OWEA 2019

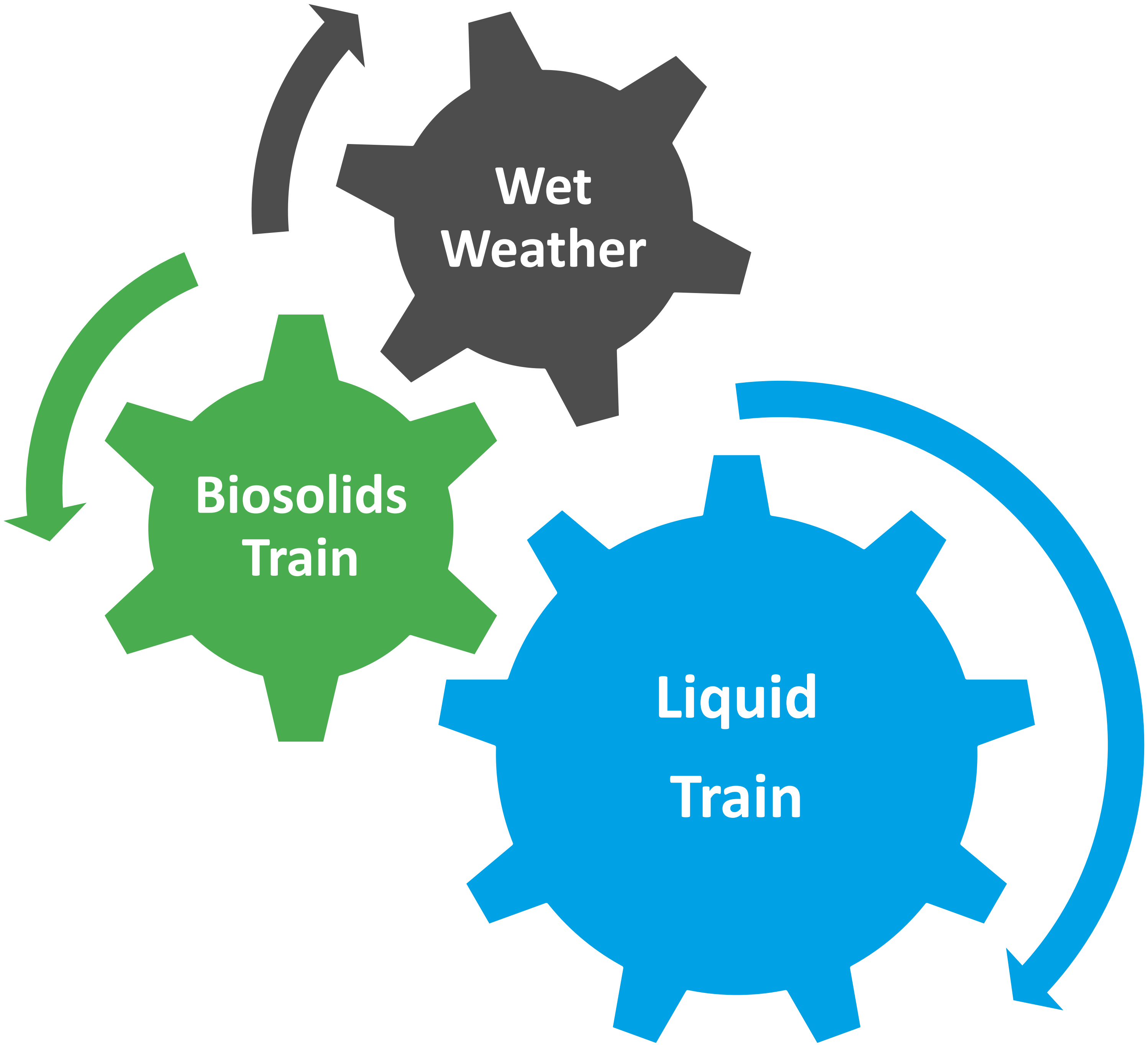
26 June 2019

Time Tested Bio-P Removal Options for Cold and Wet Weather

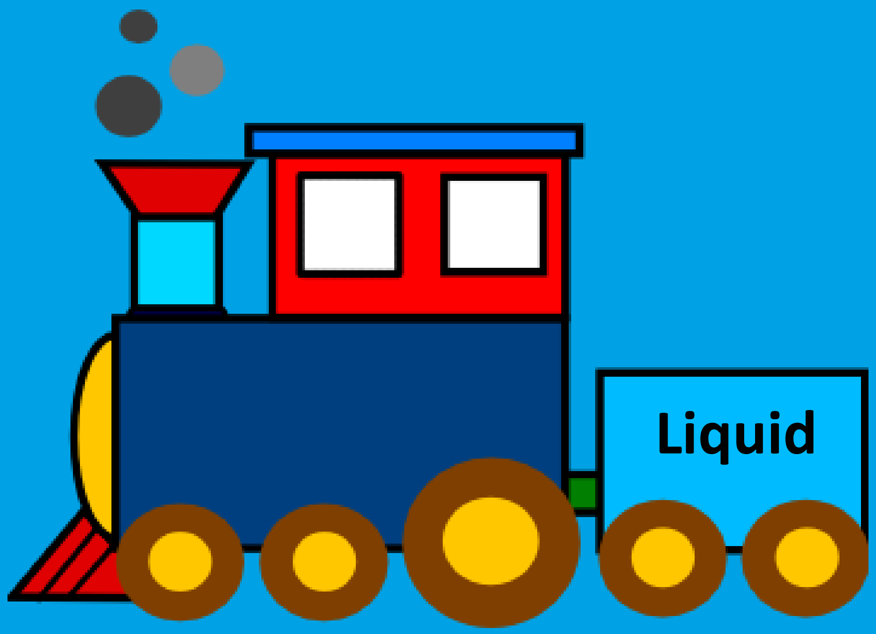
Jim Fitzpatrick
Principal Process Engineer

BLACK & VEATCH

Agenda

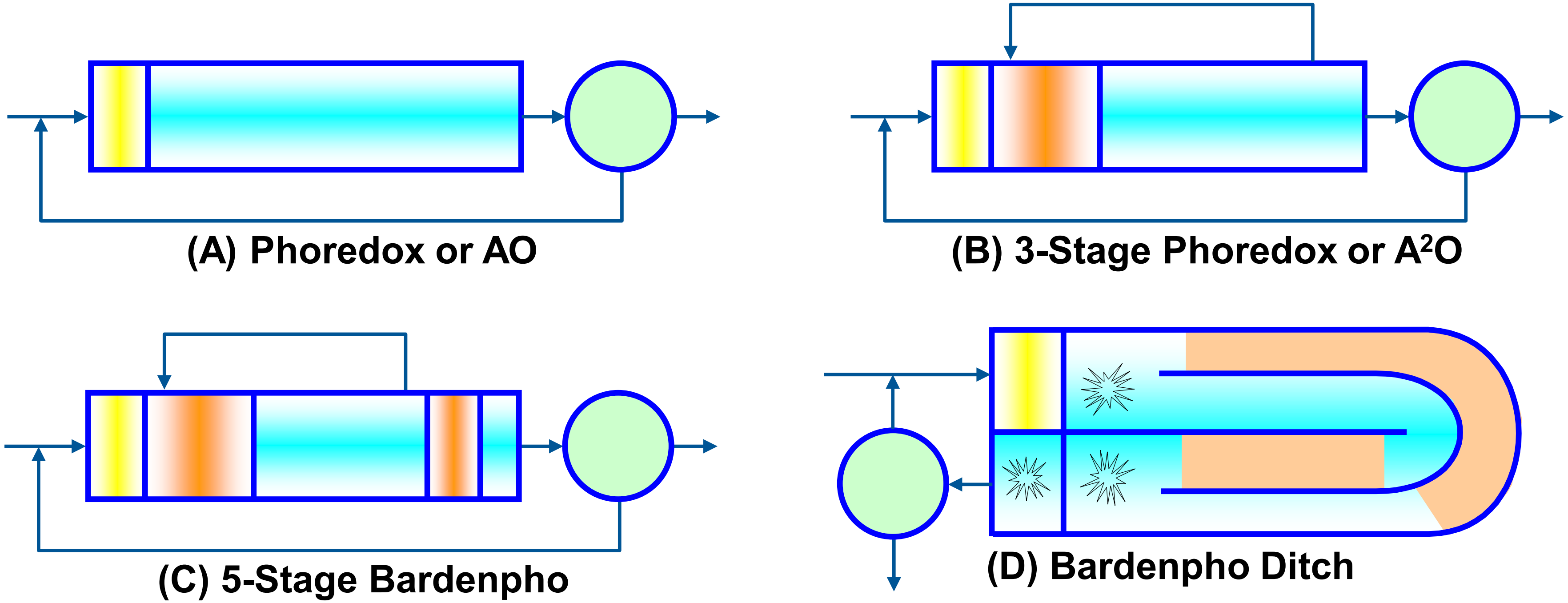


Liquid Train

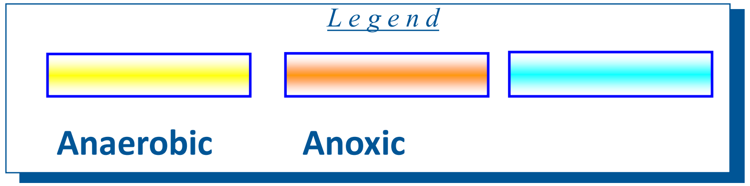


- Optimize activated sludge process
- Conventional EBPR vs. side-stream EBPR (S2EBPR)

Enhanced Biological Phosphorus Removal (EBPR)

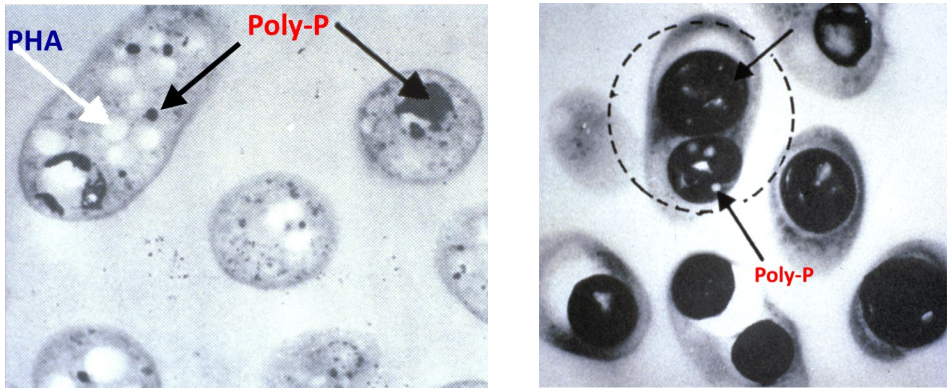


(A) for TP removal
(B), (C) or (D) for TN and TP removal



- **1970s - Mainstream anaerobic and anoxic zones standardized by Barnard and others for biological nutrient removal**
- **Phosphate accumulating organism (PAO) like *Accumulibacter* responsible for EBPR**

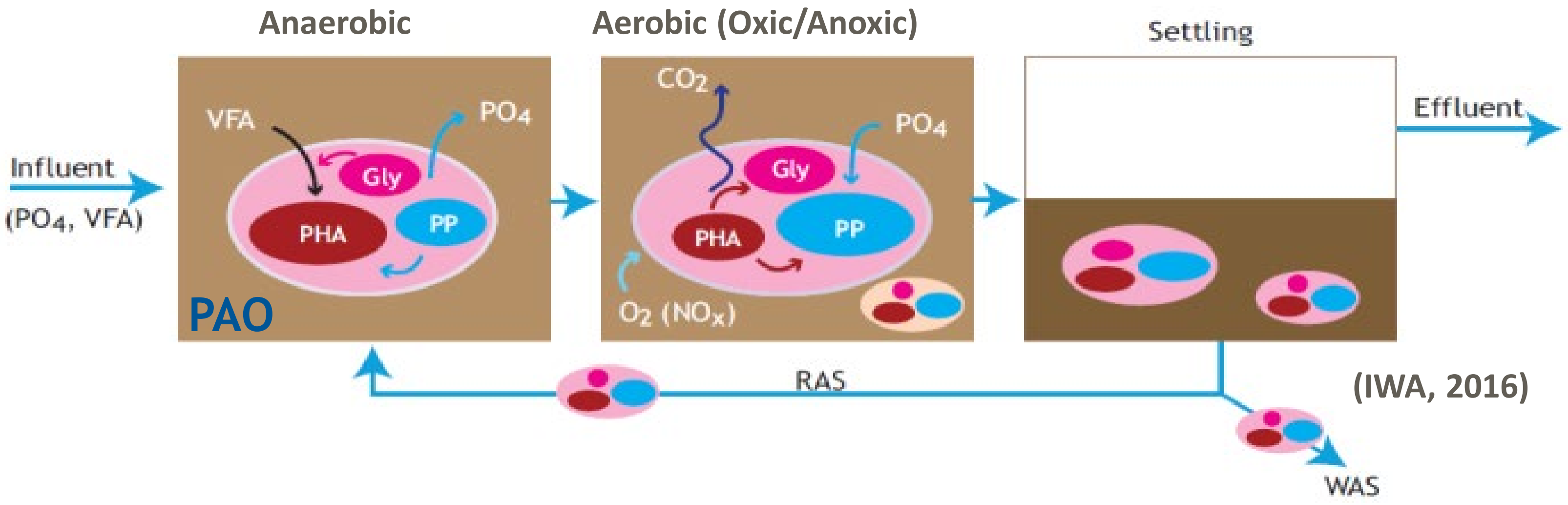
Conventional Thinking for EBPR



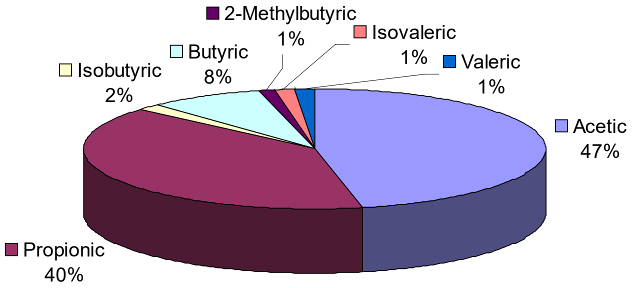
(Fuhs & Chen, 1975)

Requirements

- Anaerobic stage with volatile fatty acids (VFA) to trigger P release
- Oxic/anoxic stage for luxury uptake of P
- Fixed zones or cyclic aeration
- Mixture of VFA for PAO to outcompete glycogen accumulating organisms (GAO)



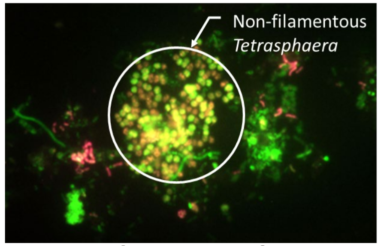
(IWA, 2016)



