Nutrient Removal in Sequencing Batch Reactors (SBRs)

US EPA webinar series for
Wastewater Treatment Plant Operators
February 17, 2022

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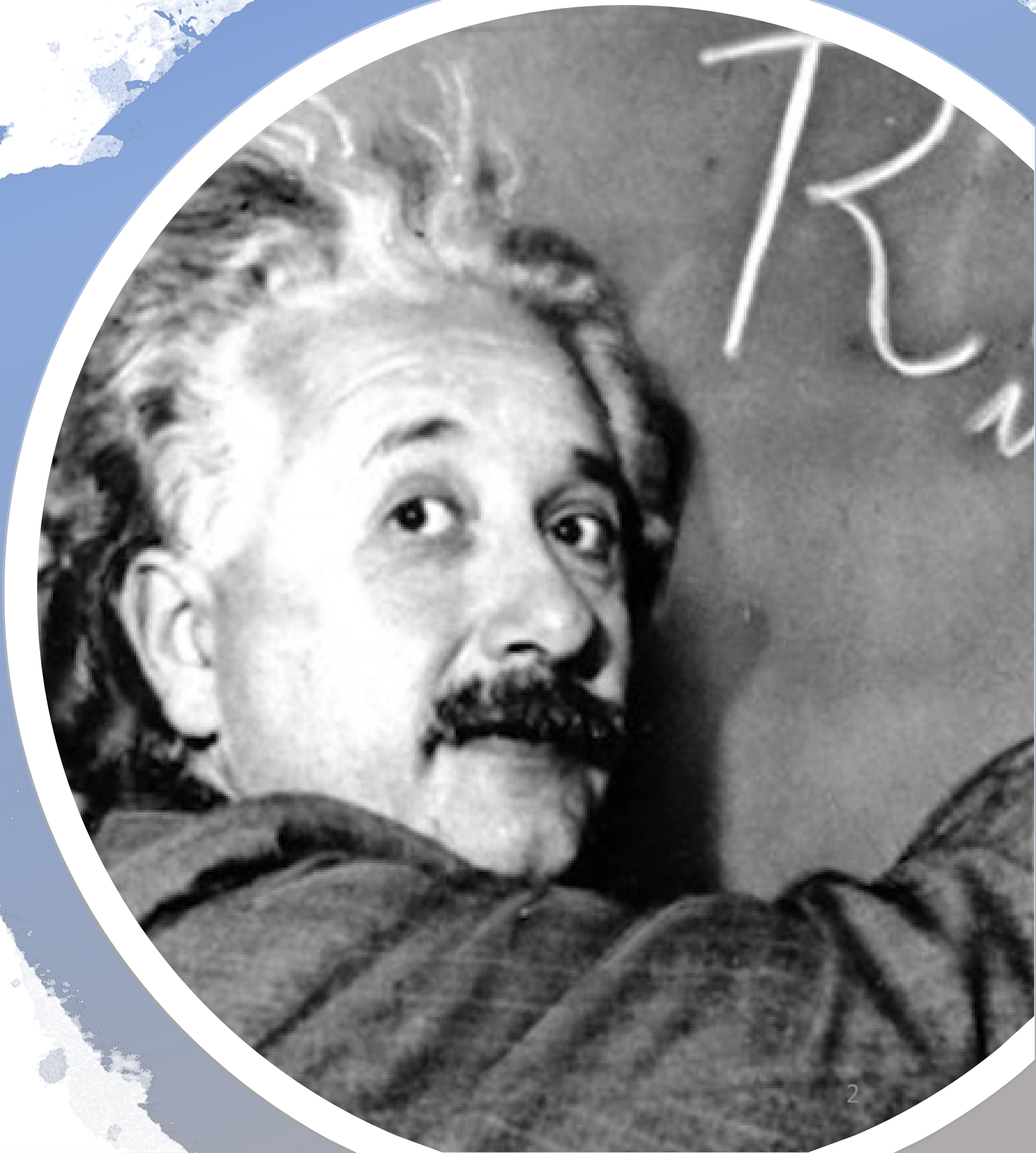
Optimizing Nutrient Removal & Wastewater Excellence

Optimizing Nutrient Removal in:

Oxidation Ditches
(Last Month)

Sequencing Batch Reactors
(Today)

Other Activated Sludge WWTPs
(March 31, 2022)

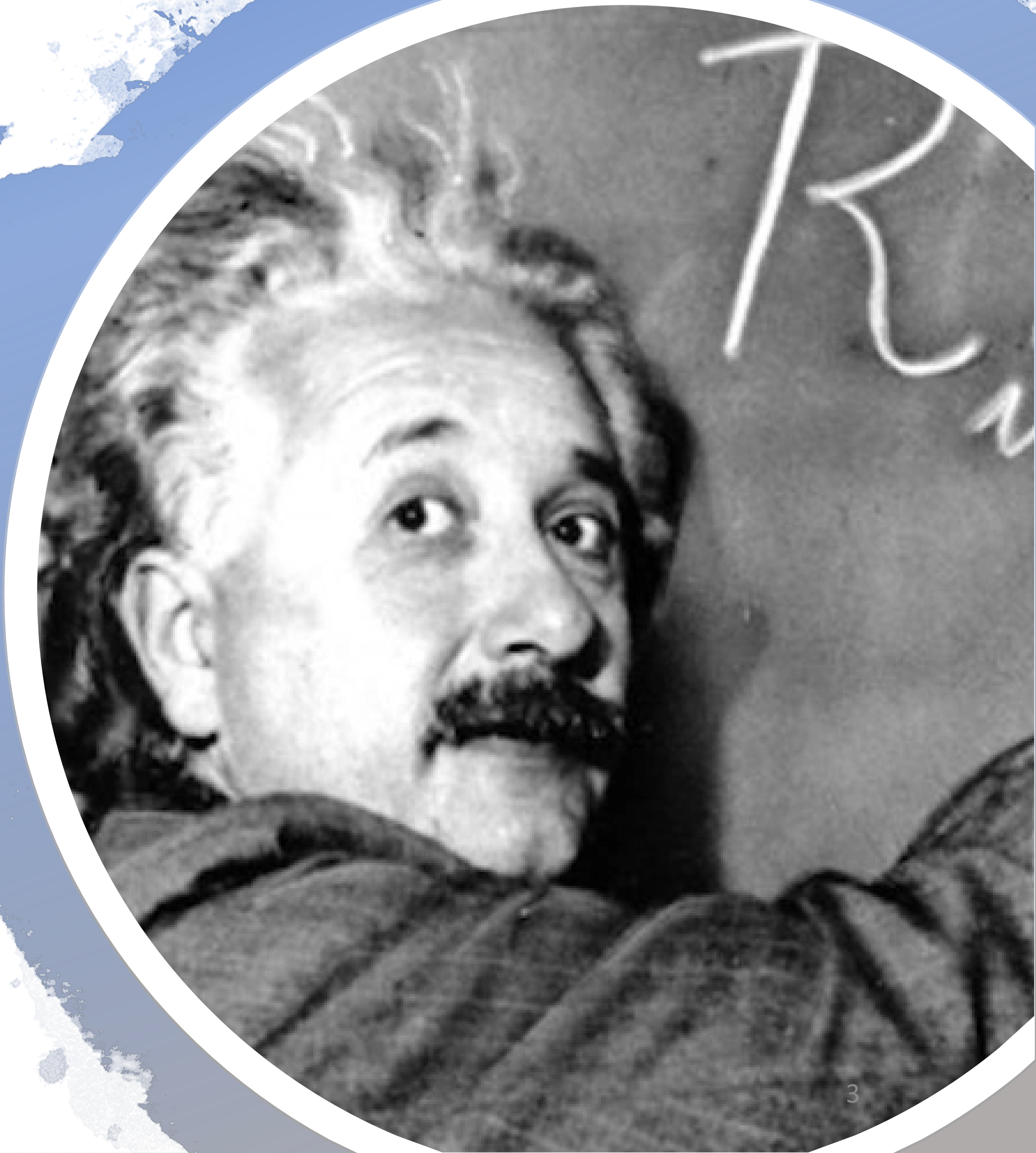


Optimizing Nutrient Removal & Wastewater Excellence

Optimizing Nutrient Removal in:

- **Oxidation Ditches**
  (Last Month)
- **Sequencing Batch Reactors**
  (Today)
- **Other Activated Sludge WWTPs**
  (March 31, 2022)

Transitioning from Permit Compliance to Wastewater Excellence
(April 28, 2022)



KEEP
CALM

AND

BLAME
ME FOR EVERYTHING

Acknowledgements

ABILENE, KANSAS G.D. Hite, Kevin Clark & Lon Schrader

EAST HADDAM, CONNECTICUT Zach Dutton, Joe Barrios & Katherine Kneeland

ELLINWOOD, KANSAS Sterling Proffitt

OSAWATOMIE, KANSAS Bruce Hurt

PRATT, KANSAS Jeff Shanline & Jay Angood

GARDNER, KANSAS (oxidation ditch) Scott Millholland

EPA Peter Bahor, Laura Paradise, Paul Shriner & Tony Tripp (**HQ**), Brendon Held & Craig Hesterlee (**R4**), Andrea Schaller & Sydney Weiss (**R5**), Tina Laidlaw (**R8**),

TENNESSEE Karina Bynum, Tim Hill & Mark Valencia (**TDEC**), Brett Ward (**UT-MTAS**), Dewayne Culpepper (**TAUD**)

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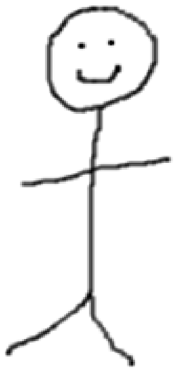
MONTANA Paul LaVigne (retired), Pete Boettcher, Josh Viall, Darryl Barton, Bill Bahr (retired), Dave Frickey (retired) & Mike Abrahamson (**DEQ**)



About case studies …


In today's
lesson...

Optimizing Nutrient Removal in SBRs

Review

Biological Nutrient Removal

- Nitrogen Removal: SBRs are designed to remove nitrogen
- Phosphorus Removal: few SBRs are designed to remove phosphorus

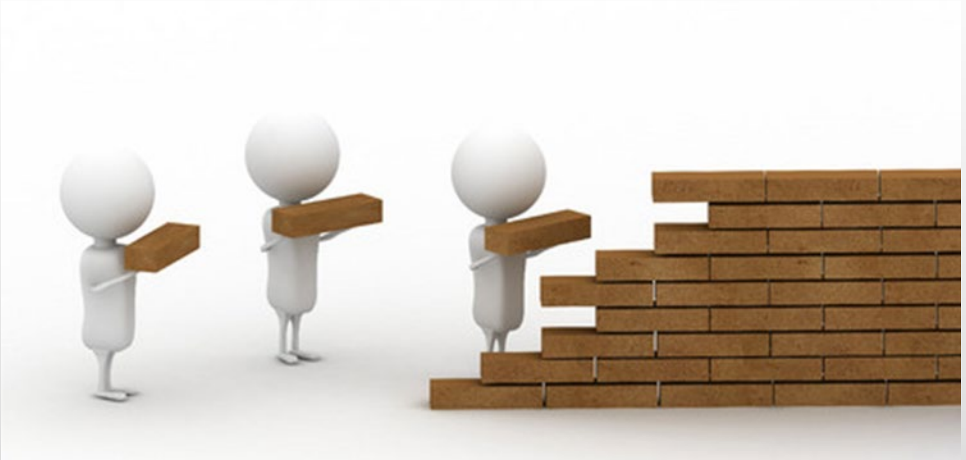
Case Studies

Wastewater treatment plants operating differently than designed to improve N&P removal

- Abilene, Kansas
- East Haddam, Connecticut
- Ellinwood, Kansas
- Osawatomie, Kansas
- Pratt, Kansas
- Gardner, Kansas (oxidation ditch)

Discussion

First, a little background information



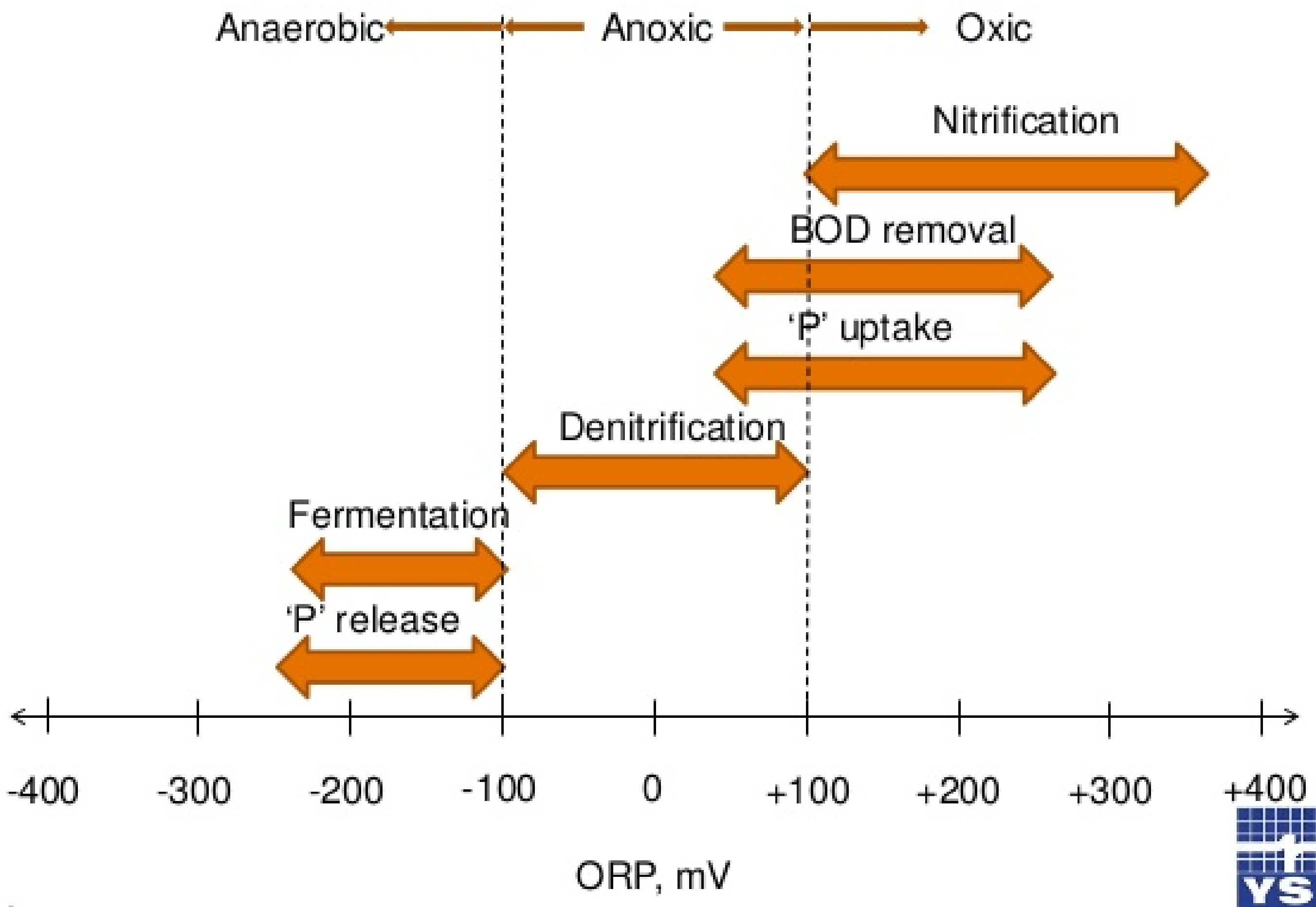

Science

Wastewater Science

DO (Dissolved Oxygen)

ORP (Oxidation Reduction Potential)

What Does ORP Tell Us About Our Process?



Questions?
Comments?


What do you
think?

