Optimizing Nutrient Removal Review & Case Studies

Webinar for Tennessee Wastewater Operators

February 17, 2021

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Strategies for Optimizing Nutrient Removal

Week 1: Nitrogen Removal
Week 2: Phosphorus Removal

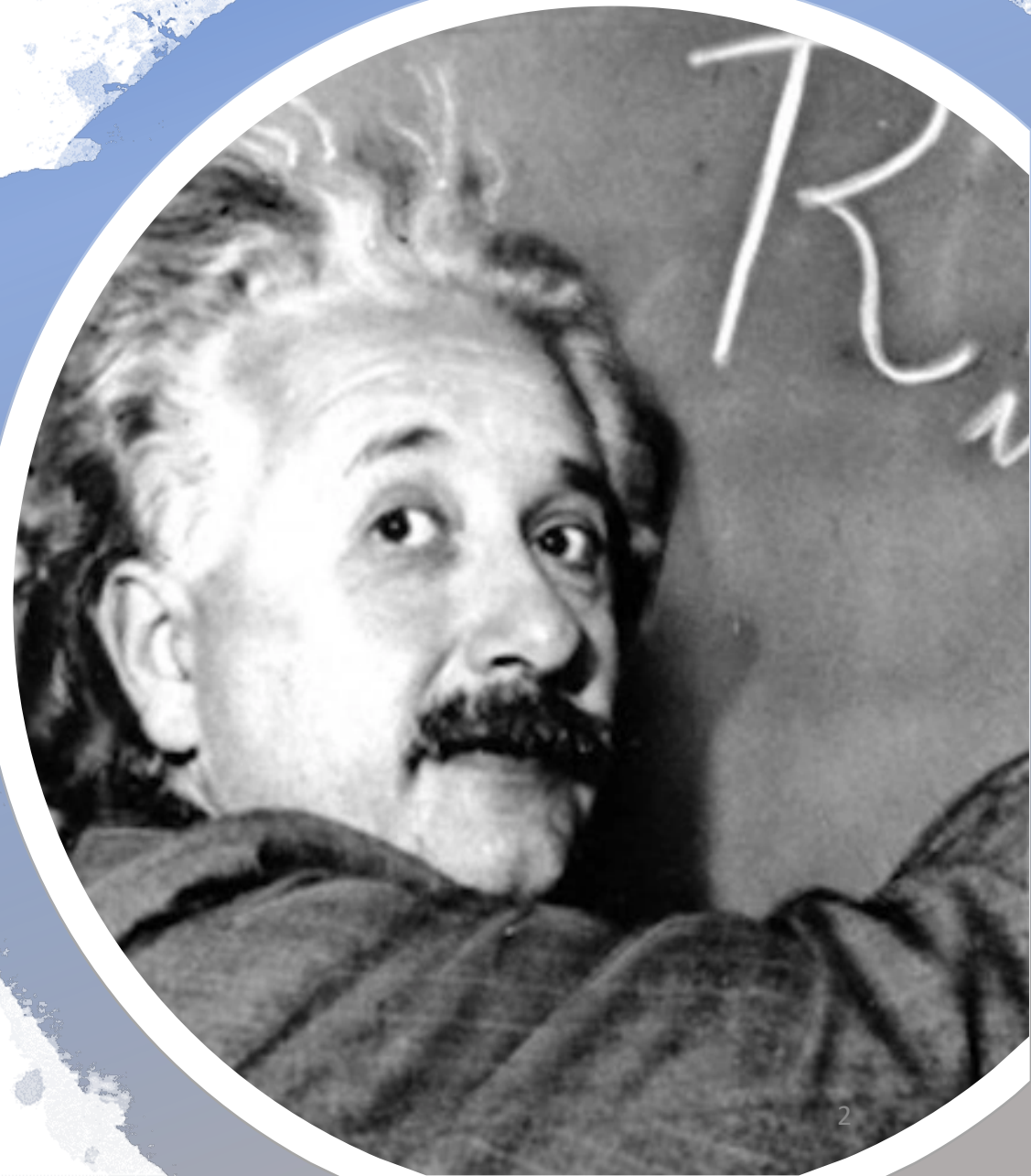
Today: Nitrogen & Phosphorus Review & Case Studies

Feb 24: N&P Removal in Oxidation Ditch wwtps

Mar 3: N&P Removal in SBRs

Mar 10: N&P Removal in Conventional Activated Sludge

Mar 17: Brainstorming N&P Removal Opportunities for Tennessee Wastewater Treatment Plants



Nutrient Removal Knowledge


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

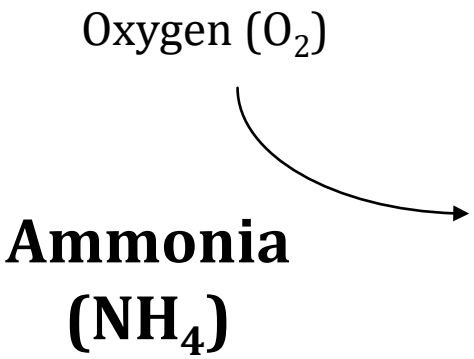
Ammonia Removal - 1st Step of N Removal

Ammonia Removal

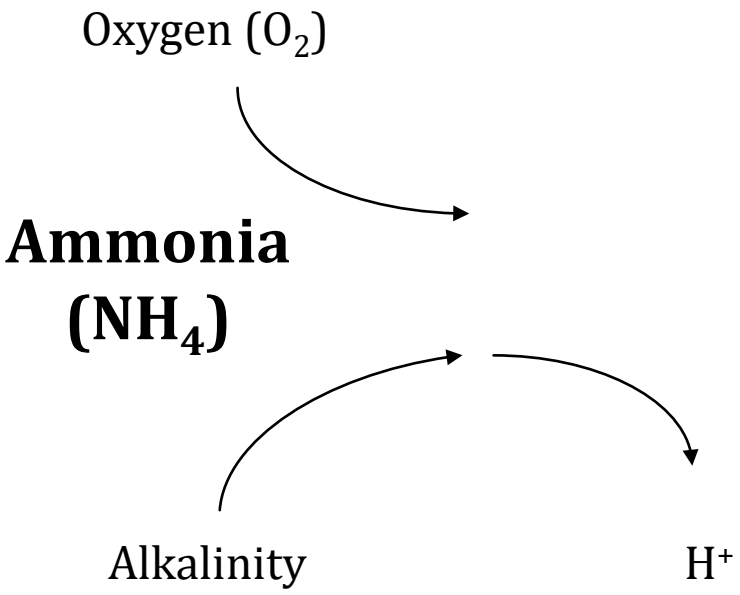
Ammonia (NH_4) is converted to Nitrate (NO_3)

Ammonia
(NH_4)

Ammonia Removal



Ammonia Removal



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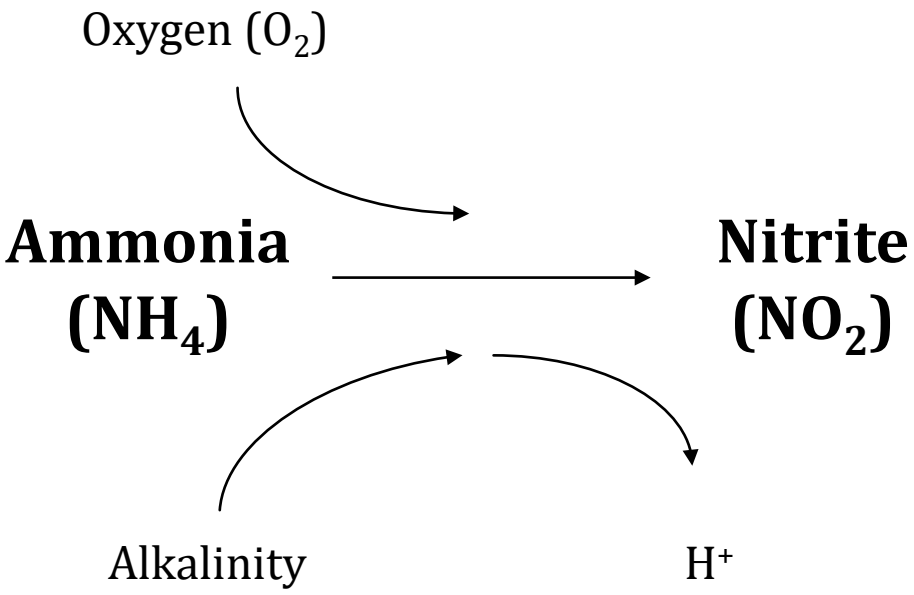

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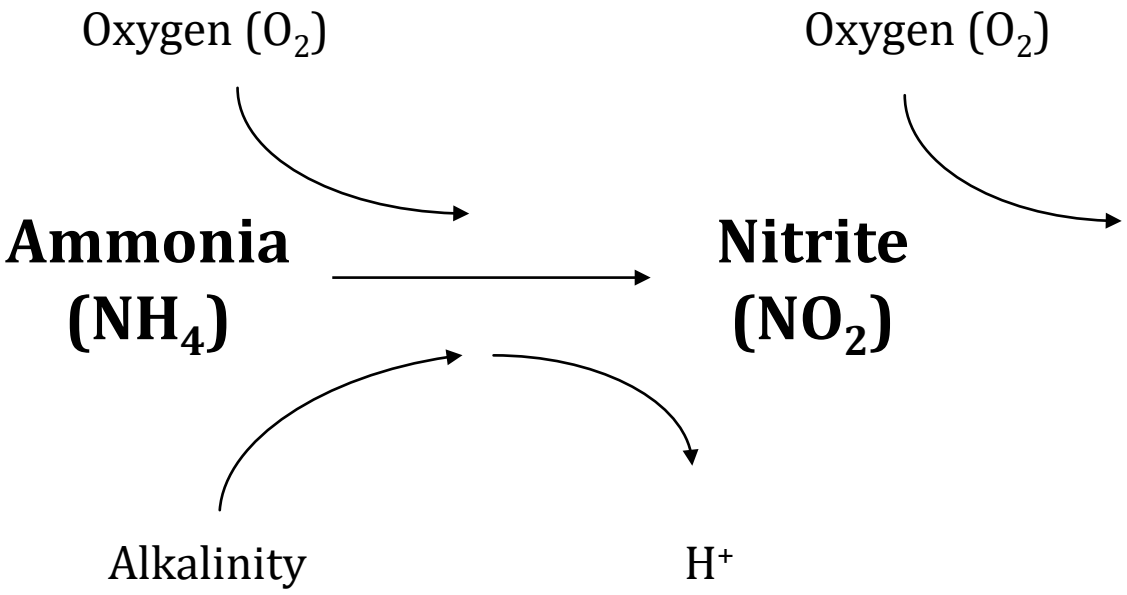
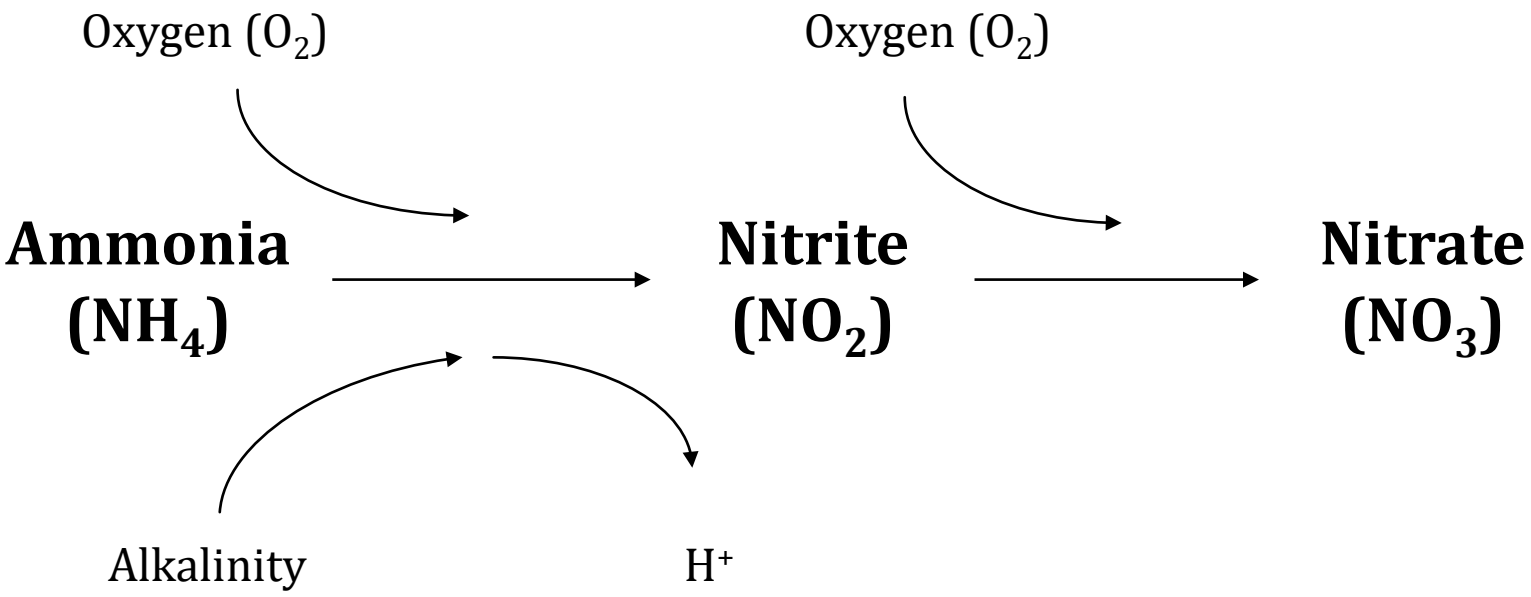


Ammonia Removal



Nitrification:
Ammonia (NH_4) is converted to Nitrate (NO_3)

Oxygen Rich Habitat

MLSS* of 2500+ mg/L (High Sludge Age / MCRT / low F:M)
ORP* of +100 to +150 mV (High DO)
Time* (high HRT … 24 hr, 12 hr, 6 hr)
Low BOD

Consumes Oxygen
Adds acid - Consumes 7 mg/L alkalinity per mg/L of $NH_4 \rightarrow NO_3$

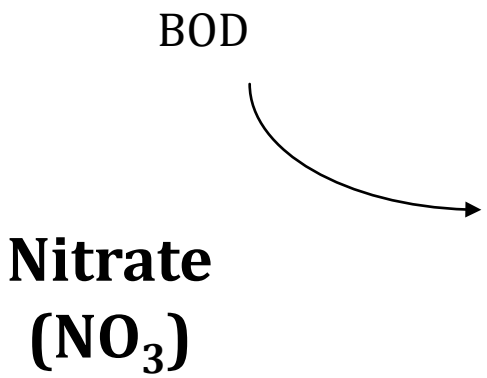
*Approximate, each facility is different.

Nitrate Removal - 2nd Step of N removal

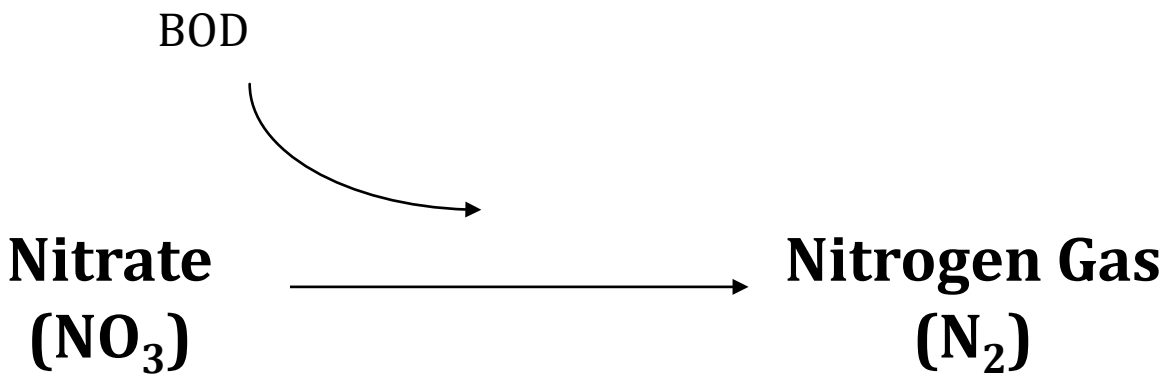
Nitrate Removal

Nitrate
(NO_3)

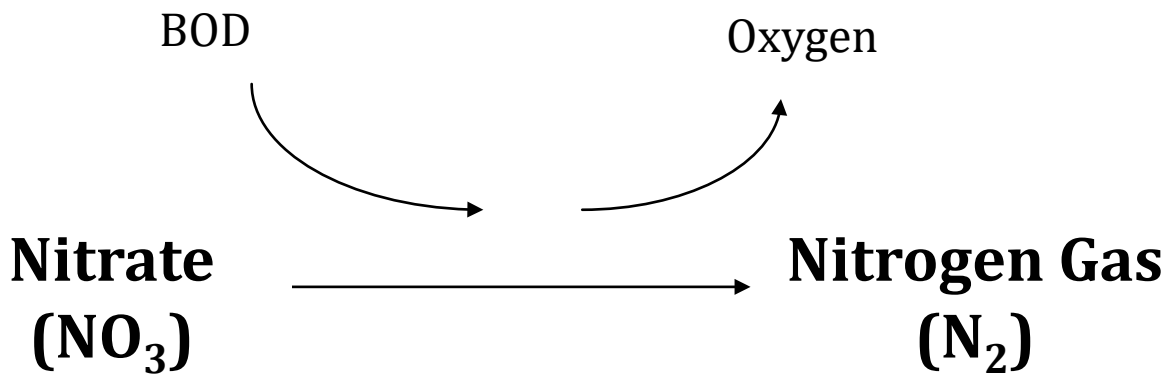
Nitrate Removal



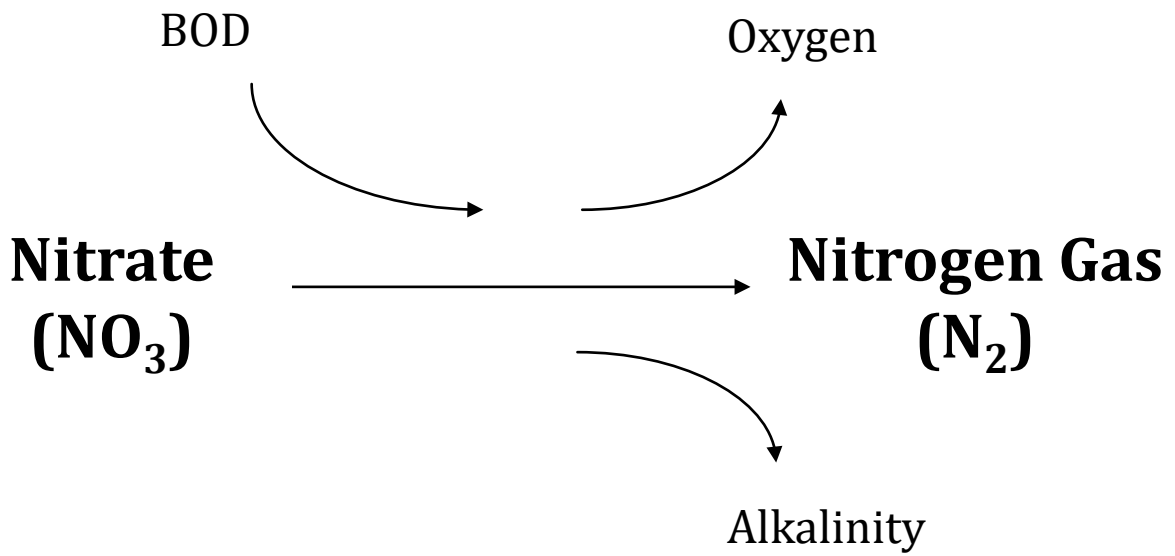
Nitrate Removal



Nitrate Removal



Nitrate Removal



Adds DO (dissolved oxygen)

Consumes BOD

Gives back alkalinity … beneficially raises pH

Denitrification:
Nitrate (NO_3) is converted to Nitrogen Gas (N_2)

Oxygen Poor Habitat

ORP* of -100 mV or less (DO less than 0.3 mg/L)
Surplus BOD* (100-250 mg/L: 5-10 times as much as NO_3)
Retention Time* of 1-2 hours

Gives back Oxygen
Gives back Alkalinity (3.5 mg/L per mg/L of $NO_3 \rightarrow N_2$)

*Approximate, each facility is different.

Nitrogen Removal

	Step 1: Nitrification (Ammonia Removal)	**Step 1: Denitrification** (Nitrate Removal)
DO: Dissolved Oxygen	1 mg/L or more	Less than 0.2 mg/L
ORP: Oxygen Reduction Potential	+100 mV or more +	Less than -100 mV
MLSS: Mixed Liquor Suspended Solids	2500 mg/L or more	Same
HRT: Hydraulic Retention Time	6 or more hours	1 or more hours
BOD: Biochemical Oxygen Demand	less than 20 mg/L	**100 mg/L or more**
Alkalinity	60 mg/L or more	
	Alkalinity is lost	***Alkalinity is gained***

Note: All numbers are approximations, “rules of thumb”

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MLE Process (Modified Ludzack-Ettinger)

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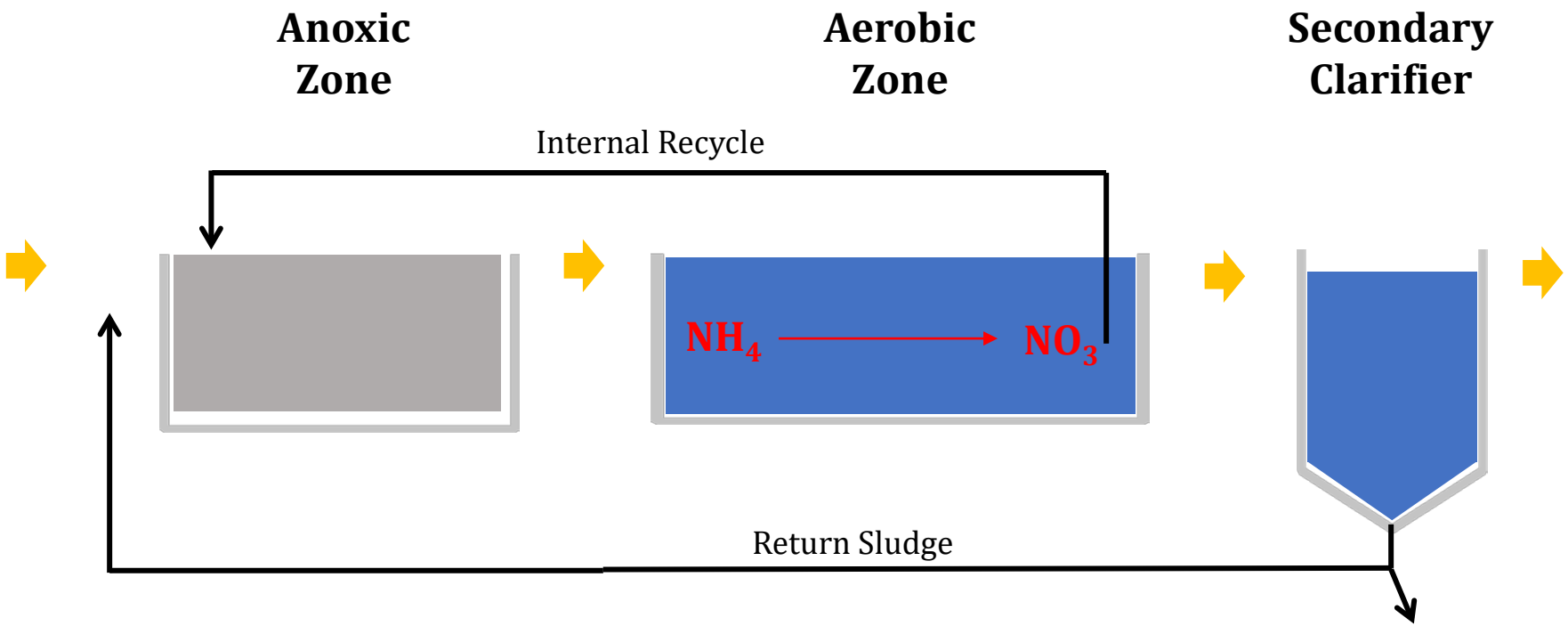

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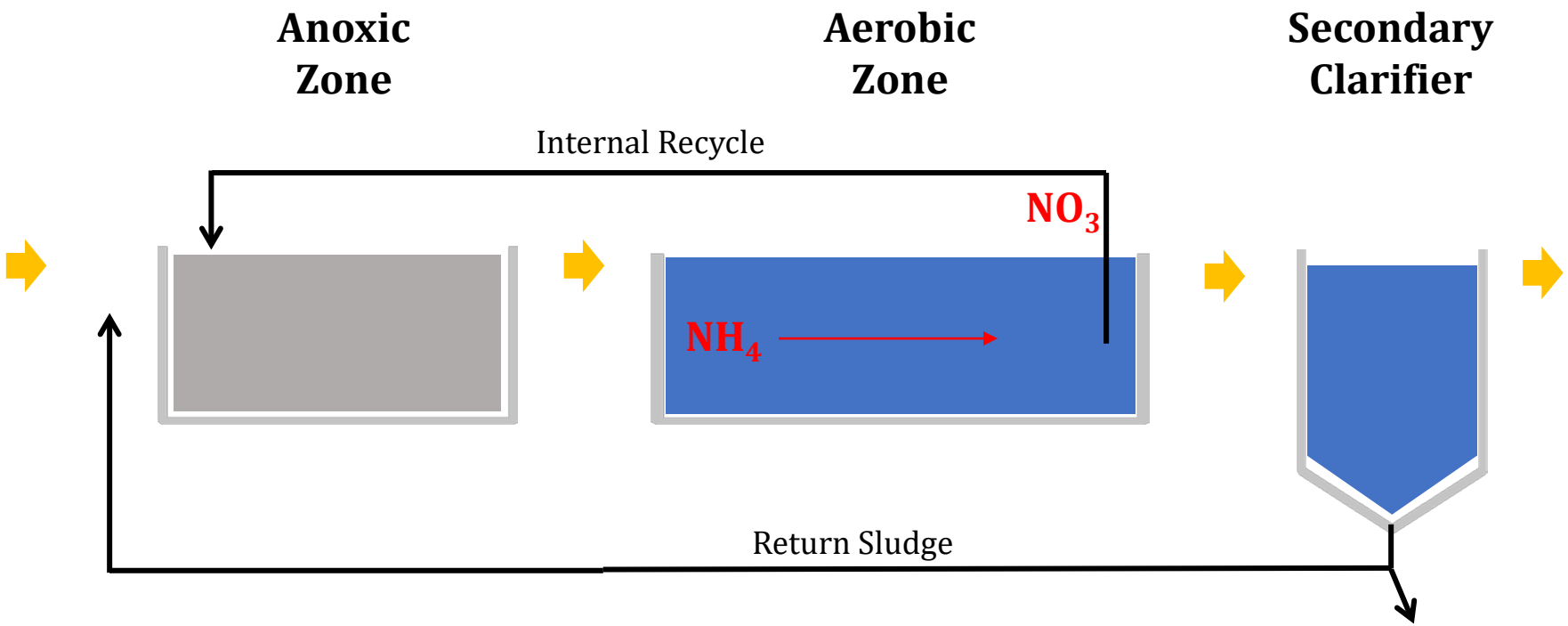

