WELCOME
TO THE DECEMBER EDITION
OF THE 2014
M&R SEMINAR SERIES

BEFORE WE BEGIN

- PLEASE SILENCE CELL PHONES & SMART PHONES
- QUESTION AND ANSWER SESSION WILL FOLLOW PRESENTATION
- PLEASE FILL EVALUATION FORM
- SEMINAR SLIDES WILL BE POSTED ON MWRD WEBSITE (www. MWRD.org: Home Page ⇒ Reports ⇒ M&R Data and Reports ⇒ M&R Seminar Series ⇒ 2014 Seminar Series)
- STREAM VIDEO WILL BE AVAILABLE ON MWRD WEBSITE (www.MWRD.org: Home Page ⇒ MWRDGC RSS Feeds)

MWRD's Efforts of Implementing Enhanced Biological Phosphorus Removal at Its Major WRPs

December 12, 2014

Y. Mwende Lefler, P.E.

Experience:

- Senior Civil Engineer at MWRDGC (2012 – present)
  - Process Design Section in Engineering Department
- Associate Civil Engineer at MWRDGC (2007 – 2012)
  - Process Design Section in Engineering Department
- Project Engineer at MWH (2000-2002)
- Research work at Northwestern University (1999 – 2000)

Education:

- MS in Environmental Engineering, Northwestern University (1999)
- BS in Civil Engineering, Duke University (1998)

Cindy Dongqi Qin, Ph.D.

Current: Associate Environmental Research Scientist,
Wastewater Treatment Process Research Section, M&R, MWRDGC

Education:

- B.S. in Polymer Chemistry and Physics from Jilin University, China
- M.S. in Chemistry from Jilin University, China
- Ph.D. in Chemistry from Beijing University, China

Experience:

- **Wastewater treatment process research and development** *(2 WEF conference proceedings)*
  - Sidestream deammonification for nitrogen removal
  - Enhanced biological phosphorus removal pilot and full-scale tests
- **Applied Chemistry** *(21 peer reviewed journal papers)*
  - synthesis and formulation of new biomedical materials
  - Organic/environmental samples analyses with various instruments
  - Method development

Acknowledgements

- Executive Team – District Strategic Business Plan
- Interdepartmental Phosphorus Task Force
- Engineering
  - Engineers have looked into many, many, many options for process modification and improvement
- M&O
  - Plant managers and engineers of treatment plant operations
  - TPOs who have collected many, many, many profile samples
  - Trades
- M&R
  - EM&RD, WTPR and Microbiology sections
  - ALD
  - IWD

Strategic Plan for Recourse Recovery and Sustainability

- Informed IEPA on steps to biologically remove P *using existing infrastructure* and recover P where possible in a November 2011 letter as a part of District long term strategic plan on recourse recovery and sustainability
- Formed a District-wide Phosphorus Task Force for leading the study and implementation of Enhanced Biological Phosphorus removal (EBPR), 2012
- Full-scale test in one battery at the Stickney and Calumet WRP since 2012
- Implement plant capacity improvements at O'Brien WRP since 2012
  - – a step towards potential EBPR implementation
- Evaluated EBPR potentials at Kirie WRP since 2012
- Fully converted to EBPR configuration at the Stickney WRP in fall 2013
- Awarded a contract for constructing a P recovery facility at Stickney in 2013
- Executive Director's direction of meeting the P removal target at Stickney starting July 2014 and getting prepared for running the P recovery facility

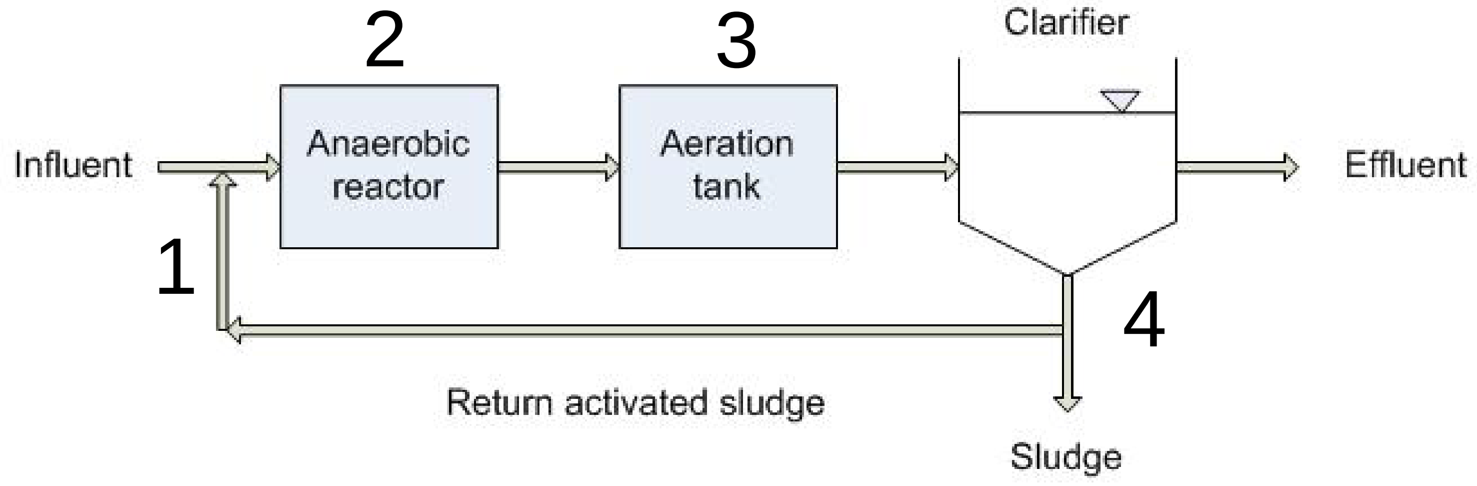
Outline

- Fundamentals of EBPR
- Factors Affecting EBPR
- Develop EBRP at Stickney
- Develop EBPR at Calumet
- Develop Bio-P Strategy at Kirie WRP
- Develop Comprehensive P Removal and Recovery Strategy at O'Brien WRP

Fundamentals of Enhanced Biological Phosphorus Removal (EBPR)

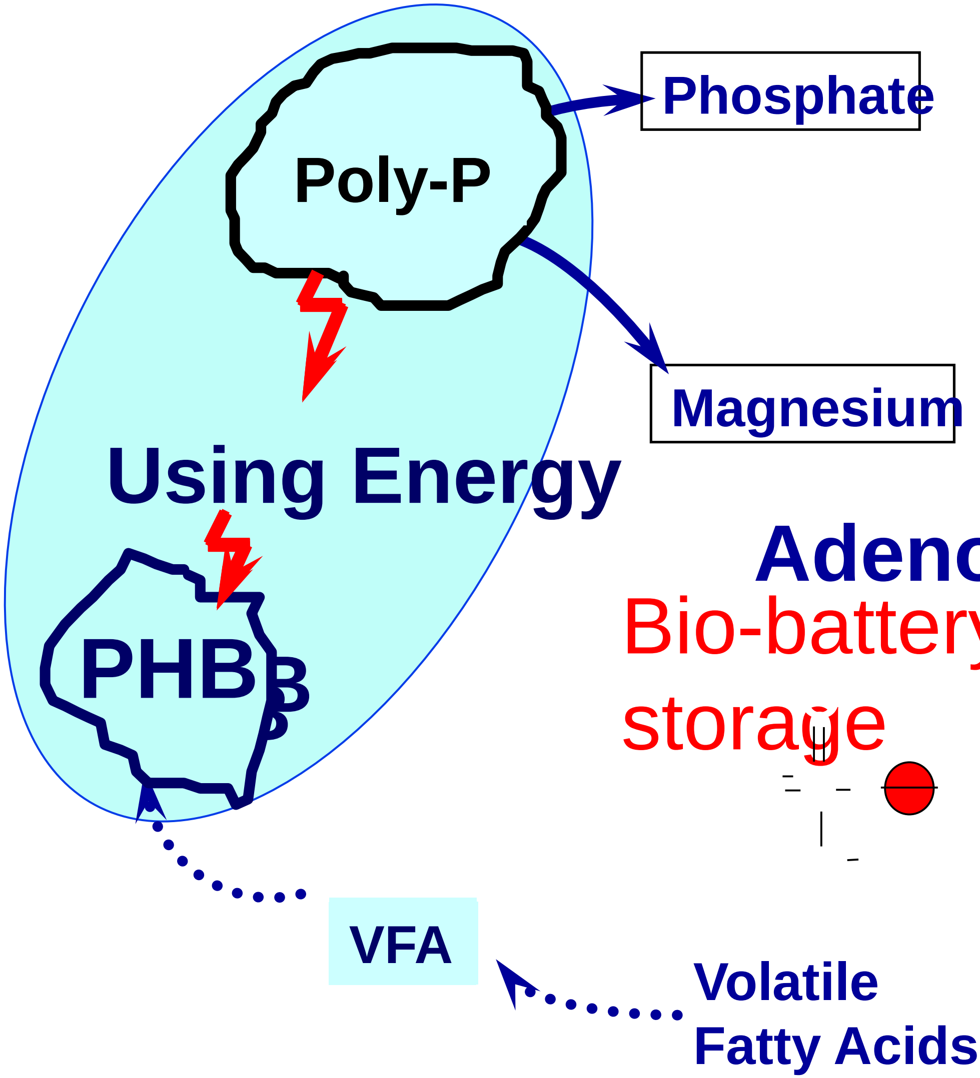
- Simple philosophy
  - Some microorganisms can have luxury uptake P into their cells if the right environment is provided (EBPR process)
  - The P accumulated cells can be removed from the main liquid stream via solids separation.
  - The P is released in proper solids processing for harvesting
- Sustainability
  - Less energy is required for EBPR compared to conventional secondary treatment process

EBPR



1. PAOs returned with RAS
2. Anaerobic Zone – no nitrate, no oxygen
3. Aerobic Zone – oxygen present
4. PAOs settle out w/ other biomass in secondary clarifiers and removed from system ➔ net removal from liquid stream

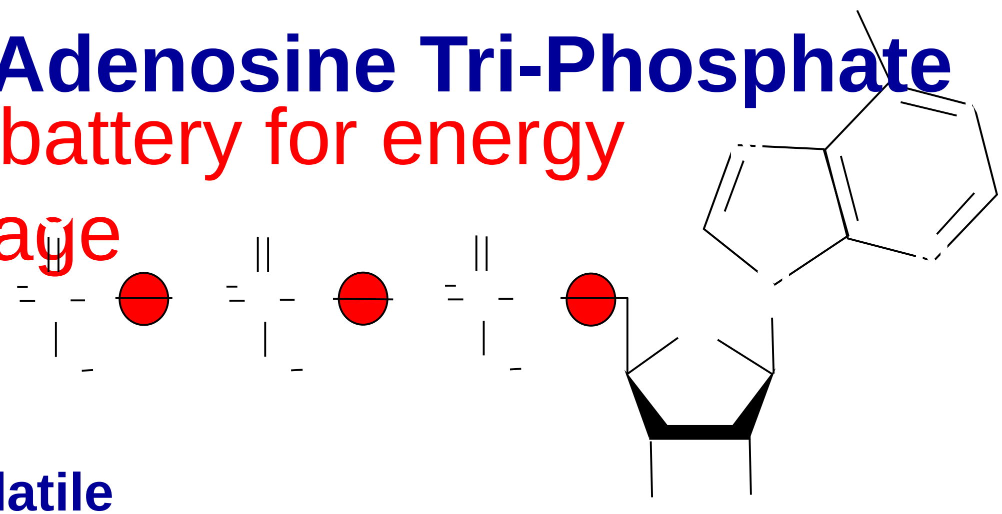
Understanding Bio-P - Under Anaerobic Conditions – phosphorus release and ATP Depletion