7

N

Nitrogen

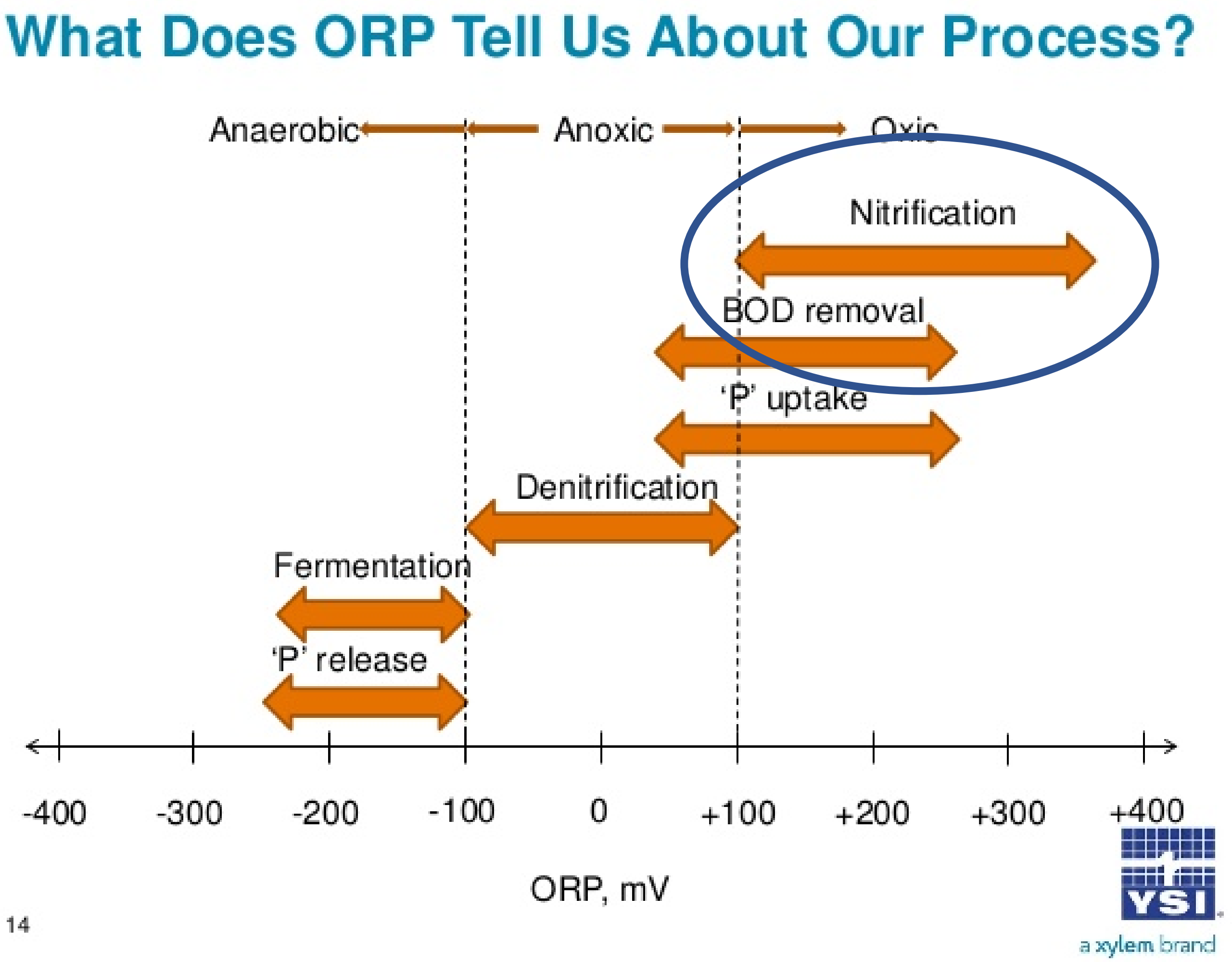
Step 1: Convert Ammonia (NH_4) to Nitrate (NO_3)

Oxygen-rich Aerobic Process
Don’t need BOD for bacteria to grow
Bacteria are sensitive to pH and temperature

Step 2: Convert Nitrate (NO_3) to Nitrogen Gas (N_2)

Oxygen-poor Anoxic Process
Do need BOD for bacteria to grow
Bacteria are hardy

Ammonia Removal: (Nitrification) - 1st Step of N Removal



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<u>Step 1: Ammonia Removal</u>

pH of 6.5+

Plenty of D[illegible]

ORP of +15[illegible]mV

Little to no [illegible]D

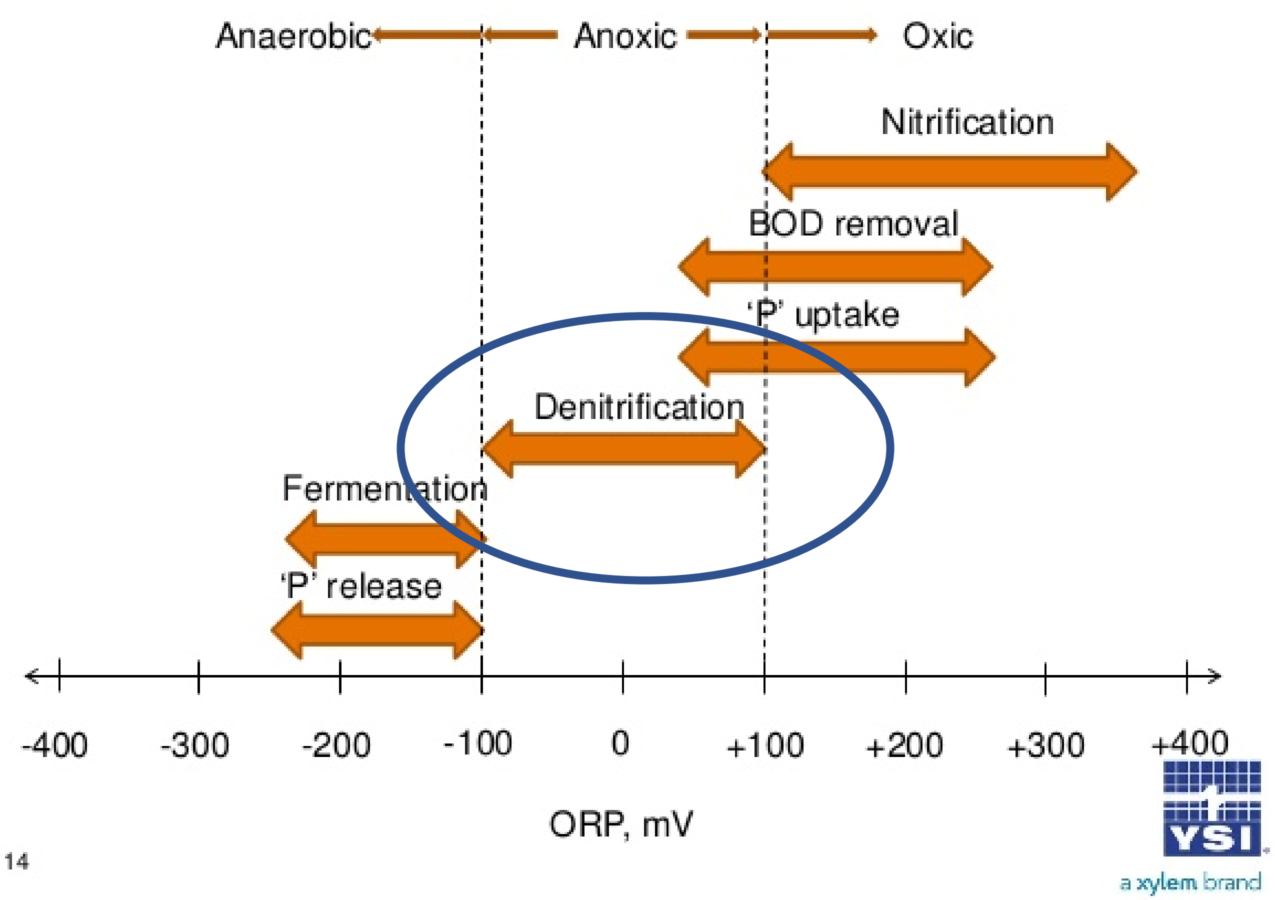
Enough retention time to meet targets

N

Nitrogen

Nitrate Removal: (Denitrification) - 2nd Step of N removal

What Does ORP Tell Us About Our Process?



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Step 2: Nit[illegible]e Remo[illegible]

Little to no [illegible]rable [illegible]

ORP of -10[illegible]V [illegible]

5-10 times [illegible]much [illegible]s Nitrate

Enough ret[illegible]ion time [illegible]meet targets

N

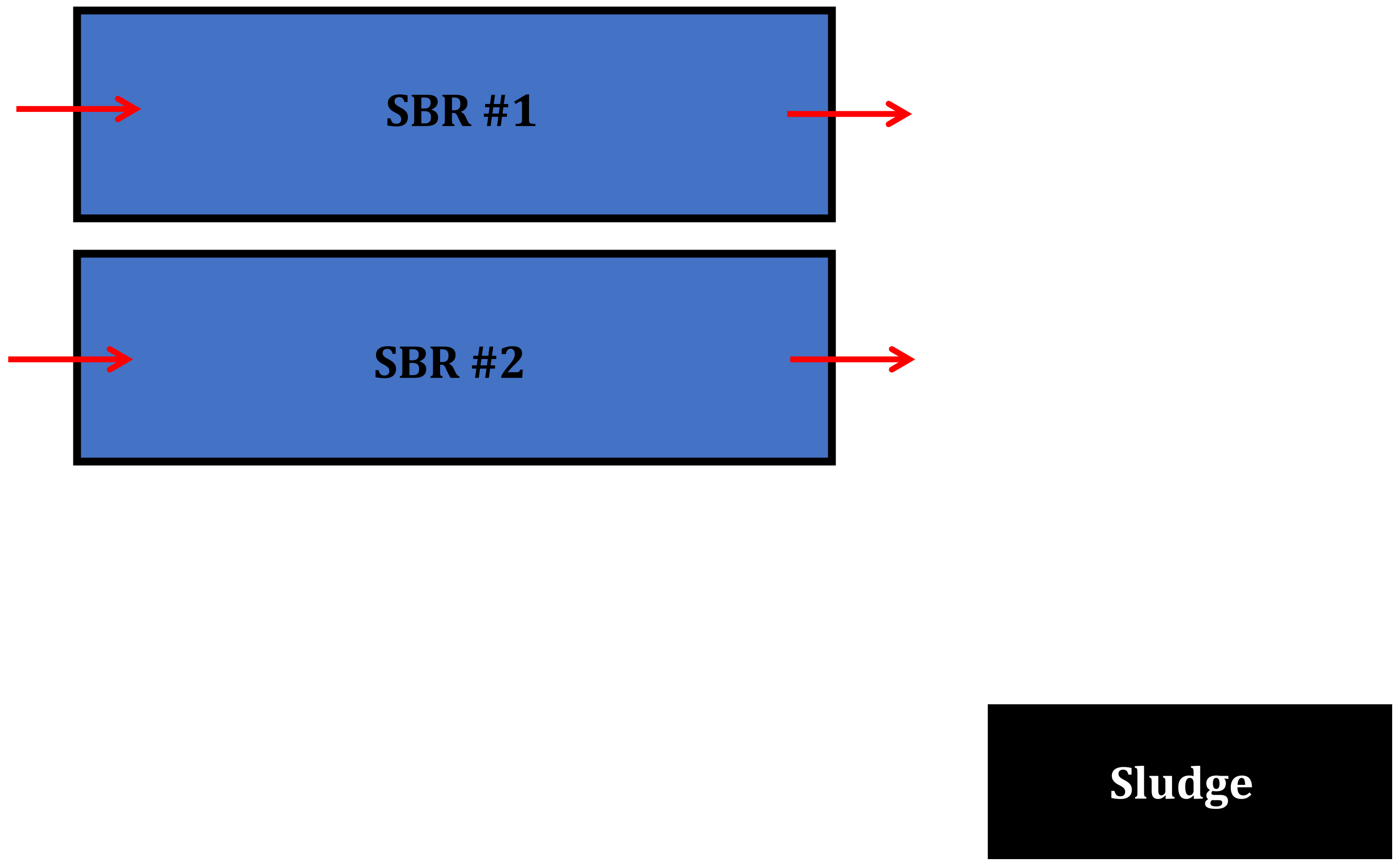
Nitrogen


Questions?
Comments?

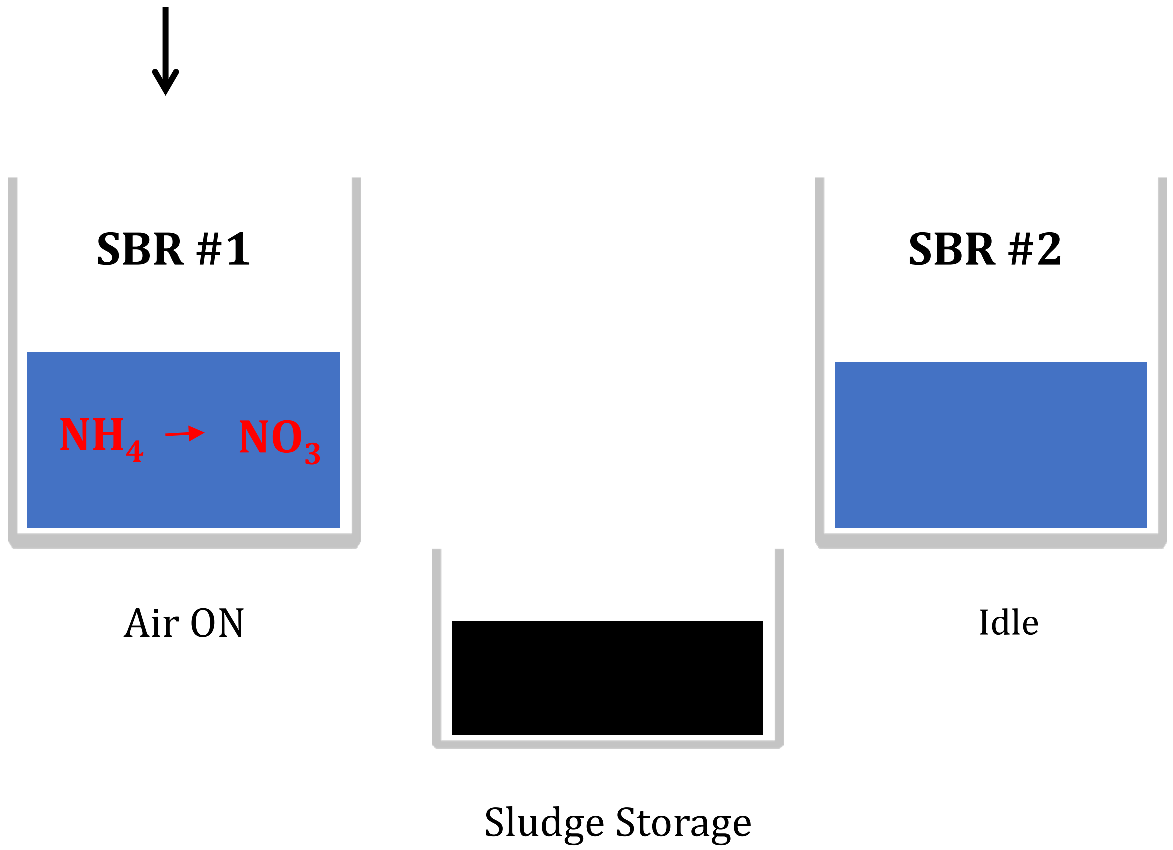

SBr

Conventional Sequencing Batch Reactor (SBR) wwtp

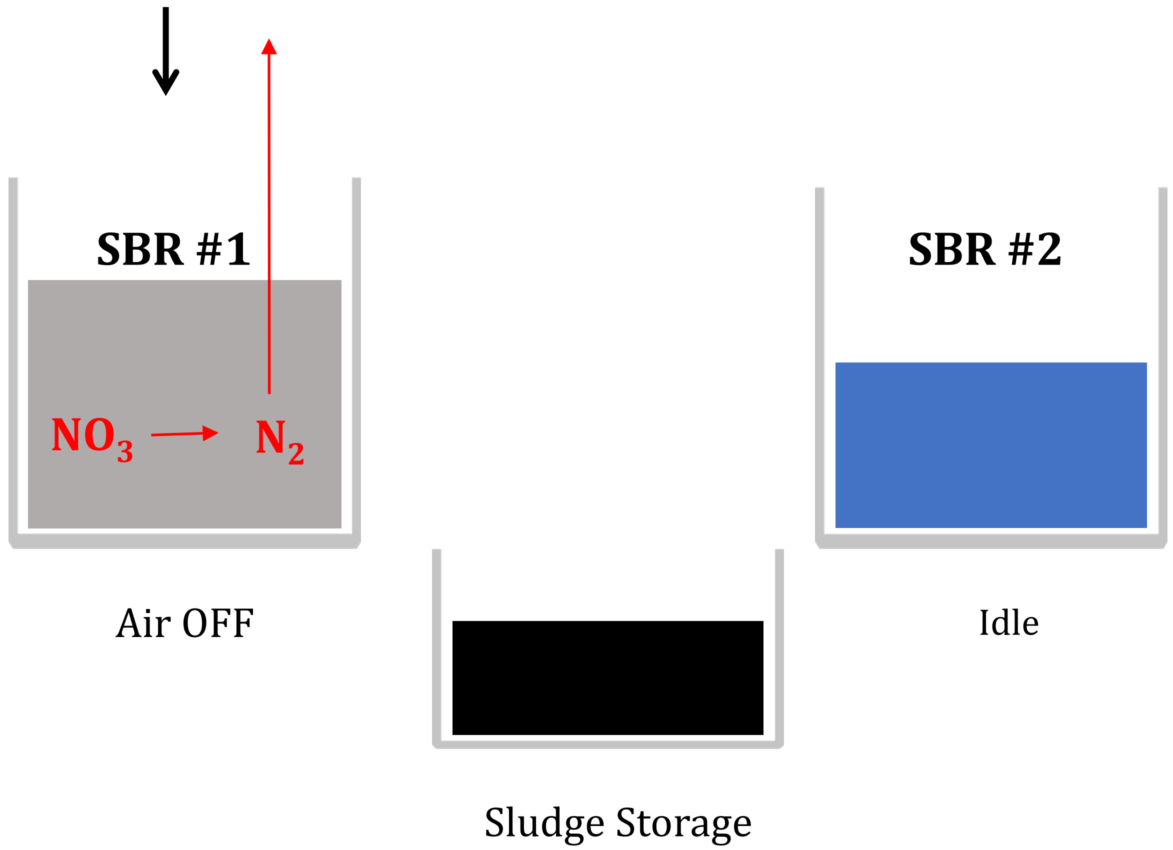
TOP VIEW



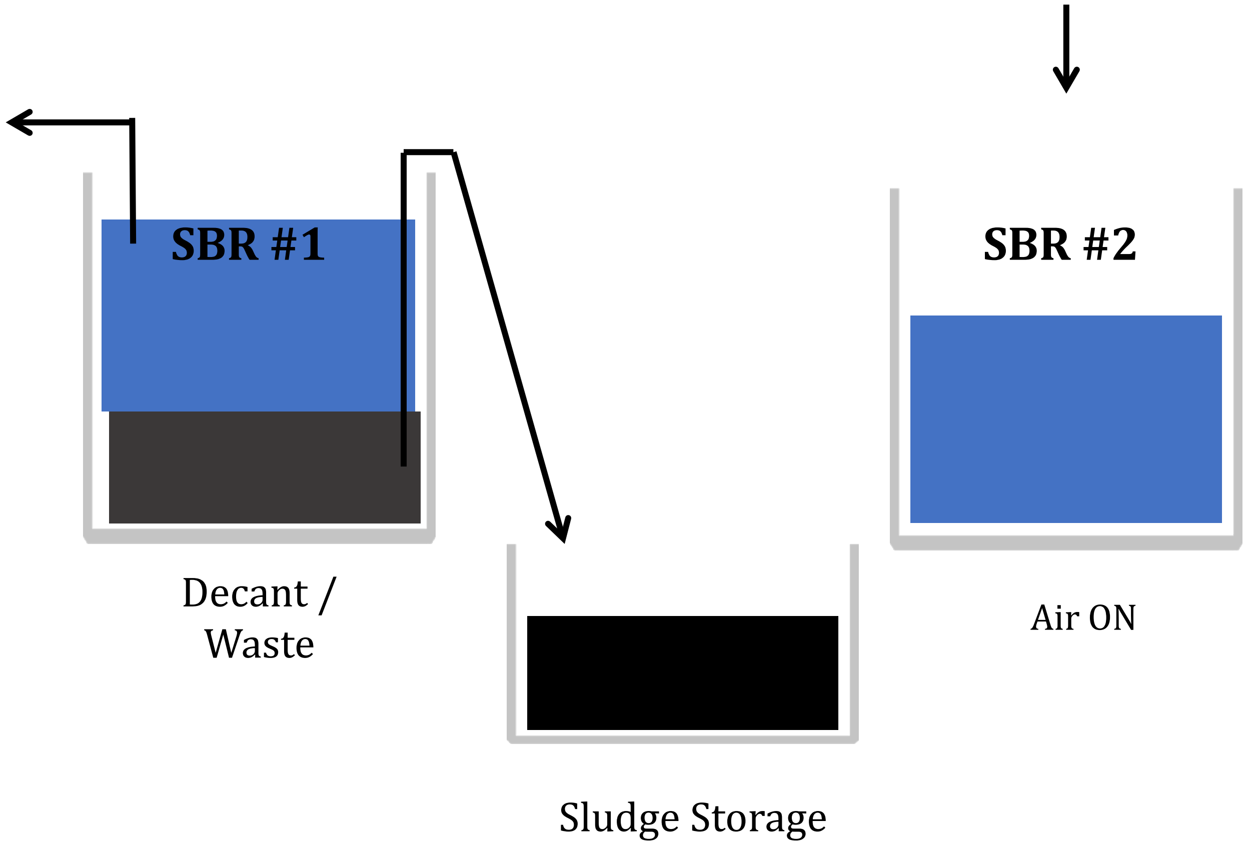
Sequencing Batch Reactor (SBR)
SIDE VIEW
Ammonia (NH_4) Removal: Nitrification



