What Operators Should Know About Phosphorus Removal, Part 2

Webinar for North Carolina Wastewater Operators
March 18, 2021
10:00 - 11:45 AM

Grant Weaver, PE & wastewater operator
G.Weaver@CleanWaterOps.com

Energy & Nutrient Optimization
of NC Municipal Wastewater Treatment Plants

Biological Nitrogen Removal, Parts 1&2

Activated Sludge, Parts 1&2

Biological Phosphorus Review, Part 1

Today: Biological Phosphorus Removal: Part 2

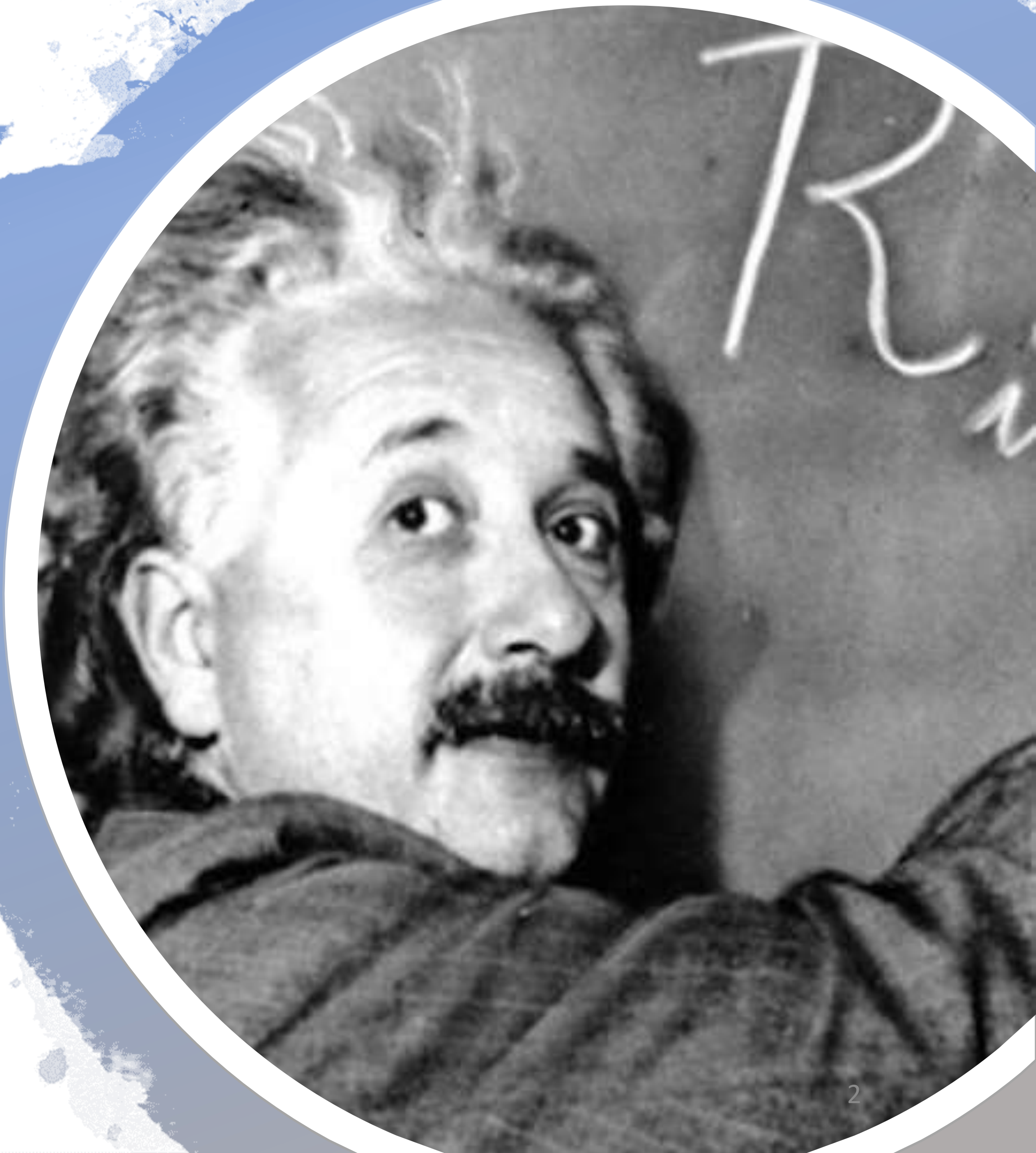
Mar 25: North Carolina Case Studies, Part 1 (your plants!)

Apr 8: North Carolina Case Studies, Part 2 (your plants!)

Apr 15: Energy Management, Part 1

Apr 22: Energy Management, Part 2

Apr 29: North Carolina Case Studies, Part 3 (your plants!)




REVIEW

Phosphorus

15

P

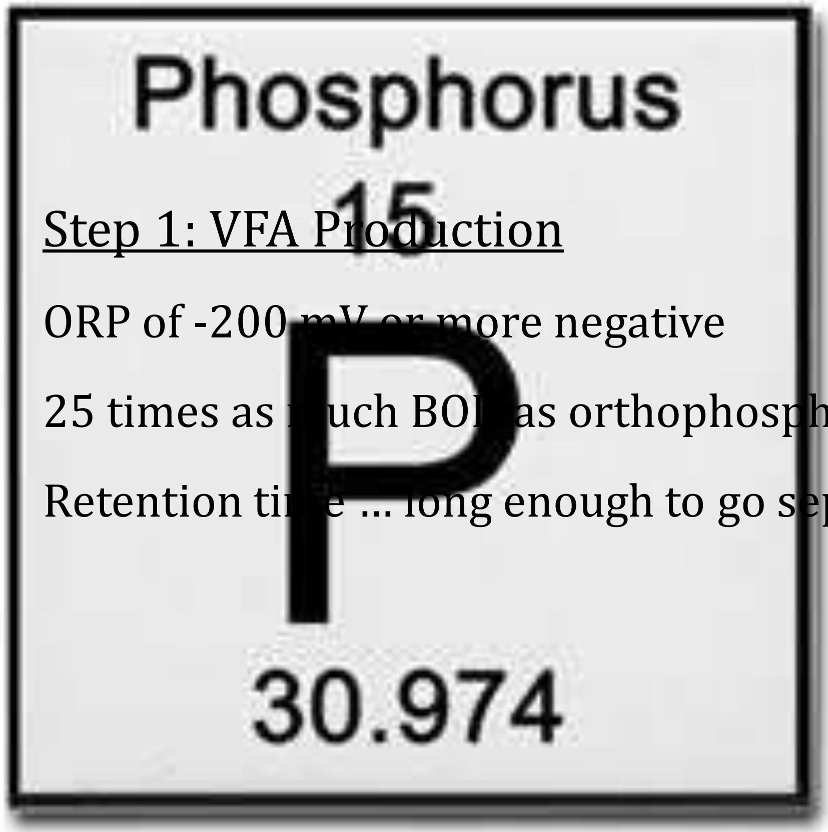
30.974


THREE
steps

Biological Phosphorus Removal

Step 1: prepare “dinner”

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

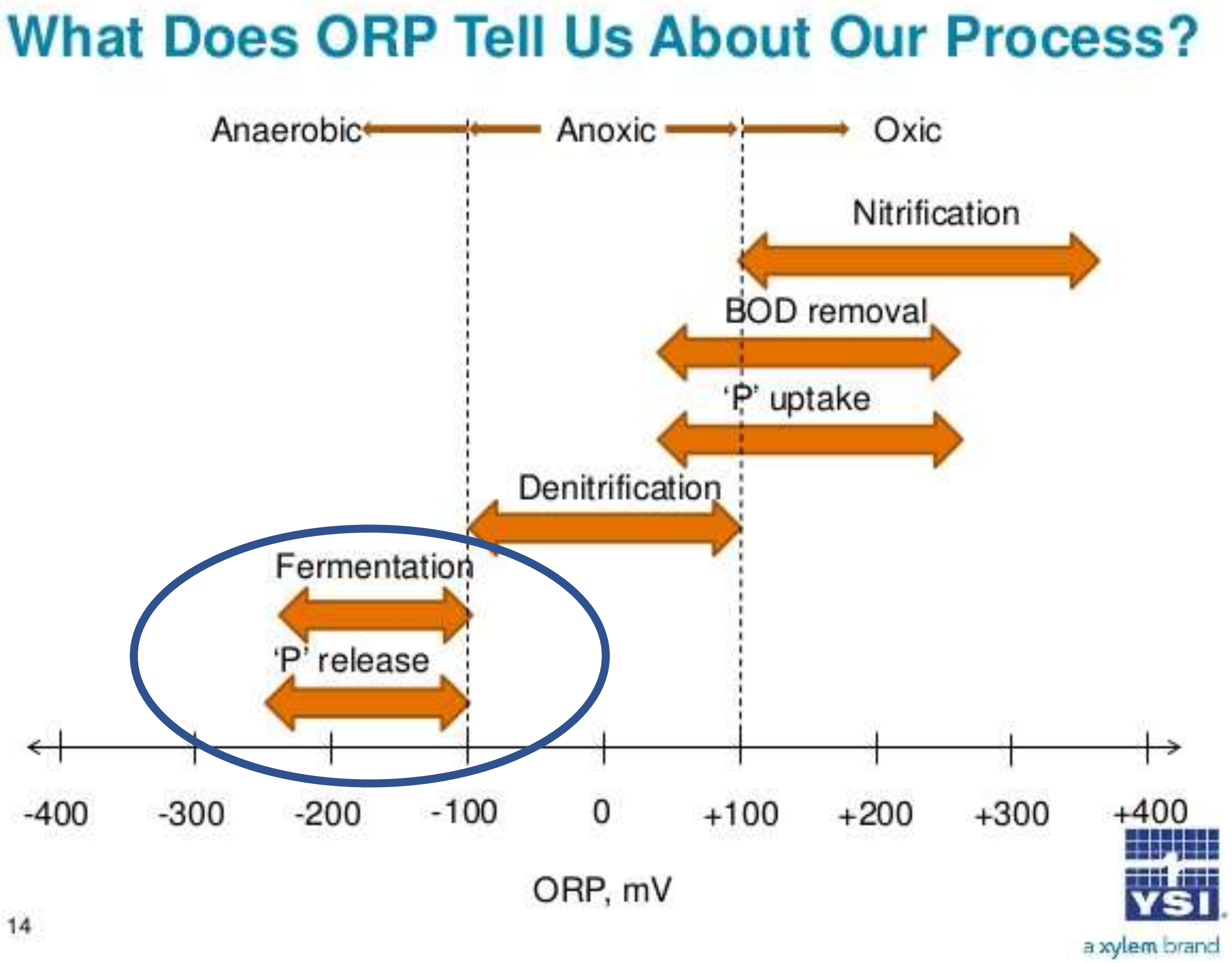


Step 1: VFA Production

ORP of -200 mV or more negative

25 times as much BOD as orthophosphate

Retention time ... long enough to go septic



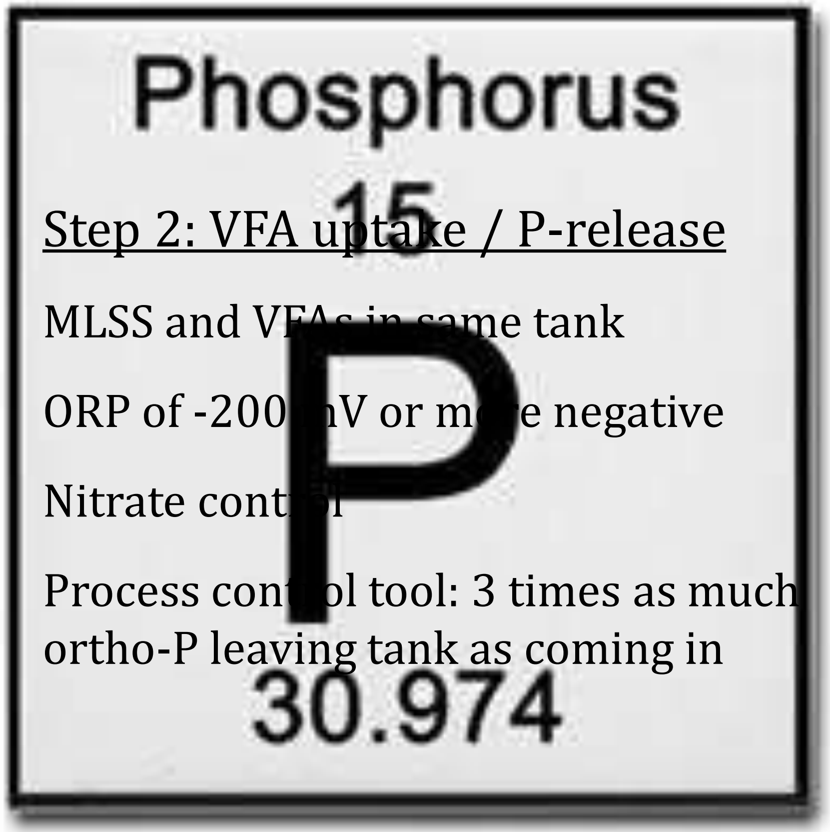
Biological Phosphorus Removal

Step 1: prepare "dinner"

VFA (volatile fatty acids) production in anaerobic/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



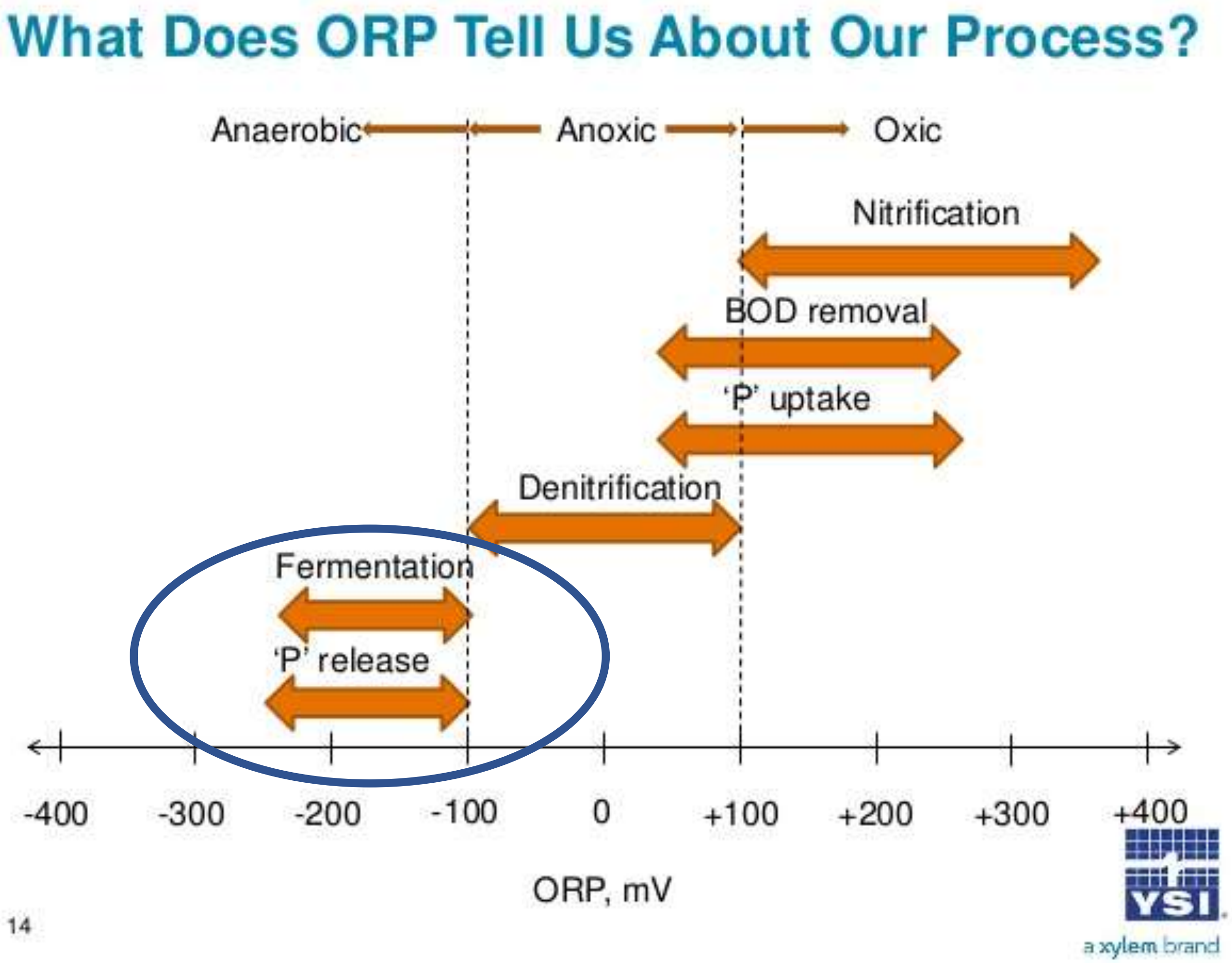
Step 2: VFA uptake / P-release

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



Biological Phosphorus Removal

Step 1: prepare "dinner"

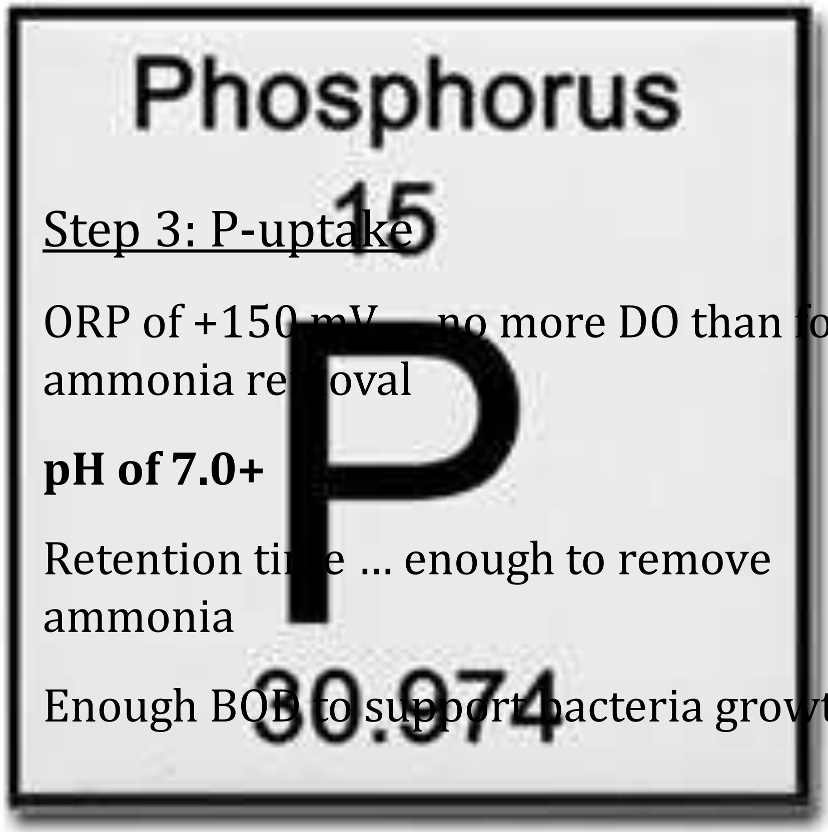
VFA (volatile fatty acids) production in anaerobic/fermentive conditions

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



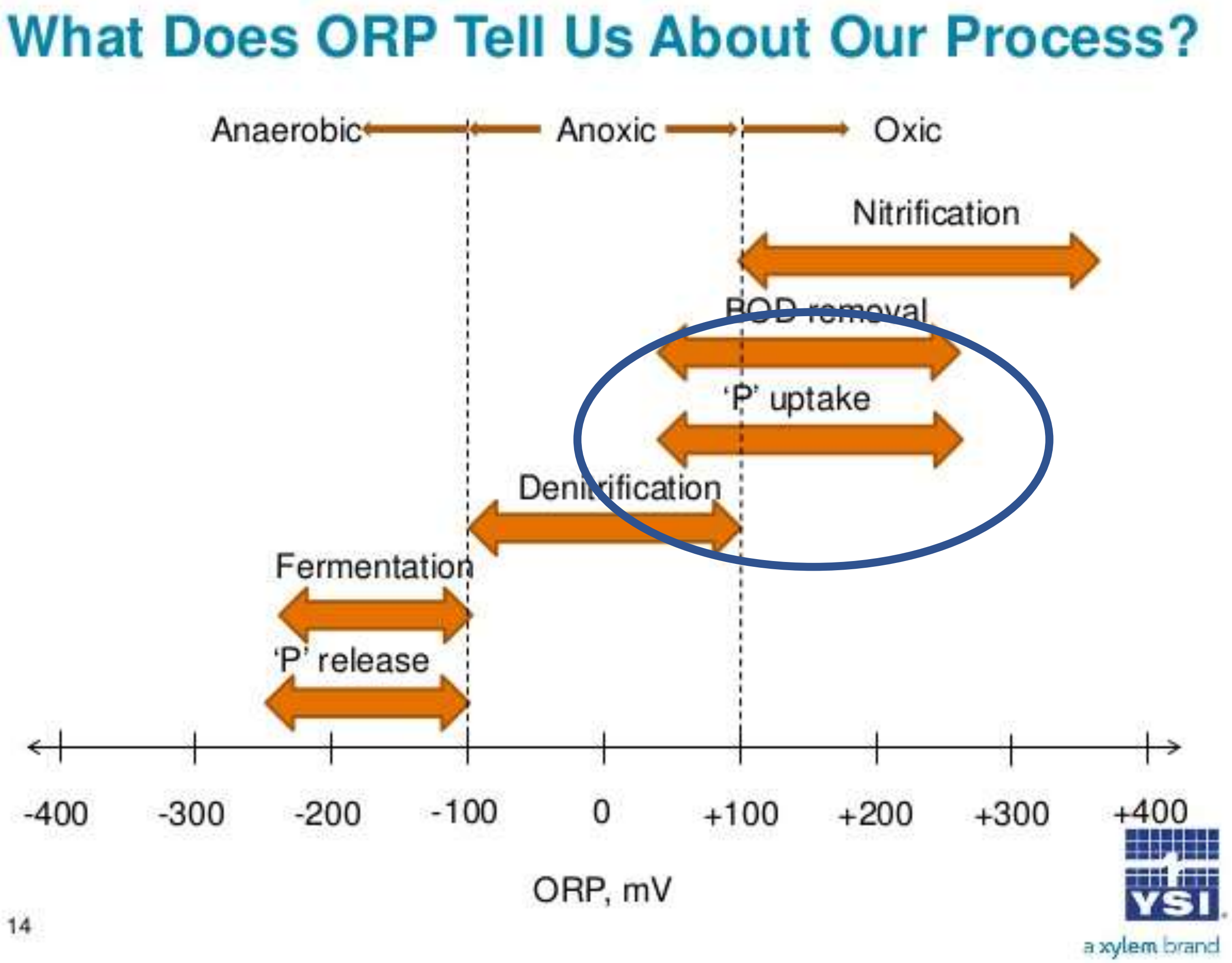
Step 3: P-uptake

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>

2 hour HRT (hydraulic retention time)*

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

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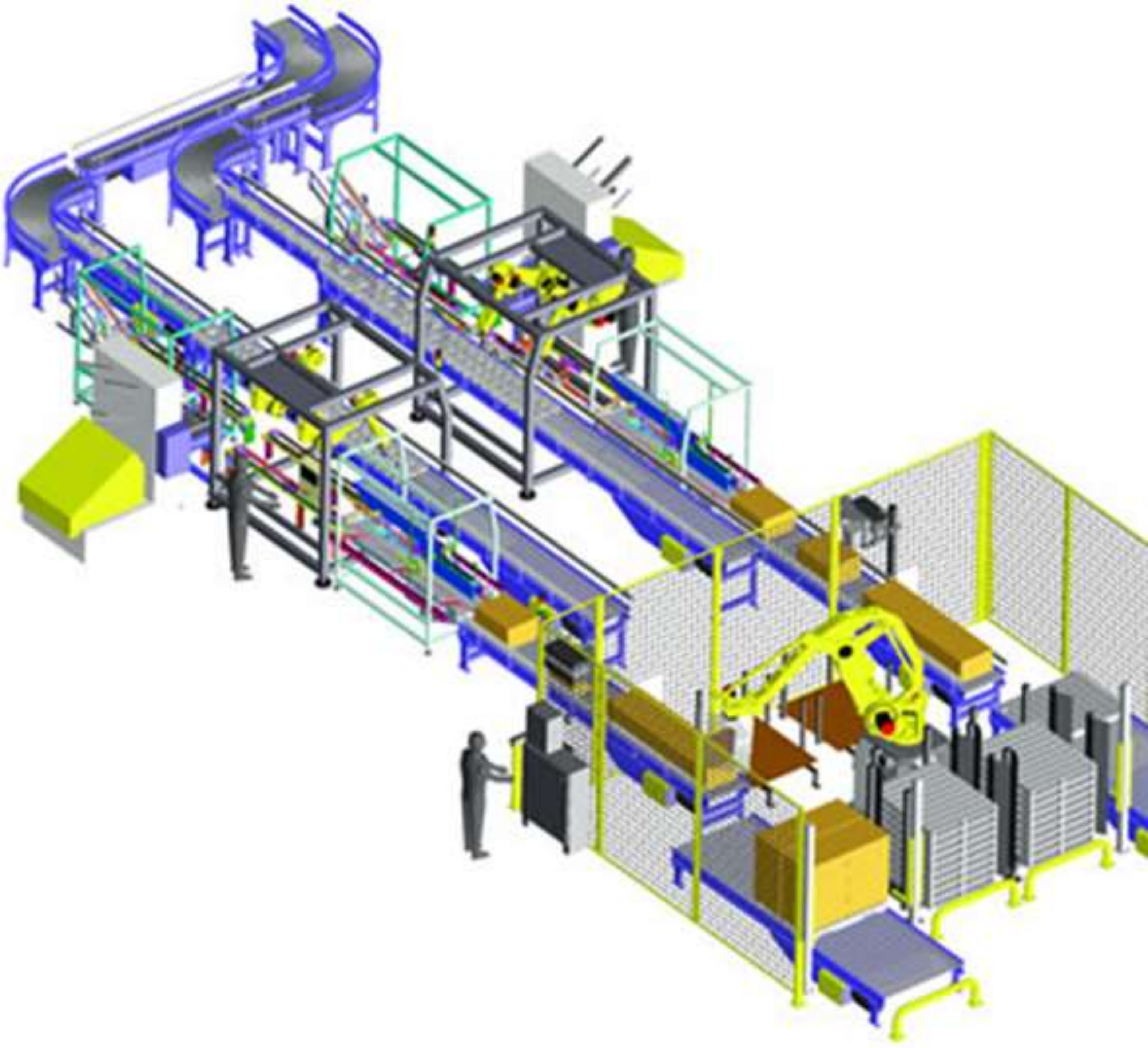
VOTE

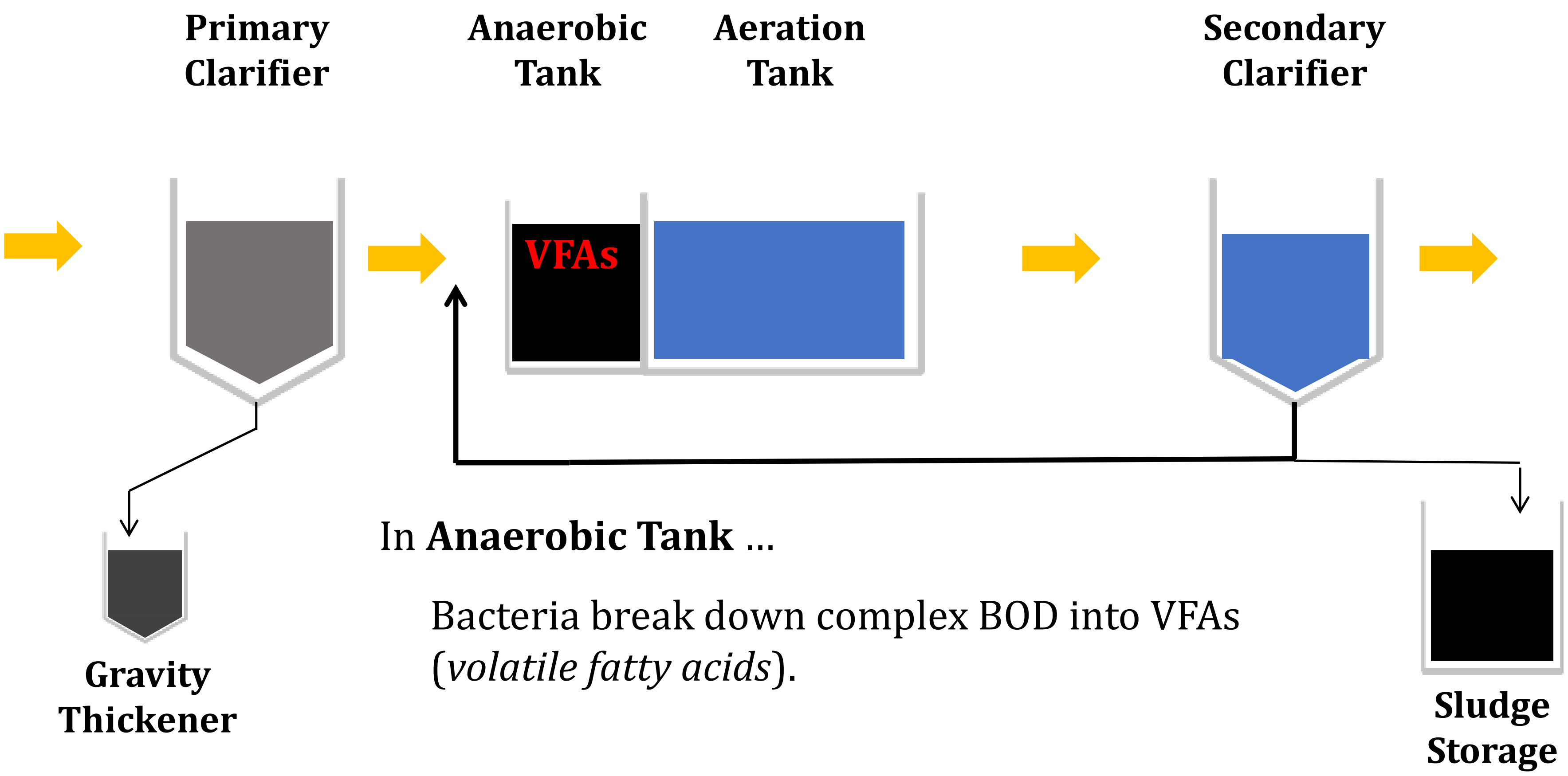
?

