New Versions of Proven Methods to Optimize P Removal and Recovery

13 November 2018

Jim Fitzpatrick
Principal Process Engineer

BLACK & VEATCH

Optimize Conventional Treatment Processes

Conversion

Convert Soluble Reactive P (SRP) to Particulate P

Biological Options OR Chemical Options

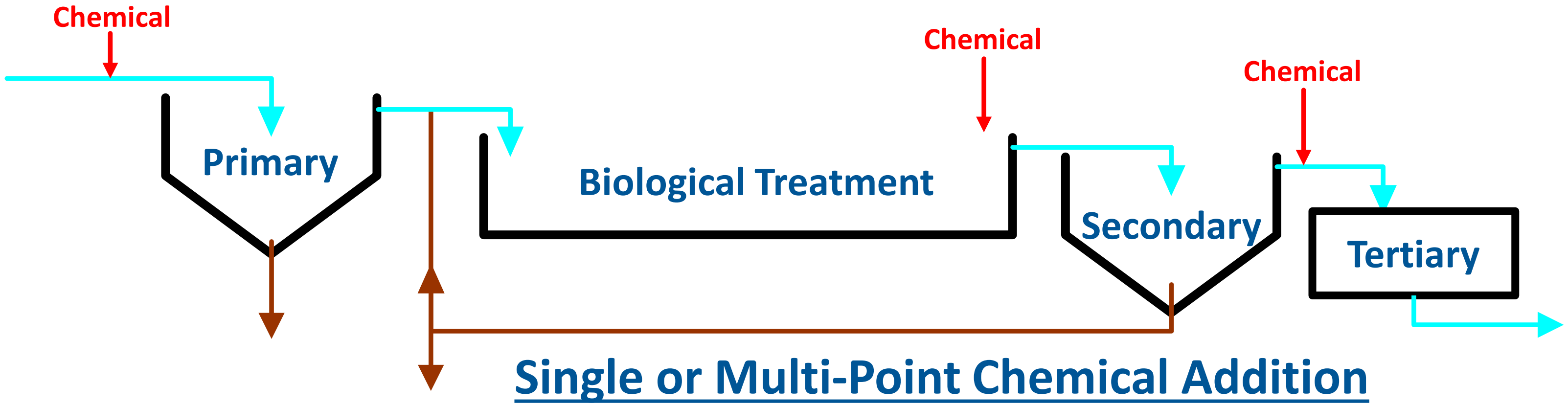
Clarification

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

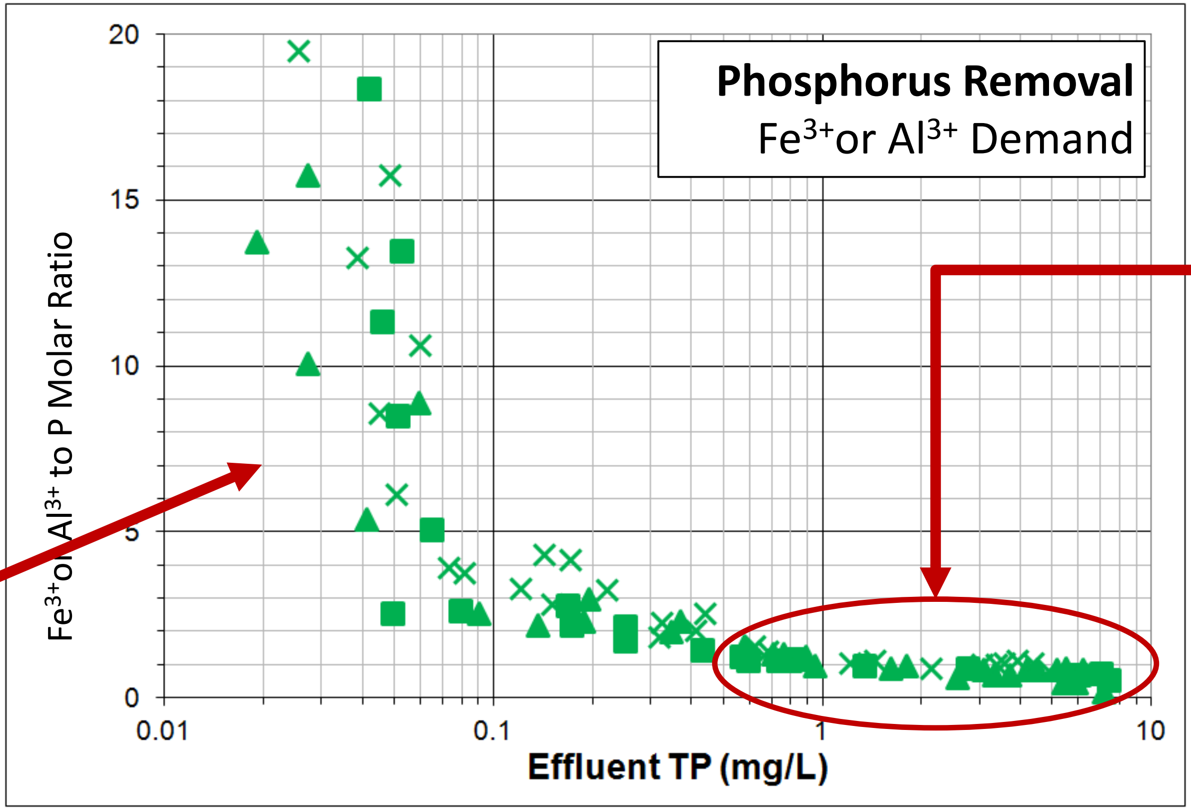
- Iron ($FeCL_2$, $FeCL_3$)
- Aluminum (Alum, PACL, etc.)
- Calcium (Lime)
- Rare earth metals emerging (cerium, lanthanum, etc.)

Advantages	Disadvantages
• Low capital costs • Simple, reliable process • Enhanced settling	• 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 struvite-based P recovery processes

Disadvantages increase as chemical dose increases to meet lower TP limits

Back of WRRF

Tertiary



Front of WRRF

Primary

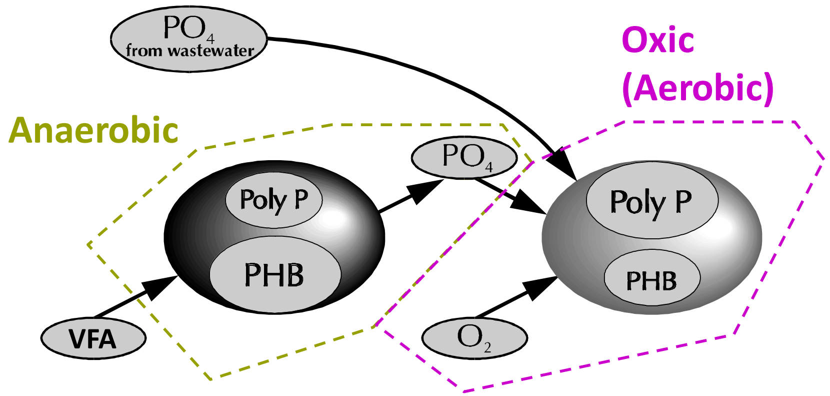
Secondary

TP<0.1 mg/L is Different Physicochemical Process than TP<1 mg/L

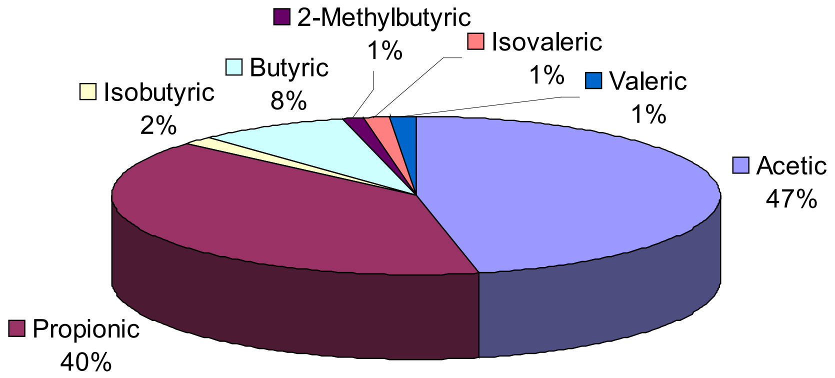
- Fe^{3+}/Al^{3+} reactions with alkalinity predominate to form hydroxyl floc for PO_4 co-precipitation, adsorption and sweep coagulation
- Much different than 1 mg/L limits where conventional PO_4 precipitation dominates
- Enhanced clarification/filtration needed
- Sludge recirculation helps lower chemical dosage
- Polymer and/or ballasting agent also required for some clarification options

Mainstream Thinking for Enhanced Biological Phosphorus Removal (EBPR)

- Volatile fatty acids (VFAs) drive EBPR mechanism of phosphate accumulating organisms (PAO)
- Anaerobic zone required
- Mixture of VFAs required for PAO to outcompete glycogen accumulating organisms (GAO)



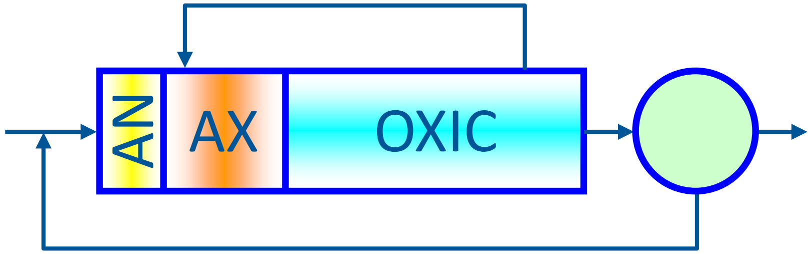
PAO Luxury Uptake Mechanism (Fuhs & Chen, 1975)



Fermentate Analysis Wakarusa WRF (Lawrence, KS 2007)

First Primary Fermenter Kelowna BC, 1979

S2EBPR is New Reality for EBPR



Traditional EBPR

- Mainstream anaerobic zone
- PAO like *Accumulibacter* needs volatile fatty acids (VFA) to trigger P removal
- Poor performance in cold, wet conditions due to lack of sewer hydrolysis and fermentation to generate VFA

Side-stream EBPR (S2EBPR)

- Side-stream anaerobic fermenter grows PAO like *Tetrasphaera* → produce VFA and uptake P in anoxic/oxic and denitrify in anoxic zone
- Not dependent on influent VFA
- Works together with *Accumulibacter*
- Deeper anaerobic conditions fatal for GAOs

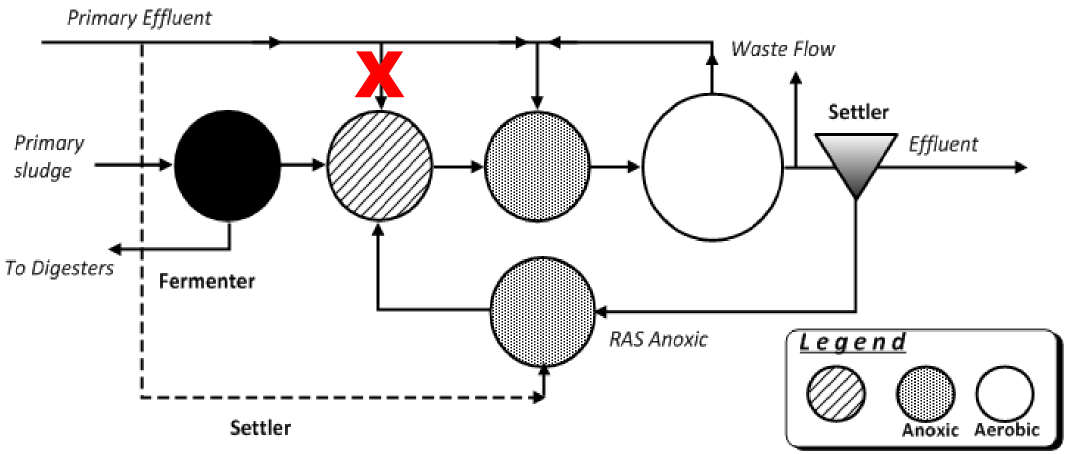
Good news for cold, weak influents!

- 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 British Columbia

Regional District of Central Okanagan

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

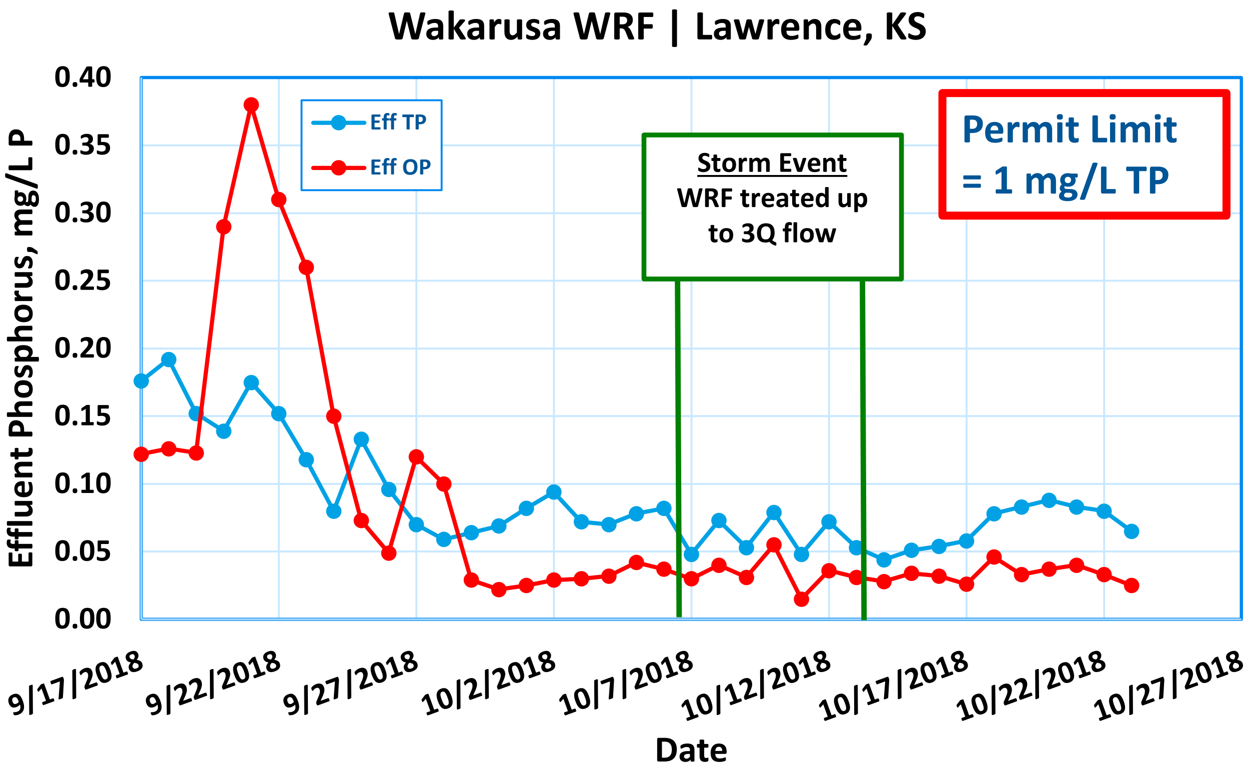


Parameter	Filtered Effluent Average
BOD	< 5 mg/L
TSS	< 2 mg/L
TN	< 6 mg/L
TP	< 0.15 mg/L

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 in 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 flow events**

Eastern Kansas Proves S2EBPR Works during Wet and Cold



Cedar Creek WWTP (Olathe, Kansas)

- 5.3-mgd ADF | 5-stage BNR with S2EBPR
- No filter, backup ferric not used
- Average effluent TP <0.5 mg/L, TN <6.0 mg/L
- Operating since Fall 2012

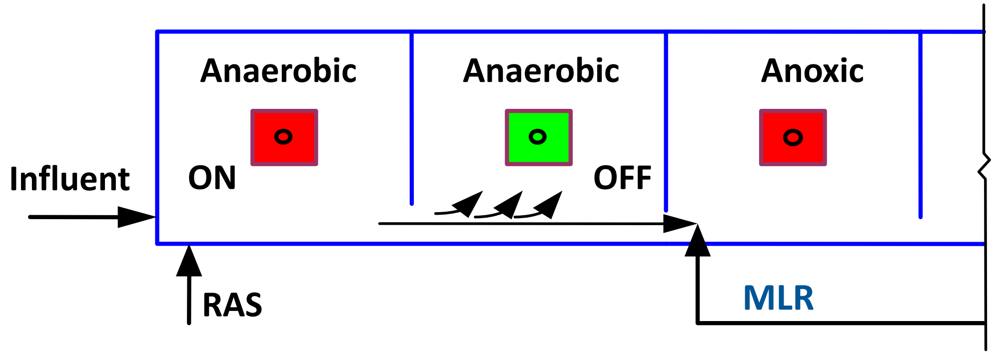
Wakarusa WRF (Lawrence, Kansas)

- 2.5-mgd ADF | 3-stage BNR with S2EBPR
- No filter, no chemicals
- Average TP<0.2 mg/L, OP<0.15 mg/L
- No upset during 3Q wet-weather event

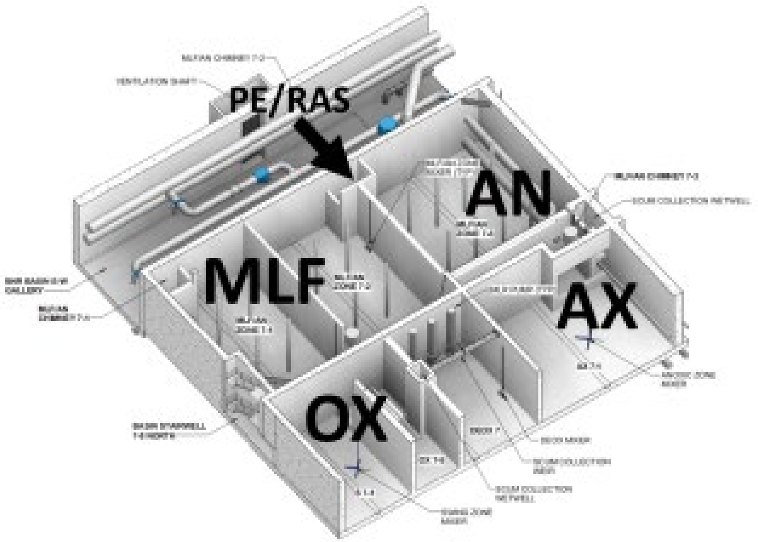
Other S2EBPR Examples

- Johnson County, Kansas
- Sacramento, California
- Lawrence, Kansas
- Olathe, Kansas
- West Kelowna, British Columbia
- Blue Lake & Seneca WWTP, Minnesota
- Joppatowne, Maryland
- South Cary, North Carolina
- St. Cloud, Minnesota
- Henderson, Nevada
- Pinery AWWTP, Colorado

Worldwide: 75+ S2EBPR facilities in 10+ configurations



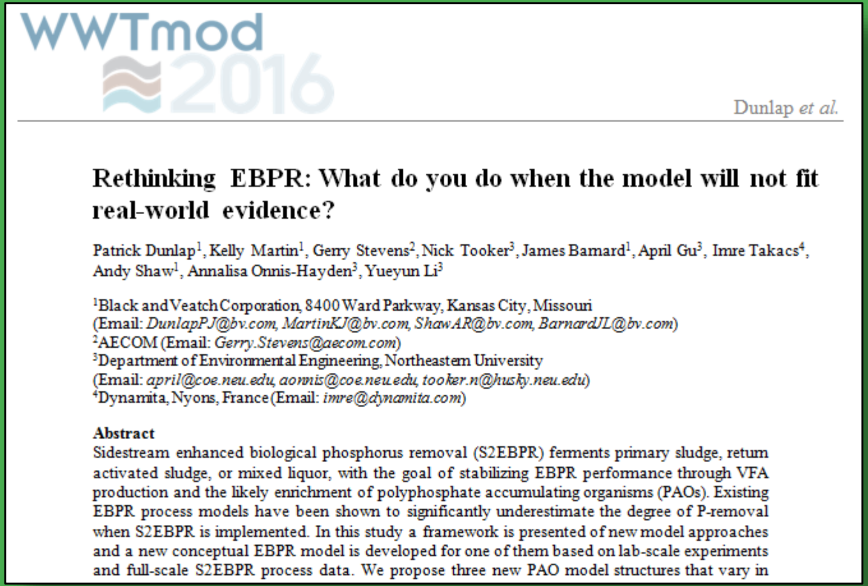
In-line Mixed Liquor Fermenter (Pinery, Henderson, St. Cloud, etc.)