Sequencing Batch Reactor (SBR)
SIDE VIEW
Nitrate (NO_3) Removal: Denitrification



Sequencing Batch Reactor (SBR)
SIDE VIEW
Settle, Decant & Waste Sludge



Establish cycle times that are long enough to provide optimal habitats.

And, short enough to allow all of the flow to be nitrified and denitrified.

Optimizing SBR operations - Nitrogen Removal

<u>Too short</u>

Will not reach +150 mV for Ammonia (NH_4) Removal.

Will not reach -100 mV for Nitrate (NO_3) Removal.

Note: Temperature and BOD affect Air OFF cycle.

<u>Too long</u>

Wastewater will pass through tank before all Ammonia (NH_4) converted to Nitrate (NO_3).

And, before all Nitrate (NO_3) is converted to Nitrogen Gas (N_2).

<u>Just right</u>

Good habitats …

ORP of +150 mV for 30 minutes

And, ORP of -100 mV for 30 minutes.


Questions?
Comments?

Phosphorus

15

P

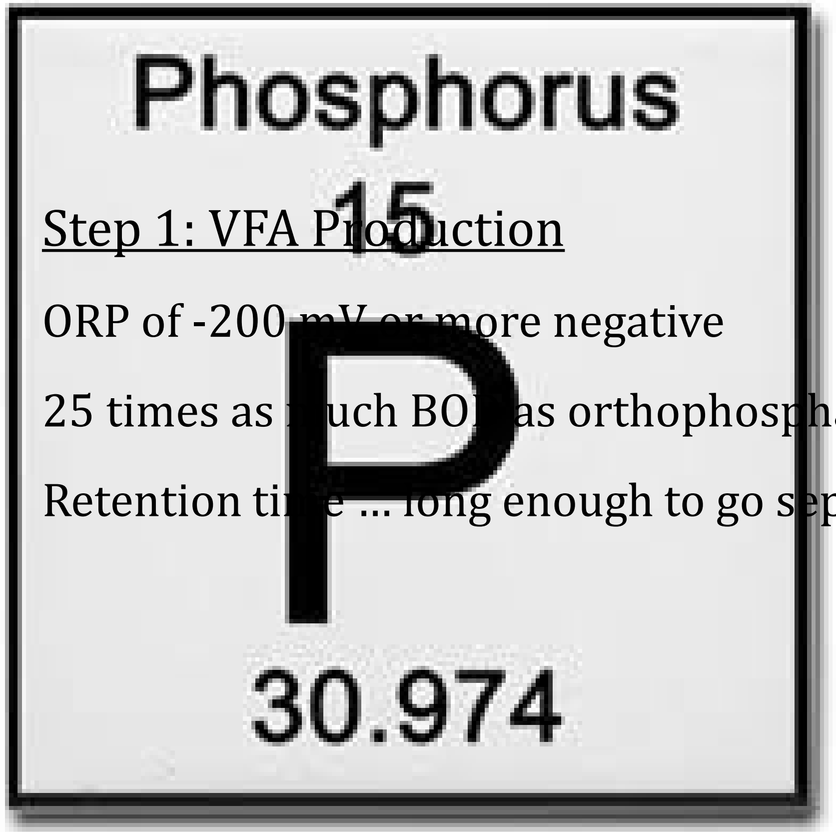
30.974


THREE
steps

Biological Phosphorus Removal

Step 1: prepare "dinner"

VFA (volatile fatty acids) production in septic/fermentive conditions

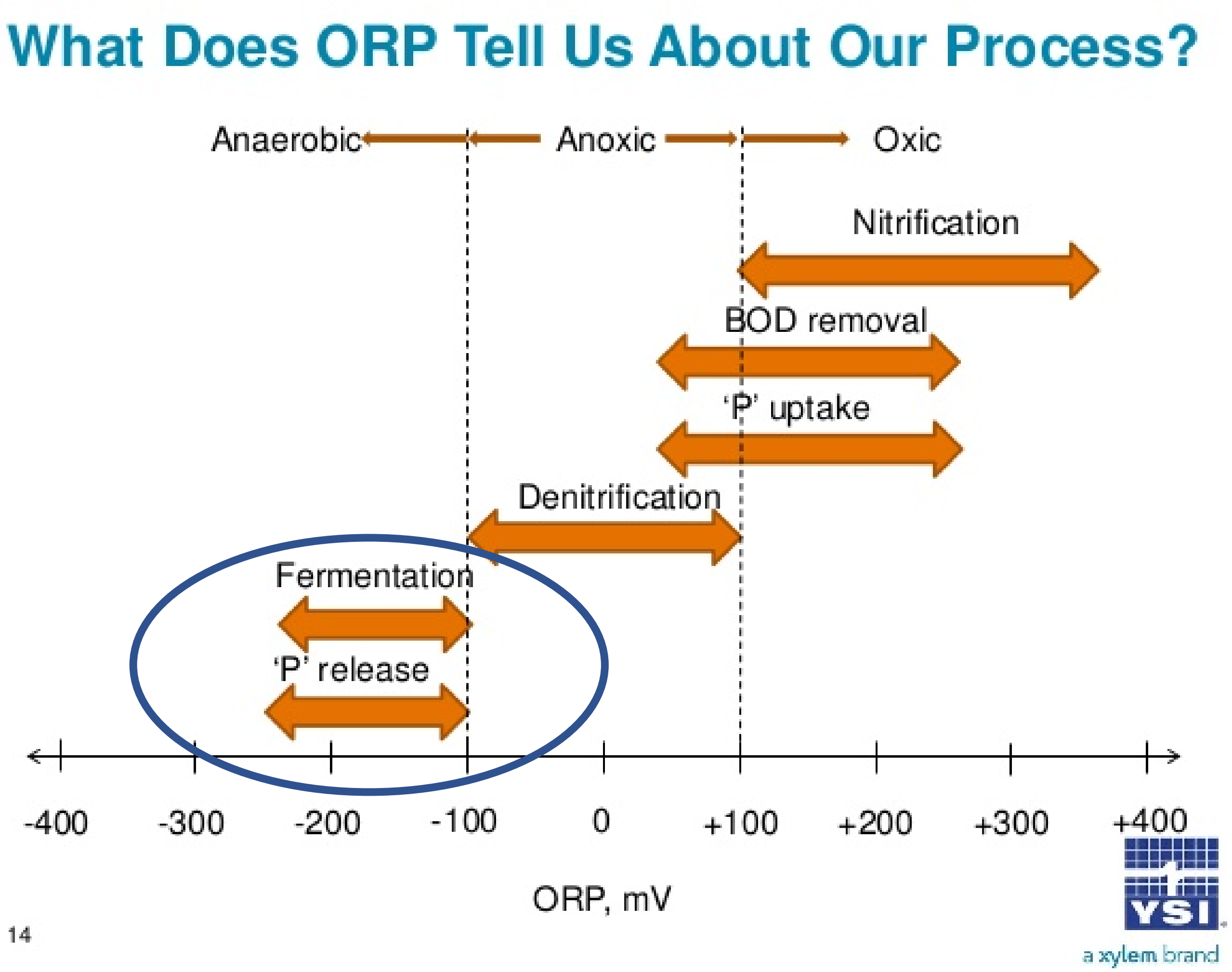


Step 1: VFA Production

ORP of -200 mV or more negative

25 times as much BOD as orthophosphate

Retention time … long enough to go septic



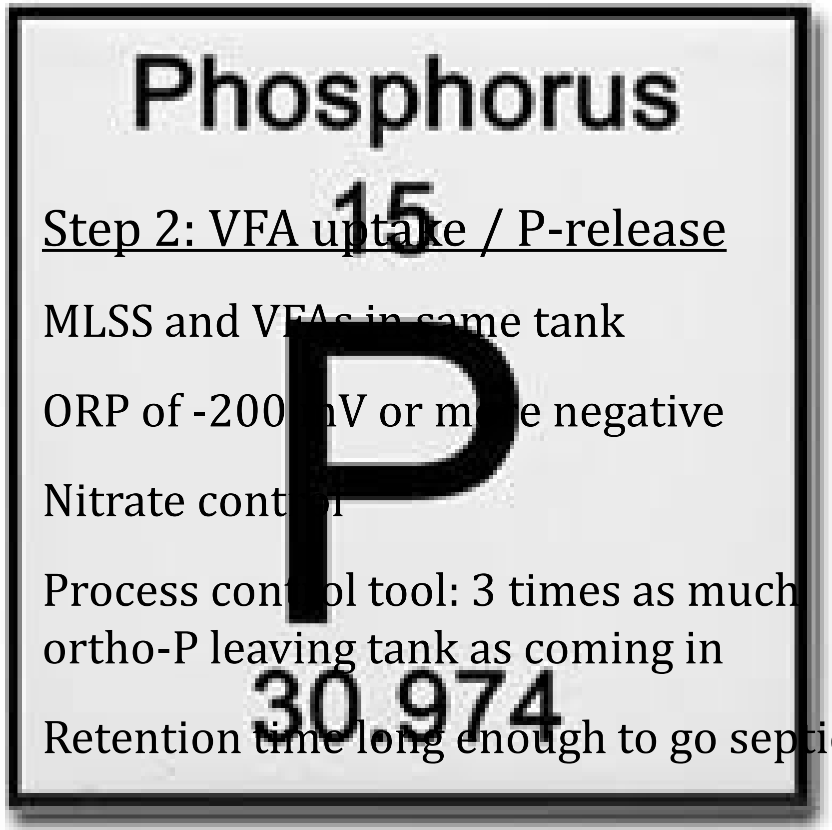
Biological Phosphorus Removal

Step 1: prepare “dinner”

VFA (volatile fatty acids) production in septic/fermentive conditions

Step 2: “eat”

Bio-P bugs (PAOs, “phosphate accumulating organisms”) eat VFAs in anaerobic/fermentive conditions … temporarily releasing more P into the water



Step 2: VFA uptake / P-release

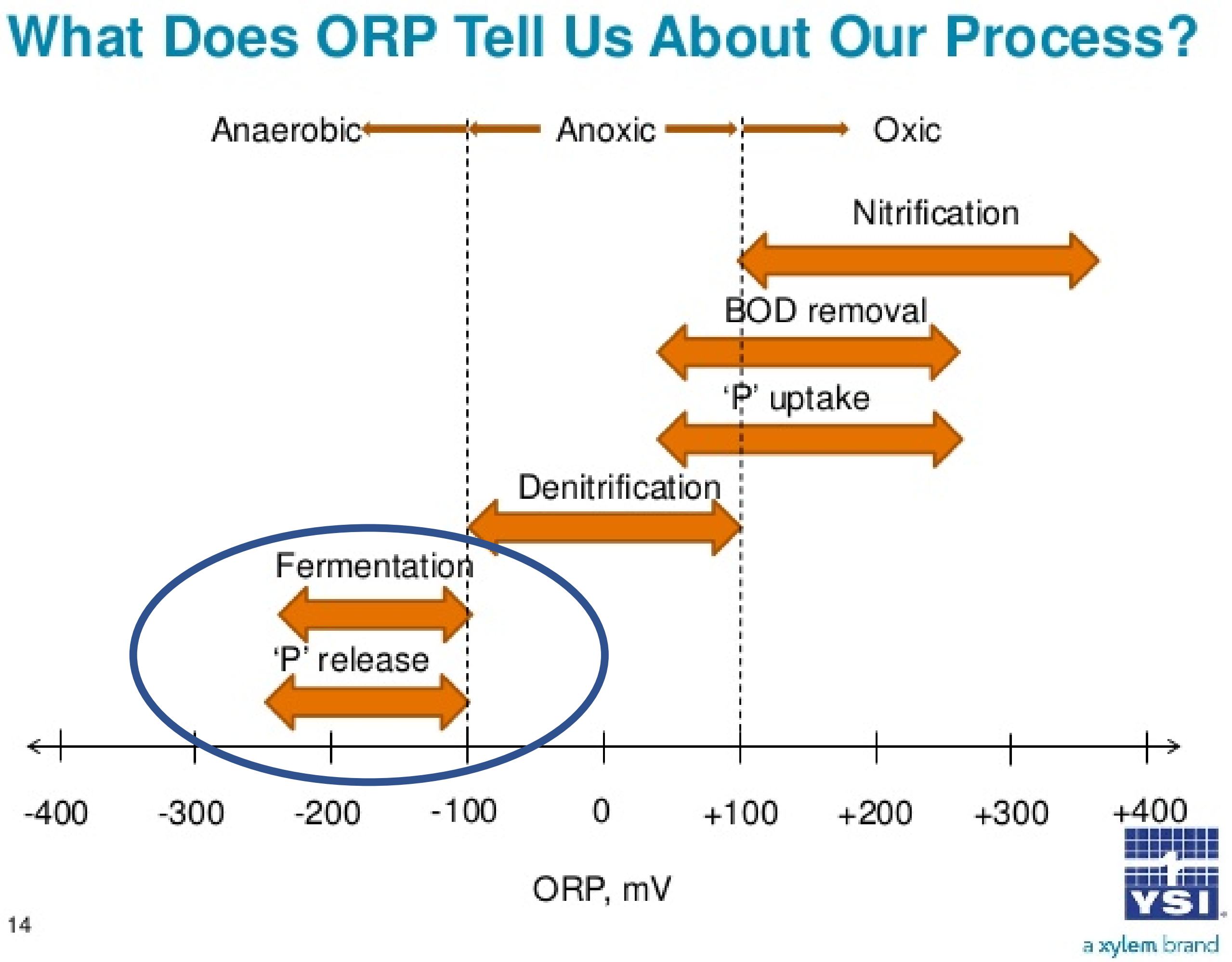
MLSS and VFAs in same tank

ORP of -200 mV or more negative

Nitrate control

Process control tool: 3 times as much ortho-P leaving tank as coming in

Retention time long enough to go septic



Biological Phosphorus Removal

Step 1: prepare "dinner"

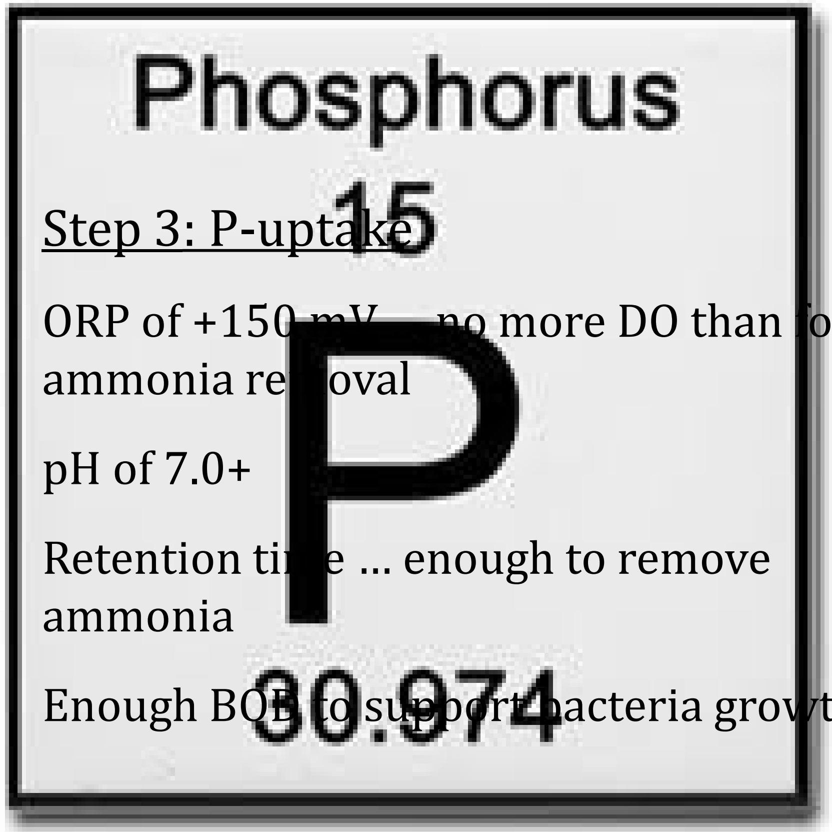
VFA (volatile fatty acids) production in septic/fermentive conditions

