Like Baskin-Robbins… Activated Sludge Has Many Flavors

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

Presentation Summary

- Activated Sludge (AS) Wastewater Treatment means
  - Microorganisms suspended in, and mixed with wastewater via mixing and an aeration system
    - Suspended, aerated microorganisms called Mixed Liquor Suspended Solids (MLSS)
      - Break down organic matter
    - Around since the 1920s
  - Aeration system concurrently provides respiration needs for microorganisms and mixing
- How the air is delivered, number of tanks, recycling, etc.
  - Generates different *process names*
    - Complete mix
    - Oxidation ditch
    - SBR
    - Etc., etc., etc.
- We will talk about some of the major types (or *flavors*) of AS
  - What makes each different?
  - Advantages/disadvantages

Activated Sludge *Flavors*

Conventional A/S

1. Complete Mix
2. Plug Flow
3. Contact Stabilization
4. Step Aeration
5. Tapered Aeration
6. Extended Aeration
7. Oxidation Ditches
8. Carousel® Oxidation Ditch
9. Orbal® Oxidation Ditch
10. Vertical Loop Reactor
11. Sequencing Batch Reactors (SBRs)
12. Pure Oxygen
13. Integrated Fixed-Film Activated Sludge (IFAS)
14. Membrane Bioreactors (MBR)

Biological Nutrient Removal (BNR) A/S

15. Sequencing Batch Reactors (SBRs)
16. Anaerobic/Oxic (A/O)
17. MLE, (Modified Ludzack-Ettinger)
18. A2/O
19. Bardenpho (4-stage and 5-stage)
20. University of Cape Town (UCT)
21. Modified UCT
22. Johannesburg
23. Modified Johannesburg
24. Westbank

Biological Nutrient Removal (BNR) - Intensification

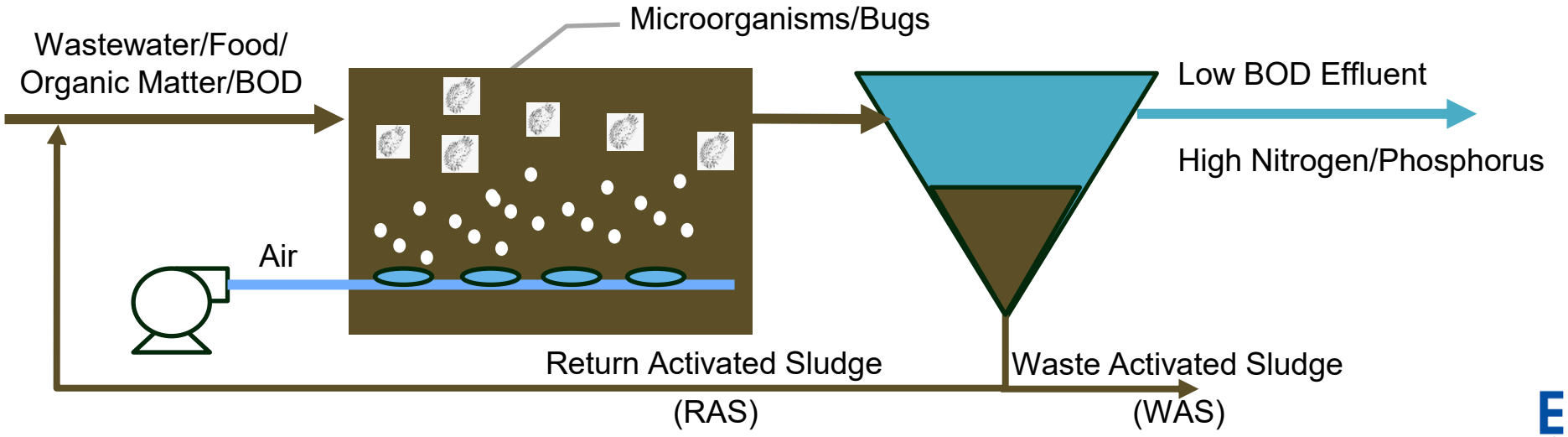
25. Densification
26. Granular
27. Membrane Aerated Biofilm Reactors (MABR)
28. Integrated Fixed-Film Activated Sludge (IFAS)

Conventional A/S

- What do I mean by *conventional* activated sludge?
  - Designed to achieve *secondary* treatment levels – 1970s
    - *Secondary Treatment* generally means carbon reduction (BOD or COD)
      - Federal Rule sets secondary treatment for processes like activated sludge as
        - BOD = 30 mg/L Monthly Average/45 mg/L Weekly Average
        - TSS = 30 mg/L Monthly Average/45 mg/L Weekly Average
        - pH = 6.0 to 9.0
  - 1980s – Designs to meet *advanced secondary* treatment levels
    - Not defined in rule, but term of art referring to secondary + *ammonia* reduction
  - 1990s – Designs for nutrient reduction
  - 2000s – Designs for intensification processes – BOD and nutrient

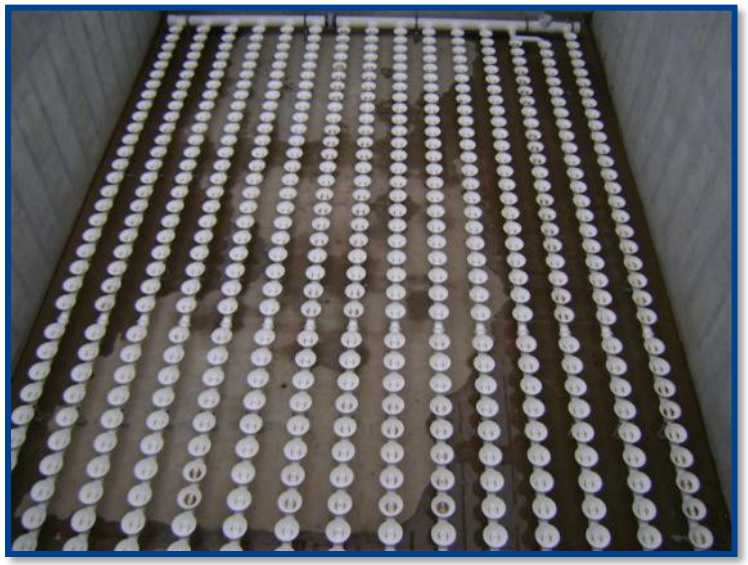
Conventional A/S – Meet Secondary Treatment

- Grow microorganisms that reduce organic matter in wastewater
  - If organic matter is not reduced significantly
    - Dissolved oxygen (DO) in the effluent receiving water will be impacted
      - Possibly killing fish/wildlife due to a lack of DO to survive
  - Organic matter generally expressed as Biochemical Oxygen Demand (BOD)
    - Food for the microorganisms (bugs)



Like Baskin-Robbins…Activated Sludge Has Many Flavors

Conventional A/S – Meet Secondary Treatment



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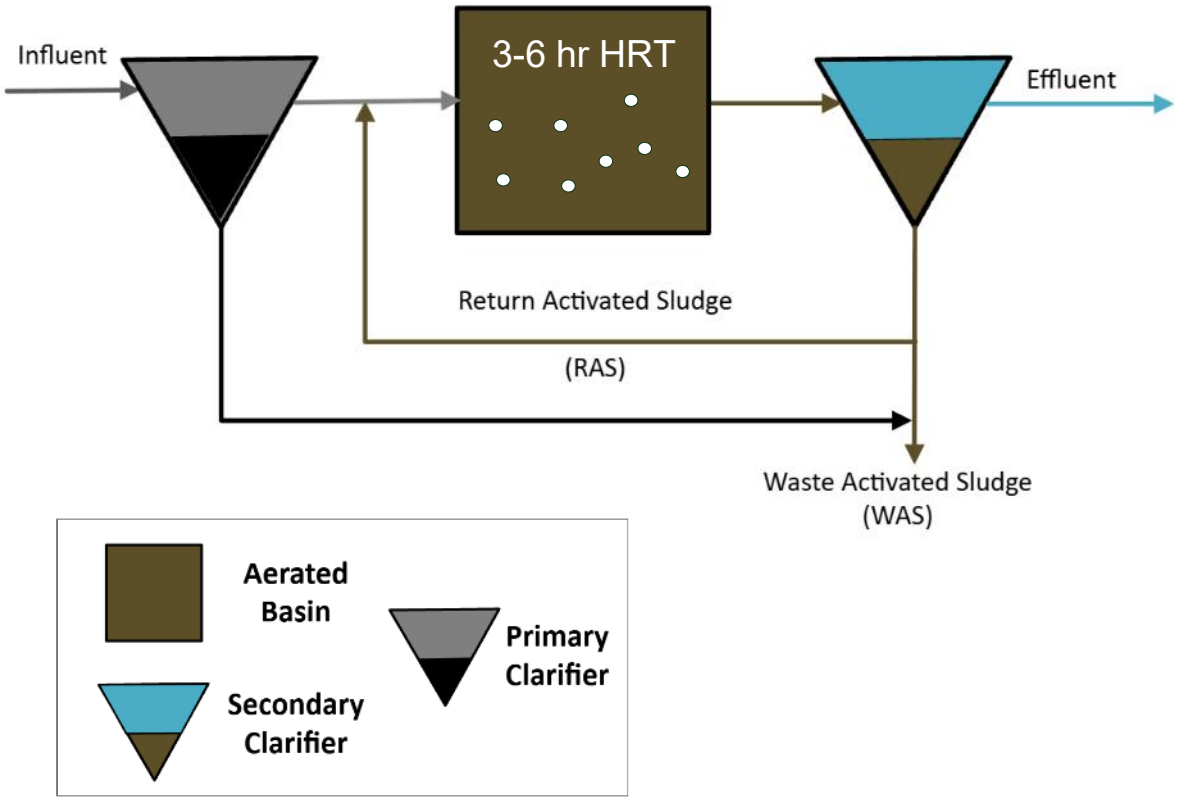
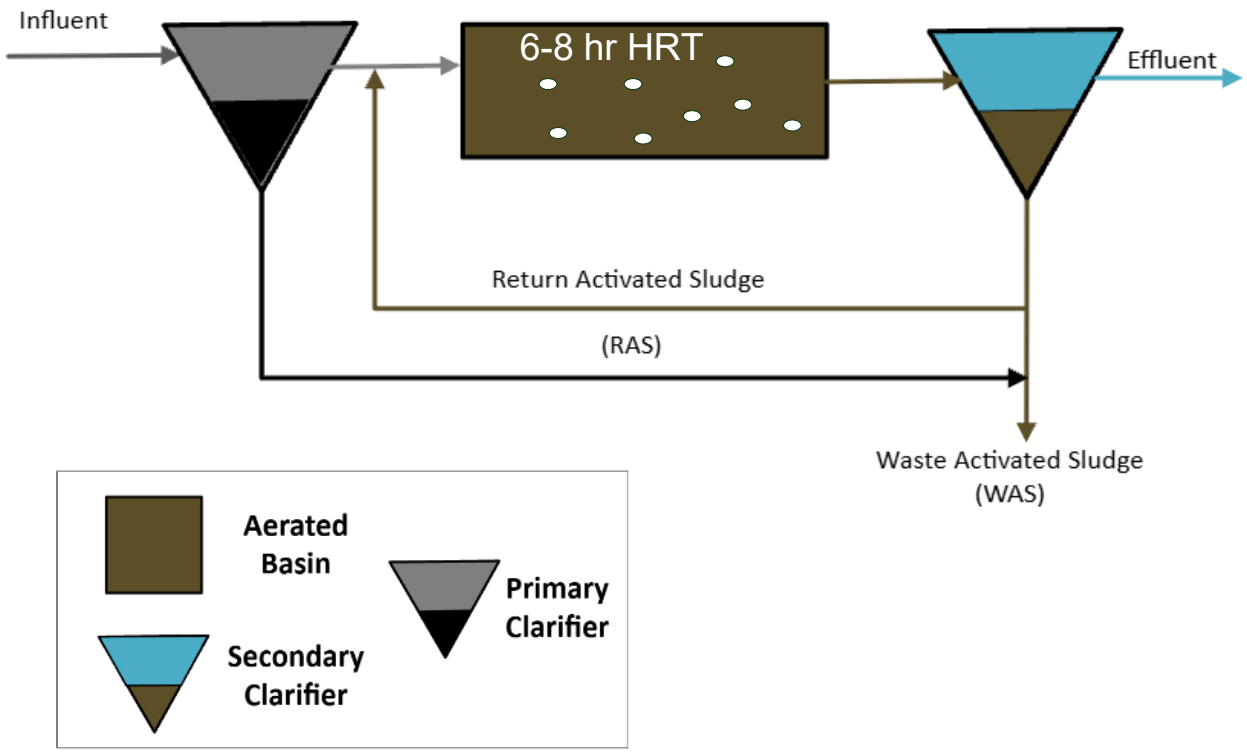
The Early Flavors – *Vanilla and Chocolate*



