# Introduction to Phosphorus Removal

By
Brett Ward
Municipal Technical Advisory Service
University of Tennessee

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# Nutrient Removal

- More Complex: Advanced Treatment, Tertiary Treatment
  - Chemical/Physical Treatment
  - Biological Treatment
    - Traditional Treatment-Oxidation Process
    - Nitrogen Removal-Oxidation then Reduction
    - Phosphorus- Reduction then Oxidation
- Conflicting and often a delicate processes

# AS Review- Plant Configurations

- Plug Flow-long basin
  - DO may vary
  - DO demand changes
  - Rate of metabolism changes
  - BOD drops
- Multi Ring Ditch
- ~Intermittent fed SBR

# AS Review- Plant Configuration

- Complete Mix~ square
  - DO ~ equal
  - DO demand ~equal
  - BOD ~ equal
  - Rate of metabolism ~equal
- Single ring ditch
- ~Continuous fed SBR

# Bacterial Habitat

Three Different Habitats

- Different by design
- Different by operations & controls

- Operators must use the tools at their disposal to control the bacteria!

# What are Nutrients? Think Fertilizer

- Nutrients
  - Nitrogen and Phosphorus
  - Two main fertilizer elements needed for growing green plants.
  - They contribute to aquatic plant growth,
  - Excess plant growth clogs streams and,
  - When they die add a organic matter/BOD and nutrient load back onto the stream

# How do you remove nutrients?

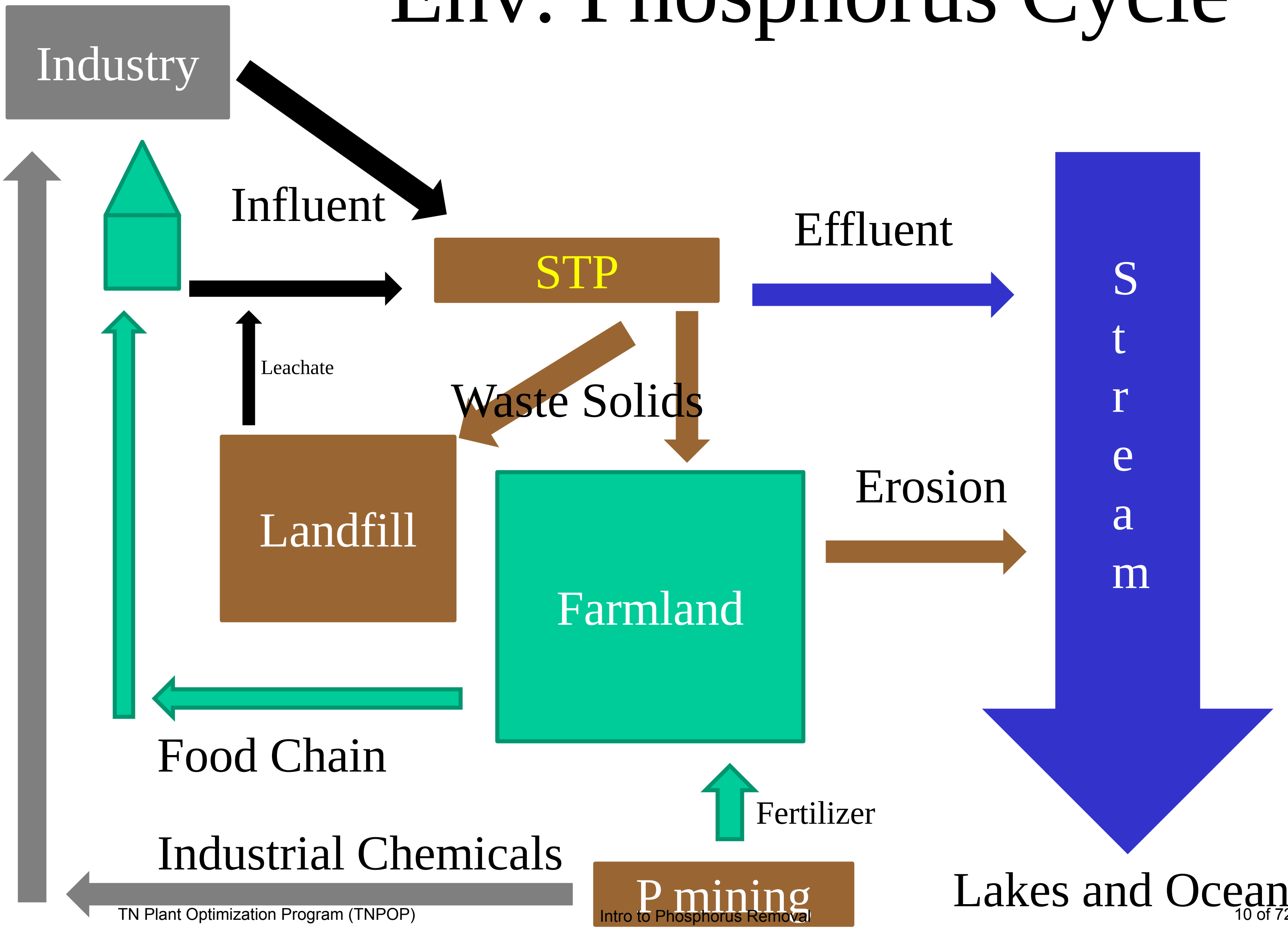
- Nitrogen
  - Biologically- nitrification followed by denitrification
  - Chemically- ammonia stripping, breakpoint $Cl_2$
- Phosphorus
  - Biologically-to ~ 0.5-1.0 mg/L
  - Chemically-with or without biological removal

# PHOSPHORUS REMOVAL

# Phosphorus Importance

- Essential for all life; human deficiency is rare
- Essential for crop production; deficiency in soil is common
- Maury Co, Tenn. was once a world leader in the production of phosphorus fertilizer

# Env. Phosphorus Cycle



# Nitrogen/Phosphorus

- Both essential elements for life; human and plant
- Both available from food; human and plant
- Both are part of wastewater influent
- Both can be removed biologically or chemically
- But there is no gaseous form of phosphorus

# Fate of Nutrients

- Nitrogen
  - Effluent
  - Sludge/Biosolids
  - Nitrogen Gas
- Phosphorus
  - Effluent
  - Sludge/Biosolids

# Phosphorus Removal

- Influent Concentrations:
  - 6-20 mg/L common levels
- Common Effluent Levels
  - Secondary treatment~ 3-4 mg/L
  - With phosphorus removal ~ 1.0- 0.01mg/L
- Common Tennessee Limits ~ 0.5 mg/L
- Limits from other states ~ 0.1 mg/L

# Phosphorus Sources

- Sewage, urine
- Soaps & Detergents
- Corrosion control:
  - Water distribution
  - Boiler feed water
- Industrial Sources
  - Food Processing
  - Metal processing
  - Fertilizer mfg.

# Phosphorus Forms

- Influent Total Phosphorus 6-20 mg/L

- Organic Phosphorus ~ 2-5 mg/L
  – Acid digestion converts this to Orthophosphorus for testing.