Step 2: "eat"

Bio-P bugs (PAOs, "phosphate accumulating organisms") eat VFAs in anaerobic/fermentive conditions … temporarily releasing more P into the water

Step 3: "breathe" and grow

Bio-P bugs (PAOs) take in almost all of the soluble P in aerobic conditions as they grow and reproduce



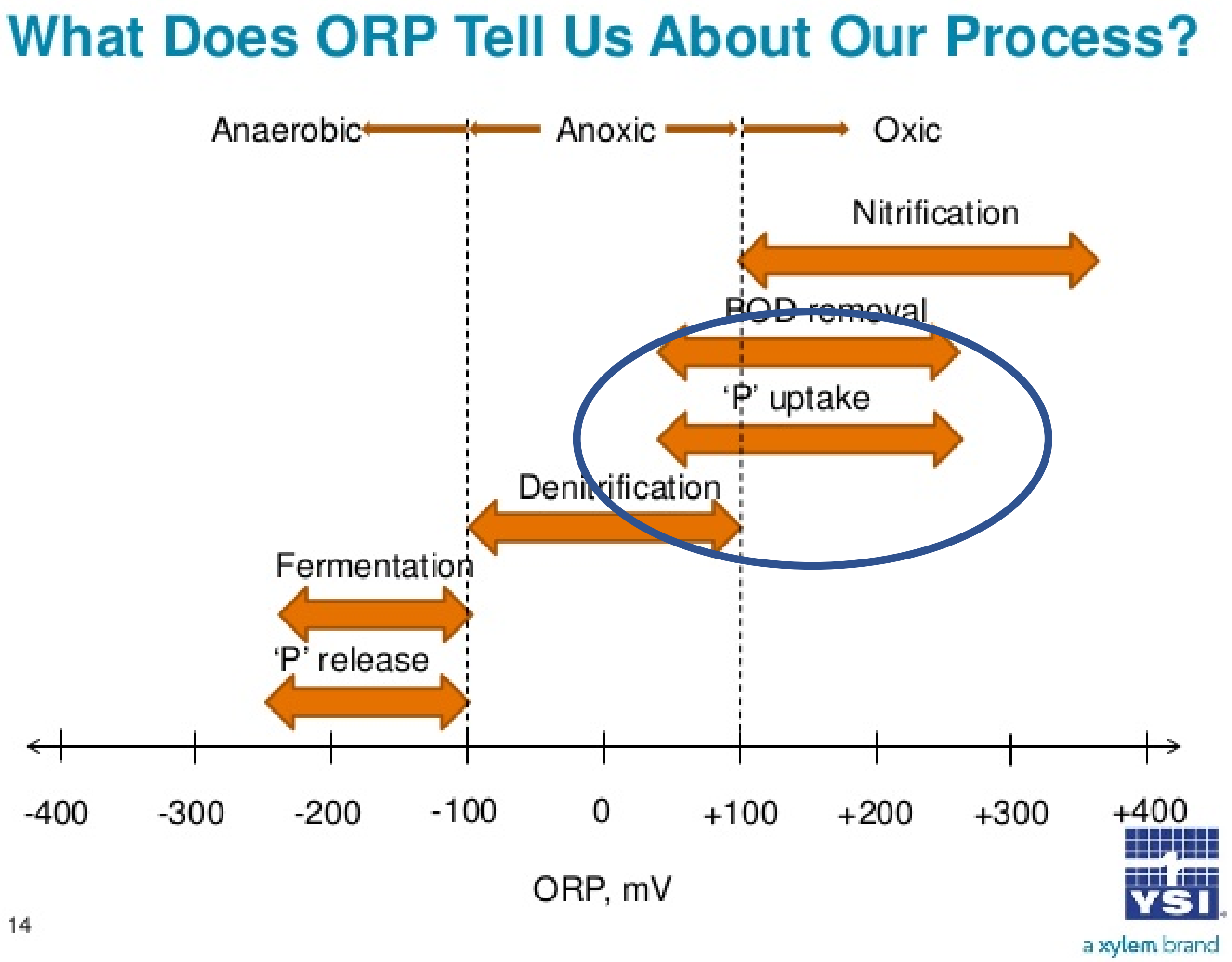
Step 3: P-uptake

ORP of +150 mV … no more DO than for ammonia removal

pH of 7.0+

Retention time … enough to remove ammonia

Enough BOD to support bacteria growth



Optimizing Bio-P Removal: Mainstream or Sidestream Fermentation

<u>Anaerobic Tank</u>

ORP of -200 mV*

25 times as much BOD as influent ortho-P*

Ortho-P release (3 times influent ortho-P)*

<u>Aeration Tank</u>

DO of 2.0 mg/L

ORP of +150 mV

pH of 7.0+*

Ortho-P concentration of 0.05 mg/L*

*Approximate: Every Plant is Different


Questions?
Comments?

Sequencing Batch Reactors

Designed for Nitrogen Removal

Most not designed for Phosphorus Removal

Getting Phosphorus Removal out of SBRs

<u>Mainstream</u>

Turn off mixing to create anaerobic blanket during part or all of air-off cycles
Extend air-off cycle to drop ORP to -200 mV

Proceed with caution: don’t let plant go septic!

<u>Sidestream</u>

Create sidestream fermenter
Cycle 10% of waste sludge (WAS) through fermenter, hold for 2-10 days, return to SBR

Getting Phosphorus Removal out of SBRs

Mainstream

Turn off mixing to create anaerobic blanket during part or all of air-off cycles

Extend air-off cycle to drop ORP to -200 mV

Proceed with caution: don’t let plant go septic!

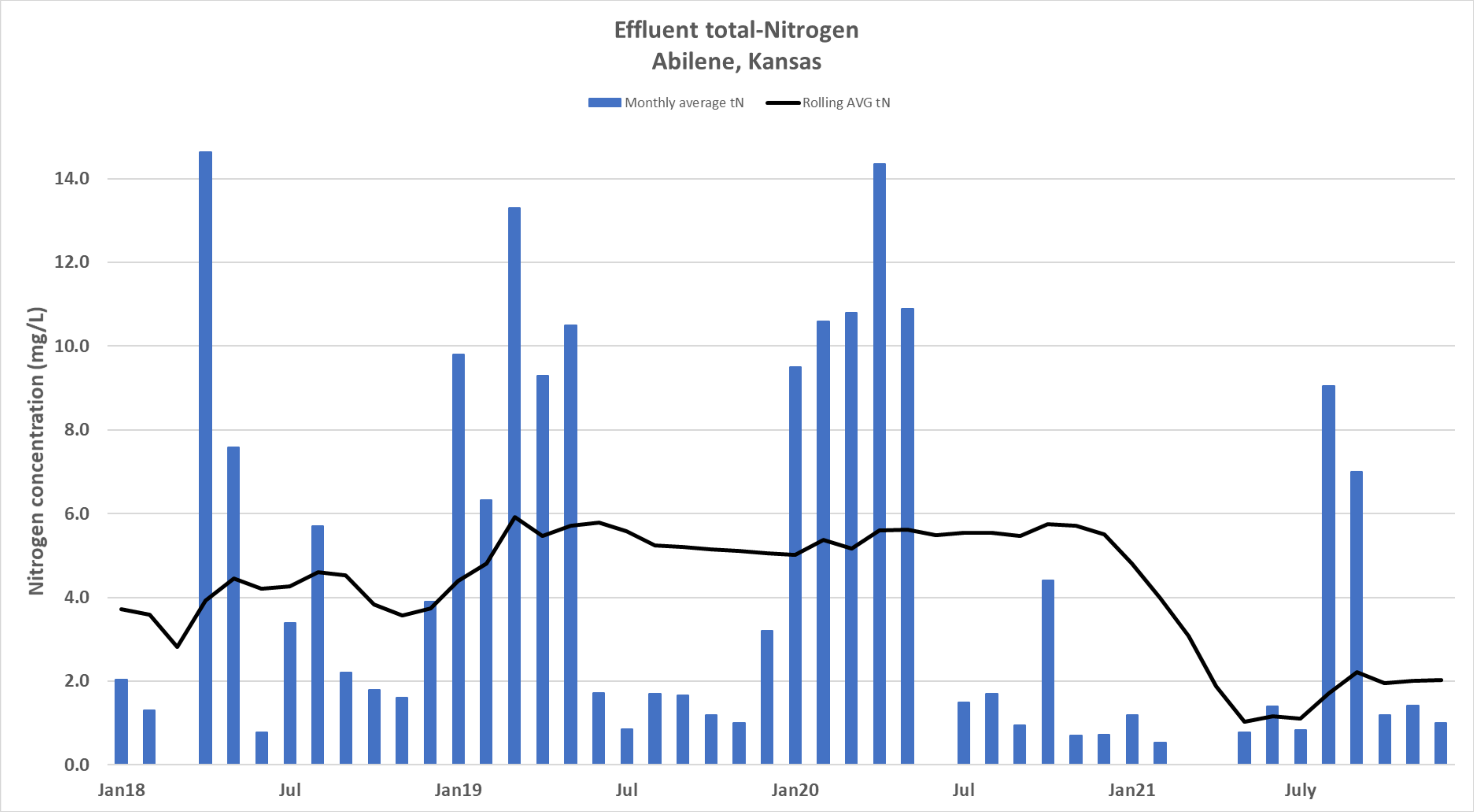
Abilene, Kansas Population: 6,400 1.5 MGD design flow


Abilene Sewer Disposal Plant

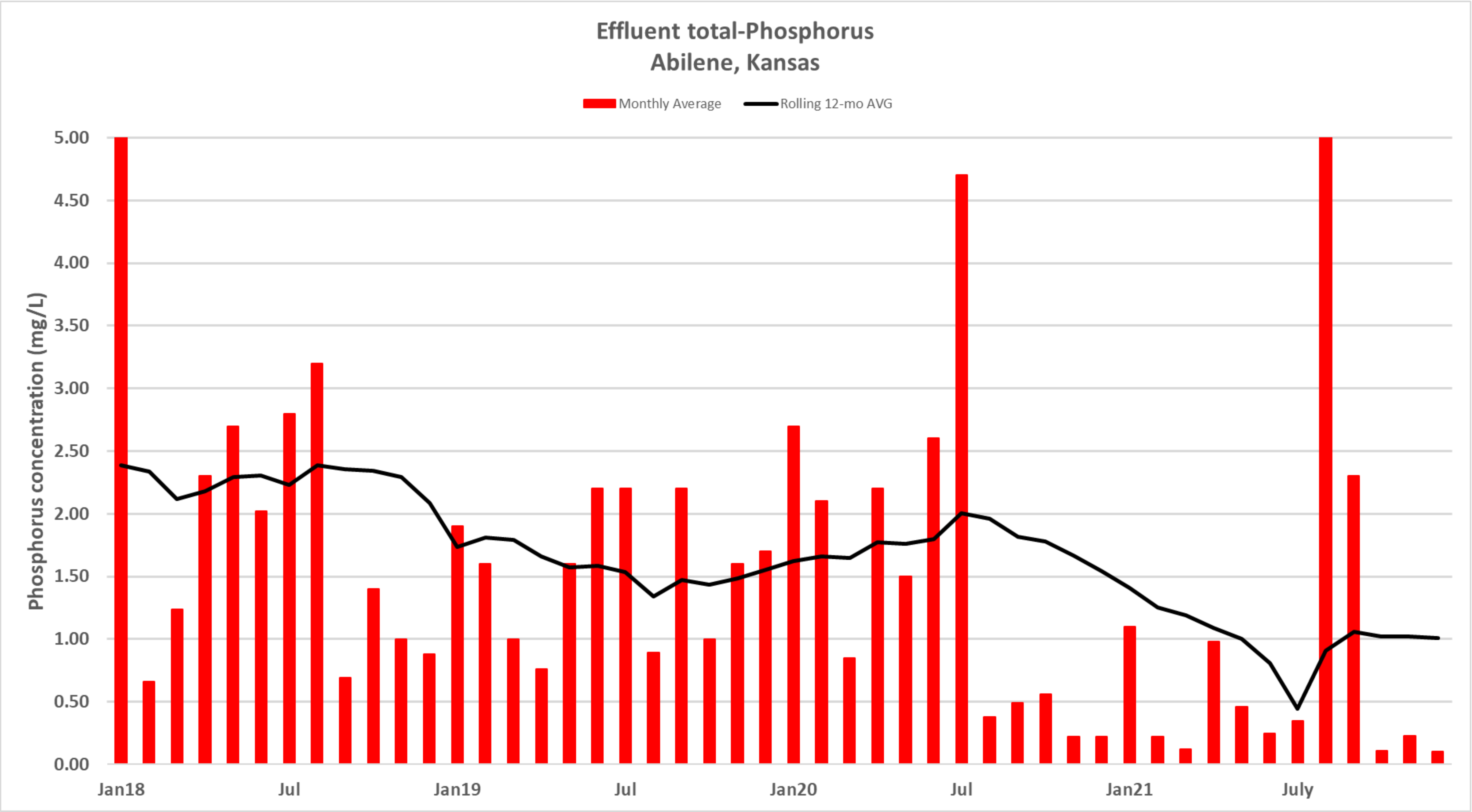
Abilene, Kansas

2021	total-Nitrogen (mg/L)		total-Phosphorus (mg/L)	
	influent	effluent	influent	effluent
Average	**39.6**	**2.0**	**9.0**	**1.01**
Minimum	26.8	0	5.9	0.10
Maximum	47.7	9.1	26.1	5.90

Influent BOD: 390 mg/L



Effluent total-Nitrogen
Abilene, Kansas
Monthly average tN
Rolling AVG tN
Nitrogen concentration (mg/L)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jan18
Jul
Jan19
Jul
Jan20
Jul
Jan21
July


Effluent total-Phosphorus
Abilene, Kansas
Monthly Average
Rolling 12-mo AVG
Phosphorus concentration (mg/L)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Jan18
Jul
Jan19
Jul
Jan20
Jul
Jan21
July


Questions?
Comments?


What do you
think?

Getting Phosphorus Removal out of SBRs

Mainstream

Turn off mixing to create anaerobic blanket during part or all of air-off cycles

Extend air-off cycle to drop ORP to -200 mV

Proceed with caution: don’t let plant go septic!

