Phosphorus Removal
Case Studies

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Summary: Biological Phosphorus Removal

Step 1: prepare "dinner"

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

Step 2: "eat"

Bio-P bugs (PAOs) 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

Summary, continued …

Anaerobic Tank

~1 hour HRT*
ORP of -200 mV*
25 times as much BOD as influent ortho-P*
Ortho-P release (3 times influent ortho-P)*

Aeration Tank

High DO / High ORP
pH of 6.8+*
Ortho-P concentration of 0.05 mg/L*

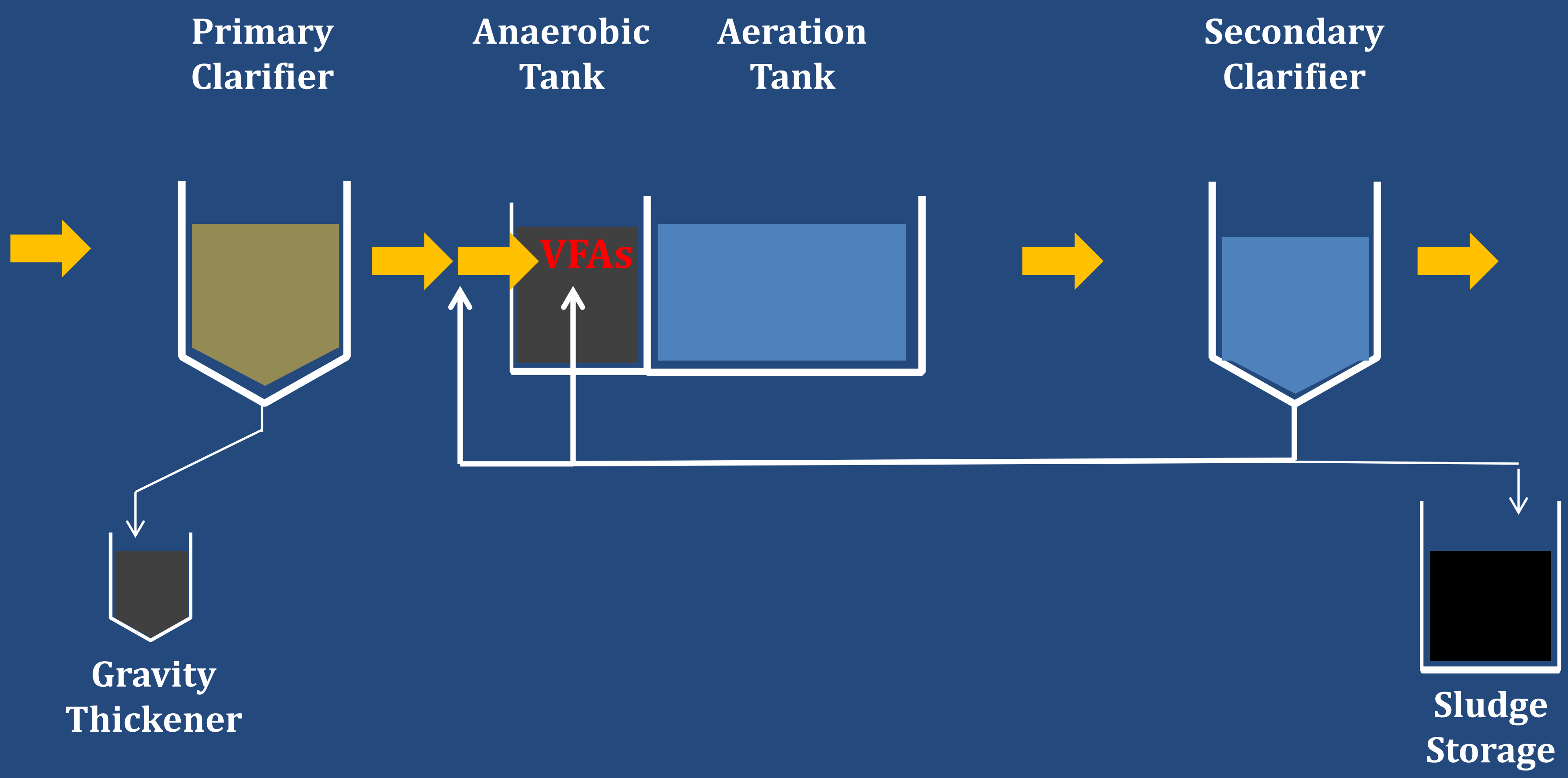
*Approximate: Every Plant is Different

Experimenting with YOUR plant:
Finding the "Right" Process Control Strategy

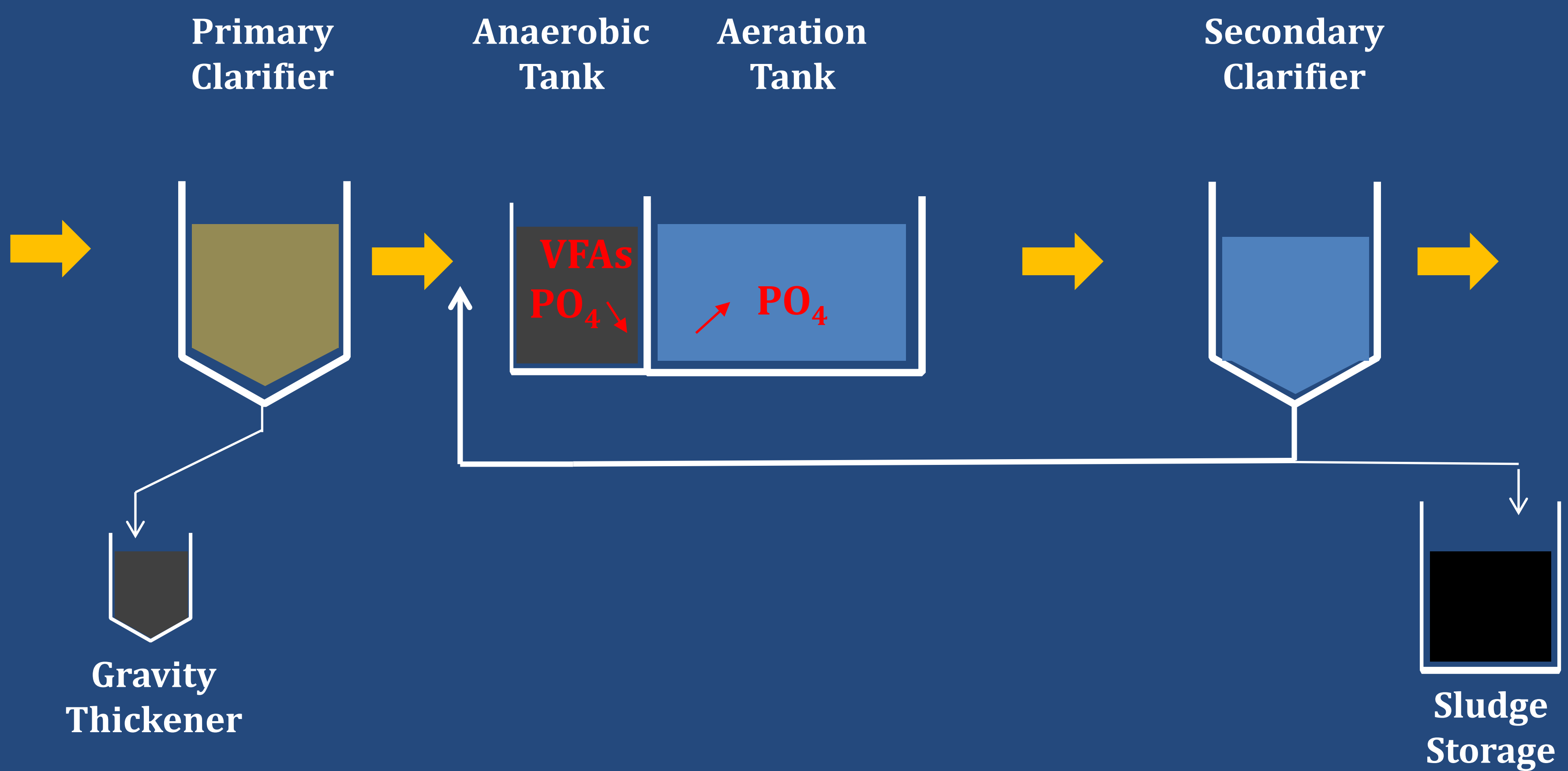
… and, Optimizing Phosphorus Removal

