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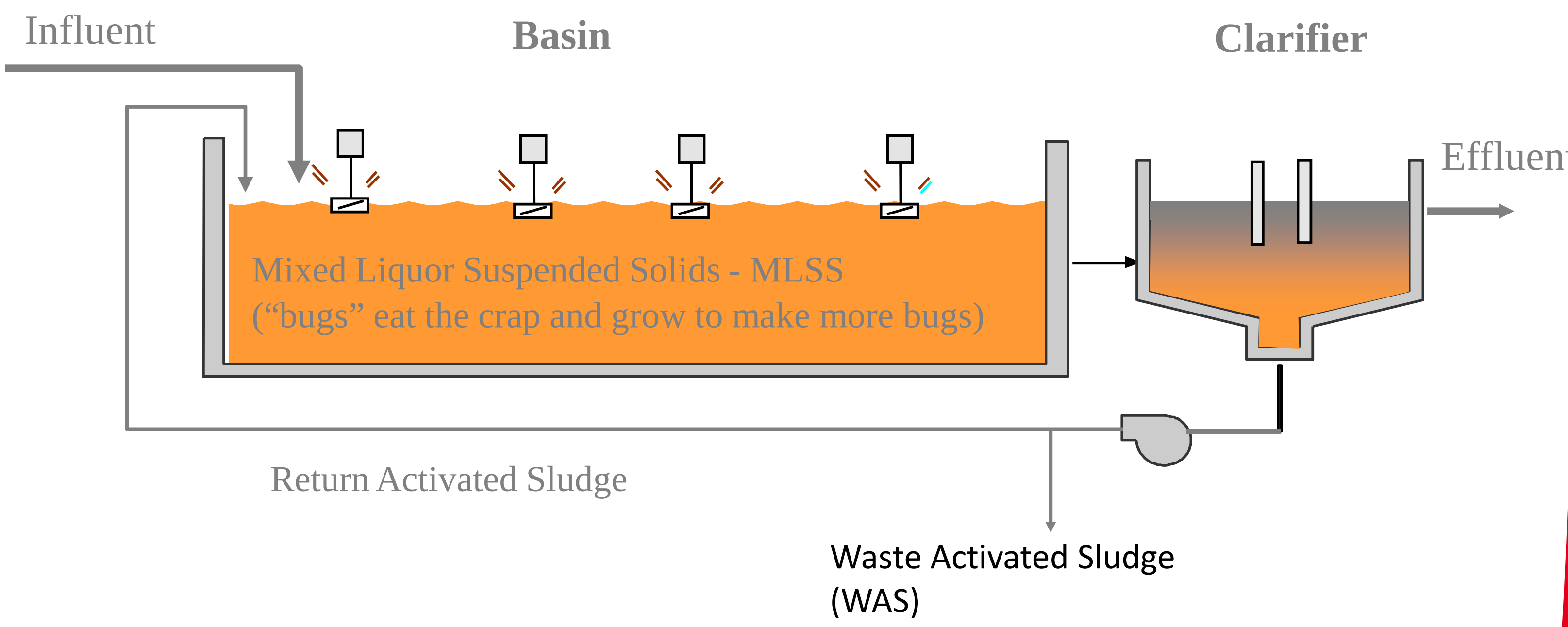
Biological Nutrient Removal

KRÜGER

VEOLIA WATER
Solutions & Technologies

Activated Sludge Process Flow Diagram



Treatment is managed by wasting excess "bugs" to control the average time MLSS stays in the system. Average time is the Sludge Residence Time (SRT) or Mean Cell Residence Time (MCRT) also known as Sludge Age.

Terminology

	Free Oxygen Present?	Nitrate (NO_3) Present?	Used For
Oxic/ Aerobic	Yes	--	Nitrification & BOD Removal
Anoxic	No	Yes	Denitrification & BOD Removal
Anaerobic	No	No	Biological Phosphorous Removal

Nutrient Removal Basics

- **Nitrogen**
  - Step 1: Nitrification
  - Step 2: Denitrification
- **Phosphorus**
  - Step 1: Release
  - Step 2: Uptake

How are N and P expressed?

Ammonia (NH_4^{+1}) OR ammonia Nitrogen (NH_4-N)

1 mg/L of NH_4^{+1} = 0.78 mg/L NH_4-N

Nitrate (NO_3^{-3}) OR Nitrate Nitrogen (NO_3-N)

1 mg/L of NO_3^{-3} = 0.23 mg/L of NO_3-N

orthophosphate (PO_4^{-3}) OR phosphate as P (PO_4-P)

1 mg/L of PO_4^{-3} = 0.33 mg/L of PO_4-P

- Know how Lab results are given. Wastewater labs may report the results differently than Water labs

Step 1 - Nitrification

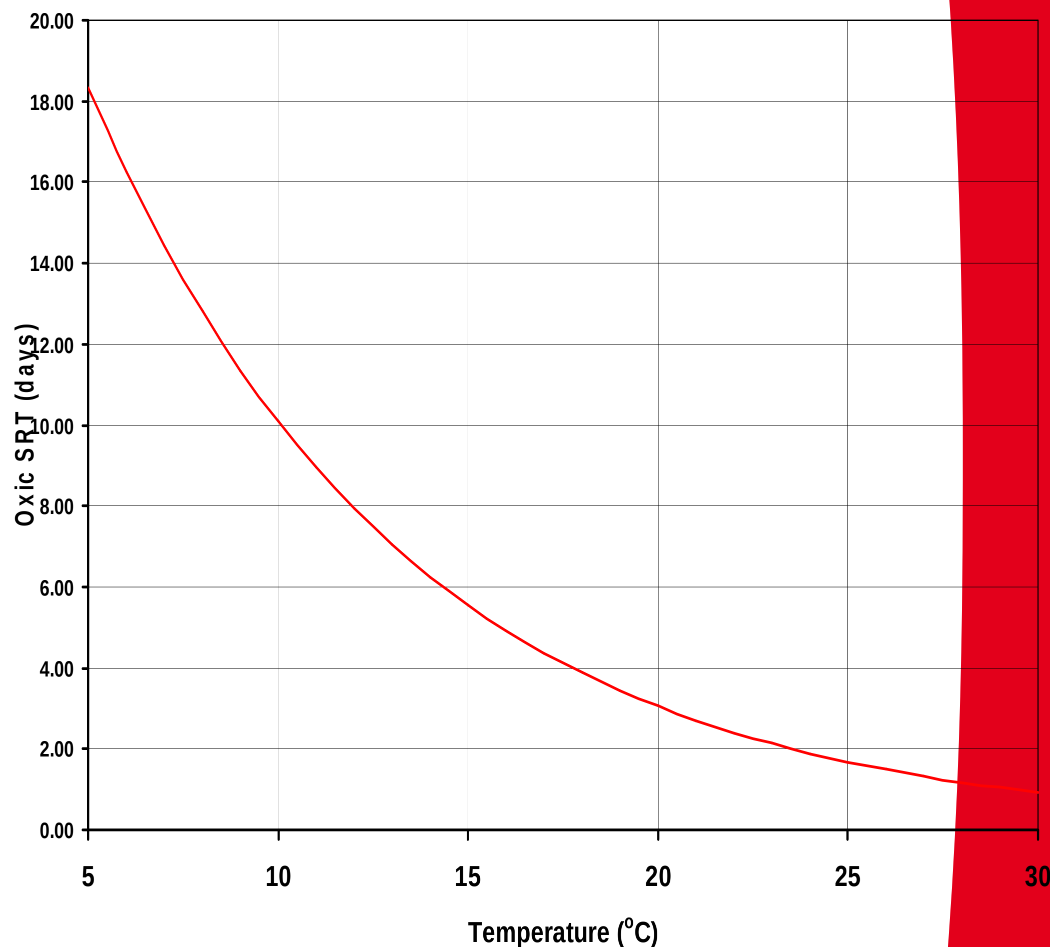
- Responsible Bacteria
  - Nitrosomonas & Nitrobactor (Autotrophs)
- Requires Oxygen
  - 4.6 mg O2 / mg NH4+-N
- Consumes Alkalinity
  - 7.1 mg $CaCO_3$ / mg NH_4^+-N
- Considerations
  - Temperature
  - Inhibition

Nitrification

>Adequate Sludge Retention Time (SRT) or Sludge Age is required for Nitrification.

> Nitrifying bacteria grow at a slow rate.

> Their growth rate is dependent on the temperature of the wastewater.



Temperature vs. Oxic Sludge Age for Nitrification

Step 2 - Denitrification

- Responsible Bacteria: Heterotrophs
- Requires BOD

  NO_3^- replaces Oxygen (electron acceptor)

  Oxygen Credit (2.9 mg O_2/ mg NO_3^-)
- Generates Alkalinity

  3.6 mg $CaCO_3$ / mg NO_3^-
- Consideration: BOD's Biodegradability   COD/TKN - Ratio (> 6-8 mg COD/ mg NO_3^-)

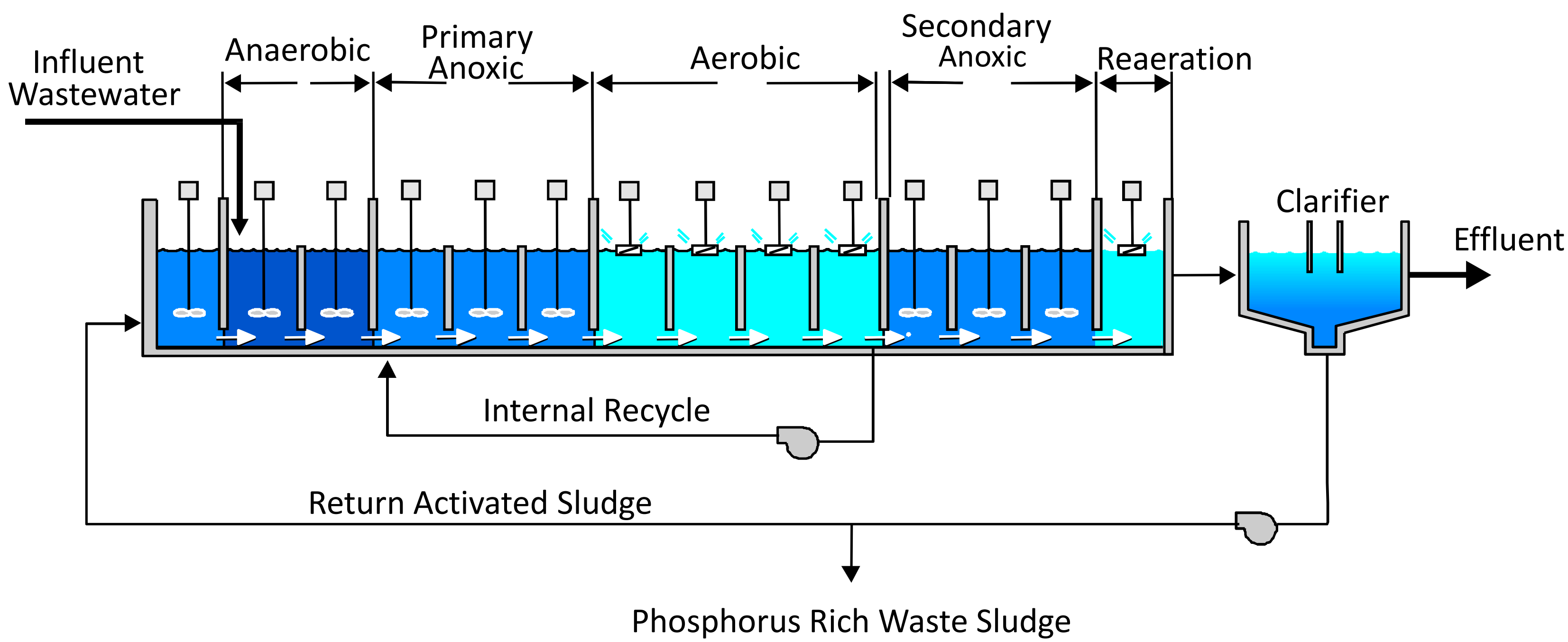
Benefits to Denitrification

- Comply with Effluent Requirements
- Saves Energy (~15%)
- Regains Alkalinity
- Improves Performance of Secondary Clarifiers
- Environmental Impacts