Sidestream

Create sidestream fermenter

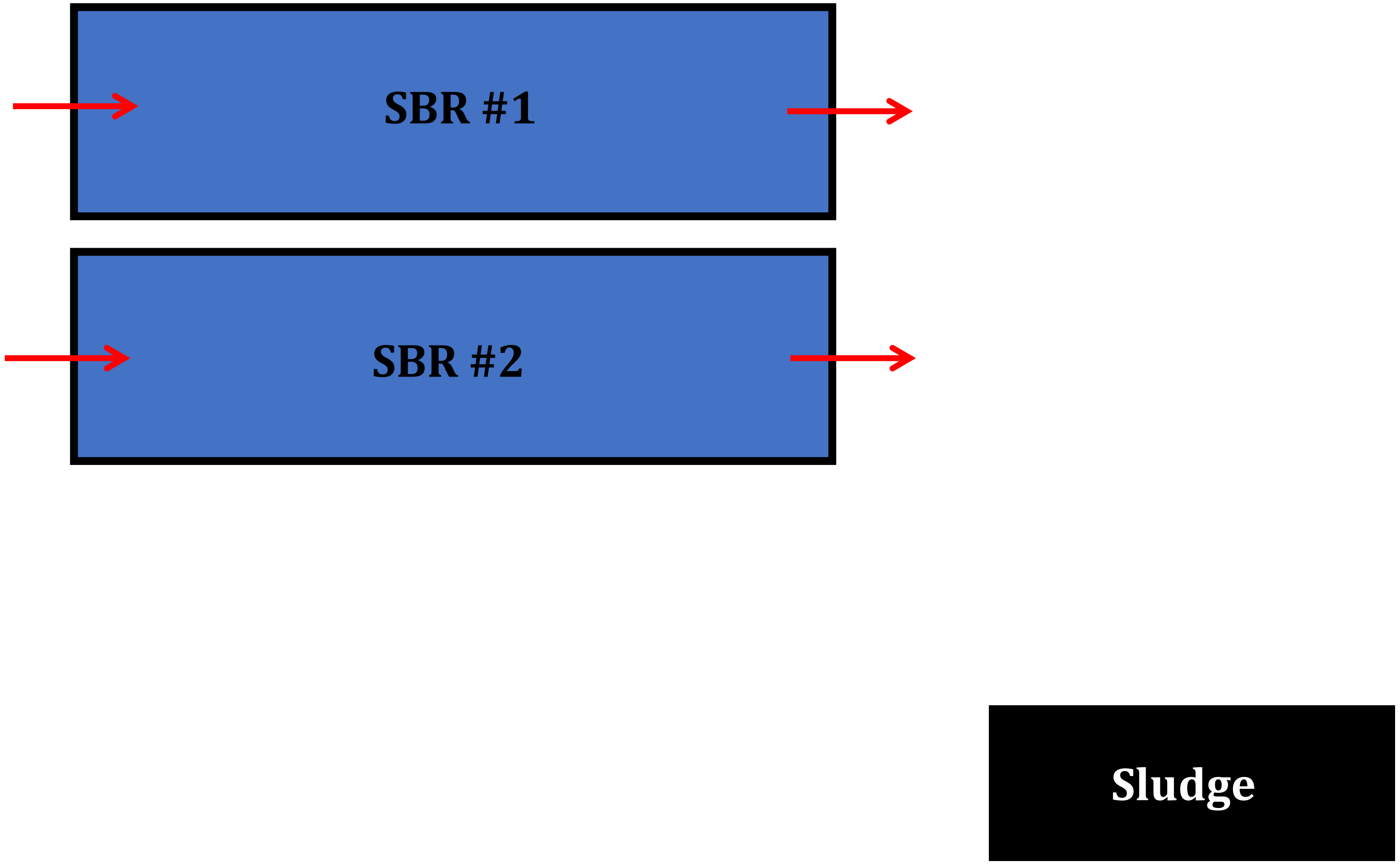
Cycle 10% of waste sludge (WAS) through fermenter, hold for 2-10 days, return to SBR

Getting creative …

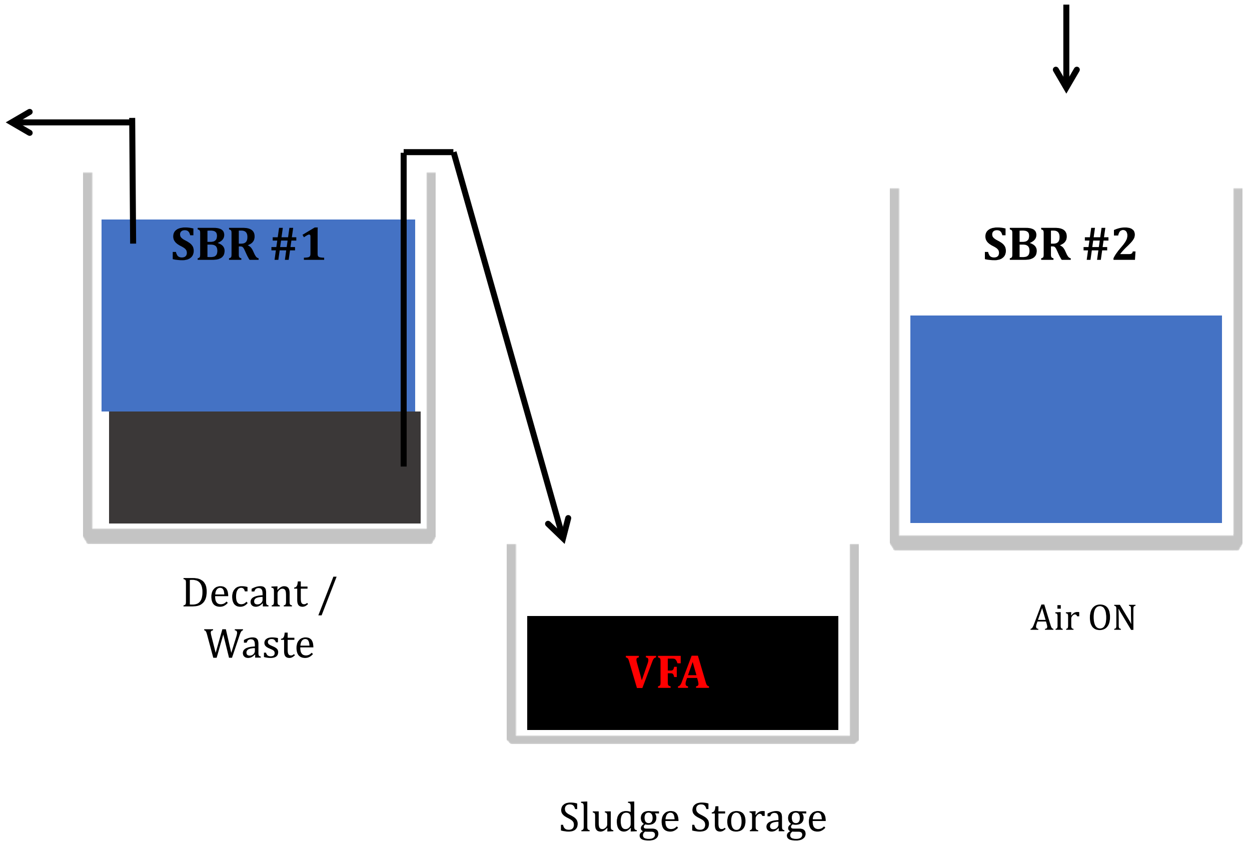
Sidestream Biological Phosphorus removal for SBRs not designed for Phosphorus removal

Conventional Sequencing Batch Reactor (SBR) wwtp

TOP VIEW

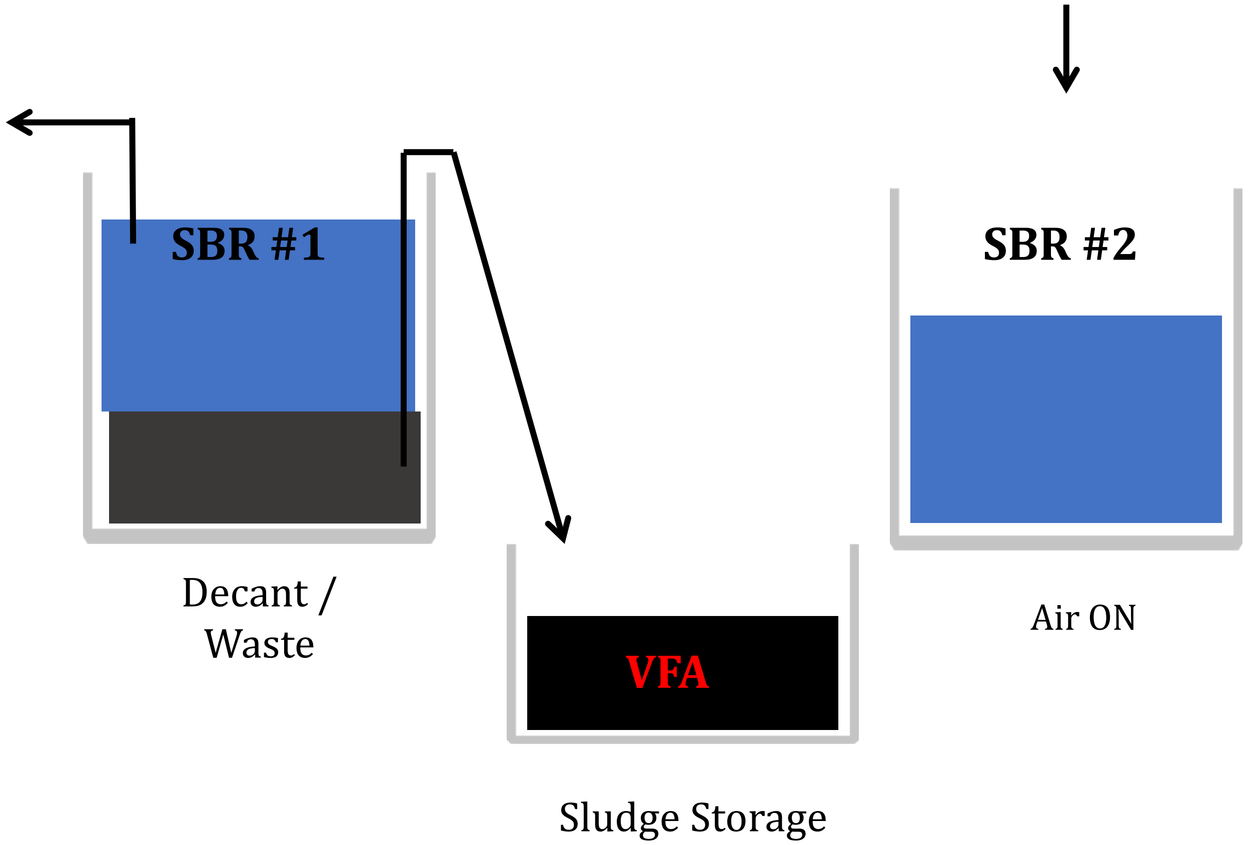


Sequencing Batch Reactor (SBR)
SIDE VIEW
Ferment Waste Sludge



In septic conditions, VFAs are formed.

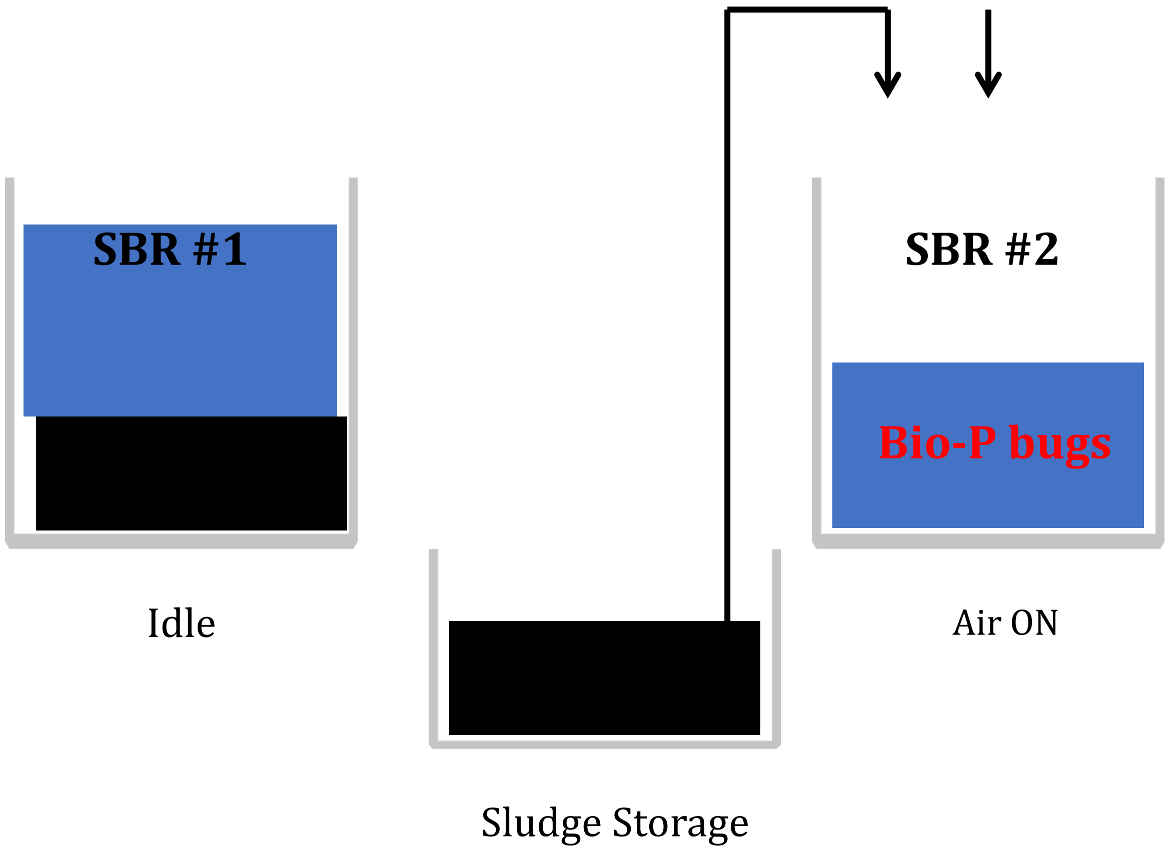
Sequencing Batch Reactor (SBR)
SIDE VIEW
Ferment Waste Sludge



In septic conditions, VFAs are formed.

Bio-P bugs living in the waste sludge feed on the VFAs.

Sequencing Batch Reactor (SBR)
SIDE VIEW
Aerate VFA-enriched bio-P bugs



In septic conditions, VFAs are formed.

Bio-P bugs living in the waste sludge feed on the VFAs.

~10% of bio-P rich sludge returned to SBR.

Bio-P bugs “eat” phosphorus as they grow during air-ON cycle.

Questions?
Comments?