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)

Real-World EBPR Outperforms Current Models


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

- B&V, Northeast University and Dynamita team helping update ASM model with S2EBPR.
- For now we have design criteria from real-world operations, and "work-arounds" with current ASM-based software (BioWin, GPS-X, etc.).
- 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*

Other Side Benefits of S2EBPR

- Increased process stability
  - Biological selector…less sludge bulking, better SVI
- Cooperative Denitrification
  - Recover some alkalinity to improve nitrification and effluent buffering
  - Offset some O_2 demand to lower aeration costs
  - Decrease N_2 bubbles in clarifier sludge blanket…less floating sludge
- Lower energy
- Potential nutrient recovery

It's not just about effluent limits

Energy/Nutrient Nexus
Anaerobic Digestion Working with BNR


It's always something

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

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.

Issues

- PAOs in WAS release $(PO4)^{3-}$, Mg^{2+} and K^{+} under anaerobic conditions
- NH^{4+} released later during digestion

Consequences

- Struvite scaling
- Vivianite scaling if Fe^{2+} present
- NH^{4+} and $(PO4)^{3-}$ recycle to main liquid stream
- Decreased biosolids dewaterability

Opportunities

- Struvite sequestration/recovery helps avoid unintended consequences
- Lightning Round 4

Five Rivers Fountain and Riverscape
Courtesy discoverdayton.org

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THANK YOU!!

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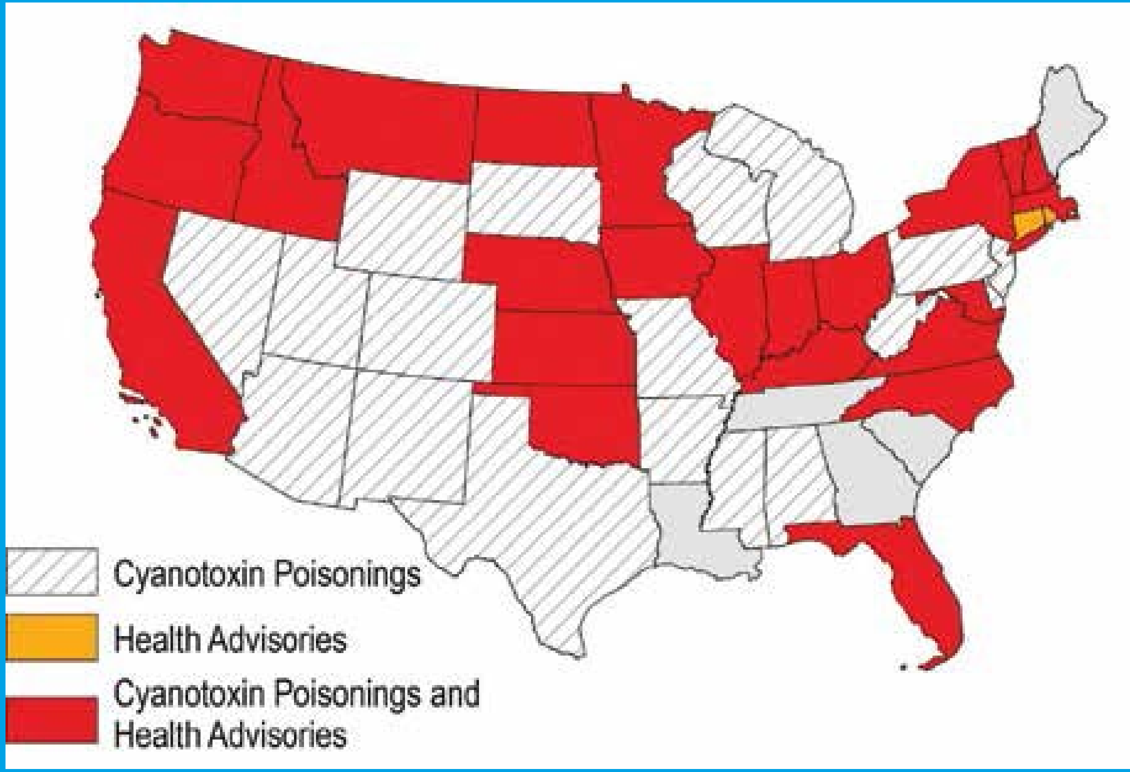
Bullpen

Drivers

- Aquatic Ecology
- Agricultural Needs
- Regulatory Pressures
- Economics

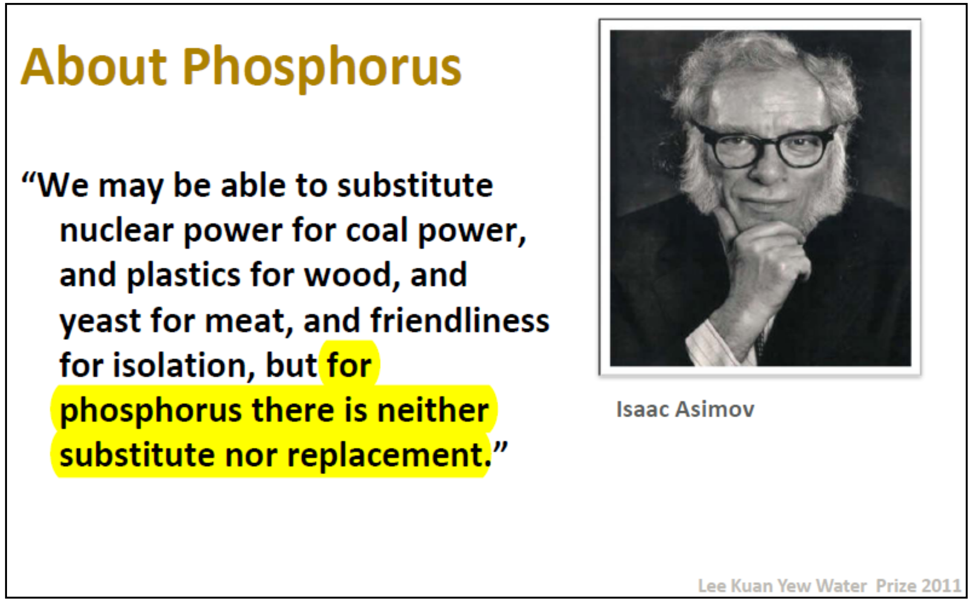


Source: P.R. Easley, Harmful Algal Blooms (HABs) and You, *Southwest Water Works Journal*, 27(2), **Summer 2016**

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…."

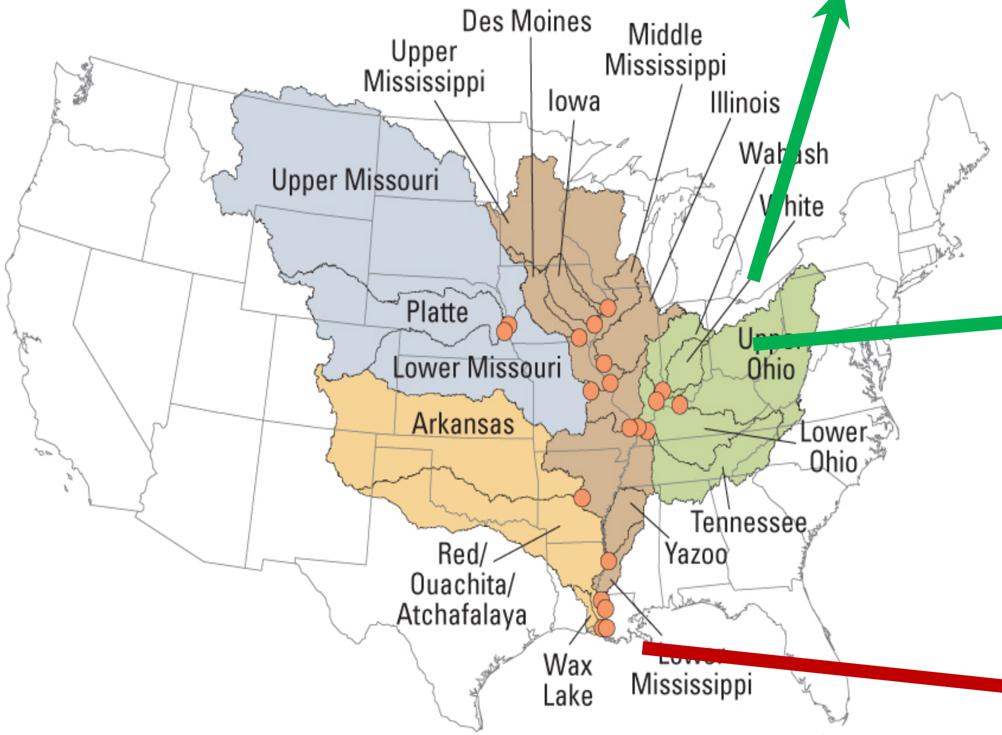
-President Franklin D. Roosevelt, 1938



Nutrient Recovery = POTWs' Return to Agricultural Roots

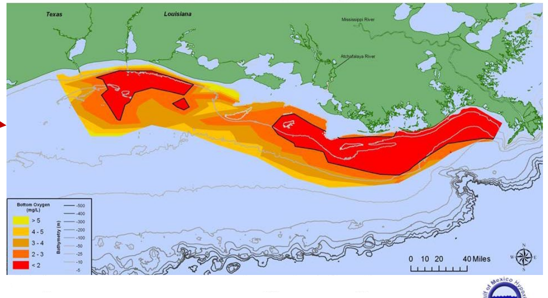
Source: K. Ashley et al. A brief history of phosphorus: From the philosopher's stone to nutrient recovery and reuse. *Chemosphere* (2011), doi:10.1016/j.chemosphere.2011.03.001

Near and Far.
Large and Small.
Point and Non-Point.



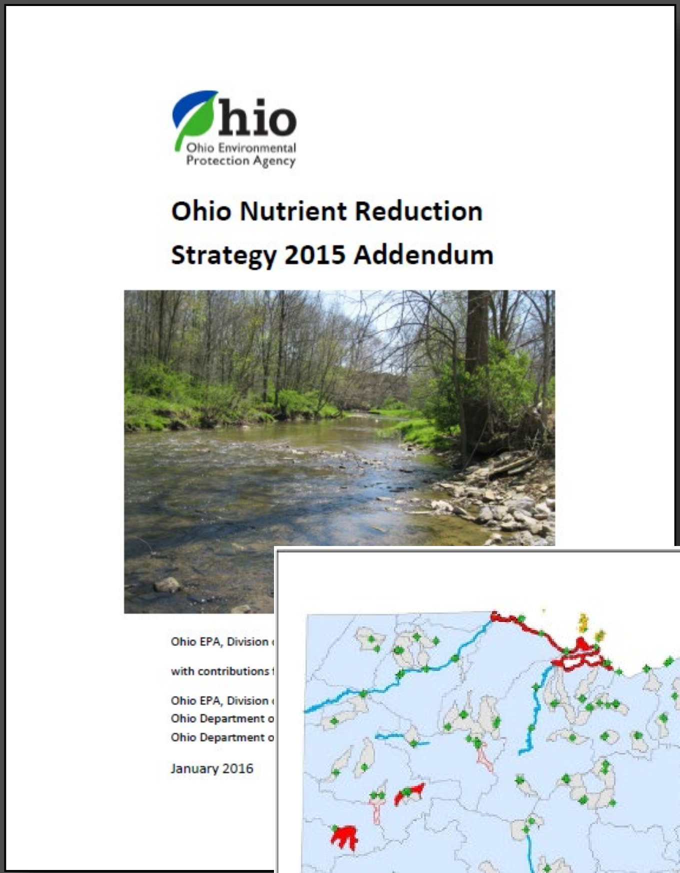
http://water.usgs.gov/nasqan/images/nasqan_ms_web.jpg

Bottom-water Dissolved Oxygen – 2014



Data source: Nancy N. Rabalais, LUMCON, and R. Eugene Turner, LSU
Funding sources: NOAA Center for Sponsored Coastal Ocean Research and U.S. EPA Gulf of Mexico Program

Phosphorus → freshwater harmful algal blooms (HAB)
Nitrogen → Estuary and marine eutrophication and hypoxia



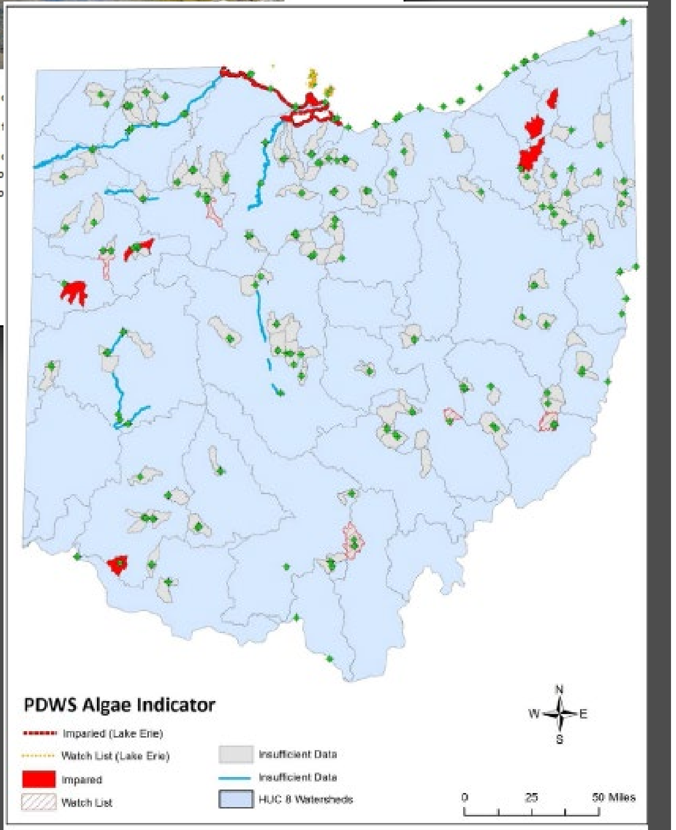


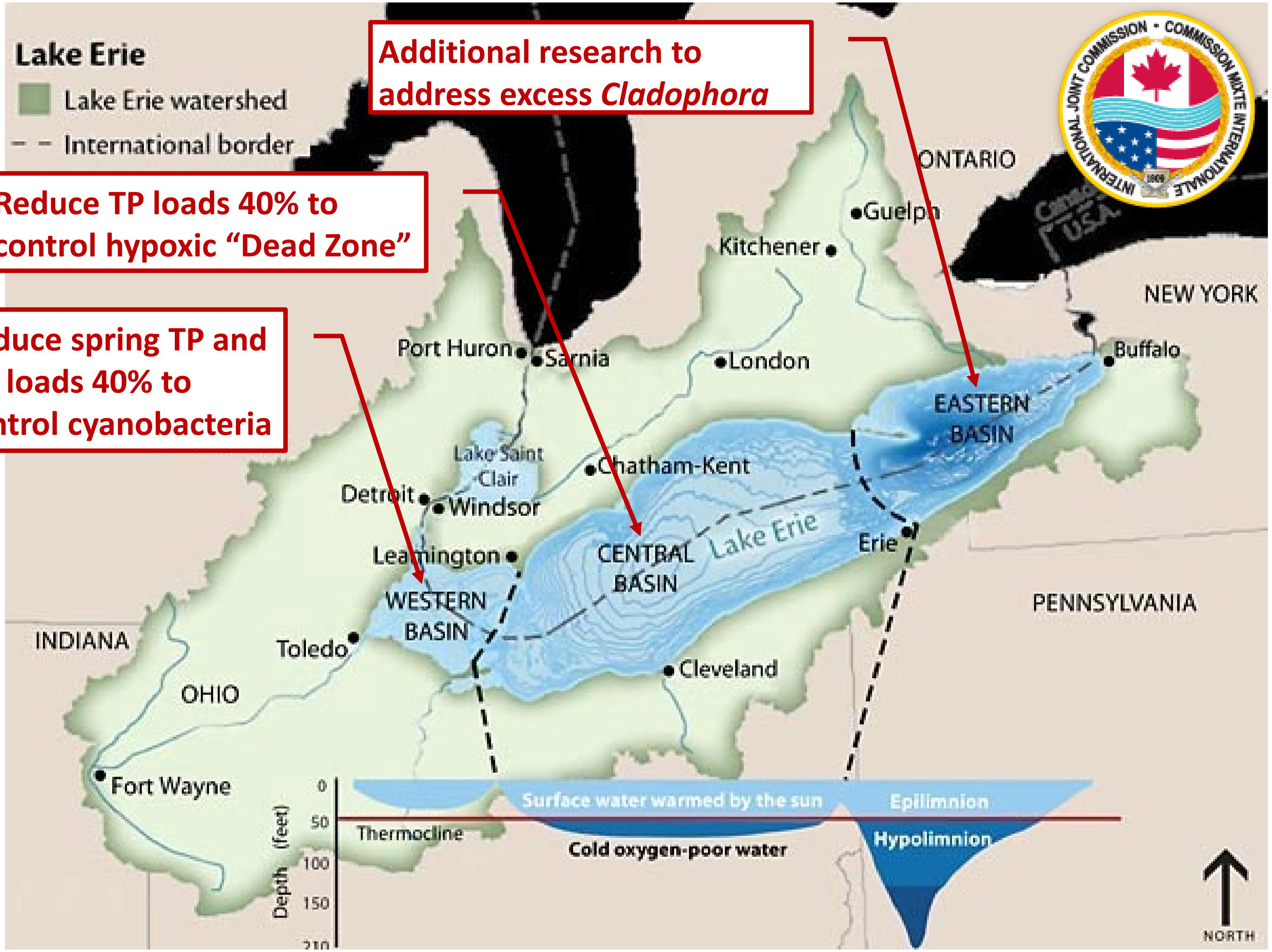
Figure 2. Assessment units with algae indicator results.