ATP

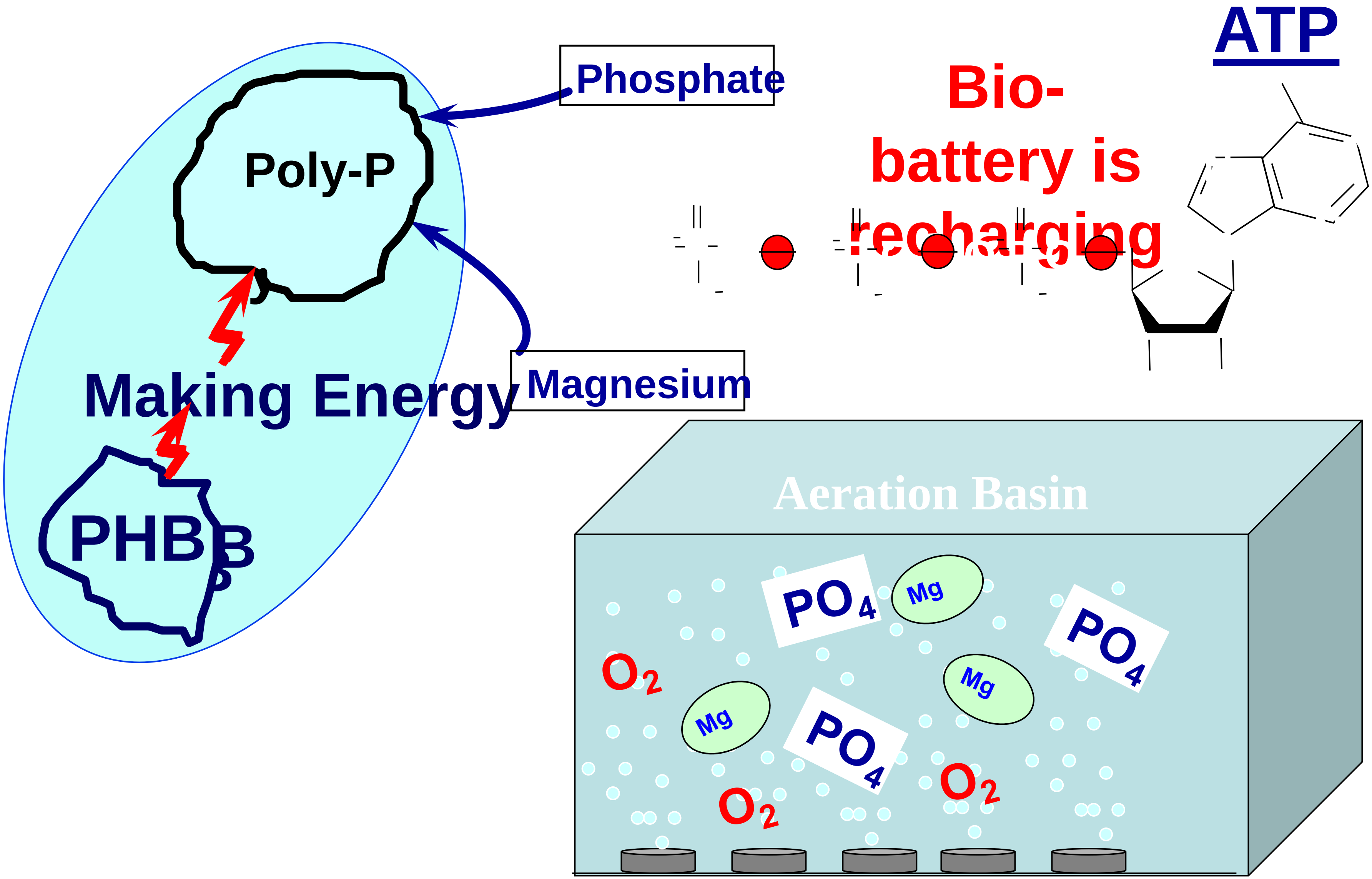
Adenosine Tri-Phosphate

Bio-battery for energy storage



Credit to Black & Veatch for slide

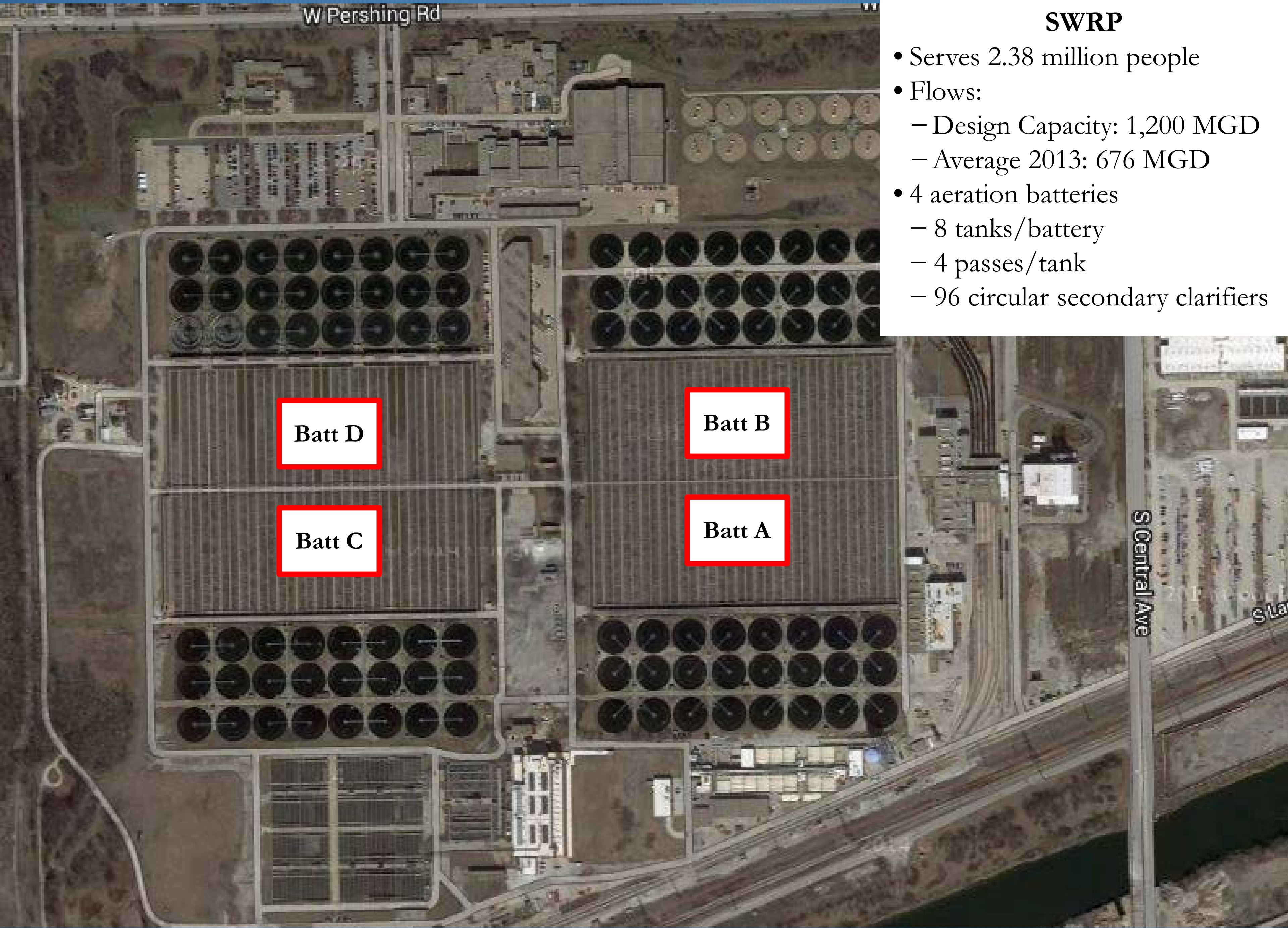
Understanding Bio-P Under Aerobic Conditions - Phosphate Uptake/ ATP Production



Credit to Black & Veatch for slide

Factors Affecting EBPR

- **DO**
  - DO=0 mg/L in anoxic and anaerobic zone
  - DO>1 mg/L in aerobic zone
- **NO3-N**
  - NO3-N = 0 mg/L in anaerobic zone
  - RAS:PE flow ratios < 0.7
- **Carbon**
  - Influent BOD:TP > 25
- **MLSS**
  - MLSS>3,000 mg/L
- **Temperature**
  - Not as critical as others
- …



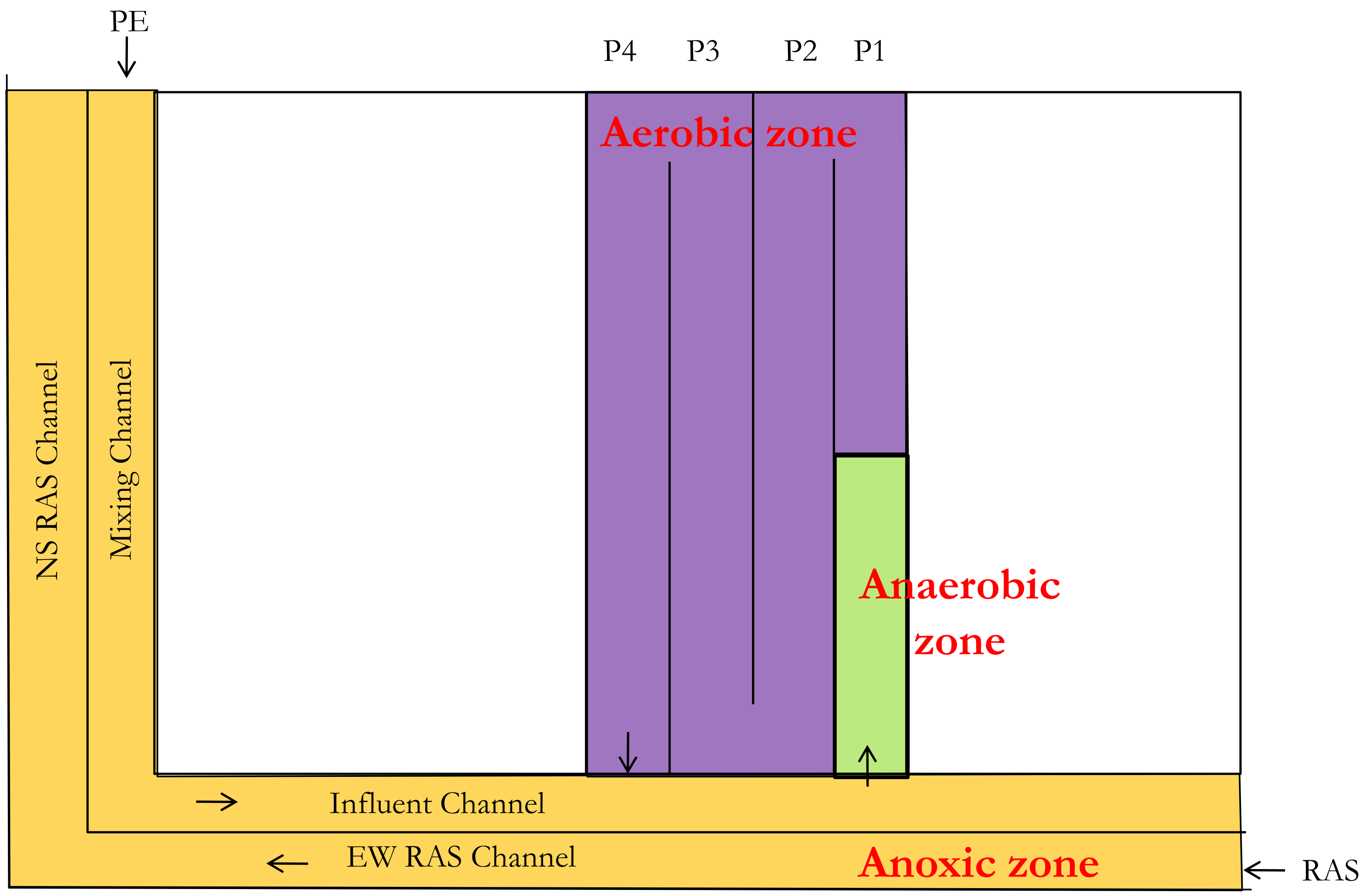
SWRP

- Serves 2.38 million people
- Flows:
  - Design Capacity: 1,200 MGD
  - Average 2013: 676 MGD
- 4 aeration batteries
  - 8 tanks/battery
  - 4 passes/tank
  - 96 circular secondary clarifiers

Developing EBPR at Stickney WRP

- October 31, 2011 – EBPR trial in Battery D started
- May 2012 – December 2013
  - Full-scale tests in Battery D to improve EBPR
- August – October 2013
  - Batteries A, B, & C converted to EBPR configuration
- January 2014 – Present
  - Monitoring and data analysis on EBPR performance
  - Continued optimization of operations using existing infrastructure
  - Beginning evaluation of options for achieving stable EBPR

Aeration Battery Conversion for EBPR at the Stickney WRP



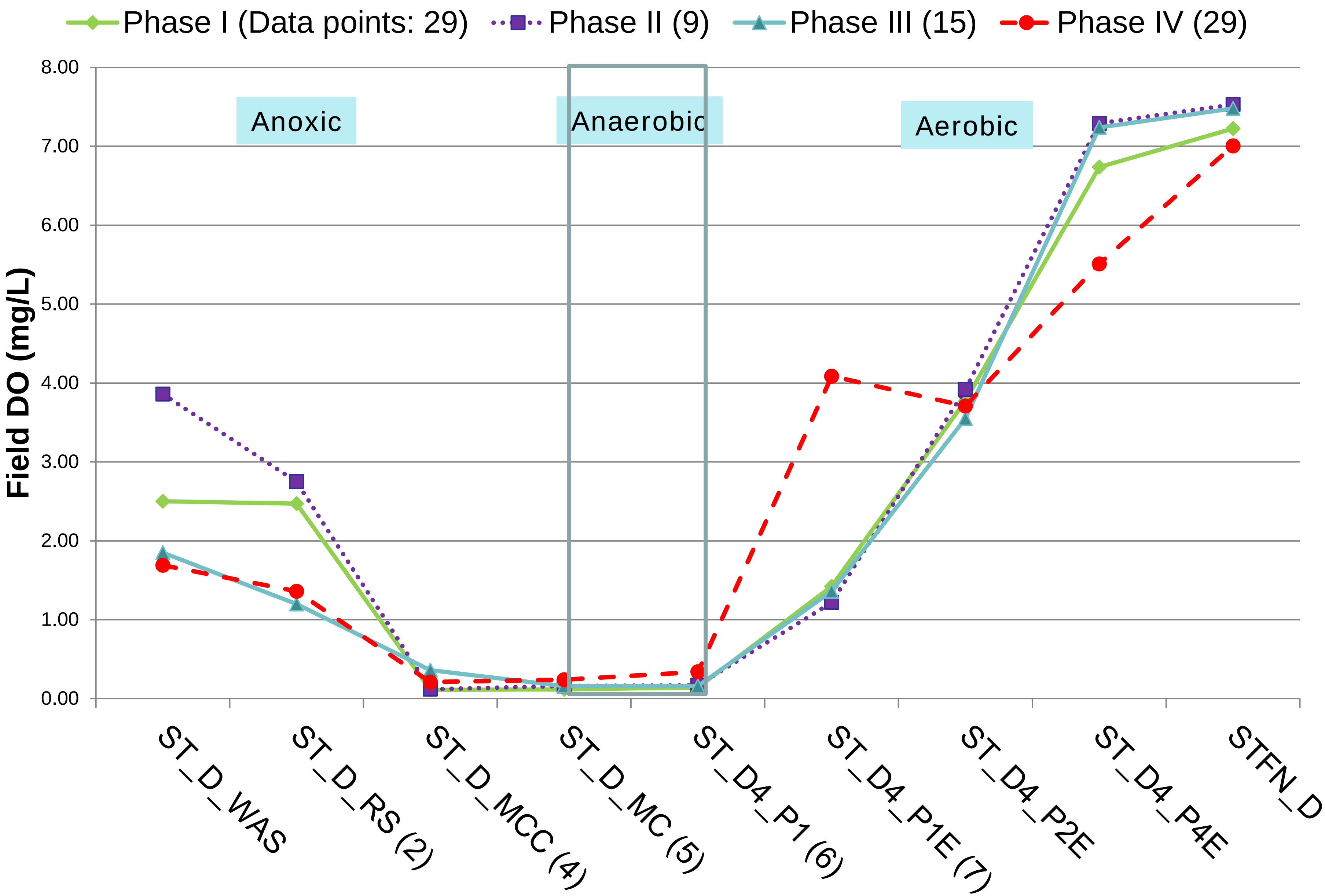
Pilot/Full scale testing in Battery D

- *Optimizing Operation Parameters for EBPR*

- Phased approach with controlled changes
  - Phase I: Baseline (5/1/12-9/12/12)
  - Phase II: Beginning of air optimization (9/13/12-10/9/12)
  - Phase III: Increased MLSS, further air optimization in RAS channel & aerobic zone (10/10/12-12/12/12)
  - Phase IV: Some primary tanks out of service, held primary sludge in preliminary tanks for longer to generate VFAs from sludge (1/28/13-12/30/13)
  - Phase V: Reduce flow of RAS and subsequently NO3-N (1/1/14-Now)