Technology!



Biological Phosphorus Removal:
Mainstream Flow Fermentation Processes

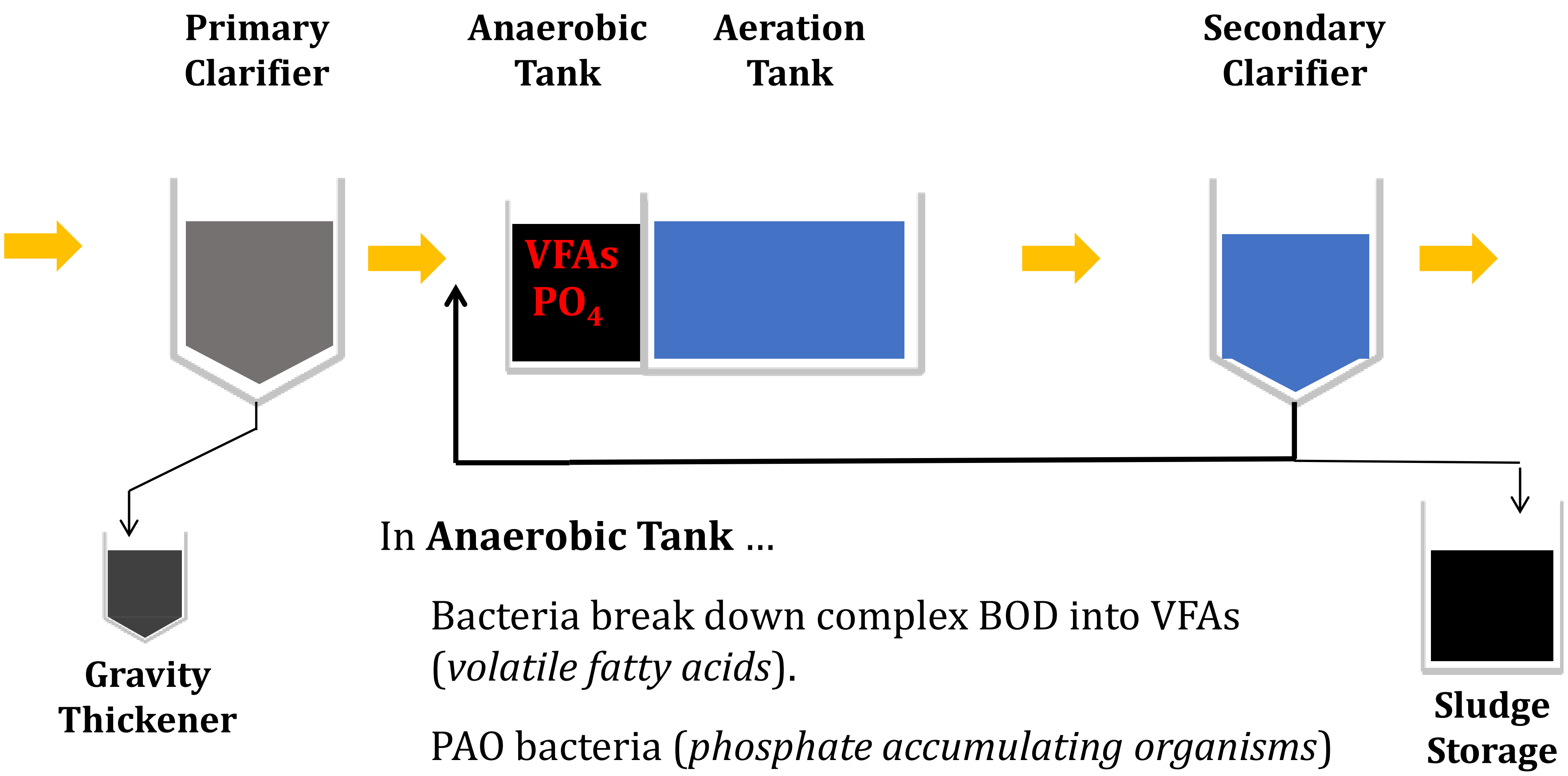
Bio-P Removal: Mainstream Fermentation Process



In **Anaerobic Tank** ...

Bacteria break down complex BOD into VFAs (*volatile fatty acids*).

Bio-P Removal: Mainstream Fermentation Process



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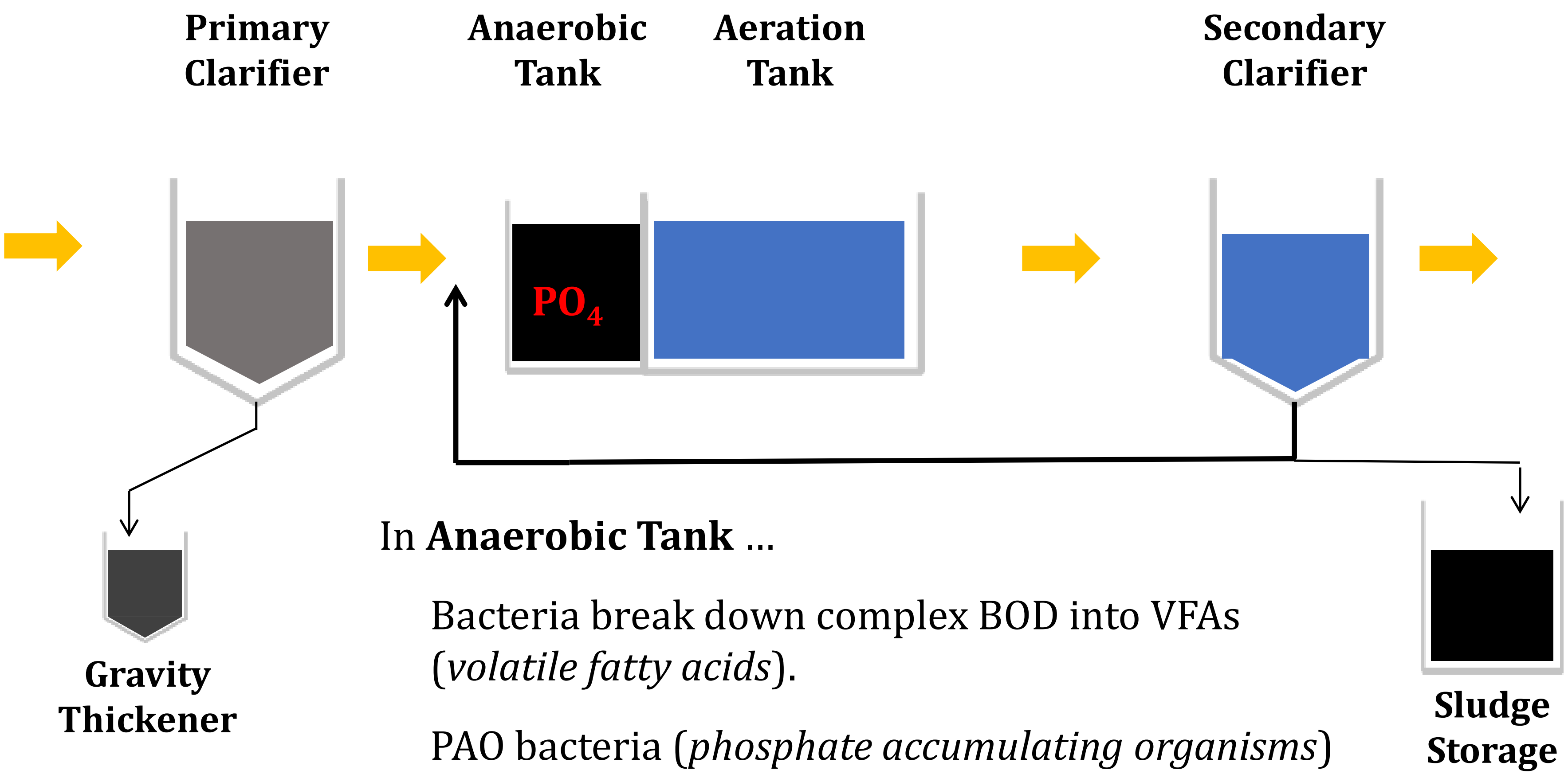
Bacteria break down complex BOD into VFAs (*volatile fatty acids*).

PAO bacteria (*phosphate accumulating organisms*) take in VFAs as energy source & temporarily release PO_4 (*phosphate*) into solution.

Bio-P Removal: Mainstream Fermentation Process



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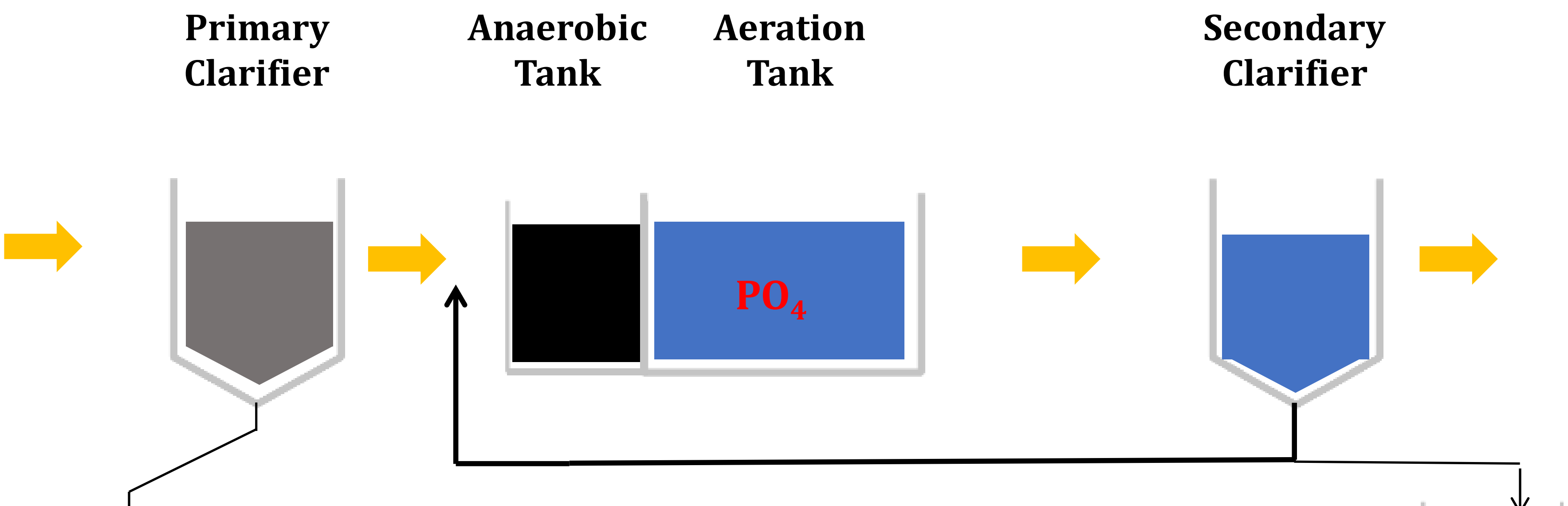
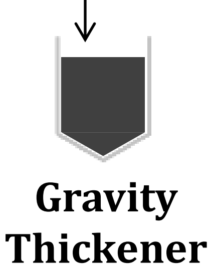
In **Aeration Tank** …

Energized PAO bacteria take PO_4 out of solution.

Bio-P Removal: Mainstream Fermentation Process





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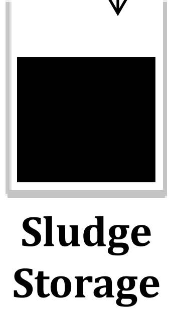

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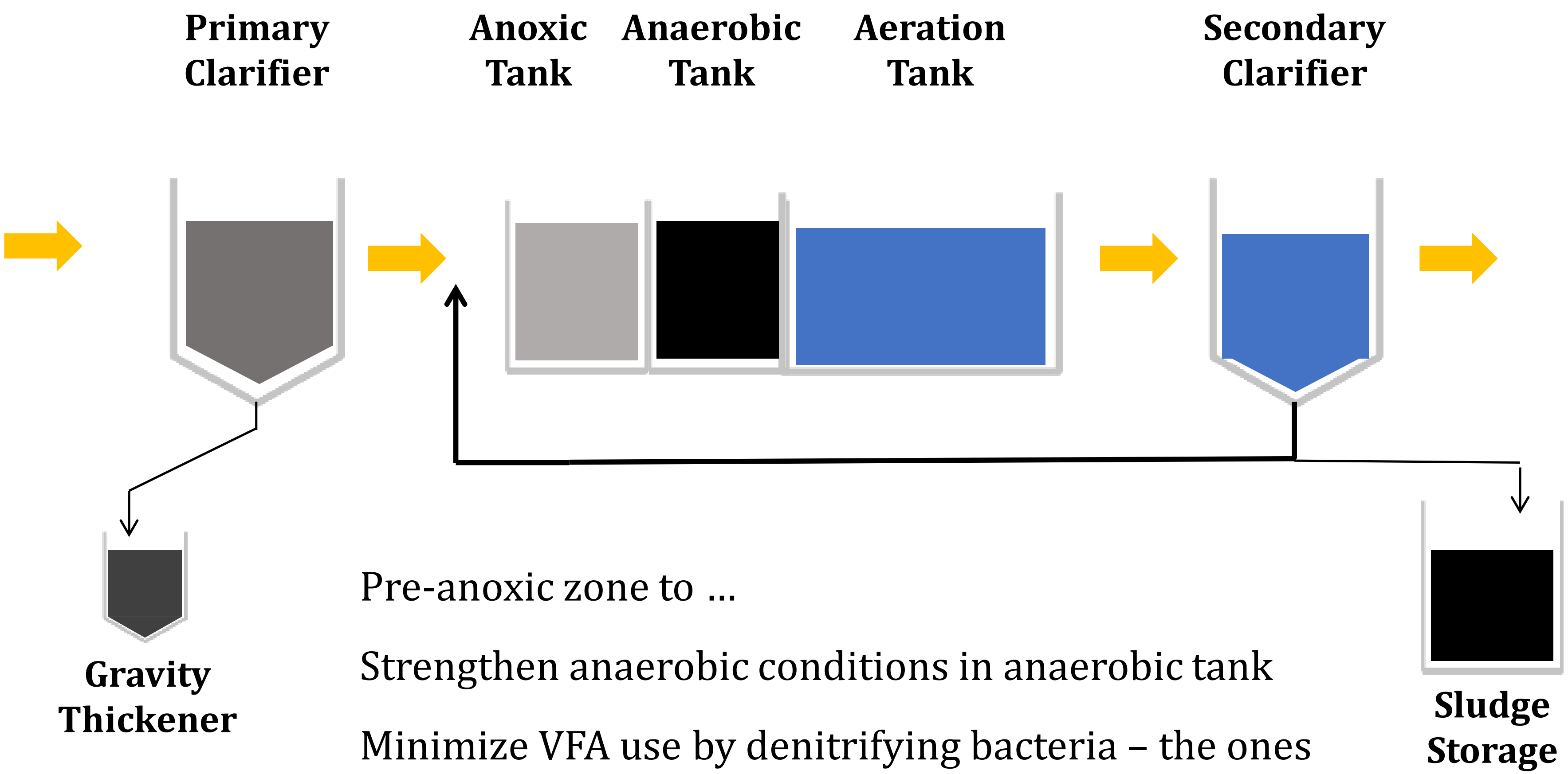
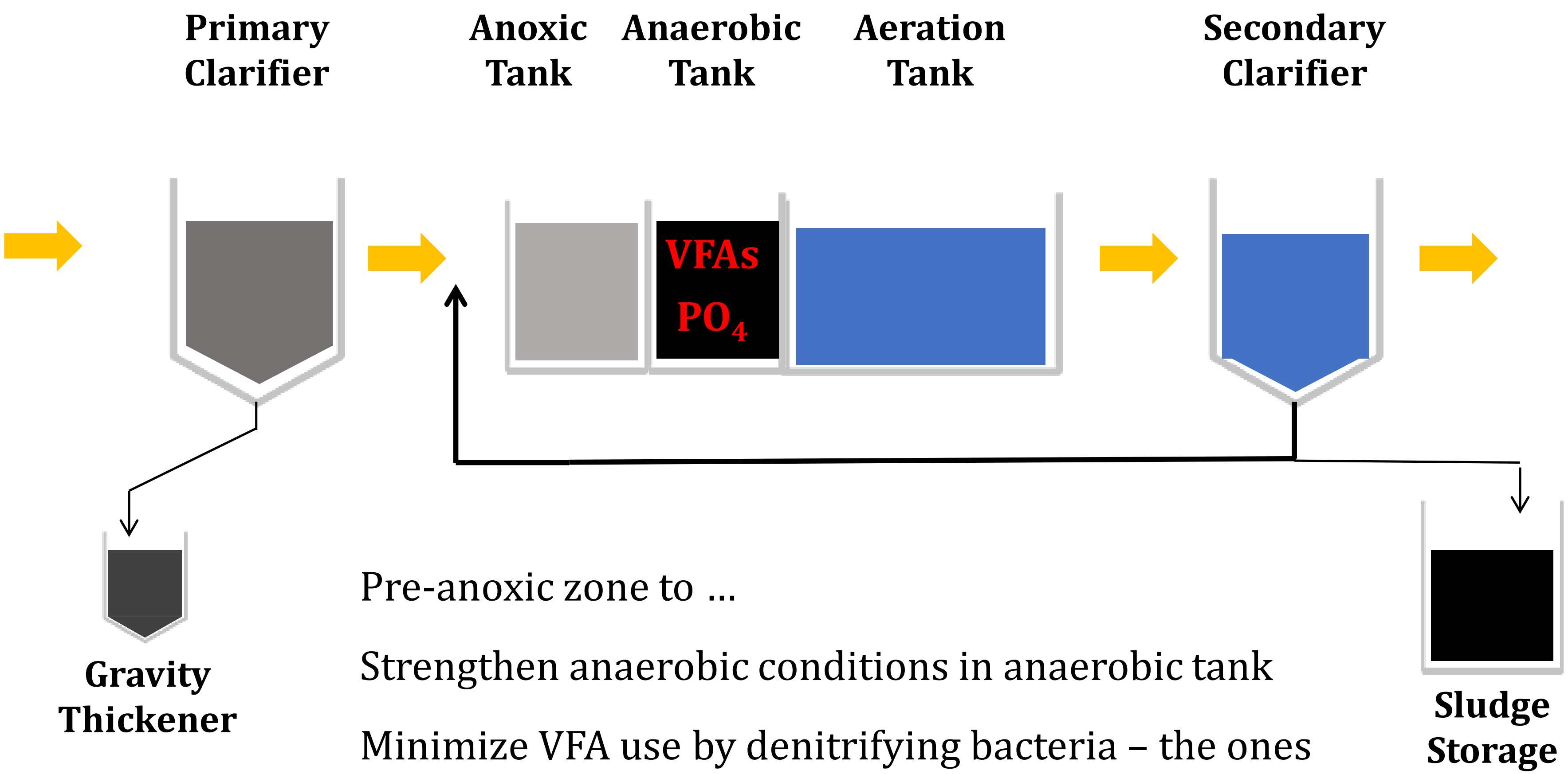


Pre-anoxic zone to …

Strengthen anaerobic conditions in anaerobic tank

Minimize VFA use by denitrifying bacteria – the ones that convert Nitrate (NO_3) to Nitrogen Gas (N_2) – by "feeding" influent to the denitrifiers.

Bio-P Removal: Mainstream Fermentation Process



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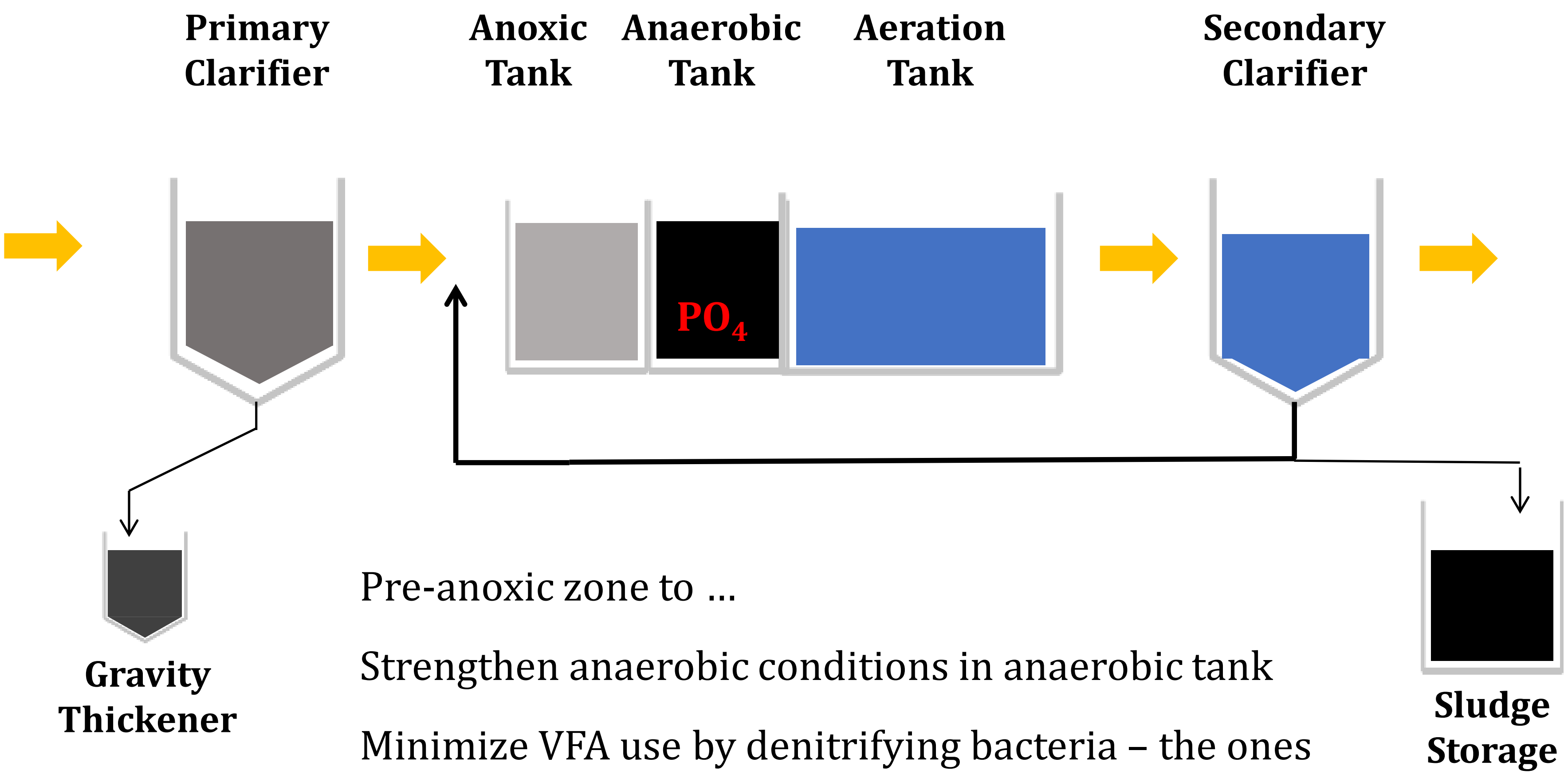