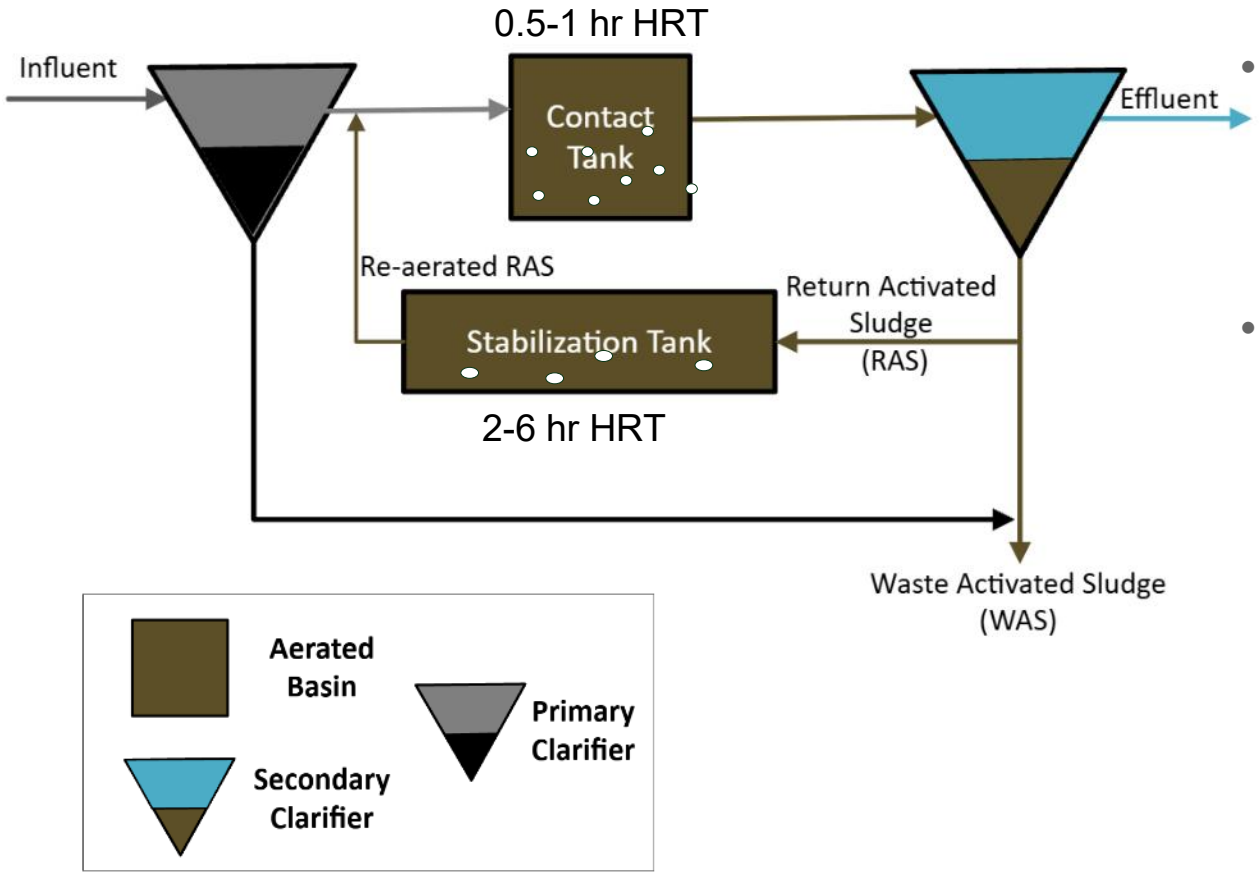
- Complete Mix
  - Immediately/Completely mix MLSS
  - Advantages
    - Small footprint
    - Meet Secondary Treatment requirements
  - Disadvantages
    - Need primary clarifier
    - Can be unstable
    - High energy consumption
    - Only treat BOD, not Nitrogen (N) or Phosphorus (P)

The Early Flavors – *Vanilla and Chocolate*



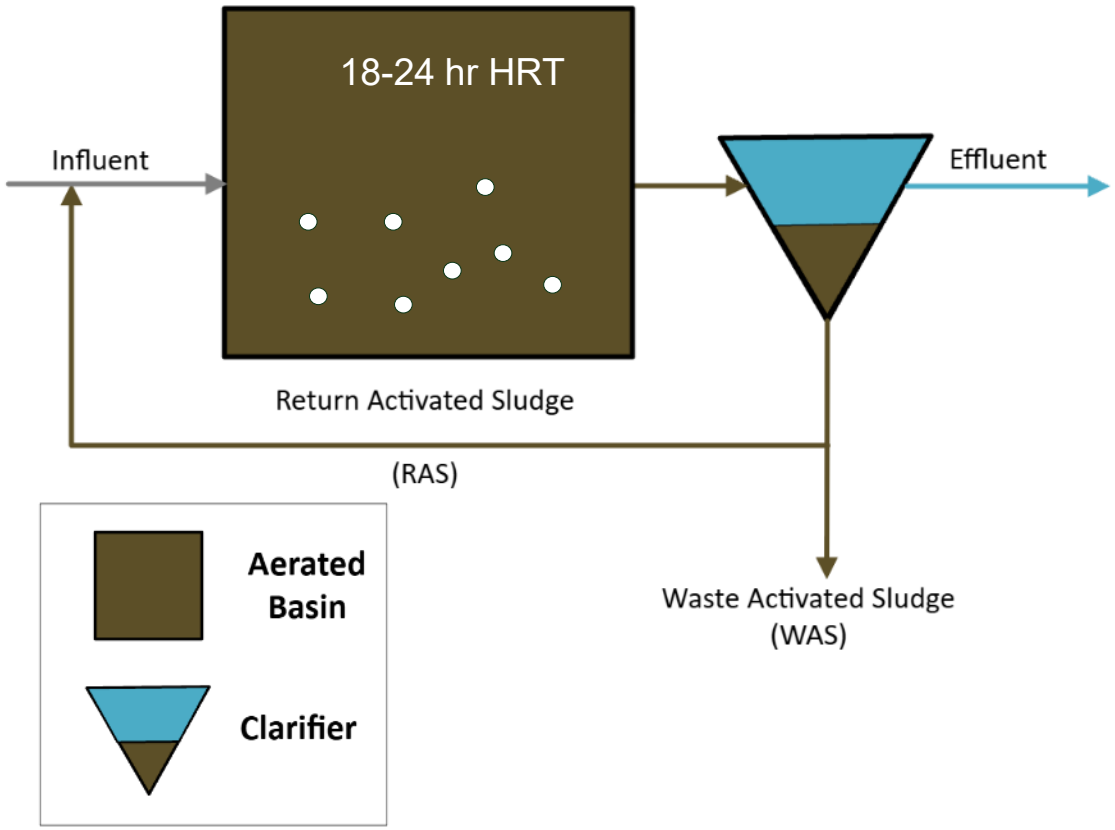
- Plug Flow
  - Can reduce/taper aeration along basin
    - Energy savings
  - Advantages
    - Small footprint
    - Some energy reduction
  - Disadvantages
    - Need primary clarifier
    - Low DO in basin inlet can lead to filaments
    - Subject to failure due to toxic load
    - Only treat BOD
      - May get some incidental N or P reduction

The Early Flavors – *Vanilla and Chocolate*



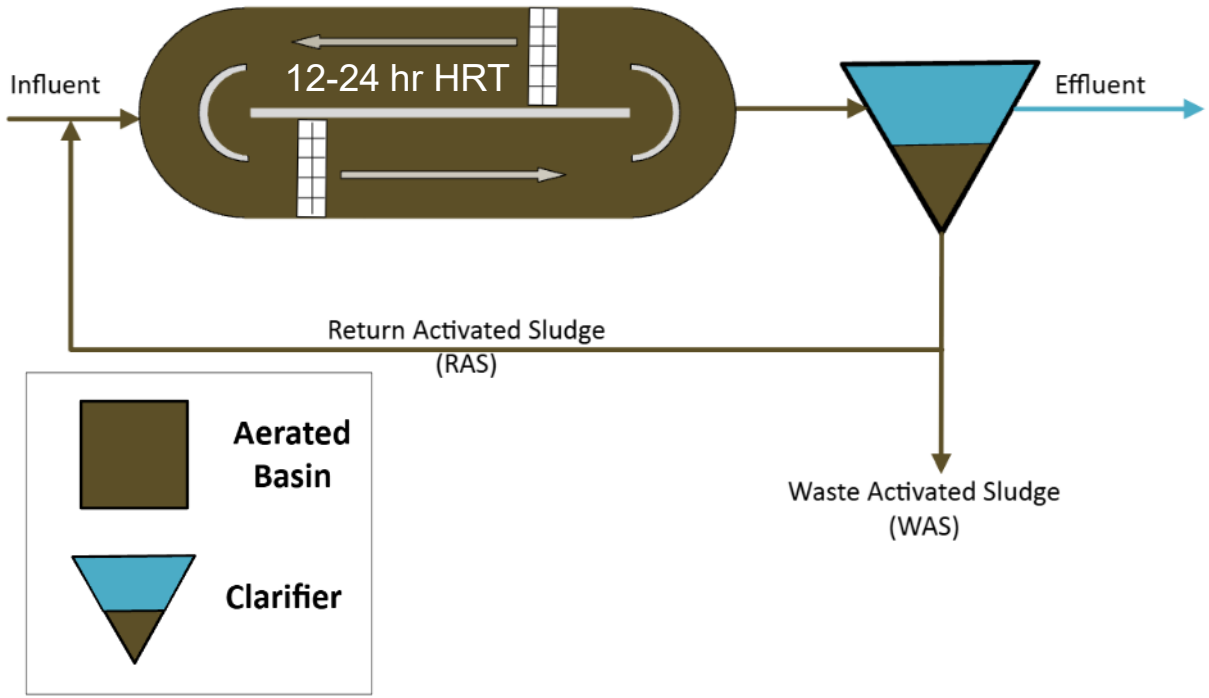
- Contact Stabilization
  - Immediately/Completely mix MLSS
    - Short retention time in Contact Tank – adsorb soluble BOD
    - Longer retention time in Stabilization Tank – stabilize BOD
  - Advantages
    - Small footprint
    - Energy reduction – small Contact Tank
    - Works well in wet weather – high solids in Stab Tank
  - Disadvantages
    - Need primary clarifier
    - More complex operation
    - Only treat BOD
      - May get some incidental N or P reduction

The Early Flavors – *Vanilla and Chocolate*



- Extended Aeration
  - Immediately/Completely mix MLSS
    - Long retention time – stabilize BOD
  - Advantages
    - No primary clarifier
    - Less waste sludge/biosolids
    - Easy operation for smaller communities
    - Can reduce ammonia
  - Disadvantages
    - Flows < 2 MGD
    - Not much opportunity for TN and TP reduction
    - Larger tank
    - More energy – more solids under aeration

The Early Flavors – *Vanilla & Chocolate w/Sprinkles*



- Oxidation Ditch
  - Air supplied by rotating brushes/discs
    - Extended retention time
- Advantages
  - No primary clarifier
  - Stable process
  - Easily operated/maintained
  - Aeration can be easily controlled
    - Allows for N and possibly P removal
- Disadvantages
  - Larger tank due to longer retention time
  - Somewhat higher energy
    - Longer sludge holding time – more air to keep active
    - Longer hydraulic retention time – more sludge to move

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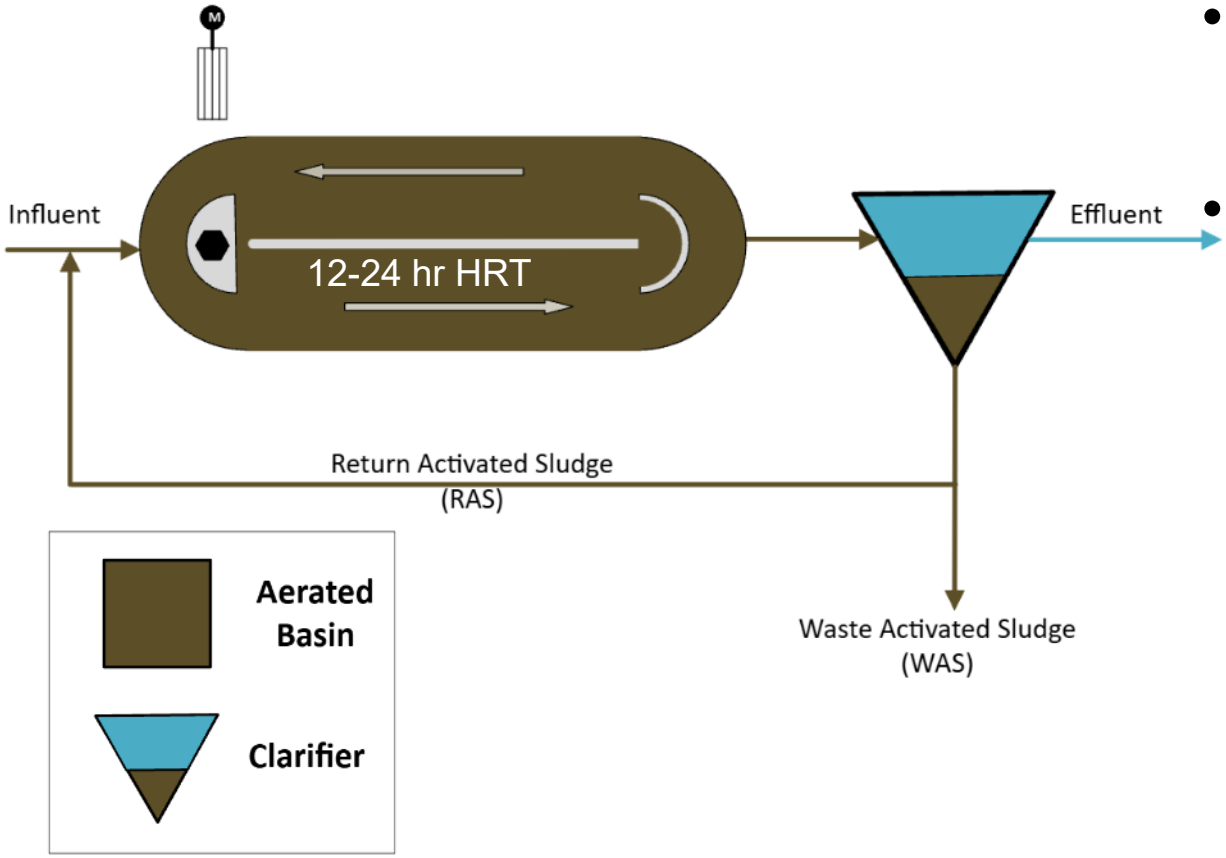