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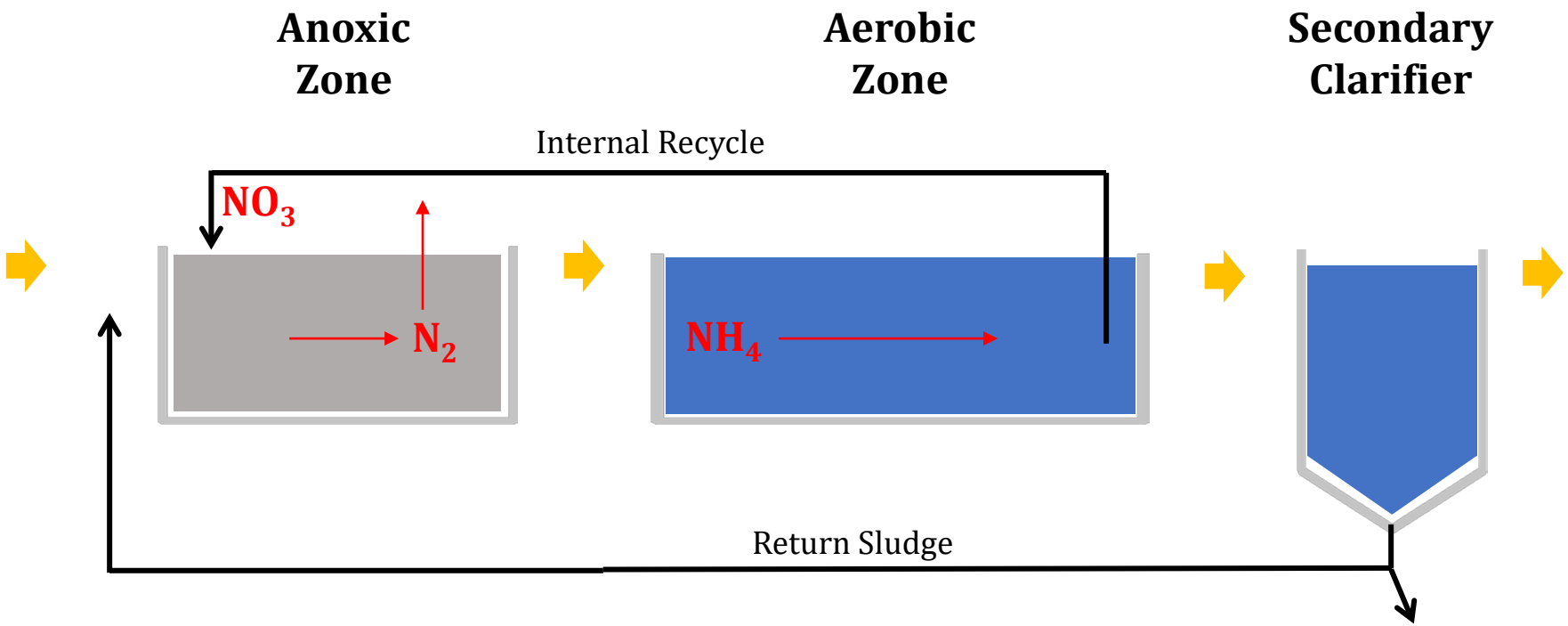

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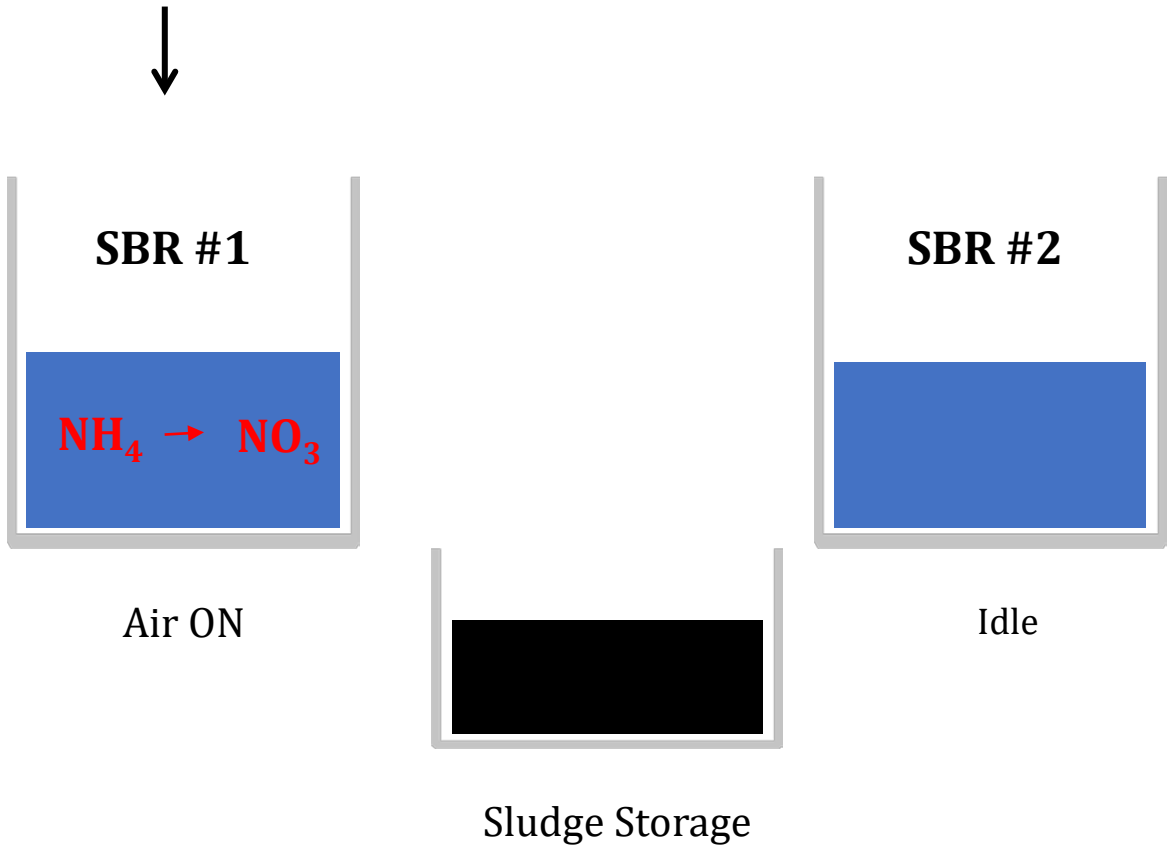
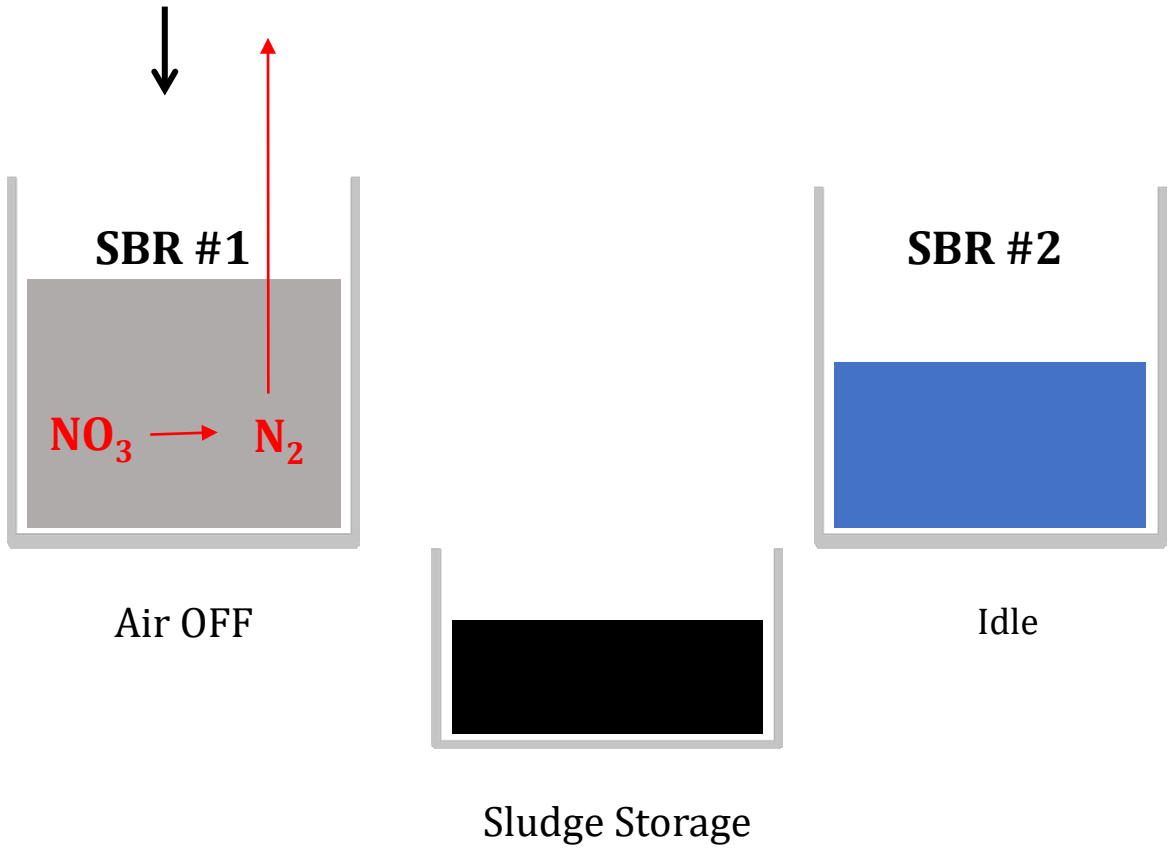
Sequencing Batch Reactor

SBR

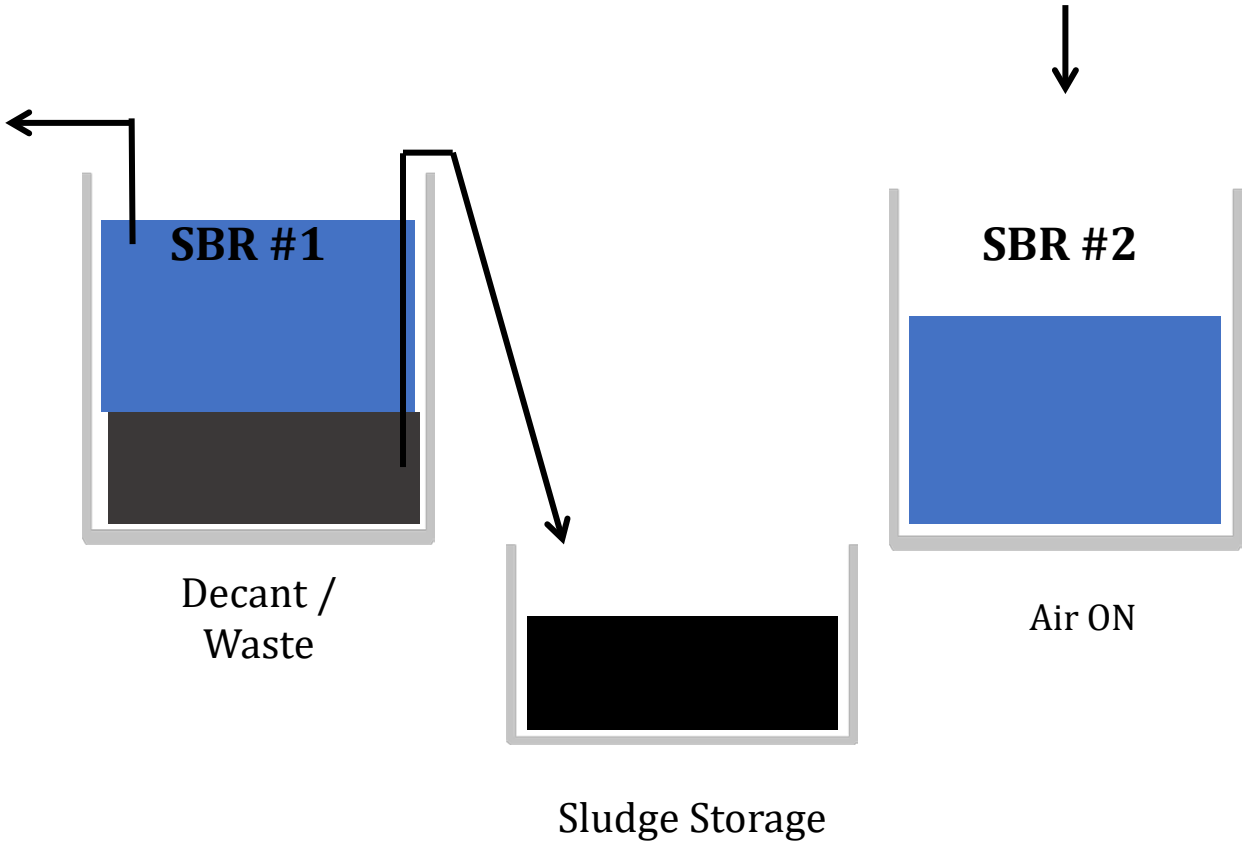
Sequencing Batch Reactor (SBR)
Ammonia (NH_4) Removal: Nitrification



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



Sequencing Batch Reactor (SBR)
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.

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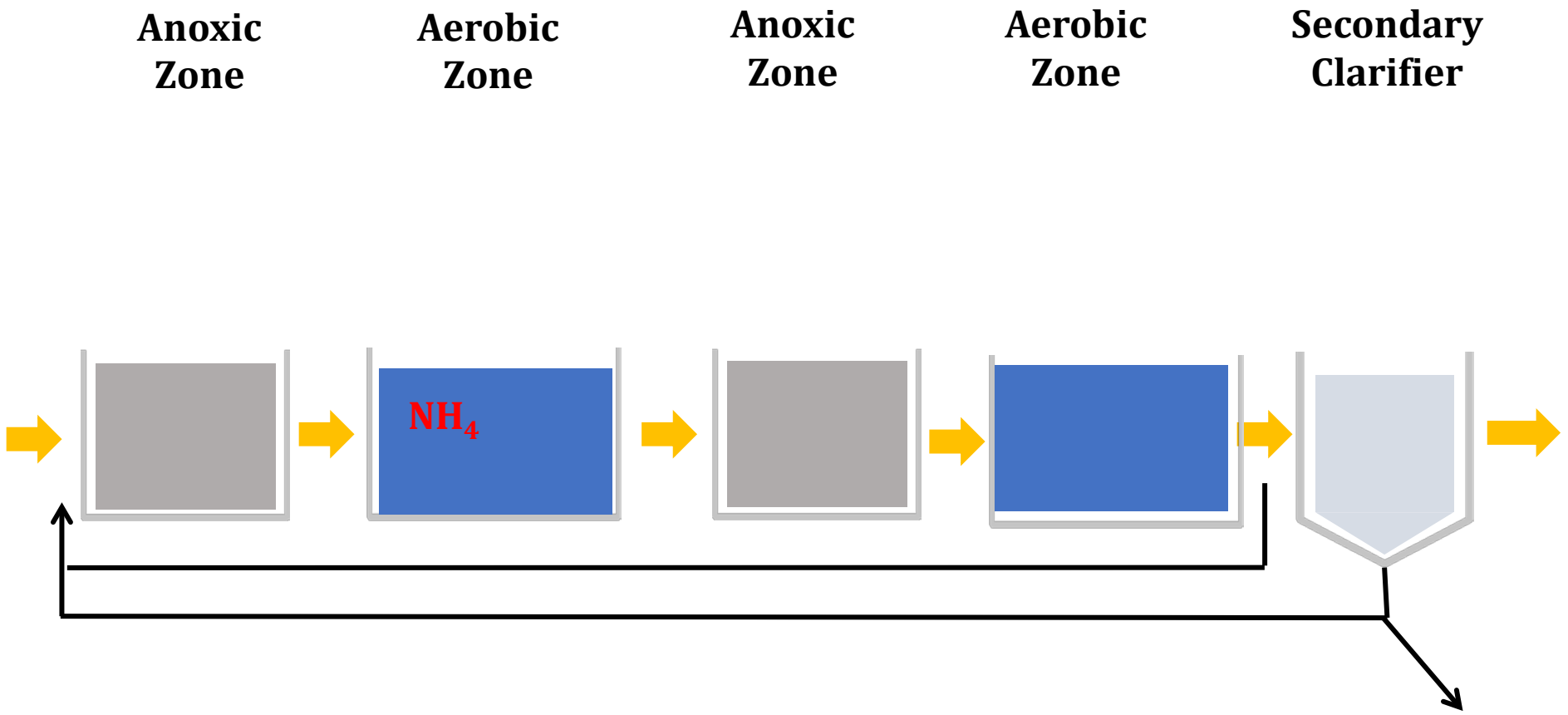
Oxidation Ditch

Oxidation Ditch



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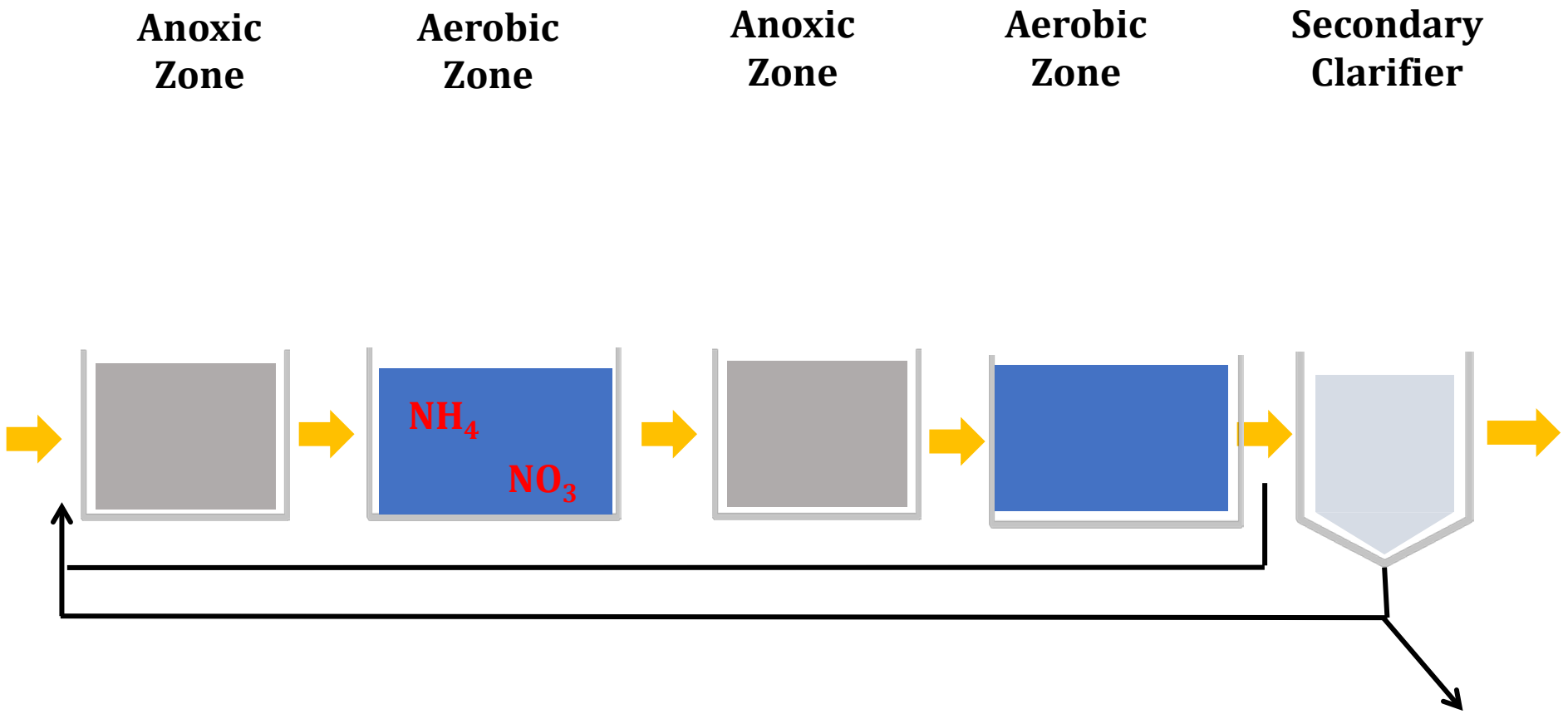

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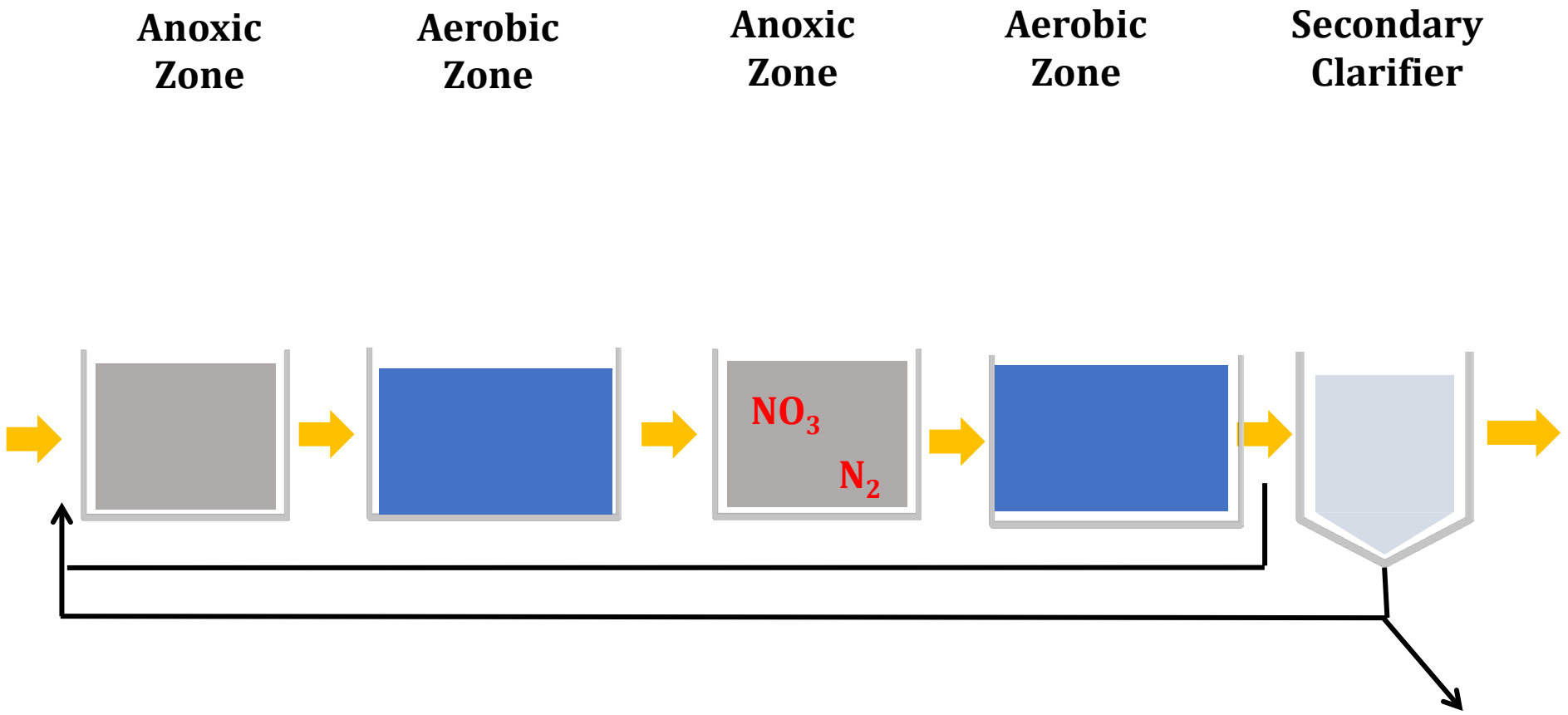

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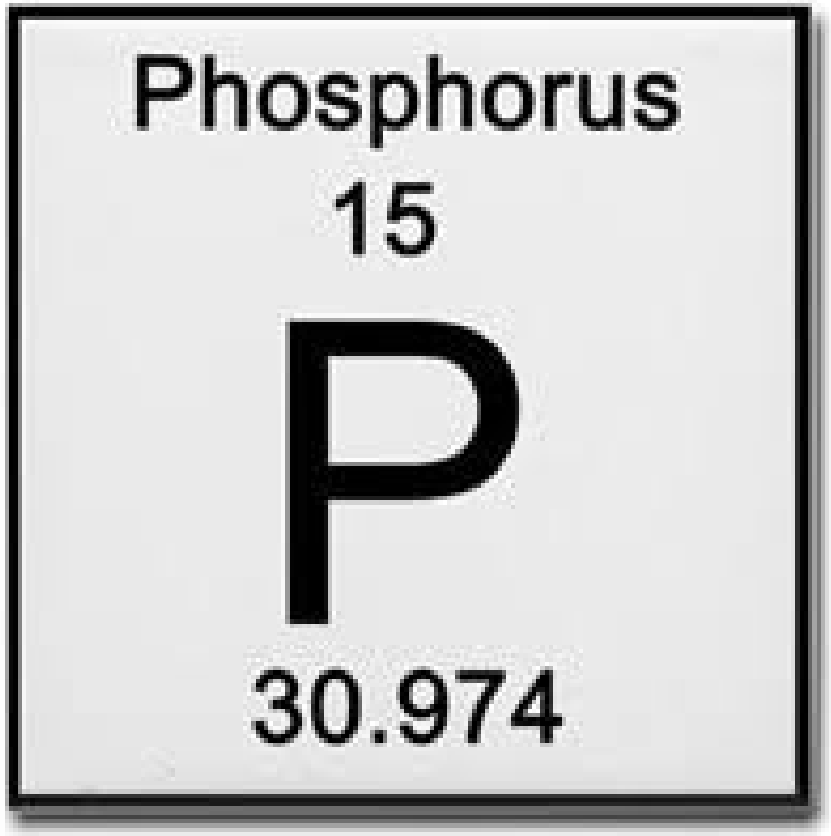
Phosphorus
15
P
30.974