Ohio regulatory strategies

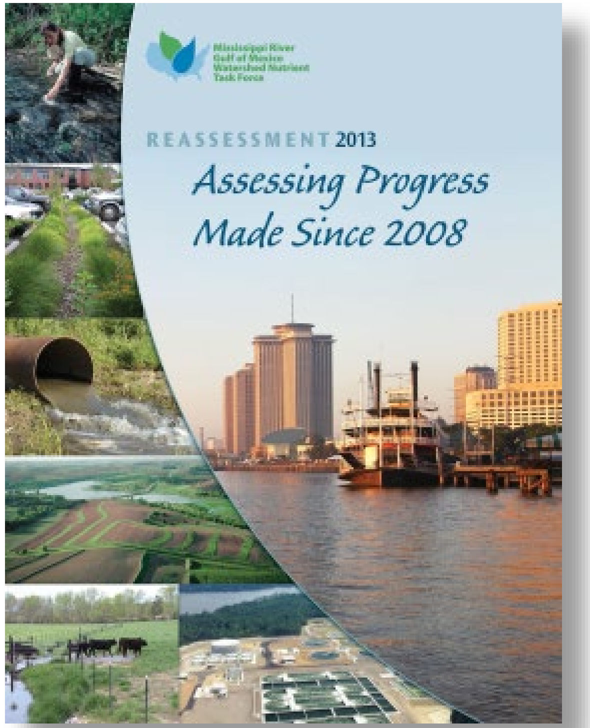
Similar to Others in Great Lakes and Upper Ohio River Watersheds

- Increased monitoring, research, and planning
- Integrated and adaptive watershed management
  1. Agricultural → Best management practices (BMPs)
  2. Urban Stormwater → Overflow control, green infrastructure
  3. POTWs → Tiered technology-based limits (BNR, ENR, LOT, etc.)

2012 Great Lakes Water Quality Agreement



From https://www.epa.gov/glwqa/recommended-binational-phosphorus-targets#what-targets



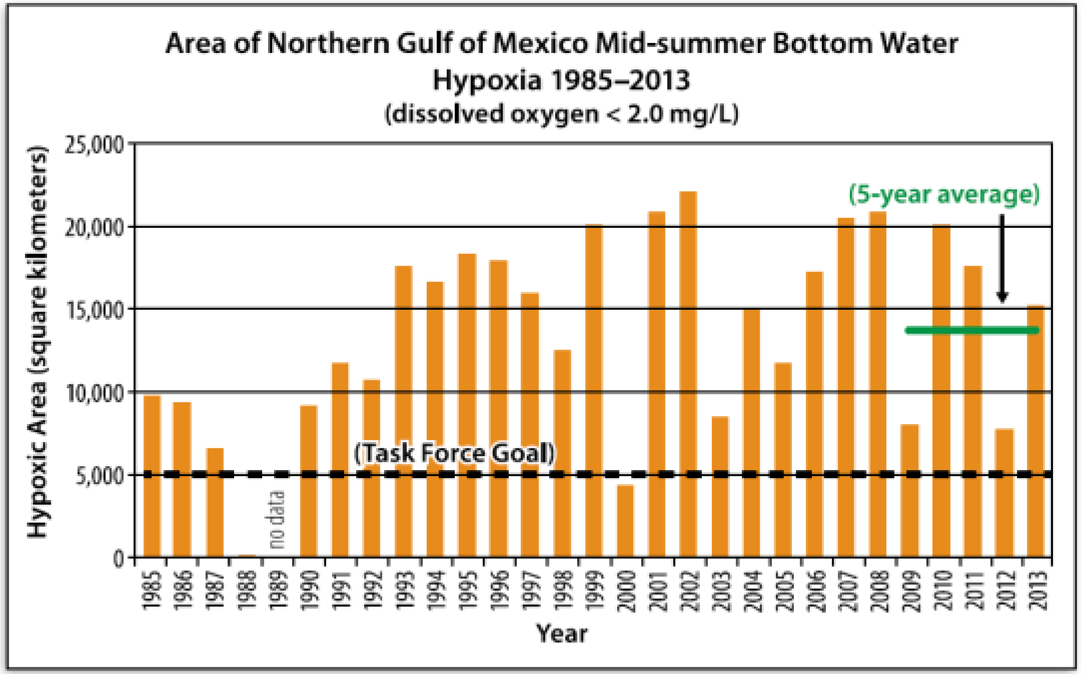


Figure 1. Size of the Gulf of Mexico hypoxic zone from 1985 to 2013.

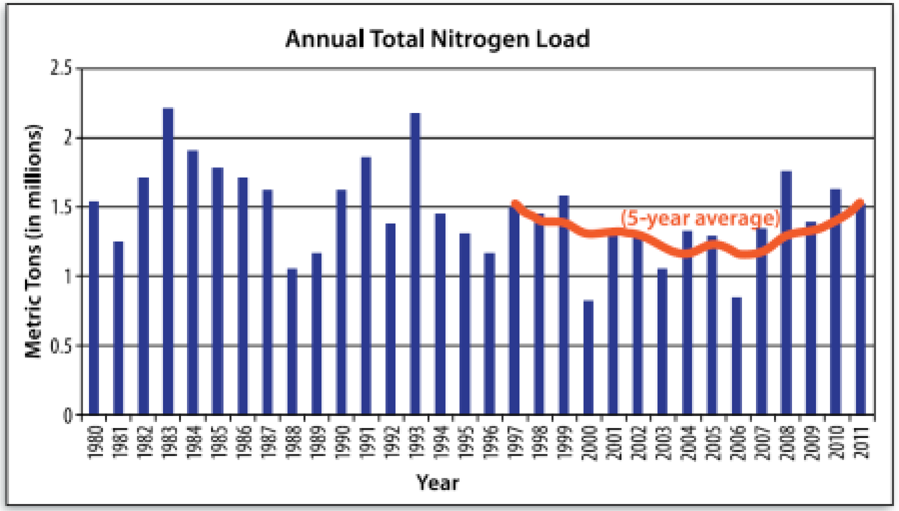


Figure 2. Annual TN loads to the Gulf of Mexico.

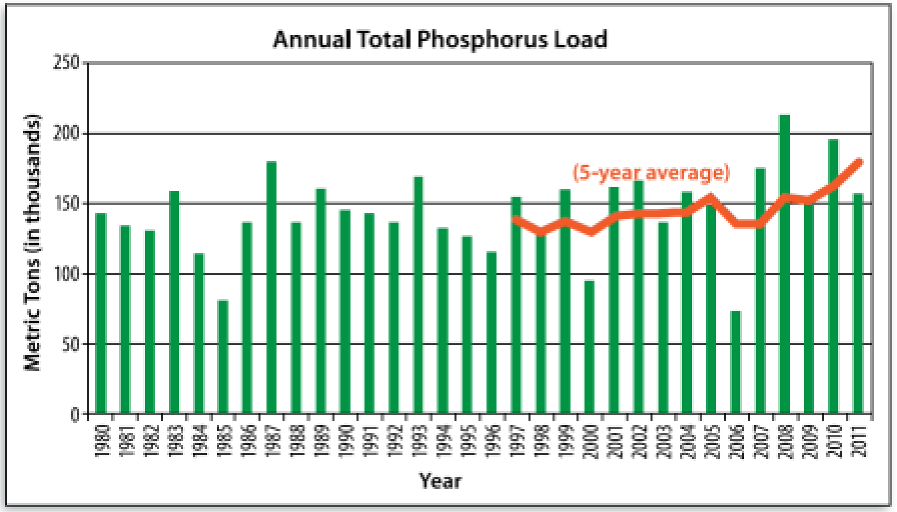
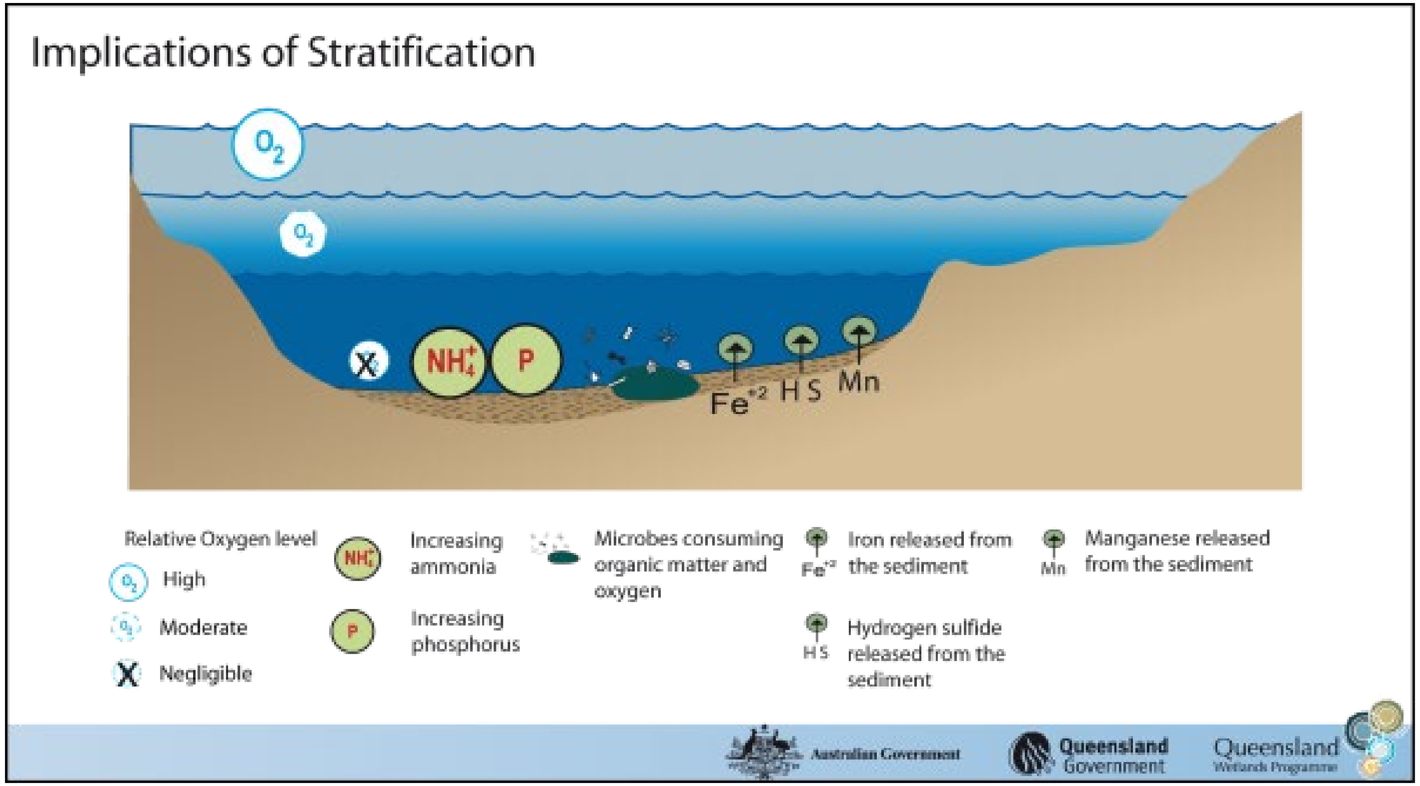


Figure 3. Annual TP loads to the Gulf of Mexico.

Sometimes Less Nitrates Increase Harmful Algal Blooms



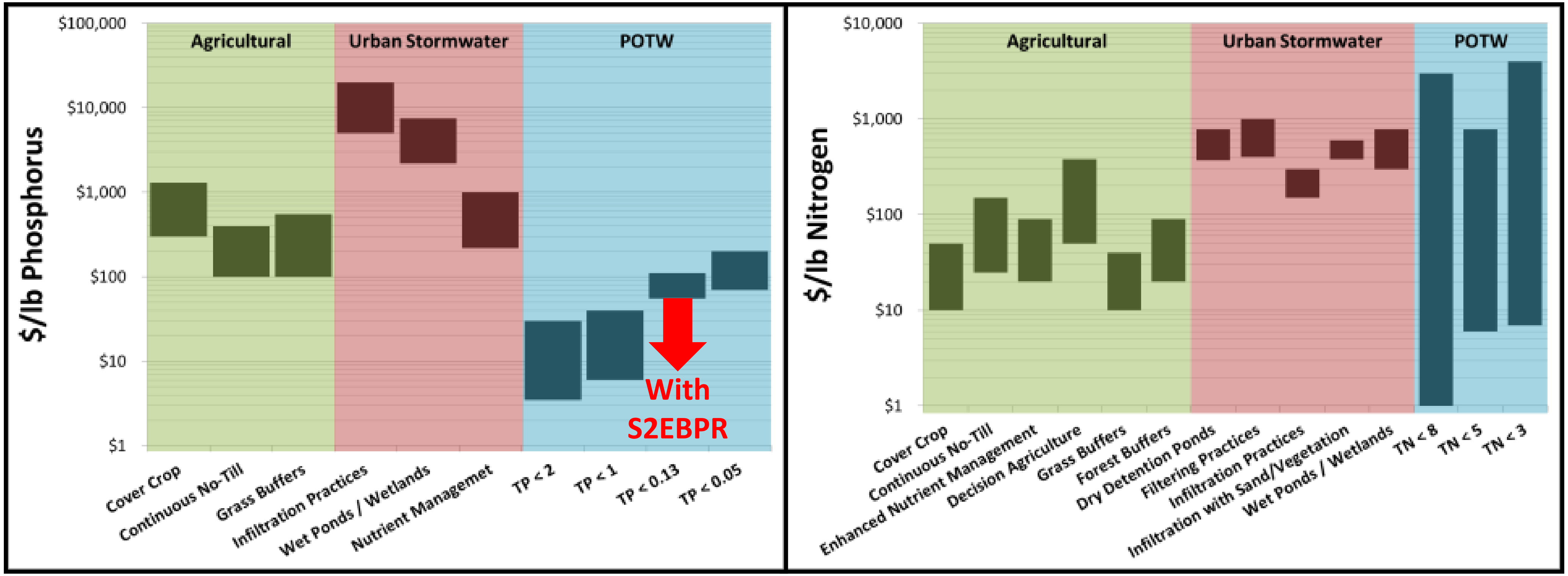
Source: http://wetlandinfo.ehp.qld.gov.au/wetlands/ecology/

Minimize internal reservoir nutrient cycling

- Keep reservoir mixed/aerated. Prevent stratification.
- Supply nitrates, air, and/or oxygen to hypolimnion.
  - Occoquan Reservoir - Cubas et al., *Water Environment Research*, Feb 2014, 123-133.
  - Crafton et al., "Assessment of Nutrient Dependency of a Mixed Cyanobacteria Culture", OWEA, 2017

Case-by-case watershed studies are required

Historical Costs of Different Practices

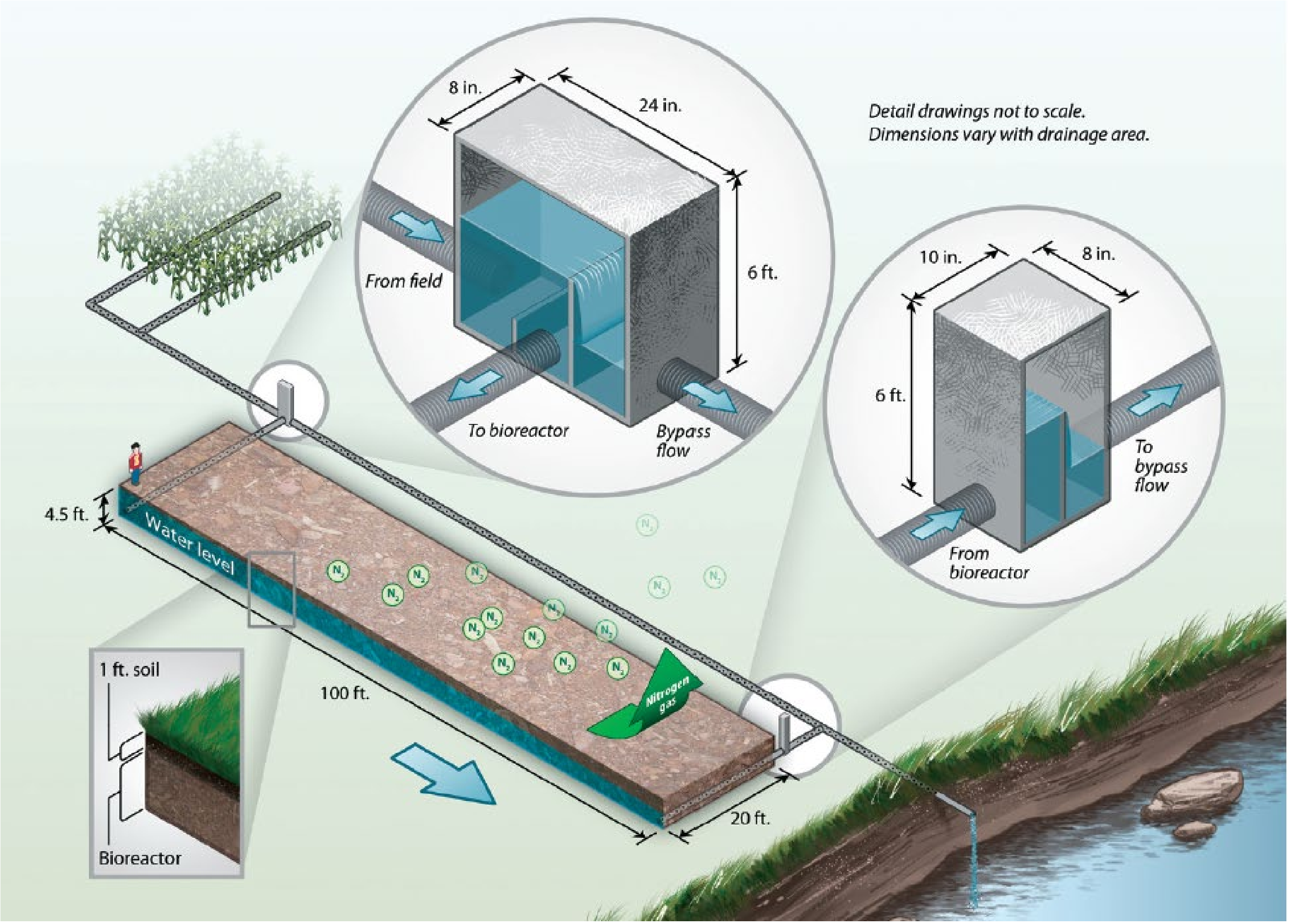


Source: WEF (2015) *The Nutrient Roadmap*, Figures 5.12 and 5.13

- **Low hanging fruits:**
  - TP removal → POTW to 0.15 < TP < 0.05 with side-stream enhanced biological phosphorus removal (S2EBPR) and filtration
  - TN removal → Agriculture (sometimes POTW)