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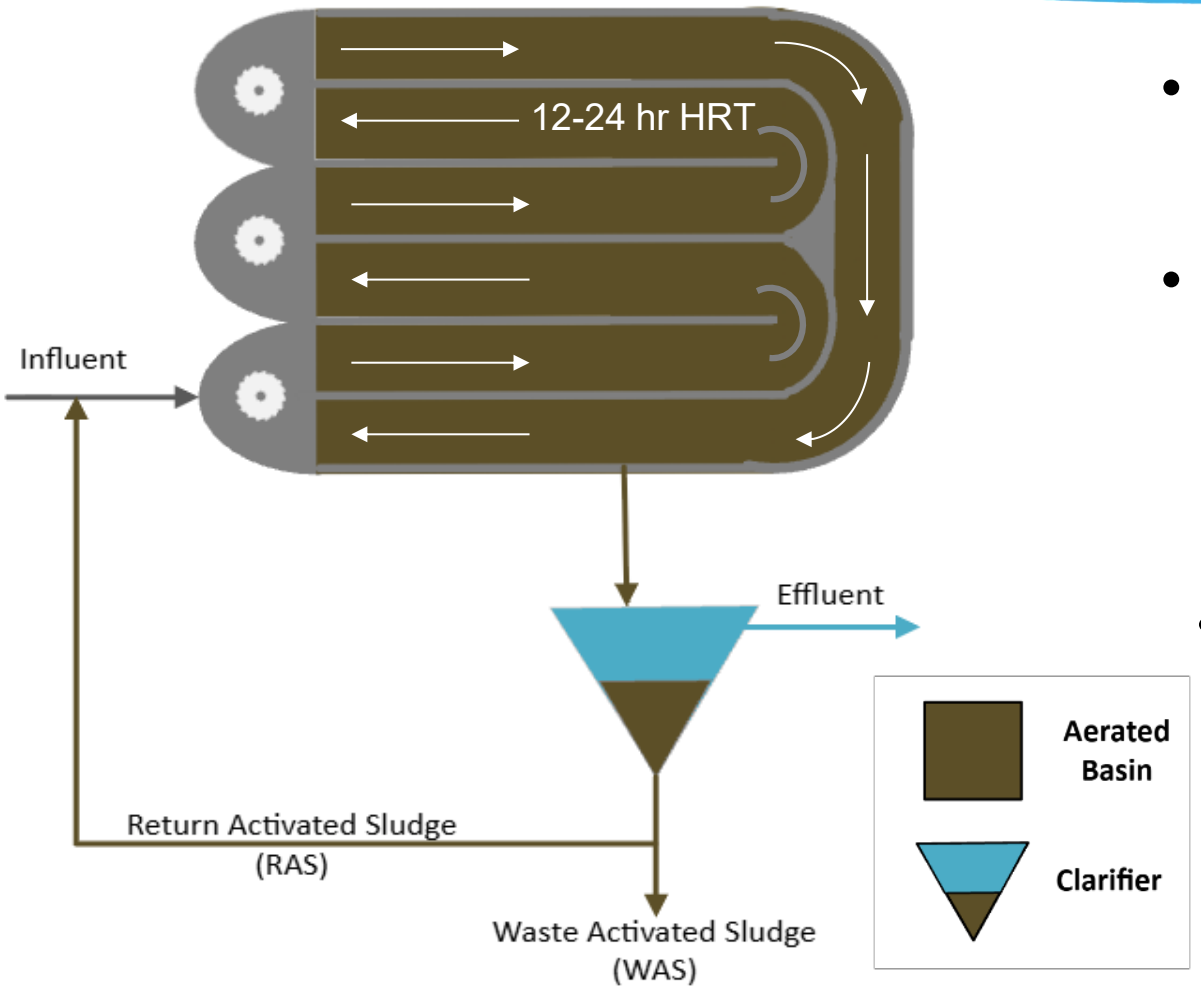

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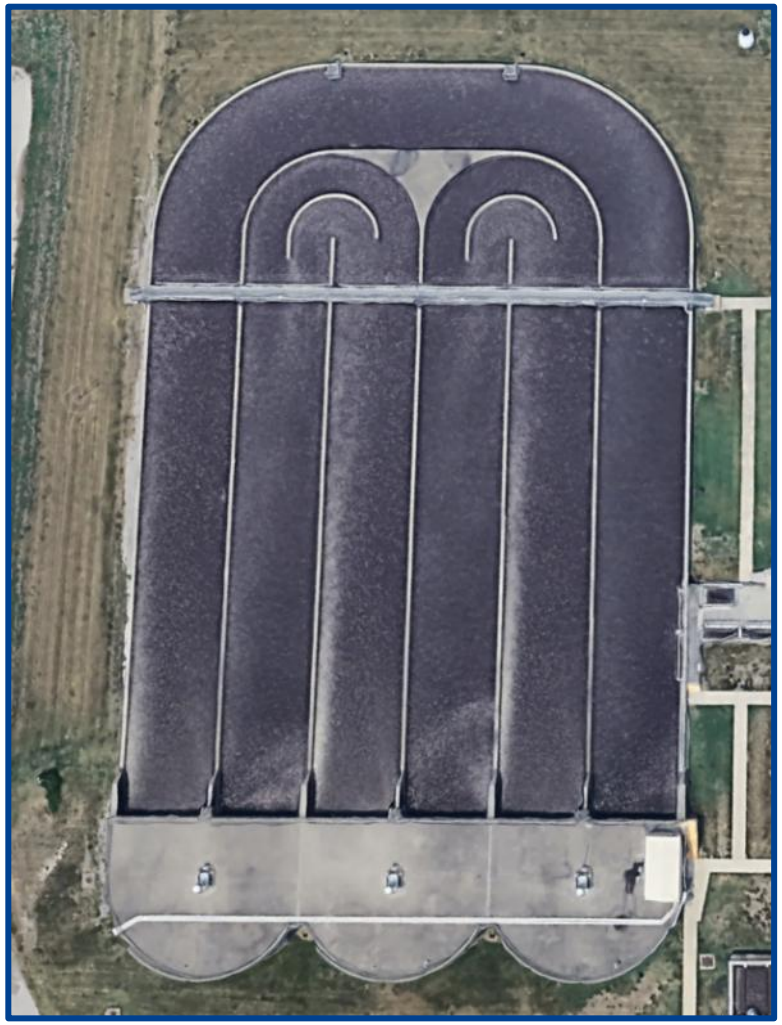

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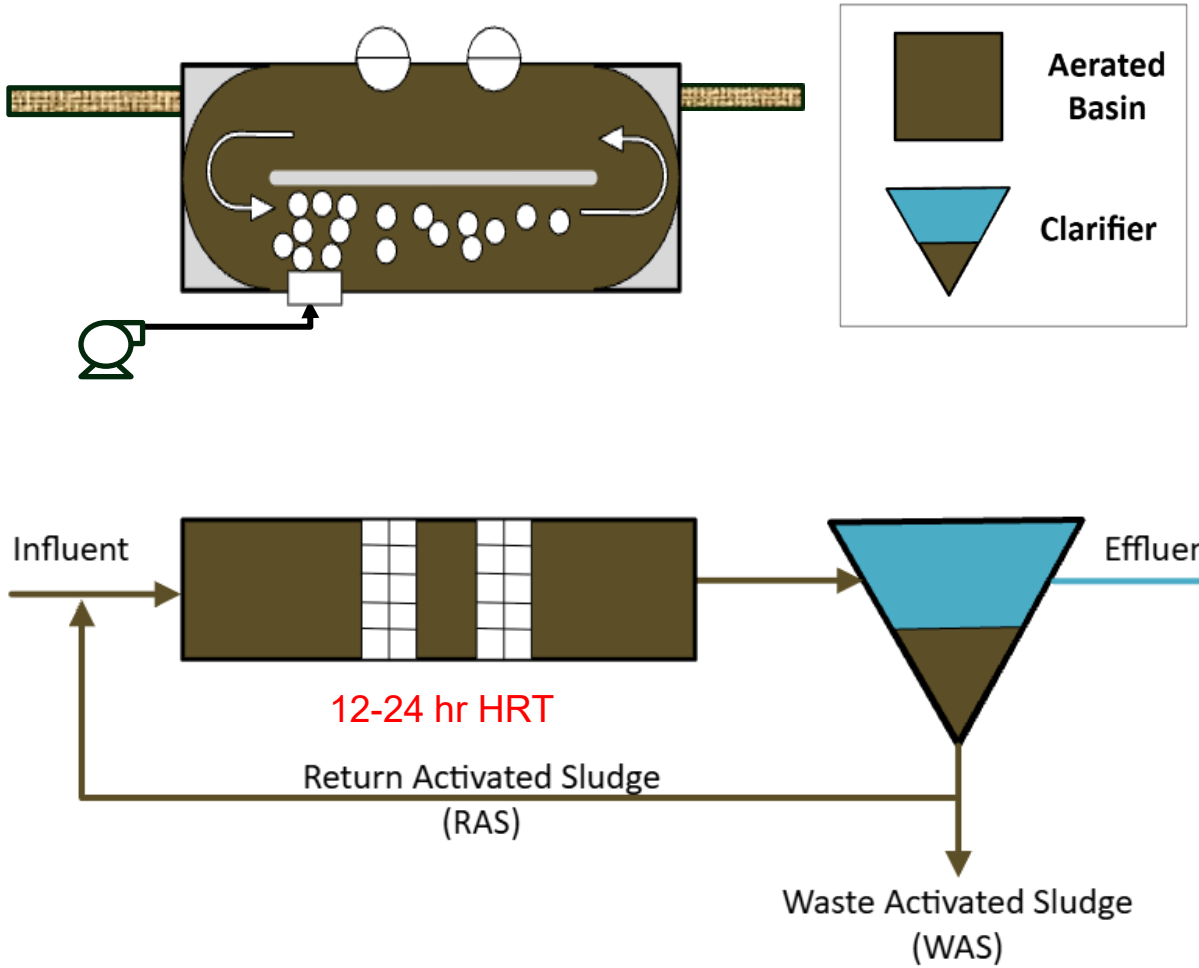

