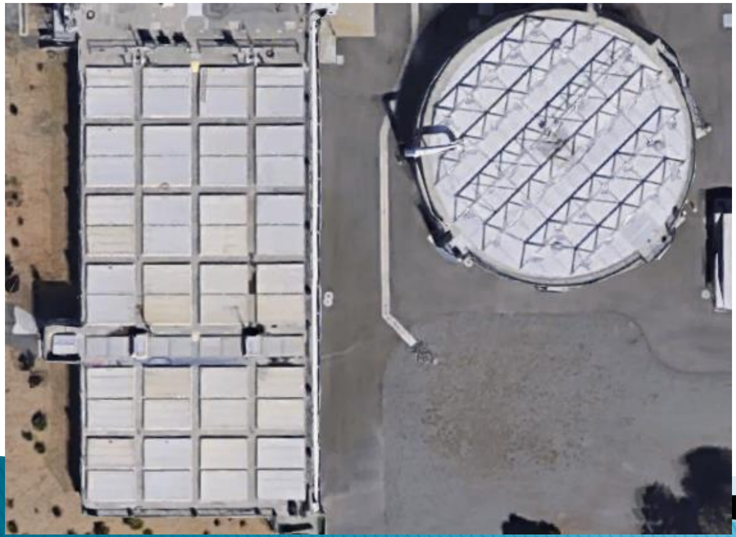
Primary and Secondary Clarifier Overview & Operational Considerations



BAYWORK
Grade I-III Wastewater Operator Exam Review
September 11, 2019

Intro/Contact Info

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Learning Objectives

- Understand the purpose of primary and secondary clarifiers
- Identify a clarifier that is performing well
- Identify and understand how to correct a poorly-performing clarifier
- Perform common clarifier math problems and understand how they apply to clarifier operation

Topics

- Types of waste removed
- How a clarifier works
- Typical mechanical components
- Common math problems
  - Removal efficiency
  - Detention time
  - Hydraulic loading—surface overflow rate
  - Hydraulic loading—weir overflow rate
  - Sludge withdrawal rate
  - Solids loading rate

Wastewater Contaminants and How to Remove Them

Solids
- 1: Physical
- 2: Biological
- S: Phys/Chem

BOD
- 1: Biological
- 2: Physical
- S: Chemical

Pathogens
- 1: Chemical
- 2: Physical
- S: Biological

KEY:
1 = main contaminant removal process
2 = supplemental removal process
S = sometimes-used process

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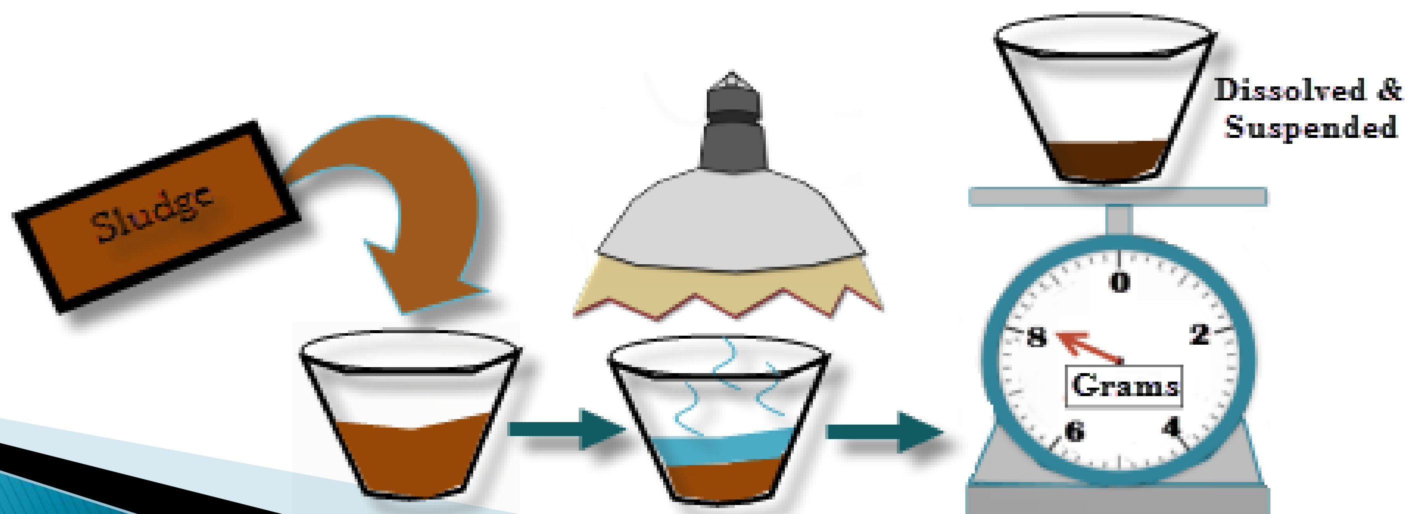
Clarifiers are a physical process to separate solids from water

Example of primary clarifier removals:

- Total Solids
  - Dissolved Solids (very little rem.)
  - Total Suspended Solids (50 – 70% rem.)
    - Floatable Solids (Scum— Fats, Oils, Grease (FOG), plastics, trash)
    - Settleable Solids (90–95% rem.)
- Biochemical Oxygen Demand (25–35% rem.)

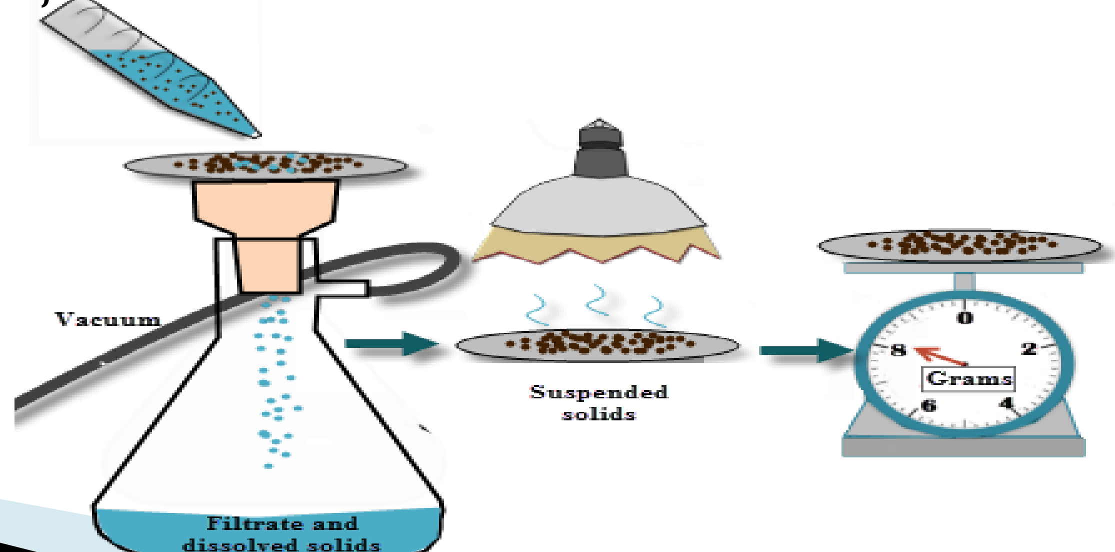
Total Solids (TS)

- All of the solids contained in a sample of wastewater (suspended and dissolved)
- To measure:
  1. Pour a known volume of sample into pre-weighed crucible
  2. Heat at 105℃ overnight (water evaporates)
  3. Weigh the sample, calculate concentration



Total Suspended Solids (TSS)

- All of the solids contained in a sample that remain in suspension (not dissolved)
- To measure:
  1. Vacuum a known volume of sample through a pre-weighed filter paper (dissolved solids pass through)
  2. Heat at 105℃ for 1-2 hours (water evaporates)
  3. Weigh the sample, calculate concentration



Dissolved Solids

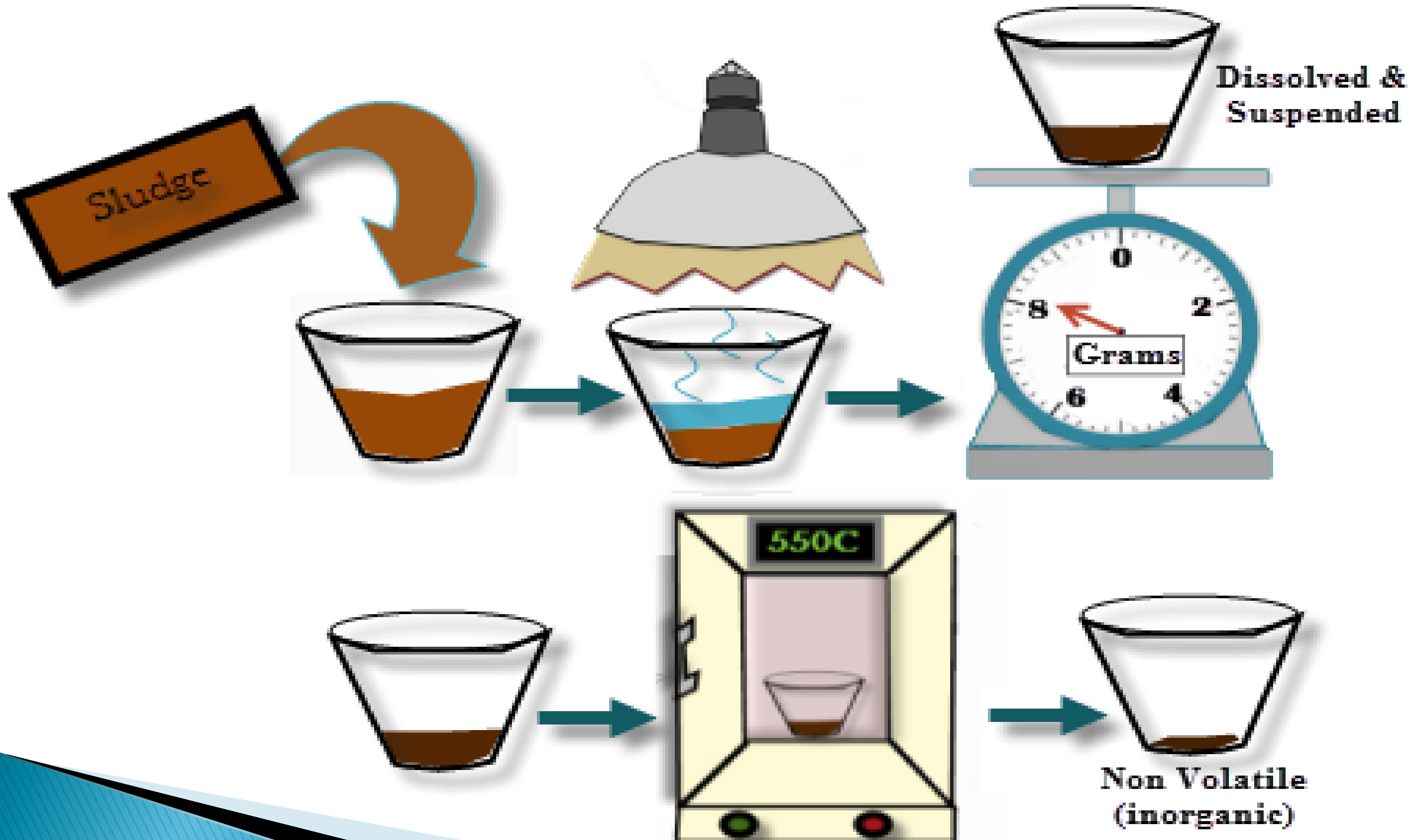
- All of the solids that are dissolved in the water and pass through a filter paper
- Won't be removed by settling
- Organic dissolved solids (e.g., sugar)
- Inorganic dissolved solids (e.g., metals, salts)
- Calculated by:

$$Dissolved\ Solids = TS - TSS$$

Volatile Solids

- A measure of how much TS or TSS are organic
  - Organic solids will burn in a furnace
  - Remaining solids are inert—non-reactive
- To measure:
  - Take the solids from the TS or TSS test
  - Burn in a furnace at 550℃ for 15 minutes
  - Weigh the sample to find non-volatile (inorganic) fraction
  - The difference between TS or TSS and the final weight is the VS or VSS

Volatile Solids (2)