Challenges of Nitrogen Removal

- Influent Nitrogen is in the form of NH_4^+
- O_2 required in Nitrification to convert NH_4^+
- BOD is also removed with the addition of O_2
- BOD is required for Denitrification to convert NO_3^-

Typical 5-Stage for Bio-P and N removal



Meeting Low Nitrogen limits

Total Nitrogen (TN)

- NH_3-N
- NO_3-N + NO_2-N
- Organic N (**rDON** = refractory dissolved organic nitrogen)
- N in effluent TSS

Effluent Total Nitrogen

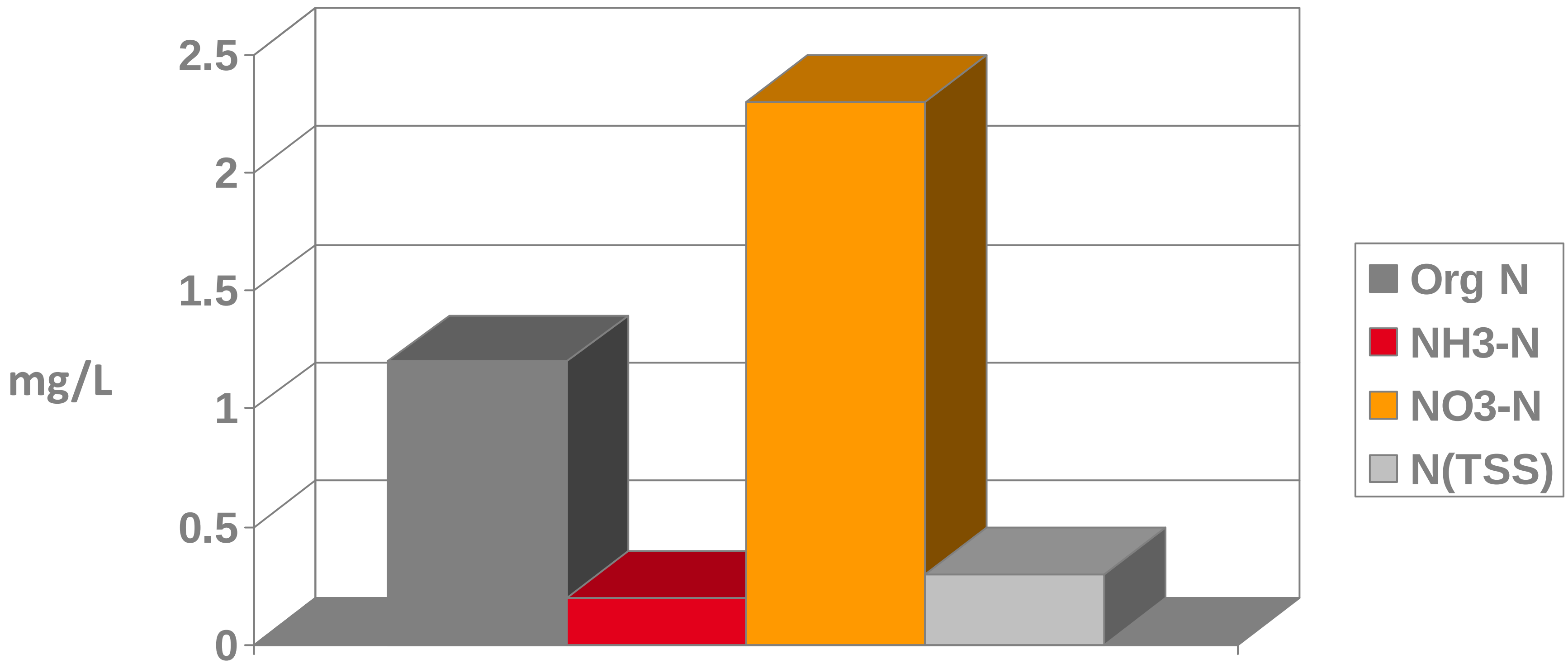
What is the limit of technology (LOT)?

- Effluent TSS needs to be low
  - Typical **6 to 8%** N content
  - N in effluent solids = (5 mg/L)(0.07) = 0.35 mg/L
- Refractory Soluble organic (rDON)
  - < 0.7 mg/L – No sludge dewatering or aerobic
  - >1.2 mg/L – Anaerobically Digested Sludge dewatering

For effluent TN < 3 mg/L

1 to 2 mg/L of TN not easily removed

Breakdown for Effluent TN < 5 mg N/L



Phosphorous Removal

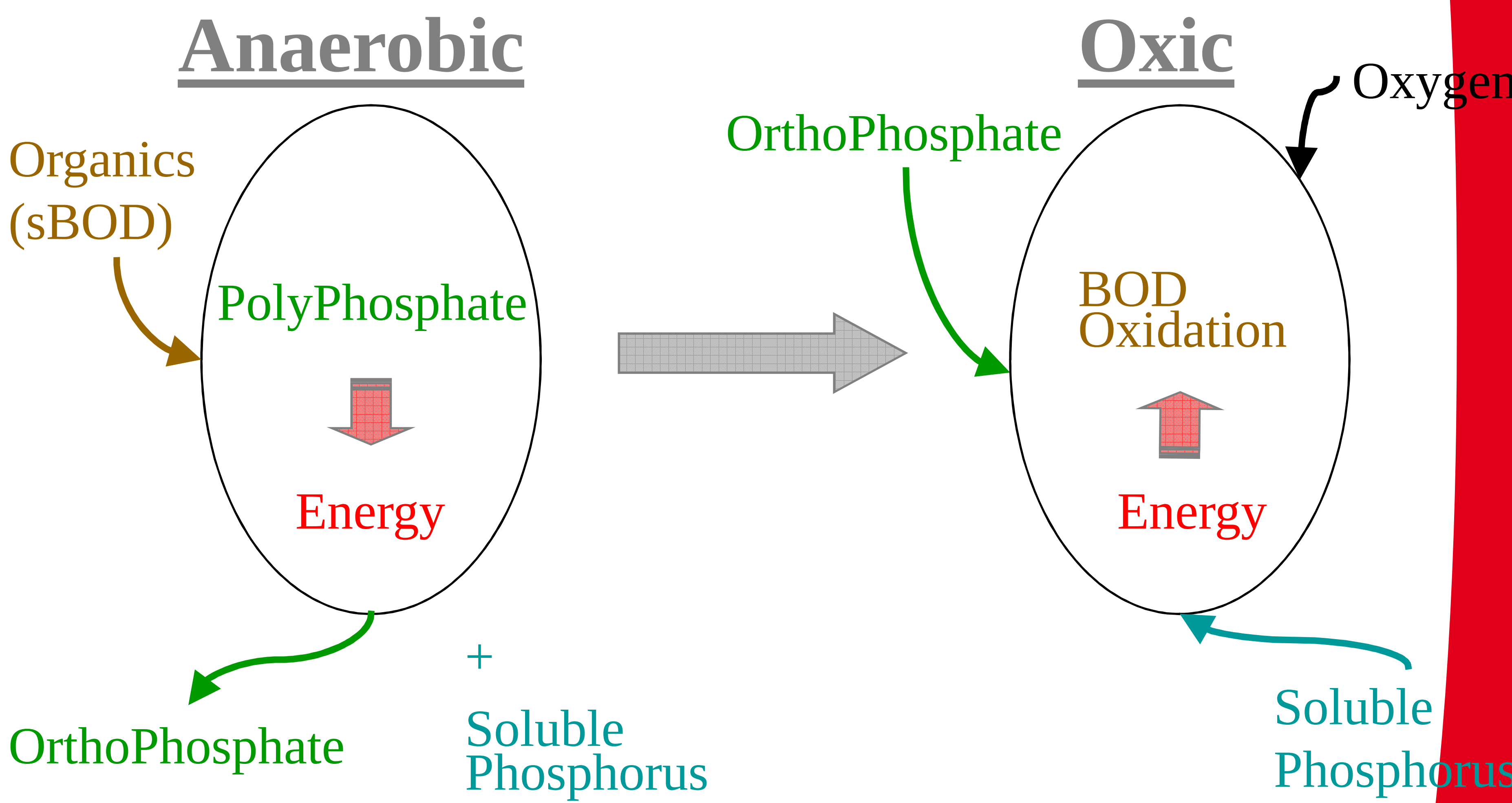
- Biological
- Chemical

Biological Phosphorus Removal

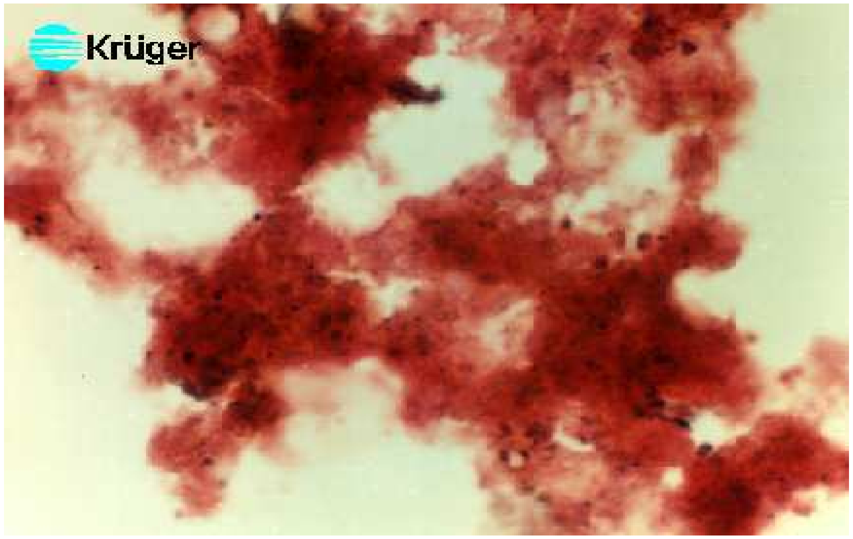
- Phosphate Accumulating Organisms (PAOs):
  - *Heterotrophic*: Require external carbon source.
  - *Facultative*: Thrive in both anaerobic and aerobic conditions.

- BPR Process requires:
  - Soluble carbon source (BOD).
  - Strict anaerobic conditions (no nitrates).
  - Anaerobic/aerobic cycling.