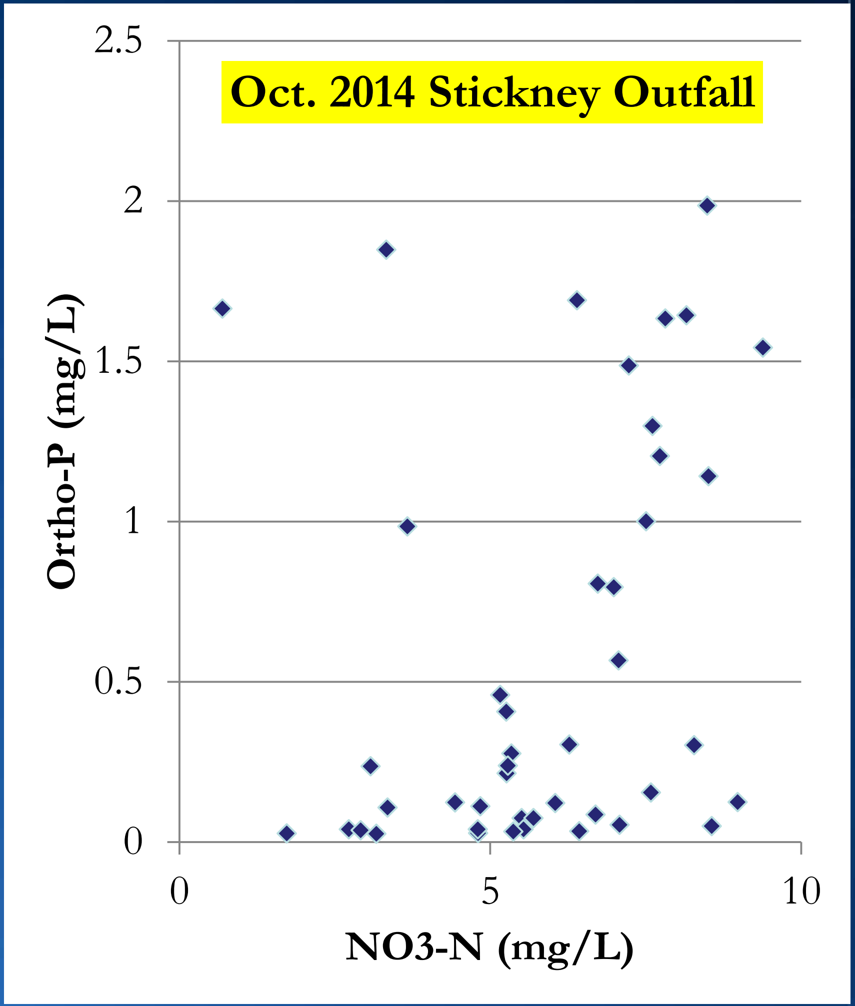
PARAMETER	PHASE I (5/1-9/12)	PHASE II (9/13-10/9)	PHASE III (10/10-12/12)	PHASE IV (1/28/13 – 12/30/13)
Battery D Effluent TP	**1.16 mg/L**	**1.42 mg/L**	**0.90 mg/L**	**0.63 mg/L**
Influent TP Conc.	4.91 mg/L	3.69 mg/L	4.17 mg/L	4.93 mg/L
Influent TP Load	7,534 lb/day	3,485 lb/day	4,006 lb/day	6,045 lb/day
SRT	6.14	9.58	16.1	10.9
Battery D Influent Flow	193 MGD	112 MGD	133 MGD	166 MGD
RAS Flow	173 MGD	139 MGD	128 MGD	158 MGD
RAS/Total Flow	0.98	1.24	1.03	1.10
Anaerobic Zone HRT (with RAS flow)	26 min	39 min	37 min	30 min
MLSS	**3343 mg/L**	**2224 mg/L**	**3227 mg/L**	**3650 mg/L**
BOD Load	187,802 lb/day	94,093 lb/day	119,578 lb/day	174,087 lb/day
BOD:TP	**24.08**	**26.37**	**27.20**	**27.74**
RAS NO3*	6.75 mg/L	6.72 mg/L	6.28 mg/L	5.77 mg/L
RAS NO3 Load*	**9,944 lb/day**	**7,389 lb/day**	**6,589 lb/day**	**7,297 lb/day**

DO Monitoring Results During Pilot Test in Battery D

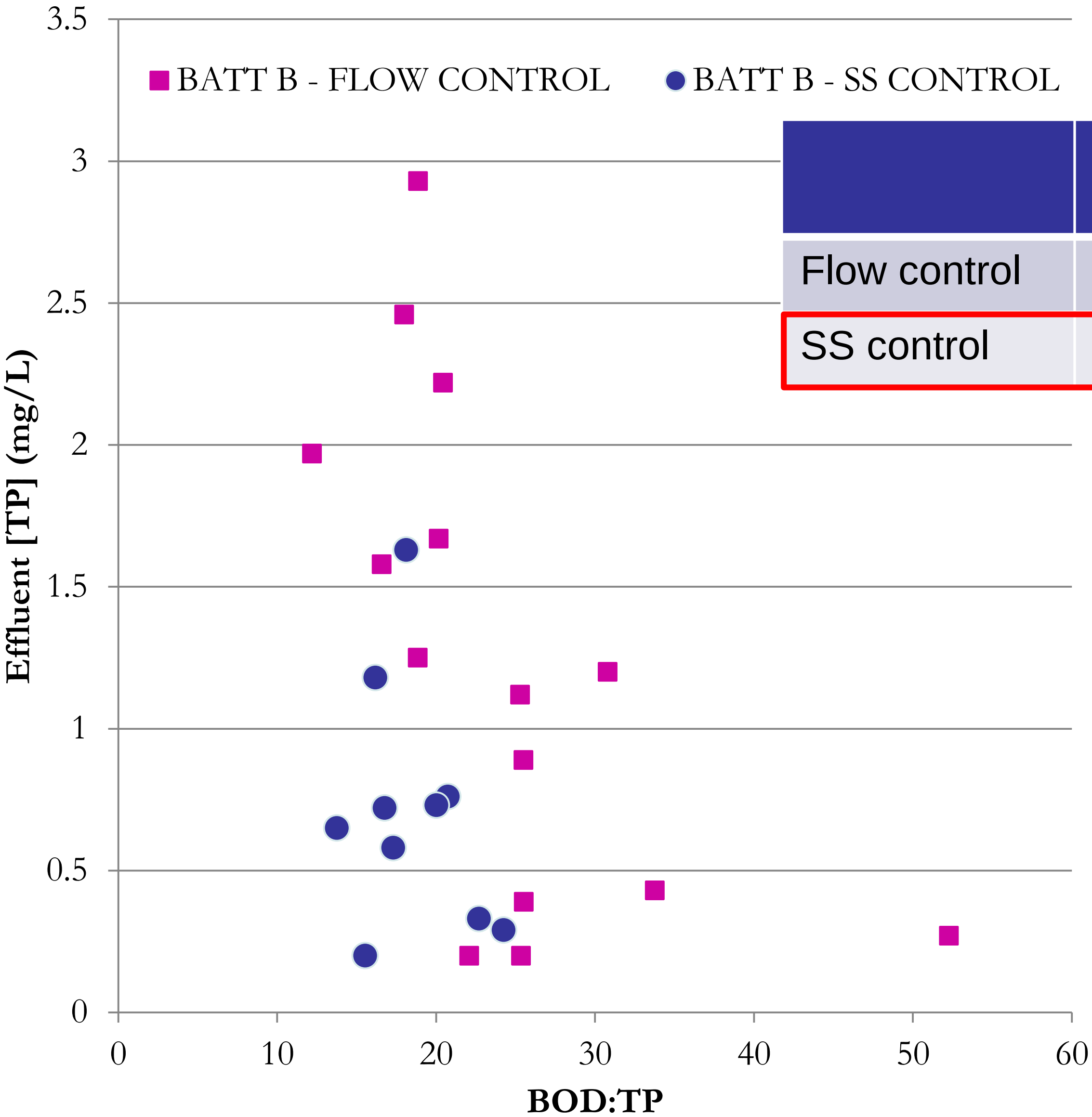


Solutions for Nitrate Impact

- Significant NO3 returned
  - SWRP is a nitrifying plant
  - Typical $[NO3]_{RAS} \approx 6$ mg/L
  - Average RAS/PE flow ≈ 1
- Affects the carbon available for P removal
  - Denitrifiers compete for most readily available carbon.
  - Can have a great BOD:TP ratio from primary effluent and experience poor TP removal due to NO3 presence in return
- Anoxic zone does not truly end until the end of the anaerobic zone.
  - Only 60% of time is NO3 depleted before anaerobic zone.



Control Return Sludge Flow via SS Control for Minimizing Nitrate Impact



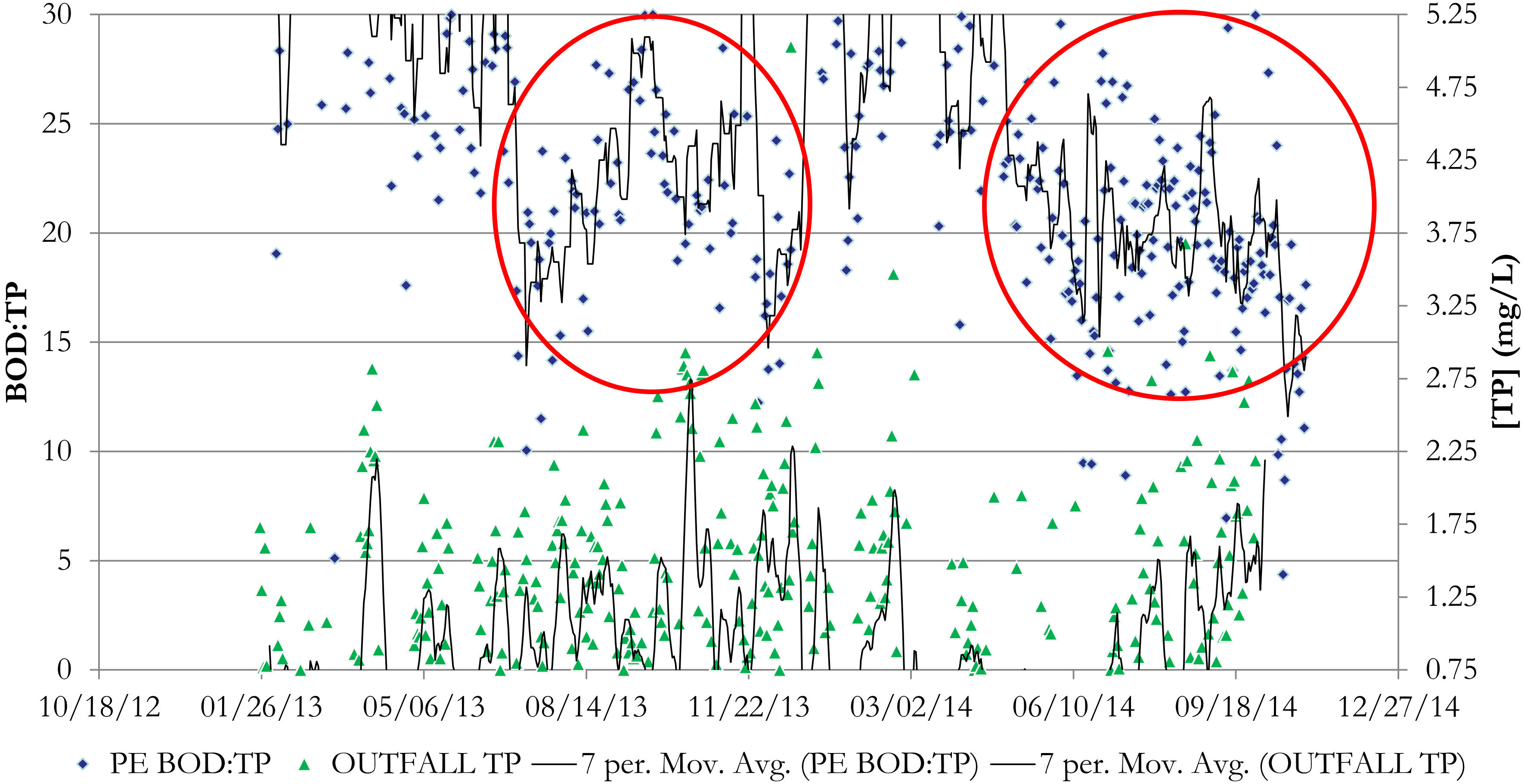
	RAS/PE	BOD:TP	Effl TP (mg/L)
Flow control	0.9	25.7	1.04
SS control	0.7	18.1	1.00

- 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.*

Carbon needs for EBPR

- 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.*

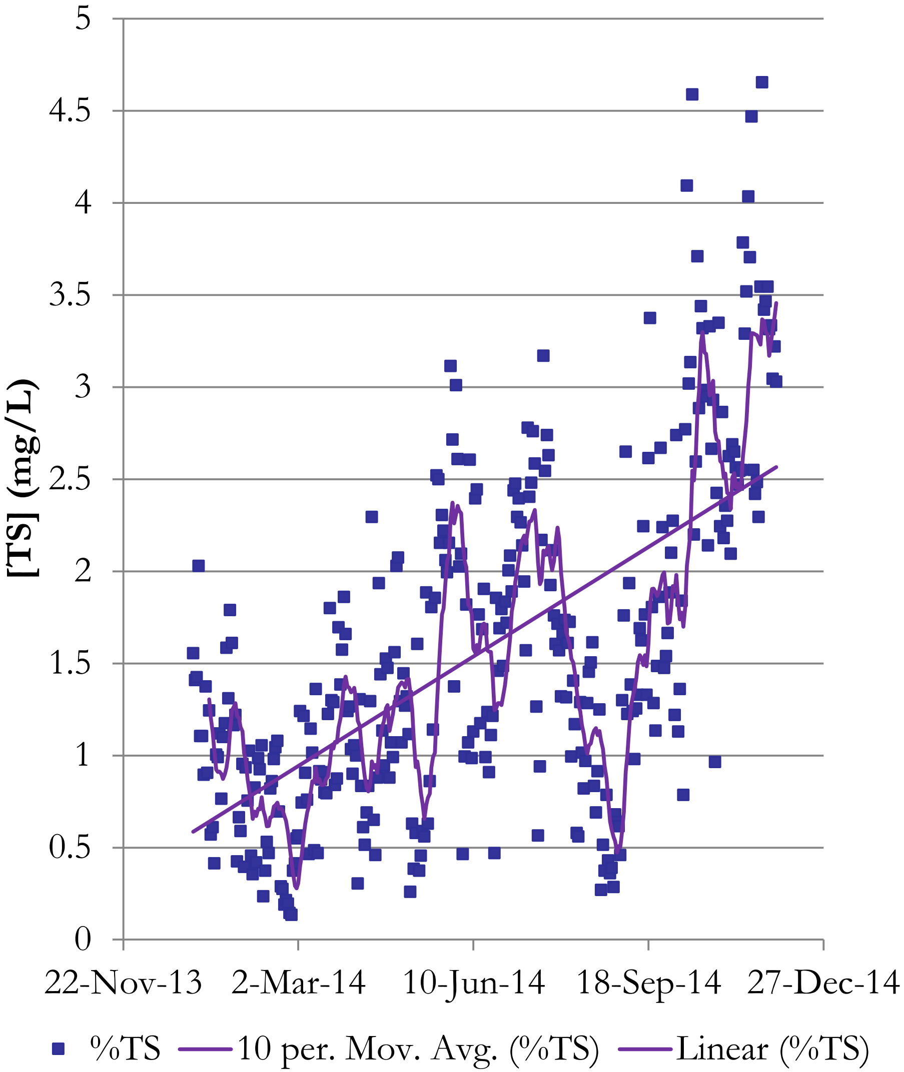
Primary Effluent BOD:TP with BOD:TP < 30 and and effluent TP concentrations with TP > 0.75



