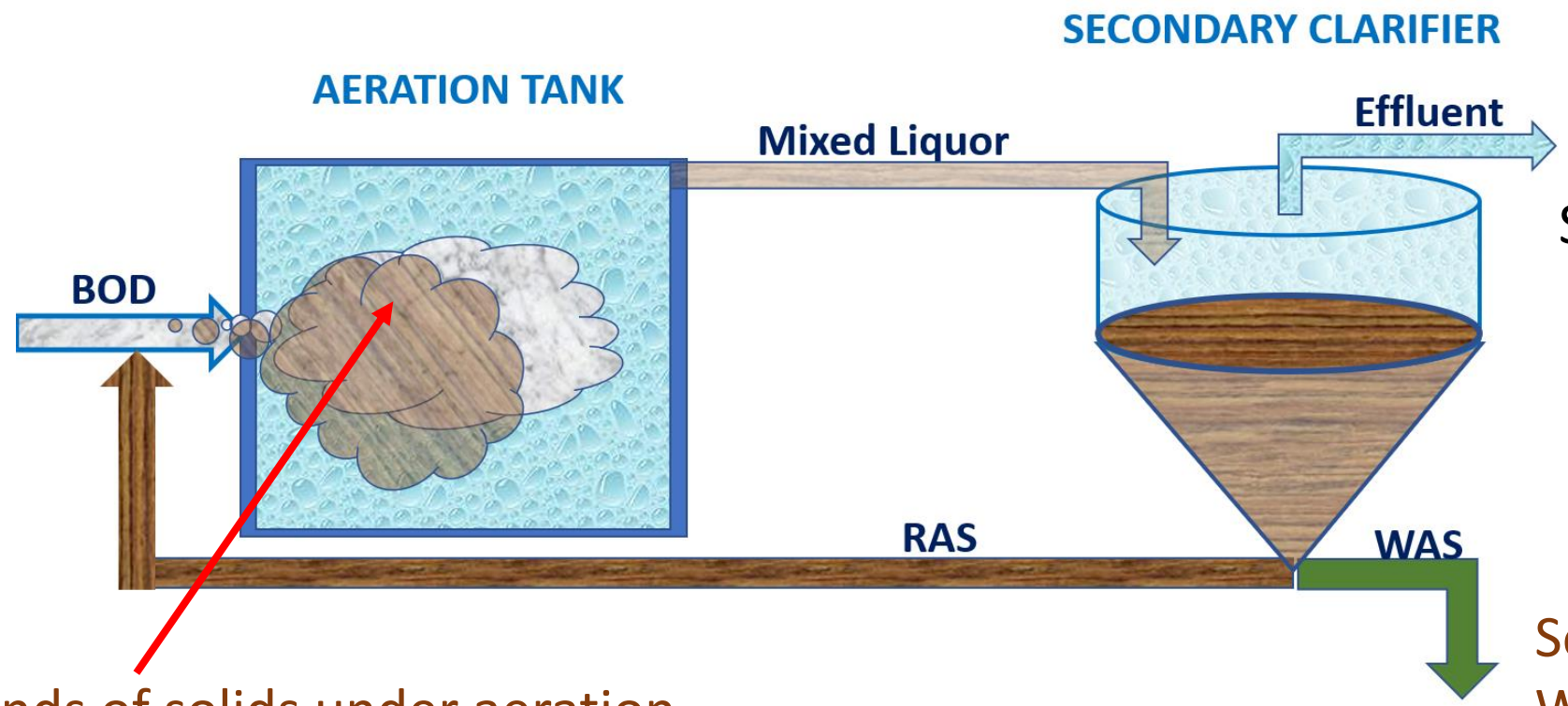
- Typical RAS flow ranges from 30 % to about 125 % of influent flow.



Mean Cell Residence Time (MCRT)

MCRT is the average length of time in days that an organism remains in the activated sludge treatment system.

