What Operators Should Know About Phosphorus Removal, Part 1

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

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G.Weaver@CleanWaterOps.com

Energy & Nutrient Optimization
of NC Municipal Wastewater Treatment Plants

Biological Nitrogen Removal, Parts 1&2

Activated Sludge, Parts 1&2

Today: Biological Phosphorus Removal: Part 1

Mar 18: Biological Phosphorus Review, Part 2

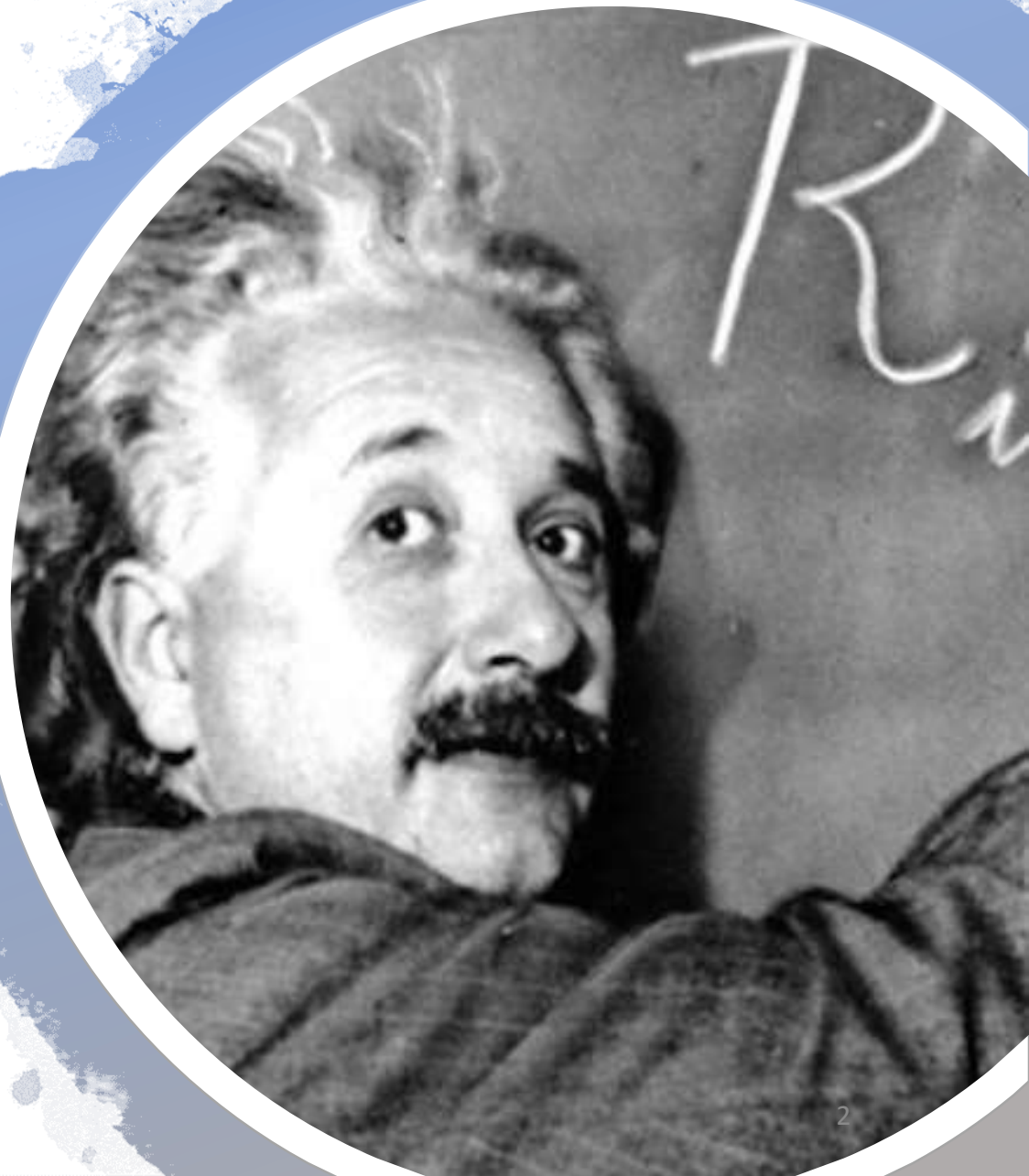
Mar 25: North Carolina Case Studies, Part 1 (your plants!)

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!)



Why North Carolina operators should care about Phosphorus Removal

From North Carolina's 2019 ***Nutrient Criteria Development Plan***

Development and adoption of nutrient criteria for the following by **2025**:

- **High Rock Lake / Yadkin River Basin**
- **Albemarle Sound / Chowan River Basin**
- **Central portion of the Cape Fear River**

Adoption of nutrient criteria **statewide by 2029**

Introducing a new way of thinking:

Facility upgrades aren't the only way to get phosphorus removal…

Empowered operators achieve amazing results!

Change day-to-day operations to
create ideal habitats for bacteria to remove phosphorus

Connecticut
Colchester-East Hampton
East Haddam
Groton
New Canaan
New Hartford
Plainfield North
Plainfield Village
Suffield
Windham

Iowa
Eldora

Kansas
Andover
Basehor
Chanute
Chisholm Creek
Derby
Eudora
Garden Plain
Goddard
Great Bend
Halstead
Hiawatha
Holton

Kansas, cont'd
Kingman
Lansing
Lyons
Medicine Lodge
Miami CO - Bucyrus
Miami CO - Walnut Creek
Osawatomie
Pratt
Riley CO - University Park
Rose Hill
Shawnee CO - Sherwood
St. Marys
Spring Hill
Topeka North
Wellington
Wellsville
Wichita Plants 1&2
Winfield

Kentucky
Hopkinsville

Massachusetts
Amherst
Barnstable
Easthampton

Massachusetts, cont'd
Greenfield
Montague
Newburyport
Northfield
Palmer
South Deerfield
South Hadley
Sunderland
Upton
Westfield

Montana
Bigfork
Big Sky
Billings
Boulder
Bozeman
Butte
Chinook
Choteau
Colstrip
Columbia Falls
Conrad
Dillon
East Helena
Forsyth

Montana, cont'd
Gallatin Gateway
Glendive
Great Falls
Hamilton
Hardin
Havre
Helena
Kalispell
Laurel
Lewistown
Libby
Lolo
Manhattan
Miles City
Missoula
Stevensville
Wolf Creek

New Hampshire
Keene

South Carolina
Greeneville

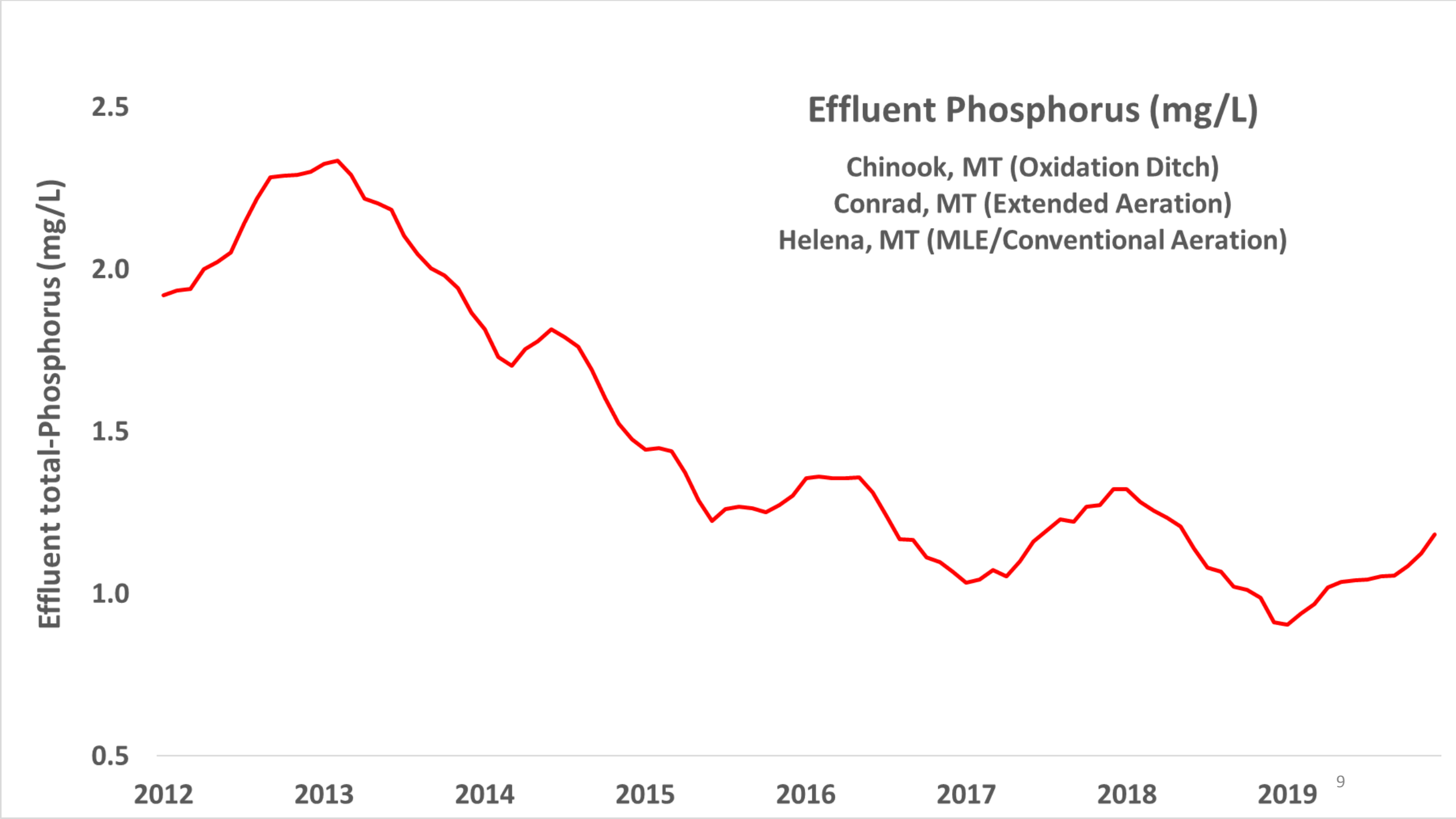
Tennessee
Athens
Baileyton
Bartlett
Chattanooga
Collierville
Cookeville
Cowan
Crossville
Harriman
Humboldt
Lafayette
LaFollette
Livingston
Millington
Nashville Dry Creek
Norris
Oak Ridge

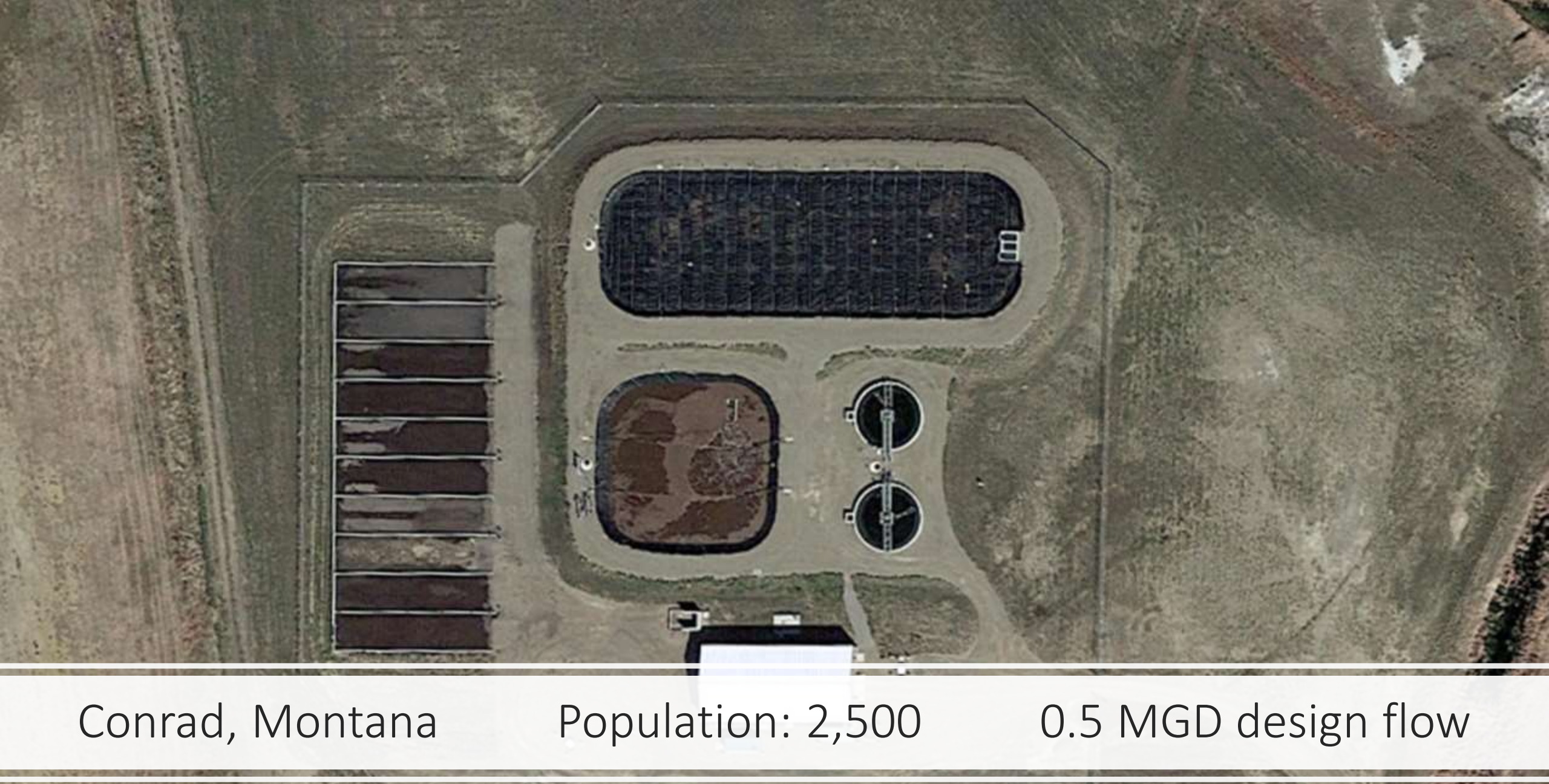
Texas
Nottingham MUD (Houston)