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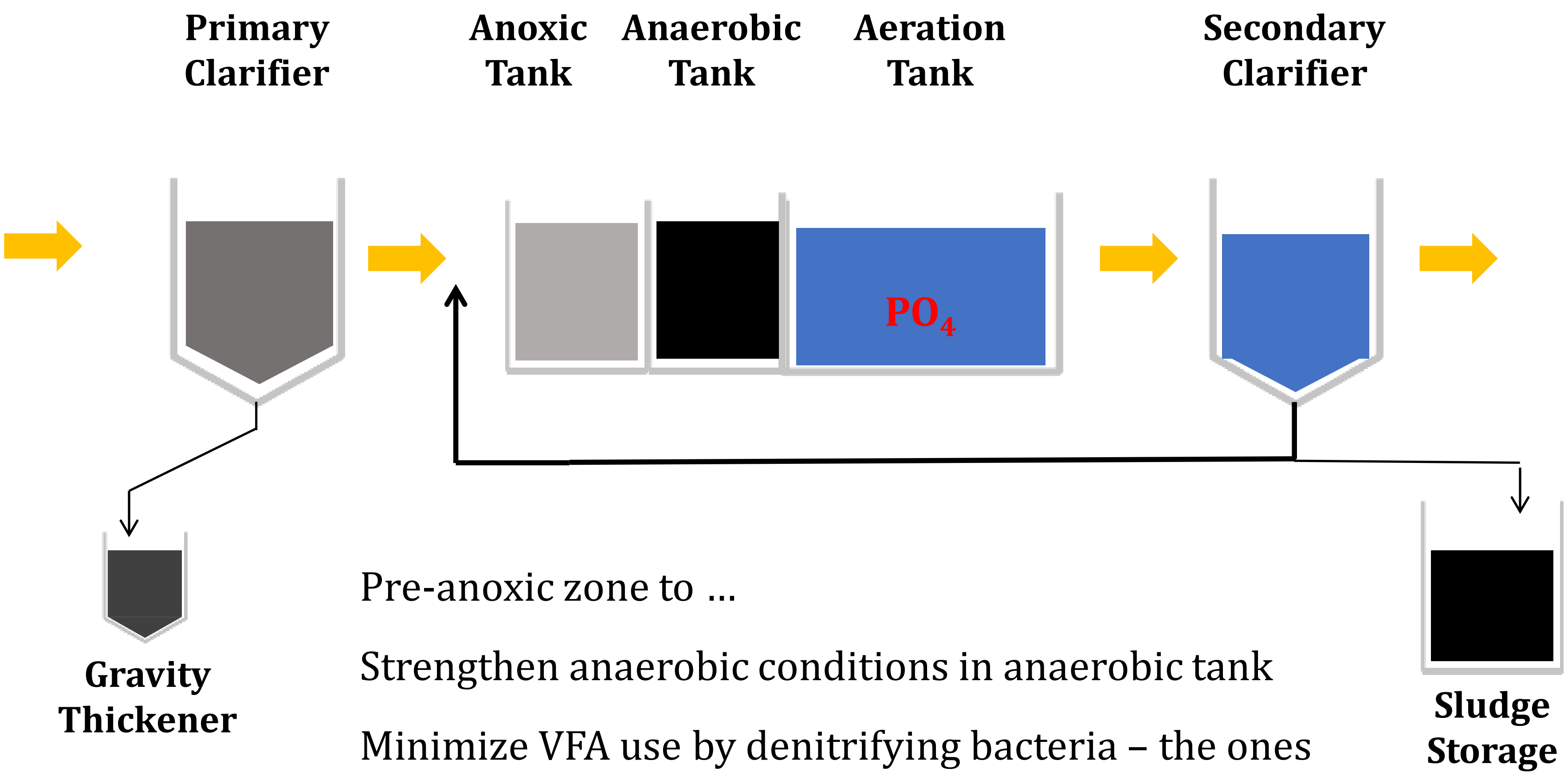

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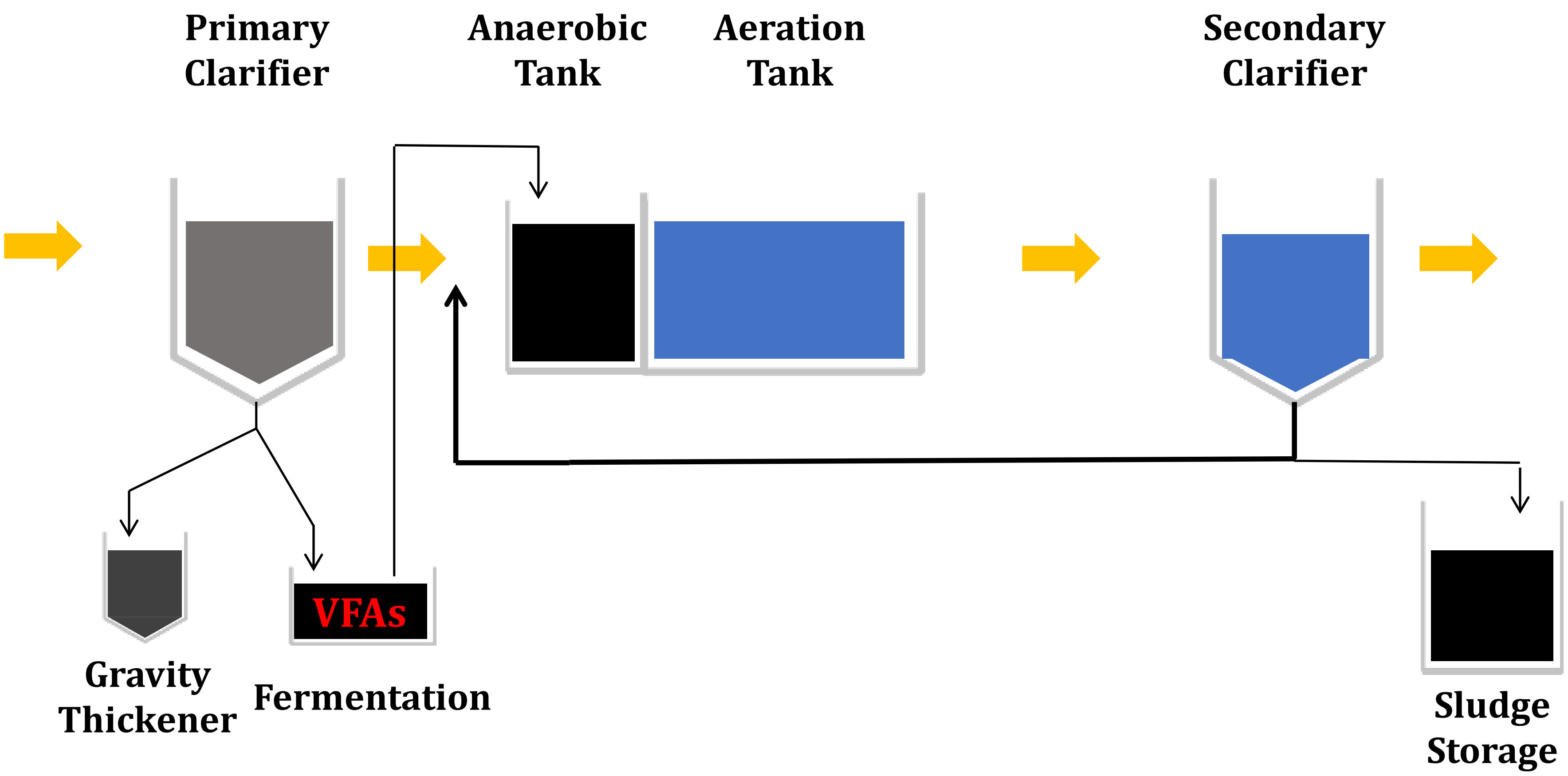
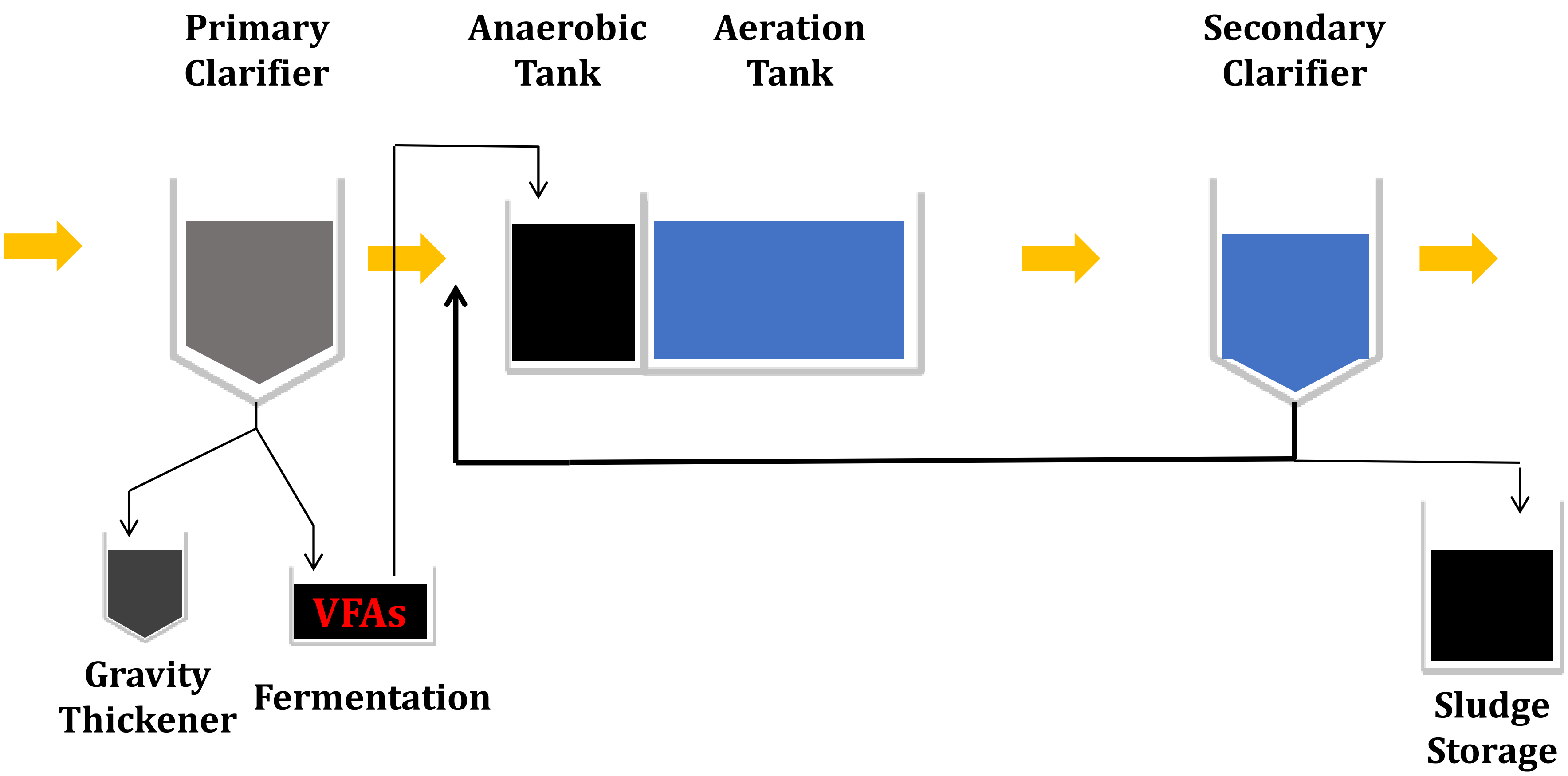
Biological Phosphorus Removal: Combined Sidestream & Mainstream Fermentation

Bio-P Removal: Sidestream Fermentation Process



Bio-P Removal: Sidestream Fermentation Process



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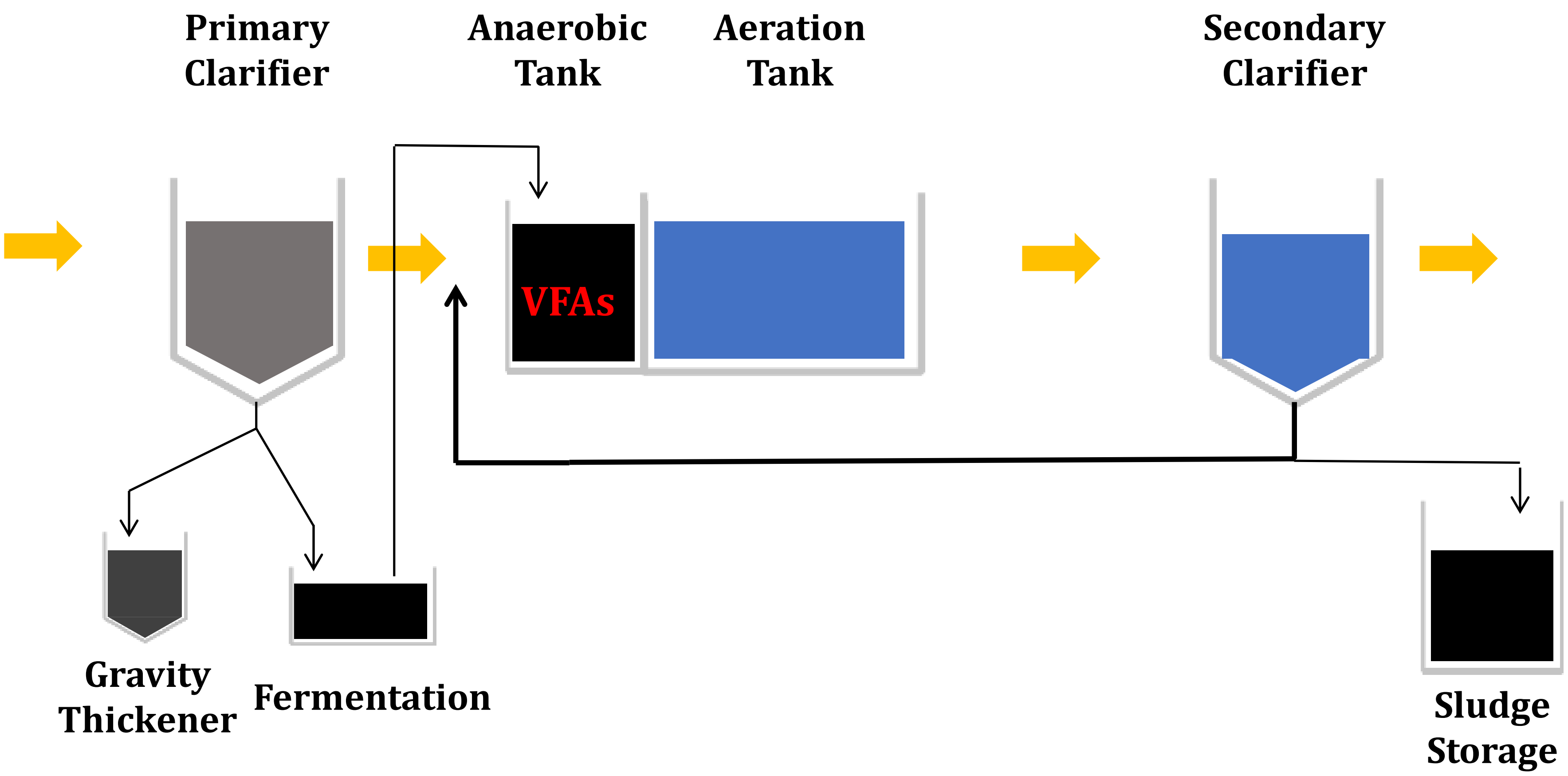

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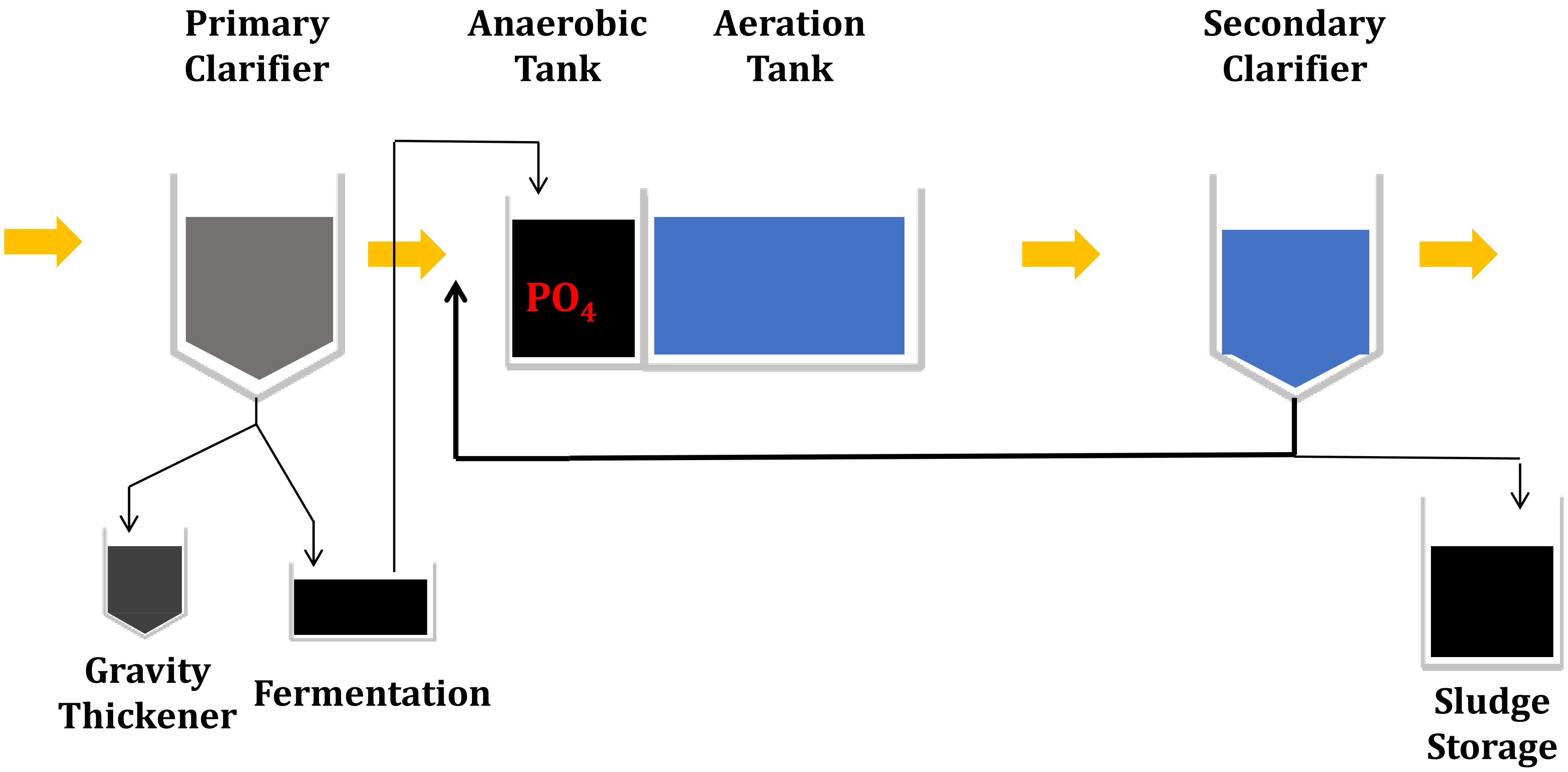

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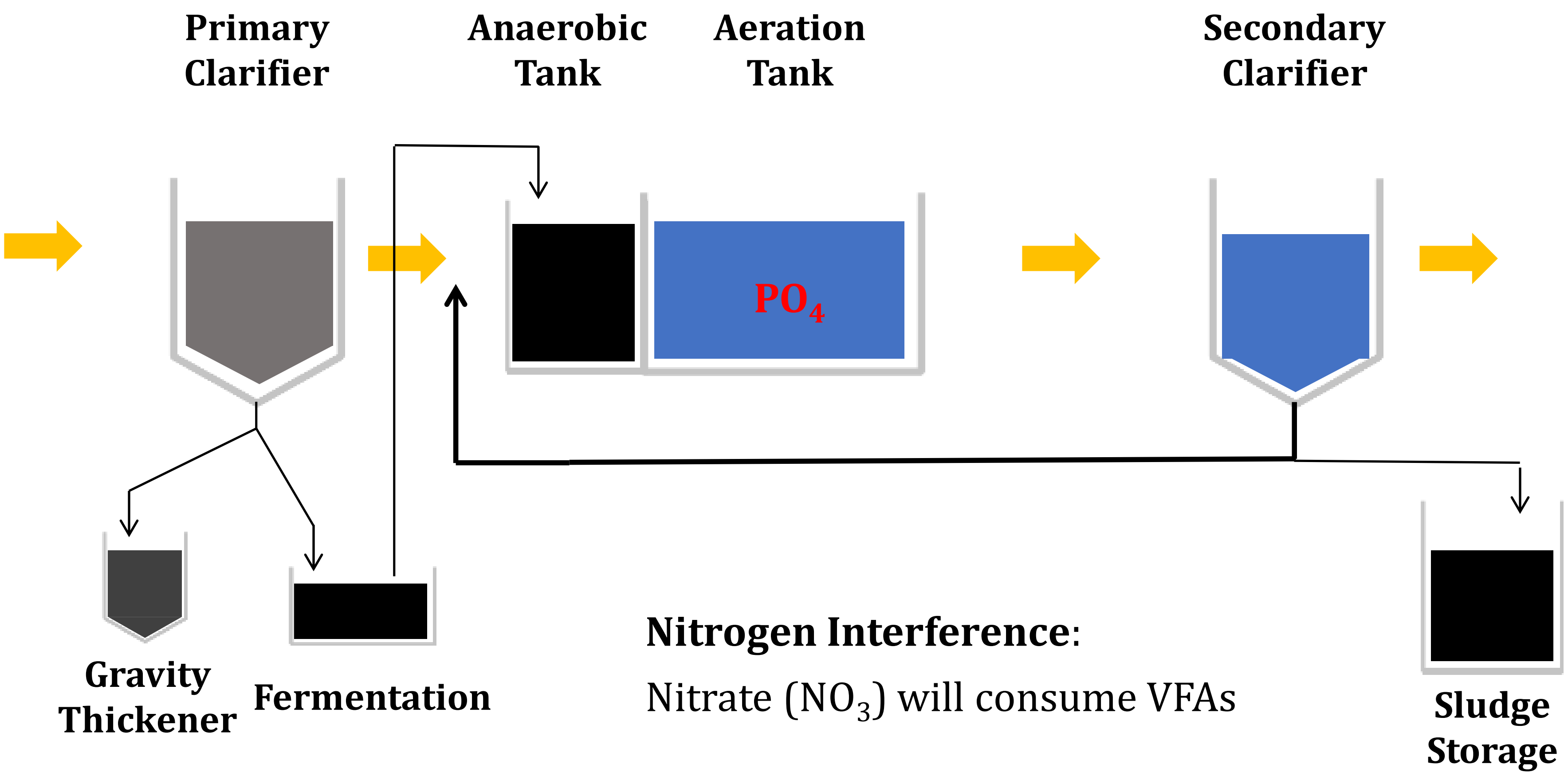
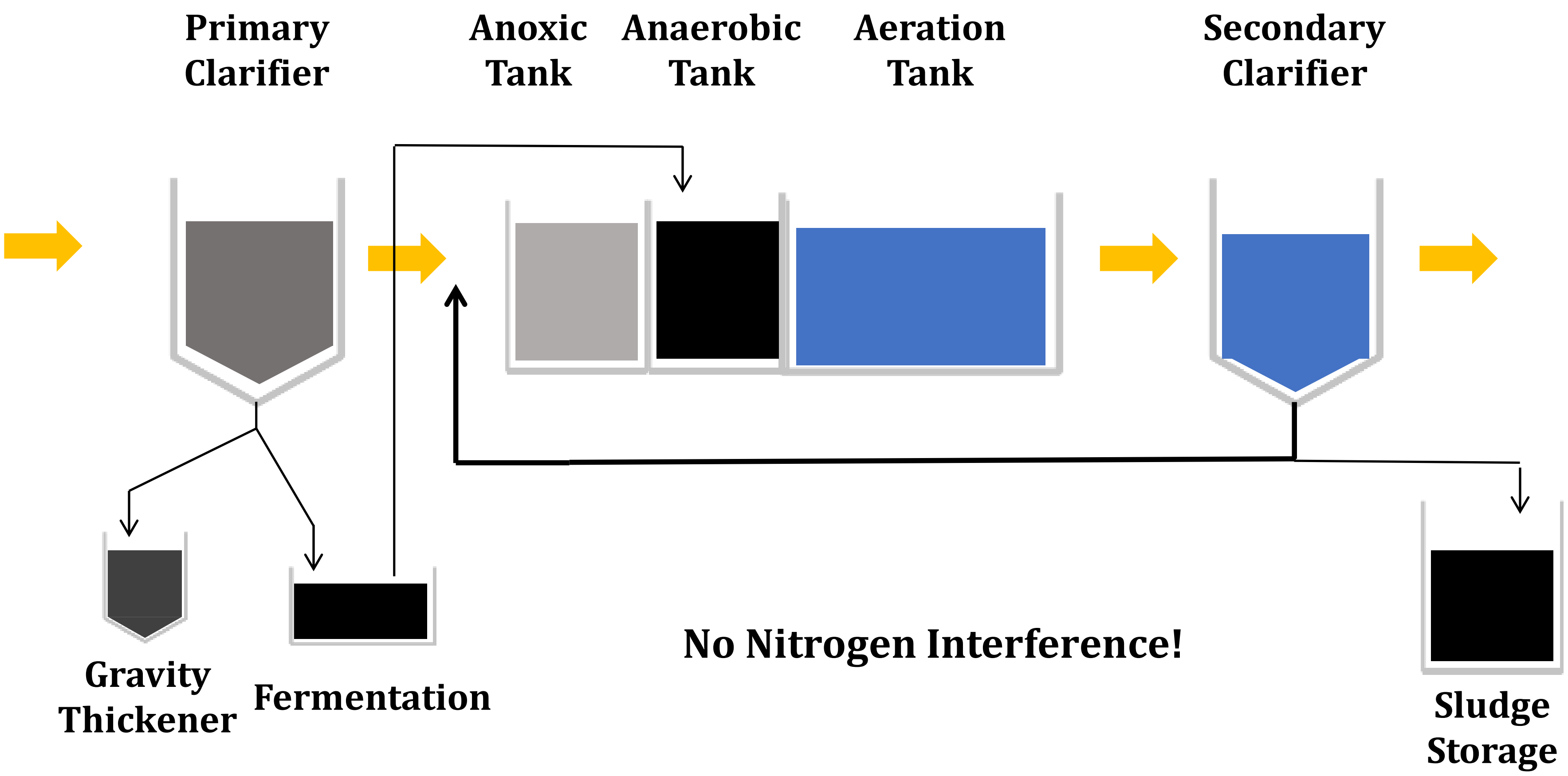


Nitrogen Interference:

Nitrate (NO_3) will consume VFAs

Bio-P Removal: Sidestream Fermentation Process



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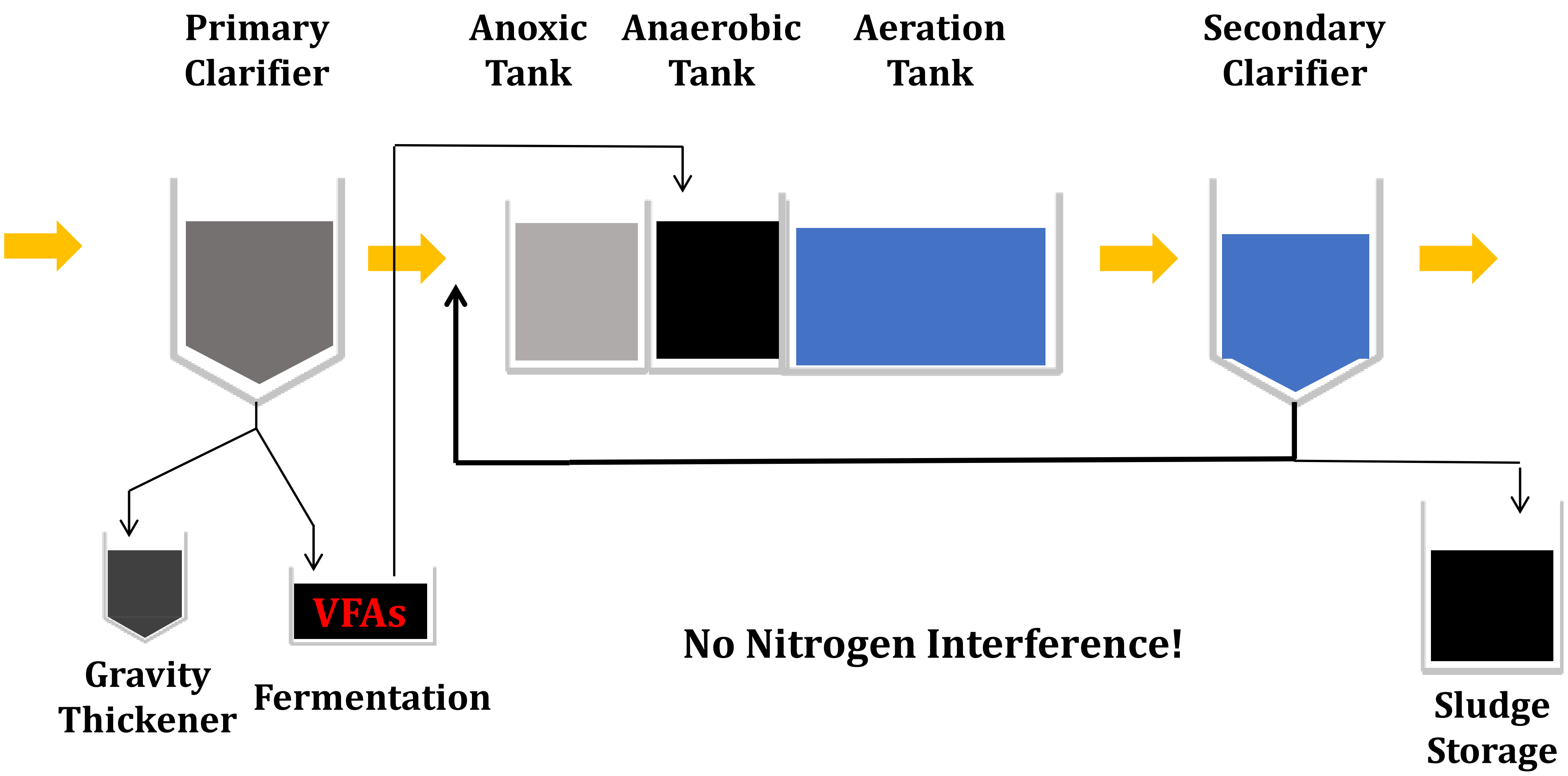

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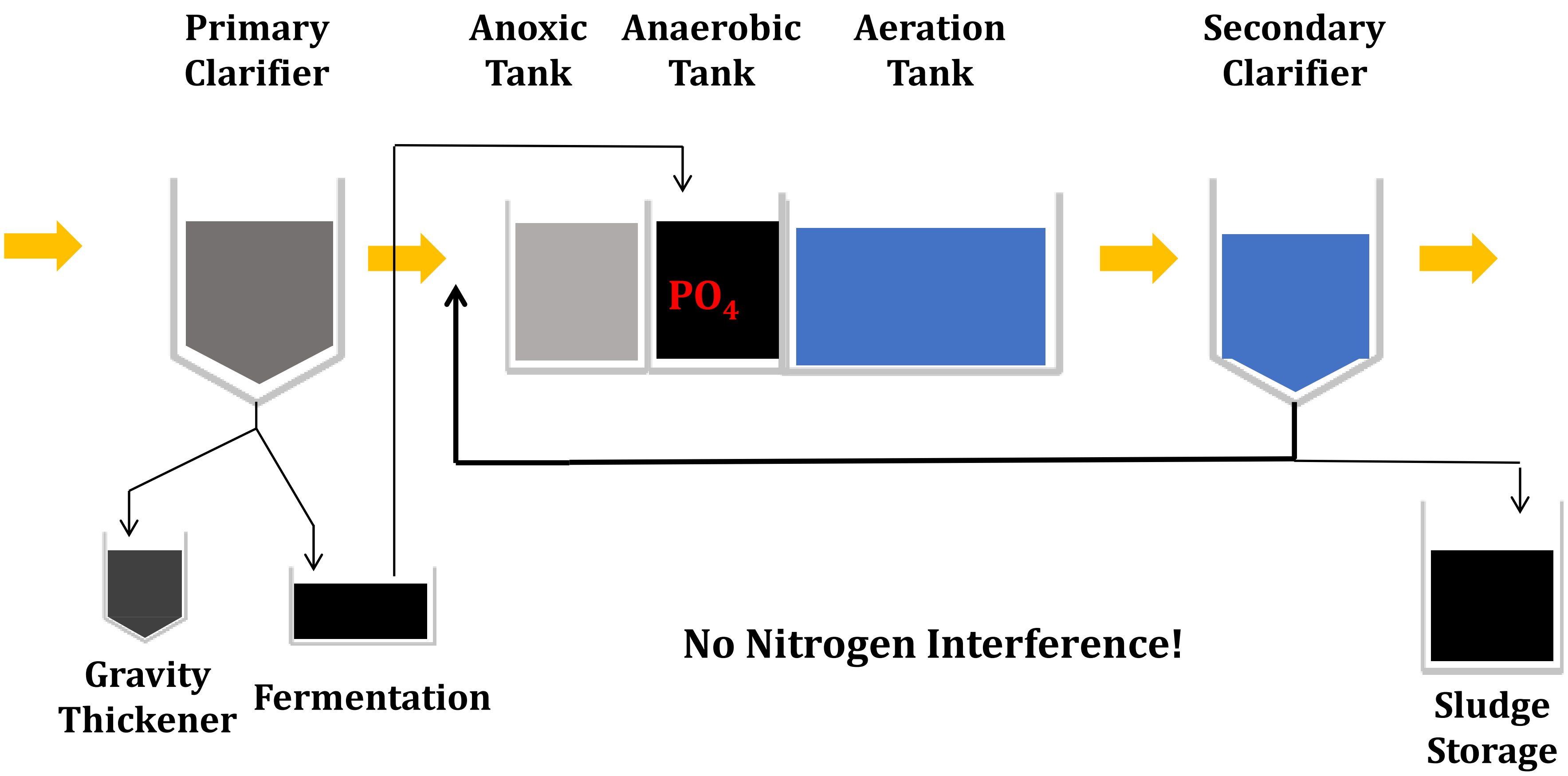

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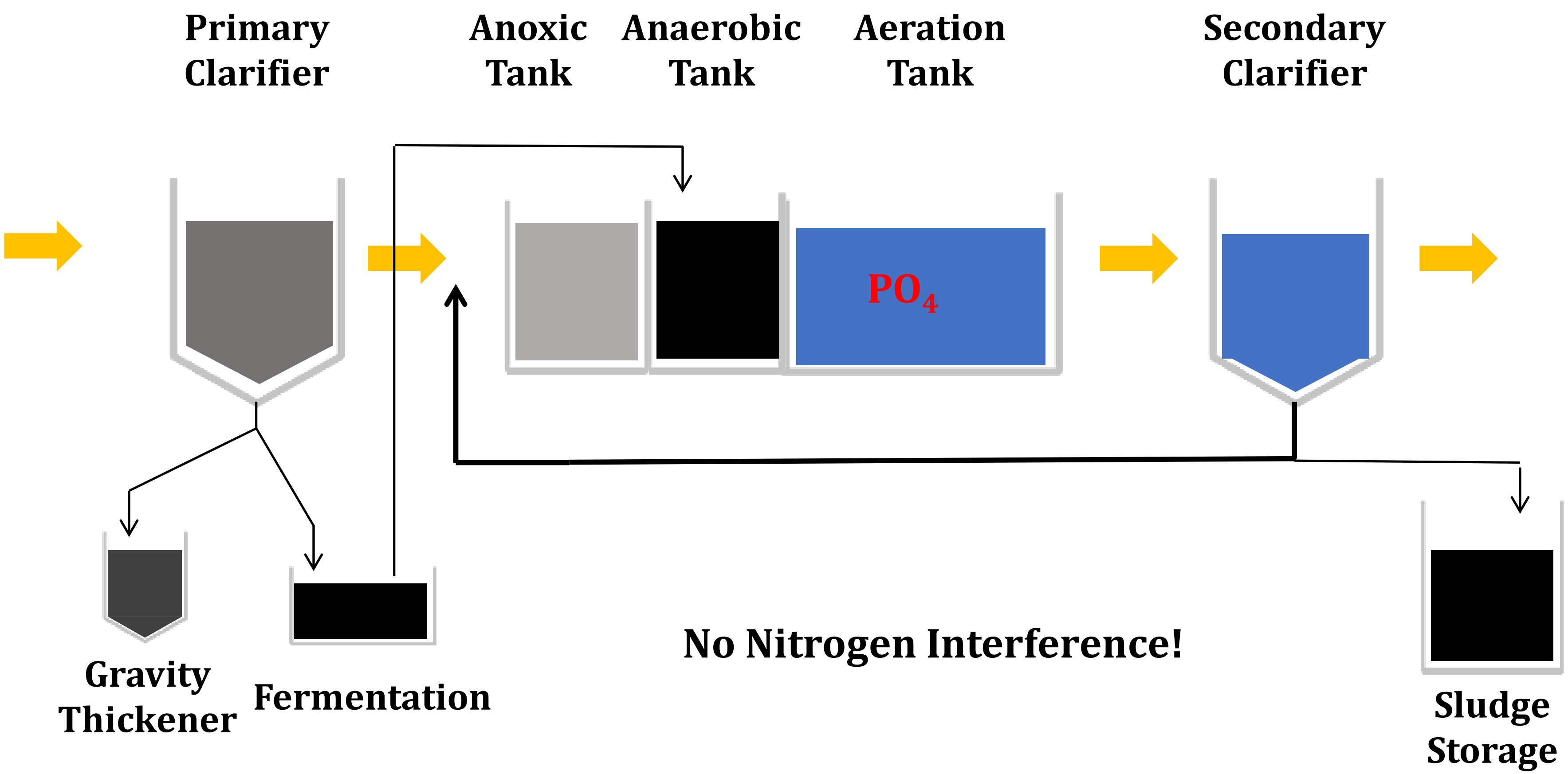

Optimizing Bio-P Removal: Mainstream or Sidestream Fermentation

Anaerobic Tank

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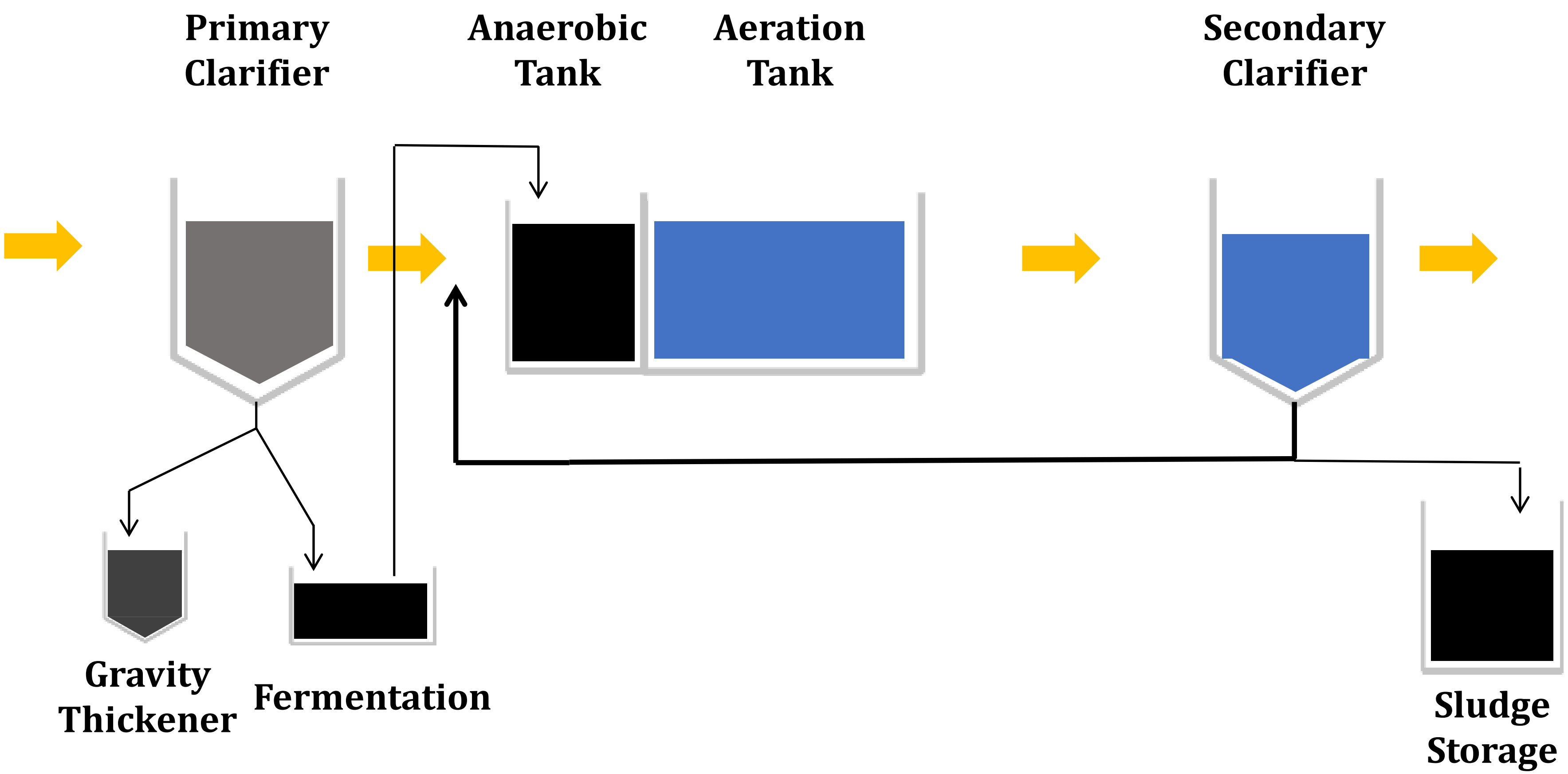
NEW
INFO

Troubleshooting Biological Phosphorus removal in Plants Designed for EBPR (enhanced biological phosphorus removal)

Less than 3x ortho-P leaving Anaerobic Tank



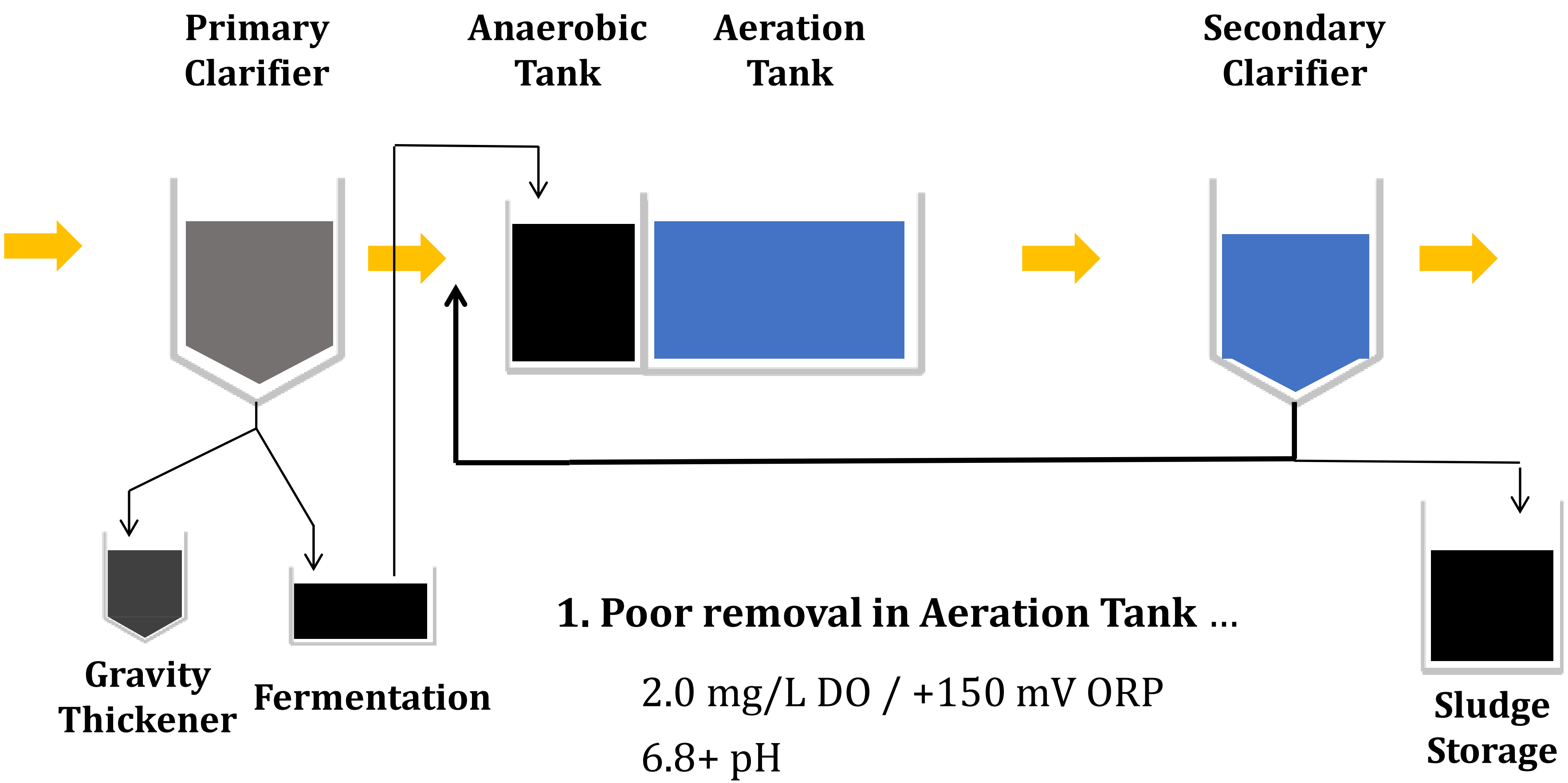
If Anaerobic Tank isn't really anaerobic …

… turn off mixer(s)

Questions?
Comments?

Grant Weaver
g.weaver@cleanwaterops.com

3x ortho-P leaving Anaerobic Tank but high effluent P



1. Poor removal in Aeration Tank …

2.0 mg/L DO / +150 mV ORP

6.8+ pH

If seasonal, maybe too little BOD

2. Rerelease … most likely in clarifier(s)

Profile ortho-P through the plant

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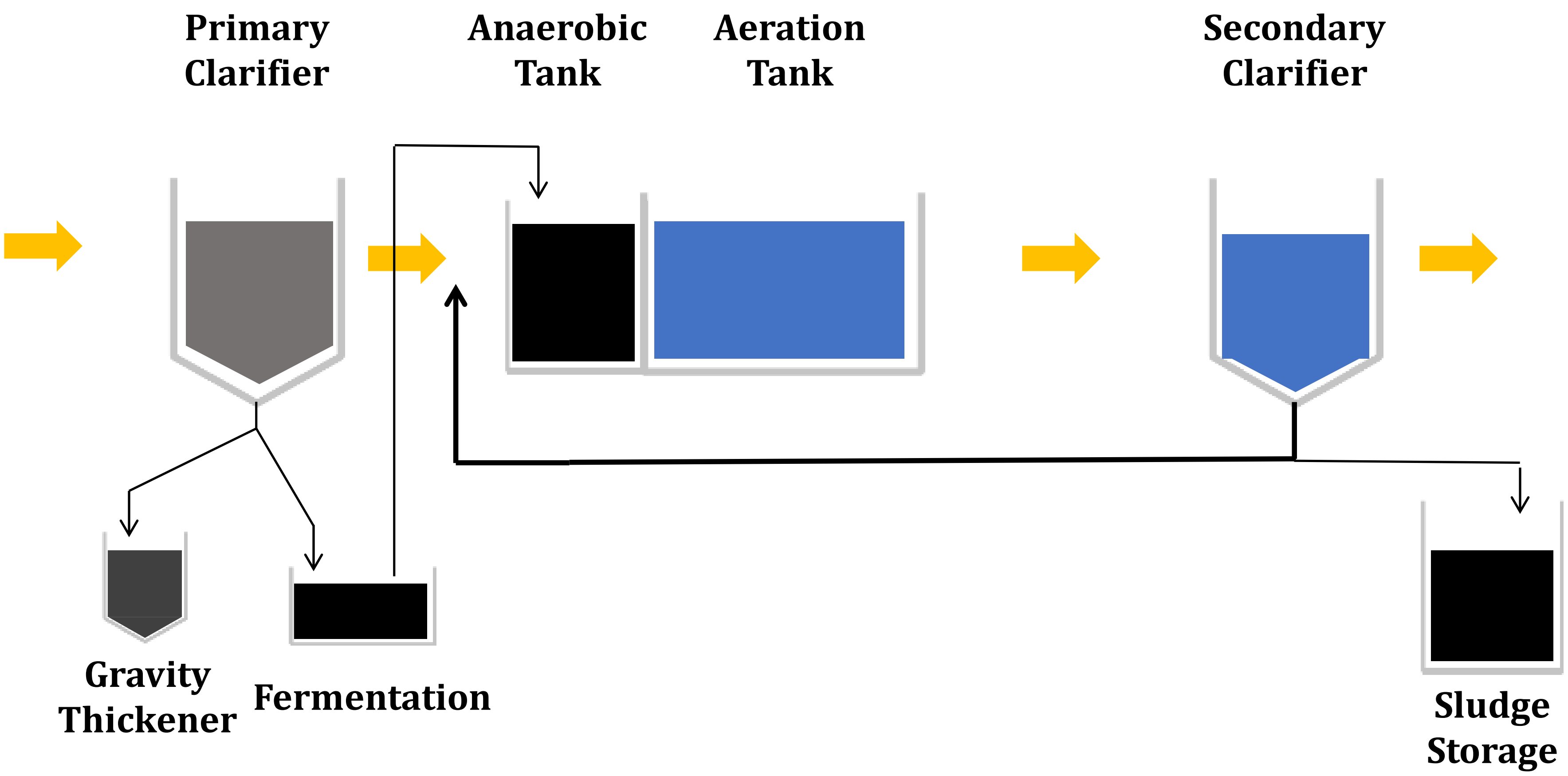
g.weaver@cleanwaterops.com

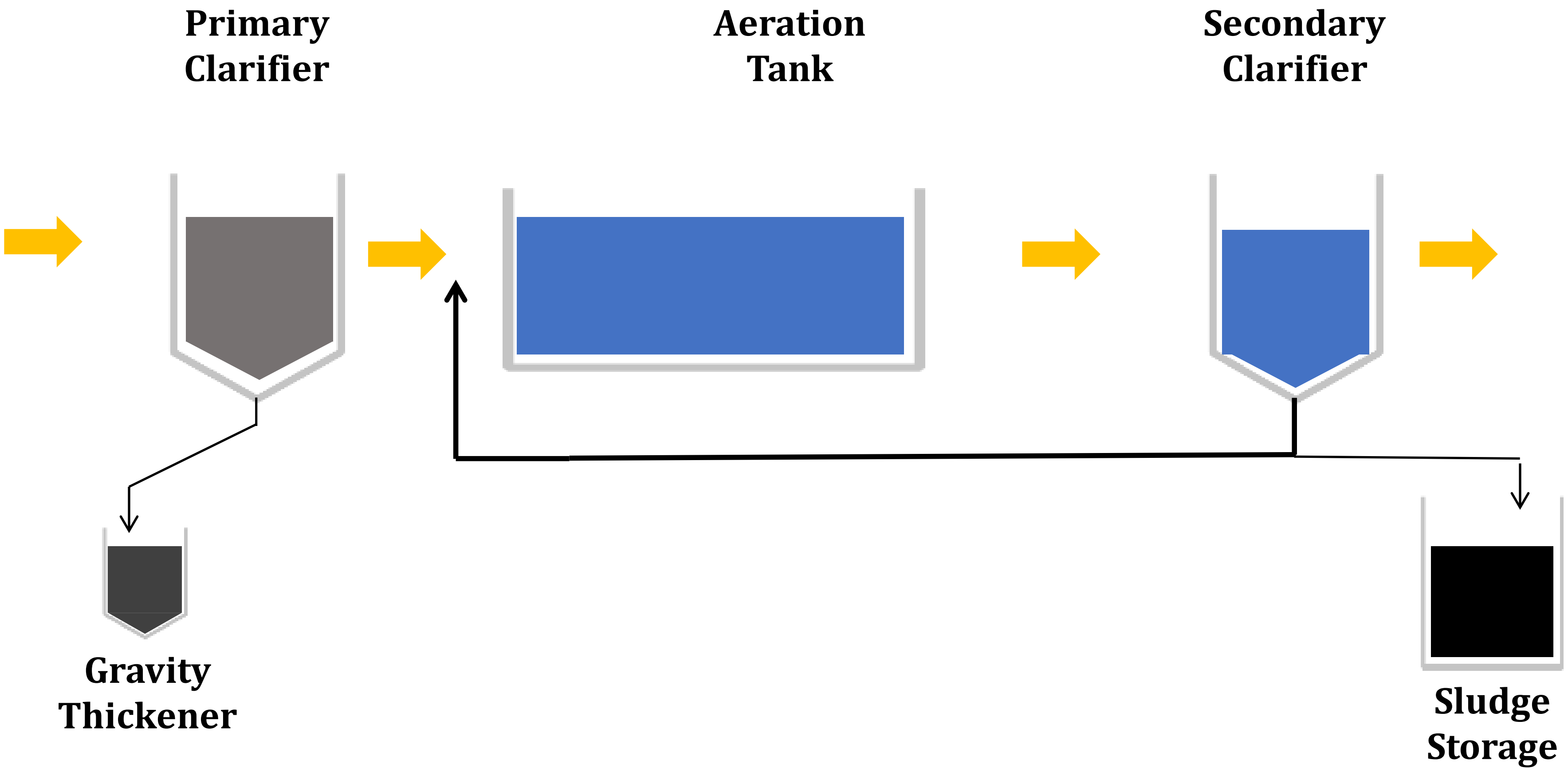
Getting creative …

Biological Phosphorus removal from plants not designed as EBPR (enhanced biological phosphorus removal) facilities

