Hazen

KWWOA

Activated Sludge Biological Nutrient Removal Process Variations

Western Chapter – Spring Wastewater Conference – May 17, 2016

Dan Miklos, Senior Associate, Midwest Region, Hazen and Sawyer

Activated Sludge Biological Nutrient Removal Process Variations Agenda

<u>Biological Nutrient Removal</u> (BNR)

- Phosphorus
  - Species of Phosphorus in the influent
- Phosphorus Removal
  - Assimilation in the Biomass
  - Phosphorus Accumulating Organisms
- Nitrogen
  - Nitrogen in the influent
- Nitrogen Removal
  - Assimilation in the Biomass
  - Ammonia oxidizing bacteria
  - Nitrite oxidizing bacteria
  - Denitrification
- Examples of Activated Sludge BNR Process Variations
  - Successive cycles of anaerobic/anoxic zones for the biomass

Phosphorus and Nitrogen

- Typically, domestic plants receive 5 to 7 mg/L phosphorus.
- This results in an influent contribution per capita per day of approximately 2.7+ grams/day/capita.
- The typical breakdown on influent P species are:
  - Ortho phosphate – 3 mg/L
  - Polyphosphates – 2+ mg/L
  - Organic Phosphates – 1- mg/L.
- Nitrogen input to a POTW
  - Average daily per capita generation of nitrogen is approximately 16 grams.
  - Approximately 60% is in organic form while 40% is ammonium form (fresh sewage).
  - Bacterial decomposition of protein results and hydrolysis moves organic nitrogen to ammonium.

Phosphorus Compound Species

- Influent Phosphorus species are:
  - Ortho phosphate – 3 mg/L
    - (dissolved, reactive or inorganic phosphate (PO_4^-)
    - Form our microbiology uptakes
    - Must be in this form for either biological uptake or chemical precipitation.
  - Polyphosphates – 2+ mg/L
    - More complex inorganic phosphates (particulate)
    - Condensed phosphates or “acid soluble”
    - Many forms are loosely bound and break down fairly quickly to ortho phosphates. Small size may be quickly “dissolved”.
  - Organic Phosphates – 1- mg/L.
    - As plants and animals excrete wastes or die, the organic phosphorus they contain is decomposed back to inorganic phosphorus. Primary source as opposed to synthetic organic phosphates.
    - Organophosphates are the building blocks for insecticides and herbicides
    - Organic phosphates are used for flame proofing and plasticizing various plastics and as anti-wear additives in lubricants.
  - Operationally, there is a small fraction of each type of phosphorus that is “refractory” (permanently unavailable).

Formation of Nitrogen Compounds

- Ammonification
  - Hydrolysis and decomposition of animal, plant tissue & fecal matter. Proteins (organic nitrogen) are decomposed to ammonia/ammonium. Why influent ammonia is higher in summer than winter.
- Nitrification
  - Biological oxidation of ammonium in two (2) steps: Ammonia to nitrite (AOB) and nitrite to nitrate (NOB). Nitrogen is still in the flow steam.
- Denitrification
  - Biological scavenging of oxygen from nitrite/nitrate. Ammonia oxidation byproducts of nitrate are removed and “gassed off” to the atmosphere. Nitrogen is removed from the flow stream.

Considerations in BNR Process Control

- Biological Nutrient Removal (BNR) typically includes both Nitrogen and Phosphorus limits.
- Just as separate cultures are optimized for nitrification, phosphorus accumulating organisms must also be selected and the population optimized for increased accumulation of P in the biomass.
- BNR introduces carbon for the first time in limiting both P and nitrate removal. Too much air is not just a waste of energy, it can be a noncompliance issue for a BNR facility.
- Carbon, BOD_5 is used in the first stage of a BNR plant to provide an **anaerobic** environment with the RAS and influent to favor phosphorus accumulating organisms.
- Carbon, BOD_5 is used in an **anoxic** stage to allow facultative anaerobes to remove nitrates.

How do we control a total Nitrogen and P in our discharge?

Typical composition of bacterial cells on a dry basis

Carbon	50%
Oxygen	20%
Nitrogen	12.5%
Hydrogen	8%
Phosphorus	3%
Sulfur	1%
Potassium	1%
Sodium	1%
Calcium	0.5%
Magnesium	0.5%
Other	2.5%

Typical bacterial cell:

$C_{60}H_{87}O_{23}N_{12}P$

Not the BioP Bugs!

Nutrient Removal – Biological MLSS Component

- Biological assimilation of N and P
  - Assume cells are 12.5% nitrogen and 2-3% phosphorus (not optimized for Phosphorus control).
  - Assume a cell yield (net growth following decay) is 0.65 (0.65 lbs of biosolids/lb BOD_5 removed)
  - Net cell yield is multiplied by the % cell content
    - N is (0.125)*(0.65)=8.15 lbs per 100 lbs biomass.
    - P is (.03)*(0.65)=1.95 lbs per 100 lbs biomass.

Phosphorus Removal – Biological MLSS Component

- Biological assimilation of Phosphorus:
  - Assume the WWTP flow of 8.0 MGD @ 180 mg/L of $CBOD_5$ resulted in a growth of 7,806 lbs of biomass (at the yield of 0.65).
  - If 2% of the biomass is Phosphorus (2% is reduced from 3% to compensate for inerts in MLSS), 156 lbs of phosphorus are removed in the biosolids.
  - If the influent concentration is 5.5 mg/L TP, 367 lbs of P are received in the influent.
  - If the target of 0.5 mg/L TP is desired for effluent, we can leave behind 33 lbs of P in the effluent
  - The remaining pounds (367 - 33 - 156) = 178 lbs additional P must be removed by BioP to meet effluent TP target concentration of 0.5 mg/L (2.7 mg/L of the total phosphorus input of 5.5 mg/L).