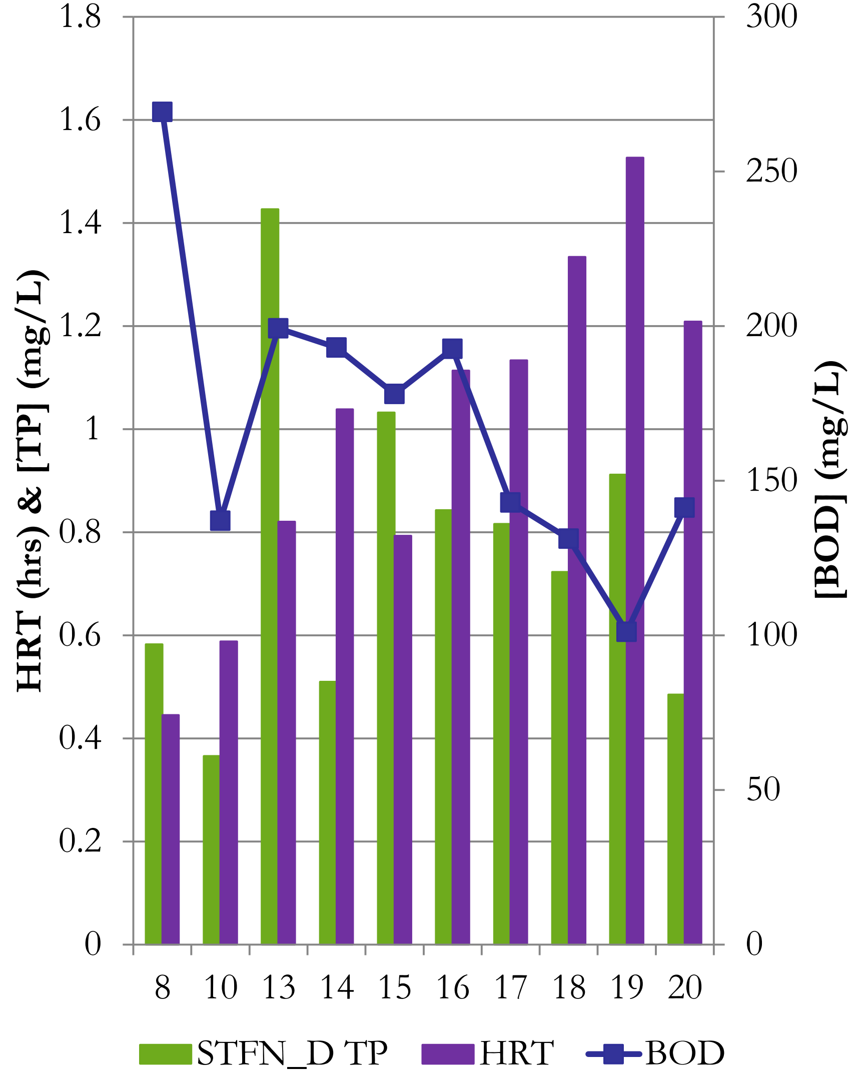
Carbon deficit accentuated in late summer/fall

Efforts to Increase Carbon

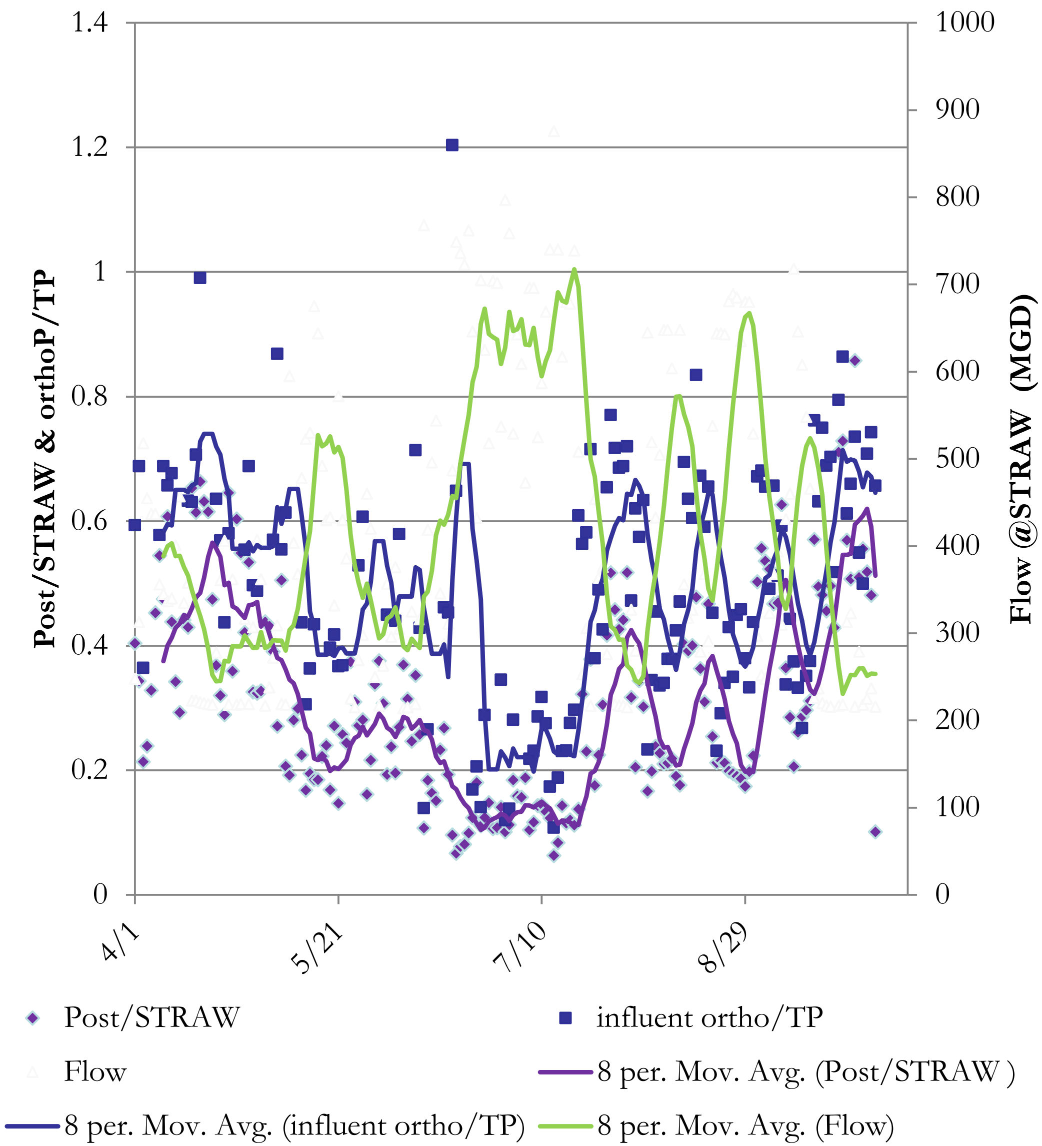
Holding Sludge in Primaries

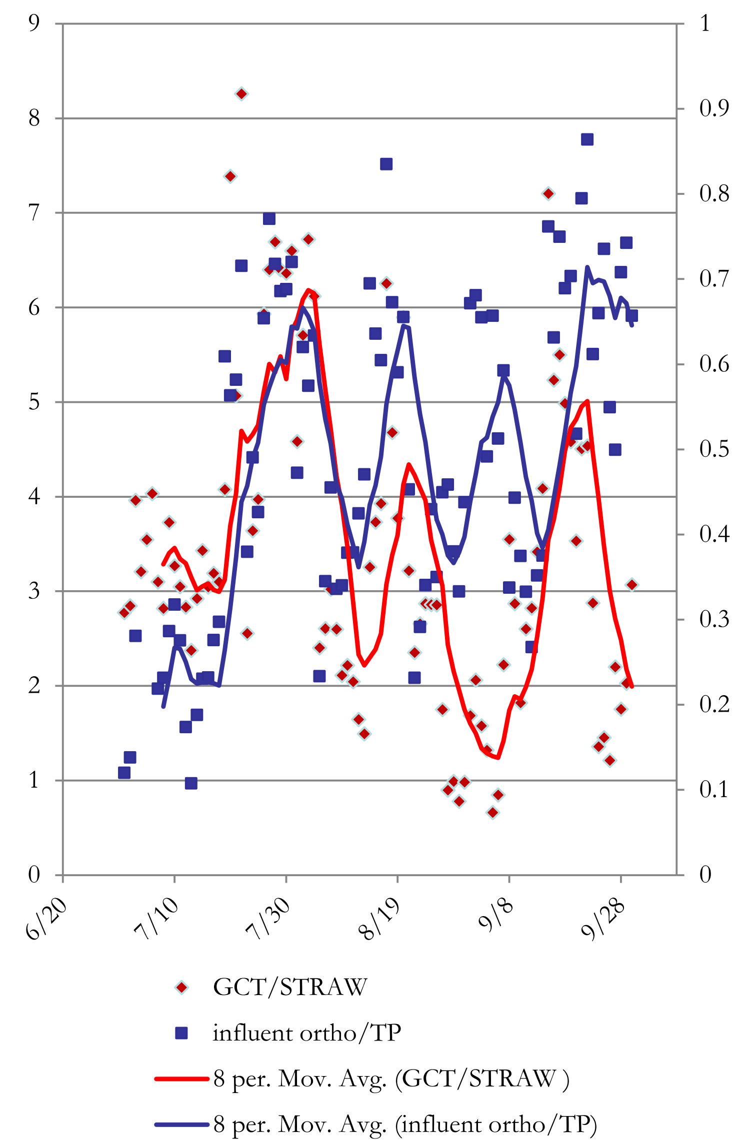


Bypassing Primary Tanks



What is Happening in Low Flows?





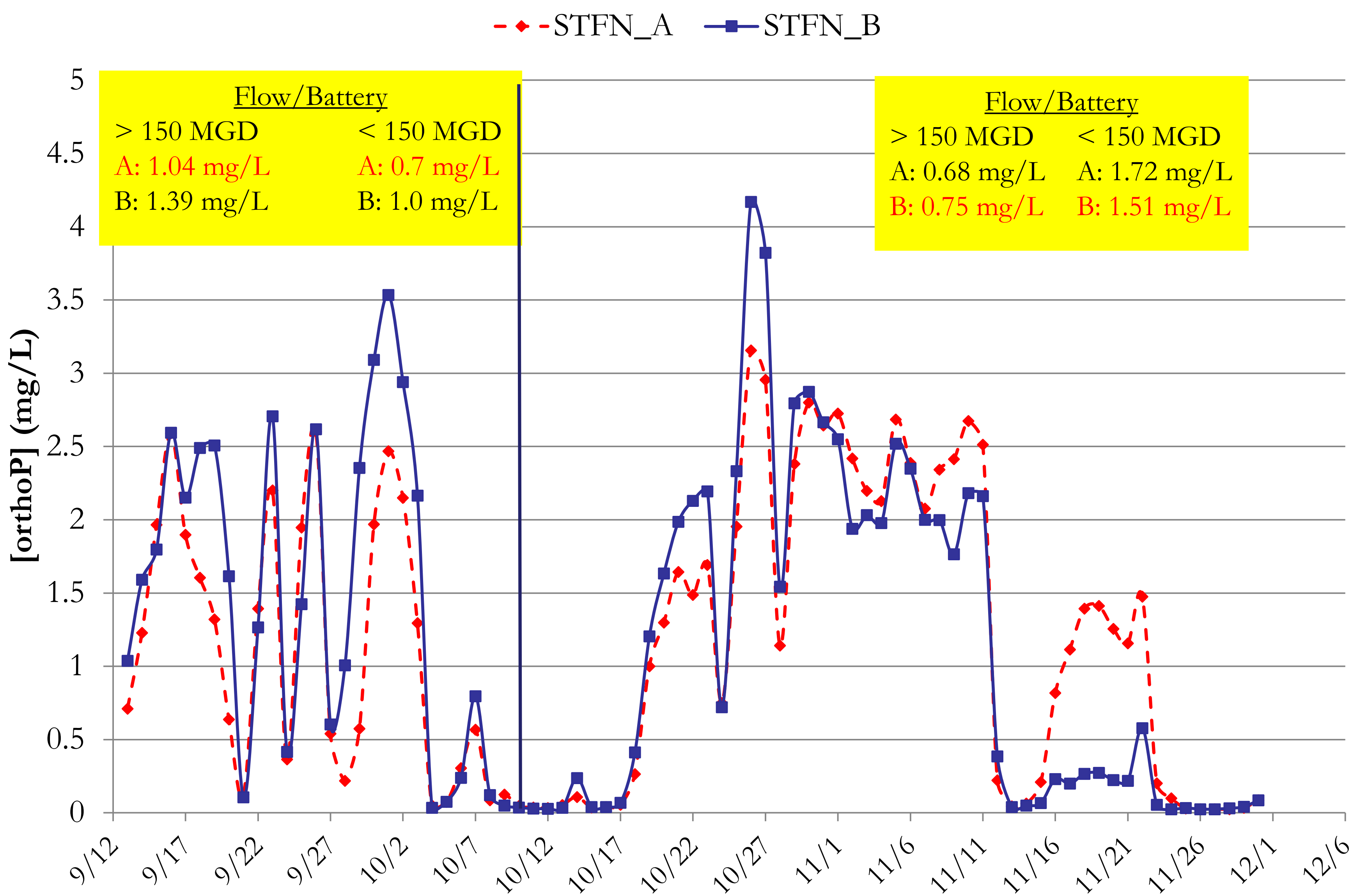
What is Happening in Low Flows?

BATTERYD FLOW (MGD)	PE orthoP/ TP	INF TP (mg/L)	INF TP LOAD (lb/day)	INF orthoP (mg/L)	INF orthoP LOAD (mg/L)	PE BOD:orthoP	PE BOD:TP	PE BOD (mg/L)	BOD Load (lb/day)
< 100	0.71	5.51	3,763	3.88	2,682	30.1	24.8	129	91,438
100-125	0.59	5.73	5,237	3.05	2,940	44.4	25.7	137	131,258
125-150	0.55	5.92	6,419	3.08	3,391	50.1	25.9	144	163,554
150-200	0.51	6.35	8,941	3.08	4,406	51.9	24.6	141	202,177
200 - 250	0.44	6.41	12,073	2.46	4,634	66.9	26.7	150	284,718
250-300	0.39	8.52	19,692	2.20	4,870	73.7	24.9	172	395,810
>300	0.34	9.20	24,871	2.31	6,072	77.0	22.0	162	439,570

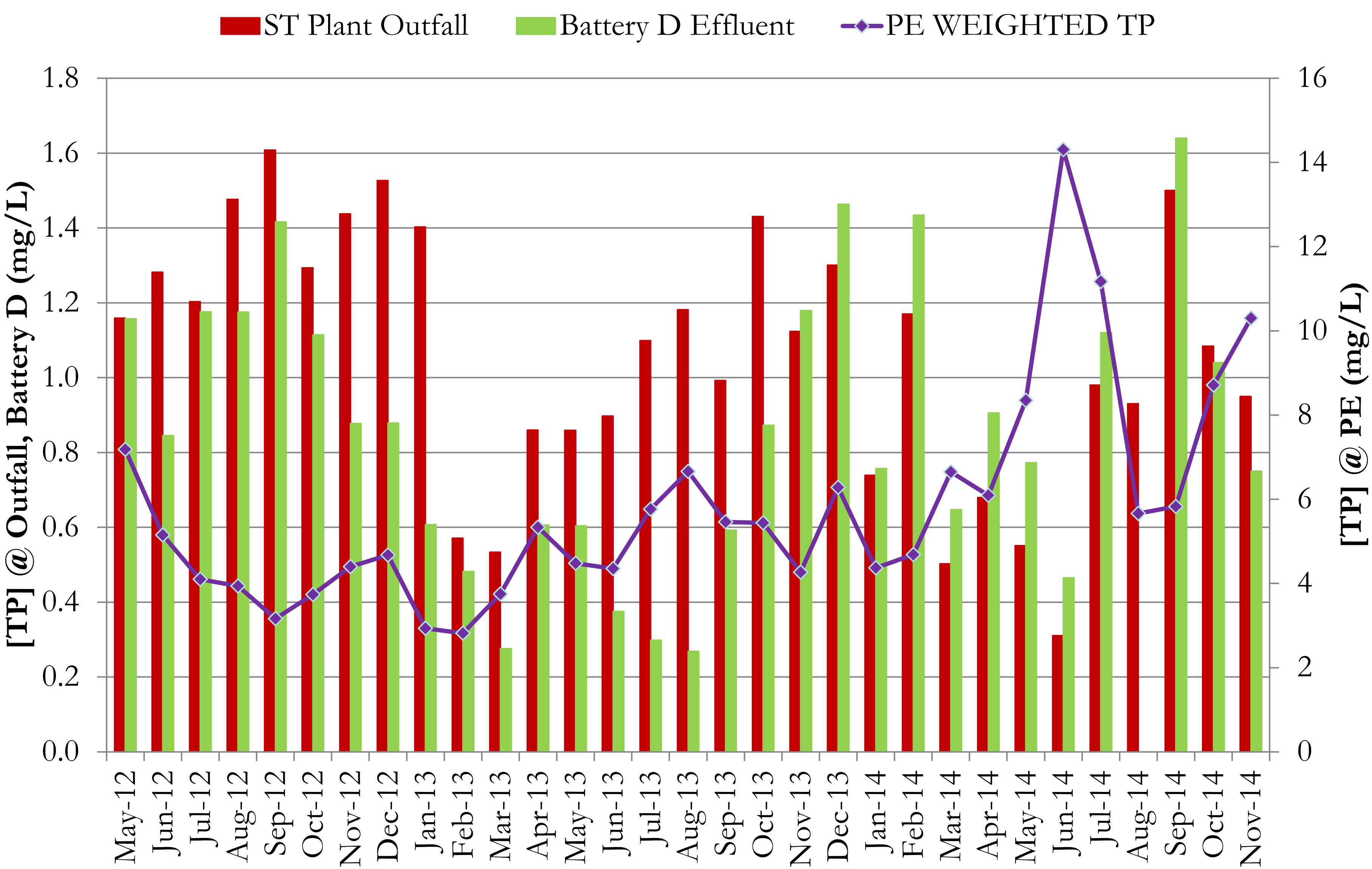
What is Happening in Low Flows?