SHALL WE BEGIN

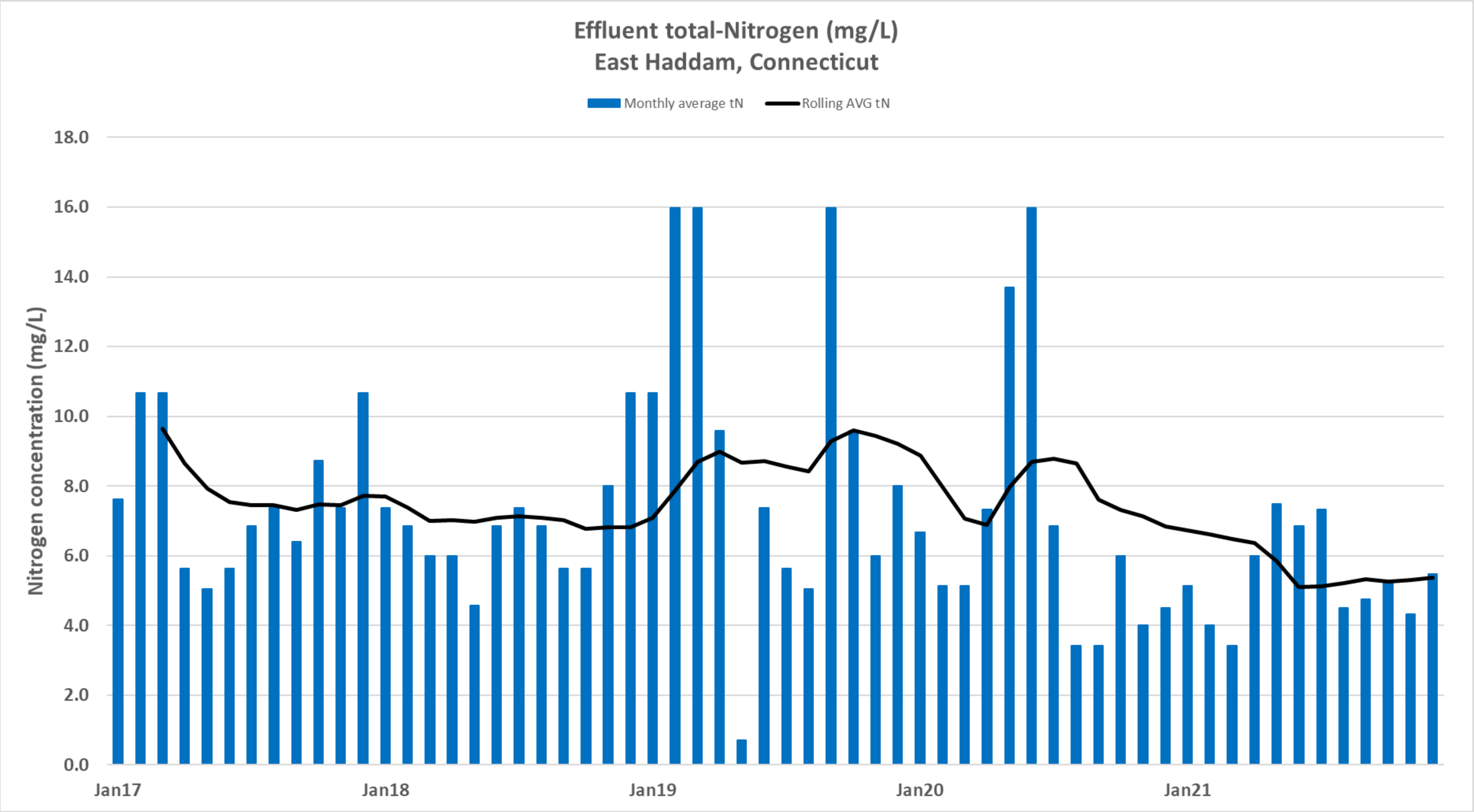

East Haddam, Connecticut

East Haddam, Connecticut Population: 9,000 0.055 MGD design flow

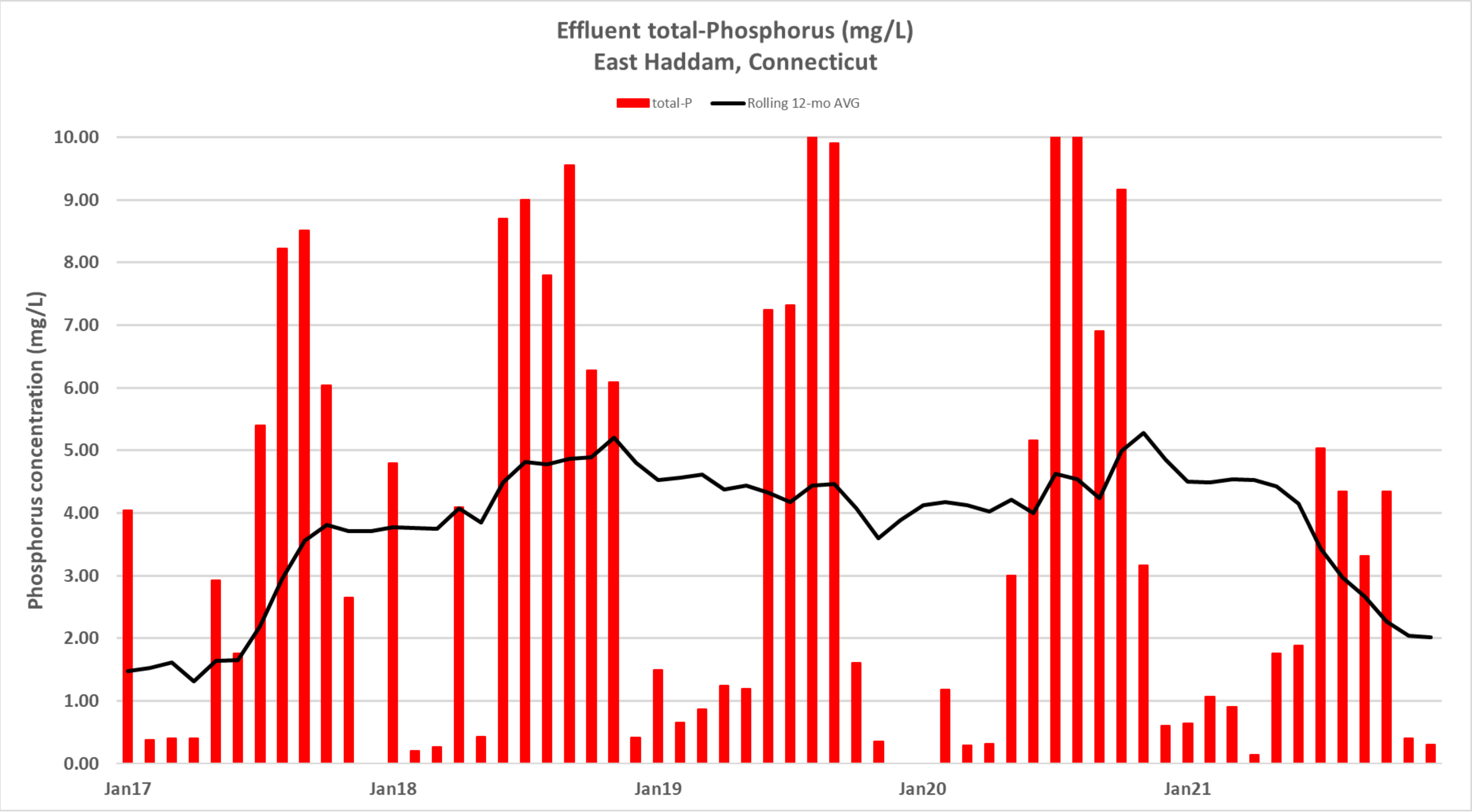
East Haddam, Connecticut

2021	total-Nitrogen		TKN		NH_3		NO_3-NO_2		total-Phosphorus	
	influent	effluent	influent	effluent	influent	effluent	influent	effluent	influent	effluent
Average	**61.3**	**5.4**	**60.6**	**1.8**	**46.6**	**0.3**	**0.9**	**3.7**	**7.3**	**2.02**
Minimum	45.9	3.4	45.8	1.3	37.5	0.1	0.1	2.9	4.8	0.14
Maximum	102.8	7.5	99.5	2.2	59.1	0.5	4.1	4.9	12.7	5.04

Influent BOD: 185 mg/L



Effluent total-Nitrogen (mg/L)
East Haddam, Connecticut
Monthly average tN
Rolling AVG tN
Nitrogen concentration (mg/L)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jan17
Jan18
Jan19
Jan20
Jan21



Effluent total-Phosphorus (mg/L)
East Haddam, Connecticut
total-P
Rolling 12-mo AVG
Phosphorus concentration (mg/L)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Jan17
Jan18
Jan19
Jan20
Jan21

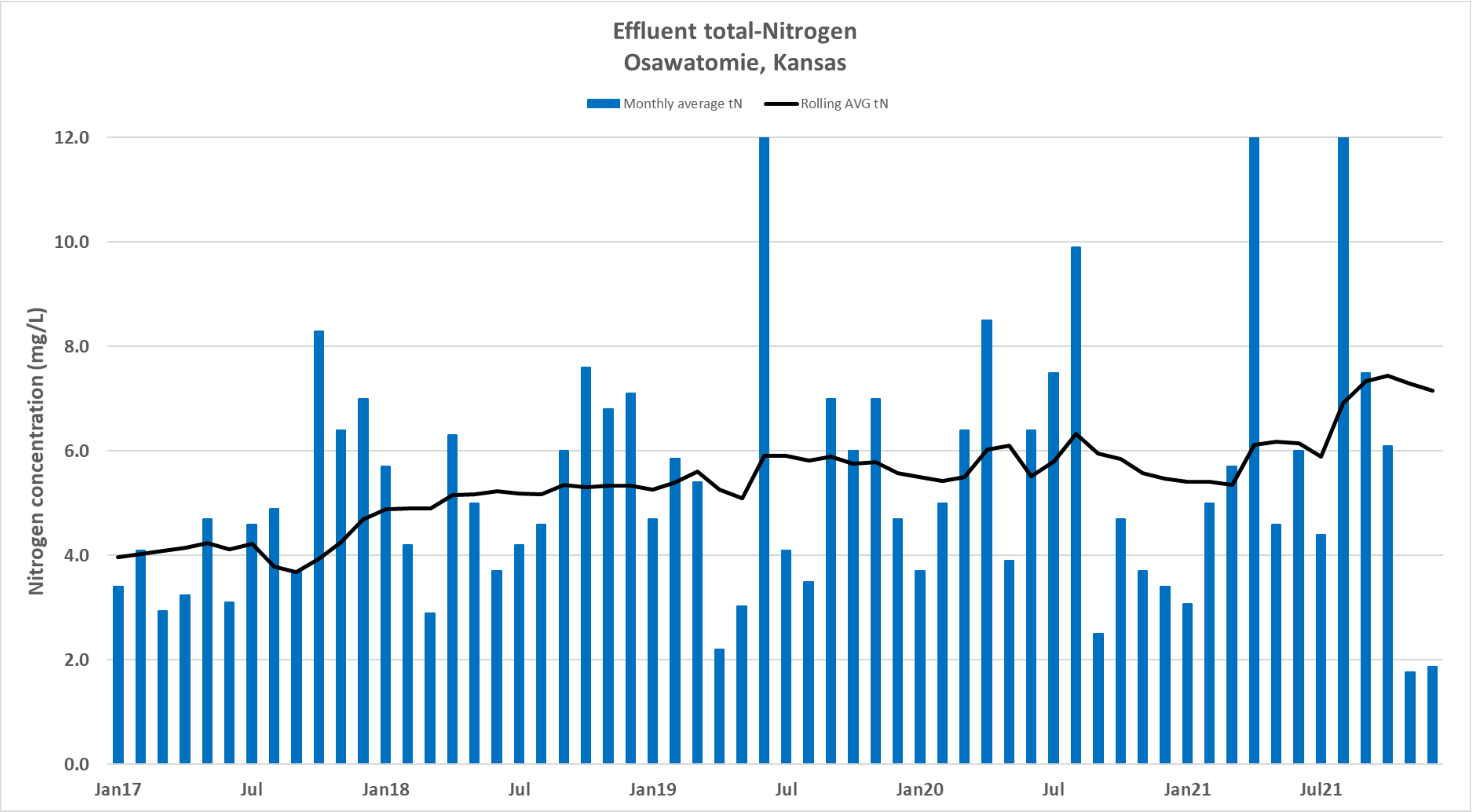

Questions?
Comments?

Osawatomie, Kansas Population: 4,300 0.56 MGD design flow

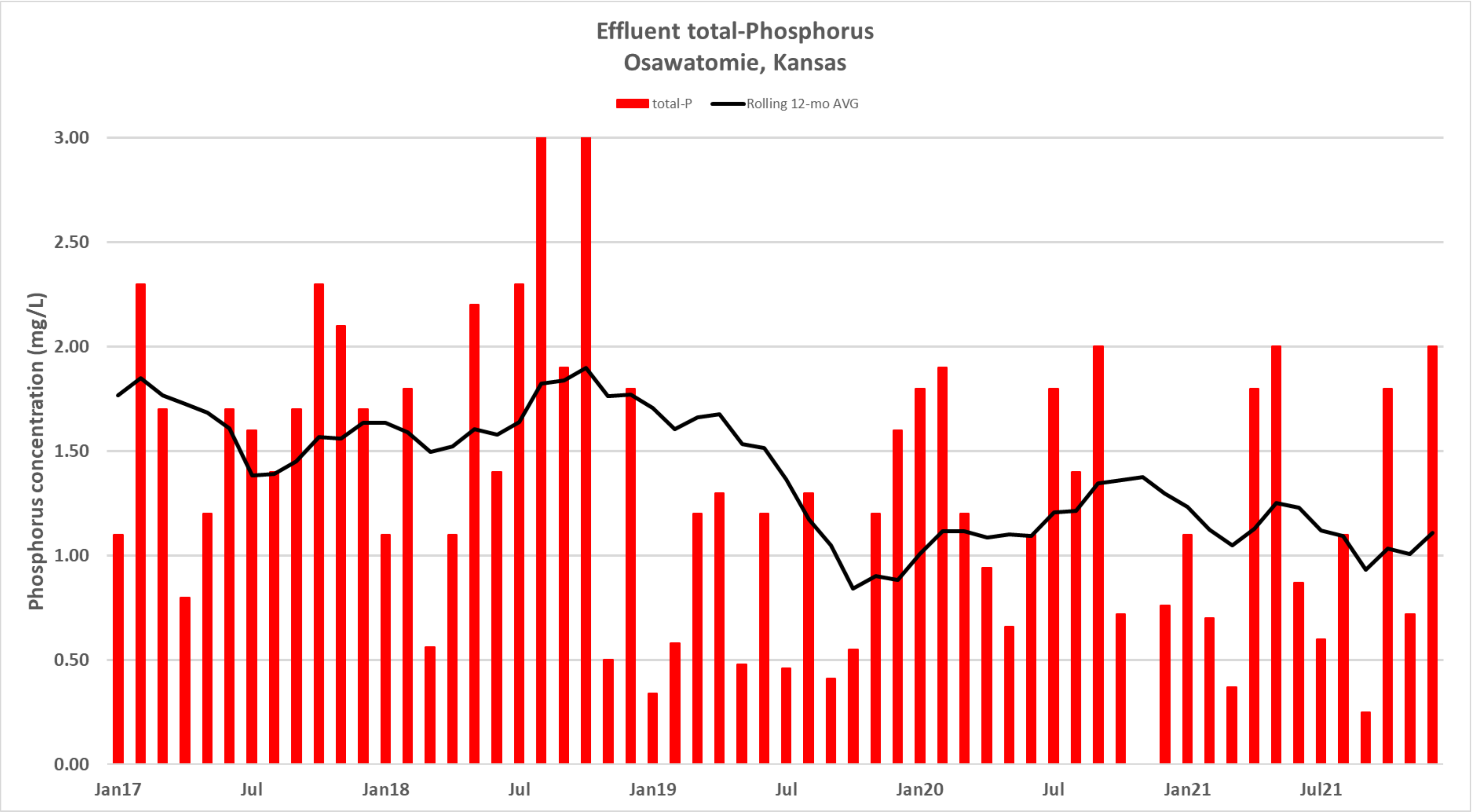
Osawatomie, Kansas

2021	**total-Nitrogen** (mg/L)		**total-Phosphorus** (mg/L)	
	influent	effluent	influent	effluent
Average	**22.5**	**7.2**	**2.6**	**1.11**
Minimum	11.2	1.8	1.2	0.25
Maximum	31.1	22.2	4.4	2.00

Influent BOD: 60 mg/L

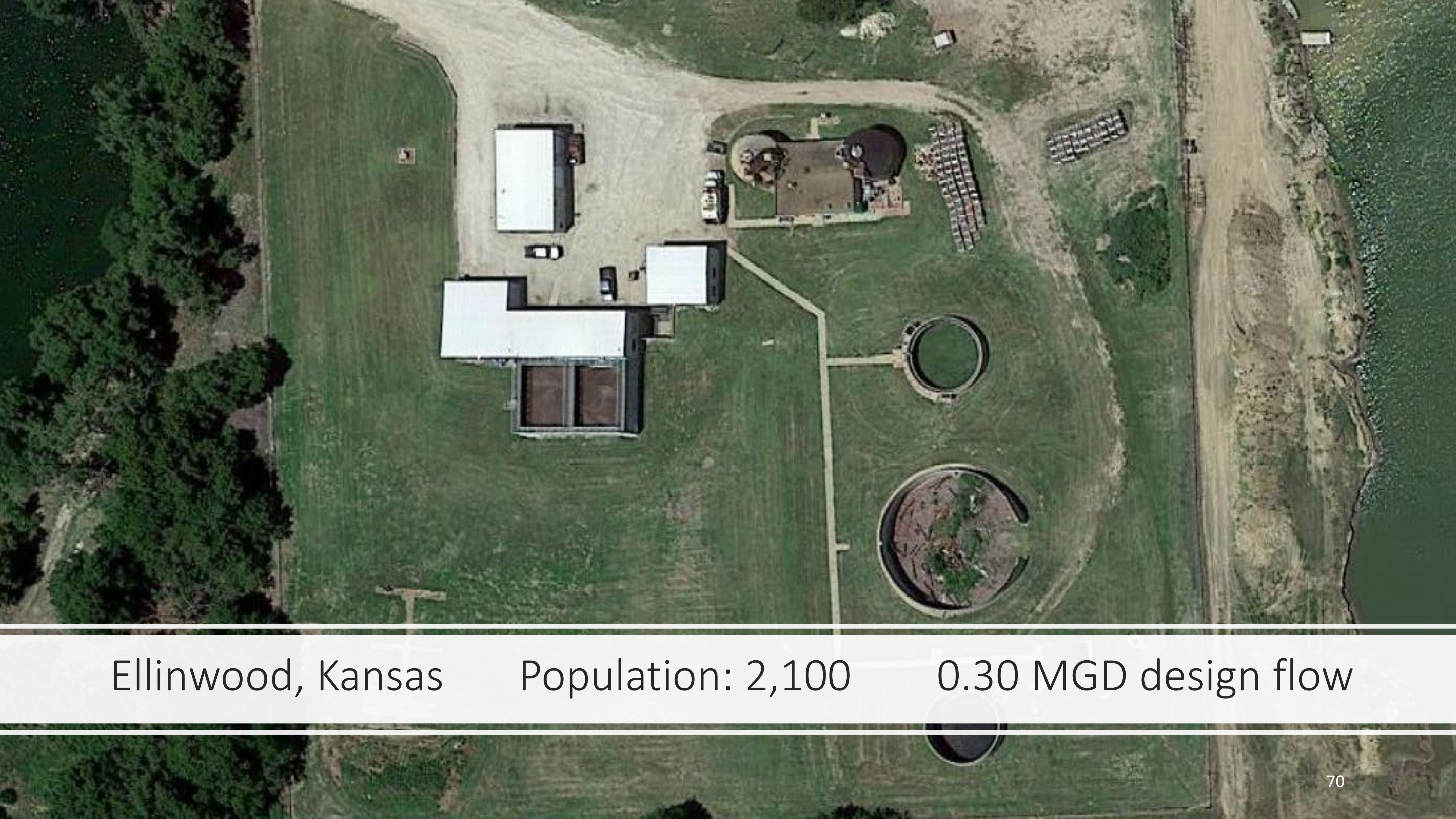


Effluent total-Nitrogen
Osawatomie, Kansas
Monthly average tN
Rolling AVG tN
Nitrogen concentration (mg/L)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jan17
Jul
Jan18
Jul
Jan19
Jul
Jan20
Jul
Jan21
Jul21



Effluent total-Phosphorus
Osawatomie, Kansas
total-P
Rolling 12-mo AVG
Phosphorus concentration (mg/L)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Jan17
Jul
Jan18
Jul
Jan19
Jul
Jan20
Jul
Jan21
Jul21


Questions?
Comments?