Virginia
Strasburg

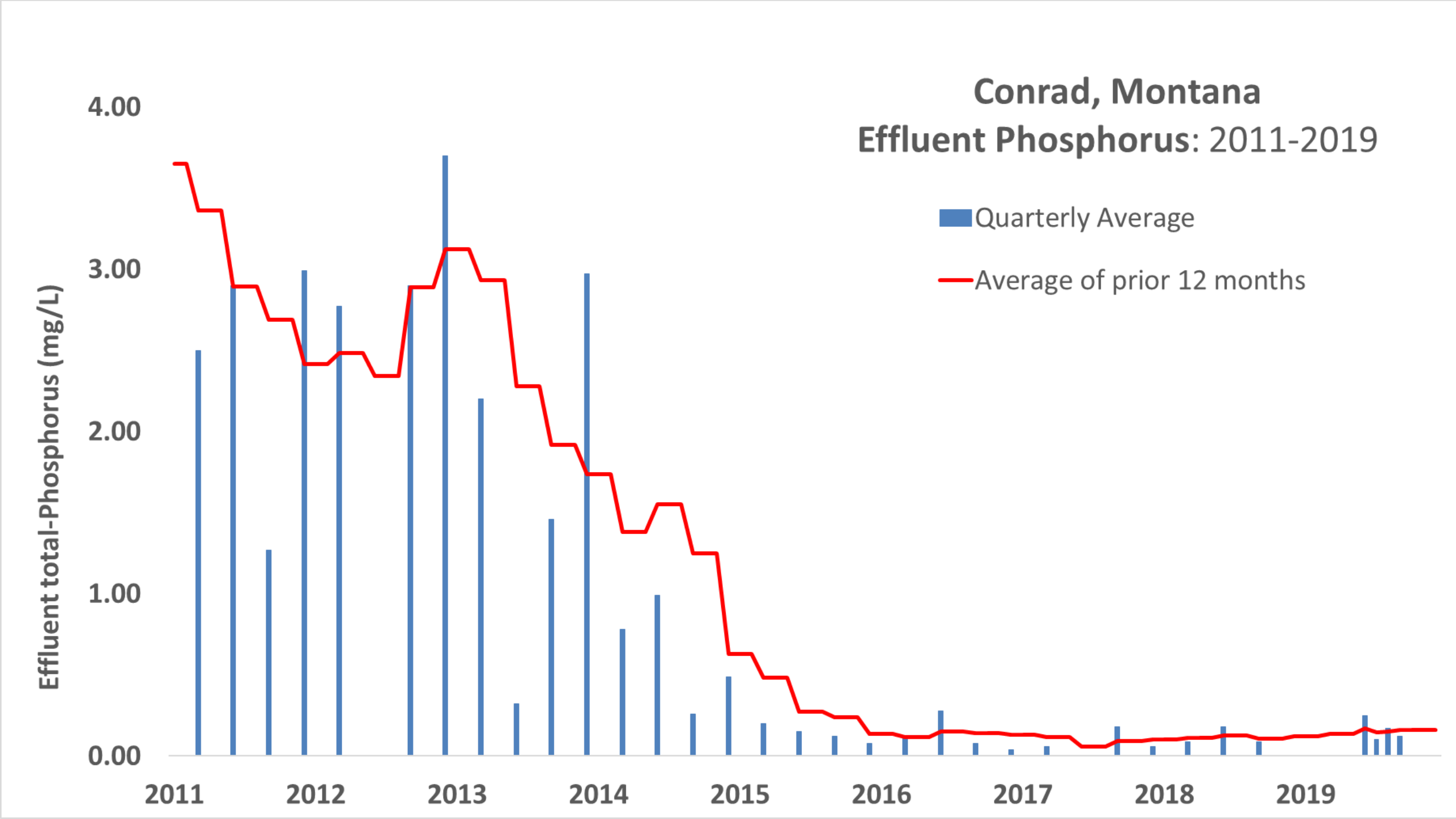
Wyoming
Laramie


MONTANA

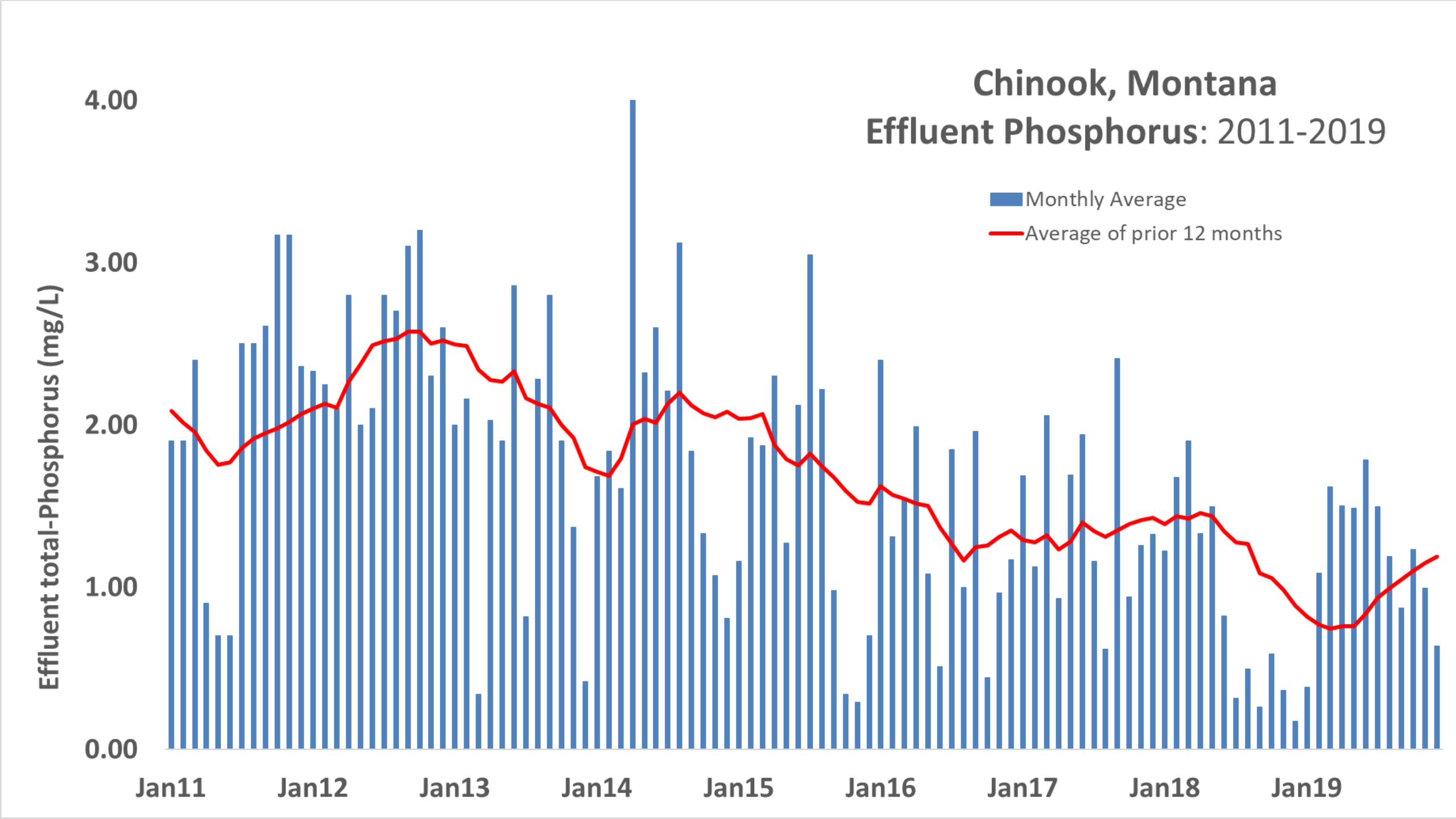

Effluent Phosphorus (mg/L)
Chinook, MT (Oxidation Ditch)
Conrad, MT (Extended Aeration)
Helena, MT (MLE/Conventional Aeration)
Effluent total-Phosphorus (mg/L)
2.5
2.0
1.5
1.0
0.5
2012
2013
2014
2015
2016
2017
2018
2019



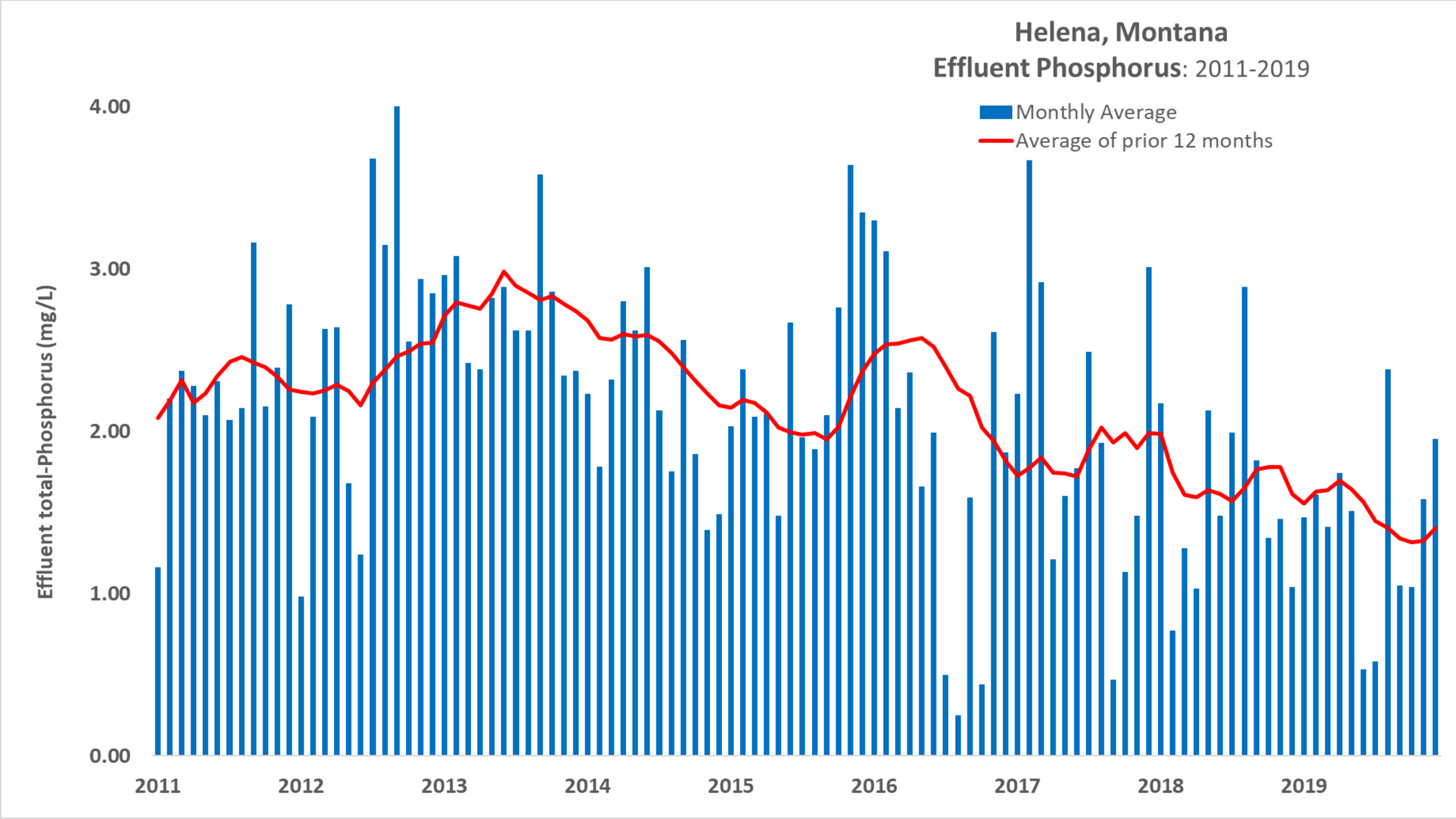
Conrad, Montana Population: 2,500 0.5 MGD design flow


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

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


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

Helena, Montana Population: 30,000 5.4 MGD design flow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Effluent Phosphorus: 2011-2019
Monthly Average
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Effluent total-Phosphorus (mg/L)
4.00
3.00
2.00
1.00
0.00
2011
2012
2013
2014
2015
2016
2017
2018
2019

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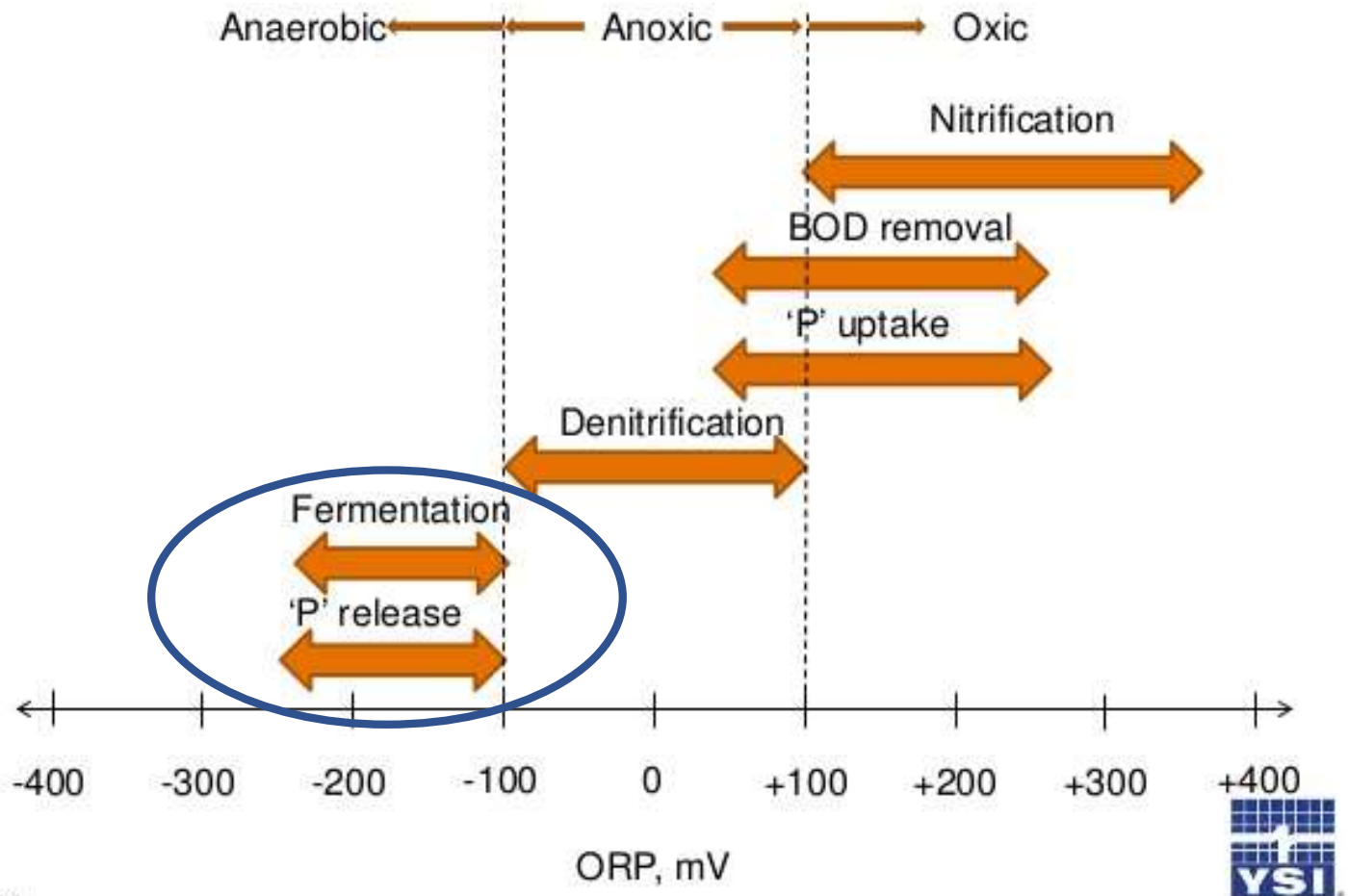
Science

Wastewater Science

DO (Dissolved Oxygen)

ORP (Oxidation Reduction Potential)

What Does ORP Tell Us About Our Process?



YSI
a xylem brand

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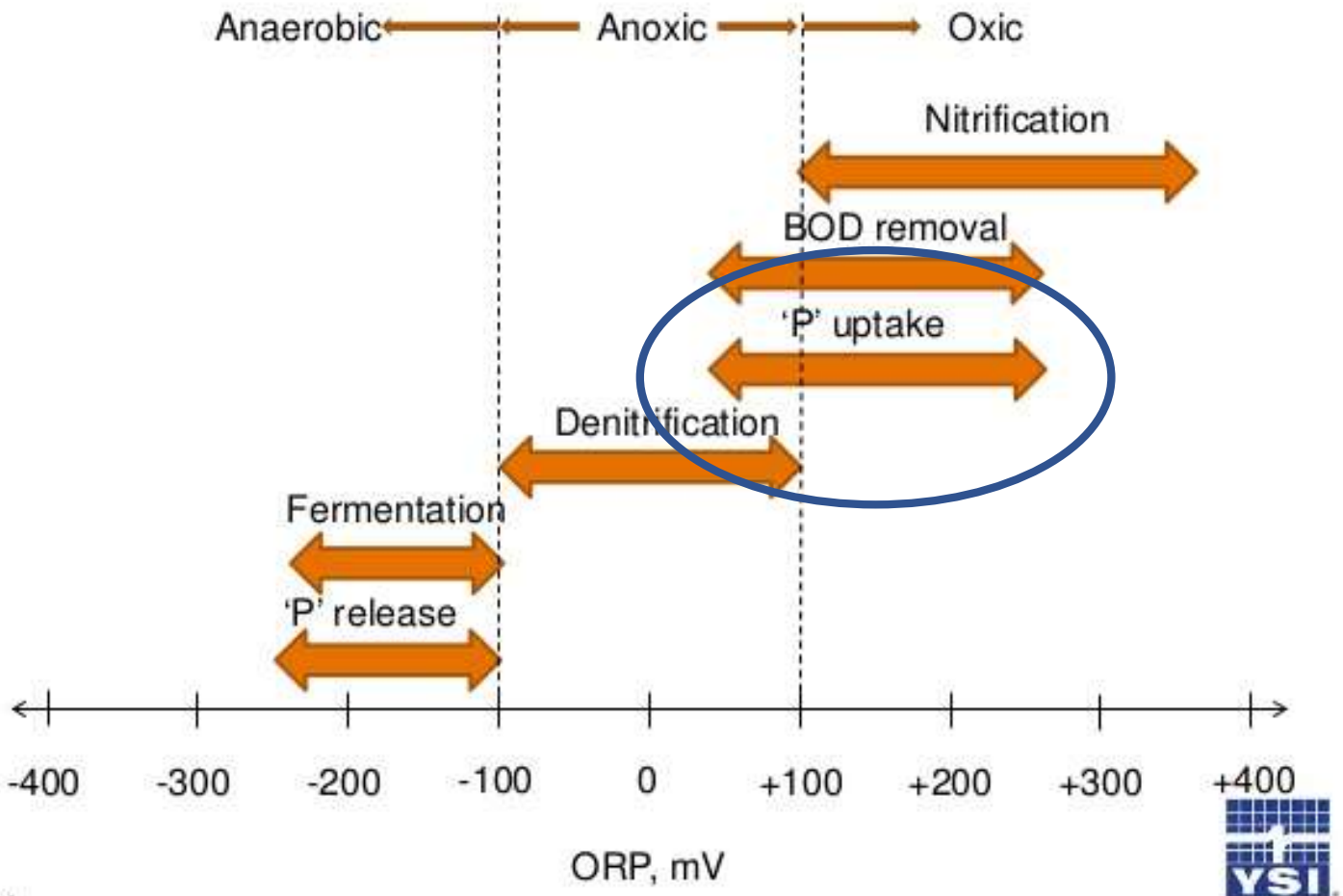

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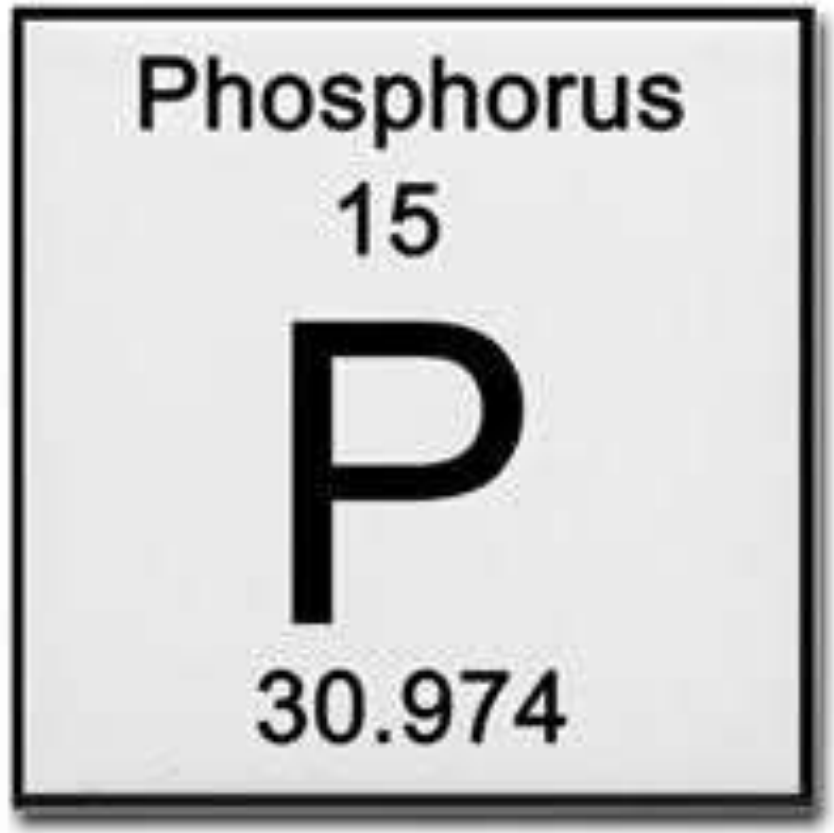