- Vertical Loop Reactor – Flipped Ox Ditch
  - Air supplied by rotating brushes/discs
    - Sometimes dissolved aeration
- Advantages
  - No primary clarifier
  - Smaller footprint
  - Stable process
  - Easily operated/maintained
  - Aeration can be easily controlled
    - Allows for N and possibly P removal
- Disadvantages
  - Somewhat higher energy
    - Longer sludge holding time – more air to keep active
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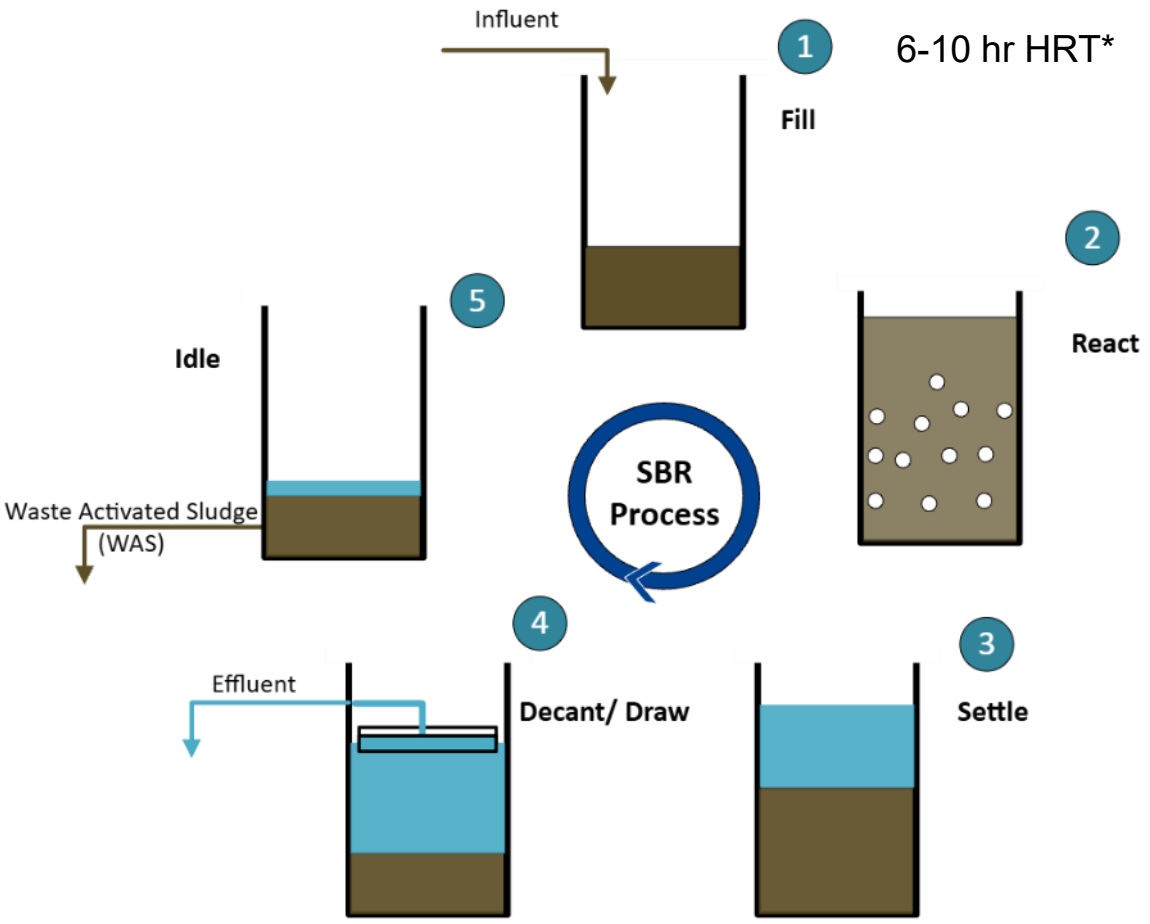
Later More Complex Flavors



- Sequencing Batch Reactor (SBR)
  - Air supplied by compressors/diffusers
    - Extended retention time
- Advantages
  - Everything in one tank – no outboard clarifier
    - Need at least two tanks
  - Small footprint
  - Lower construction cost – no recycle or clarifier
  - Can be automated to handle varying flows
  - Reduce ammonia
    - Can readily be adapted to nutrient removal – *more later*
- Disadvantages
  - Sophisticated controls
  - More automated than most plant types
    - Maintenance on automatic PLCs, switches, valves, decanters
  - Need uninterrupted power

Later More Complex Flavors

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Advance Secondary A/S

- What do I mean by ***advanced secondary*** activated sludge?
  - Designed to achieve ***secondary*** treatment levels for BOD/TSS/pH
    - Secondary treatment is *technology-based* – 30 mg/L BOD and TSS, and pH = 6.0 to 9.0
  - Also designed to reduce ***ammonia*** – called *nitrification*
  - Again, this is a term of art with no regulatory definition like ***secondary treatment***
- Ammonia is very toxic to aquatic life
  - Limits are *water quality-based*; not a fixed value like BOD or TSS
  - Limit depends on pH and temperature – more stringent as each increases
- Nitrification will occur if BOD is reduced and sufficient DO exists
  - Nitrification does not remove ammonia, it only converts it to nitrate (NO_3)
    - NO3 is not toxic, but it is like candy to algae – they rapidly consume

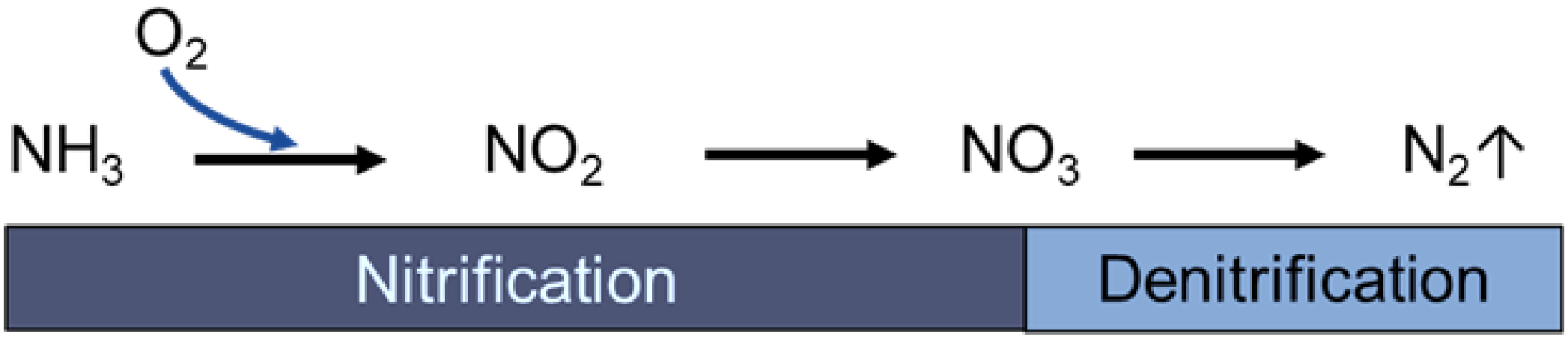
Nutrient Reduction

- In addition to organic matter (BOD) like basic activated sludge
  - Reduce total nitrogen (TN) and total phosphorus (TP)
    - TN = Total Kjeldahl Nitrogen (TKN) + Nitrate (NO_3)
    - TP = Soluble P (Phosphate/PO4) + P Bound to Solids
- How is that done biologically?
  - For BOD we just added a bunch of oxygen
  - For nutrients we establish zones
    - Oxic (Aerobic) – oxygen rich – oxygen supplied by mechanical mean blowers/mechanical aerators
      - Soluble BOD and phosphorus uptake
      - Nitrification - convert ammonia to nitrate
    - Anoxic – low oxygen - mostly supplied by the oxygen associated with NO_3
      - Denitrification – nitrate converted to nitrogen gas
    - Anaerobic – no oxygen – often need mixing
      - Soluble BOD uptake and phosphorus release

Nutrient Reduction

- Brief explanation of ***biological*** nutrient reduction - Nitrogen
  - Influent Total Nitrogen (TN) = 25 – 40 mg/L
    - Organic nitrogen (Org-N) from urea and protein and converted to ammonia (NH_3) in sewer
      - Called “ammonification”
    - At a WWTF, 20 mg/L of NH_3 is converted back to Org-N in the growth of microbial cells
      - Remainder of ammonia:
        - Discharged as NH_3 in lower oxygen/higher BOD environment – toxic to aquatic life
        - May be converted to nitrite (NH_2)/nitrate (NO_3) in oxygen-rich/lower BOD (<15 mg/L) environment
          - Called “nitrification”
      - Nitrate
        - Discharged as NO3 if oxygen-rich environment
        - Converted to nitrogen gas (N) which goes into the atmosphere in oxygen-deficient environment
          - Called “denitrification”