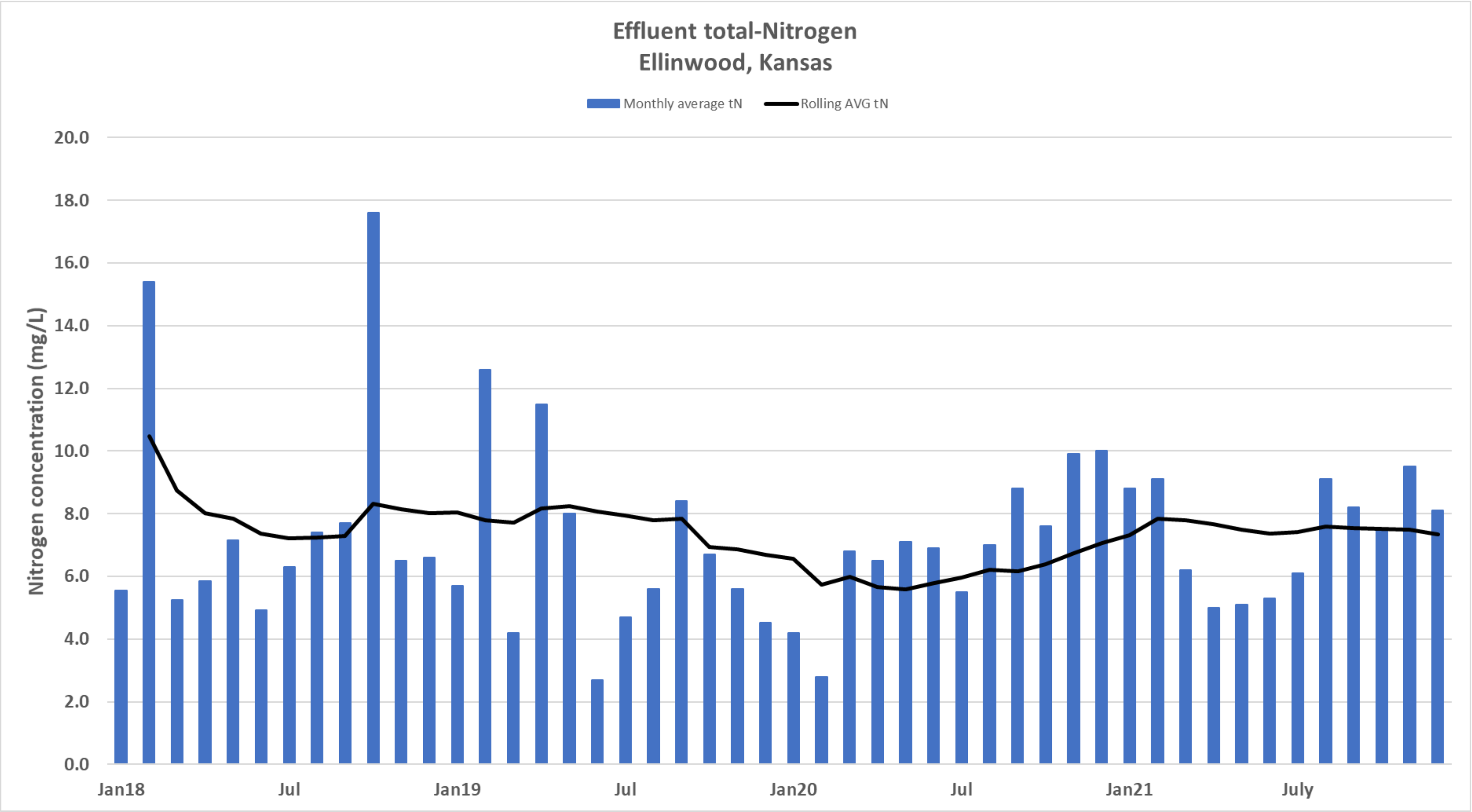


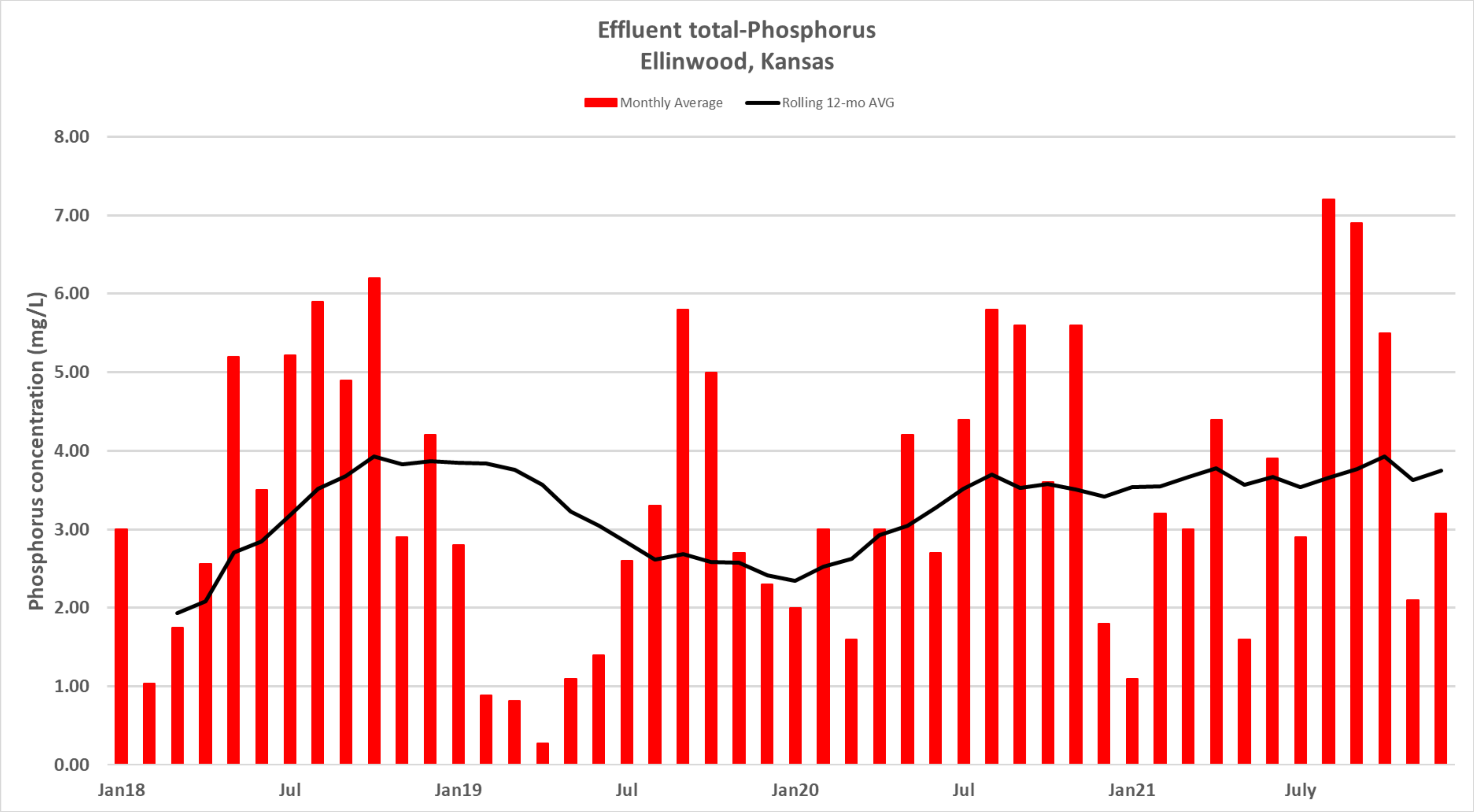
Ellinwood, Kansas Population: 2,100 0.30 MGD design flow

Ellinwood, Kansas

2021	**total-Nitrogen** (mg/L)		**total-Phosphorus** (mg/L)	
	influent	effluent	influent	effluent
Average	**37.7**	**7.3**	**6.2**	**3.75**
Minimum	25.5	5.0	4.1	1.10
Maximum	52.3	9.5	11.2	7.20

Influent BOD: 145 mg/L


Effluent total-Nitrogen
Ellinwood, Kansas
Monthly average tN
Rolling AVG tN
Nitrogen concentration (mg/L)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jan18
Jul
Jan19
Jul
Jan20
Jul
Jan21
July


Effluent total-Phosphorus
Ellinwood, Kansas
Monthly Average
Rolling 12-mo AVG
Phosphorus concentration (mg/L)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Jan18
Jul
Jan19
Jul
Jan20
Jul
Jan21
July

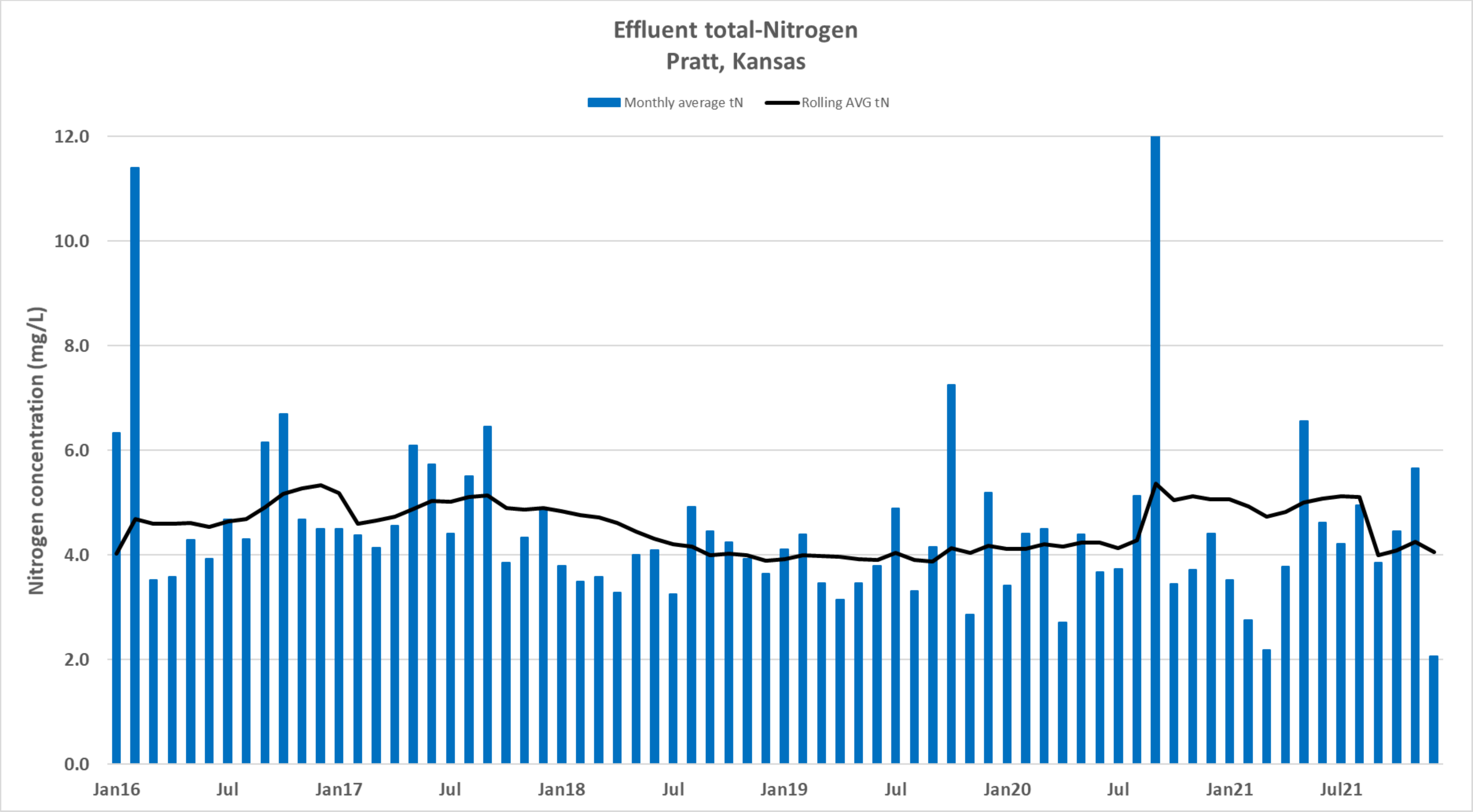

Questions?
Comments?

Pratt, Kansas Population: 6,600 1.0 MGD design flow

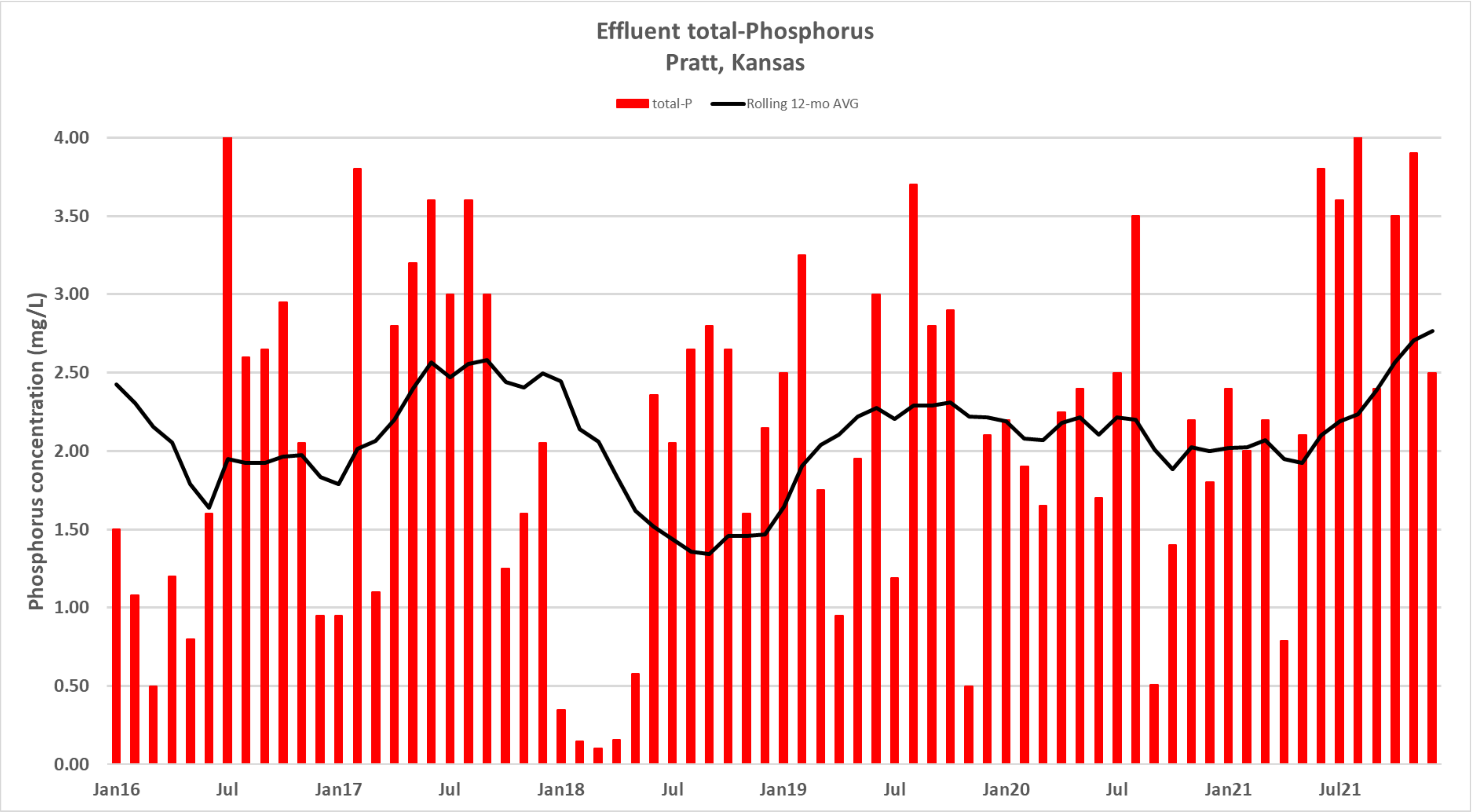
Pratt, Kansas

2021	**total-Nitrogen** (mg/L)		**total-Phosphorus** (mg/L)	
	influent	effluent	influent	effluent
Average	**44.4**	**4.1**	**6.5**	**2.77**
Minimum	35.0	2.1	3.4	0.79
Maximum	58.8	6.6	9.8	4.00

Influent BOD: 215 mg/L

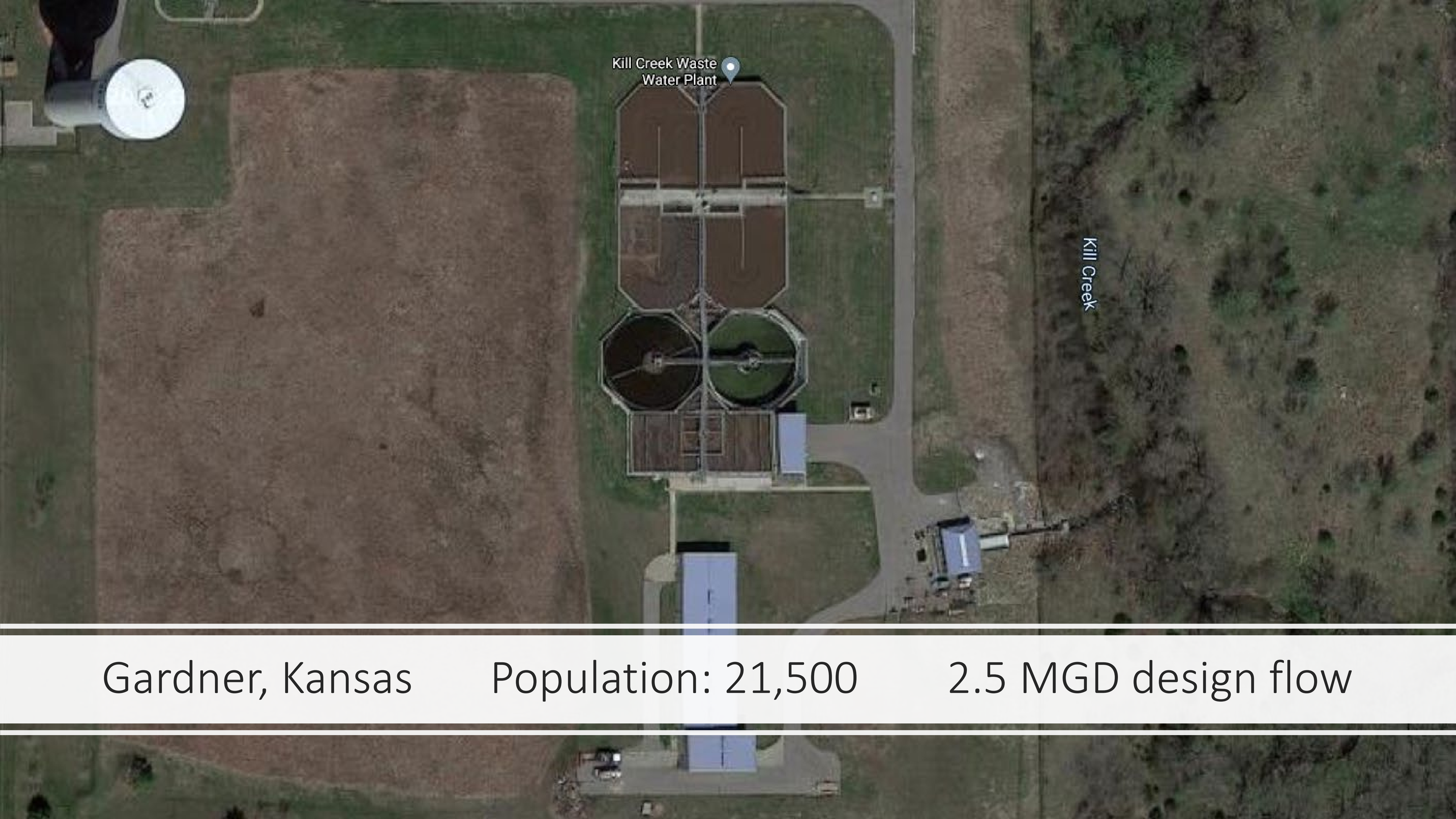


Effluent total-Nitrogen
Pratt, Kansas
Monthly average tN
Rolling AVG tN
Nitrogen concentration (mg/L)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jan16
Jul
Jan17
Jul
Jan18
Jul
Jan19
Jul
Jan20
Jul
Jan21
Jul21



Effluent total-Phosphorus
Pratt, Kansas
total-P
Rolling 12-mo AVG
Phosphorus concentration (mg/L)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Jan16
Jul
Jan17
Jul
Jan18
Jul
Jan19
Jul
Jan20
Jul
Jan21
Jul21


Questions?
Comments?