Phosphorus
15
P
30.974

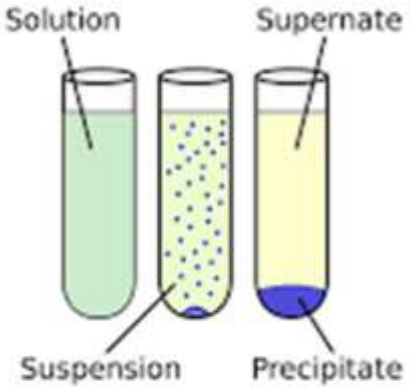
Phosphorus Removal:
What an Operator needs to know

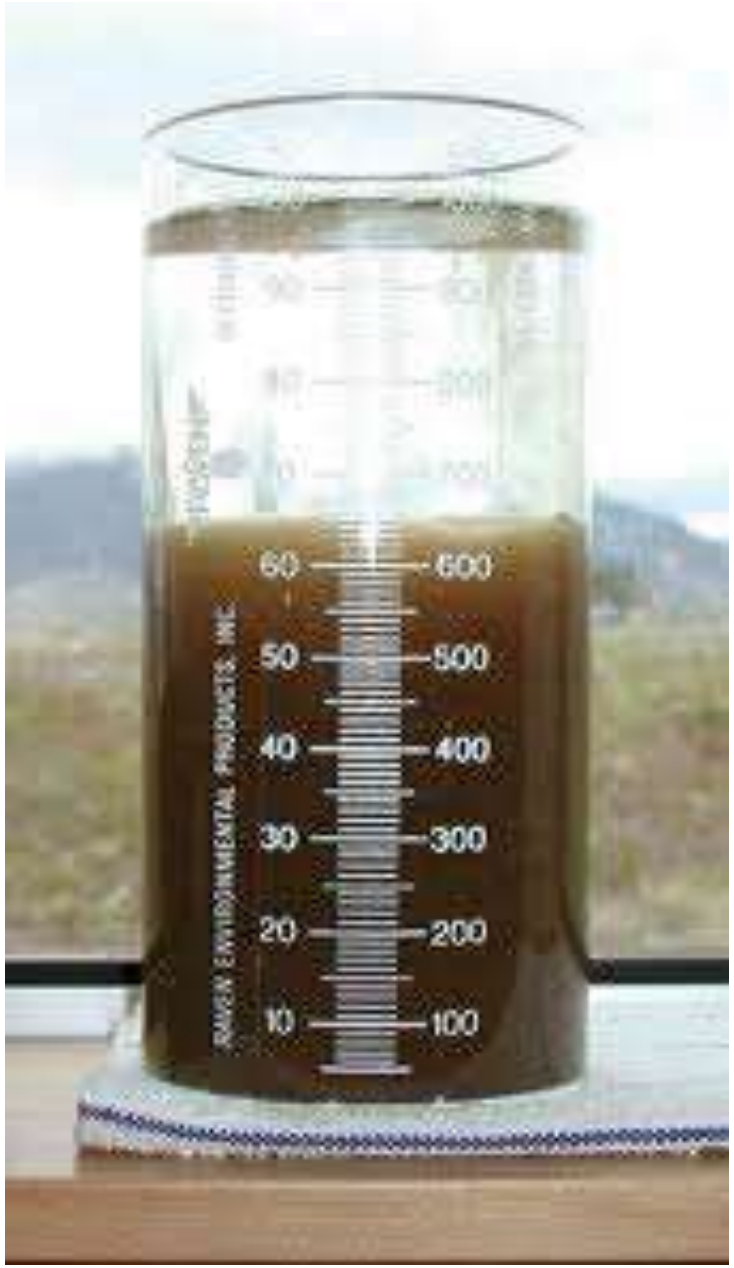
ONE. Convert soluble phosphorus to TSS (total suspended solids)…

Biologically

Chemically

TWO. Remove TSS





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

Phosphorus Removal:
What an Operator needs to know

orthophosphate = soluble phosphorus

orthophosphate, reactive phosphorus, phosphate, ortho-P, PO_4, PO_4-P, $PO_4^{=}$, $PO_4^{=}$-P, PO_4^{-2}, PO_4^{-2}-P

total-Phosphorus = soluble + particulate phosphorus (non-reactive)

phosphorus, total-P, TP, t-P, tP, P

Typical plant, an example

Influent phosphorus: 6 mg/L

Effluent phosphorus: 3 mg/L

Effluent TSS: 15 mg/L

Effluent total-P = particulate P + soluble P

How much effluent phosphorus is soluble and how much is in the TSS?

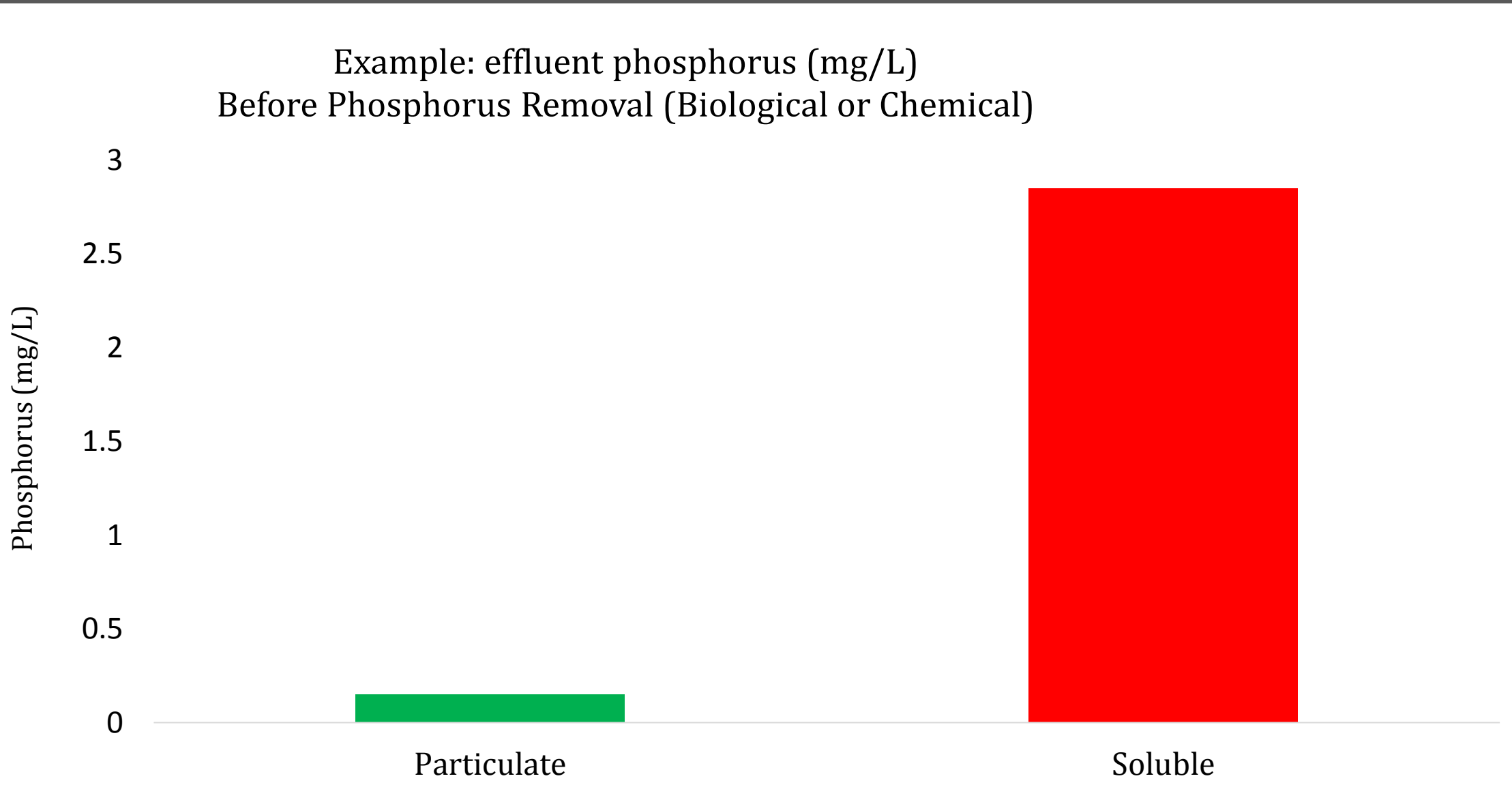
Approximately 1% of effluent TSS (conventional plant) is phosphorus …

Effluent P = particulate P + soluble P

Particulate (P in the TSS): 15 mg/L TSS x 0.01 = **0.15** mg/L

Soluble = 3 mg/L – 0.15 mg/L with TSS = **2.85** mg/L

Total = **0.15** mg/L (Particulate) + **2.85** mg/L (Soluble) = **3.0** mg/L


Example: effluent phosphorus (mg/L)
Before Phosphorus Removal (Biological or Chemical)
Phosphorus (mg/L)
3
2.5
2
1.5
1
0.5
0
Particulate
Soluble

Same example … after SOLUBLE phosphorus is converted to PARTICULATE phosphorus

Influent phosphorus: 6 mg/L

Effluent TSS: 15 mg/L

Effluent total-P = particulate P + soluble P

Biological Phosphorus removal, when fully optimized, will remove all but 0.05 mg/L of the soluble Phosphorus

Chemical Phosphorus removal, the same, all but 0.05 mg/L

Either way, only **0.05 mg/L** of soluble Phosphorus remains

Meanwhile, what used to be soluble Phosphorus is now part of the MLSS (mixed liquor suspended solids) …

And, as the bio-P bugs take in phosphorus, the percentage of the MLSS and TSS that is Phosphorus increases from 1% to as high as 5%

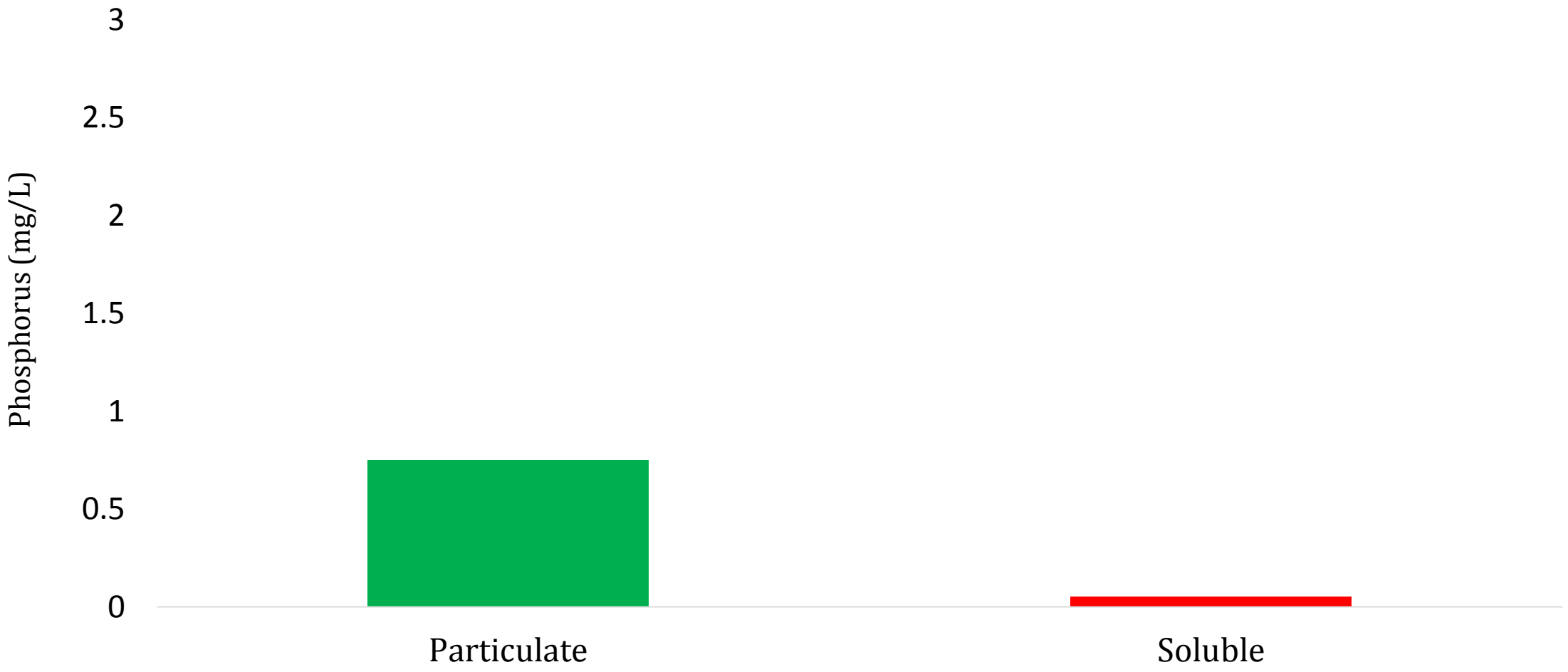
Effluent P = soluble P + particulate

Soluble = **0.05** mg/L

Particulate (P in the TSS): 15 mg/L TSS x **5%** = **0.75** mg/L

Total = **0.05** mg/L (Soluble-P) + **0.75** mg/L (Particulate-P) = **0.80** mg/L

Example: effluent phosphorus (mg/L)
After Phosphorus Removal (Biological or Chemical)



TSS Removal Requirements

Since all but 0.05 mg/L of the soluble Phosphorus can be converted to TSS Phosphorus (Biologically and/or Chemically)

And, because approximately 5% of Effluent TSS is Phosphorus

… To meet a total-P limit, the effluent TSS needs to be kept to the max TSS number shown in the table.

P Limit	max TSS
0.1	1
0.2	3
0.3	5
0.4	7
0.5	**9**
0.6	11
0.7	13
0.8	15
0.9	17
1.0	**19**
1.1	21
1.2	23
1.3	25
1.4	27
1.5	29

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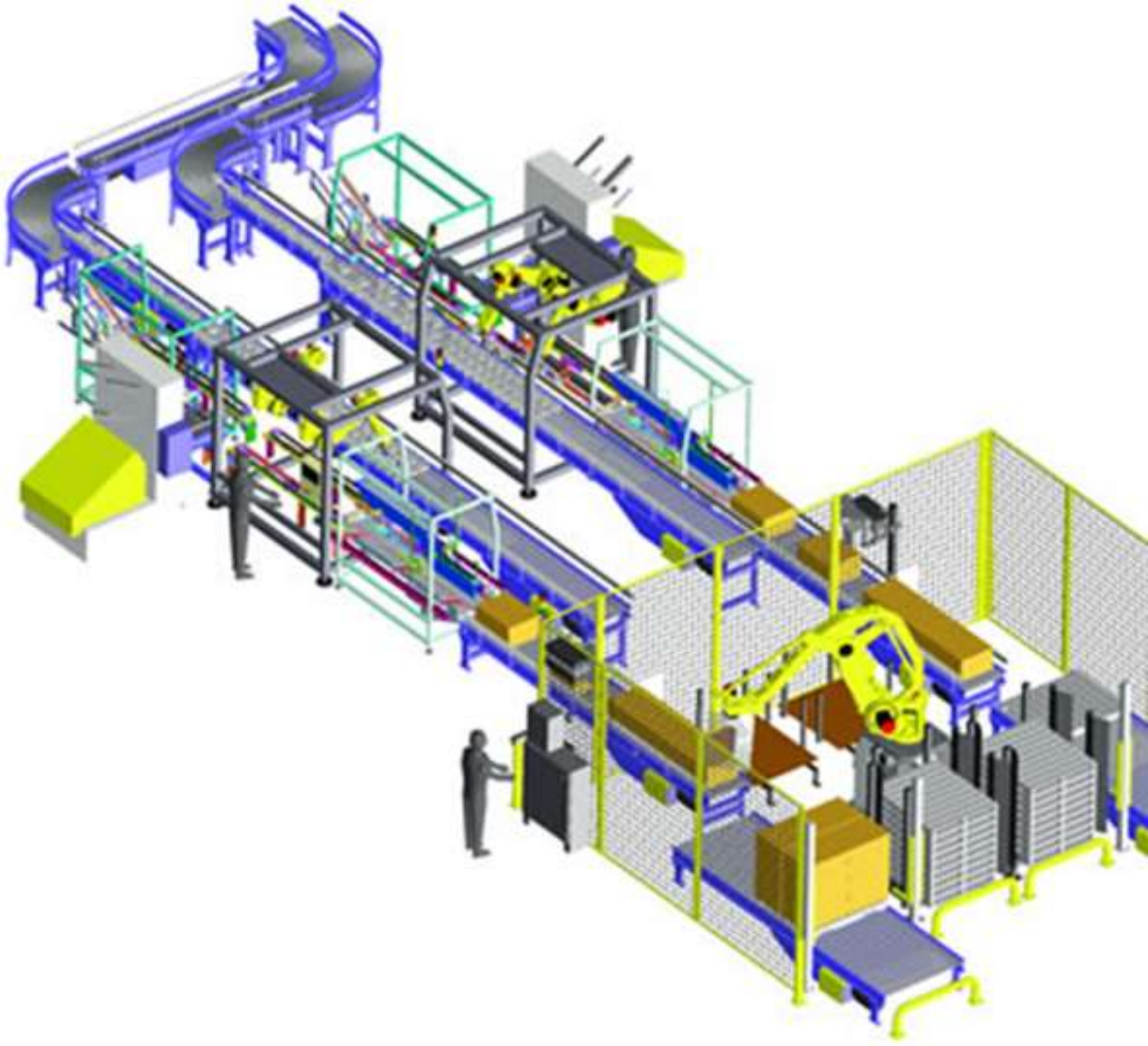
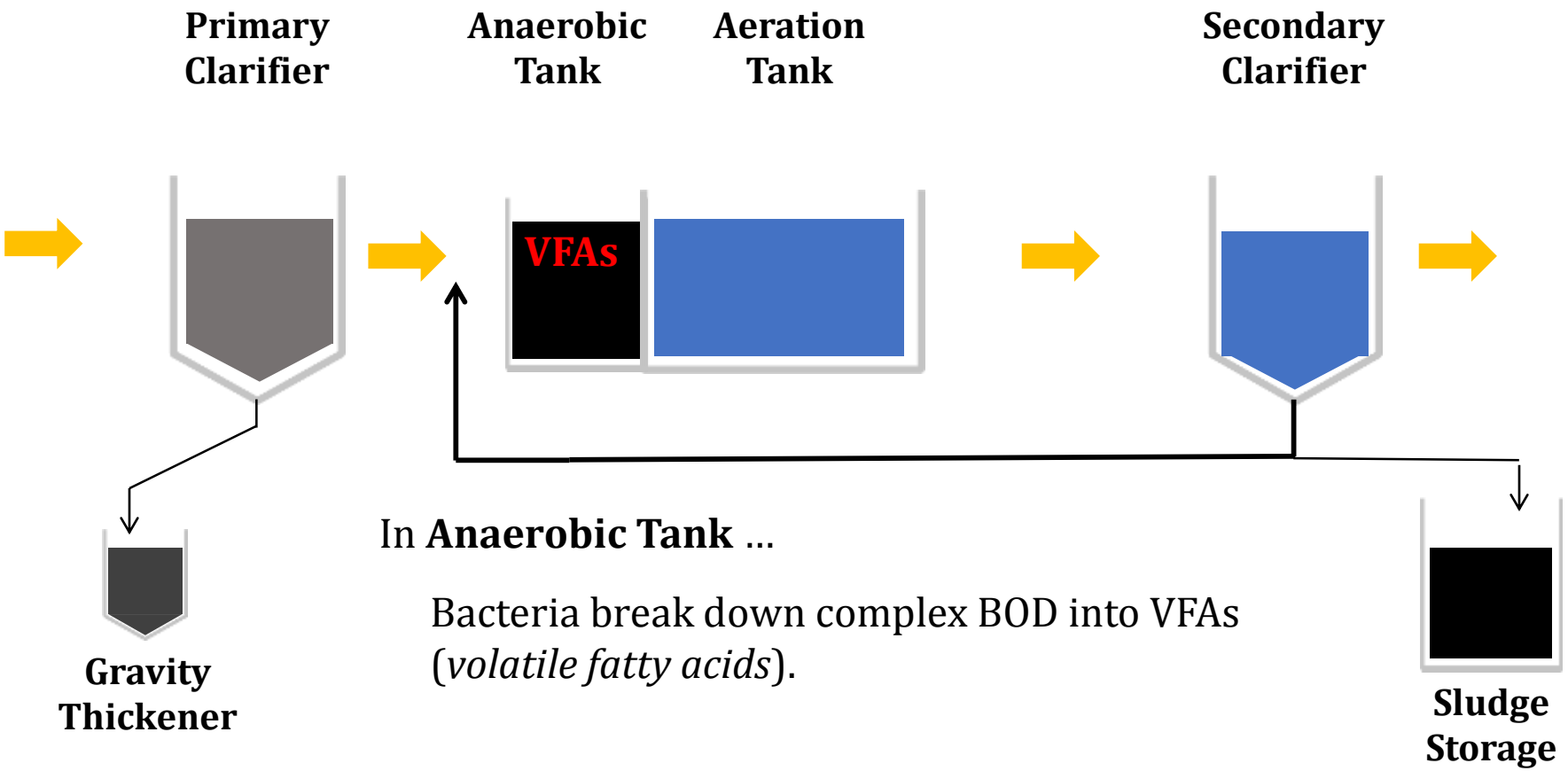
BREAK TIME

