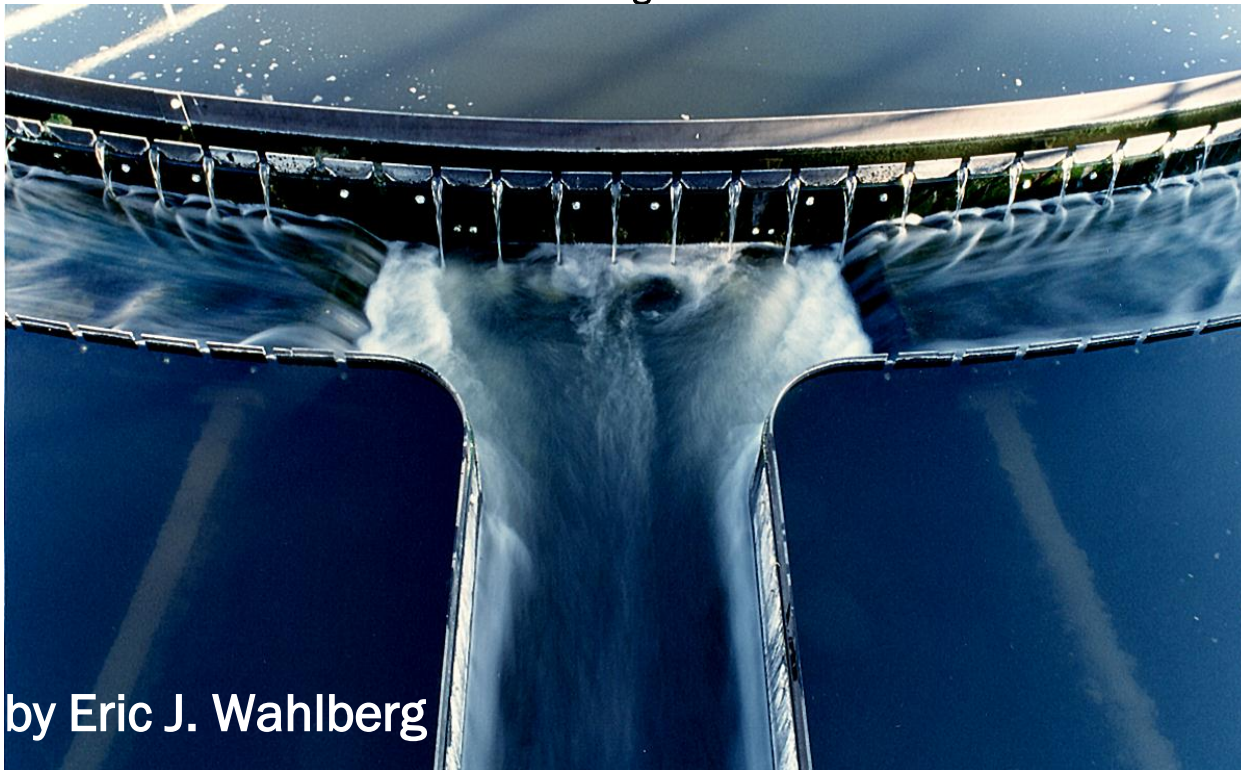


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Where Activated Sludge Design Meets Operations:

$$MLSS = (SRT/HRT)[ISS_{in} + Y_g(BOD_{in} - BOD_{out})/(1 + b \cdot SRT)]$$



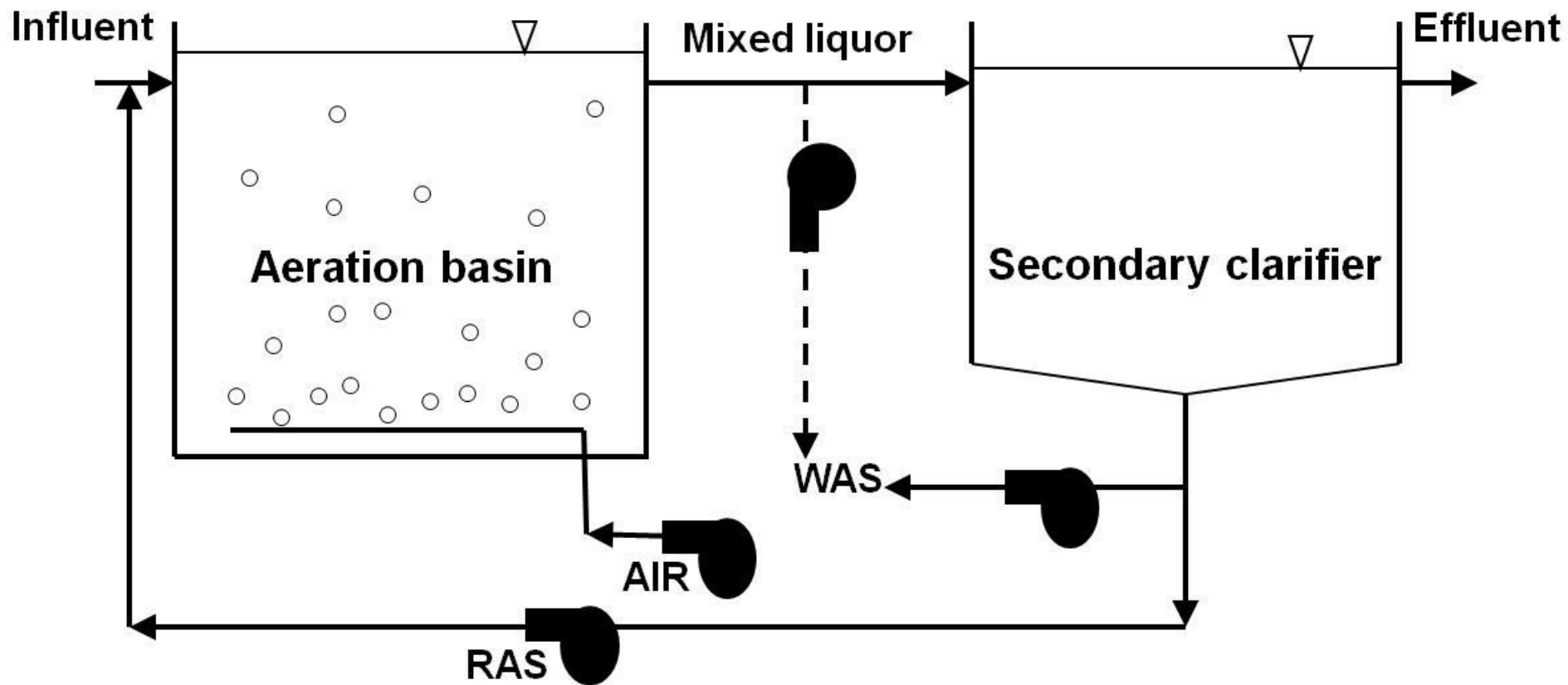
by Eric J. Wahlberg



In the beginning . . .

- Bridging the gap between engineers and operators...
- What I have concluded:
 - A most difficult bridge to gap
 - But that's okay because the bugs are smarter than the engineers and operators

A properly designed activated sludge system is flexible, reliable, and controllable



That's good news and bad news

Good news:

- Minor operational changes can be implemented to accommodate changes in influent characteristics and/or effluent requirements.

Bad news:

- Minor operational changes can result in changes in sludge and effluent quality.

