Metropolitan Water Reclamation District of Greater Chicago

Welcome to the October Special Edition of the 2020 M&R Seminar Series

NOTES FOR SEMINAR ATTENDEES

- All attendees' audio lines have been muted to minimize background noise.
- A question and answer session will follow the presentation.
- Please use the Q&A feature to ask a question via text.

Dr. Dongqi (Cindy) Qin

- Cindy Qin has been with the Metropolitan Water Reclamation District of Greater Chicago for over 11 years. She is a Senior Environmental Research Scientist in the Capital Planning, Wastewater Research and New Technology Section of the Monitoring and Research Department's Environmental Research and Monitoring Division.
- Cindy has a Bachelor of Science and Master of Science in chemistry from Jilin University, Changchun, China and received her Ph.D. in polymer chemistry and physics from Beijing University, Beijing, China. Prior to joining the District in 2009, Cindy worked on research projects at various universities in the U.S. and China.

Metropolitan Water Reclamation District of Greater Chicago

BIOLOGICAL PHOSPHORUS REMOVAL EFFORTS AT THE METROPOLITAN WATER RECLAMATION DISTRICT'S STICKNEY AND CALUMET WRPS

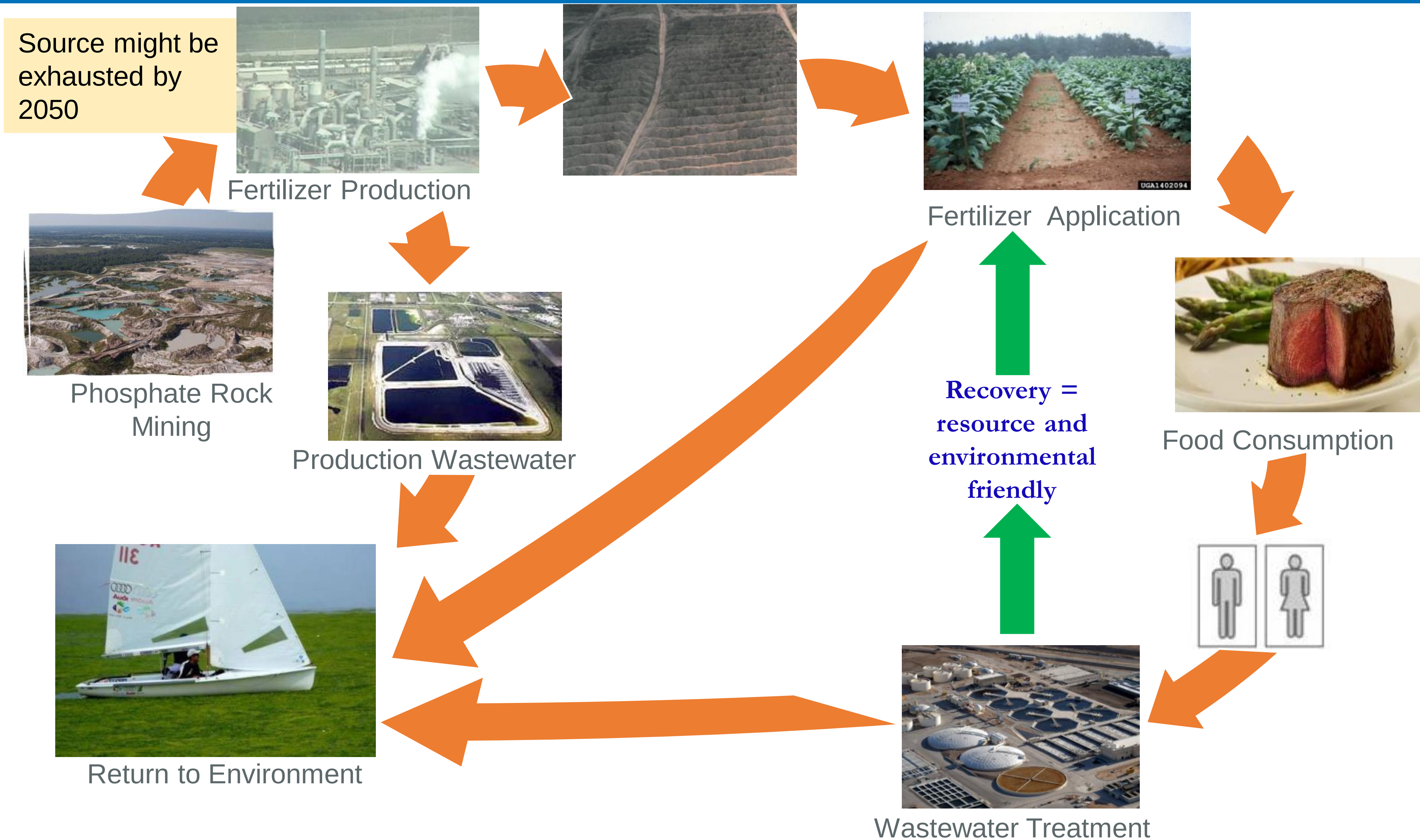
Dr. Cindy Dongqi Qin

October 16, 2020

Outline

- Overview
  - District Nutrient Efforts
- Understanding Phosphorus (P) Removal
  - Enhanced Biological P Removal (Bio P)
  - Chemical P Removal (Chem P)
- Stickney WRP P Removal Road Map
- Calumet WRP P Removal Efforts
- Findings and Next Steps
- Acknowledgements

Phosphorus “Life Cycle”: Current to Future



District Nutrient Efforts – Strategic Plan for Resource Recovery and Sustainability

2011

Informed IEPA on steps:

- To biologically remove P *using existing infrastructure*
- Recover P where possible
- To work within District's long term strategic plan on resource recovery and sustainability

2012

Formed a District-wide Phosphorus Task Force to study and implement of EBPR

Full-scale test in one battery at the Stickney and Calumet WRPs

2013

Converted all SWRP to EBPR configuration

Awarded contract for construction of Ostara® facility at Stickney

2014

EBPR pilot study @ Kirie WRP

Full-scale carbon test at Calumet WRP

2015

EBPR pilot study @ O'Brien WRP

2016

P recovery facility Ostara® I/S @ Stickney WRP

2017

New NPDES permits issued for big three plants

2011 – PRESENT

Actively participating in IEPA Nutrient Standards development

Big Three Phosphorus Permits

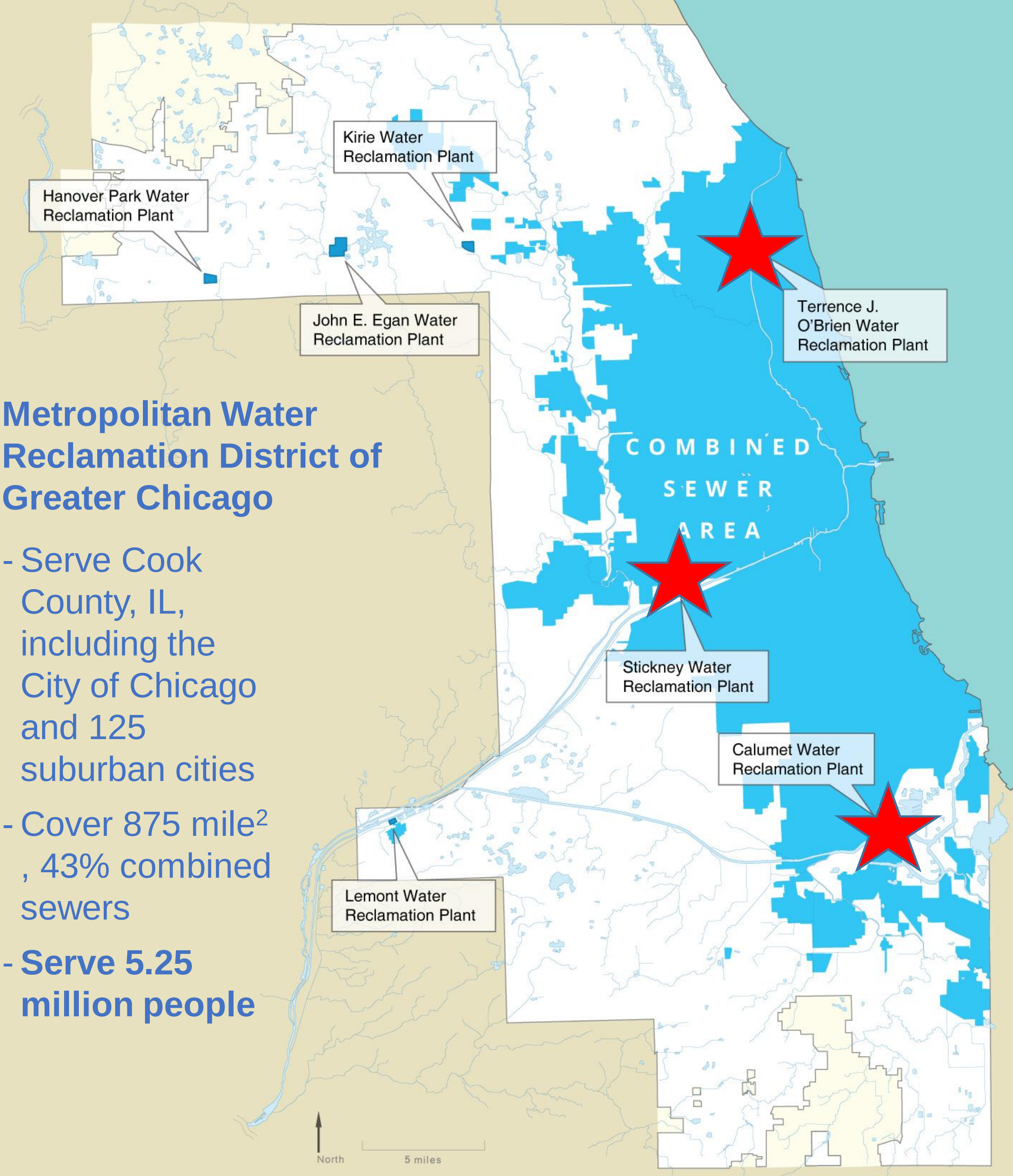
- NPDES permits
  - Big 3 plants (Stickney, Calumet, O’Brien) have finalized permits w/ compliance schedules
  - Required P feasibility study to identify methods and cost to meet the permit

- Avg. monthly of 1 mg/L TP in outfall
  - Stickney 49 months from 7/6/2017➔Aug 2021
  - Calumet 77 months from 8/1/2017➔Jan 2024
  - O’Brien 120 months from 8/1/2017➔Aug 2027

- Annual geomean of 0.5 mg/L TP in outfall by 2030

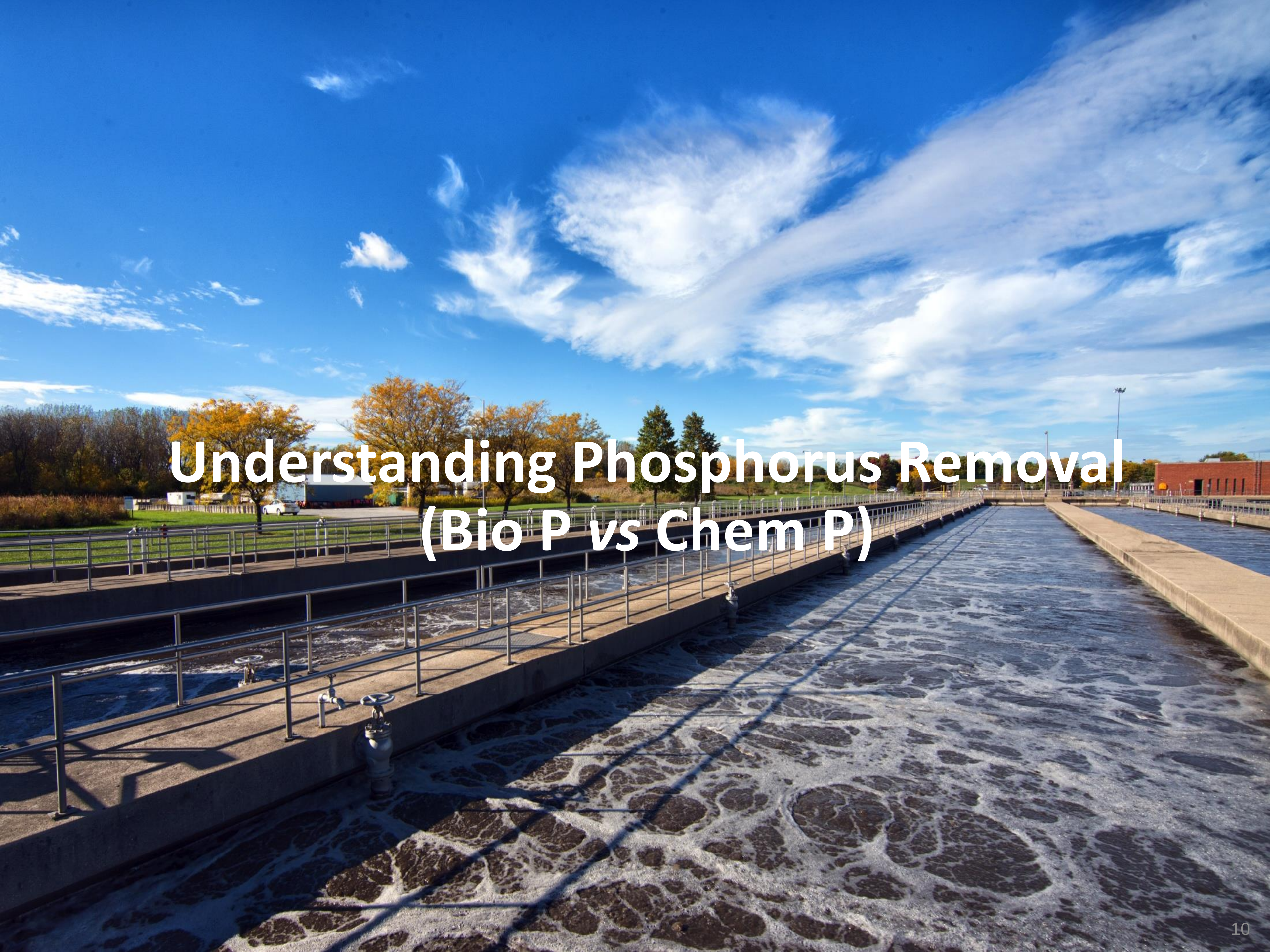
Metropolitan Water Reclamation District of Greater Chicago