Technology!



Biological Phosphorus Removal: Mainstream Flow Fermentation Processes

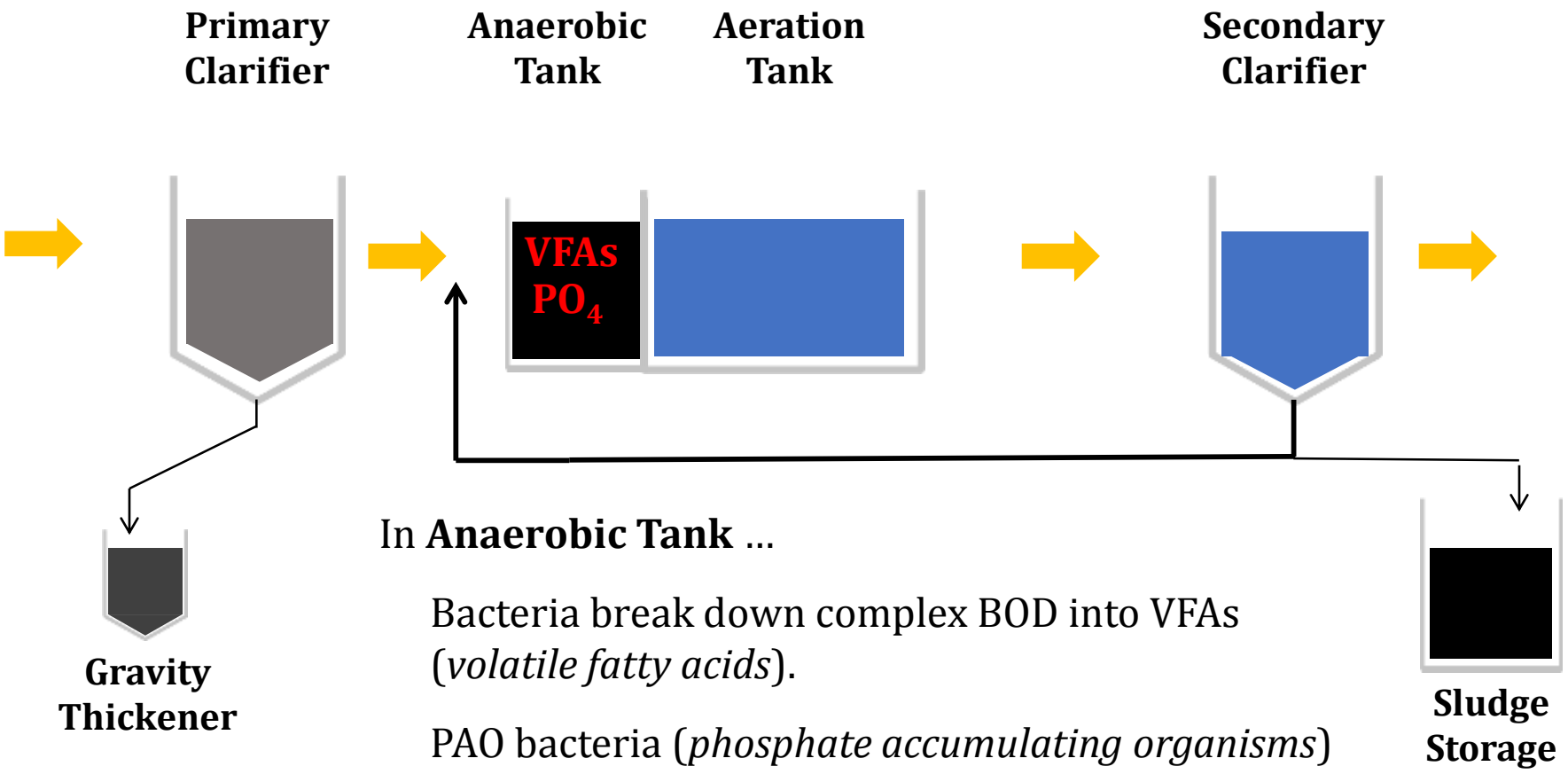
Bio-P Removal: Mainstream Fermentation Process



In **Anaerobic Tank** …

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

Bio-P Removal: Mainstream Fermentation Process



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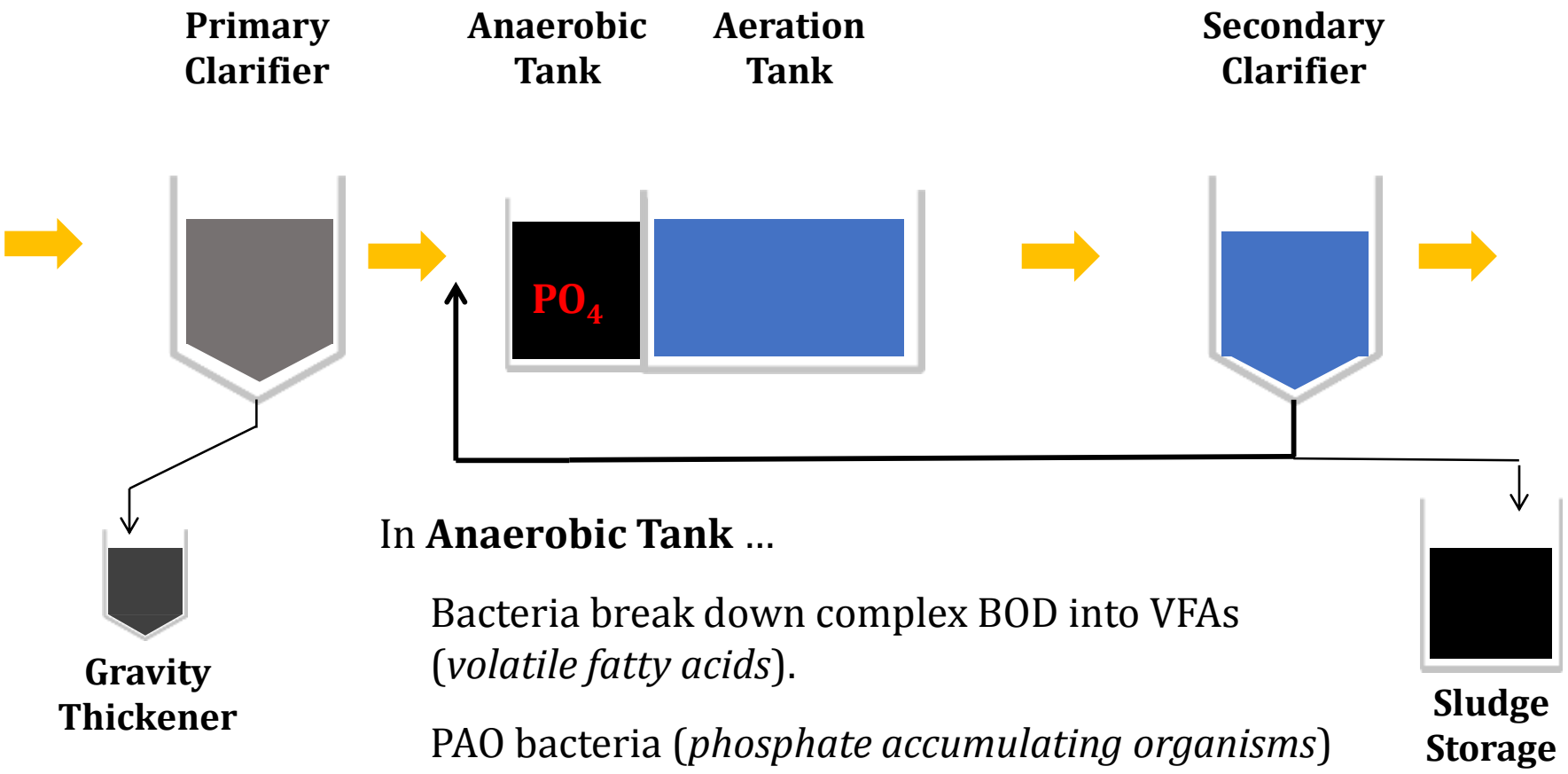
PAO bacteria (*phosphate accumulating organisms*) take in VFAs as energy source & temporarily release PO_4 (*phosphate*) into solution.

Bio-P Removal: Mainstream Fermentation Process



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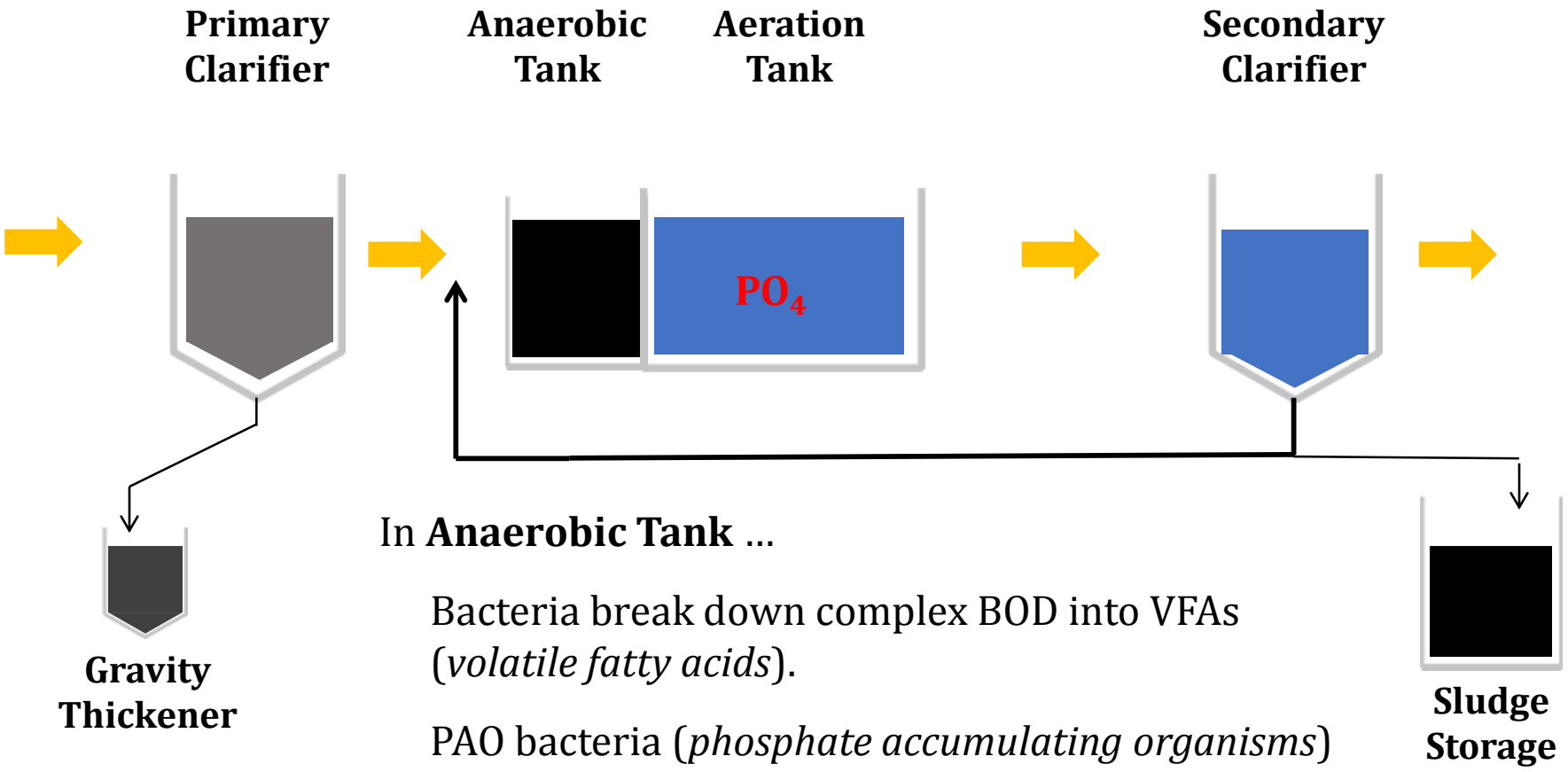
In **Aeration Tank** …

Energized PAO bacteria take PO_4 out of solution.