BATTERY D FLOW (MGD)	ORP @ Anoxic (mV)	NO3 @ Anoxic (mg/L)	NO3 @ RAS (mg/L)	ORP @ Anaerobic (mV)	NO3 @ Anaerobic (mg/L)	NO3 @ RAS (mg/L)	RAS DO (mg/L)
< 100	-121	3.80	4.37	-195	1.40	2.71	5.74
100-125	-127	2.91	4.16	-220	0.84	3.34	5.03
125-150	-164	1.94	3.62	-269	0.42	3.08	3.38
150-200	-179	1.26	3.14	-301	0.41	2.55	2.37
200 - 250	-162	1.37	2.38	-252	0.38	1.49	3.15
250-300	-209	1.29	1.56	-284	0.72	1.20	1.44
>300	-246	1.19	1.57	-263	1.39	1.41	0.96

Strategy to Deal with Low Flow Tested: Shortened Anaerobic Zone



Stickney EBPR Progress – Monthly Means



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

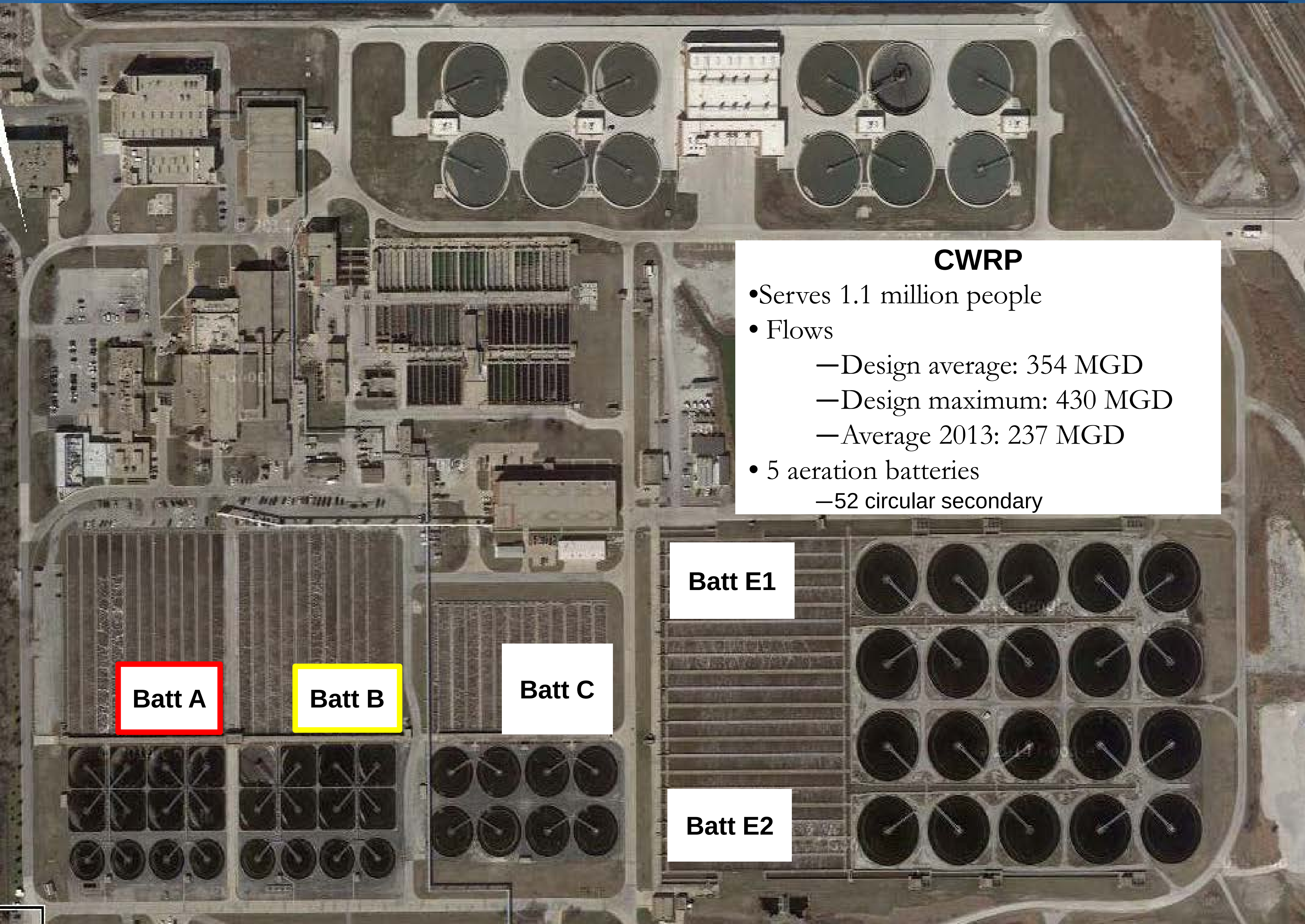
1. *Carbon Limitations*
2. *Flow → Low flow and recycle stream contribution correlated with high TP*
3. Biological Inconsistencies/Inhibition
4. Plant Shutdowns/Batteries O/S
5. *Excess DO in Aeration Tanks or DO sags*
6. Inconsistent Return Sludge Control

Moving Forward

- Refine operation strategies for dealing with wet weather, low flow and TARP pumpback conditions
- Carbon
  - Test inline ML fermentation and other inplant sludge fermentation options
- Recycle Streams
  - Recycle stream analysis after the new GCTs are online and solids are separated
  - P recovery will reduce P from recycle stream significantly
- DO
  - Continued optimization of DO at the end of the aerobic zone

CWRP

- Serves 1.1 million people
- Flows
  - Design average: 354 MGD
  - Design maximum: 430 MGD
  - Average 2013: 237 MGD
- 5 aeration batteries
  - 52 circular secondary

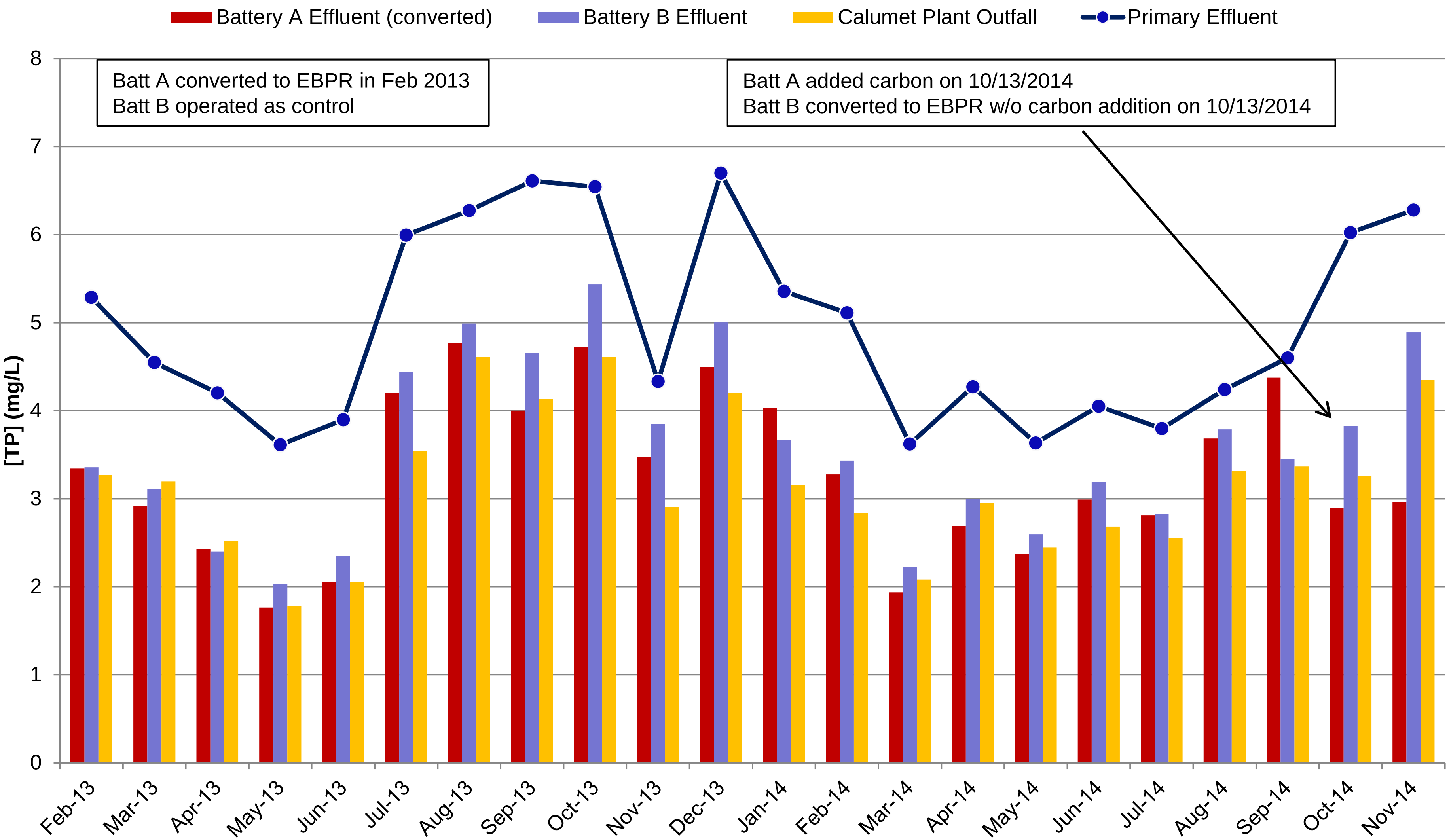


Developing EBPR at Calumet WRP

- Pilot/full scale tests verified that plant is carbon-limited for EBPR
  - *June-August 2012, Batteries E1&E2 EBPR evaluation with existing infrastructures*
  - *February 2013 – October 2014, Batteries A&B EBPR evaluation with existing infrastructures*
  - *February – December 2014, SBR study to evaluate carbon needs to establish EBPR*
  - *October – December 2014, Battery A full scale carbon study*
- Phosphorus Source Tracking
  - *All sources of P to the plant have not been accounted for*
  - *Sent letters to industries for voluntary P reduction (March 21, 2014)*
- Paper study to evaluate carbon supplementation options
- Primary sludge, RAS, and ML fermentation lab tests

Test Result Summary for Full-scale Test at Batteries A and B

- **Conversion of Battery A to EBPR setting over 1 yr, but no sign of EBPR until carbon added.**



*TP results available until 11/22. Samples taken daily for CAPREF and taken twice per week for CAFN_A and CAFN_B.

Limitation and Solution of Bio-P at CWRP

- Carbon Limitation
  - Primary Eff BOD:TP averaged 15 in 2013 (recommended BOD:TP > 25)
  - Carbon deficit happened about 80% of time
  - Carbon deficit at CWRP based on paper study: ~50,000 pounds rbCOD/day or adding 25-30 mg COD/L
- SBR Study verified the extent of carbon needs
  - w/o MicroC addition: no sign of EBPR
  - w/ 15 mg/L as COD MicroC addition: mixed results
  - w/ 30 mg/L as COD MicroC addition: sustainable EBPR established after one week
- Full Scale Carbon Supplement for Bio-P Study
  - 30 mg/L as COD MicroC addition

SBR & Its Cycles

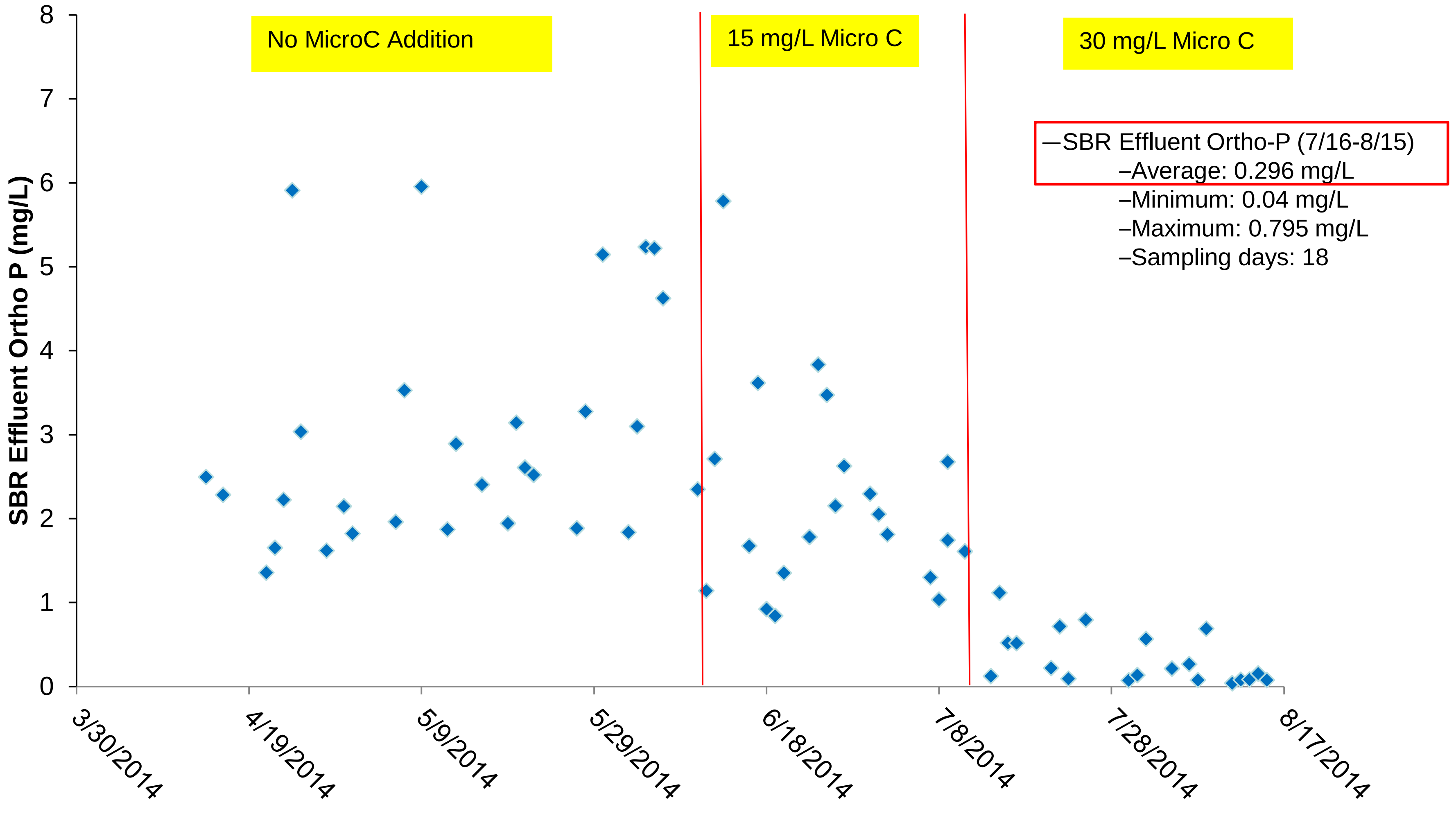
- Sequential Batch Reactor (SBR)

50 gal reactor, controller, mixer, air flow piping, aeration diffusers, effluent discharge piping and a sludge removal valve.