- Inorganic Phosphorus ~ 4-15 mg/L
  – Orthophosphorus, $PO_4^{3-}$ (reactive phosphorus)

# Fate of Phosphorus

- Effluent
  - Organic P in BOD & TSS
  - Dissolved in the water

- Sludge or Biosolids
  - Organic P in the solids
  - Dissolved in the water

# Low Effluent Phosphorus

- To achieve Low Effluent Phosphorus:
- Phosphorus must be high in the waste sludge and remain high when sludge or biosolids are removed from the plant.

# Load Must Balance

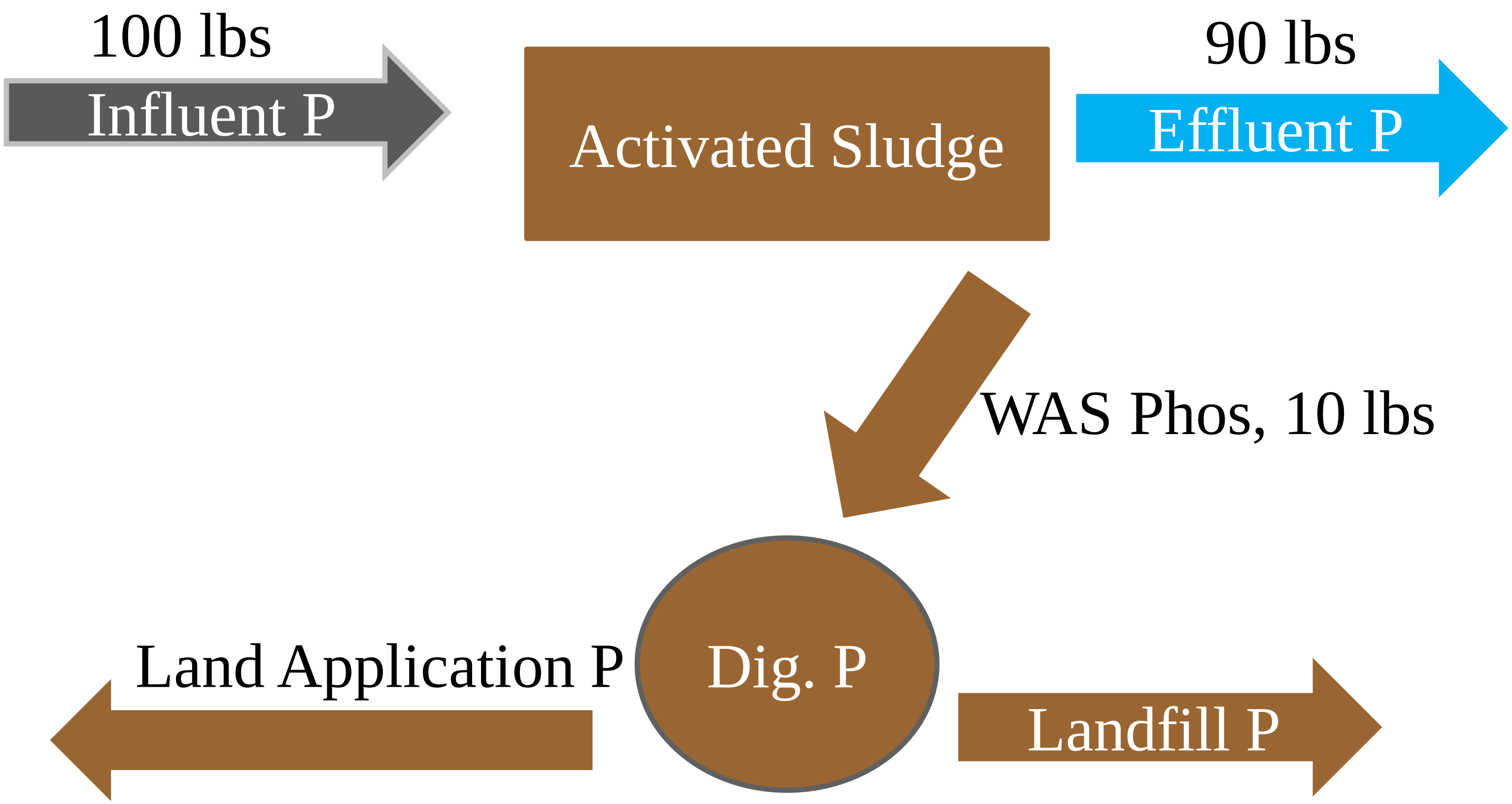
- Influent: 100 lbs. Phosphorus
- Effluent 90 lbs. Phosphorus
- Waste Sludge 10 lbs. Phosphorus
  - Stored in Digester/Holding Tank or,
  - Removed in Sludge or Biosolids
  - Caution: Decant/Supernatant Phosphorus

# Phosphorus does not just disappear.

- The Law of Conservation of Matter.
- It was discovered by Antoine Laurent Lavoisier about 1785.

- In a chemical reaction, or biochemical reaction, matter is neither created nor destroyed, though its form may change.

# Plant Phosphorus Routes



# Biological Phosphorus Removal

- Three Steps
  - Pass-through Phos
  - Assimilative Removal
  - Enhanced Biological Phosphorus Removal (EBPR)