Create a Mainstream Fermentation Zone

Mainstream Bio-P Removal in Conventional AS Plant

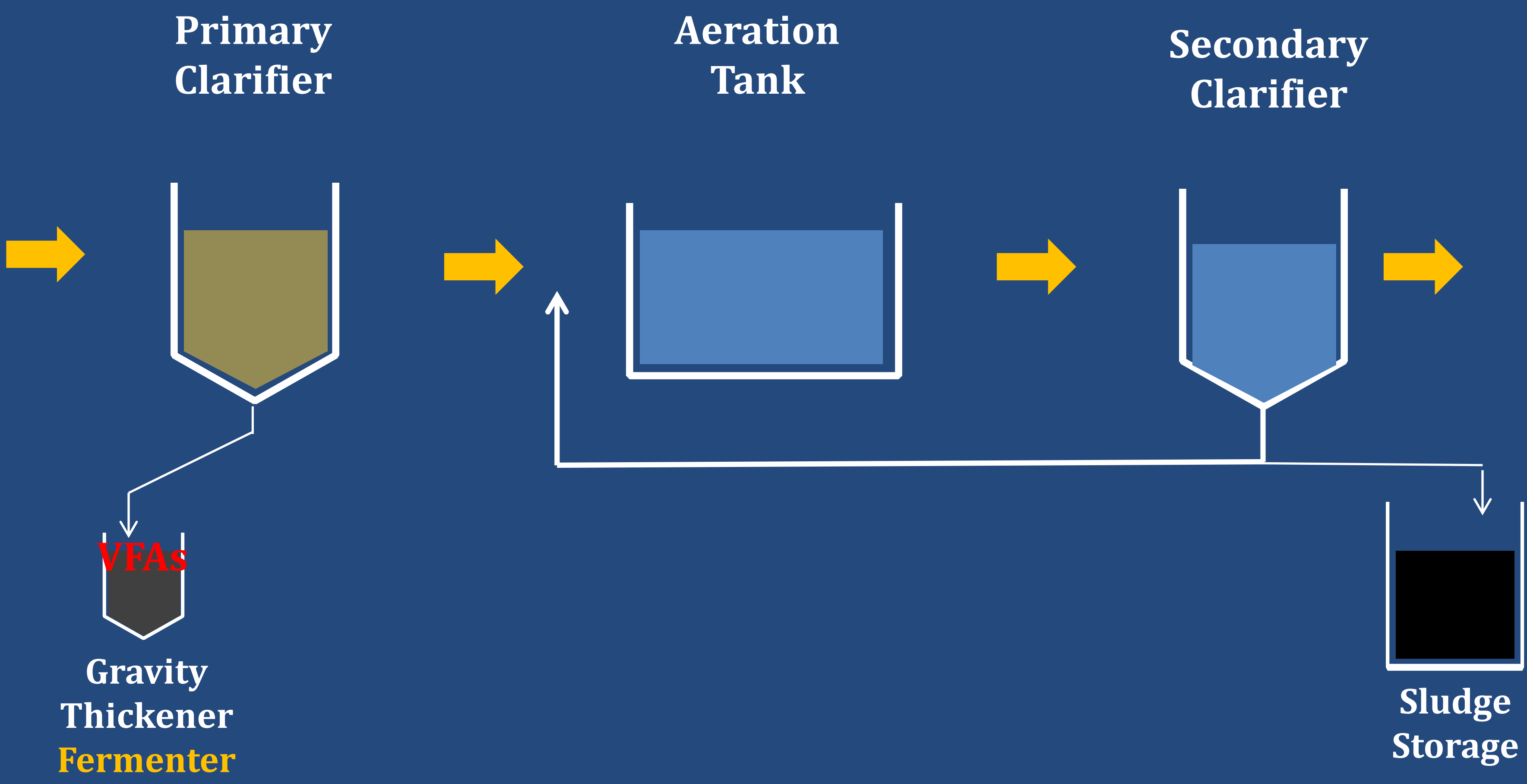


Mainstream Bio-P Removal in Conventional AS Plant

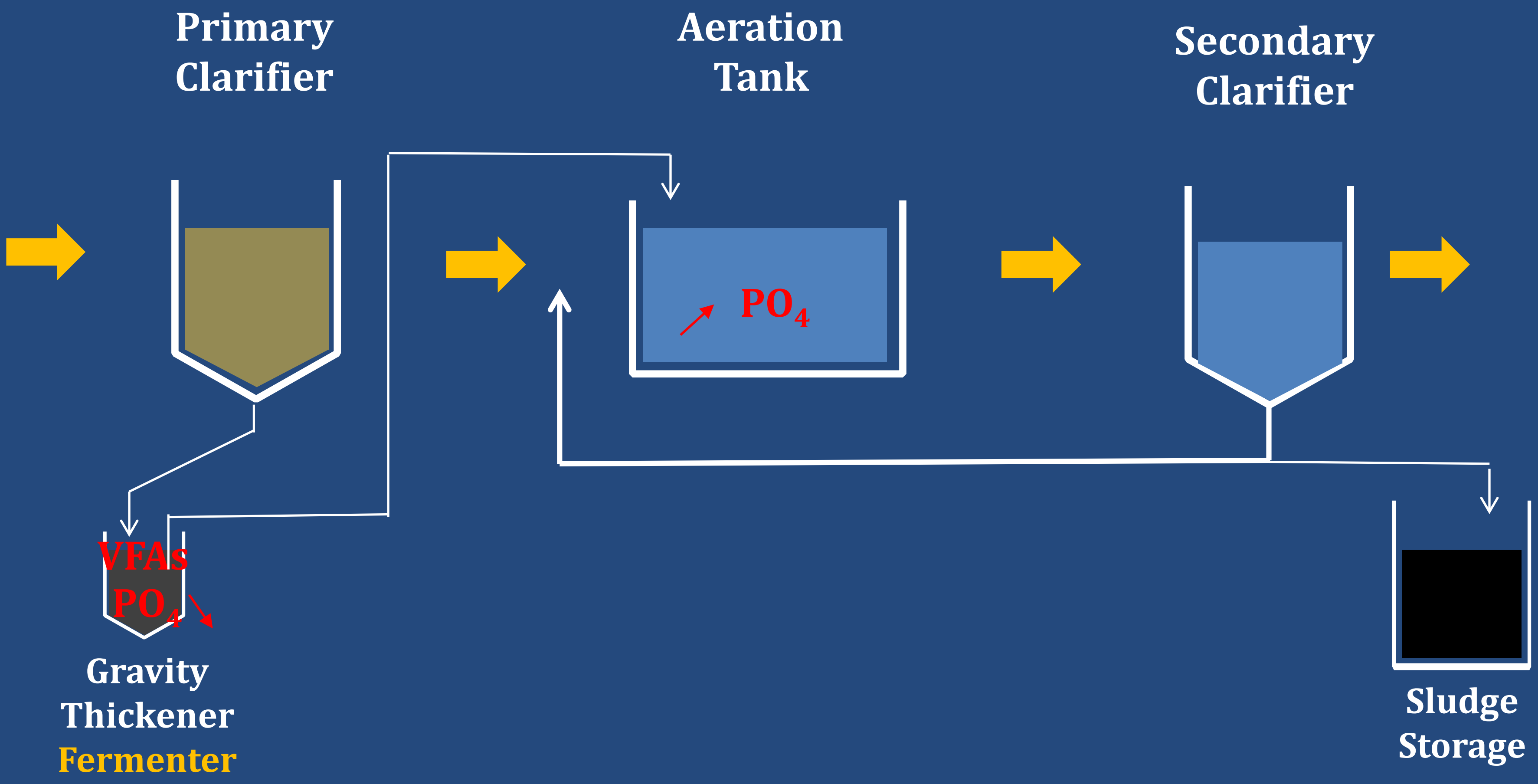


Create a Sidestream Fermentation Zone

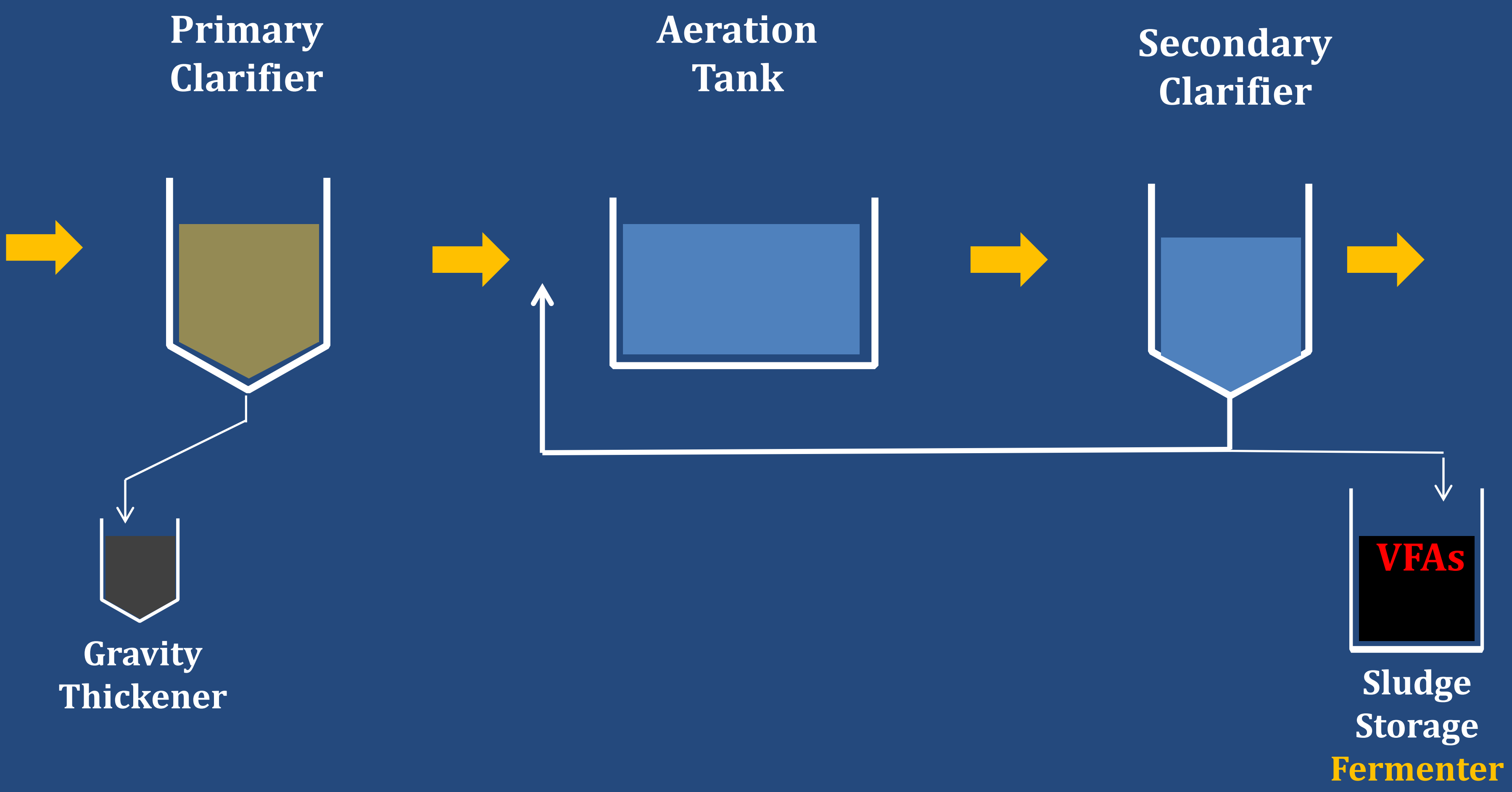
Sidestream Biological-P Removal: Gravity Thickener



