environmental finance center network

Environmental Finance Center
Syracuse University

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

Nutrient Removal Optimization

For Small Wastewater Treatment Plants

Thursday, Aug 7, 2025: 1:00 – 2:00 pm EST

www.efcnetwork.org

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

Certificate of Completion

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

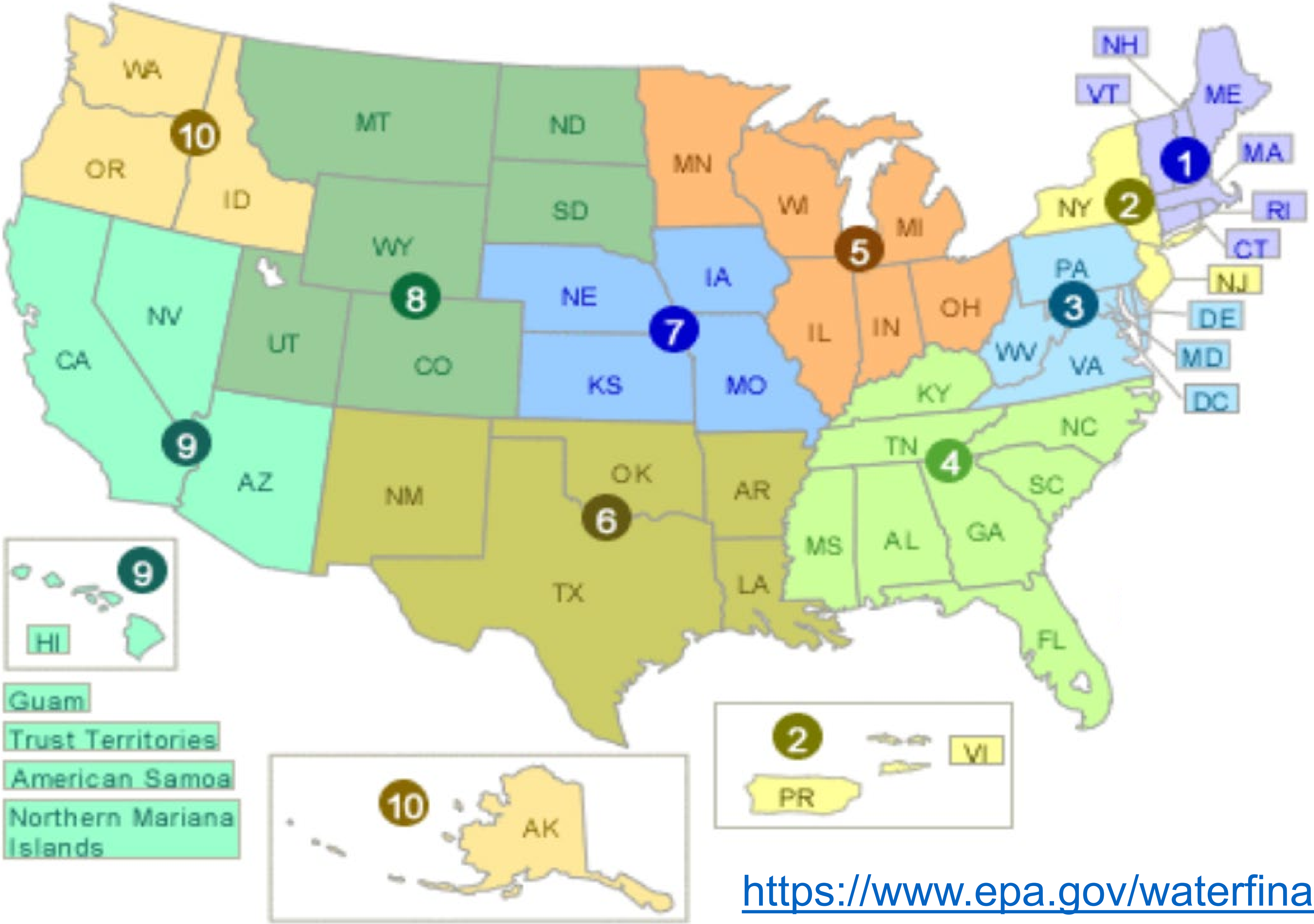
If you have questions or need assistance, please contact

EFCN
environmental finance center network

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 water 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 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

Our focus today

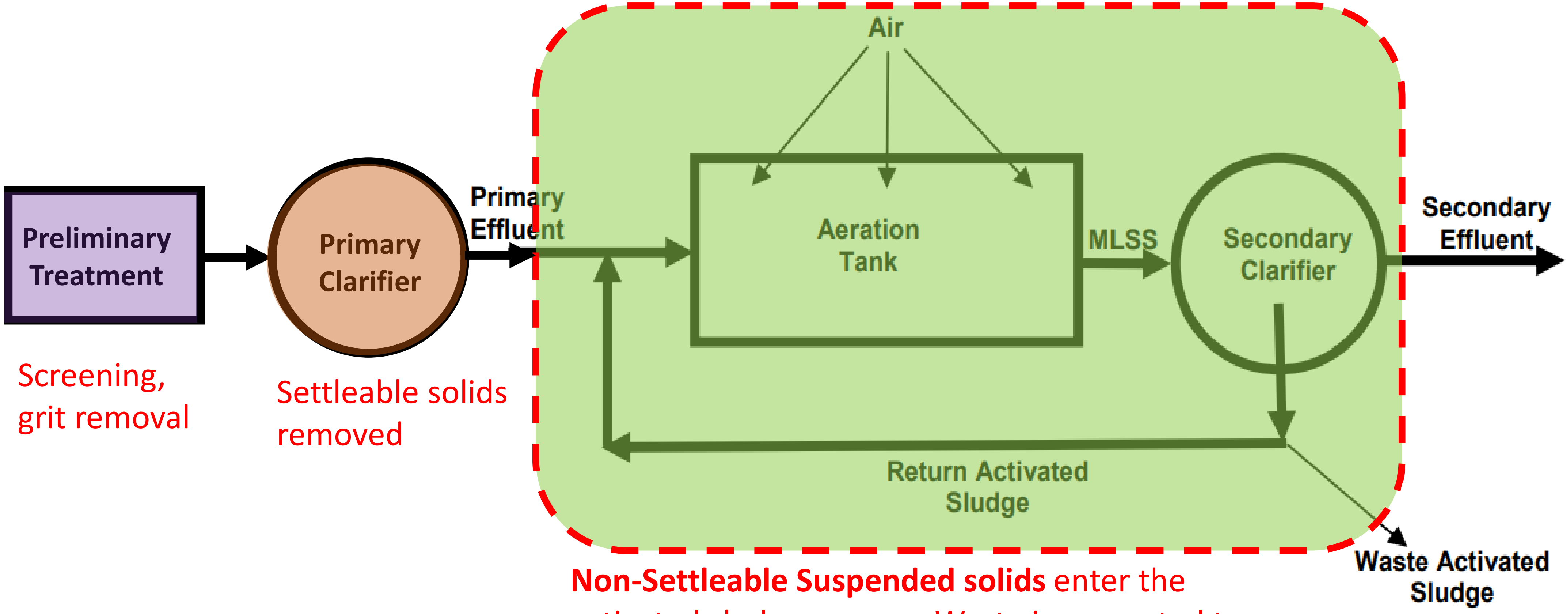
Problem

How to optimize nutrient removal to meet discharge permit requirements for wastewater treatment plants that were primarily designed to remove BOD, TSS, & Ammonia

What we need to be able to do

- Understand the processes used for nitrogen and phosphorus removal.
- Apply modifications to wastewater treatment processes to improve nutrient removal.
- Analyze process control monitoring results.

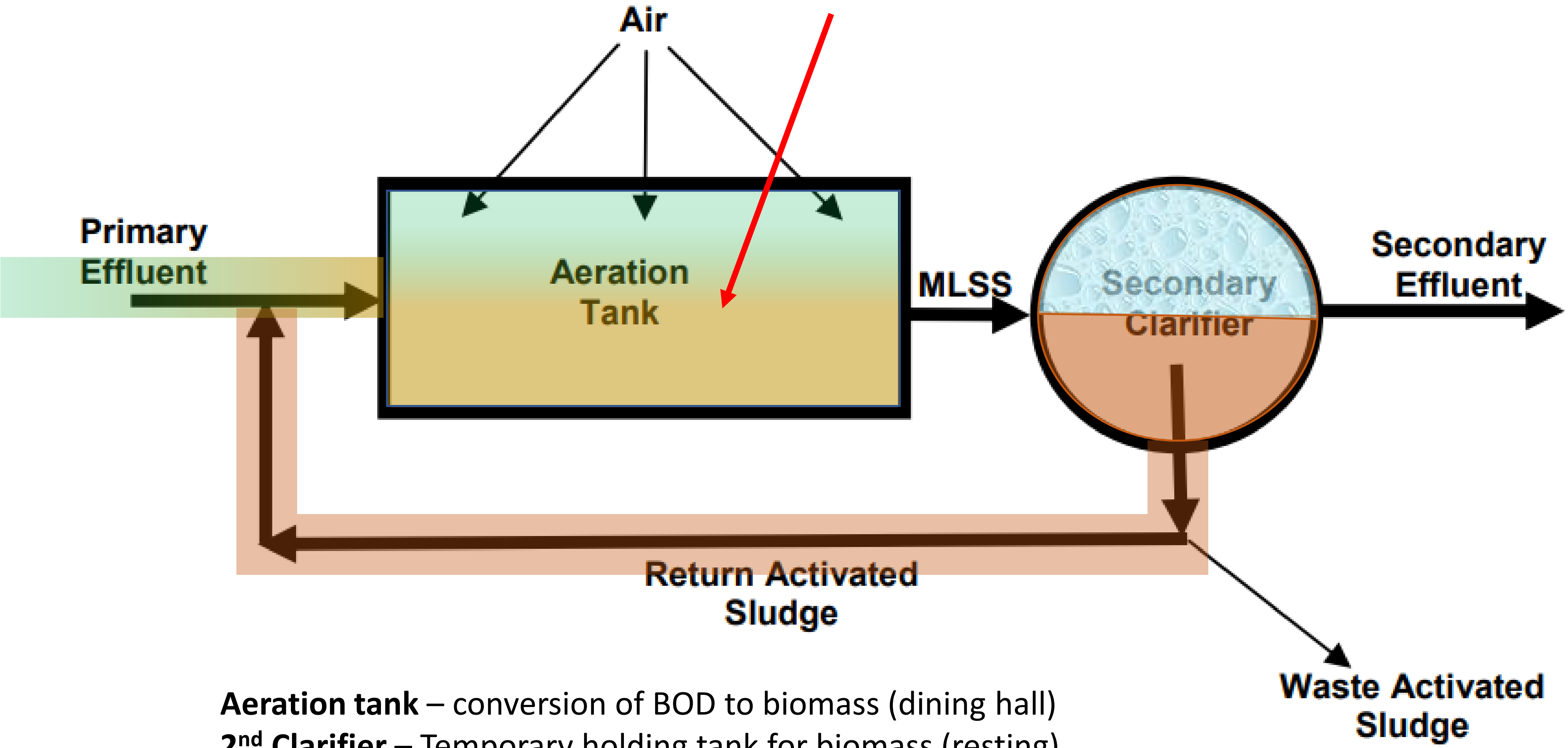
Review: Basics of activated sludge



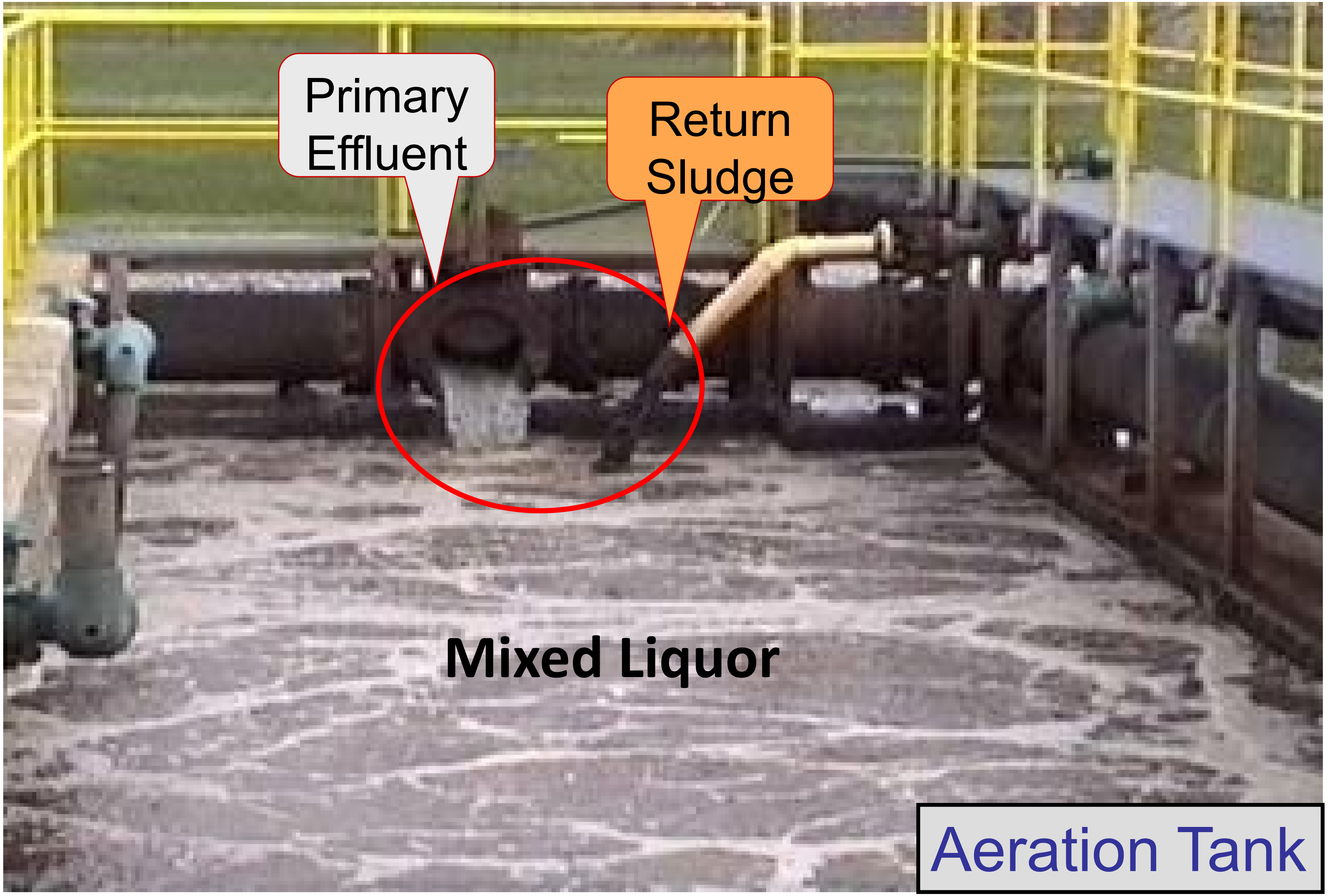
Non-Settleable Suspended solids enter the activated sludge process. Waste is converted to cellular biomass.