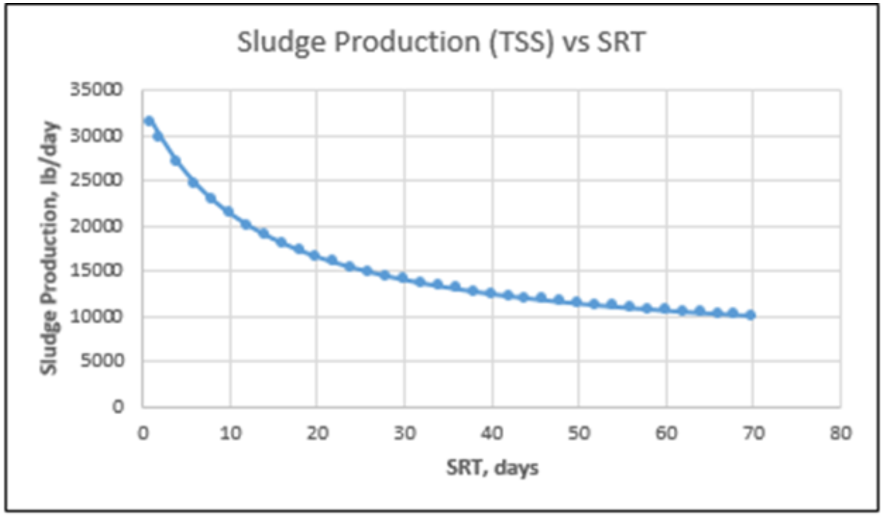
# 1. Pass-Through Phosphorus

**Low: BOD, TSS = Lower Phosphorus**

**High: BOD, TSS = Higher Phosphorus**

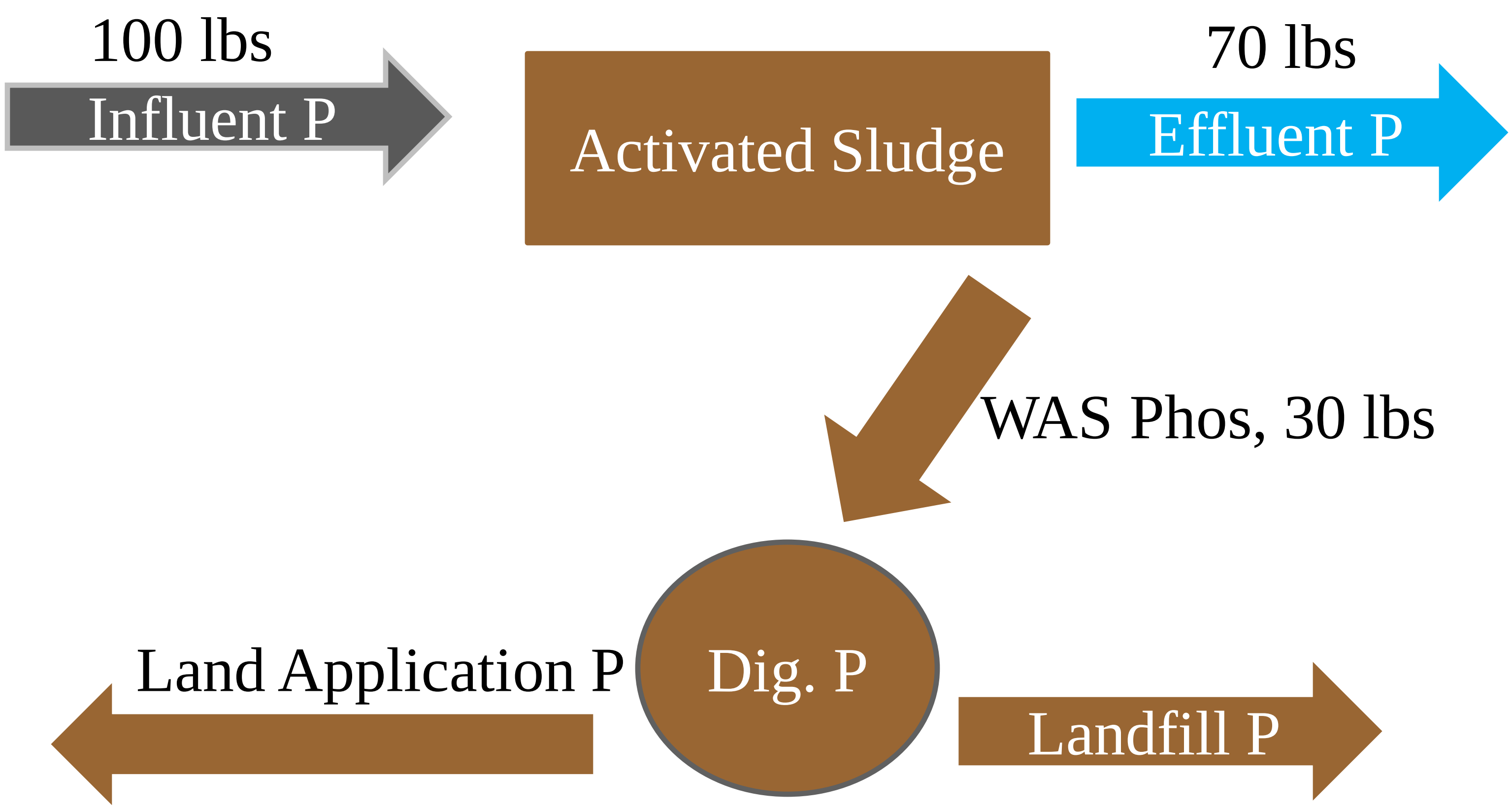
- Keep effluent BOD & TSS low! Filters help.

# 2. Assimilative Phosphorus




- Keep a lower MLSS, MCRT, & younger sludge, that is waste more!
- 10 day SRT= 22,000 lbs
- 40 day SRT= 13,000 lbs
- 70 day SRT= 10,000 lbs
- More lbs wasted, more Phosphorus removed

# Plant Phosphorus Routes



# Nutrient Removal Conflict

- Phosphorus Removal
  - Lower MLSS, MCRT, sludge age
- Ammonia Removal
  - Higher MLSS, MCT, sludge age

Balancing Act: Lowest MLSS/MCRT/ sludge age that will fully nitrify. Watch ammonia levels; you may have to accept higher effluent ammonia to get low Phosphorus.

# Bacteriological Conflict

| Parameter | Nitrifiers | Denitrifiers | PAO |
|---|---|---|---|
| Preferred SRT | Long | Short | Short |
| F/M | Low | High | High |
| ORP (DO) | High | Low | Very low → High |
| rbCOD | No | Yes | Yes: VFA |
| $NO_X$-N | Ok | Must | No[1] |
| Temperature sensitivity | Very high | Moderate | Low |

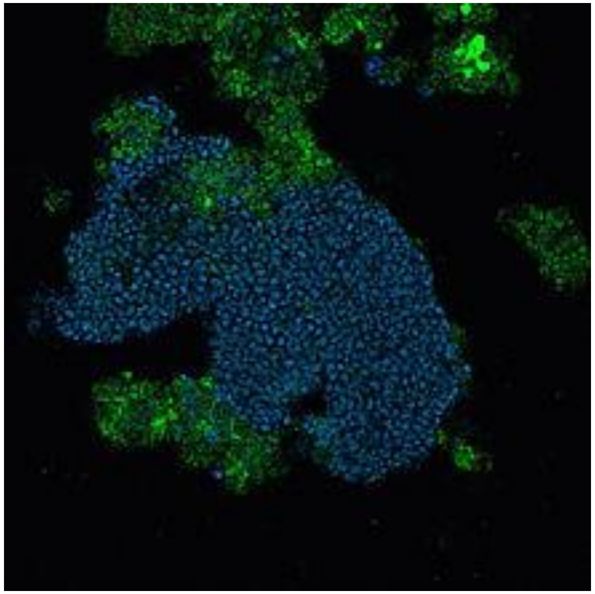
*1 – When conditions for secondary release are not present.*

*Developed after Metcalf and Eddy (2014); EPA (2010); Downing et al. (2009); Kang et al. (2008); Brown et al. (2007); Oleszkiewicz and Barnard (2006).*

Canadian Water Network, March 2015

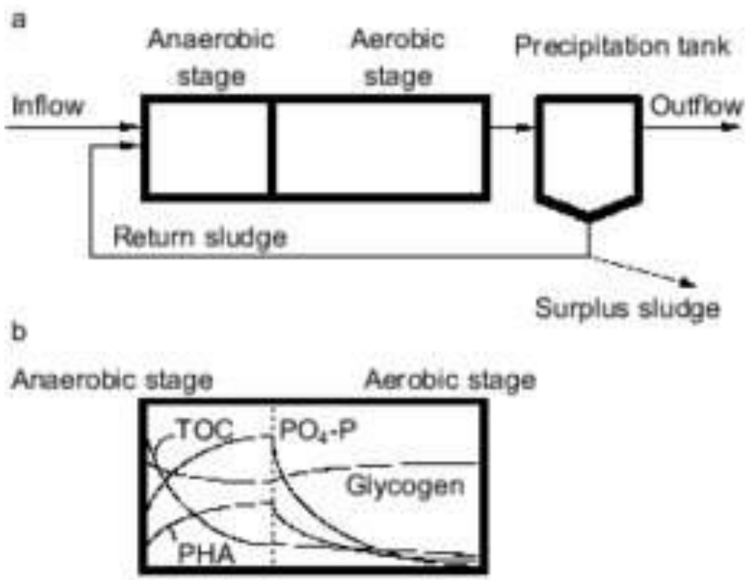
# 3. Enhanced Biological Phosphorus Removal, EBPR