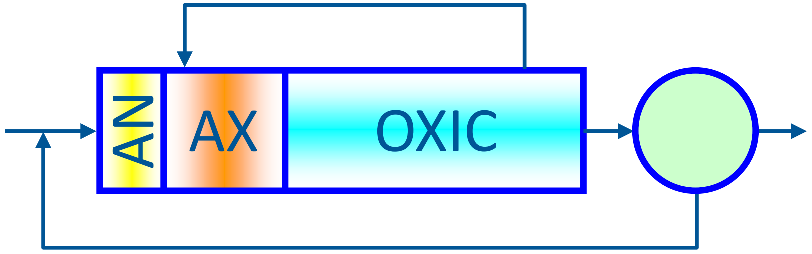
2007 Fermenter Study (Wakarusa WRF | Lawrence, KS)

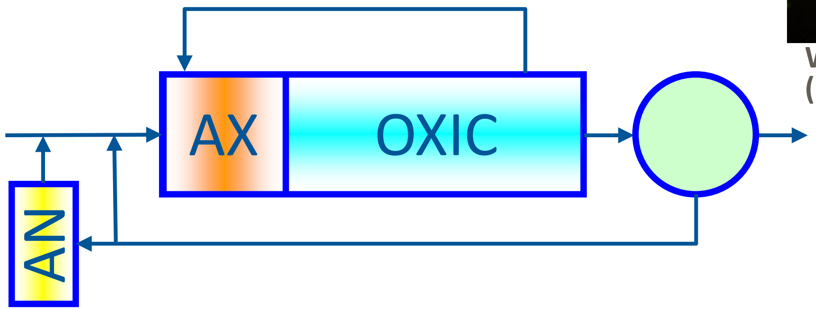
First Primary Fermenter (Kelowna BC, 1979)

S2EBPR is New Reality for Phosphorus Removal



Westside Regional WRRF (Nguyen et al. 2011)





Enhanced Biological Phosphorus Removal (EBPR)	Side-Stream EBPR (S2EBPR)
Promotes growth of PAOs like *Accumulibacter* for luxury uptake of P in oxic zone	Side-stream fermenter produces VFA **and** also grows PAO like *Tetrasphaera* to uptake P **and** denitrify in anoxic zone
Needs volatile fatty acids (VFA) in anaerobic zone to trigger P removal mechanism	• Not dependent on influent VFA • Works together with *Accumulibacter*
Upset by cold, wet conditions due to lack of VFA	• PAOs outcompete GAOs in cold temperatures • Deeper anaerobic conditions fatal for GAOs

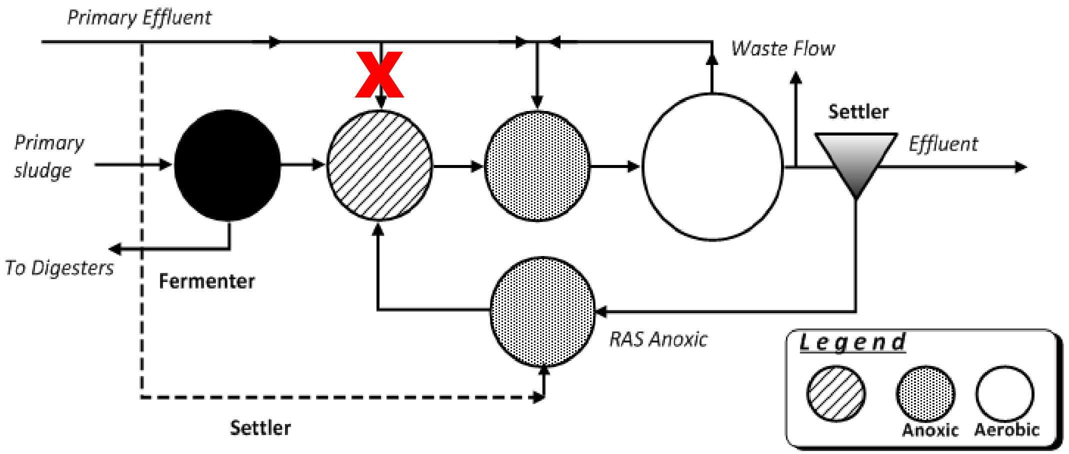
Good news for cold, weak influents!

- **More efficient use of influent carbon for TP and TN removal**
- **Less need for chemicals (ferric, alum, methanol, etc.)**
- **Negligible impact from cold or wet-weather flows**

Long-Term S2EBPR Proof in Western Canada

Regional District of Central Okanagan

Westside Regional WRRF
aka West Bank WWTP
(West Kelowna, BC)



Parameter	Filtered Effluent Average
BOD	< 5 mg/L
TSS	< 2 mg/L
TN	< 6 mg/L
TP	< 0.15 mg/L

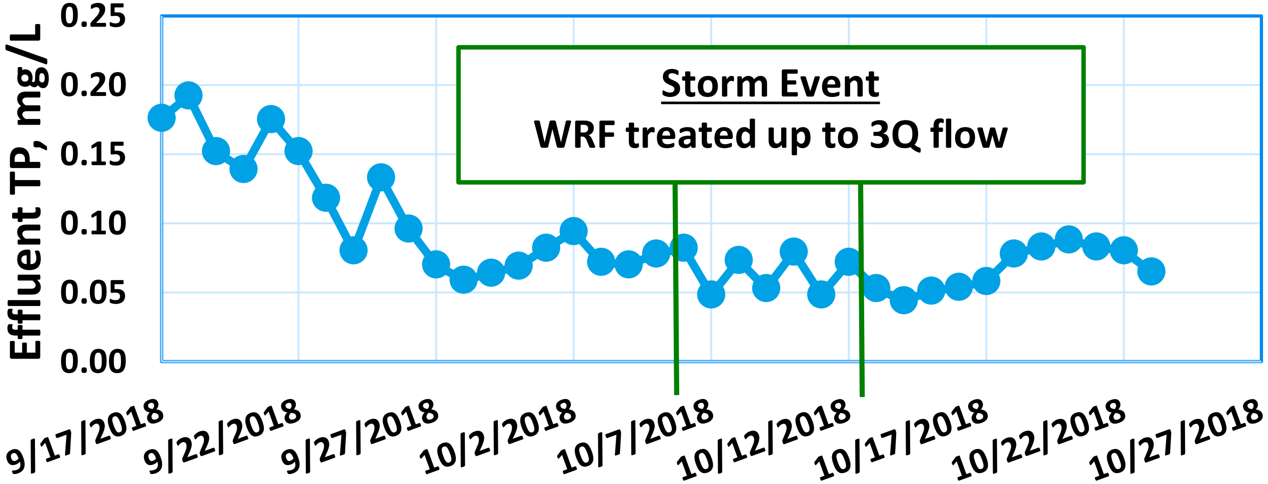
More S2EBPR Proof from Eastern Kansas

Cedar Creek WWTP (Olathe, Kansas)

- 5.3-mgd ADF | 5-stage Bardenpho, ML Fermenter
- Unfavorable COD:P, no supplemental carbon
- Backup ferric not used, no filter
- Average effluent TP <0.5 mg/L, TN <6 mg/L
- Operating since Fall 2012

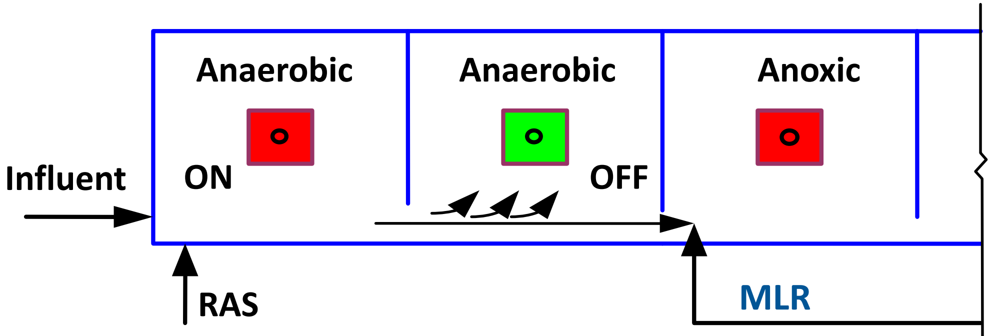
Wakarusa WRF (Lawrence, Kansas)

- 2.5-mgd ADF | 3-stage oxidation ditch with S2EBPR
- No filter, no chemicals
- Average TP <0.2 mg/L, NO_3-N <8 mg/L
- No upset during 3Q wet-weather event



Other S2EBPR Examples

Operating	Pinery AWWTP, Colorado
	Kalispell, Montana
	Henderson, Nevada
	St. Cloud, Minnesota
	South Cary, North Carolina
	West Kelowna, British Columbia
	Blue Lake & Seneca WWTPs, Minnesota
	Joppatowne, Maryland
	Olathe, Kansas
	Lawrence, Kansas
	Medina County, Ohio
Pilot / Design / Construction	Charlotte Water, North Carolina
	Sacramento, California
	Johnson County, Kansas
	Clean Water Services, Oregon
	Centennial Water, Colorado
	Ten Mile Creek, TRA, Texas
	MWRD Greater Chicago, Illinois
	Ashbridges Bay, Toronto, Ontario



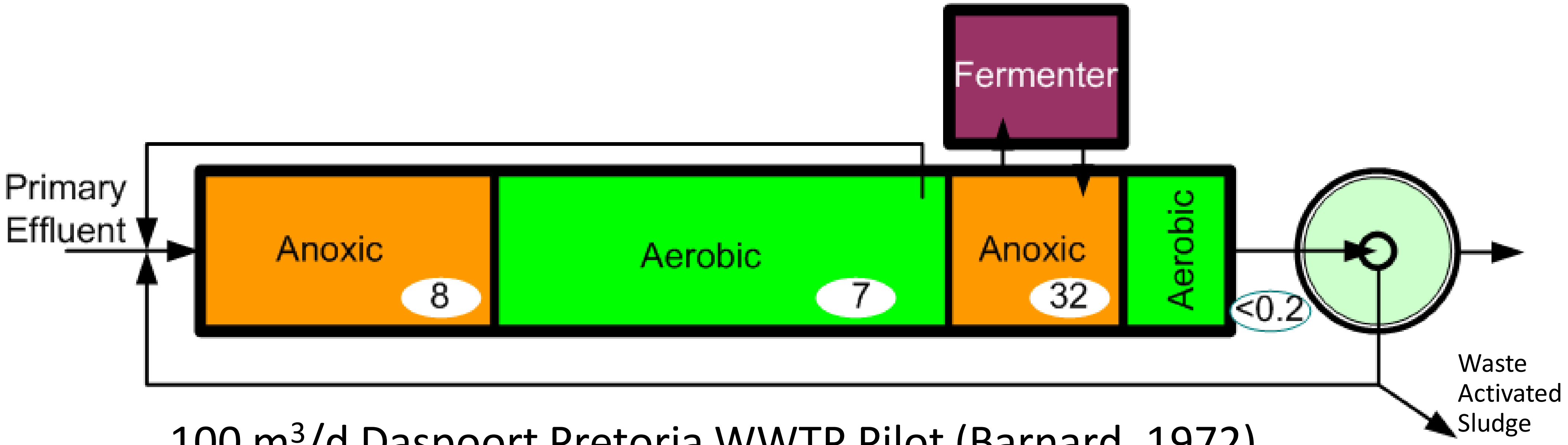
In-line Mixed Liquor Fermenter (Pinery, Henderson, St. Cloud, etc.)

S2EBPR Design for 181-mgd BNR EchoWater Project (Sacramento, California)

Off-line Mixed Liquor Fermenter with 5-stage Bardenpho 5.3-mgd Cedar Creek WWTP (Olathe, Kansas)

Worldwide: 75+ S2EBPR facilities in 10+ process configurations

S2EBPR in Original Bardenpho Pilot

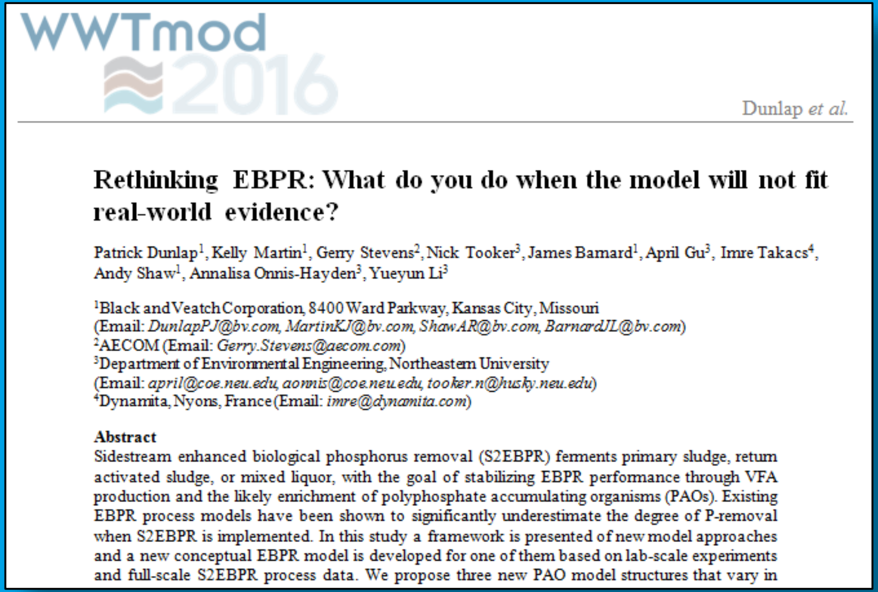


100 m^3/d Daspoort Pretoria WWTP Pilot (Barnard, 1972)

Role of side-stream mixed liquor fermenter was not realized for over a decade

S2EBPR Busts Bio-P Myths

Myth	Reality
Bio-P can't reliably achieve TP<1 mg/L	S2EBPR generates VFA to reliably drive TP down to same levels as chem-P (typically <0.2-0.5 mg/L)
All biomass must pass through anaerobic zone	S2EBPR works with as little as 7-8% of the RAS fermented
Bio P doesn't work when it's cold	Bio P works at low temperature if VFA is present + S2EBPR generates VFA, sewer fermentation not needed + PAOs outcompete GAOs at low temperatures → S2EBPR works winter, spring, summer and fall
Bio P doesn't work with wet-weather flows	Side-stream fermenter is not in main liquid stream + Fermentation and PAO release/uptake unaffected + PAO biomass settles better than AOB/nitrifying biomass → S2EBPR works during peak wet-weather flows


WWTmod 2016

Dunlap *et al.*

Rethinking EBPR: What do you do when the model will not fit real-world evidence?