Implementing Biological Phosphorus Removal

- Biological assimilation of Additional P:
  - A BNR facility would optimize biomass P uptake and increase the Phosphorus content of biomass (2x in our example – from 2% to 4% or 334 lbs / 7,806 lbs).
  - The activated sludge process will have to be changed to favor Phosphorus Accumulating Organisms (PAOs) and increase the Phosphorus content of the biosolids by taking the biology through successive cycles of anaerobic release and aerobic uptake of P in the presence of a carbon source ($cBOD_5$).
  - Biological treatment of Phosphorus requires the addition of an anaerobic zone (a PAO selector) for mixing RAS and raw influent.
  - If enough carbon is available, the P content of the biomass could easily be tripled (near 0 mg/L) in this example.

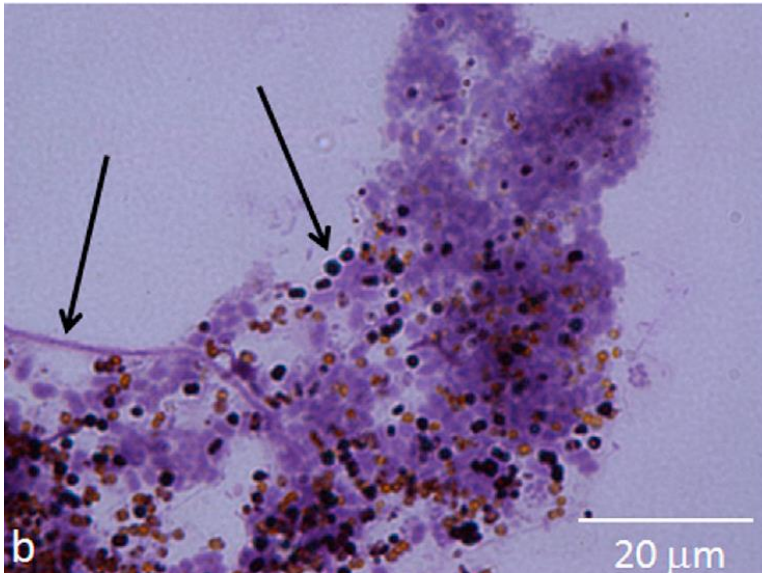
Implementing Biological Phosphorus Removal

- Biological assimilation of P:
  - Unlike chemical precipitation, polyphosphates are formed inside the bacteria cell and held for future use by the organism.
  - PAOs (Phosphorus Accumulating Organisms) are provided an influent selector process where they have first pick of the available carbon and are provided an opportunity to increase their population predominance.
  - The Phosphorus is used as an energy storage medium. Any lengthy anoxic or anaerobic condition will cause a Phosphorus release.
  - The biomass has been “trained” to provide for rapid release of phosphorus (using stored energy of phosphorus compounds) to enable the intake of carbon when anaerobic.
  - Phosphorus is absorbed when anoxic and aerobic as the PAOs accumulate far more P than first released in the anaerobic selector.

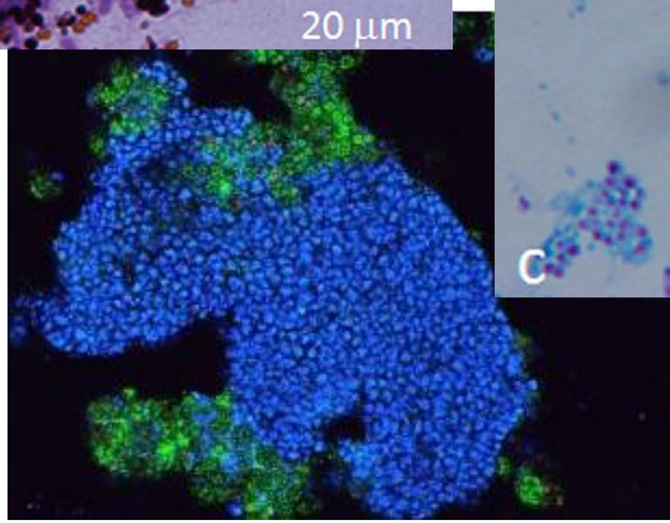
PAOs Can also be Denitrifiers....

- A portion of the PAOs are denitrifiers.
- Once nitrates are available, they can use nitrate as an electron acceptor in addition to free dissolved oxygen. DN-PAO as opposed to just a PAO (aerobic).
- Anoxic PUR versus Aerobic PUR. POA uptake of P under anoxic conditions is common.
- Anoxic conditions cannot slip to anaerobic or phosphorus will release.
- Tetracycline hydrochloride was found to stain polyphosphate granules with high specificity. This gets around the staining problems tied to specific genes with traditional “FISH” staining techniques. Many different “species” of PAOs.

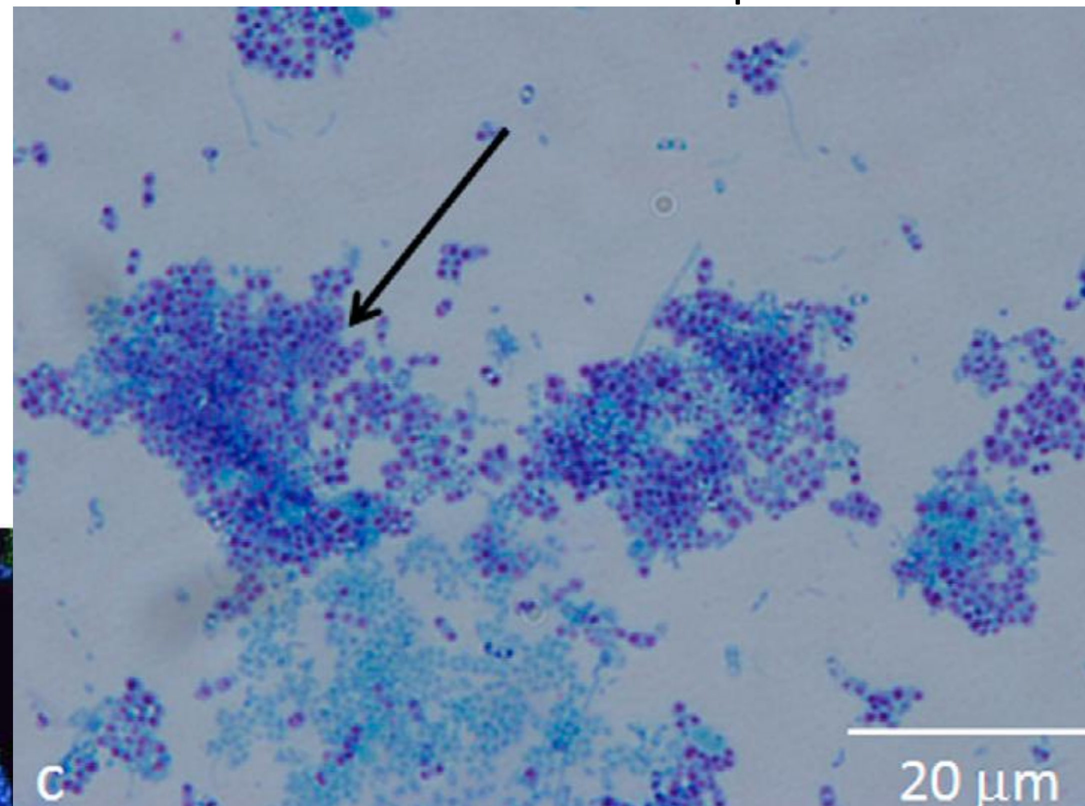
FISH (Fluorescent in situ Hybridization) staining of PAOs