- Serve Cook County, IL, including the City of Chicago and 125 suburban cities
- Cover 875 mile^2, 43% combined sewers
- **Serve 5.25 million people**



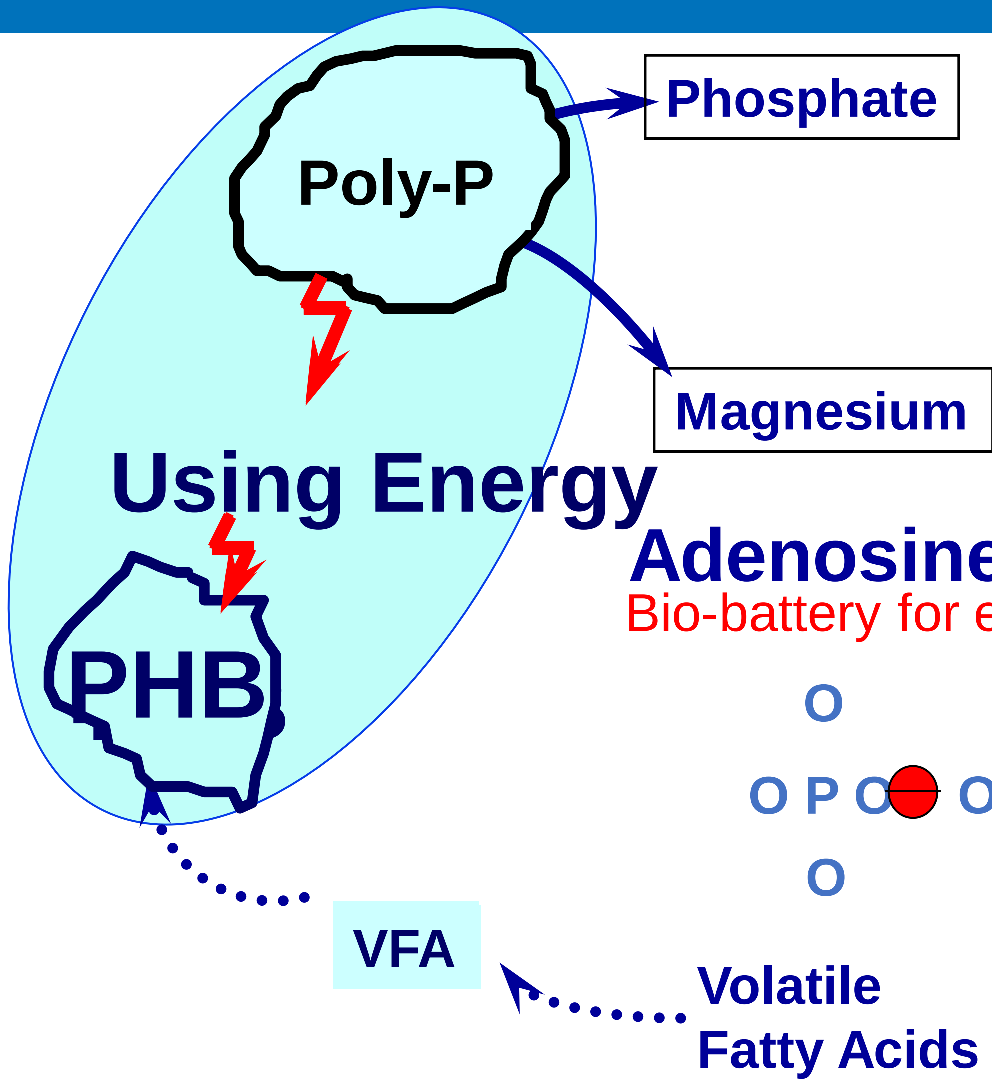
- Collection system: 554 miles of intercepting sewers and force mains fed by approximately 10,000 local sewer connections
- **Operate 7 WRPs and 22 pumping stations, handling daily flow of 1.4 billion gallons**

Understanding Phosphorus Removal (Bio P *vs* Chem P)



Understanding Bio P - Under Anaerobic Conditions – VFA uptake and P release

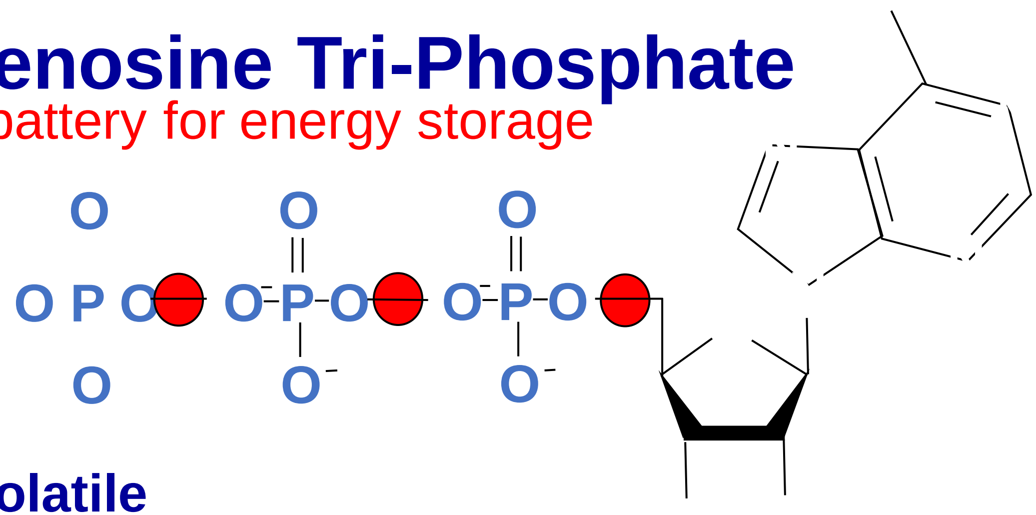
NO Nitrate & Oxygen



ATP

Adenosine Tri-Phosphate

Bio-battery for energy storage



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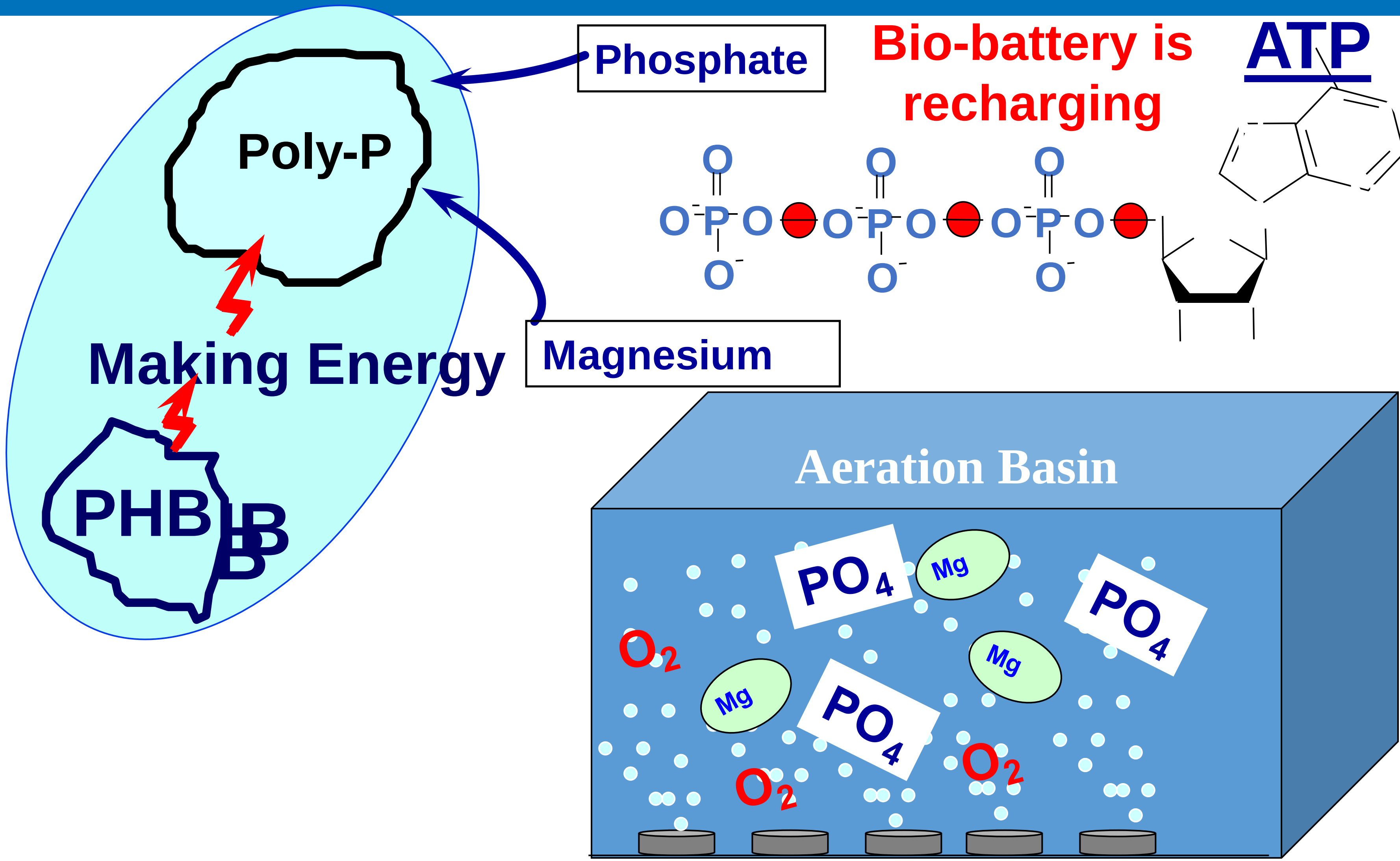
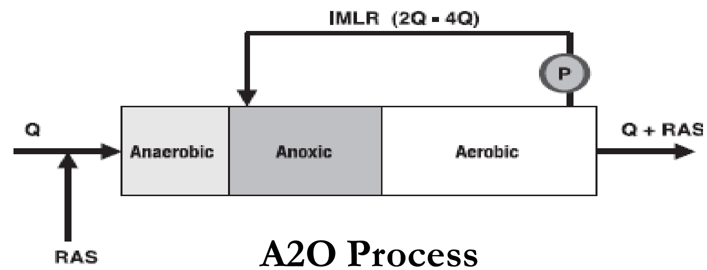
Understanding Bio P Under Aerobic Conditions - Phosphate Uptake/ATP Production



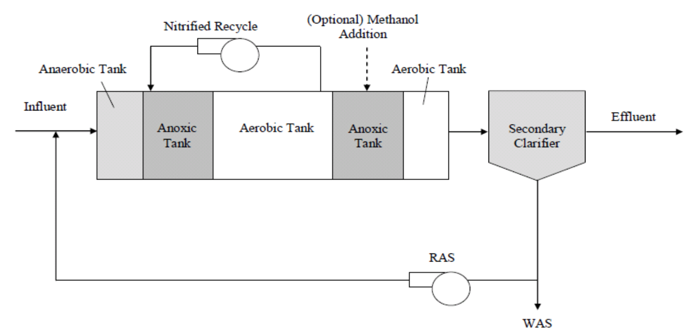
Credit to Black & Veatch for slide

Traditional Bio P Processes and Infrastructure Needs

- Baffles
  - Separation of zones
  - Allows for sludge blanket accumulation
- Mixers
  - To create truly anaerobic zone
  - To keep solids in suspension
  - To occasionally refresh the sludge blanket
- Recirculating Pumps



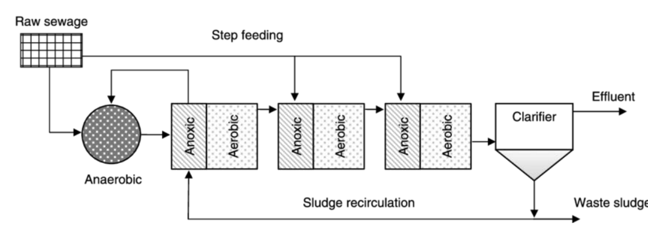
A2O Process



Modified Bardenpho Process

Process	Nitrogen Removal	Phosphorus Removal
MLE	Good	None
A^2/O	Good	Good
Step Feed	Moderate	None
Four-Stage Bardenpho	Excellent	None
Modified Bardenpho	Excellent	Good
SBR	Moderate	Inconsistent
Modified UCT	Good	Excellent
Oxidation Ditch	Excellent	Good

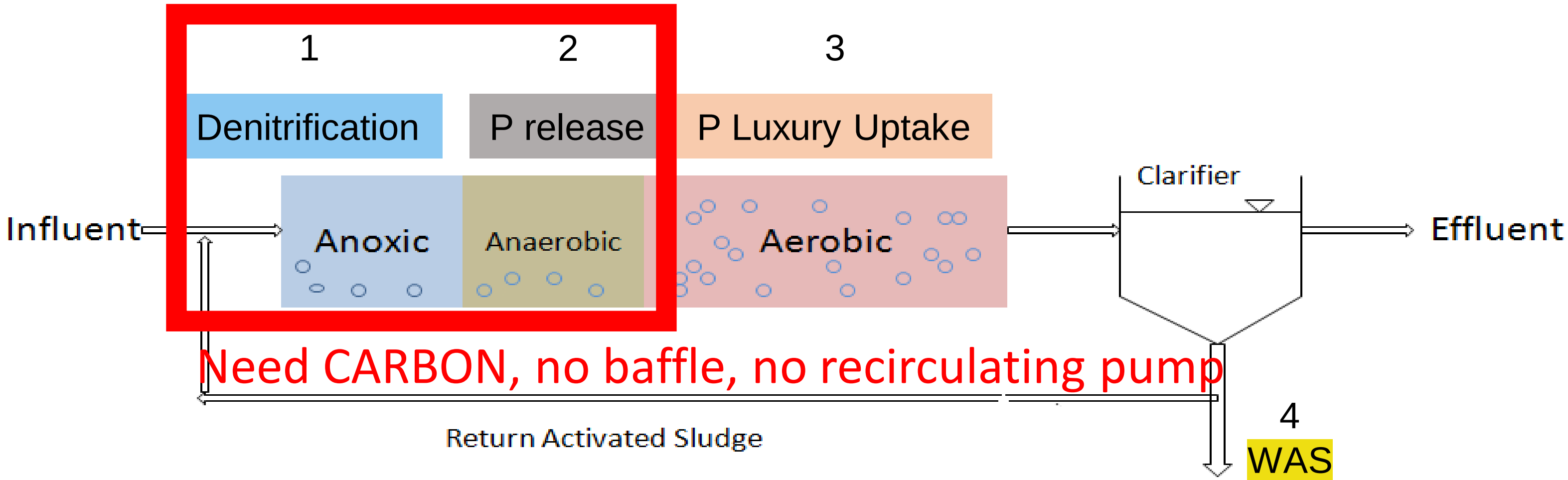
Source: Jeyanayagam (2005).