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



Solids leaving system as effluent

Pounds of solids under aeration

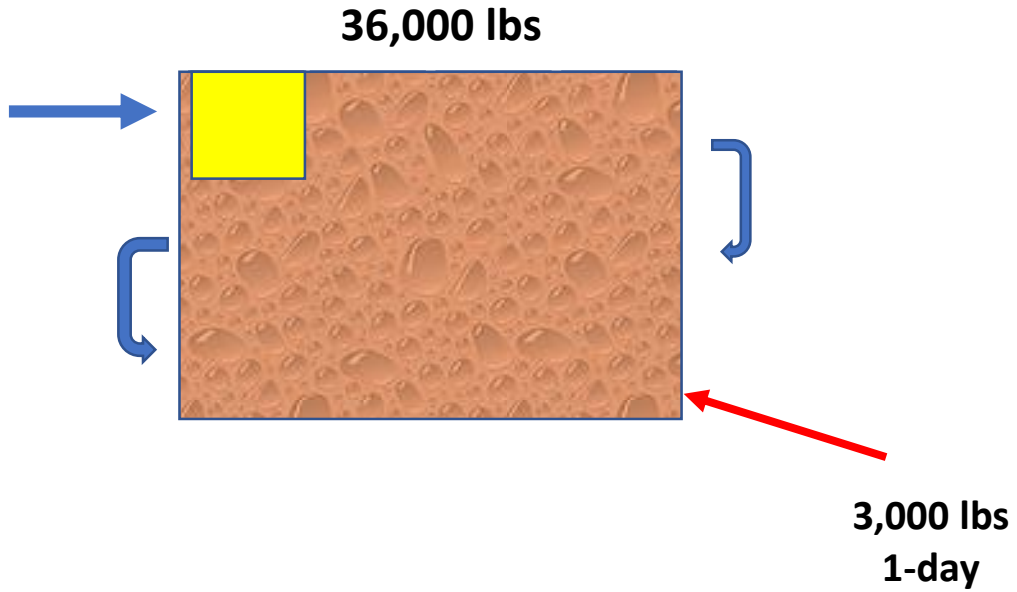
Solids leaving system as WAS

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

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

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

= 12 days



How long does one microorganism remain in the system?

What is the MCRT of a wastewater treatment facility with the following parameters?

- Aeration Volume = 5 MG | MLSS = 2,280 mg/L
- WAS Q = 115 gpm | WAS Conc. = 8,110 mg/L

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

Step 1: Use pounds formula to determine Lbs under aeration:
5 MG x 2,280 mg/L x 8.34 lbs/gal = 95,076 lbs

Step 2: Convert WAS flow to MGD:
115 gpm x 1440 = 0.1656 MGD

Step 3: Use pounds formula to determine Lbs per day wasted
0.1656 MGD x 8,110 mg/L x 8.34 = 11,200 lbs/day

Step 4: Divide to determine MCRT
95,076 lbs ÷ 11,200 lbs/day = **8.5 days**

Mean Cell Residence Time (MCRT)

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

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

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 | MLSS conc = 2,050 mg/L.
- Secondary clarifier operational volume: 0.250 MG
- WAS flow: 0.0550 MGD. | WAS conc = 7,980 mg/L.

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

$$\text{MCRT} = \frac{\text{(1.0 MG + 0.25 MG) x 2,050 mg/L x 8.34}}{\text{[0.055 MGD x 7,980 mg/L x 8.34] + [3.25 MGD x 21.2 mg/L x 8.34]}}$$

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

WAS Rates

$$\text{MCRT(days)} = \frac{\text{Lbs of MLSS in aerators}}{\text{Lbs/day WAS SS}}$$

Rearrange to solve for pounds per day of WAS solids

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

Use the pounds formula to solve for WAS flow

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

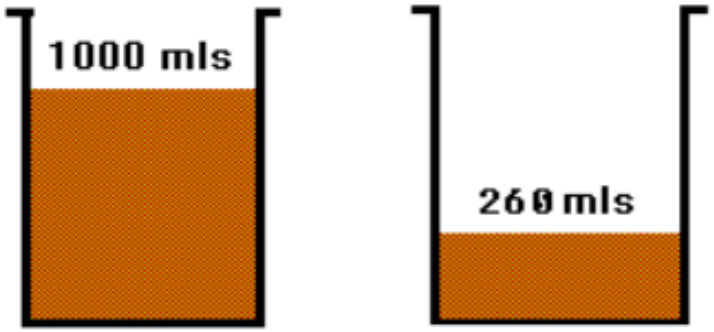
Sludge Volume Index (SVI)