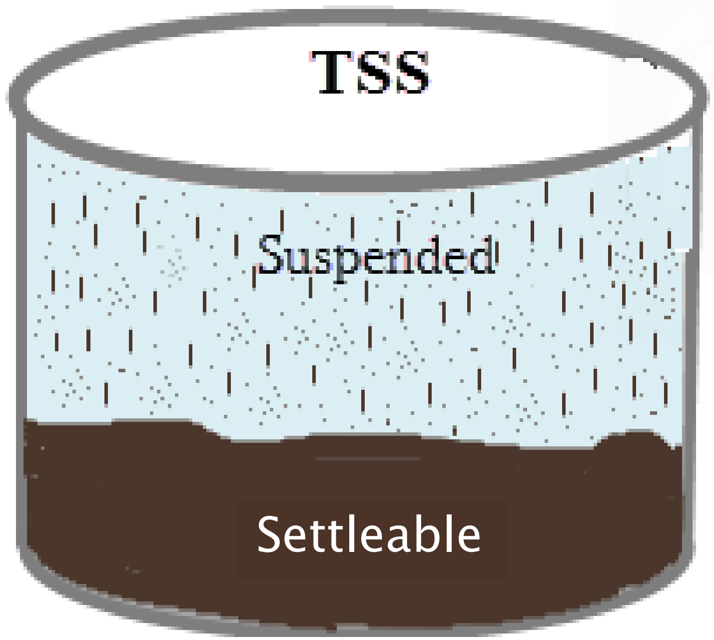


Floatable Solids

- Commonly called **scum**
- Material that is less dense than water and floats when given enough time to separate

Settleable Solids

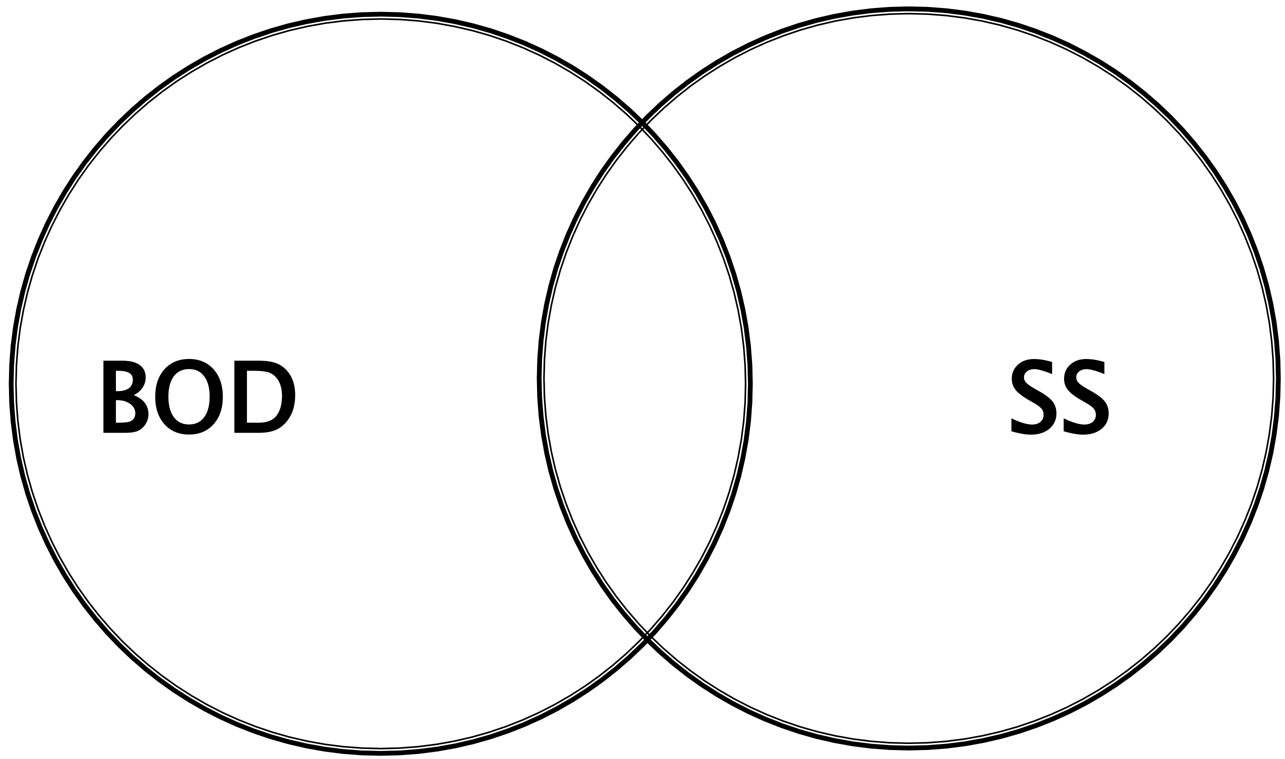
- Material that is more dense than water and settles when given enough time to separate



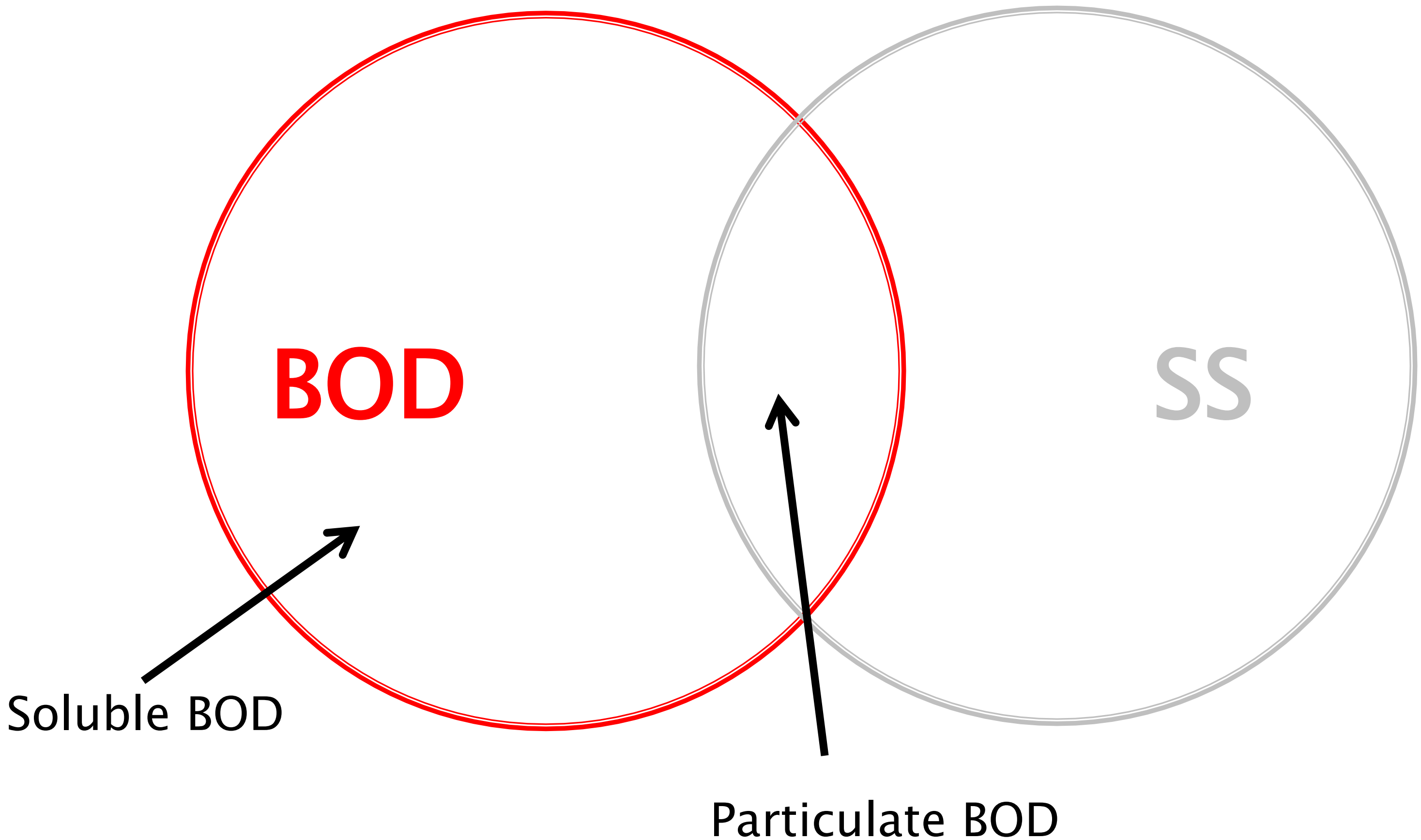
Biochemical Oxygen Demand

- BOD is an indirect measure of the organic strength of wastewater
- Rather than measuring a waste concentration directly, we measure the oxygen that microorganisms use up in order to consume the waste
- BOD is treated mainly in **secondary treatment (biological)**, but some can be removed in a primary clarifier