PAOs stained black



PAOs stained Purple



PAOs stained blue

Nitrogen Removal – Biological MLSS Component

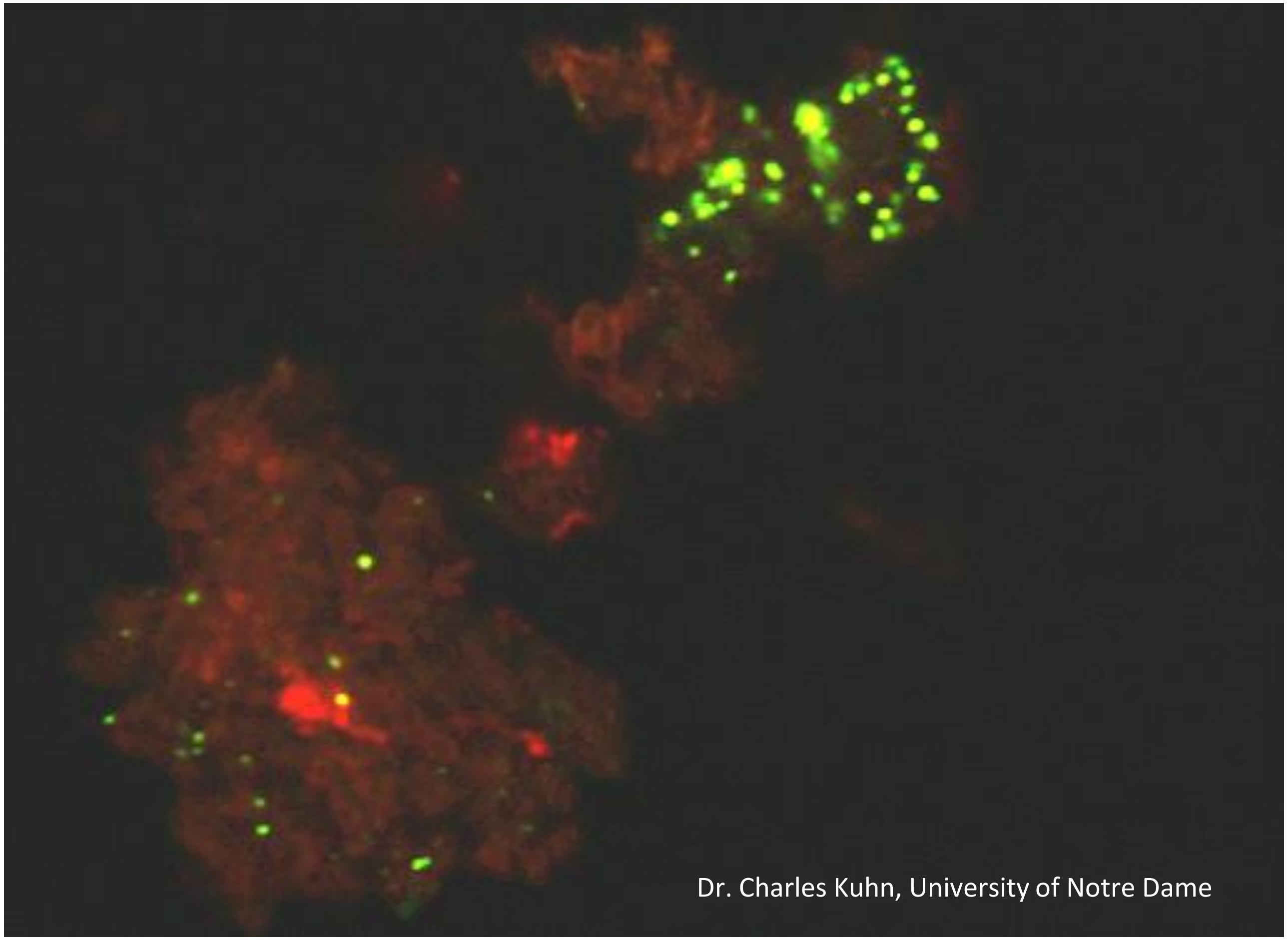
- Biological assimilation of nitrogen:
  - Assume the WWTP flow of 8.0 MGD @ 180 mg/L of $CBOD_5$ resulted in a growth of 7,806 lbs of biomass (at the yield of 0.65).
  - If 12.5% of the biomass is nitrogen, 976 lbs of nitrogen are removed in the biosolids.
  - If the influent concentration is 37 mg/L TKN, 2,469 lbs of N were received in the influent.
  - The remaining pounds (2,469 - 976) = 1,493 lbs must be nitrified to meet NPDES effluent ammonia limitations (22 mg/L of the total nitrogen input of 37 mg/L).