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)


Primary Effluent
Return Sludge
Mixed Liquor
Aeration Tank

Activated Sludge Process Control

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

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

Process Control Calculations

MCRT

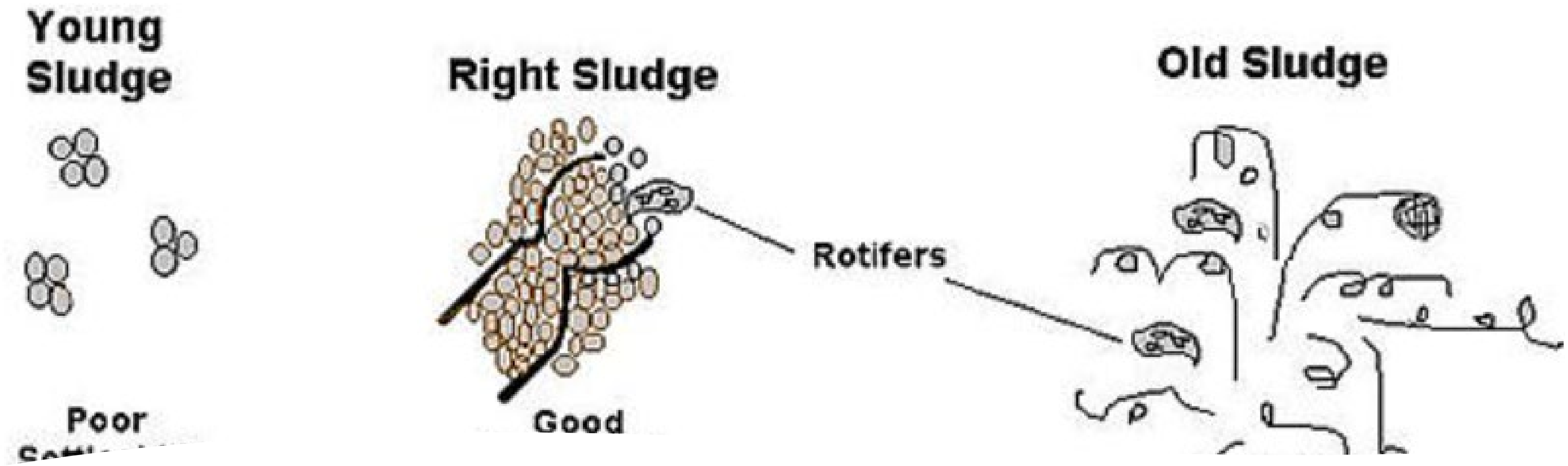
- Activated sludge: 5 – 15 days | Extended aeration: 20 – 30 days

$$\textbf{MCRT (days)} = \frac{\text{Pounds of solids in the activated sludge system}}{\text{Pounds/day of solids leaving the system}}$$

F:M Ratio

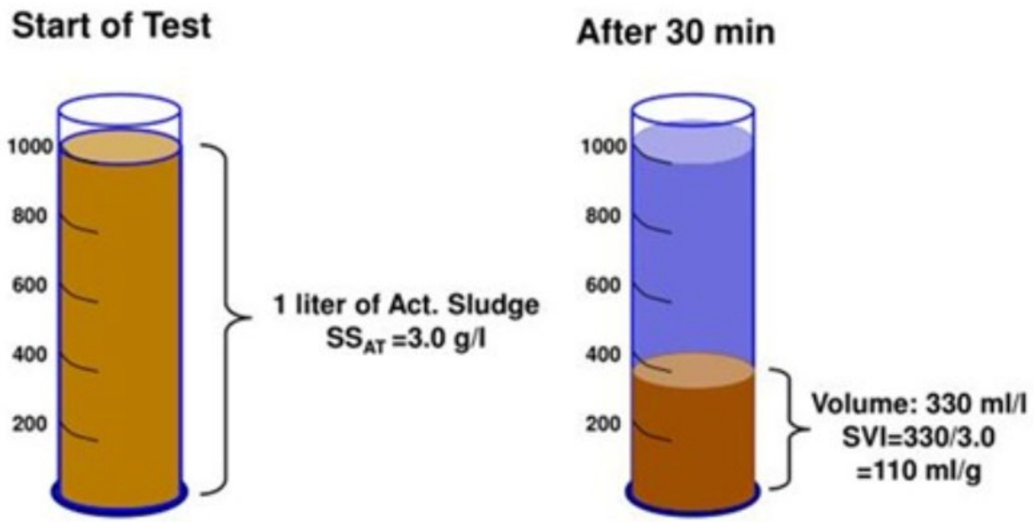
- Activated sludge: 0.25 to 0.45 | Extended aeration: 0.05 and 0.15

$$\textbf{F:M Ratio} = \frac{\text{Pounds/day of BOD entering the activated sludge system}}{\text{Pounds of microorganism (MLVSS) in aeration tank}}$$

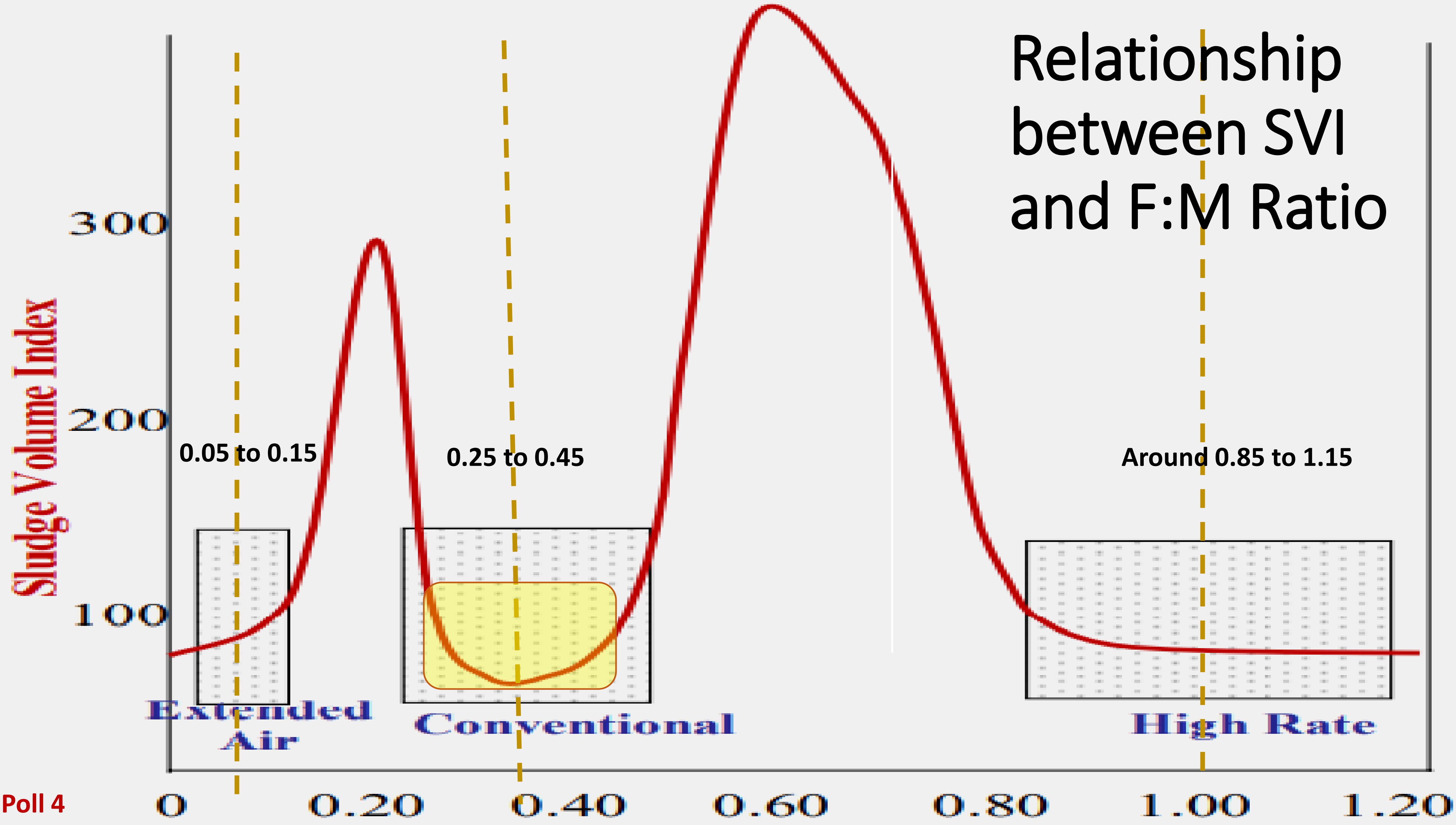


Settling measurement and examination of sludge

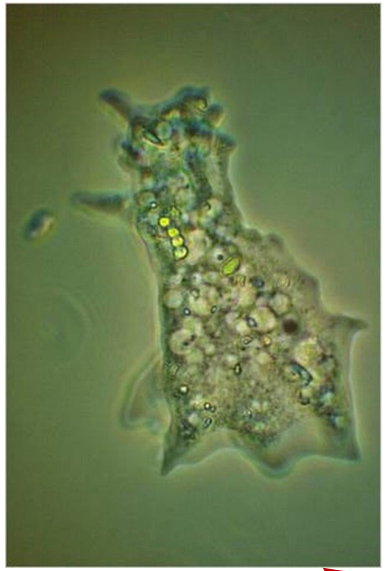
- Ensure sufficient healthy biomass for optimal treatment
- Optimize sludge settling and quality