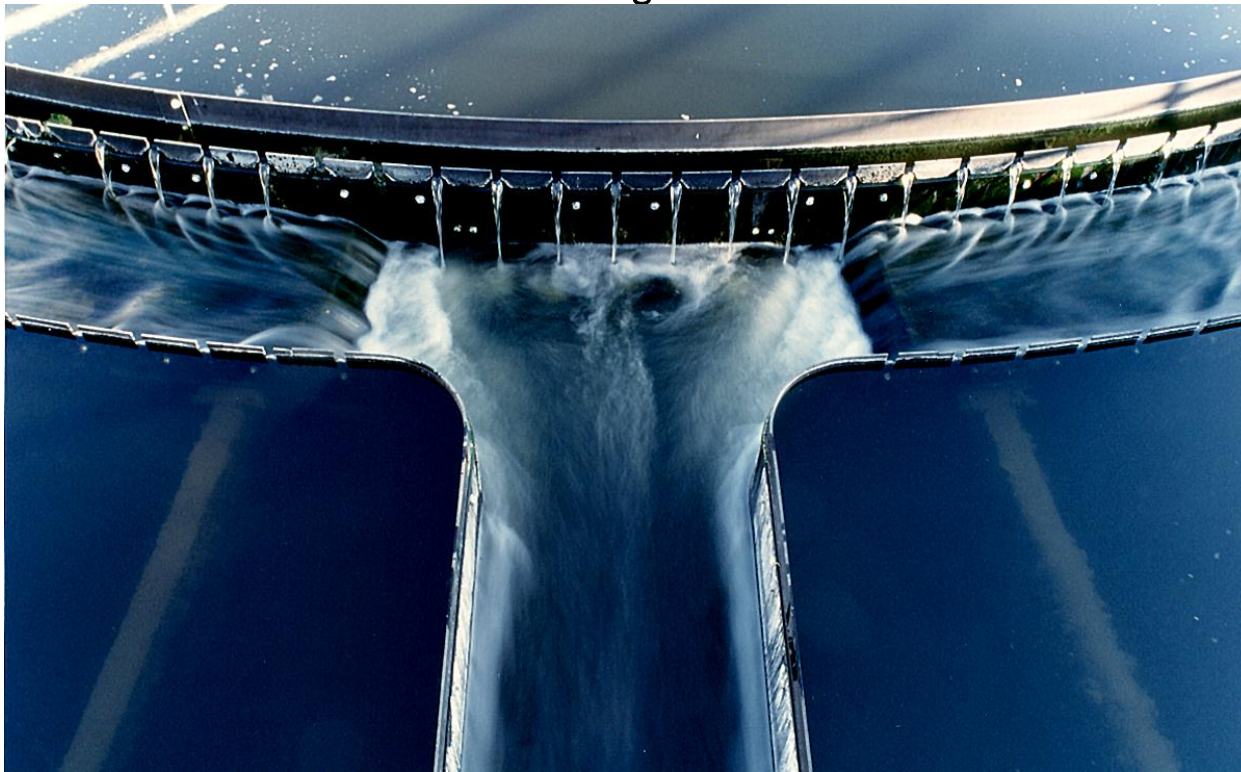
Plant attendants versus water quality professionals

- One of my most favorite soapboxes.
- Raising the bar by embracing the math and science of wastewater treatment and process engineering fundamentals.
- Example: I wish I had \$1.00 for every time someone has told me, “You can’t use an equation in a presentation to operators.”
- So there it is in my title, the most important equation an activated sludge plant operator will ever know.

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Where Activated Sludge Design Meets Operations:

$$MLSS = (SRT/HRT)[ISS_{in} + Y_g(BOD_{in} - BOD_{out})/(1 + b \cdot SRT)]$$



The equation—big and bold

SRT = solids residence time

$$\text{MLSS} = \frac{\text{SRT}}{\text{HRT}} \left(\text{ISS}_{\text{in}} + Y_g \frac{\text{BOD}_{\text{in}} - \text{BOD}_{\text{out}}}{1 + b \cdot \text{SRT}} \right)$$

HRT = hydraulic residence time

MLSS = mixed liquor suspended solids conc.

The equation—big and bold

$$MLSS = \frac{SRT}{HRT} \left(ISS_{in} + Y_g \frac{BOD_{in} - BOD_{out}}{1 + b \cdot SRT} \right)$$

$Y_g = \text{yield}$

$b = \text{decay coefficient}$

$ISS_{in} = \text{influent inorganic suspended solids conc.}$

The equation—big and bold

BOD_{in} = influent BOD concentration

$$MLSS = \frac{SRT}{HRT} \left(ISS_{in} + Y_g \frac{BOD_{in} - BOD_{out}}{1 + b \cdot SRT} \right)$$

BOD_{out} = effluent BOD concentration

This is the equation engineers use to design activated sludge plants

$$\text{MLSS} = \frac{\text{SRT}}{\text{HRT}} \left(\text{ISS}_{\text{in}} + Y_g \frac{\text{BOD}_{\text{in}} - \text{BOD}_{\text{out}}}{1 + b \cdot \text{SRT}} \right)$$

If you remember nothing else of my talk today, know this:

$$\text{MLSS} = \frac{\text{SRT}}{\text{HRT}} \left(\text{ISS}_{\text{in}} + Y_g \frac{\text{BOD}_{\text{in}} - \text{BOD}_{\text{out}}}{1 + b \cdot \text{SRT}} \right)$$

The MLSS concentration is a **response** variable, not a **control** variable

The equation does NOT include TSS_{in} What's up with that?

$$MLSS = \frac{SRT}{HRT} \left(ISS_{in} + Y_g \frac{BOD_{in} - BOD_{out}}{1 + b \cdot SRT} \right)$$

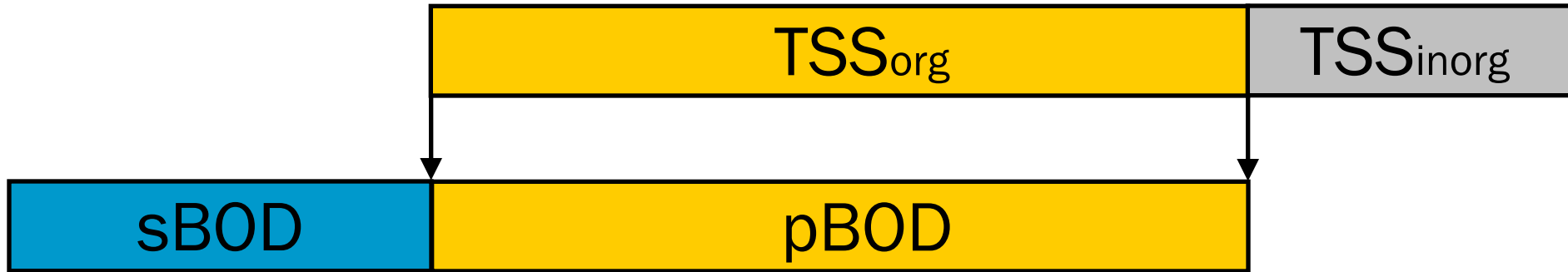
The TSS coming down the pipe at us are organic (i.e., VSS) or inorganic (i.e., ISS)



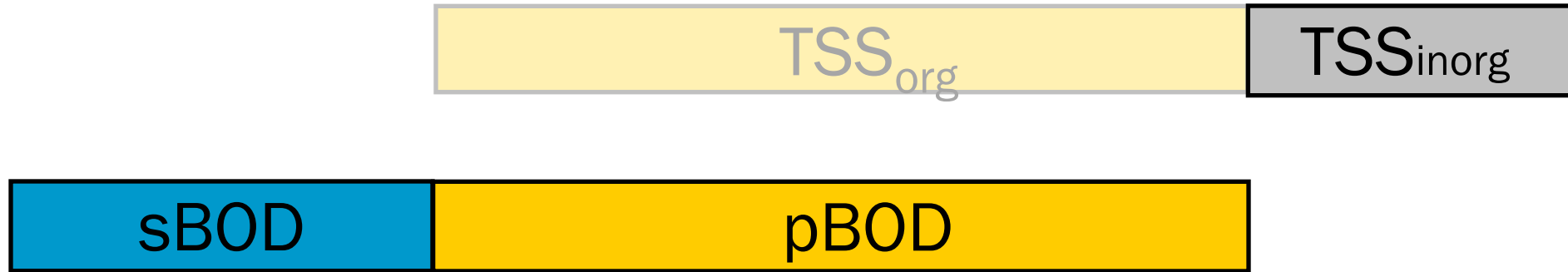
The BOD coming down the pipe at us is either soluble or particulate