Nitrogen Removal Nitrification/Denitrification

- Nitrogen removal must first count on additional microbiology other than assimilation ($CBOD_5$) if an effluent ammonia limit is to be met.
- A separate culture of nitrifying bacteria must be optimized for ammonia removal (to remove ammonia that is left after assimilation and growth). **Nitrification is an aerobic zone**.
- Then a separate culture of denitrifiers must also be optimized for removal of the oxidized ammonia byproducts (nitrite/nitrate) for total N compliance
- The separate culture of "denitrifiers" must also be optimized in the BNR process to utilize carbon ($CBOD_5$) to denitrify the oxidized ammonia byproducts (nitrite/nitrate**). Facultative anaerobes denitrify in anoxic zones.** But, carbon (BOD_5) must be available to drive the reaction.

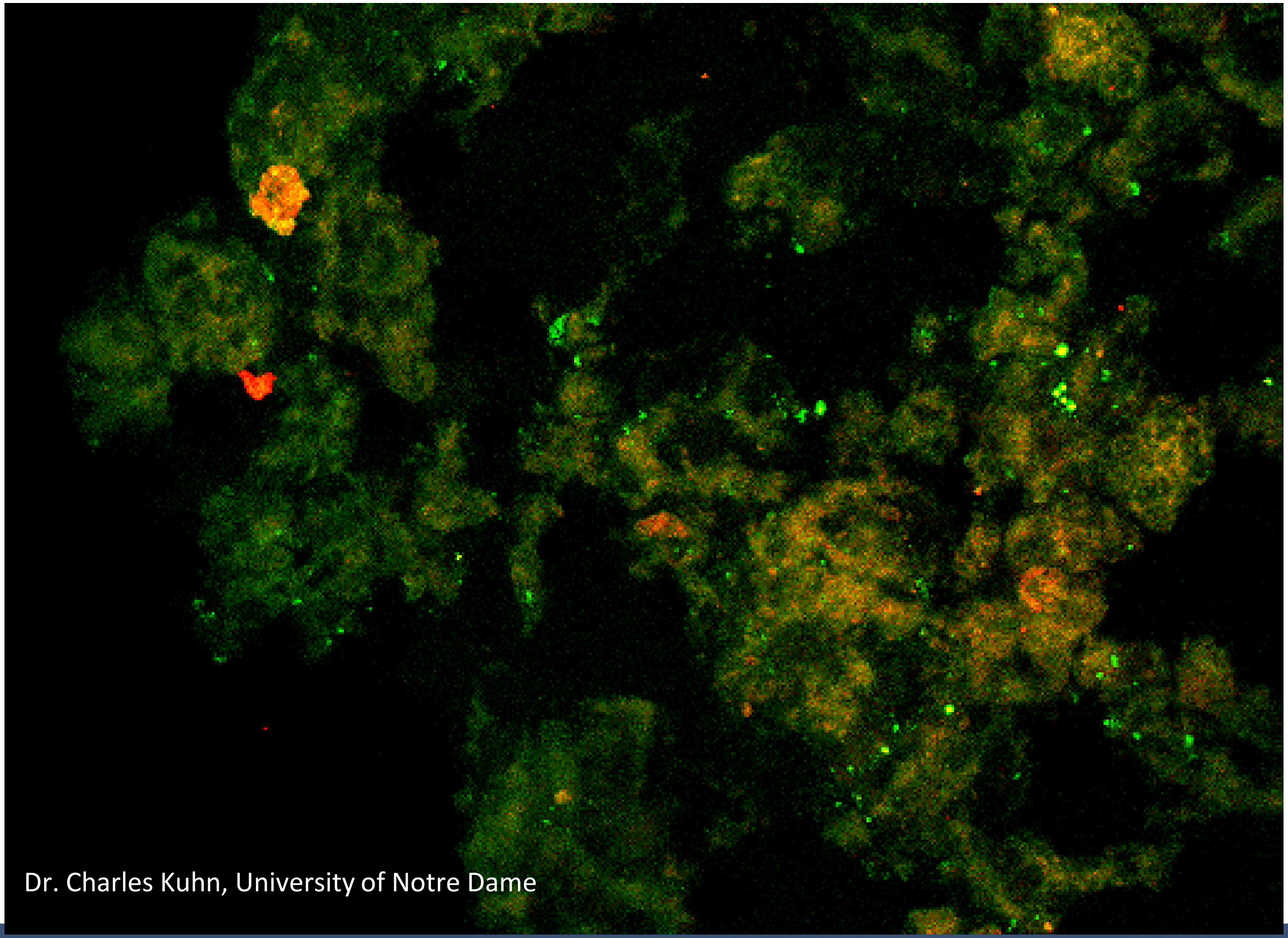
Nitrosomonas and Nitrobacter Laser Imaging

Nitrosomonas (green). Note that the cells appear to be scattered within the floc. Nitrosomonas generally does not form colonies like those observed with Nitrobacter (orange).



Nitrosomonas and **Nitrobacter** Laser Imaging

Red-orange colonies are Nitrobacter while the green speckles are from the Nitrosomonas. In most cases the 2 nitrifying species are not in close physical contact.