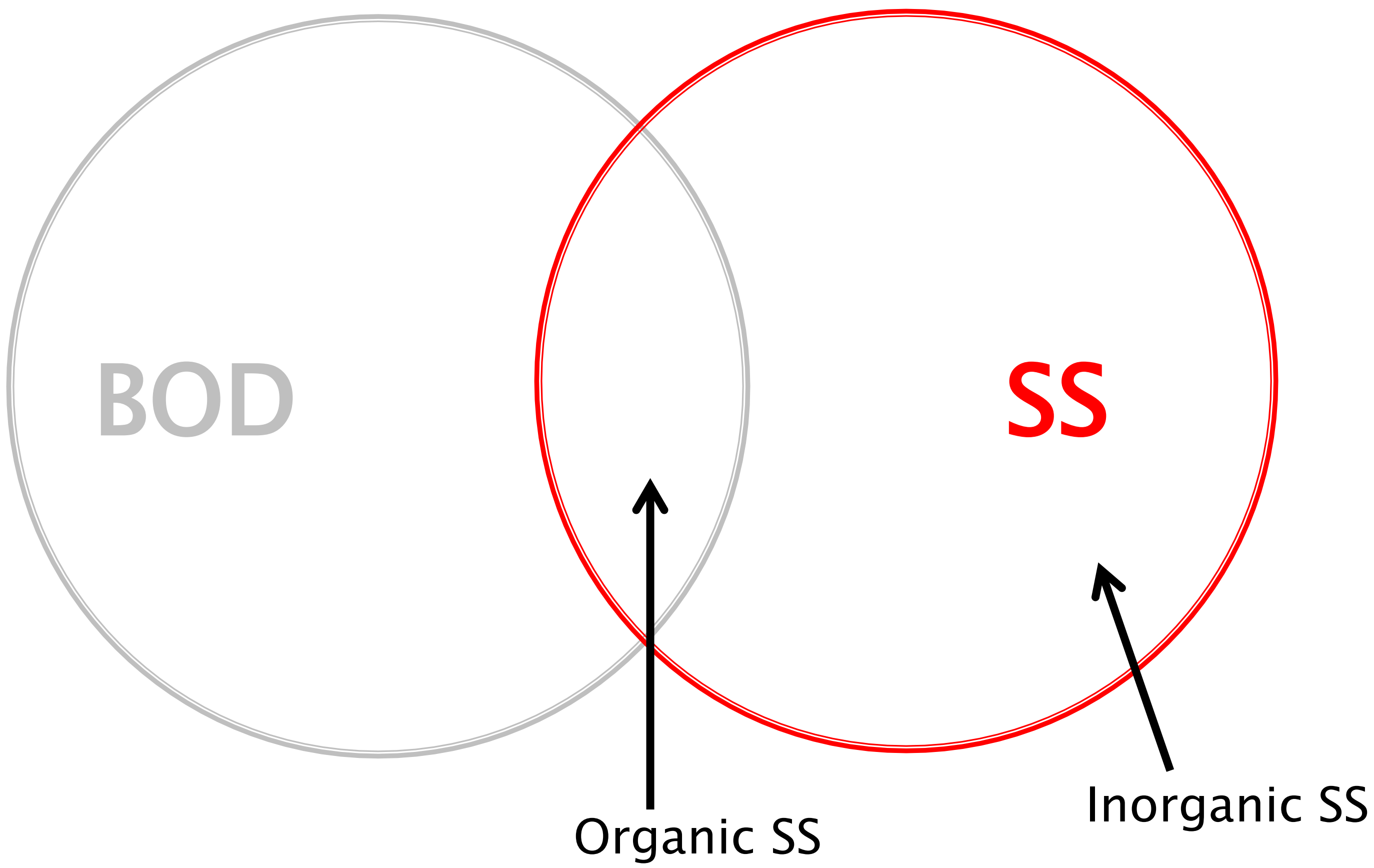
BOD vs. Solids



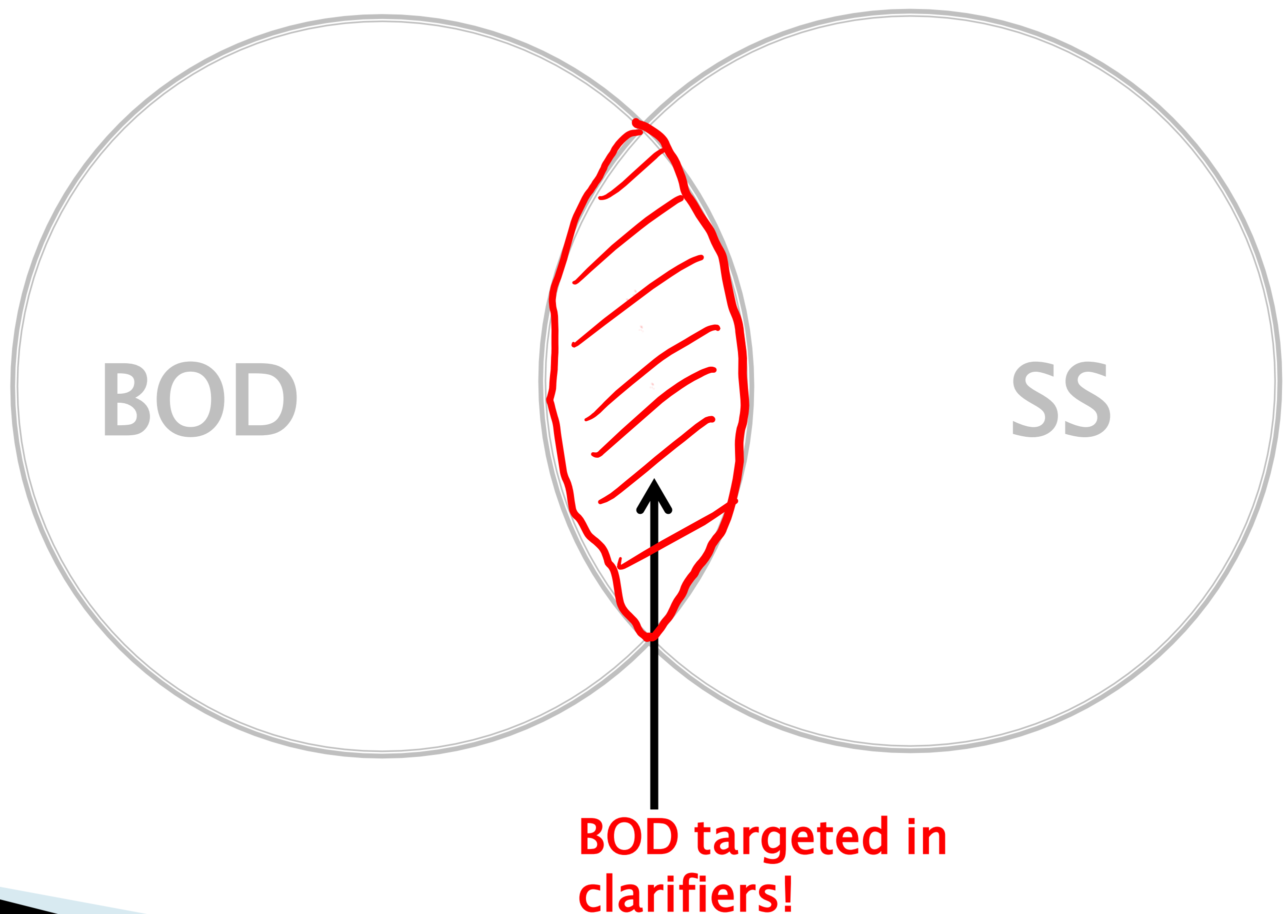
BOD vs. SS



BOD vs. SS



BOD vs. SS



Primary Clarifier Purpose

- Typically located after **preliminary treatment** (e.g., headworks—screening, grit removal)
- Designed to remove **settleable solids** and **floatable solids**
- These solids have high organic concentration (energy!) and can be sent to an anaerobic digester

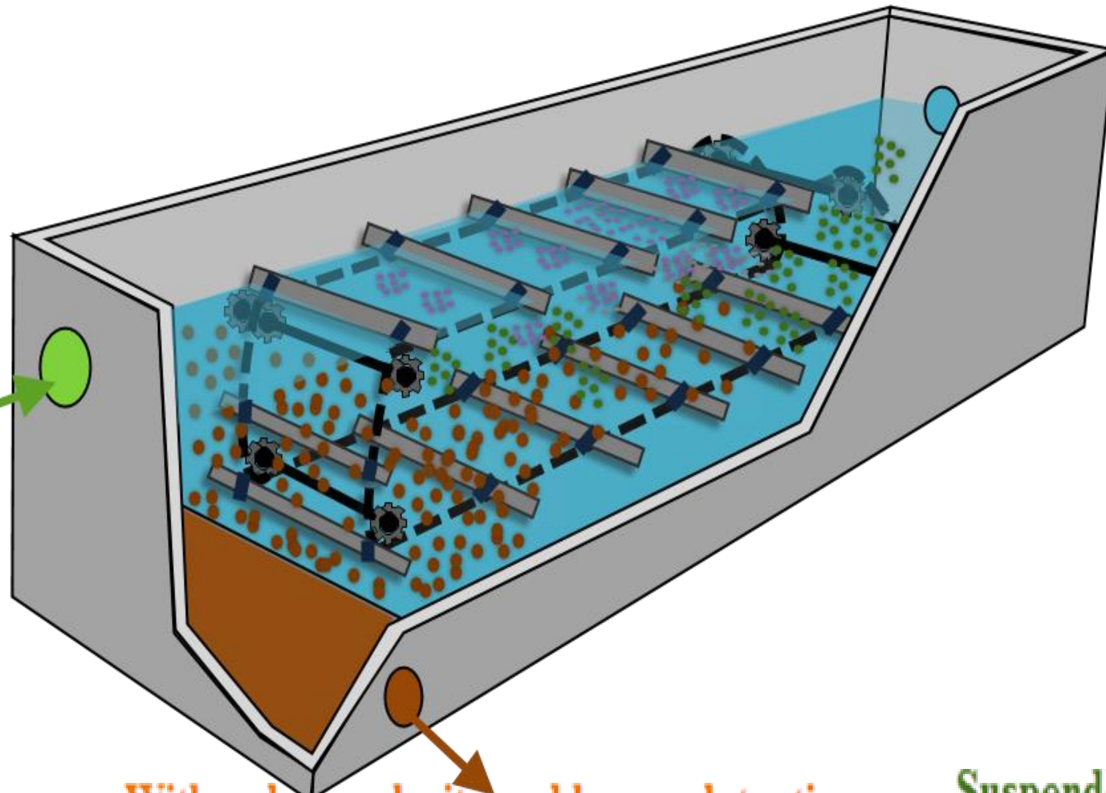
Secondary Clarifier Purpose

- Located after a biological process such as a **trickling filter** or **activated sludge**
- Used to separate microorganism solids (**mixed liquor suspended solids**) from the low-BOD effluent
- Secondary clarifier concentrates the solids as **return activated sludge (RAS)** for re-use in the biological process
  - This will be discussed more in activated sludge discussion later….

How a clarifier works

Scum (FOG, debris, and floatable solids) are collected and sent to solids handling or disposed of.

Influent raw wastewater containing solids that need to be removed flow into a tank to reduce the water's velocity, and increase it's detention time.



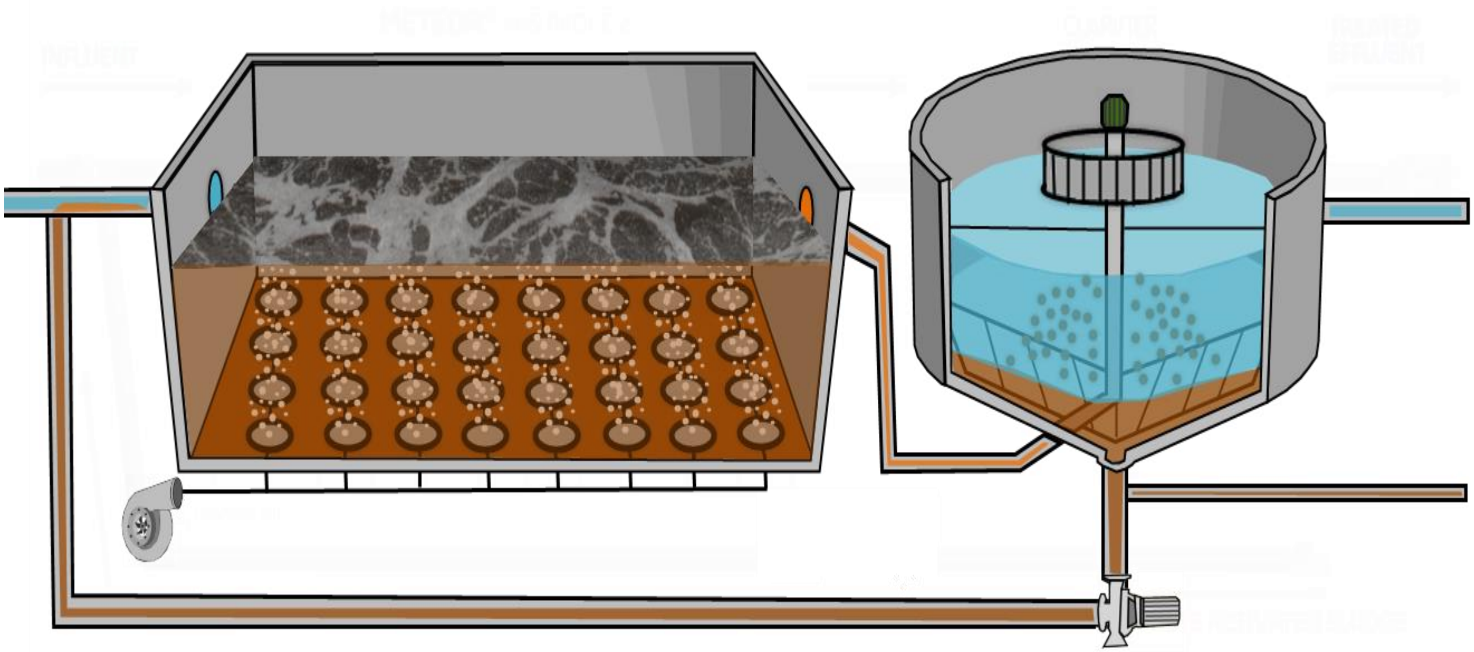
Primary effluent flows over weirs and continue to downstream processes

Primary sludge once thickened, is sent to solids handling

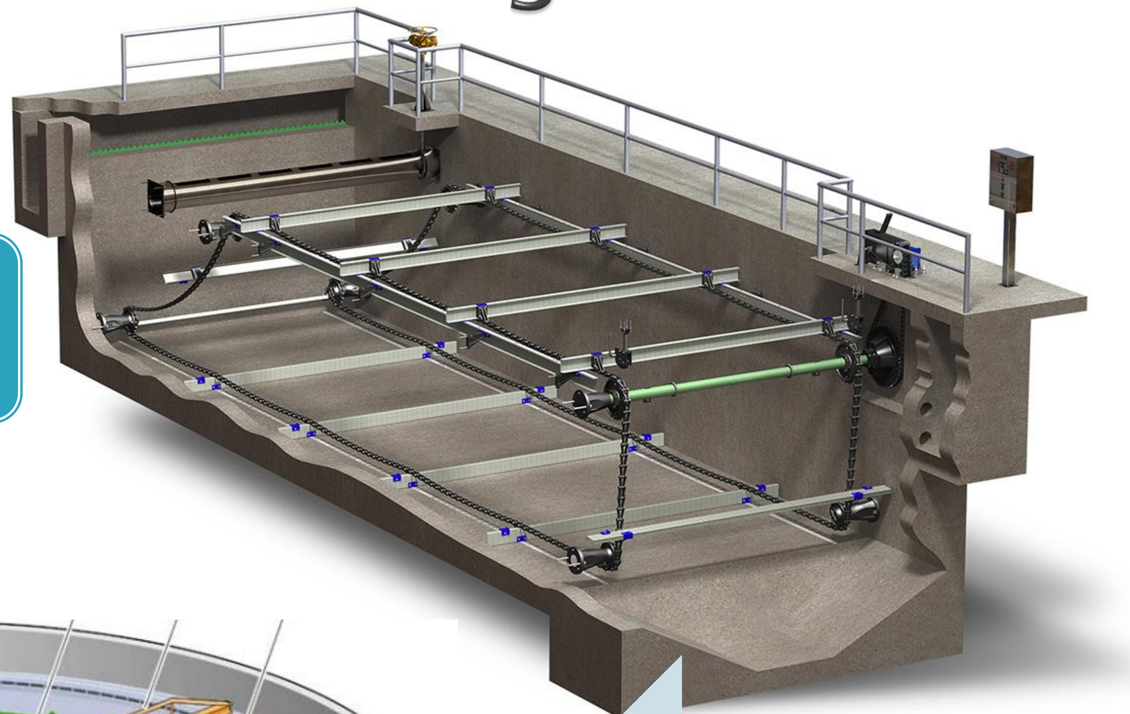
With reduce velocity and longer detention time settable solids are able to sink, collected by rakes and concentrated in a pump hopper.