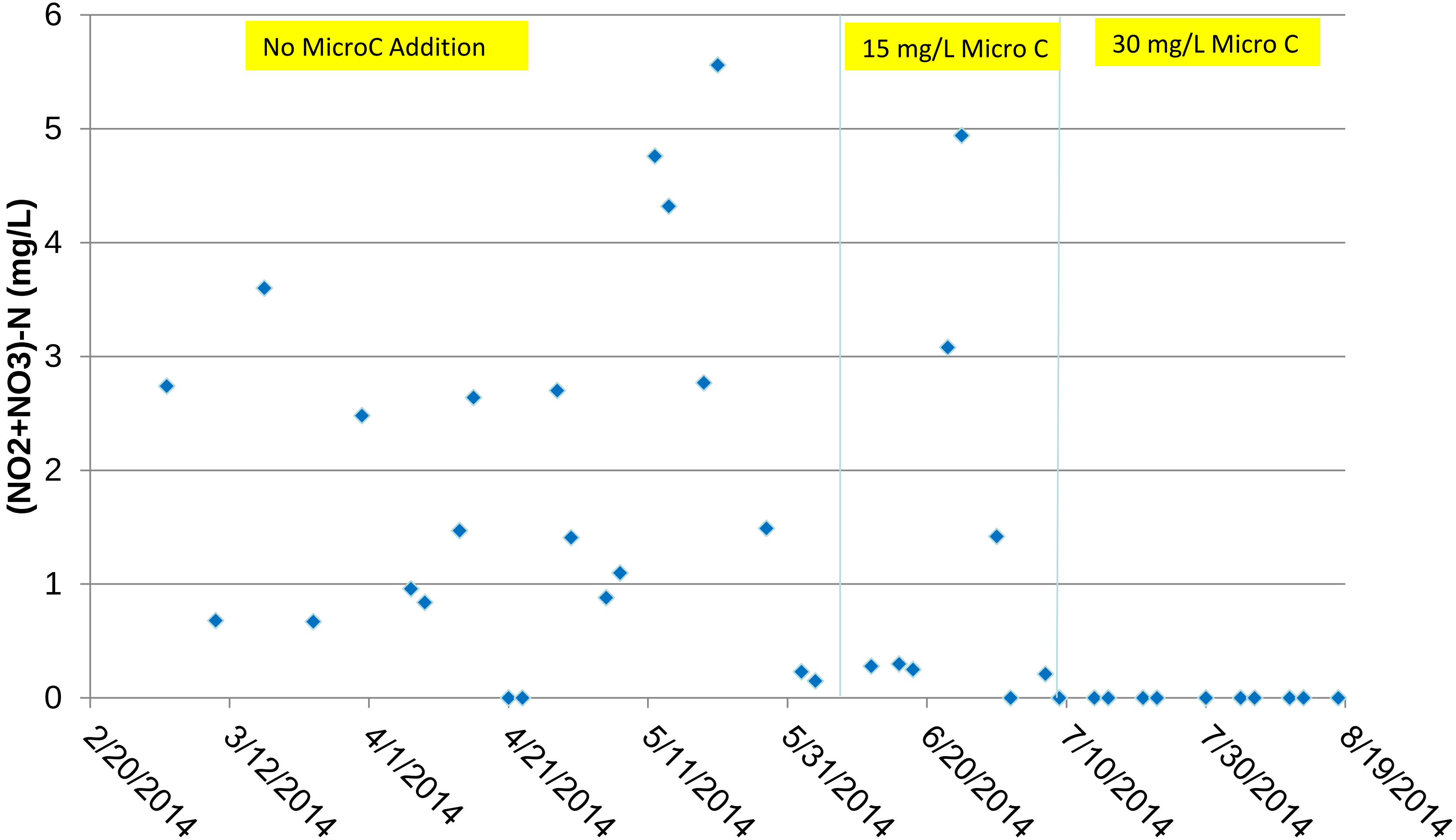
•Test Cycle
(three 8 hrs cycles/day)

1. Influent: ~ 10 min
2. Anoxic/Anaerobic: 1-1.5 hours
3. Aerobic: 6-5.5 hours
4. Settling: 35 min
5. Discharge: ~ 15 min

SBR Effluent Ortho P Concentrations

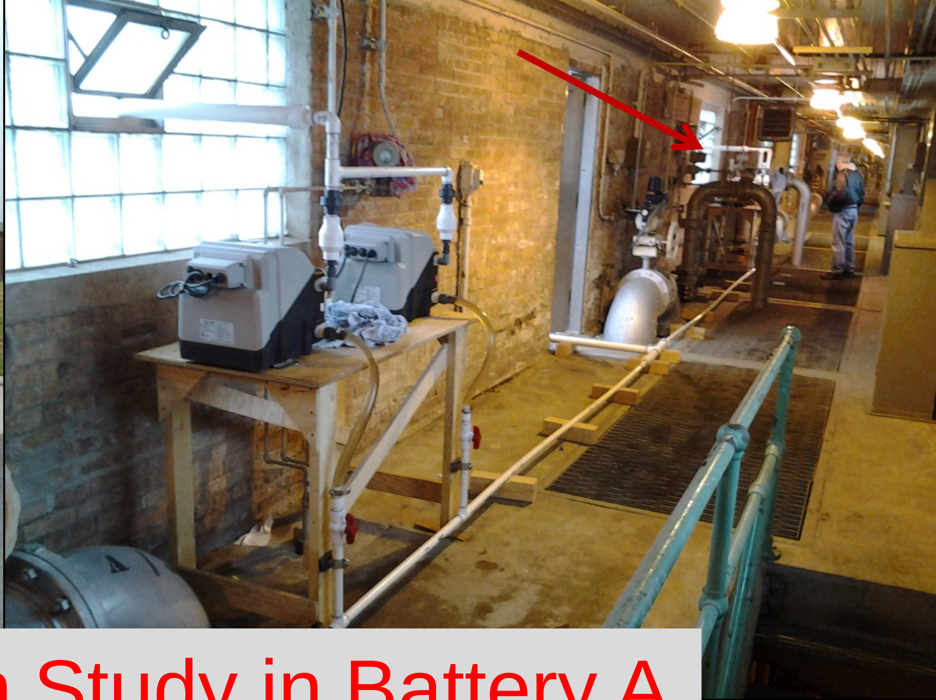


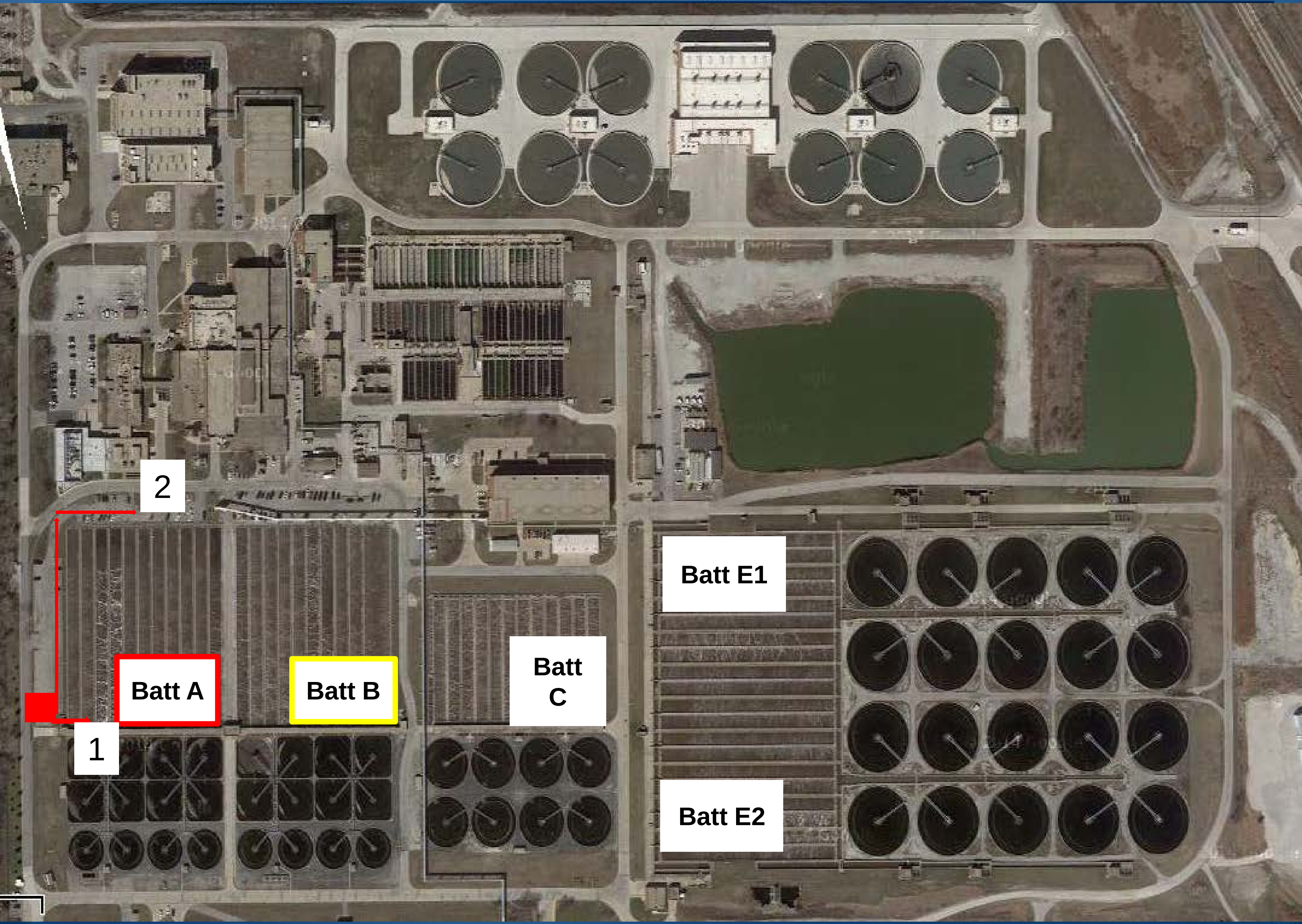
NOx-N by the End of SBR Anaerobic Zone



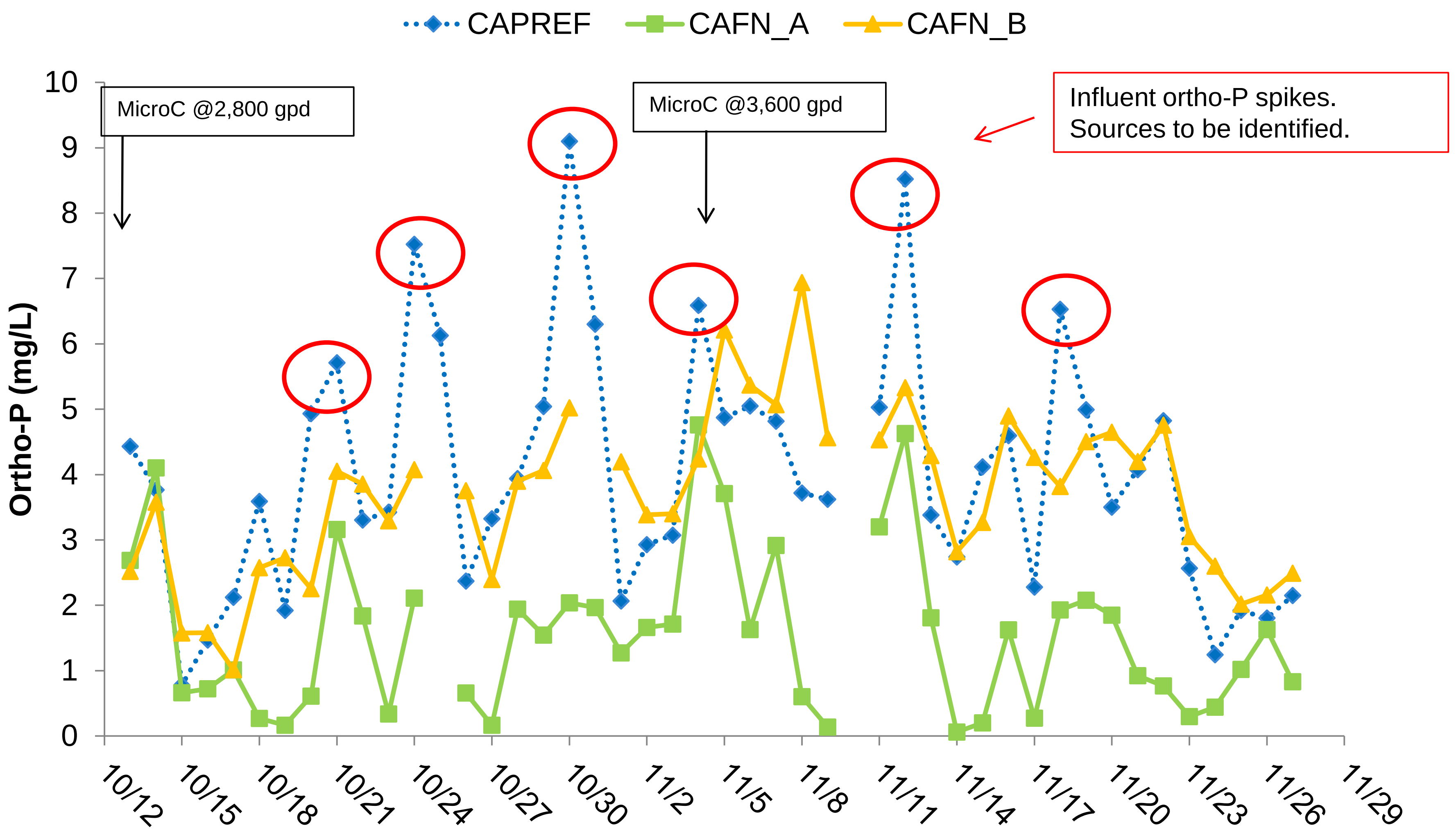
Nitrate was eliminated before the beginning of anaerobic zone-true anaerobic zone