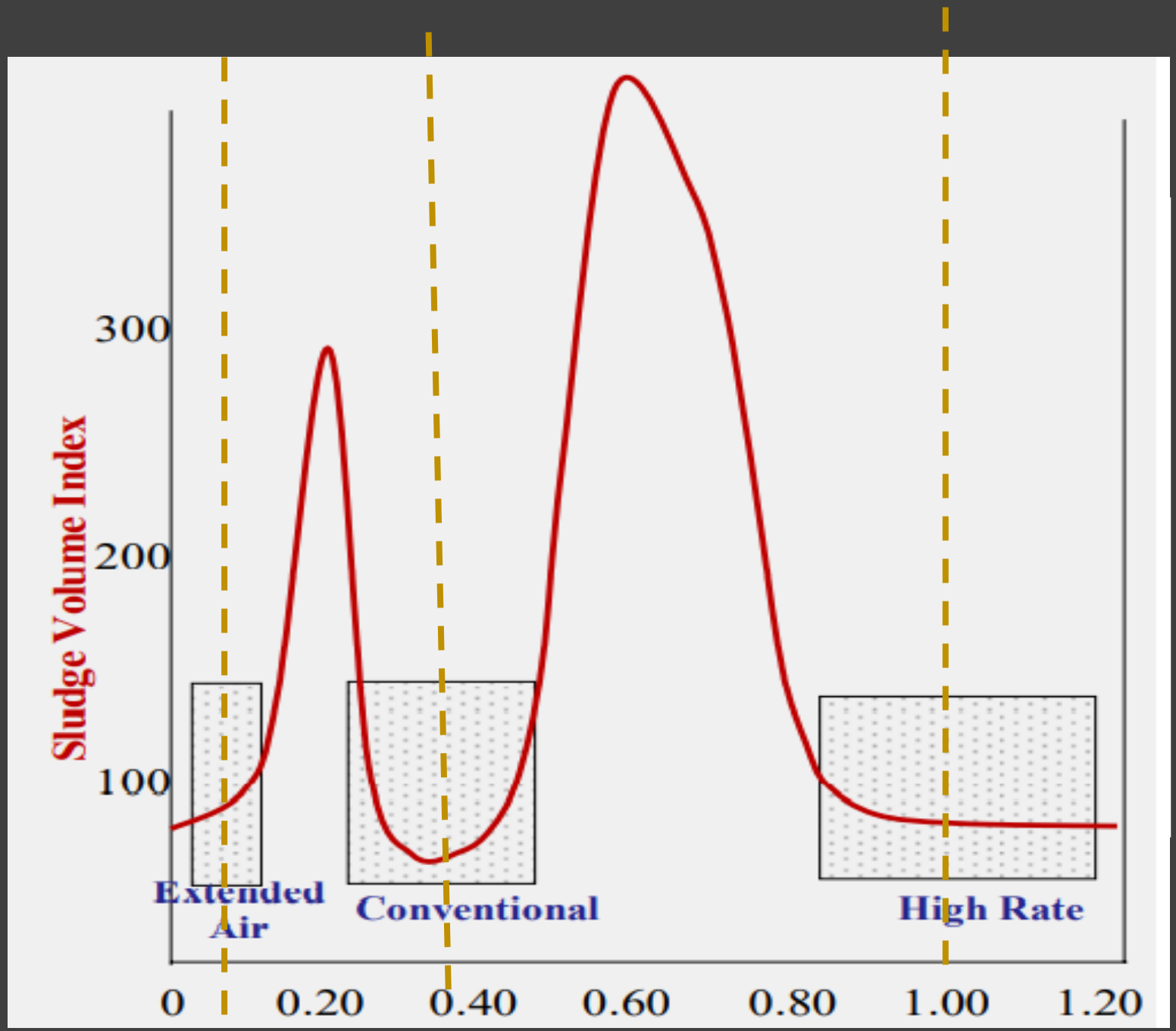
SVI = $\frac{\text{mls Settled in 30 min}}{\text{MLSS, mg/L/1000}}$

- An SVI between 80 and 120 is considered to produce good settling

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.