Not a substitute for project-specific cost/benefit evaluations

Tile Field Woodchip Filters for Nitrate Removal



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

Tile Field Filters for both N and P Removal

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

University of Illinois research finds potential to pair P adsorption media filters with denitrifying woodchip filters

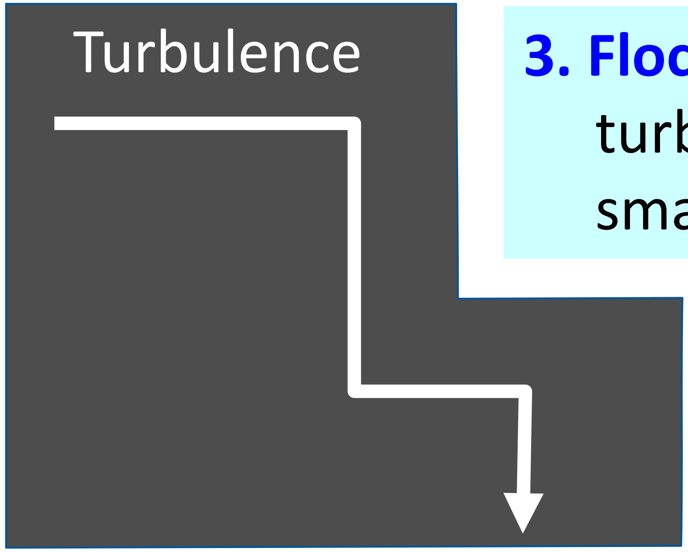
Optimize Conventional Treatment

- Phosphorus Removal
- Fermentation and VFA
- Side-stream EBPR (S2EBPR)

Conventional Chemical P Removal Fundamentals

1. Precipitant / Coagulant Addition. Rapid mix. Add metal salt (Ca^{2+}, Fe^{3+}, Al^{3+}). Fe^{2+} option if oxidized/adsorbed.

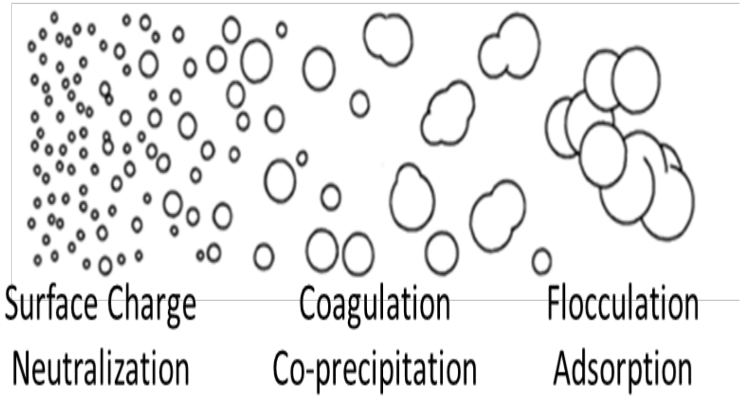
2. Flocculant Addition. Optional depending upon P limit and clarification technology. Polymer. Ballast in some cases.



3. Flocculation. Medium to low turbulence. Build floc and "sweep" small particles. Enhance floc removal.

4. Clarification. Separate solids from liquids. Settling, filtration, or flotation.

Particle Conditioning



Same mechanisms as turbidity removal for potable water and industrial process water applications

Steps 1, 2 and 3 are keys to how well Step 4 will work

Applying BNR Lessons from Mother Nature

1970's — Barnard introduces PhoRedox & Bardenpho in South Africa

1980's — U.S. patents for A/O, A2O, etc.

1990's — Primary sludge fermentation in northwest U.S. and Canada

2000's — Deammonification

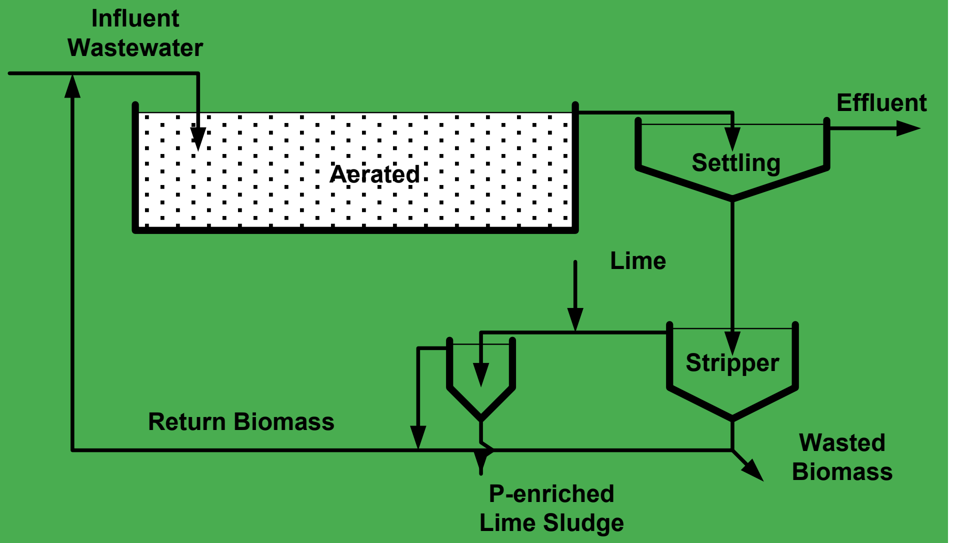
Struvite Recovery

2010's — **S2EBPR**

Process Intensification

"We've come a long way, baby" - Loretta Lynn, 1978

Early Phosphorus Removal & Recovery

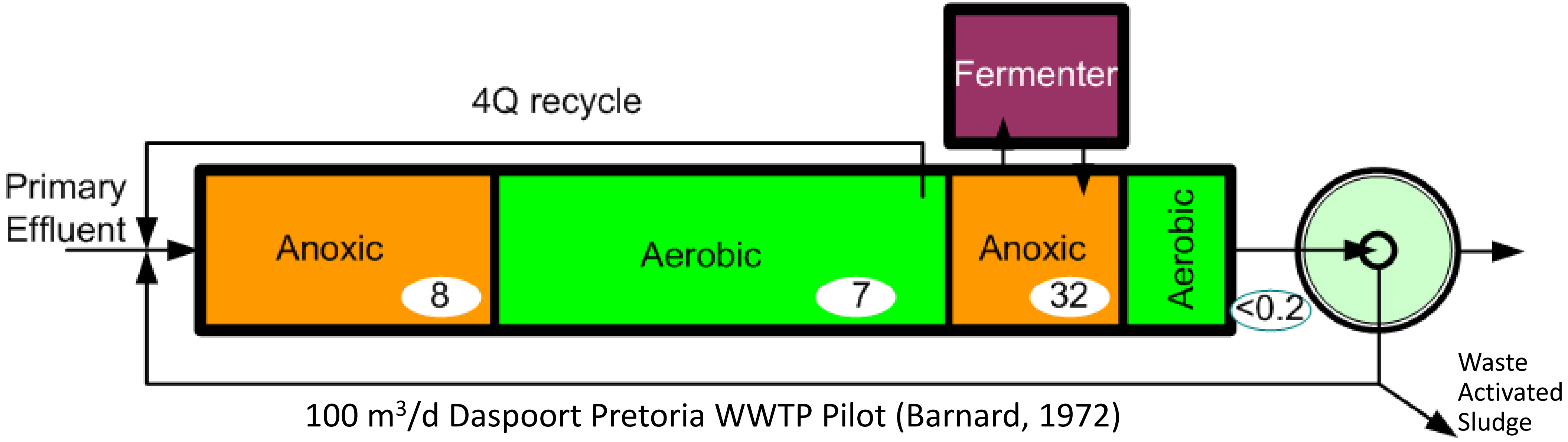


Phostrip Process (1962)

- **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 P uptake…side-stream P release and recovery

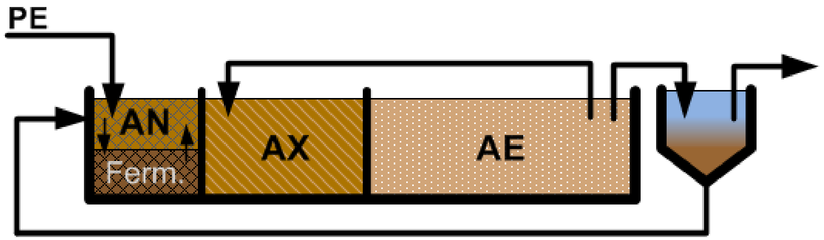
S2EBPR in Original Bardenpho Pilot



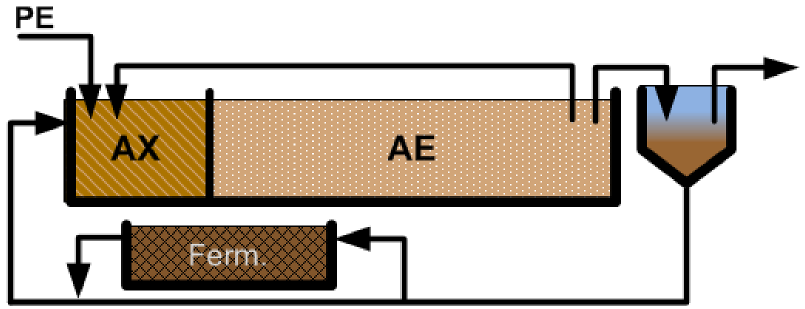
100 m³/d Daspoort Pretoria WWTP Pilot (Barnard, 1972)

Side-stream anaerobic mixed liquor fermenter

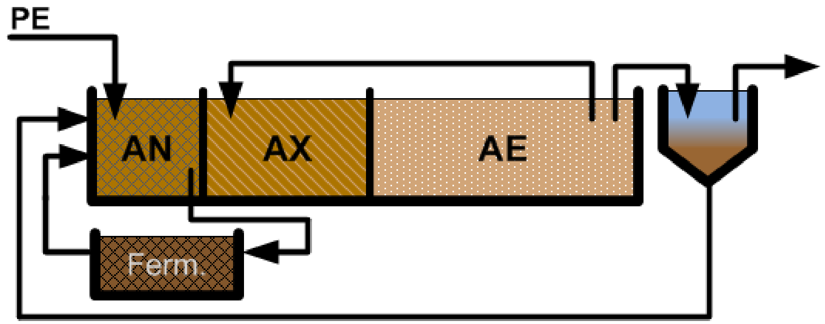
Four Major S2EBPR Process Examples



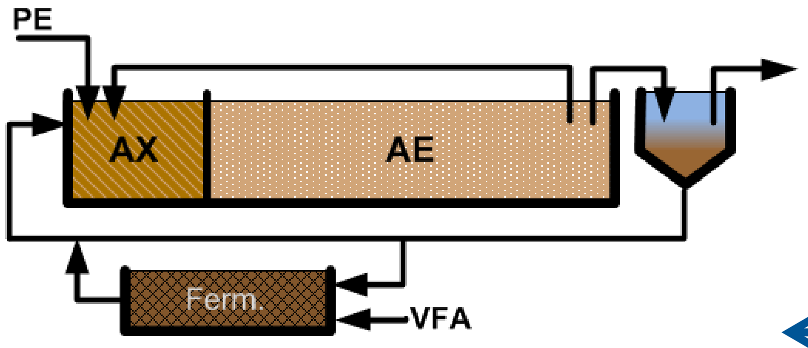
Unmixed In-Line Mixed Liquor Fermentation (UMIF)



Side-Stream RAS Fermentation (SSR)



Side-Stream Mixed Liquor Fermentation (SSM)

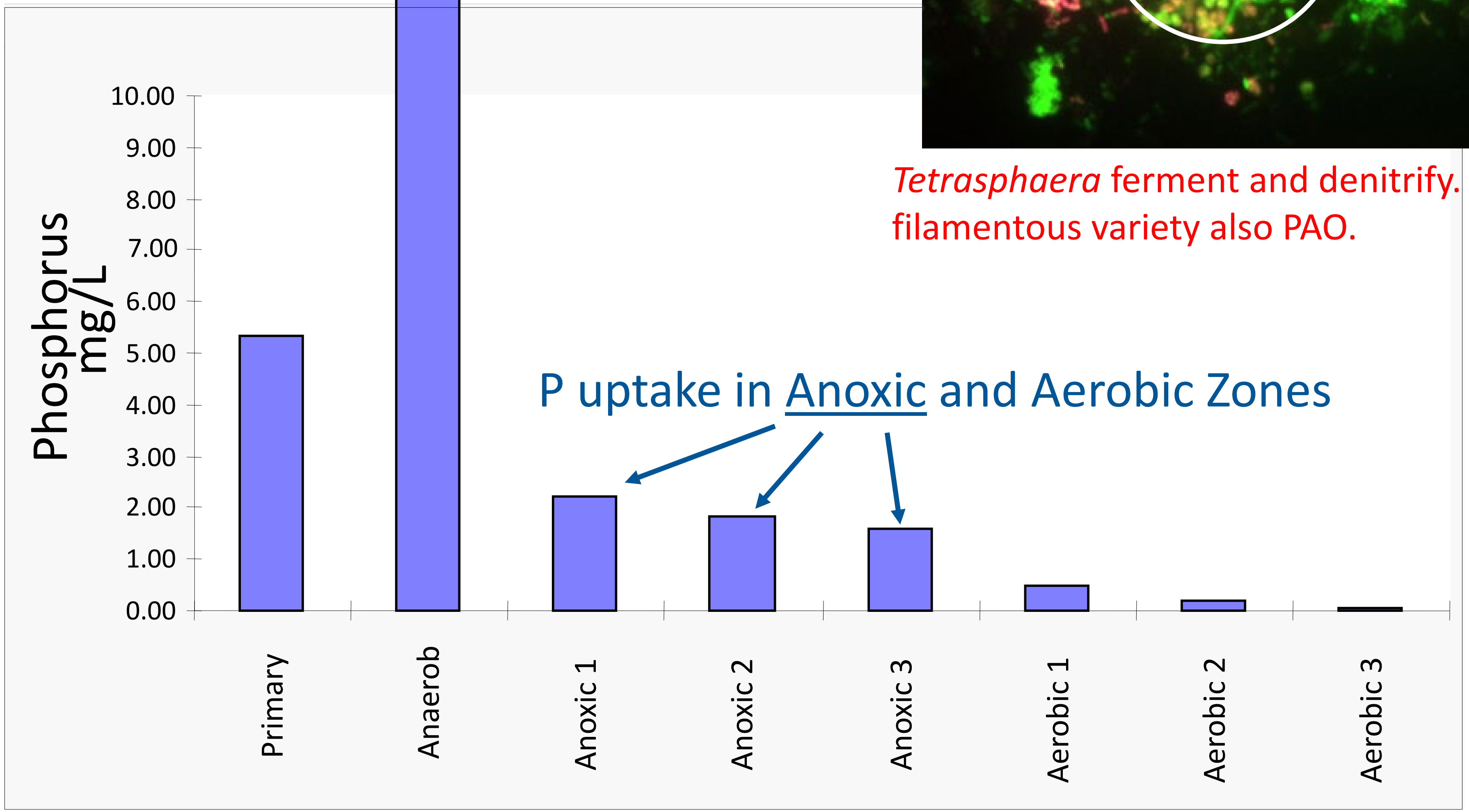


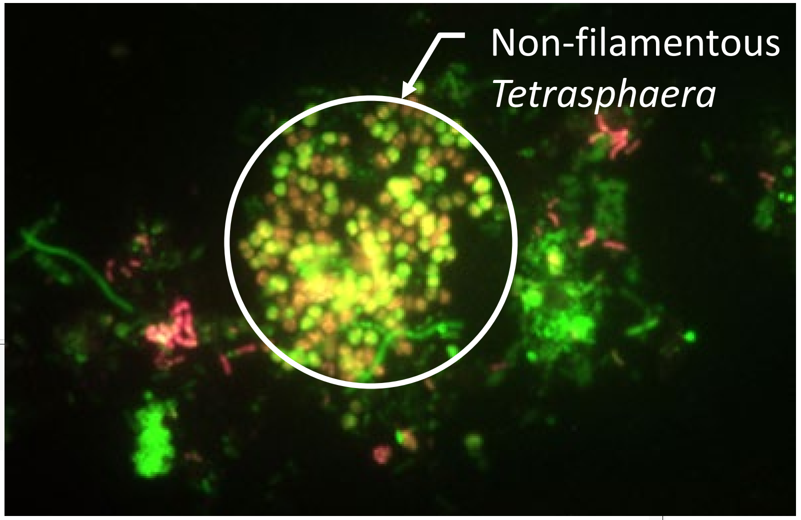
Side-Stream RAS Fermentation w/ Additional Carbon (SSRC)

- Offers same stability and carbon efficiency as w/o VFA (above SSR)
- Smallest AN volume
- Requires PS fermenter or external VFA source

WERF research team found S2EBPR in 75+ facilities in 10+ configurations

S2EBPR at Westside Regional WWTP (West Kelowna, BC)