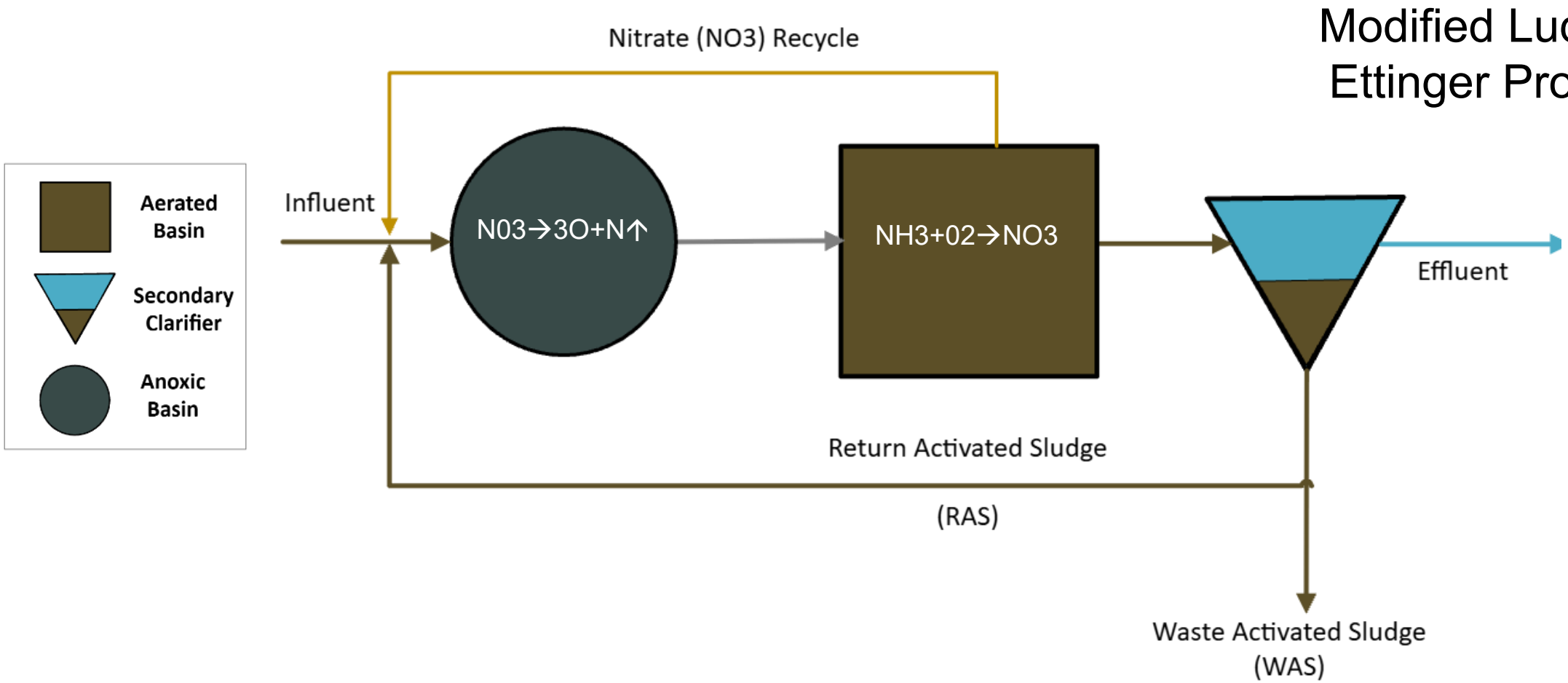
Nutrient Reduction – Nitrogen



Oxic

Anoxic

Nutrient Reduction – Nitrogen Reduction

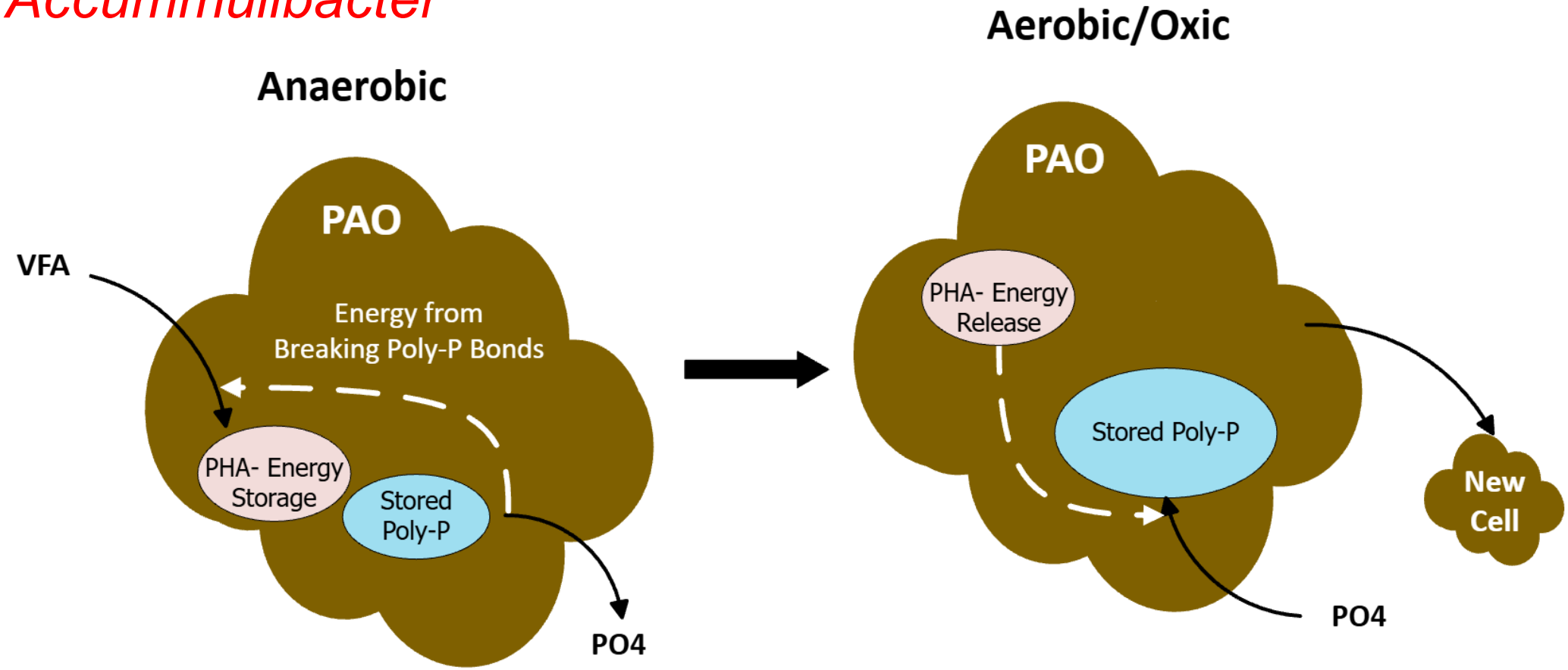


Nutrient Reduction

- Brief explanation of ***biological*** nutrient reduction - Phosphorus
  - Influent Total Phosphorus (TP) = 3 – 10^{+} mg/L
    - From human excreta, cleaning products and industrial wastes
    - At a WWTF, 1-2 mg/L of TP is taken up by microbial cell growth
  - To get out more out, we first cause soluble P to release from microorganisms
    - Then we take up the released P plus more P – sometimes referred to as *luxury uptake*
    - Volatile Fatty Acids (VFAs) created in anaerobic/septic conditions
    - P-Accumulating Organisms (PAOs) store energy eating VFAs in anaerobic conditions
    - Energized PAOs multiply and concentrate P in their cells under aerobic conditions
    - Phosphorus is removed as sludge is wasted from the process
      - Not like N which is released to the atmosphere as a gas

Nutrient Reduction – Phosphorus

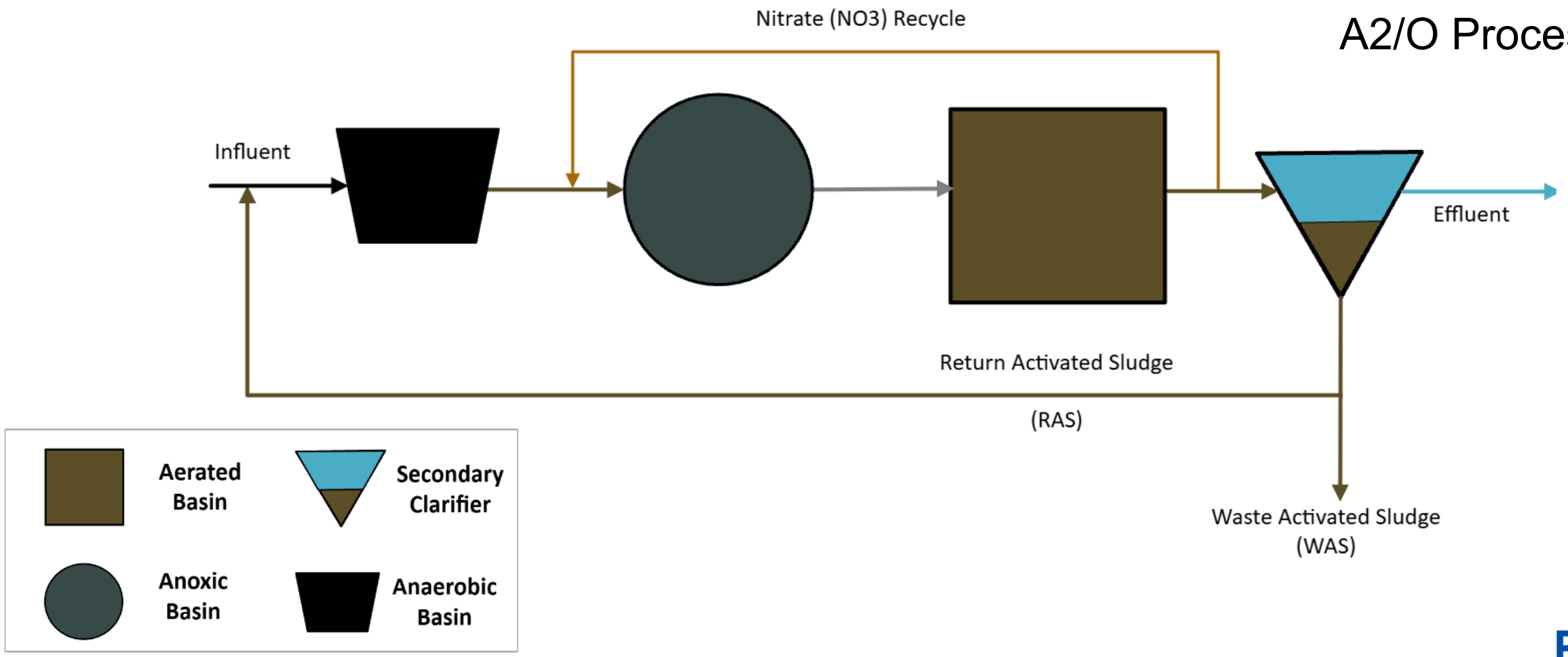
Accummulibacter



Nutrient Reduction

- Brief explanation of ***biological*** nutrient reduction - Phosphorus
  - Another more recent finding is that *Tetrasphaera* bacteria are super P-accumulators
    - They also take up the released P plus more P in greater amounts – *luxury uptake*
    - Volatile Fatty Acids (VFAs) are not needed
      - They use organic matter in waste and can ferment
      - Also use stored Poly-P for energy in anaerobic conditions
    - *Tetrasphaera* multiply and concentrate P in their cells under aerobic conditions
    - Phosphorus is removed as sludge is wasted from the process
      - Not like N which is released to the atmosphere as a gas
    - To promote *Tetrasphaera*, we need to
      - Design longer sludge holding times
      - Control pH better
      - Control anaerobic zone better–absolutely no O_2 or NO_3 to create deeper anaerobic zone

Nutrient Reduction – Nitrogen/Phosphorus



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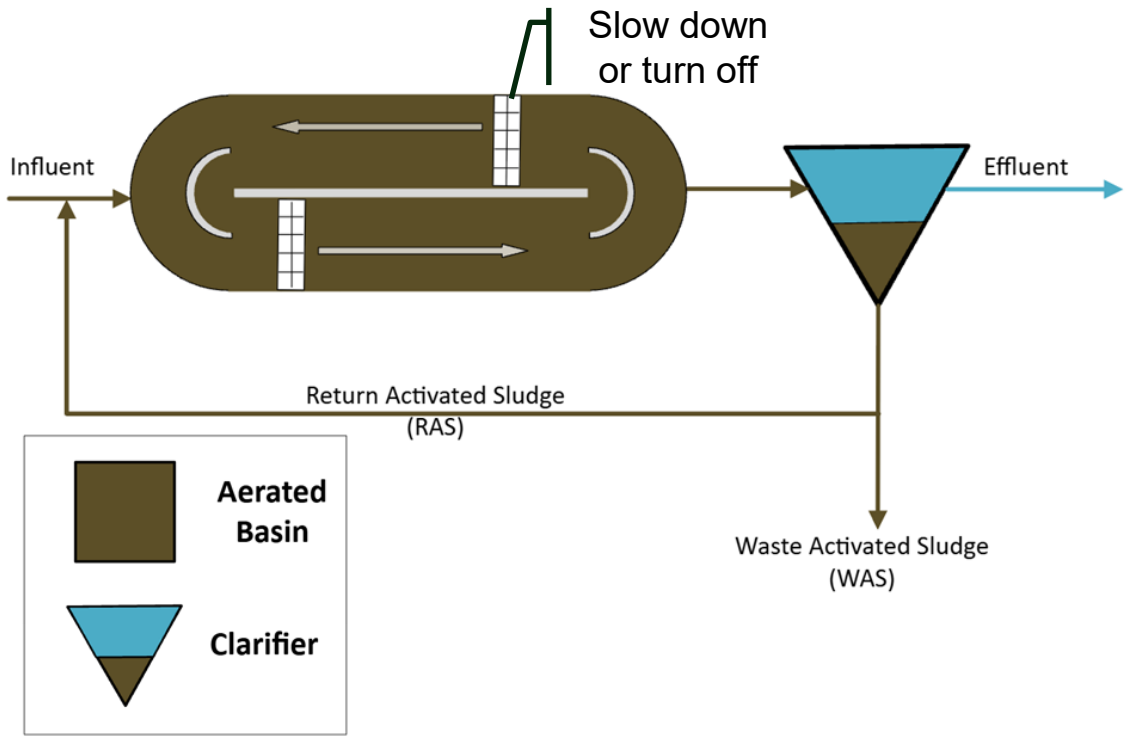
Nutrient Reduction – Chemical Phosphorus

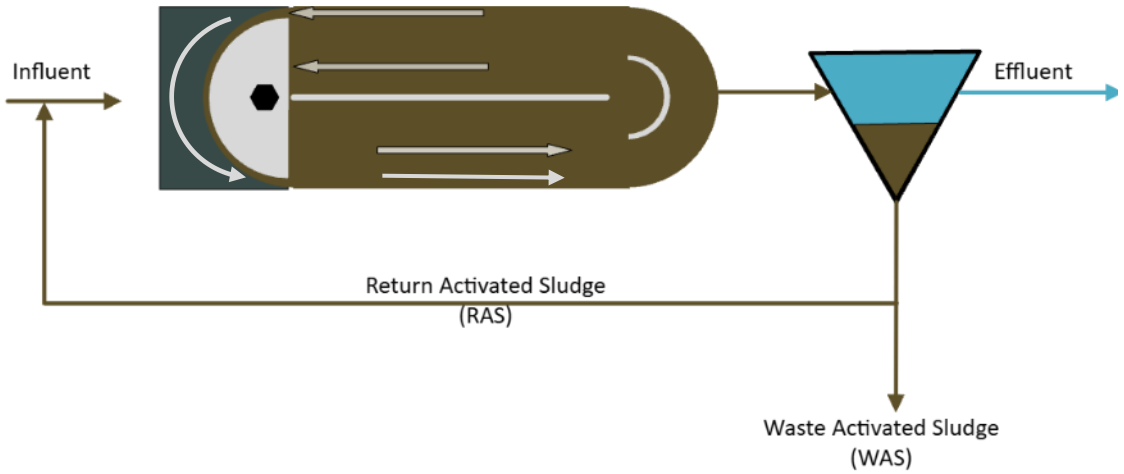
- Brief explanation of ***chemical*** nutrient reduction - Phosphorus
  - TP can also be removed chemically using metal salts
    - Ferric sulfate
    - Ferrous sulfate
    - Ferric chloride
    - Ferrous chloride
    - Aluminum sulfate (Alum)
  - Chemicals cause P to bind to microorganisms/sludge
    - Pros – easy and relatively cheap to install chemical feeder system – low capital cost
    - Cons
      - More expensive operationally than biological reduction – high operating cost
        - Chemicals are expensive and an ongoing cost
        - Chemicals tend to produce more waste sludge, thus higher sludge handling costs

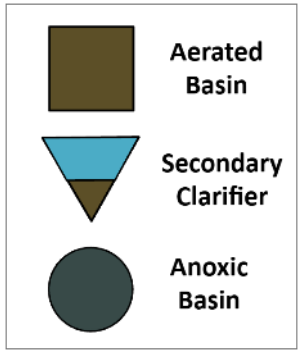
Nutrient Reduction - Nitrogen



- Modified MLE Process – kind of
  - Can also be in an oxidation ditch configuration
  - Air supplied by rotating brushes/discs
    - BOD and TN
- Advantages
  - Simultaneous Nitrification/Denitrification (SND)
  - Reduce ammonia and nitrate
- Disadvantages
  - Little phosphorus reduction
  - With single aerator, can be a challenge to operate