Modified UCT Process

Mainstream Biological P Removal

- Bio P is a process cycling between Anaerobic and Aerobic zones
  - Anaerobic: uptake VFA and release Phosphate (ortho P)
  - Aerobic: luxury uptake ortho P and store energy



1. Denitrification: NO_3 + carbon → N_2
2. P release: uptake VFA, release ortho P via the PAOs
3. P luxury uptake: uptake ortho P by PAOs

- PAOs settle out w/ other biomass in secondary clarifiers and removed from system ➔ net removal from liquid stream

Chemical P Removal

- With addition of metal salts
  - Ferric chloride, ferrous sulfate
  - Alum
  - Lime
- Soluble phosphorus & soluble metal combine
  - insoluble precipitate forms (removed through sedimentation or filtration)

$$M^{+3} + PO_4^{-3} = MPO_4(s)$$

- Using iron,

$$FeCl_3 + H_3PO_4 = \downarrow FePO_4(s) + 3HCl_3$$

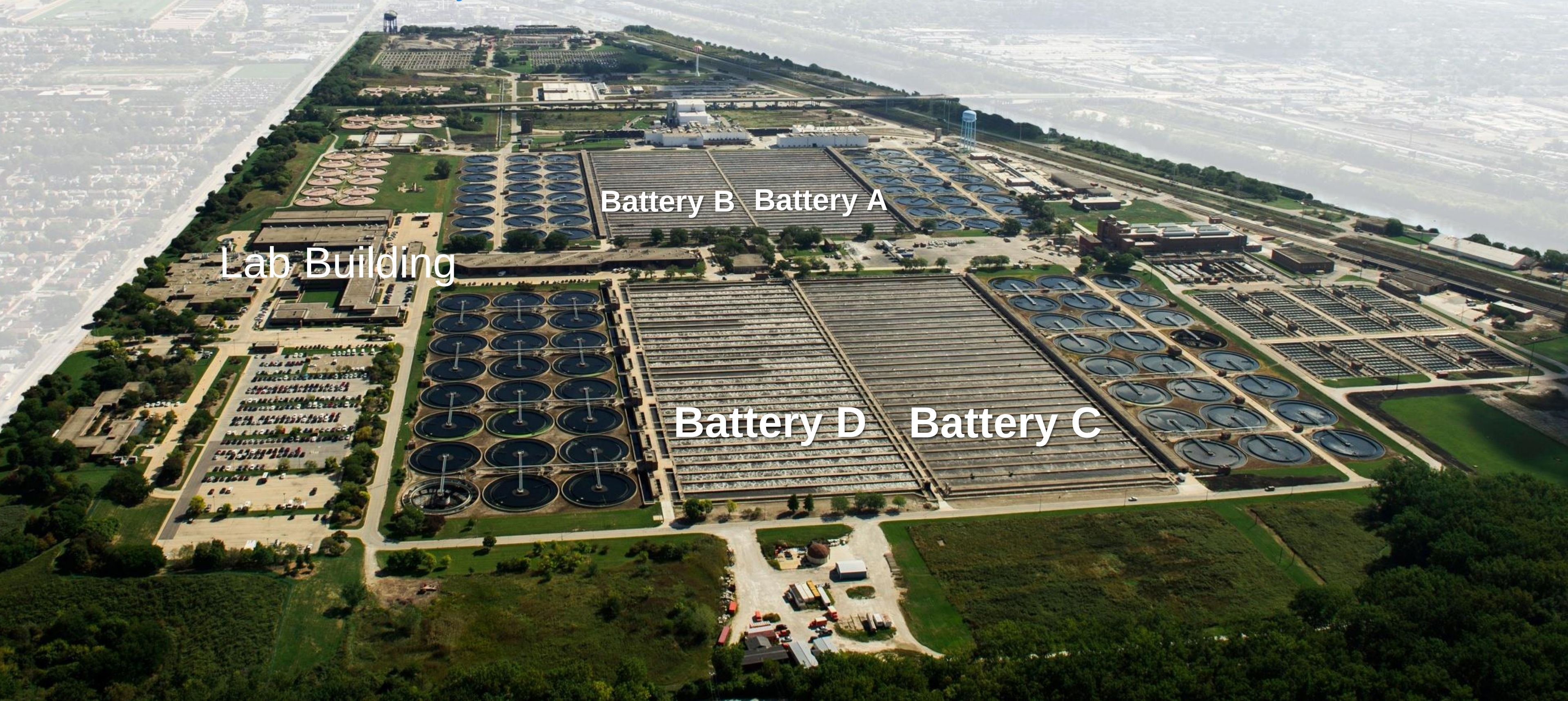
- Dosing
  - 1 mole of Fe reacts with 1 mole P
  - Typically, ratio of ~2 mole of Fe/mole P used
  - Results in 5.2 – 10.5 mg $FeCl_3$/mg P

Bio P versus Chem P

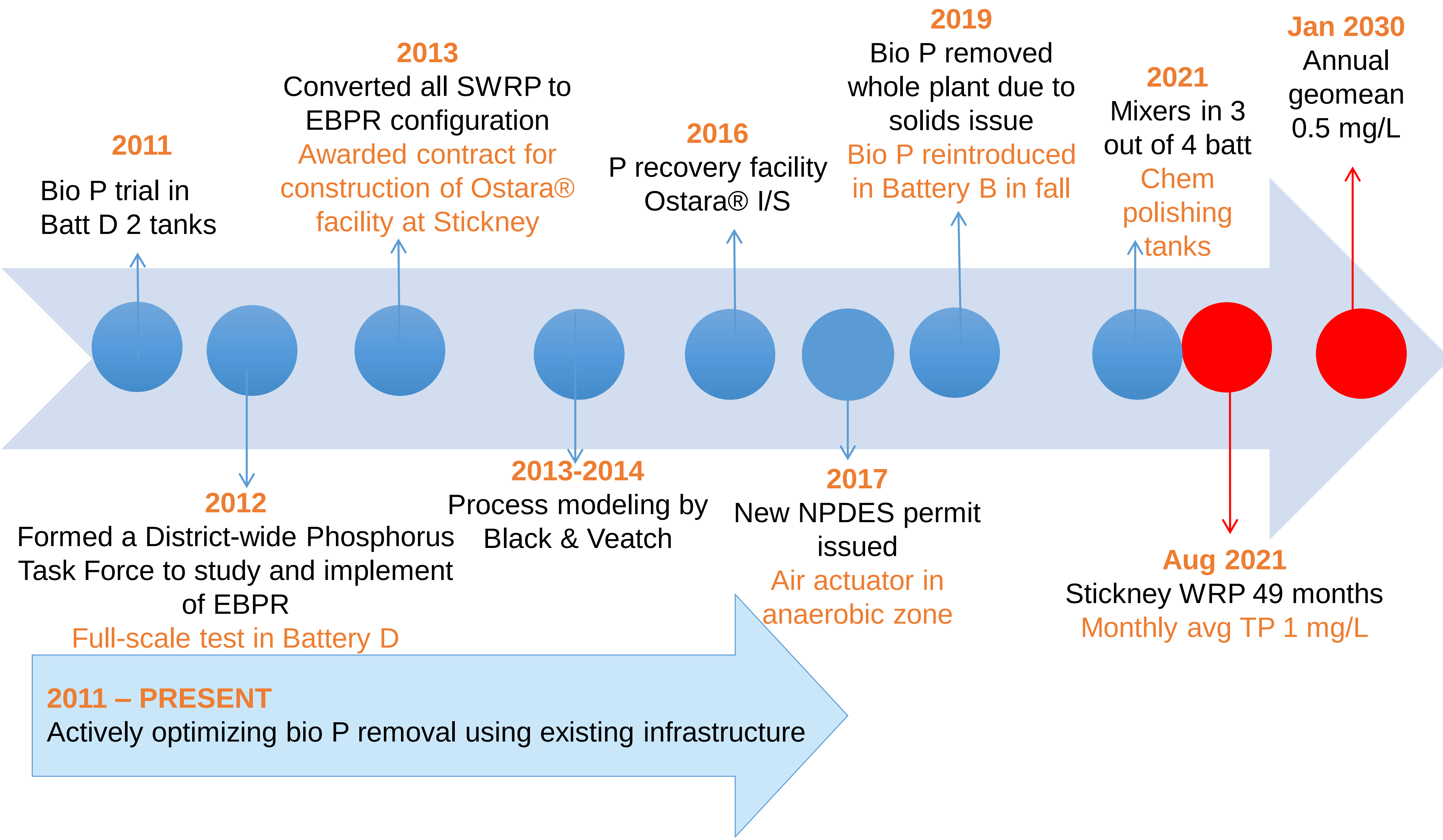
	BENEFITS	DISADVANTAGES	CAPITAL COSTS
Chem P	• Easy to implement • **Low capital costs** • Smaller footprint (little additional infrastructure) • **Reliable** (no toxicity issues)	• Increased sludge production (up to 25%) • **Unable to recover P from sludge** • **Ongoing chemical costs** • Possible UV inhibition if overdosed w/ $FeCl_3$ • Consumed alkalinity • Increase MLSS • Vivianite formation	• Pumps • Piping • Chemical feed system • Storage tanks • Building (potentially) • Additional sludge handling (potentially)
Bio P	• Less sludge production • **Less chem costs** • **Can recover P** • Can be coupled w/ chem P • Lower operational costs	• **More complex control** • **Toxicity upsets** • Hard to dewater sludge • **Takes up nitfrication capacity** • Possible backmixing if no baffles • Downstream struvite formation	• Baffles • Pumps • Mixers • Instrumentation

Stickney Water Reclamation Plant

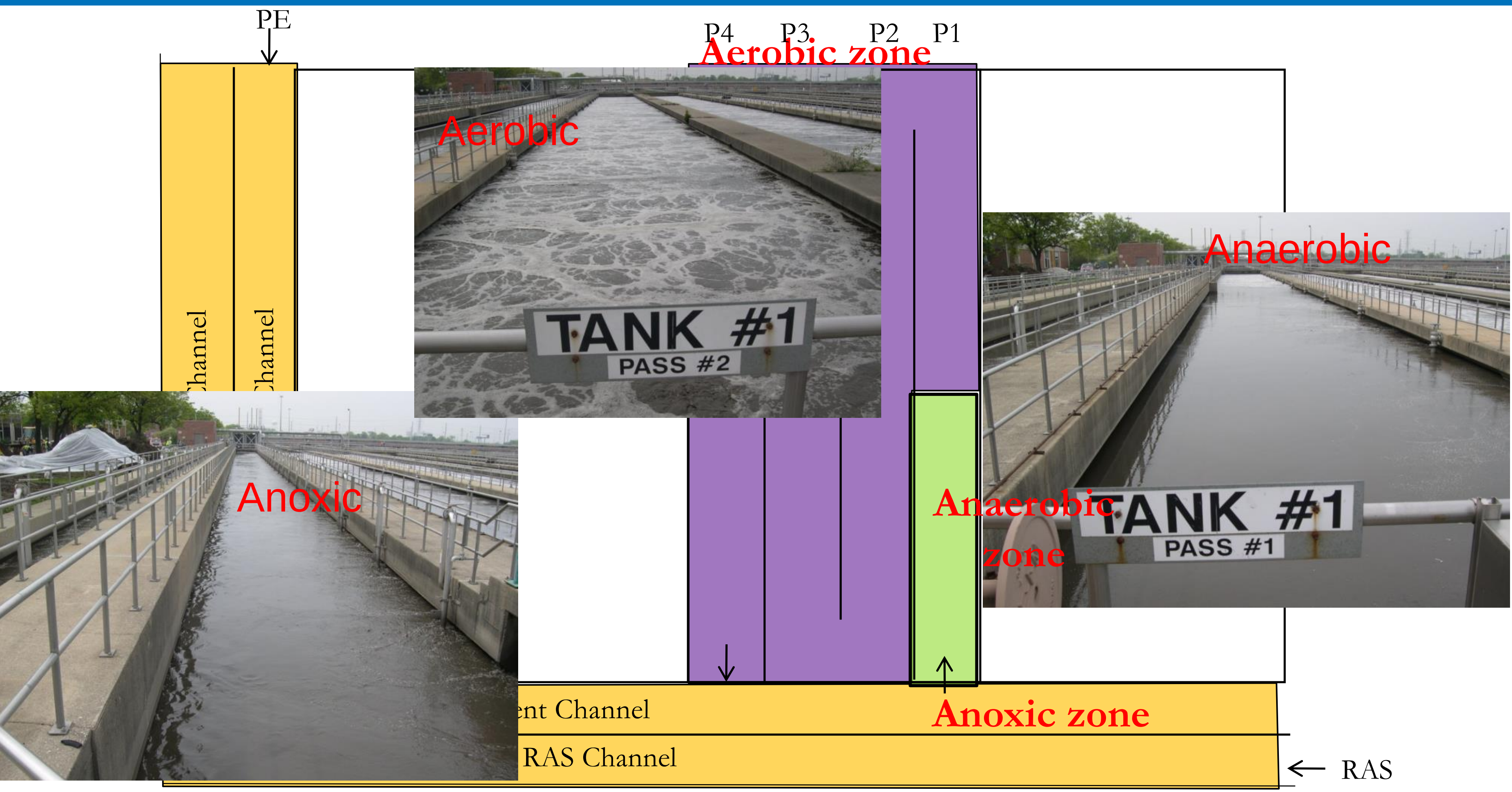
- Serves 2.38 million people
- Flows:
  - Avg Design Capacity: 1,200 MGD
  - Average 2019: 827 MGD
- 4 aeration batteries
  - 8 tanks/battery
  - 4 passes/tank
  - 96 circular secondary clarifiers