Biological Mechanism of P Removal

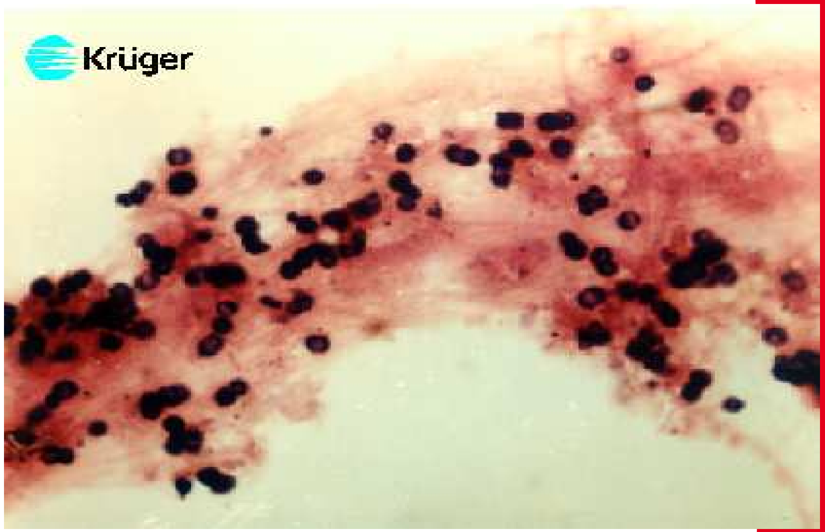


Polyphosphate shown in an A/O plant WAS sample



CONTROL SLUDGE
(NO GRANULES)

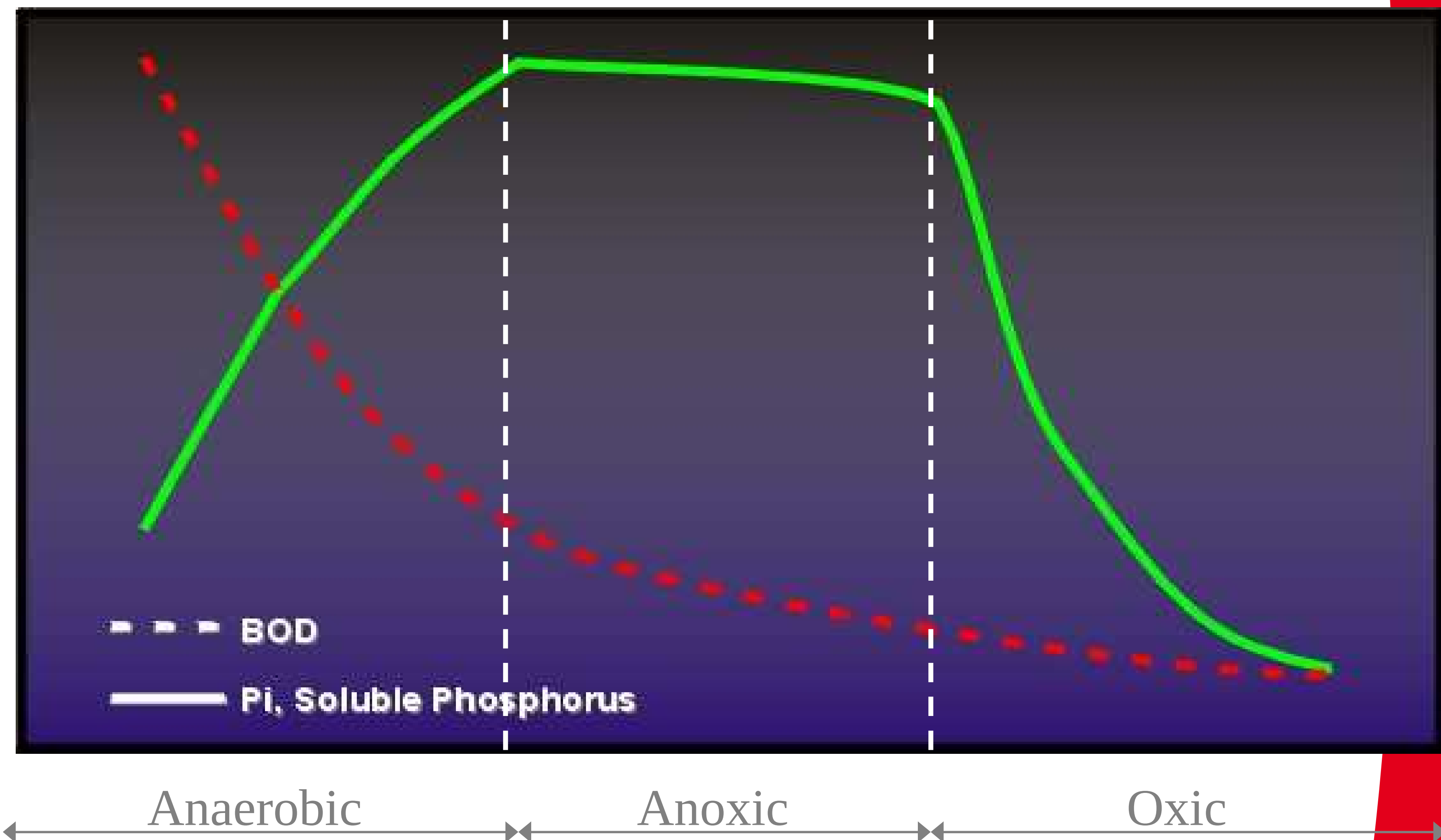
1000 x



POLYPHOSPHATE
(GRANULES)

1000 x

Phosphate and BOD Profiles



Anaerobic Selector Technology for Bio-P

Principle:

The microorganism which accumulates the majority of the available food will dominate an activate sludge culture.

Biological Phosphorus Removal

KEY CONSIDERATIONS

1. Influent Soluble BOD/P ratio ? If this is high (>25) system can be very forgiving.

2. Eliminate/minimize electron acceptors to anaerobic selector

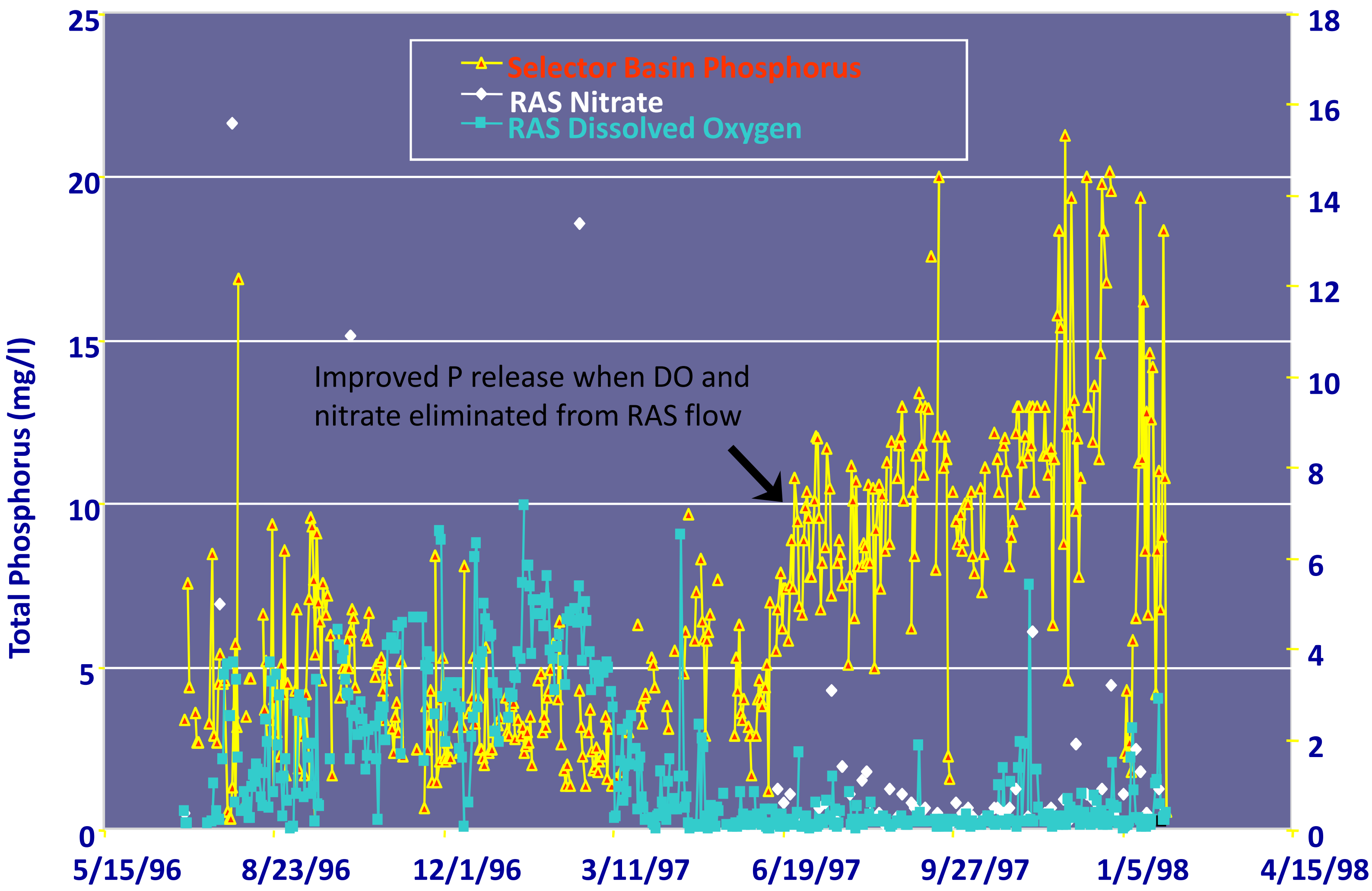
   - avoid adding DO

   - NO3 in concentration in selector feed stream?

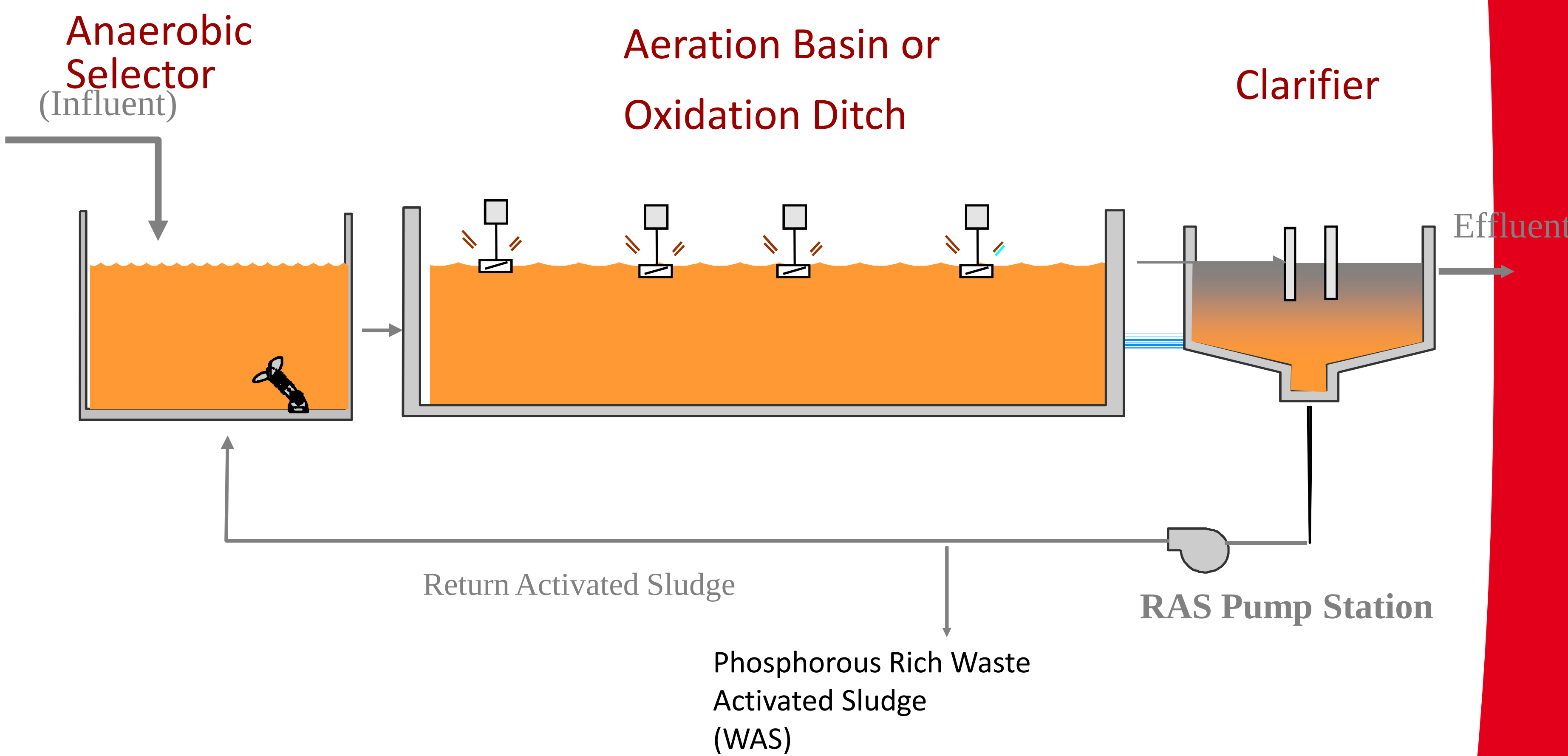
   - recycle streams (digestion releases part of bio-P)