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





Relationship between SVI and F:M Ratio

Cell retention time in activated sludge

Conventional Activated Sludge

- CRT 4 – 6 days
- High aeration rates
- Simple organisms
- Smaller footprint and higher rate of treatment

Extended Aeration Activated Sludge

- CRT 15 – 25 days
- Lower aeration rates
- More complex organisms
- Larger footprint to hold large microorganism population longer.

Poll #3: What is the biggest challenge facing wastewater utilities for the next 20 years?

a) Aging infrastructure
b) Labor shortages
c) Economic factors
d) Additional regulations
e) Other

Poll #4: Which funding source would your municipality most likely use for upgrading wastewater infrastructure?

a) WIFIA (Water Infrastructure Finance and Innovation Act)

b) SRF (State Revolving Fund)

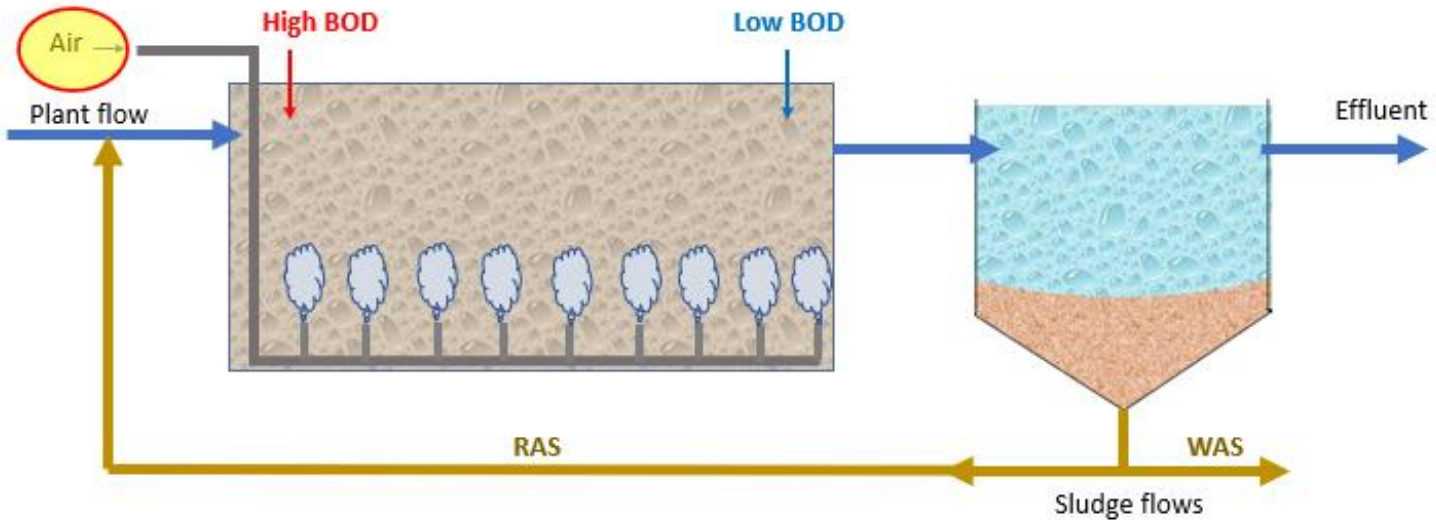
c) USDA RD (US Dept. of Agriculture Rural Development)

d) Self-funded through reserve funds and impact fees.

e) Other

What we covered today

- FM Ratios
- MCRT
- Sludge Index
- RAS and WAS flows



Resources for further study

1. Fundamentals of Clarifier Performance, Voutchkov, N. https://s3.amazonaws.com/suncam/docs/279.pdf

2. Activated Sludge Process Control Manual - State of Michigan. https://www.michigan.gov/-/media/Project/Websites/egle/Documents/Programs/WRD/Operator-Certification/activated-sludge-manual.pdf?rev=18ceb928163f4dac8689e2f34dd365ae

3. Wastewater Treatment Plant Operator Certification Course – Activated Sludge, State of PA Townships Assoc. https://files.dep.state.pa.us/water/bsdw/OperatorCertification/TrainingModules/ww16_sludge_2_wb.pdf

Thank you for attending!

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