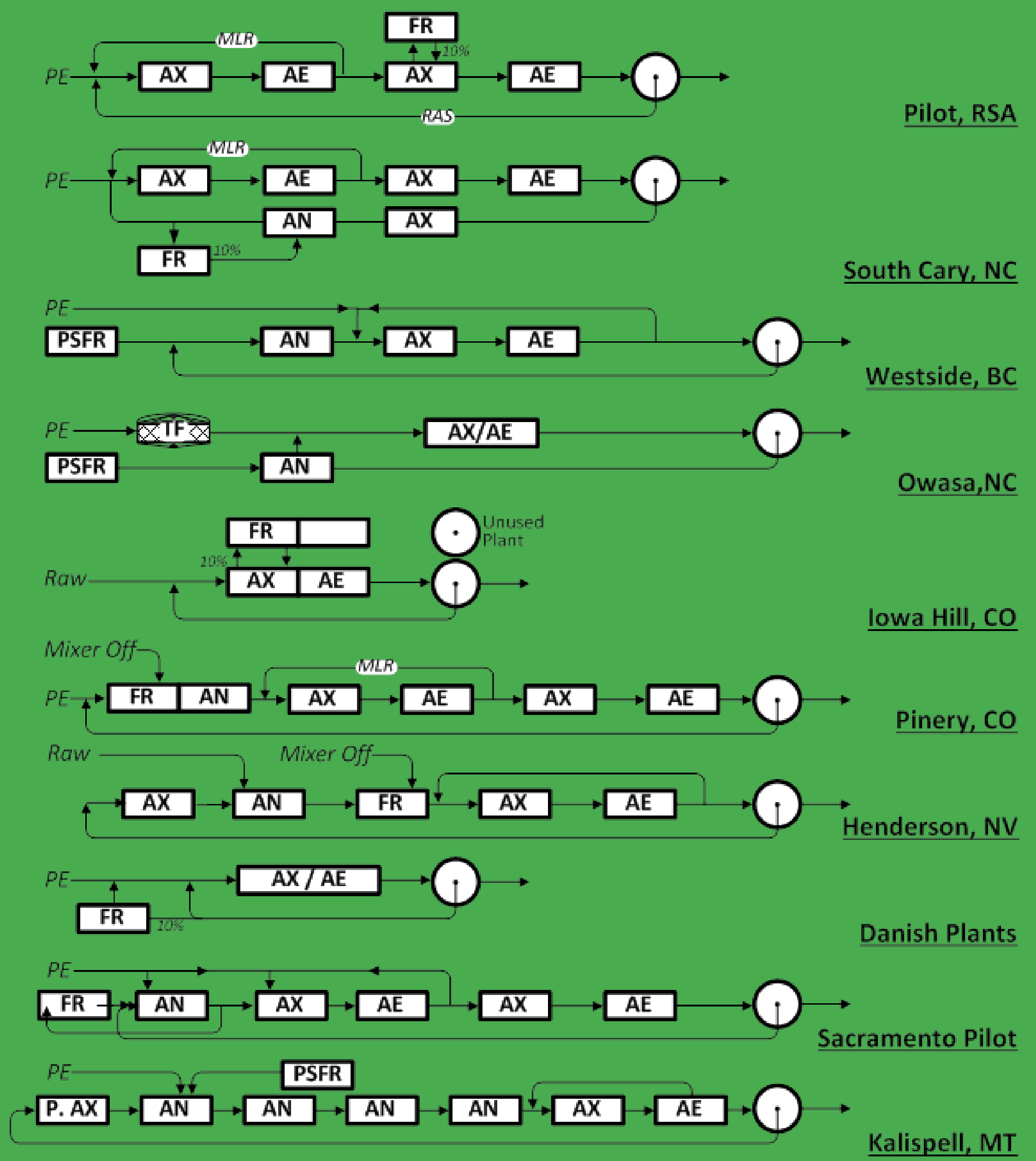


Tetrasphaera ferment and denitrify. Non-filamentous variety also PAO.

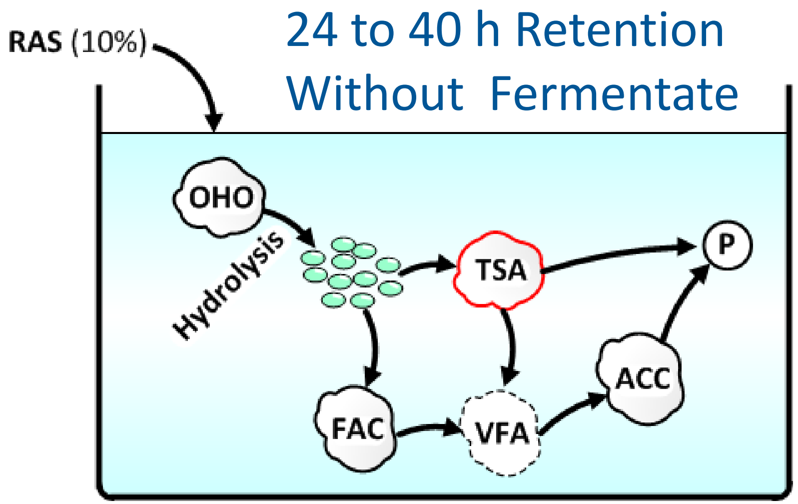
WERF Team Found S2EBPR in 75+ Facilities in 10+ Configurations

Legend

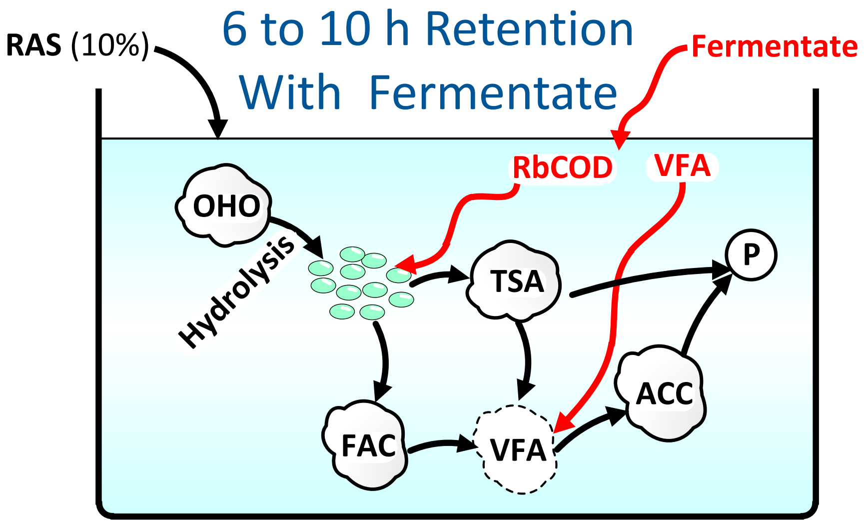
PE-Primary Effluent
AN-Anaerobic
AX-Anoxic
AE-Aerobic
AX/AE-SND
PSFR-Primary Sludge Ferment
FR-Mixed Liquor/RAS Ferment
TF-Trickling Filter



S2EBPR retrofits more easily than conventional EBPR



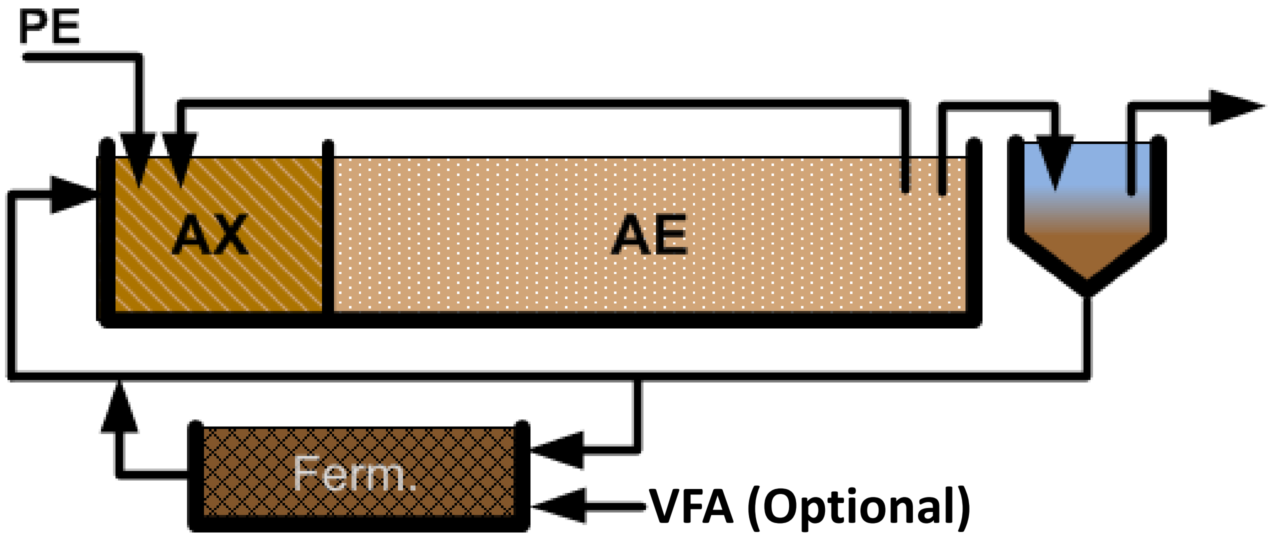
OHO – Other Heterotrophs	FAC – Facultative Bacteria
TSA – Tetrasphaera	ACC - Accumulibacter



New Understanding with S2EBPR

- **Traditional concept was one PAO - *Accumulibacter***
- **Deeper anaerobic conditions also select for *Tetrasphaera* (ORP<-250 mV)**
  - **Another class of PAO!**
  - **Deep anaerobic conditions are fatal for undesirable GAOs!**
- ***Tetrasphaera* ferment higher carbon compounds, take up phosphorus and produce additional VFA that can support *Accumulibacter*…and also denitrify.**
- **Current process models under-predict S2EBPR performance**

Motivation for S2EBPR



Motivations

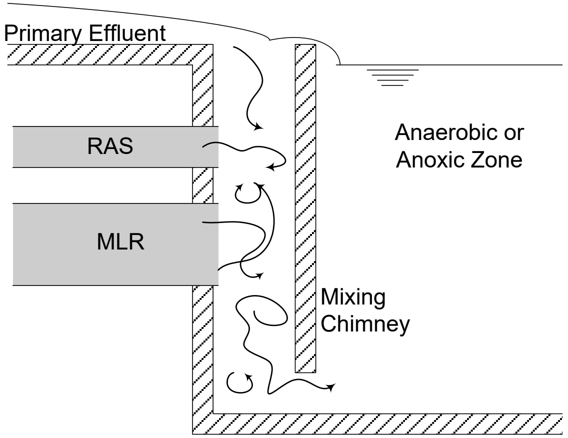
- Stable anaerobic conditions reduce upsets
- Internal VFA generation reduces reliance on influent characteristics
- Microbial selection leads to more efficient and effective use of carbon
- More retrofit options

Drawbacks

- Relatively new and gaining adopters
- Research remains for predictive modeling
- May need odor control

Energy Efficient Mixing is One Key

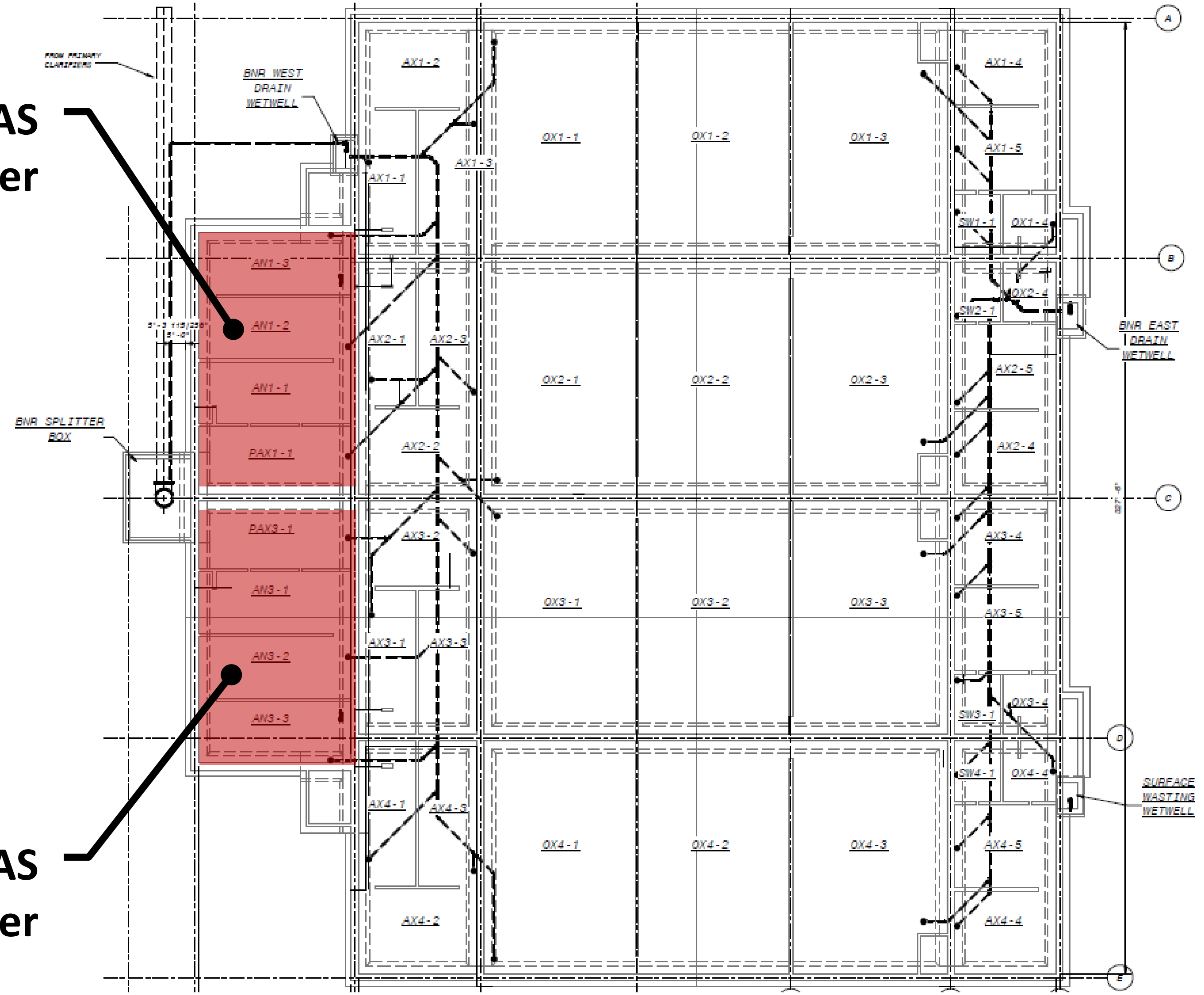
- Static Mixing Chimneys



- Low-Speed Impellers

S2EBPR with 5-Stage Bardenpho at Tomahawk Creek

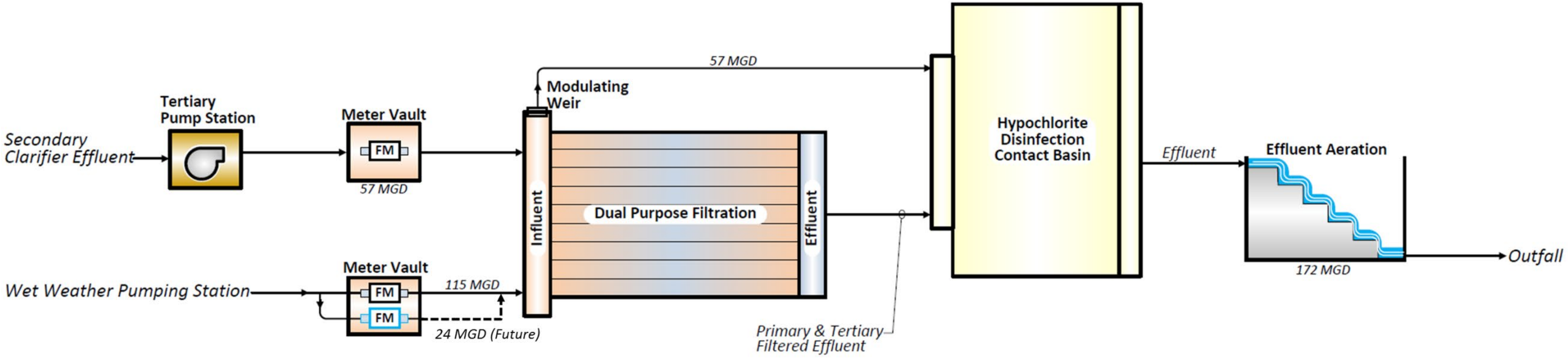
North RAS Fermenter



South RAS Fermenter

- 19-mgd design annual average, 57-mgd peak
- 4 trains
- Side-stream RAS fermenters instead of traditional mainstream anaerobic zones
- Mainstream anoxic, oxic, post-anoxic and reaeration zones
- Surface MLSS wasting to help decrease SVI

Tomahawk Creek Dual-Purpose Tertiary Process

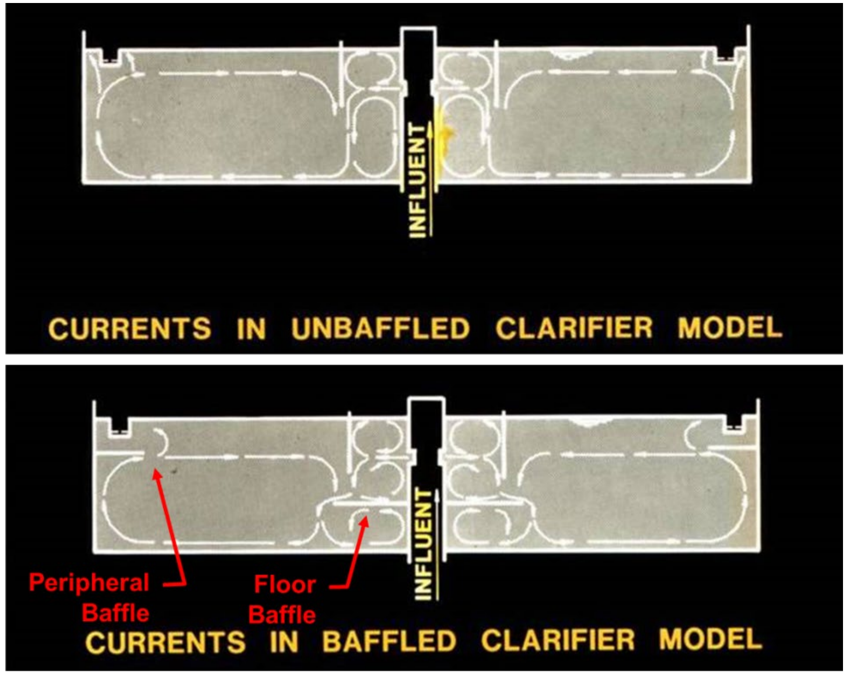


Parameter	Effluent Limit (*Goal)	Averaging Period
TSS	30 mg/L 45 mg/L	Monthly Weekly
BOD_5	15 – 20 mg/L 25 – 30 mg/L	Monthly Weekly
NH_3-N	0.6 – 2.3 mg/L 6.6 – 11.8 mg/L	Monthly Daily
TN	*10 mg/L	Annual
TP	*0.5 mgd/L	Annual

Tertiary polishing up to 3Q = 57 mgd
+ Peak wet-weather EHRT up to 115 mgd
Peak WWTF capacity = 172 mgd

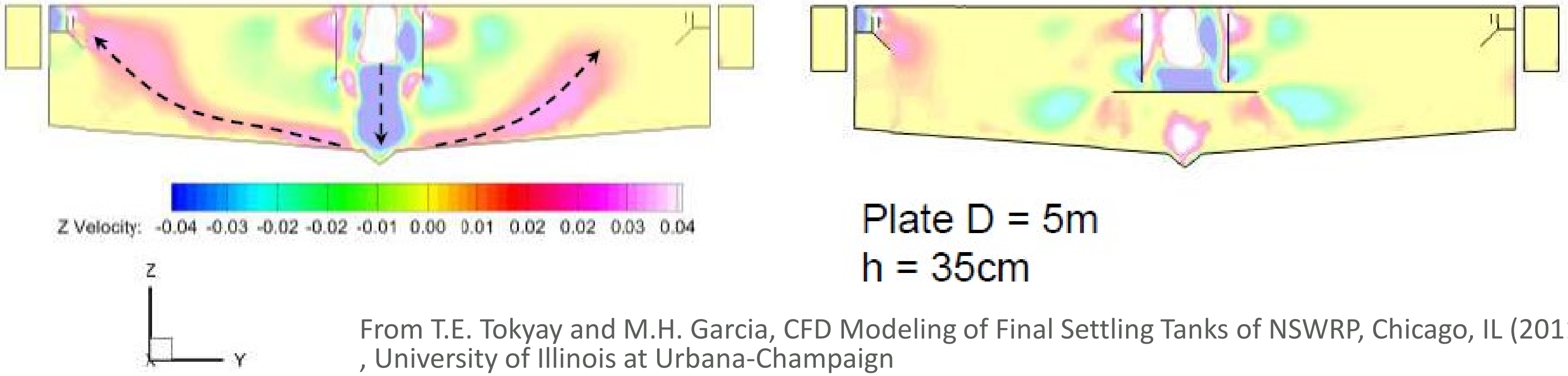
McKinney Floor Baffle Alternative to "Standard" Energy Dissipating Inlet to Improve Secondary Clarification

- Peripheral density current baffles well established in U.S. and abroad
- Floor baffle standard in UK and Germany
- CFD model and full-scale pilot at MWRDGC's 330-mgd O'Brien WRP. Retrofits in progress.