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

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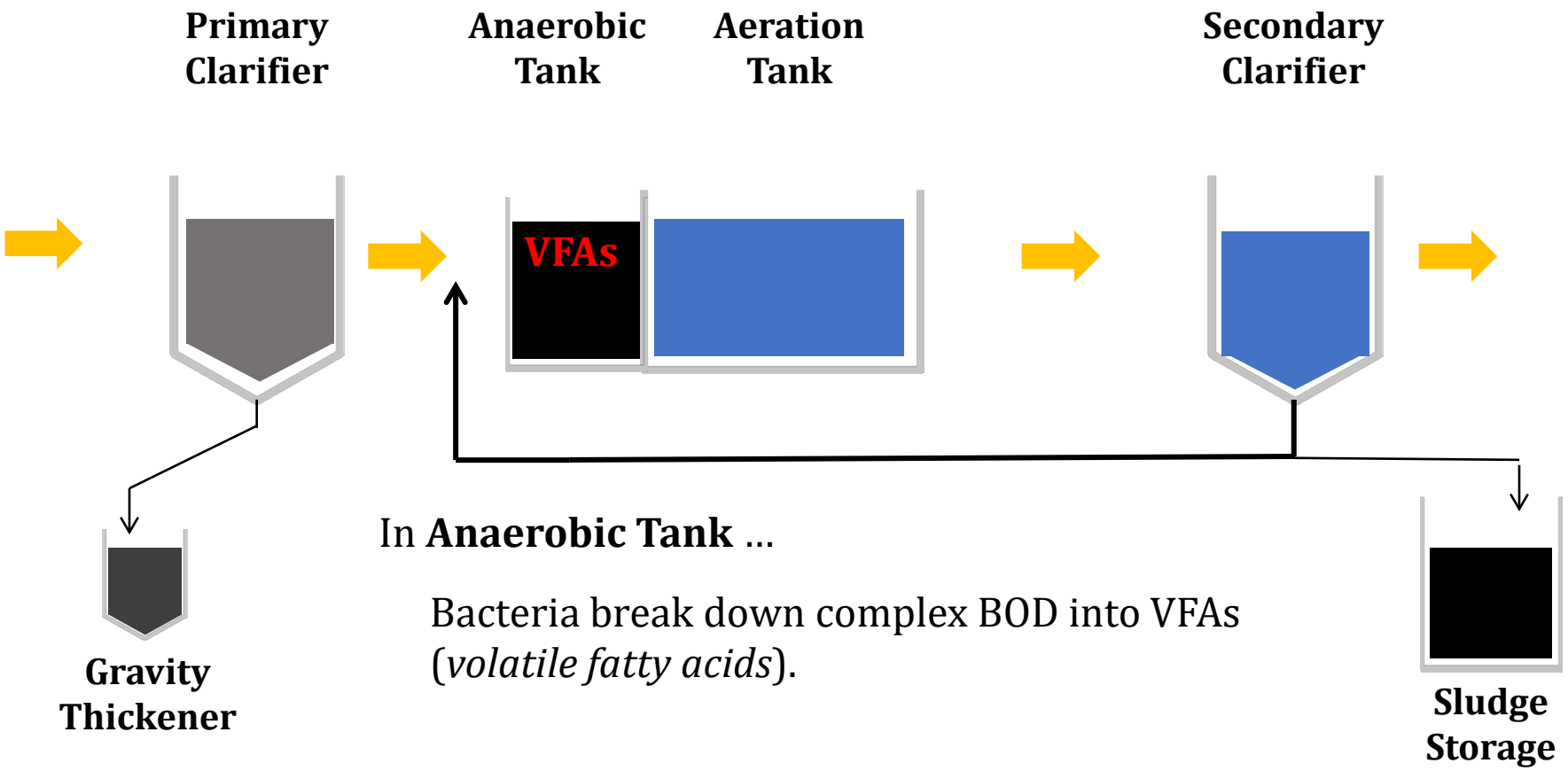
Biological Phosphorus Removal: Mainstream Flow Fermentation Processes

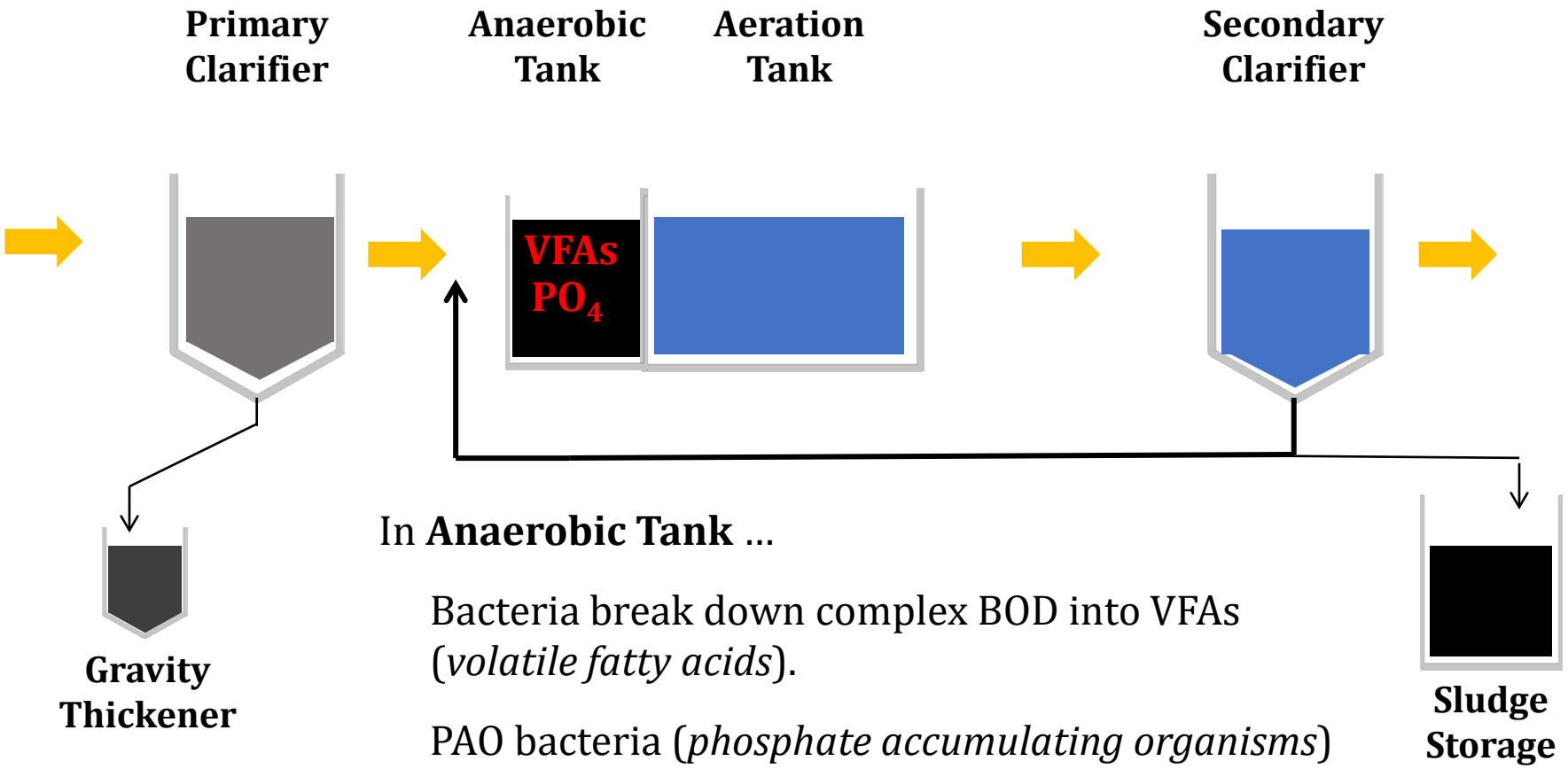
Bio-P Removal: Mainstream Fermentation Process



In **Anaerobic Tank** …

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

Bio-P Removal: Mainstream Fermentation Process



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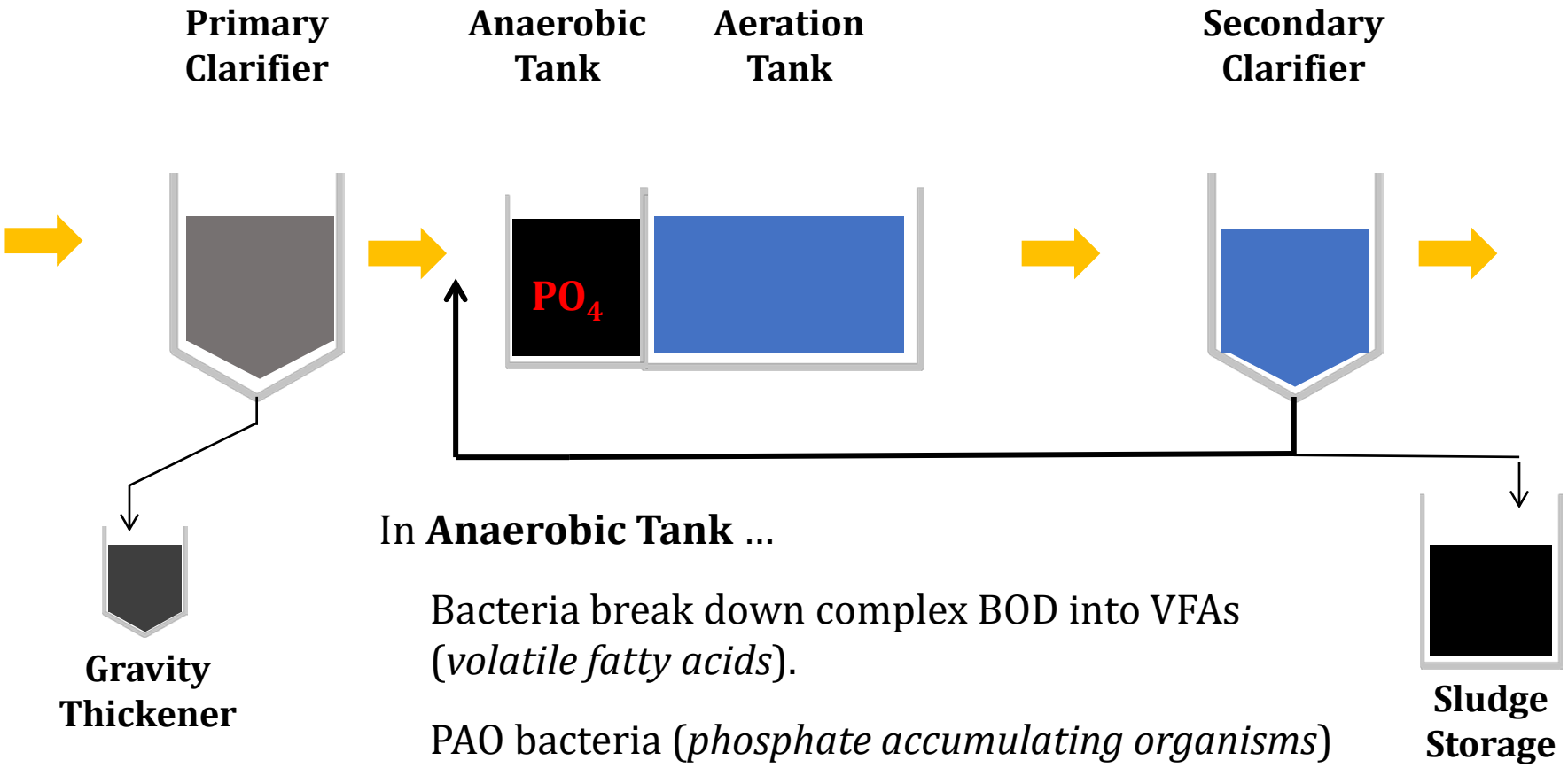

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In **Aeration Tank** …

Energized PAO bacteria take PO_4 out of solution.

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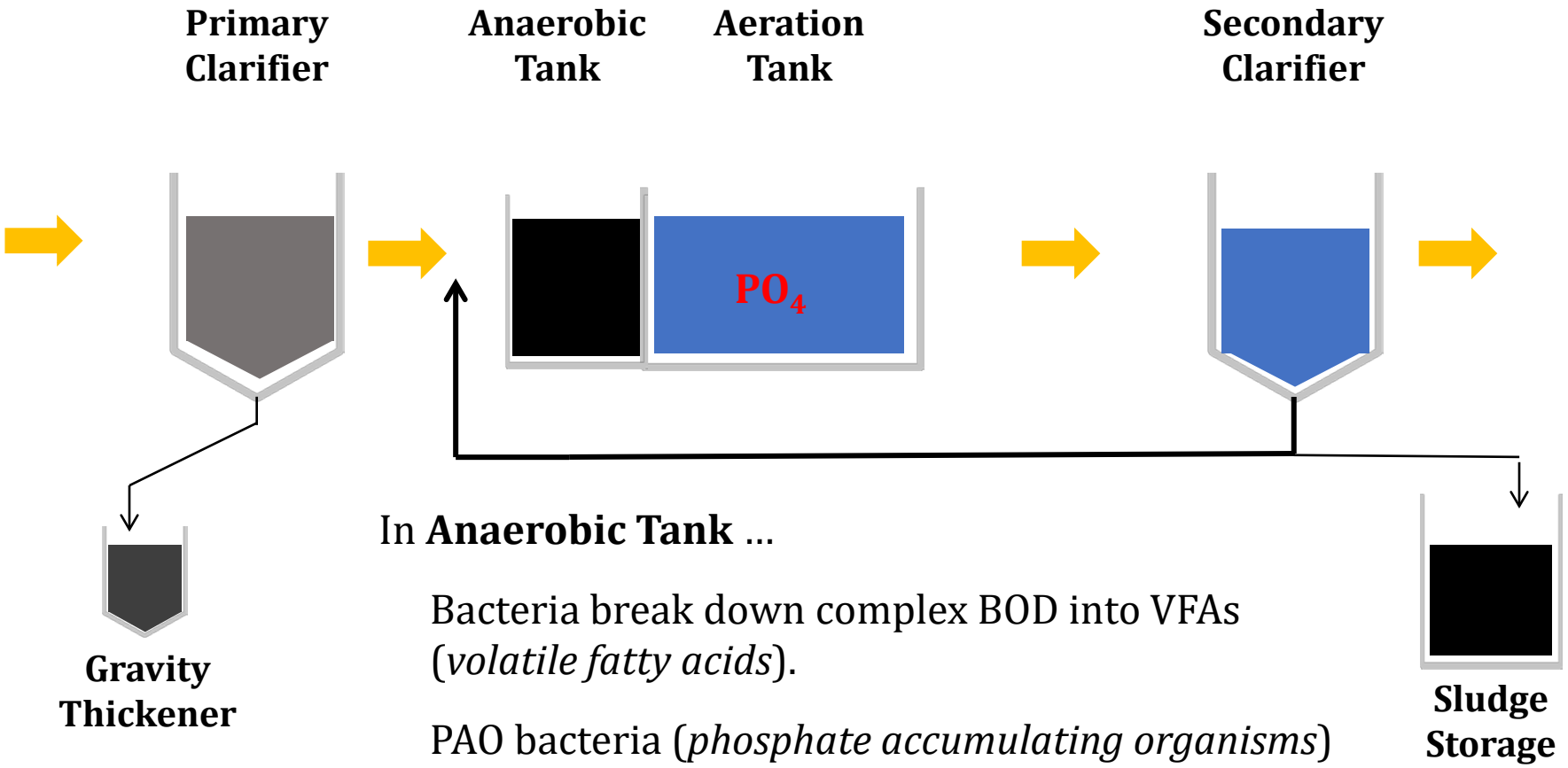

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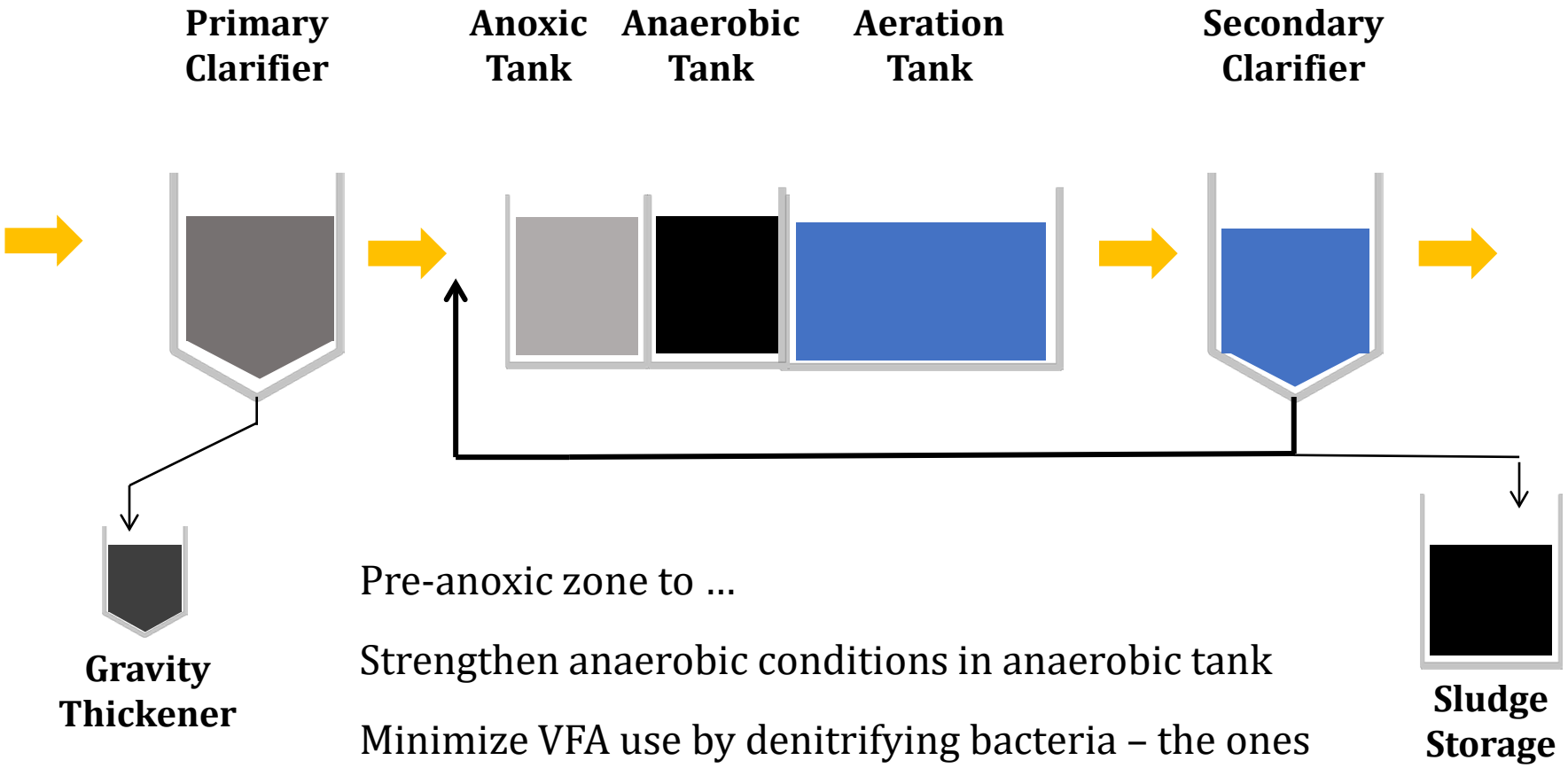
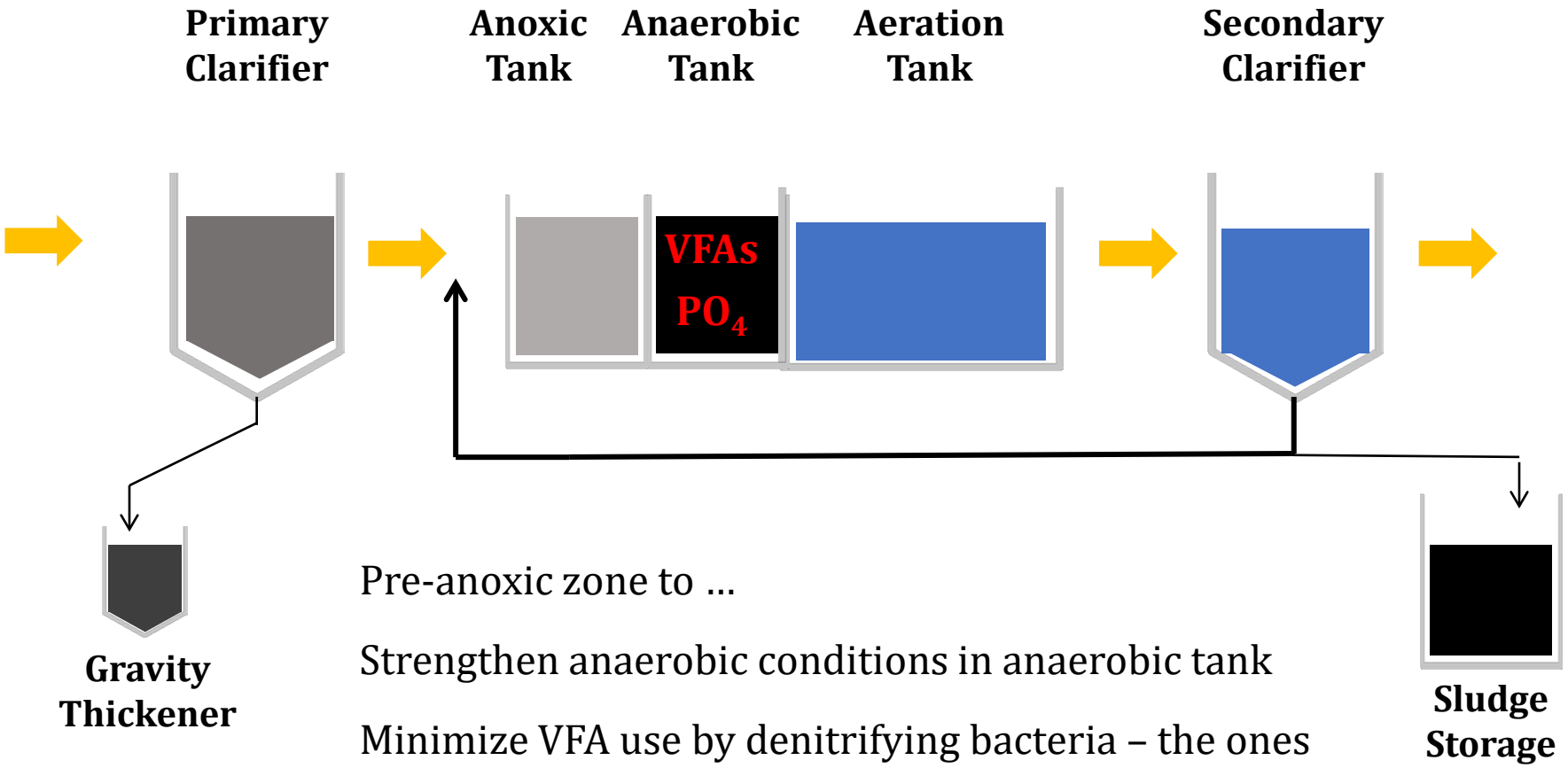


Pre-anoxic zone to …

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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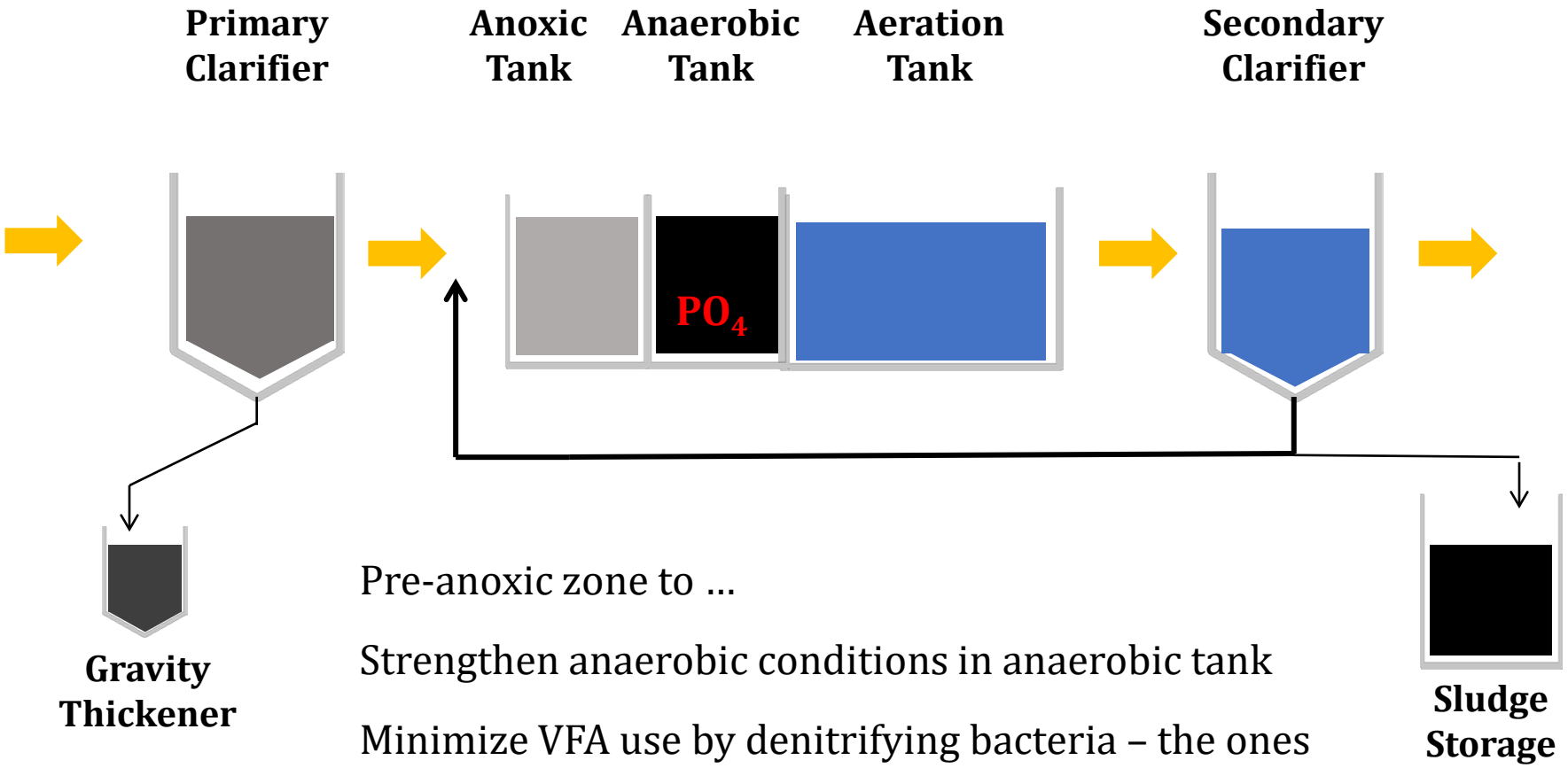