Bio-P Removal: Mainstream Fermentation Process



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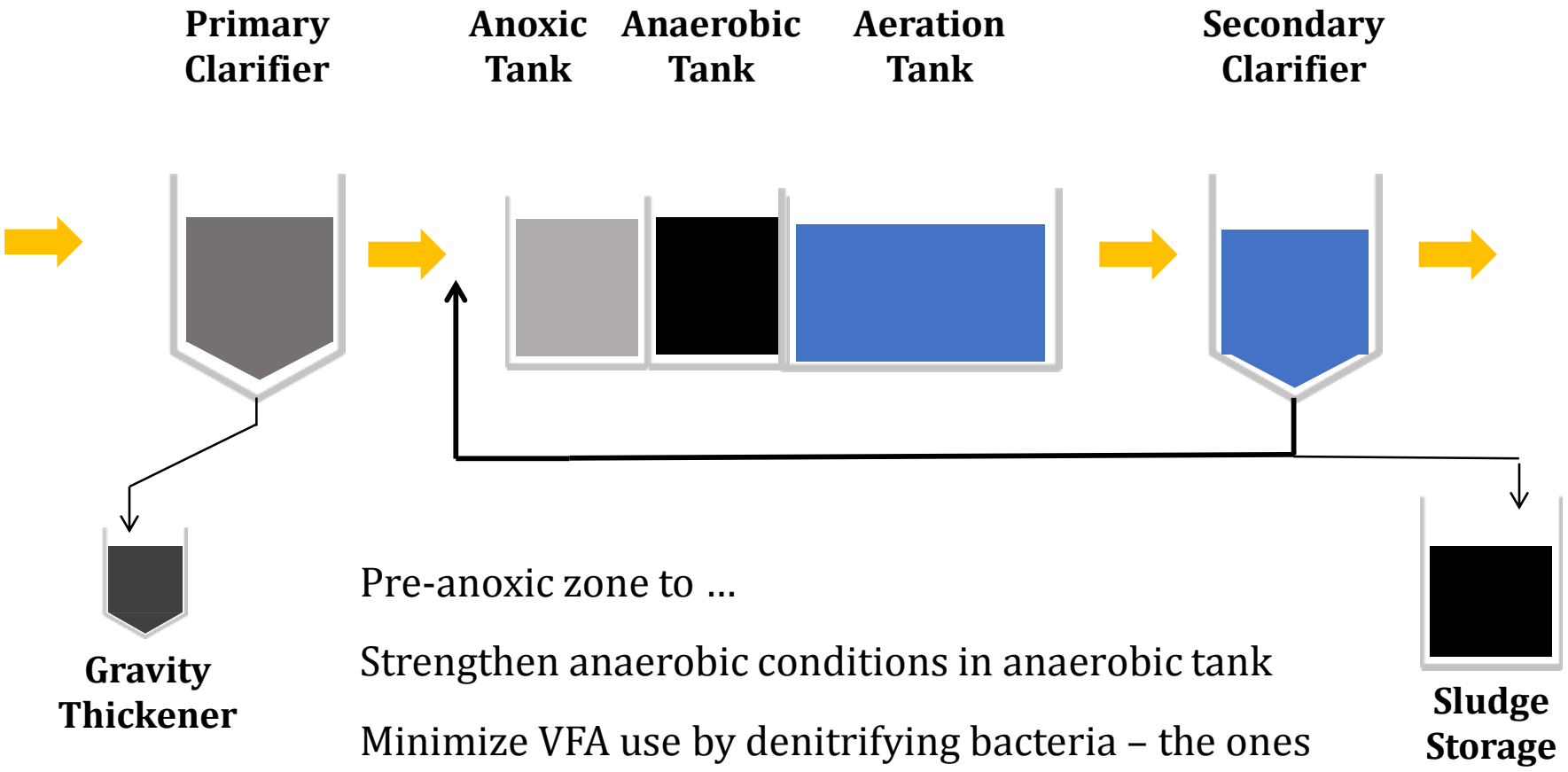
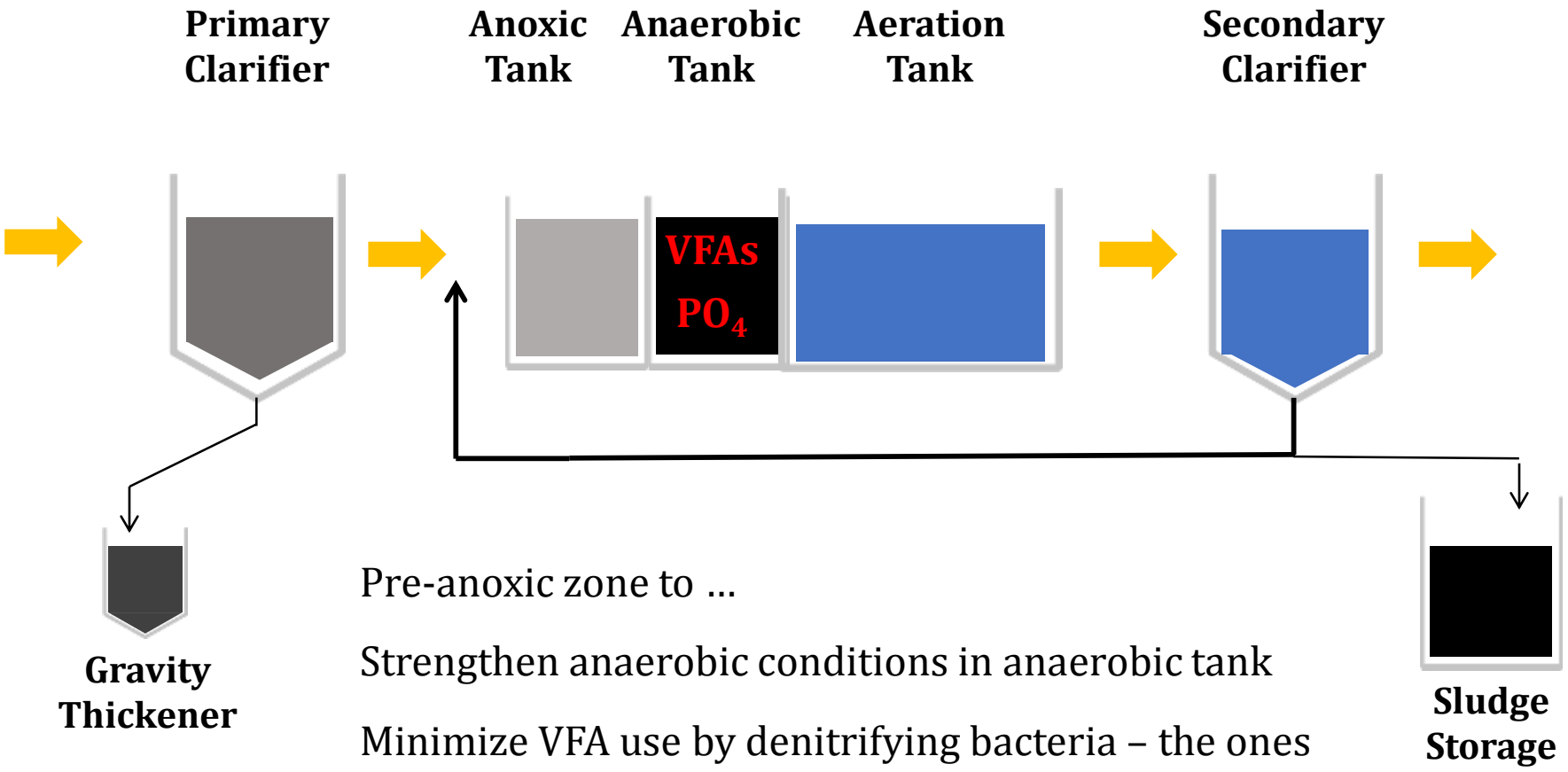


Pre-anoxic zone to …

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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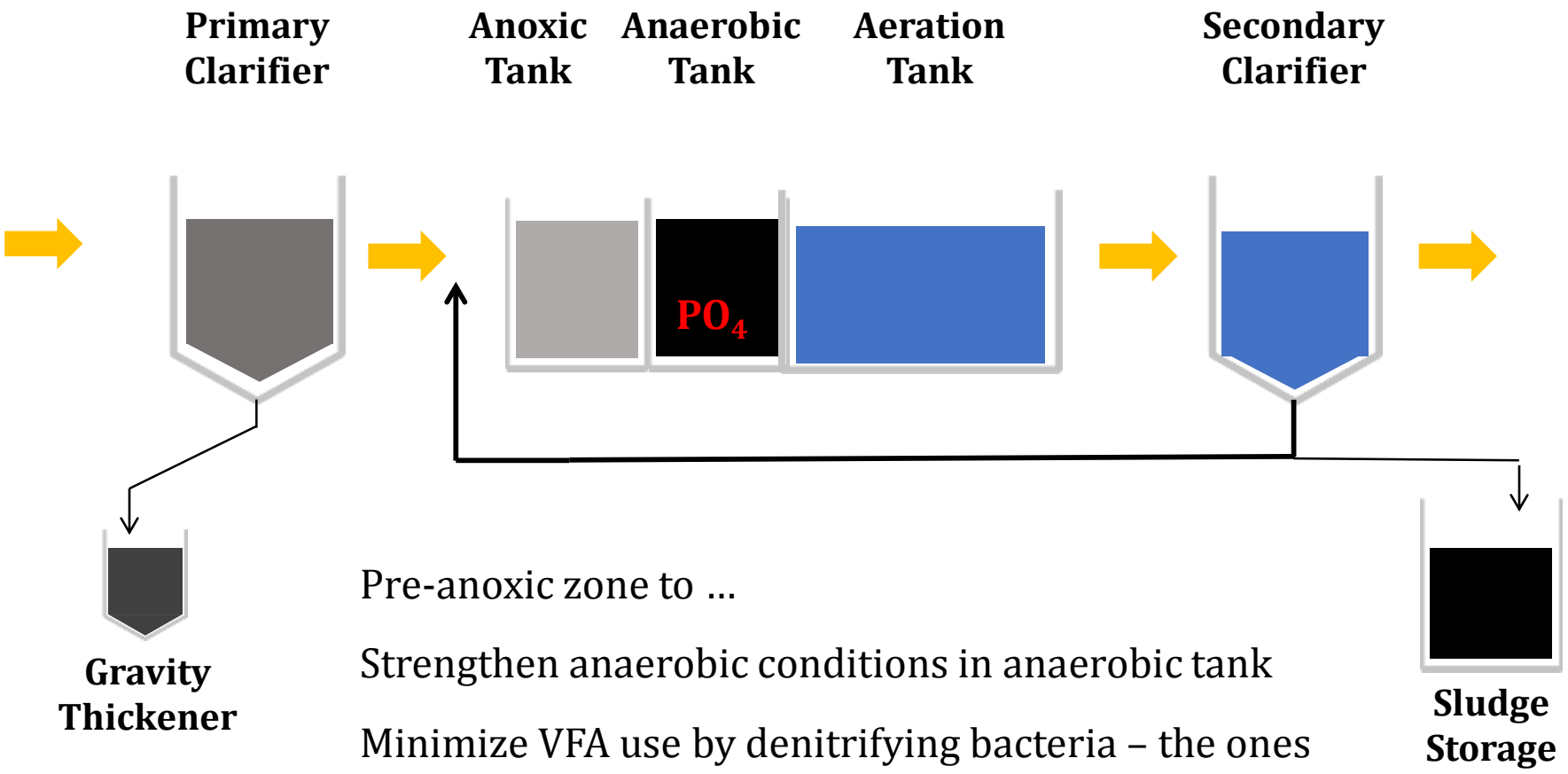

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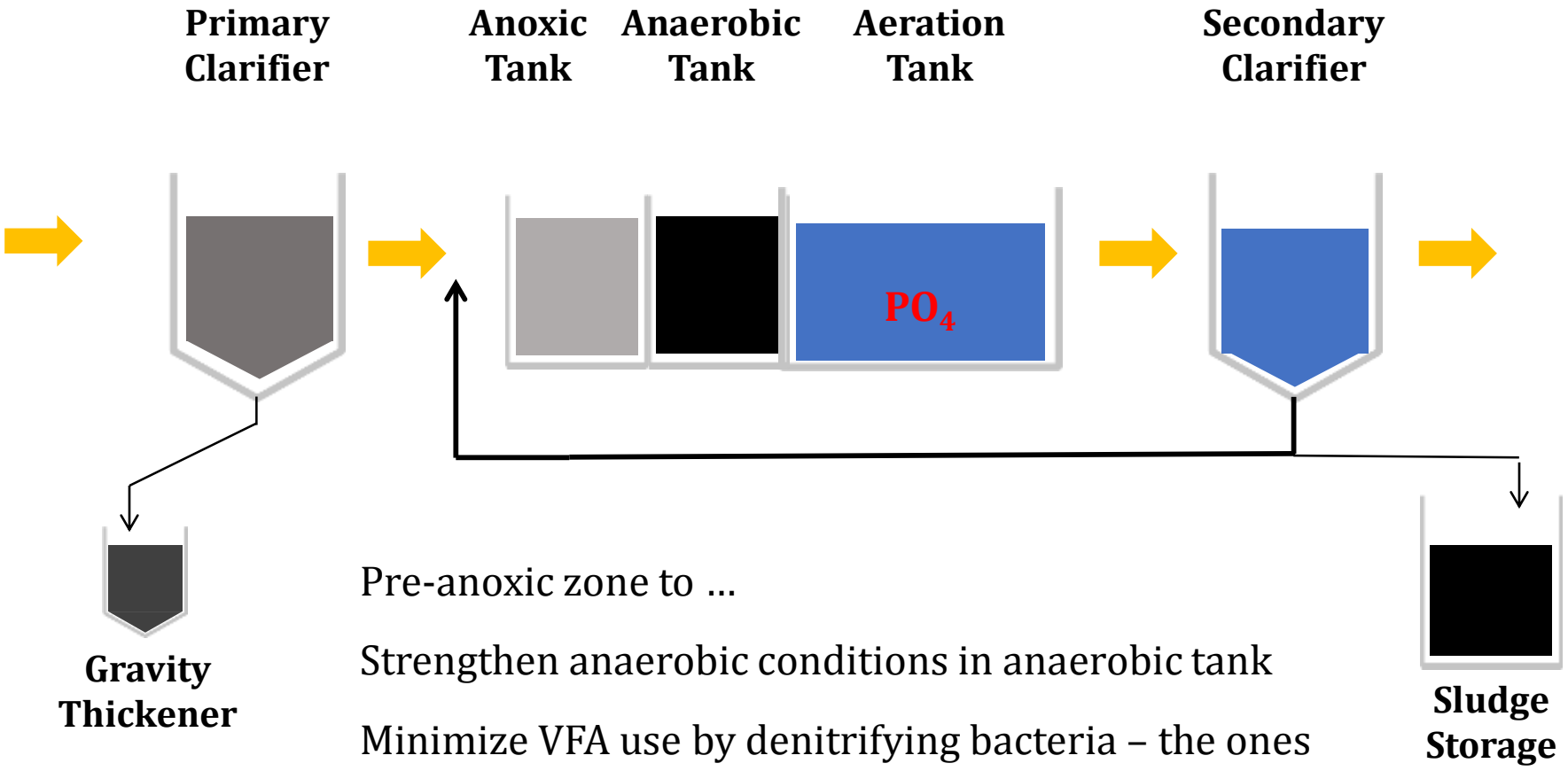

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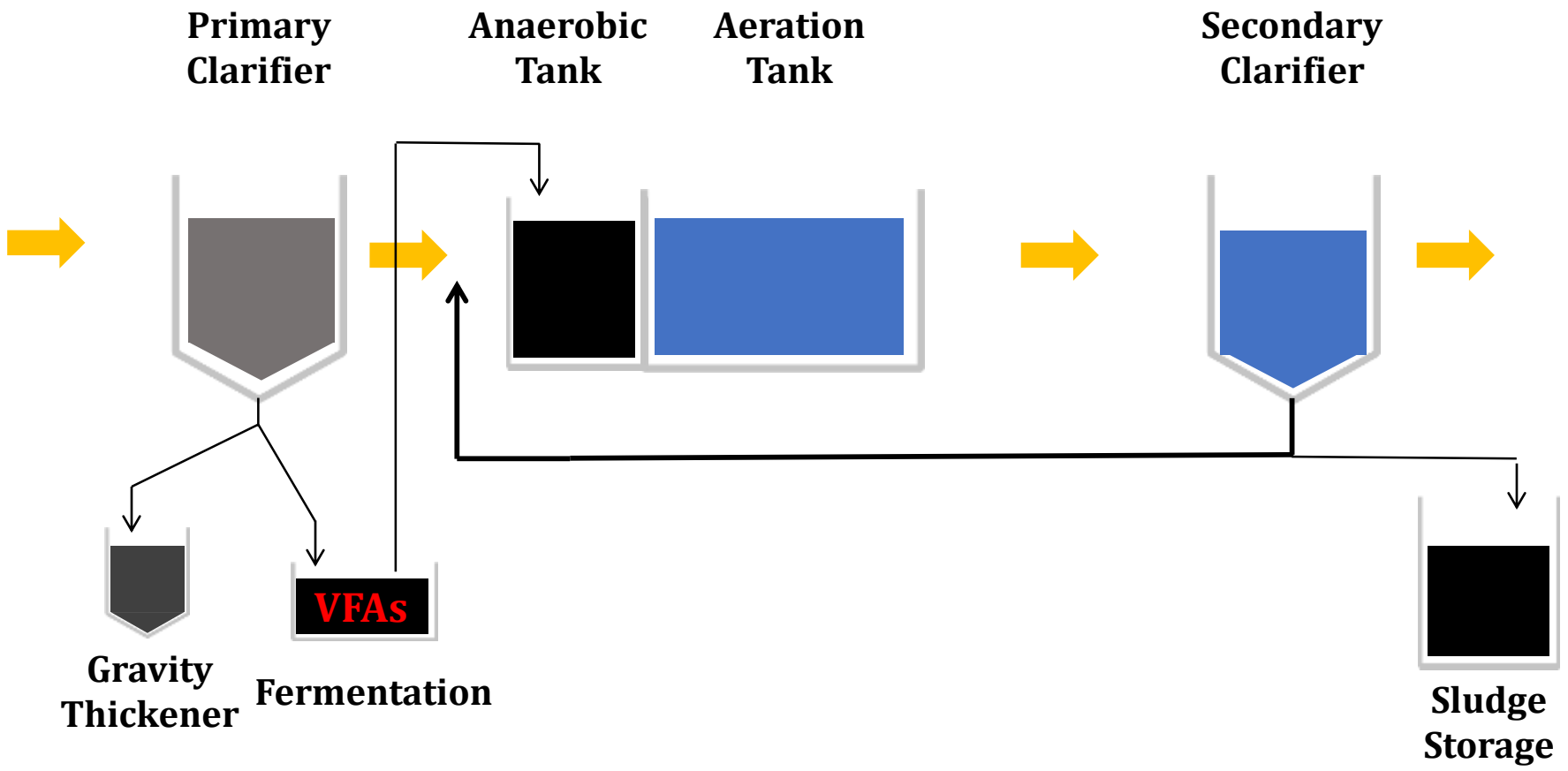
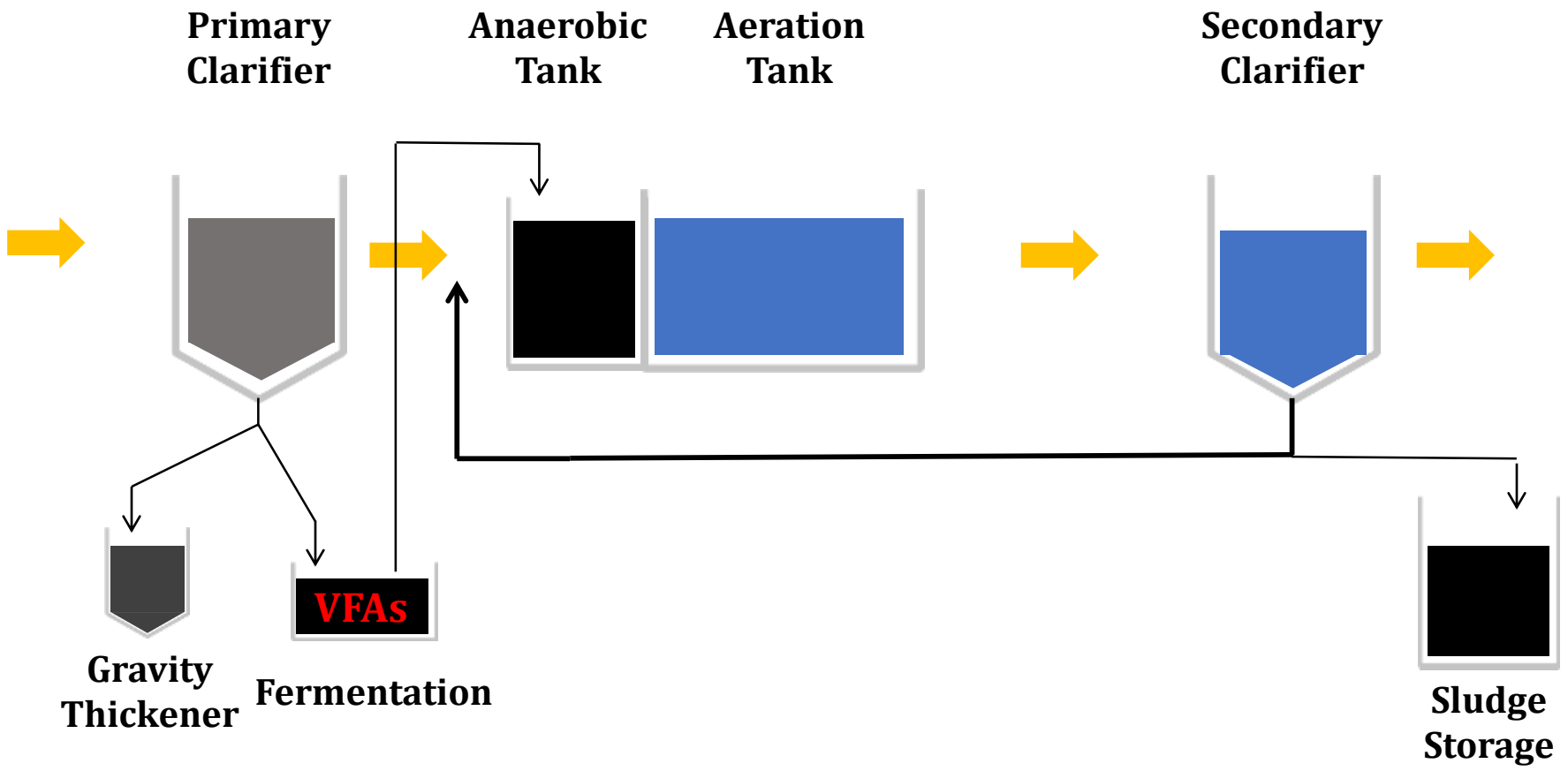
Biological Phosphorus Removal: Combined Sidestream & Mainstream Fermentation