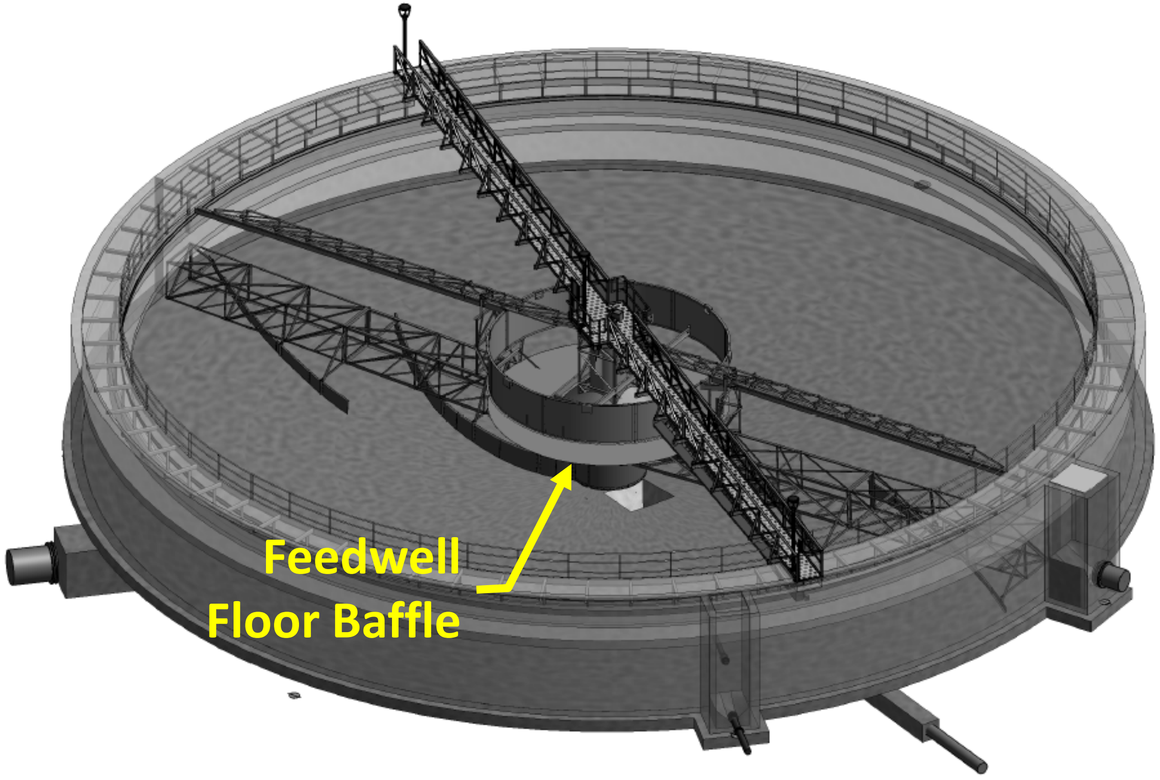
J. Robinson (1974) *A Study of Density Currents in Final Sedimentation Tanks*, M.S. Thesis, University of Kansas.

From Analysis & Design for the Budds Farm Final Clarifiers, MMI Engineering 2011



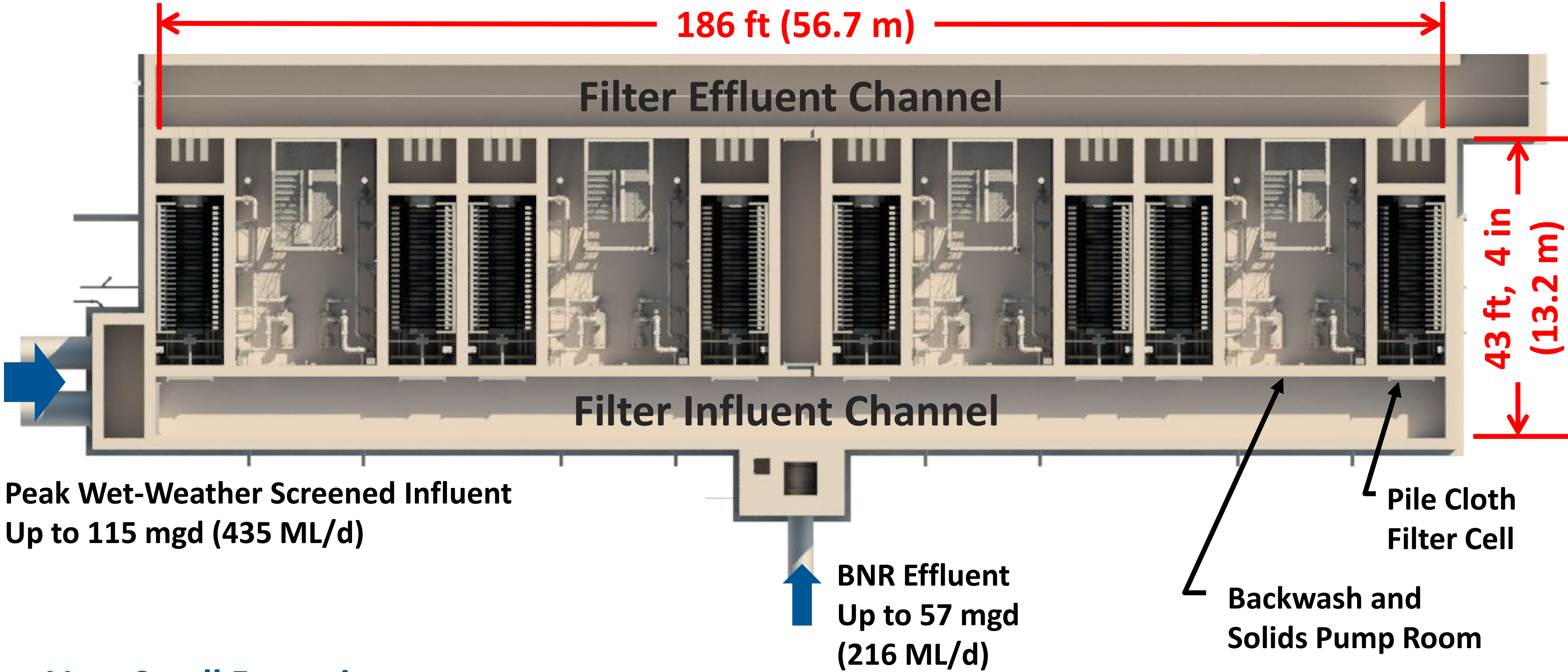
From T.E. Tokyay and M.H. Garcia, CFD Modeling of Final Settling Tanks of NSWRP, Chicago, IL (2011) , University of Illinois at Urbana-Champaign

Tomahawk Creek Secondary Clarifiers



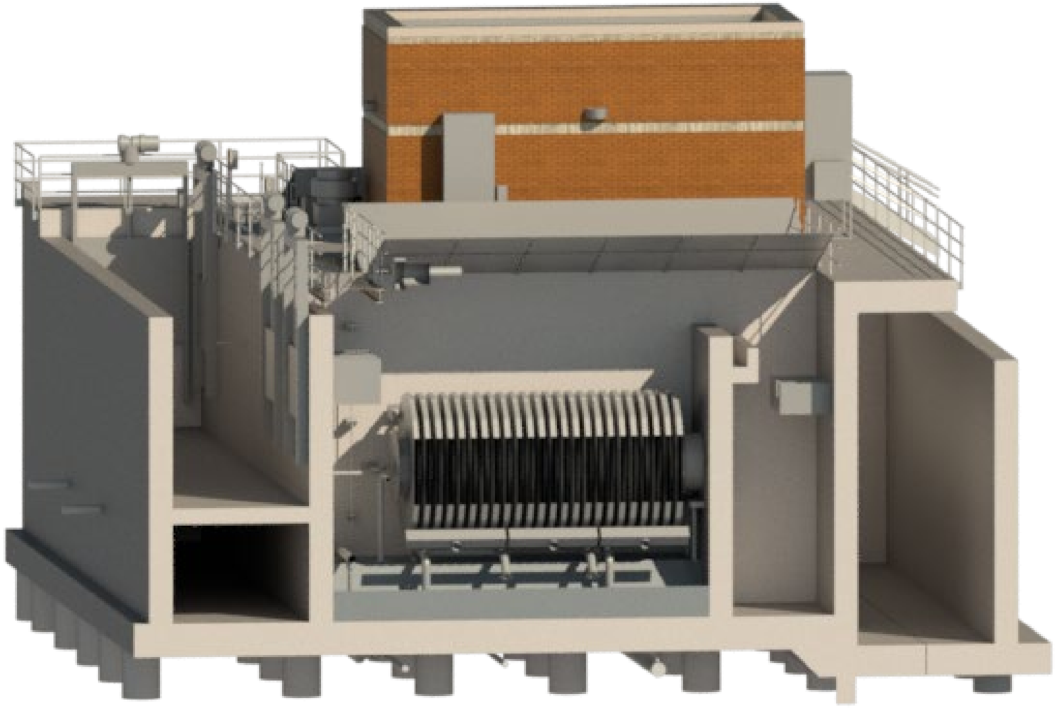
- Four basins @ 125-ft diameter (38.1 m) x 12.7-ft SWD (3.86 m)
- Center feed column with feedwell and floor baffle
- Peripheral effluent launder with density current baffle extension
- Spiral rake sludge scrapers
- Full radius beaching scum trough and twin skimmers
- Walk-on launder covers

Tomahawk Creek Filter Facility Plan View

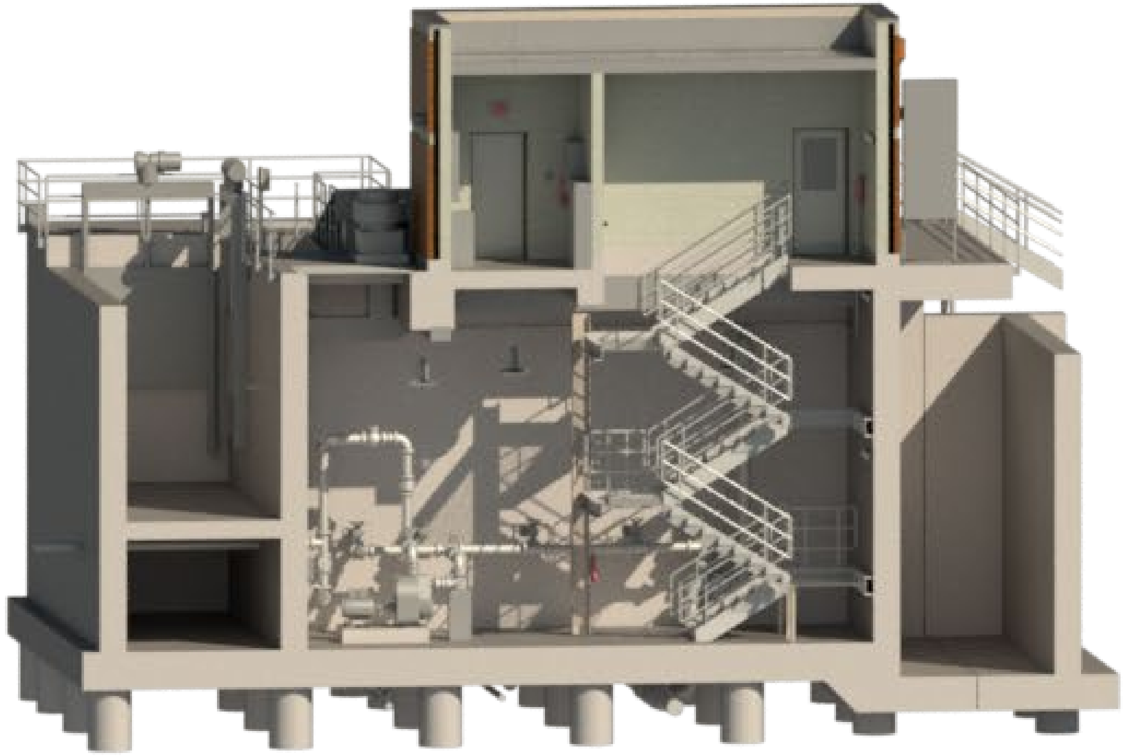


Very Small Footprint

Tomahawk Creek Filter Facility Section Views



Pile Cloth Filter Cell
(Typical of 8)



Backwash and Solids Pump Room
(Typical of 4)

Avoid Unintended Consequences

- Solutions to Biosolids Impacts
- Control Nuisance Struvite
- Reduce Nutrient Return Load
- Recover Nutrients

Hydroxylapatite Formation (pH~9)

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

Struvite Formation (pH~8)

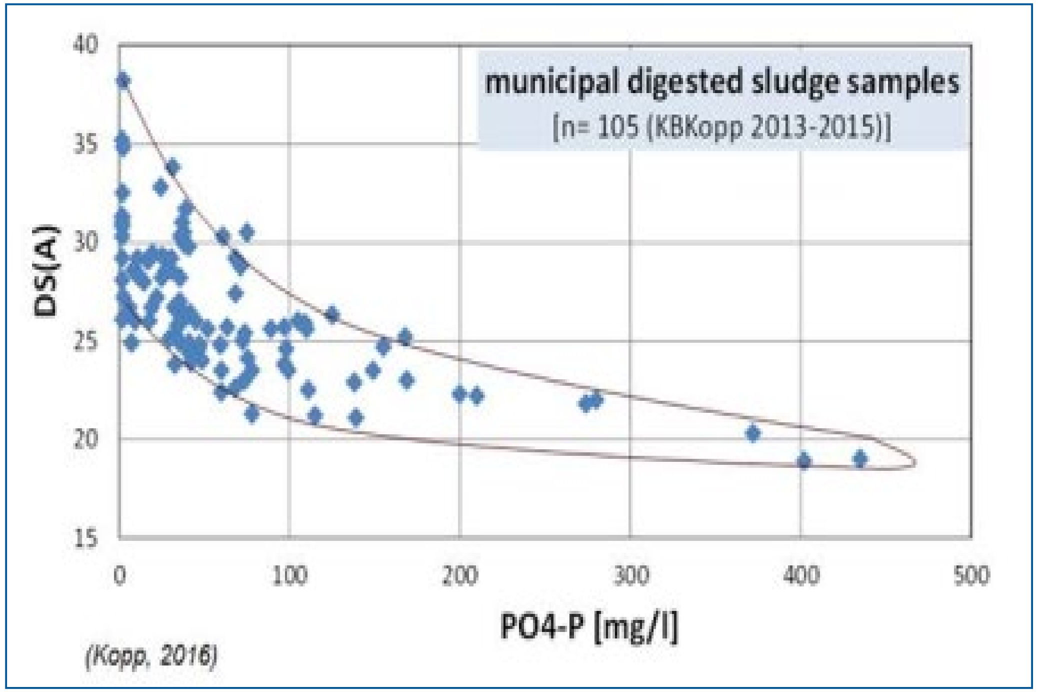
$NH_4^+ + Mg^{2+} + HPO_4^{2-} + 6H_2O \leftrightarrow \mathbf{NH_4MgPO_4 \cdot 6H_2O} + H^+$

Brushite Formation (pH~4.5-6.5)

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

Biosolids Dewaterability

- Plants converted to EBPR/S2EBPR have experienced deterioration in dewatering performance
  - Lower cake solids
  - Higher polymer dose
- Two theories
  - High ortho-P
  - High ratio of monovalent to divalent cations