Home Grown Sidestream Fermenter



Home Grown Sidestream Fermenter



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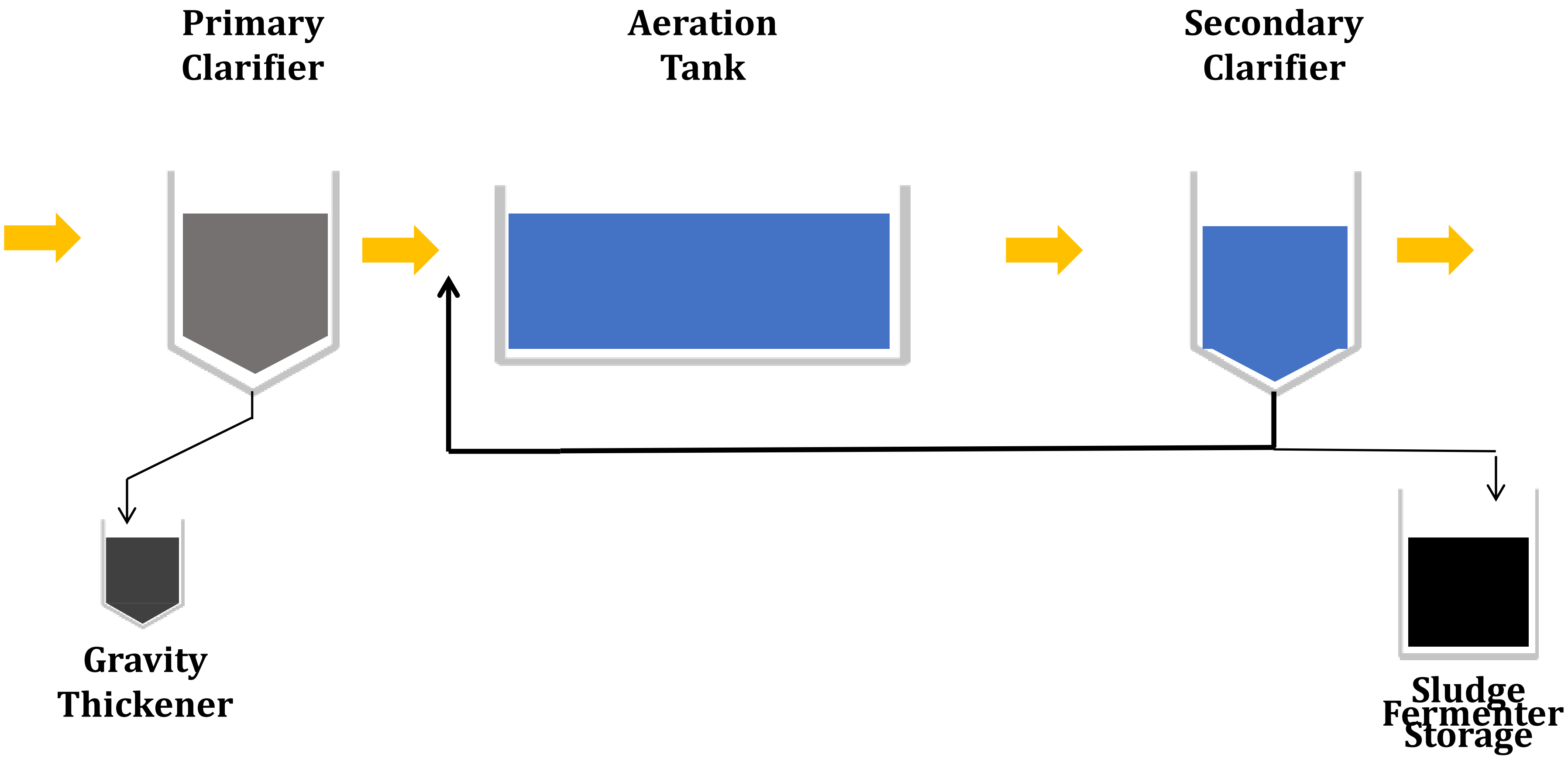

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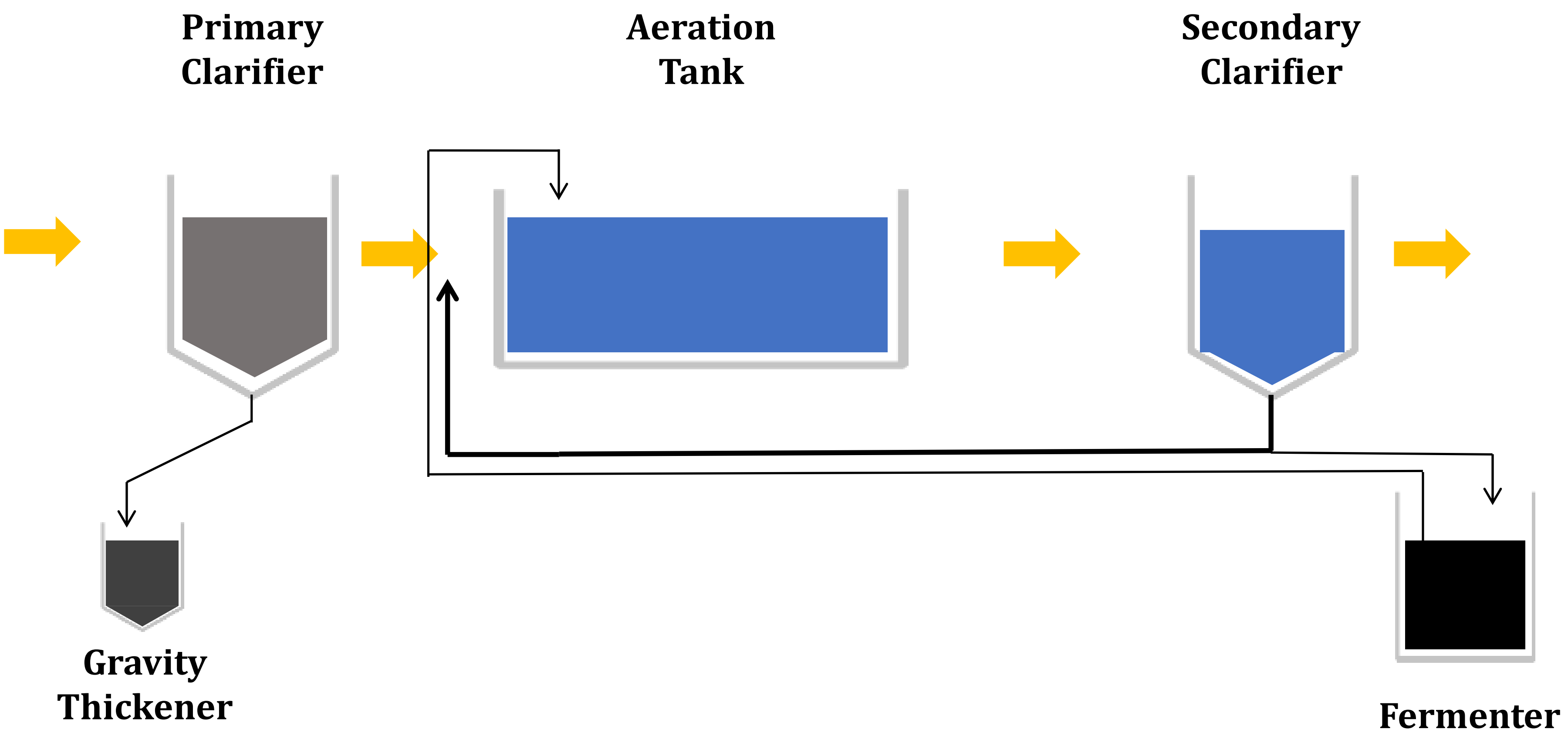

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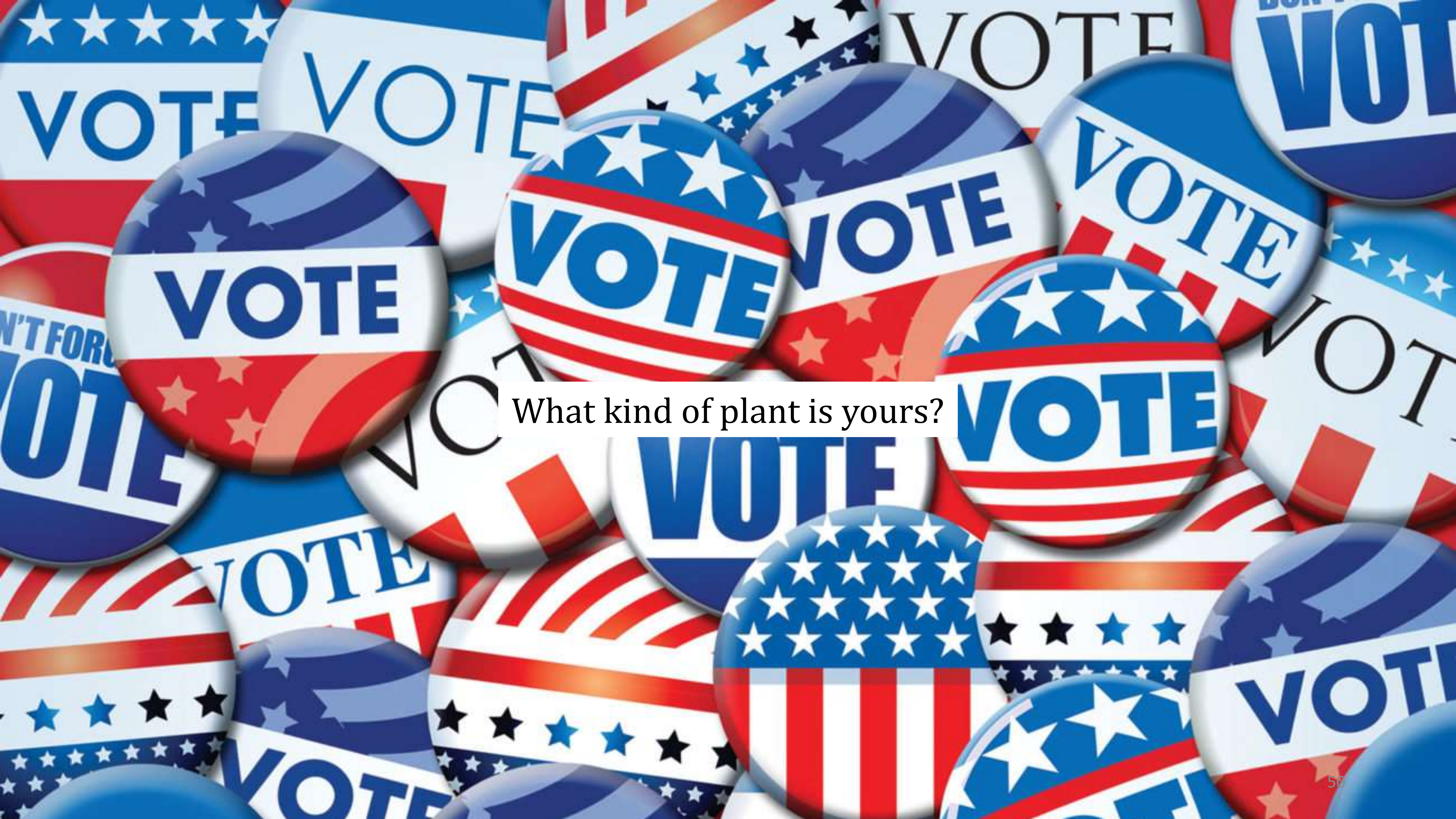


What kind of plant is yours?


BREAK TIME

TENNESSEE

Norris, Tennessee Population: 1,450 0.2 MGD design flow

GOVERNOR'S ENVIRONMENTAL STEWARDSHIP AWARDS

Norris, Tennessee


Norris, TN

Norris, TN:
Nitrogen Removal

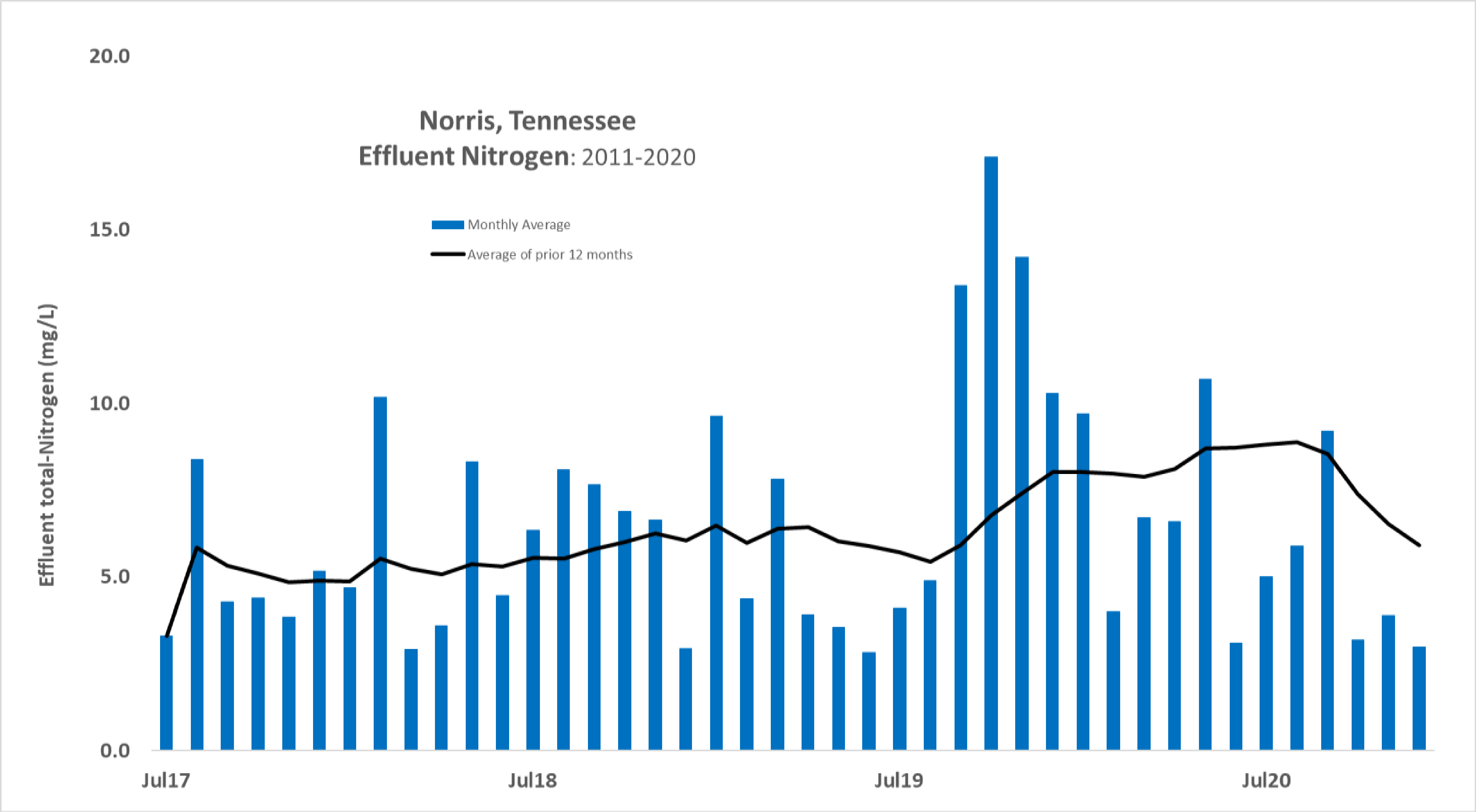
Nitrogen Removal

Raise MLSS concentration

Cycle aeration:

ON 2-3 hours

OFF 1½-2 hours



Norris, Tennessee
Effluent Nitrogen: 2011-2020
Monthly Average
Average of prior 12 months
Effluent total-Nitrogen (mg/L)
20.0
15.0
10.0
5.0
0.0
Jul17
Jul18
Jul19
Jul20

Norris, TN: First try at Phosphorus Removal

Phosphorus Removal

Recycle RAS through fermenters

Norris, TN: Second try at Phosphorus Removal

Phosphorus Removal

Create Fermentation Zone in Aeration Tank

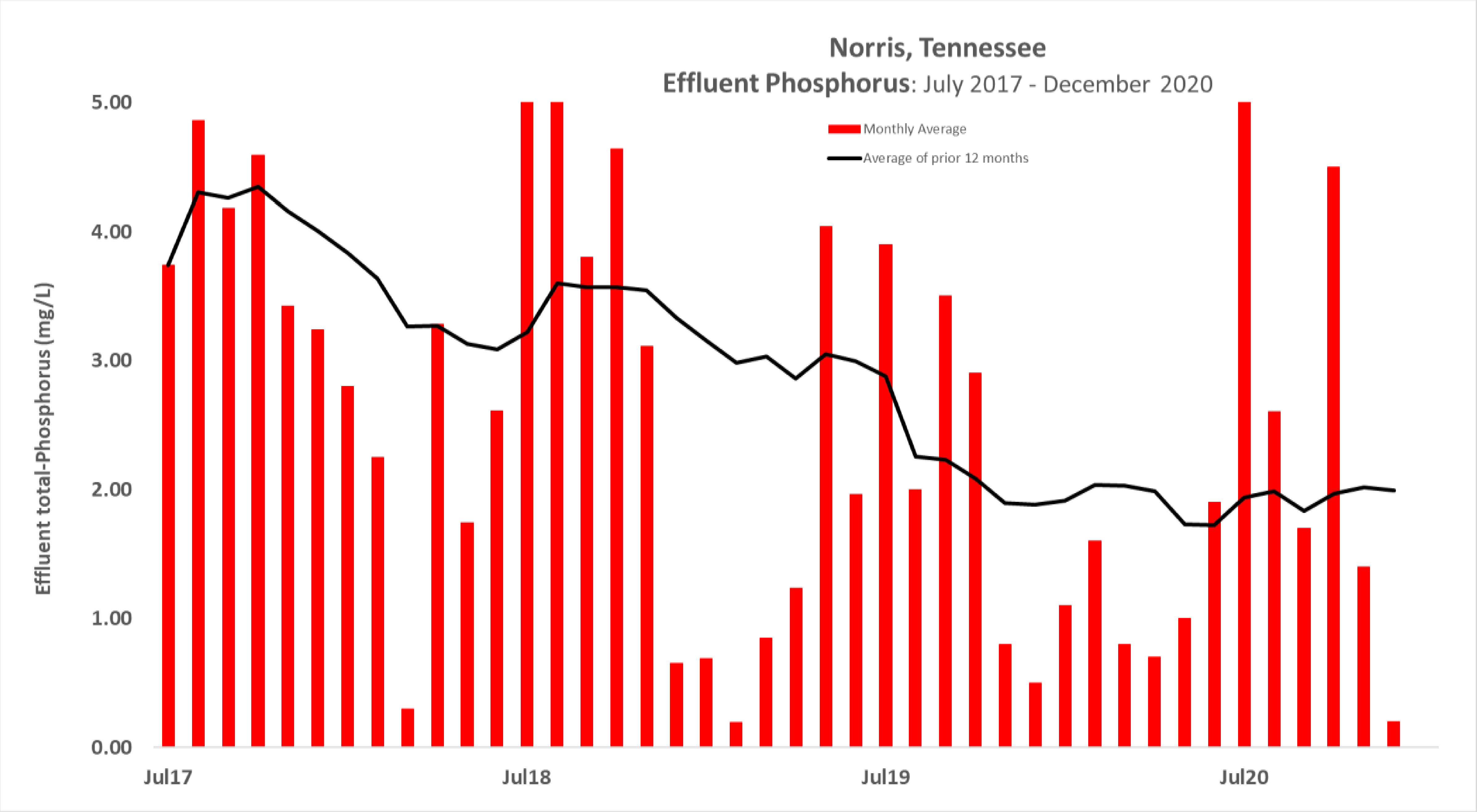
Norris, TN: Third try at Phosphorus Removal

<u>Phosphorus Removal</u>

Recycle RAS through fermenters

- and -

Create Fermentation Zone in Aeration Tank



Norris, Tennessee
Effluent Phosphorus: July 2017 - December 2020
Monthly Average
Average of prior 12 months
Effluent total-Phosphorus (mg/L)
5.00
4.00
3.00
2.00
1.00
0.00
Jul17
Jul18
Jul19
Jul20

Questions?
Comments?

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Harriman, Tennessee Population: 6,200 1.5 MGD design flow

United States Environmental Protection Agency

Office of Water
EPA 820-F-20-004
January 2021

www.epa.gov/eg/national-study-nutrient-removal-fact-sheets

TENNESSEE: QUEST FOR ENERGY EFFICIENCY INSPIRES OPERATORS' PURSUIT OF NUTRIENT REMOVAL

Energy Efficiency Measures Provide Opportunities for Nutrient Reduction

At many publicly owned treatment works (POTWs), operators experimenting with cost-saving energy efficiency find their plants also benefit from improved nitrogen removal. These successes provide staff with confidence to implement low-cost modifications and operational changes to further reduce effluent nutrient discharges. EPA's **National Study of Nutrient Removal and Secondary Technologies** investigates optimization efforts across the country, and this fact sheet highlights achievements at the Harriman POTW in Tennessee.

In 2011, the Tennessee Water and Wastewater Energy Efficiency Partnership (TWEEP) was formed between many associations, including EPA and the Tennessee Department of Environment and Conservation (TDEC). The partnership supplied Tennessee wastewater utilities with energy efficiency tools and expertise to support operators in reducing energy costs and pollution. This included providing in-person technical assistance to staffs across Tennessee, including Harriman POTW in 2014.

Harriman POTW

Harriman POTW has a design capacity flow of 1.5 million gallons per day (MGD) and an average daily flow of 0.5 MGD. The plant has two equalization basins, two oxidation ditches, two secondary clarifiers, chlorine disinfection, and two aerobic digesters. Each ditch has two fixed-speed rotors, and no chemicals are added for phosphorus removal.

Prior to the partnership's visit, aeration for Harriman POTW's oxidation ditches and digesters consumed

Harriman Staff: Donnie Fitzhugh and Ray Freeman

43% of the plant's total energy use. The four ditch rotors ran continuously and the digester blowers ran 16 hours each night during the week and continuously on weekends.

Harriman POTW's staff started by following the partnership's suggestion to cycle the four rotors 1 hour on/1 hour off, which decreased aeration energy use by 50%. They noticed a drop in effluent Total Nitrogen (TN), although concentrations were still high, averaging over 20 mg/L. Inspired to realize greater energy savings, staff continued to refine the plant's aeration cycling on their own, resulting in a TN concentration consistently under 10 mg/L beginning in 2017.

In July 2018, Ray Freeman took over as Chief Plant Operator, and, assisted by Operator Donnie Fitzhugh, the two began a quest to drive effluent TN as low as possible. They experimented by ratcheting down rotor run times in small increments and alternating the rotors' operation. The plant now operates 1 rotor per ditch, cycling 1 hour on/2 hours off in the summer and 1 hour on/3 hours off in the winter.

> "I started by taking baby steps to reduce power consumption. In that process, I could see the reduction in nitrogen. I just kept altering DO levels and equipment run times until I could no longer reduce TN without negatively effecting other parameters, such as BOD." -Ray Freeman

Dissolved oxygen (DO) readings are obtained with a hand-held probe near the influent inlet on the aft side of the first rotor. The DO upper set point averages 1.75 mg/L on the aft side of the rotor, with the lower set point targeted to 0.18 mg/L or less. The plant does have a limited SCADA system that incorporates some timers for the digesters, but the two operators closely monitor and manage all aeration cycling in the ditches by hand. Beginning in 2020, the average effluent TN concentration was an impressive low of 2 mg/L.

Ray also adjusted the digester valves so only one blower is needed to aerate both digesters for six hours each night, further reducing plant energy costs. These aeration strategies save the plant $30,000/year in energy costs, achieving a total reduction in aeration energy use nearing 85%.

Ray and Donnie have now turned their attention to reducing total phosphorus (TP) effluent concentrations and improving the plant's biological phosphorus removal. Over the summer, they began interrupting the 1 hour on/2 hours off schedule twice each day to let the rotors run for 2 hours to drive DO up to 2 mg/L. This was followed by 2 hours off before resuming the 1 hour on/2 hours off schedule. When the plant transitioned to the winter 1 hour on/3 hours off schedule, the 2 hours on/2 hours off cycle was introduced only once per day. Harriman POTW's average effluent TP concentration has already been reduced 25% by these rotor cycling changes over the course of the year.

Harriman Daily Maximum Monitoring Data

	Effluent TN Concentration (mg/L as N)	Effluent TP Concentration (mg/L as P)
Q1 – Q4 2017*	9.2	1.9
Q1 – Q4 2020	2.1	1.4
Percent Removal	77%	25%

**Monitoring data from the first phases of optimization (2014-2016) are not available.*

Optimization Opportunities and Benefits

Optimizing existing treatment systems not only effectively reduces nutrient discharges from POTWs, but it can also result in significant energy and cost savings for utilities. Support from regulatory agencies, onsite consulting, and, most importantly, operator ambition and enthusiasm enabled these Tennessee POTW operators to reach both their nutrient reduction and energy efficiency goals.

Acknowledgements

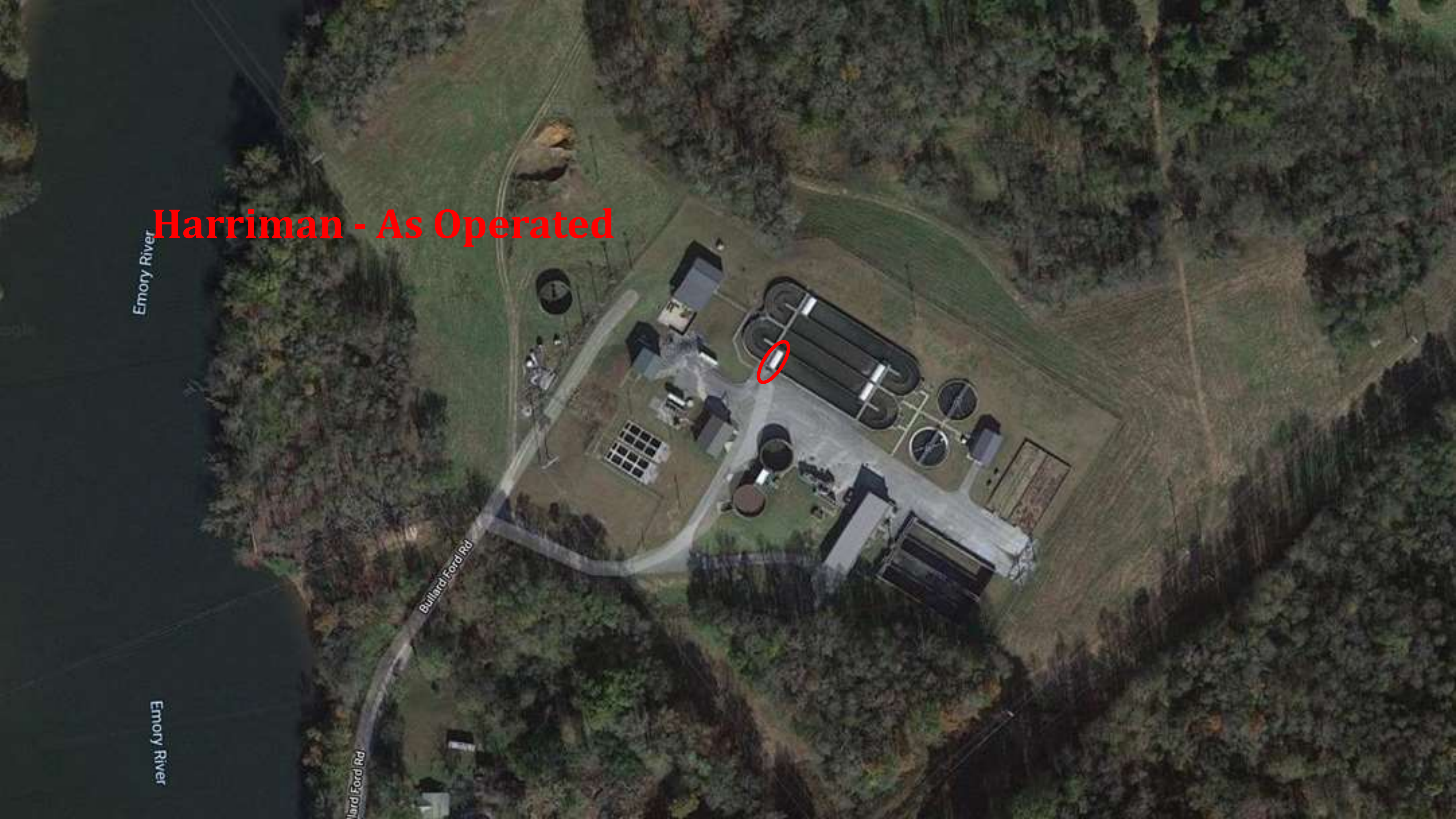
Nutrient monitoring data were collected from EPA's Integrated Compliance and Information System-National Pollutant Discharge Elimination System (ICIS-NPDES) and internal plant records. Energy savings are also from internal plant records. TDEC and the TWEEP Partnership Team aided POTWs in Tennessee in improving their energy efficiency and, in some cases, nitrogen discharges. Grant Weaver of CleanWaterOps has supported Harriman staff with improving biological phosphorus removal.