For purposes of our discussion, TSS_{org} (VSS) is same “material” as pBOD



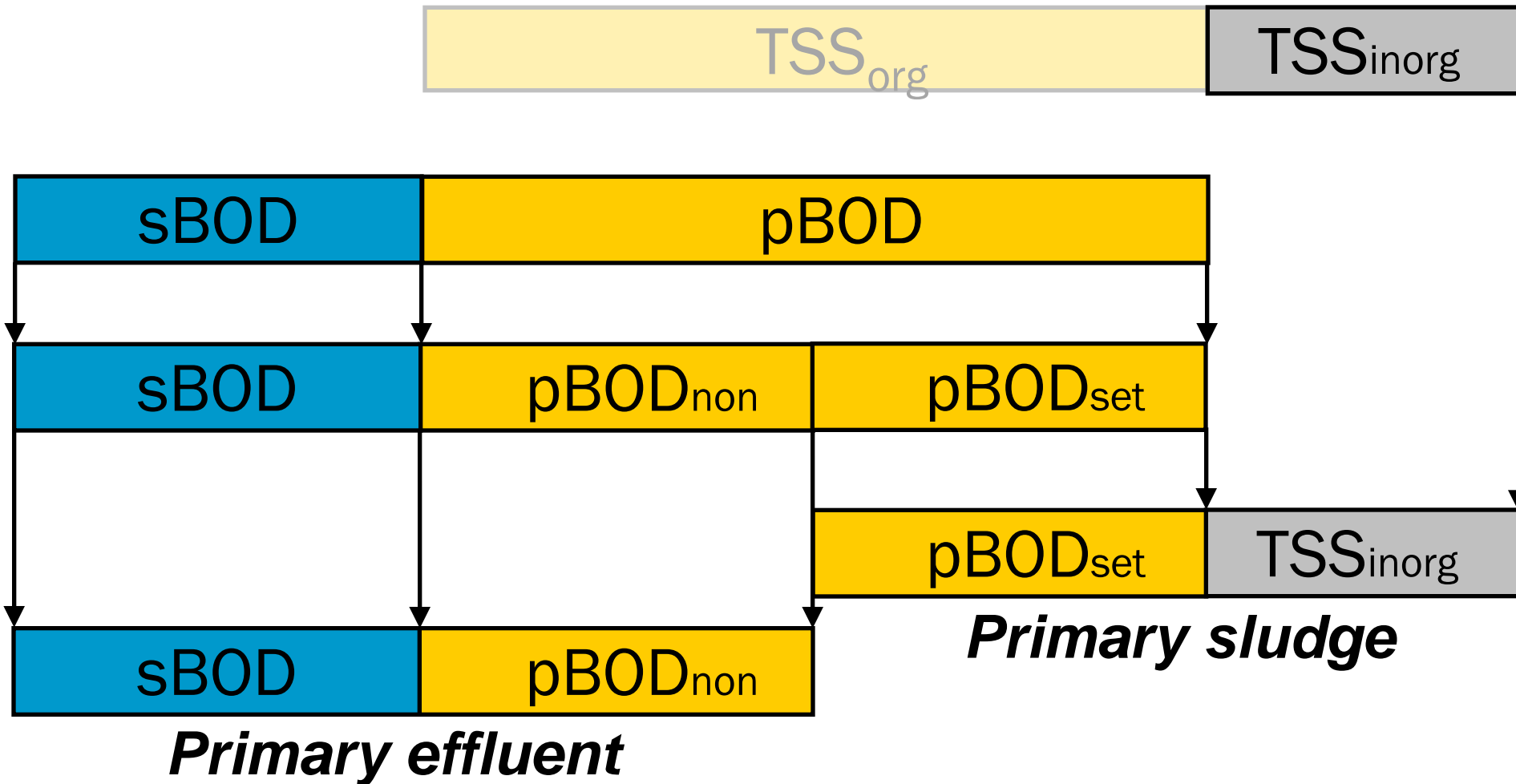
So it's only these three in the influent we really need to care about



The particulate BOD is either settleable ($pBOD_{set}$) or not ($pBOD_{non}$)

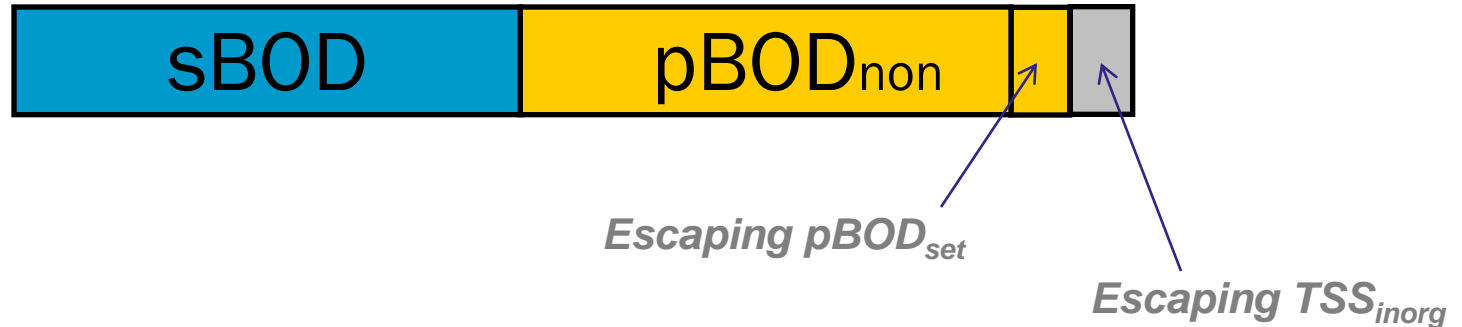


Primary clarifiers remove most of $pBOD_{set}$, TSS_{inorg} , and floatables



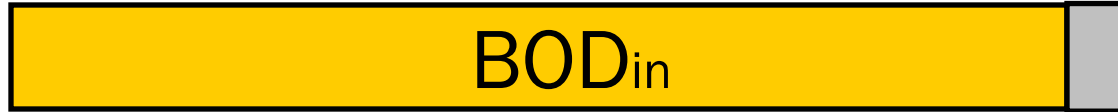
Primary clarifiers aren't perfect so some of what shouldn't escapes