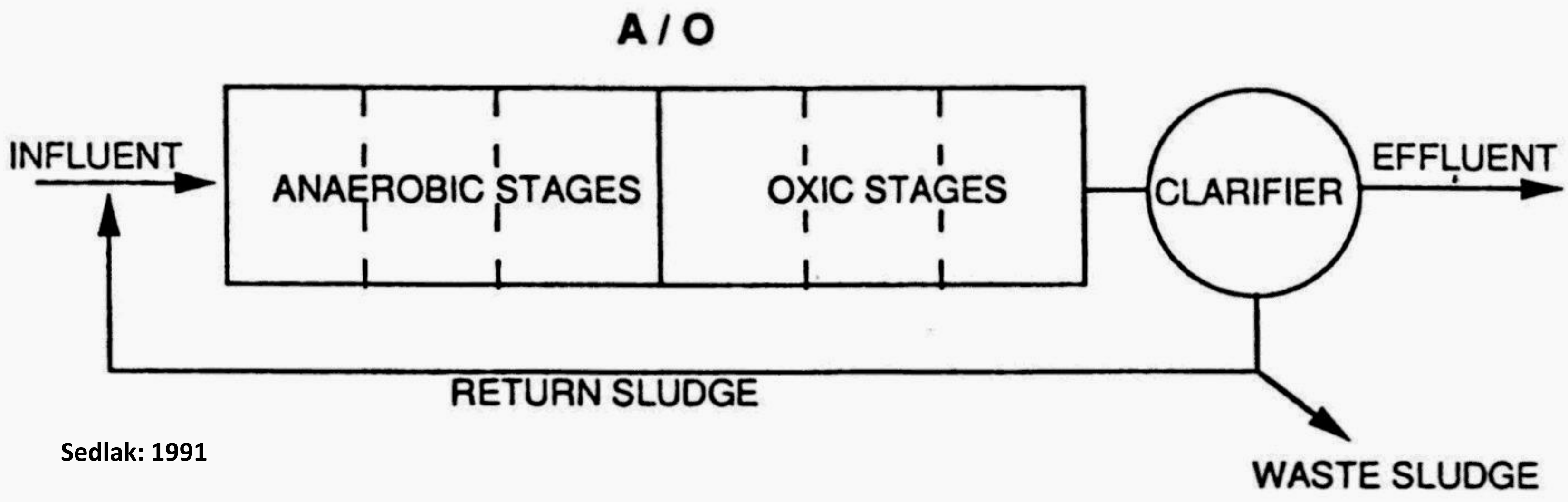


Examples of Activated Sludge BNR Continuous Flow Multi Zone Reactors

- Continuous Flow – Multi Zone
  - Distinct Zone operation for Biological Phosphorus Removal
  - Distinct Zone operation for Denitrification
  - Typically employs Internal Recycle
    - A/O Process
    - Modified Ludzack Ettinger (MLE) Process
    - A^2/O Process
    - University of Capetown (UCT) Process
    - Modified UCT Process
    - Bardenpho – 5 Stage
- Pho Strip
  - Biological stripping of P with chemical treatment of sidestream. Preview to Phosphorus Session 3.

Activated Sludge Process Variations
Multi Zone – Continuous Flow Reactors

Anaerobic / Oxic (A/O) – 2 Stage No Internal Recycle (IR)

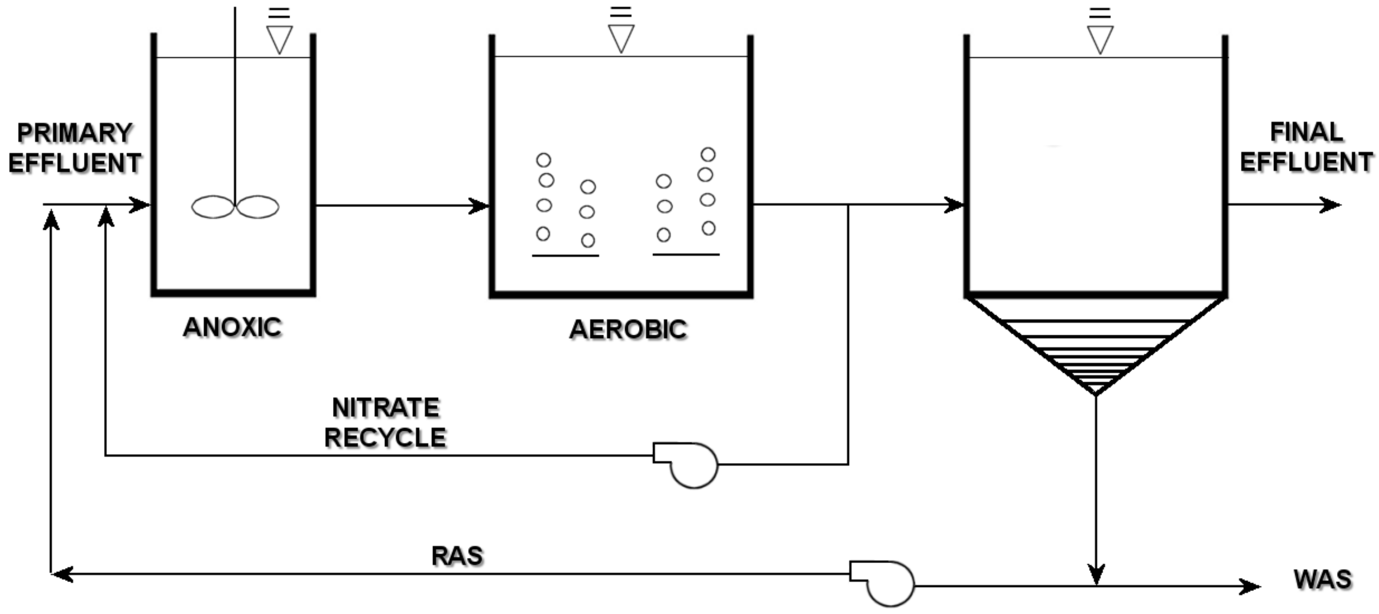


Sedlak: 1991

Activated Sludge Process Variations
Multi Zone – Continuous Flow Reactors

Two (2) Stage with Internal Recycle (IR)