Bio-P Removal: Sidestream Fermentation Process



Bio-P Removal: Sidestream Fermentation Process



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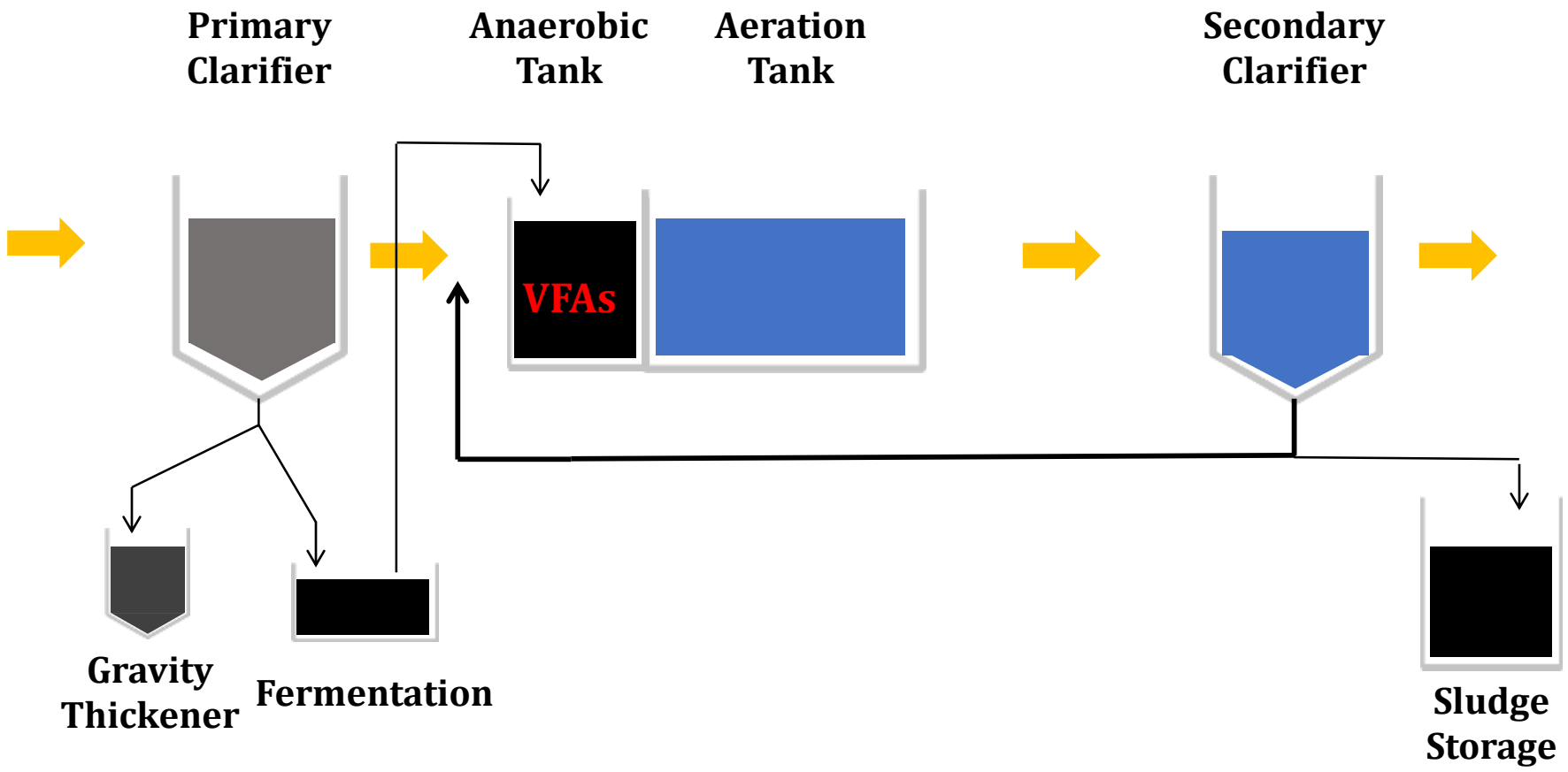
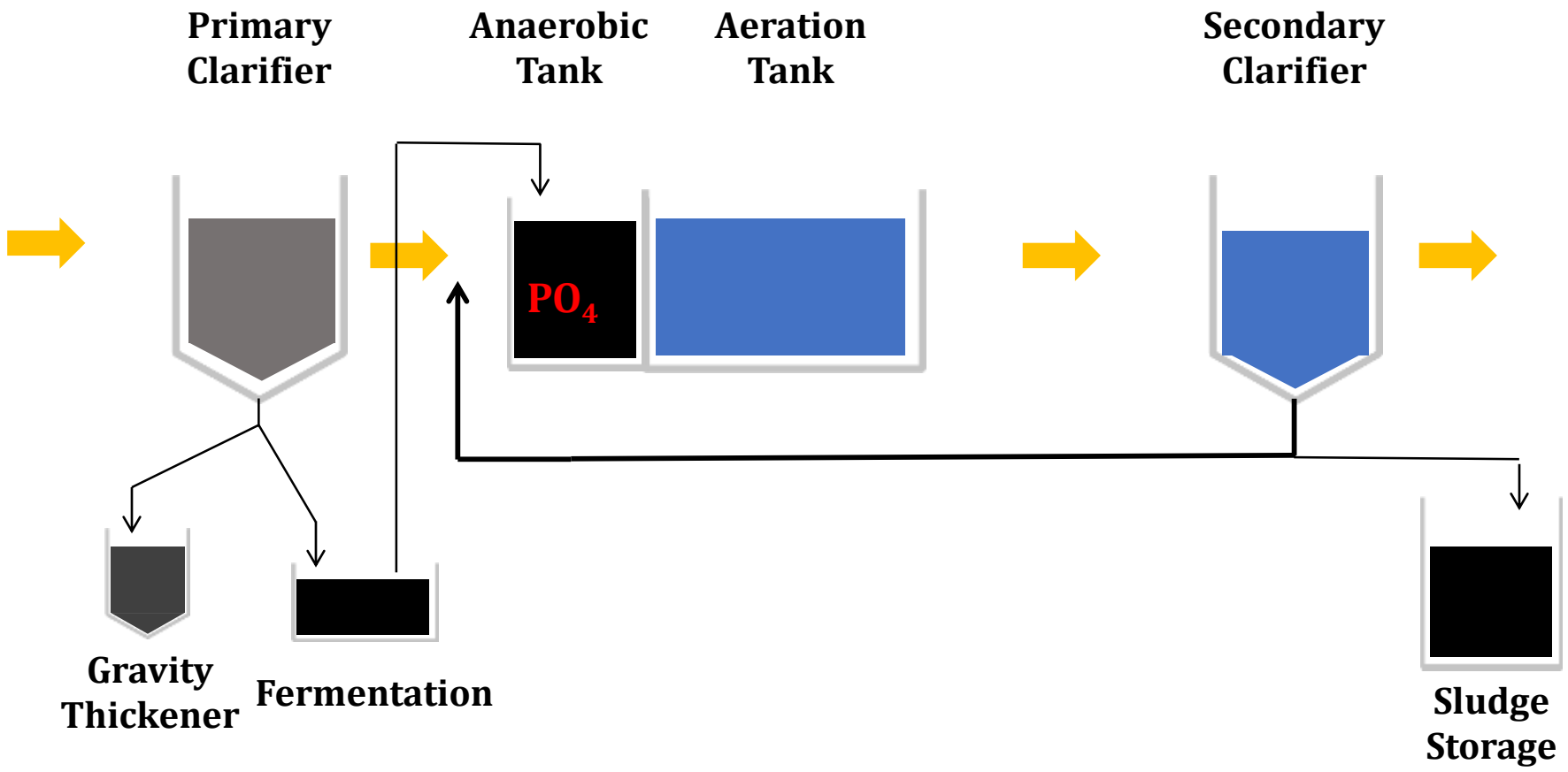


Bio-P Removal: Sidestream Fermentation Process



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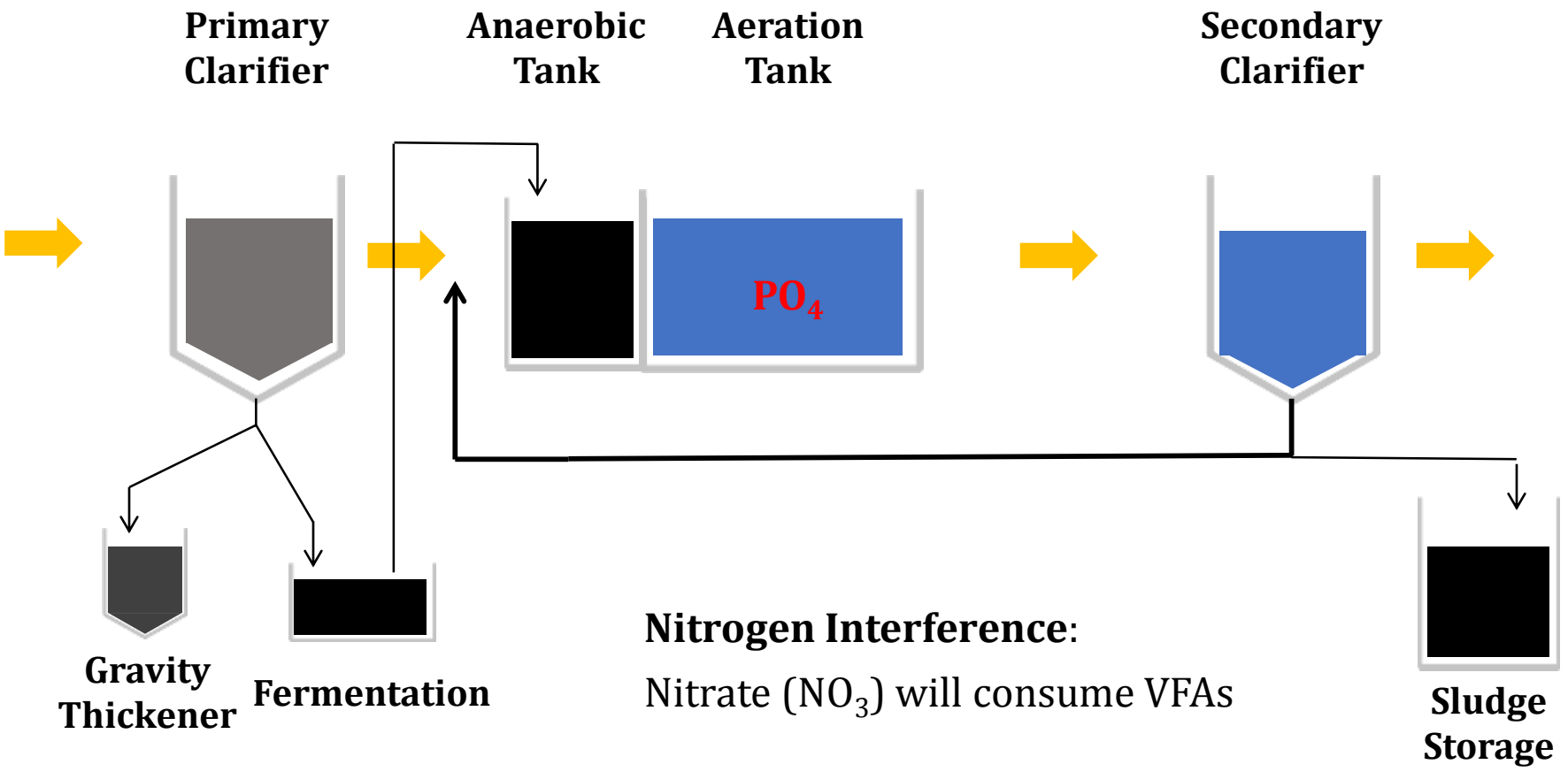
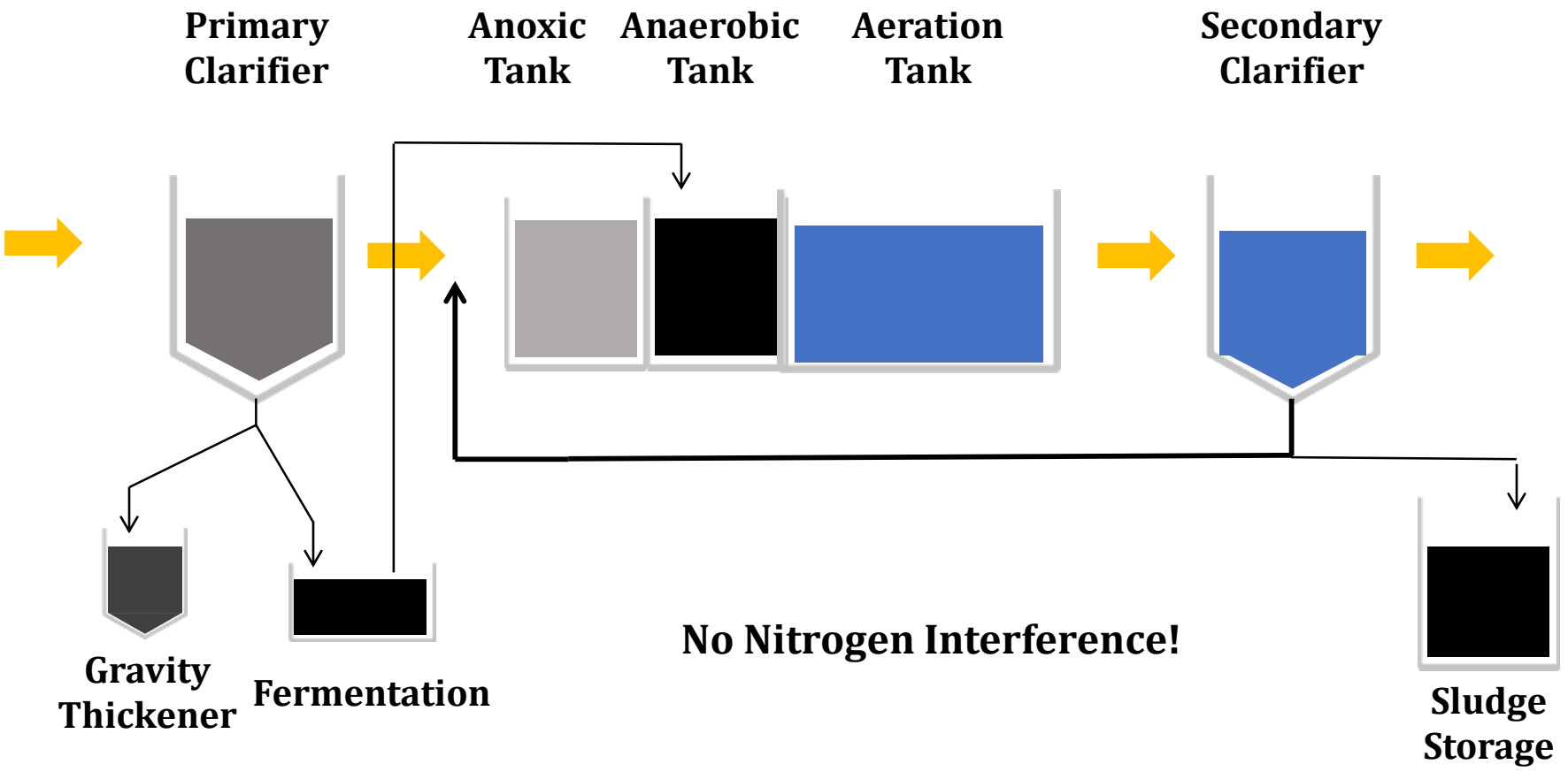