Primary effluent



With primary clarifiers, this is the BOD_{in} of our equation

Primary effluent

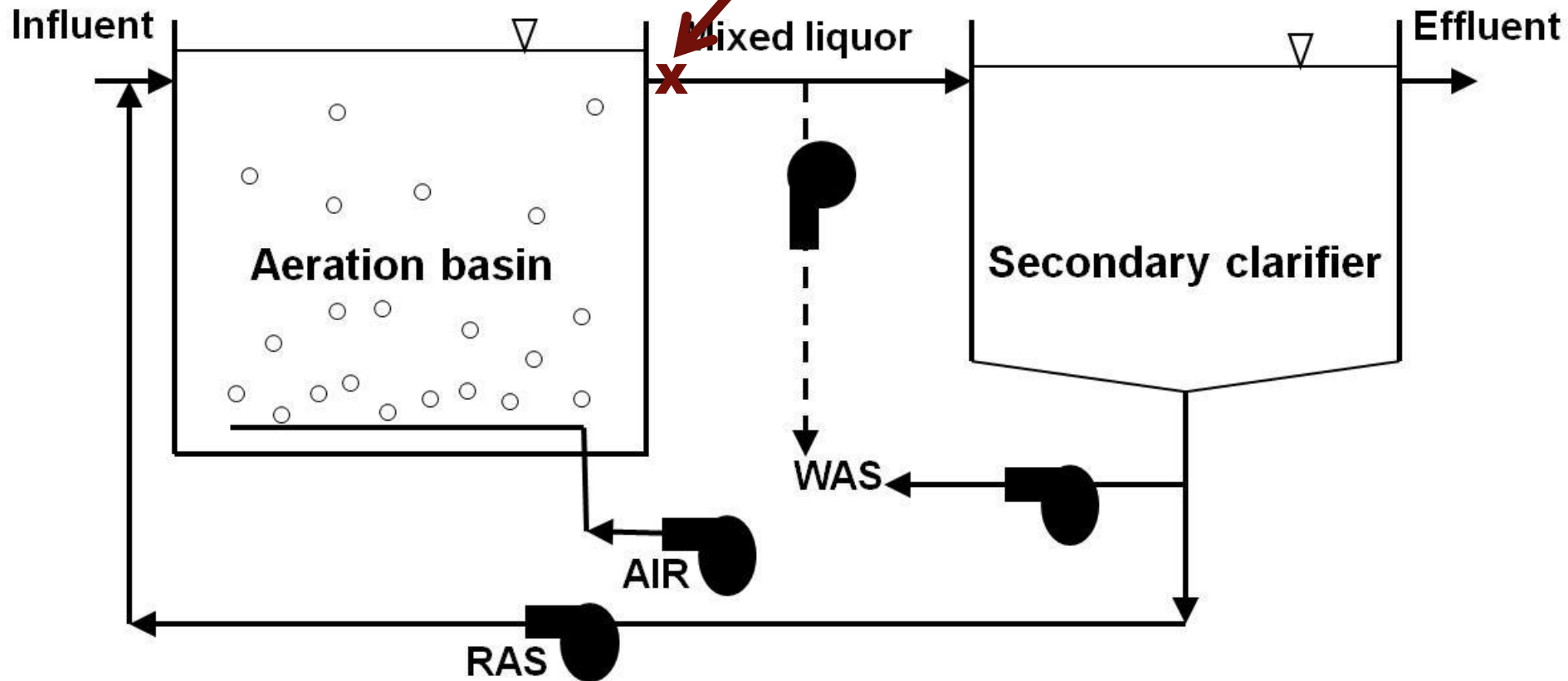


BOD_{out} is not what you think it is

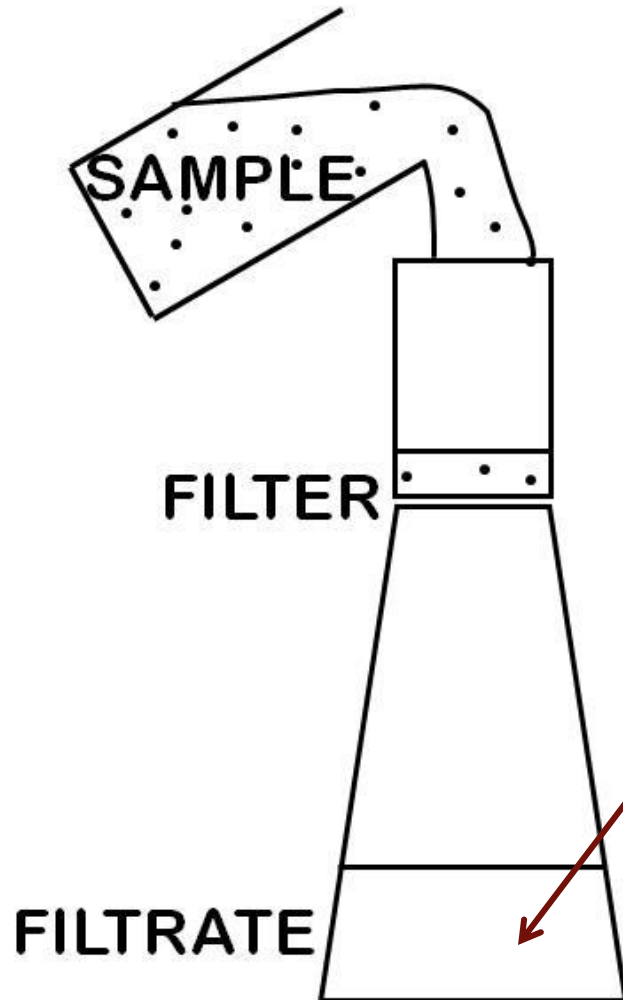
$$MLSS = \frac{SRT}{HRT} \left(ISS_{in} + Y_g \frac{BOD_{in} - BOD_{out}}{1 + b \cdot SRT} \right)$$

It is not the secondary clarifier effluent total BOD

Measure soluble BOD concentration here



sBOD test on exiting mixed liquor an indispensable process control test

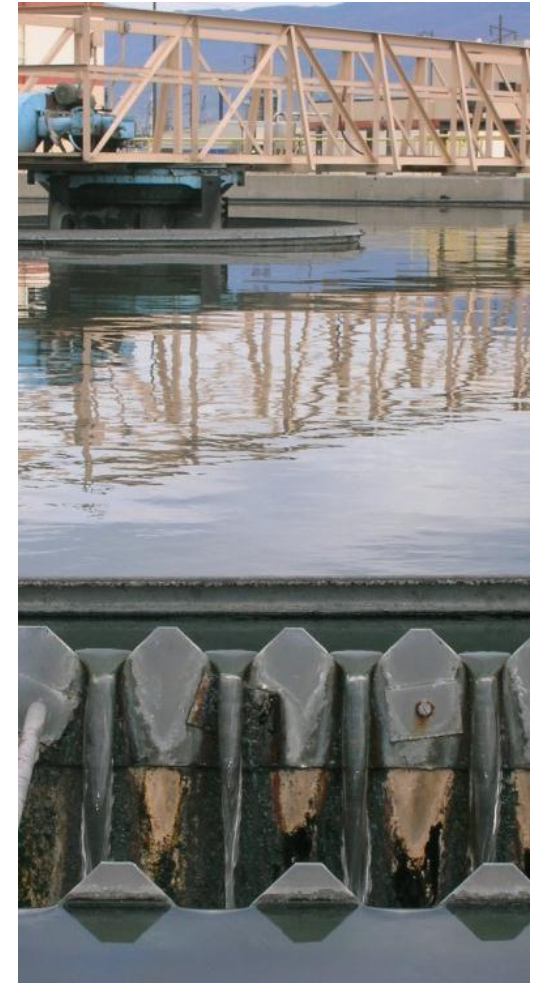


Procedure:

1. Collect mixed liquor sample at aeration basin exit.
2. Immediately filter it as if to do a MLSS analysis.
3. Measure BOD_{out} in filtrate.
4. Do it often as it is only true measurement of the efficiency of influent BOD conversion to biomass that occurs in the aeration basin.