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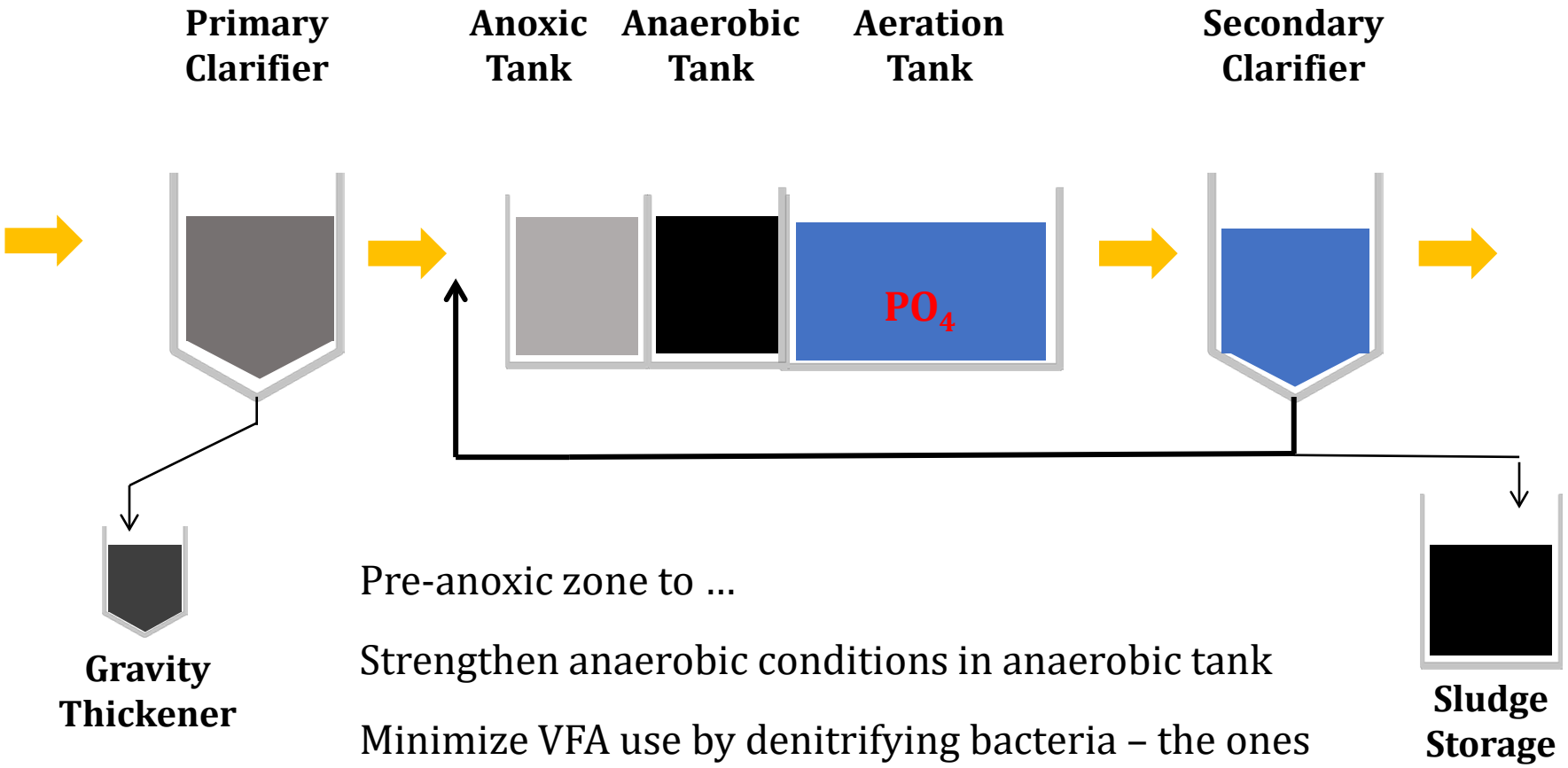

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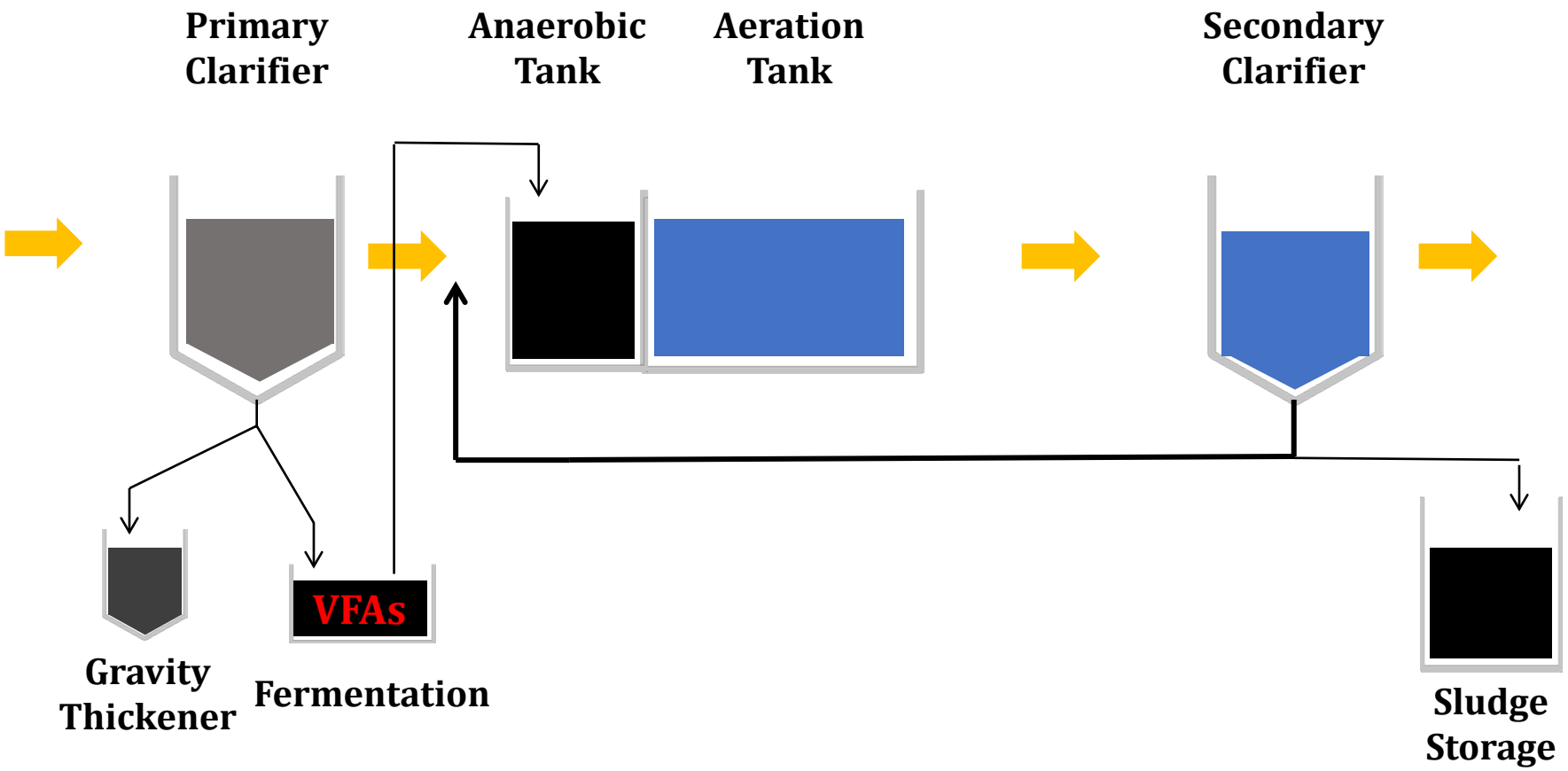
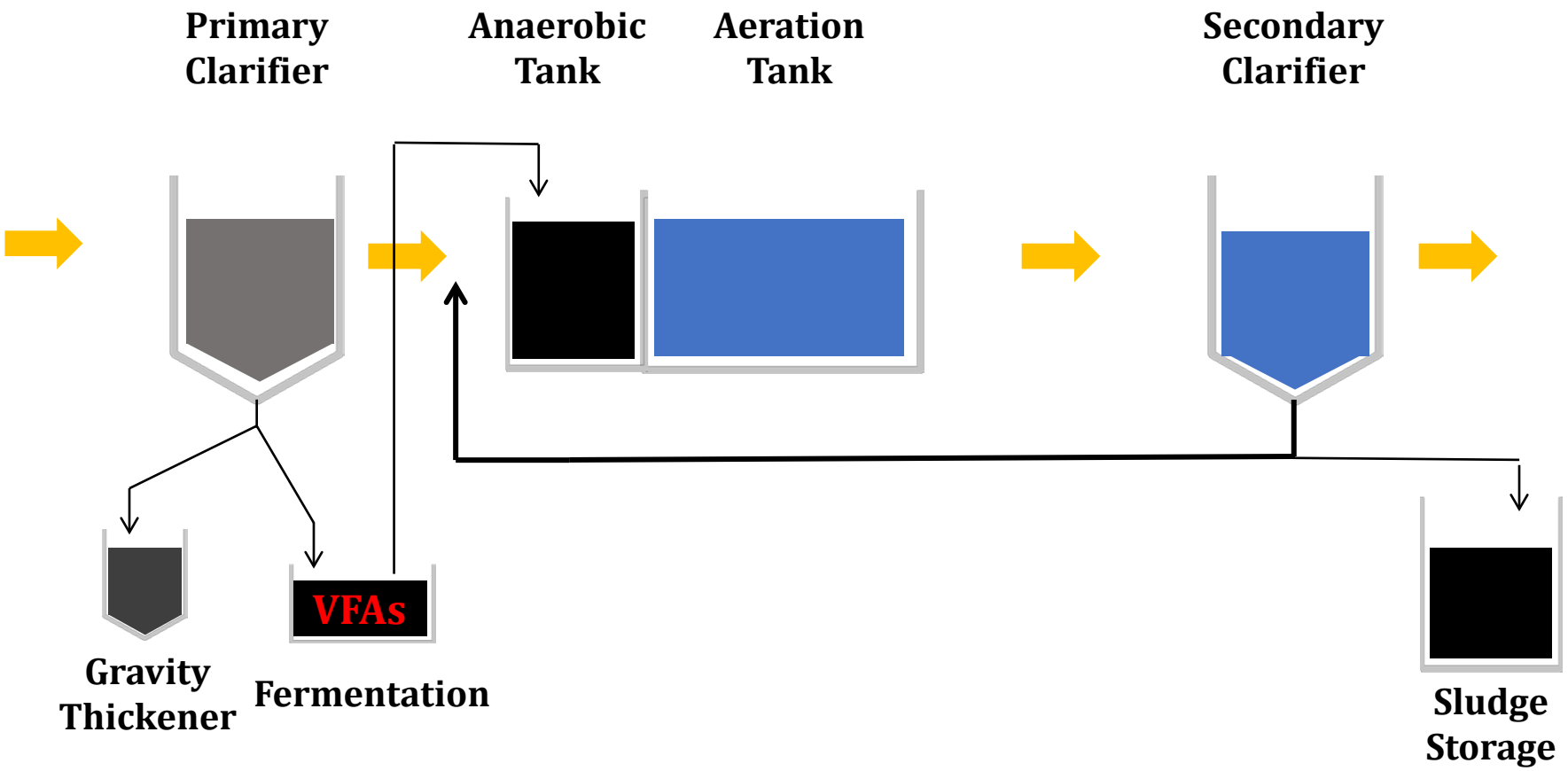
Biological Phosphorus Removal: Combined Sidestream & Mainstream Fermentation

Bio-P Removal: Sidestream Fermentation Process



Bio-P Removal: Sidestream Fermentation Process



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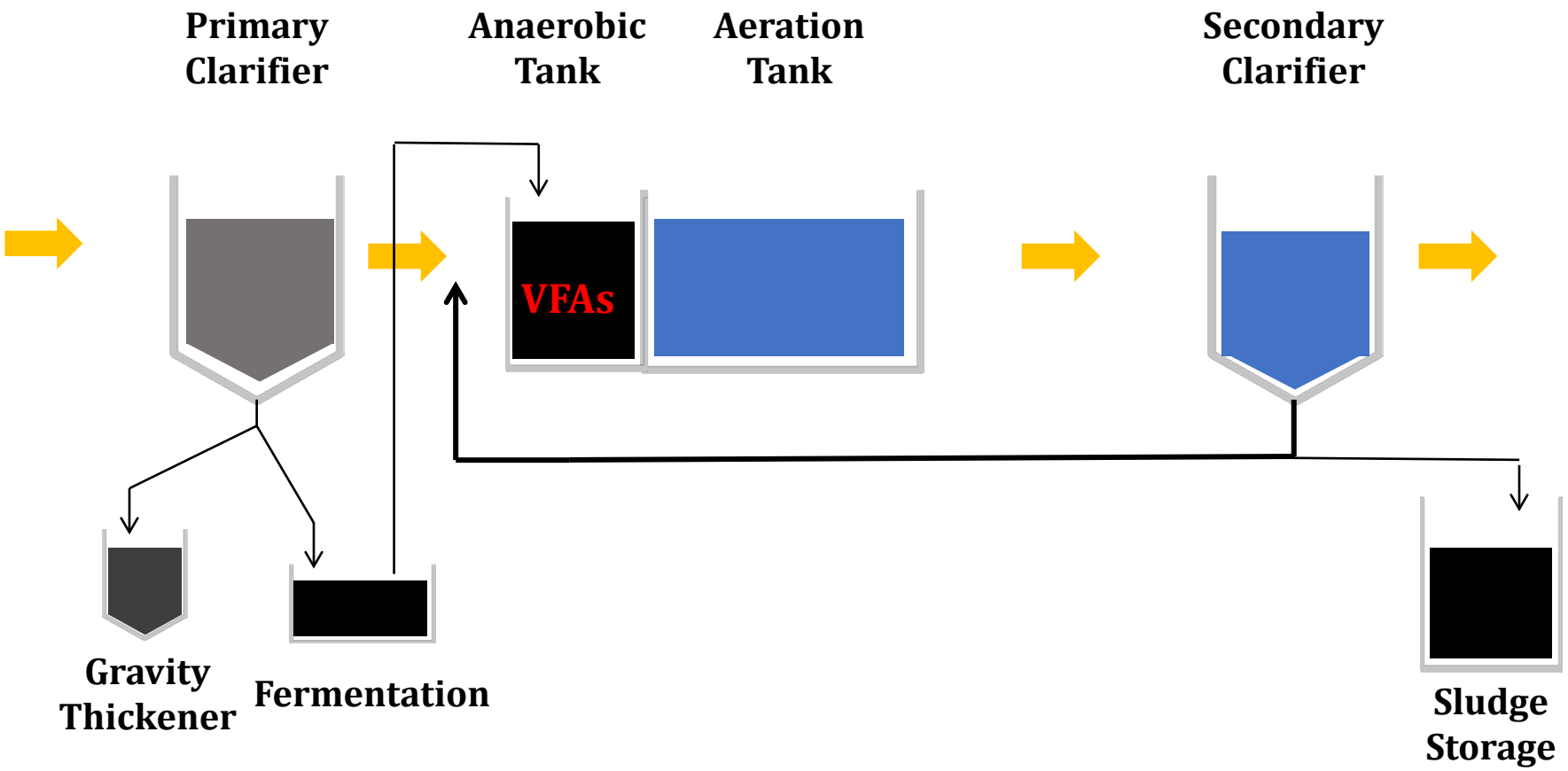
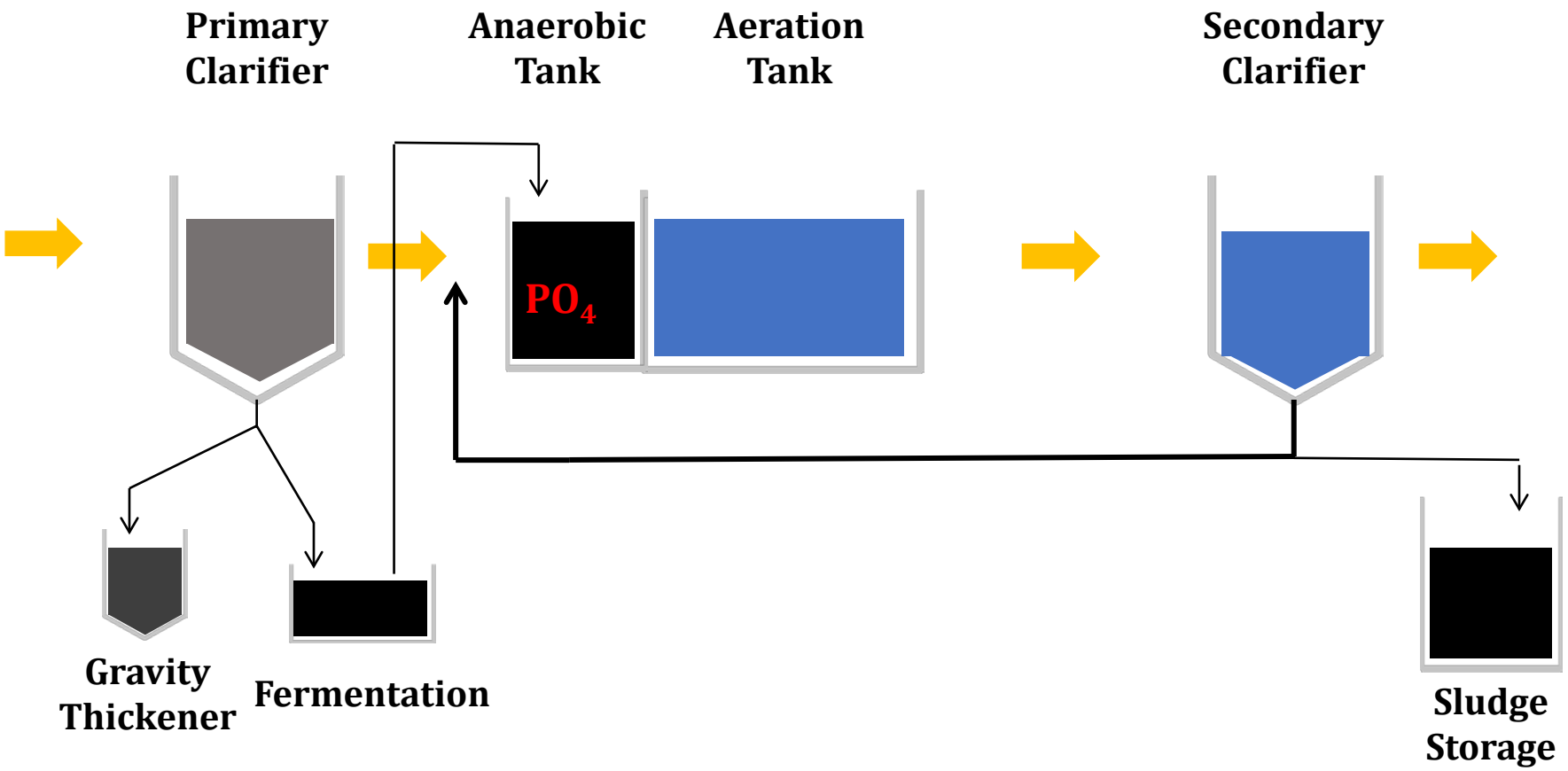


Bio-P Removal: Sidestream Fermentation Process



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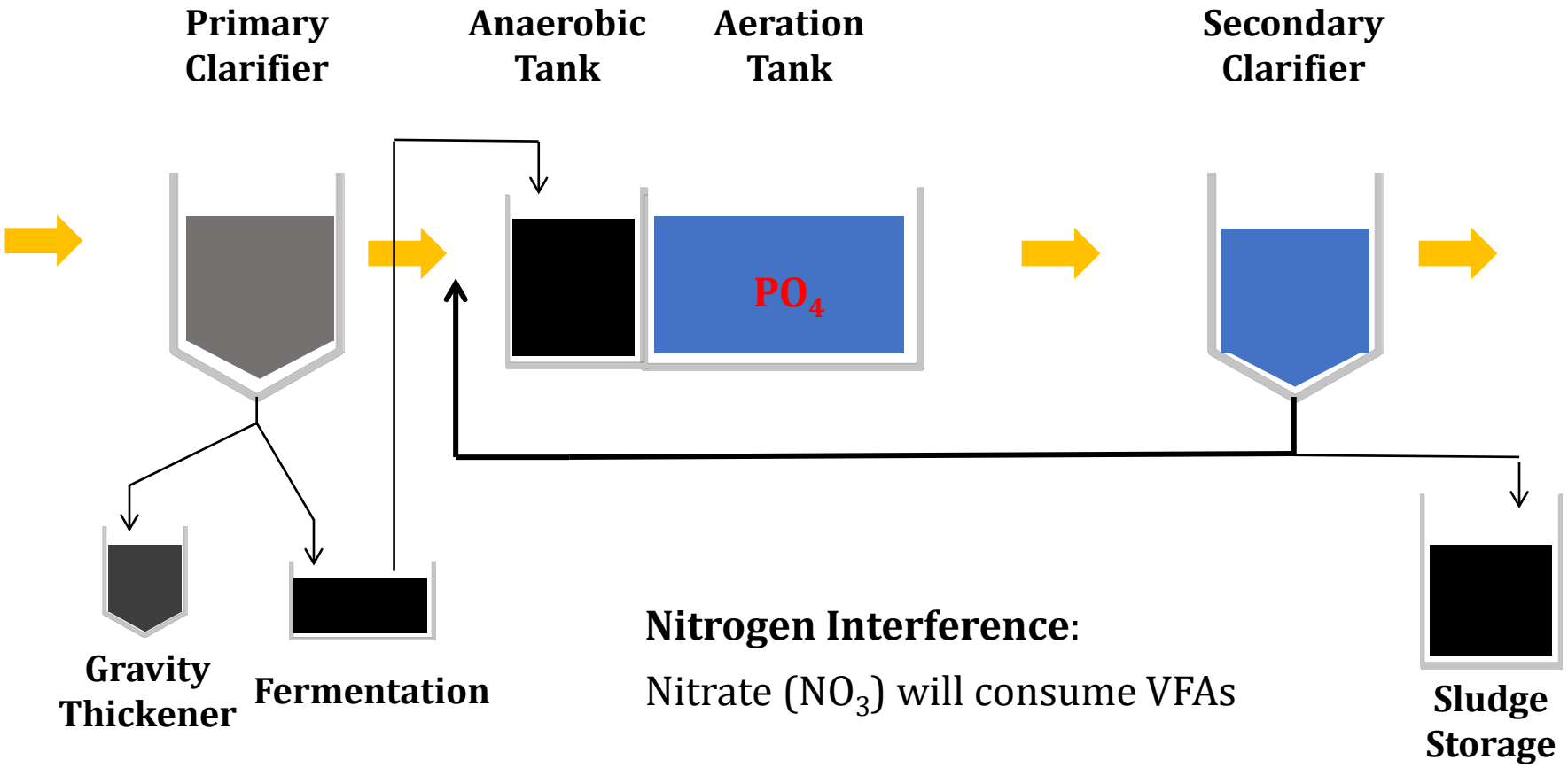
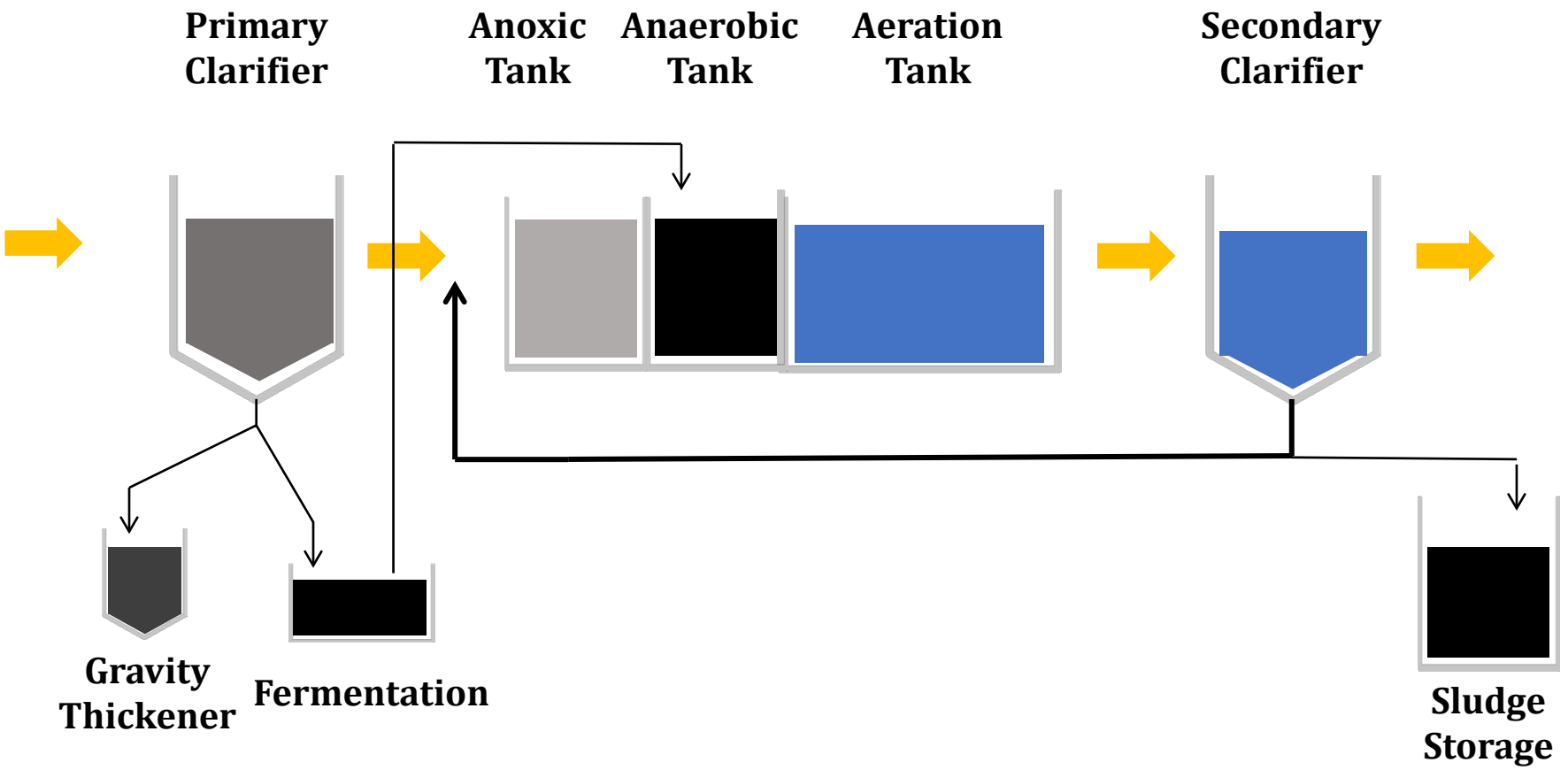


Nitrogen Interference:

Nitrate (NO_3) will consume VFAs

Bio-P Removal: Sidestream Fermentation Process



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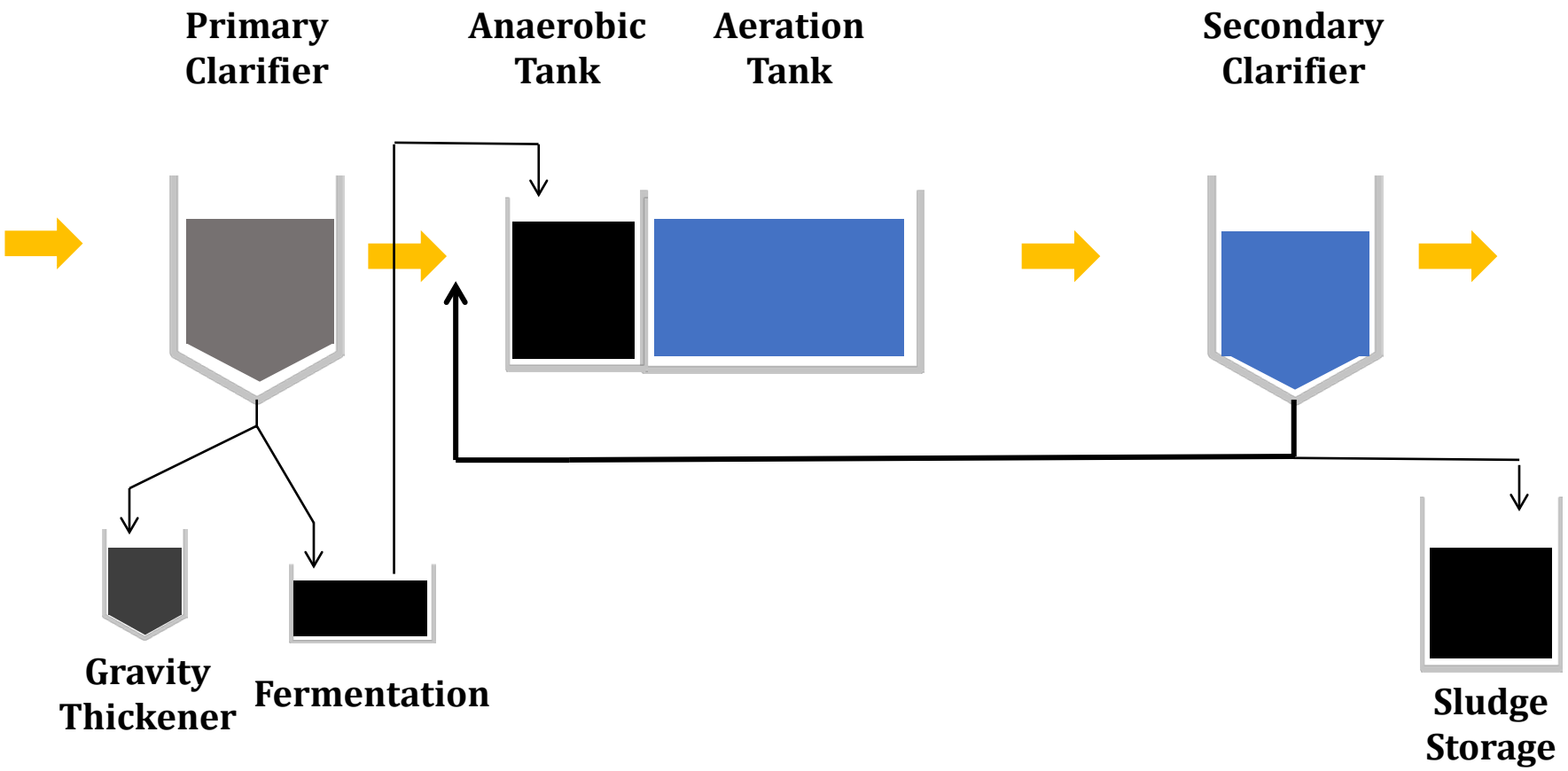
PROCESS CONTROL

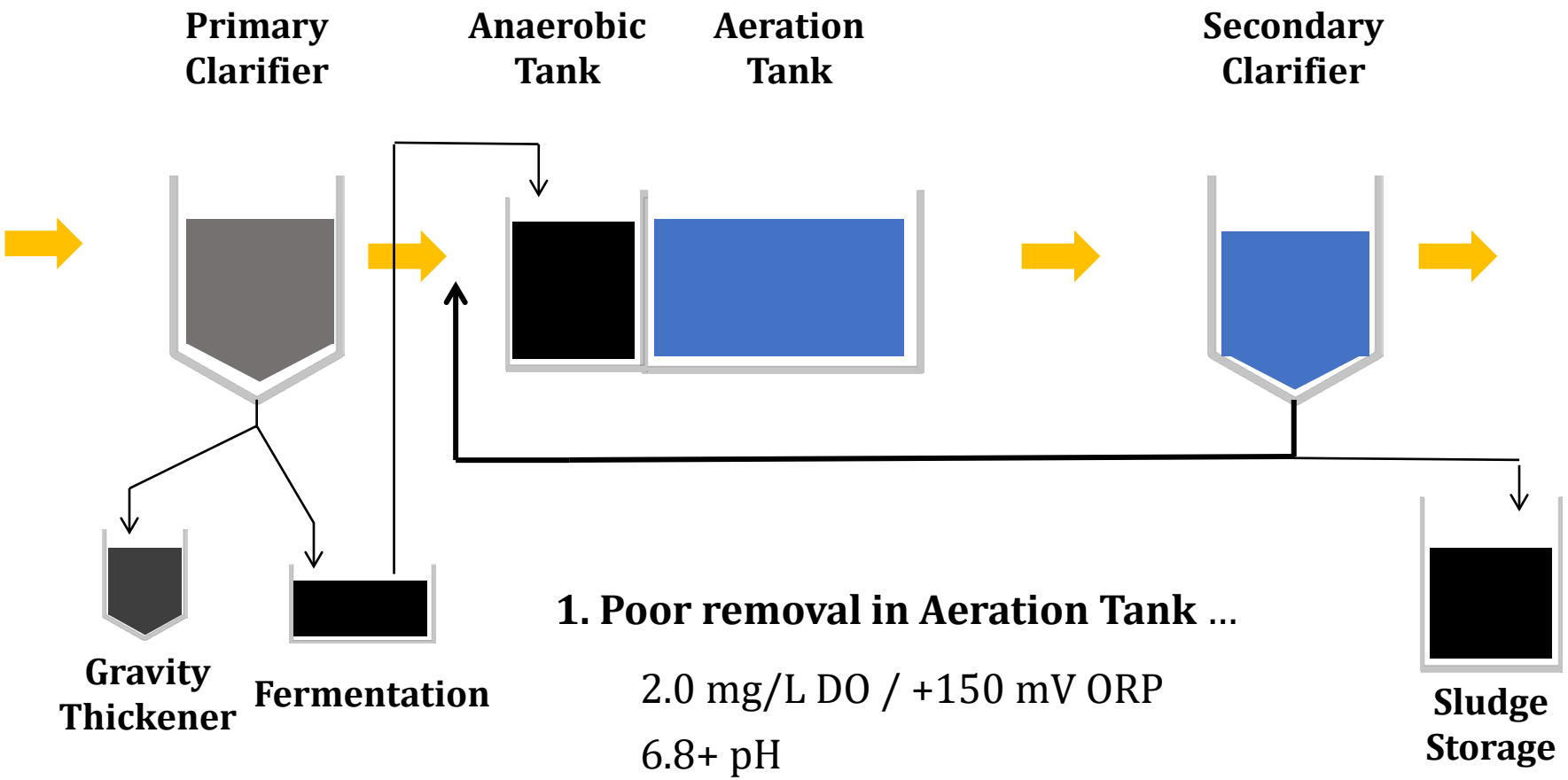
Less than 3x ortho-P leaving Anaerobic Tank



If Anaerobic Tank isn't really anaerobic …

… turn off mixer(s)

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

Optimizing Bio-P Removal: Mainstream or Sidestream Fermentation

Anaerobic Tank

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)*

Aeration Tank

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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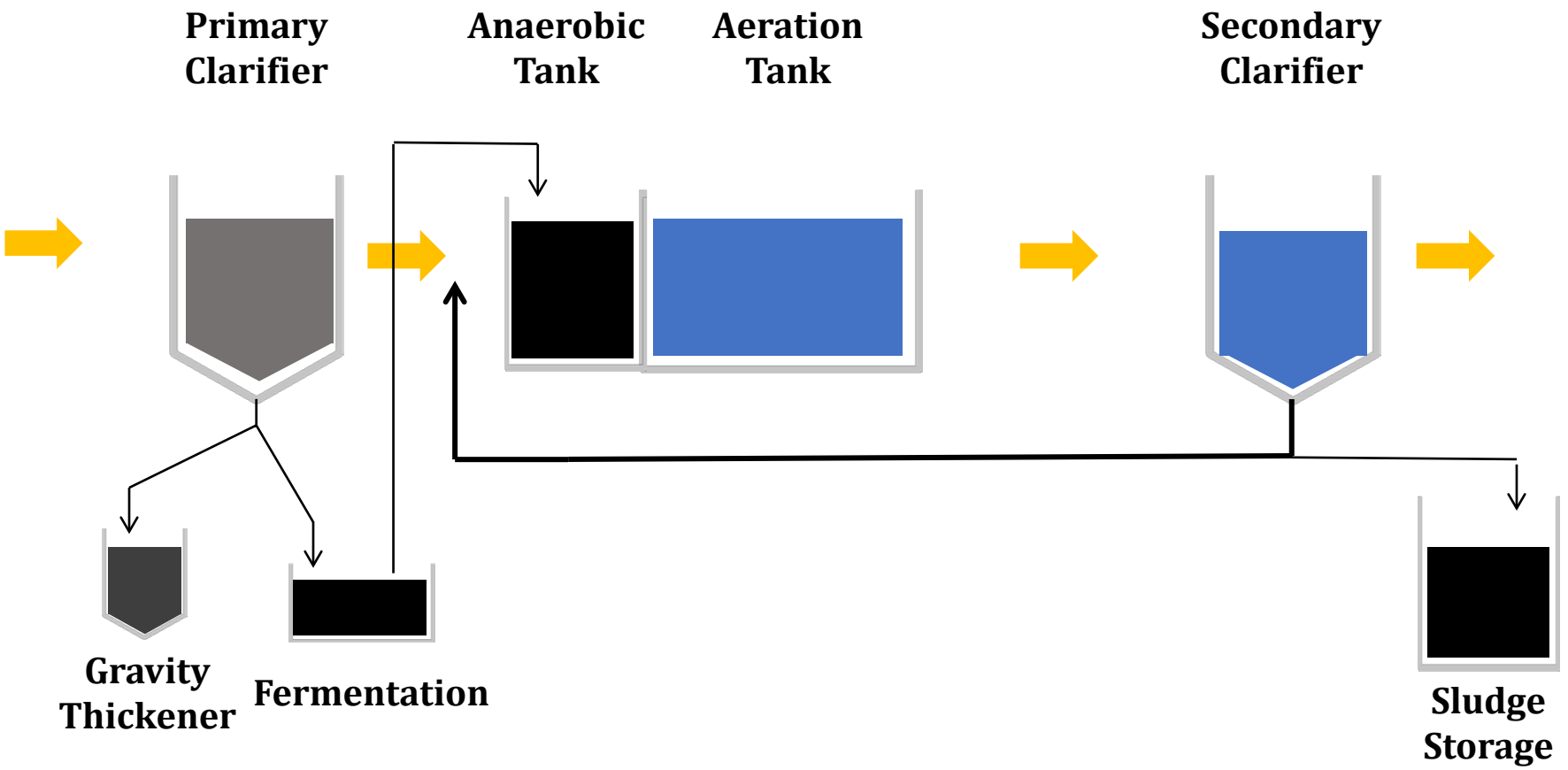
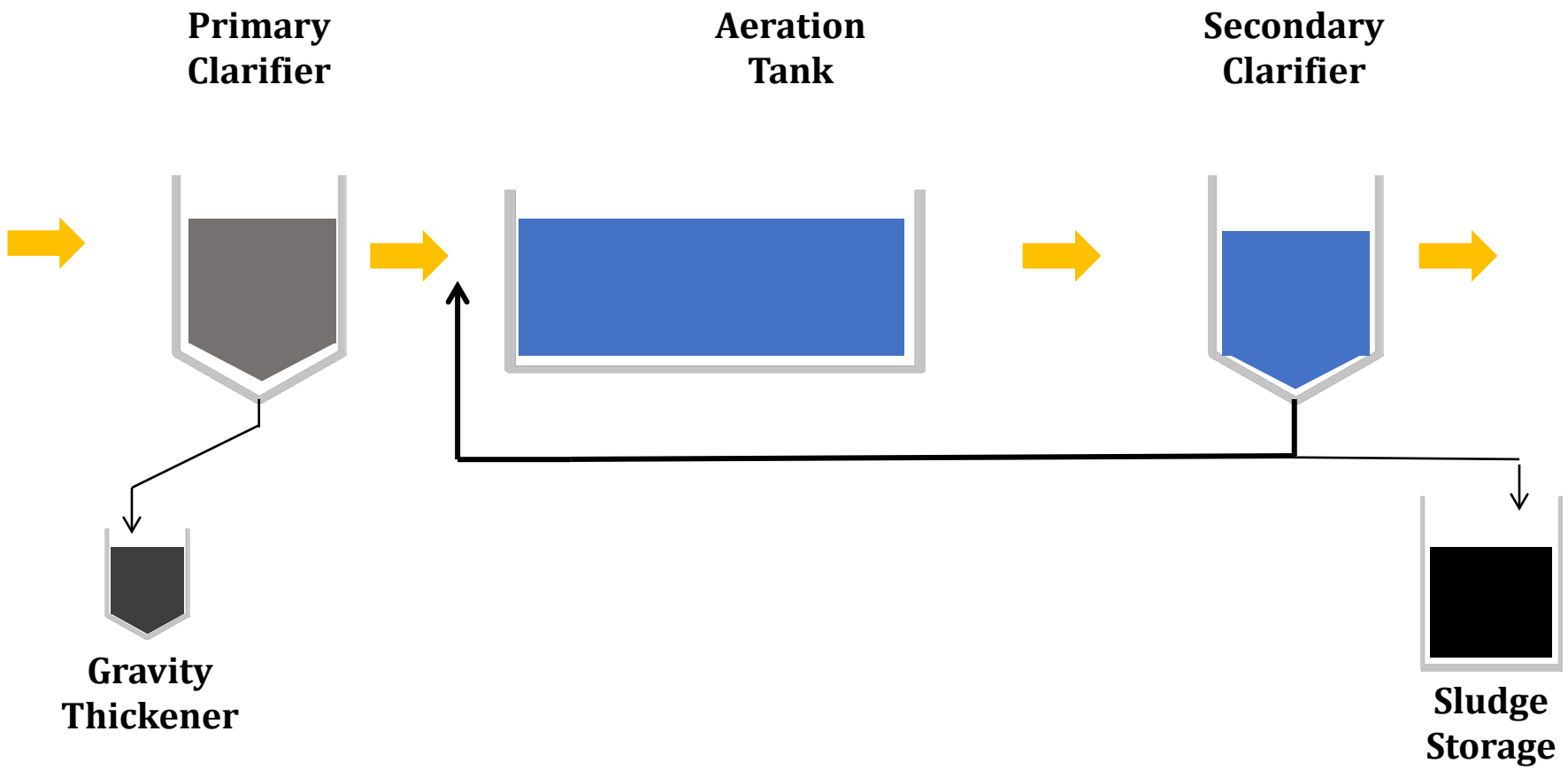
Getting creative …

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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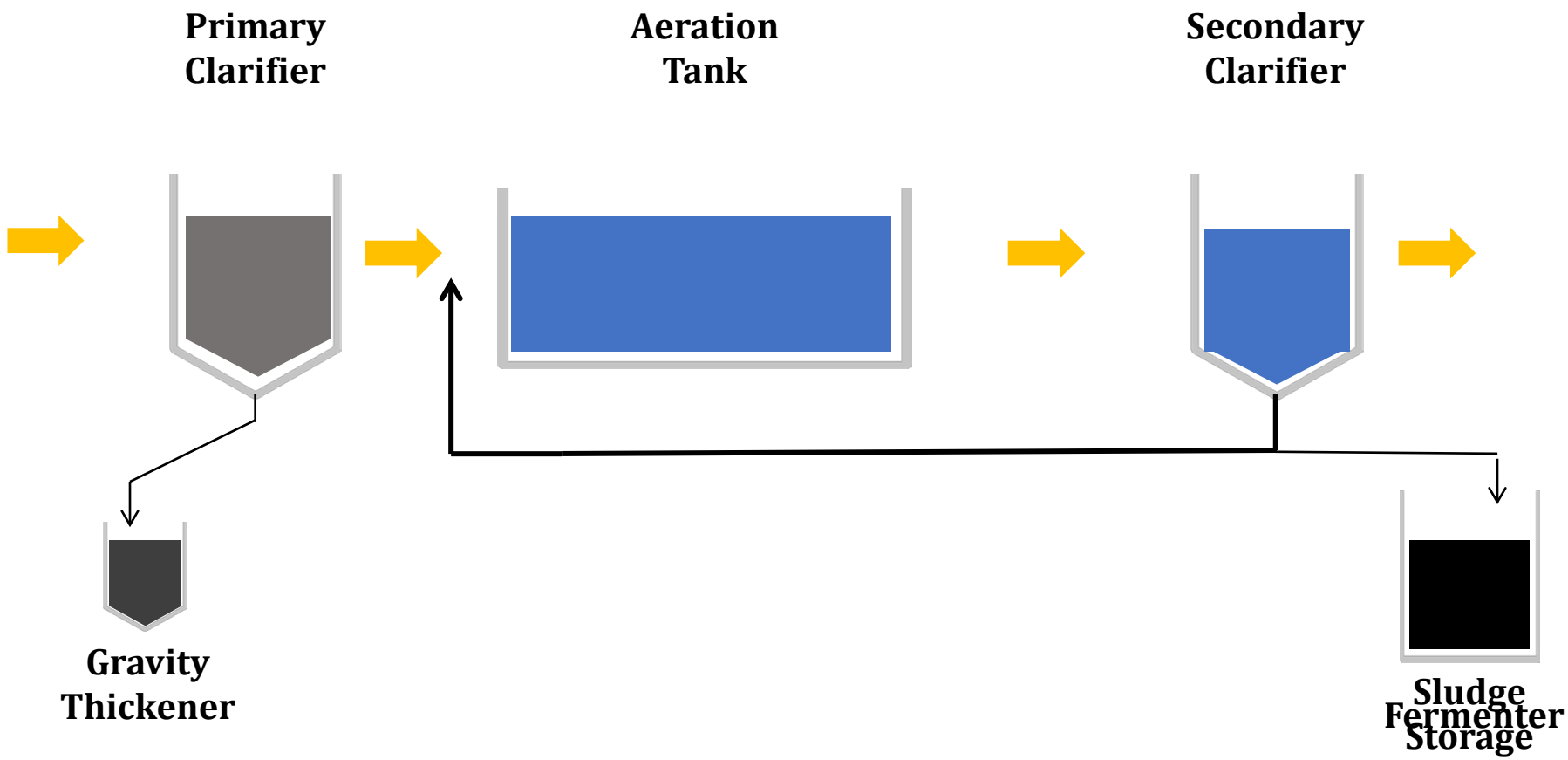
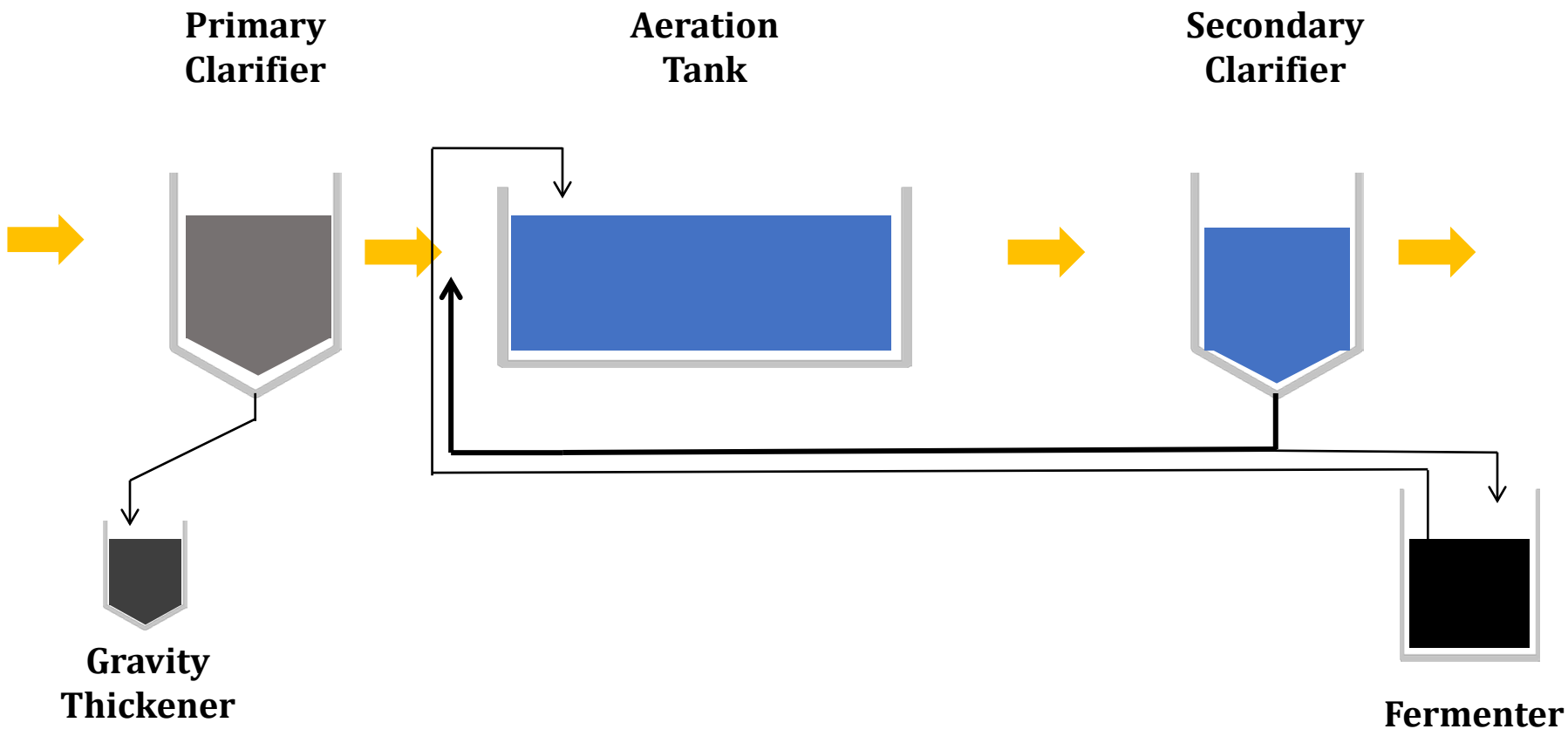


Home Grown Sidestream Fermenter



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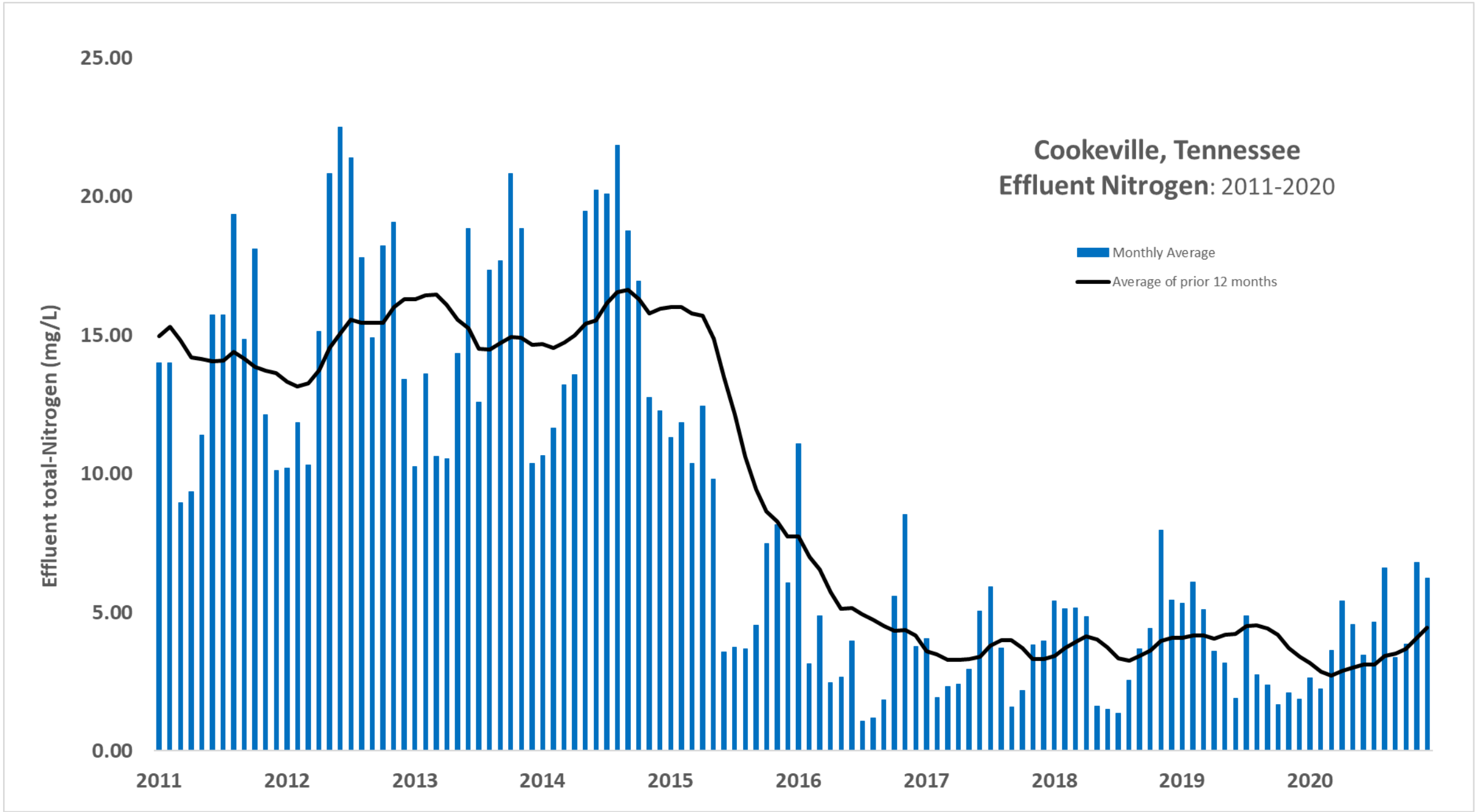
Number of Operators at your plant