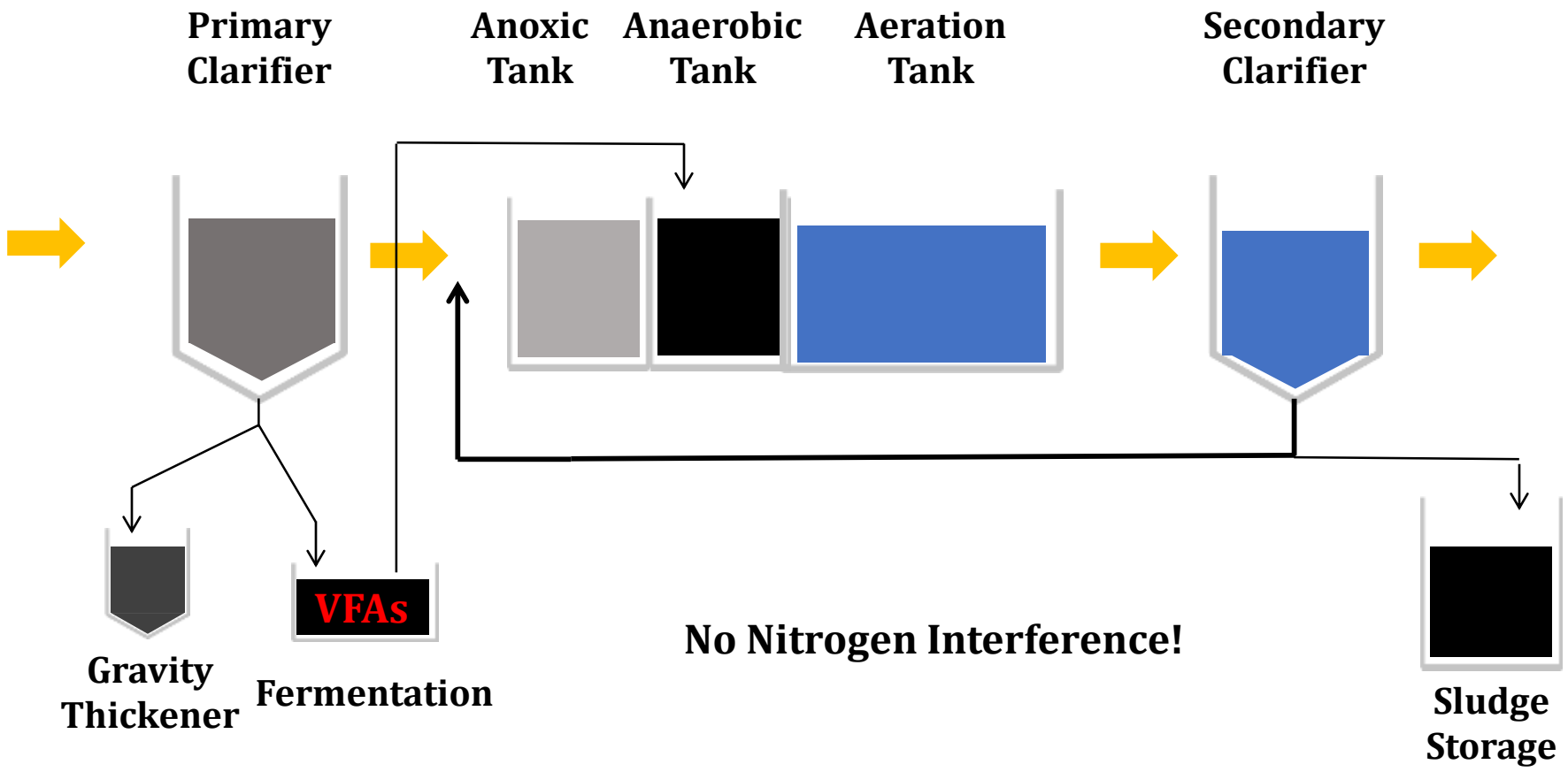
Nitrogen Interference:

Nitrate (NO_3) will consume VFAs

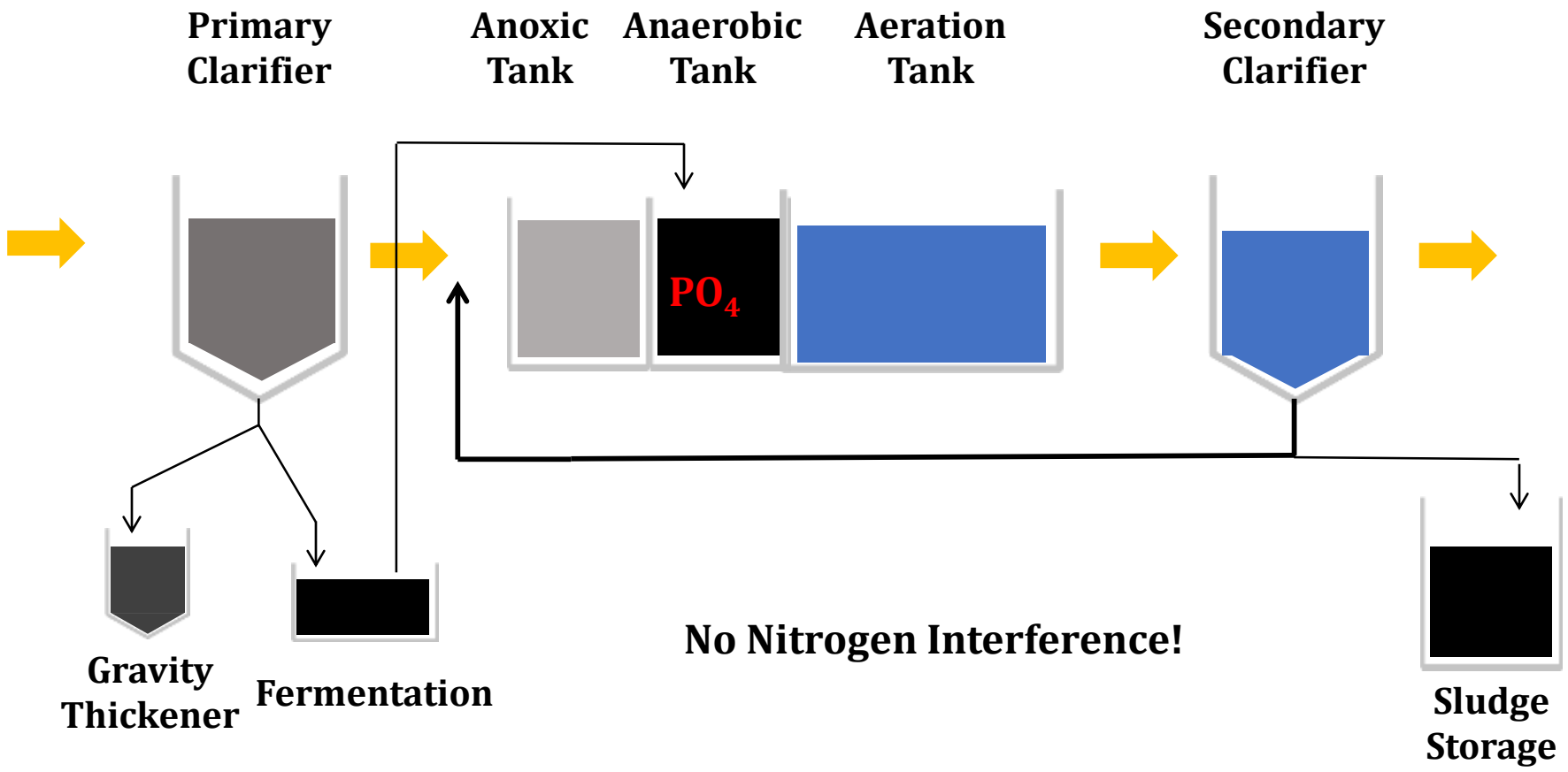
Bio-P Removal: Sidestream Fermentation Process



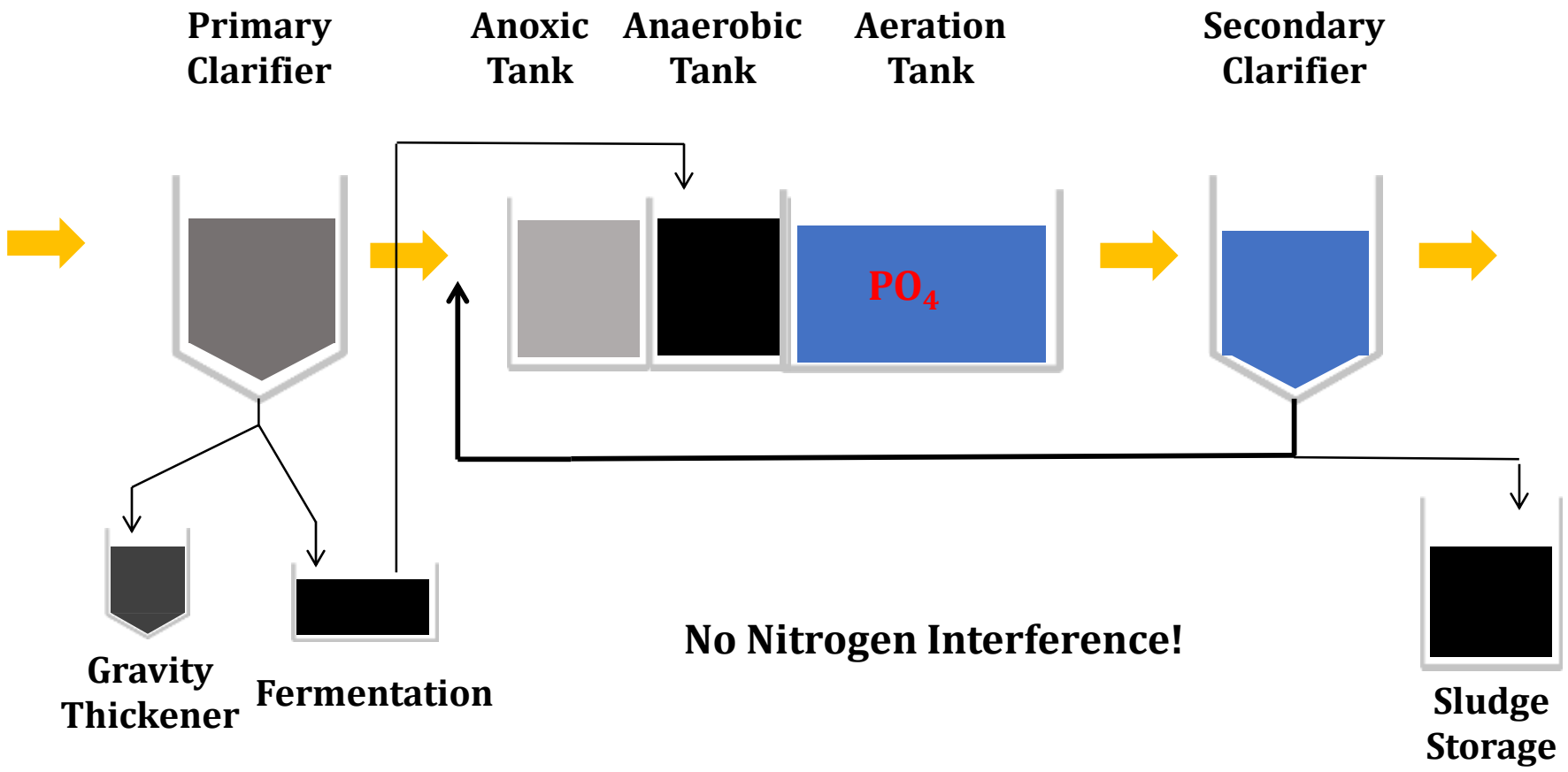
Bio-P Removal: Sidestream Fermentation Process



Bio-P Removal: Sidestream Fermentation Process



Bio-P Removal: Sidestream Fermentation Process



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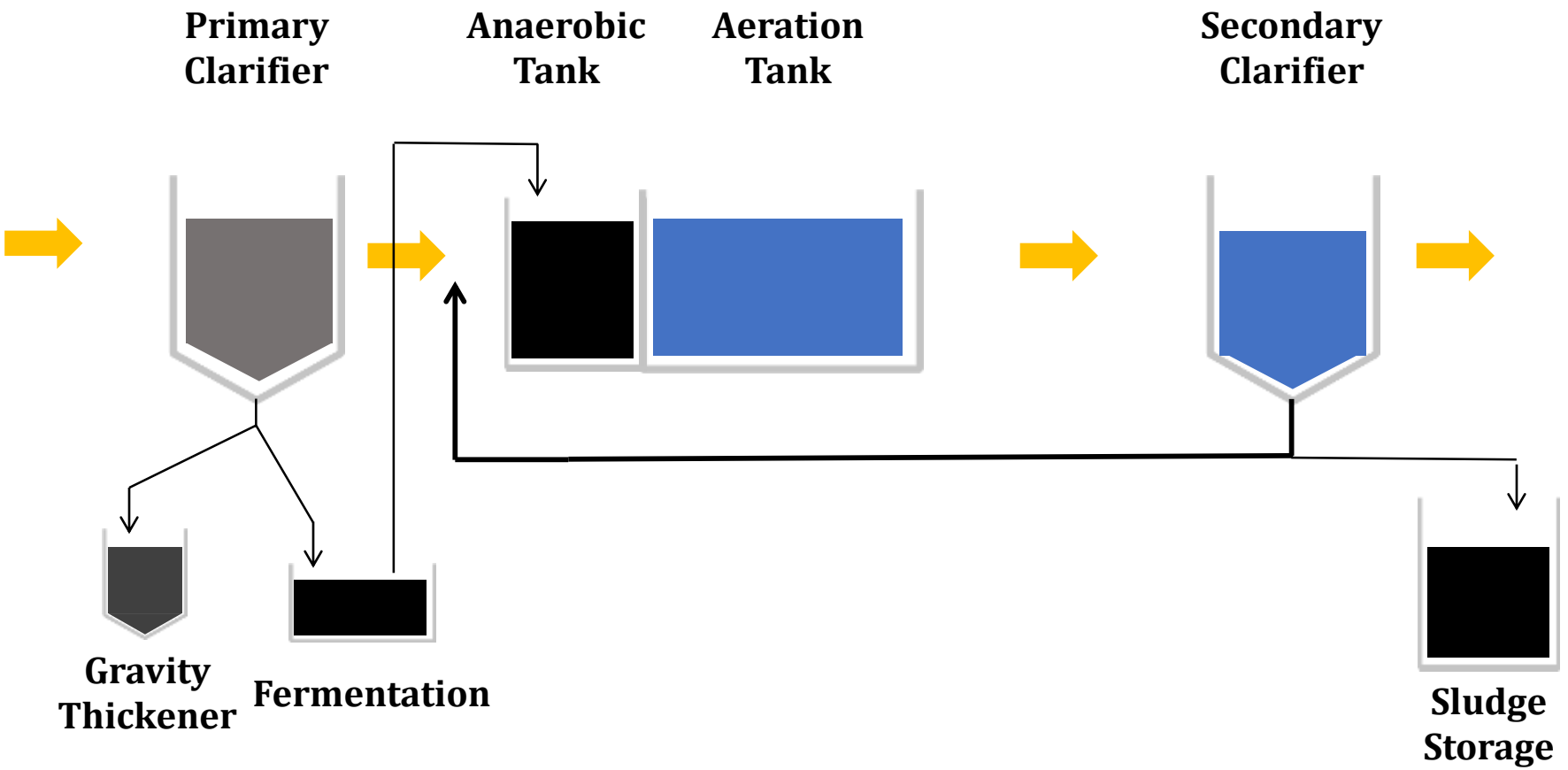
Troubleshooting Biological Phosphorus removal in Plants Designed for EBPR (enhanced biological phosphorus removal)

Less than 3x ortho-P leaving Anaerobic Tank



If Anaerobic Tank isn't really anaerobic …

… turn off mixer(s)

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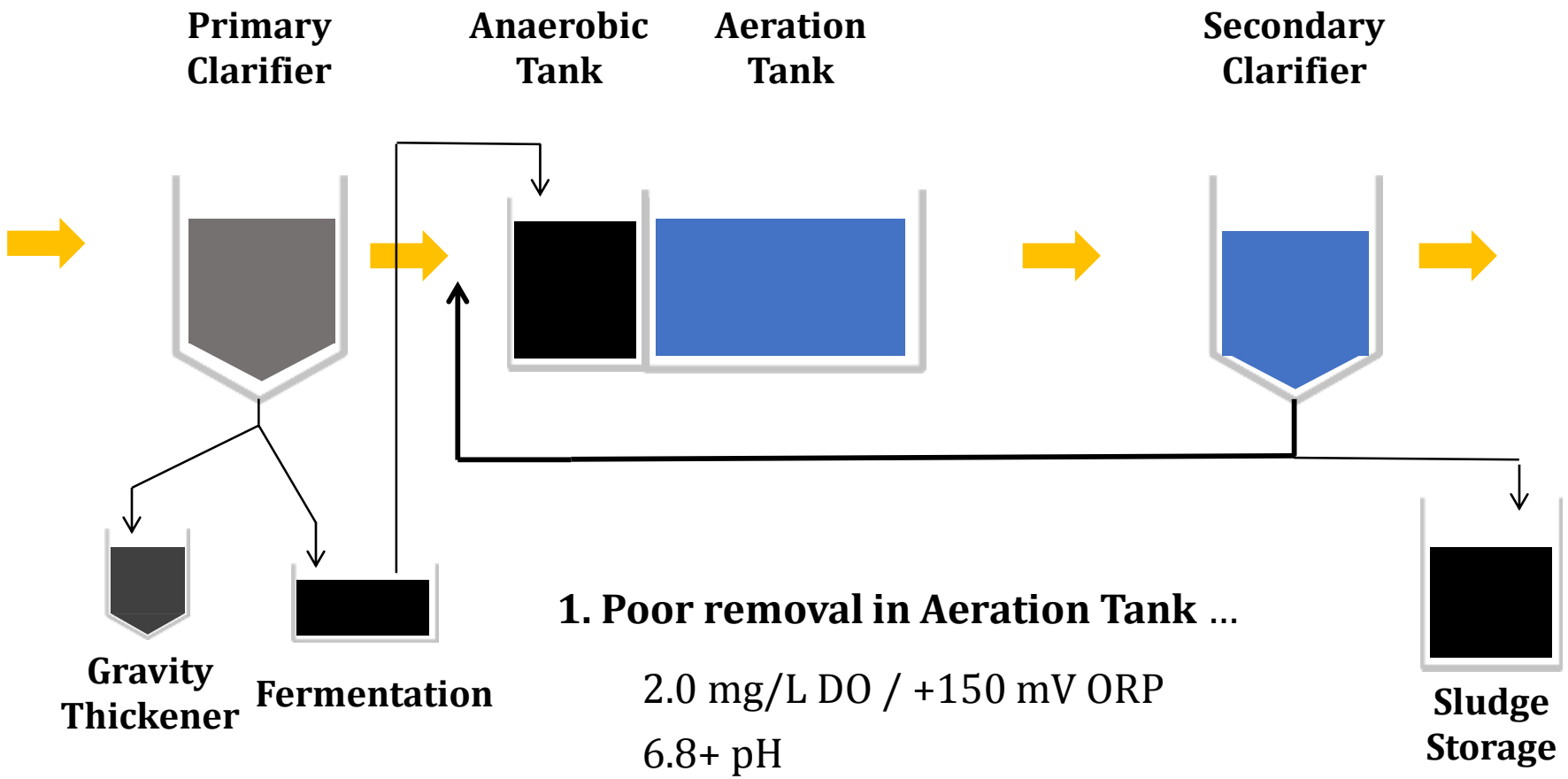
3x ortho-P leaving Anaerobic Tank but high effluent P