Nutrient Reduction - Nitrogen





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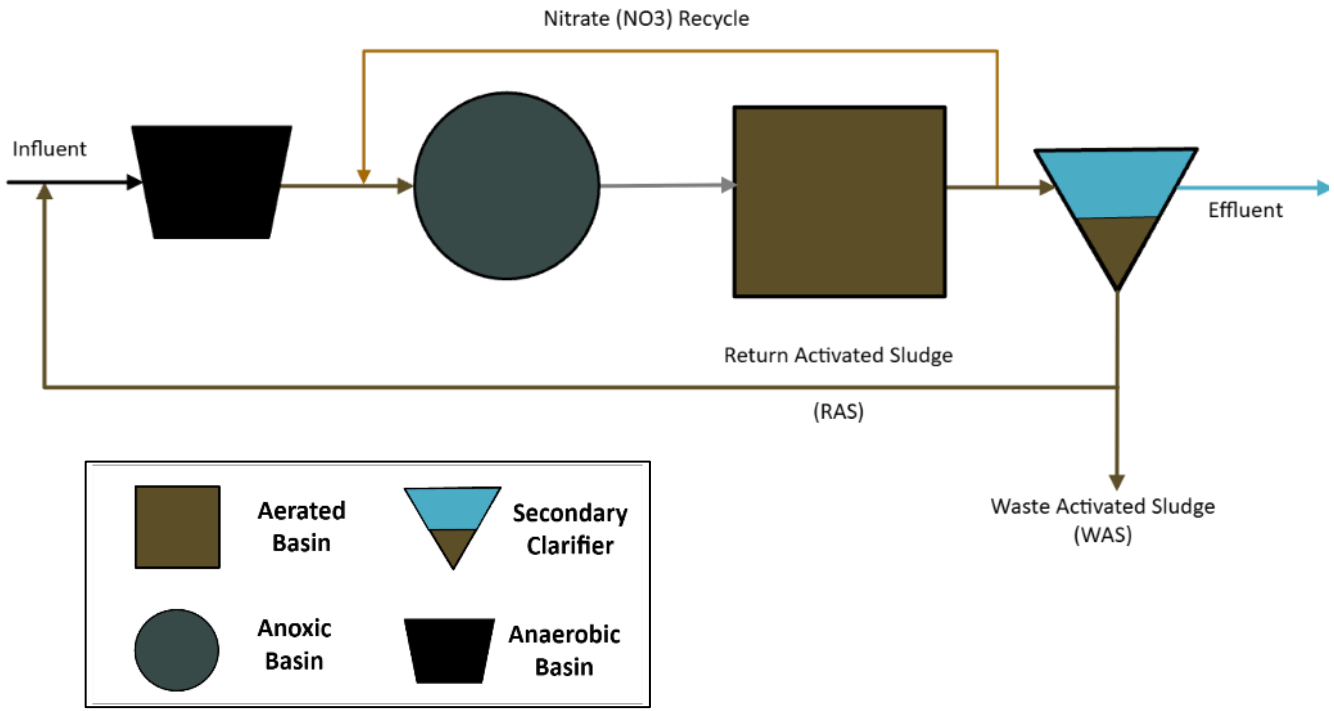
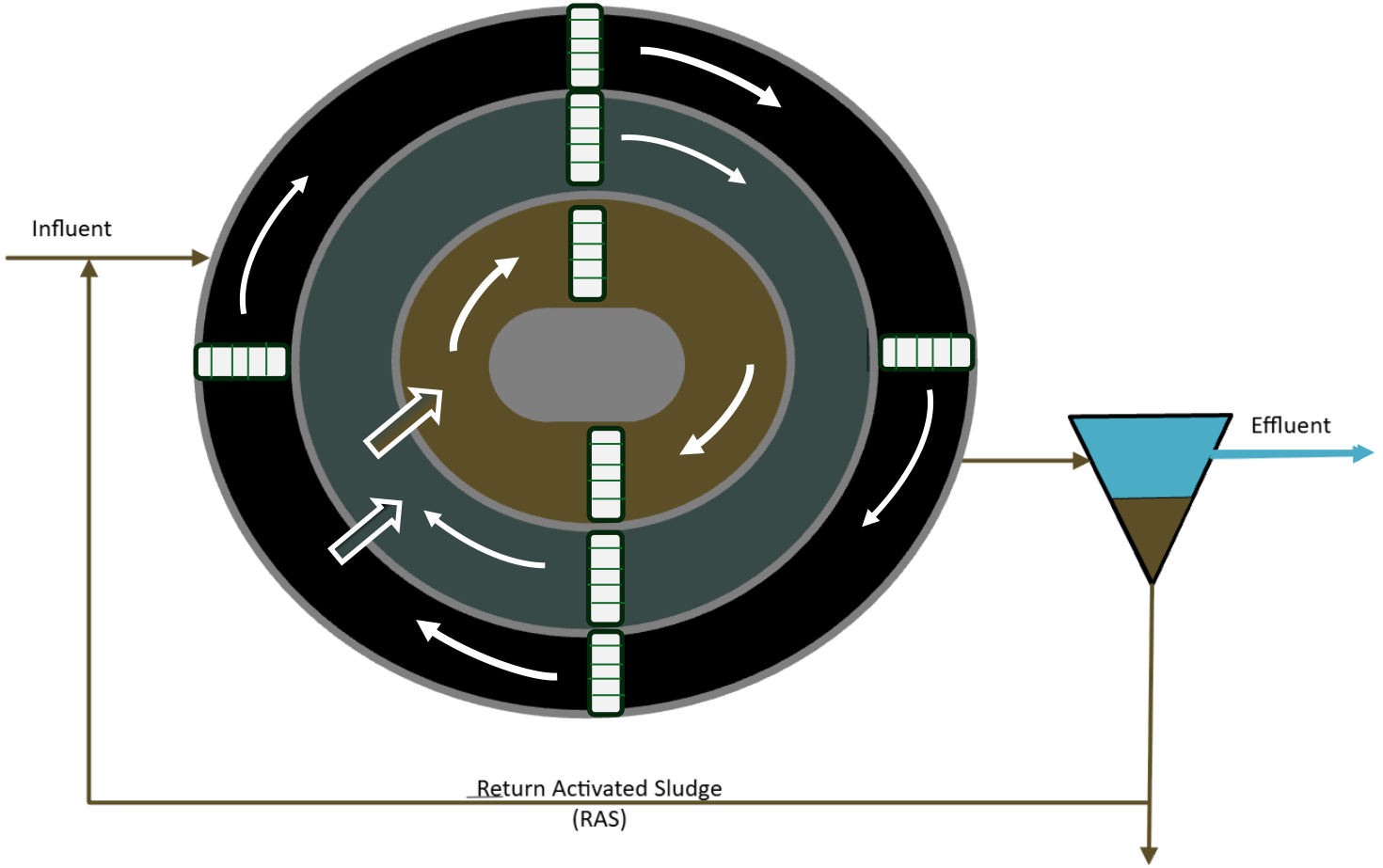
Nutrient Reduction – Nitrogen/Phosphorus

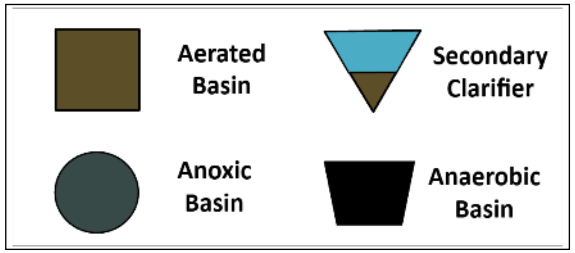


- A2/O (Anaerobic/Anoxic/Oxic)
  - Air supplied by compressors/diffusers
    - Extended retention time
- Advantages
  - Simpler design/easy to understand
- Disadvantages
  - Nitrate carryover to anaerobic zone
  - Higher energy costs
    - High-rate nitrate return
    - High-rate sludge return
  - Cost of multiple tanks

Nutrient Reduction – Nitrogen/Phosphorus

Orbal™

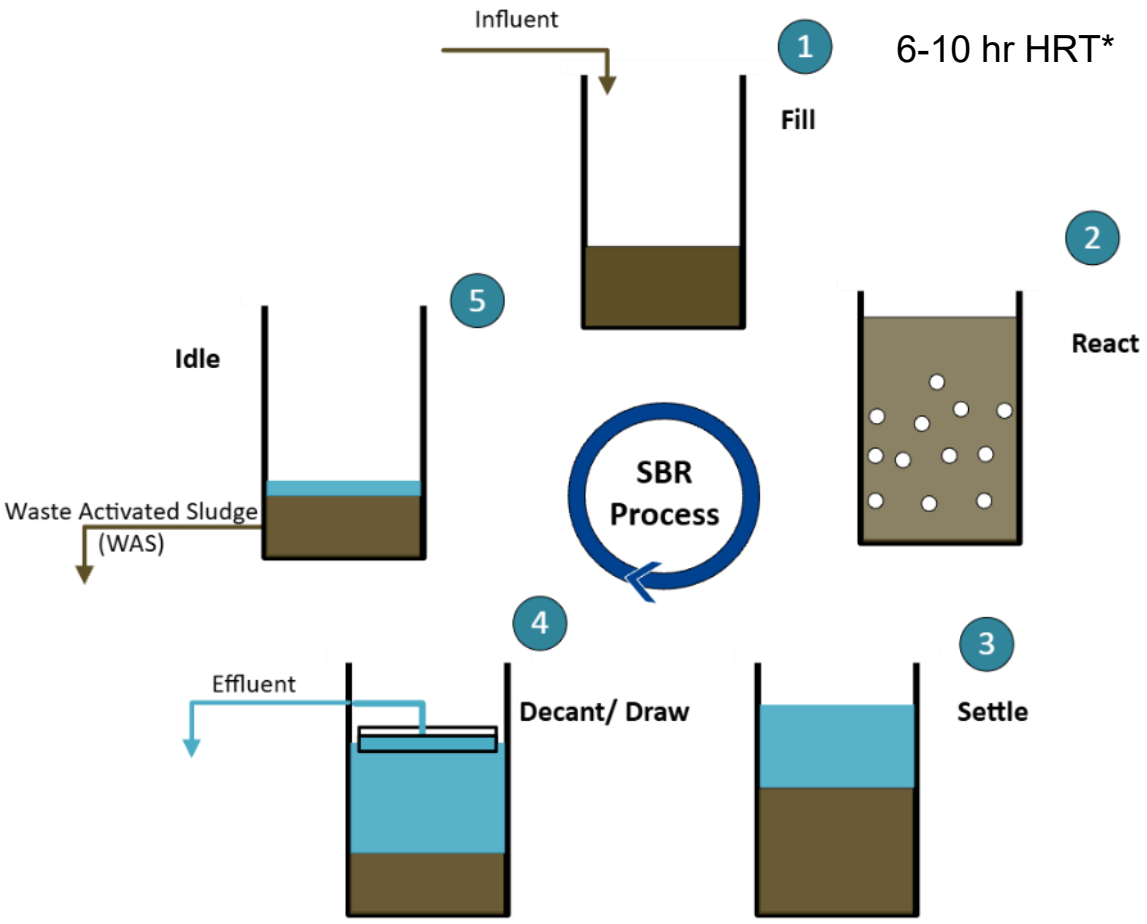




Nutrient Reduction – Nitrogen/Phosphorus

Orbal™

Nutrient Reduction – Nitrogen/Phosphorus



- SBR
  - Air supplied by compressors/diffusers
    - Extended retention time
- Advantages
  - Everything in one tank – no outboard clarifier
  - Small footprint
  - Lower construction cost – no recycle or clarifier
  - Fill, settle, decant and idle provide no air
    - By changing timing w/o air, can create anoxic and anaerobic zones
    - Voila – nutrient reduction!
- Disadvantages
  - Less optimal anoxic and anaerobic basin configuration
  - More automated than most plant types
    - Maintenance on automatic PLCs, switches, valves, decanters
  - Sophisticated controls
  - Need uninterrupted power