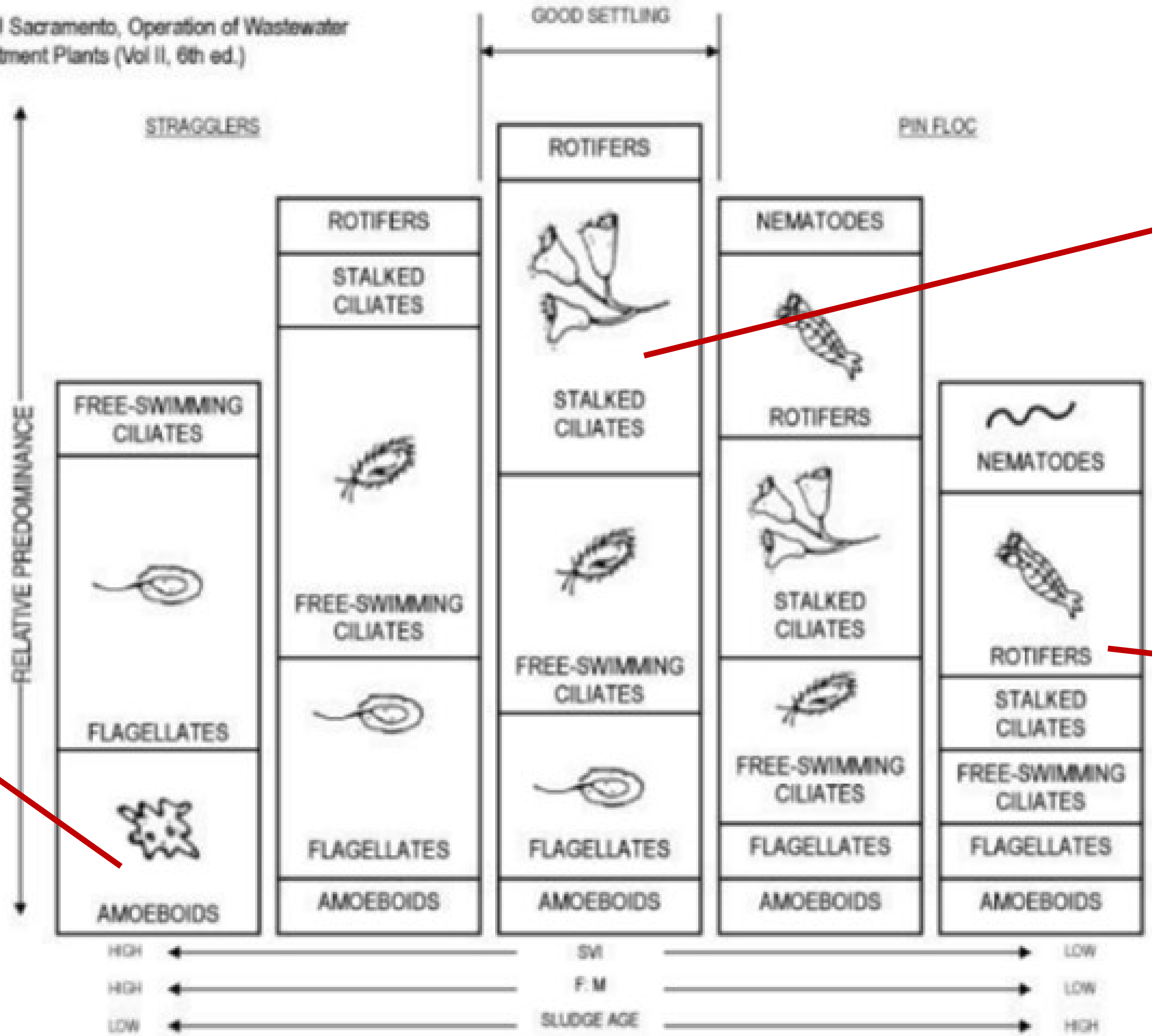


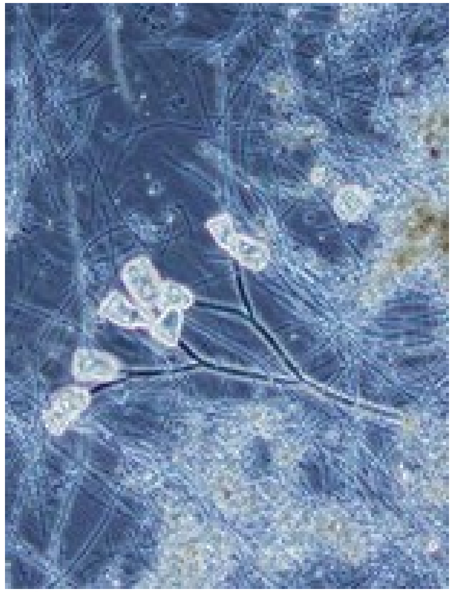
Relationship between SVI and F:M Ratio



Poll 4





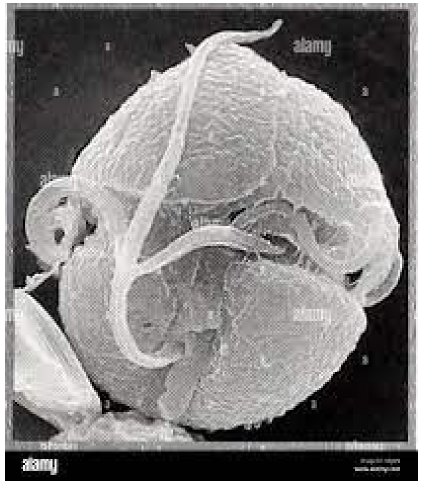


Microbial evaluation of sludge

Nitrogen and Phosphorous

Nitrogen and phosphorus are the primary causes of eutrophication in surface waters.

- Eutrophication results in algal blooms, oxygen depletion, and is harmful to aquatic life.
- Increases in algae and turbidity in water sources can increase the need to chlorinate drinking water and higher levels of disinfection by-products.
- Nutrients can also stimulate the activity of harmful microbes, such as Pfisteria.



What is the outcome of the conventional activated sludge process

- 85 – 90% % BOD removed
- 85 - 90 % TSS removed
- 90 – 95% Ammonia removed

Nitrogen – In a conventional plant with only an aeration tank, nitrogen in ammonia is only converted to a different form, not necessarily removed. Some removal can occur as organisms use nutrients to grow and then are settled out with sludge.

Phosphorus - Some removal occurs as organisms use nutrients to grow and then are settled out with sludge.

POLL #1

Poll #1: Which of the following describes how conventional activated sludge treats wastewater?

a) Solids are filtered out through a semi-permeable membrane.

b) A population of microorganisms is retained to consume wastes

c) Solids are vaporized through high oxidation levels

d) All of the above

Poll 1 Feedback

Which of the following describes how conventional activated sludge treats wastewater?

a) Solids are filtered out through a semi-permeable membrane.

b) A population of microorganisms is retained to consume wastes

c) Solids are vaporized through high oxidation levels

d) All of the above

Solids are retained in the activated sludge process for a number of days. MLSS consists of about 70% microorganisms. These microorganism use oxygen to rapidly consume wastes (BOD).

Biological nutrient removal processes

Nitrogen removal

1. Nitrification: converting ammonia to nitrate (aerobic)
2. Denitrification: converting nitrate to N2 gas (anoxic)

Biological phosphorus removal

1. Energize and build the population of Polyphosphate-Accumulating Organisms (PAOs) (anaerobic)
2. PAOs rapidly consume phosphorus compounds (aerobic)

Treatment processes to remove nitrogen

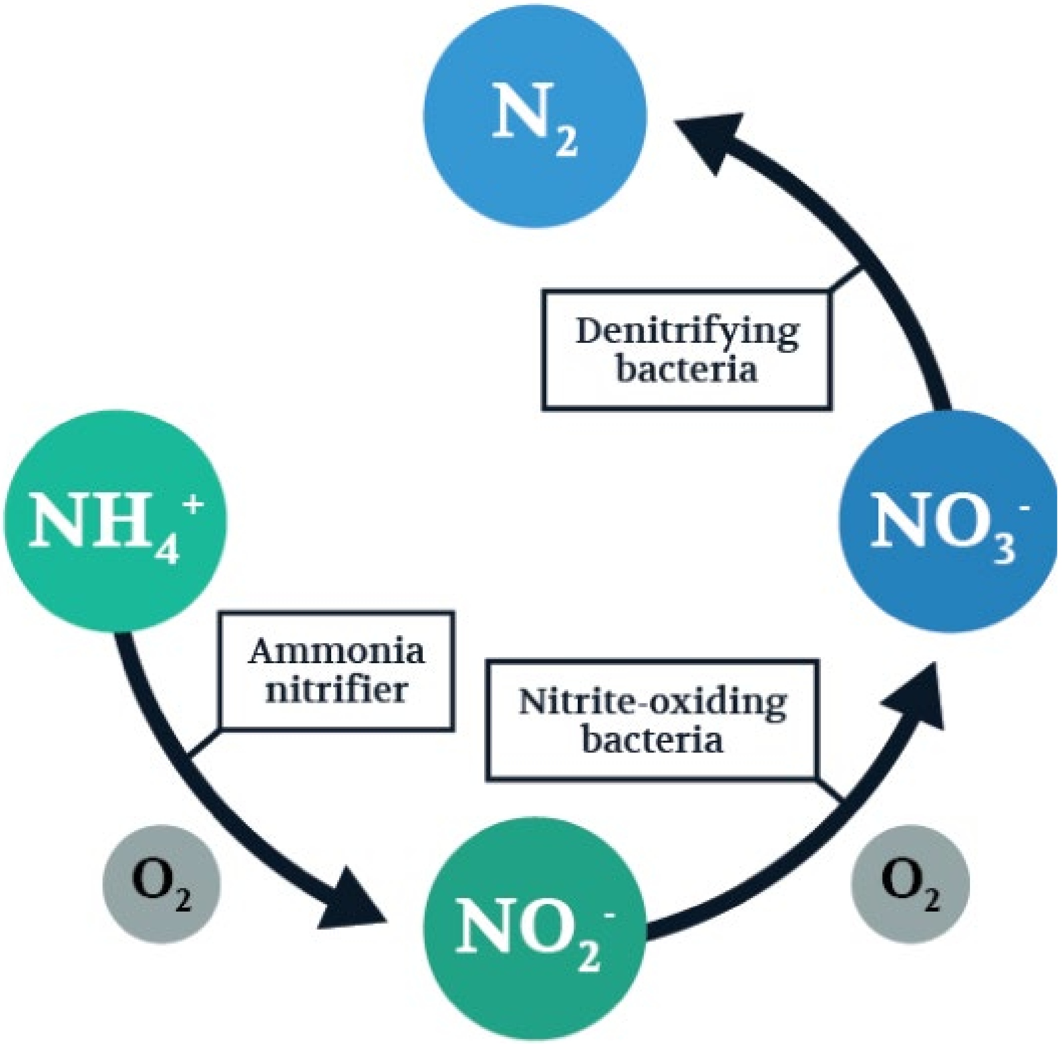
Nitrification (Aerobic environment)

$NH_3 \rightarrow NO_2 \rightarrow NO_3$

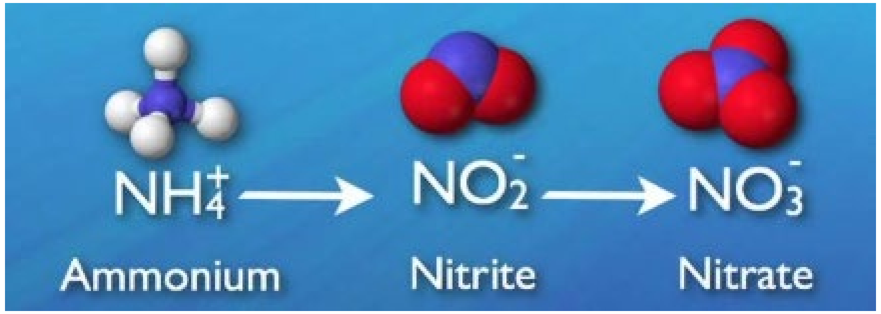
↓

Denitrification (Anoxic environment)

$NO_3 \rightarrow NO_2 \rightarrow N_2O \rightarrow N_2$



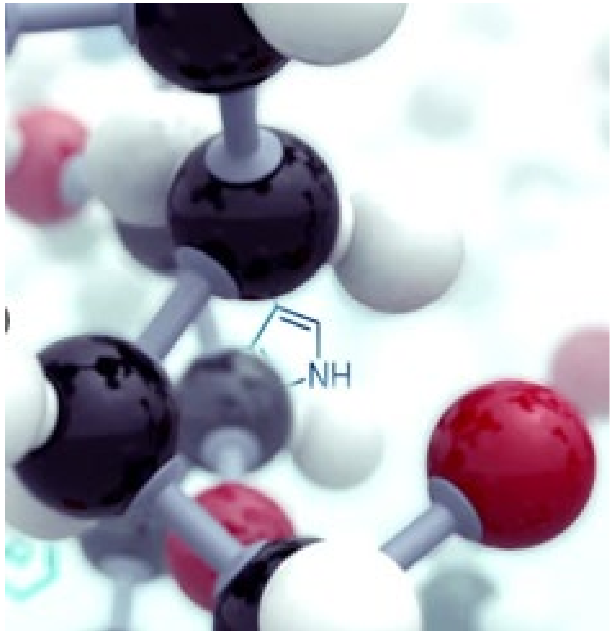
Nitrification



Nitrification requires aerobic conditions

1: Ammonia (NH3) is oxidized to nitrite NO2 by Nitrosomonas bacterial

2: Nitrite (NO2) is oxidized to nitrate (NO3) by Nitrobacter bacteria



- Ammonia is oxidized to NO3 by bacteria
- Bacteria are sensitive to pH, temp, toxins, and over production of heterotrophic bacteria that consume BOD
- Therefore, Nitrifying bacteria grow best when most BOD is gone
- If discharge limits for N are met, there is no need for denitrification

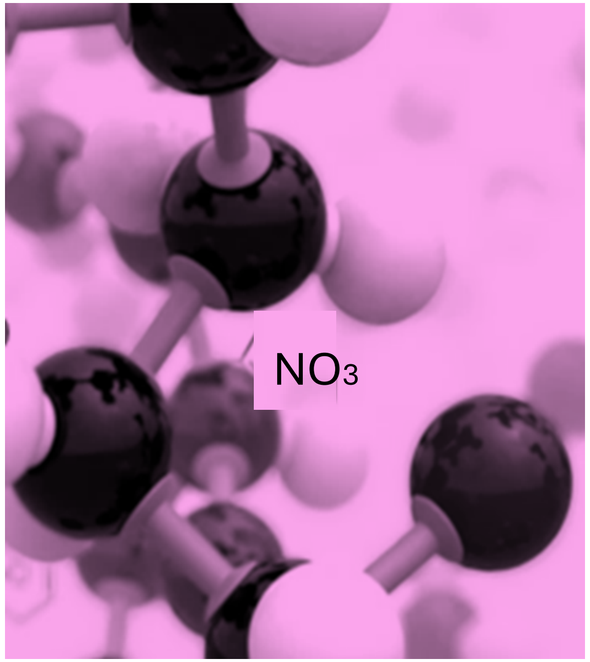
Heterotrophs are organisms that cannot produce their own food and must obtain nutrients from other organic sources

Denitrification

Denitrification requires anoxic conditions

Pseudomonas species bacteria obtain oxygen from nitrates as they consume BOD or an added carbon source. Nitrate is converted to nitrogen gas, which bubbles off into the atmosphere.

- Pseudomonas are facultative organisms – they prefer Oxygen, but can use nitrate.
- Pseudomonas biologically reduce Nitrate NO3 to Nitrogen gas N2 using special enzymes to strip Oxygen from nitrate.
- Requires a carbon source - BOD or an added source. Consuming a food source is what creates a need for oxygen.
- The problem is that most of the BOD is gone by the time ammonia is converted to NO3.