Stickney WRP Bio P Implementation Timeline



Aeration Battery Conversion to Bio P at Stickney WRP

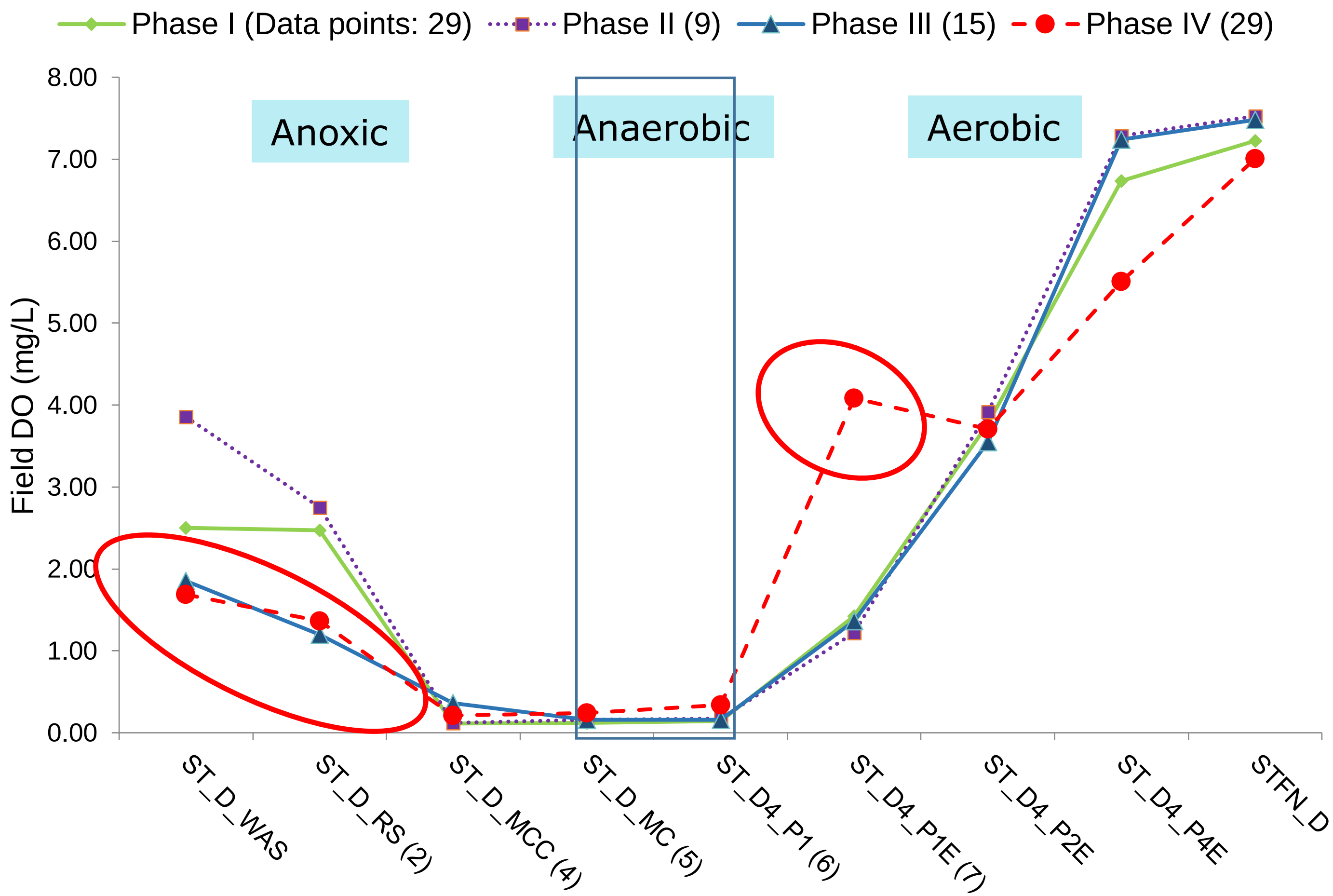


- Using current air distribution system for mixing
- No baffles
- No recirculating pumps

Optimizing Operation Parameters for Bio P at Stickney WRP

- Phased approaches with controlled changes
  - Air optimization
    - Create Anoxic/Anaerobic zones by closing air in RAS, influent and mixing channels and minimizing air in first half of pass 1s
  - RAS flow reduction
    - Suspended solids control for air lifts to reduce RAS flow and subsequently minimize NO_3 and O_2 return
  - Carbon optimization
    - Holding primary sludge to generate VFA in preliminary settling tanks, however, this caused downstream sludge transfer issue ✗
    - Use less preliminary tanks to send more BOD to secondary, however, no correlation was found in improving P removal ✗
    - Resource Recovery Ordinance to bring high strength organic material in ⏻
    - Inline mixed liquor fermentation - inconclusive ?
    - Rotating preliminary settling tanks in low flows to ferment primary effluent in preliminary tanks ✓
  - Control recycle streams in low flows

DO Monitoring Results During Pilot Test in Battery D



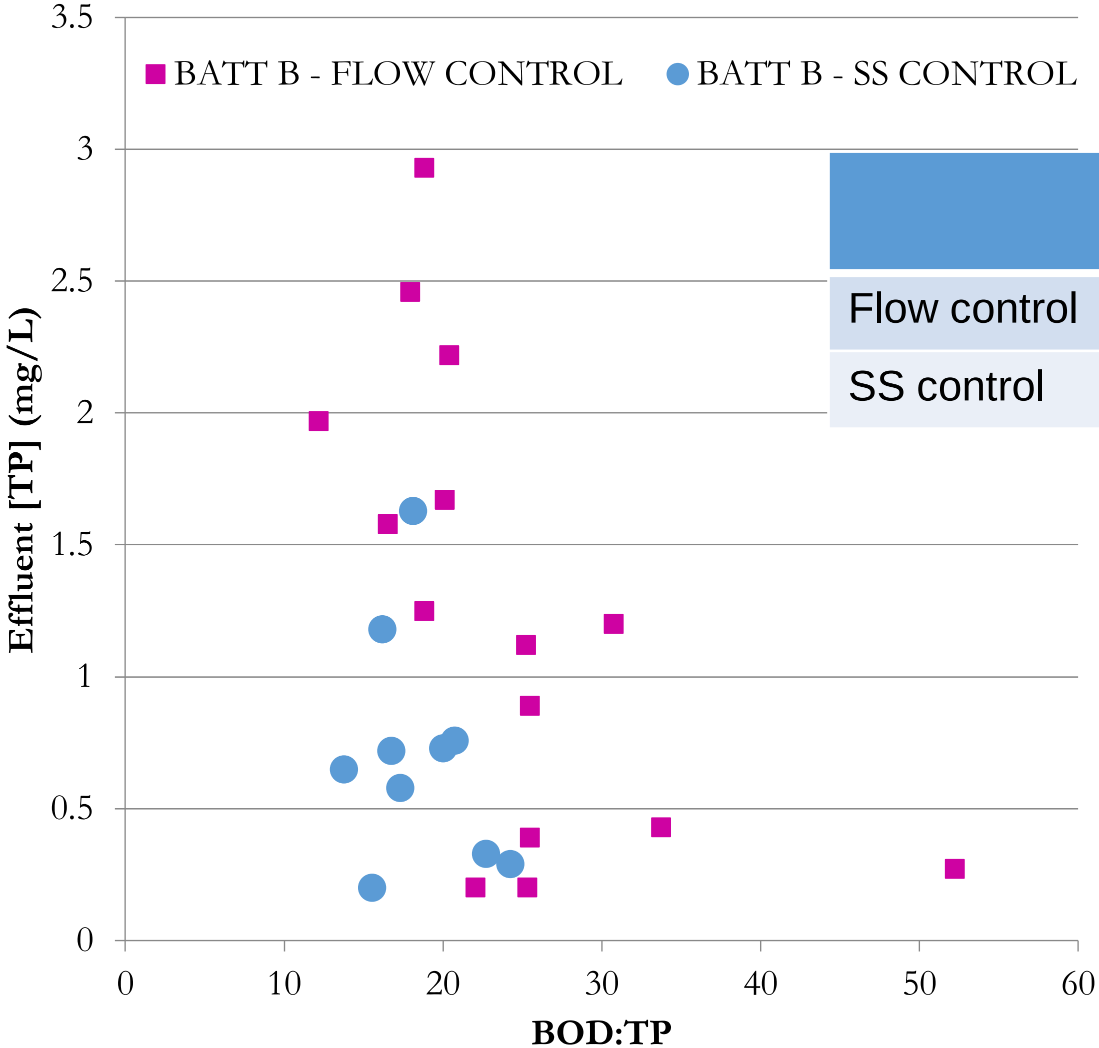
Phase I: Baseline

Phase II: Minimize air in first half in pass 1

Phase III: Turn off air in channels

Phase IV: Open up second half in pass 1

Control Return Sludge Flow via SS Control for Minimizing Nitrate Impact



	RAS/PE	BOD:TP	Effl TP (mg/L)
Flow control	0.9	25.7	1.04
SS control	0.7	18.1	1.00

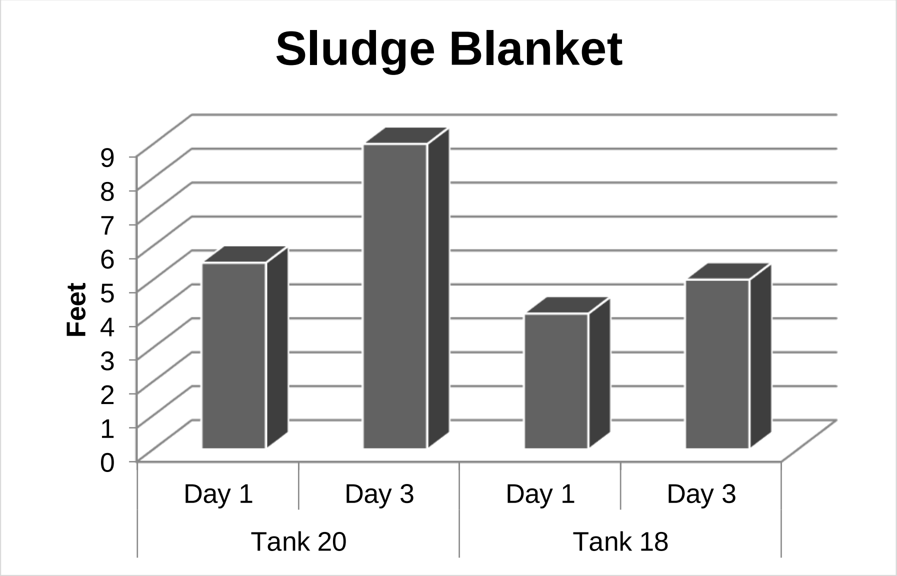
- RAS/PE ratio was dropped via SS control in Battery B, especially compared to other batteries.
- *Can operate at a lower BOD:TP ratio to get to the same TP with lower RAS/PE.*

Stickney Carbon Optimization for Bio P

- All carbon ratios indicate that SWRP is near the lower end of recommended ratios
  - BOD:TP ~ 24.5 (2014) vs. recommended > 25
  - rbCOD:TP ~ 11.5 (2014) vs. recommended 11-16
  - *On daily basis, the process may be carbon limited about 50% of time.*
- Prolonged periods of low BOD:TP have longer lasting impact
  - PAOs could be essentially starved over a period of insufficient carbon.
  - P release rates recover faster than uptake rates
    - Release rates recover within a day
    - Can take 3 days to recover orthoP uptake rates
  - *May need BOD:TP to increase for a prolonged period to see recovery of system.*

Preliminary Settling Tanks Rotation

- After 48 hours isolating preliminary tanks, carbon concentrations of primary effluent from tanks increased:
  - COD by 17% to 224%
  - solCOD by -10 to 161%
  - and VFA by 207% to 683%
- Sludge blanket in isolated prel tanks increased after 48 hours sitting time



Complete Ostara System

OSTARA
Creating Value from Waste

Crystal Green Storage & Bagging

Dewatering Screen & Dryer

Pearl Reactors

Chemical Storage & Feed

Finished Product

Crystal Green®

High Purity (99.5% Struvite)