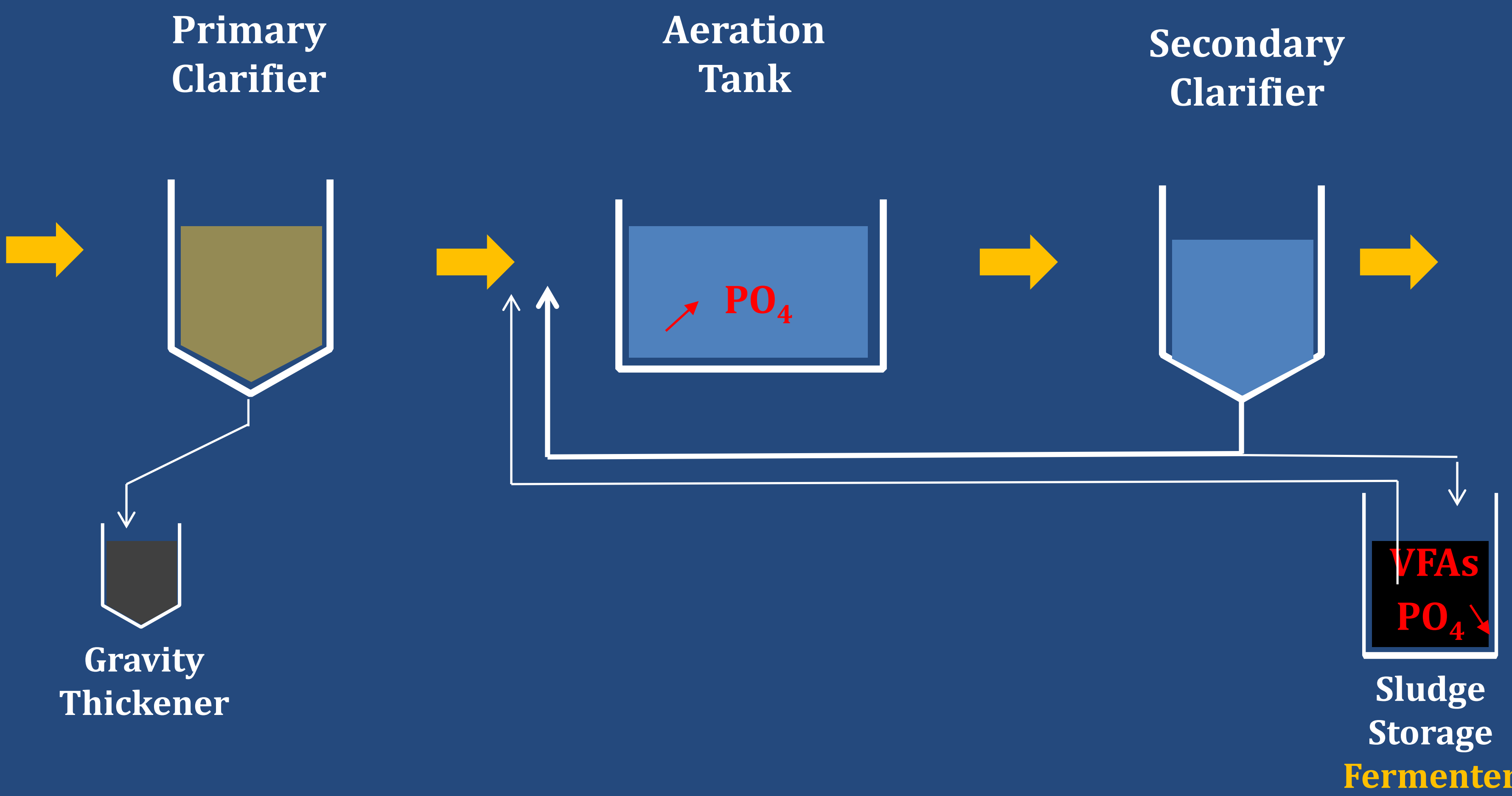
Sidestream Biological-P Removal: Gravity Thickener