3. What is the design MCRT? Is sludge going to be adequately wasted? Will there be a bottleneck?

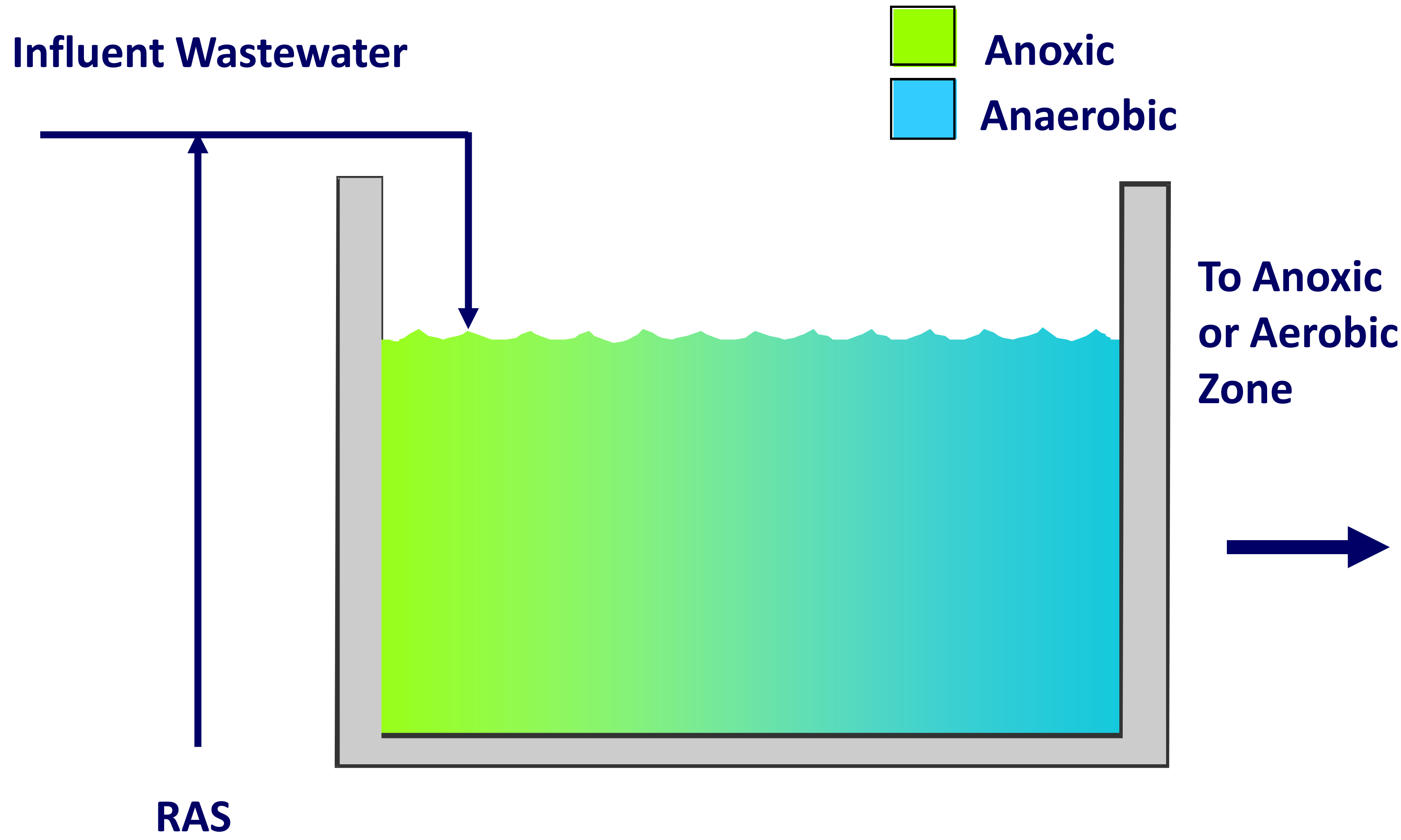
Hollister, MO P-Release Profile



Anaerobic Selector Technology

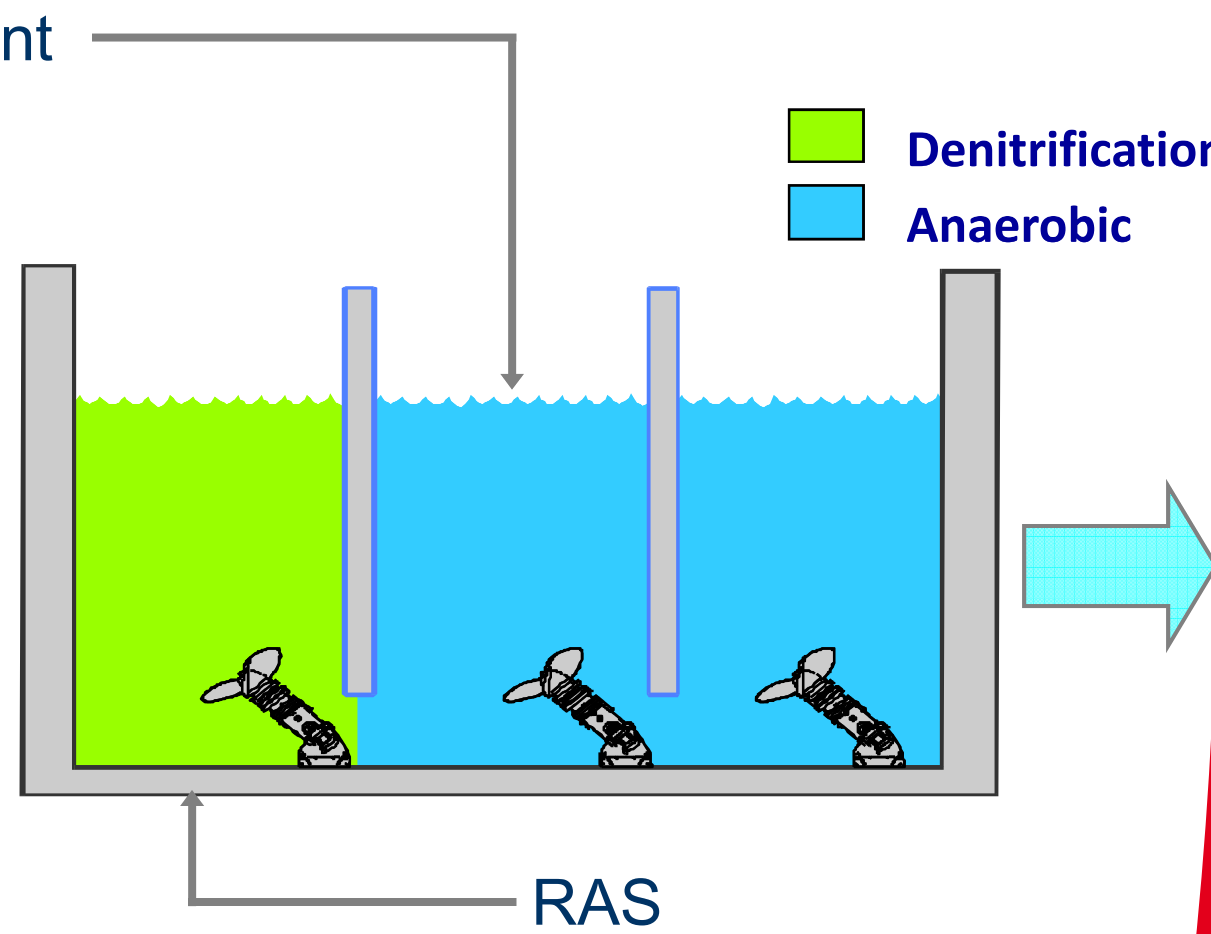


Single Stage Selector



Block and Hong Anaerobic Selector Configuration

- Excellent for low influent BOD/TP
- Avoid consumption of influent soluble carbon by removing residual NO_3



Elizabethtown, PA – Block and Hong Anaerobic Selector

Block and Hong
Anaerobic Selector

Effluent TP 0.2 to 2 mg/l from Bio-P Removal

Effluent P achieved depends on influent soluble BOD in the form of VFAs (Volitale Fatty Acids)