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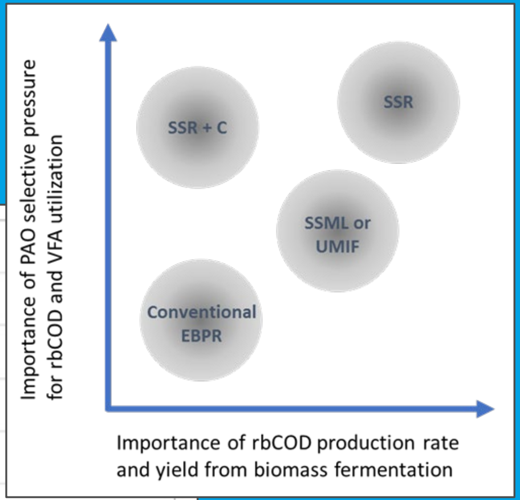
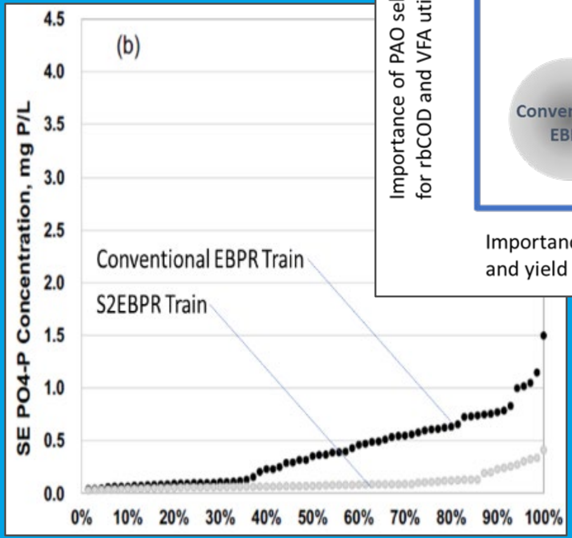
Abstract
Sidestream enhanced biological phosphorus removal (S2EBPR) ferments primary sludge, return activated sludge, or mixed liquor, with the goal of stabilizing EBPR performance through VFA production and the likely enrichment of polyphosphate accumulating organisms (PAOs). Existing EBPR process models have been shown to significantly underestimate the degree of P-removal when S2EBPR is implemented. In this study a framework is presented of new model approaches and a new conceptual EBPR model is developed for one of them based on lab-scale experiments and full-scale S2EBPR process data. We propose three new PAO model structures that vary in





Real-World EBPR Outperforms Current Models

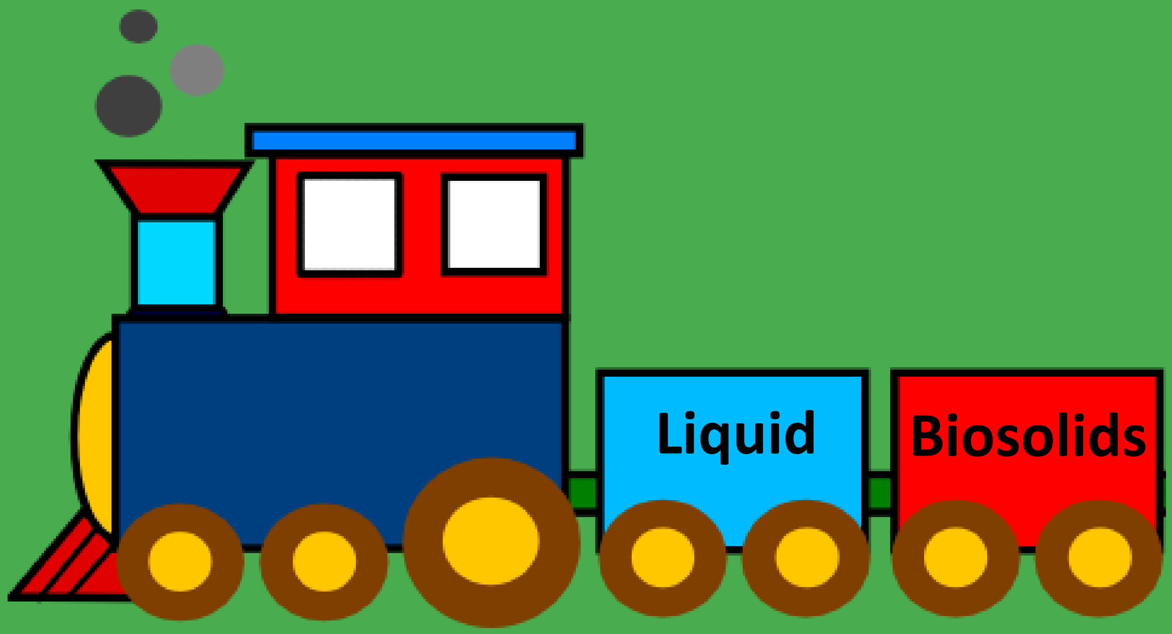
- Water Research Foundation Project 4975
  - Black & Veatch is principal investigator
  - Follow-up to WERF Project U1R13
  - Develop design, operation and modeling tools to improve practice of biological phosphorus removal
  - Update models with new PAO mechanisms, fermentation and characteristics observed in real-world S2EBPR
- Why did profession miss this until now?
  - *Tetrasphaera* need ORP ≤ -250 mV; most main-stream anaerobic zones struggle to get -150 mV
  - Impossible to achieve with NO_3 or DO present
  - Turbulence, air entrainment, or coarse bubble air mixing prevent low ORP
  - Too much mixing and/or too much aeration inhibit *Tetrasphaera*

Motivation for S2EBPR

- Process Stability
  - Biological selector…less sludge bulking, lower SVI…better settling
  - Better BNR during cold and wet-weather
- Process Efficiency
  - In-situ hydrolysis and fermentation doesn't require external VFA
  - Lower oxygen requirements
- Denitrification Synergies
  - More efficient use of influent carbon for TP and/or TN removal
- More Retrofit Options
- Potential Nutrient Recovery

It's not just about effluent limits

Biosolids Train



- Avoid unintended consequences
- Nutrient recovery

Energy/Nutrient Nexus

Anaerobic Digestion with Biological Phosphorus Removal

It's always something

Understanding the connections among biological phosphorus removal, anaerobic solids digestion, dewatering, and land application

Gary F. Shimp, James L. Barnard, and Charles B. Bott

Biological phosphorus removal (BPR) is gaining momentum because it offers both chemical-cost savings and struvite-recovery advantages. But increased biological nutrient removal use necessitates a closer look at its effect on such subsequent processes as solids treatment – especially for facilities using anaerobic digestion.

Most BPR facilities report increased struvite formation in digesters, solids pumps and piping, dewatering equipment, and centrate and filtrate return lines. An additional detriment of BPR is lower-than-anticipated cake solids content and higher operating costs for polymer conditioning, downstream processing, and truck hauling. This phenomenon is another reminder of the interrelationships between liquid treatment and solids processing – a change in one unit operation often affects another.

From Shimp, G.F.; Barnard, J.L.; Bott, C.B.; It's always something. *Water Environment & Technology*, **June 2014**, 26(6), 42-47.

Cause for Concern

- Anaerobic WAS release of $(PO_4)^{3-}$, Mg^{2+} and K^+
- NH^{4+} released during digestion

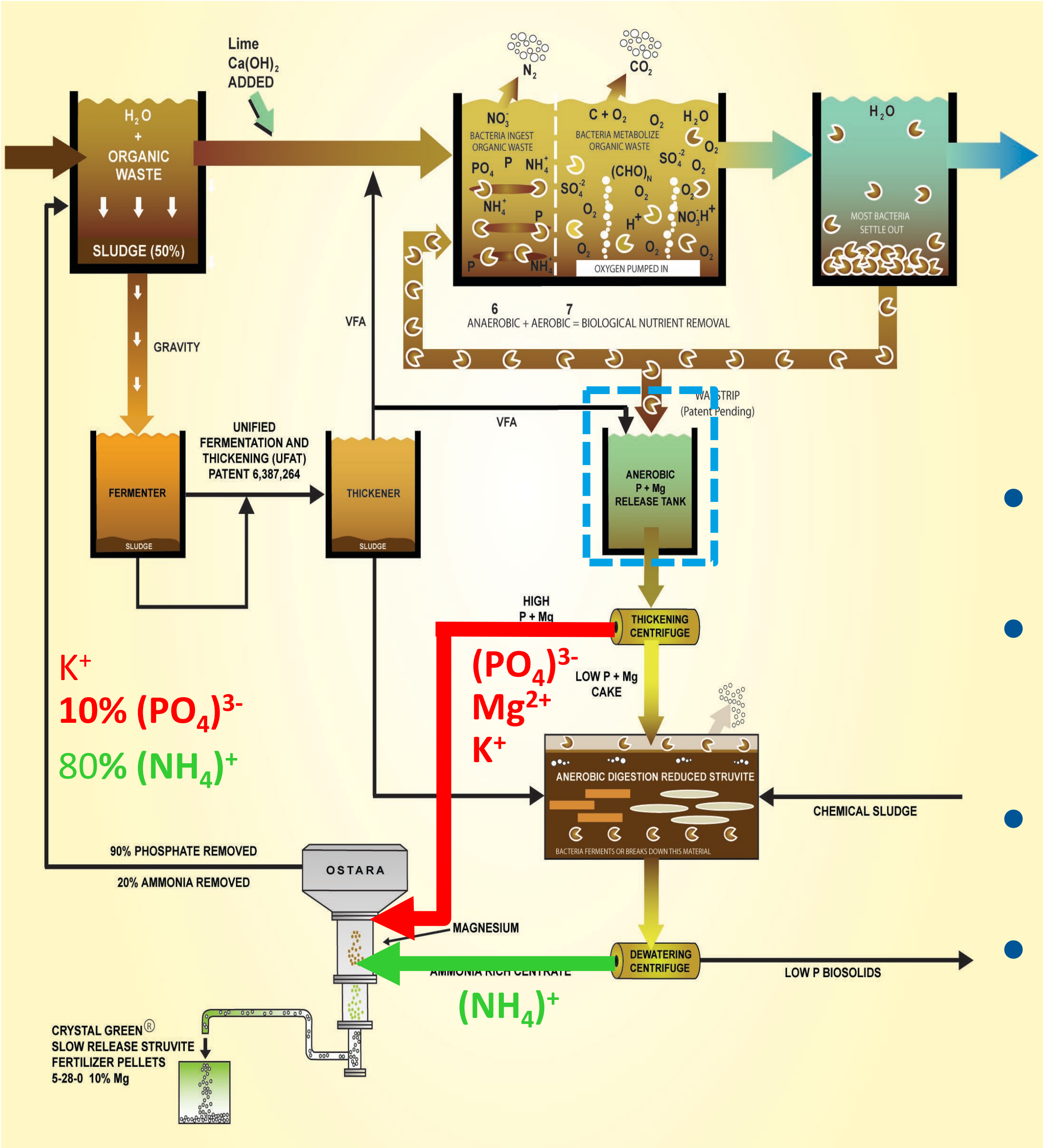
Potential Consequences

- Struvite scaling
- Vivianite scaling if Fe^{2+} present
- NH^{4+}, $(PO_4)^{3-}$, and K^+ recycle to main liquid stream
- Decreased biosolids dewaterability

Opportunity

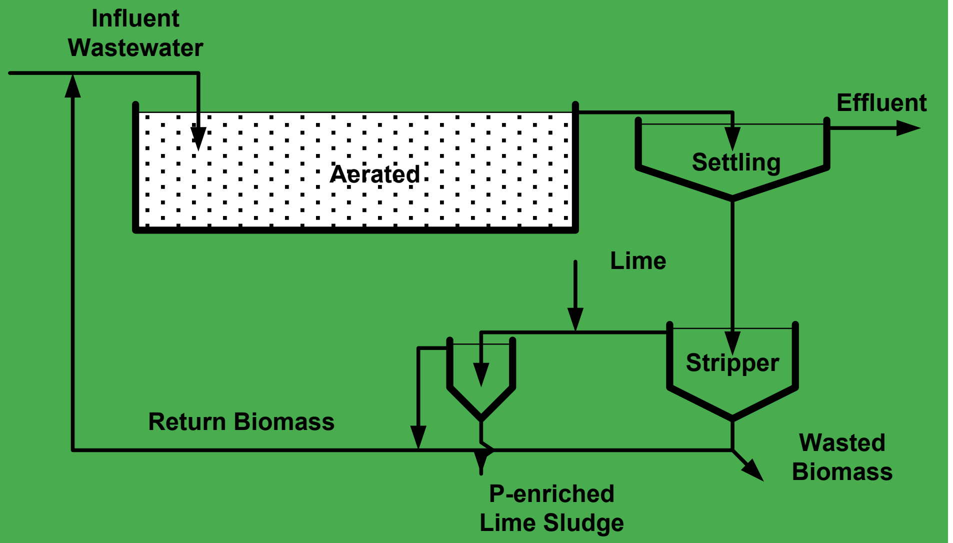
Struvite sequestration/recovery helps avoid unintended consequences

Pre-Digestion Stripping + Struvite Recovery Addresses Concerns



(Schauer et al, 2009)

- **Strip Tank** - WAS releases $(PO_4)^{3-}$, Mg^{2+} and K^+
- **Thickening Liquor** - $(PO_4)^{3-}$, Mg^{2+} and K^+ shunted around digester to crystallizer
- **Digestion** - NH_4^+ released
- **Dewatering Liquor** - NH_4^+ sent to crystallizer
- **Struvite Crystallizer** - $MgNH_4PO_4{\cdot}6\ H_2O$ precipitated



Phostrip Process (1962)

Similar to Early P Removal & Recovery

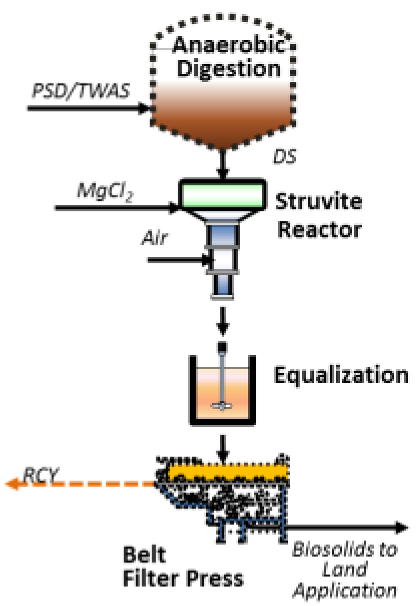
- **High-rate activated sludge process**
  - No nitrification
  - All influent to aeration basin
- **RAS stripper tank**
  - 30-40 hr SRT
  - P release from deep anaerobic conditions
- **Supernatant treated with lime**
  - P removed as calcium hydroxylapatite, $Ca_3(PO_4)_2 \cdot H_2O$
- **Fuhs & Chen find phosphate accumulating organism (PAO) *Acinetobacter***