5-28-0 +10% - Slow Release Fertilizer

Phosphorus | Nitrogen | Magnesium

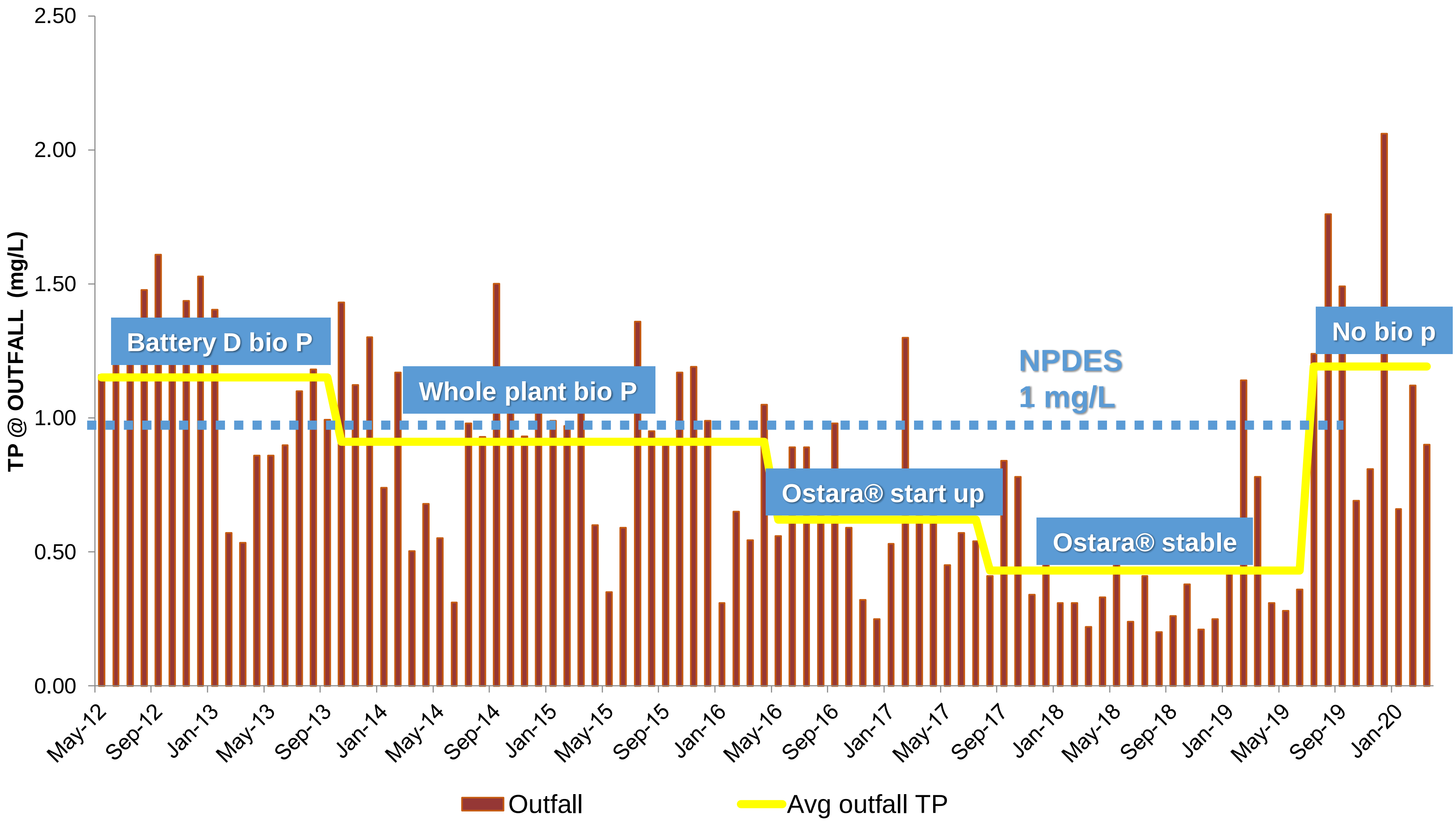
- Enhanced Efficiency Fertilizer
- Reduces risk of nutrient run-off
- Sustainably made, with eco-friendly, high-performance benefits

COMPARISON OF MODEL OUTPUTS

Scenario		EFFLUENT TP		RECOVERED TP	
		mg/L	lbs/day	lbs/day	% of Inf TP
Baseline	Current configuration	0.6	3500		
Baseline_no Al	No Al or Fe in influent	1.5	8200		
Mod_Baseline	New Primaries, new GCT, and dedicated WAS thickening	0.9	5100		
Option 1	Post Digestion	0.6	3300	1900	9
Option 2	WASSTRIP and Post Digestion	0.3	1700	6300	28
Option 3	P recovery from LASMA	0.6	3600	2200	10
Option 4	Options 2 and 3 Combined	0.2	1400	7300	32

- 0.3 mg/L Effluent TP reduction w/ post-centrate recovered by Ostara® only.
- 0.6 mg/L effluent TP reduction w/ both post- and pre-centrate recovered by Ostara ® and WASSTRIP processes.

Stickney WRP TP Removal - Monthly Averages



Operational Changes Made for Stickney Bio P

- Did not include
  - Baffles
  - Mixers
    - Use of existing air distribution for mixing
  - Recirculation pumps
- Optimizing existing infrastructure included:
  - Air input to all zones
  - Increased MLSS concentrations
  - Operating preliminary tanks to increase carbon loadings to Bio P process
  - Operating final tanks to minimize NO_3 load from RAS
  - Limiting P-loading variability by equalizing recycle stream flow and recovering P

Phosphorus Feasibility Study Summary – Stickney WRP

Technology Combinations For 0.5 mg/L

- For annual average loadings: bio P + Ostara (partial) or bio P + PS fermentation
- For maximum month loadings: bio P only; however, nitrification with TARP flow could not be achieved in winter

Technology Combinations For 0.3 mg/L

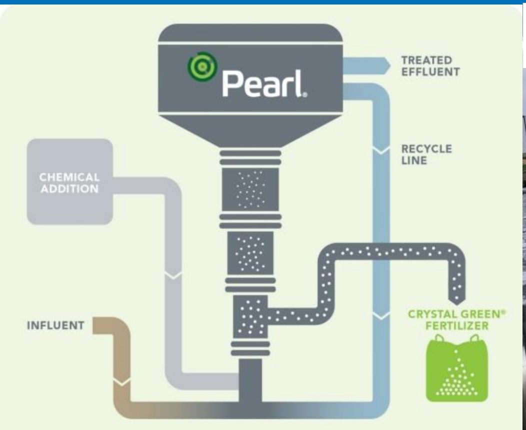
- For annual average loadings:
  - Combinations of bio P + WASSTRIP + Ostara + tertiary or + PS fermentation
- For maximum month loadings: TARP flow could not be accommodated in winter condition

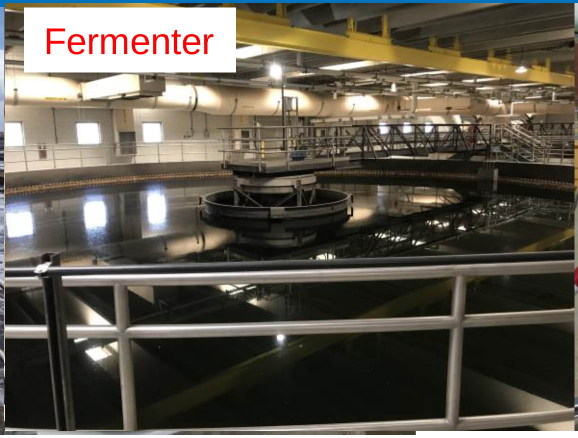
Phosphorus Feasibility Study Summary – Stickney WRP Cont.

Technology Combinations For 0.1 mg/L

- For annual average loadings:
  - Combinations of bio P + tertiary + WASSTRIP + Ostara or + ferric in secondary and tetiary or + PS fermentation
- For maximum month loadings: TARP flow could not be accommodated in winter condition

Major Capital Projects to Meet Phosphorus Permit Limit at Stickney WRP



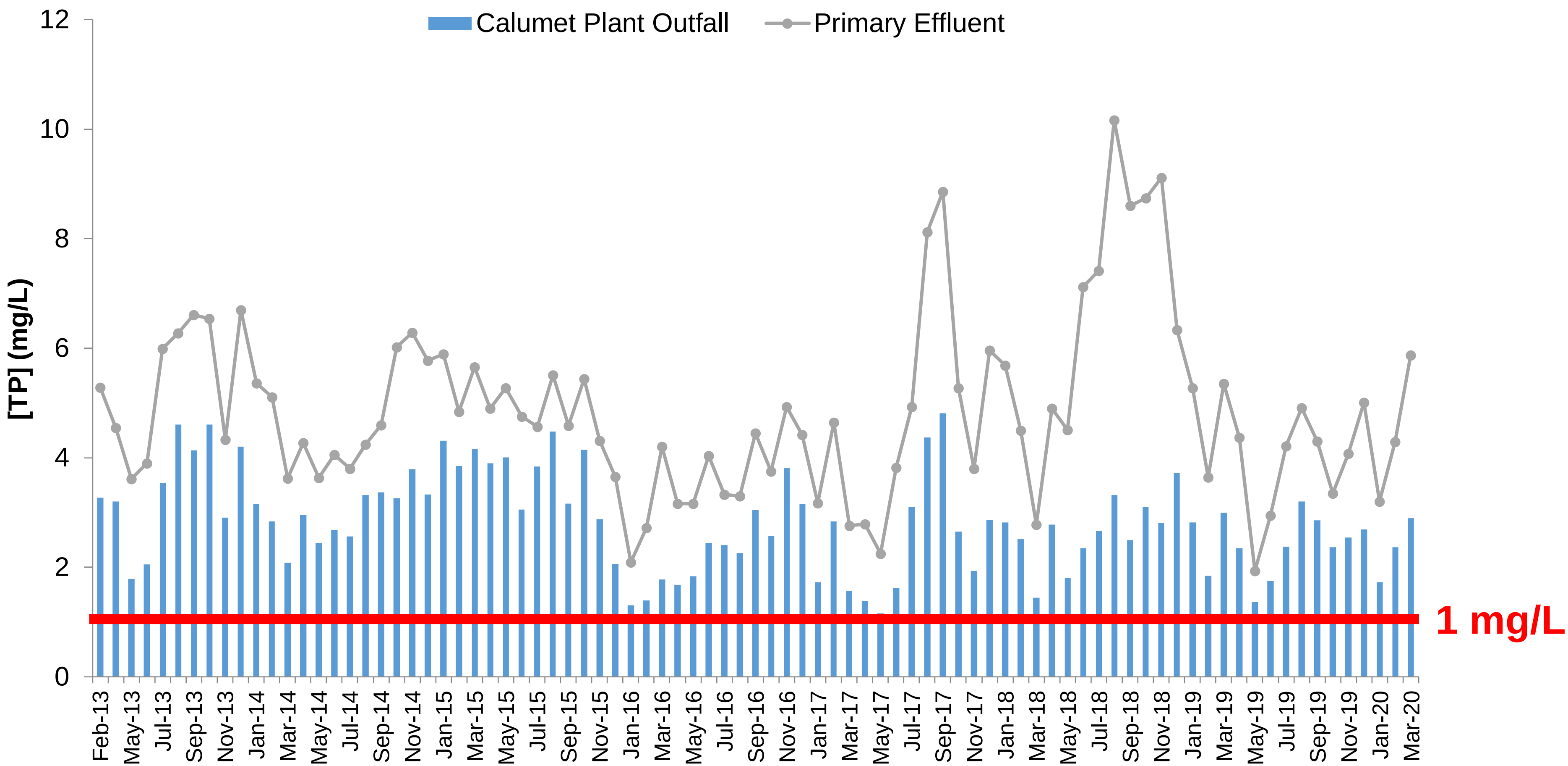


Contract #	Projects	Completion Years
11-195-AP	P-Recovery System (Pearl®)	2016
15-122-3P	Actuation of Pass 1 Valves	2018
15-120-3P	WASSTRIP®	2018
15-124-3P	GCT Conversion to Fermenters	2019
19-157-3P	Mechanical Mixers in Pass 1	2021
19-159-3P	Chemical Polishing System	2021

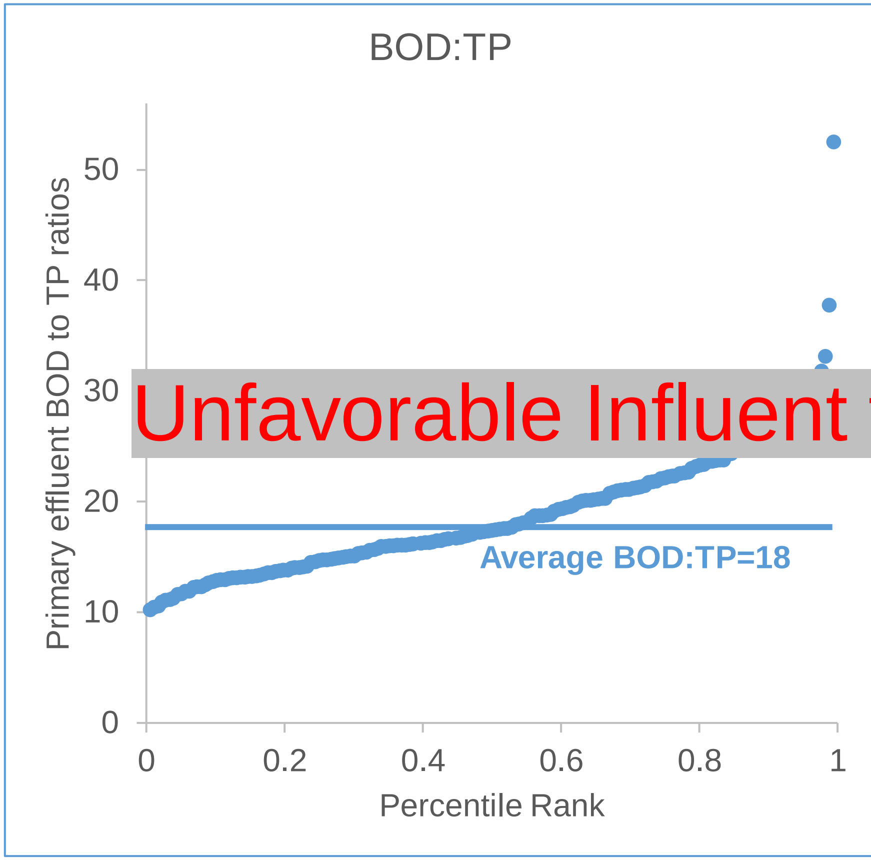
Calumet Water Reclamation Plant

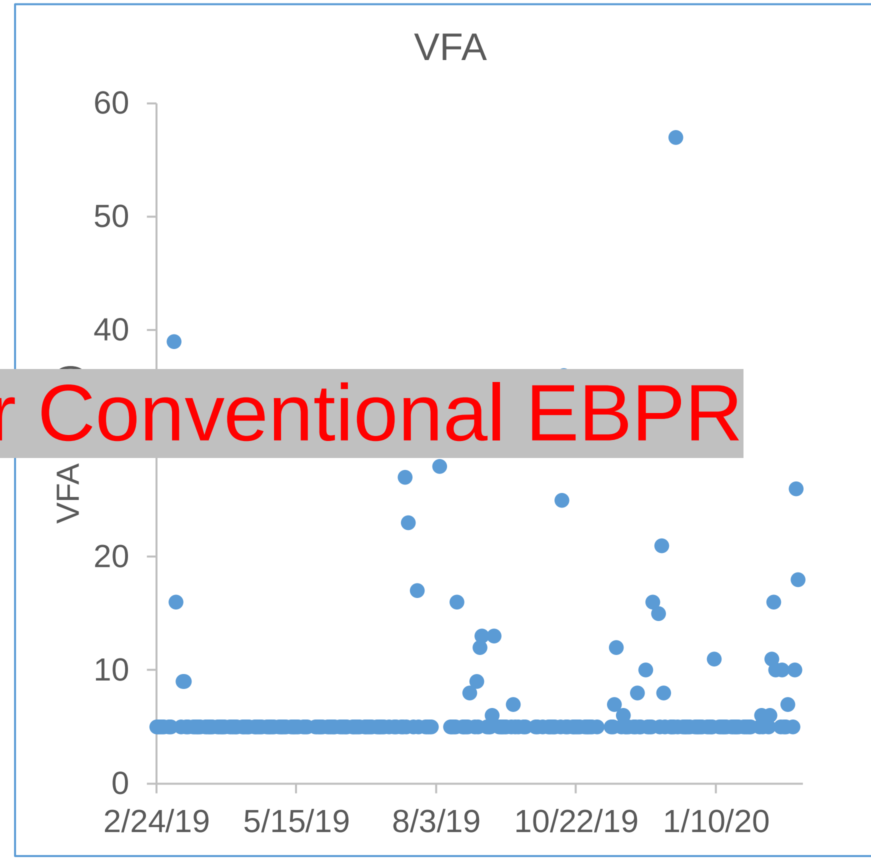
- Serves over 1 million people
- Flows:
  - Avg Design Capacity: 354 MGD
  - Average 2019: 308 MGD
- Full nitrification
- 5 aeration batteries
  - 48 aeration tanks
  - Conventional one or two passes/tank
  - 52 circular secondary clarifiers