P in effluent TSS can be significant from Bio-P removal

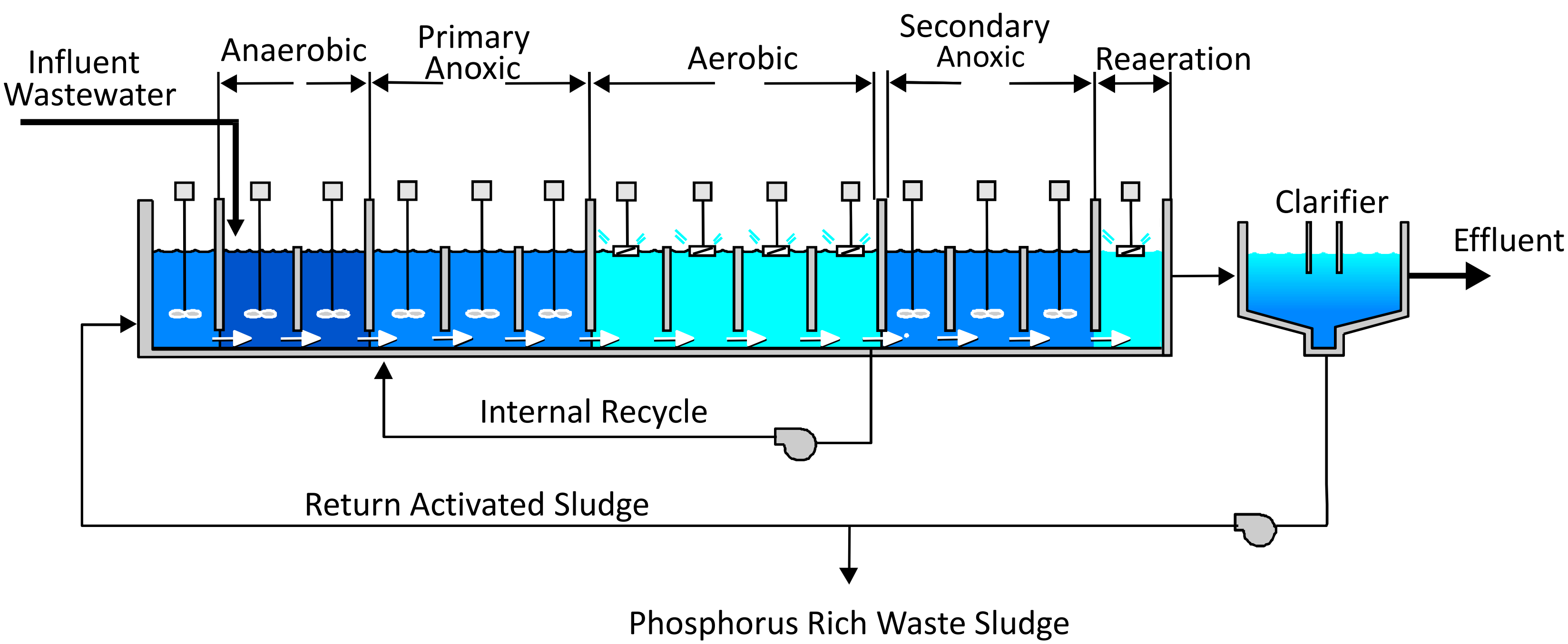
For Low P - Effluent TSS needs to be very low

- Normal activated sludge P content is **2**%
- Typical **4%** on dry basis
- As high as **8%** referenced in literature

TP in effluent solids = (5 mg/L)(0.04) = 0.2 mg/L

Applications

Typical 5-Stage for Bio-P and N removal



Primary Anoxic Zones

- Internal Recycle returns nitrate ahead of the oxic zone where BOD is available for Denitrification
- Utilizes BOD available in the influent
- Recycle Rates typically 200 to 400% of influent Flow
- Typically can achieve 60 to 80% removal of influent TN
- 6 to 10 mg/L effluent TN

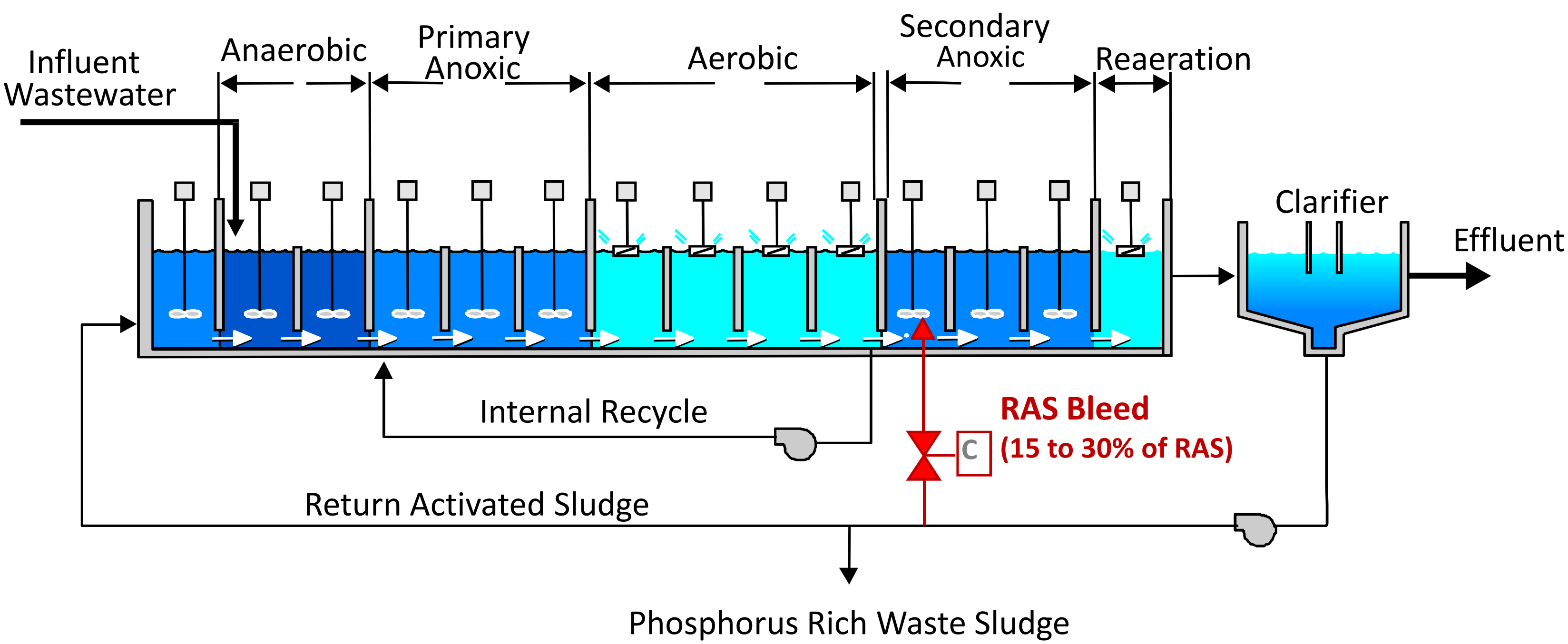
OVERVIEW of Secondary Anoxic Zones

- Added downstream of the aerobic (nitrification stage) in MLE, A20, processes, etc
- 4 or 5-Stage Process (A^NO)
- Typically yields 3 to 5 mg/l effluent TN
  (85 to 93 % removal of oxidizable influent TKN)
- Low specific denitrification rates (endogenous) can result in large volumes
  - Rates 5 to 10 times lower than primary anoxic zones
- Carbon limitations may necessitate supplemental carbon addition (i.e. methanol, acetate)
  - ex: high TKN return streams from anaerobic or thermophilic sludge processing

OVERVIEW of Secondary Anoxic Zones

- Typically add a supplemental carbon
- Achieves 2 to 4 mg/L effluent TN
- The most common is methanol
- Utilized only by Methylotrophs
- Typical ratio 2.8 to 3.1 mg MeOH / mg NO3
- Current cost is $1.25/gal
- Has been $2.50/gal
- Typical detention time is 2 to 2.5 hours
- Usually followed by an aerobic sage to burn off excess methanol

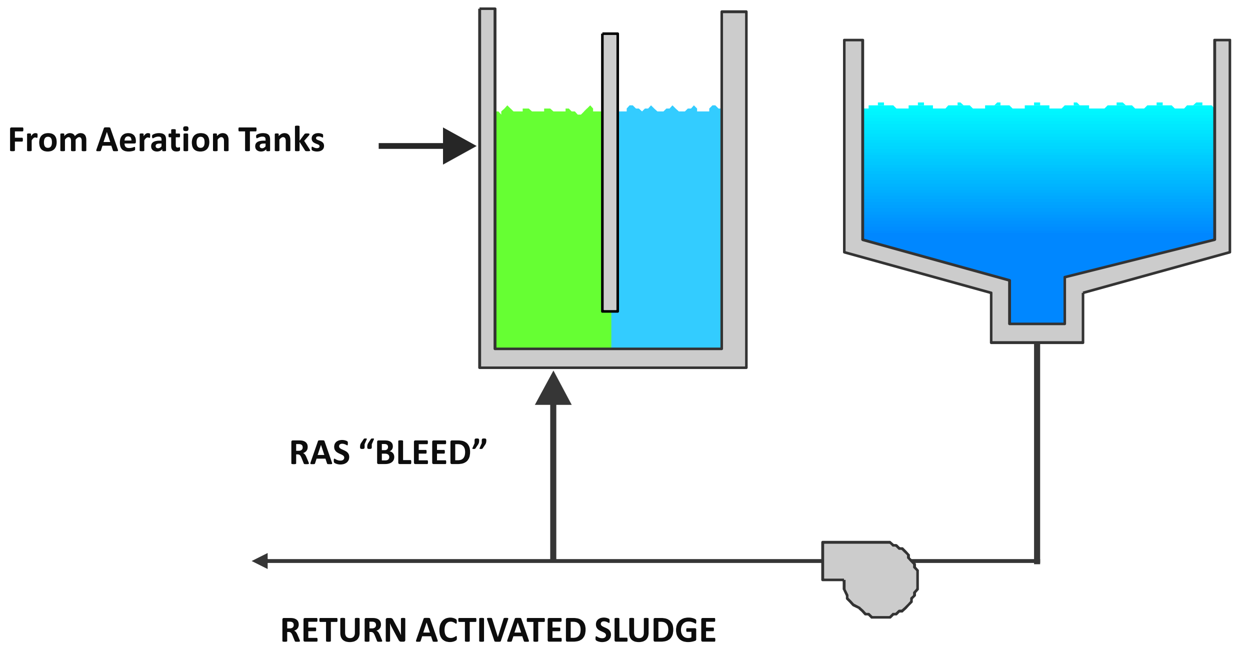
Secondary Anoxic Zone Enhancement



Secondary Anoxic Zone Enhancements

- RAS bleed technology (ADD
  - Smaller footprint
  - Reduce or eliminate supplemental carbon
  - More efficient nitrogen removal
- TN < 5 mg/L without supplemental carbon

Kruger Secondary Anoxic Zone



Expected Benefits of RAS Addition

- Increases working biomass
- Enhances specific denitrification rate (SDNR)
  - Additional substrate
  - Enzymatic adaptations completed


DERRY TOWNSHIP
WWTP
Primary
Anoxics
Oxic
Zones
Secondary
Anoxics

DERRY Township An/O Process

Anaerobic Digesters recycle ammonia back to head of plant

Low BOD/TN ratio in influent (< 3.9 mg/L BOD / mg/L N)

Enhanced DO control based on ammonia concentration in process (i.e Like STAC - Load Based DO control