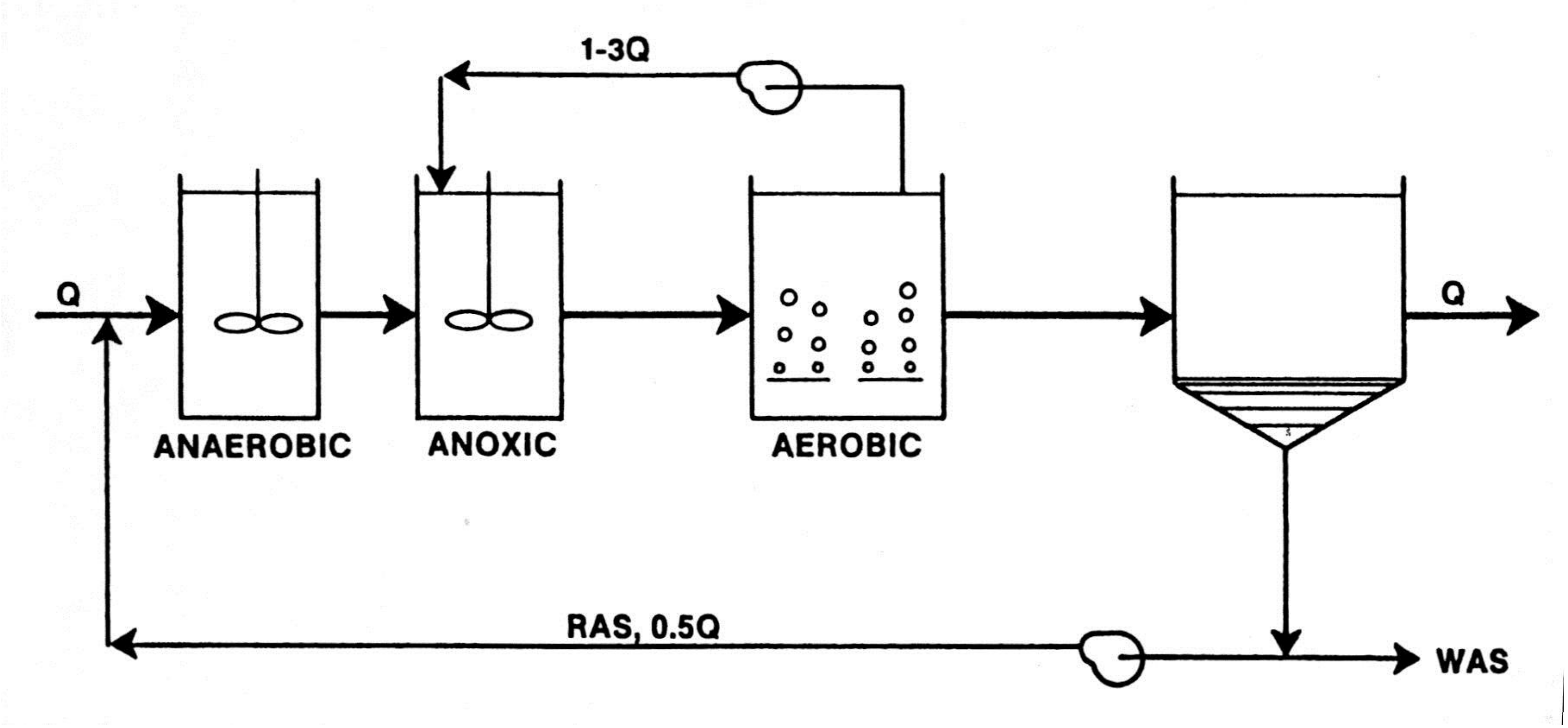
MODIFIED LUDZACK-ETTINGER (MLE) PROCESS



Sedlak: 1991

Activated Sludge Process Variations
Multi Zone – Continuous Flow Reactors

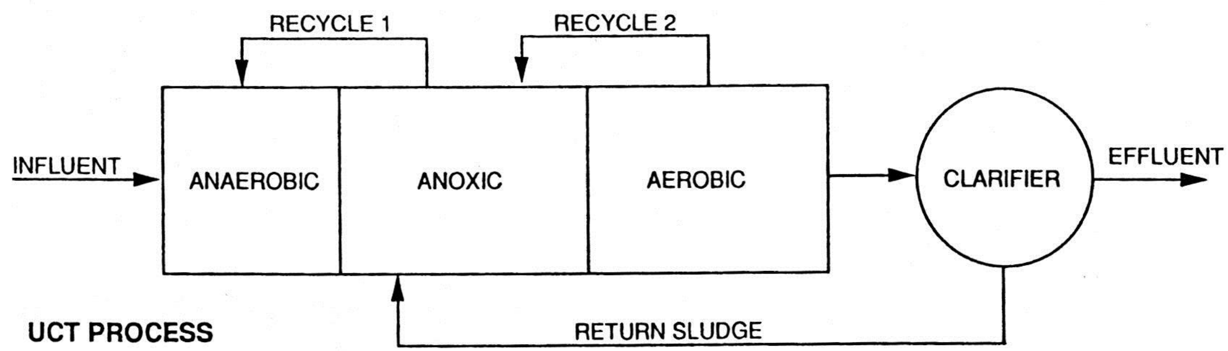
Anaerobic / Anoxic and Oxic (A^2/O) Process – 3 Stage/1 IR