Calumet Outfall and Primary Effluent Monthly Average TPs



Low Carbon Primary Effluent

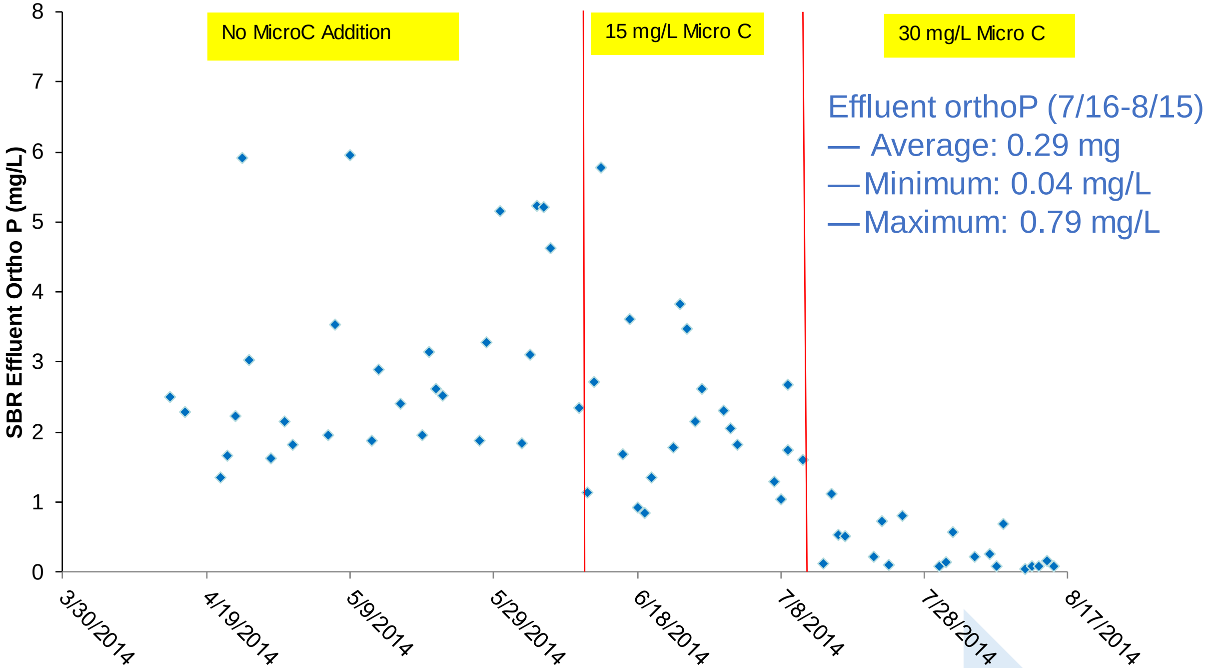




Unfavorable Influent for Conventional EBPR

- 80% of the time below EBPR minimum BOD:TP requirement; similar observation in rbCOD:TP
- 77% of the time VFA concentrations below detection level

Calumet WRP P Removal Efforts

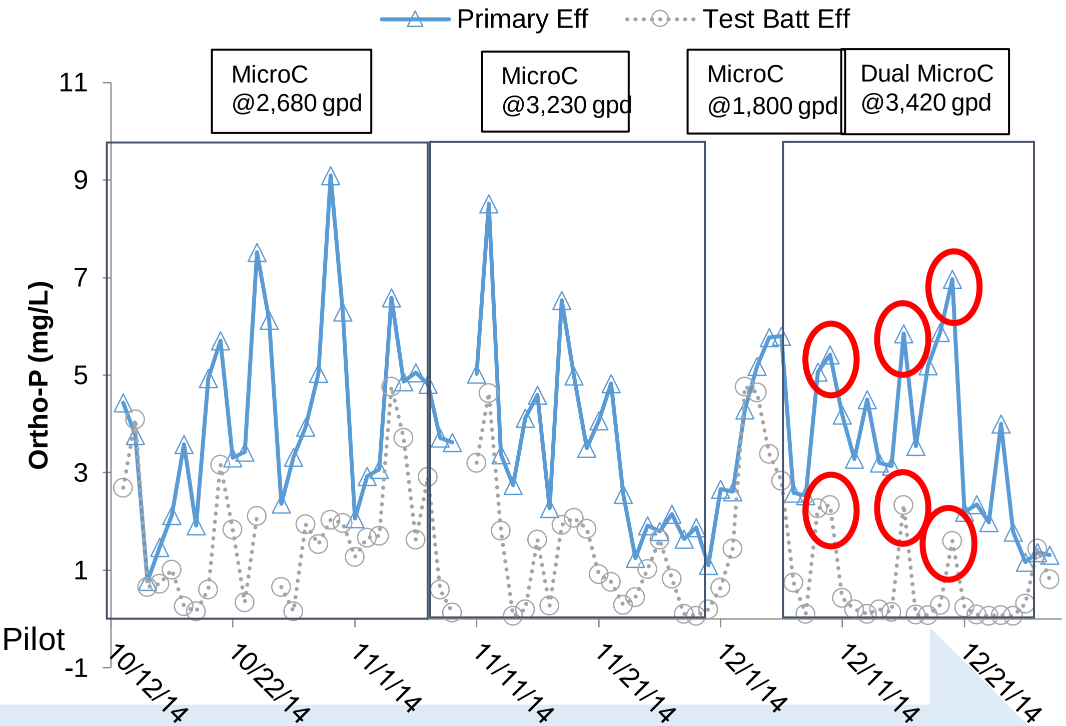


Spring 2014
SBR Carbon Pilot

2012
Formed a District-wide Phosphorus Task Force to study and implement of EBPR
Full-scale test in two batteries

Calumet WRP P Removal Efforts

Effluent orthoP (12/6-12/24)
- Average: 0.79 mg/L
- Highly fluctuated influent
- Effluent spikes followed influent spike



Spring 2014
SBR Carbon Pilot

Fall 2014
Full-scale Carbon Pilot

2012
Formed a District-wide Phosphorus Task Force to study and implement of EBPR
Full-scale test in two batteries

Calumet WRP P Removal Efforts

Alternative:	Chemical	Biological (EBPR)		
	Alum	HSOM	HSOM + P Recovery	MicroC+ P Recovery
Annual O&M ($ millions)	5.7	0.7	0.9	7.1
Capital Cost ($ millions)	9.0	10.2	22.3	27.3
Present Value ($ millions)	112.3	22.9	38.8	155.6

Carbon deficit:

- w/o P recovery 200,000 lb/d
- w/ P recovery 100,000 lb/d

2012
Formed a District-wide Phosphorus Task Force to study and implement of EBPR
Full-scale test in two batteries

Spring 2014
SBR Carbon Pilot

Fall 2014
Full-scale Carbon Pilot

2016-2017
P Removal Modeling and Feasibility Study

Calumet WRP P Removal Efforts

2012
Formed a District-wide Phosphorus Task Force to study and implement of EBPR
Full-scale test in two batteries

Spring 2014
SBR Carbon Pilot

Fall 2014
Full-scale Carbon Pilot

2016-2017
P Removal Modeling and Feasibility Study

2018
S2EBPR SBR Pilot

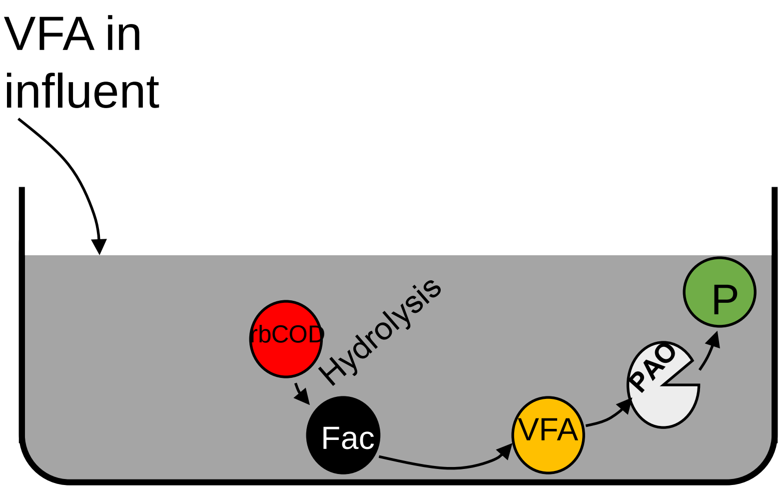
2020
S2EBPR Full-scale Pilot

Jan 2024
Calumet WRP
Monthly avg TP 1 mg/L

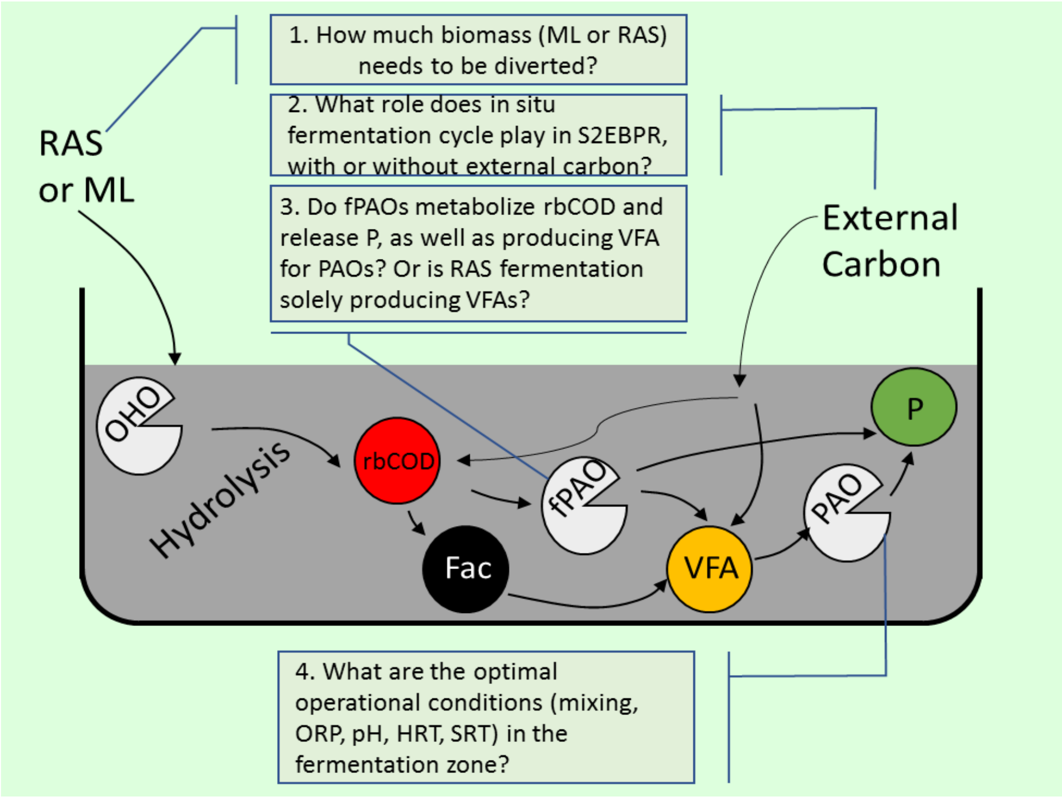
Jan 2030
Big three plants
Annual geomean 0.5 mg/L