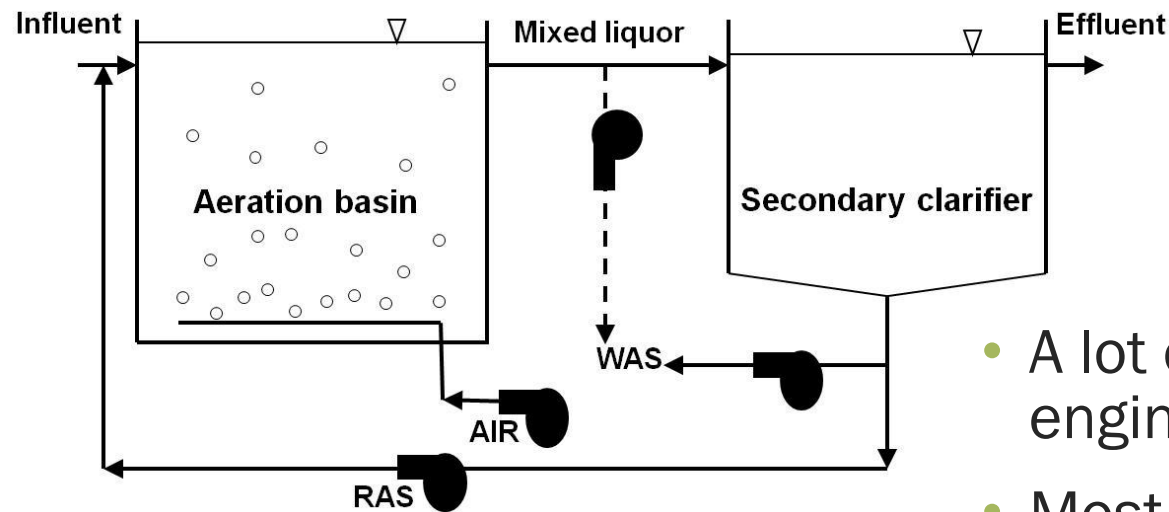
Yield— Y_{g}

- Expressed in units of mass of biomass produced per mass of BOD removed (i.e., mg MLVSS/mg BOD removed).
- Yield quantifies the fact that biological treatment—activated sludge in this case—is more a process of organic carbon conversion than removal.
- This term is affected by several factors, one of which is temperature.



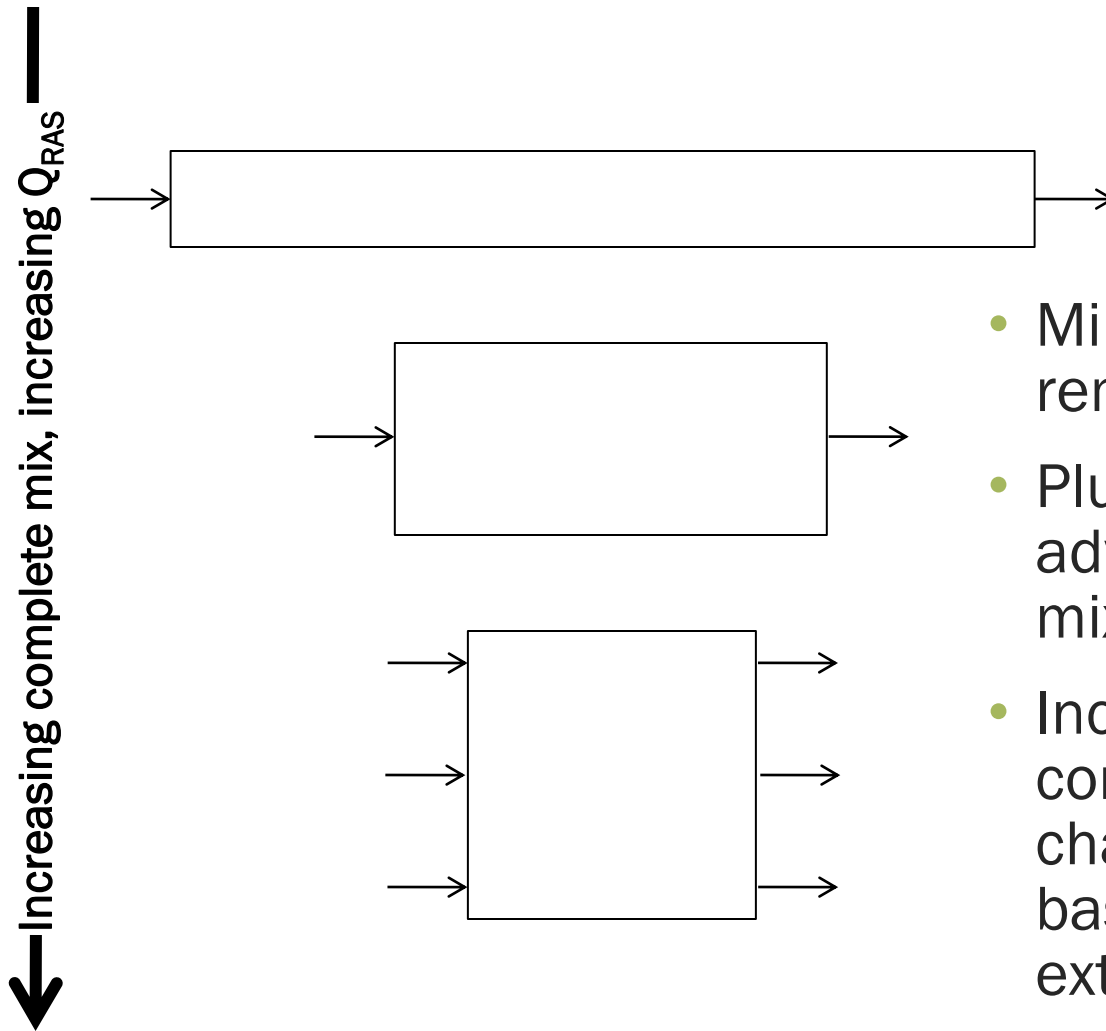
This primary effluent is flowing to conventional activated sludge

Hydraulic residence time—HRT



- A lot of operators (and engineers) have this wrong.
- Most agree that the system $HRT = V_{\text{system}}/Q$.
- Since the volume of the system is $V_{ab} + V_{sc}$:
 $HRT = (V_{ab} + V_{sc})/Q$, which is
 $HRT = (V_{ab}/Q) + (V_{sc}/Q)$ where V_{ab}/Q is the HRT of the aeration basin.
- **Not** $V_{ab}/(Q + Q_{RAS})$.

RAS flow (Q_{RAS}) does not affect the HRT but does affect treatment ... a little



- Minimal effect of Q_{RAS} on BOD removal.
- Plug-flow reactors have kinetic advantage over completely mixed reactors.
- Increasing Q_{RAS} increases the completely mixed characteristics in the aeration basin thereby decreasing extent of BOD conversion.

Substituting $HRT = V_{ab}/Q$ into the equation gives

$$MLSS = \frac{SRT \cdot Q}{V_{ab}} \left(ISS_{in} + Y_g \frac{BOD_{in} - BOD_{out}}{1 + b \cdot SRT} \right)$$

What is in the operator's control?

$$\text{MLSS} = \frac{\text{SRT} \cdot Q}{V_{ab}} \left(\text{ISS}_{in} + Y_g \frac{\text{BOD}_{in} - \text{BOD}_{out}}{1 + b \cdot \text{SRT}} \right)$$

- SRT—yes
- Q—some with flow equalization, otherwise no
- V_{ab} —yes in plants with multiple aeration basins, otherwise no
- ISS_{in} —no
- Y_g —no
- BOD_{in} —no
- BOD_{out} —this is what we're really trying to control but it is what it is
- b—no
- Conclusion: MLSS is controlled by SRT and, to some extent, aeration basin volume

Notice I didn't list the MLSS concentration because it is fixed by the other variables

$$\text{MLSS} = \frac{\text{SRT} \cdot Q}{V_{ab}} \left(\text{ISS}_{in} + Y_g \frac{\text{BOD}_{in} - \text{BOD}_{out}}{1 + b \cdot \text{SRT}} \right)$$

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- Conclusion: MLSS is controlled by SRT and, to some extent, aeration basin volume

But MLSS is important

$$\text{MLSS} = \frac{\text{SRT} \cdot Q}{V_{\text{ab}}} \left(\text{ISS}_{\text{in}} + Y_{\text{g}} \frac{\text{BOD}_{\text{in}} - \text{BOD}_{\text{out}}}{1 + b \cdot \text{SRT}} \right)$$

- MLSS too high—high solids loading rate on secondary clarifier limits capacity and may lead to poor performance
- MLSS too low—solids don't settle in distinct interface leaving “stragglers”
- What to do?