- Phosphorus Accumulating Organisms, PAO's
- Heterotrophic, Obligate Aerobes
  - Feed on CBOD
  - Must have Oxygen
  - But have a unique metabolic capacity



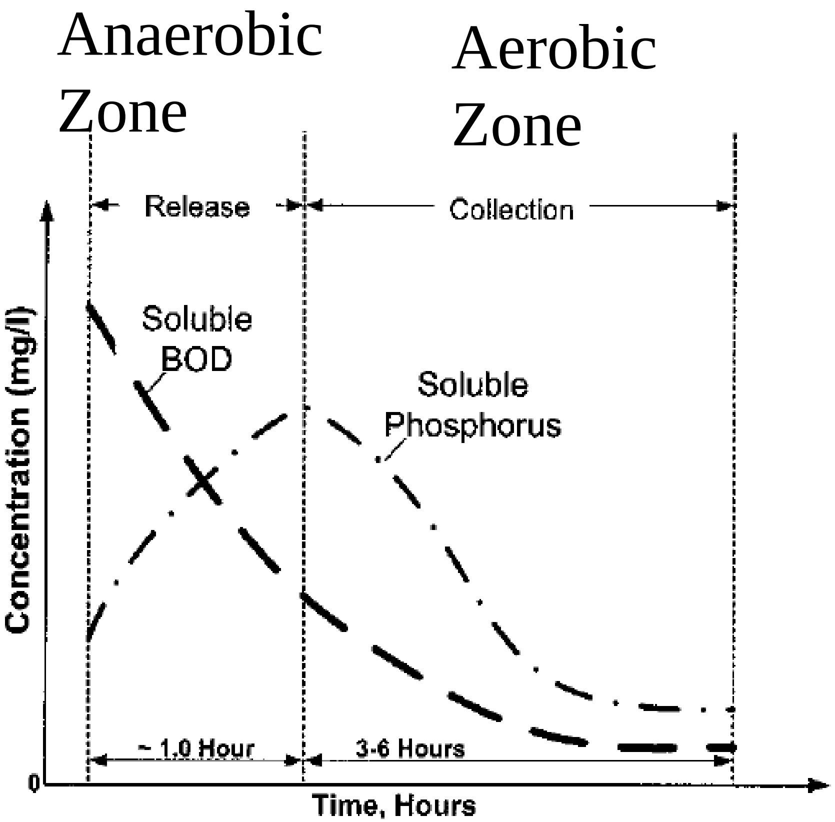
*Candidatus* Accumulibacter phosphatis (blue cells)

# PAO's Unique Metabolic Capacity




- PAO- phosphorus accumulating organisms
- Also called Luxury Uptake of Phosphorus
- Process includes:
  - Anaerobic zone where phosphorus is released
  - Aerobic zone- Luxury Uptake of Phosphorus
- There are many variations of this basic flow

# Biological Phosphorus Removal




- PAO bacteria
- To enhance their proliferation they must be cycled through two habitates
  - Anaerobic (release) stage
  - Aerobic (luxury uptake) stage

# PAO Metabolism

**Anaerobic Zone, two processes**

Substrate = CBOD

Facultative Bacteria, not POA's

Acetate is a VFA

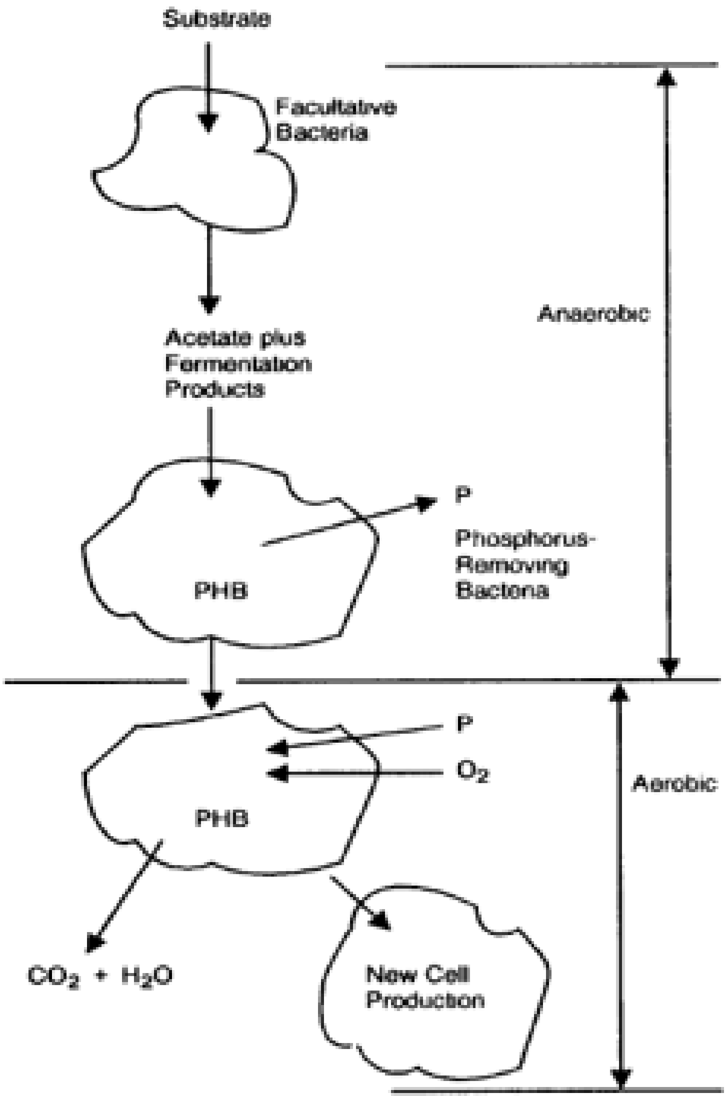
PHB= Polyhyroxybutyrate, stored energy using VFA's and $O_4$ from stored $PO_4$