Suspended solids, unable to settle leave in the primary effluent

What about a secondary clarifier?

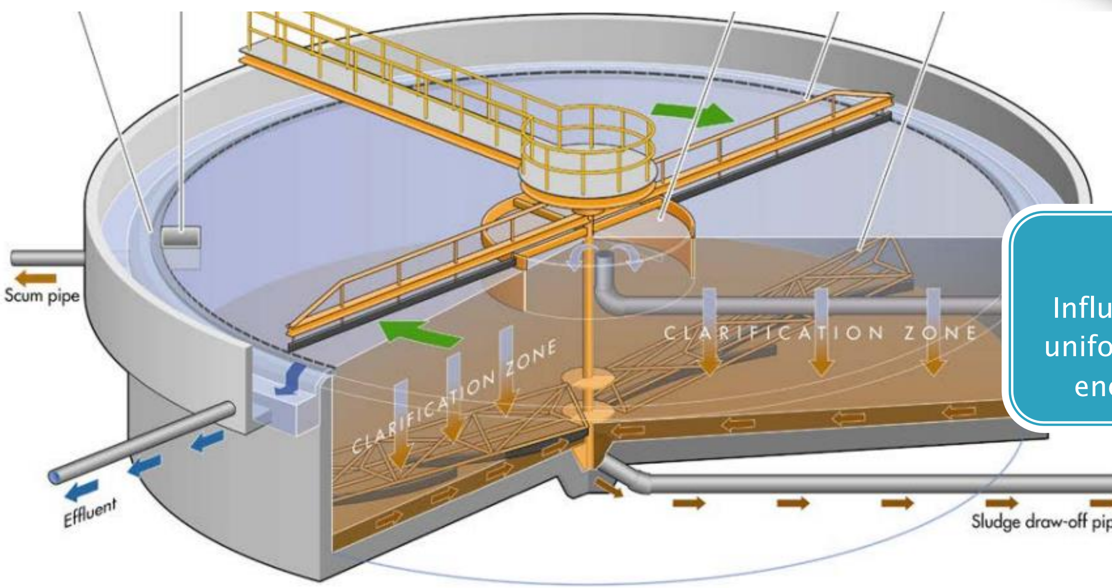


Different sizes and configurations



Rectangular Clarifier or sedimentation basin.

- Typically has lengths several times its width, provides long linear travel for excellent settling abilities, even at higher flows.



Circular Clarifier

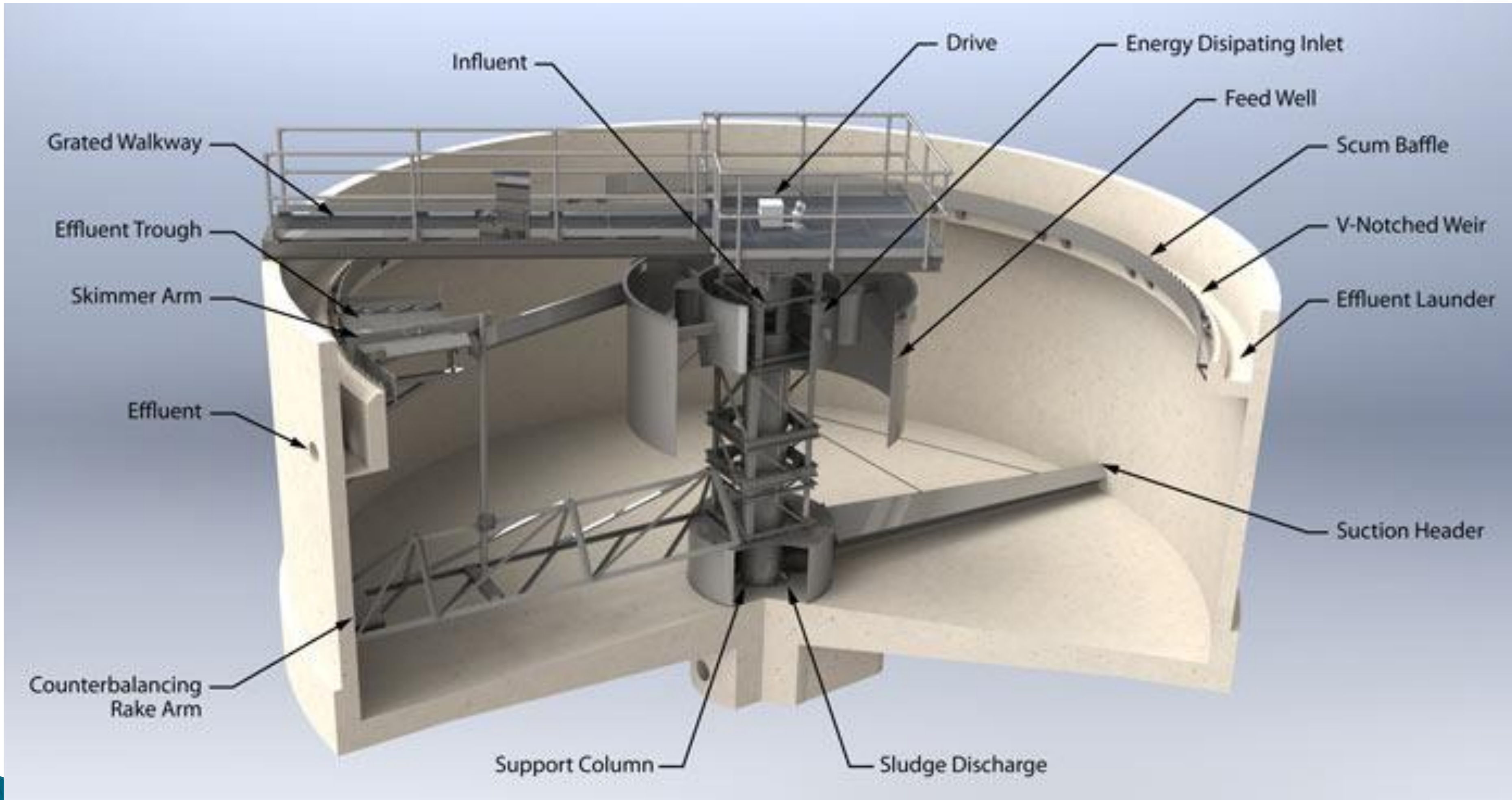
Influent flow enters through a center feed pipe and is uniformly distributed by a baffle wall, which dissipates energy and can help form better settling particles.

Item	Rectangular Clarifiers	Circular Clarifiers
Advantages	Less land required for construction of multiple units. Potential construction cost savings due to use of common walls between individual tanks. Longer flow path minimizing short-circuiting. Higher effluent weir loading rates acceptable. Better sludge thickening.	Shorter detention time for settling sludge favoring use as secondary clarifiers. More simple sludge collection system. Easier to accommodate in-tank flocculation chamber – a benefit for activated sludge settling. Overall, lower maintenance requirements. Easier to remove heavy sludge.
Disadvantages	Longer detention time of the settled sludge – not favorable for plants with septic wastewater influent. Less effective for high solids loading conditions.	Higher short-circuiting potential. Higher flow distribution headlosses. Small circular tanks require more yard piping than rectangular tanks of similar size.

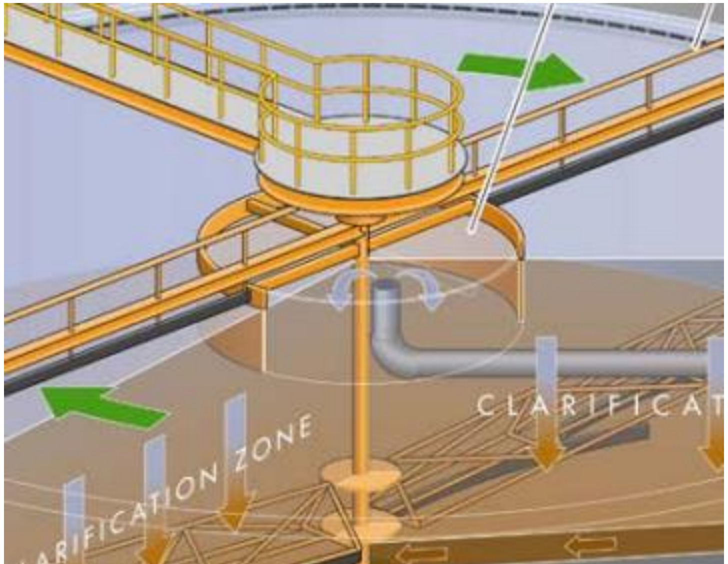
Sludge collectors

- "Chain and flight system"
- Flights are long scrapers that move around the clarifier lengthwise
    - Push sludge along the bottom of the clarifier to a collection sump
    - Push scum along the water surface to a trough
- Both primary sludge and scum can be pumped to an anaerobic digester for further processing