Sidestream Biological-P Removal: Sludge Storage

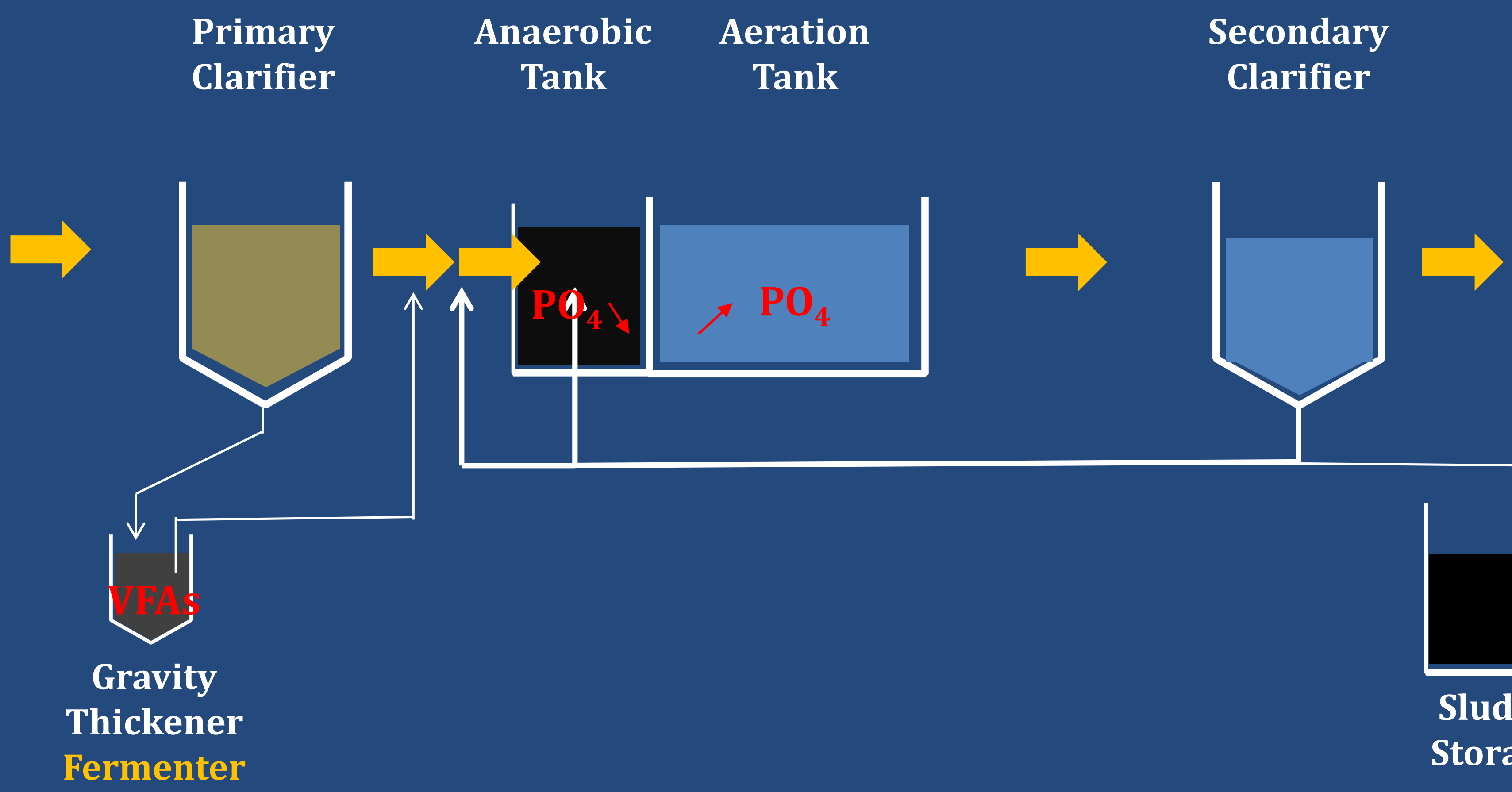


Sidestream Biological-P Removal: Sludge Storage

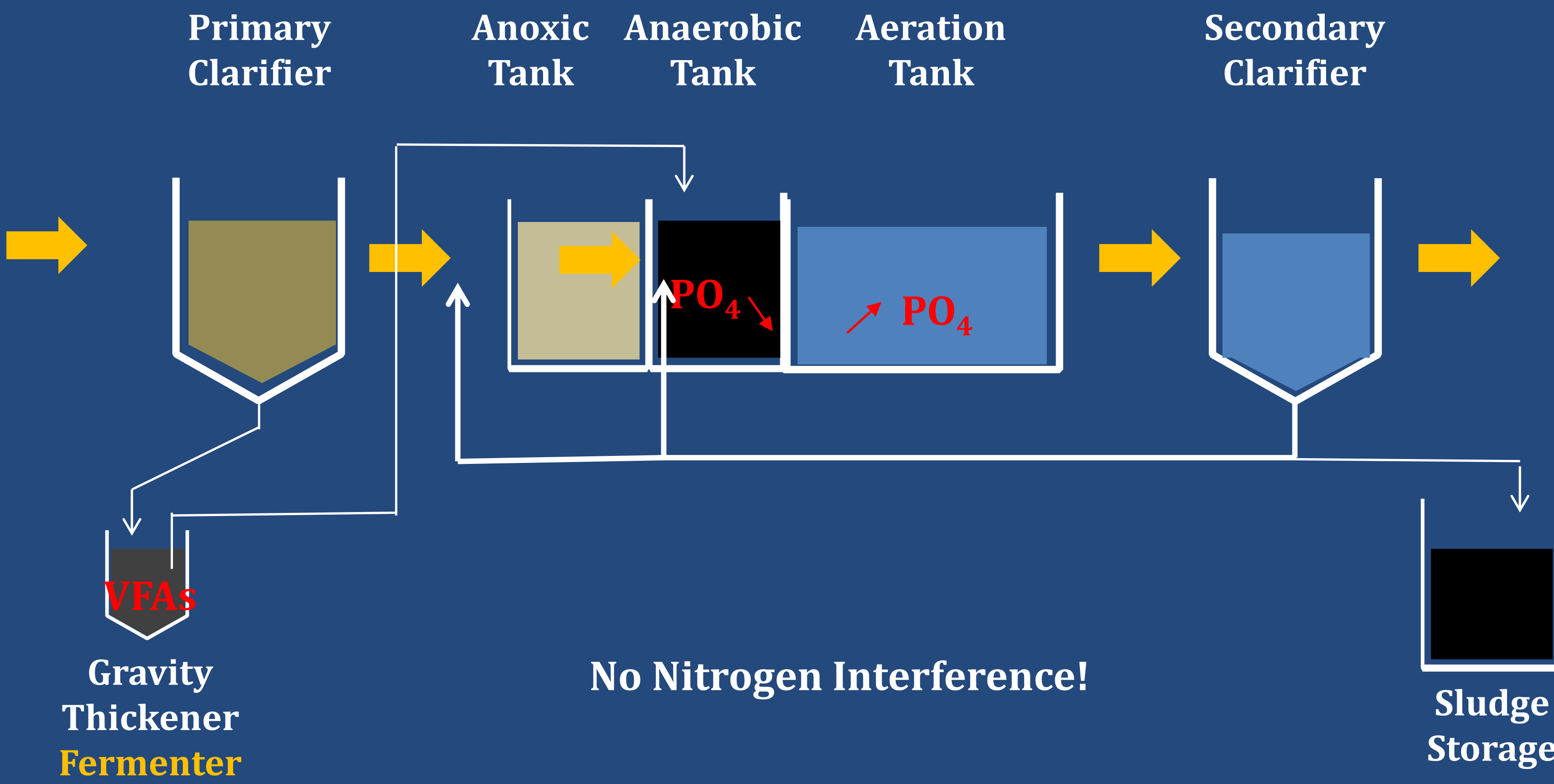


Create Both Mainstream & Sidestream Fermentation Zones

Sidestream & Mainstream Bio-P Removal



Sidestream & Mainstream Bio-P Removal



Optimizing Fermentation: Mainstream or Sidestream

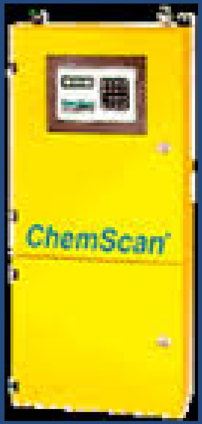
<u>Anaerobic Tank</u>

~1 hour HRT*
ORP of -200 mV*
25* times as much BOD as influent ortho-P
ortho-P release (3-4 times influent ortho-P)*