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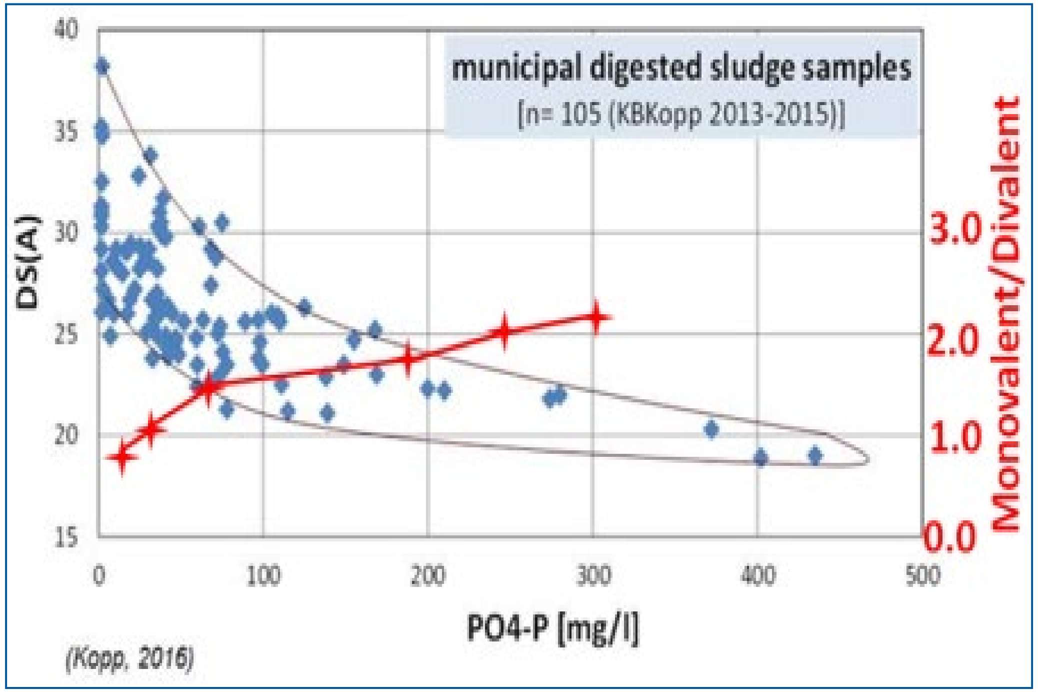
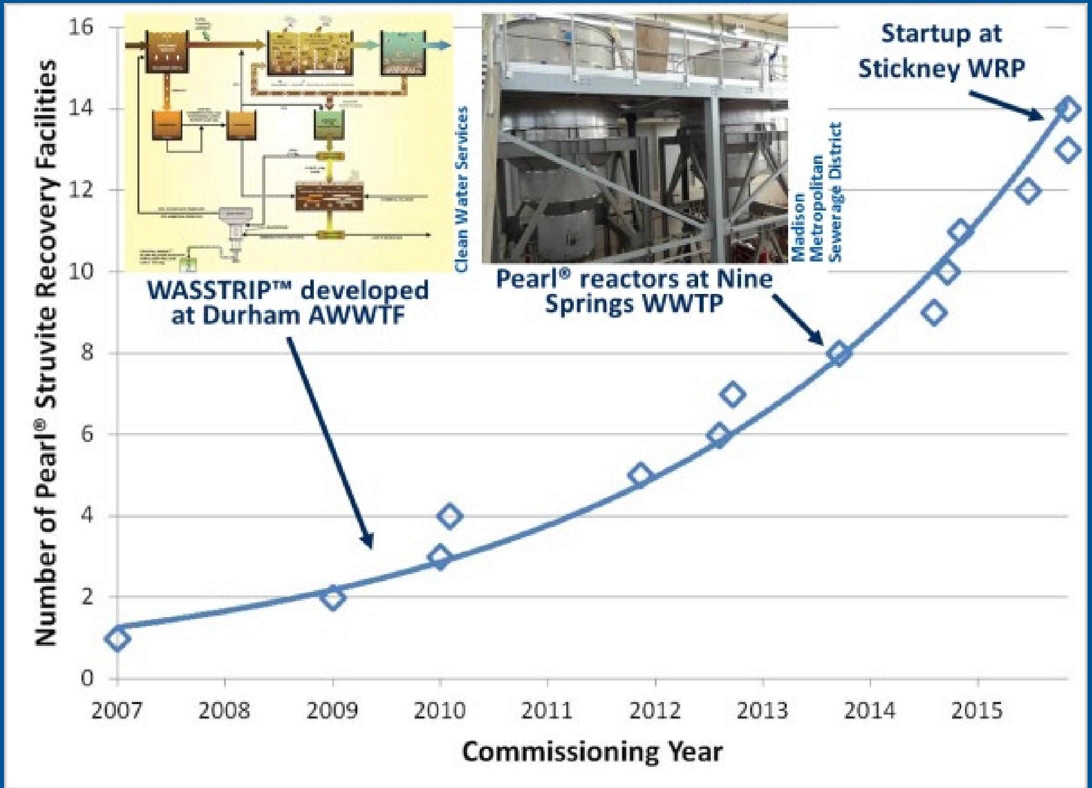


Excess monovalent cations disrupt flocculation of biosolids, degrading dewaterability

Answering with Side-Stream Crystallizers

Goals / Benefits

- **Minimize nuisance scaling and deposits**
- **Improve biosolids dewaterability**
- **Reduce P & N recycle loads**
- **Decrease P content of biosolids**
- **Recover fertilizer product**

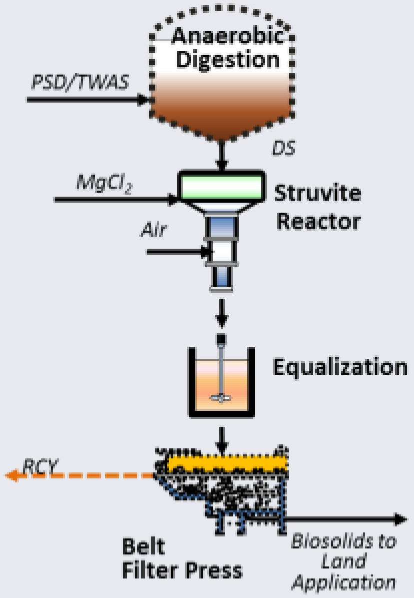


Struvite Recovery Alternatives	Brushite Recovery Alternatives
Ostara Pearl®, MHI Multiform™, CNP AirPrex®, Schwing Bioset/NuReSys®, Paques PHOSPAQ™, KEMA Phred™ and DHV Crystalactor®	CNP CalPrex®

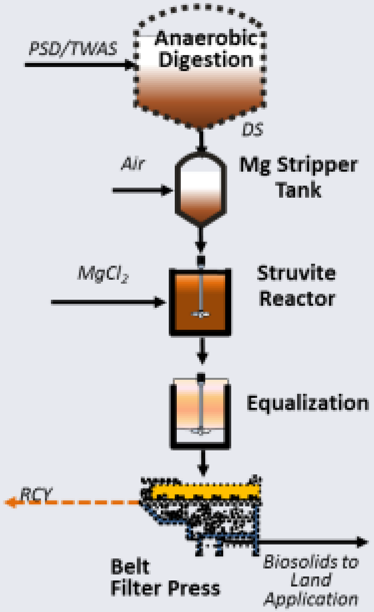
Turn Struvite Problem into the Answer

Struvite Sequestration

AirPrex



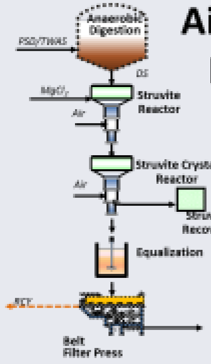
NuReSys



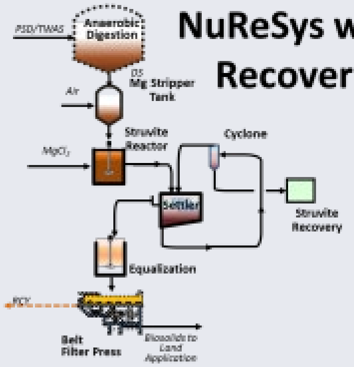
- Struvite crystals remain in biosolids
- Optional recovery add-on

Struvite Recovery

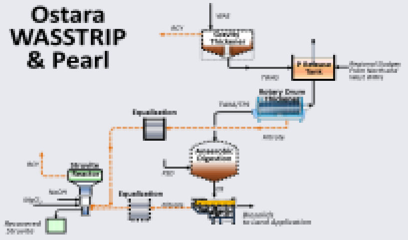
AirPrex with Recovery



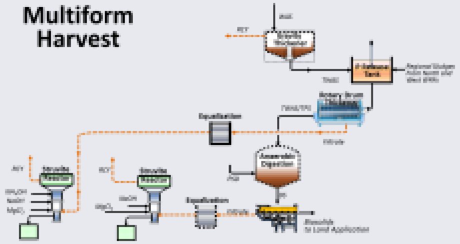
NuReSys with Recovery



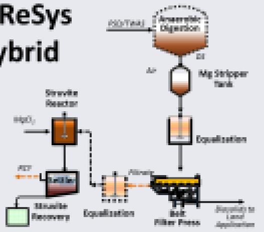
Ostara WASSTRIP & Pearl



Multiform Harvest



NuReSys Hybrid



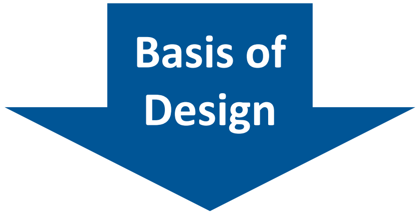
- Separate struvite crystal fertilizer product
- Decrease P content of biosolids

Project-specific evaluation and selection required

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

Design-Build Improvements Include Struvite Sequestration + S2EBPR



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

On schedule for 2019 completion under energy savings performance contract

Side-Stream Deammonification Gaining Traction for TN Control

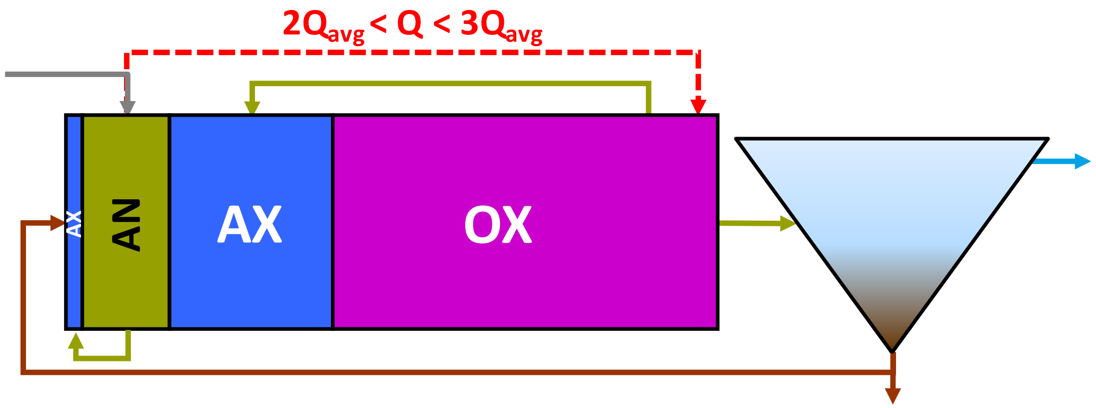
- **Minimizes ammonia return**
- **Digester liquors ideal for anammox**
- **Advantages to conventional nite/denite:**
  - Less energy
  - No carbon required
  - Lower alkalinity demand

Full-Scale Installations	Pilots
■ HRSD, VA ■ Alexandria, VA ■ Greeley, CO ■ Guelph, Ontario, CAN ■ Durham, NC ■ Washington, DC ■ Pierce County, WA ■ Egan WRP, MWRDGC, IL	■ St. Joseph, MO ■ Tomahawk WWTF, Johnson County, KS ■ Mill Creek WWTP, Cincinnati, OH ■ Henrico, VA ■ Brooklyn, NY ■ Egan WRP, MWRDGC, IL ■ Robert W. Hite WRF, Denver, CO ■ Joint WPCP, Los Angeles County, CA

Wet-Weather Strategies

- Don’t Upset Your BNR Bugs
- Different 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

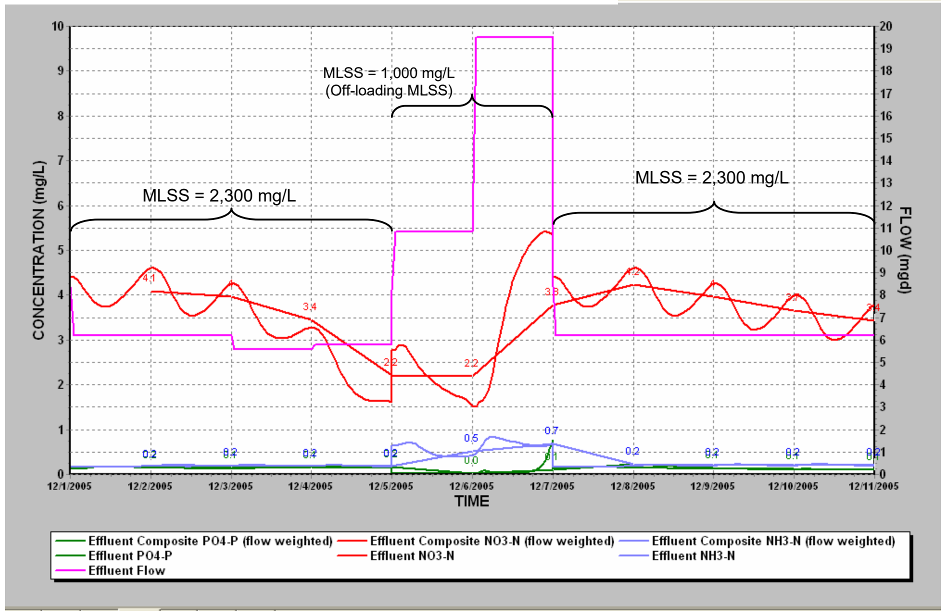
Maximizing biological treatment of wet-weather flows

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.**

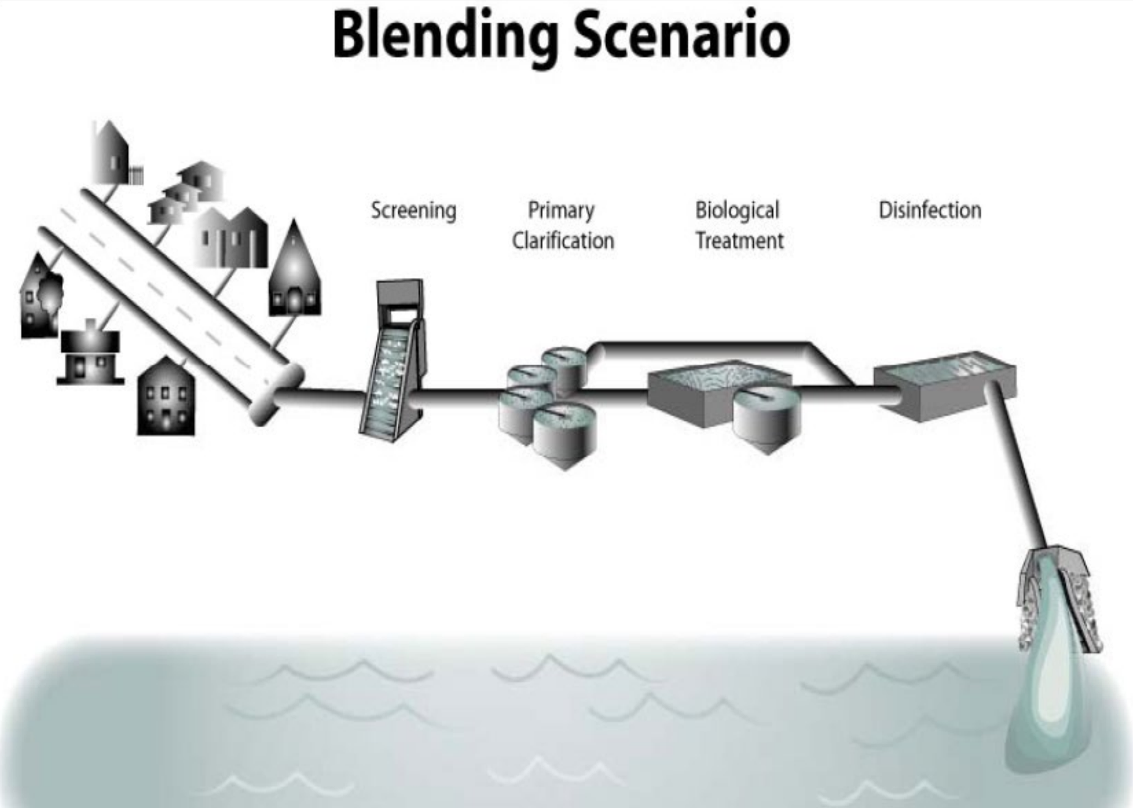
Offline Biomass Storage
Rogers, Arkansas
5-stage Bardenpho Oxidation Ditch

BioWin Process Model of Rogers' Biomass Transfer Operations



Another way to reduce SLR to clarifiers … temporarily

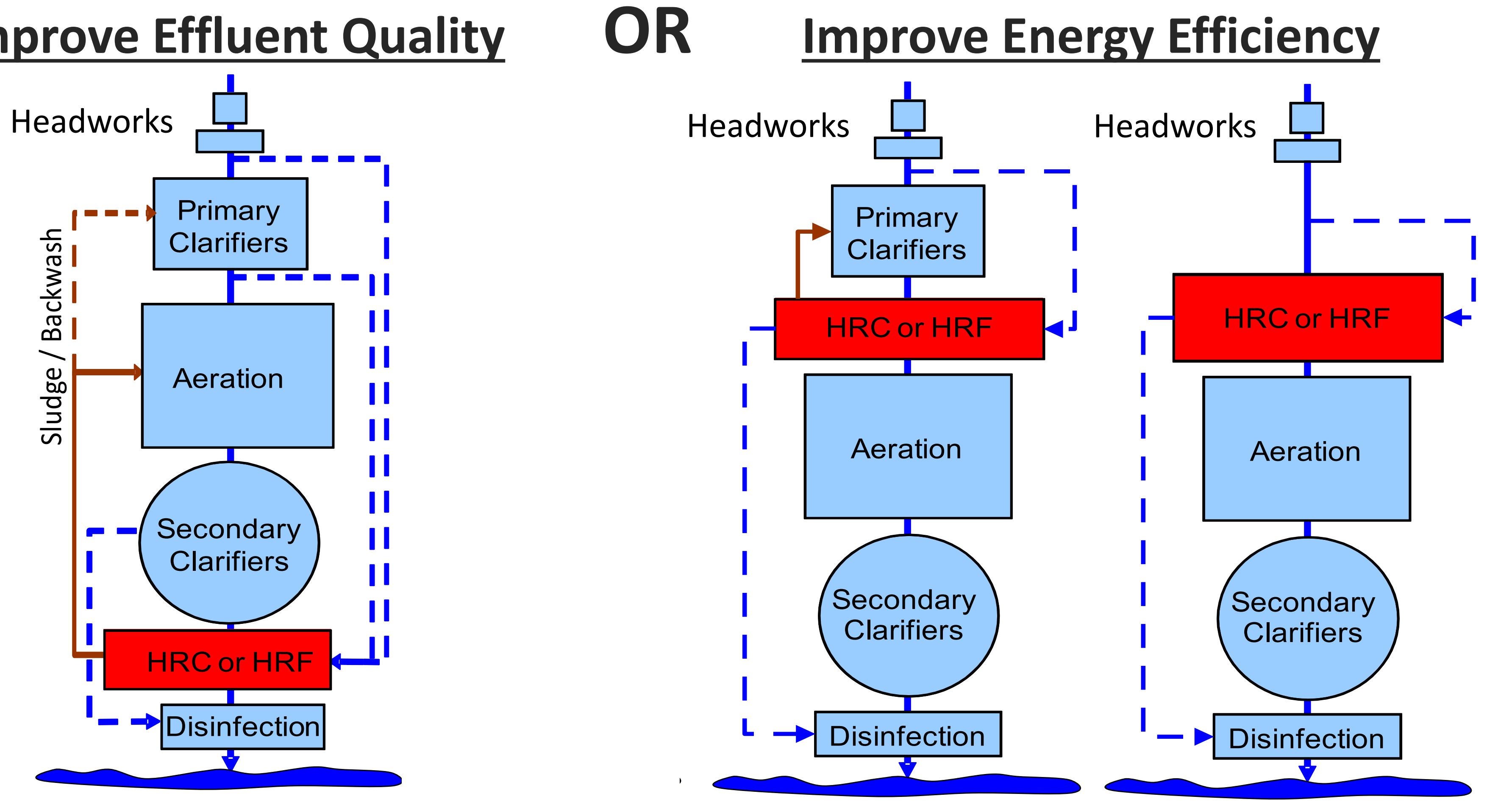
Blending or Auxiliary Treatment for Higher Peaking Factors