Full scale Carbon Study in Battery A




2
Batt A
Batt B
Batt C
Batt E1
1
Batt E2

Full-Scale Carbon Addition Study In Battery A



Carbon Addition –
Statistical Summary of Test Data

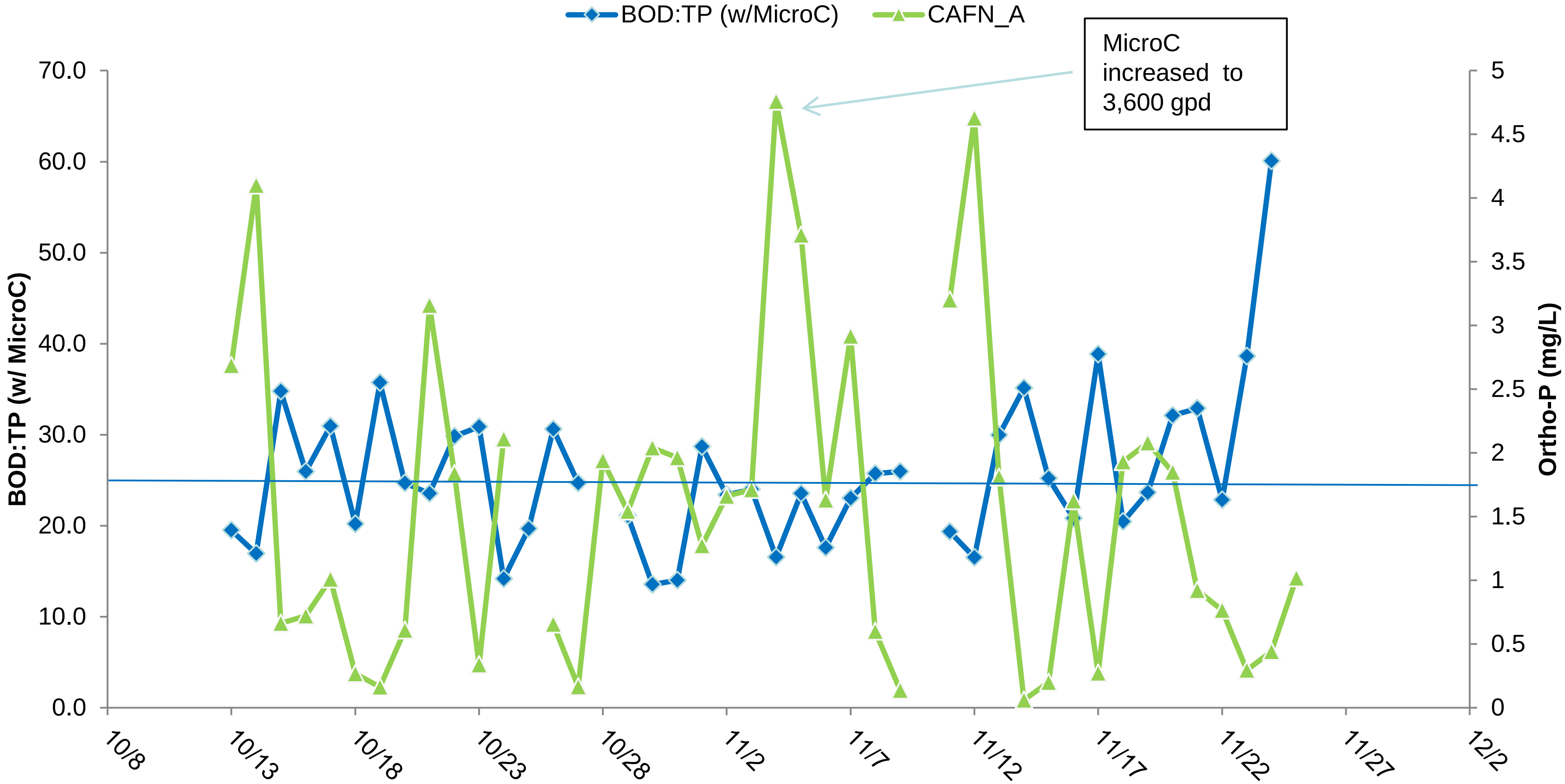
	Ortho-P (mg/L)			% Ortho-P removal		Ortho-P removal relative to control Batt (mg/L)	Ortho-P removal from CAPREF (mg/L)
	CAPREF	CAFN_A	CAFN_B	CAFN_A	CAFN_B		
No. of Samples	41	41	40	41	40	40	41
Average*	4.15	1.48	3.86	64	7	2.38	2.62
Min.*	0.78	0.06	1.02	15	-103	-0.52	0.12
Max.*	9.1	4.76	6.94	98	54	6.34	7.06

**Statistical analysis uses data from 10/15/2014 to 11/24/2014.*

Carbon Addition – Microbiology Monitoring Data

Date	Ortho-P (mg/L)			PHB (µ2/mgVSS)		POLY_P (µ2/mgVSS)	
	CAPREF	CAFN_A	CAFN_B	Batt A	Batt B	Batt A	Batt B
10/20/2014	4.93	0.61	2.25	83,779	71,677	59,459	<100
10/27/2014	3.33	0.17	2.40	64,126	64,698	58,841	<100
11/3/2014	3.07	1.71	3.40	nd	71,597	69,783	1,907
11/5/2014	4.87	3.71	6.21	68,307	71,344	54,345	11,088
11/10/2014	nd	nd	nd	53,913	241,201	53,413	8,103
11/12/2014	8.52	4.63	5.33	151,750	124,187	53,597	5,104
11/17/2014	2.28	0.27	4.26	*150,131*	116,578	*118,645*	2,305
11/20/2014	3.50	1.85	4.65	*351,117*	82,676	*71,621*	5,541
11/24/2014	1.24	0.44	2.60	177,077	NS	144,291	NS
Averages	3.97	1.67	3.89	137,525	105,495	75,999	5,675
Min	1.244	0.165	2.254	53,913	64,698	53,413	1,907
Max	8.520	4.628	6.210	351,117	241,201	144,291	11,088

Primary Effluent BOD:TP & Battery A Effluent Ortho-P

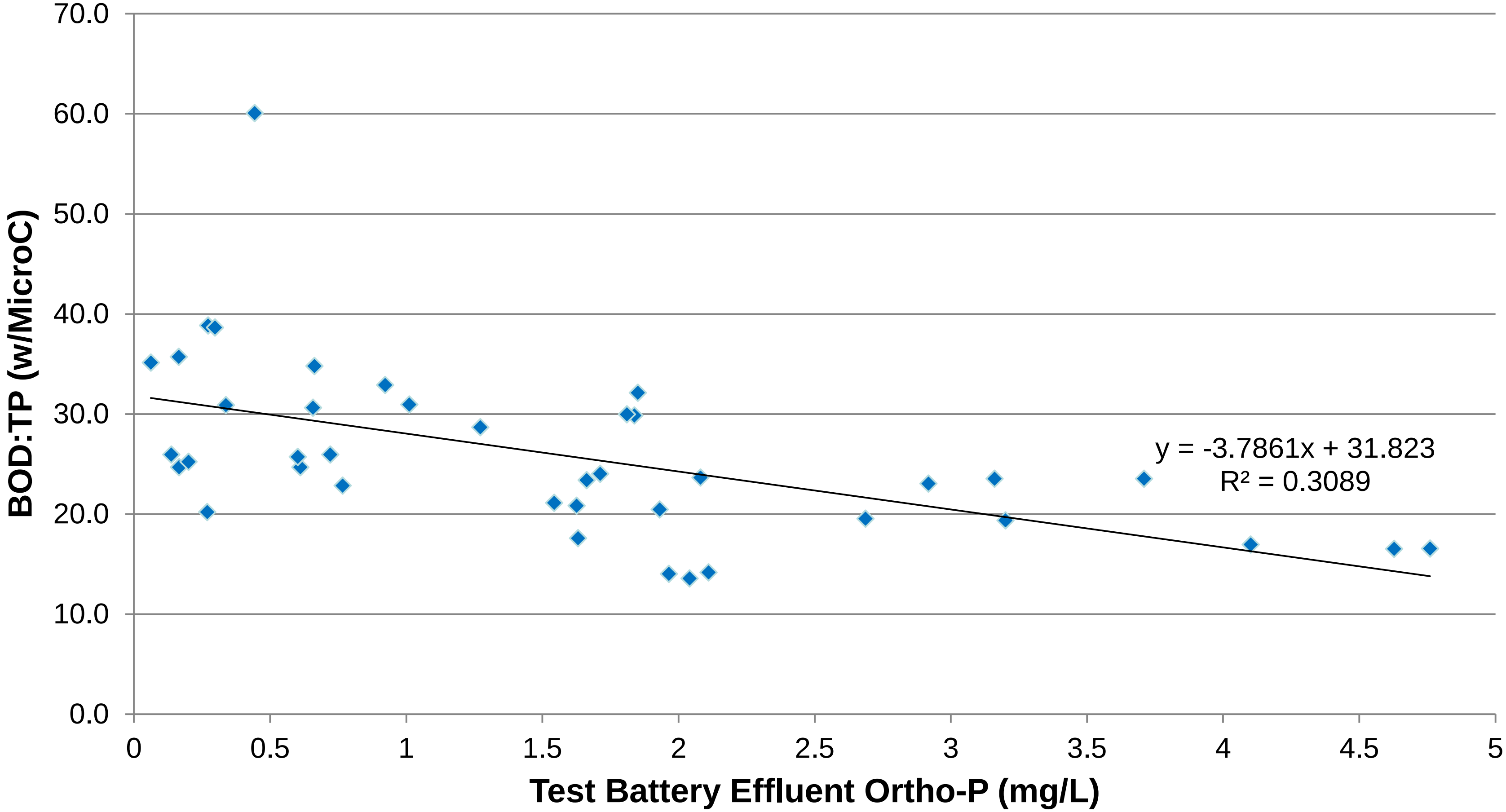


- TP results are only available from 10/13 to 11/3. An assumption of Ortho-P:TP=0.7 in CAPREF was made for BOD:TP calculation on 11/4 and after.

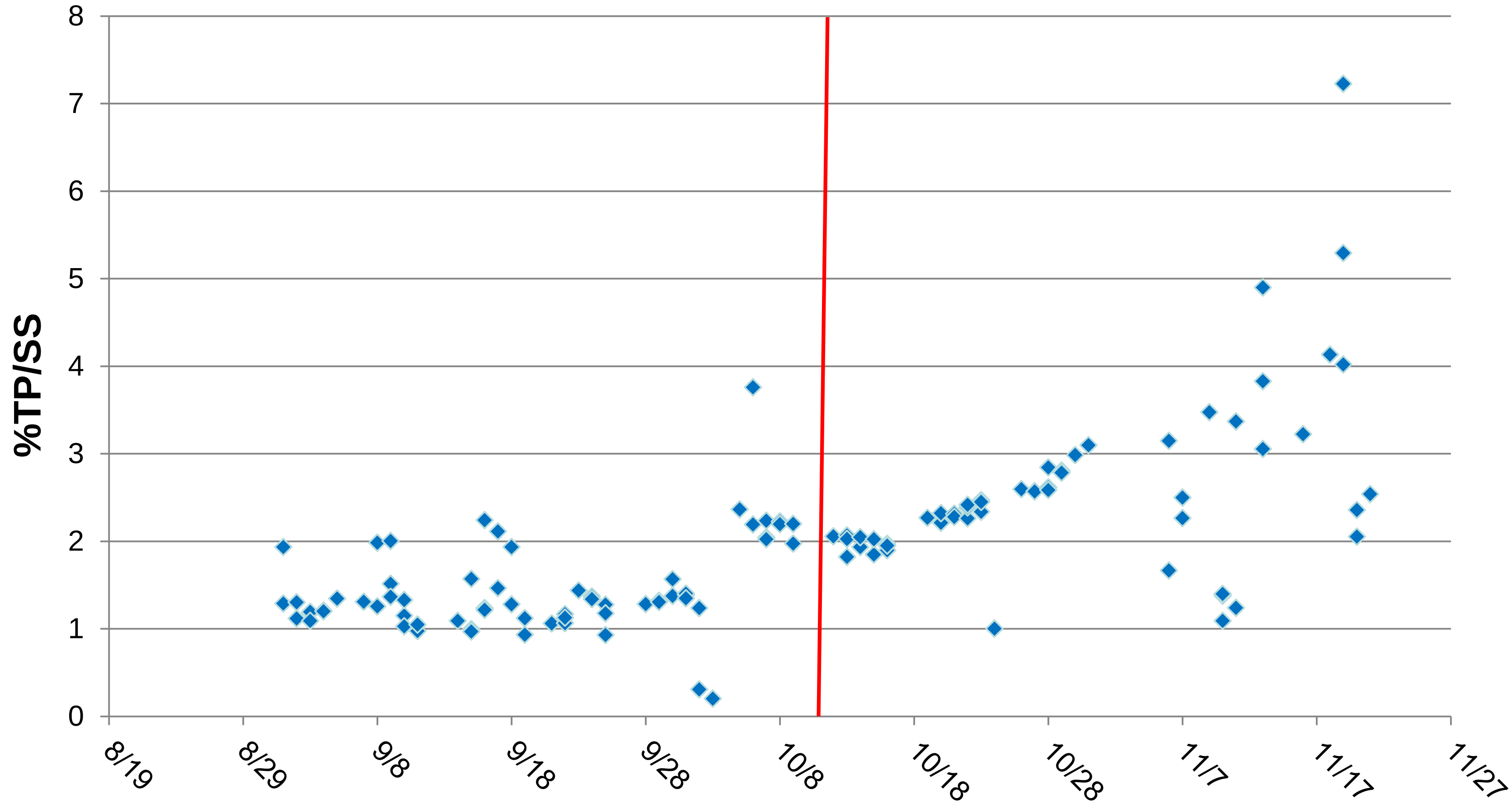
W/ MicroC feed rate @ 2,800 gpd, BOD:TP ratios were less than the recommended minimum value of 25 about 50% of the time.

W/MicroC feed rate @ 3,600 gpd, BOD:TP was still less than 25 sometime due to higher TP in CAPREF.