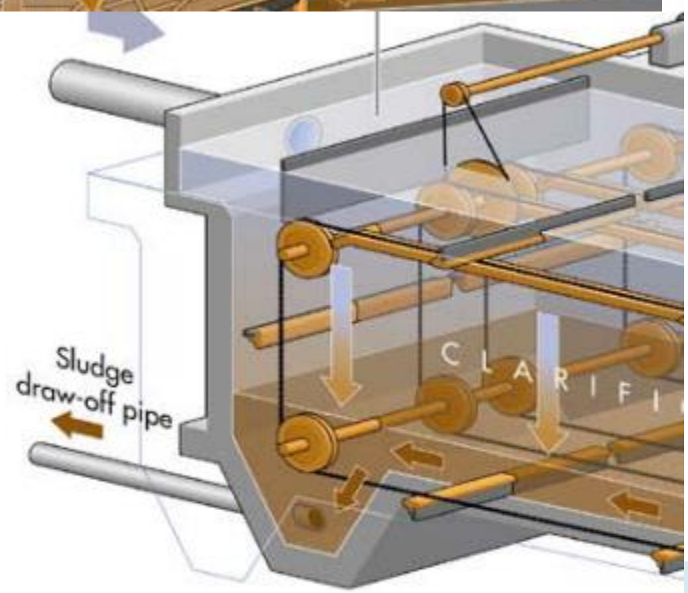
Sludge collectors

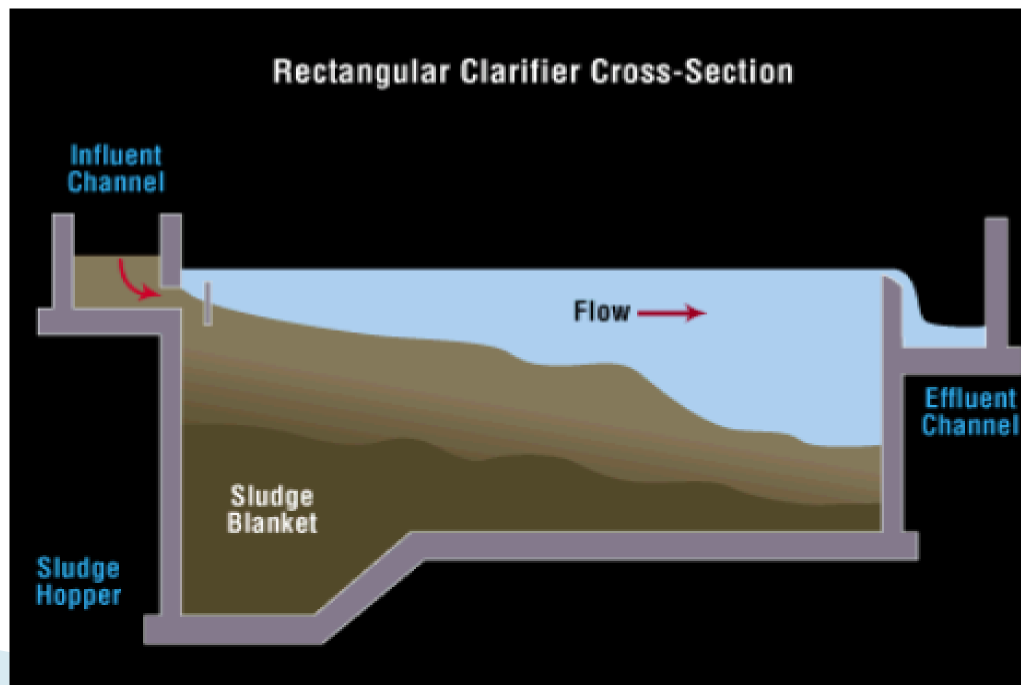


Inlet baffles



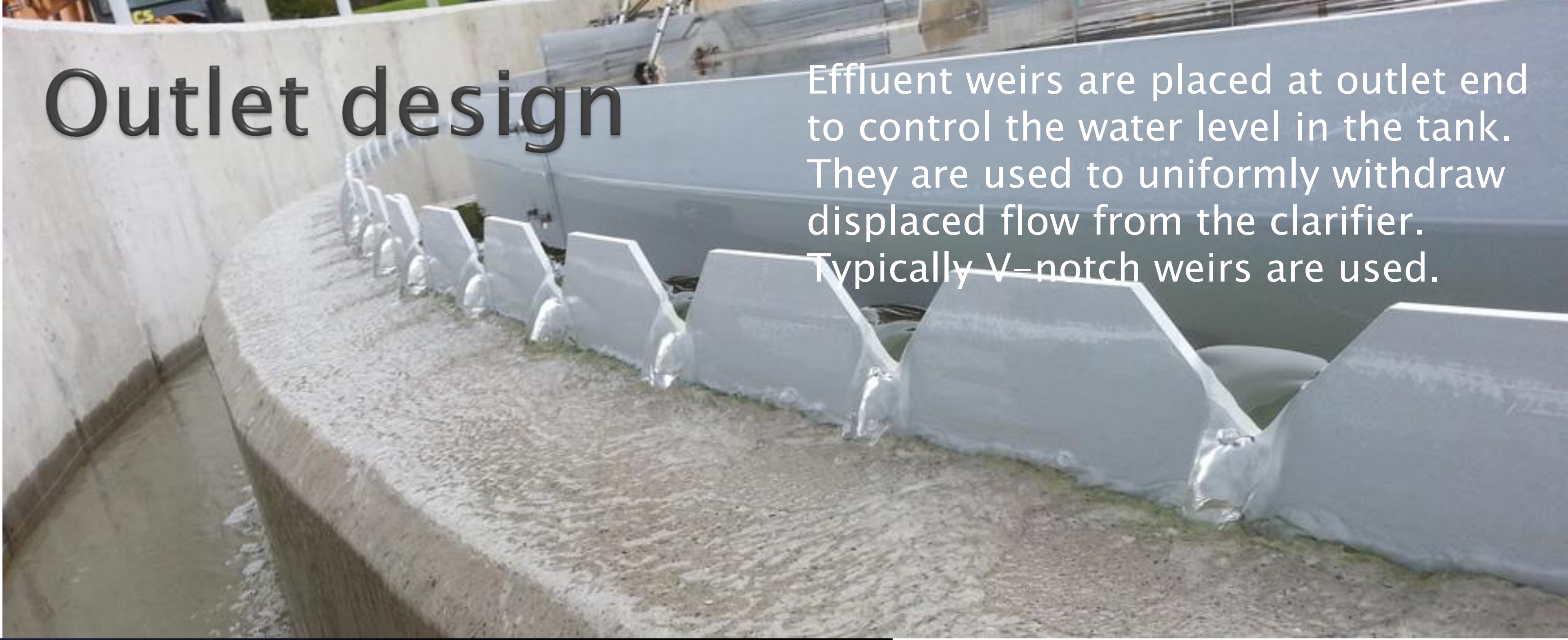
- Designed to slow down flow
- Dissipates influent energy
- Uniformly distribute flow
- Reduce density currents
- Minimize sludge blanket disturbance

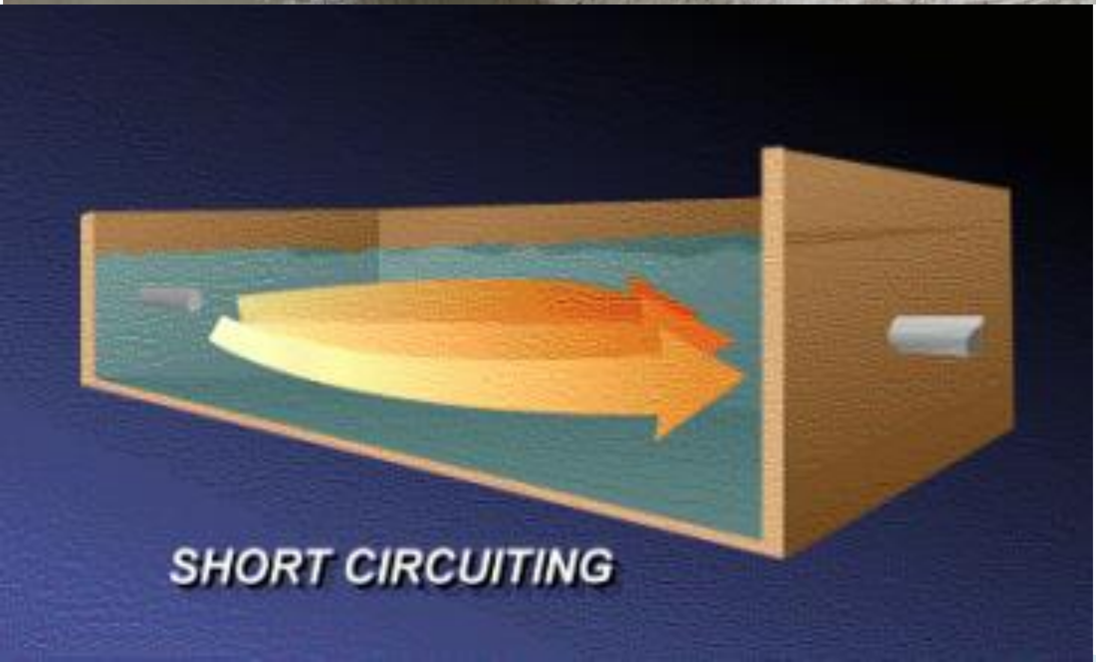




Outlet design

Effluent weirs are placed at outlet end to control the water level in the tank. They are used to uniformly withdraw displaced flow from the clarifier. Typically V-notch weirs are used.



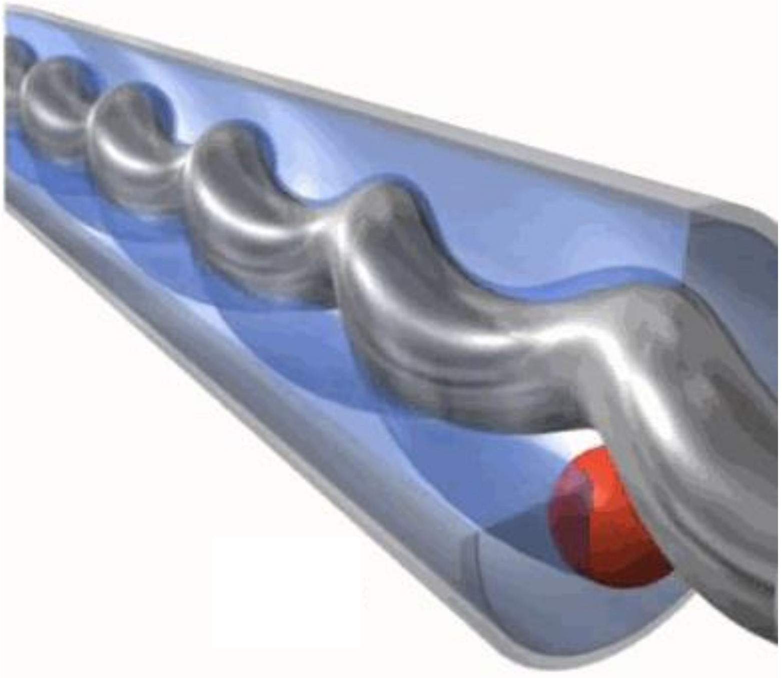


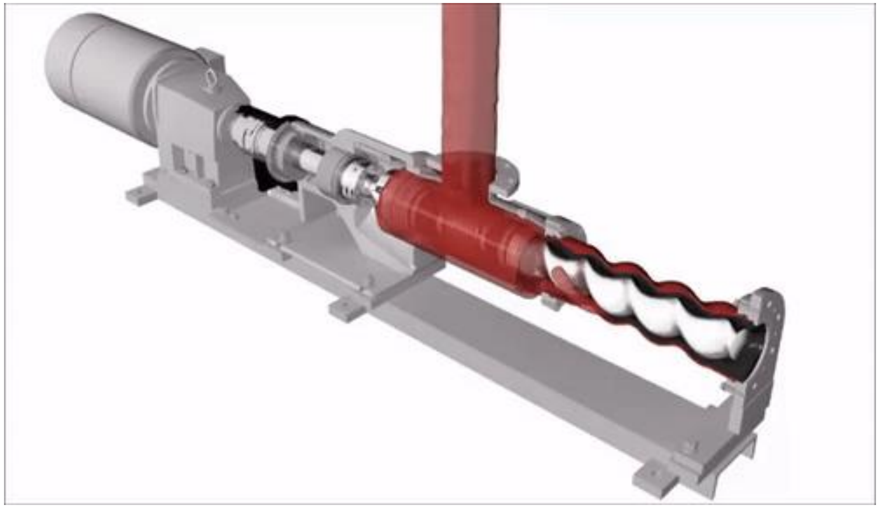
The inlet and outlet design is important for proper flow distribution. Improper distribution could cause the areas in the clarifier where the velocity of the wastewater tis greater preventing solids form settling. These particles are forced in suspension get carried out in the effluent, a condition called "short-circuiting“.

Pumps

Progressive Cavity

- Screw shaped **rotor** rotates inside a tight rubber sleeve called a **stator**.
- Cavities exist between portions of the rotor and stator that fills with the liquid being pumped.
- As the rotor rotates, the cavity moves down the length of the pump and discharges the liquid out of the pump.