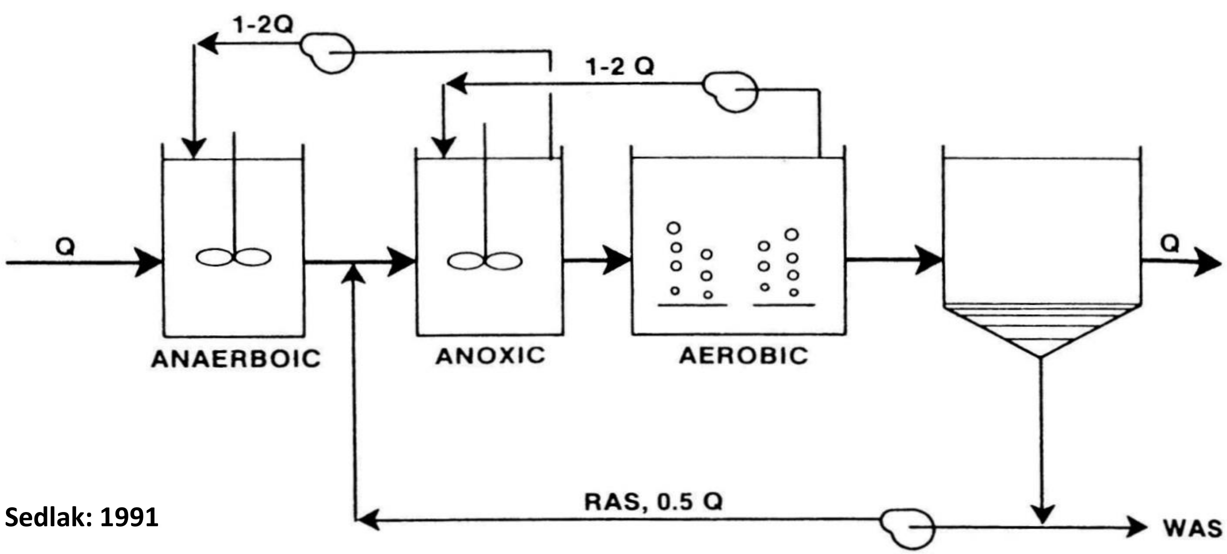


Sedlak: 1991

Activated Sludge Process Variations
Multi Zone – Continuous Flow Reactors

UCT (University of Capetown) Process – 3 Stage/2 IR



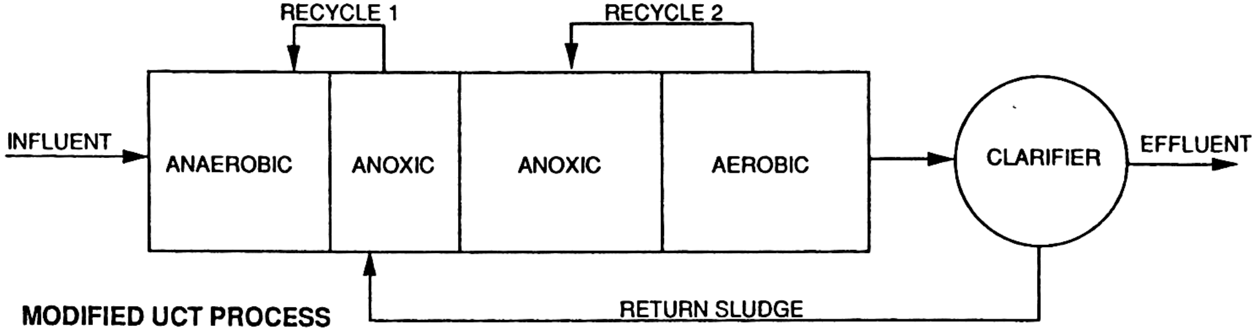


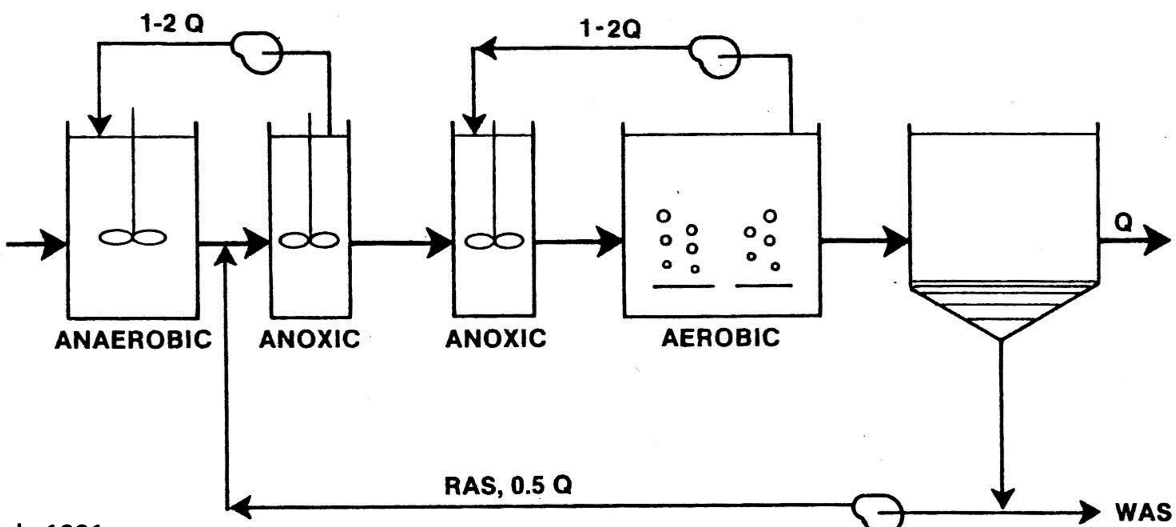
Sedlak: 1991

Hazen

Activated Sludge Process Variations
Multi Zone – Continuous Flow Reactors

Modified UCT Process – 4 Stage/2 IR