P is released

**Aerobic Zone**

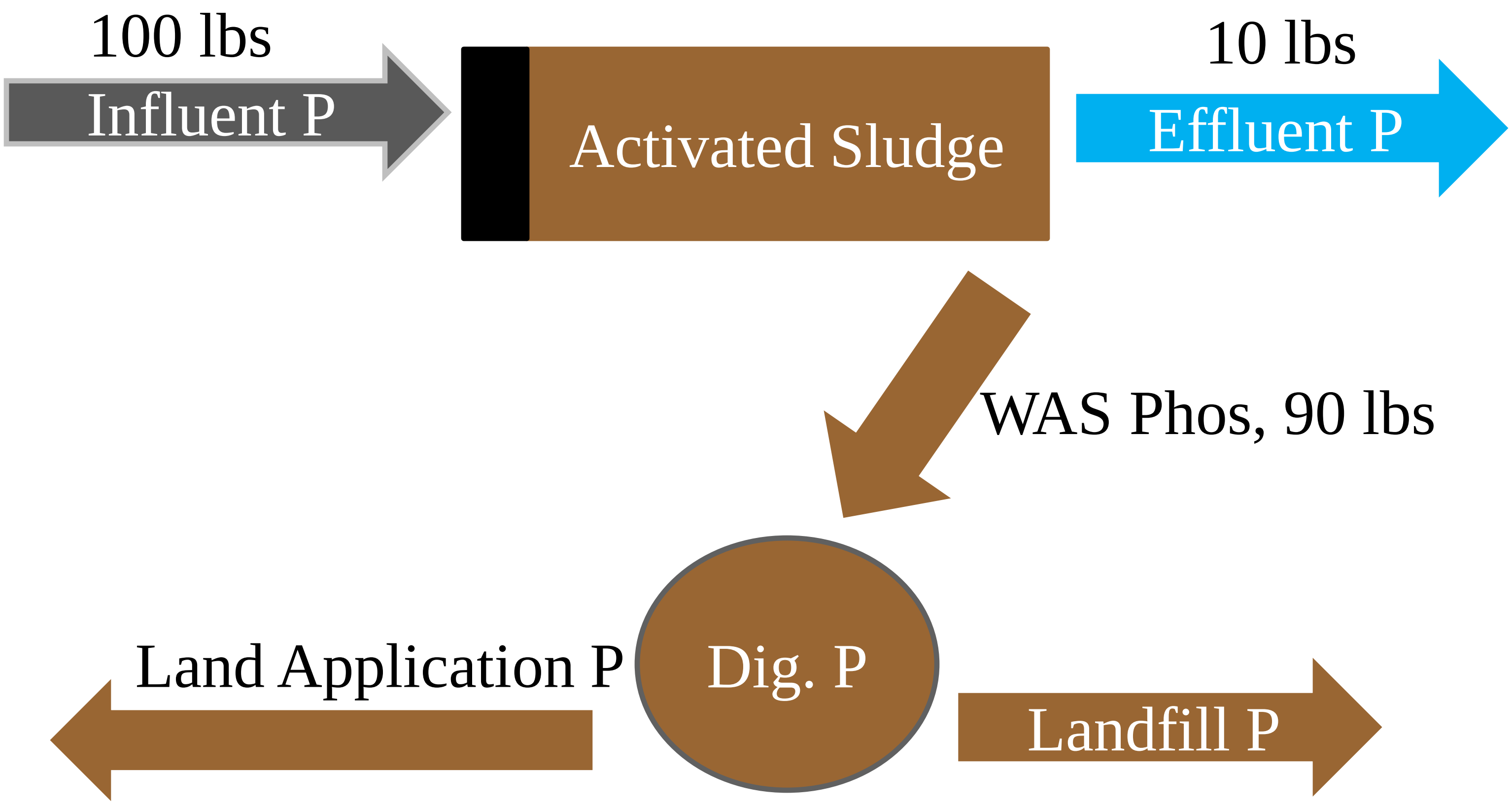
Oxygen present PHB is metabolized releasing $CO_2$ and water, aerobic metabolism like all other heterotrophs for maintenance and growth (new cells)

Phos & $O_2$ taken in to form new PHB or $PO_4$ (luxury uptake)




This should give low P water and high P- PAO's/cells/MLSS/solids

# Plant Phosphorus Routes



# Three Stage $A^2$/O Process

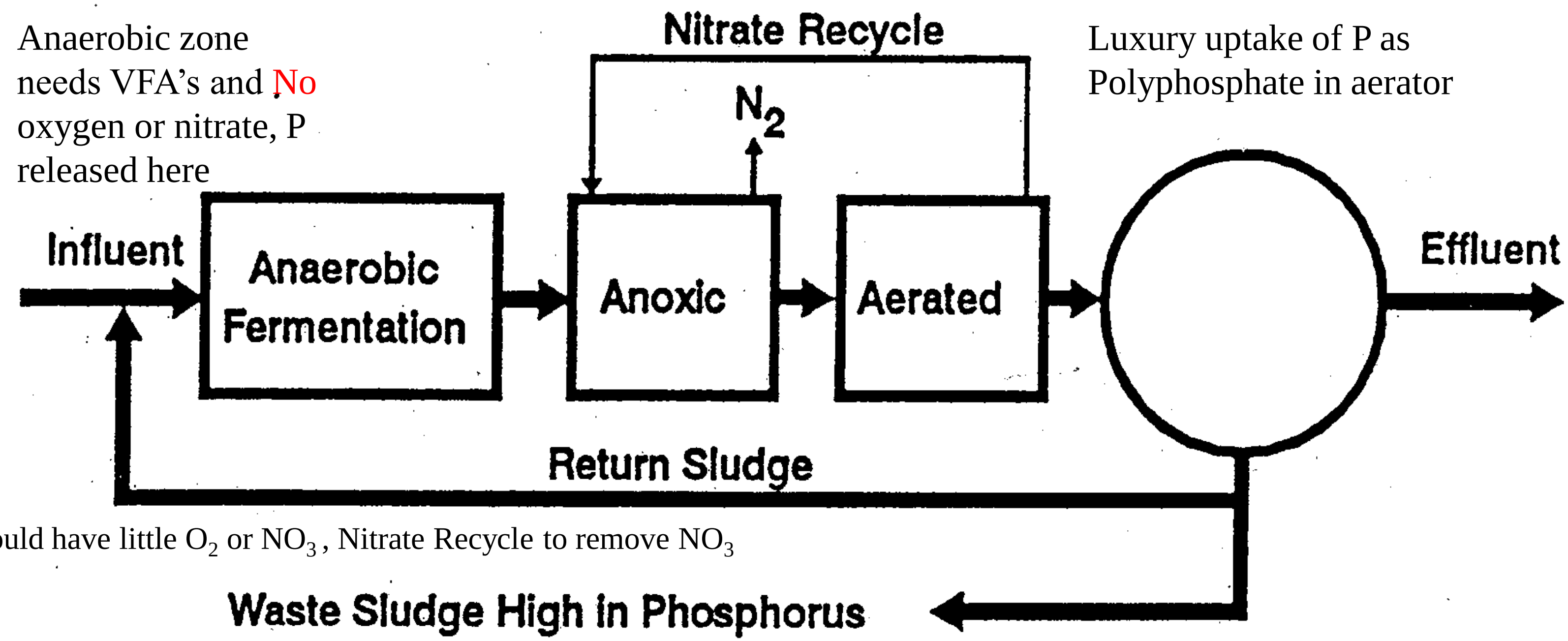
## BIOLOGICAL NUTRIENT REMOVAL (BNR)

*(1970's)*

Recycle flow = 2-5* Q

Anaerobic zone needs VFA's and No oxygen or nitrate, P released here

Luxury uptake of P as Polyphosphate in aerator




RAS should have little $O_2$ or $NO_3$ , Nitrate Recycle to remove $NO_3$

# Enhanced Biological Phosphorus Removal

- EBPR is known for “process instability”
- Requires more:
  - Careful operations
  - Process control testing
  - Communications and teamwork

# Other Phos Removal Processes

- Three Stage $A^2/0$
- Five Stage Bardenpho
- University of Cape Town (UCT)
  - Also UCT with Virginia Initiative Process
- Johannesburg and Modified Johannesburg processes
- All have some pattern of Anaerobic/Aerobic

# Biological Phosphorus Removal

- Anaerobic zone
- ~ 2 hours HDT
- Fermenter for VFA's but IBOD is down so adding Alum
- Reducing environment needed, ORP , -150 to -250 mV