Rearrangement shows mixed liquor mass calculation

$$\text{MLSS} \cdot V_{ab} = \text{SRT} \cdot Q \left(\text{ISS}_{in} + Y_g \frac{\text{BOD}_{in} - \text{BOD}_{out}}{1 + b \cdot \text{SRT}} \right)$$

A word about temperature

$$\text{MLSS} = \frac{\text{SRT} \cdot Q}{V_{ab}} \left(\text{ISS}_{in} + Y_g \frac{\text{BOD}_{in} - \text{BOD}_{out}}{1 + b \cdot \text{SRT}} \right)$$

Our equation, like MLSS, can be broken down into two parts: MLISS and MLVSS

$$\text{MLSS} = \frac{\text{SRT} \cdot Q}{V_{ab}} \left(\text{ISS}_{in} + Y_g \frac{\text{BOD}_{in} - \text{BOD}_{out}}{1 + b \cdot \text{SRT}} \right)$$

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$$\text{MLISS} = \frac{\text{SRT} \cdot Q \cdot \text{ISS}_{in}}{V_{ab}}$$

$$\text{MLVSS} = \text{SRT} \cdot Q \cdot Y_g \cdot \frac{\text{BOD}_{in} - \text{BOD}_{out}}{V_{ab}(1 + b \cdot \text{SRT})}$$

The ISS_{in} can be very important—consider two plants

Municipal plant: SRT=5 d; HRT=8 hr;
 $ISS_{in}=15$ mg/L, then:

$$MLISS = 225 \text{ mg/L}$$

Industrial plant: SRT=30 d; HRT=24 hr;
 $ISS_{in}=75$ mg/L, then:

$$MLISS = 2,250 \text{ mg/L}$$

The second part of our equation, the MLVSS part, can be rearranged ...

$$\text{MLSS} = \frac{\text{SRT} \cdot Q}{V_{ab}} \left(\text{ISS}_{in} + Y_g \frac{\text{BOD}_{in} - \text{BOD}_{out}}{1 + b \cdot \text{SRT}} \right)$$

$$\text{MLISS} = \frac{\text{SRT} \cdot Q \cdot \text{ISS}_{in}}{V_{ab}}$$

$$\text{MLVSS} = \text{SRT} \cdot Q \cdot Y_g \cdot \frac{\text{BOD}_{in} - \text{BOD}_{out}}{V_{ab}(1 + b \cdot \text{SRT})}$$

... resulting in:

$$\frac{Q \cdot (\text{BOD}_{\text{in}} - \text{BOD}_{\text{out}})}{V_{\text{ab}} \cdot \text{MLVSS}} = \frac{\text{SRT} \cdot Y_{\text{g}}}{1 + b \cdot \text{SRT}}$$

The left-hand side of this equation looks a lot like F/M , and because b is small...

$$\frac{Q \cdot (\text{BOD}_{\text{in}} - \text{BOD}_{\text{out}})}{V_{\text{ab}} \cdot \text{MLVSS}} = \frac{\text{SRT} \cdot Y_{\text{g}}}{1 + b \cdot \text{SRT}}$$

... we see that the F/M also is controlled by the SRT

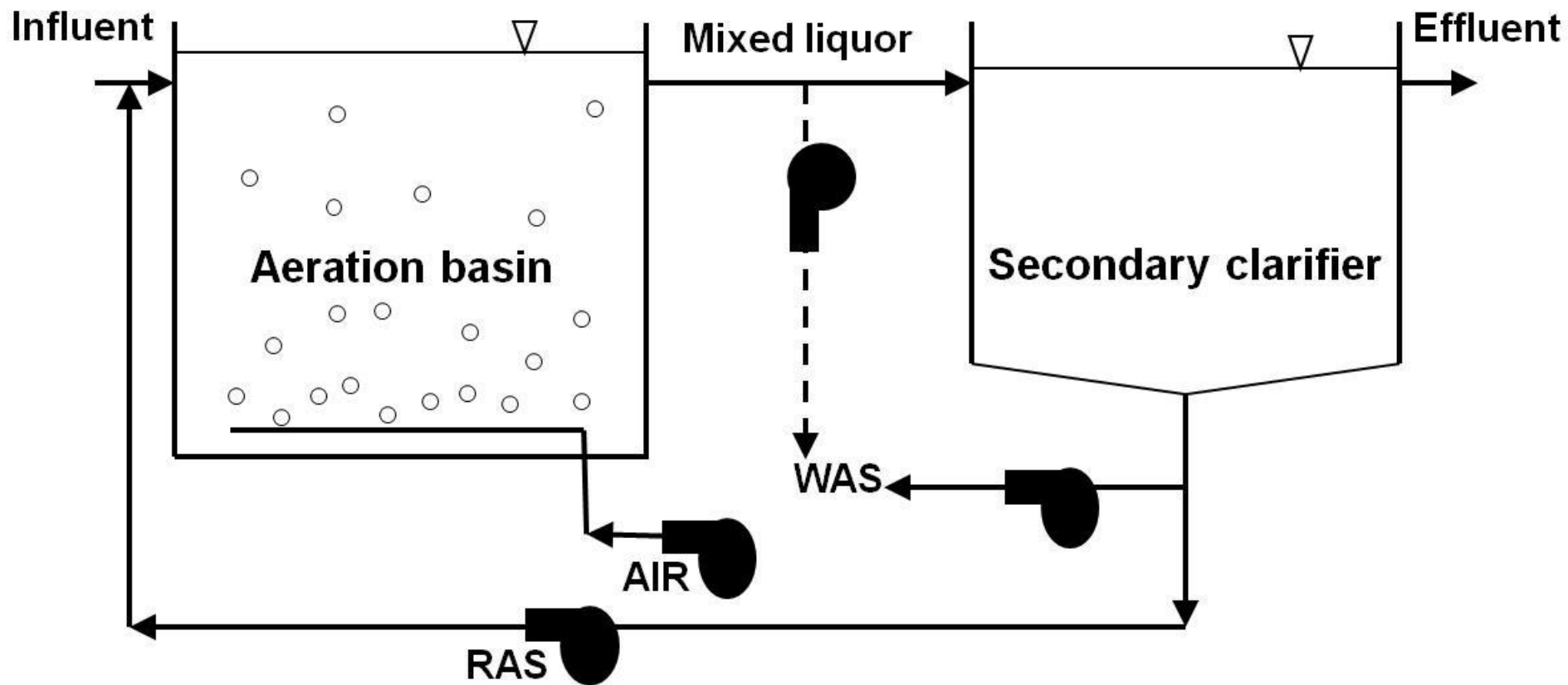
$$\frac{F}{M} \approx \frac{1}{\text{SRT} \cdot Y_{\text{g}}}$$

SRT controls all of them

1. MLSS concentration
2. MLSS mass
3. MLVSS concentration
4. MLVSS mass
5. F/M

So . . . where have we been?