Understanding S2EBPR

Conventional EBPR metabolism



Fermentative metabolism

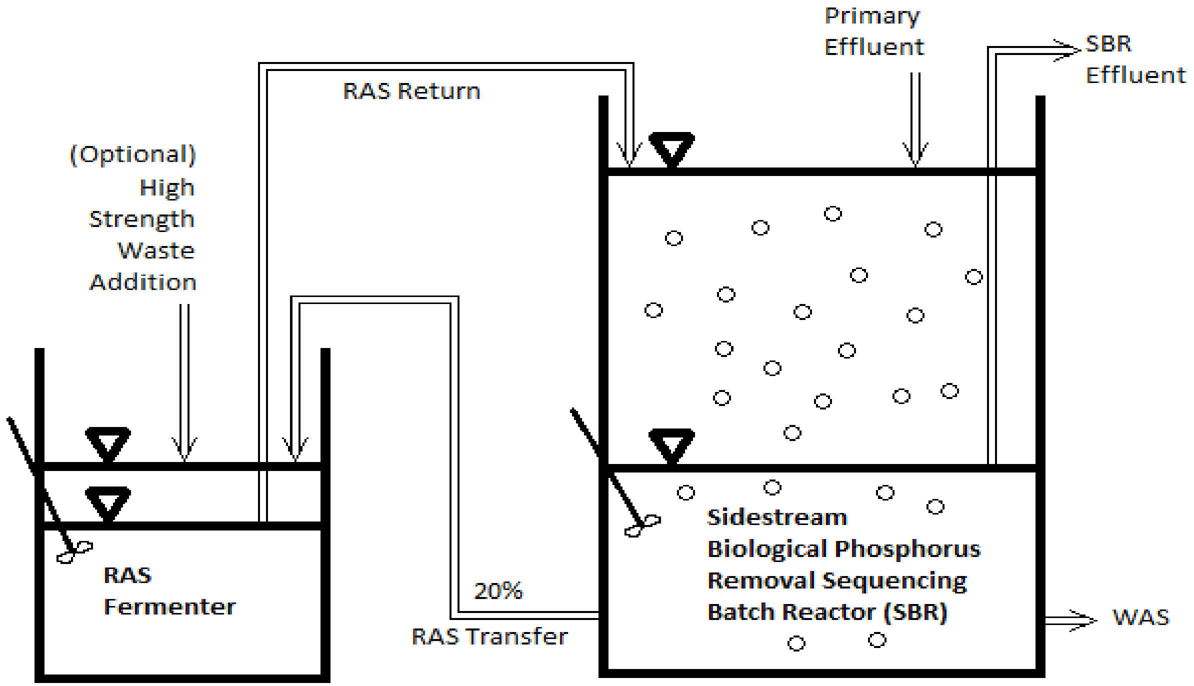


Motivations of using S2EBPR

- Stable anaerobic conditions reduce upsets
- Carbon production reduces reliance on influent characteristics
- Selective pressure leads to more effective use of carbon

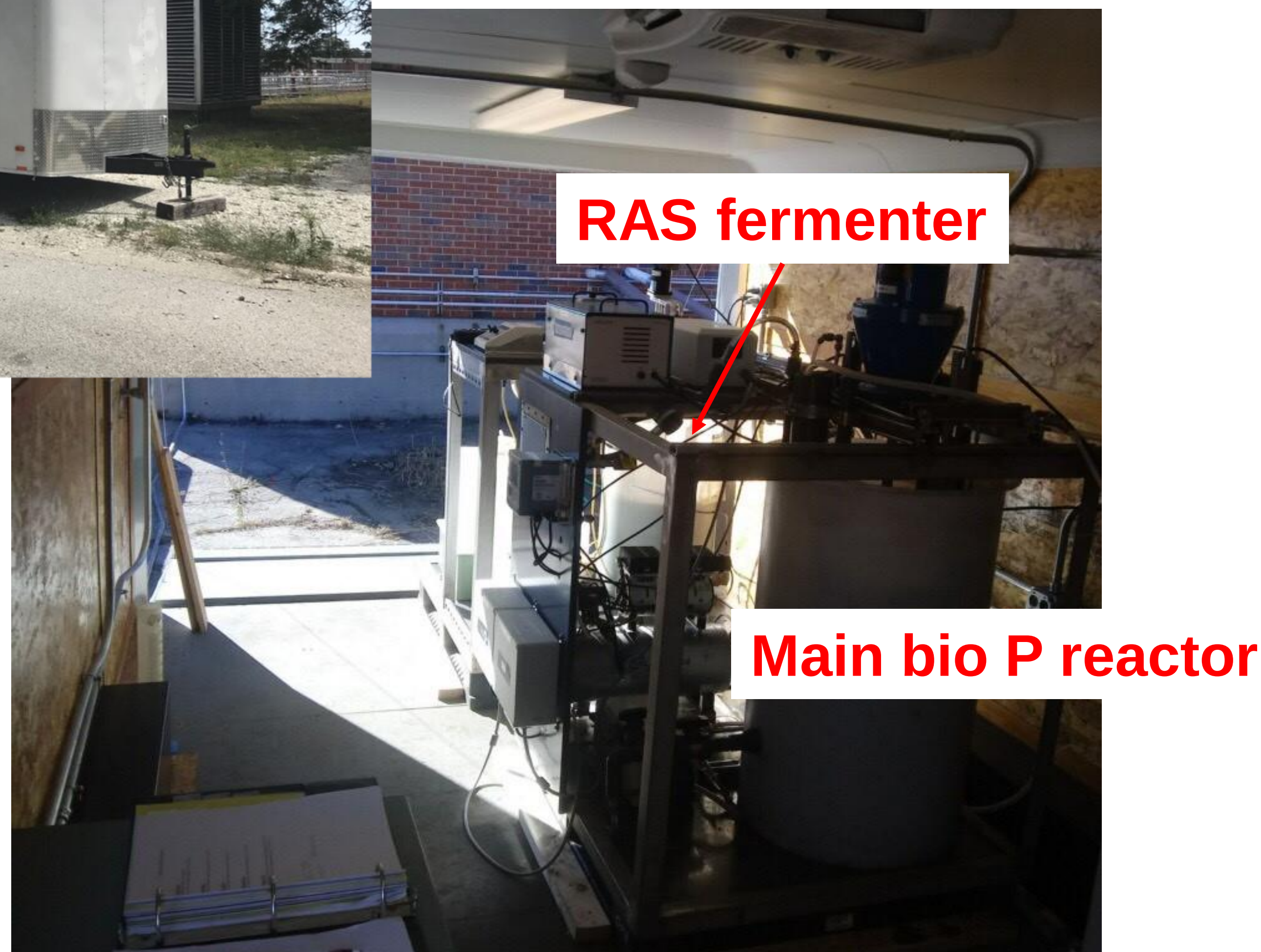
Credit to Black & Veatch for slide

Schematic Sidestream Enhanced Biological Phosphorus (S2EBPR) Removal Process – Calumet Sequence Batch Reactor (SBR)

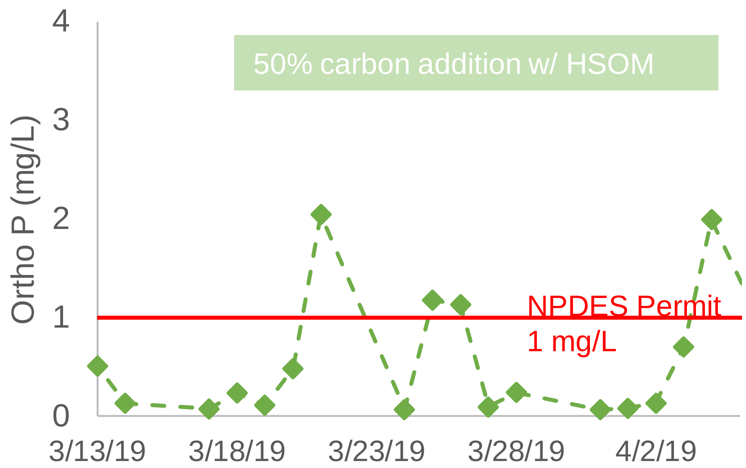


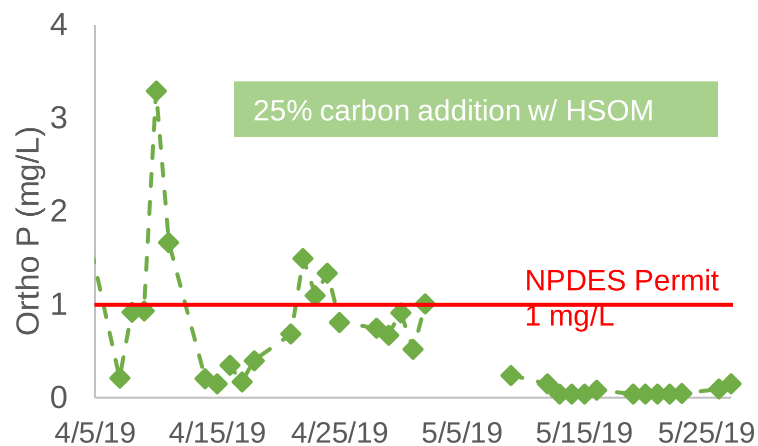
- S2EBPR process is a means for improving P removal performance as an alternative to adding large amount of external carbon source with low strength influent.
- Our goals are to overcome the challenge and meet the upcoming NPDES P permit in a sustainable way

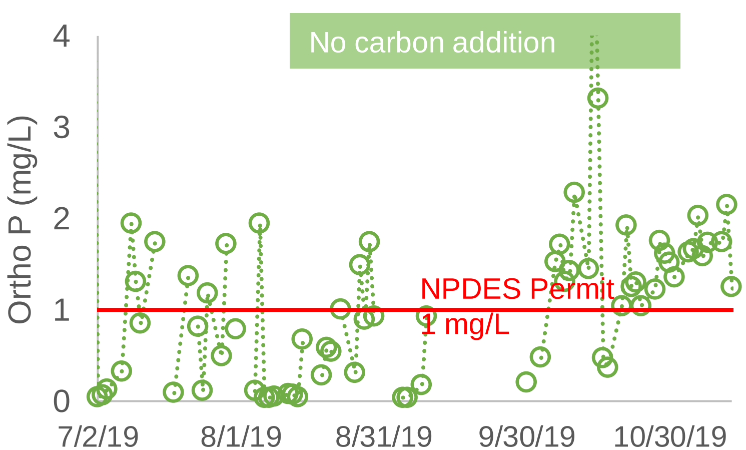

SBR Trailer


RAS fermenter
Main bio P reactor

Calumet S2EBPR SBR Effluent Ortho P Concentrations (Scenarios #1,2&3)





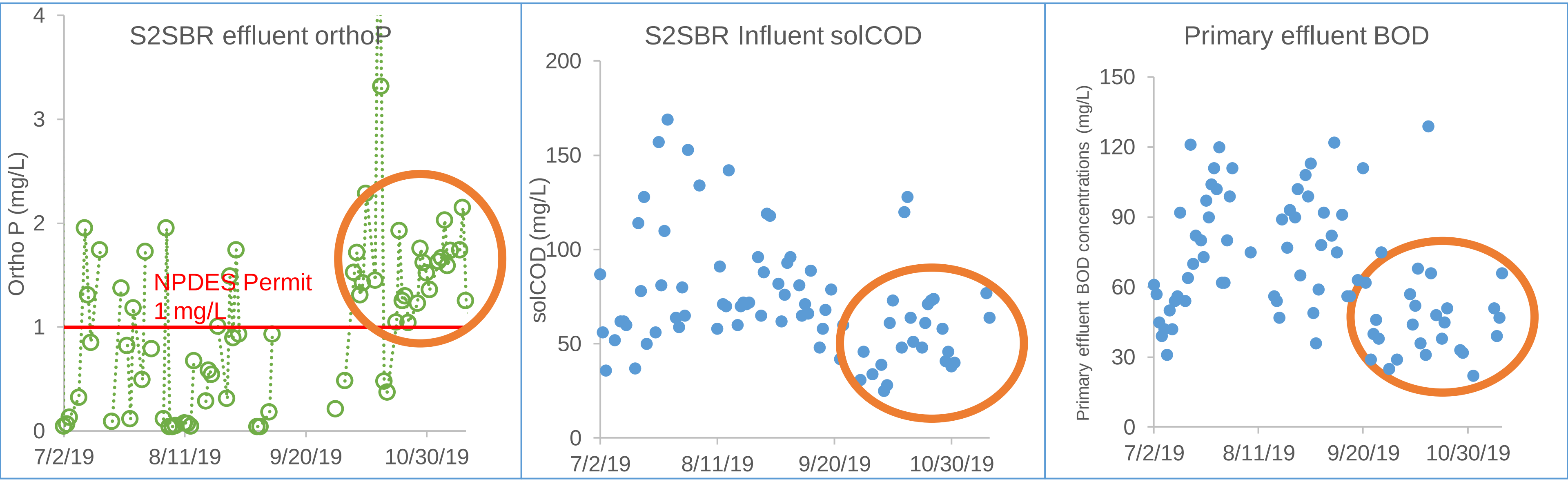


- Biological P removal was successfully established with reduced carbon needs or possibly eliminating external carbon addition in SBR scale.
- More external carbon addition achieved higher average percent removal and stable operation

Test scenarios 20% RAS + 1 day SRT	50% carbon addition HSOM	25% carbon addition HSOM	No carbon addition
Stable operation periods	Mar 13 to Apr 4, 2019	Apr 7 to May 27, 2019	Jul 2 to Nov 12, 2019
Average effluent ortho P concentrations	0.55 mg/L	0.55 mg/L	1.07 mg/L
Ortho P removal	86%	81%	70%

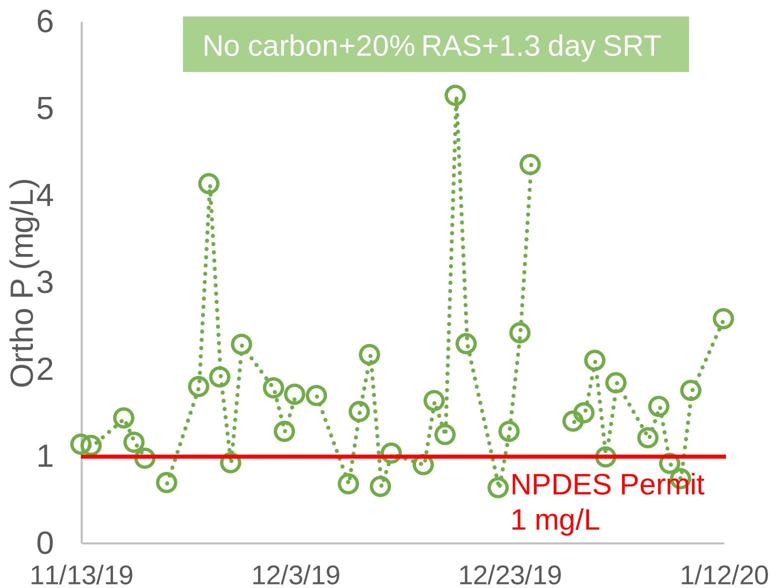
*data are excluded due to compressor failure and DO control failure; excluded 5/2-5/9/19, 6/25-6/30/19, 7/15-7/17/19/19, 7/22/19, 7/30/19, 8/15/19, and 9/10-9/29/19 data due to not aeration, no sludge transfer and autosampler w/ ML samples issues. No carbon addition scenario used data 7/2/19 and after with stable operation period.