In hindsight…mainstream bio-P uptake…side-stream P release and recovery

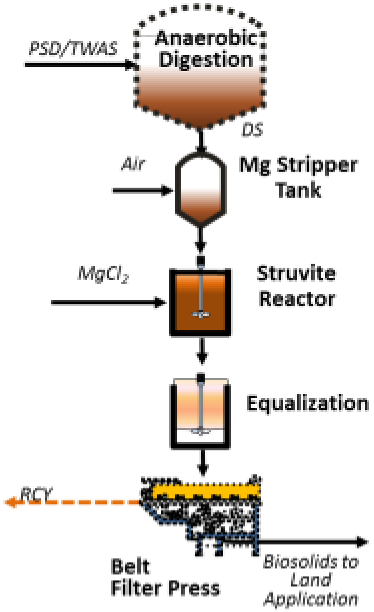
Struvite Technology Alternatives

Sequestration

AirPrex



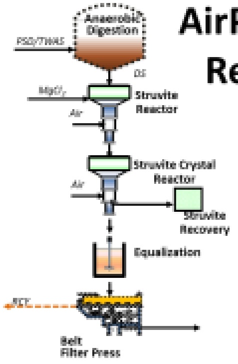
NuReSys



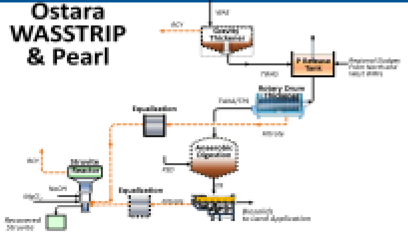
- Struvite crystals remain in biosolids
- Optional recovery add-on

Recovery

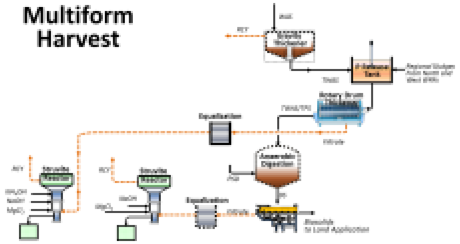
AirPrex with Recovery



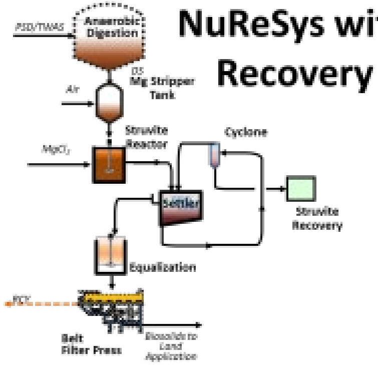
Ostara WASSTRIP & Pearl



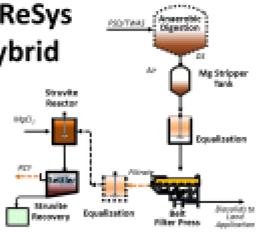
Multiform Harvest



NuReSys with Recovery



NuReSys Hybrid



- Separate struvite crystal fertilizer product
- Decrease P content of biosolids

Project-specific evaluation and selection required

Goals and Benefits

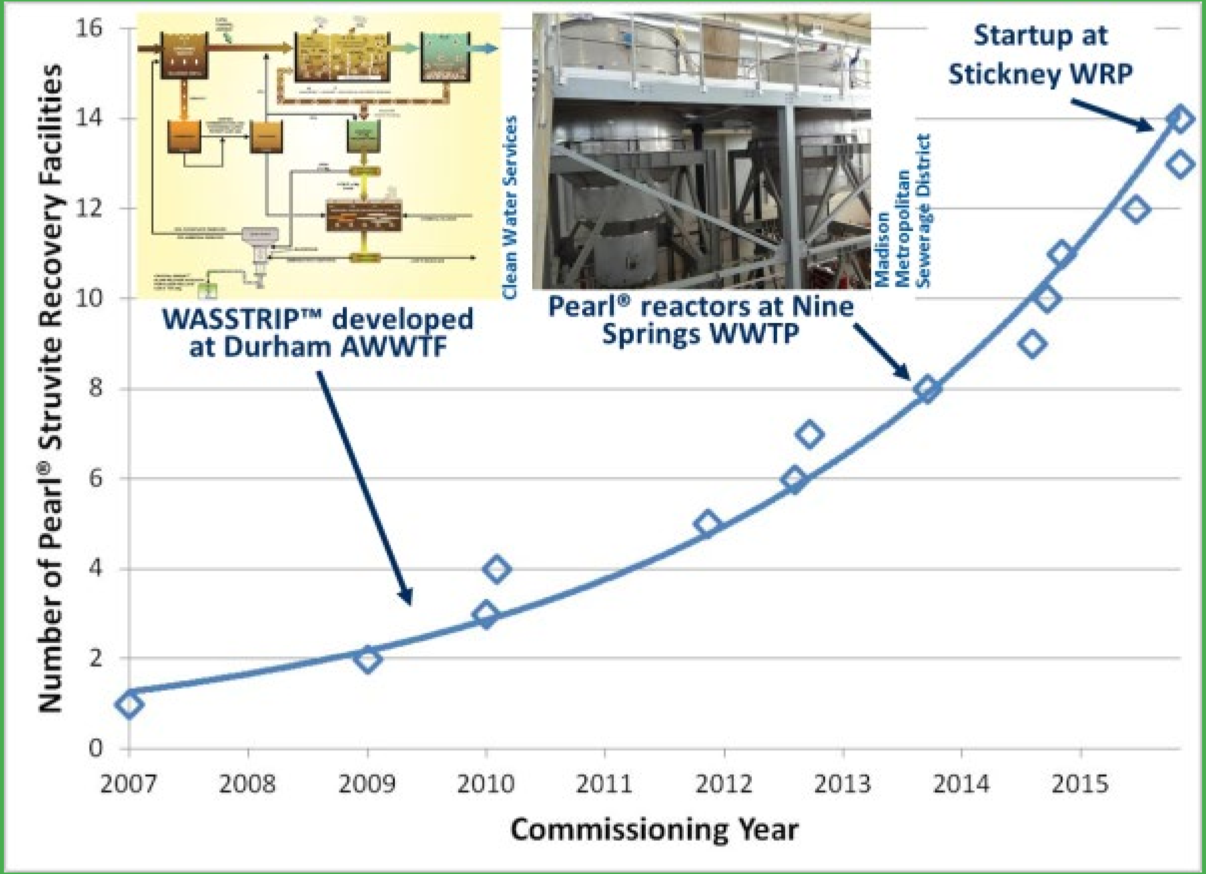
Recovery

- Decrease biosolids P content
- Recover fertilizer product

Sequestration

- Minimize nuisance scale and deposits
- Improve biosolids dewaterability
- Reduce P & N recycle loads

Recent Advances



Hydroxylapatite (pH~9)

$3Ca^{2+} + 2HPO_4^{2-} + H_2O \leftrightarrow \mathbf{Ca_3(PO_4)_2 \cdot H_2O} + 2H^+$

Struvite (pH~8)

$NH_4^+ + Mg^{2+} + HPO_4^{2-} + 6H_2O \leftrightarrow \mathbf{NH_4MgPO_4 \cdot 6H_2O} + H^+$

Brushite (pH~4.5-6.5)

$Ca^{2+} + H_2PO_4^- + 2H_2O \leftrightarrow \mathbf{CaHPO_4 \cdot 2H_2O} + H^+$

Struvite Alternatives	Brushite Alternatives
Ostara Pearl®, MHI Multiform™, CNP AirPrex®, Schwing Bioset/NuReSys®, Paques PHOSPAQ™, KEMA Phred™ and DHV Crystalactor®	CNP CalPrex®

World's Largest Nutrient Recovery Facility

- **1.4 BGD capacity**
- **TP ≤ 1 mg/L (1 Feb 2018)**
  - Optimize EBPR
  - Reduce TP recycle
- **Predicted struvite recovery**
  - 5,350 lb/day PO_4-P
  - 7,700 ton/yr fertilizer

Struvite Sequestration Part of Design-Build Performance Contract in Ohio

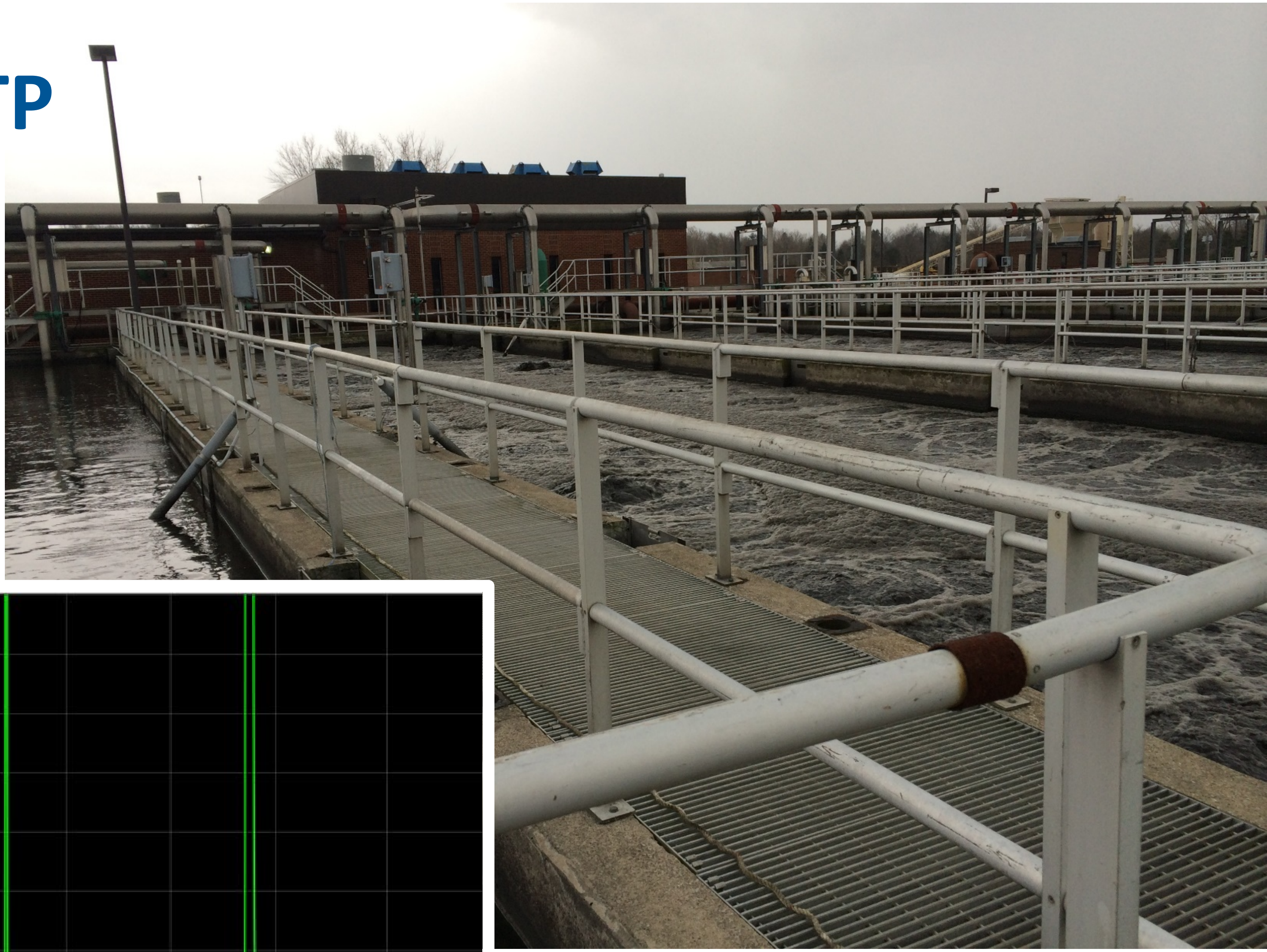
16-mgd Kenneth W. Hotz WRF
Medina County, Ohio

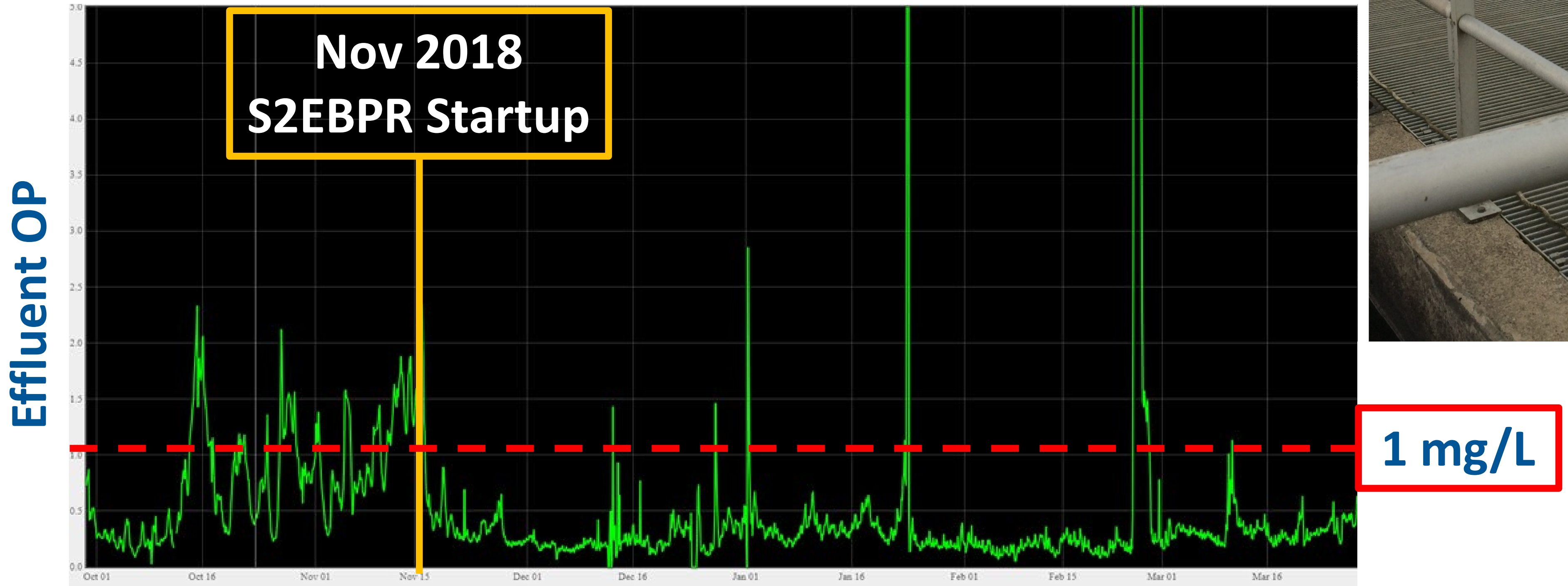
Struvite Reactor

- Thermal hydrolysis process (Cambi)
- Stainless-and-galvanized steel anaerobic digesters (Lipp)
- Combined heat and power system
- Struvite sequestration (Airprex)
- Side-stream EBPR
- Side-stream nitrification and denitrification

THP and side-stream trains commissioning now. On schedule for 2019 completion.

S2EBPR at Liverpool WWTP (Medina County, Ohio)





Black & Veatch part of WRF LIFT team evaluating brushite technology for P recovery

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WRF Launches Project to Demonstrate Phosphorus Recovery Using CalPrex™ System

DENVER, CO 11/30/18 – The Water Research Foundation (WRF) has launched a project, *Demonstrating the CalPrex™ System for High Efficiency Phosphorus Recovery* (5004), between the Milwaukee Metropolitan Sewerage District (Milwaukee, Wisconsin), Madison Metropolitan Sewerage District (Madison, Wisconsin), Metro Wastewater Reclamation District (Denver, Colorado), Massachusetts Water Resources Authority (Boston, Massachusetts), and Centrisys/CNP (Kenosha, Wisconsin), to demonstrate a high-rate, pre-digestion phosphorus removal and recovery technology. The technology, developed at the University of Wisconsin-Madison and licensed from Nutrient Recovery and Upcycling (NRU) by Centrisys/CNP under the name CalPrex™, ran as a ~10 gallon per minute pilot system from October through the end of November 2018 at the Madison Metropolitan Sewerage District. The demonstration has provided high-quality data that will allow utilities to evaluate high-rate phosphorus recovery and its effects on phosphorus load management.