Parameters for growth of nitrifying bacteria

BOD Removal – At least 80% reduction in BOD

D.O. > 2 mg/L

Temperature

- Optimal range 77-86°F (25-30°C) highest activity and growth rates.
- 50% decrease for every 10°C drop in temperature

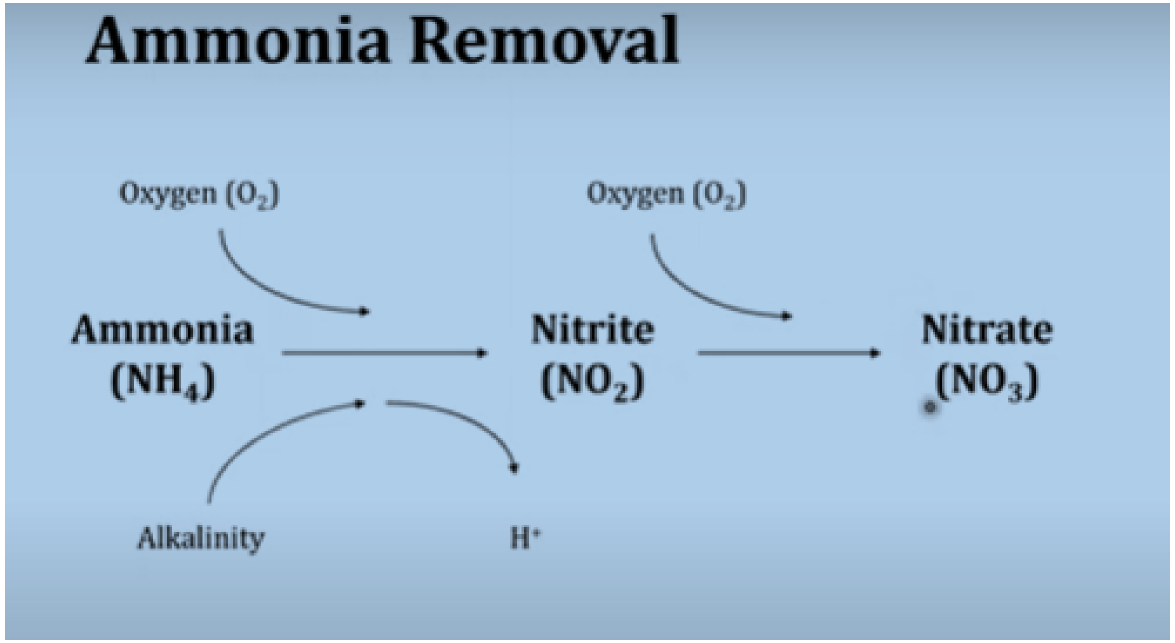
Alkalinity– during the conversion of ammonia into nitrate, many H+ ions are released, and pH can drop affecting nitrification.

pH Should be around neutral and 7.5 is optimal. Acidic pH will decrease nitrification rate.

MCRT 10 days minimum is recommended by some sources. For practical limitations, an MCRT toward the higher end of the range for your plant will help support a population of nitrifying bacteria.

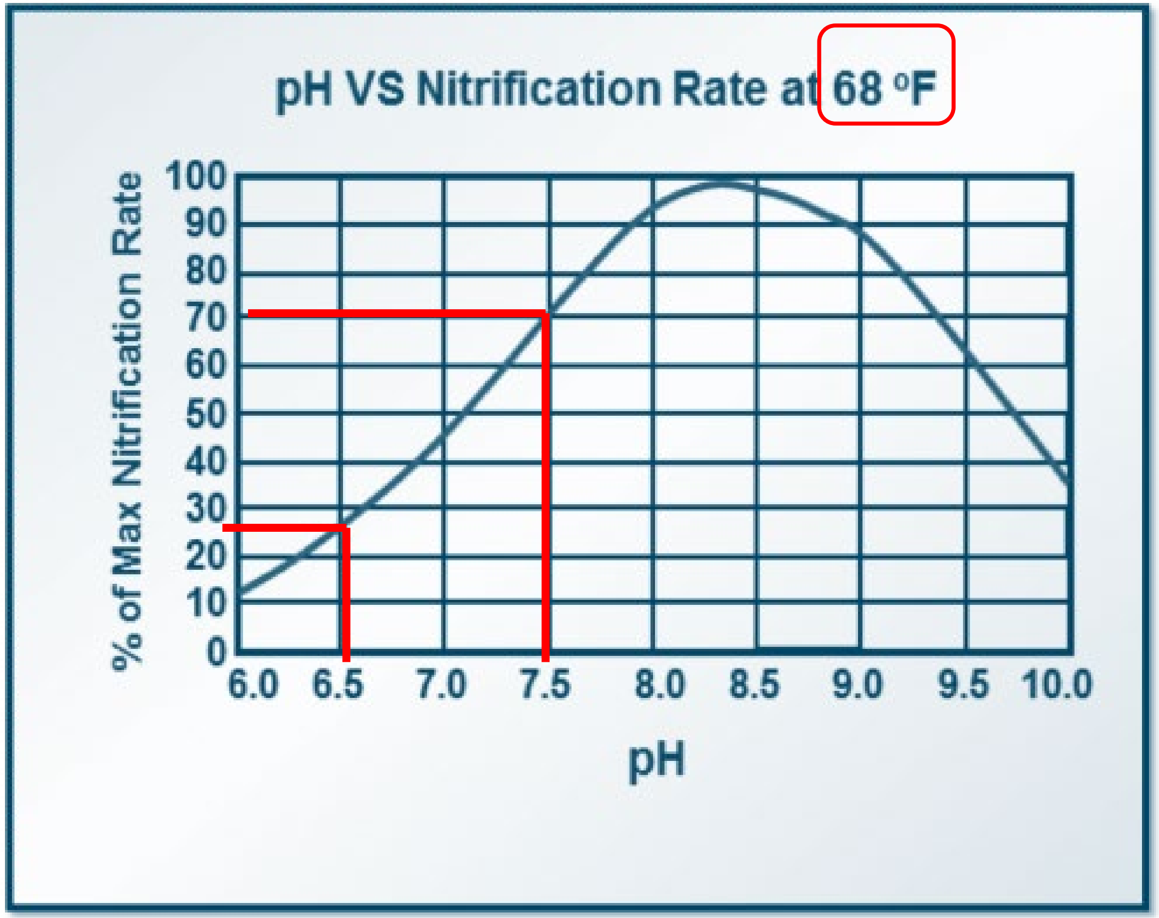
Lower F:M ratio and higher MLVSS (less food, more bugs in the aeration tank)

Ammonia removal: H+ ions can cause acidity



$NH_3 + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$

- Nitrification releases H+ ions which can reduce pH.
- For every 1mg/L of ammonia, in the influent, 7.14 mg/L of alkalinity are needed.



Low pH can impede nitrification

- pH 7.5 = about 70% of max rate
- pH 6.5 = about 25% of max rate

Alkalinity

A wastewater plant has influent raw wastewater with 150 mg/L of alkalinity and15 mg/L of ammonia. Calculate how much alkalinity would be used up by complete nitrification of the ammonia, and how much alkalinity will remain in the wastewater?

Alkalinity used up by nitrification:

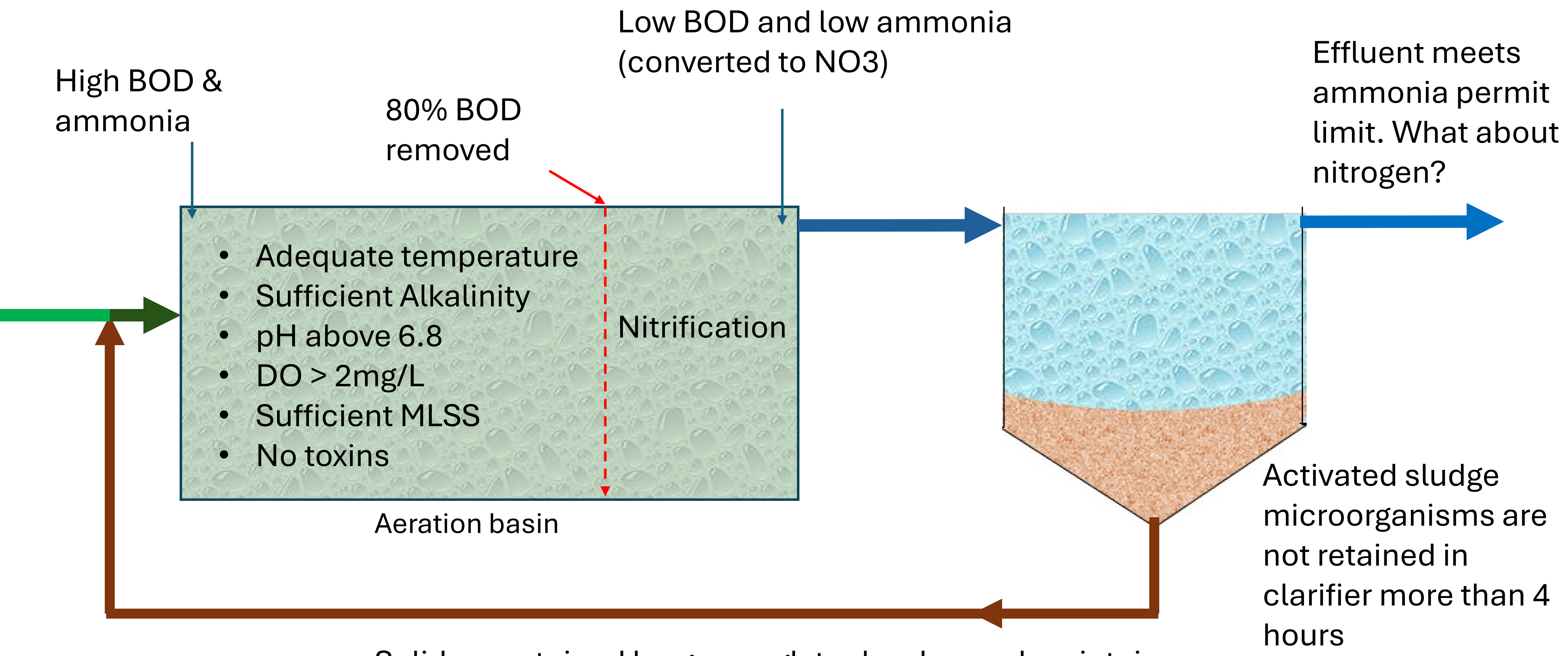
$$15 \text{ mg/L } NH_3 \times \frac{7.14 \text{ parts Alkalinity}}{1 \text{ part Ammonia}} = \mathbf{107.1 \text{ mg/L}} \text{ of alkalinity as } CaCO_3$$

Alkalinity remaining

150 mg/L – 107 mg/L = **43 mg/L**

There should be a minimum of 50 mg/L of alkalinity remaining after nitrification (and 75 mg/L is preferable. You may need to add sodium carbonate (Na_2CO_3), or lime ($Ca(OH)_2$) to increase the alkalinity if it falls below 50 mg/L as $CaCO_3$.

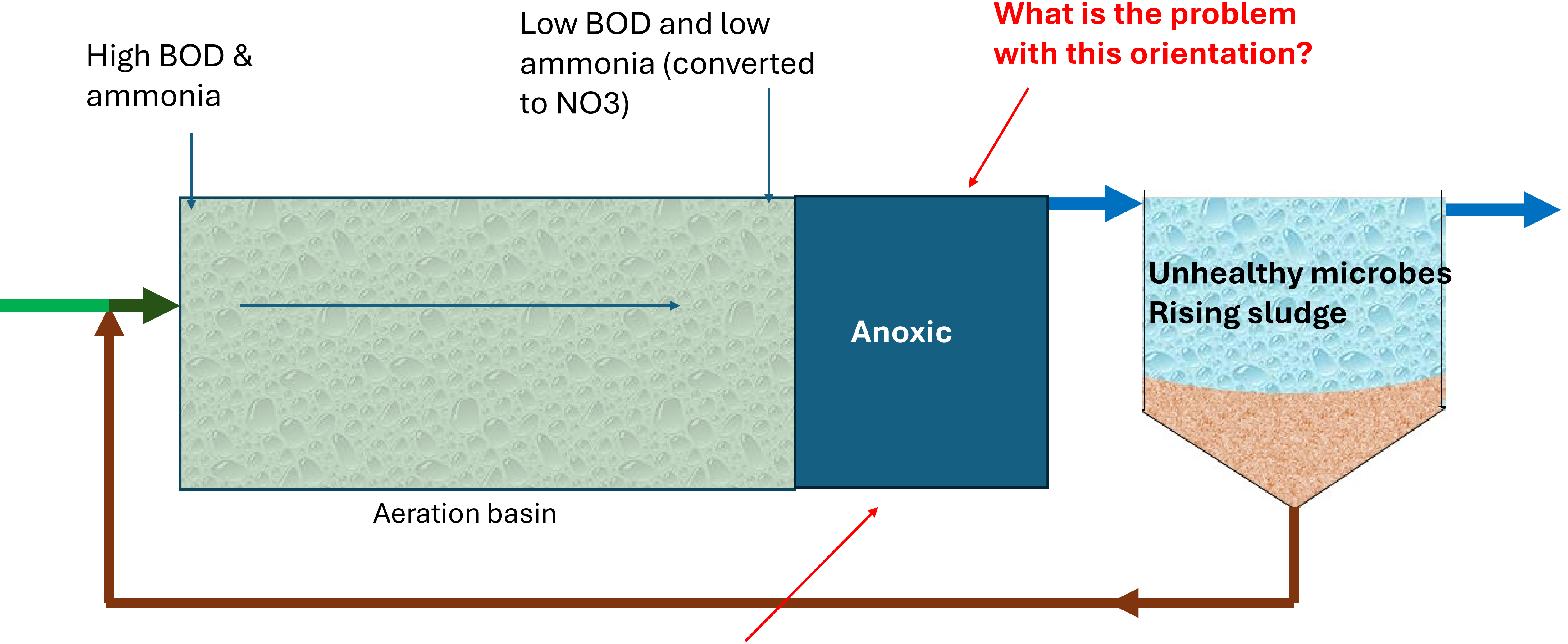
Nitrification



Solid are retained long enough to develop and maintain a sufficient nitrifying bacteria population. MCRT is near the higher range for the plant (lower wasting rate)