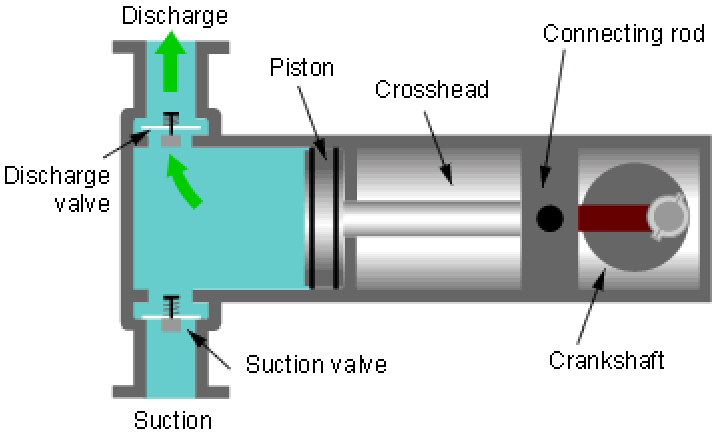




Pumps

Piston Pump

- **Piston** moves back and forth and creates a suction and discharge force.
- Check valves in the suction and discharge lines open and close to direct the flow in each stroke



Pumps

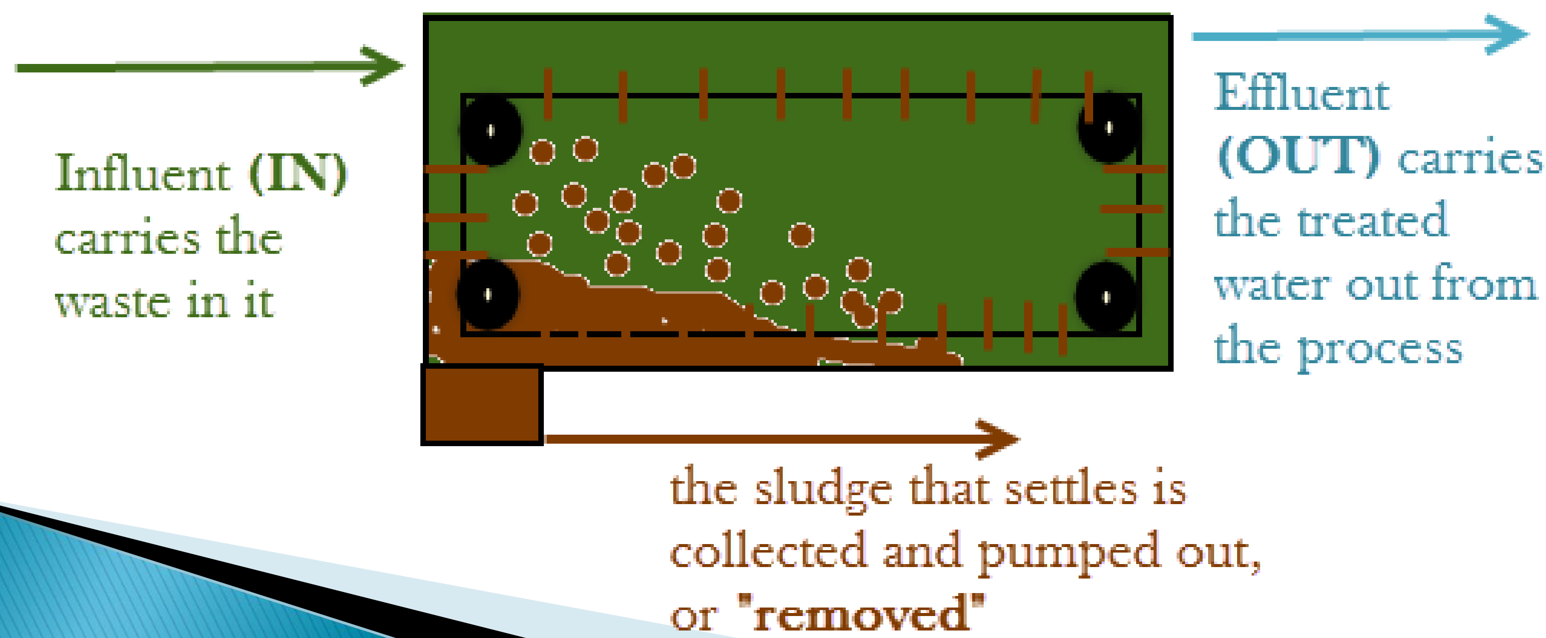
Centrifugal Pumps

- Pump **impeller** is spun by a **motor** in a **pump casing (volute)**.
- Using centrifugal force vanes on the impeller throws water outward to the pump discharge pipe.
- If this pump is run dry or left running unprimed, the pump can be damaged due to cavitation and overheating. Water acts as a lubricant and heat sink. Running pumps dry creates a lot of heat and friction

Removal Efficiency

- Efficiency is a measure of how effective a process is at removing contaminants

$$Eff = \left[\frac{Concentration\ In - Concentration\ Out}{Concentration\ In}\right] x\ 100$$



Primary Clarifier Removal Eff.

- Influent TSS concentration 200–300 mg/L
- Influent BOD concentration 500–700 mg/L

- **TSS removal efficiency** is about 50–70%
- **BOD removal efficiency** is about 25–35%
- **Settleable solids removal efficiency** is 90–95%**.**

- But only if the water stays in the tank for long enough to allow material to settle!

What is the TSS removal efficiency of a primary clarifier if the Influent TSS measures 250 mg/l and the clarifier Effluent TSS measures 83 mg/l?

$$\left[\frac{In - Out}{In}\right] \; x \; 100$$

$$\left[\frac{250 - 83}{250}\right] \; x \; 100$$

$$\left[\frac{167}{250}\right] \; x \; 100$$

66.8%

What is the TSS removal efficiency of a primary clarifier if the Influent TSS measures 300 mg/l and the clarifier effluent TSS measures 124 mg/l?

$$\left[\frac{In - Out}{In}\right] \; x \; 100$$

$$\left[\frac{300 - 124}{300}\right] \; x \; 100$$

$$\left[\frac{176}{300}\right] \; x \; 100$$

58.7%

Detention Time

- Detention time is the average amount of time that a drop of water or contaminant particle spends in the process

$$\boldsymbol{Detention\ time = \frac{Tank\ Volume}{Influent\ Flow\ Rate}}$$

- Units are a time (hours, days, etc.)

- Recall that if there's short-circuiting, not all of the water is meeting the theoretical detention time!

What is the detention time in hours of a 1,500,000 gallon clarifier receiving a flow of 12.5 MGD?

- Make volume units consistent:

$$Volume = 1{,}500{,}000\ \cancel{gal} \times \left(\frac{1\ MG}{1{,}000{,}000\ \cancel{gal}}\right) = 1.5\ MG$$

- Use detention time formula:

$$Detention\ time = \frac{Tank\ Volume}{Influent\ Flow}$$

$$DT = \frac{1.5\ \cancel{MG}}{12.5\ \cancel{MG}D} = 0.12\ days$$

- Convert units to hours:

$$DT = 0.12\ \cancel{days} \times \left(\frac{24\ hours}{1\ \cancel{day}}\right) = \mathbf{2.88\ hours}$$

What is the detention time in hours of a 1.85 million gallon basin receiving a flow of 1250 GPM?

- Need to use the same volume units (e.g., convert both numbers to be in terms of million gallons)

$$Influent\ Flow = \left(\frac{1{,}250\ \cancel{gal}}{1\ min}\right) \times \left(\frac{1\ MG}{1{,}000{,}000\ \cancel{gal}}\right) = 0.00125\ MG/min$$

- Use detention time formula:

$$Detention\ time = \frac{Tank\ Volume}{Influent\ Flow}$$

$$DT = \frac{1.85\ \cancel{MG}}{0.00125\ \frac{\cancel{MG}}{min}} = 1{,}480\ min$$

- Convert to hours:

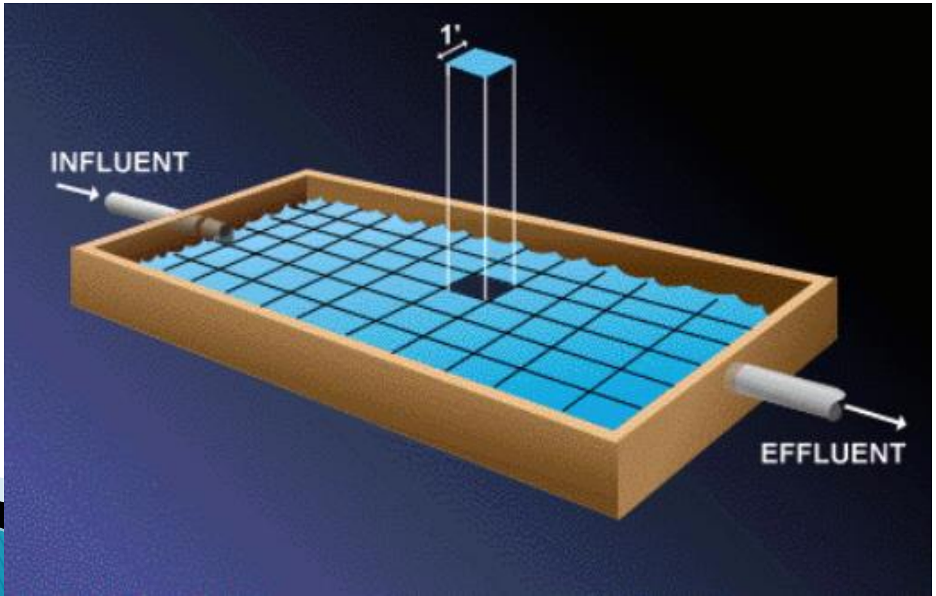
$$DT = 1{,}480\ \cancel{min} \times \left(\frac{1\ hour}{60\ \cancel{min}}\right) = \mathbf{24.7\ hours}$$

Surface Overflow Rate

A measure of **hydraulic loading** (how much water is being processed through the clarifier)

Measured as the influent flow rate divided by the total available surface area of your clarifier(s), also known as Surface Loading rate. Typical SORs are between **800 – 1,200 gpd/ft^2**

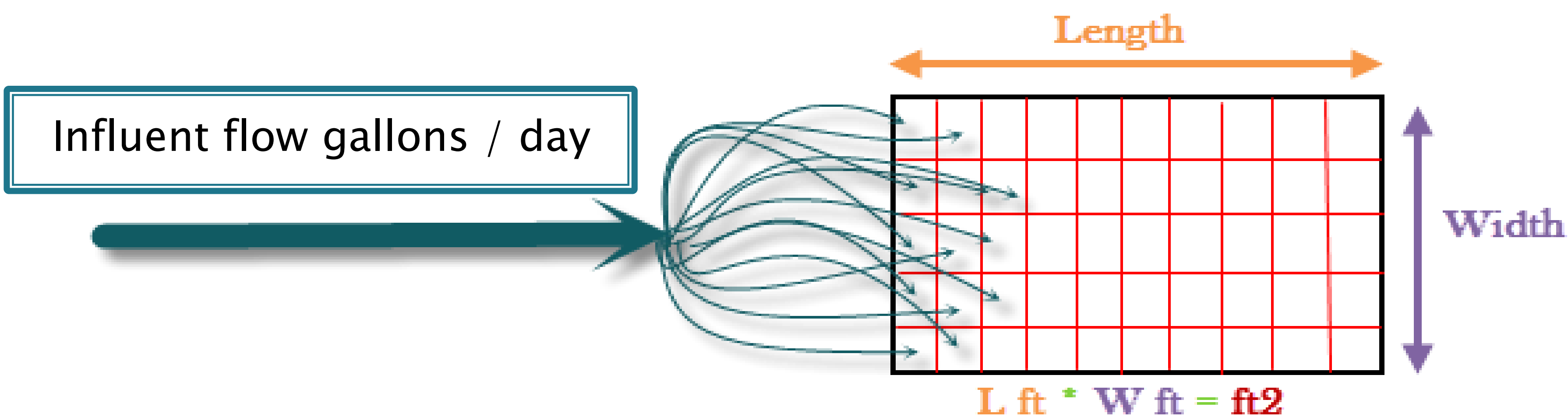
Hydraulically overloading or exceeding the SOR causes solids to be washed out in the effluent and incomplete treatment.



Surface Overflow Rate

Calculated by: dividing the influent flow rate by the surface area.

$$SOR = \frac{\text{Influent flow}}{\text{Tank Surface Area}} \qquad \text{Typical units} = \frac{gal/d}{ft^2}$$