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

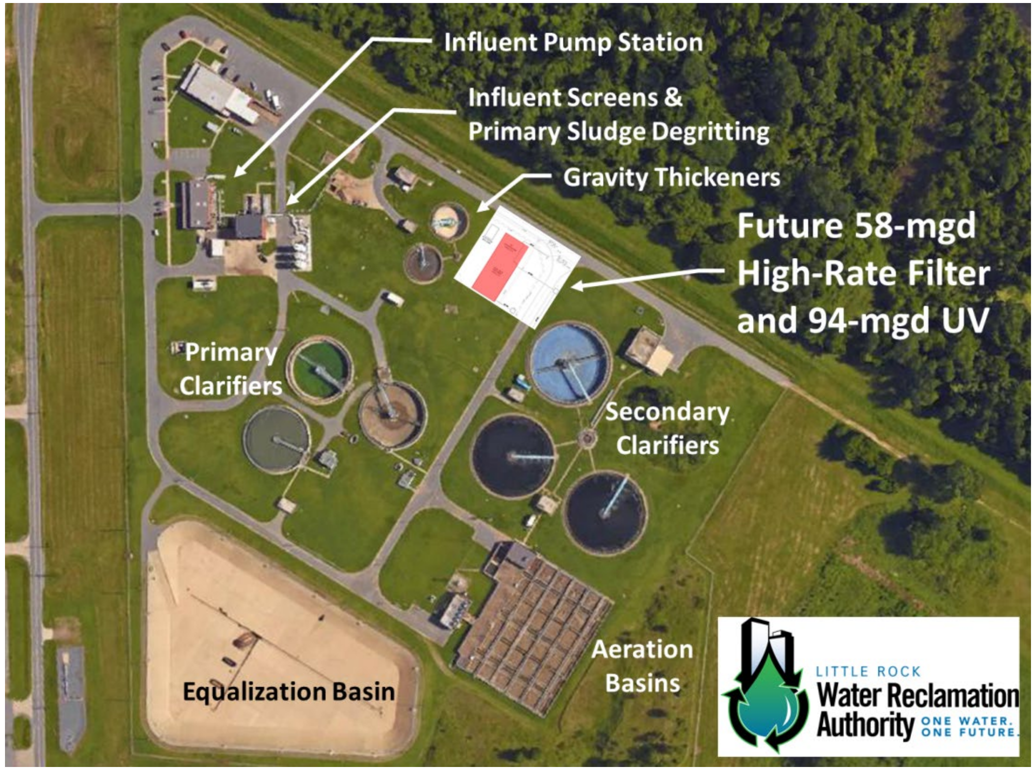
Background diagram from: U.S. EPA, Sanitary Sewer Overflows and Peak Flows Listening Session, June 30, 2010

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



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

Dual-Use High-Rate Filter for Adams Field WWTF

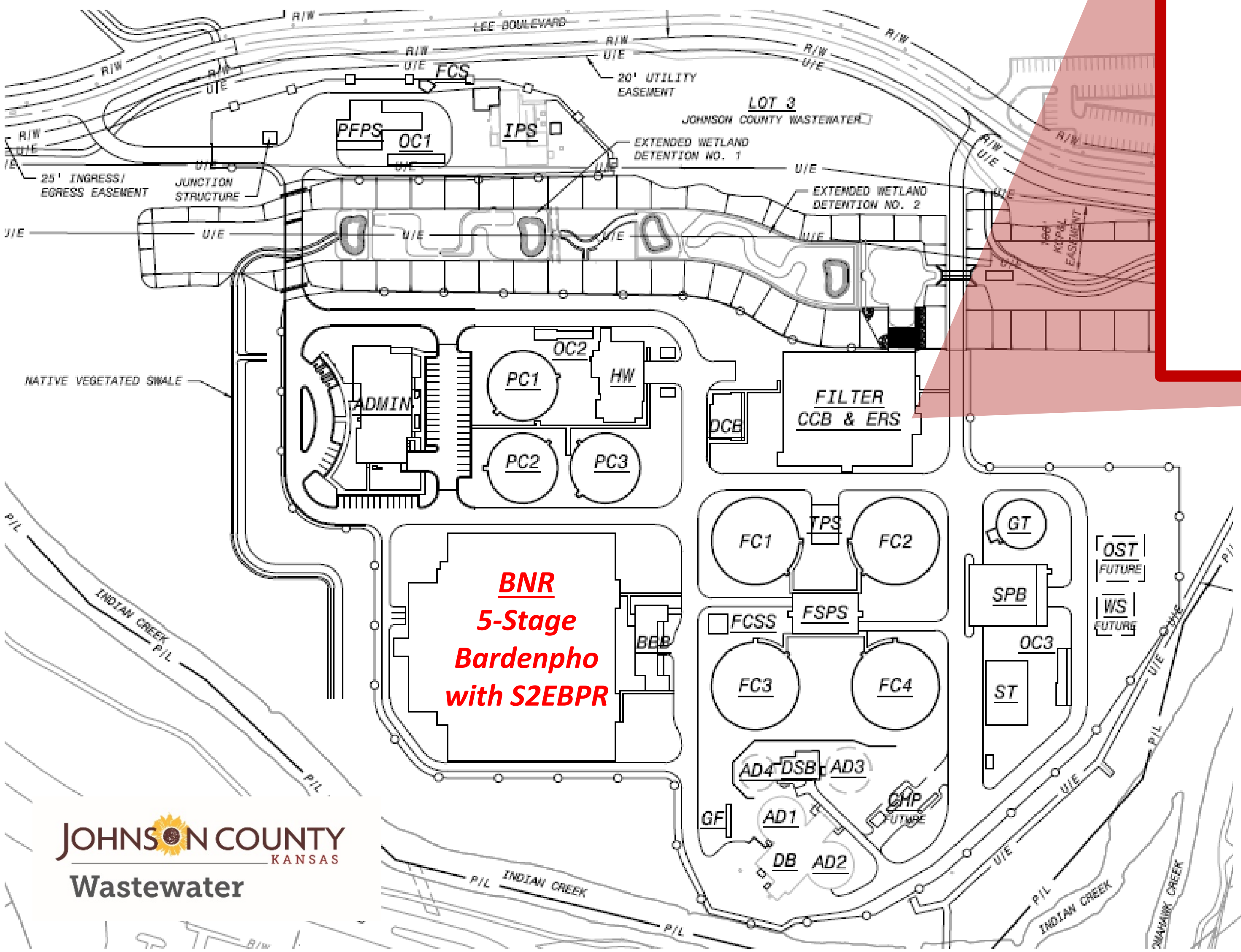


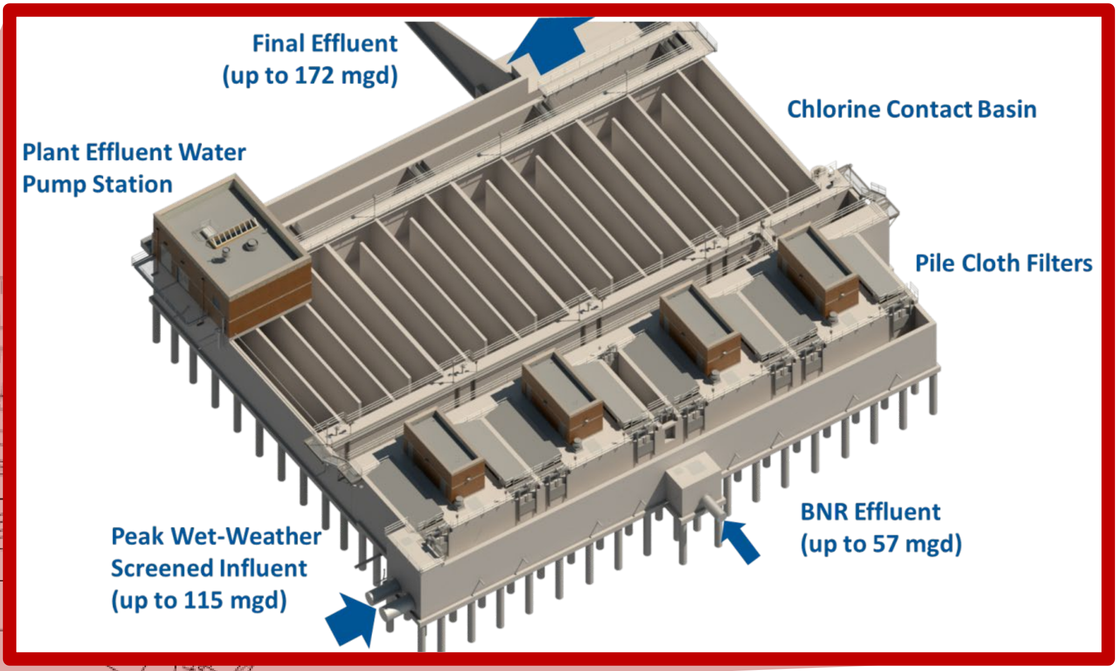
Triple Bottom Line Evaluation	
EHRT Process	**EHRT Technology**
CES with Ballasted Flocculation	ACTIFLO® (Veolia/Kruger)
	CoMag® (Evoqua)
Compressible Media Filtration	FlexFilter™ (WesTech/WWETCO)
	Fuzzy Filter™ (Schreiber)
Pile Cloth Media Filtration	MegaDisk® (Aqua-Aerobics)

- Dec 2015 – NPDES permit, no comment from USEPA
- 2016 – Onsite HRF pilot, TBL evaluation of conceptual designs, reference facility tours
- Pile cloth filter recommended:
  - Improve existing UV disinfection
  - Simple O&M
  - Lowest cost for tertiary dual-use
  - No alkalinity or effluent foaming issues
  - Non-potable reuse potential

60% design completed.
On track for startup in 2019.

S2EBPR and Dual-Purpose Filter for Tomahawk Creek WWTF





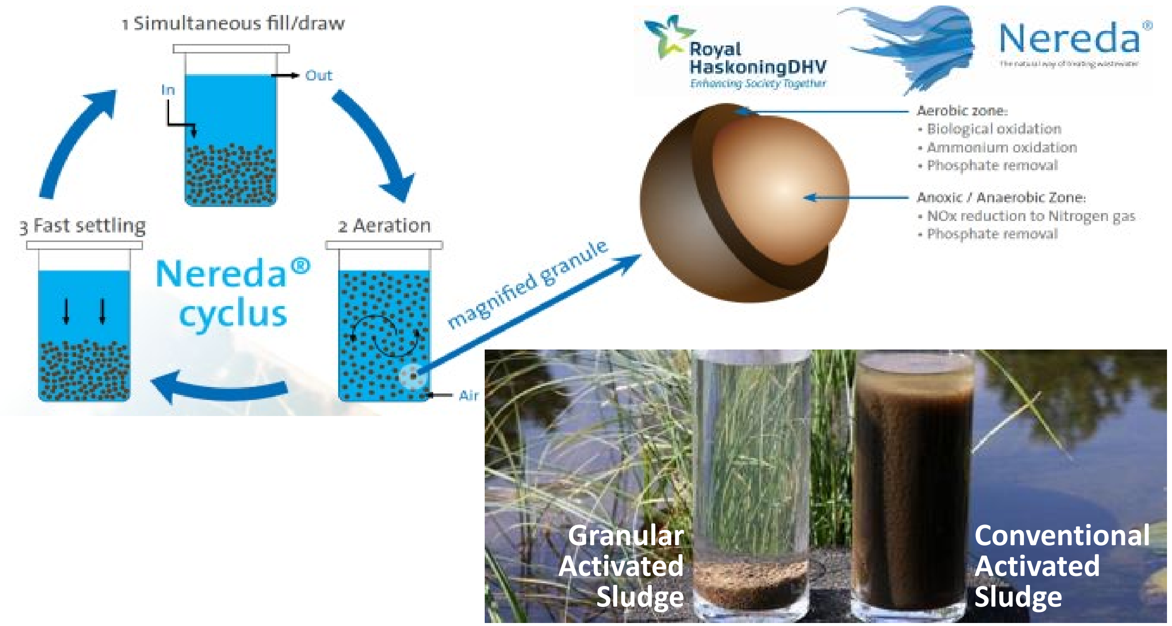
- Upgrade and expand 10-mgd (ADF) trickling filter WWTP
- Under construction, 2020 startup

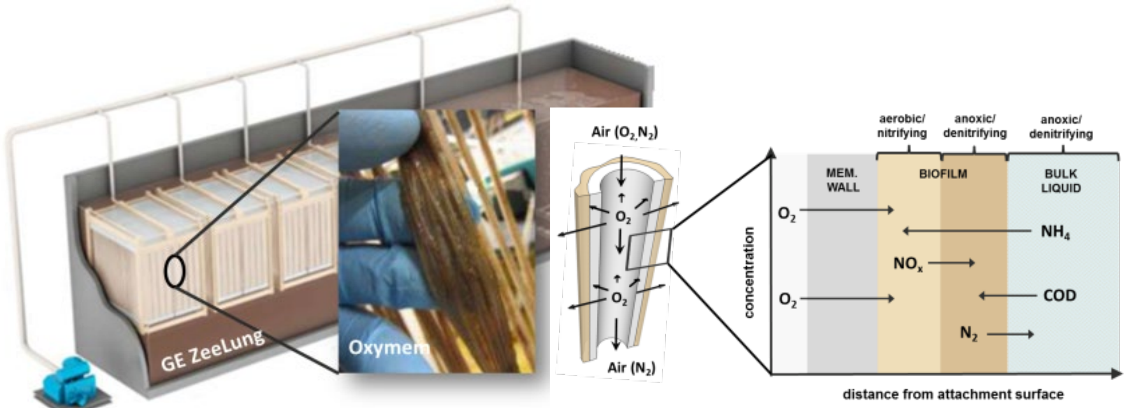
BNR and tertiary up to 3Q = 57 mgd
\+ Auxiliary EHRT up to 115 mgd
Peak WWTF capacity = 172 mgd

Closing Thoughts and Open Discussion

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

Process Intensification Examples





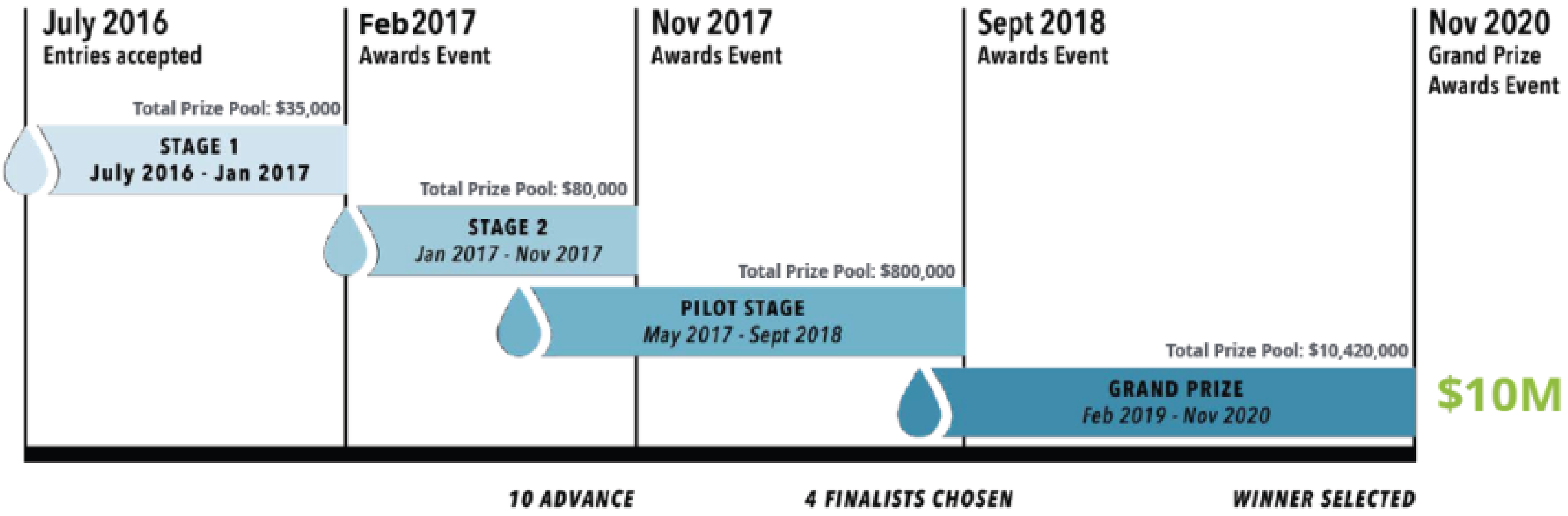
aeration membranes support low-energy biofilm nitrification and denitrification

- **Granular Activated Sludge**
  - Nereda® licensed to Aqua-Aerobic Systems
  - B&V non-disclosure agreement with RHDHV
- **Membrane Aerated Biofilm Reactor**
  - GE ZeeLung
  - OxyMem OxyFILM
  - Fluence/Emefcy

1. Less energy, smaller footprint, lower costs than conventional AS
2. S2EBR can be integrated with these fixed-film nitrogen removal technologies

Seeking Radically Cheaper Technology for <0.01 mg-P/L

Prize Structure



EVERGLADES FOUNDATION

THE GEORGE BARLEY WATER PRIZE

Stay tuned!

- http://www.barleyprize.com/
- #barleyprize
- B&V on judging panel