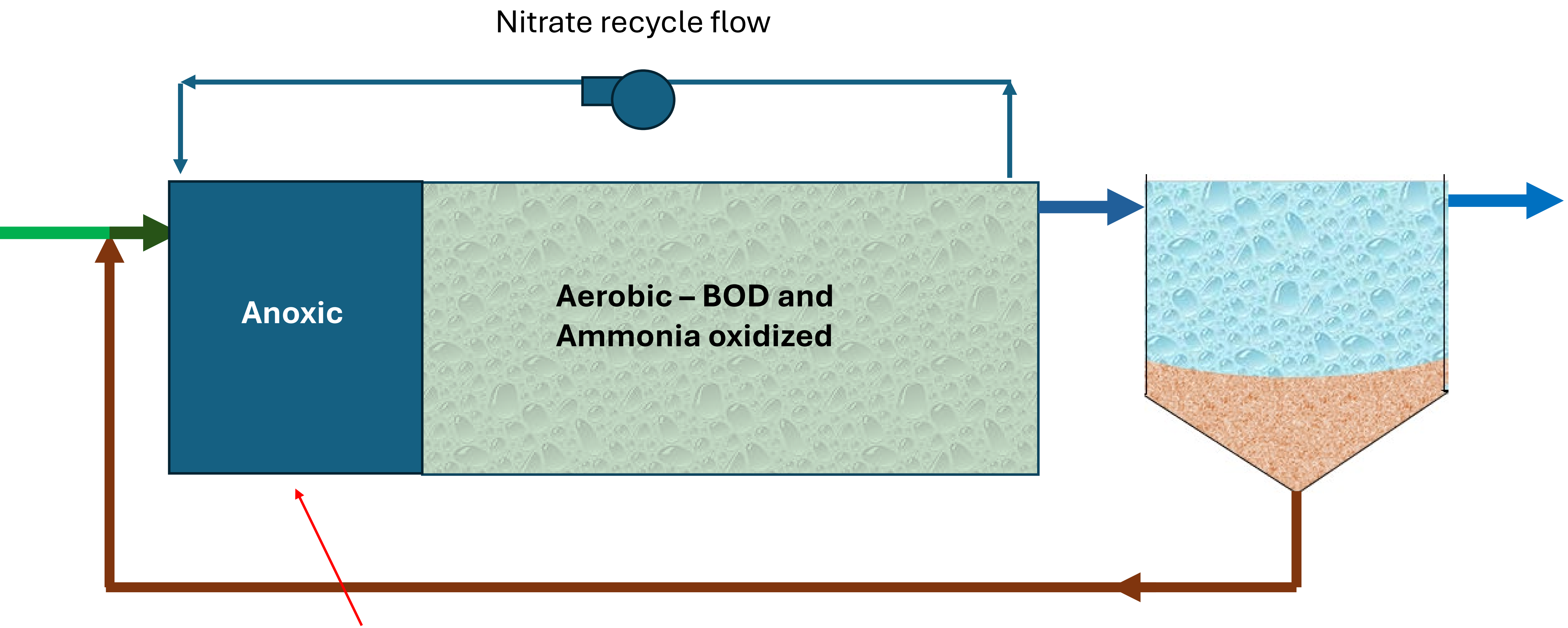
Denitrification?

What if we add an anoxic zone here?
What is the problem with this orientation?



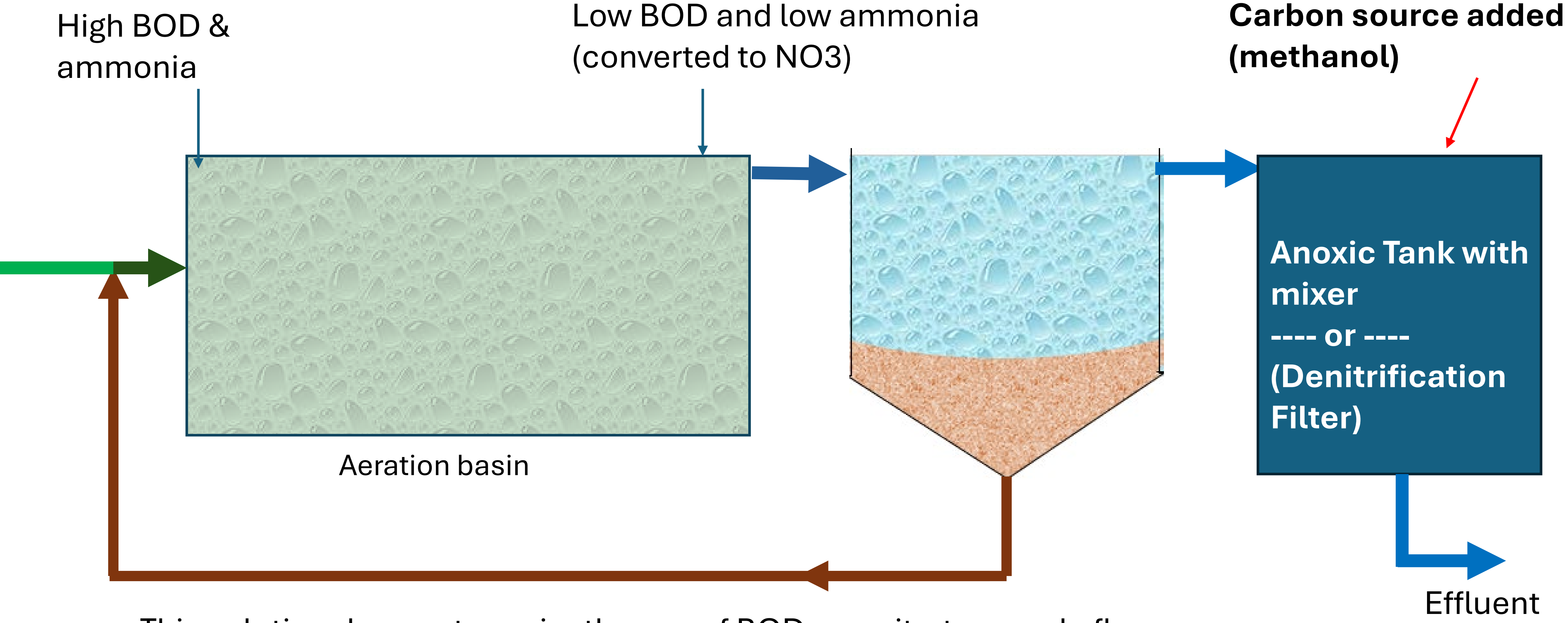
At this point in the treatment process there is no BOD present. Therefore, denitrifying bacteria have nothing to eat and no reason to strip oxygen from nitrate.

Denitrification with nitrate recycle flow



Now, denitrifying bacteria have a food source to consume and nitrate as a source of oxygen. Nitrate is converted to nitrogen gas.

Denitrification with external carbon source



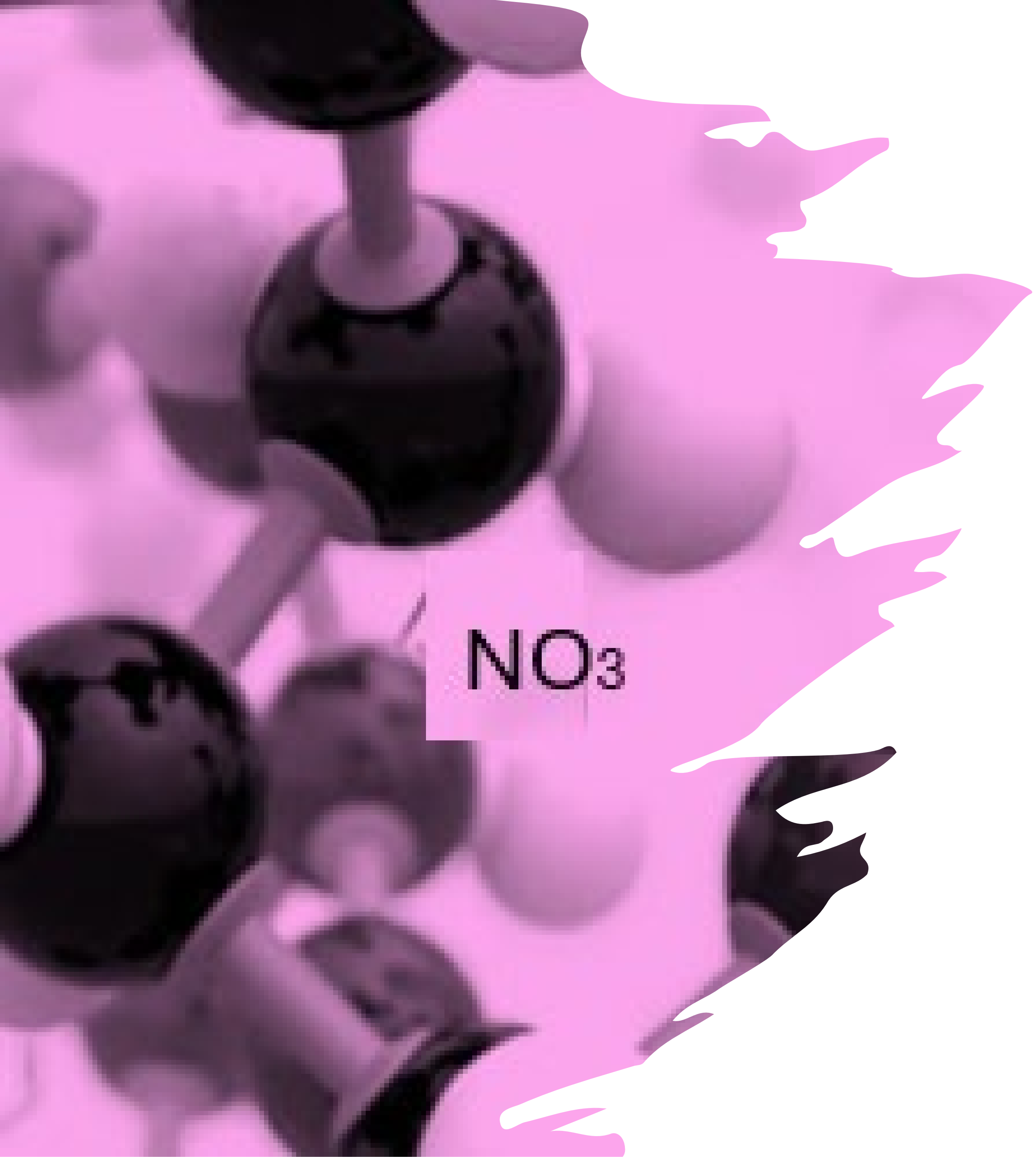
This solution does not require the use of BOD or a nitrate recycle flow. Instead, an external carbon source is introduced for denitrifying bacteria to consume instead of BOD.

Optimizing nitrifying bacteria

Nitrosomonas grow and reproduce at slower rates than other bacteria and are sensitive to environmental conditions including pH, temperature and the presence of toxic compounds.

To optimize nitrification operators should do the following:

- Maintain a sufficient sludge age so that there is a sufficient population of nitrifying bacterial (Higher MCRT).
- Use a higher biomass concentration in aeration, especially in colder weather. (Lower F:M ratio)
- Control the pH of the system by ensuring sufficient alkalinity and aeration.
- Maintain a DO level of at least 2 mg/L.
- Prevent toxins in the system and enforce industrial pretreatment standards.



Denitrification

Denitrification proceeds well across a wide range of temperatures (5 to 60°C) and across a pH range from 6 and 8

- Less sensitive to pH and temperature
- Sufficient carbon must be present
- Denitrification adds alkalinity because the conversion of nitrate to nitrogen gas releases hydroxide ions (OH-)

POLL #2

Poll #2: Influent wastewater has 195 mg/L of alkalinity and 20 mg/L of ammonia. Estimate how much alkalinity is left over after complete nitrification?

a) 32 mg/L
b) 42 mg/L
c) 52 mg/L
d) 62 mg/L

Poll 2

Influent wastewater has 195 mg/L of alkalinity and 20 mg/L of ammonia. Estimate how much alkalinity is left over after complete nitrification?

a) 32 mg/L

b) 42 mg/L

c) 52 mg/L

d) 62 mg/L

Poll 2 Feedback

Influent wastewater has 195 mg/L of alkalinity and 20 mg/L of ammonia. Estimate how much alkalinity is left over after complete nitrification?

Alkalinity used up by nitrification:

$$20 \text{ mg/L } NH_3 \times \frac{7.14 \text{ parts Alkalinity}}{1\text{-part } NH_3} = \mathbf{142.8 \text{ mg/L}}$$

Alkalinity remaining

195 mg/L – 142.8 mg/L = **52.2mg/L**

Biological phosphorous removal

1: **Create an anaerobic zone**. Not long enough to go septic (fermentation).