RAS Bleed to Secondary Anoxic Zone to improve N removal

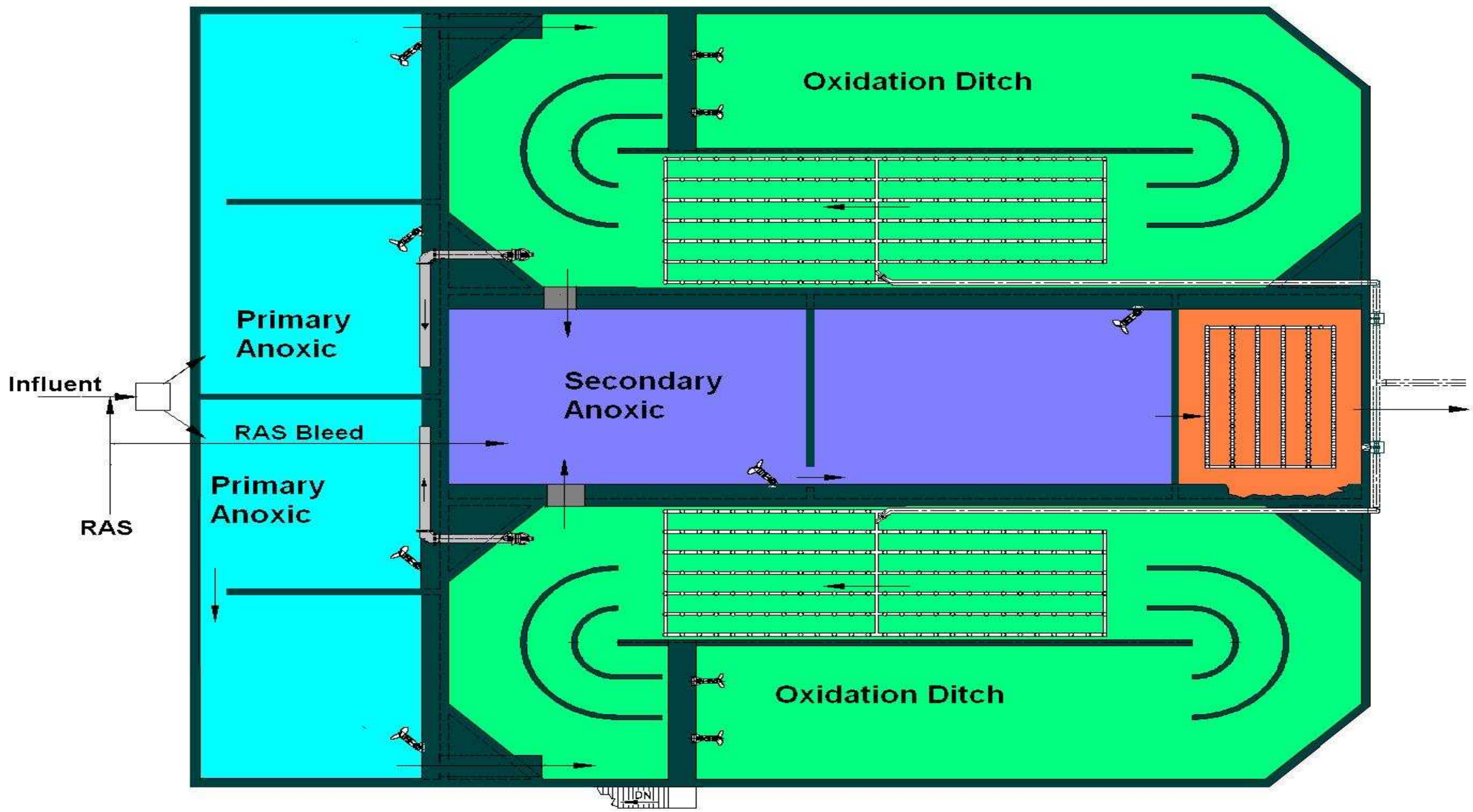
DERRY Township An/O Process

	Primary Effluent	Final Effluent	Unit
Average Daily Flow	6.3	--	MGD
Peak Daily Flow	18	--	MGD
BOD	152	< 15	mg/l
TSS	81	< 15	mg/l
NH3-N	30	< 1.0	mg/l
TN	--	< 7.0*	mg/l
Temp (min/max)	8/20	--	°C

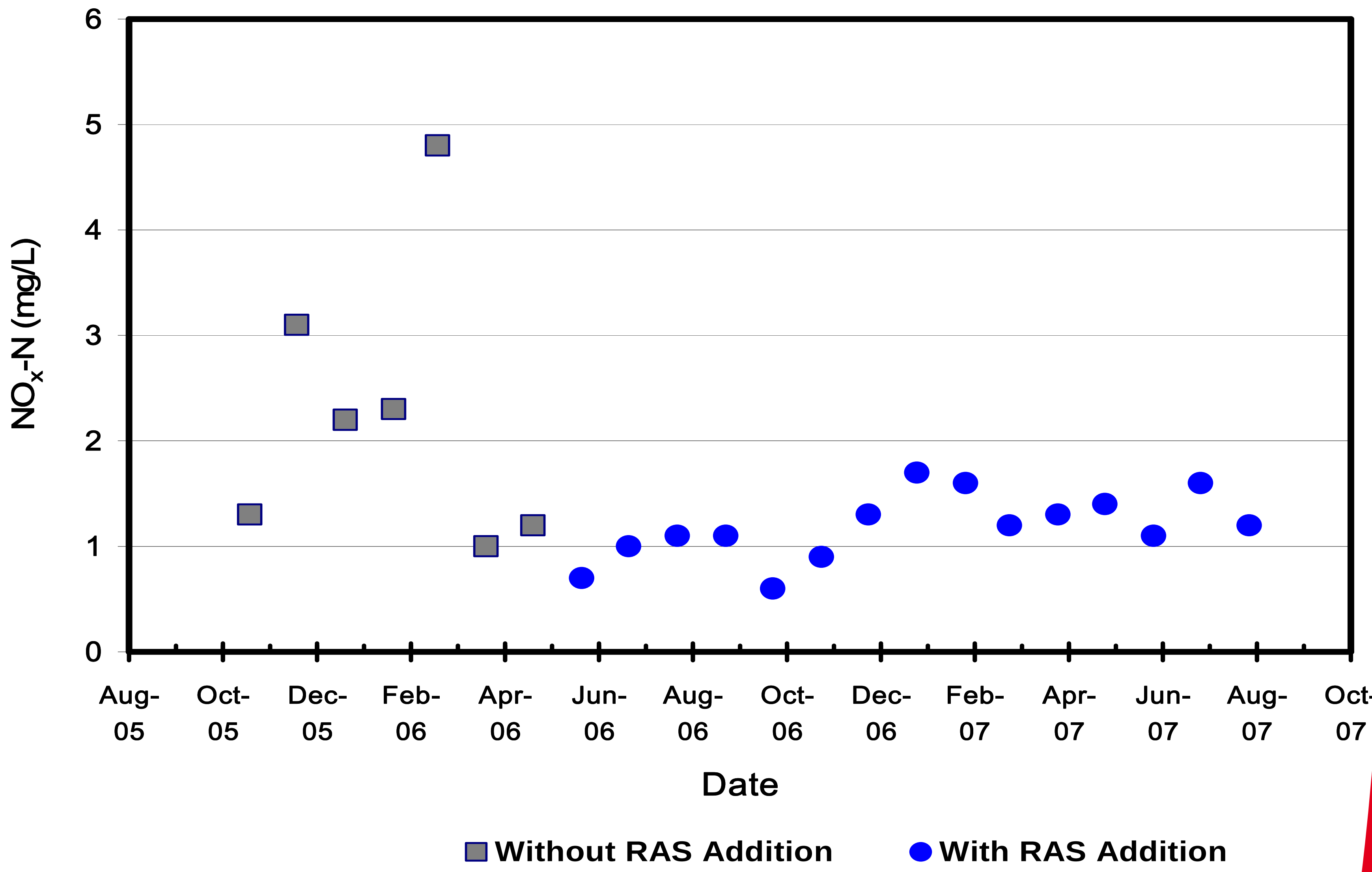
Derry Township RAS Bleed Study

	With RAS Bleed	W/O RAS Bleed
RAS Bleed (% of RAS Flow)	25	--
MLSS Increase in Secondary Anoxic Zone (mg/L)	650 (≈ 20% over Oxic Zone)	--
Soluble BOD in RAS (mg/L)	11	--
SDNR in 1st Stage of Secondary Anoxic Zone (mg NO3-N / g VSS•hr)	0.76	0.62
NO3-N Removed in Secondary Anoxic Zone (lbs/day)	158	109
Effluent TN (mg/L)	3.5	5.3*

Branford, CT – 6.5 MGD An/O



Branford, CT



6
5
4
3
2
1
0
NO_x-N (mg/L)
Aug-05
Oct-05
Dec-05
Feb-06
Apr-06
Jun-06
Aug-06
Oct-06
Dec-06
Feb-07
Apr-07
Jun-07
Aug-07
Oct-07
Date
Without RAS Addition
With RAS Addition

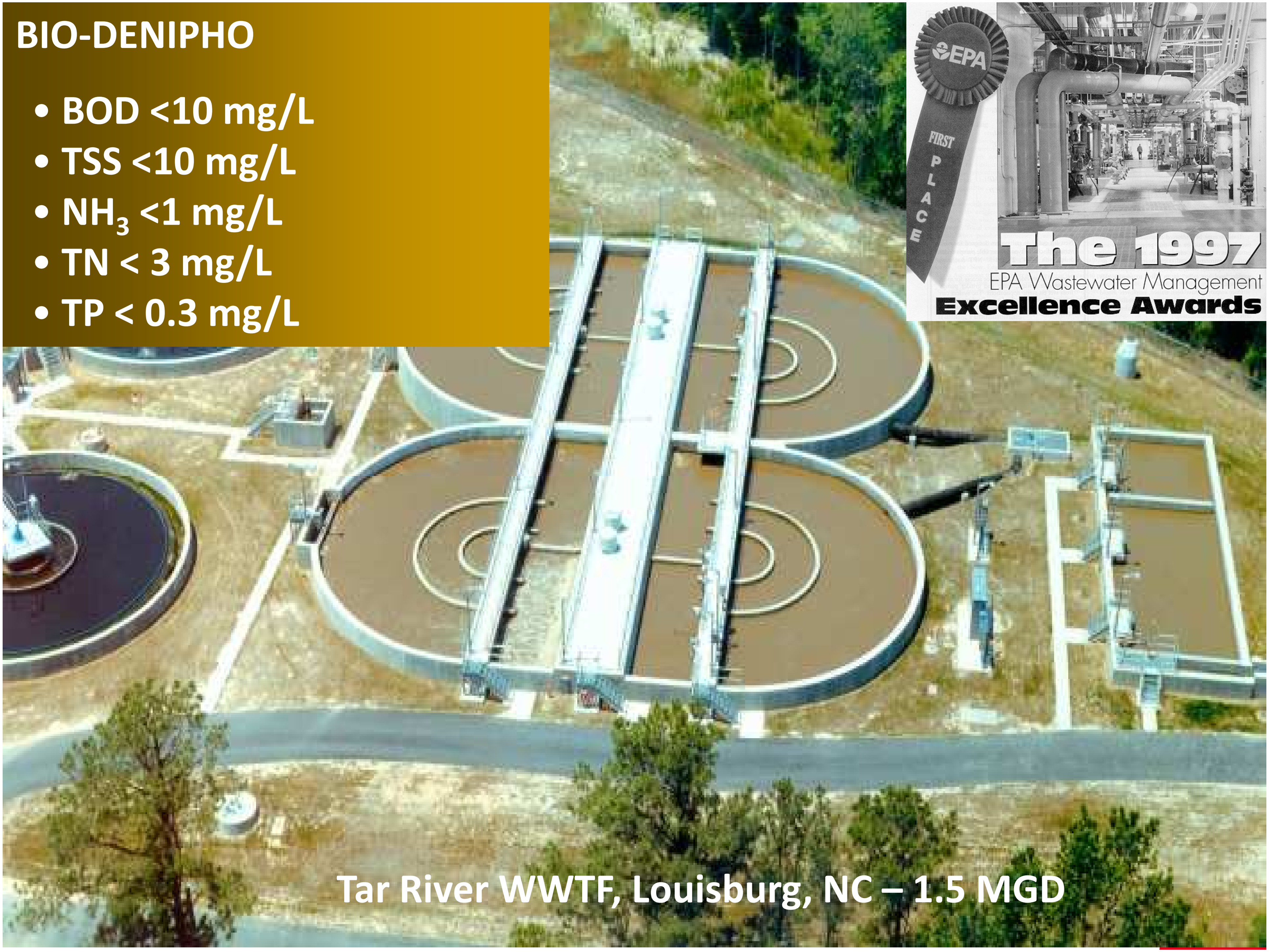
BIO-DENIPHO Technology

Two or more phased ditches with an Anaerobic Selector to facilitate bio-P removal.