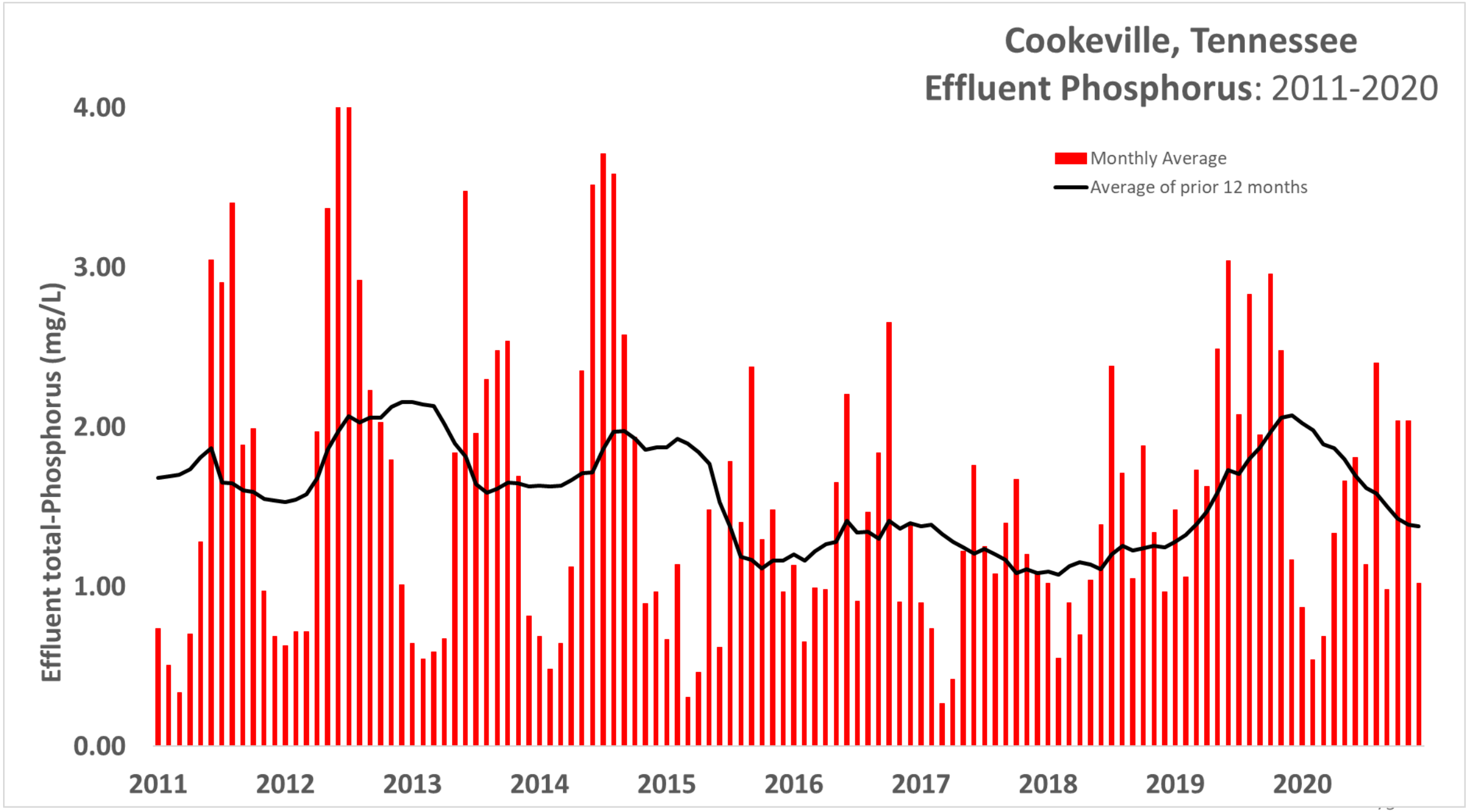

TENNESSEE
Athens
Collierville
Cookeville
Cowan
Harriman
Lafayette
Nashville Dry Creek
Norris

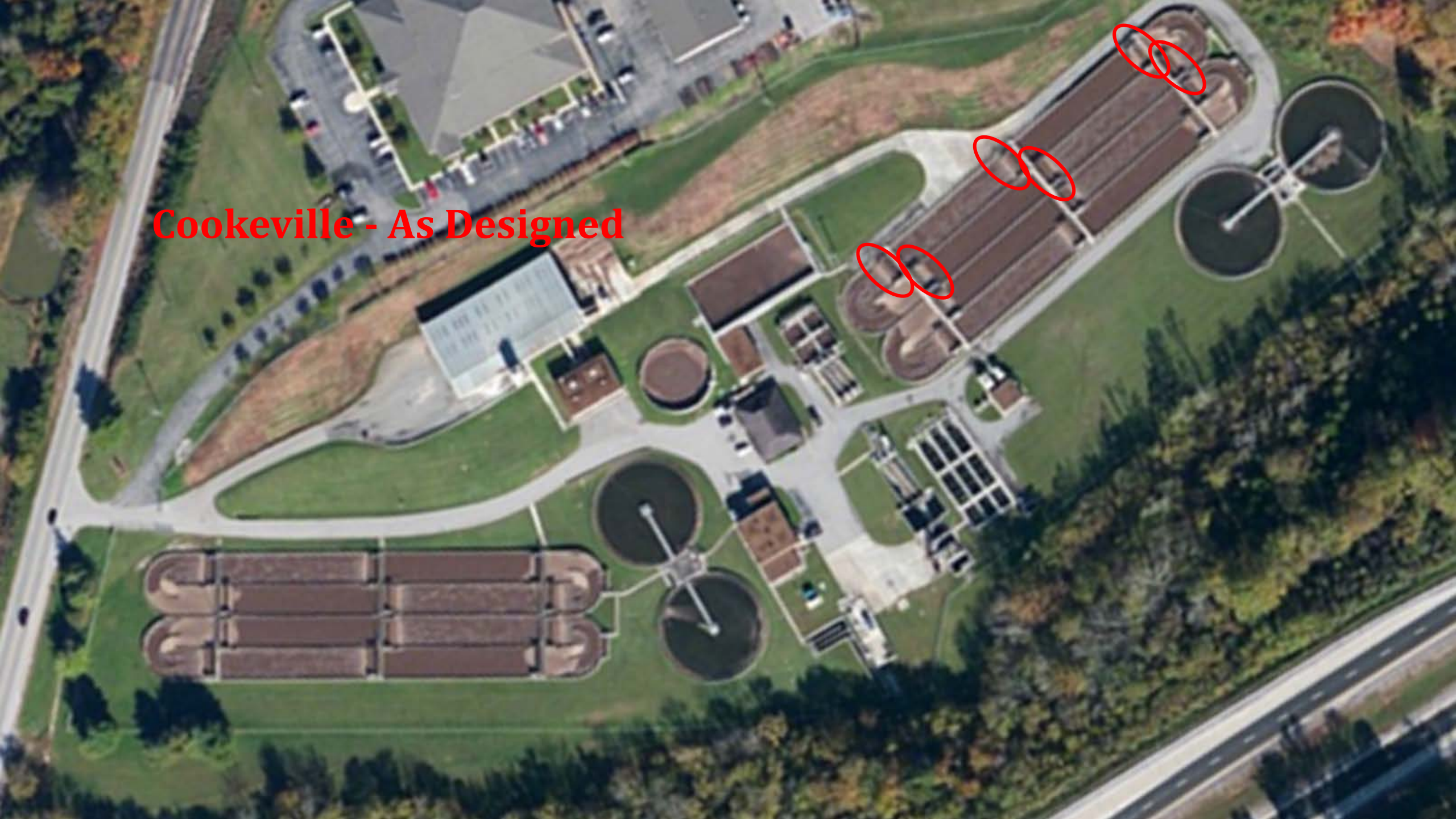
Cookeville, Tennessee Population: 33,500 15 MGD design flow

Cookeville


TREATMENT PLANT OPERATOR
tpo
LET'S BE CLEAR:
Are you a technophobe? | 6
IN MY WORDS:
Treatment innovations for small communities | 22
TECH TALK:
A new approach to flood protection | 14
From Learner to Mentor
MICHELE HIGDON SAYS THANKS FOR HER SUCCESS BY GIVING BACK AS A VOLUNTEER
SPECIAL FEATURE:
PLANT PROFICIENCIES


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


Cookeville, Tennessee
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


Cookeville - As Designed


Cookeville - As Now Operated


Cookeville - As Now Operated


Cookeville - As Now Operated

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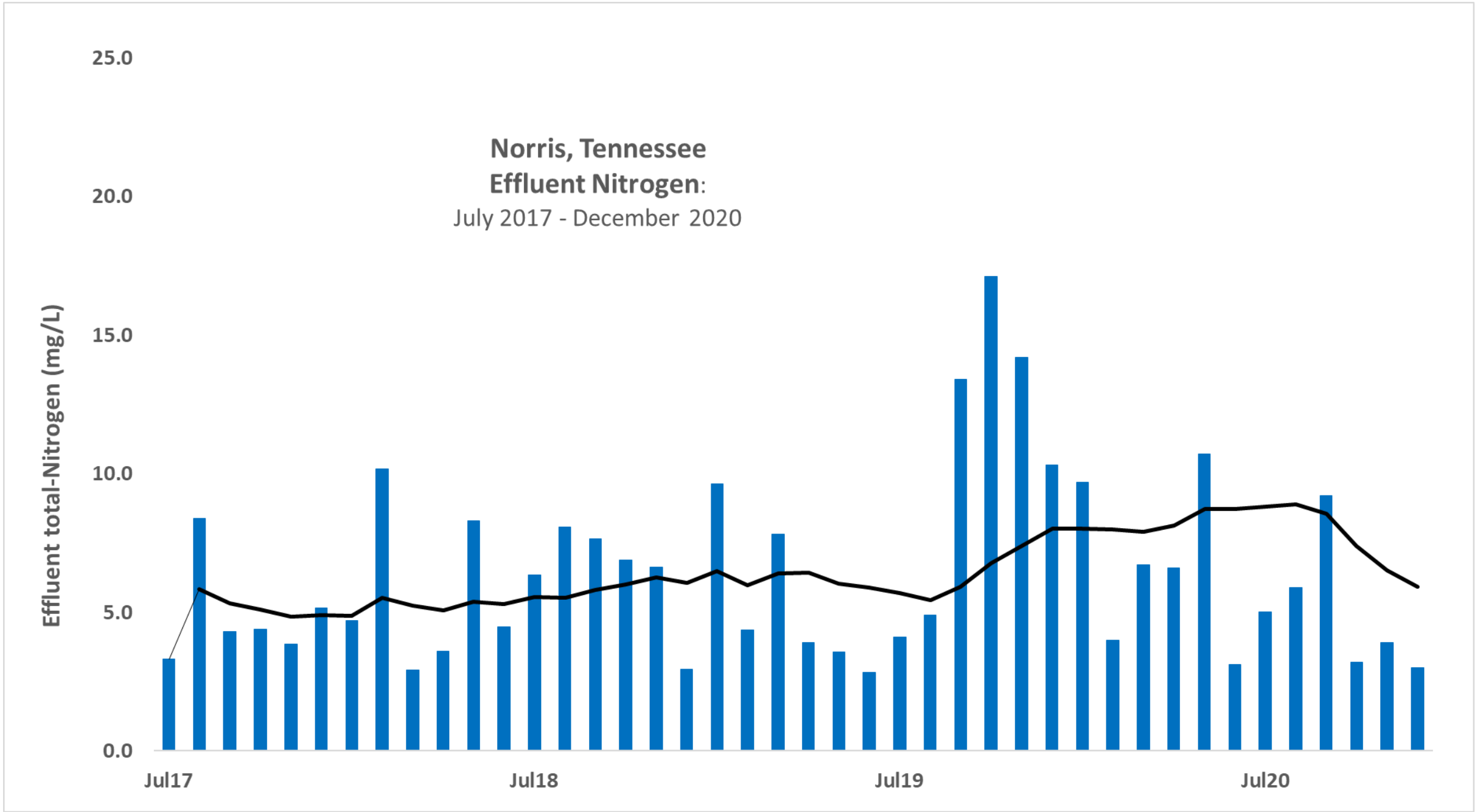
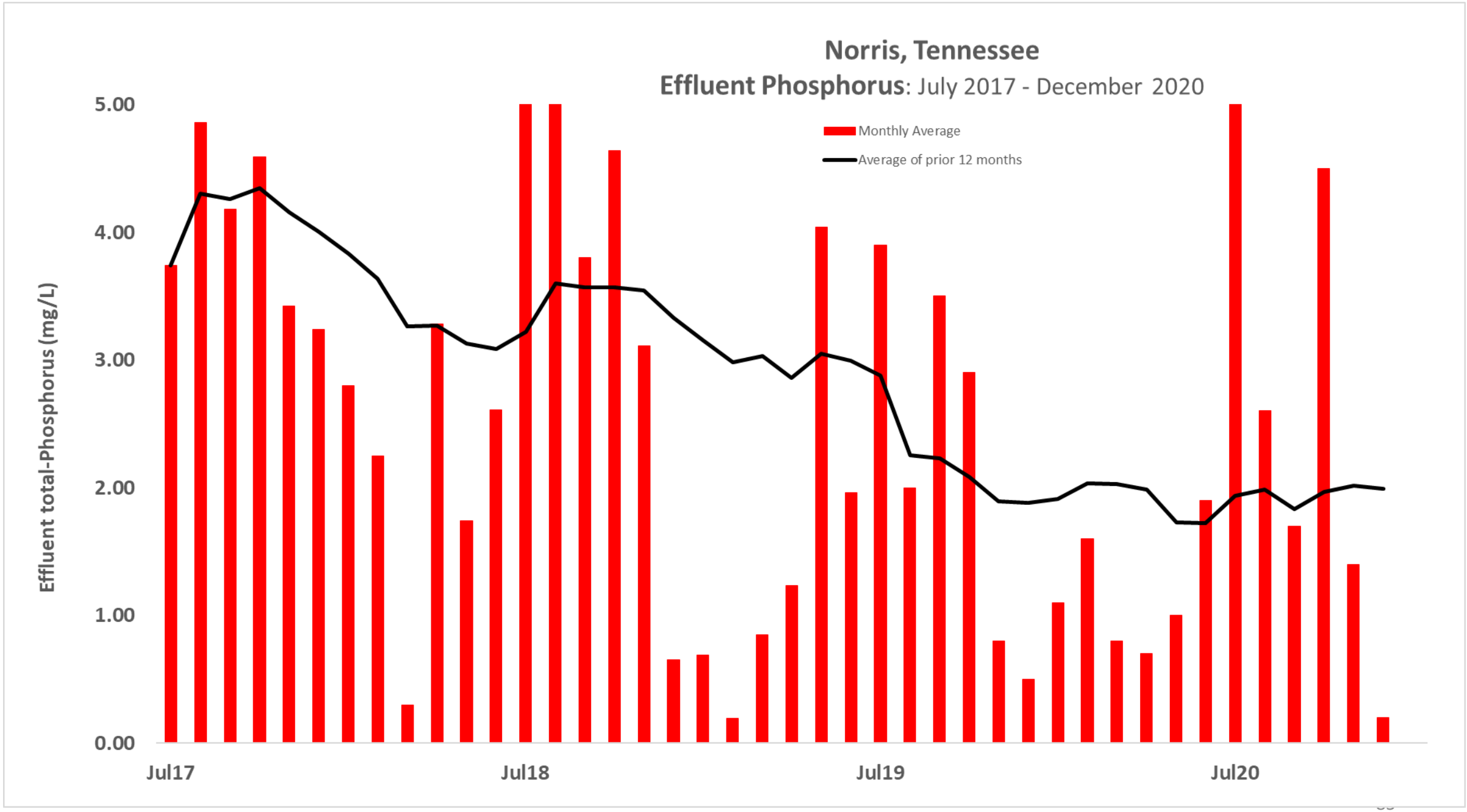
Norris, Tennessee Population: 1,450 0.2 MGD design flow

Norris


Norris, Tennessee
Effluent Nitrogen:
July 2017 - December 2020
Effluent total-Nitrogen (mg/L)
25.0
20.0
15.0
10.0
5.0
0.0
Jul17
Jul18
Jul19
Jul20


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


Norris

Norris

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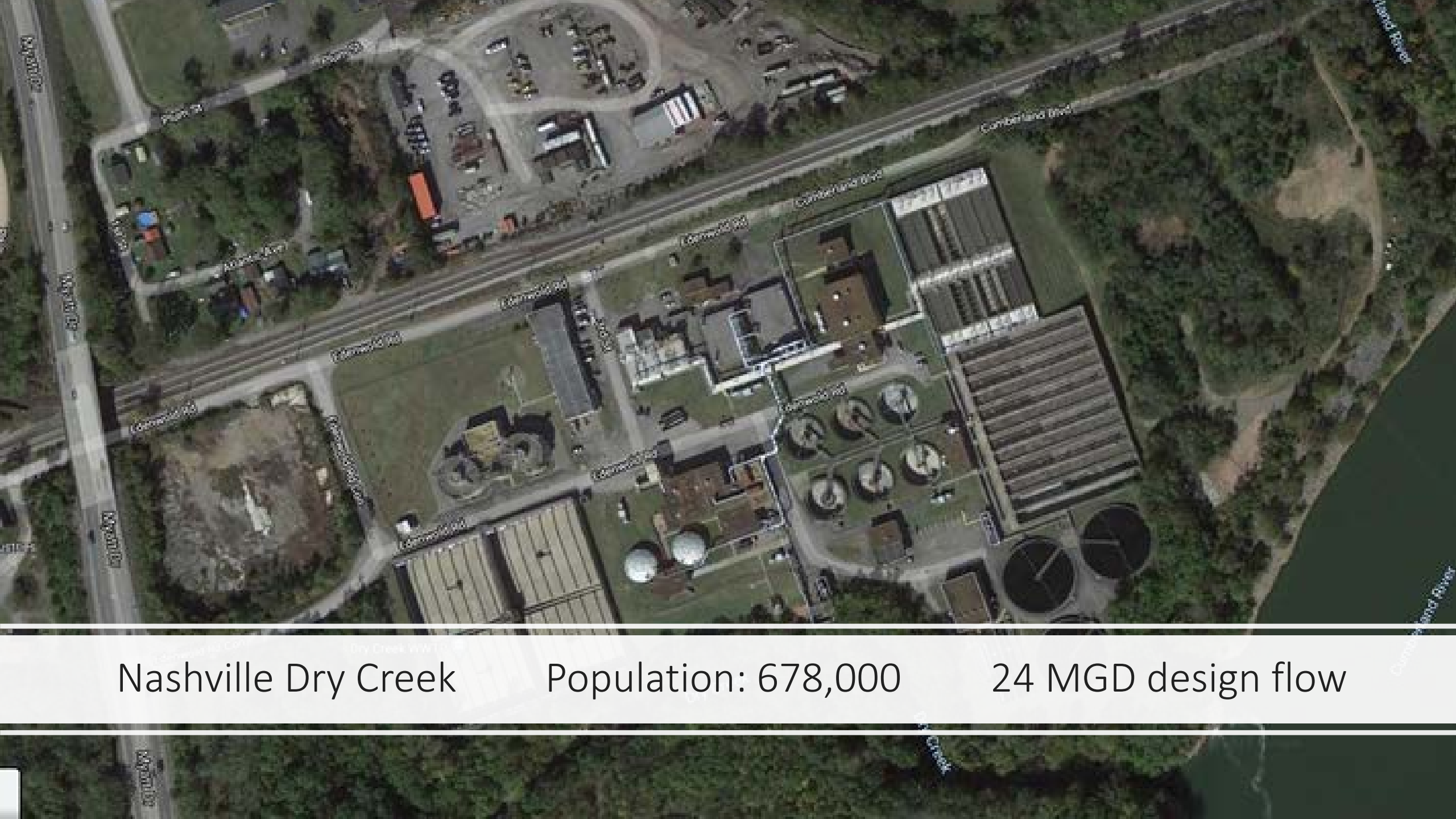

Nashville Dry Creek Population: 678,000 24 MGD design flow


Nashville Dry Creek
Dry Creek WWTP
Dry Creek
Dry Creek
Cumberland River
Cumberland River


Nashville Dry Creek
Dry Creek WWTP
Dry Creek
Dry Creek
Cumberland River
Cumberland River


Nashville Dry Creek
Dry Creek WWTP
Dry Creek
Dry Creek
Cumberland River
Cumberland River


Nashville Dry Creek
Dry Creek WWTP
Dry Creek
Dry Creek
Cumberland River
Cumberland River

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

Harriman, Tennessee

Actual Flow	Effluent Nitrogen (mg/L)		Effluent Phosphorus (mg/L)	
(MGD)	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
Bullard Ford Rd


Harriman - As Operated
Emory River
Bullard Ford Rd
Emory River


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


Harriman - As Operated
Emory River
Emory River
Bullard Ford Rd


Harriman - As Operated
Emory River
Bullard Ford Rd
Emory River

Harriman - As Operated

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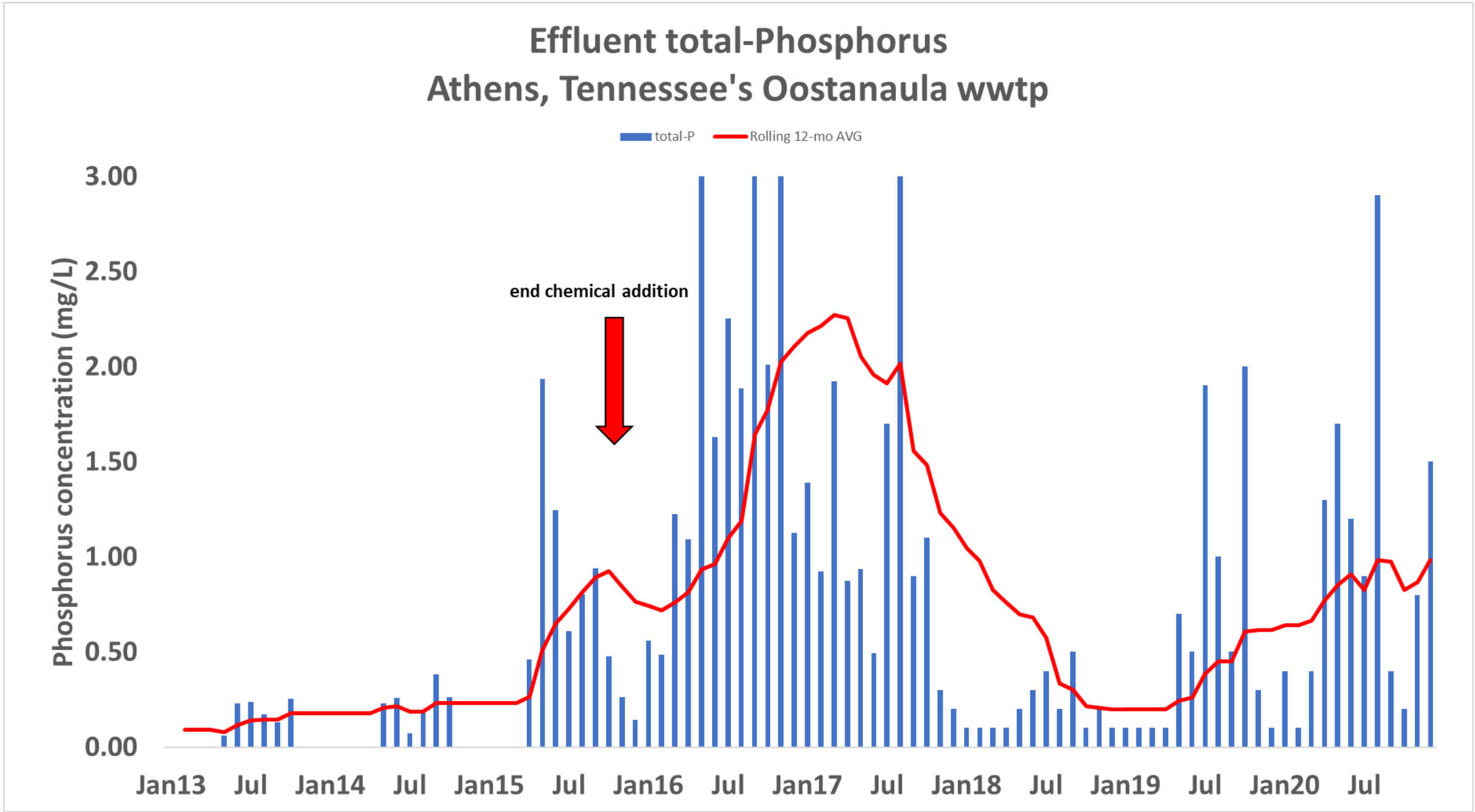
Athens, Tennessee Population: 13,850 6.0 MGD design flow


Effluent total-Phosphorus
Athens, Tennessee's Oostanaula wwtp
total-P
Rolling 12-mo AVG
Phosphorus concentration (mg/L)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
end chemical addition
Jan13
Jul
Jan14
Jul
Jan15
Jul
Jan16
Jul
Jan17
Jul
Jan18
Jul
Jan19
Jul
Jan20
Jul


Athens

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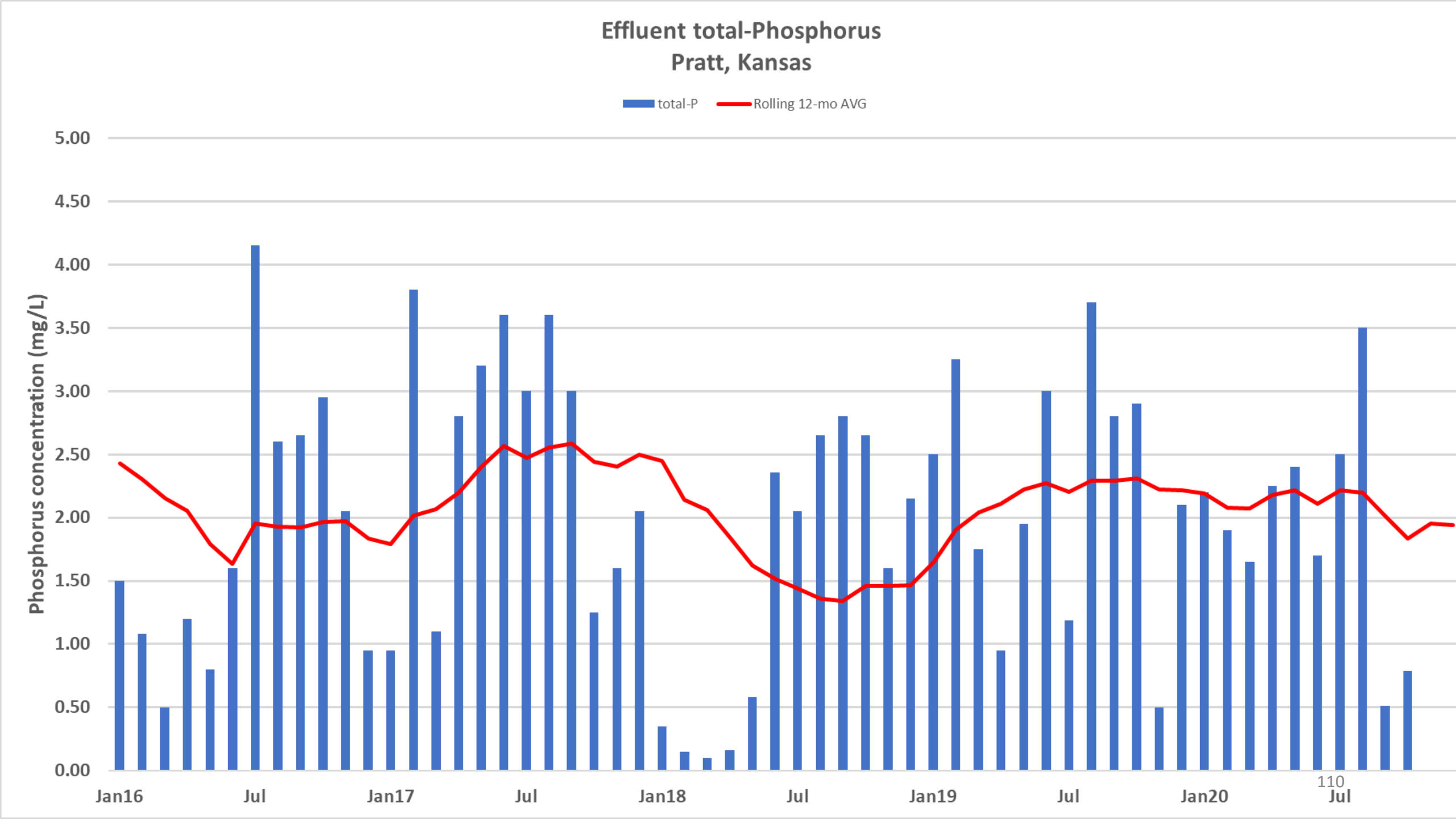
KANSAS