The CalPrex™ phosphorus removal and recovery system incorporates a thickened sludge fermentation tank to increase the amount of soluble and reactive species of phosphorus, thereby increasing the recovery potential of that phosphorus. The system diverts over 50% of soluble phosphorus from the methane digester and, ultimately, from resulting biosolids. The CalPrex™ system recovers phosphorus in the form of brushite, a calcium phosphate mineral with high potential as a slow-release phosphorus fertilizer. The project will support and leverage efforts that NRU is undertaking in conjunction with a USDA SBIR grant and a supporting grant from the Center for Technology Commercialization in Wisconsin to establish brushite in the fertilizer market.

Results of the project will help water resource recovery facilities (WRRFs) evaluate and benchmark state-of-the-art alternatives for removing phosphorus from sludge going to digesters. The goal is for utilities to use phosphorus recovery technologies such as CalPrex™ to mitigate operations and maintenance issues related to struvite scaling in pipes and poor sludge dewaterability. Simultaneously, WRRFs implementing such technologies will better meet increasingly stringent regulations on phosphorus while recovering a valuable fertilizer. An expert review of the project findings will be conducted, and the results will be disseminated to industry professionals through the WRF LIFT Link platform in May 2019.

Preliminary results show promising performance

Validation Criteria	Target Value	Average Field Value
Solubilization of P in Bio-P sludge	at least 60%	66%
Soluble P in CalPrex reactor	50-100 mg/L	50 mg/L
Reduction of total P in biosolids	up to 50%	TBD*

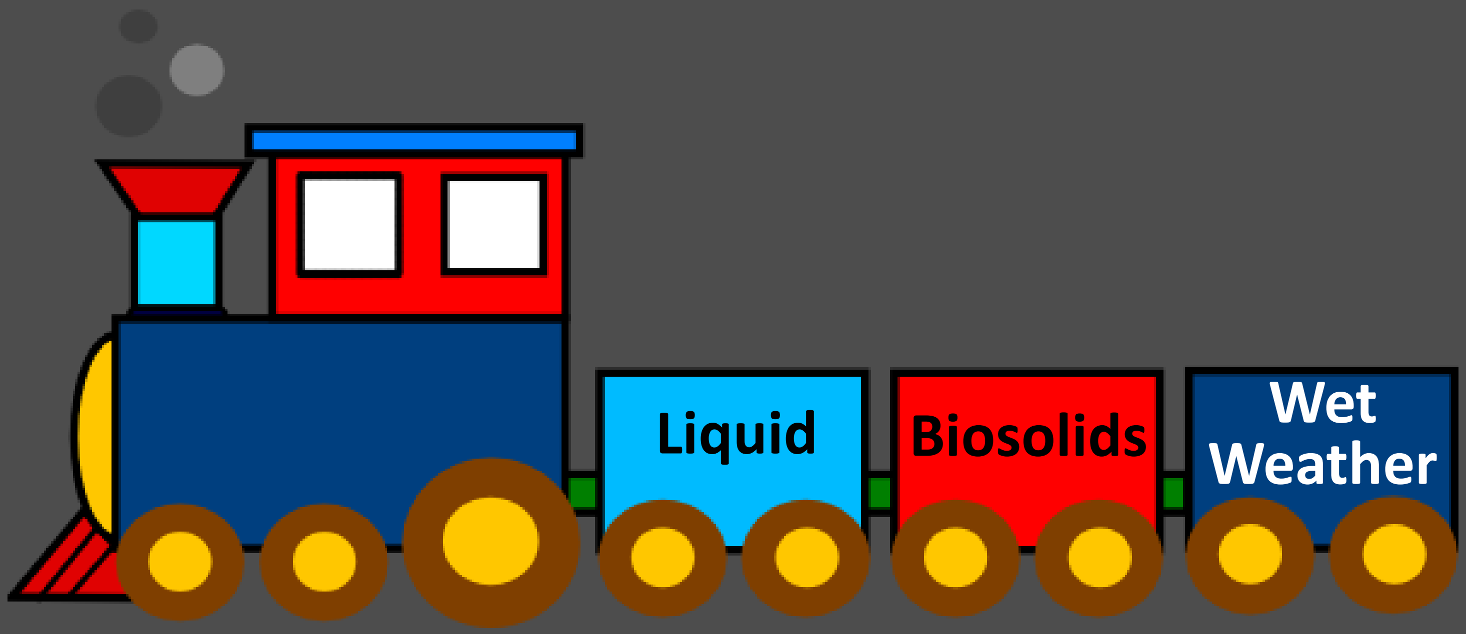
43% average recovery of total P from sludge feed

65% average recovery of ortho P that could otherwise precipitate as struvite downstream

(CNP/Centrisys, 2019)

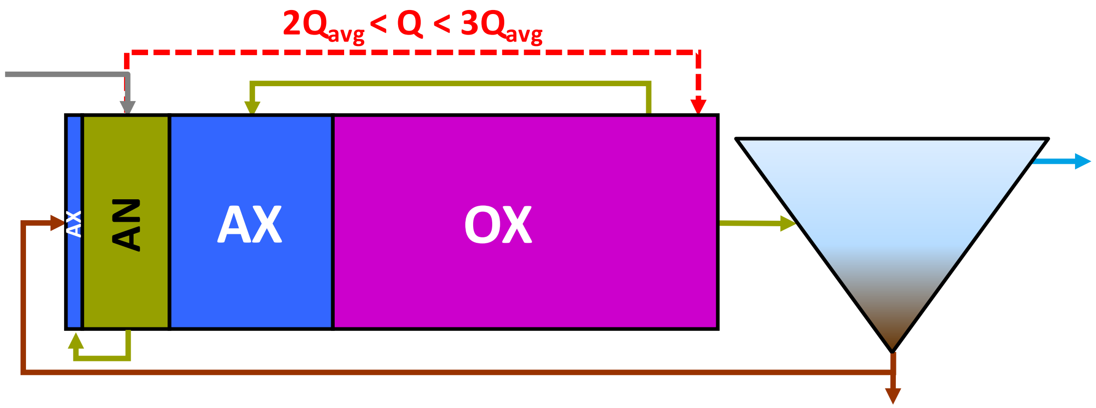
P recovery at low pH, fit for acid-phased digestion

Wet Weather



- Don’t upset your BNR bugs
- Ways to weather the storm

Deep Step-Feed Helps "Weather the Storm"



MJHB with Wet-Weather Step-Feed

- Temporary change to contact stabilization mode for wet-weather flows
- "Biological contact" or "biocontact"
- Good for plug-flow basins

Maximizing biological treatment of wet-weather flows

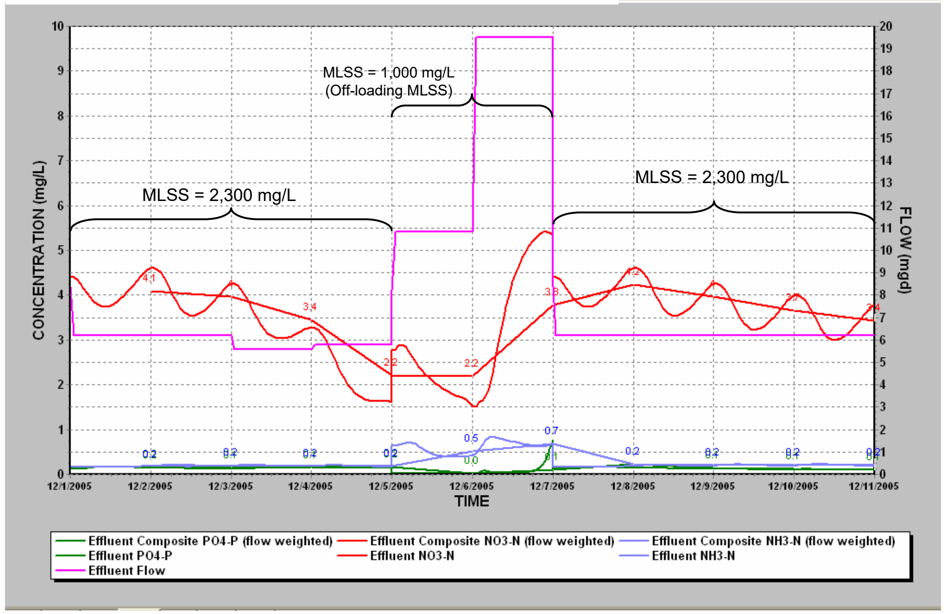
Biomass Transfer Accomplishes Same

- **Transfer some RAS or MLSS to offline storage.**
- **Return biomass after storm flows pass.**
- **Good for complete-mix basins, oxidation ditches, etc.**

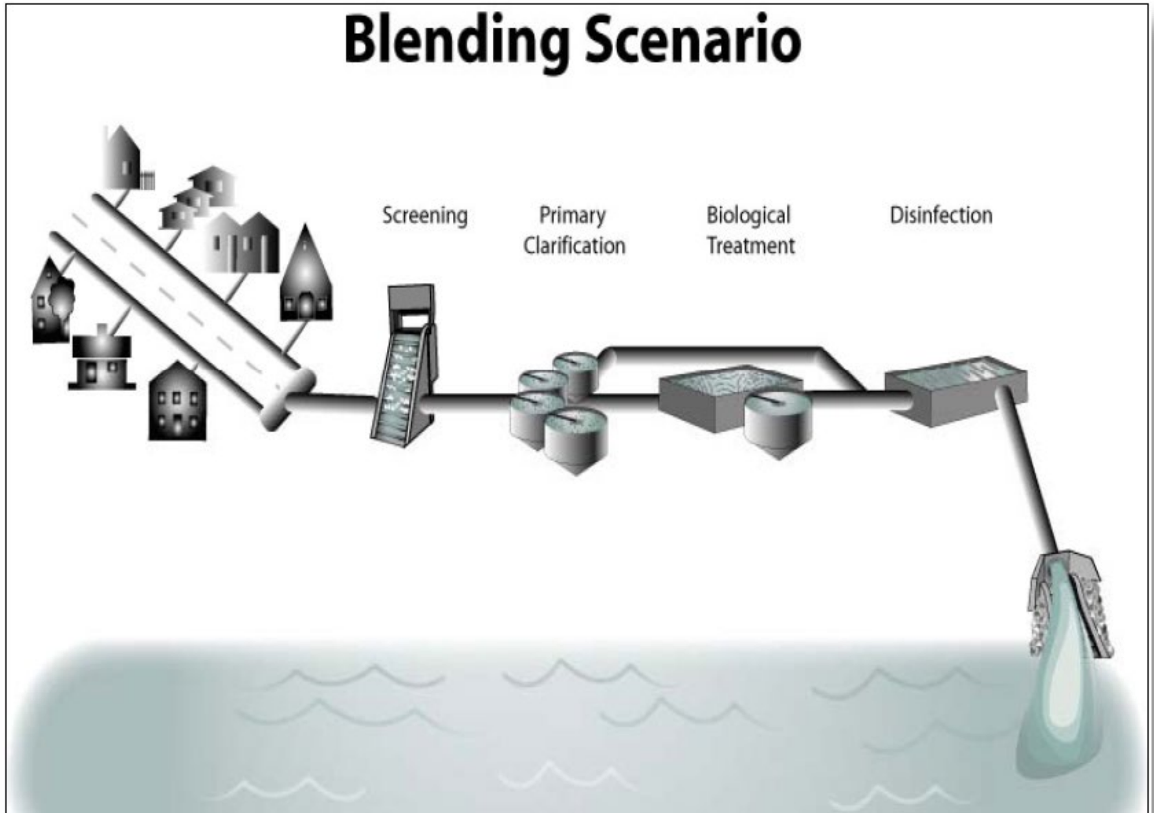
Another way to reduce SLR to clarifiers … <u>temporarily</u>

Offline Biomass Storage
Rogers, Arkansas
5-stage Bardenpho Oxidation Ditch

BioWin Process Model of Rogers
Biomass Transfer Operations



Blending or Auxiliary Treatment for Higher Peaking Factors

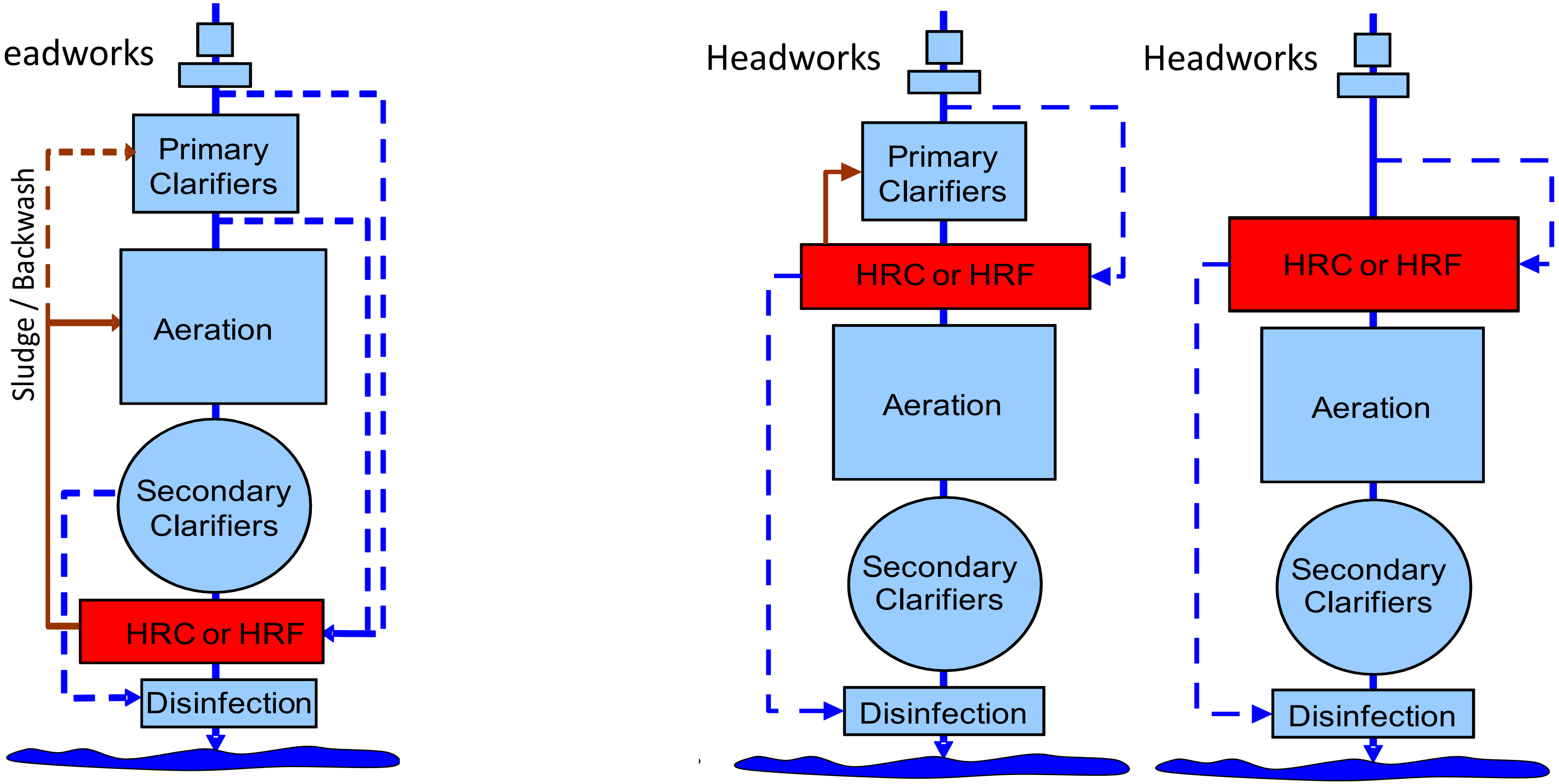


Background diagram from: U.S. EPA, Sanitary Sewer Overflows and Peak Flows Listening Session, June 30, 2010