2. Phosphorous accumulating organisms (PAO) grow and consume nutrients in this environment (30 minutes or more)

4: PAOs are introduced to an oxygen rich aerobic zone and take in soluble phosphorous

4. PAO bacteria are settled out and removed with sludge

Anaerobic zone

PAO organisms grow and are energized

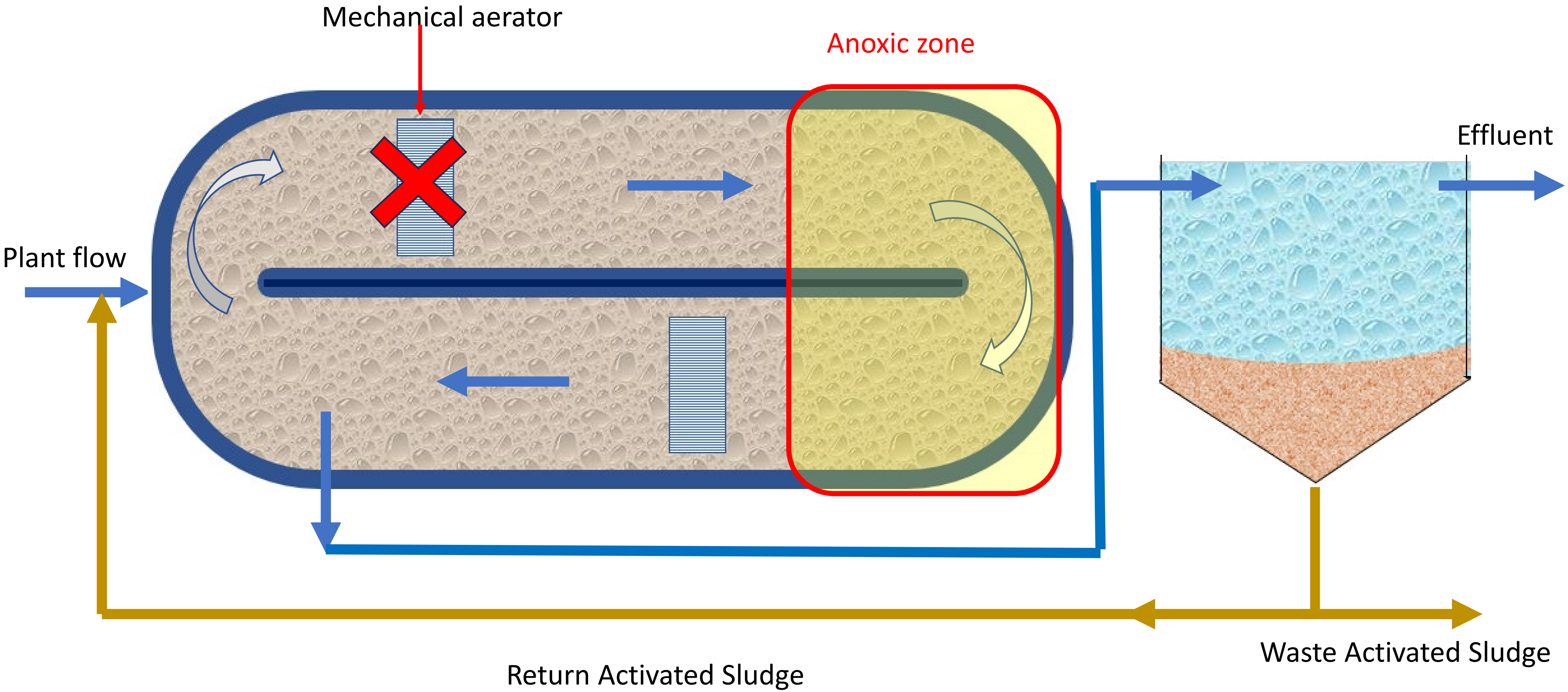
↓

Aerobic zone

PAO organisms accumulate phosphorus into their cells

Nutrient removal in oxidation ditch

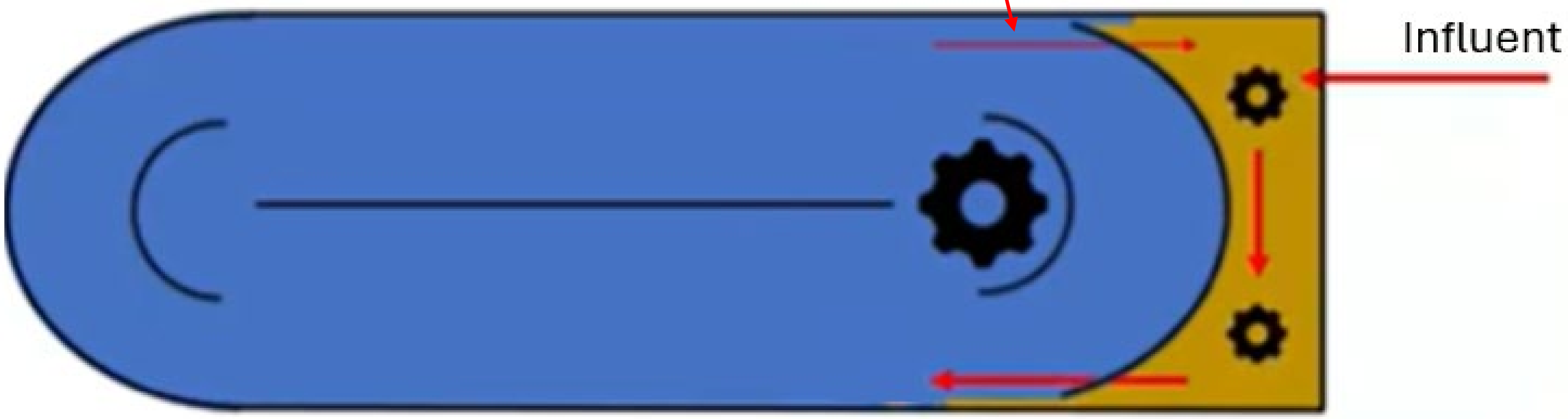
Oxidation Ditch



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

Designed for Nitrate Removal

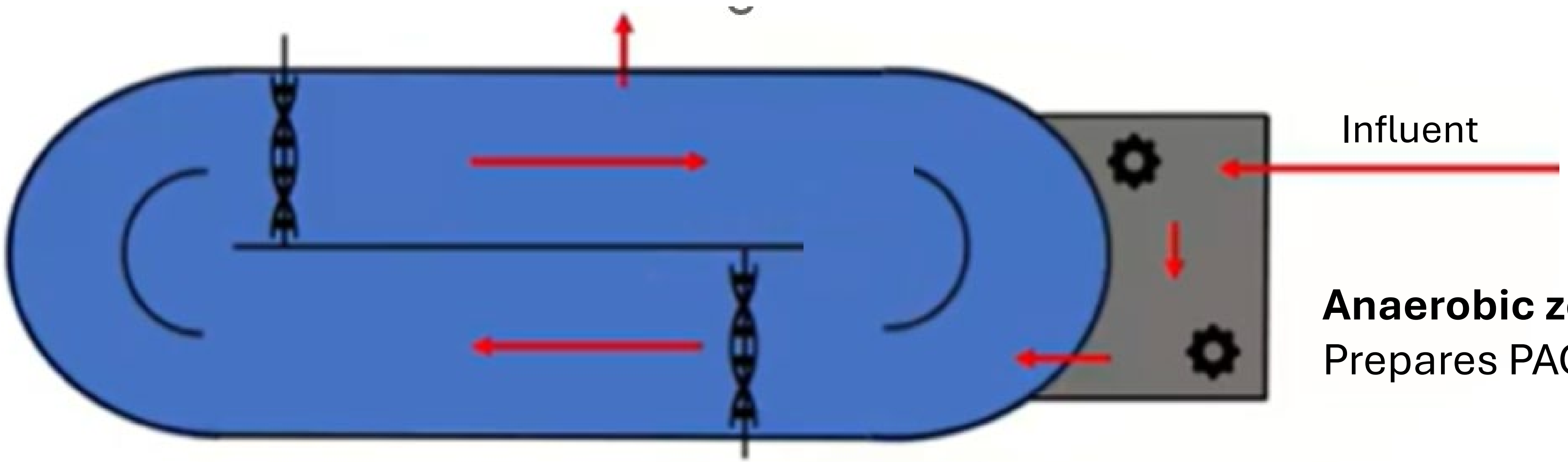
Recycle flow
High NO3, dissolved oxygen has been used up



Aerobic zone
- Removes BOD
- Oxidizes ammonia to nitrate

Anoxic zone
- Denitrifying bacteria consume BOD and convert nitrate to nitrogen gas

Designed for phosphorus removal



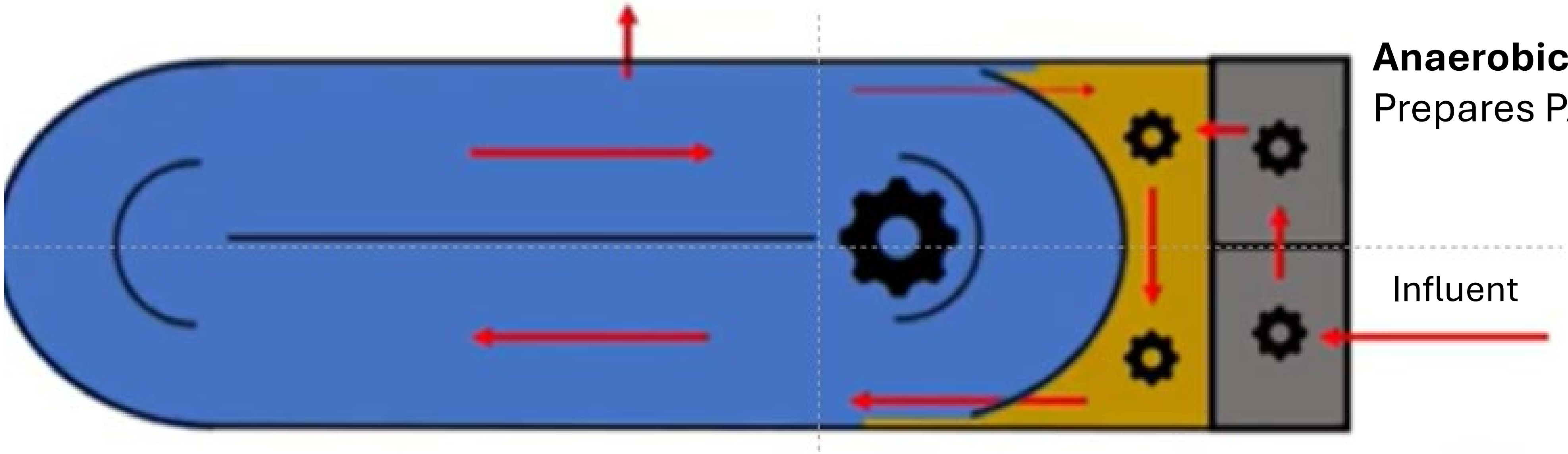
Anaerobic zone
Prepares PAOs

Aerobic zone

- Removes BOD and ammonia
- Uptake of phosphorus by PAOs

Design for phosphorus and nitrogen removal

Recycle flow
High NO3, dissolved oxygen has been used up. (to anoxic zone)