Anaerobic Zone

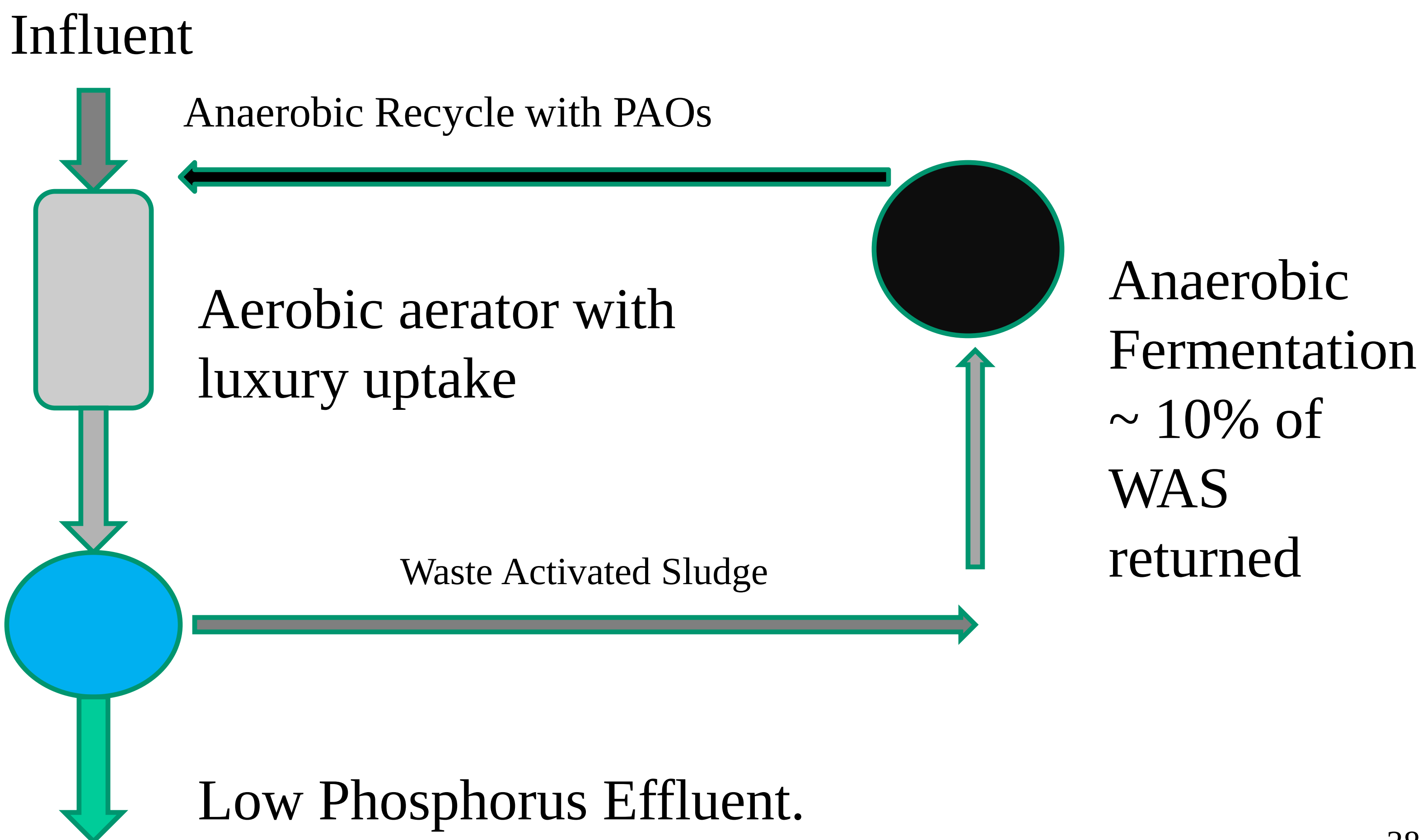
# Biological Phosphorus

- Oxidation Ditch
  - Off/On cycles
    - 90 on, DO~2 ORP ~300
    - 60 off, ORP ~ -100mV
  - Subsurface mixing
  - DO controlled and ORP monitored
  - Limits TN=8, TP=2

# Other Technology and Methods

- Many proprietary nutrient removal methods
- Side stream treatment processes
  - Treat part of the flow to develop PAO’s then add them to the full flow
  - Treat internal flows such as digester supernatant

# Side Stream Anaerobic System



# Athens Utility Board, 2018

- WAS recycle to old thickener, then to ditch
- 2nd trial, to middle ring
- Success with no Chemicals
- Winter Performance is better
- Ortho P < DL

# AUB- North Mouse Creek

- WAS holding tank
  - ORP = - 200 mV
  - Side stream fermenter
  - 6000 gpd returned
  - Eff Ortho P < DL

# Madisonville


- Aeromod Plant
  - Headworks
  - Anaerobic Zone
  - Selector
  - Aerobic- Off/On Zones
  - Clarifiers

# Madisonville


- Anaerobic Zone
  - Sewage only
  - Air Mixed 5 minutes- twice per day
  - ORP -300 to -200 mV
- Selector
  - RAS added
  - Subsurface mixing
  - ORP -200 to -100 mV

# Madisonville


- Effluent
  - Total Phosphorus 3.0-0.3 mg/L
  - Total Nitrogen ~ 4.0
  - CBOD ~ 5
  - TSS ~6

# Baileyton

- Low Pressure CS- very septic influent- VFA's ~ 100 mg/L
- Preaeration Ferm Zone
  - MLSS recycle
  - Did not work?????
- Aeration off/on
  - 10 hr off- 4/2/4
  - TP < 2.0 lbs (< 5 mg/L)

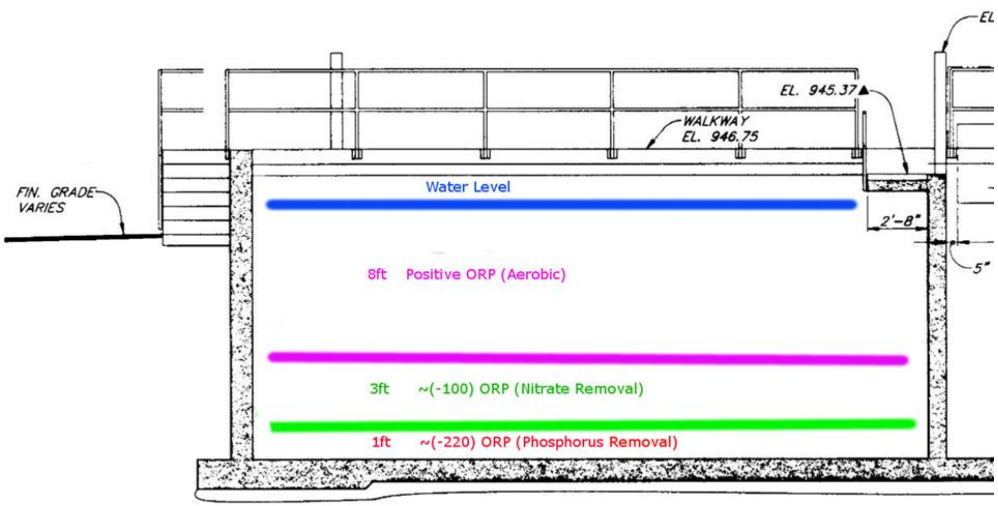
# Baileyton Lessons Learned

- Keep Trying
- Onsite Testing Valuable
- Phos Removal may not follow the books
- Digesters: decant & dewatering impact effluent
- TDEC will change limits

# Cookeville- Success!

- 4 Oxidation Ditches
- 6 Brush Rotors each
- Rotating Brush Rotor operation
- Settled Blanket-Ferm Zone.