<u>Aeration Tank</u>

DO of 2.0 mg/L*
pH of 6.8+*
ortho-P concentration of 0.05 mg/L*

*Approximate: Every Plant is Different



Summary

Operational changes allow many (most) Activated Sludge Plants to biologically remove phosphorus - and - as a bonus create a biological selector for filament control.

Find opportunities for mainstream as well as sidestream fermentation zones.

Recognize that two things occur in the anaerobic tanks:

- VFA formation (hard to digest compounds converted to easy-to-eat molecules)
- PAOs use volatile fatty acids as an energy source (food)

Aeration Tank habitat is important: DO & pH

Bio-P converts soluble-P to an effluent TSS rich in P …

- TSS control is critical!

Minimize VFA use by Nitrate (NO_3)

Monitor and Adjust DAILY for the rest of your life!

Discussion

Case Studies

Massachusetts

- **Palmer**: complete mix activated sludge
- **Westfield**: plug-flow activated sludge

New Hampshire

- **Keene**: plug-flow activated sludge

Connecticut

- **East Haddam**: SBR (sequencing batch reactor)
- **Plainfield**: mechanical aeration activated sludge
- **Suffield**: oxidation ditch

Montana

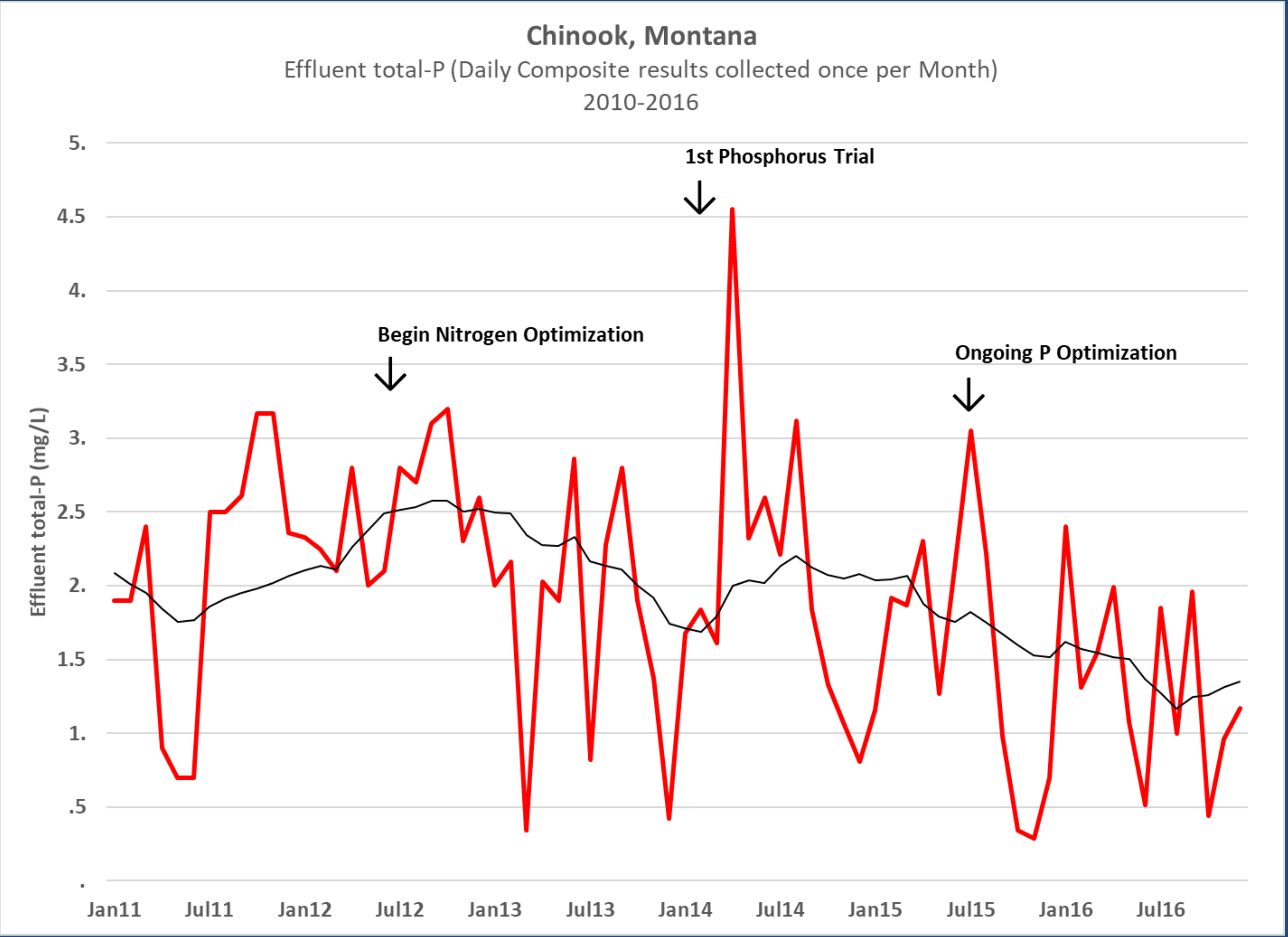
- **Chinook**: oxidation ditch
- **Conrad**: extended aeration
- **Helena**: MLE activated sludge

Tennessee

- **Athens**: oxidation ditch & orbital ditch
- **Bartlett**: oxidation ditch
- **Cookeville**: oxidation ditch
- **Crossville**: plug-flow activated sludge
- **LaFollette**: oxidation ditch
- **Livingston**: SBR (sequencing batch reactor)