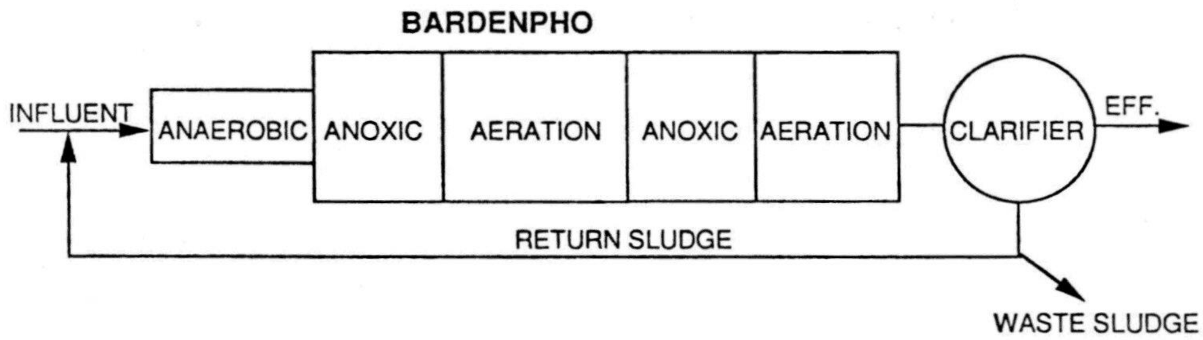


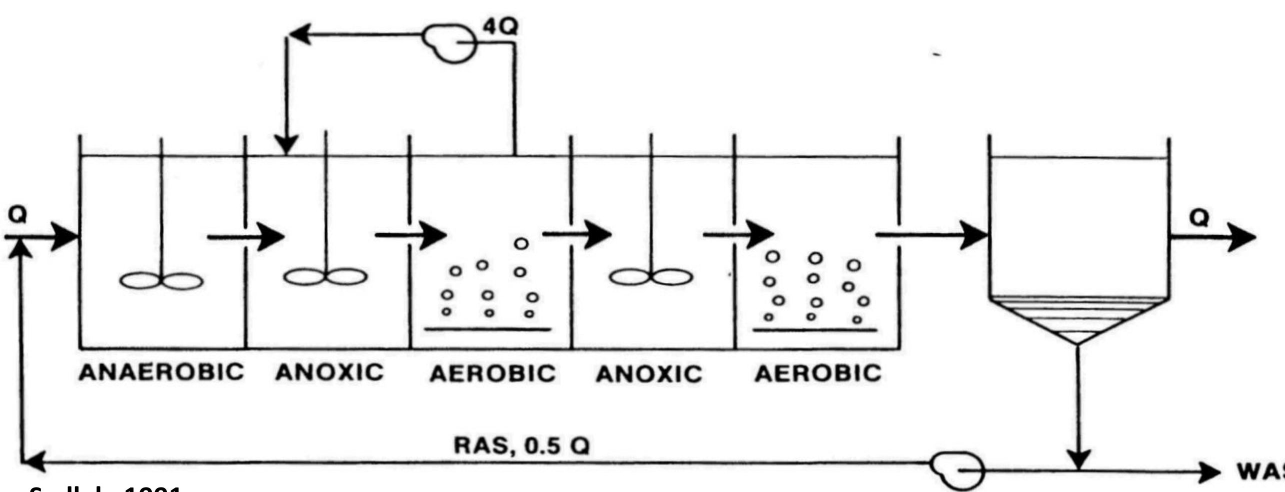


Sedlak: 1991

Activated Sludge Process Variations
Multi Zone – Continuous Flow Reactors

Bardenpho – 5 Stage/1 IR

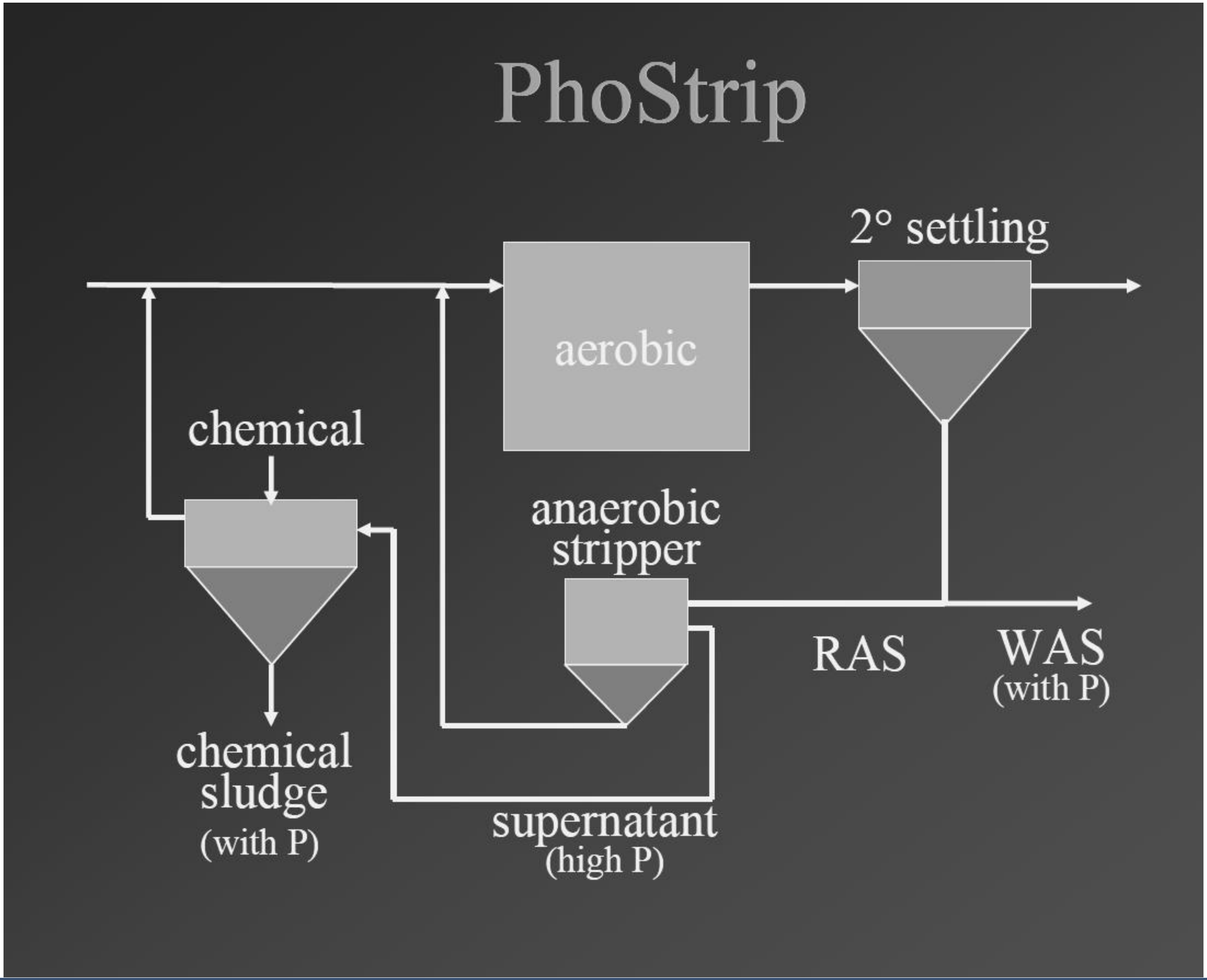




Sedlak: 1991

Hazen

Activated Sludge Process Variations
Biological Phosphorus Stripping with Chemical Treatment of Sidestream



Questions

Dan Miklos
dmiklos@hazenandsawyer.com