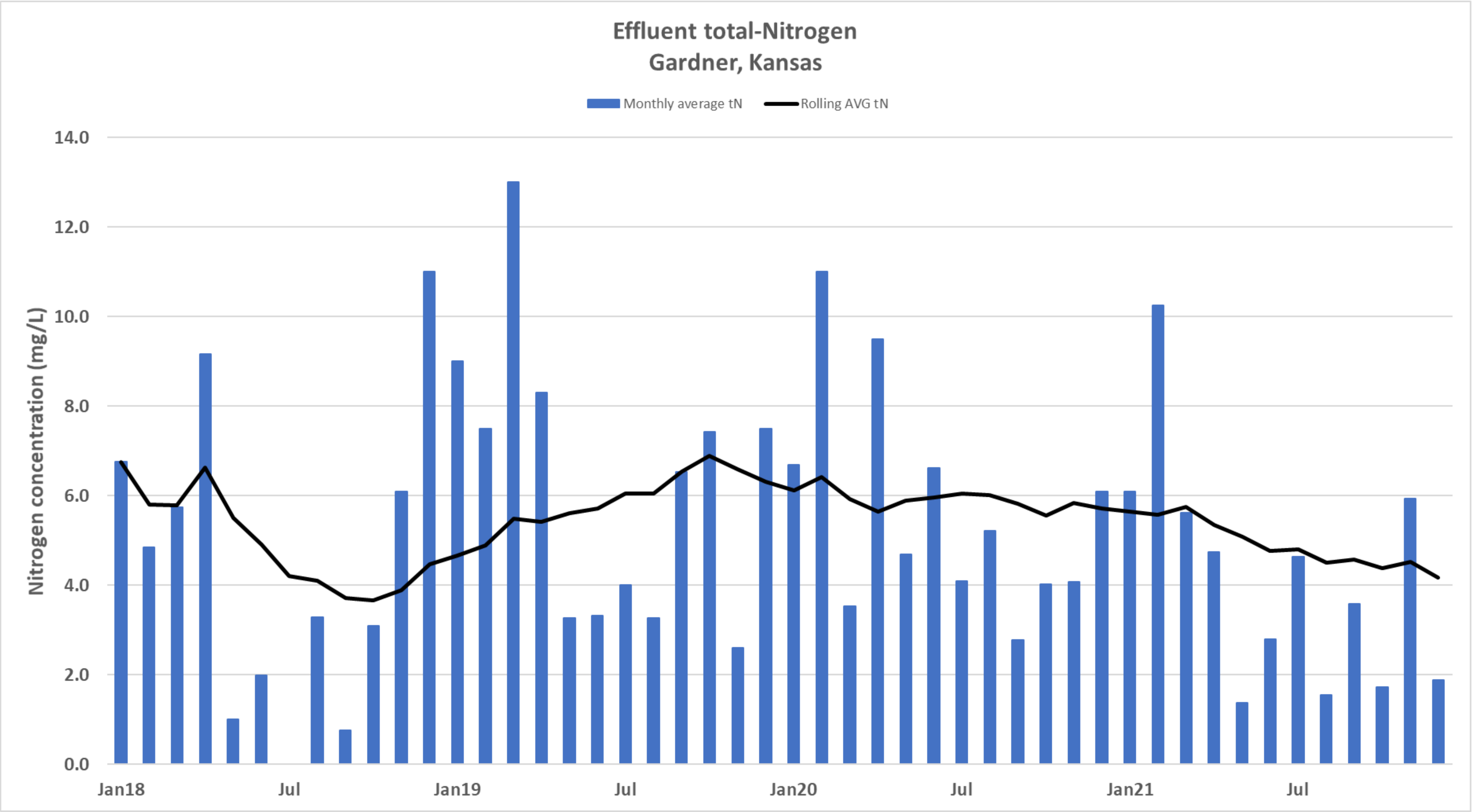
Gardner, Kansas Population: 21,500 2.5 MGD design flow

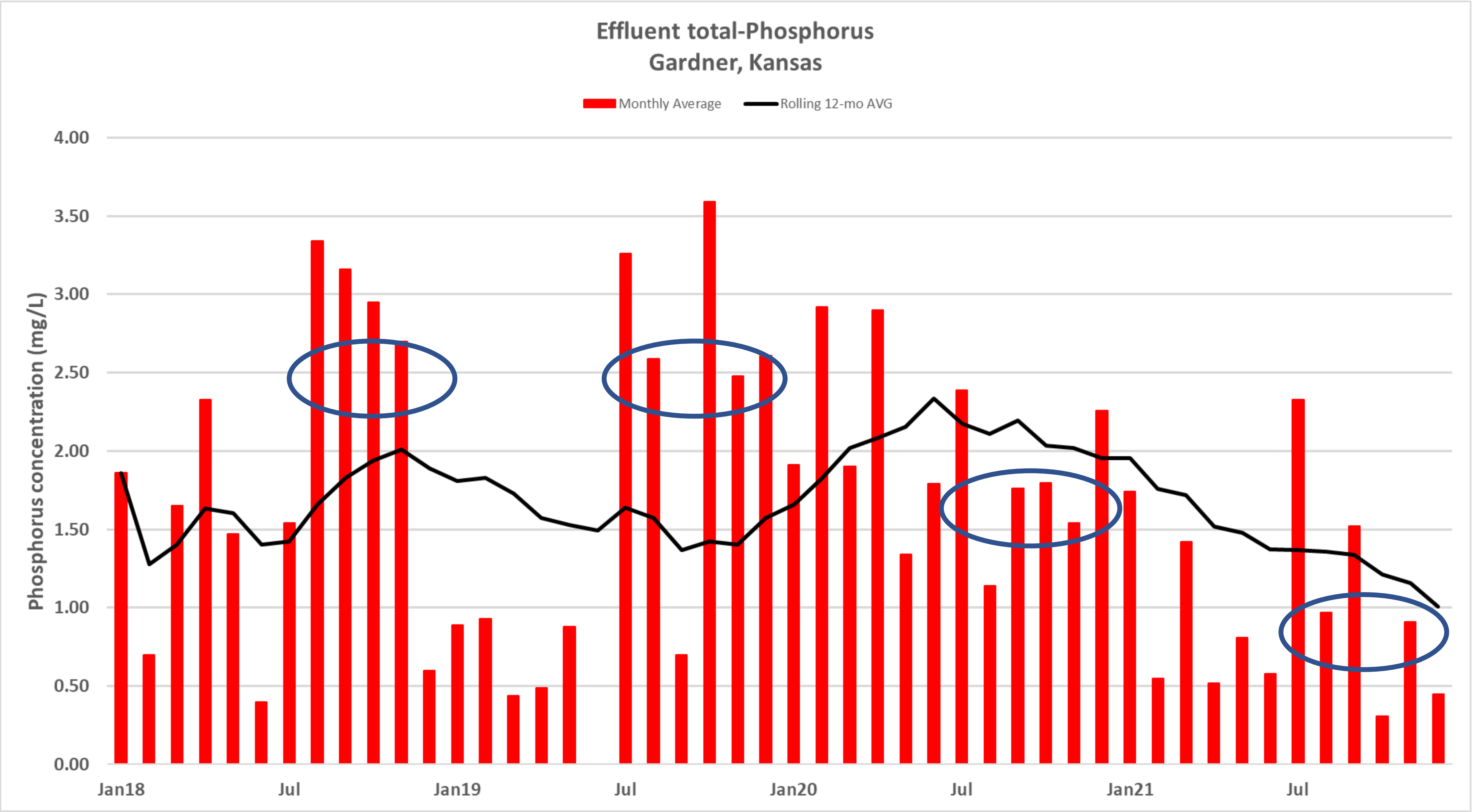

Kill Creek Waste Water Plant
Kill Creek

Gardner, Kansas
(Oxidation Ditch)

2021	**total-Nitrogen** (mg/L)		**total-Phosphorus** (mg/L)	
	influent	effluent	influent	effluent
Average	**49.5**	**4.2**	**11.0**	**1.01**
Minimum	26.4	1.4	4.1	0.31
Maximum	95.2	10.3	21.8	2.33

Influent BOD: 370 mg/L


Effluent total-Nitrogen
Gardner, Kansas
Monthly average tN
Rolling AVG tN
Nitrogen concentration (mg/L)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jan18
Jul
Jan19
Jul
Jan20
Jul
Jan21
Jul


Effluent total-Phosphorus
Gardner, Kansas
Monthly Average
Rolling 12-mo AVG
Phosphorus concentration (mg/L)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Jan18
Jul
Jan19
Jul
Jan20
Jul
Jan21
Jul


Questions?
Comments?

Phosphorus Removal in SBRs

Create food:
In septic conditions … Create VFAs

Feed bio-P bugs:
In septic conditions … bio-P bugs “eat” VFAs

Grow bio-P bugs:
In aerobic conditions … bio-P bugs remove soluble phosphorus as they multiply

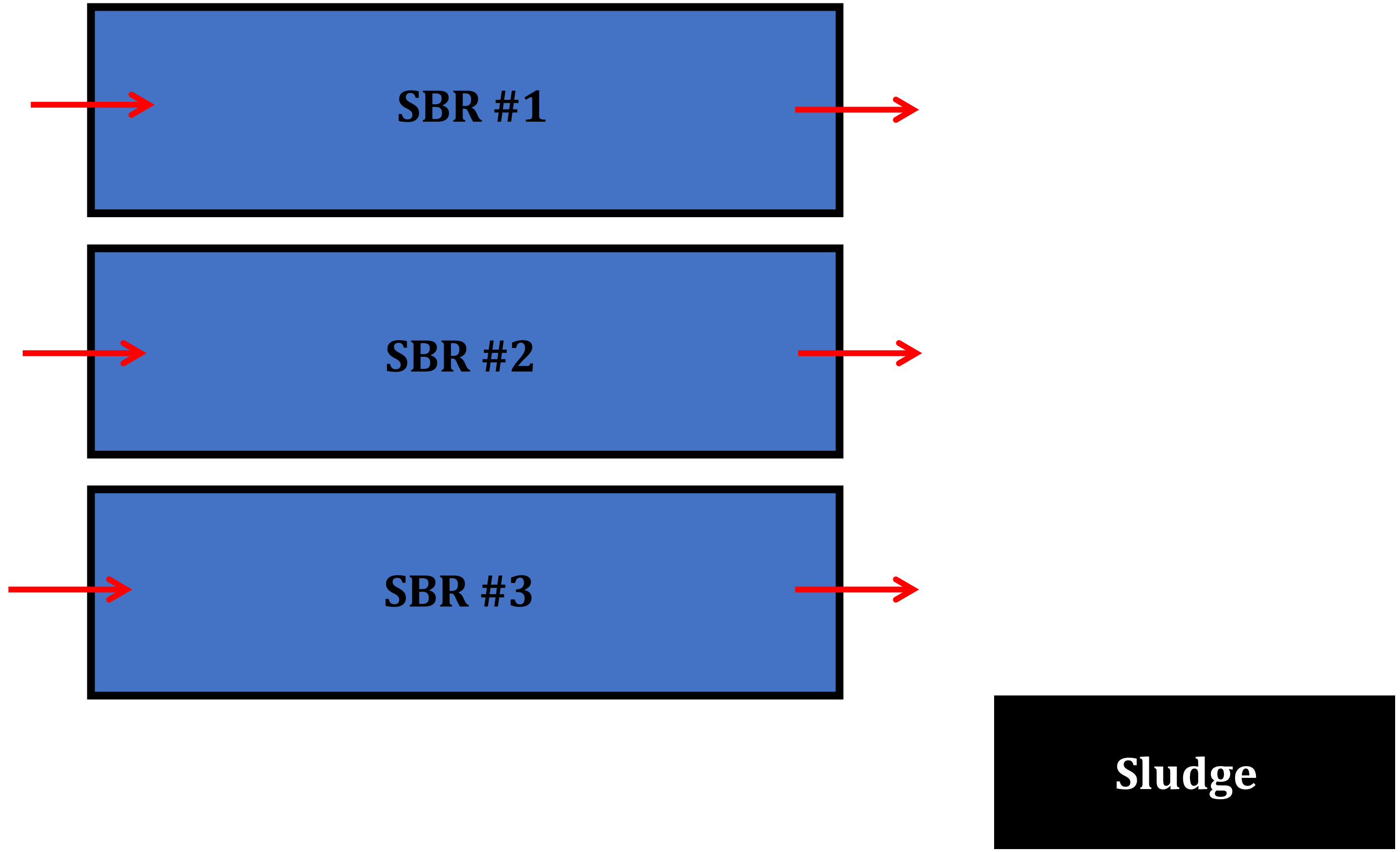
Prevent Re-Release:
Prevent settled sludge from releasing phosphorus back into solution before/during decant cycle


What do you
think?

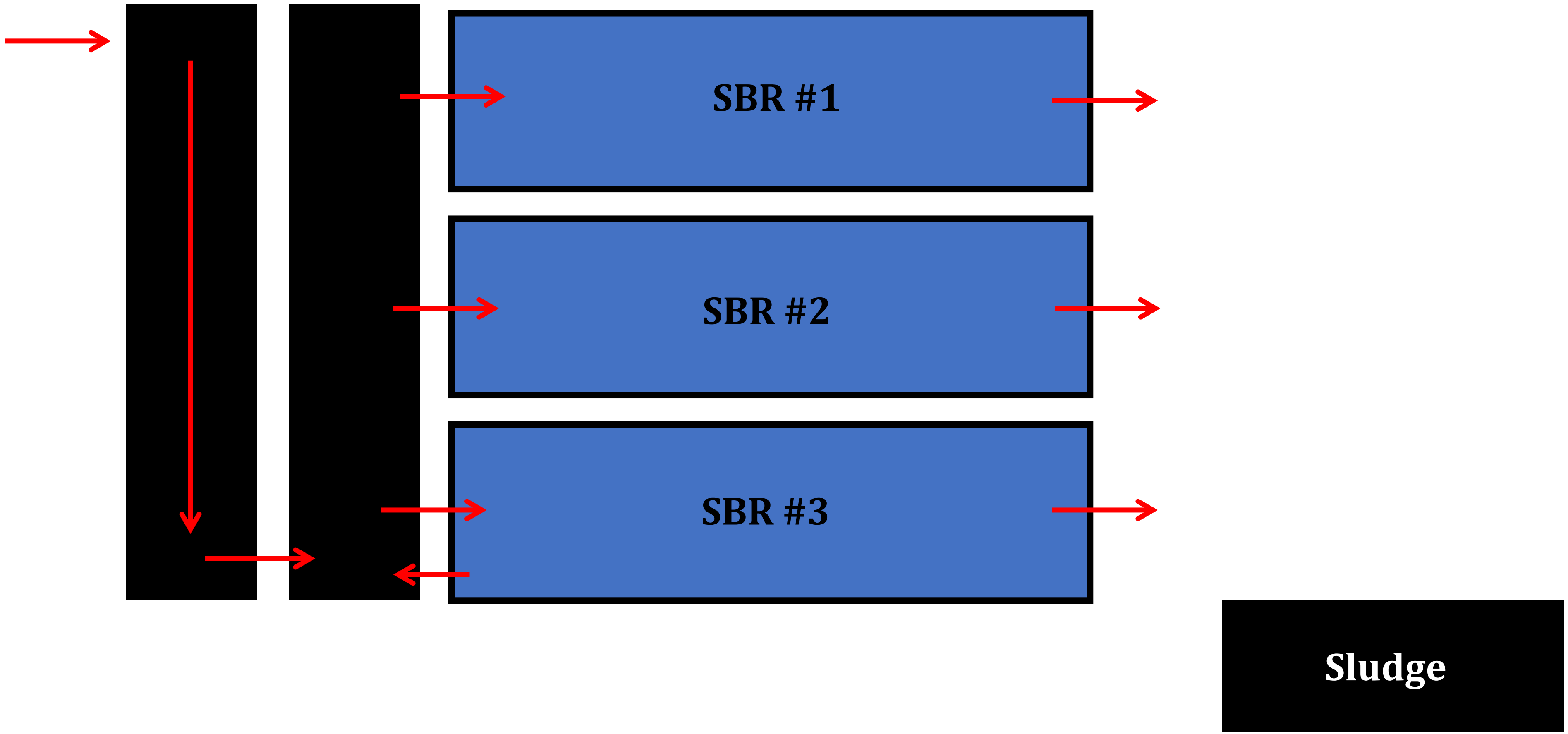
Sequencing Batch Reactors

Designed for Nitrogen and Phosphorus Removal
(Pre-Anaerobic Tank)

Sequencing Batch Reactor (SBR) without Pre-Anaerobic Zone
TOP VIEW



Sequencing Batch Reactor (SBR) with Pre-Anaerobic Zone
TOP VIEW




Questions?
Comments?

Optimizing Nutrient Removal & Wastewater Excellence

Optimizing Nutrient Removal

March 31: Optimizing Nutrient Removal in Other Aeration Activated Sludge wwtps

Wastewater Excellence

April 28: Transitioning from Permit Compliance to Wastewater Excellence

Comments & Questions

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