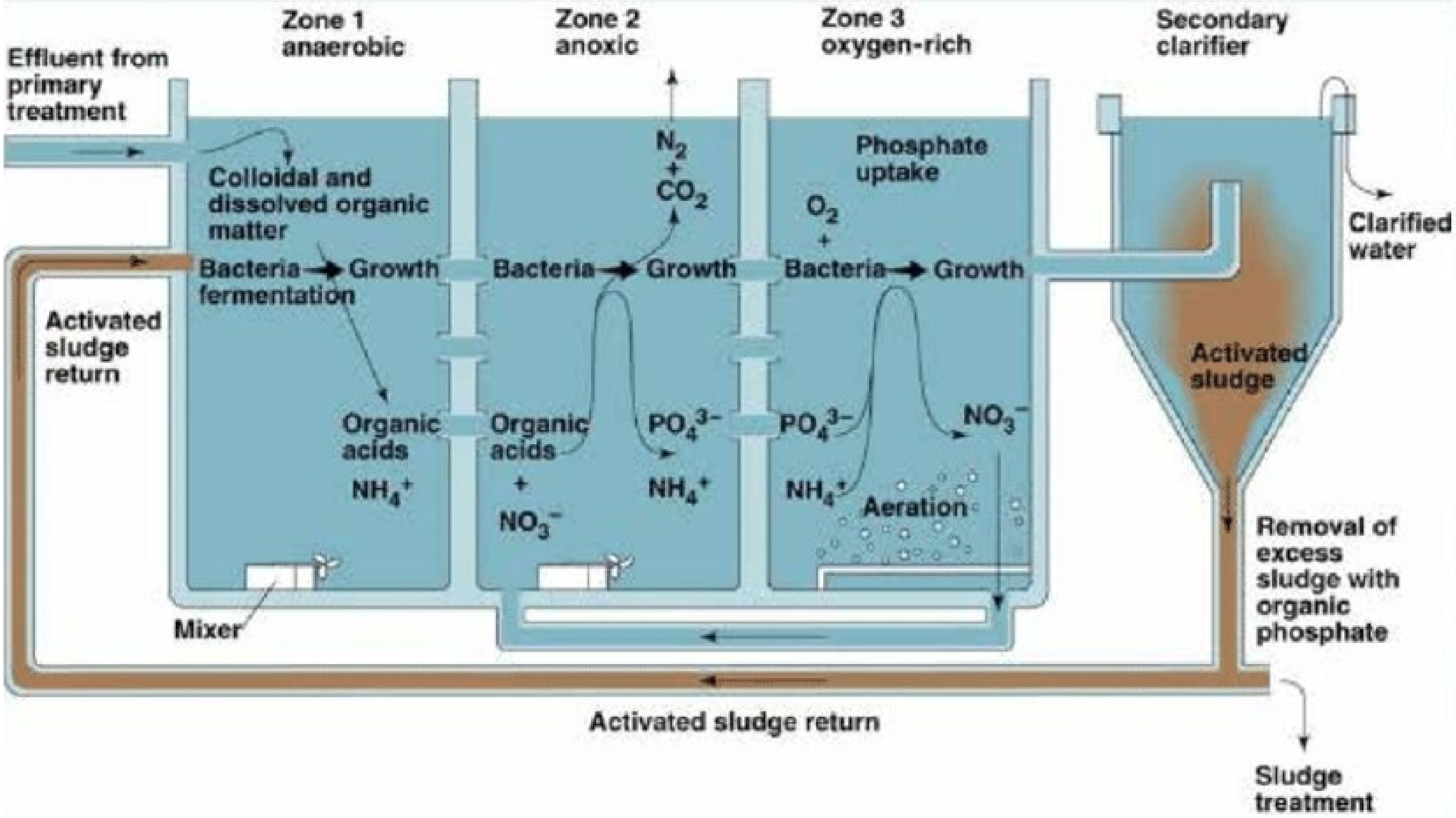
Anaerobic zone
Prepares PAOs

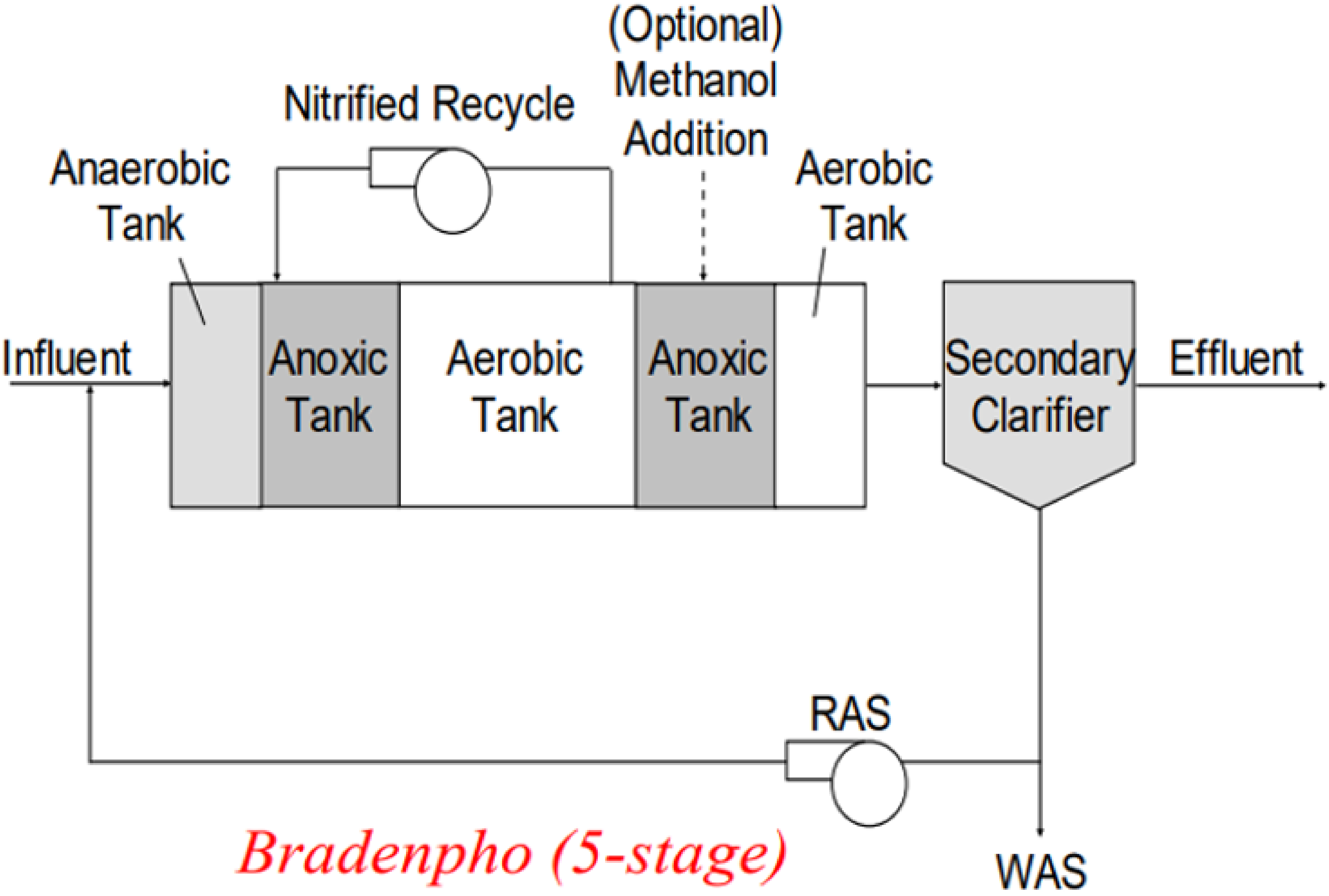
Influent

Aerobic zone
- Removes BOD
- Oxidizes ammonia to nitrate
- PAOs uptake phosphorus

Anoxic zone
Denitrifying bacteria consume BOD and convert nitrate to nitrogen gas

Nutrient Removal - Activated Sludge



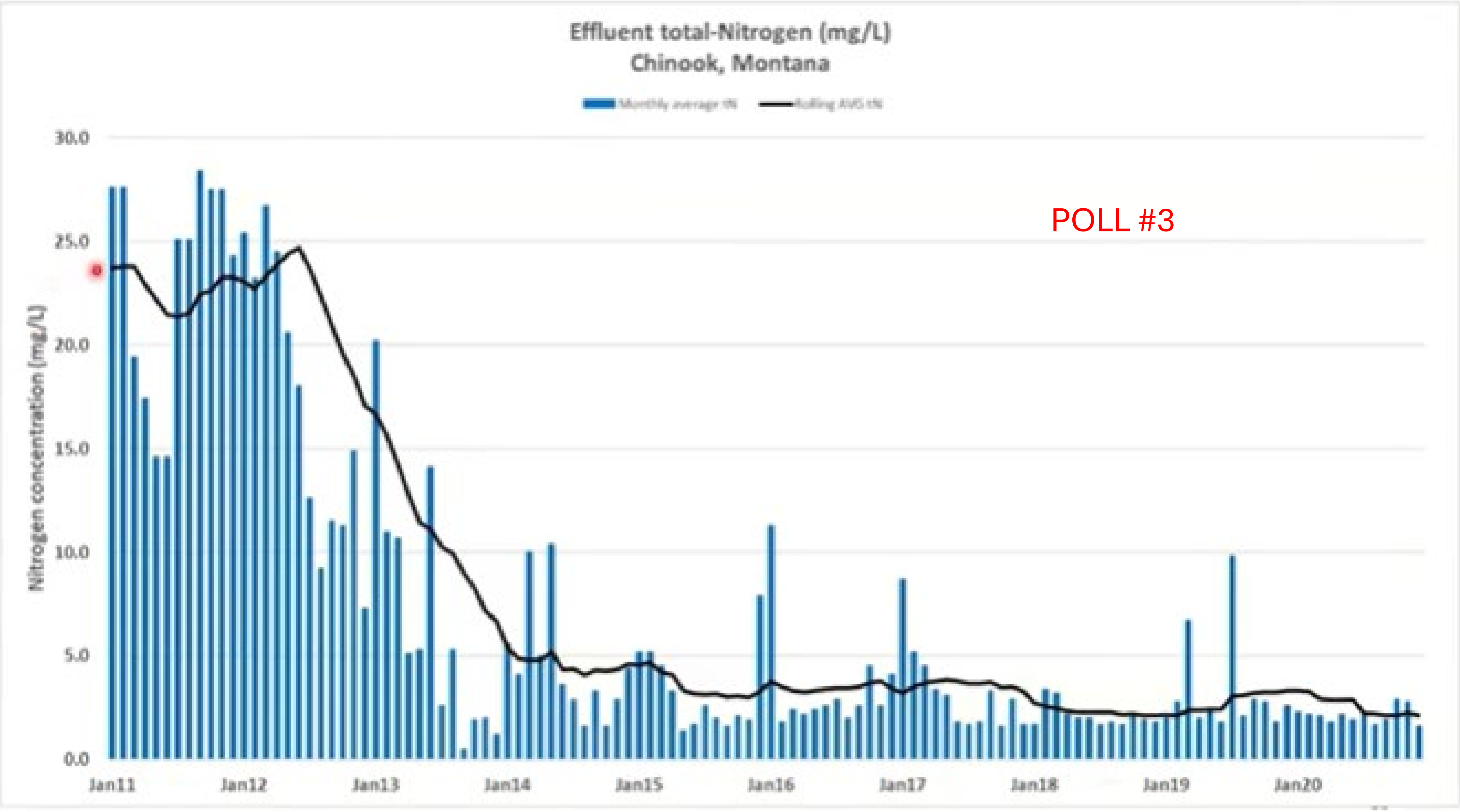


Bradenpho (5-stage)

Chinook Montana

Began turning off one aerator for 1 then 2 hours at a time to create an anoxic zone to facilitate nitrogen removal.

Reduced effluent nitrogen from around 25 mg/L to around 5 mg/L.


Effluent total-Nitrogen (mg/L)
Chinook, Montana
Nitrogen concentration (mg/L)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Jan11
Jan12
Jan13
Jan14
Jan15
Jan16
Jan17
Jan18
Jan19
Jan20

POLL #3

Poll #3: What condition is necessary for denitrification to occur and why?

a) Anoxic, to force bacteria to consume oxygen from nitrate.

b) Anaerobic, to change the ORP of wastewater.

c) Septic, to cause bacteria to consume nitrogen.

d) Aerobic, to ensure that nitrogen gas is oxidized.

Poll 3 answer

What condition is necessary for denitrification to occur and why?

a) Anoxic, to force bacteria to consume oxygen from nitrate.
b) Anaerobic, to change the ORP of wastewater.
c) Septic, to cause bacteria to consume nitrogen.
d) Aerobic, to ensure that nitrogen gas is oxidized.

In an anoxic environment, the only source of oxygen is nitrate. If a source of carbon is available, denitrifying bacteria can use it as food but will need to strip oxygen from nitrate to metabolize it – and the nitrate will be converted to N_2.

Great Bend, Kansas Oxidation Ditch

- Operator modified treatment for N and P in the main ditch
- Established anaerobic zone for POA preparation
- Installed an Oxygen probe to establish aeration and anoxic zones for nitrogen removal
- Controlled aerator operation and intensity with VFD to control aeration and an integrated DO probe (SCADA)
- Saved $6M upgrade

Great Bend Kansas

Influent to Anaerobic Zone POA growth & preparation

Aeration set to run out of DO by this point. Creates an Anoxic zone to remove Nitrogen

Aerated aerobic zone –BOD removal, uptake of phosphorus, and nitrification of ammonia

Process environments

Aerobic – contains dissolved oxygen (O_2). 2 to 3 mg/L

- Aerobic organisms consume BOD and oxidize ammonia. PAO uptake phosphorus.

Anoxic – contains nitrate (NO_3) but no DO.

- Denitrifying organisms strip oxygen from nitrate Requires carbon.

Anaerobic – no sources of oxygen of any kind

- PAOs grow and become energized. Requires BOD and nutrients. Raw WW.

ORP (Oxidation-Reduction Potential)

A positive ORP value suggests an oxidizing environment, while a negative value indicates a reducing environment.