Nutrient Reduction – Nitrogen/Phosphorus

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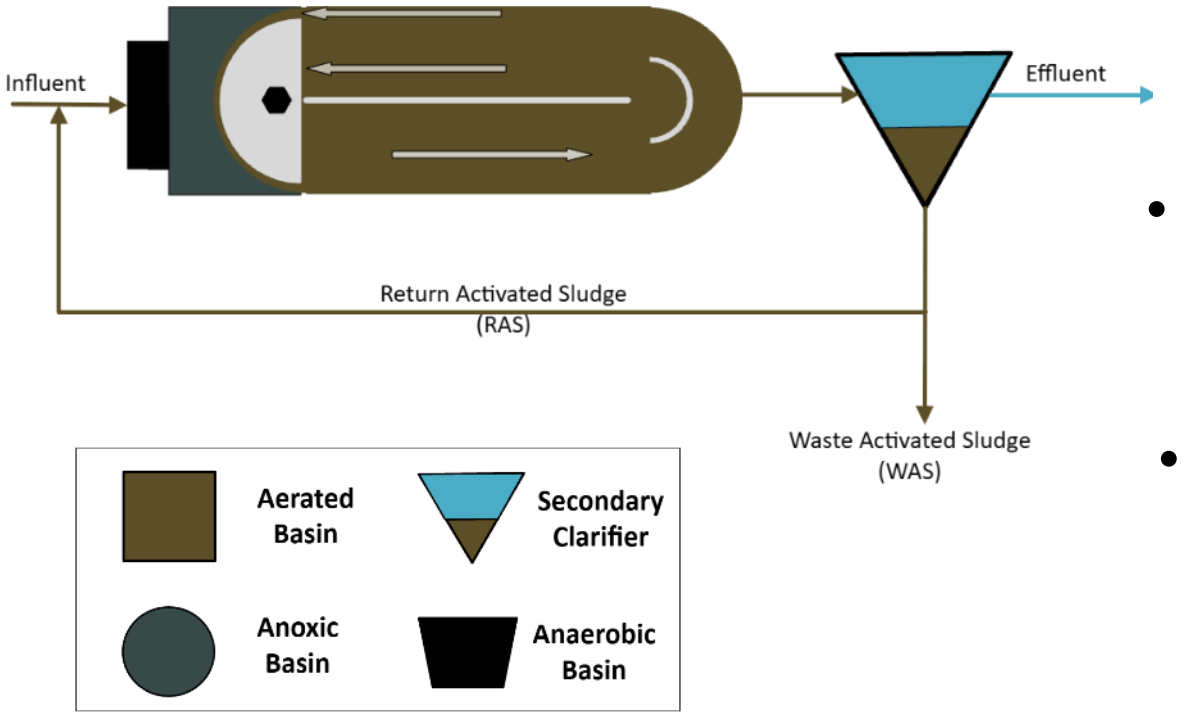
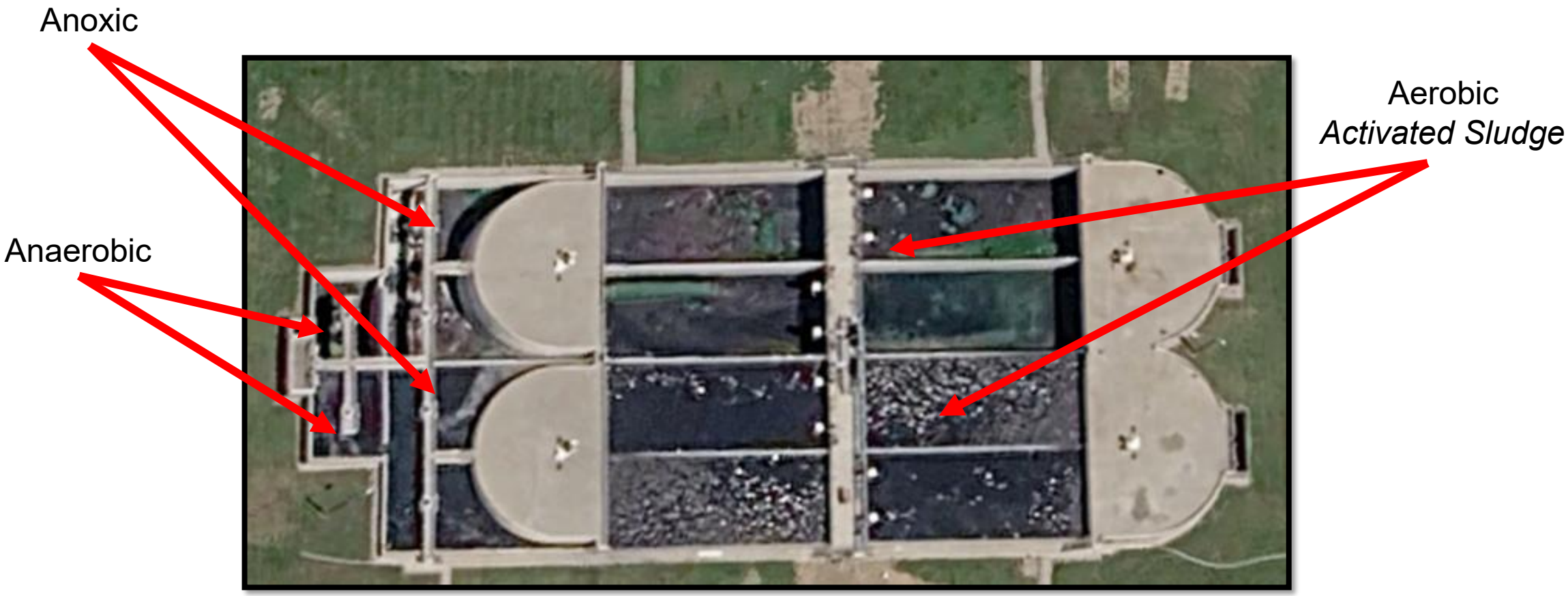
Nutrient Reduction – Nitrogen/Phosphorus

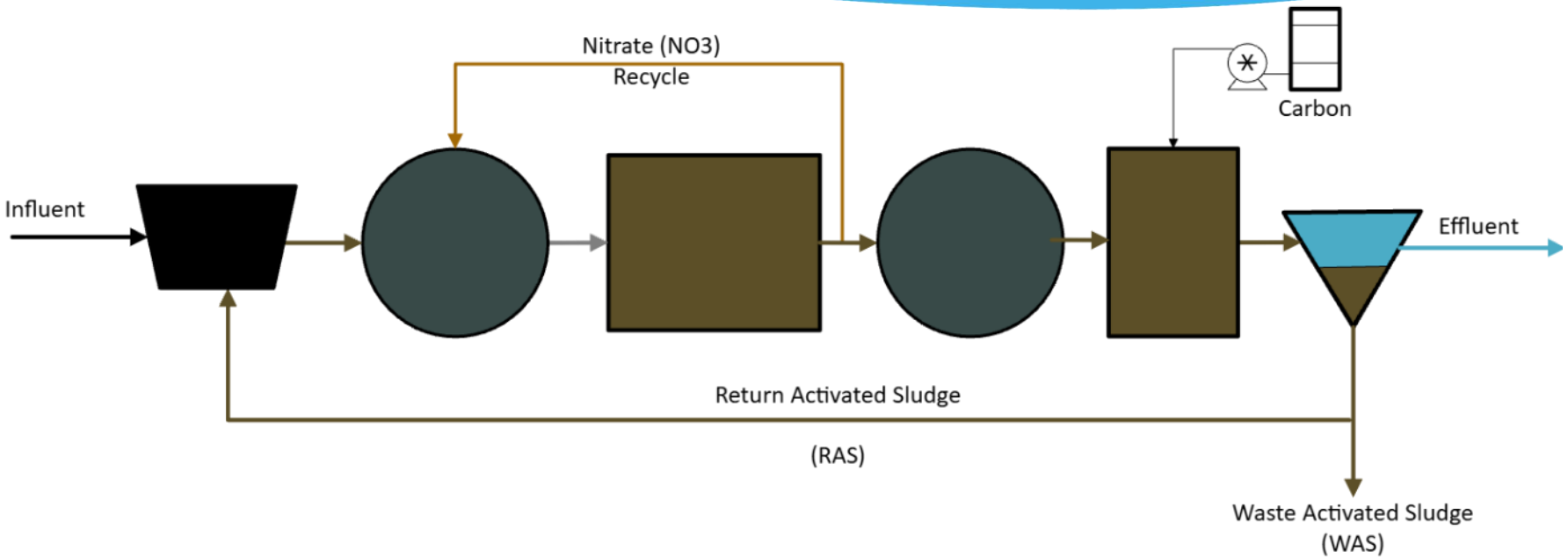


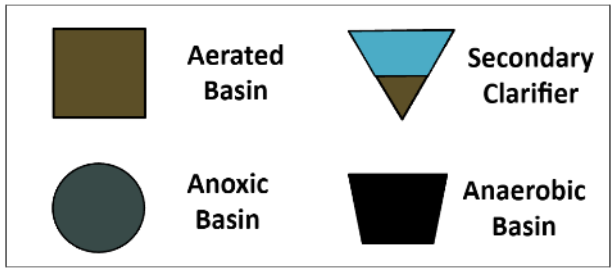
- Modified A2/O Process – kind of
  - Can also be in an oxidation ditch configuration
  - Air supplied by rotating brushes/discs
    - BOD and TN
- Advantages
  - Simultaneous Nitrification/Denitrification (SND)
    - Reduce ammonia and nitrate
  - Phosphorus reduction
- Disadvantages
  - Some limitation on degree of N/P reduction

Nutrient Reduction – Nitrogen/Phosphorus



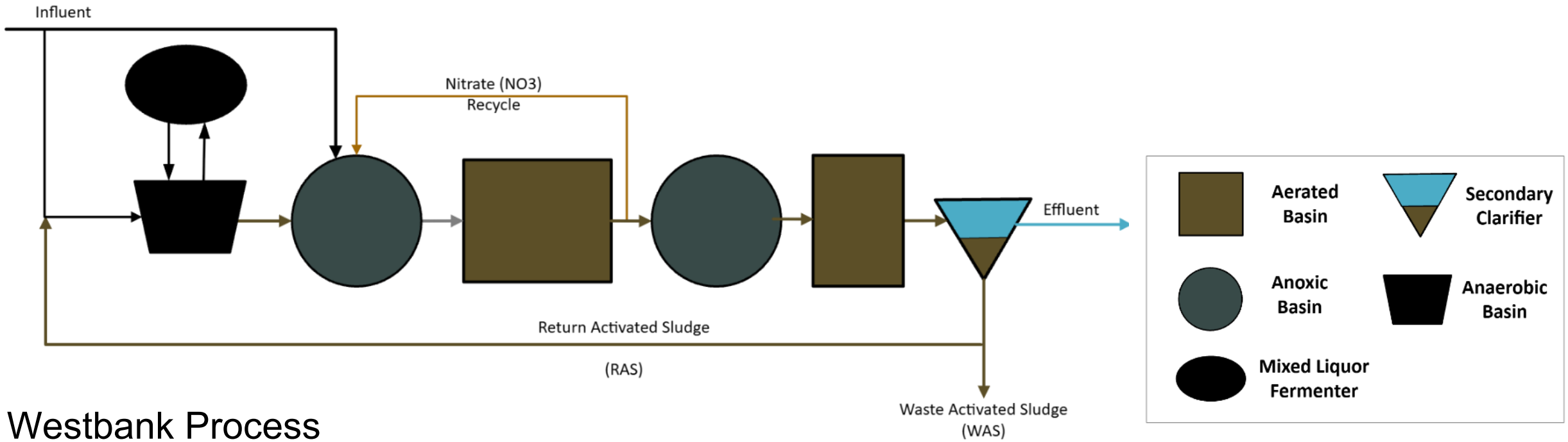
Nutrient Reduction – Nitrogen/Phosphorus





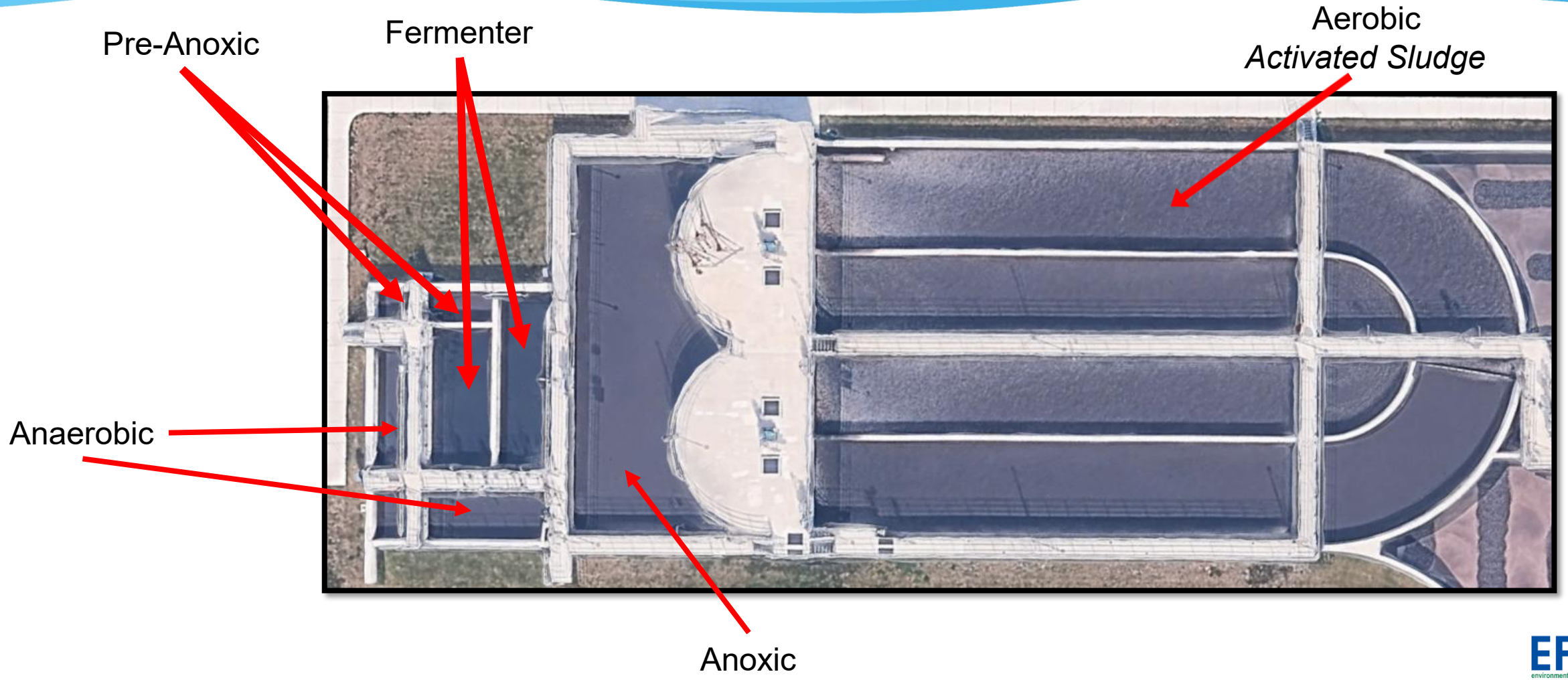
- 5-stage Bardenpho
  - Advantages
    - Low level BNR N and P in effluent
  - Disadvantages
    - Multiple basins – high capital cost
    - Multiple stages – more complex operation
    - Carbon addition - cost