A properly designed activated sludge system is flexible, reliable, and controllable



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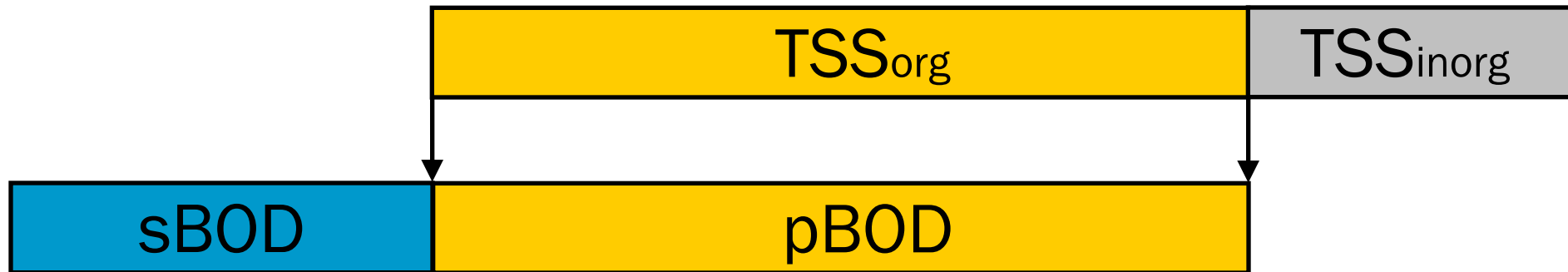
- As operators, we have to understand the results of our actions
- As engineers, we have to maintain plant flexibility, reliability, and controllability in our designs

If you remember nothing else of my talk today, know this:

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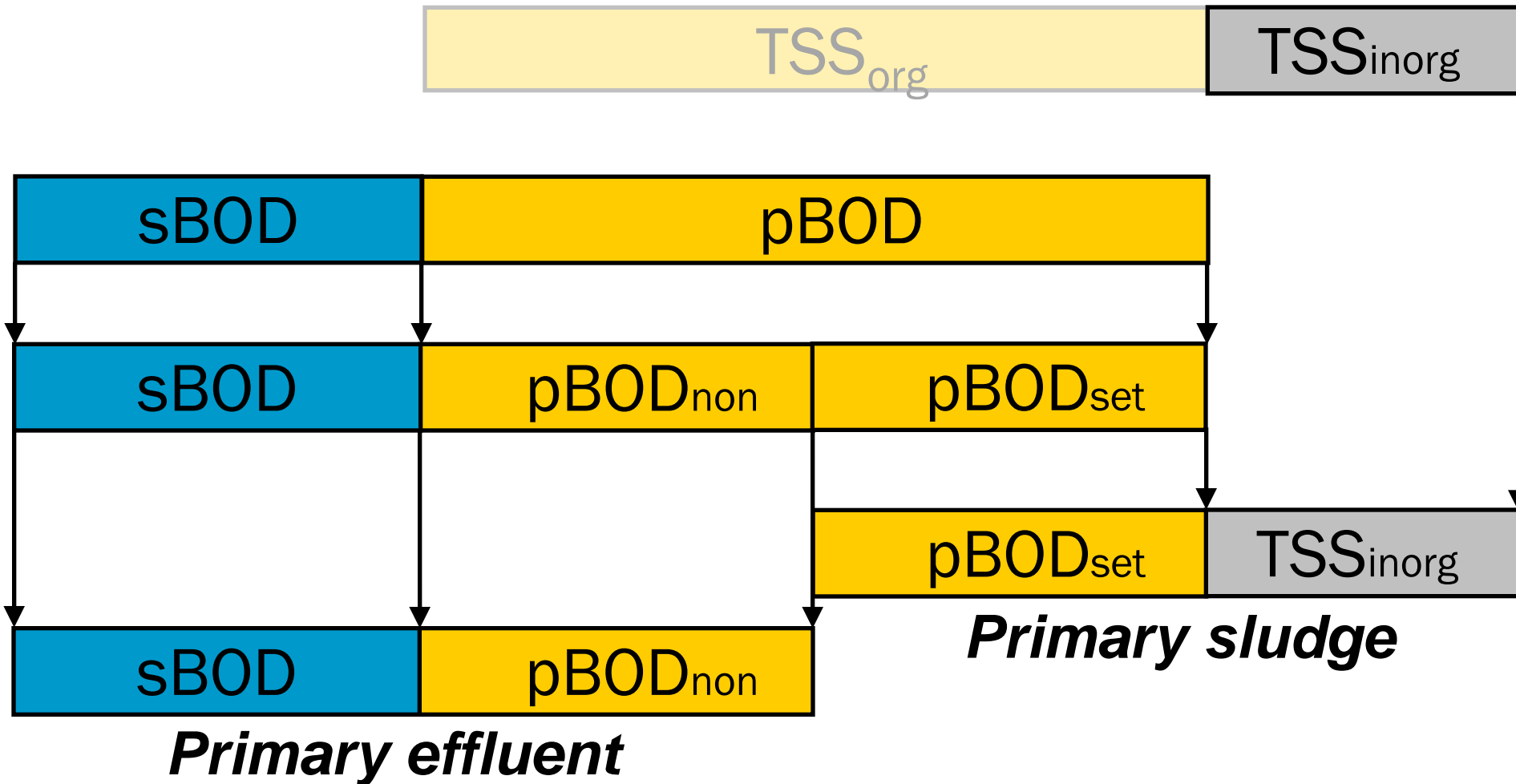
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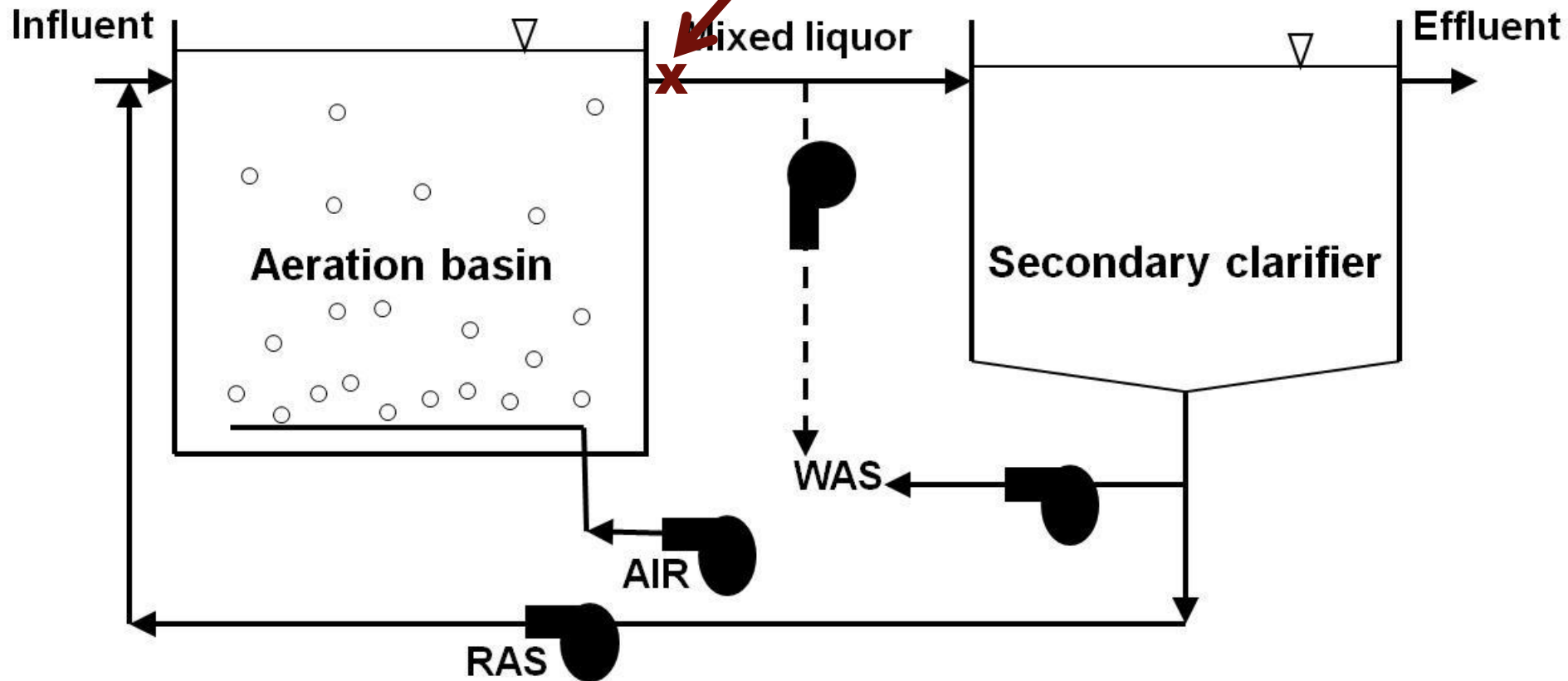