Background diagram from: U.S. EPA, Sanitary Sewer Overflows and Peak Flows Listening Session, June 30, 2010

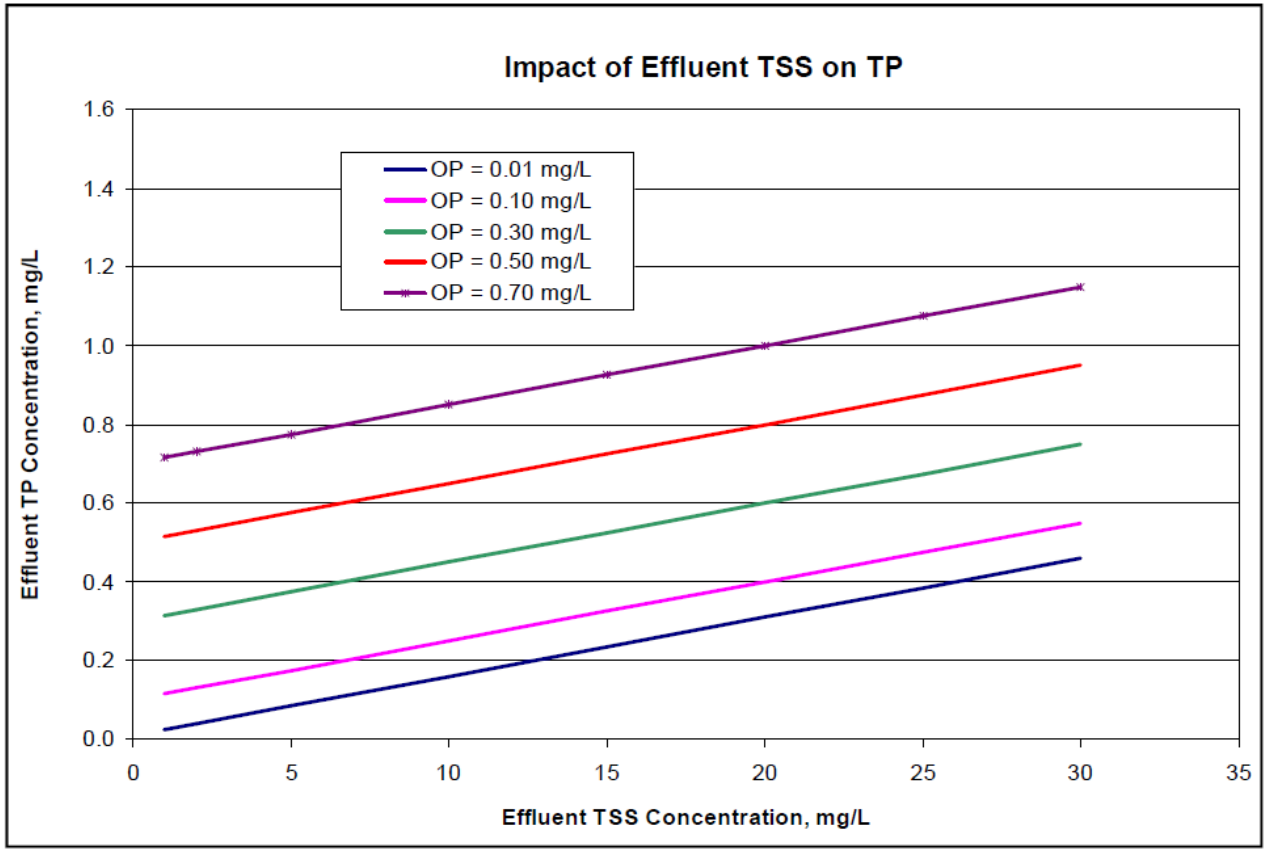
Dual-Use Auxiliary Facilities for More Benefit Than Just Wet Weather

Improve Effluent Quality **OR** **Improve Energy Efficiency**



Examples include Fox Metro, IL; Rushville, IN; Little Rock, AR; Johnson County, KS

Dual-Use Tertiary Filter also Enhances P Removal…with Either Bio-P or Chem-P

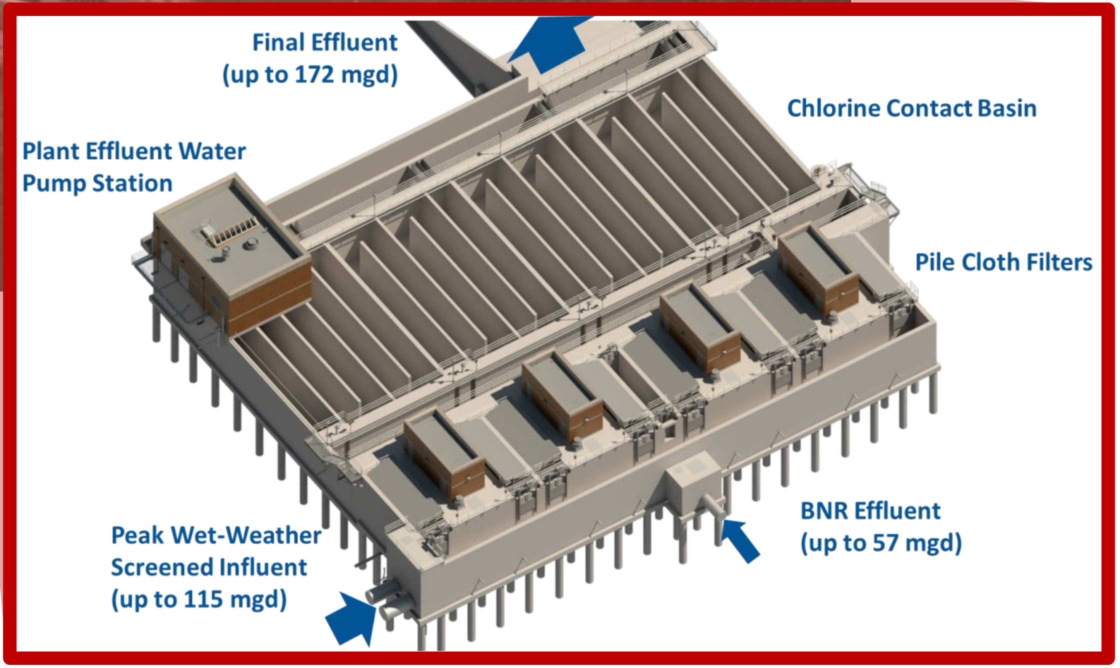


From Schauer, P. and deBarbadillo, C. (2009) Pushing the Envelope with Low Phosphorus Limits, PNCWA

Lower TP…

…requires lower TSS

Enhanced P Removal and Wet Weather Treatment

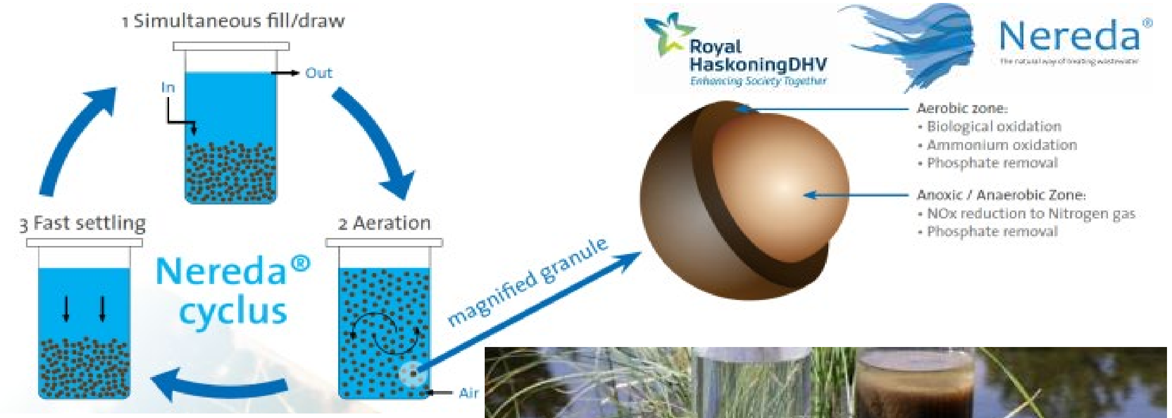


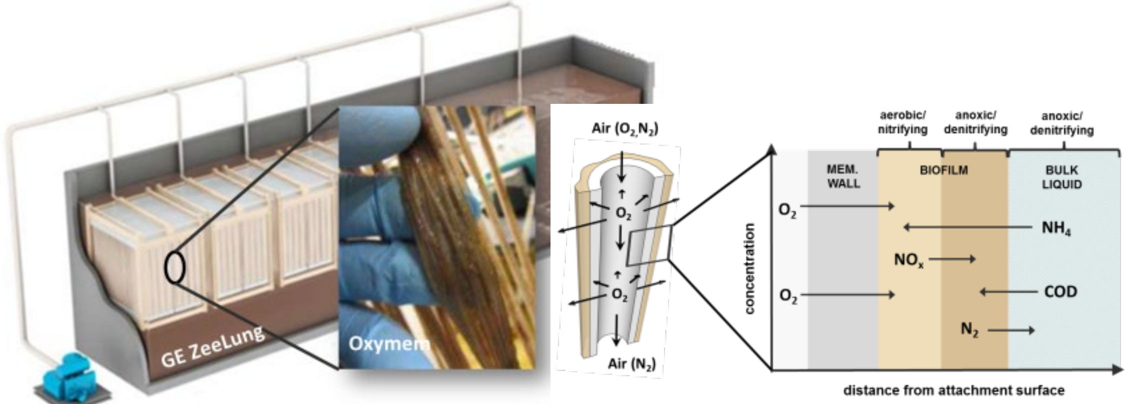
- Expand 7-mgd WWTP to 19-mgd ADF
- S2EBPR + Bardenpho for TP<0.5 mg/L, TN<10 mg/L
- 2020 startup with CMAR design-build

- BNR + filter up to 57 mgd
  + Auxiliary EHRT up to 115 mgd
  Peak WWTF capacity = 172 mgd

Closing Thoughts and Open Discussion

- BNR Process Intensification
- $10M Prize to Lower Phosphorus





aeration membranes support low-energy biofilm nitrification and denitrification

Process Intensification Examples

- **Aerobic Granular Sludge**
  - **AquaNereda® in U.S.**
  - **S2EBPR coincidental granulation**
- **Membrane Aerated Biofilm Reactor**
  - **Suez ZeeLung™, OxyMem, Fluence**
  - **B&V pilot in Hayward, California**
  - **Synergies with S2EBPR**

Less energy, smaller footprint, lower OPEX than conventional AS

$10M Prize for Much Cheaper Technology for TP<0.01 mg/L

THE GEORGE BARLEY WATER PRIZE
PRESENTED BY THE Scotts Miracle-Gro FOUNDATION

EVERGLADES FOUNDATION

Ontario
Ministry of the Environment and Climate Change

KNIGHT FOUNDATION

xylem
Let's Solve Water

Barley Prize Stage 3 Pilot Site
(Courtesy Everglades Foundation)

Stay tuned!

- http://www.barleyprize.org/
- B&V on judging panel
- 2020 final four piloting in Lake Jesup, Florida

THANK YOU!!

OWEA 2019

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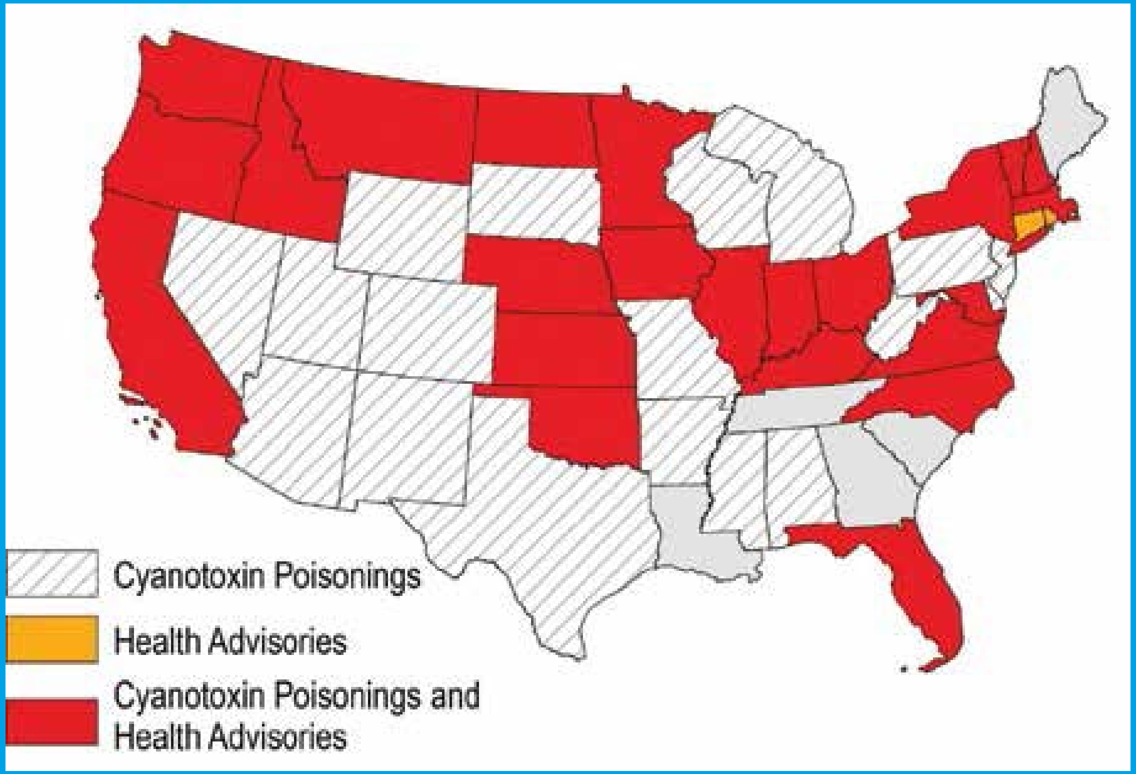
Bullpen