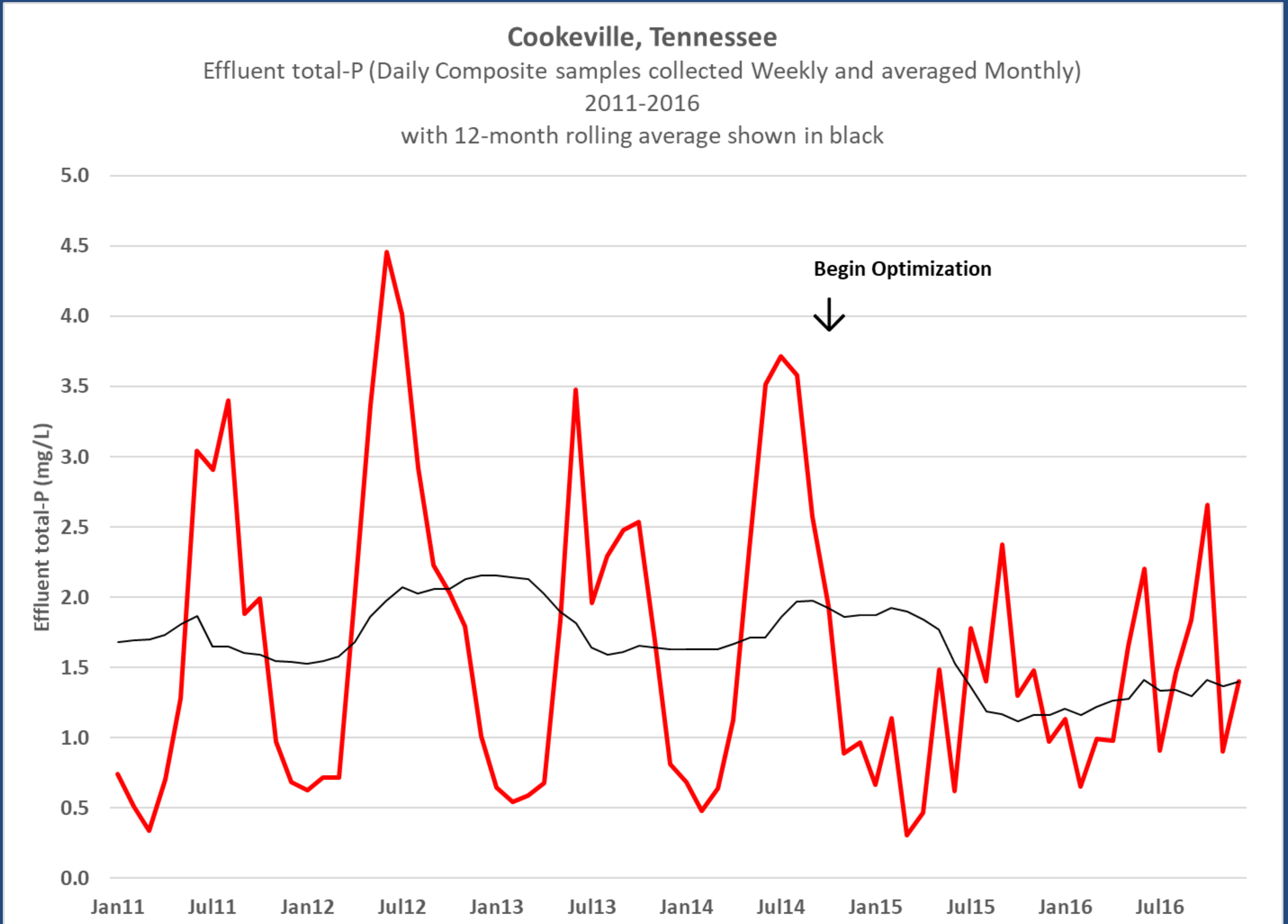
	total-Phosphorus (mg/L)		
	before	after	
Conrad, Montana	2.1	0.15	
Keene, New Hampshire	1.0	0.20	50% less chemicals
Chinook, Montana	2.8	0.30	
East Haddam, Connecticut (2 month trial)	3.5	0.35	
Palmer, Massachusetts	0.5	0.50	25% less chemicals
Westfield, Massachusetts	0.5-2.5	0.50	50% less chemicals
Athens, Tennessee: Oostanaula	0.5	0.50	100% less chemicals
Plainfield, Connecticut: Village Plant	2.5	0.70	
Suffield, Connecticut	3.0	0.70	
Cookeville, Tennessee	2.0	1.4	
Helena, Montana	2.9	0.5-2.0	
Athens, Tennessee: North Mouse Creek	2.8	0.3-3.0	