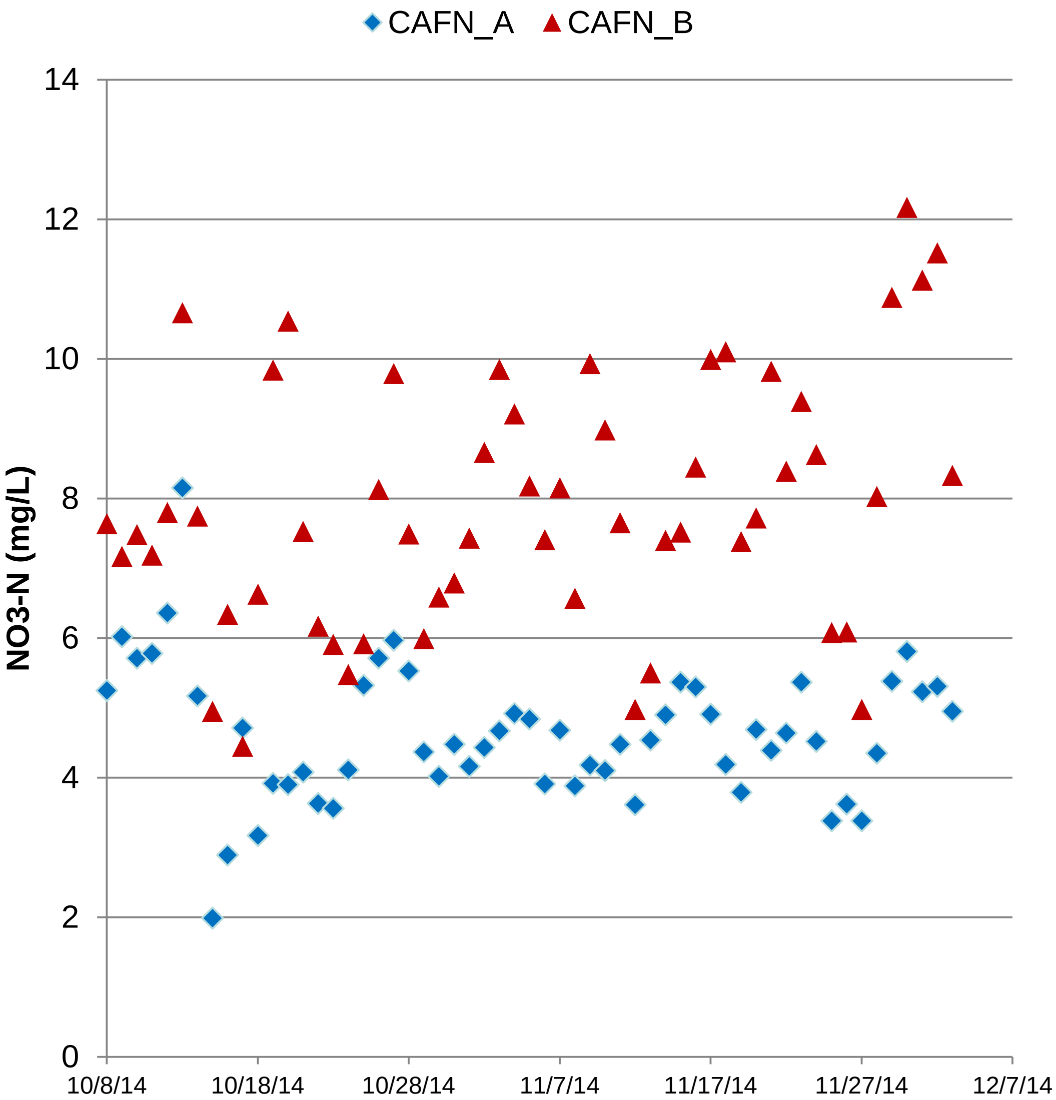
BOD:TP *vs* Battery A Effluent Ortho-P during Full-Scale Test (10/15/2014 – 11/24/2014)



TP Content in RAS in Test Battery A



Nitrification/Denitrification



NH3-N Statistical Summary (mg/L)

	CAPREF	CAFN_A	CAFN_B
Average	14.15	<0.12	<0.11
Min	6.38	<0.1	<0.1
Max	17.13	0.38	0.17

- Nitrification completed in both test and control batteries prior to Batt B conversion
- Denitrification performed better in test vs control after Batt B conversion.

Findings from Full-Scale Carbon Addition Test

- EBPR was evident in test Battery A with MicroC as supplement carbon source.
  - Test Battery A outperformed control Battery B
  - An average of 2.62 mg/L ortho-P was removed from CAPREF in test Battery A
  - TP content in RAS increased after EBPR established
  - PAOs were enriched in Test Battery A with MicroC addition
  - BOD:TP ratio of 30 is recommended using current configuration and infrastructure to achieve effluent ortho-P less than 0.75 mg/L
  - Carbon needs appear to be higher than literature value possibly due to the existing configuration and infrastructure limitations
- Nitrification performed similar in both test and control batteries, but denitrification was more in the test battery

Moving Forward

- **Source Control**
  - Further investigation
  - Working with industries
- **Carbon Generation Options at CWRP**
  - Primary sludge fermentation (provides ~ 10-20% of deficit)

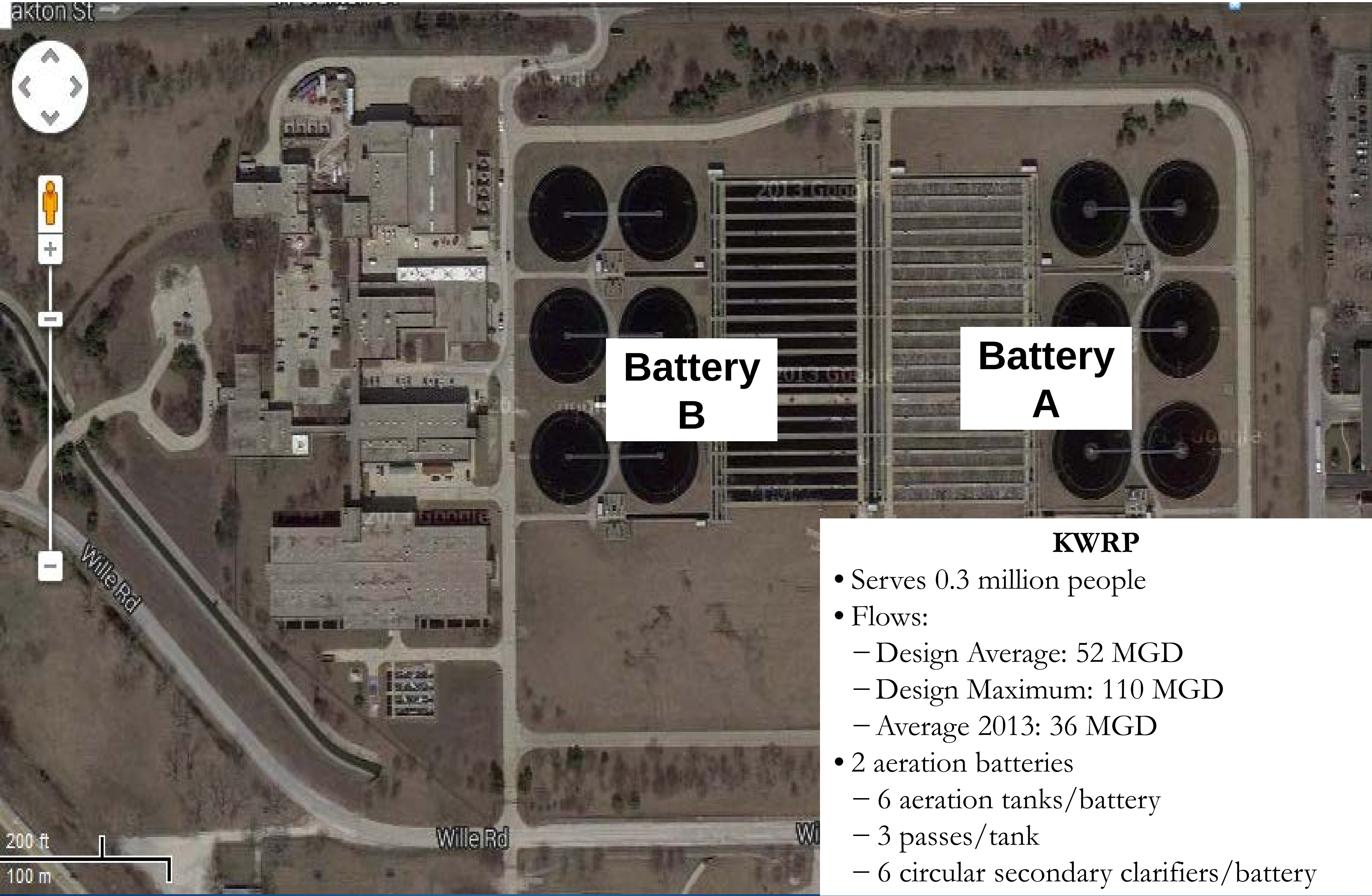
    WAS thickened by GBT; convert GCT for primary sludge fermentation and add fermentate to anaerobic zone directly (need pumps and pipes)
  - RAS fermentation (provides ~ 20-40% of deficit)

    Convert old primary settling tanks to sludge fermentation tanks
  - Possible External Sources for supplemental carbon (may provide ~ 60% deficit)

    (1) Using GCT tanks for holding and fermenting

    (2) Fermentate transfer to anaerboic zone directly

Kirie WRP Layout



KWRP

- Serves 0.3 million people
- Flows:
  - Design Average: 52 MGD
  - Design Maximum: 110 MGD
  - Average 2013: 36 MGD
- 2 aeration batteries
  - 6 aeration tanks/battery
  - 3 passes/tank
  - 6 circular secondary clarifiers/battery

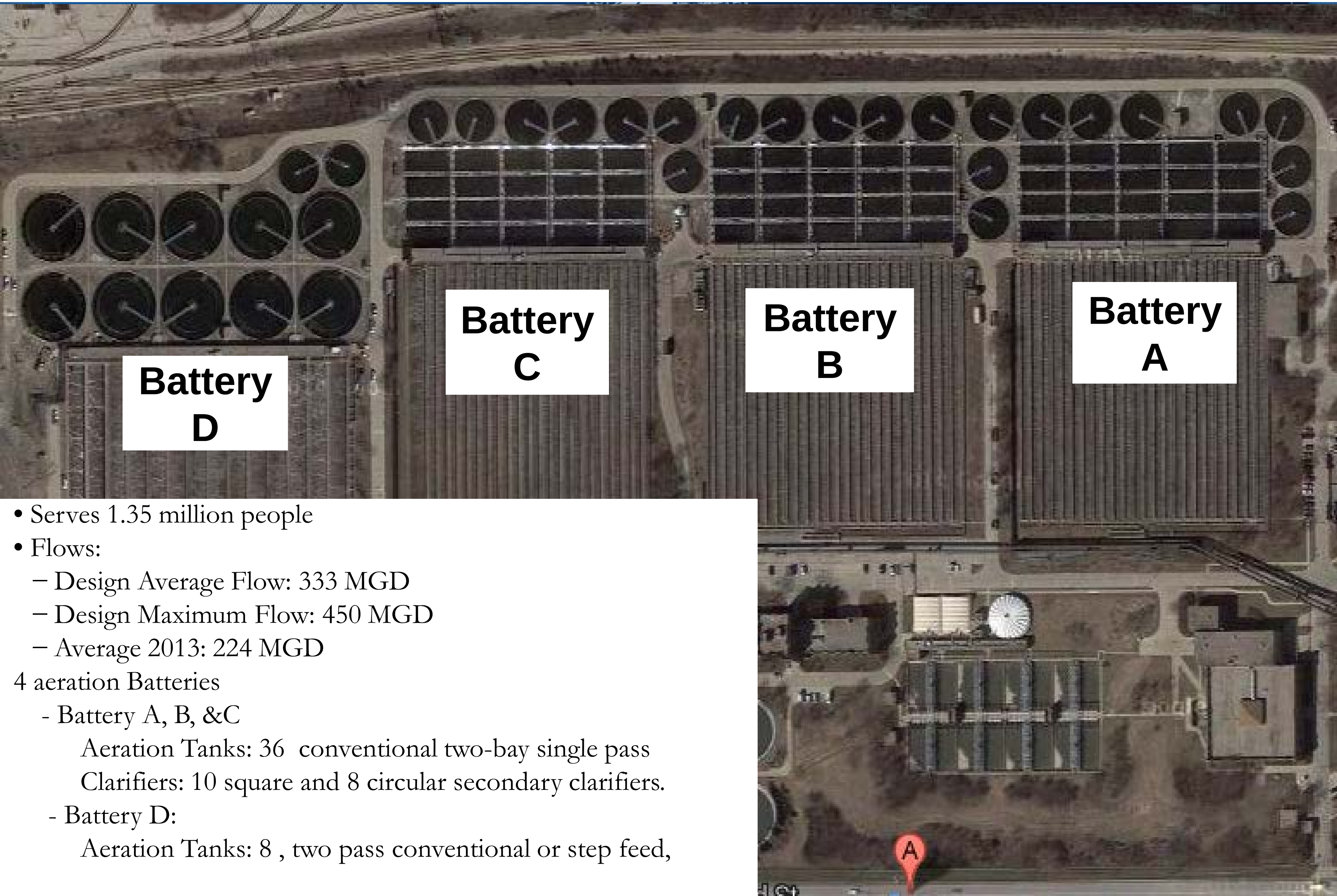
Develop Bio-P Strategy at Kirie WRP (1)

- **Assess key process parameters and infrastructure capabilities**
  - Influent examination and characteristic analysis to evaluate carbon availability for EBPR
  - Mixed Liquor (ML) and Return Activated Sludge (RAS) fermentation study to evaluate internal carbon source for EBPR
  - Capacity analysis to evaluate the existing infrastructure capability for nitrification and EBPR

Develop Bio-P Strategy at Kirie WRP (2)

- **Develop Bio-P Options for the plant**
  - Designed a pilot study for EBPR based on Kirie existing infrastructure capability and wastewater characteristic
  - Use pilot study to evaluate EBPR capacity at Kirie WRP using Battery A
    - Phase I – Baseline study, pilot tanks were not isolated, but quasi anoxic/anaerobic zones were generated by reducing air in the beginning of pilot tanks (completed)
    - Phase IB – Isolate pilot test tanks (2 out of 6), evaluate EBPR potential using existing infrastructure and air mixing; Pilot test expect to run between December, 2014 – June, 2015
    - Phase II – Evaluate the performance of EBPR by adding baffle wall and mixers to provide isolated anaerobic zone and swing zone (contingent upon Phase IB study result)
    - Phase III – Evaluate improvement on the performance of EBPR by adding RAS or ML fermentation with isolated fermentation zone (contingent upon Phase IB study result)

O’Brien WRP Secondary Treatment layout



- Serves 1.35 million people
- Flows:
  - Design Average Flow: 333 MGD
  - Design Maximum Flow: 450 MGD
  - Average 2013: 224 MGD

4 aeration Batteries

- Battery A, B, &C

  Aeration Tanks: 36 conventional two-bay single pass

  Clarifiers: 10 square and 8 circular secondary clarifiers.

- Battery D:

  Aeration Tanks: 8 , two pass conventional or step feed,

Develop Comprehensive P Removal and Recovery Strategy at O'Brien WRP (1)

- **P Source Tracking**
  - ➢ The average loading to OWRP in 2013 was 5,679 lbs TP/day
  - ➢ P from Egan centrate/UDP 11 = approximately 280 lbs P/day, or approximately 5%
  - ➢ Industrial sources are not a major contributor of P to OWRP, accounting for 442 lbs P/day, or approximately 8%
  - ➢ Drinking water plants may contribute 0.2 mg/L of P from their process , 335 lbs P/day or approx. 6%
- **Algae for P Removal and Recovery**

  Pilot test in 2015

Develop Comprehensive P Removal and Recovery Strategy at O'Brien WRP (2)

- **Develop EBPR**
  - Battery D Tank 8 was added to increase capacity
  - Finished stress testing of baffle plate and underflow pump to improve secondary clarifier performance
    - Clarifier with baffle plate outperformed other test clarifiers
  - Finished desktop analysis on O'Brien EBPR potentials based on influent characteristics
    - BOD:TP ratio in influent meets recommendation for EBPR on average
    - Influent characters will change slightly due to intercepting Egan centrate and reduced UDP 11 flow
    - OWRP may have enough aeration tank volume for nitrification and EBPP, but require retrofit
- **Engineering evaluation on retrofit for EBPR**

Questions?

Y. Mwende Lefler
Senior Civil Engineer
yvonne.lefler@mwrd.org

Cindy Dongqi Qin
Associate Environmental Research Scientist
dongqi.qin@mwrd.org