# Cookeville- Success



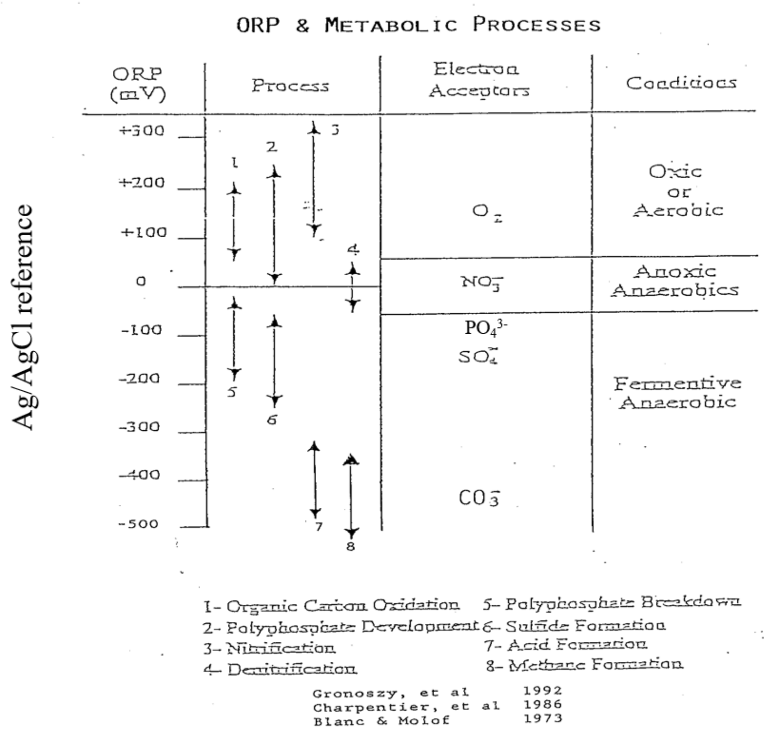

- Initial Side Stream
- Layered Ditch
- ORP testing

# ORP-Oxidation Reduction Potential

- ORP Measurements
  - pH meter with OPR probe, use mV scale
  - Only “quick” and insightful parameter for unaerated treatment units

# ORP: Classic & Practitioners Values

- Ignore Positive Values use DO Meter
- Denit ~ -50 to -150 mV
- Fermentation Zone ~ -200 to -300 mV

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# Practitioners ORP Values

ORP & Metabolic Processes

| ORP Condition | ORP mV | Process Ranges | Process |
|---|---|---|---|
| Mildly Negative | +50<br>0<br>-50<br>-100 | Classic Anoxic Zone<br>Extended Anoxic Zone | Anoxic Zone |
| Moderately Negative | -150<br>-200<br>-250<br>-300 | Classic Ferm Zone<br>Extended Ferm Zone | Fermentaion Zone |
| Strongly Negative | -350<br>-400<br>-450<br>-500 | Fully Anaerobic | Anaerobic (Methane) Zone |

# Influent & Phos. Removal

- $\geq$ 20 mg/L $BOD_5$ / 1 mg/L TP removed
  - 30-40: 1 may be better
- $\geq$15 mg/L $sBOD_5$ / 1 mg/L TP removed
- 7.5 mg/L VFA / 1 mg/L TP removed
  - 5-10 mg/L range
  - > 25 mg/L VFA needed in Ferm. Zone
  - Lack of VFA a common point of failure

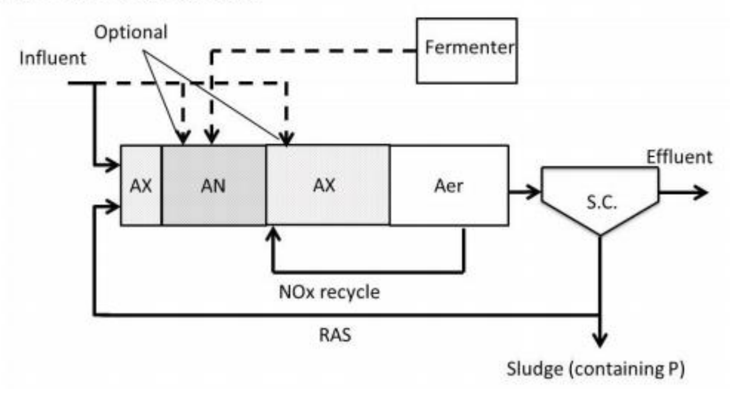
# Fermentation Zone

- Dissolved Oxygen = 0.0 mg/L
- ORP = - 250 mV, perhaps -300 mV
- Mixing: 1-2.5 hp/ 50,000 gallons
  - Bernard recommends as low as 0.65 hp / 50,000gallons
- HDT 1-3 hours, with prefermentor ~ 1 hour
- SRT 4-5 days

# Fermentation Zone

- Various Shapes & Flow Patterns
- Two Purposes
  - VFA Formation- Slow
  - VFA Uptake- Fast
  - Can be two tanks
- Flexibility- Swing Tanks

Westbank state-of the art EBPR



# Aerobic Zone

- Dissolved Oxygen: 1-6 mg/L
  - 3.0 mg/L being the most frequently recommended
  - Higher values because of nitrification
  - Higher values recommended at head end to satisfy high initial oxygen demand
    - PAO oxygen uptake is rapid
  - Lower residual ( 0.25- 0.5 mg/L) is recommended at Clarifier end to prevent DO transport to Ferm. Zone

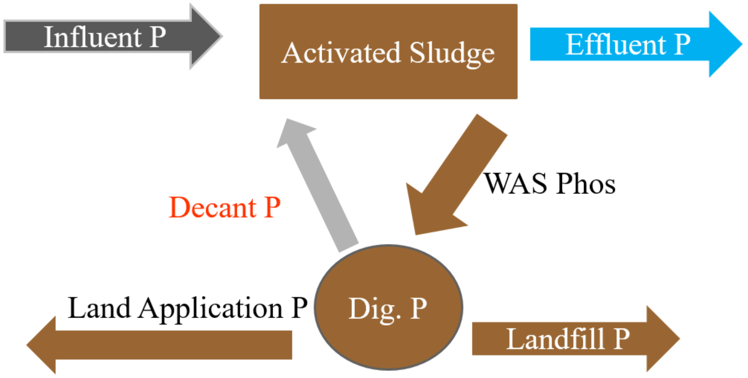
# Activated Sludge Biomass

- MCRT- 8-15 Days
  - 10 Days ***
- More Assimilative Uptake
- Less opportunity for Secondary Release
- PAO:VFA (VFA’s often low)