Drivers

- Harmful Algal Blooms
- Agricultural Needs
- Regulatory Pressures
- Economics

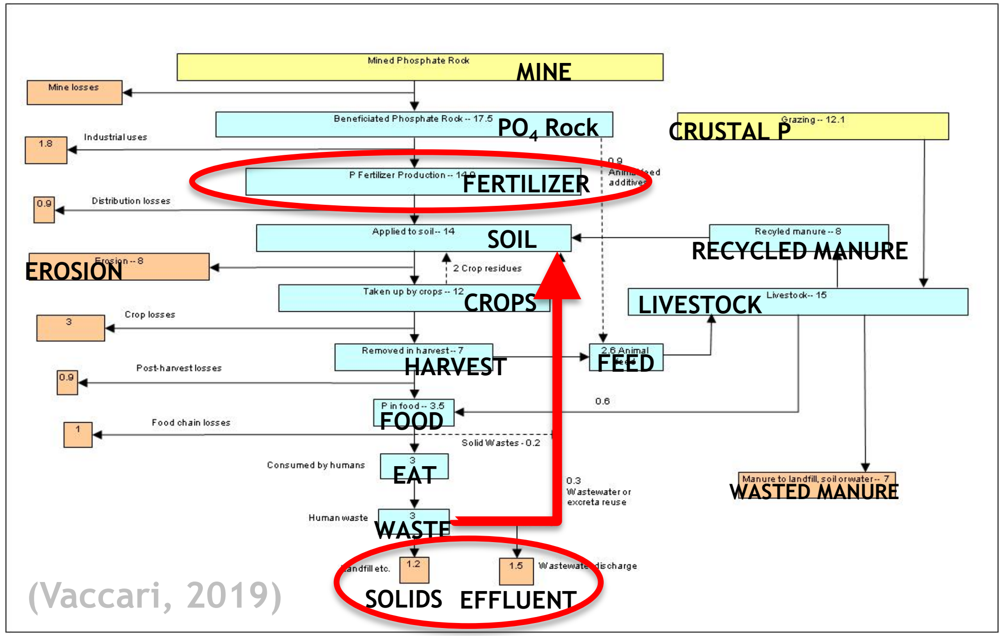


Source: P.R. Easley, Harmful Algal Blooms (HABs) and You, *Southwest Water Works Journal*, 27(2), Summer 2016

Phosphorus – A Finite Resource

- >200 years of economical PO_4 rock reserves…but largest fertilizer producers (China and USA) will run out within decades **at current usage/production**
- Potential impact to fertilizer trade and economics

USGS 2017 Report	2017 Prod (Mt/yr)	Prod % of global	Reserves (Mt)	Reserves % of global	Life (yrs)
Morocco_and_Western_Sahara	27	10%	50,000	71%	1,852
China	140	53%	3,300	5%	24
United_States	28	11%	1,000	1%	36
Rest of the World	68	26%	15,939	22%	234
World_total_(rounded)	**263**	100%	70,000	100%	266



(Vaccari, 2019)

Increasing value of P recovery

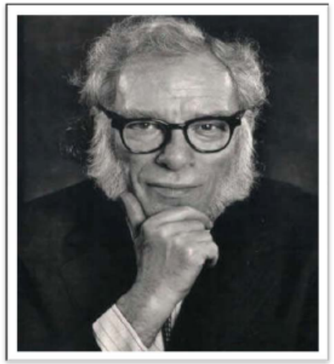
Increasing Population Requires Better Phosphorus Management

"The phosphorus content of our land, following generations of cultivation, has greatly diminished. It needs replenishing. I cannot over-emphasize the importance of phosphorus not only to agriculture and soil conservation, but also the physical health and economic security of the people of the nation. Many of our soil deposits are deficient in phosphorus, thus causing low yield and poor quality of crops and pastures…."

-President Franklin D. Roosevelt, 1938

About Phosphorus

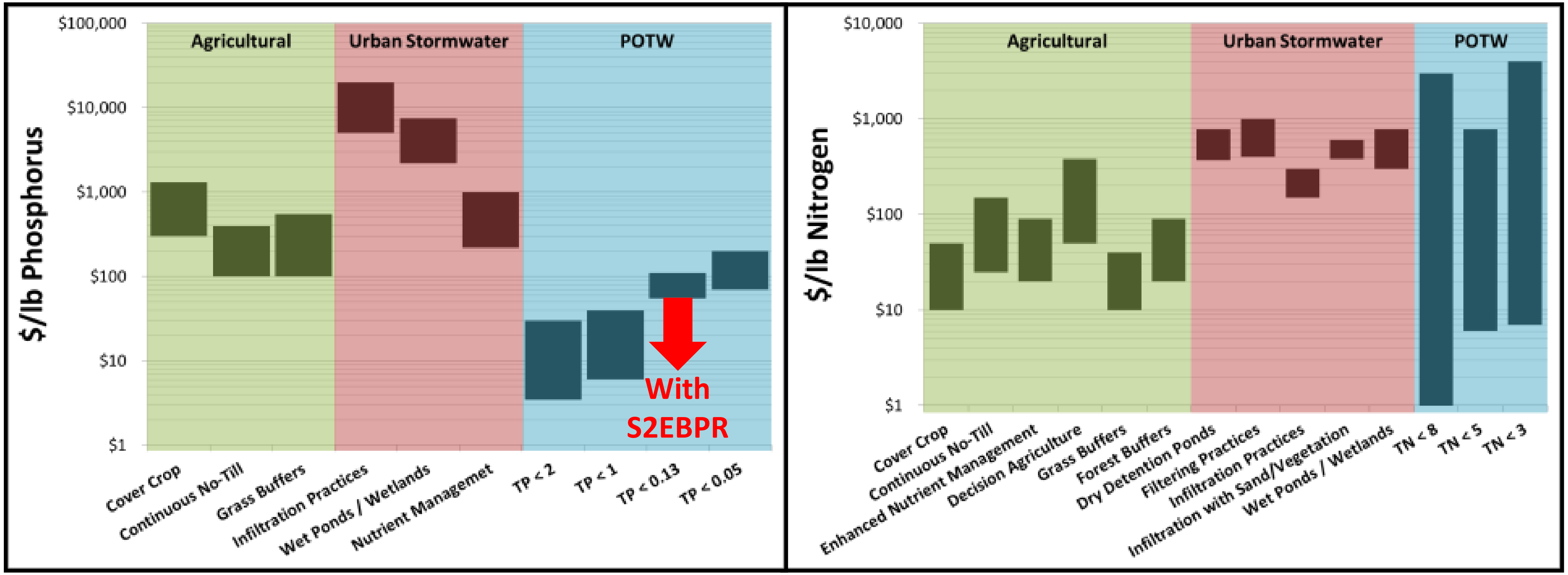
"We may be able to substitute nuclear power for coal power, and plastics for wood, and yeast for meat, and friendliness for isolation, but for phosphorus there is neither substitute nor replacement."



Isaac Asimov

Lee Kuan Yew Water Prize 2011

Historical Costs of Different Practices

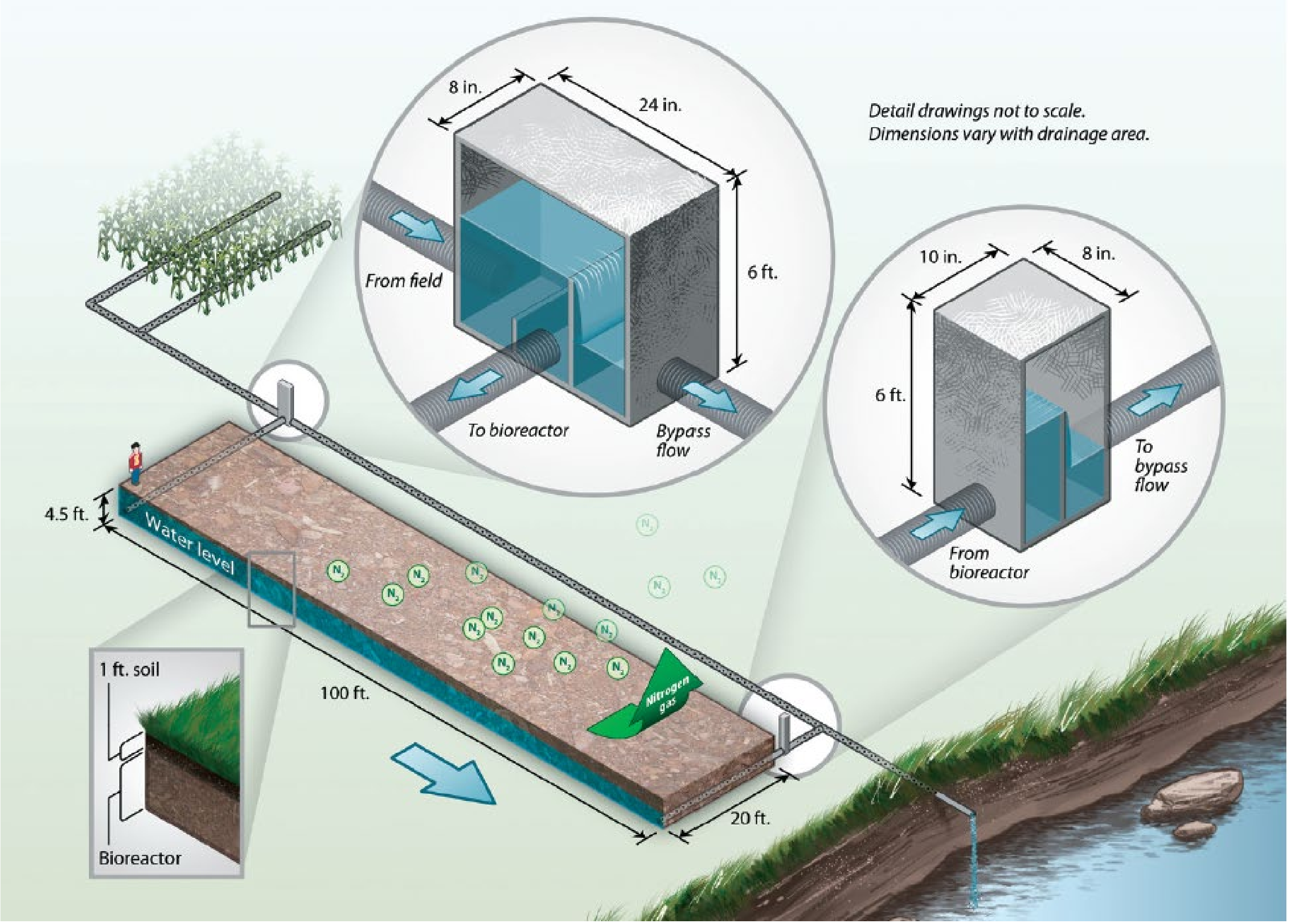


Source: WEF (2015) *The Nutrient Roadmap*, Figures 5.12 and 5.13

- **Low hanging fruits:**
  - TP removal → POTW with enhanced phosphorus removal
  - TN removal → Agriculture (sometimes POTW)

Not a substitute for project-specific cost/benefit evaluations

Ag Drainage Treatment Focuses on Nitrogen



Source: L. Christiansen et al., Woodchip Bioreactors for Nitrate in Agricultural Drainage, Iowa State University, October 2011

Research for N and P Removal from Ag Drainage

Source: L.E. Christianson et al, *Water Research* 121 (2017) 129-139

University of Illinois pairs denitrifying woodchip filters with P adsorption filters

Optimize Conventional Treatment for P Removal

Conversion

Convert Soluble Reactive P (SRP) to Particulate P

Biological Options OR Chemical Options

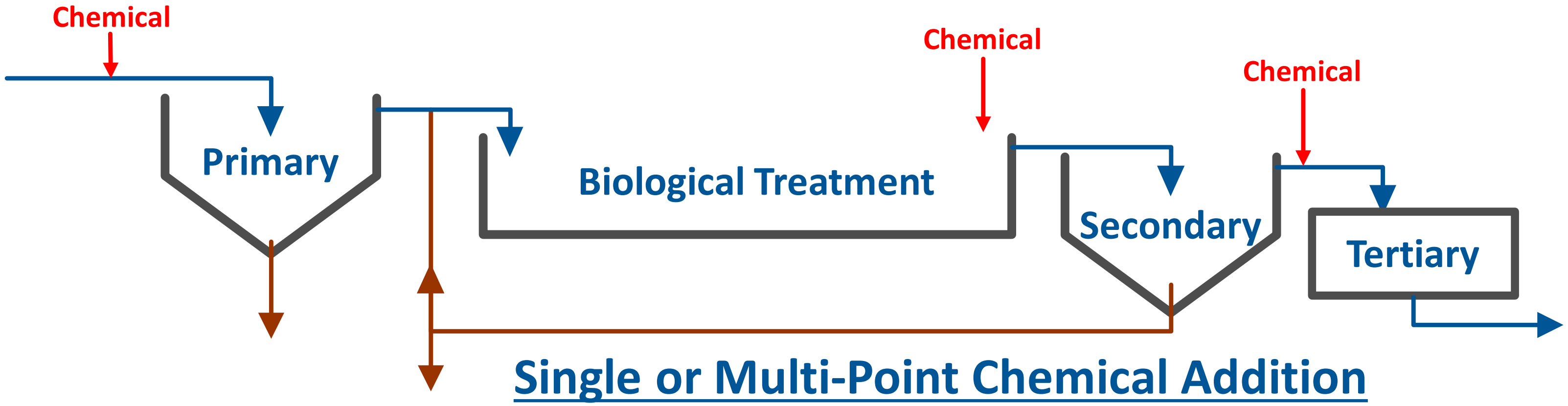
Clarification

Remove Particles from Liquid

Settling Options OR Filtration Options OR Flotation Options

Primary, Secondary and Tertiary Applications

Chemical Phosphorus Removal



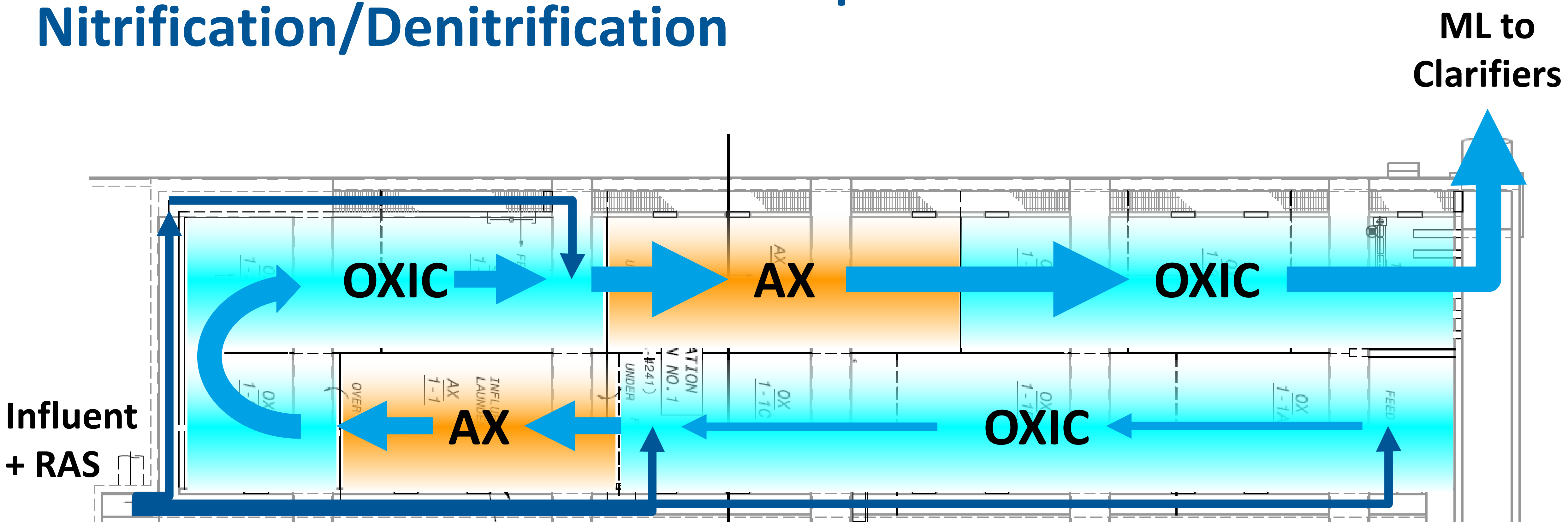
Single or Multi-Point Chemical Addition

- Iron ($FeCl_2$, $FeCl_3$)
- Aluminum (Alum, PACl, etc.)
- Calcium (Lime)
- Rare earth metals emerging (cerium, lanthanum, etc.)