S2EBPR SBR Effluent Ortho P and Influent Carbon During No Carbon Addition Scenario

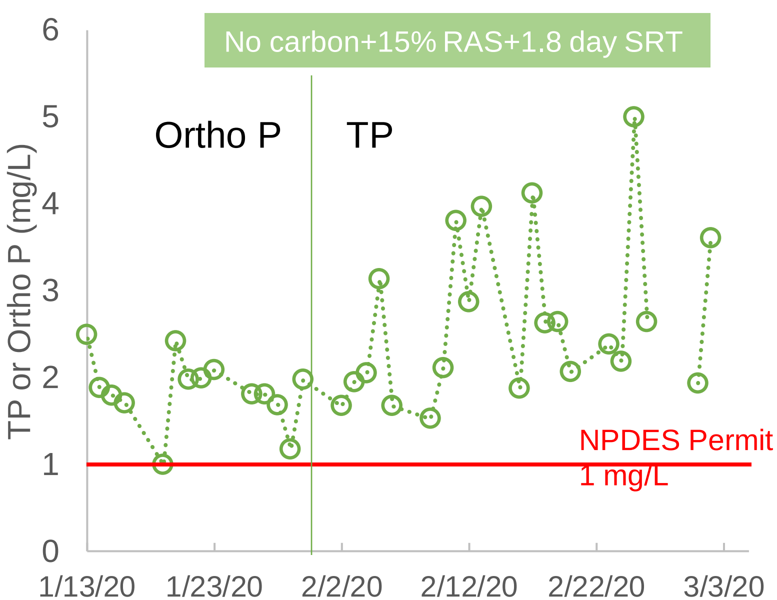


- Deteriorated performance might due to low influent carbon → insufficient carbon to ferment

Calumet S2EBPR SBR Effluent Ortho P Concentrations (Scenarios #4&5)



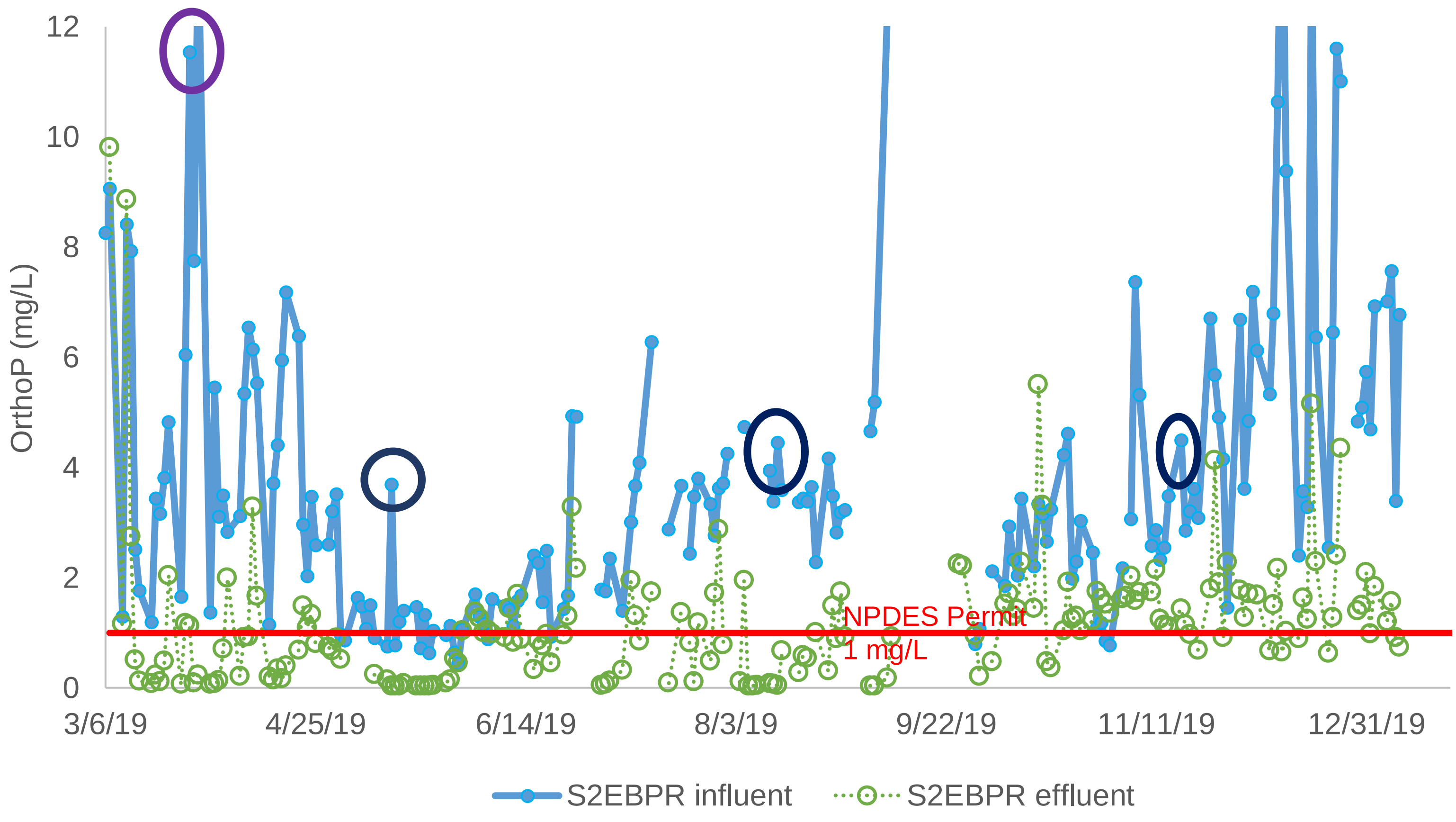
- Biological P removal was not improved by using larger fermenter volume and longer solids retention time.



Test scenarios	No carbon 20% RAS+1 d SRT	No carbon 20% RAS+1.3 d SRT	No carbon 15% RAS+1.8 d SRT
Stable operation periods	Jul 2 to Nov 12, 2019	Nov 13, 19 to Jan 12, 2020	Jan 13 to Mar 13, 2020
Average effluent ortho P or TP concentrations	1.07 mg/L	1.66 mg/L	2.33 mg/L
Ortho P removal	70%	67%	52%

*data are excluded due to compressor failure and DO control failure; excluded 7/15-7/17/19/19, 7/22/19, 7/30/19 and 8/15/19 data due to not aeration and no sludge transfer issues. 0% scenario used data 7/2/19 and after with stable operation period.

Influent Spikes

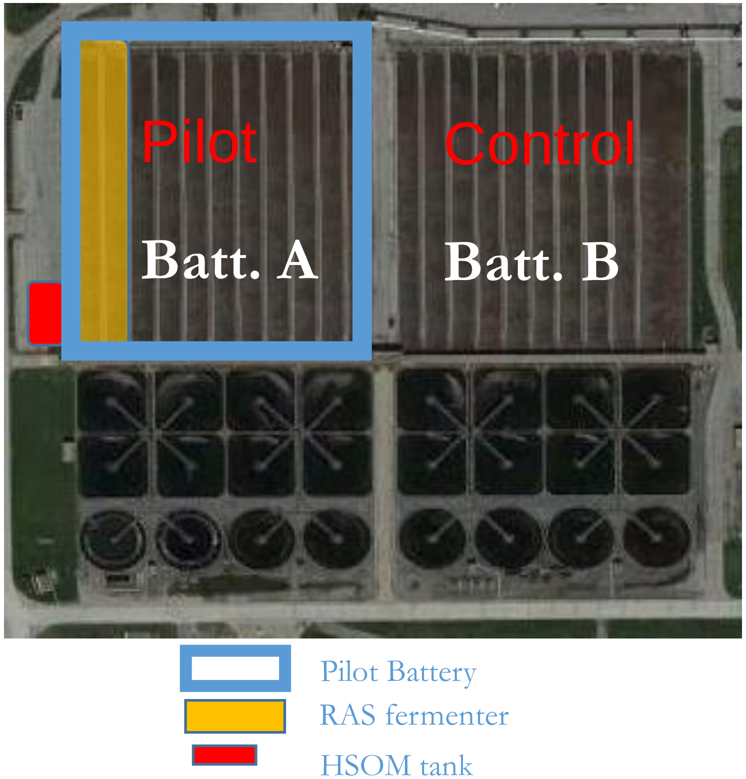


- S2EBPR can shave off influent P spikes

Full-scale S2EBPR Pilot Design S2EBPR Configuration and Construction Schedule

	RAS (w/ or w/o HSOM as carbon source)
	Battery A
RAS Flow	44 MGD
Flow through Fermenter	8 MGD (~20% RAS)
Target SRT	12 – 24 hours
Volume Needed	4 mil gal
Number of Tanks Utilized	2 tanks (425'x34.5'x15.5' = 1.7 mil gal)
Notes	• Pump from open RAS channel to 2 tanks using submersible pumps with VFDs • Use gates to block inflow and outflow to 2 tanks • Installation of mixers • Pump out of RAS fermentation tanks to PE channel • HSOM as carbon source – could take from tank near Battery A • No PS fermentation/fermentate

Construction start date 3/11/2020
Contract completion date 3/11/2021



Phosphorus Feasibility Study Summary – Calumet WRP

Based on triple bottom line analysis, Chem P with ferric chloride is the recommended process for all treatment levels.

A phased implementation can be considered *if S2EBPR pilot proven successful*:

- To meet an effluent TP of 1.0 mg/L, 0.5 mg/L, and 0.3 mg/L: Chem P
- To meet an effluent TP of 0.1 mg/L: EBPR + S2EBPR + supplemental carbon + P recovery + cloth disk filters
    - ❖ More sustainable alternative if carbon can be generated from within the plant.

Findings and Next Steps

- Stickney WRP has completed biological phosphorus removal optimization with existing infrastructure.
  - More capital projects in place/ongoing to meet future stringent P permit
  - However, nitrification limitation due to TARP flow during maximum loading month in winter might be problematic
- Stickney WRP has re-converted all Batteries to bio P set up. Process optimization is ongoing but having some difficulties.
- Calumet WRP will be pilot testing S2EBPR in Battery A in an effort to reduce carbon needs to remove P in a sustainable way.
  - HSOM receiving station and possible primary sludge fermentation to provide carbon for better bio P performance
- Calumet WRP chemical polishing system is under design.
  - To consistently meet the upcoming P permit

Acknowledgements

Interdepartmental Phosphorus Task Force

Joe Cummings, **M&O**

Brett Garelli , **M&O**, retired

Pat Connelly, **M&O**

Brian Perkowich, **M&O**, ED

Tom Convey, **M&O**, retired

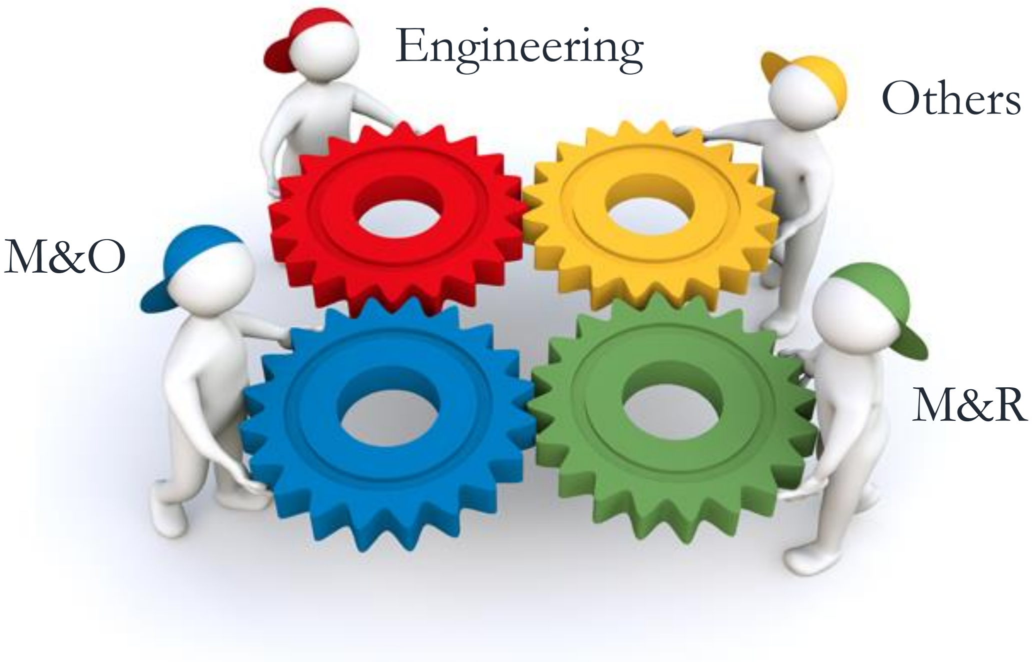
Mwende Lefler, **Engineering**

Glenn Rohloff, **Engineering**

Catherine O'Connor, **Engineering**

Joe Kozak, **M&R**

Heng Zhang, **M&R**



Thank you!

Questions?

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Identified Causes of Unstable Bio-P Performance at SWRP in Order of Importance

1. *Carbon Limitations*
2. *Flow → Low flow nitrate toxic and recycle stream contribution correlated with high TP*
3. *Solids deposition in first half of Pass 1s – mixers to implement by 2021*
4. *Inconsistent Return Sludge Control*
5. Biological Inconsistencies/Inhibition
6. *Excess DO in Aeration Tanks or DO sags*
7. *Plant Shutdowns/Batteries O/S*