For more information, visit epa.gov/eg/national-study-nutrient-removal-and-secondary-technologies.

Harriman, Tennessee				
Actual Flow (MGD)	Effluent Nitrogen (mg/L)		Effluent Phosphorus (mg/L)	
	Historical Average	After Optimization	Historical Average	After Optimization
1.2	21.5	2.3	2.9	1.4

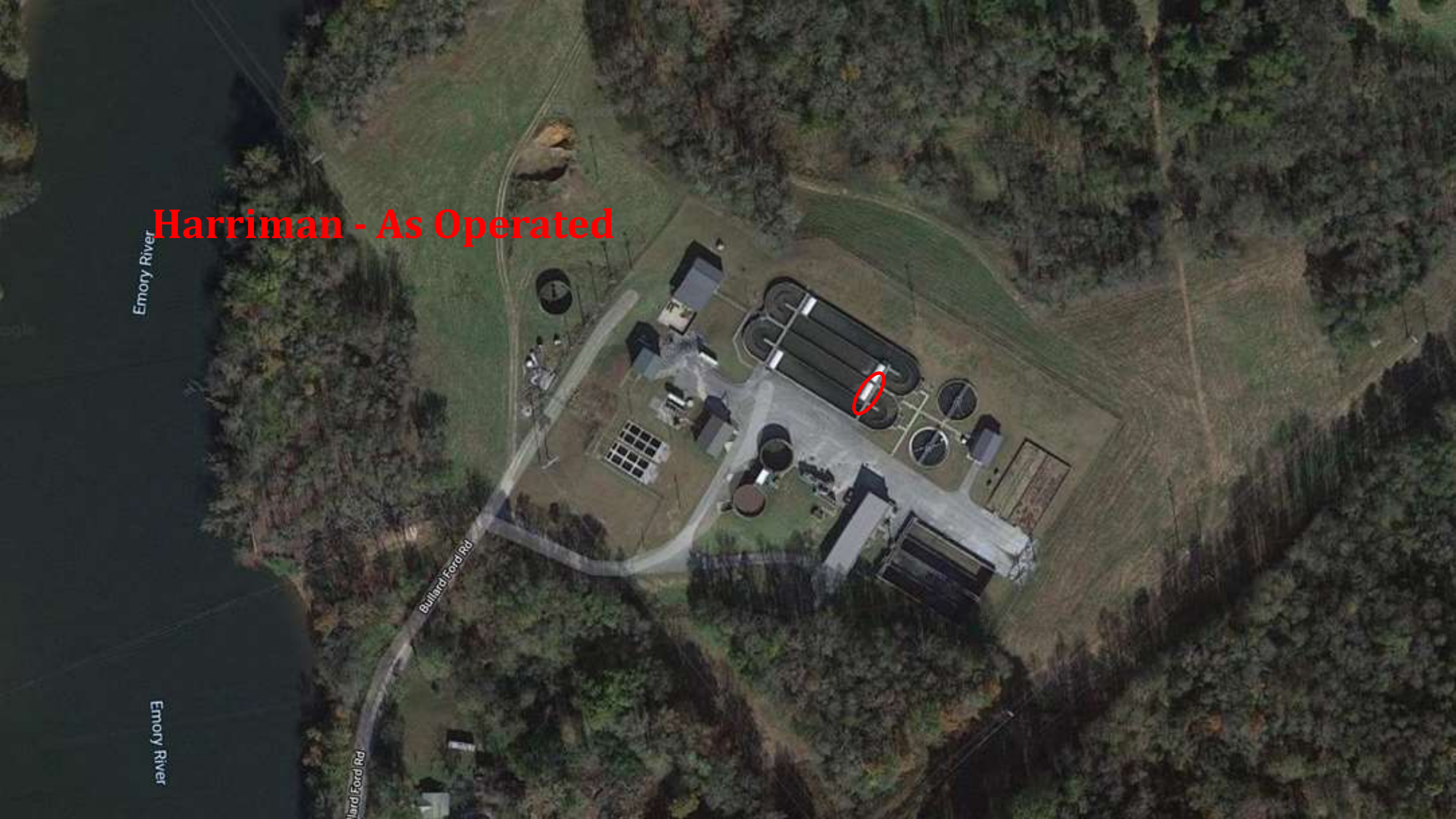

Harriman - As Designed
Emory River
Bullard Ford Rd
Emory River


Harriman - As Operated
Emory River
Emory River
Bullard Ford Rd
llard Ford Rd


Harriman - As Operated
Emory River
Emory River
Bullard Ford Rd
Bullard Ford Rd

Harriman - As Operated
Emory River
Bullard Ford Rd
Emory River

Harriman - As Operated




Harriman - As Operated
Emory River
Bullard Ford Rd
Emory River
Bullard Ford Rd

Harriman - As Operated

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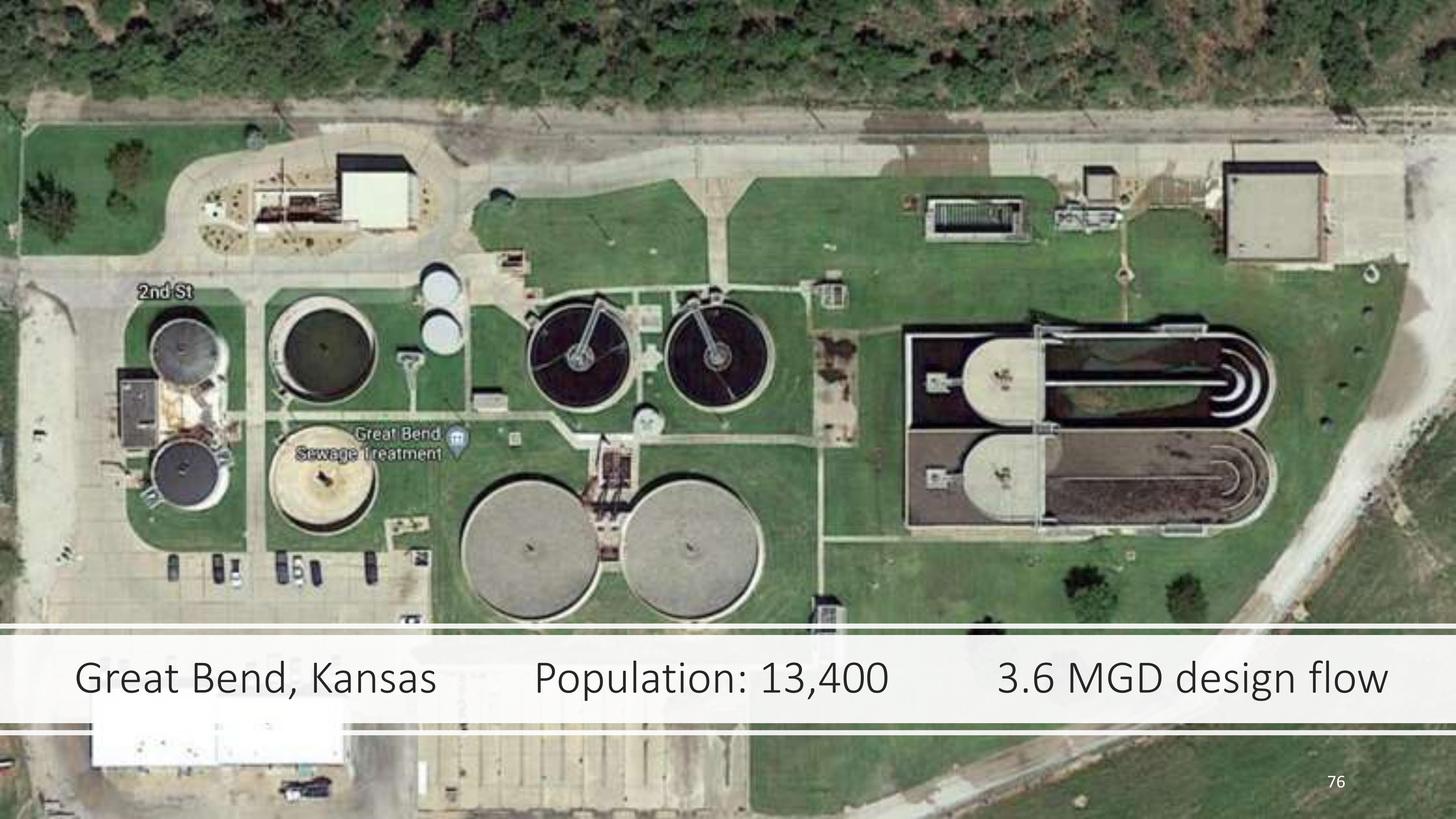
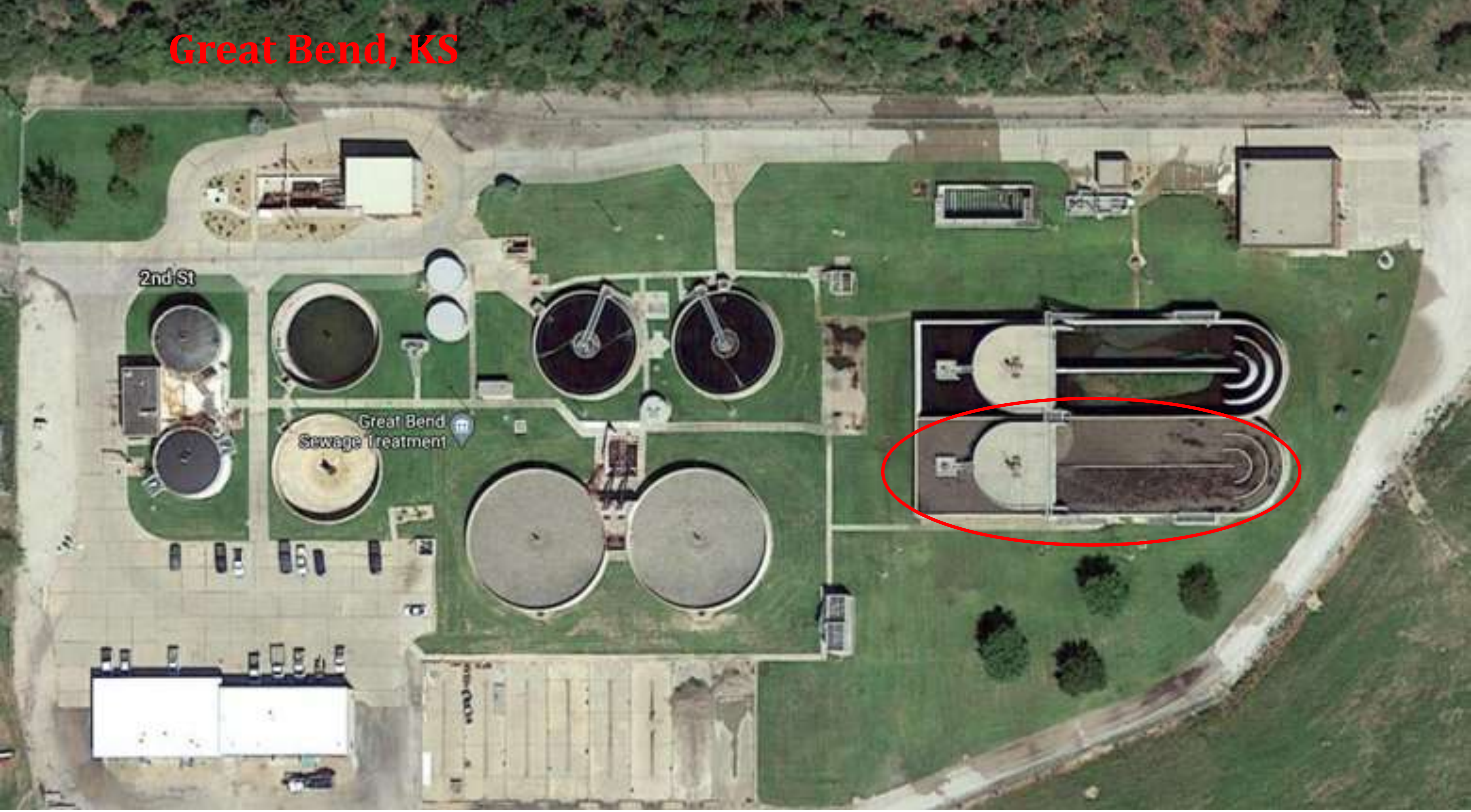
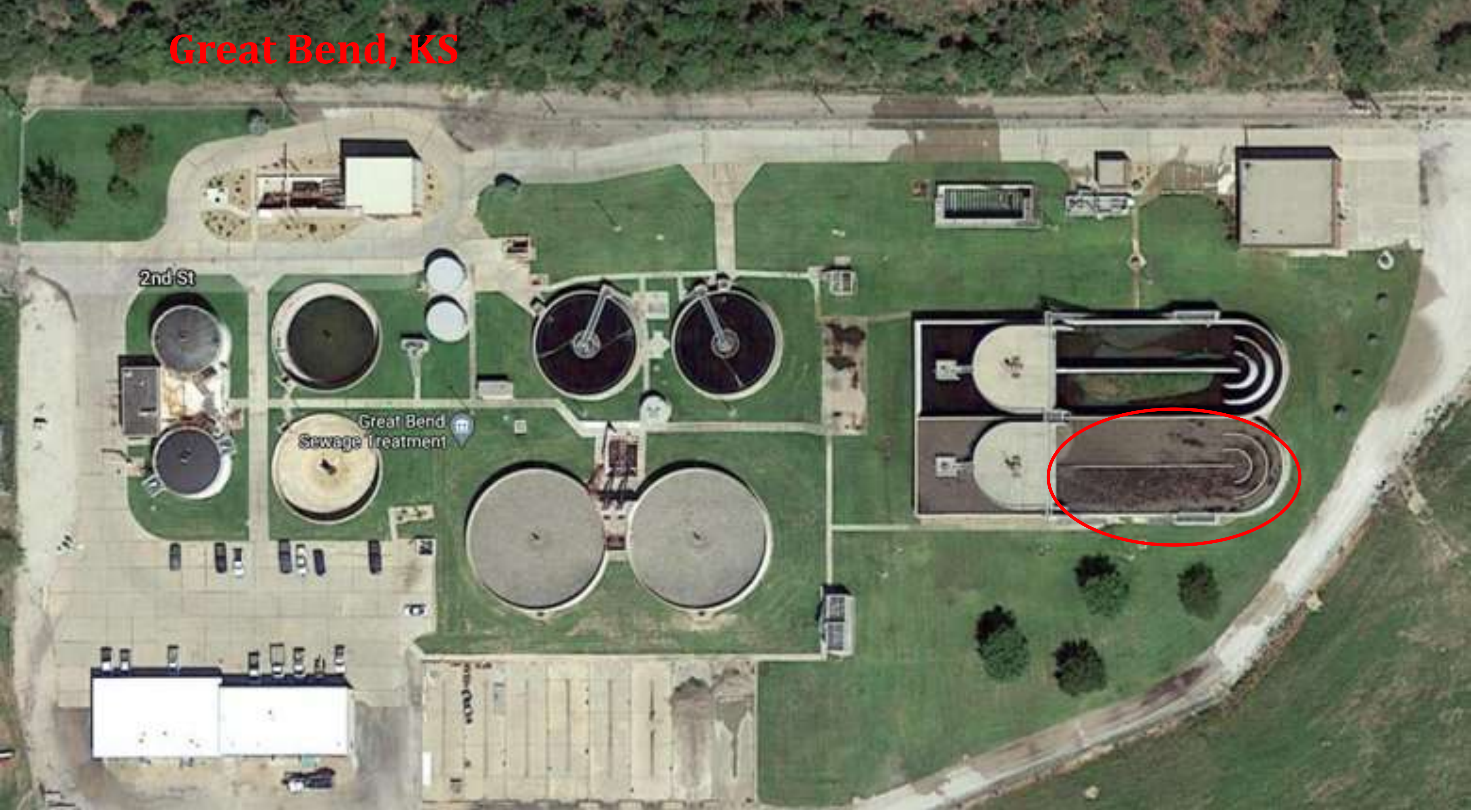
KANSAS

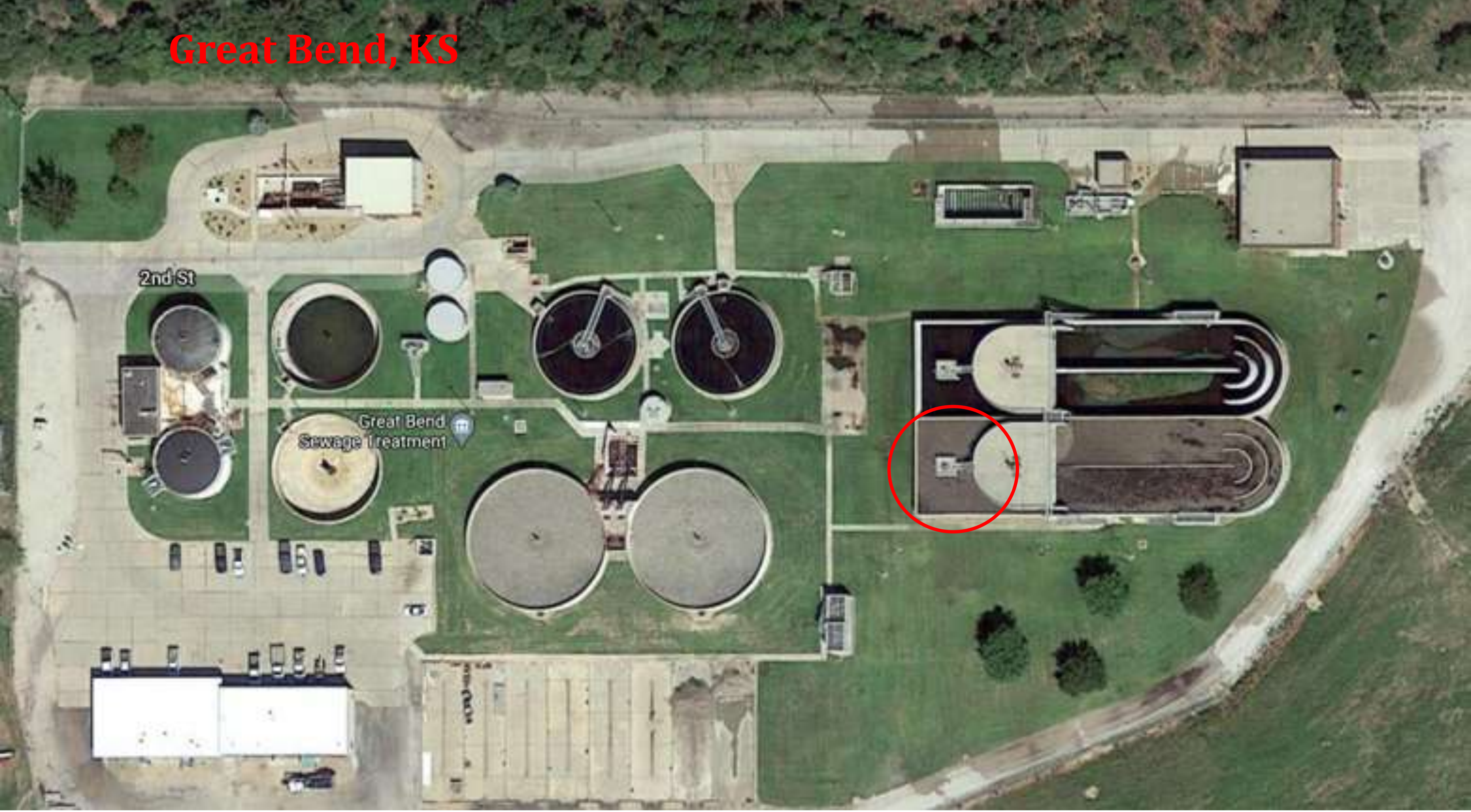


Great Bend, Kansas Population: 13,400 3.6 MGD design flow


Great Bend, KS
2nd St
Great Bend
Sewage Treatment

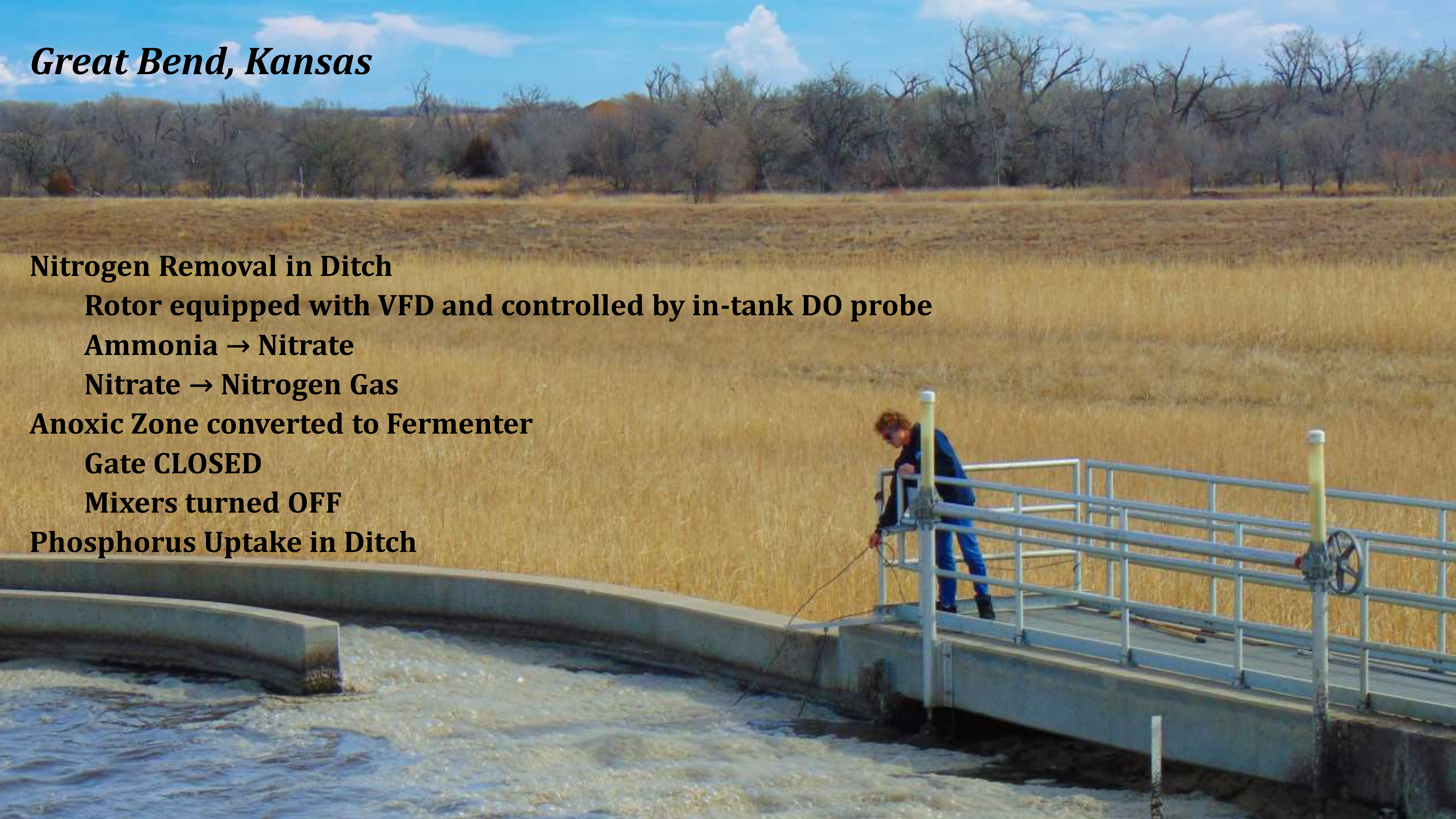
Great Bend, KS




Great Bend, KS
2nd St
Great Bend
Sewage Treatment

Great Bend, Kansas

- Nitrogen Removal in Ditch
  - Rotor equipped with VFD and controlled by in-tank DO probe
  - Ammonia → Nitrate
  - Nitrate → Nitrogen Gas
- Anoxic Zone converted to Fermenter
  - Gate CLOSED
  - Mixers turned OFF
- Phosphorus Uptake in Ditch



Questions?
Comments?