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


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

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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

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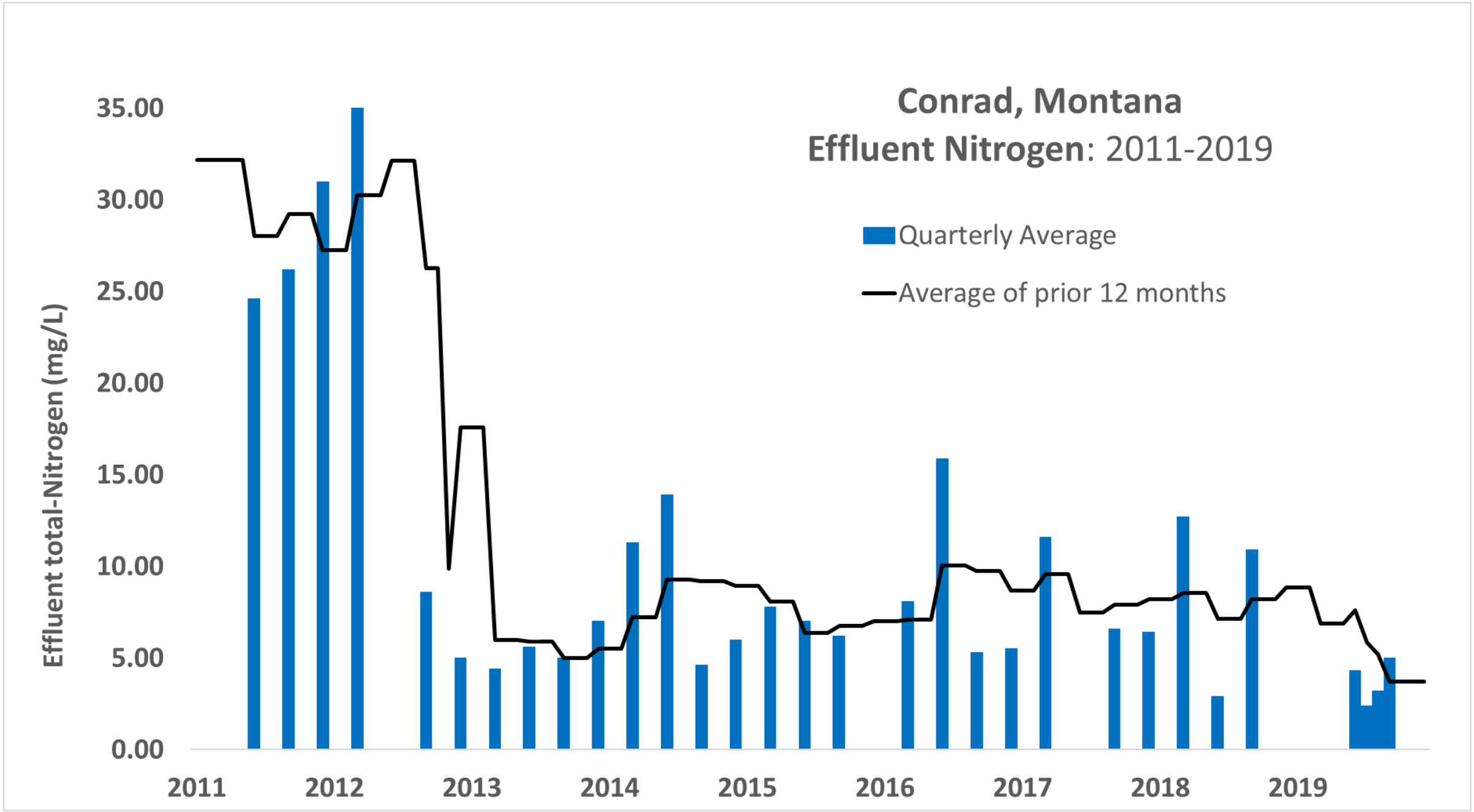
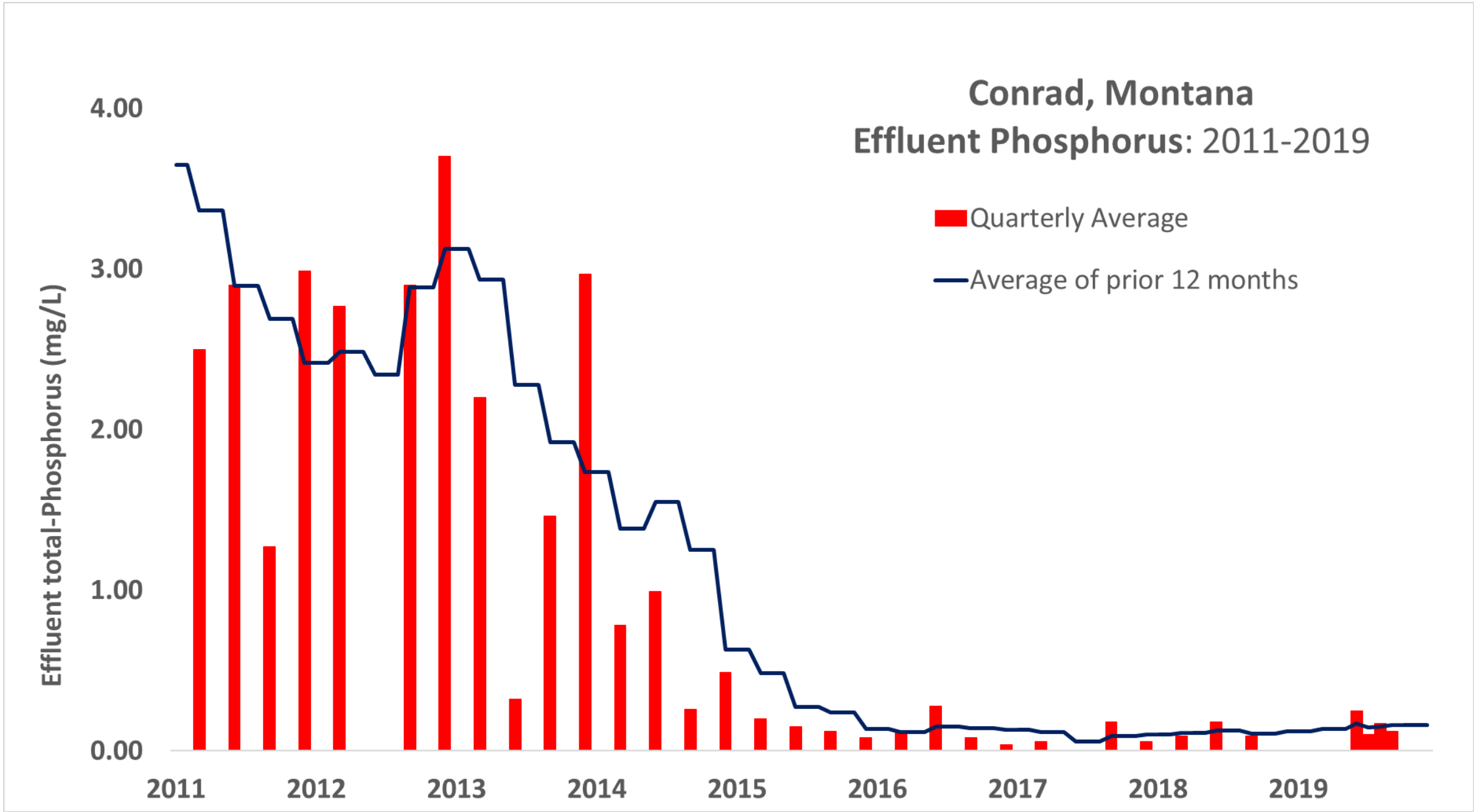
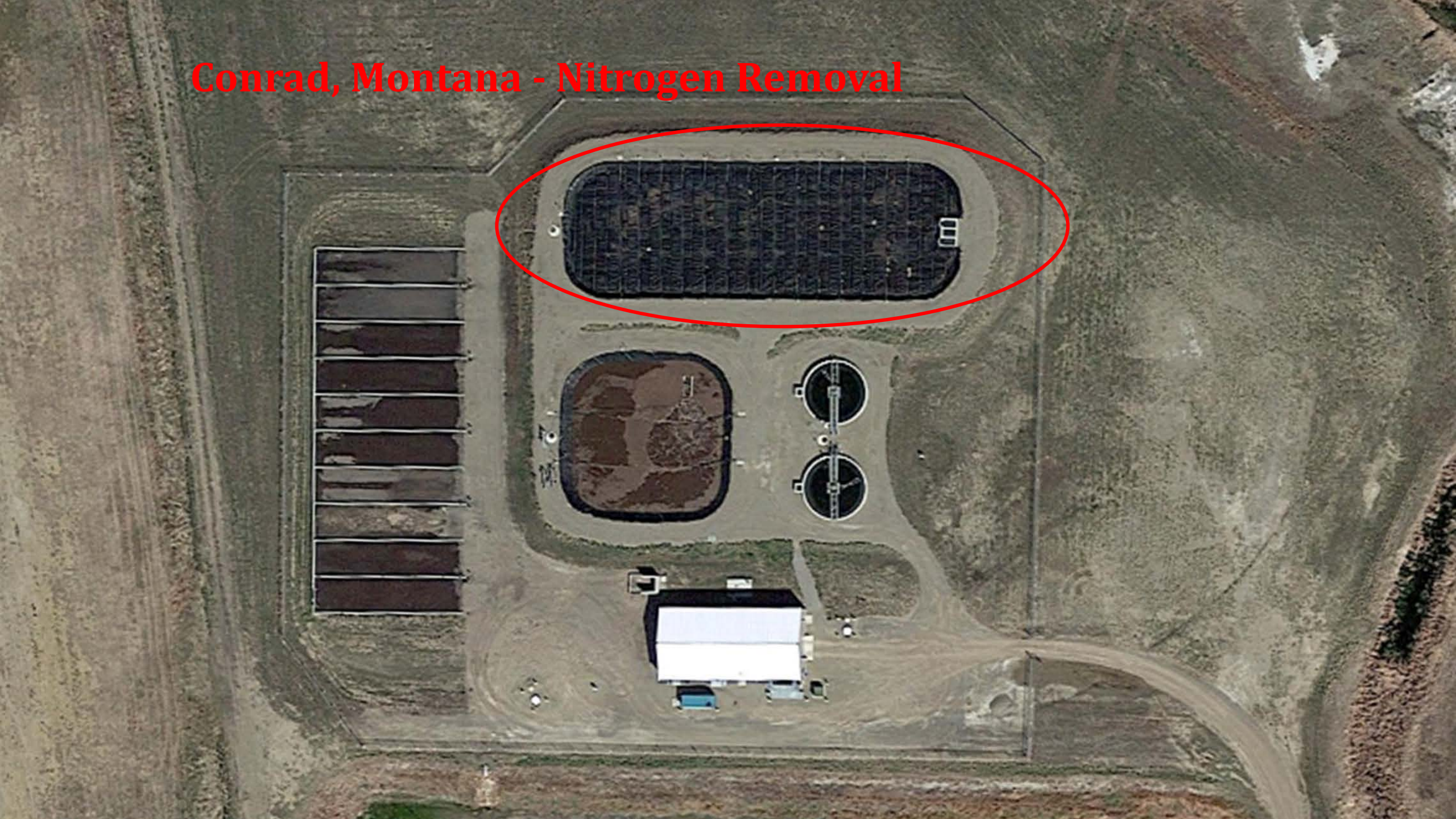
MONTANA

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


Conrad, Montana
Effluent Nitrogen: 2011-2019
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

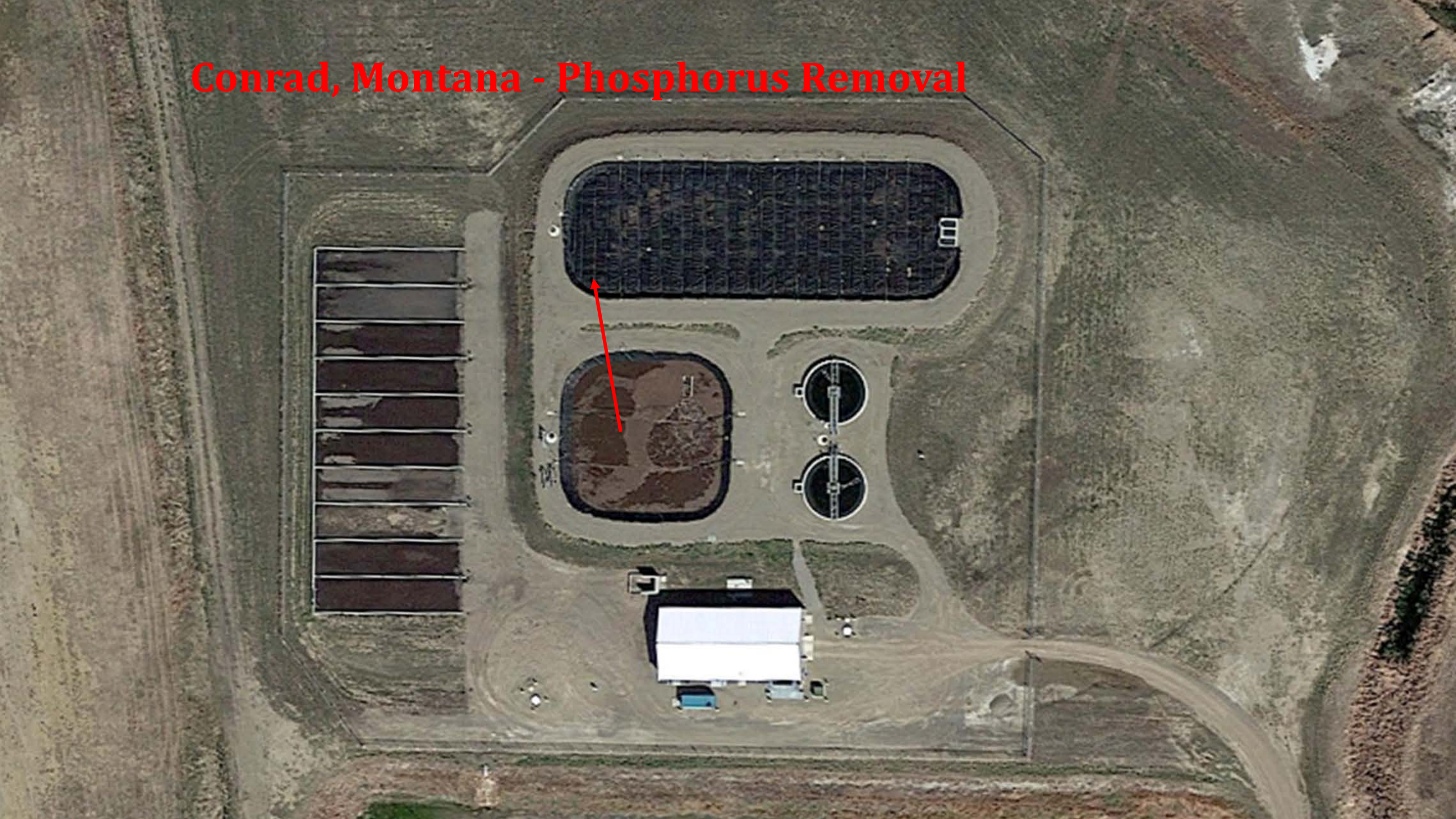

Conrad, Montana
Effluent Phosphorus: 2011-2019
Quarterly Average
Average of prior 12 months
Effluent total-Phosphorus (mg/L)
4.00
3.00
2.00
1.00
0.00
2011
2012
2013
2014
2015
2016
2017
2018
2019

Conrad, Montana - Nitrogen Removal



Conrad, Montana - Phosphorus Removal

Conrad, Montana - Phosphorus Removal



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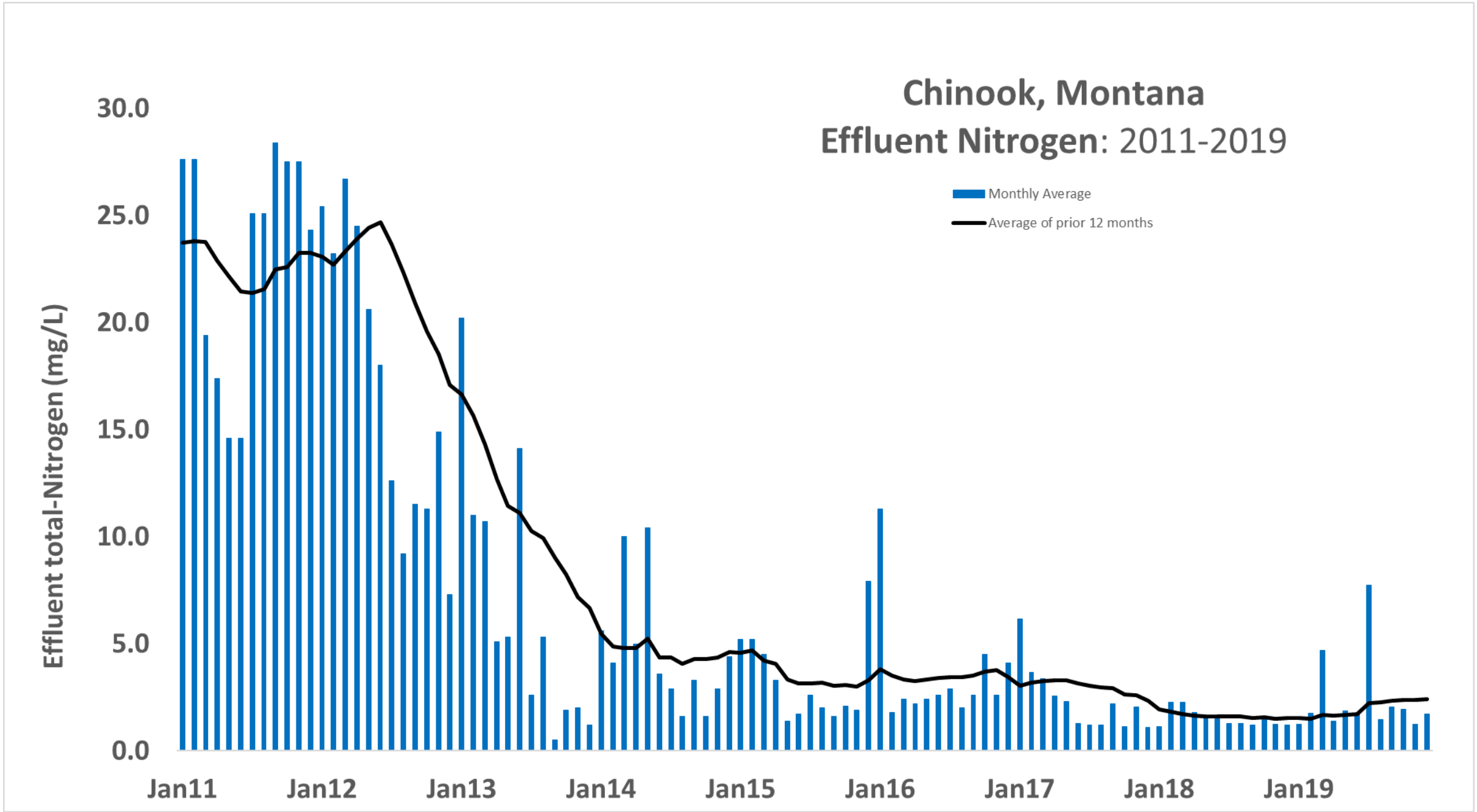
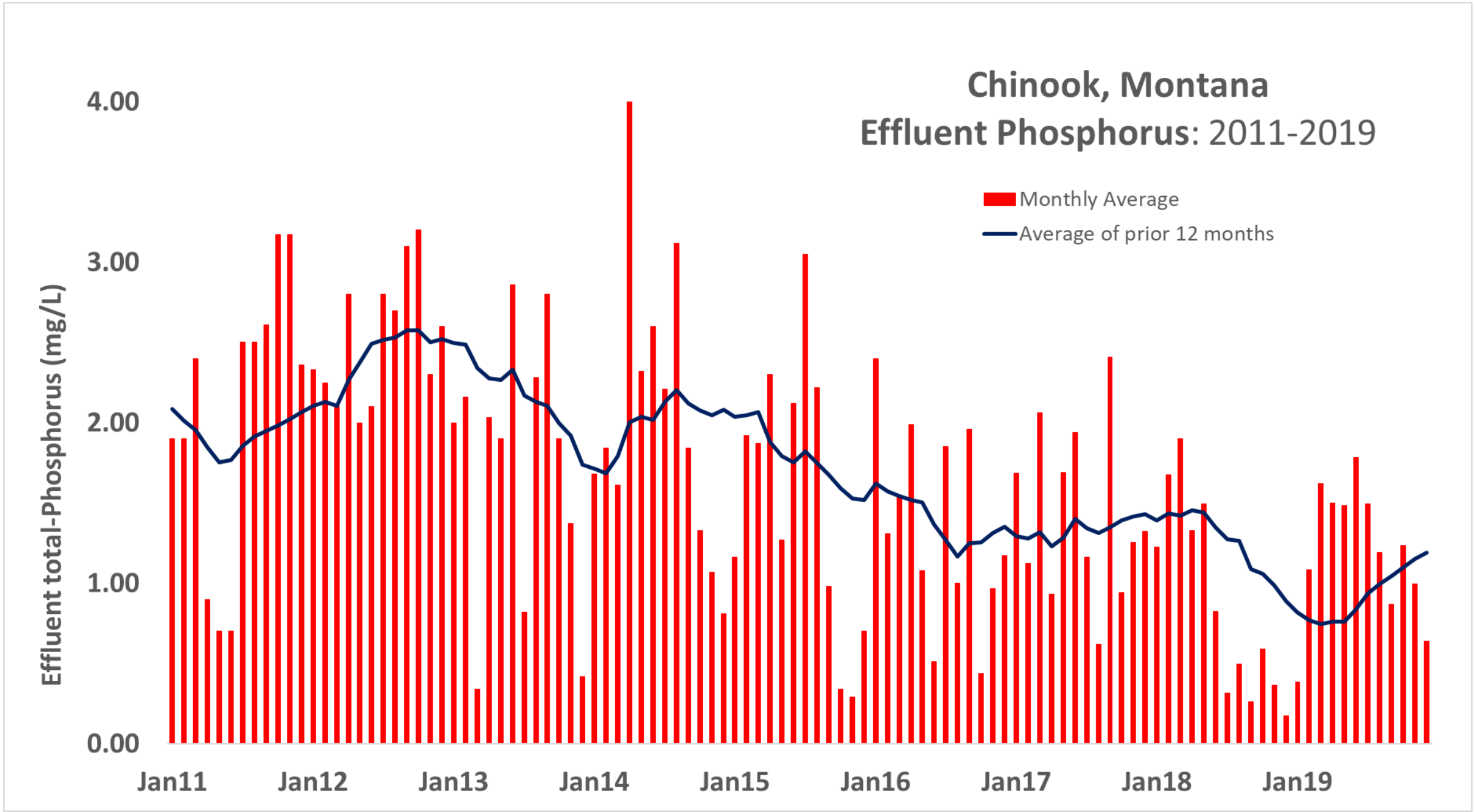
Chinook, Montana Population: 1,250 0.5 MGD design flow


Chinook, Montana
Effluent Nitrogen: 2011-2019
Monthly Average
Average of prior 12 months
Effluent total-Nitrogen (mg/L)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Jan11
Jan12
Jan13
Jan14
Jan15
Jan16
Jan17
Jan18
Jan19


Chinook, Montana
Effluent Phosphorus: 2011-2019
Monthly Average
Average of prior 12 months
Effluent total-Phosphorus (mg/L)
4.00
3.00
2.00
1.00
0.00
Jan11
Jan12
Jan13
Jan14
Jan15
Jan16
Jan17
Jan18
Jan19