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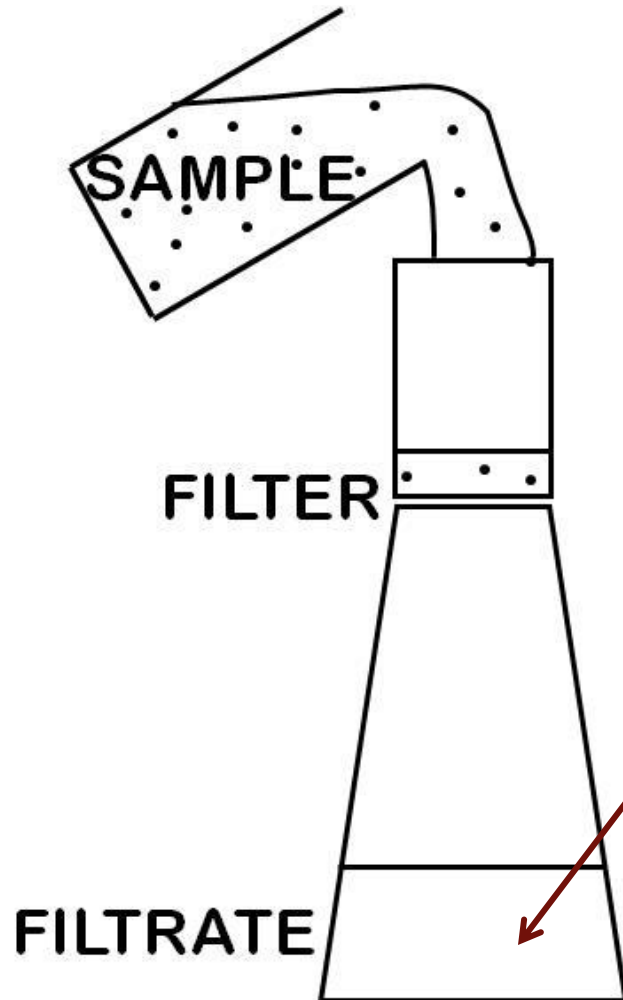


BOD_{out} is not the secondary clarifier effluent total BOD

Measure soluble BOD
concentration here



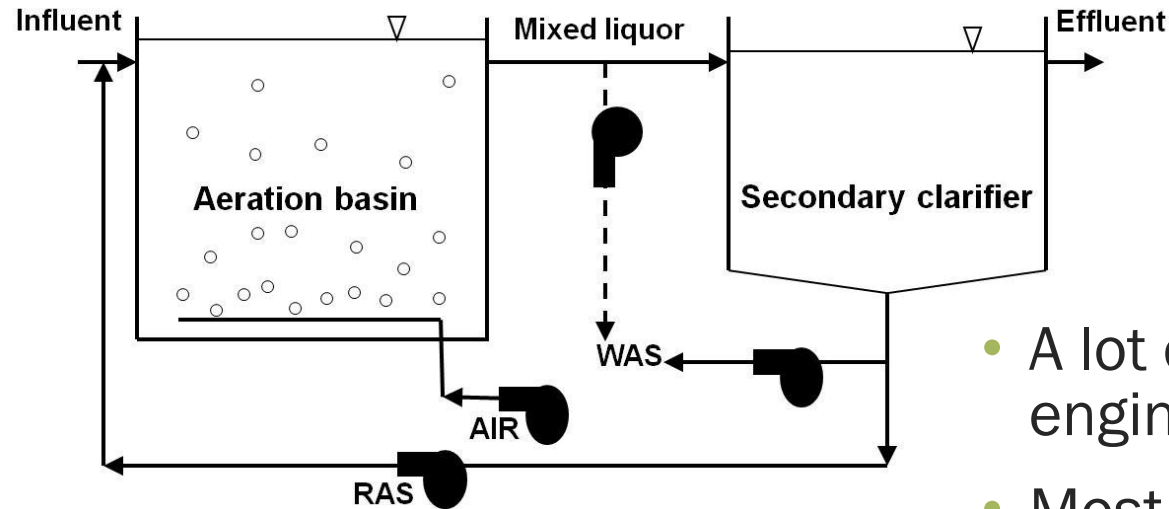
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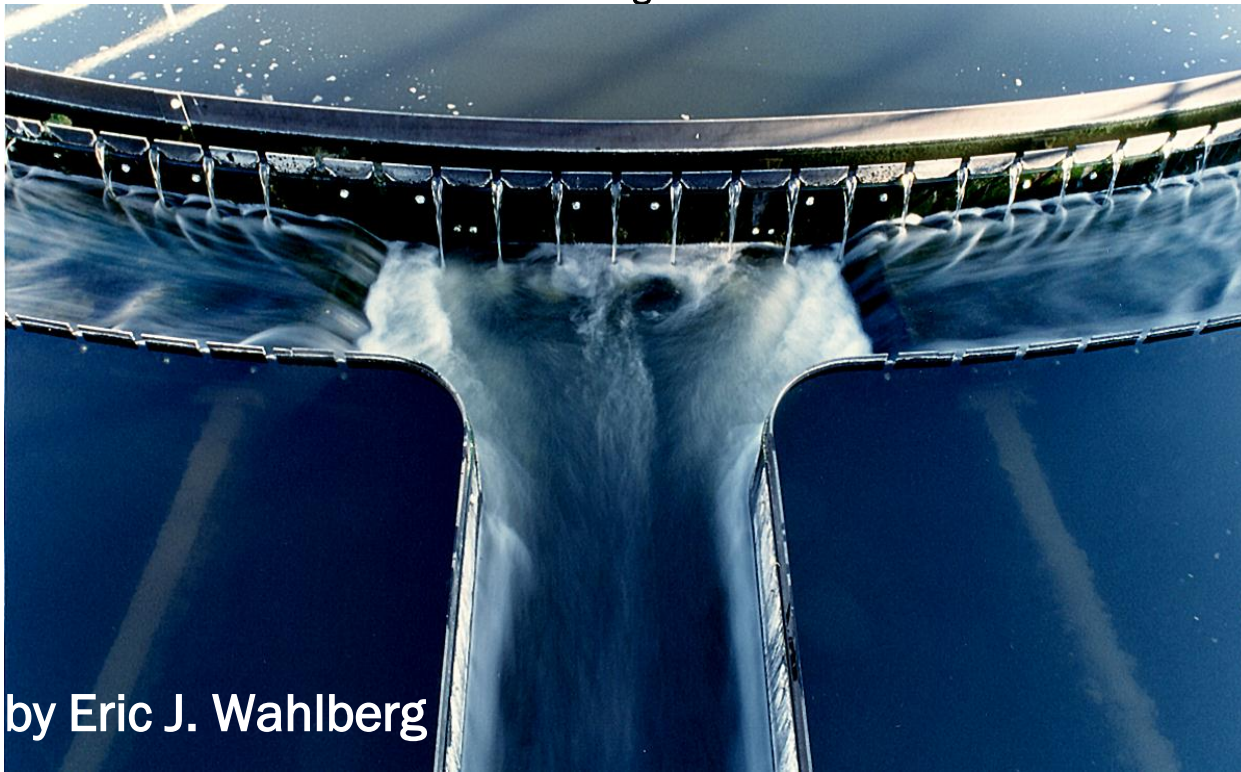
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