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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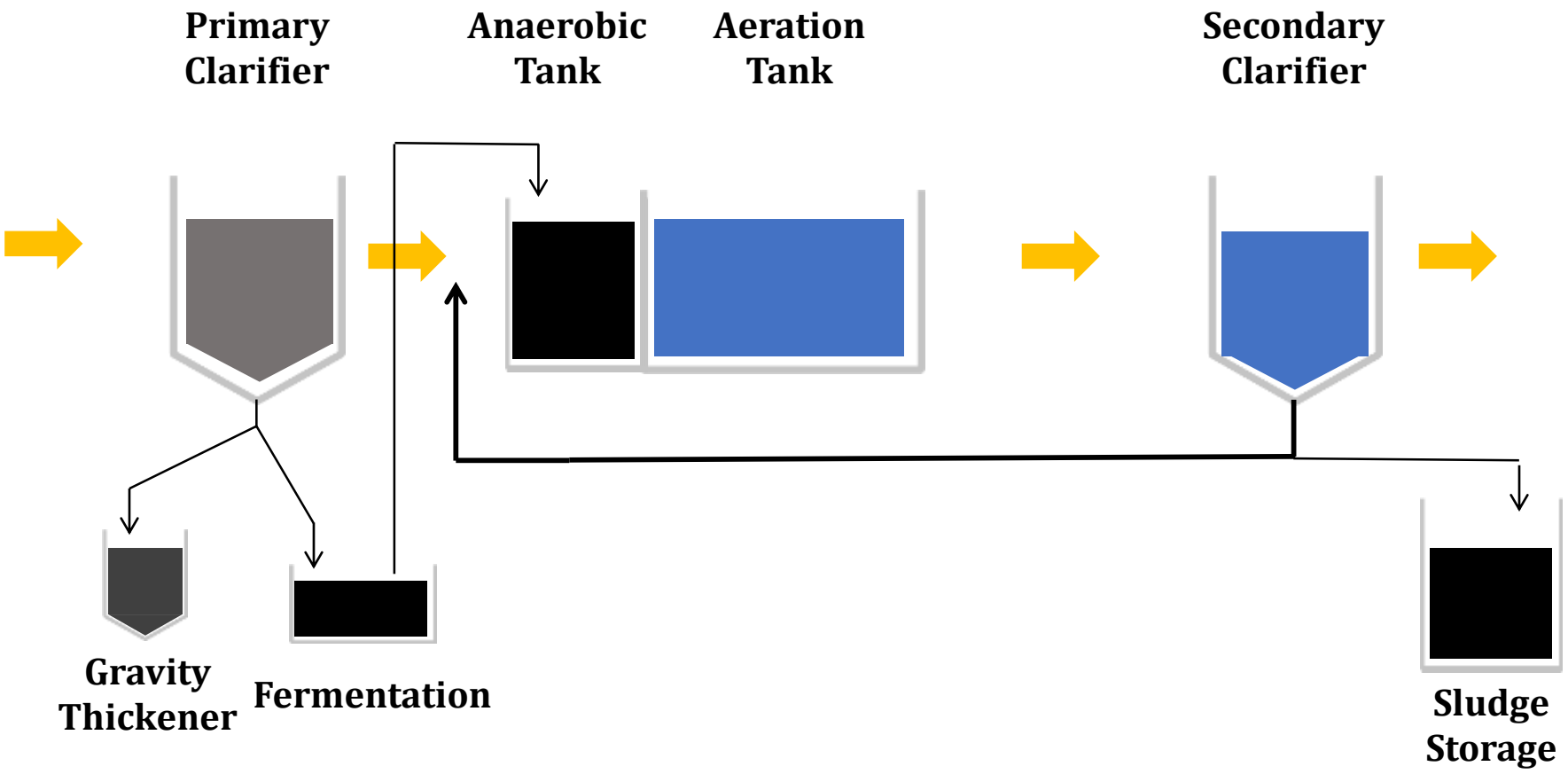
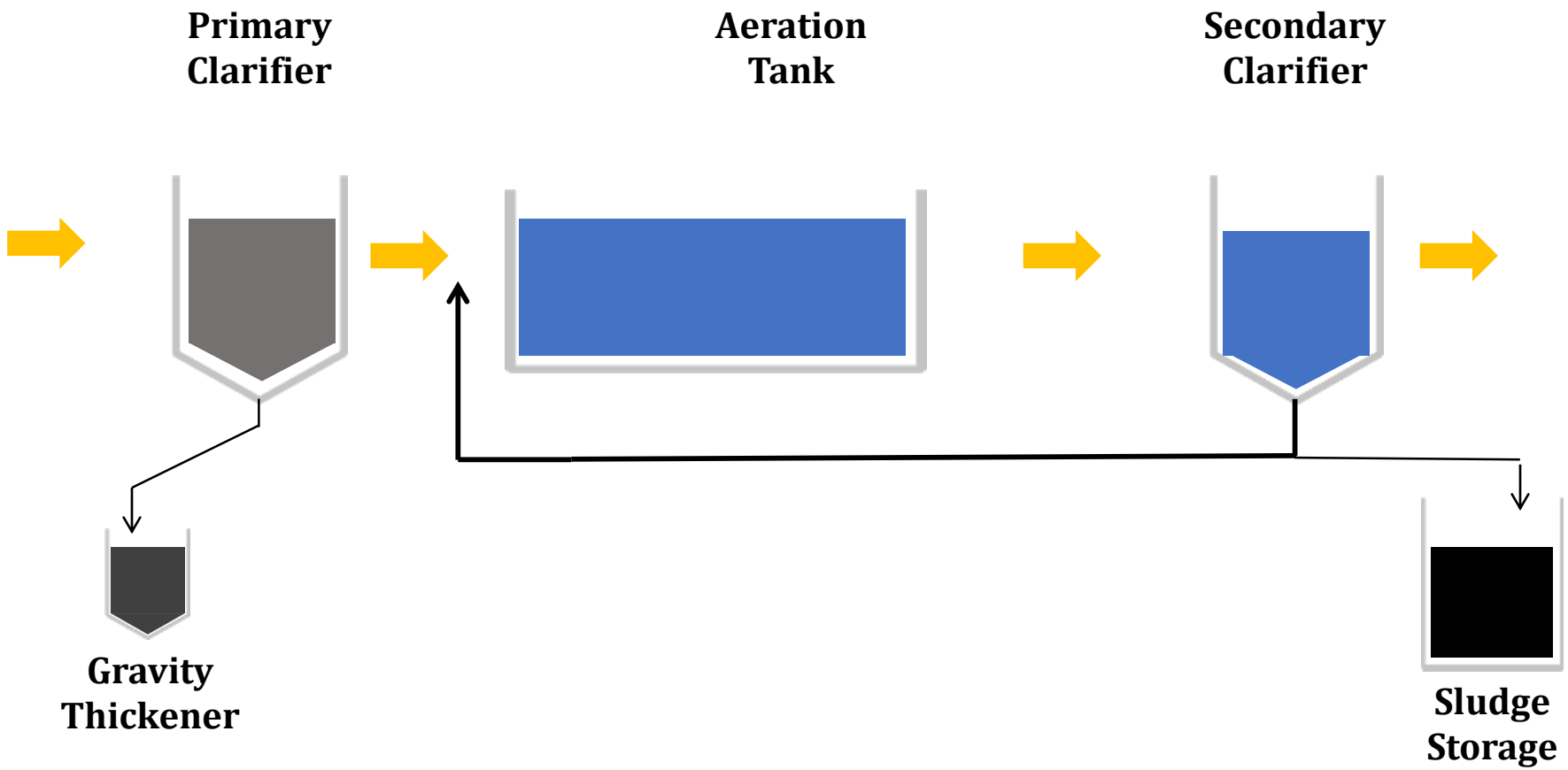
Getting creative …

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

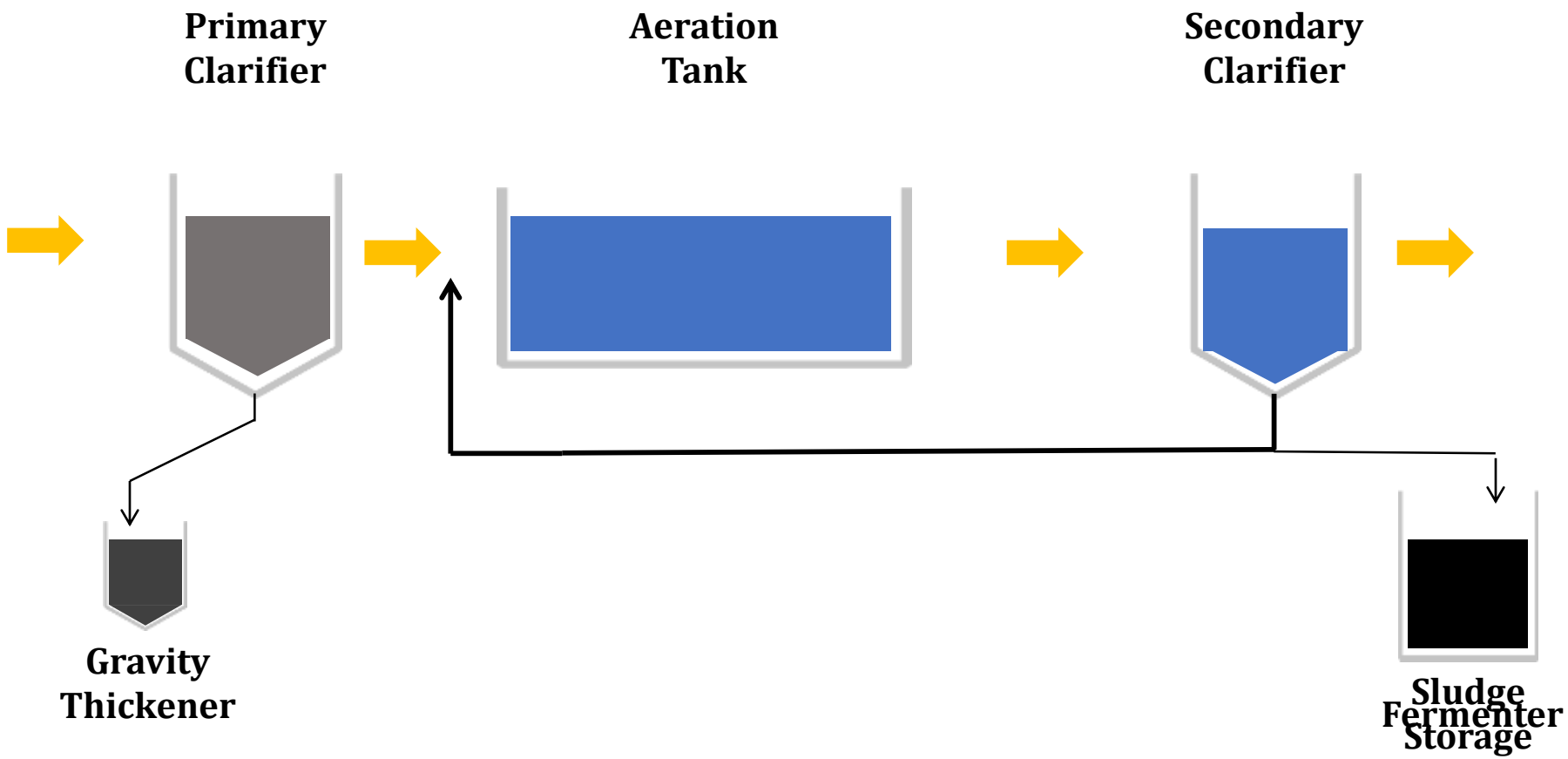
Home Grown Sidestream Fermenter



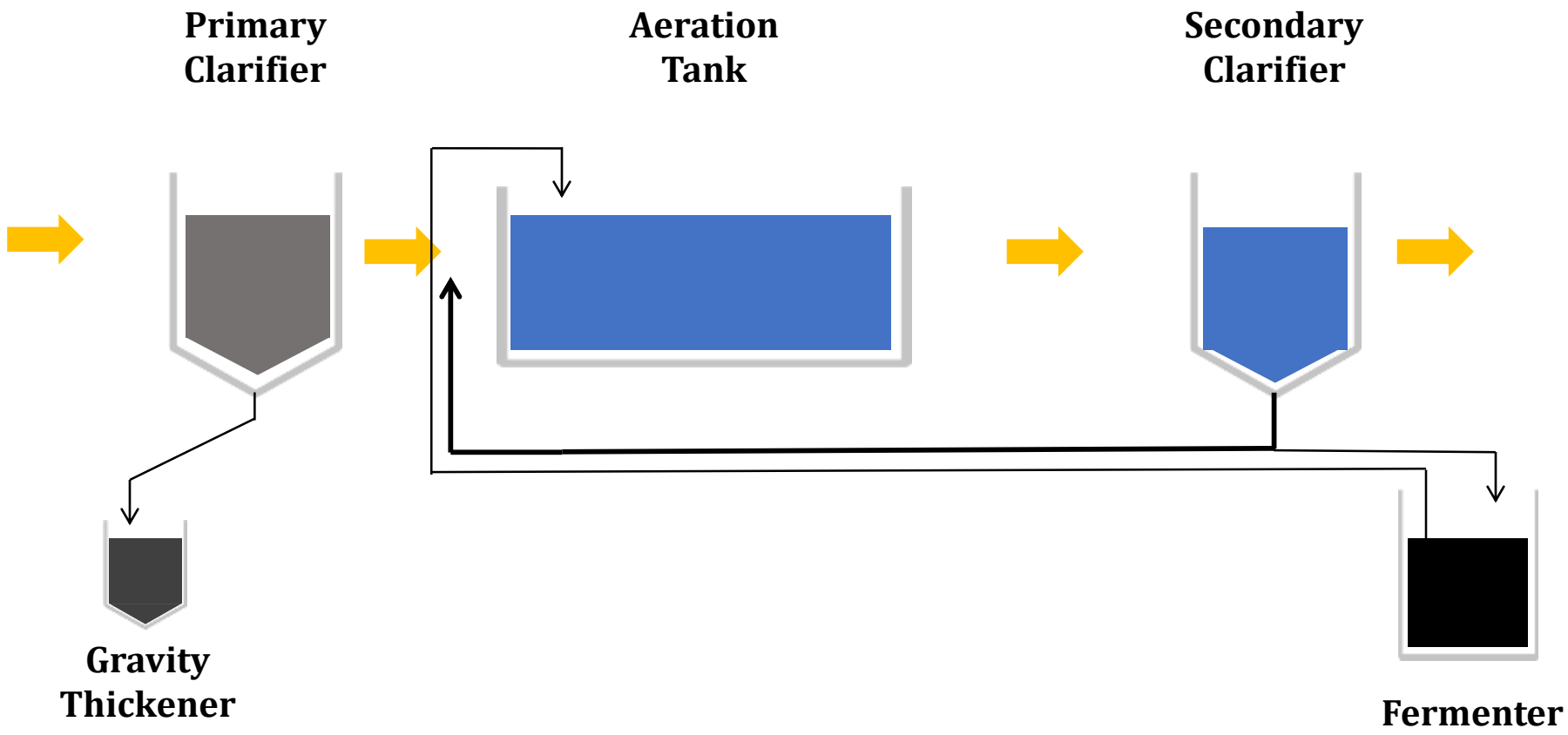
Home Grown Sidestream Fermenter



Home Grown Sidestream Fermenter



Home Grown Sidestream Fermenter



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Acknowledgements

US EPA
Brendan Held & Craig Hesterlee

NC DEQ
Terry Albrecht, Corey Basinger & Ron Haynes

U MEMPHIS
Larry Moore, PhD

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

TENNESSEE
Karina Bynum, Sherry Wang, George Garden, Jen Dodd (**TDEC**), Brett Ward (**UT-MTAS**), Dewayne Culpepper (**TAUD**), Tony Wilkerson & Doug Snelson (**Norris**), Ronnie Kelly, Tom Graham & John Buford (**Cookeville**)

… and, many more!

Next Week's Webinar
Phosphorus Removal: part 2

Thursday, March 18
10:00 - 11:45 AM

NC Case Studies *(3/25 & 4/8)*
Energy Management *(4/15 & 4/22)*
NC Case Studies *(4/29)*

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