Advantages	Disadvantages
• Low capital costs • Simple, reliable process	• Additional O&M costs (chemicals, solids) • Consumes alkalinity and P needed for biological treatment • Increased sludge production • Co-precipitation of metals and P into biosolids • Interferes with P recovery chemistry

Disadvantages increase as chemical dose increases to meet lower TP limits

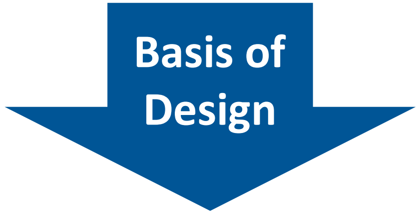
S2EBPR Also Pairs Well with Step-Feed Nitrification/Denitrification



Nutrient Removal Upgrades for Adams Field WRF (Little Rock, Arkansas | 2019)

No mixed liquor pumping = lower energy alternative than MLE denitrification

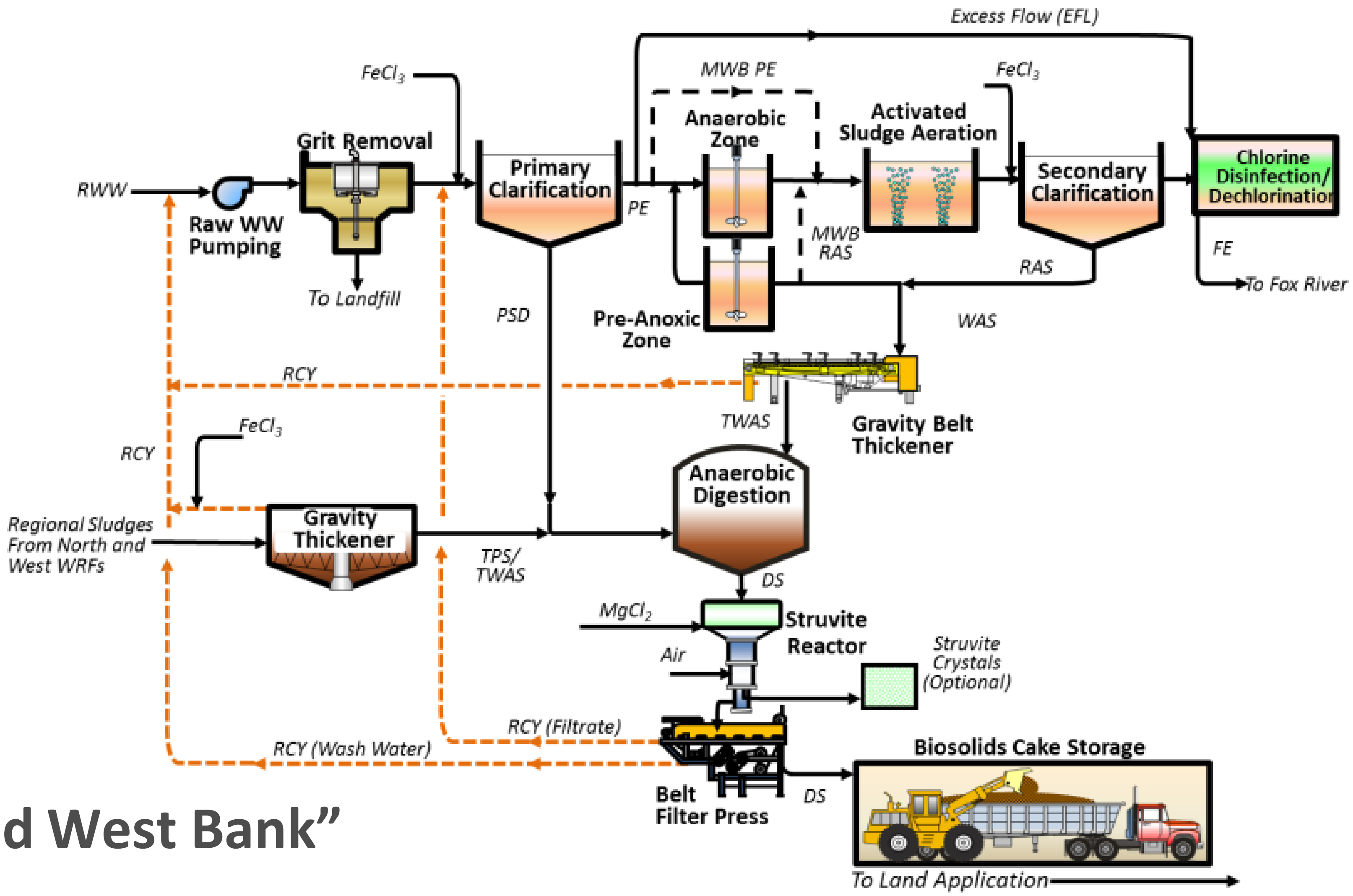
Design-Build Includes Struvite Sequestration + S2EBPR Under Energy Savings Performance Contract



Criterion	Pearl + WASSTRIP	AirPrex w/ Harvesting	AirPrex	Degas + Ferric	Ferric
1. WWTP Performance					
Reduce nuisance precipitate formation	High	Medium	Medium	Medium	Low
Improve phosphorus removal capacity	High	Medium	Medium	High	Medium
Improve reliability to meet TP limits	High	Medium	Medium	Medium	Medium
Offers improvements to the dewatering process	High	High	High	Medium	High
2. Environmental / Health / Social / Economic					
Perform nutrient recovery	High	Medium	Low	Low	Low
Reduce chemical sludge quantity produced/disposed	High	High	Medium	Low	Low
3. Financial					
Net Present Value of alternative	High	Medium	Low	Medium	Medium
Capital costs of alternative	High	Medium	Low	Medium	Medium
4. Risk Assessment					
Technological track record	Medium	Low	Low	High	High
Manpower hours and skill required	Medium	Medium	Medium	Low	Low

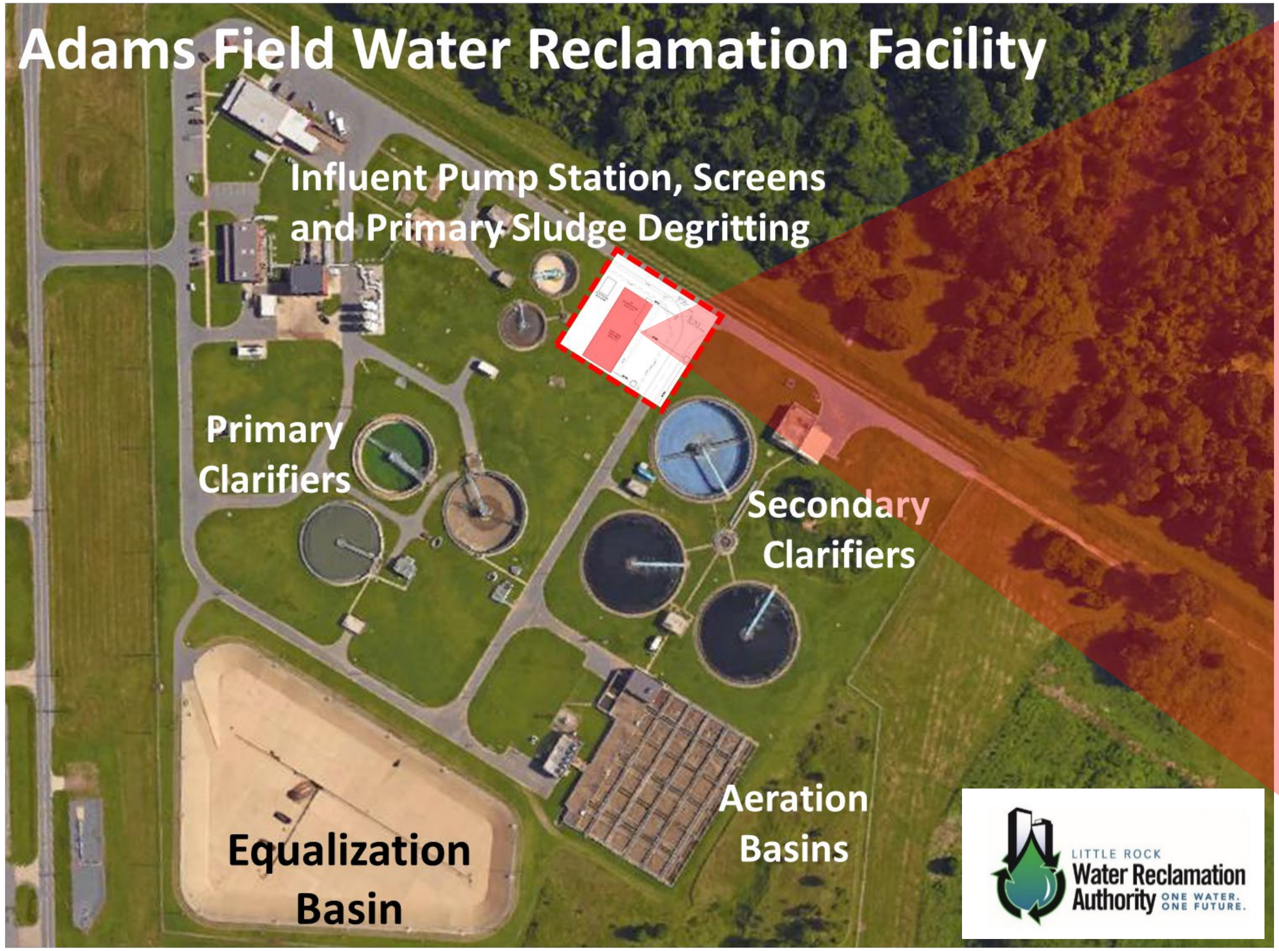
Cambi and side-stream trains commissioning now. On schedule for 2019 completion.

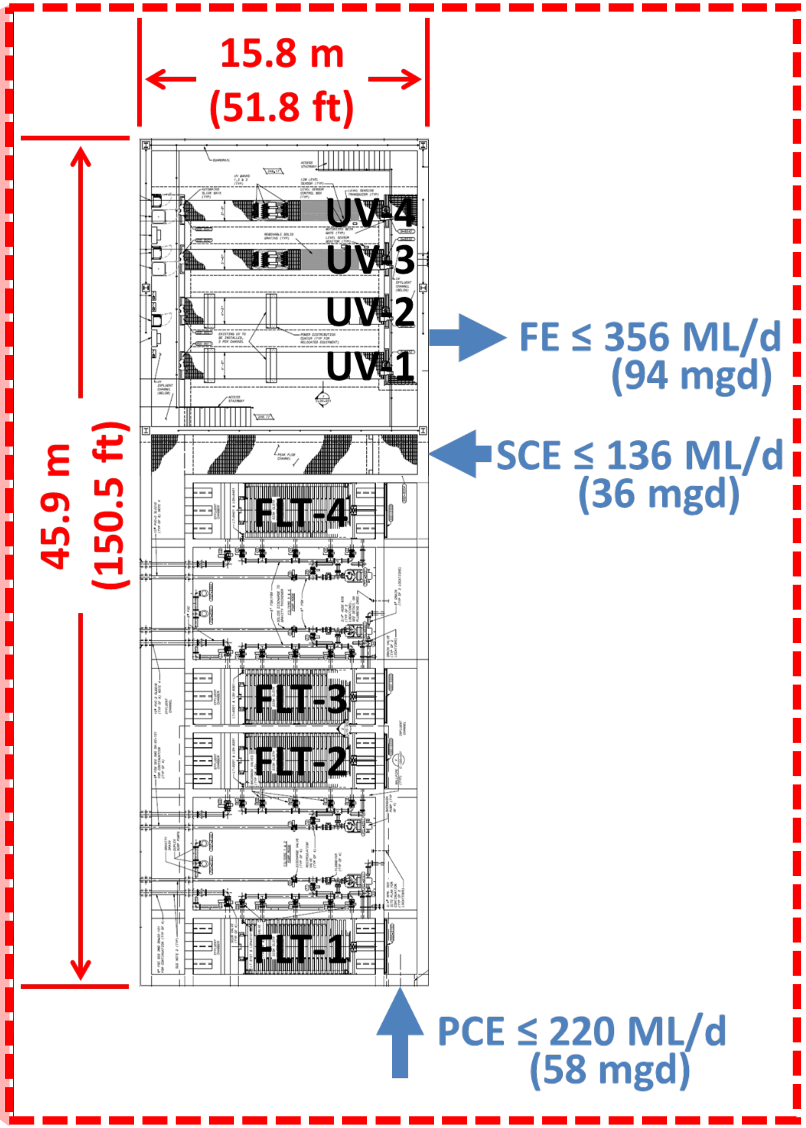
Struvite recovery + S2EBPR retrofit for 25-mgd Albin D. Pagorski WRF



- S2EBPR = "Modified West Bank"
- Struvite Recovery = AirPrex®

Dual-Use EHRT in Arkansas





- Increase peak wet-weather capacity to 94 mgd
- Improve UV disinfection performance
- Simple O&M
- Lowest life-cycle cost alternative