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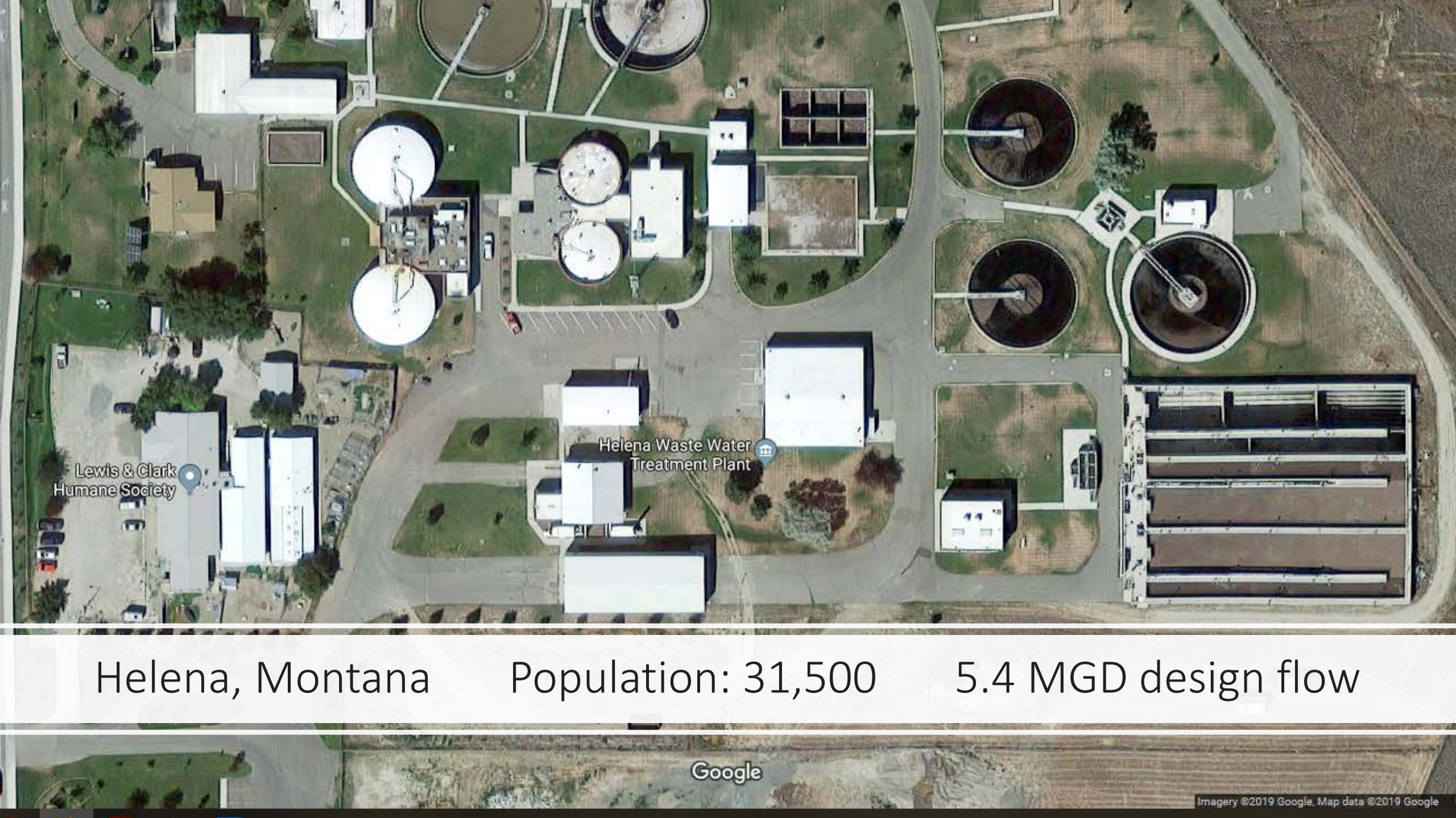
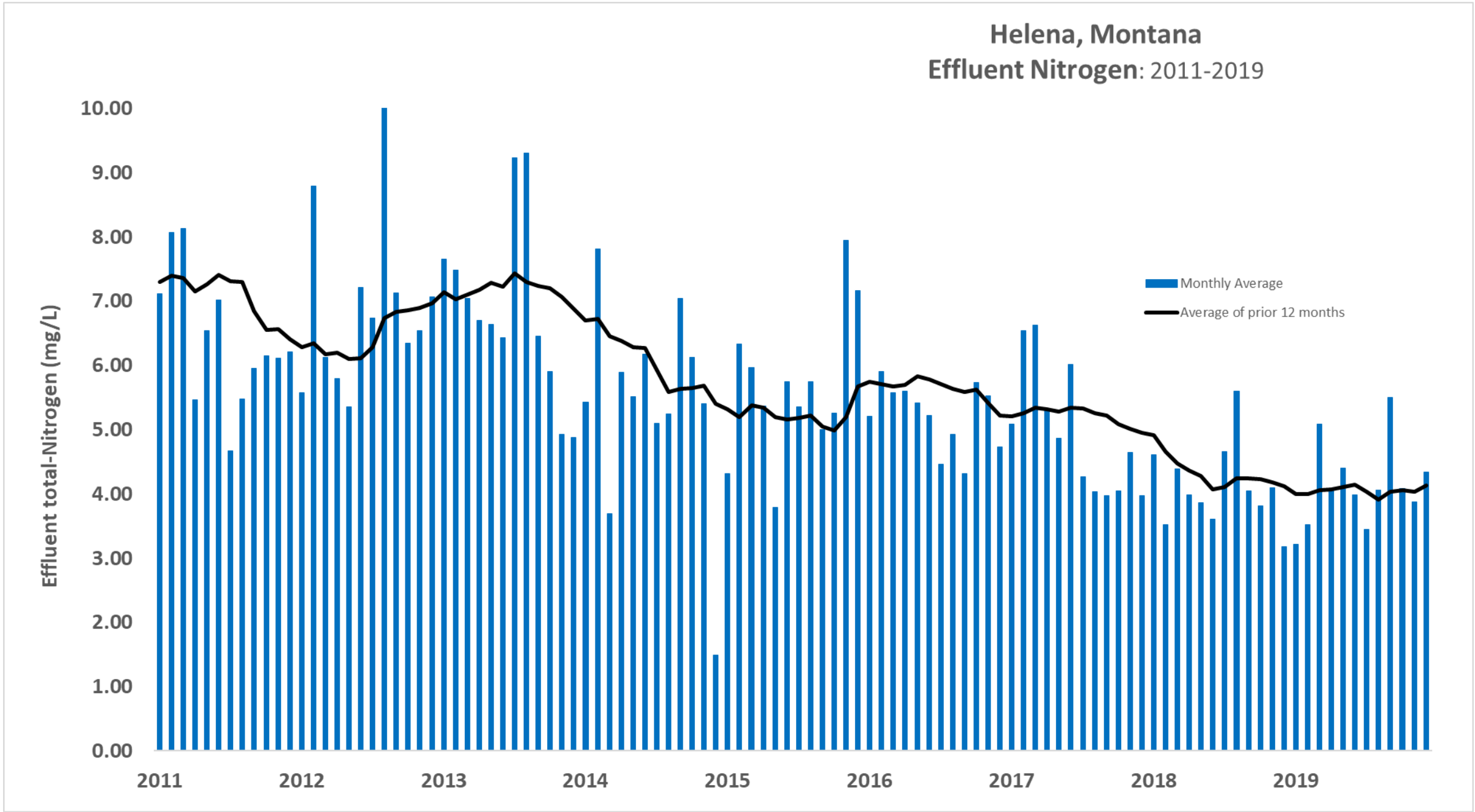
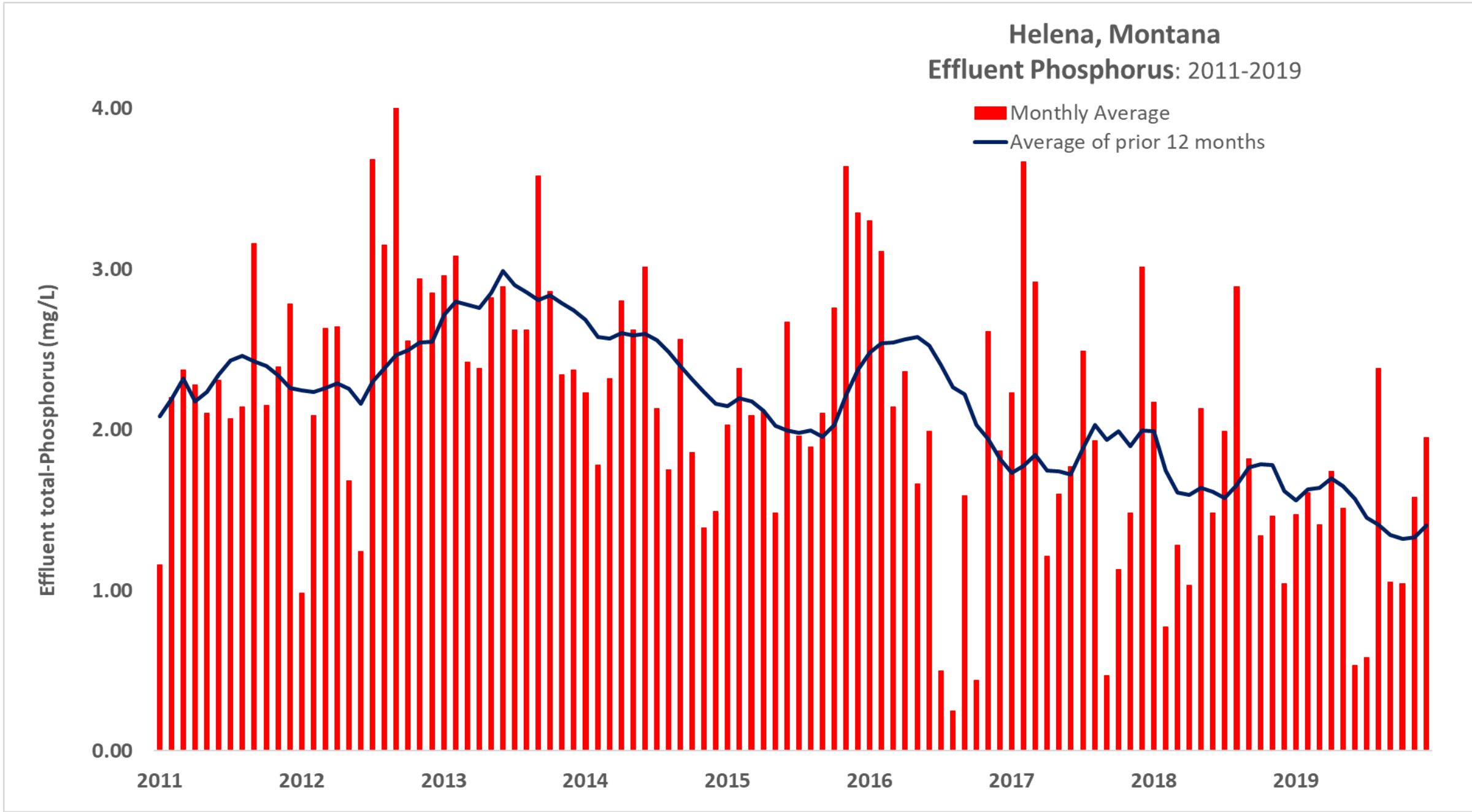


Helena, Montana Population: 31,500 5.4 MGD design flow


Helena, Montana
Effluent Nitrogen: 2011-2019
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
Monthly Average
Average of prior 12 months


Helena, Montana
Effluent Phosphorus: 2011-2019
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

Helena, Montana - Nitrogen Removal

Helena, Montana - Phosphorus Removal

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Acknowledgements, Part 1

TENNESSEE DEPARTMENT OF ENVIRONMENT & CONSERVATION (TDEC)
Karina Bynum, Sherry Wang, George Garden, Jenny Dodd, Jason Benton, Eddie Bouzied, Bryan Carter, David Duhl, Jordan Fey, Oakley Hall, Michael Murphy, Steve Owens, Rob Ramsey, Sherwin Smith, Robert Tipton, Sandra Vance, John West, Ariel Wessel-Fuss …

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COOKEVILLE
Ronnie Kelly, Tom Graham & John Buford

HARRIMAN
Ray Freeman

NASHVILLE
Johnnie MacDonald & David Tucker

NORRIS
Tony Wilkerson & Doug Snelson

…

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EPA Paul Shriner … Tina Laidlaw … Brendon Held … Craig Hesterlee … Tony Tripp …

… and, many more!


Nutrient Removal Knowledge

Nitrogen & Phosphorus Removal in Oxidation Ditches

Wednesday, February 24

10:00 - 11:45 AM Central Time

.....

Mar 3: N&P Removal in SBRs

Mar 10: N&P Removal in Conventional Activated Sludge

Mar 17: Brainstorming N&P Removal Opportunities for Tennessee Wastewater Treatment Plants

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

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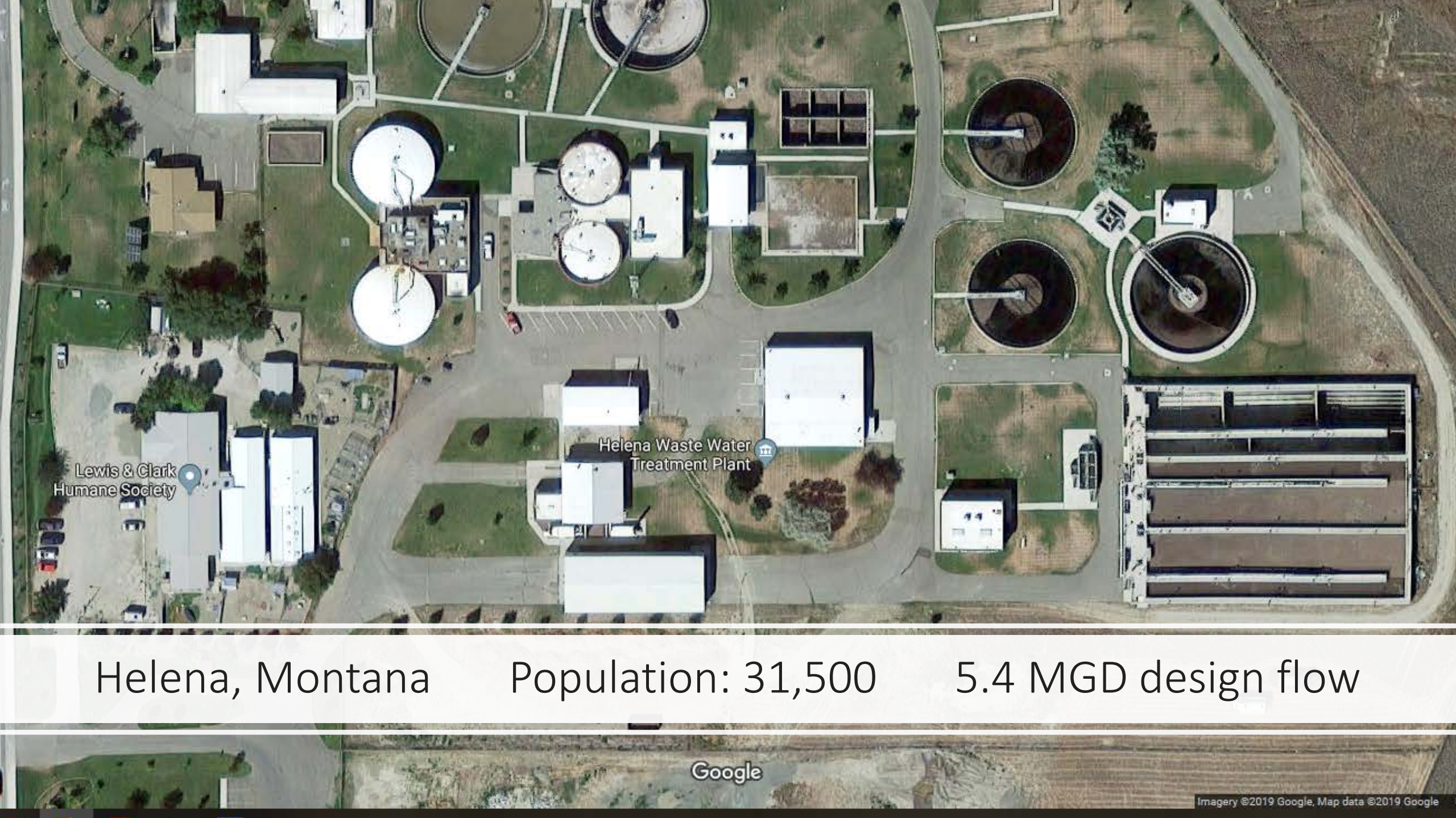
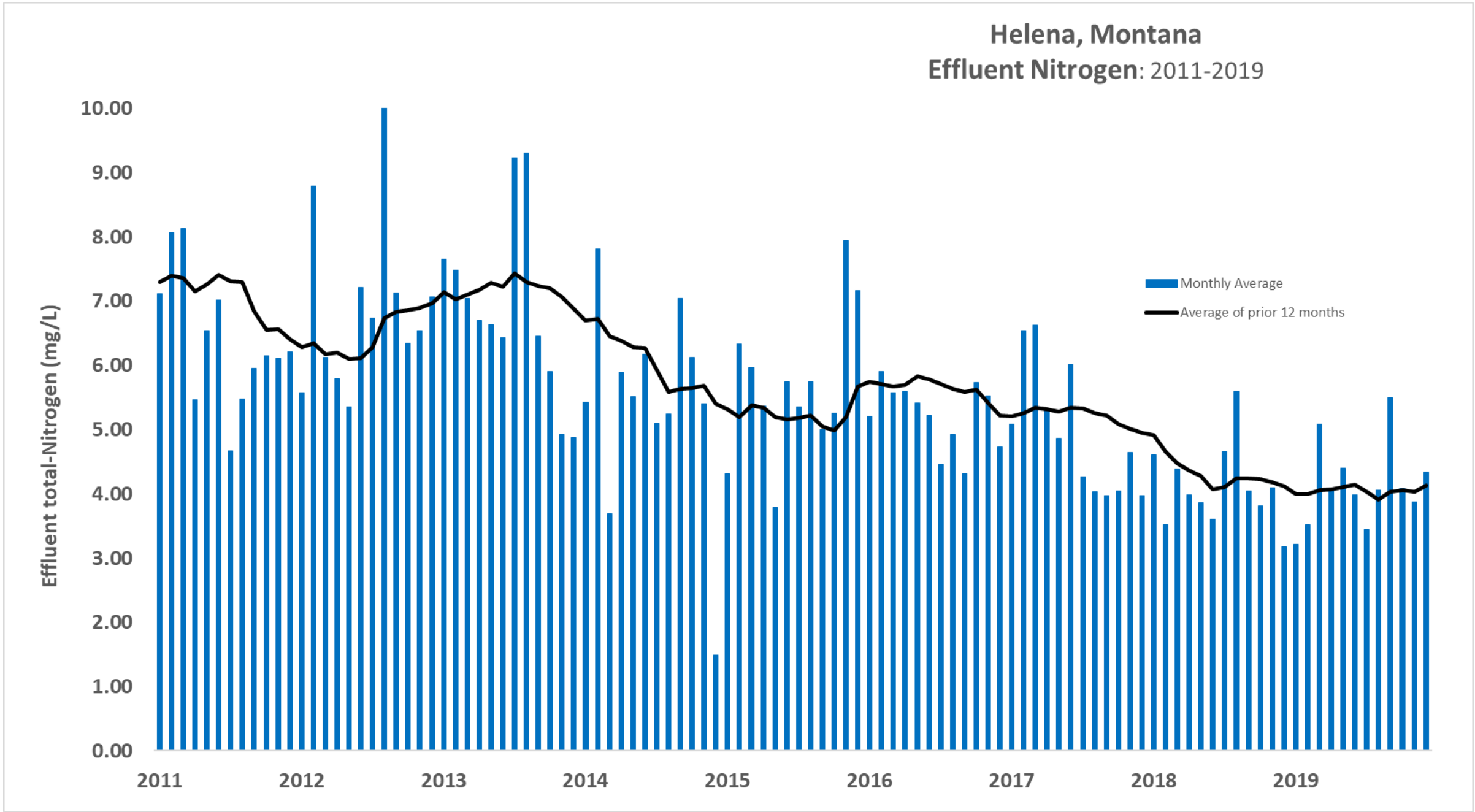
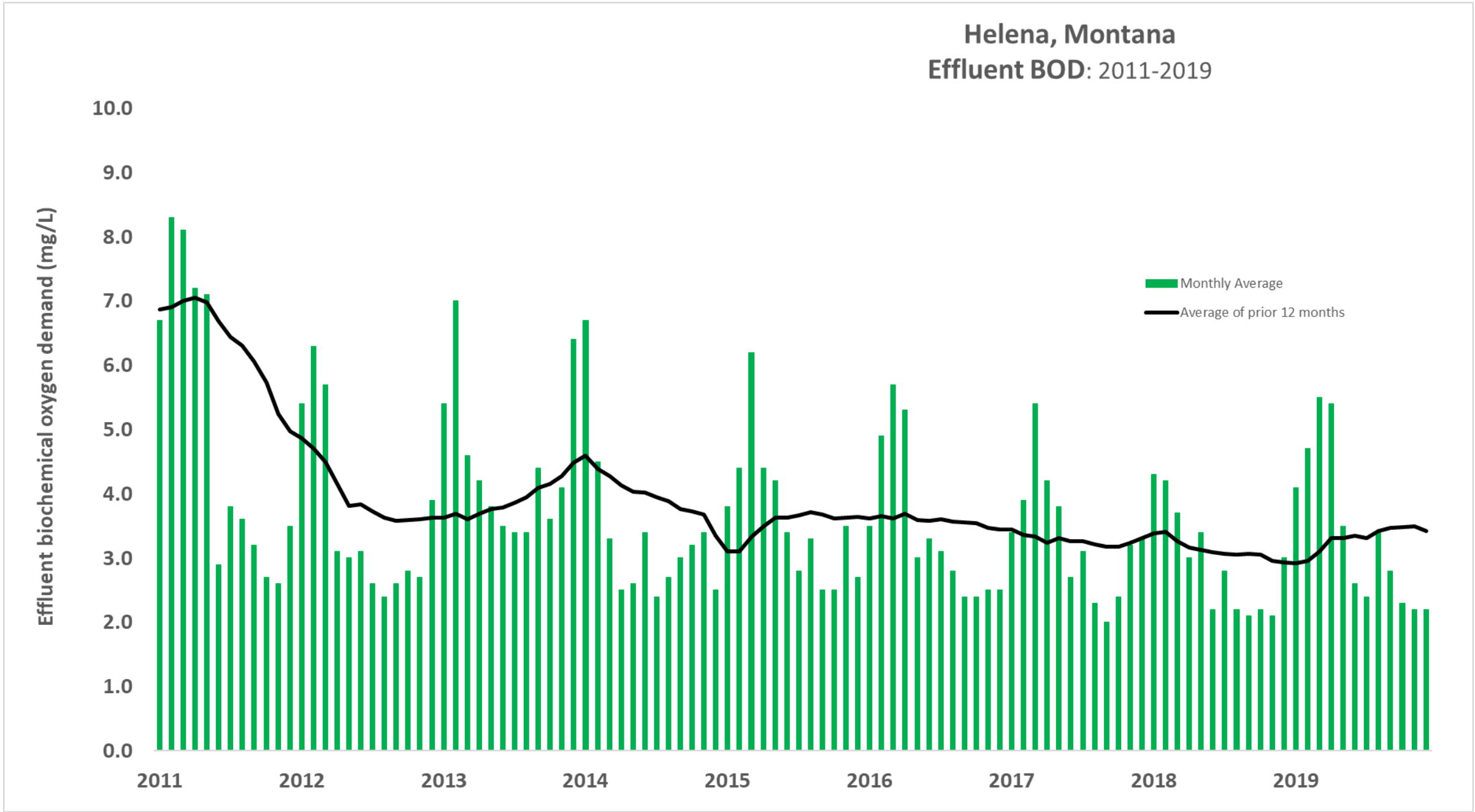
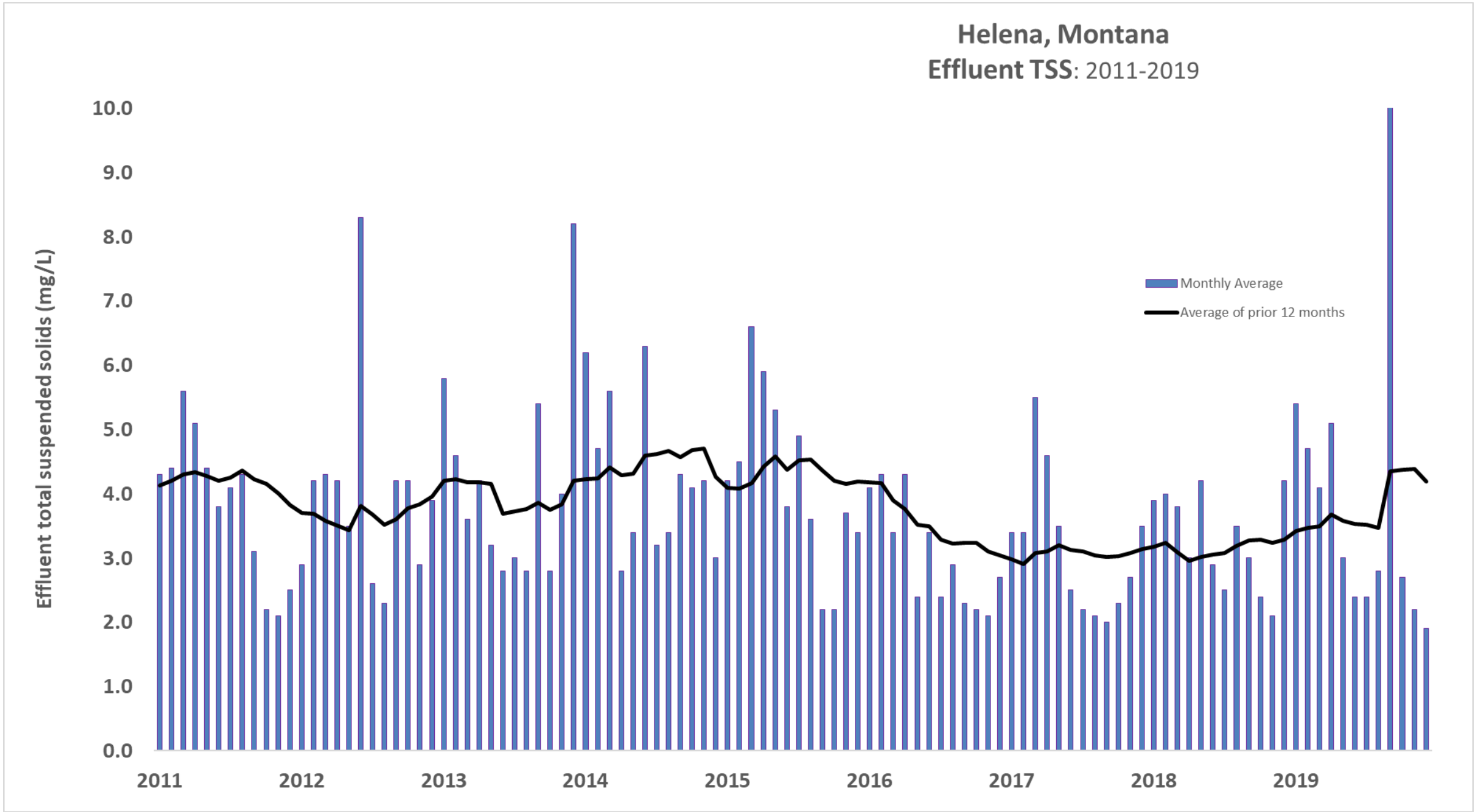


Helena, Montana Population: 31,500 5.4 MGD design flow


Helena, Montana
Effluent Nitrogen: 2011-2019
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
Monthly Average
Average of prior 12 months


Helena, Montana
Effluent BOD: 2011-2019
Effluent biochemical oxygen demand (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2011
2012
2013
2014
2015
2016
2017
2018
2019
Monthly Average
Average of prior 12 months


Helena, Montana
Effluent TSS: 2011-2019
Effluent total suspended solids (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2011
2012
2013
2014
2015
2016
2017
2018
2019
Monthly Average
Average of prior 12 months


Helena Waste Water
Treatment Plant
Lewis & Clark
Humane Society
Google
Imagery ©2019 Google, Map data ©2019 Google


TENNESSEE

PROCESS CONTROL