Nutrient Reduction – Nitrogen/Phosphorus



- Westbank Process
  - Advantages
    - Low level BNR N effluent
    - Lower level BNR P in effluent due to fermenter
      - Fermenters referred to as a *sidestream* process
  - Disadvantages
    - Multiple basins – high capital cost
    - Multiple stages – more complex operation

Nutrient Reduction – Nitrogen/Phosphorus



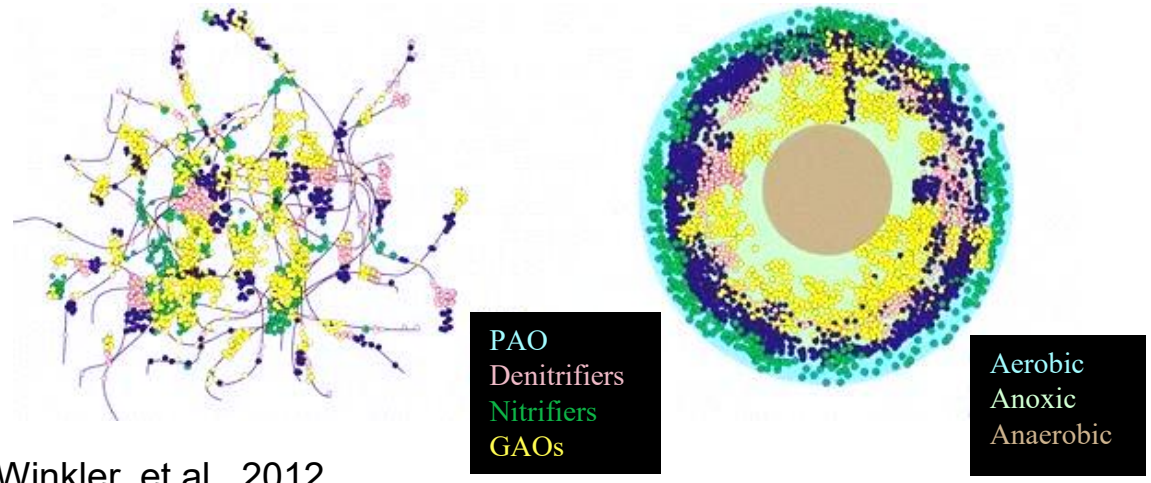
Nutrient Reduction – N&P – The Latest

- Aerated Granular Sludge (AGS)/Densified Activated Sludge (DAS)
  - *Intensification* of treatment
- Still have aeration and mixing, but control the *bug* characteristics
- Each forms granules that have:
  - Aerobic microorganisms
  - Anoxic microorganisms
  - Anaerobic microorganisms

  } "Glued" together by Extracellular Polymeric Substances (EPS)
  - Polysaccharides
  - Proteins
- Promote granules by
  - Feast/famine feeding of wastewater
  - Selectively wasting less dense floccular sludge
  - High shear
- Can run at higher concentration of sludge
  - Higher levels and volume of treatment in the same footprint
    - Lower capital and energy costs

Nutrient Reduction – N&P – The Latest

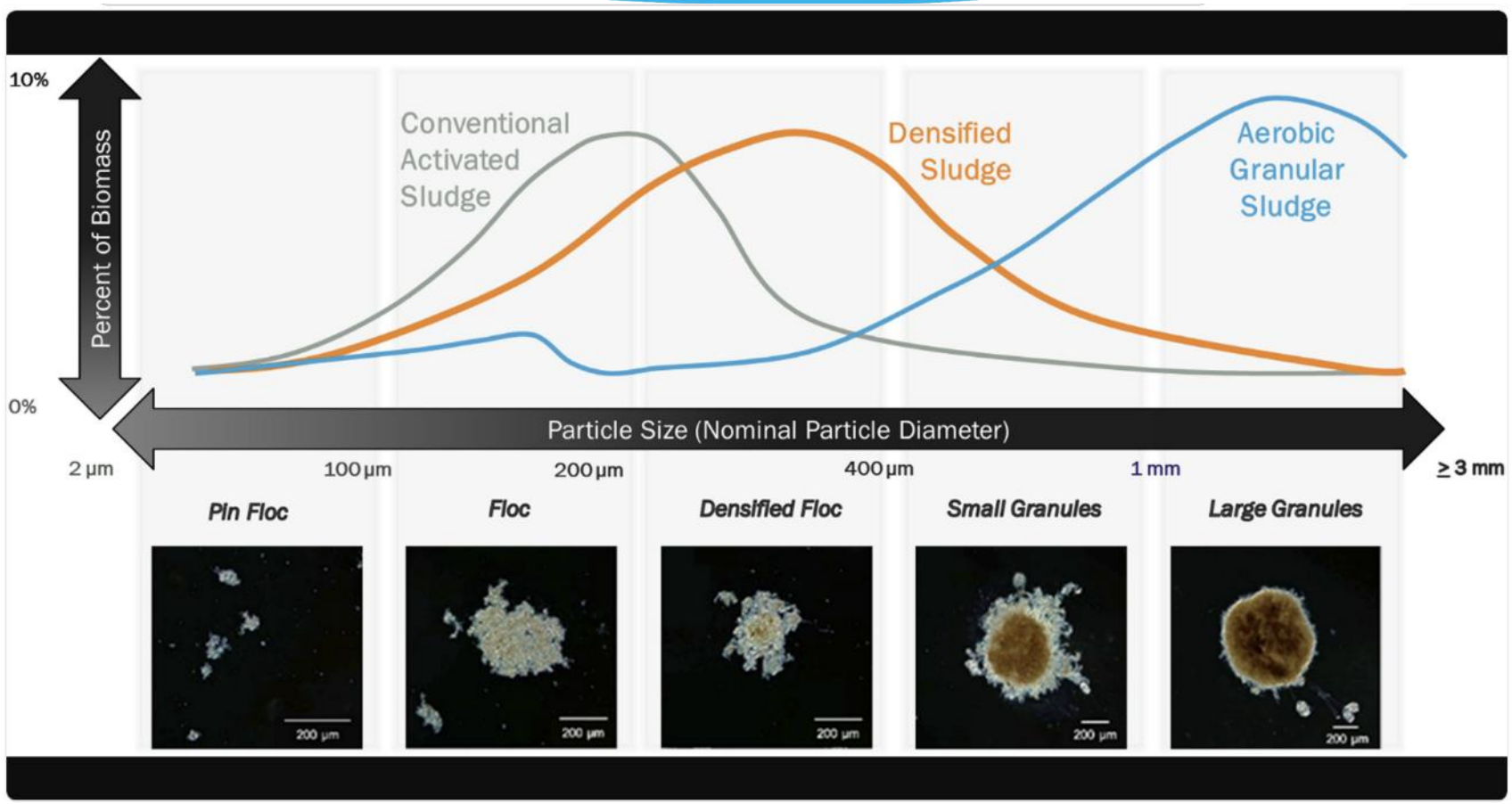
- Aerated Granular Sludge (AGS)
  - SBR-type operations
  - Mostly proprietary processes
  - More complex operation
  - Great settling sludge/TN and TP



Winkler, et al., 2012

- Densified Activated Sludge (DAS)
  - Forms smaller granules and flocs
    - Promote granules
    - Selectively waste flocs
      - Surface wasting
      - Hydrocyclone
  - Can retrofit some existing AS plants
  - Again, more complex operation
  - Good settling sludge/TN and TP

Nutrient Reduction – N&P – The Latest



Bauhs, et al., 2024

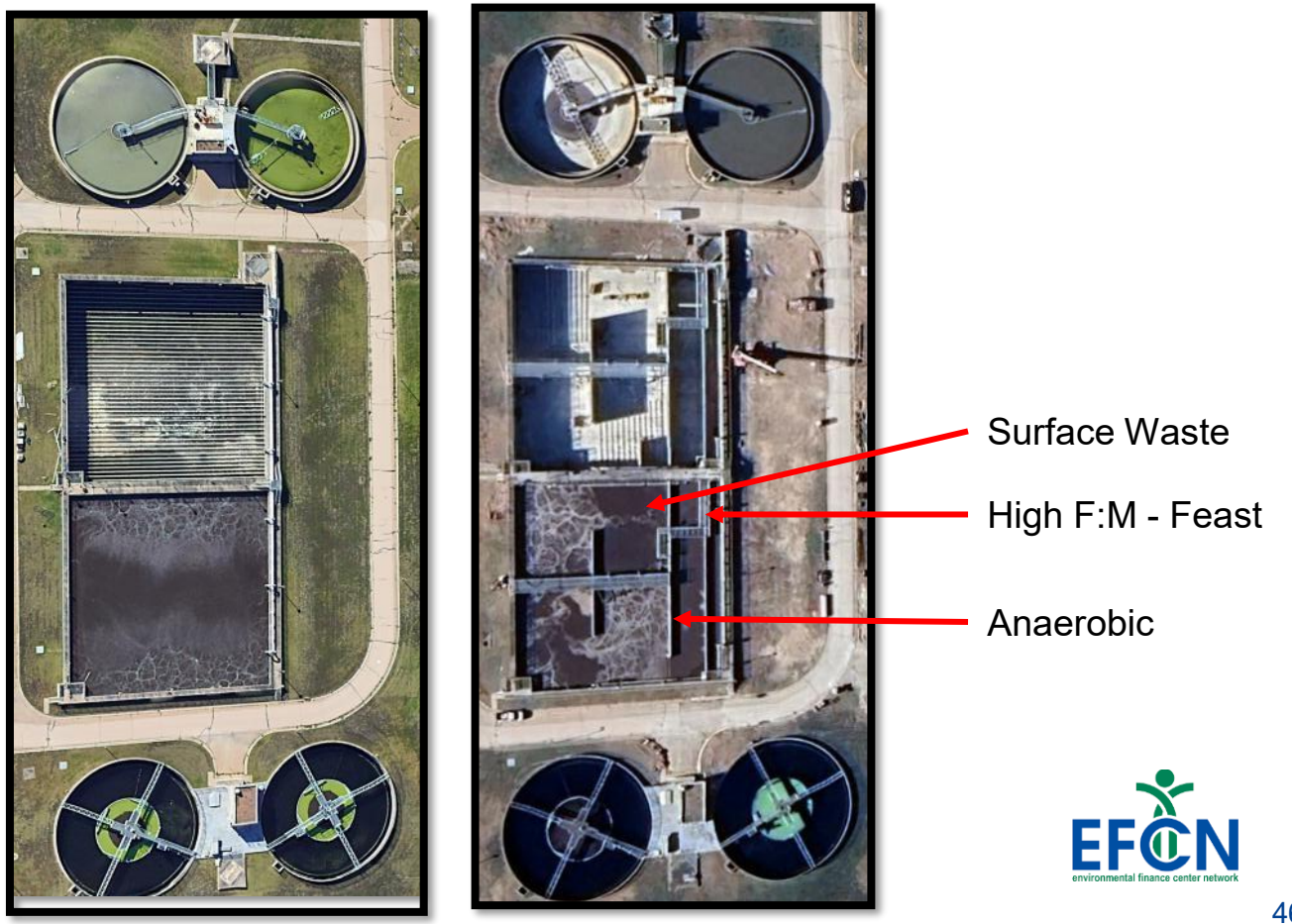
Nutrient Reduction – N&P – The Latest

Treatment Type	MLSS (mg/L)	Energy	Footprint
Conventional A/S	3,000	1.00	1.00
Densified Activated Sludge	5,000	20% Less	25-30% Less
Aerobic Granular Sludge	8,000	25-30% Less	25-30% Less

Nutrient Reduction – N&P – The Latest

Aerated Granular Sludge (AGS)

Densified Activated Sludge (DAS)



Like Baskin-Robbins…Activated Sludge Has Many Flavors

Questions/Comments!

Hot funk, cool punk, even if it's old junk it's still rock and roll to me

-Billy Joel – It's Still Rock and Roll To Me

BNR, MBR even if it's SBR it's still activated sludge to me

-Mike Tate

Thank You!

Mike Tate, PE

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Environmental Finance Center

EFCN environmental finance center network