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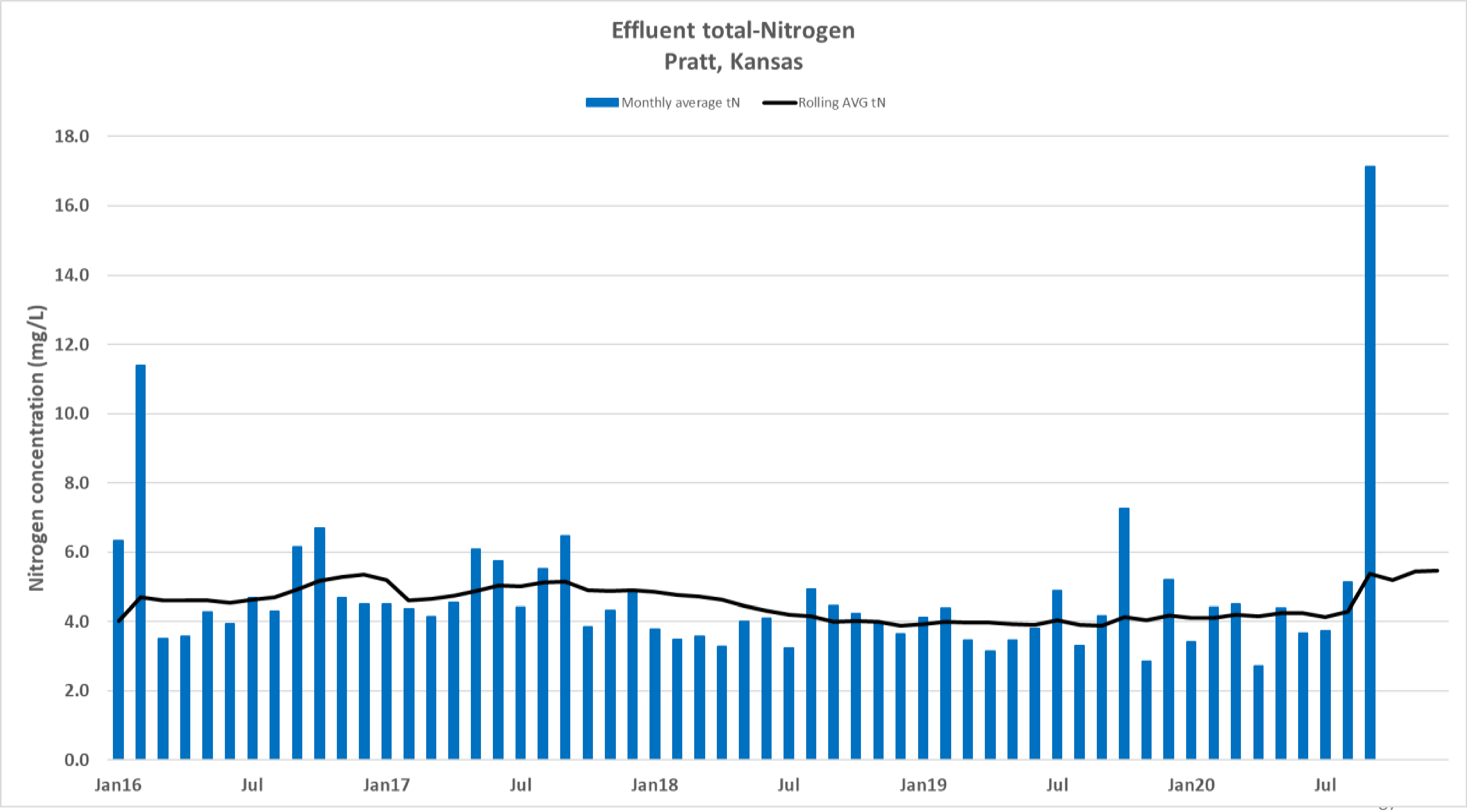
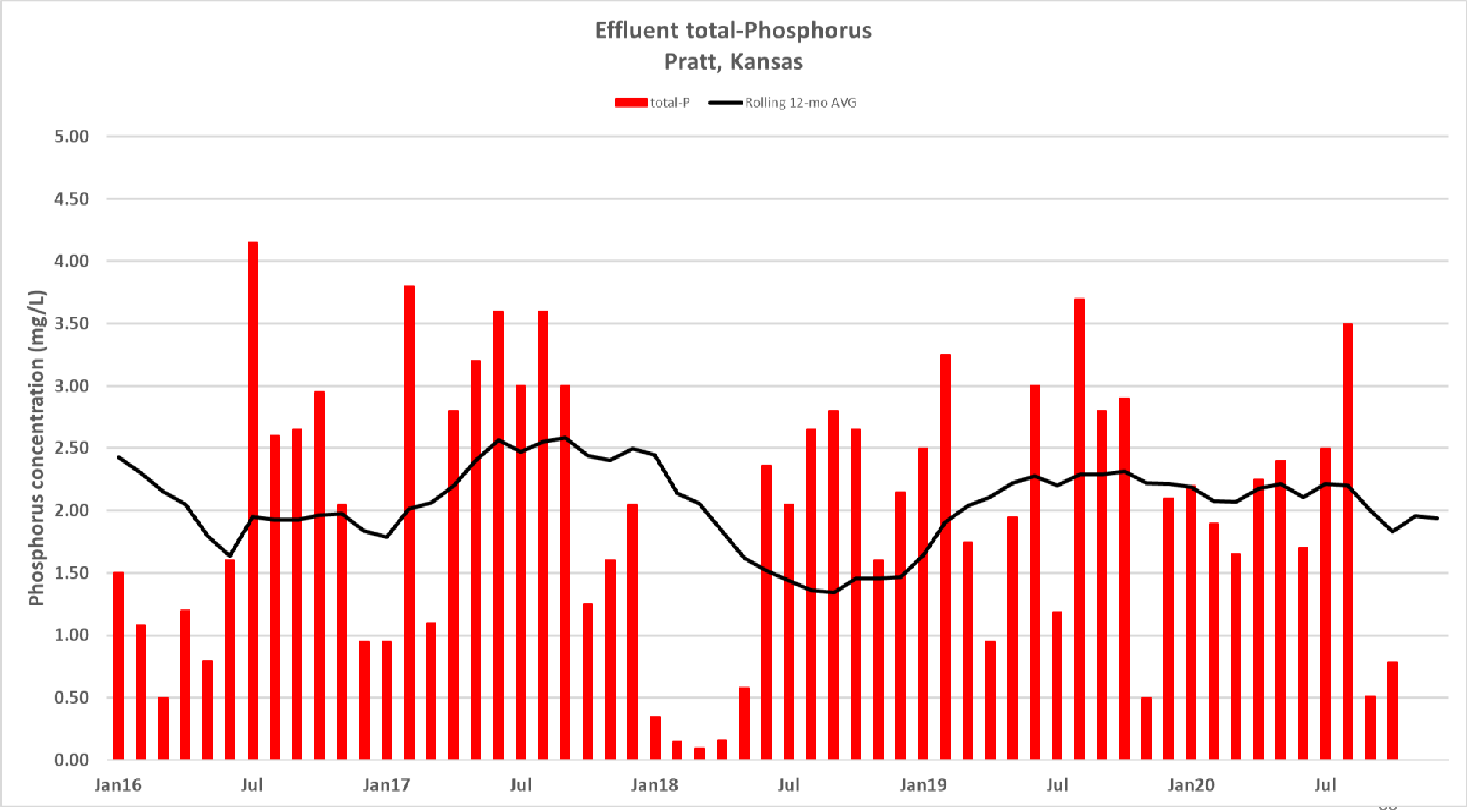
Pratt, Kansas Population: 6,600 1.0 MGD design flow


Effluent total-Nitrogen
Pratt, Kansas
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
Jan16
Jul
Jan17
Jul
Jan18
Jul
Jan19
Jul
Jan20
Jul


Effluent total-Phosphorus
Pratt, Kansas
total-P
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
Jan16
Jul
Jan17
Jul
Jan18
Jul
Jan19
Jul
Jan20
Jul

Questions?
Comments?

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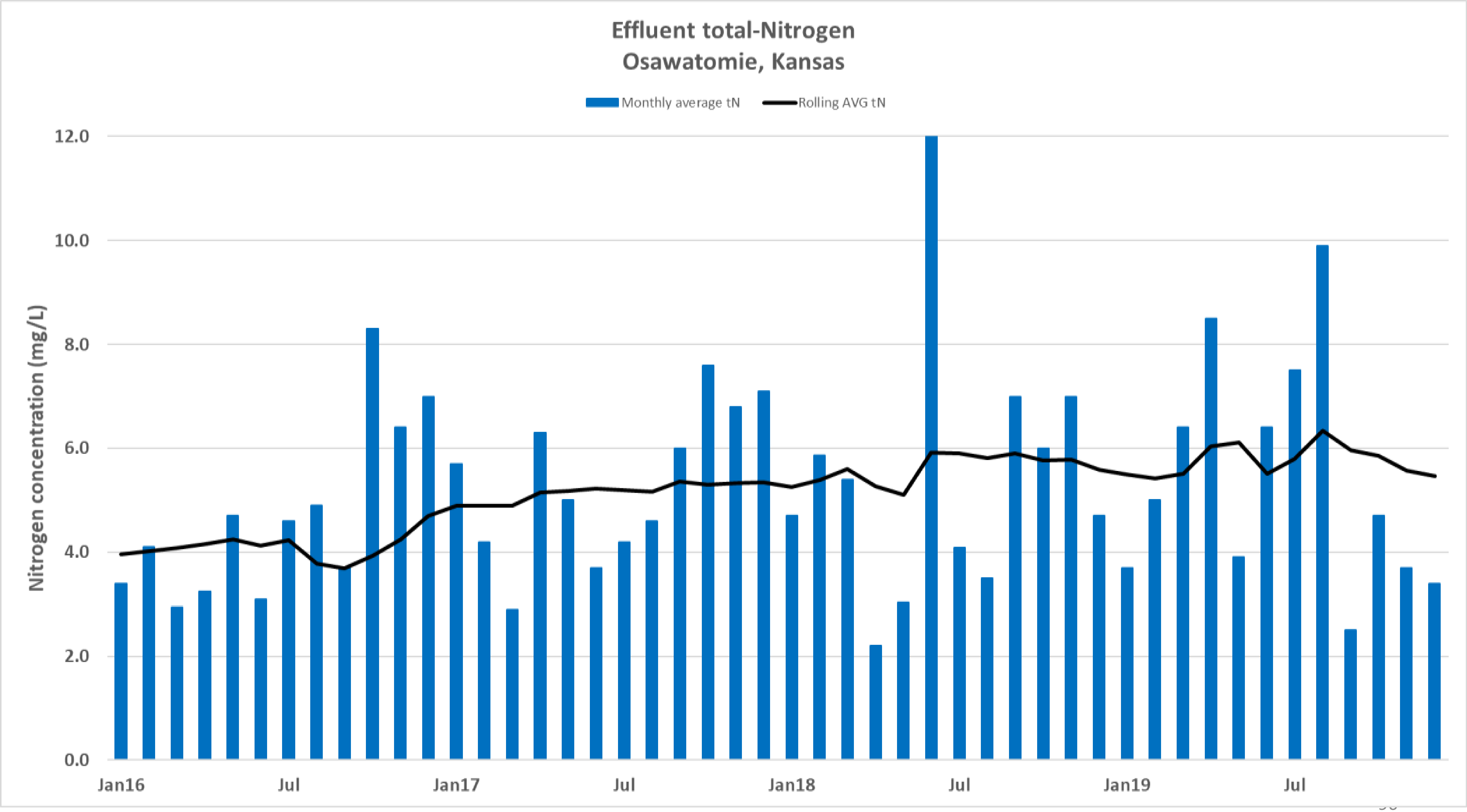
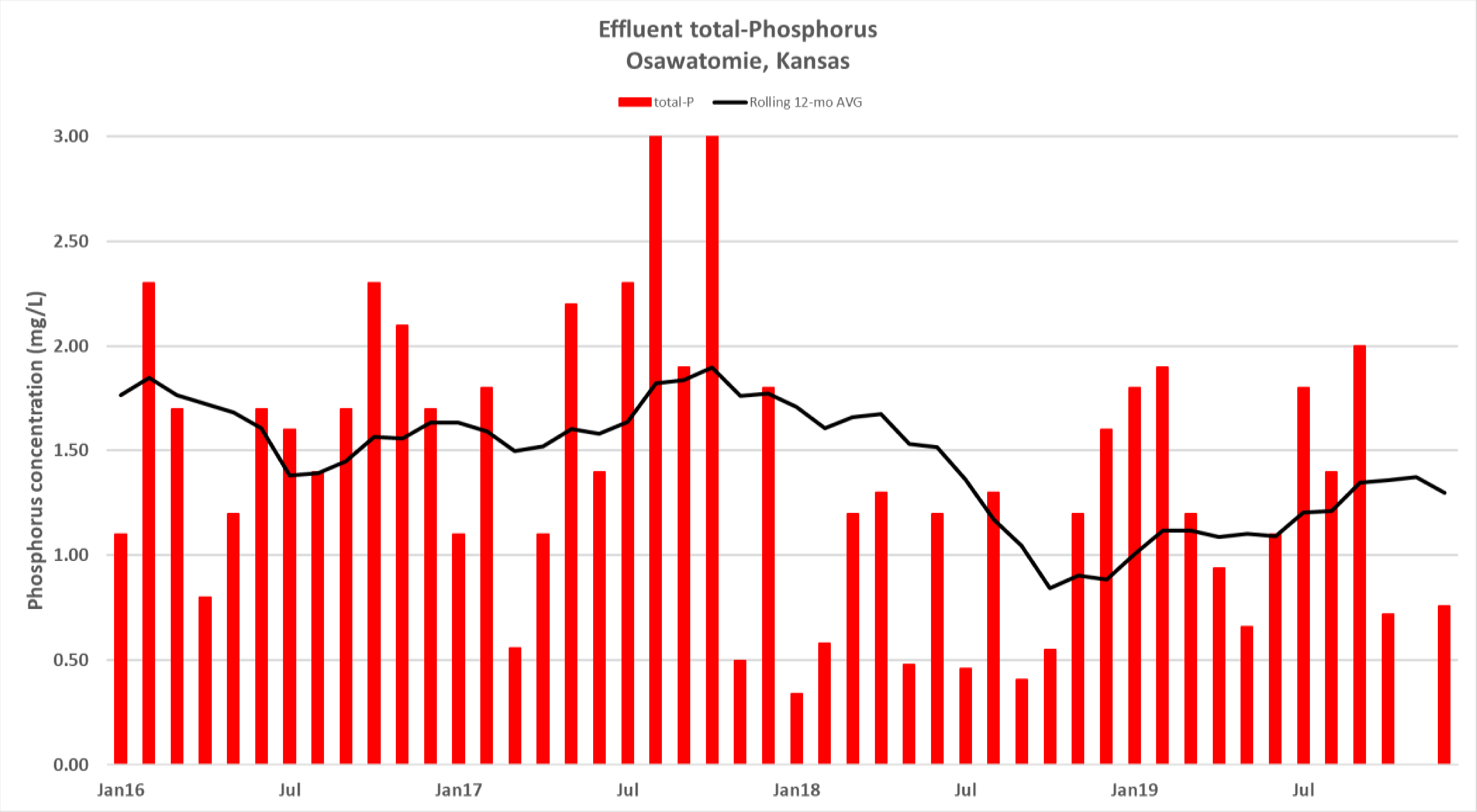
Osawatomie, Kansas Population: 4,300 MGD design flow



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
Jan16
Jul
Jan17
Jul
Jan18
Jul
Jan19
Jul



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
Jan16
Jul
Jan17
Jul
Jan18
Jul
Jan19
Jul

Questions?
Comments?

Grant Weaver
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Wichita, Kansas Population: 390,000 54.4 MGD design flow

Wichita Pilot Study

Nitrogen Removal
Cycle aeration on/off in Aeration Basin 6

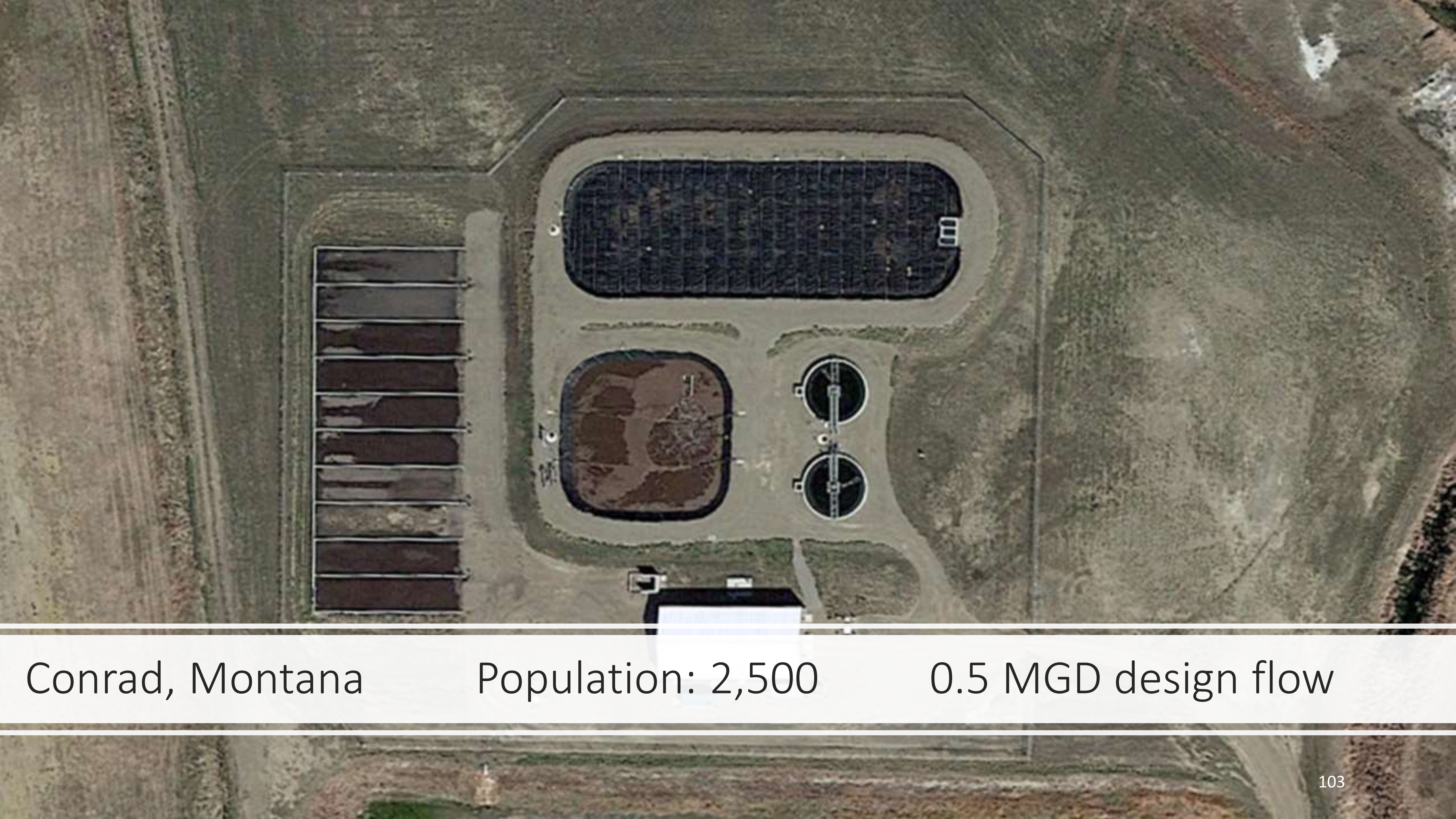
Phosphorus Removal
Side stream fermenter using abandoned centrate tanks

Increase BOD loading
Take Trickling Filters off-line

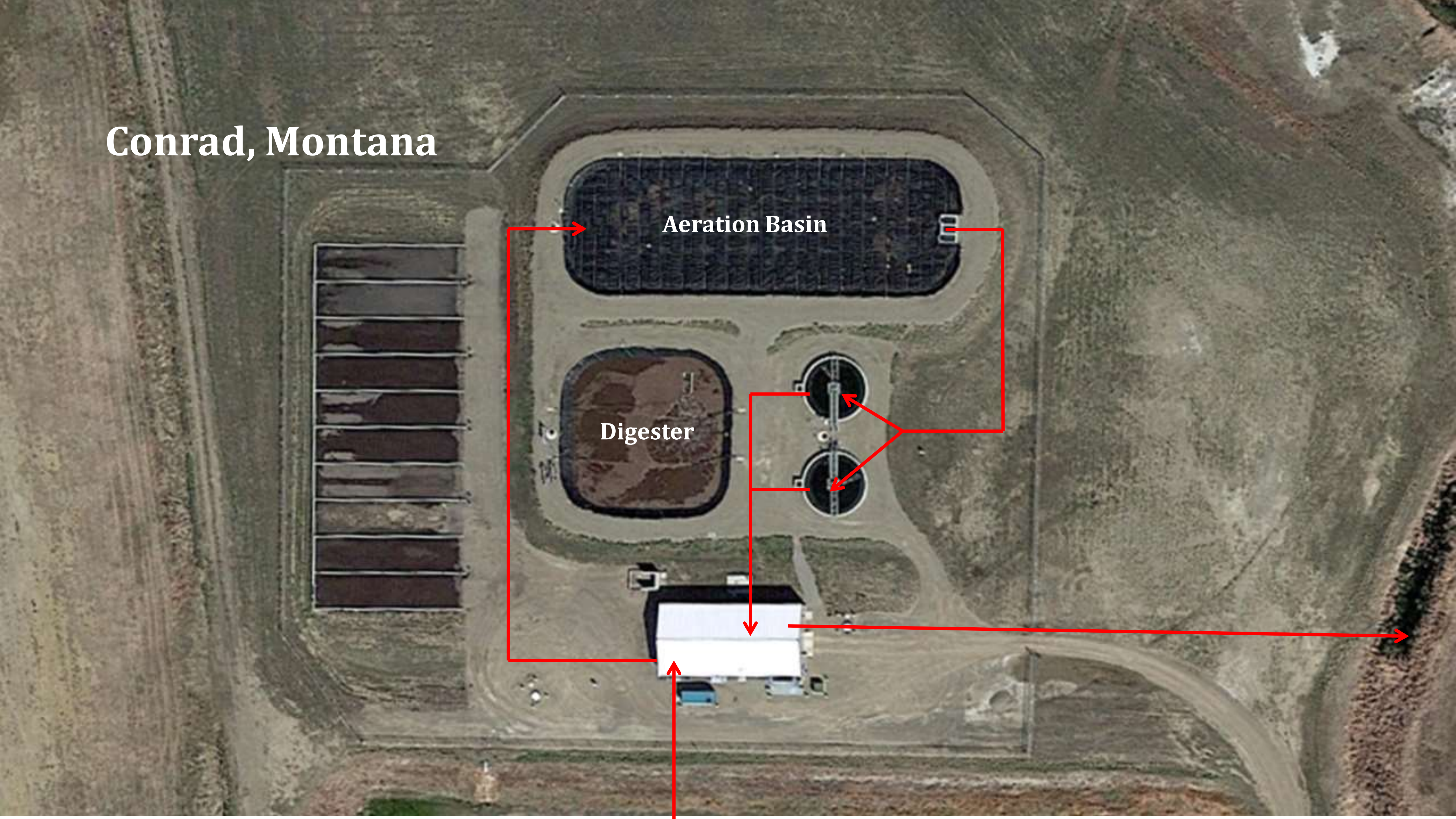
Questions?
Comments?

Grant Weaver
g.weaver@cleanwaterops.com


MONTANA



Conrad, Montana Population: 2,500 0.5 MGD design flow


Conrad, Montana
Aeration Basin
Digester

Conrad, Montana
Nitrogen Removal

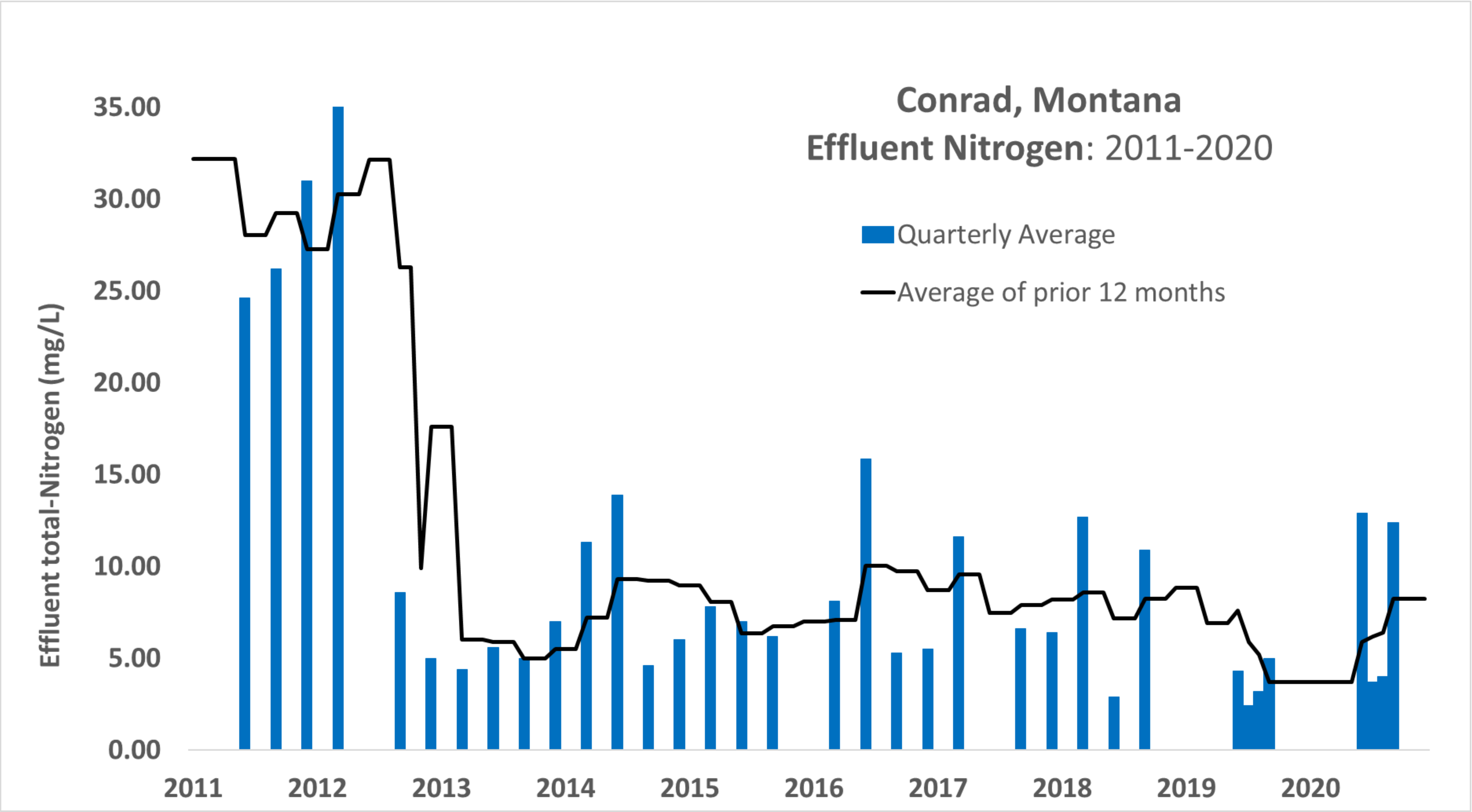
<u>Nitrogen Removal</u>

Raise MLSS concentration

Cycle aeration:

ON 2-3 hours

OFF 1½-2 hours


Conrad, Montana
Effluent Nitrogen: 2011-2020
Quarterly Average
Average of prior 12 months
Effluent total-Nitrogen (mg/L)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Conrad, Montana
Phosphorus Removal