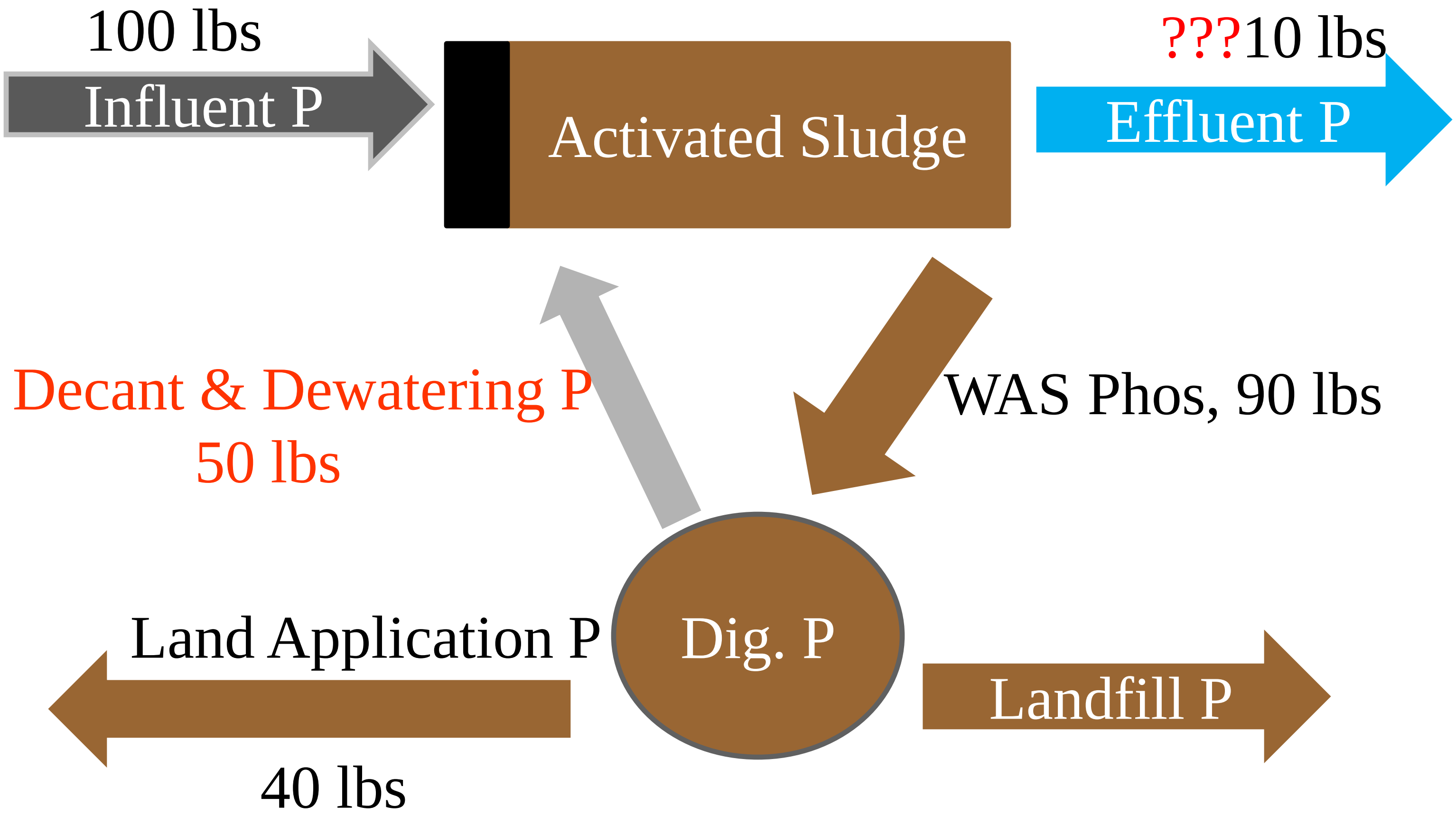
# Wasting from Aerator

- Operators #1 AS Control Method

- EBPR Wasting
  - Fully Aerobic
  - Uptake is Complete



# Digester Phos. Return



# Aerobic Digesters

- Keep the Phos in the Sludge
  - Avoid Secondary Release
    - JJ&G- 6hr anoxic/2hr aerobic, BNW???
  - Low MCRT
    - Move sludge or biosolids out ASAP
    - Volatile Solids Reduction releases P

# Secondary Release

- Great effort to "train" PAO's into a cycle of release and uptake.
- Given the right condition release can occur where we do not want it to happen- secondary release.
  - Digesters, Anoxic Zones, Clarifier Blankets, RAS wells, Oversized Ferm. Zone.
  - Test internal processes and flows!

# Glycogen Accumulating Organisms

- GAO’s compete with PAO’s for VFA’s but do not remove phosphorus.
- Competition Factors- GAO’s Prefer:
  - Higher Temperatures
  - Lower pH
  - Longer MCRT
  - Very high organic loading

# EBPR- Known for “process instability”

Know the Basics and Theory

Know your Plant

Test, Test, Test

Experiment- Notify TDEC

Ask for Help

# Phosphorus Removal

- Permit Limits ?
  - Long-term Limits, Pounds
- BOD/TSS Pass Through
- Assimilative Removal
- Enhanced Biological Phosphorus Removal

- Chemical Phosphorus Removal

# Chemical Phosphorus Removal

- Common Chemicals
  - Aluminum & Ferric
  - Lime, pH>11
  - Proprietary Products
- Need feed equipment
- Mixing
- Alkalinity
- Effluent filters improve removal

Alum Feed System

# Chemical Precipitation of Phos.

- Coagulation- chemicals added which change the electromagnetic forces between suspended particles
- Flocculation- gentle mixing to build floc which will settle or be more easily filtered
- Sedimentation/Filtration- removal of the Phosphorus floc from the water

# Chemical Process Equipment

- Chemical Storage- Bulk tanks, day tanks, piping, valves, containment
- Chemical Feeding- Dry, liquid
- Mixing- Flash Mix, Flocculation
- Settling/Filters
- Chemical Sludge- with WAS to solids processing

# Process Operations

- Proper equipment operation
- Calibration of feed equipment
- Monitoring- more that ever!
  - pH, Alkalinity, Ortho & Total Phosphorus
  - Influent & Effluent and also through the process
- Process Adjustments- Flow, Loading, Performance

# Chemical Phosphorus RemovaL


Ferric Sulfate Tank

- Alum dose ~ 1.75gallons alum/lbs P
- Ferric Sulfate ~1.3 gallons ferric sulfate /lbs P
- Varies with:
  - Alkalinity, pH
  - Limit to meet

# Chemical Phosphorus Removal

- Ferric Sulfate, 24 gpd in 0.24MGD, fed into influent interceptor, meeting a 0.5 mg/L limit
- SBR with BioP removal to ~1.0 mg/L then alum @ 60 gpd into 1.5MGD to reach 0.5 mg/L limit.

# Athens Utility Board, Original

- Limits
  - TN=5mg/L,TP= 1mgL
- Ditch Rings
  - Outer- anoxic
  - Middle, DO~1.0
  - Inner, DO ~2.0
- Ferric Chloride added to clarifier center well
  - 60-120 gpd into 2.0 MGD

# Phosphorus Removal

Floc. basin and filters

- Filters
  - TSS will contain 1-7% Phosphorus
  - Effluent filters improve removal with or without chemical addition
  - Plants constructed to remove P will have filters.
- Flow Equalization

# Phosphorus Removal

- May be a limited parameter in the future.
- Two main removal methods.
- Phosphorus only leaves the plant in effluent or sludge.
- Retrofits may be chemical or biological.

- Operator Knowledge in Key.

# Questions, Comments, Discussion