Anaerobic – 200 mV

- Prepares PAOs

Aerobic +150 mV

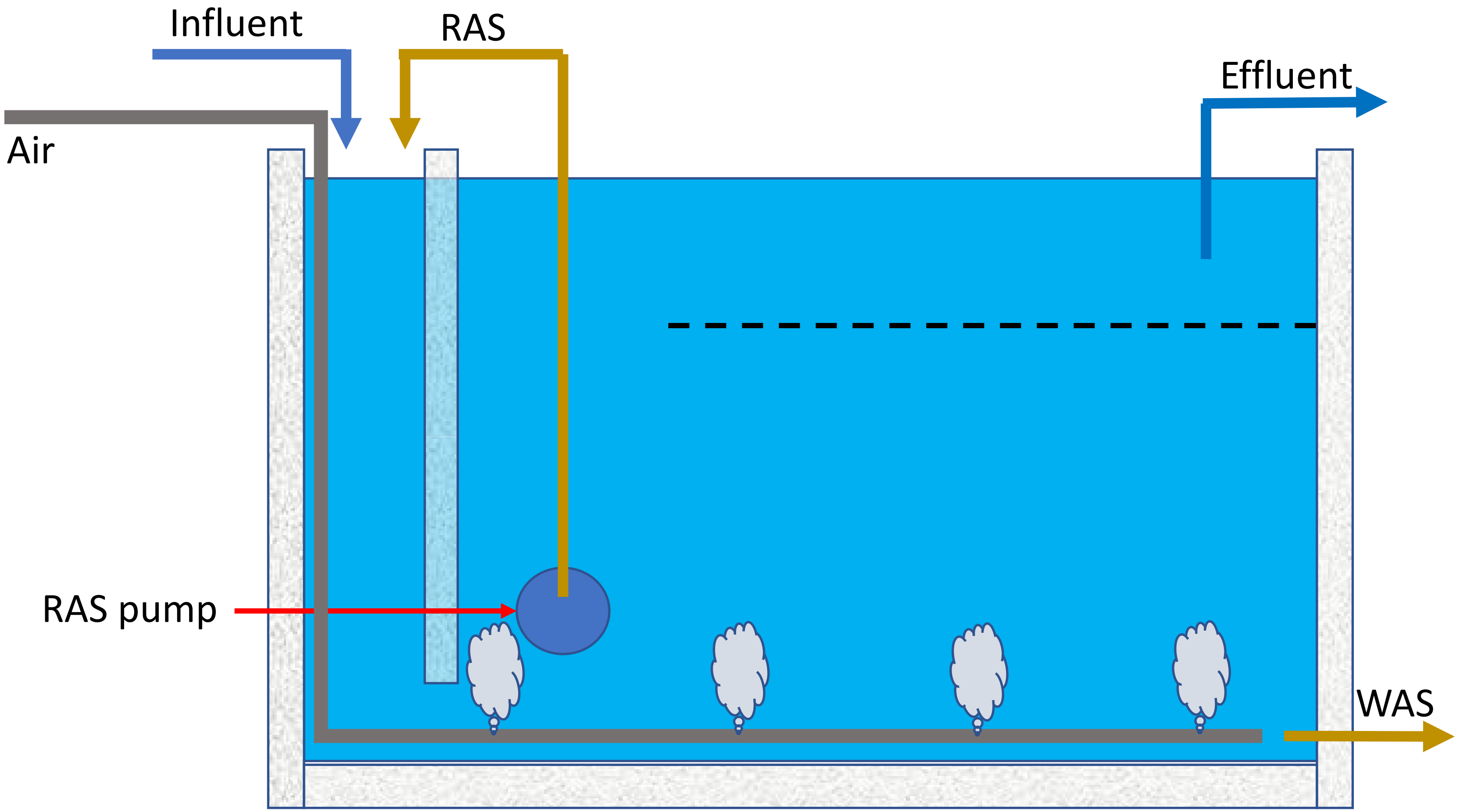
- BOD removal
- PAO uptake
- Nitrification

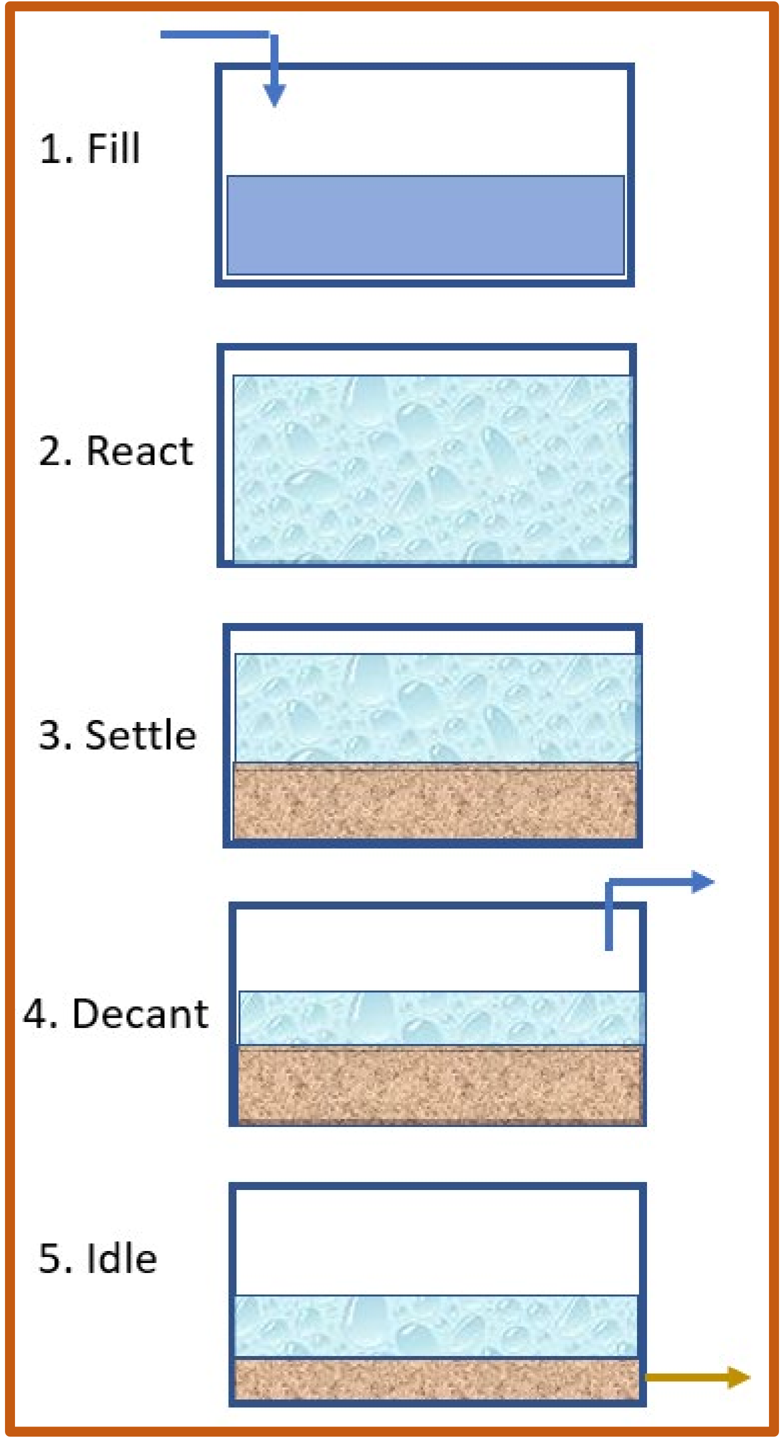
Anoxic –100 mV

- Denitrification

This ORP meter shows +217-mV, indicating an oxygen-rich aerobic environment

Sequencing Batch Reactor





Anaerobic zone: Extended period of air off in the fill cycle

Anoxic zone: Extended period of air off in the settle cycle

Time periods should be long enough for bacteria to work (30 min)

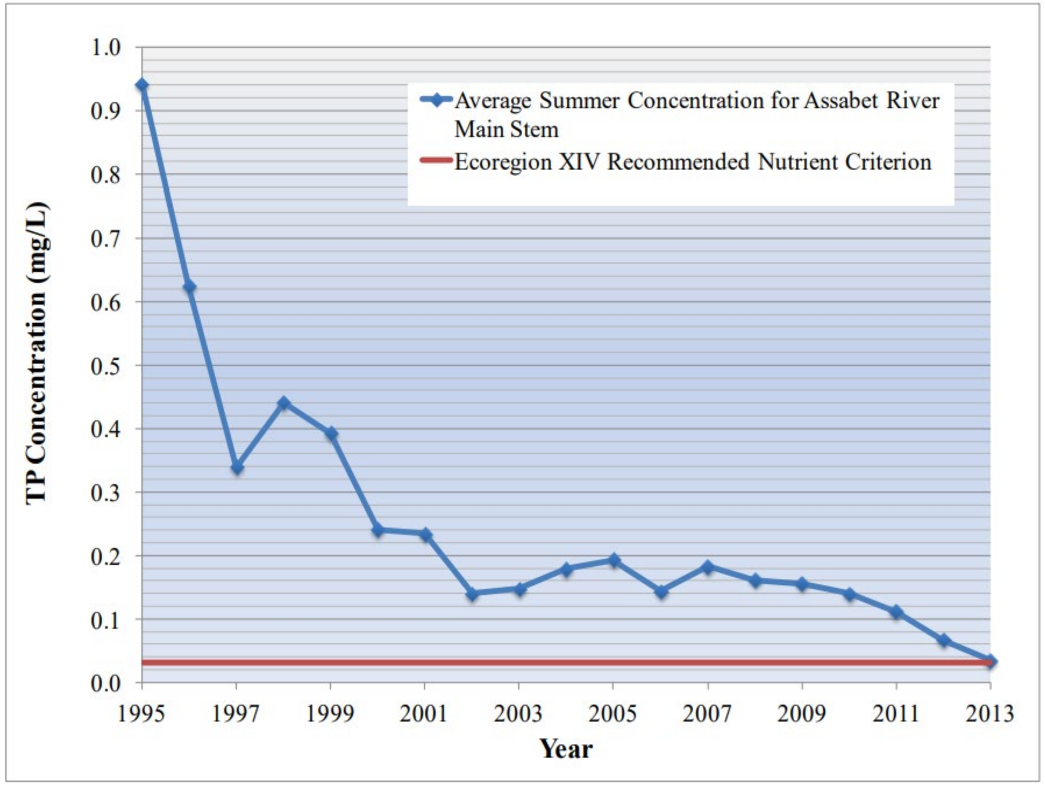
Sunderland MA - 0.5 MGD SBR

- Operator began to hold more biomass and to cycle between air and no-air
- DO would drop and bacteria would use nitrate – bubbles could be seen as N2 coming off.
- Took a week to populate nitrifiers – hour off, hour on.
- Air off time expanded to 1.5 and then 2.0 hours; shorted aeration from 6 to 5 hours.
- Measured cycle time, ammonia , DO, and ORP
- Total nitrogen went from 25 mg/L to 8 mg/L

Non-biological phosphorus treatment

Tertiary Treatment – chemical precipitation

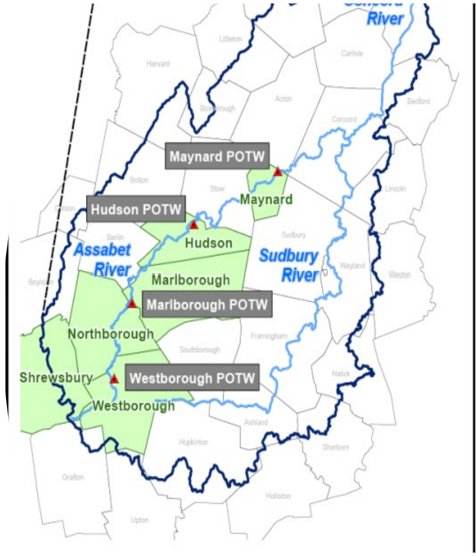
1. Chemical treatment to convert soluble phosphorus to TSS and non-settleable to settleable solids
2. Remove TSS through settling and filtration



EPA Case Study: Six Municipalities, One Watershed. Assabet River Watershed, MA

- Four different treatment strategies used to achieve <0.1 mg/L phosphorus for an impaired water body.

https://www.epa.gov/sites/default/files/2015-03/documents/assabet-river-removal-casestudy.pdf



Circular economy

Ammonia, nitrogen, and phosphate can be recovered for reuse.

- Fertilizers
- Industrial chemicals
- Reduce environmental impact

POLL #4

Circular economy of nitrogen and phosphorus. https://www.jcu.edu.au/research-and-innovation-services/contract-and-commercial/our-technologies/engineering-projects/circular-economy-of-phosphorus-and-nitrogen
Nitrogen and phosphorus recovery: https://www.sciencedirect.com/science/article/abs/pii/S2214714424013710

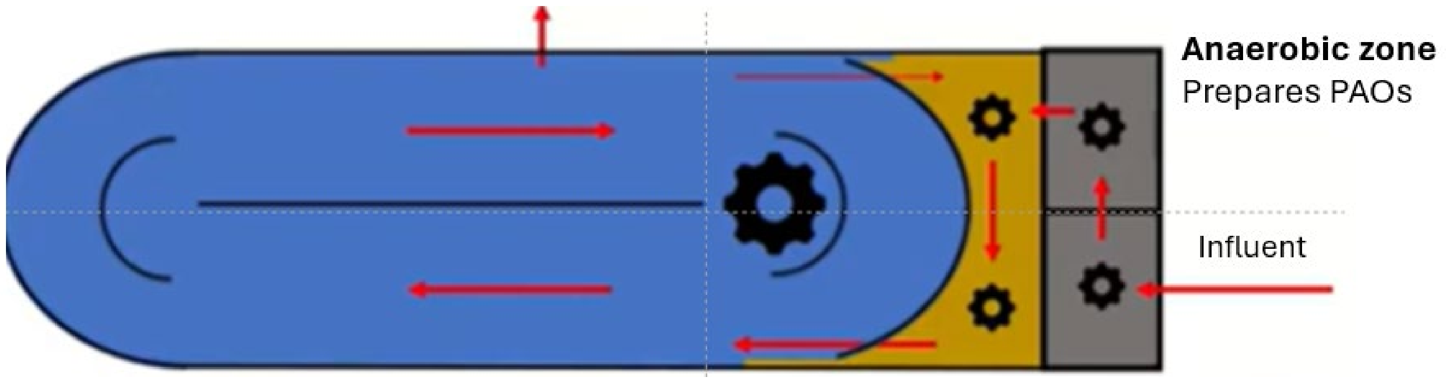
Scenario

A utility is told they need a $20M project for a chemical phosphorus removal wastewater treatment plant upgrade to meet a new permit requirement.

The operator wants to try modifying the existing oxidation ditch process to remove phosphorus.

What process control measurements indicate a correct anaerobic zone?

POLL #4



Poll #4: An operator wants to try modifying an oxidation ditch. What process control measurements indicate a correct anaerobic zone?

a) DO of 3.0 mg/L and ORP of +250 mV
b) DO of 1.0 mg/L and high NO3 levels
c) DO of zero and ORP of -200 mV
d) DO of 2.0 mg/L and ORP of 0.0 mV

Poll 4 feedback

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Anaerobic zone should have NO oxygen, NO nitrate, and an ORP of around -200 mV.