The ditches alternate between oxic and anoxic conditions in order to achieve efficient and flexible nitrogen removal without internal recycle pumps.

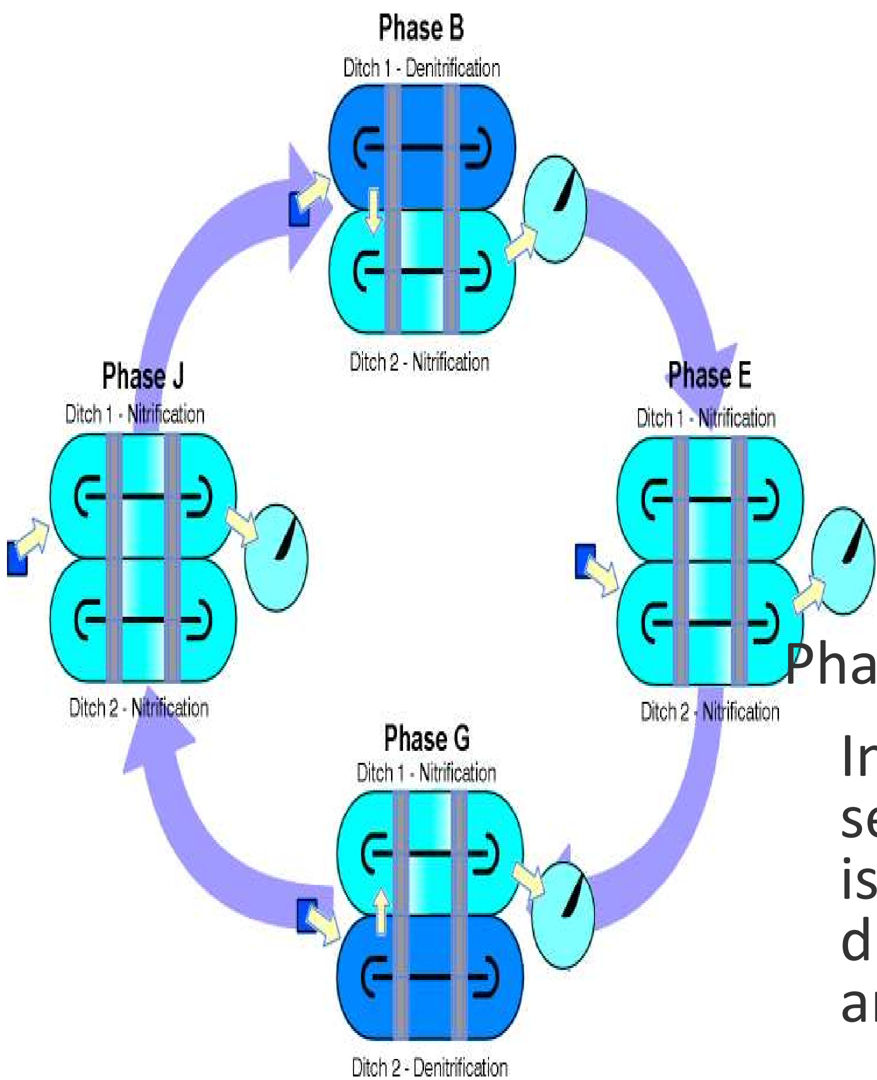
BIO-DENIPHO

- BOD <10 mg/L
- TSS <10 mg/L
- NH_3 <1 mg/L
- TN < 3 mg/L
- TP < 0.3 mg/L



Tar River WWTF, Louisburg, NC – 1.5 MGD

BioDenitro/BioDenipho Phasing



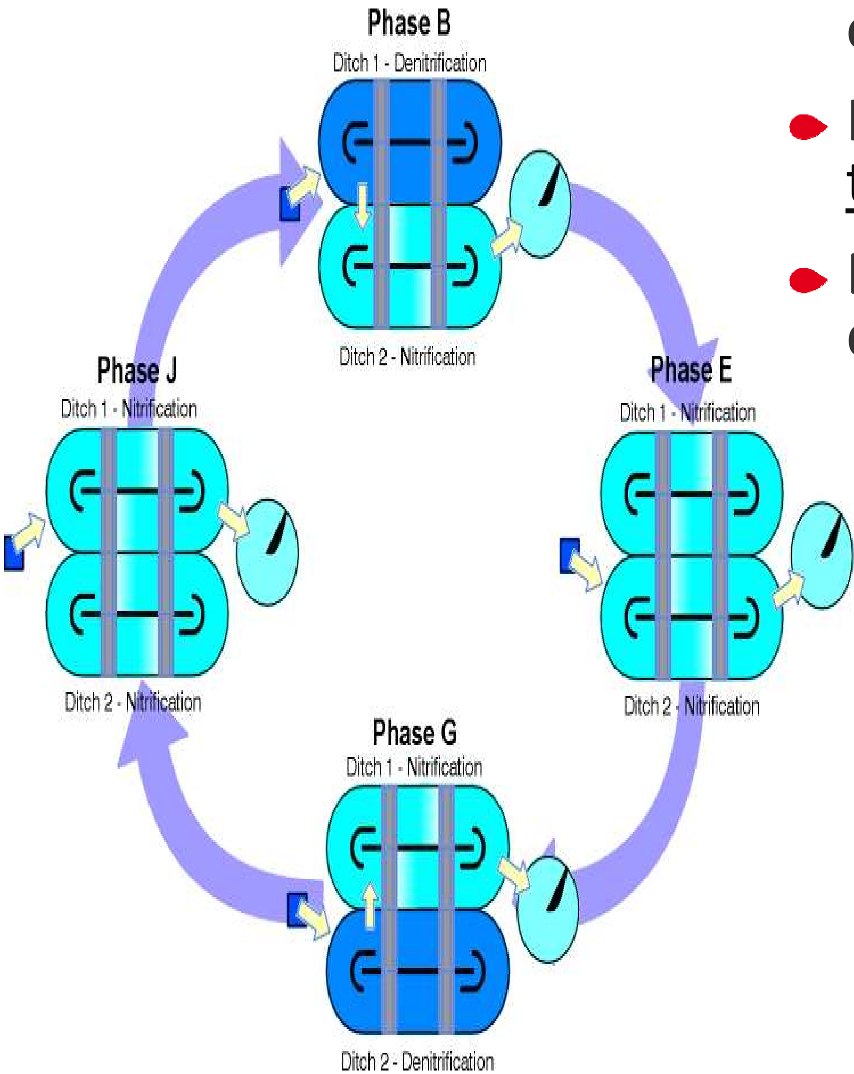
Phase B and G

Influent is directed to the anoxic ditch providing BOD for denitrification reducing the NO_3^- concentration (produced in the previous phase). Flow is then directed to the oxic ditch where NH_4^+ and remaining BOD is removed.

Phase E and J

Influent is redirected to the second ditch. The first ditch is isolated. Both ditches nitrify during this phase to nitrify NH_4^+ and remove BOD.

BioDenitro/BioBenipho



- Phases G and J are mirror images of Phases B and E.
- Historically Phasing was fixed time length controlled by PLC
- Effluent is generally always directed out of an Oxic Ditch.
  - Typical Performance
    - BOD < 10 mg/L
    - TSS < 10 mg/L
    - TN < 5 mg/L
    - TP < 1 mg/L

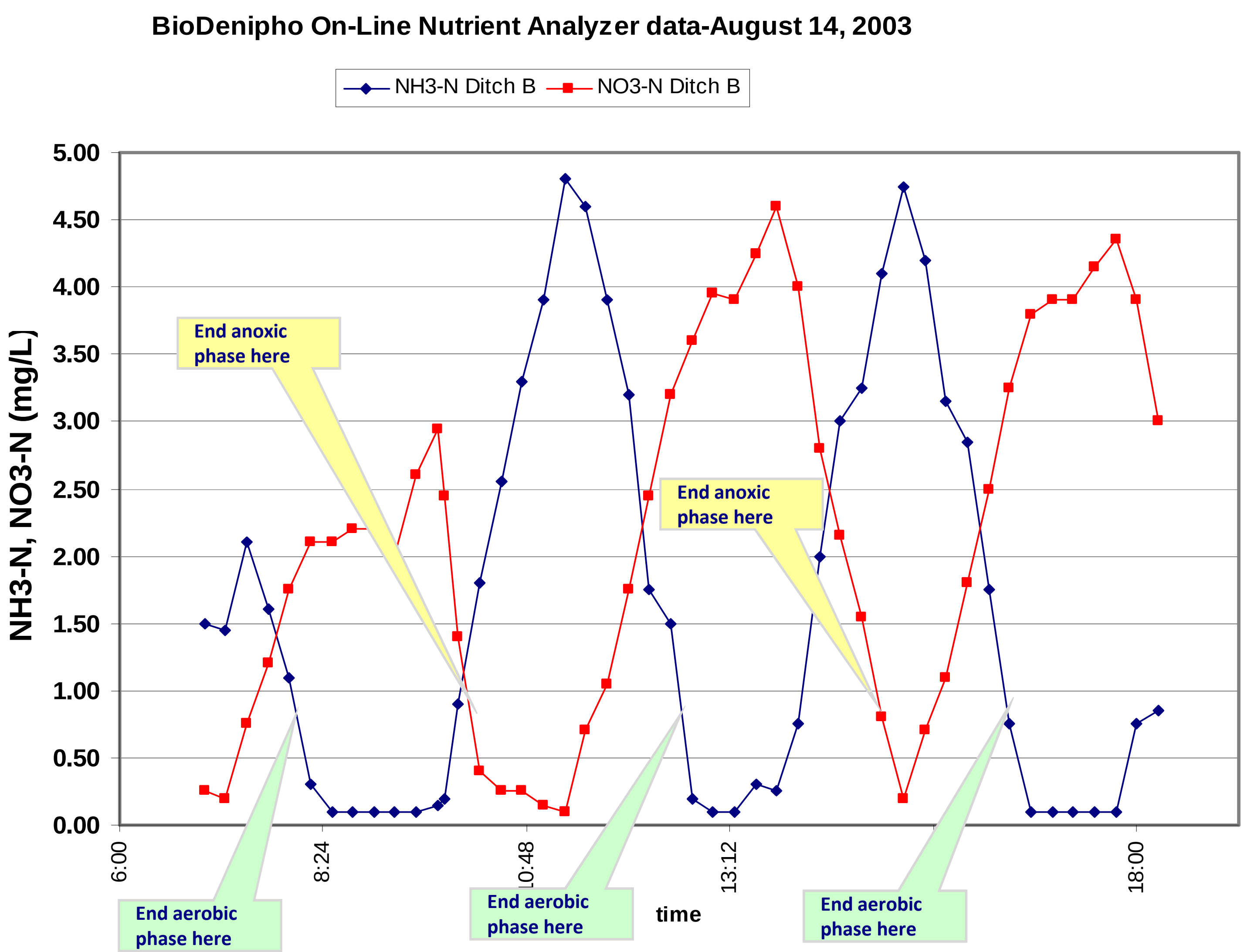
Dynamic Phasing
(Variable Phase Lengths based)