Surface Overflow Rate

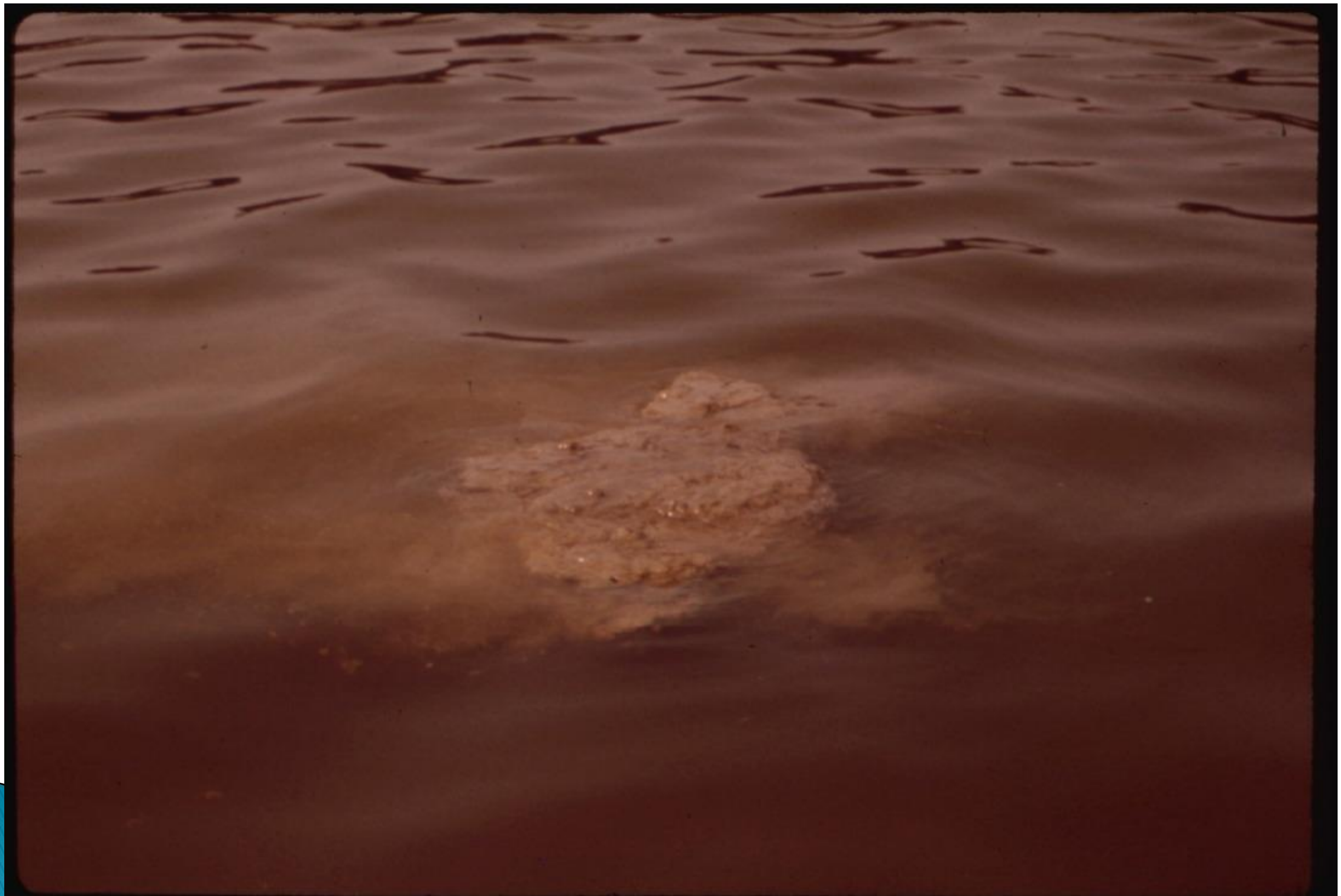
IF SOR IS TOO HIGH:

- Reduce the flow into the clarifiers (e.g., equalization)
- Put more clarifiers in service—increases total surface area

ALSO AFFECTS DETENTION TIME:

- High flow rate means that the detention time will be shorter as well
- For proper clarifier operation, we need to maintain a long enough detention time to allow for settling, but not so long that the oxygen is depleted and the clarifier goes septic
- Target = **1–3 hours**

Secondary clarifier with long detention time…



What is the surface overflow rate (gals/day/ft^2) of a rectangular sedimentation tank measuring 125 ft by 25 ft with a daily flow of 5 MGD?

- Calculate surface area of tank:

$$Area = length \times width = (125\ ft)(25 ft) = 3{,}125\ ft^2$$

- Convert flow to gallons per day:

$$Flow = \left(\frac{5\ \cancel{MG}}{1\ day}\right) \times \left(\frac{1{,}000{,}000\ gal}{1\ \cancel{MG}}\right) = 5{,}000{,}000\ \frac{gal}{day}$$

- Calculate SOR:

$$SOR = \frac{Influent\ Flow}{Tank\ Surface\ Area} = \frac{5{,}000{,}000\ \frac{gal}{day}}{3{,}125\ ft^2} = \mathbf{1,600}\ \frac{\boldsymbol{gpd}}{\boldsymbol{sf}}$$

What is the surface overflow rate (gpd/sf) of a circular clarifier with a diameter of 100 ft and an operating depth of 15 ft, with a daily flow of 7 MGD?

- Find surface area:

$$Area = \pi r^2 = (3.14) \times (50ft)^2 = 7{,}850\ sf$$

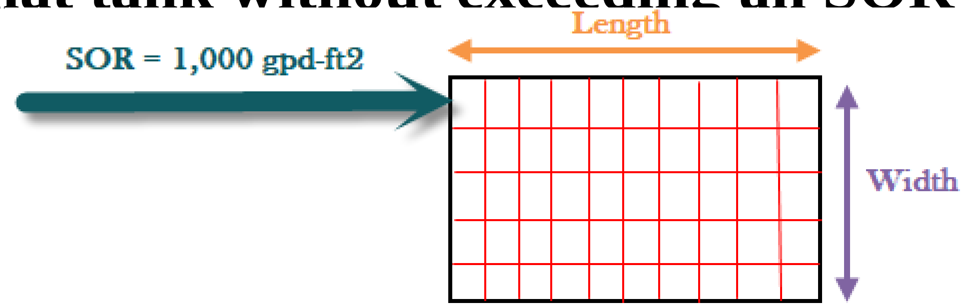
- Convert flow to gpd:

$$Flow = \left(\frac{7\ MG}{1\ day}\right) \times \left(\frac{1{,}000{,}000\ gal}{1\ MG}\right) = 7{,}000{,}000\,\frac{gal}{day}$$

- Apply SOR formula:

$$SOR = \frac{Influent\ Flow}{Surface\ Area} = \frac{7{,}000{,}000 gpd}{7{,}850\ sf} = \mathbf{892}\,\frac{\boldsymbol{gpd}}{\boldsymbol{sf}}$$

A rectangular primary sedimentation tank (100 ft x 20 ft) is operated at a depth of 12.5 ft. What flow (expressed in MGD) can be treated in that tank without exceeding an SOR of 1000 gpd/sf?



- Find surface area:

$$Area = (100ft) \times (20ft) = 2{,}000\ sf$$

- Use algebra to solve SOR formula for a flow rate:

$$SOR = \frac{Influent\ Flow}{Surface\ Area}$$

$$1{,}000\,\frac{gpd}{sf} = \frac{Flow}{2{,}000\ sf}$$

$$Flow = 2{,}000{,}000\ gpd$$

- Convert to MGD:

$$Flow = 2{,}000{,}000\,\frac{\cancel{gal}}{day} \times \left(\frac{1\ MG}{1{,}000{,}000\ \cancel{gal}}\right) = \mathbf{2\ MGD}$$

NOTE:
The depth of the tank was not used!

A circular primary clarifier with a radius of 55 ft. is operated at a depth of 14 ft. What flow (expressed in MGD) can be treated in that tank without exceeding an SOR of 850 gallons/day-ft2?

- Find surface area of clarifier:

$$Area = \pi r^2 = (3.14) \times (55\ ft)^2 = 9{,}498.5\ sf$$

- Use algebra to solve for flow rate:

$$\boldsymbol{SOR = \frac{Influent\ Flow}{Surface\ Area}}$$

$$850\frac{gpd}{sf} = \frac{Influent\ Flow}{9498.5\ sf}$$

$$Influent\ Flow = 8{,}073{,}725\ gpd$$

- Convert answer to MGD:

$$Flow = 8{,}073{,}725\frac{gal}{day} \times \left(\frac{1\ MG}{1{,}000{,}000\ gal}\right) = \mathbf{8.07\ MGD}$$

Weir Overflow Rate

- Another measure of **hydraulic loading** on the clarifier

- Expressed in terms of the total length of overflow weirs on the clarifier
  - Rather than the surface area, as in SOR

- Typical value = 5,000–15,000 gpd/ft

- A high WOR means that the water flow velocity over the weir is too high which might carry solids over the weir and onto the next process

$$WOR = \frac{Influent\ Flow}{Total\ Weir\ Length}$$

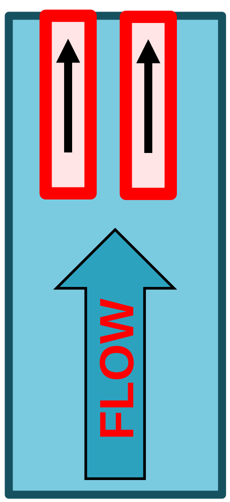
$$Typical\ units = \frac{gpd}{ft}$$

Rectangular WOR

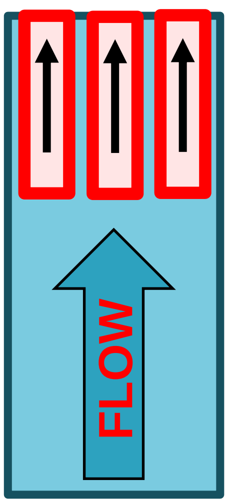
Rectangular tanks with parallel effluent launders:

$$Weir\ length = (length\ of\ launder) \times (number\ of\ sides\ overflowing)$$

= Length X 4



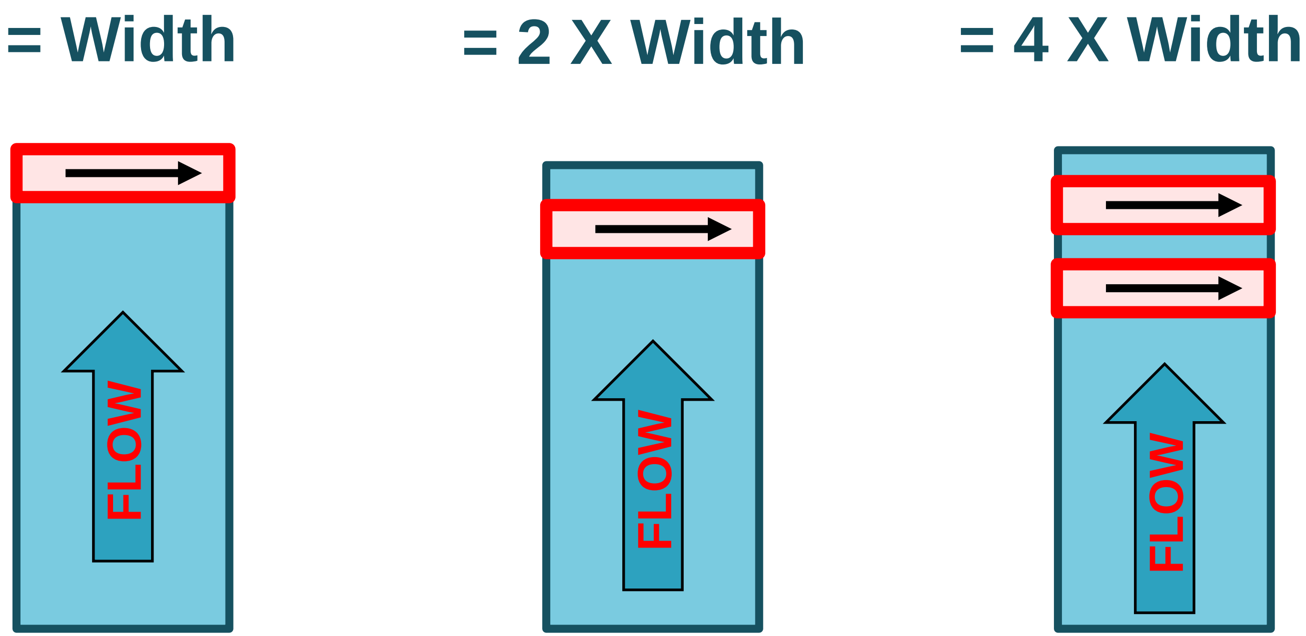
= Length X 6



Rectangular WOR

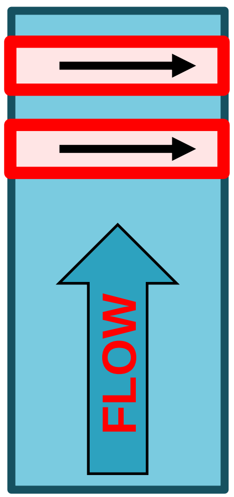
Rectangular tanks with perpendicular weir placement:

$$Weir\ length = (width\ of\ clarifier) \times (number\ of\ sides\ overflowing)$$



A primary clarifier is 20 feet wide, 60 feet long, and has a SWD of 12 feet. The clarifier has two effluent troughs across the width that allow the water to flow over both sides of each trough. The average flow to the clarifier is 0.65 MGD. Calculate the weir overflow rate for this clarifier.

$$\boldsymbol{WOR} = \frac{\text{Influent flow } gpd}{\text{total weir length } ft}$$



- Convert flow to MGD:

$$Flow = \left(\frac{0.65\ \cancel{MG}}{1\ day}\right) \times \left(\frac{1{,}000{,}000\ gal}{1\ \cancel{MG}}\right) = 650{,}000\ gpd$$