Phosphorus Removal

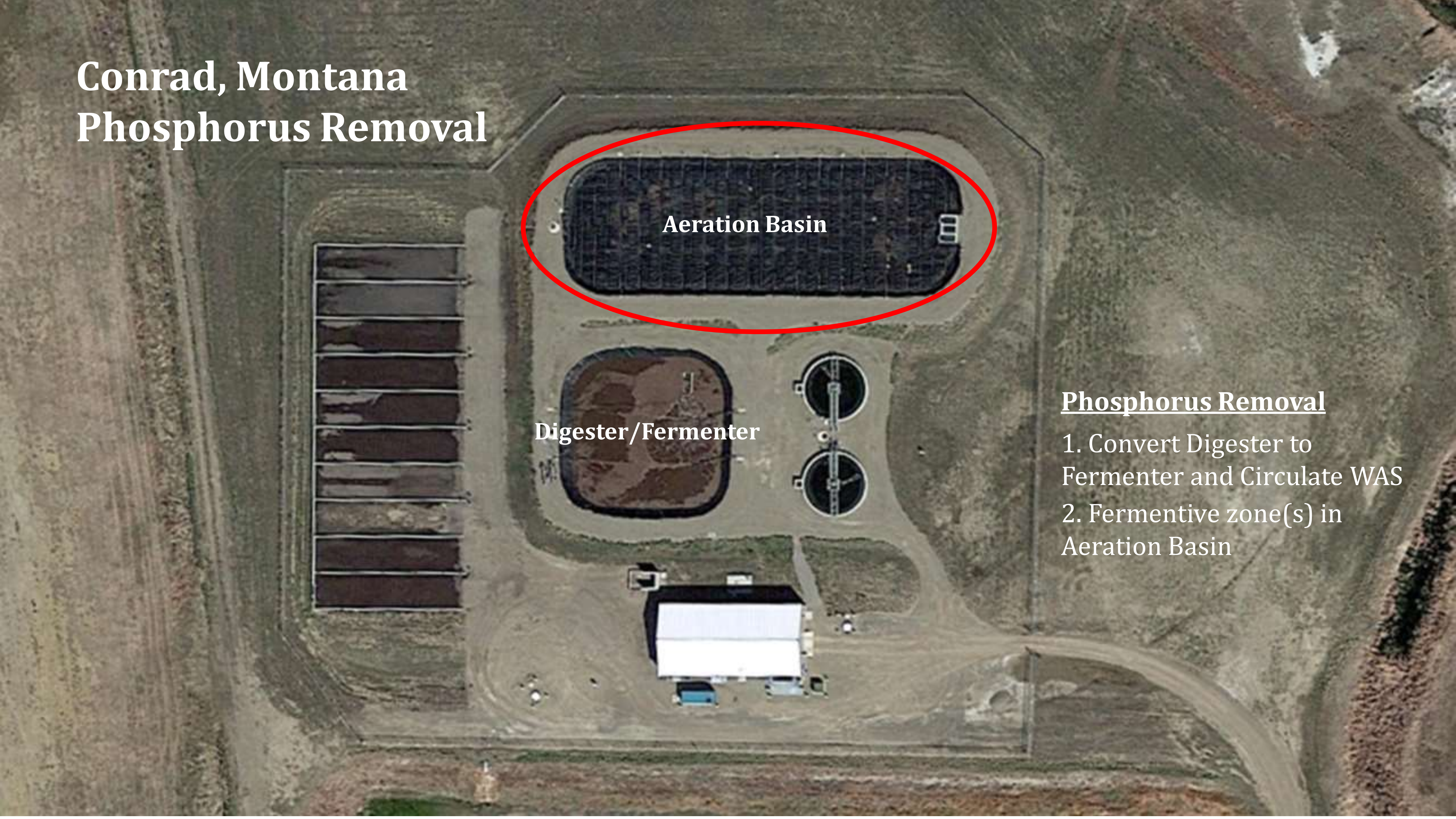
1. Convert Digester to Fermenter and Circulate WAS

Conrad, Montana
Phosphorus Removal

Phosphorus Removal

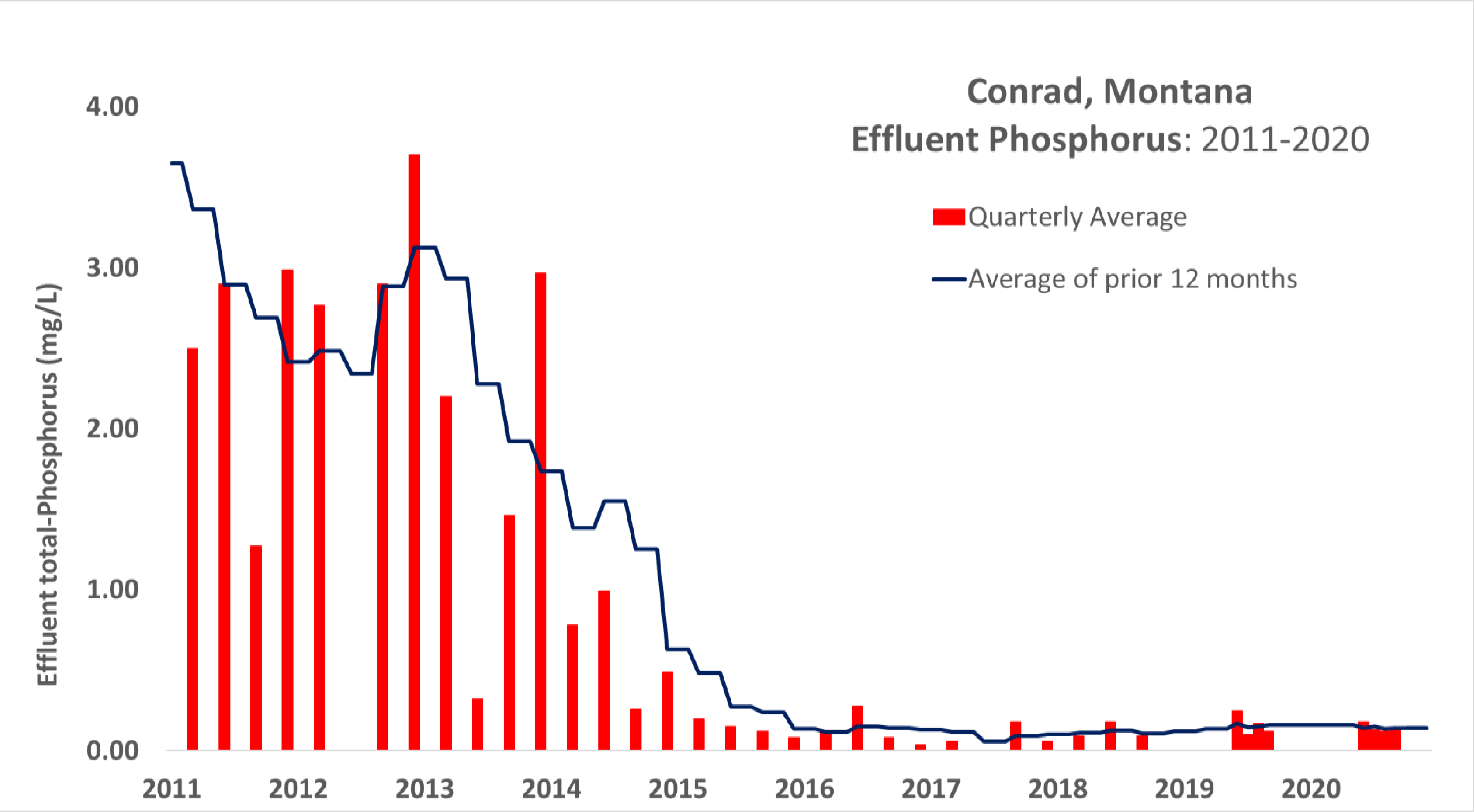
1. Convert Digester to Fermenter and Circulate WAS

Conrad, Montana
Phosphorus Removal



Phosphorus Removal

1. Convert Digester to Fermenter and Circulate WAS
2. Fermentive zone(s) in Aeration Basin


Conrad, Montana
Effluent Phosphorus: 2011-2020
Quarterly Average
Average of prior 12 months
Effluent total-Phosphorus (mg/L)
4.00
3.00
2.00
1.00
0.00
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

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Helena, Montana Population: 30,000 5.4 MGD design flow


Helena,
Montana
E Custer Ave
Frontage Rd
Frontage Rd
Washington St
Google

Helena, Montana
Nitrogen Removal

Nitrogen Removal

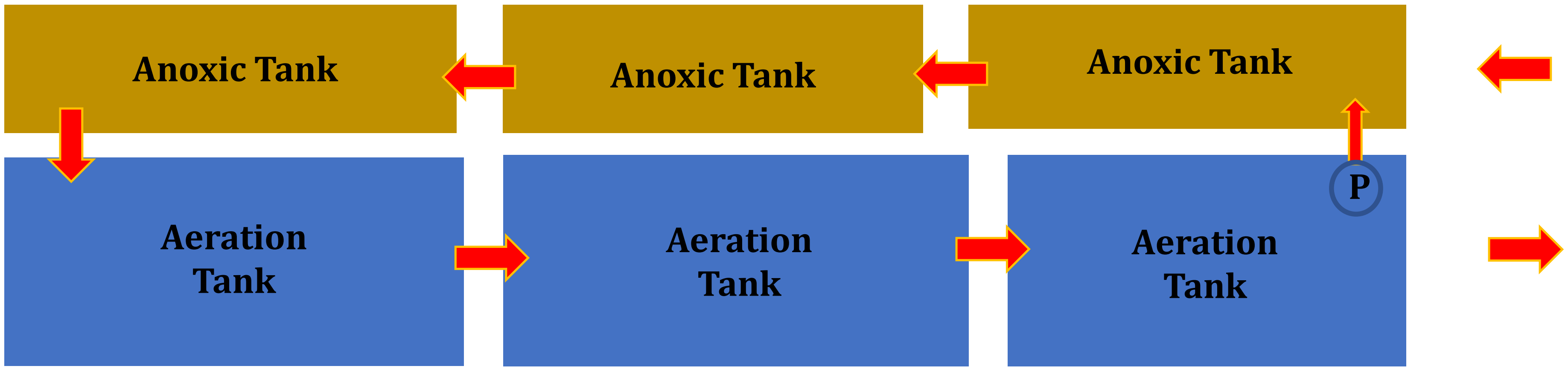
Raise MLSS concentration

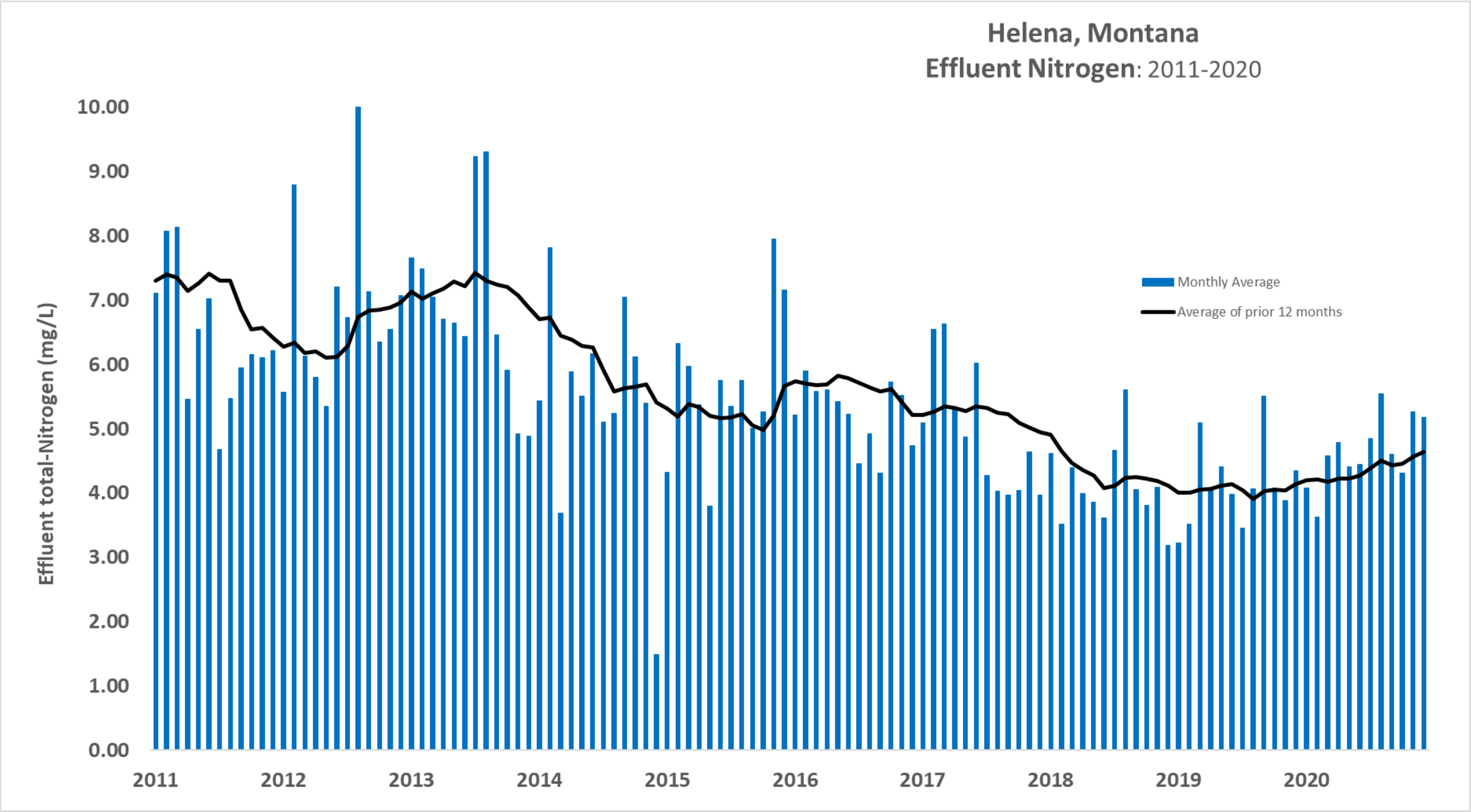
Add third Aeration Basin

Monitor ORP, NH_4 & NO_3

Adjust Internal Recycle

Helena BioReactor




Helena, Montana
Effluent Nitrogen: 2011-2020
Effluent total-Nitrogen (mg/L)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Monthly Average
Average of prior 12 months

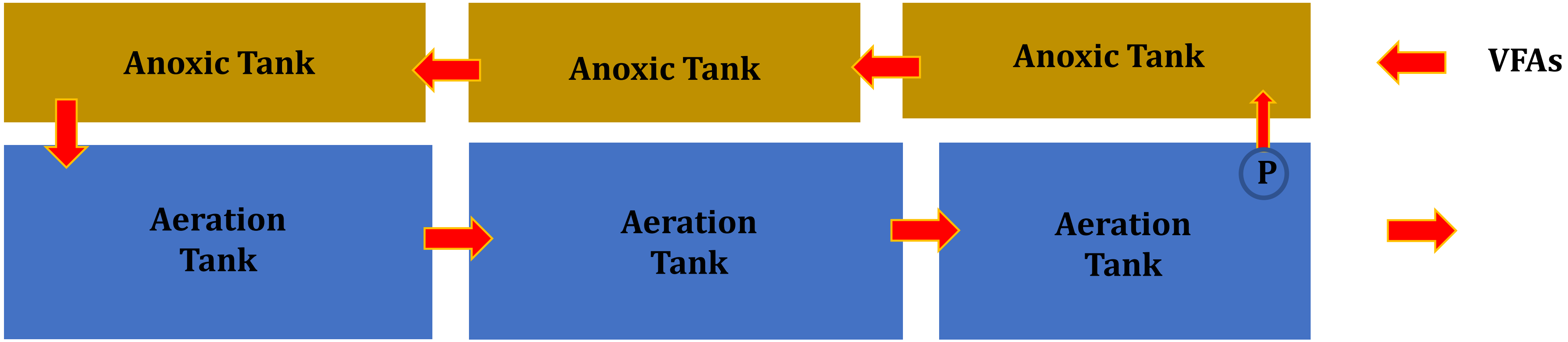
Helena, Montana

Phosphorus Removal, short term plan

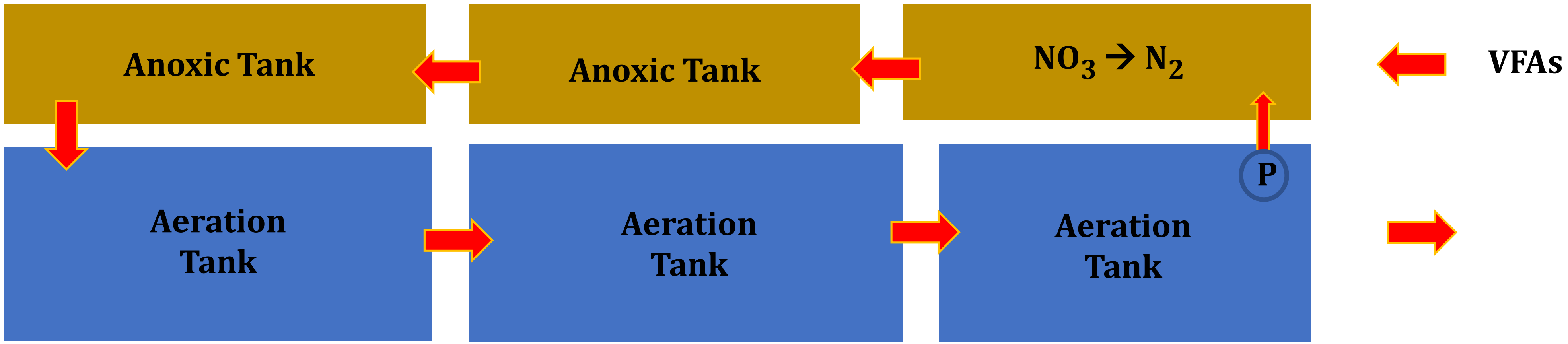
<u>Phosphorus Removal</u>

Generate surplus VFAs in primary clarifier and feed to anoxic zone

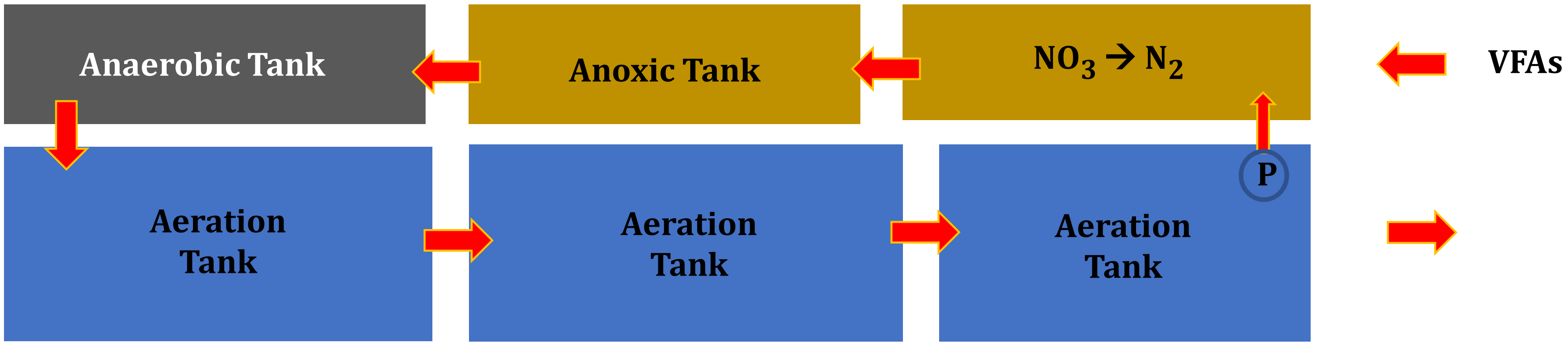
Helena BioReactor



Helena BioReactor



Helena BioReactor



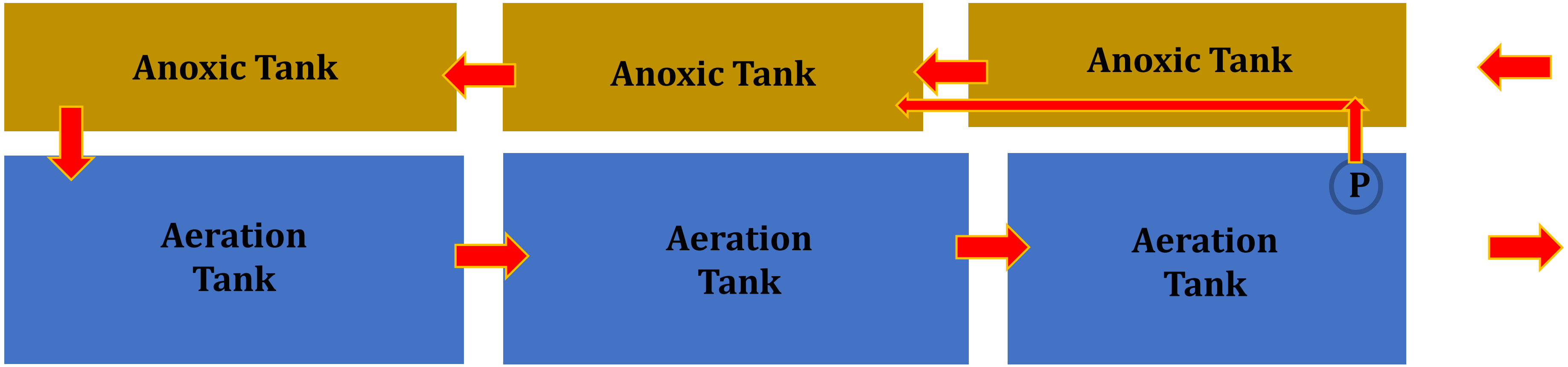
Helena, Montana

Phosphorus Removal, long term plan

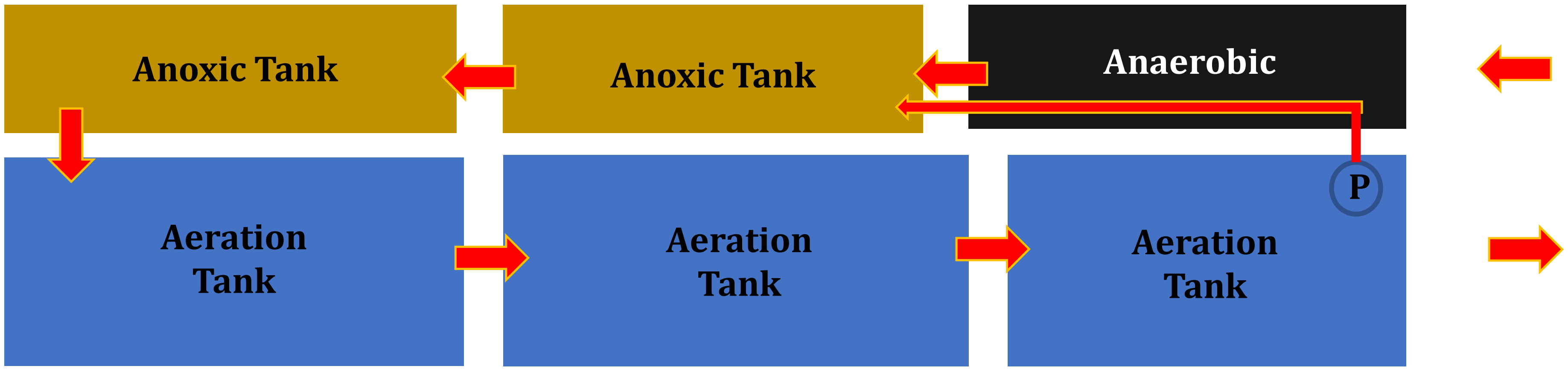
<u>Phosphorus Removal</u>

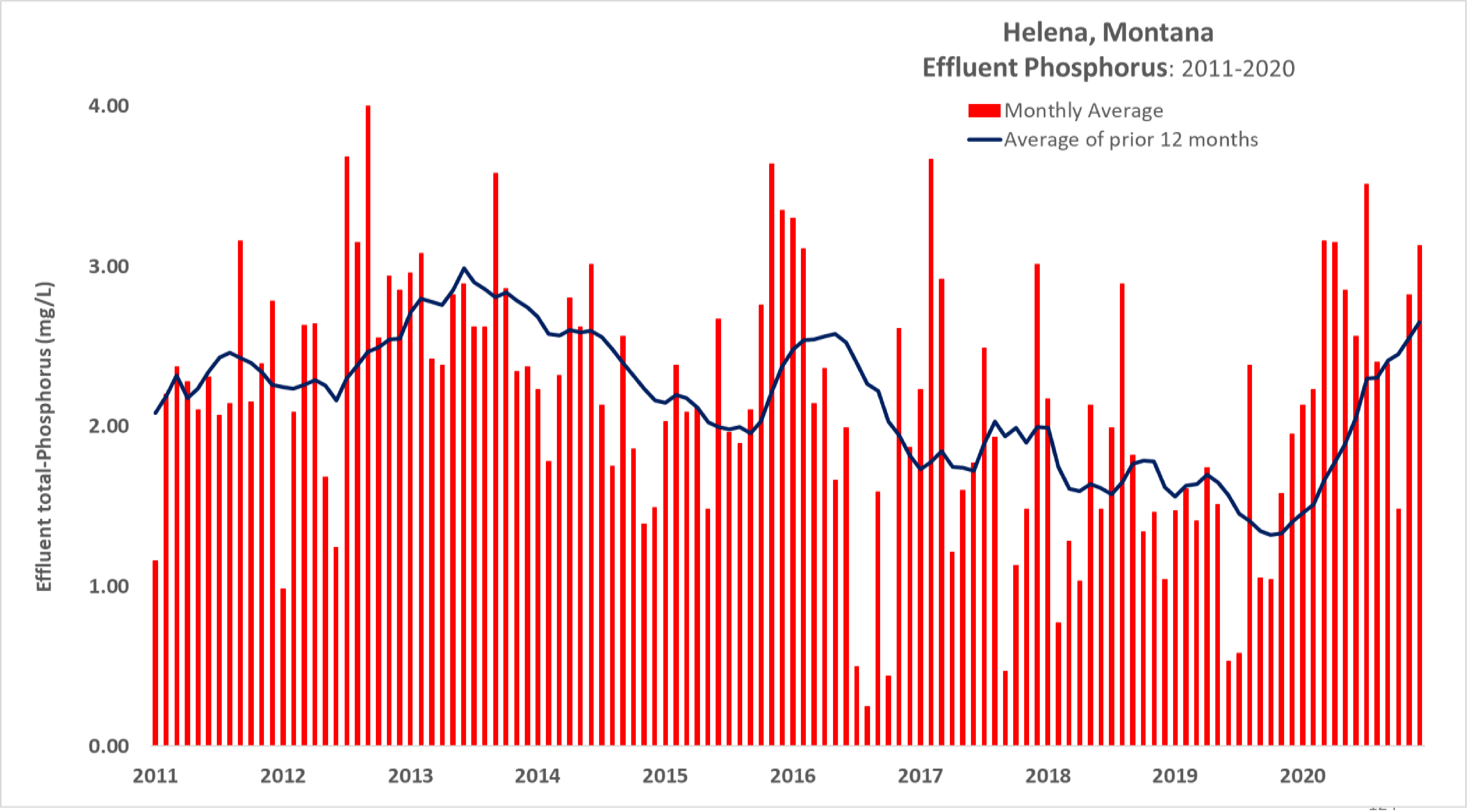
Convert first anoxic zone to fermenter by relocating Internal Recycle to second anoxic zone

Helena BioReactor



Helena BioReactor




Helena, Montana
Effluent Phosphorus: 2011-2020
Monthly Average
Average of prior 12 months
Effluent total-Phosphorus (mg/L)
4.00
3.00
2.00
1.00
0.00
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

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US EPA
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NC DEQ
Terry Albrecht, Corey Basinger & Ron Haynes

U MEMPHIS
Larry Moore, PhD

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KANSAS
Tom Stiles, Rod Geisler (retired), Shelly Shores-Miller, Nick Reams & Ryan Eldredge (**KDHE**), Jason Cauley, Reuben Martin, April Batts & James Gaunt (**Great Bend**), Jeff Shanline & Jay Angood (**Pratt**), Bruce Hurt (**Osawatomie**) & Jamie Belden & Becky Lewis (**Wichita**)

MONTANA
Paul Lavigne (retired), Pete Boettcher, Josh Vial & Ryan Weiss (**MDEQ**), Keith Taut (**Conrad**) & Mark Fitzwater and staff (**Helena**)

… and, many more!

Next Week's Webinar
North Carolina Case Studies: part 1

Thursday, March 25
10:00 - 11:45 AM

NC Case Studies *(4/8)*

Energy Management *(4/15 & 4/22)*

NC Case Studies *(4/29)*


VOTE

?

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Questions
Comments
Discussion