- Variable Phase length based on incoming load to plant

- End the aerobic phase if NH_3 is below the setpoint
  - Saves soluble organic carbon for denitrification
  - Allows more time for denitrification
  - Reduces nitrate peaks

- End the anoxic phase if NO_3 is below the setpoint
  - Lowers ammonia accumulations
  - Avoids potential secondary release of P if NO_3 is depleted

Fixed Phase Length Operation



STAC – Superior Tuning & Control

- Uses on-line NH_4-N and NO_3-N analyzers
- Continuously adjusts oxic and anoxic phase lengths based on criteria using measured NH_3 and NO_3 concentrations
- More efficient use of reactor volumes results in reduction in effluent soluble N and lower energy use

STAC Case Study

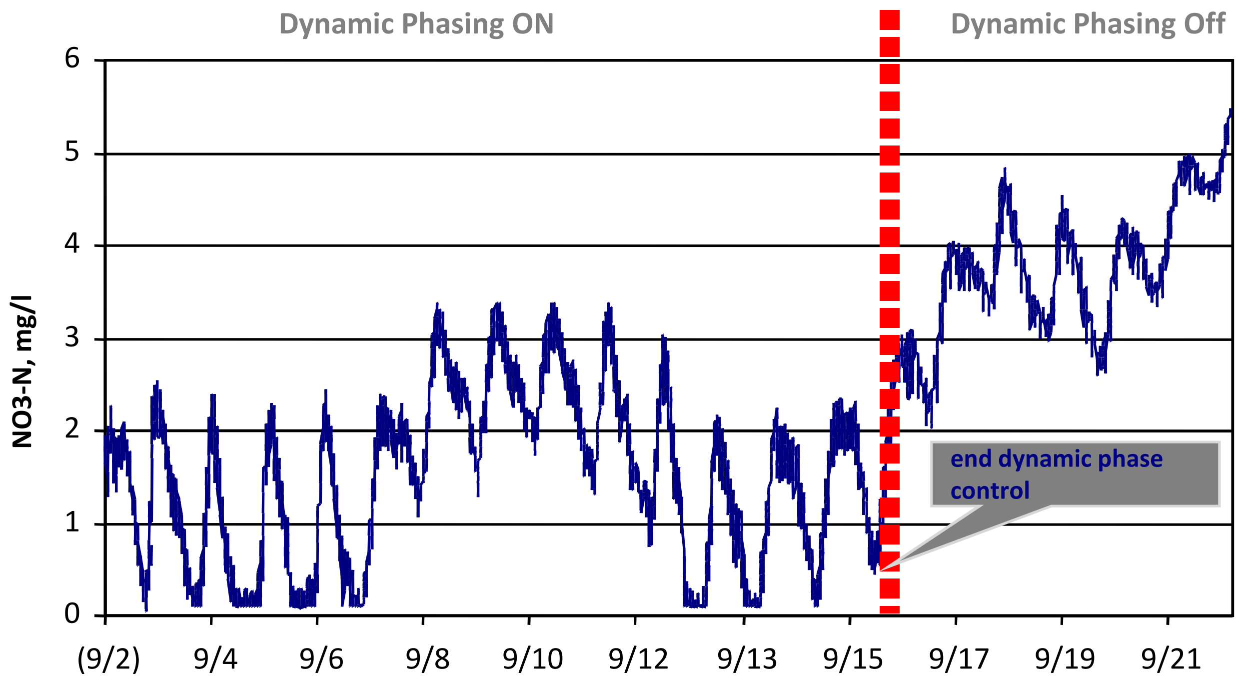
Conducted at Kill Creek WWTF – Gardner, KS

Demonstrated that Dynamic Phase Control

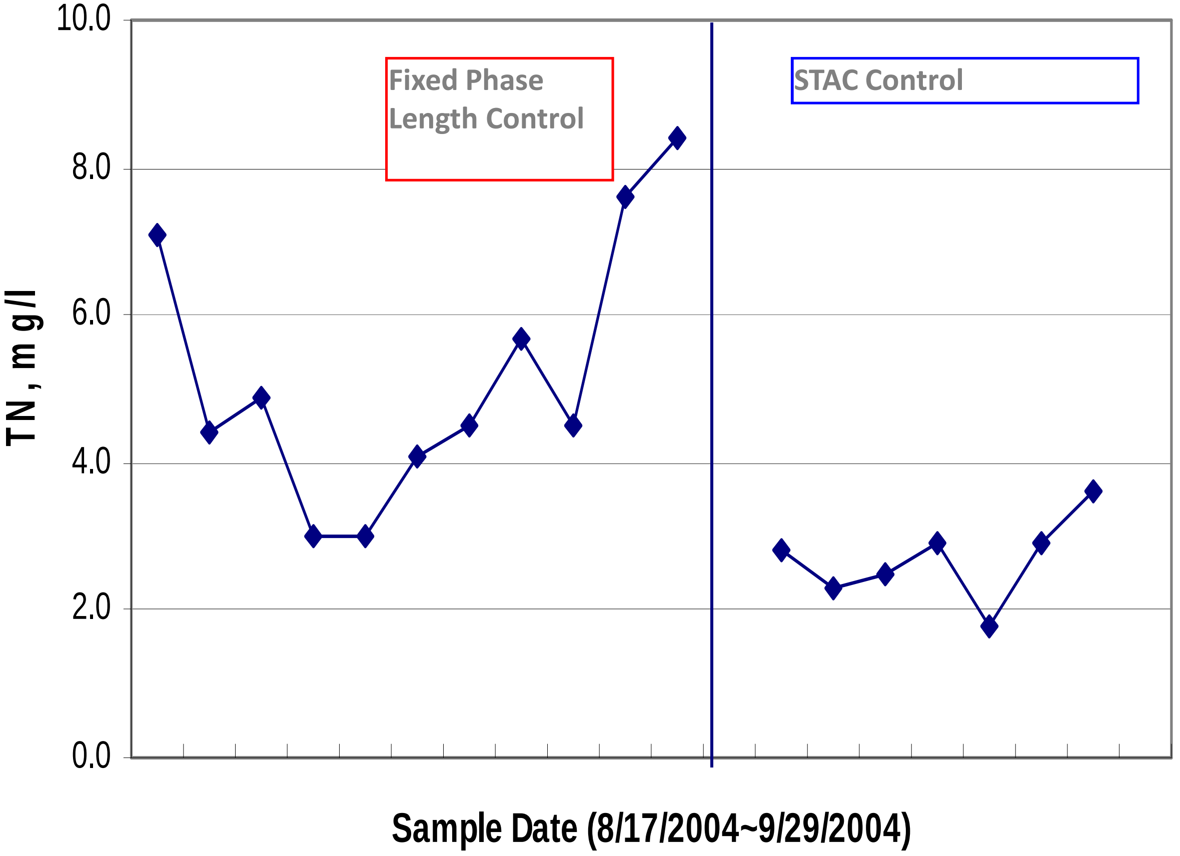
1. Improves TN Removal
2. Saves Energy

Dynamic Phasing Pilot Study

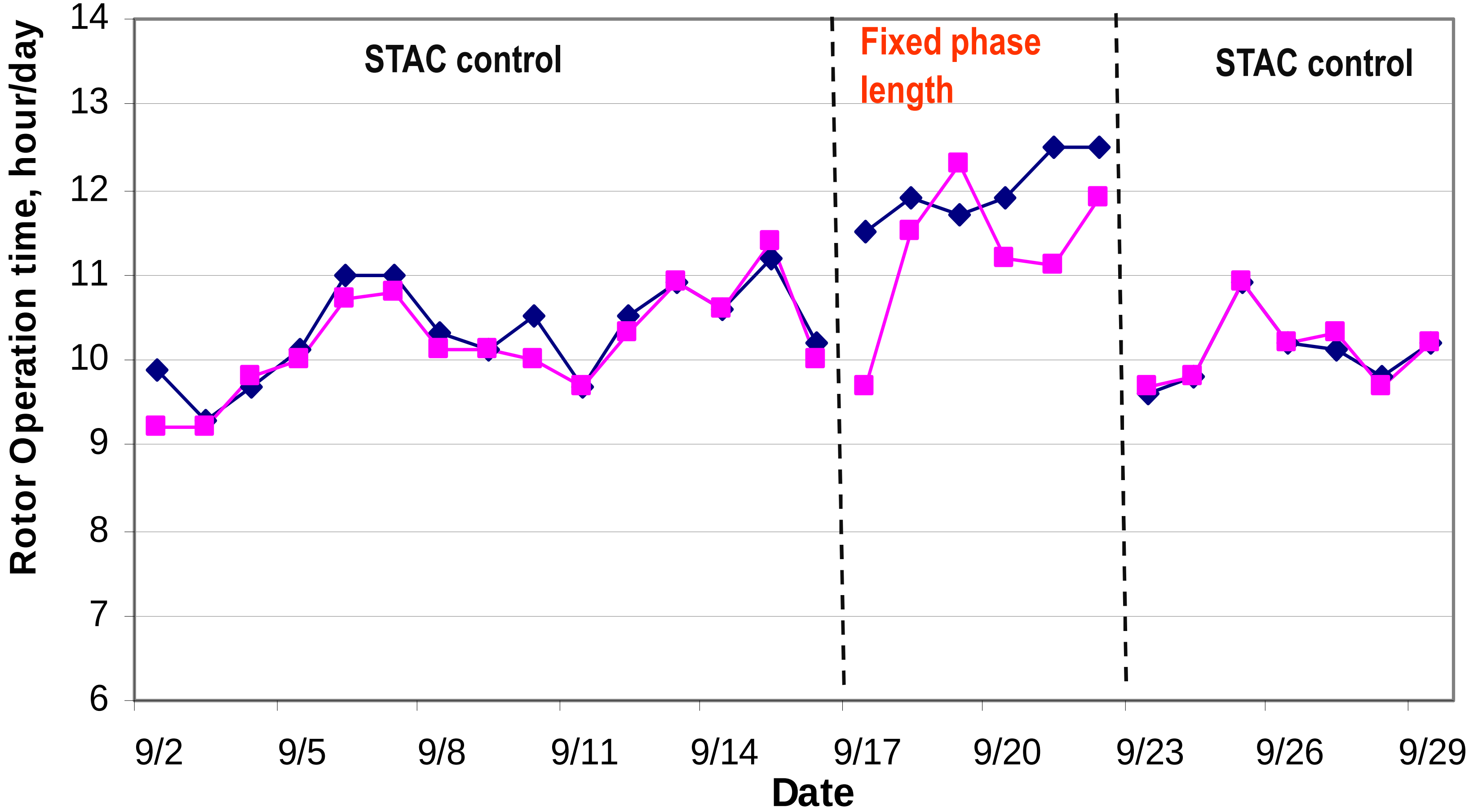
Kill Creek WWTP – Gardner, KS



Full Scale Results from STAC Demonstration – Kill Creek WWTP BIO-DENITRO



Kill Creek WWTP BIO-DENITRO - Rotor Runtime Evaluation



Kill Creek STAC Demonstration Conclusions

- Increase TN removal by 2 – 3 mg/l
- Reduce rotor runtime by 10 – 15%
- Easy to upgrade existing control systems
- Low maintenance, < 2 hours per week
- Achieves effluent TN 2 to 4 mg/L without secondary anoxic zones or supplemental carbon addition