- Calculate total weir length:

$$Weir\ length = 4\ sides \times \left(\frac{20\ ft}{side}\right) = 80\ ft$$

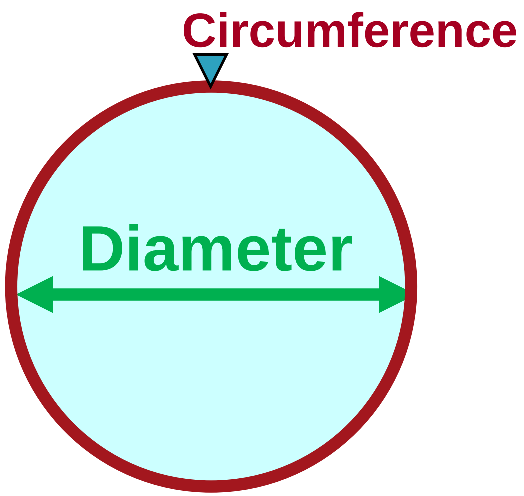
- Calculate WOR:

$$WOR = \frac{650{,}000\ gpd}{80\ ft} = \mathbf{8{,}125}\,\frac{\boldsymbol{gpd}}{\boldsymbol{ft}}$$

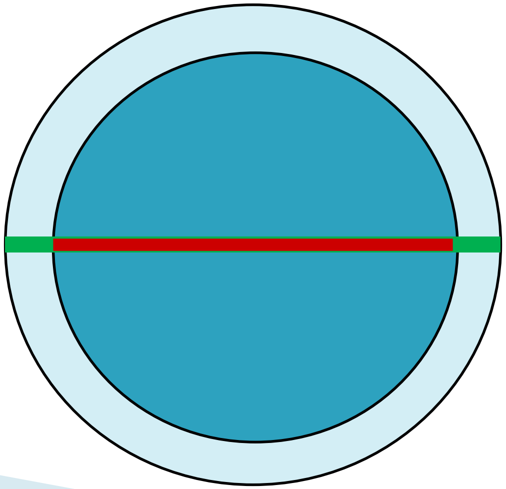
Circular Clarifier WOR

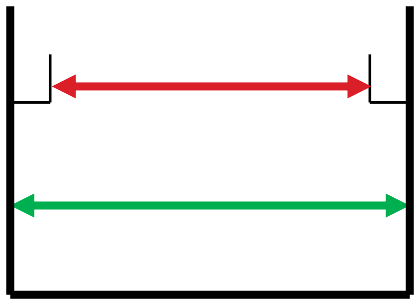
Circumference = distance around circle

$$Circumference = \pi \times Diameter$$

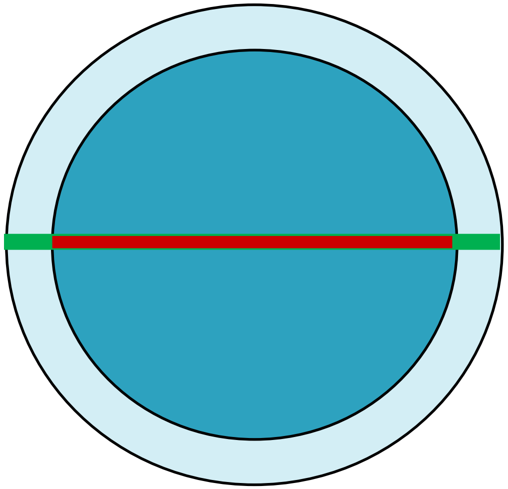


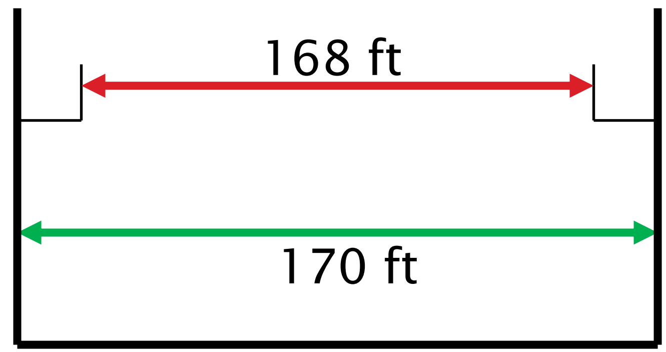
- Be aware that sometimes the diameter of the weir is less than the diameter of the clarifier!





A circular clarifier is operated at a depth of 15 ft. with a diameter of 170 ft, and the weirs are set in 1 foot from the outside wall. What is the Weir Overflow Rate if it receives 5 MGD?





- $Flow = 5\ MGD = 5{,}000{,}000\,\frac{gal}{d}$
- $Weir\ length = \pi D = (3.14) \times (168\ ft) = 527.52\ ft$
- $WOR = \frac{Influent\ Flow}{Total\ Weir\ Length} = \frac{5{,}000{,}000\ gpd}{527.52\ ft} = \mathbf{9{,}478\,\frac{gpd}{ft}}$

Sludge Withdrawal Rate

- The sludge that collects at the bottom of a clarifier typically collects in a sump
- If given enough time to settle, the sludge is concentrated to typically 3-7% total solids by weight

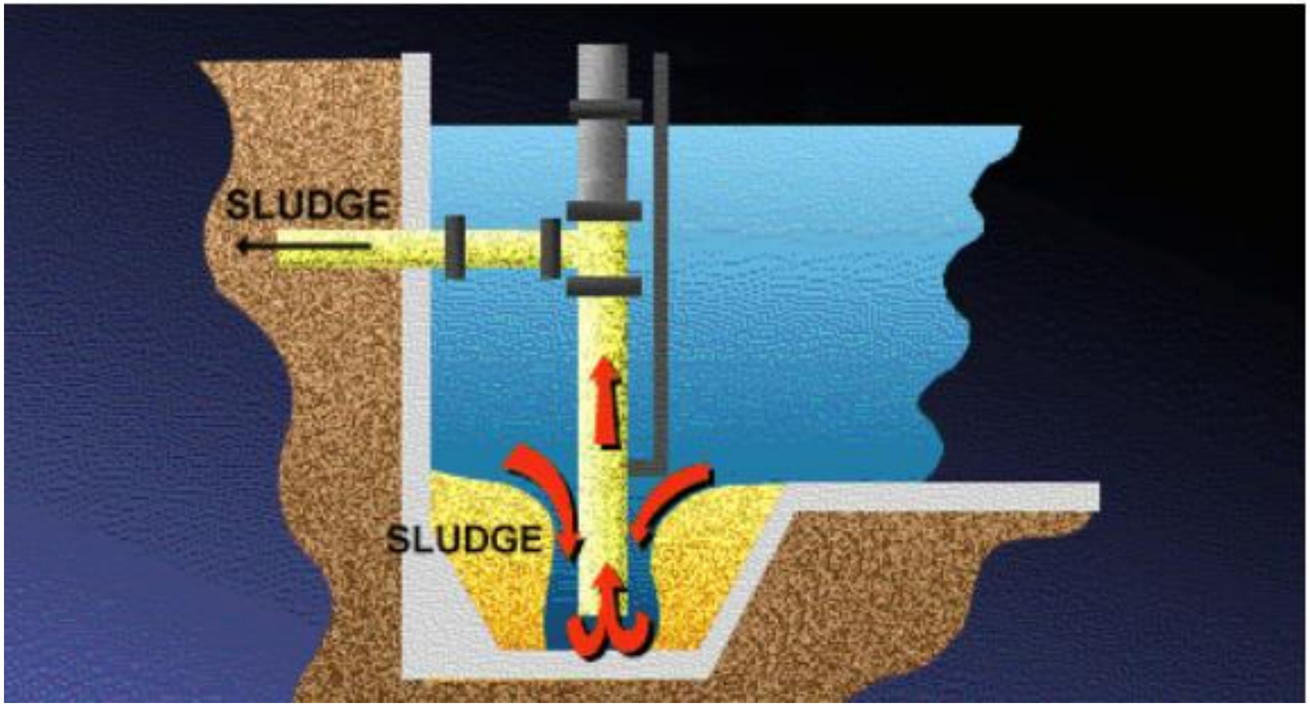
IF YOU PUMP TOO MUCH:

- Thin sludge (mostly water) gets passed on to solids treatment processes and overloads them with water

IF YOU PUMP TOO LITTLE:

- Sludge starts to break down and produce gas
- Sludge blanket builds up higher and higher
- Eventually, sludge starts escaping over the effluent weirs

Coning—Pumping Too Much



Total Solids of Sludge:

$$\textit{Sludge weight} = \textit{total weight of solids plus water in sludge mixture}$$

$$\textit{Total solids weight} = (\textit{sludge weight}) \times \frac{\%TS}{100}$$

OR

$$\%TS = \frac{\textit{total solids weight}}{\textit{sludge weight}} \times 100$$

You can also calculate %TS from a solids concentration:

$$\boldsymbol{\%TS = \frac{concentration, \frac{mg}{L}}{10,000}}$$

Primary sludge is pumped to an anaerobic digester 10 minutes every hour at a rate of 360 GPM. An operator tested the primary sludge at 5.6% total solids and found them to be 79% volatile. Calculate the how many lbs./day TS was removed?

- Calculate total weight of sludge pumped per day:

$$weight\ of\ sludge = \left(\frac{360\ \cancel{gal}}{1\ \cancel{min}}\right) \times \left(\frac{10\ \cancel{min}}{1\ \cancel{h}}\right) \times \left(\frac{24\ \cancel{h}}{1\ d}\right) \times \left(\frac{8.34\ lbs}{1\ \cancel{gal}}\right) = \frac{720{,}576\ lbs\ sludge}{d}$$

- Calculate total weight of solids in this sludge:

$$weight\ of\ solids = \left(\frac{720{,}576\ \cancel{lbs\ sludge}}{1\ day}\right) \times \left(\frac{5.6\ lbs\ TS}{100\ \cancel{lbs\ sludge}}\right)$$

$$weight\ of\ solids = \mathbf{40,352}\ \frac{\mathbf{lbs\ TS}}{\mathbf{d}}$$

Solids Loading Rate

- Unlike SOR, SLR doesn't measure the amount of water (gallons) but the amount of solids (lbs) applied to the clarifier

- Otherwise, it's calculated similar to SOR

- Typical value = 25-30 lbs/d/sf
- Peak day value = 30-50 lbs/d/sf

$$\boldsymbol{SLR = \frac{Pounds\ of\ solids\ applied\ to\ clarifier}{Tank\ surface\ area}}$$

$$Typical\ units = \frac{lbs/d}{sf}$$

Calculate the Solids Loading Rate for a clarifier with a 22 ft radius and a depth of 8.5 feet, and receives a flow of 1,450,000 gallons per day with a suspended solids concentration of 3400 mg/L.

- Calculate clarifier surface area:

$$Area = \pi r^2 = (3.14) \times (22\ ft)^2 = 1{,}519.76\ ft^2$$

- Calculate percent solids:

$$\%TS = \frac{3{,}400\,\frac{mg}{L}}{10{,}000} = 0.34\%\ TS$$

- Calculate pounds per day of solids applied to clarifier:

$$\frac{lbs}{d} = \left(\frac{1{,}450{,}000\ gal}{1\ day}\right) \times \left(\frac{8.34\ lbs}{1\ gal}\right) \times \left(\frac{0.34\ lbs\ TS}{100\ lbs\ sludge}\right) = 41{,}116\,\frac{lbs}{d}$$

- Calculate SLR:

$$SLR = \frac{41{,}116\,\frac{lbs}{d}}{1{,}519.76\ ft^2} = \mathbf{27.1\frac{\frac{lbs}{d}}{sf}}$$

Multiple Choice

1. In order to remove solids, primary settling tanks rely on:
a. Gravity.
b. Pressure
c. Vacuum
d. Heat

2. The length of time wastewater remains in a settling tank is called:
a. Surface overflow rate
b. Weir overflow rate
c. Solids loading rate
d. Detention time

3. The settleable solids removal efficiency in a properly operating primary tank is in the range of:
a. 10 to 20%
b. 40 to 50%
c. 50 to 60%
d. 90 to 95%

4. If an operator sees numerous gas bubbles across the primary tank, it can be assumed that:
a. The primary tank is operating properly
b. The sludge is starting to turn septic at the bottom of the tank
c. There has been too much sludge removed from the primary tank
d. There is excessive dissolved oxygen in the sludge as a result of heavy rain

5. Good primary sludge withdrawn from a primary settling tank is about:
a. 0.1 to 0.5% solids
b. 5 to 6% solids
c. 10 to 20% solids
d. Over 50% solids