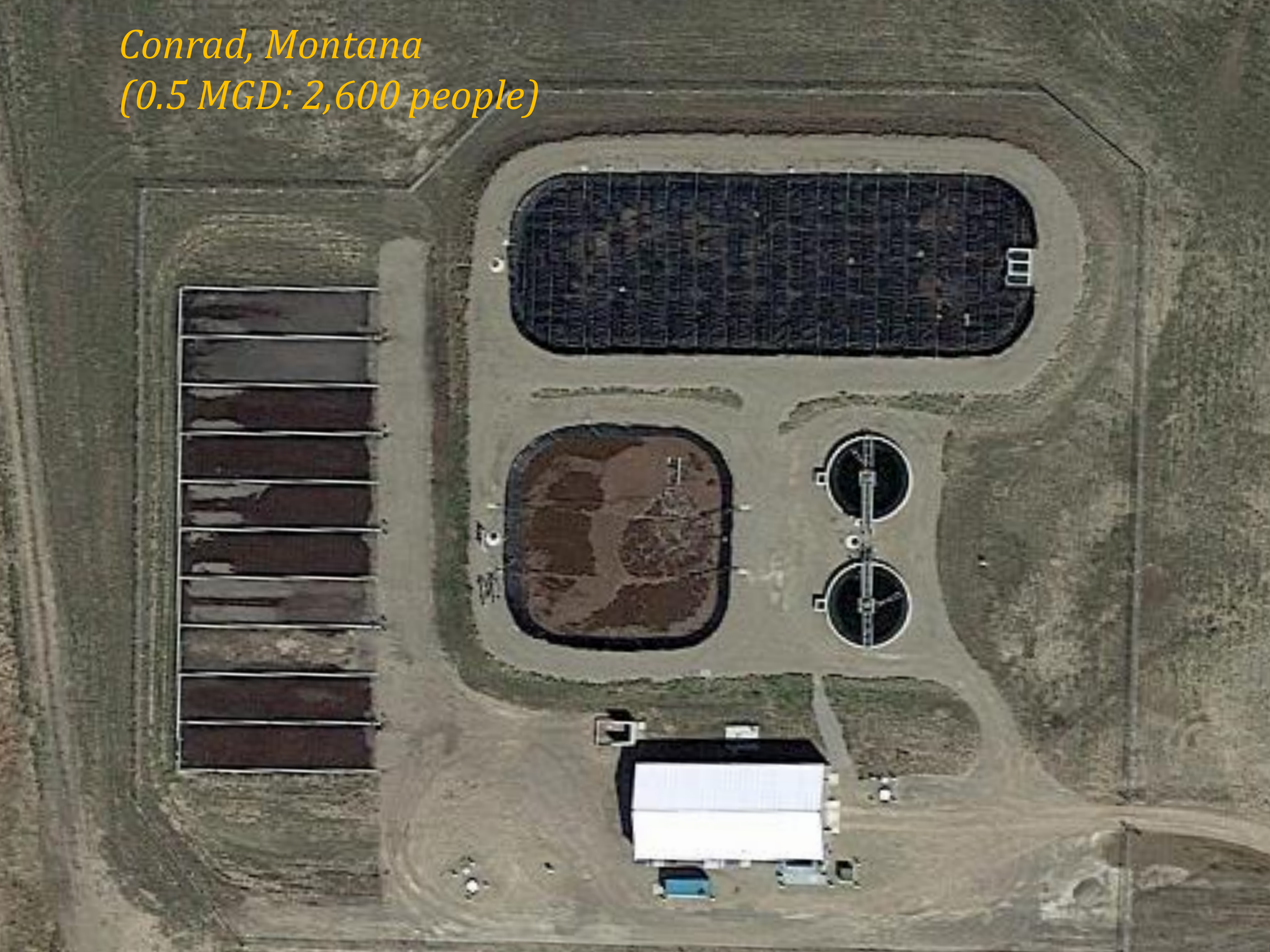

Chinook, Montana
(0.5 MGD: 1,200 people)

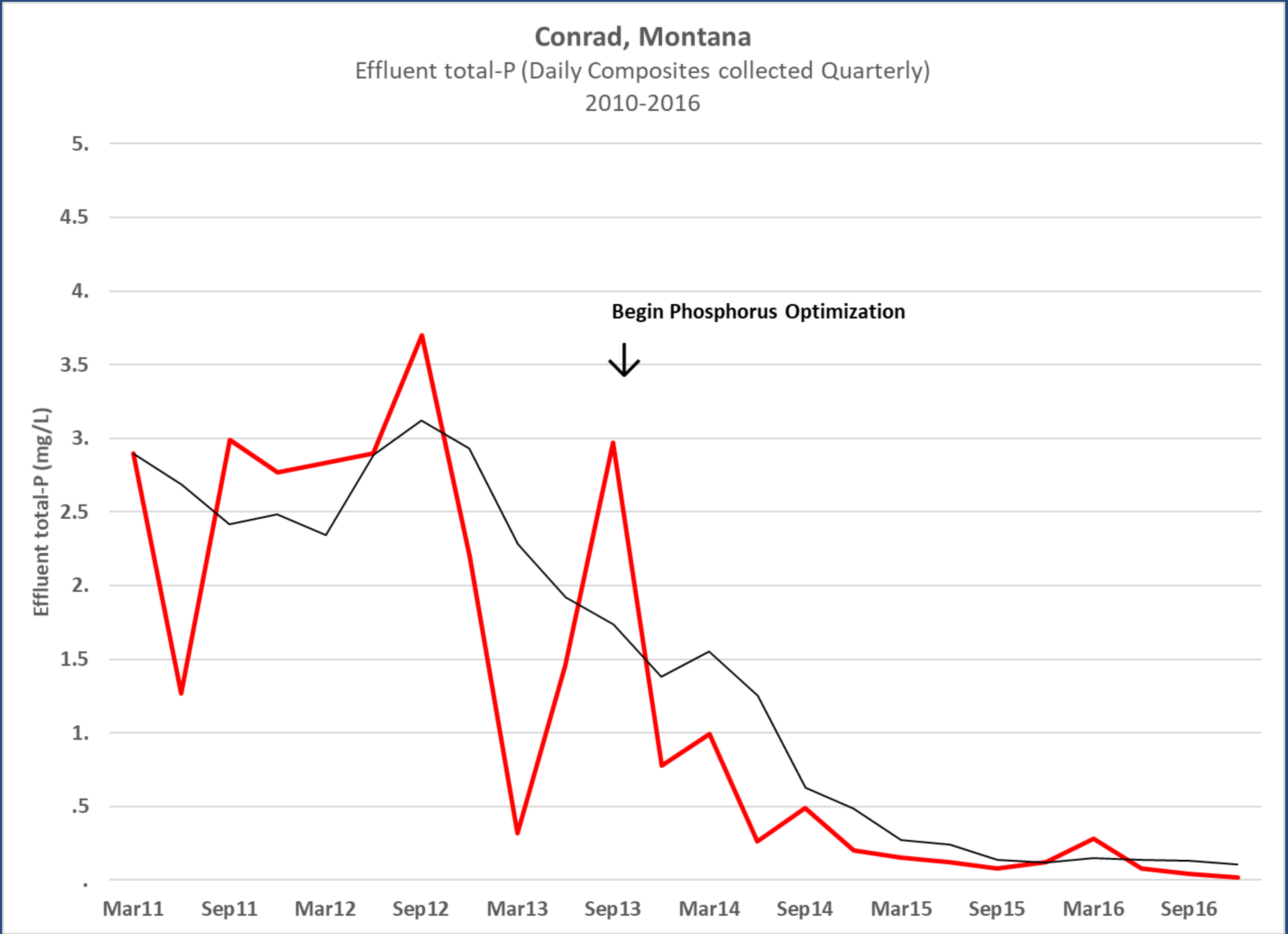


Chinook, Montana
Effluent total-P (Daily Composite results collected once per Month)
2010-2016
1st Phosphorus Trial
Begin Nitrogen Optimization
Ongoing P Optimization
Effluent total-P (mg/L)
5.
4.5
4.
3.5
3.
2.5
2.
1.5
1.
.5
.
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15
Jan16
Jul16


Cookeville, Tennessee
14 MGD (31,000 people)


Cookeville, Tennessee
Effluent total-P (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
with 12-month rolling average shown in black
Begin Optimization
Effluent total-P (mg/L)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15
Jan16
Jul16

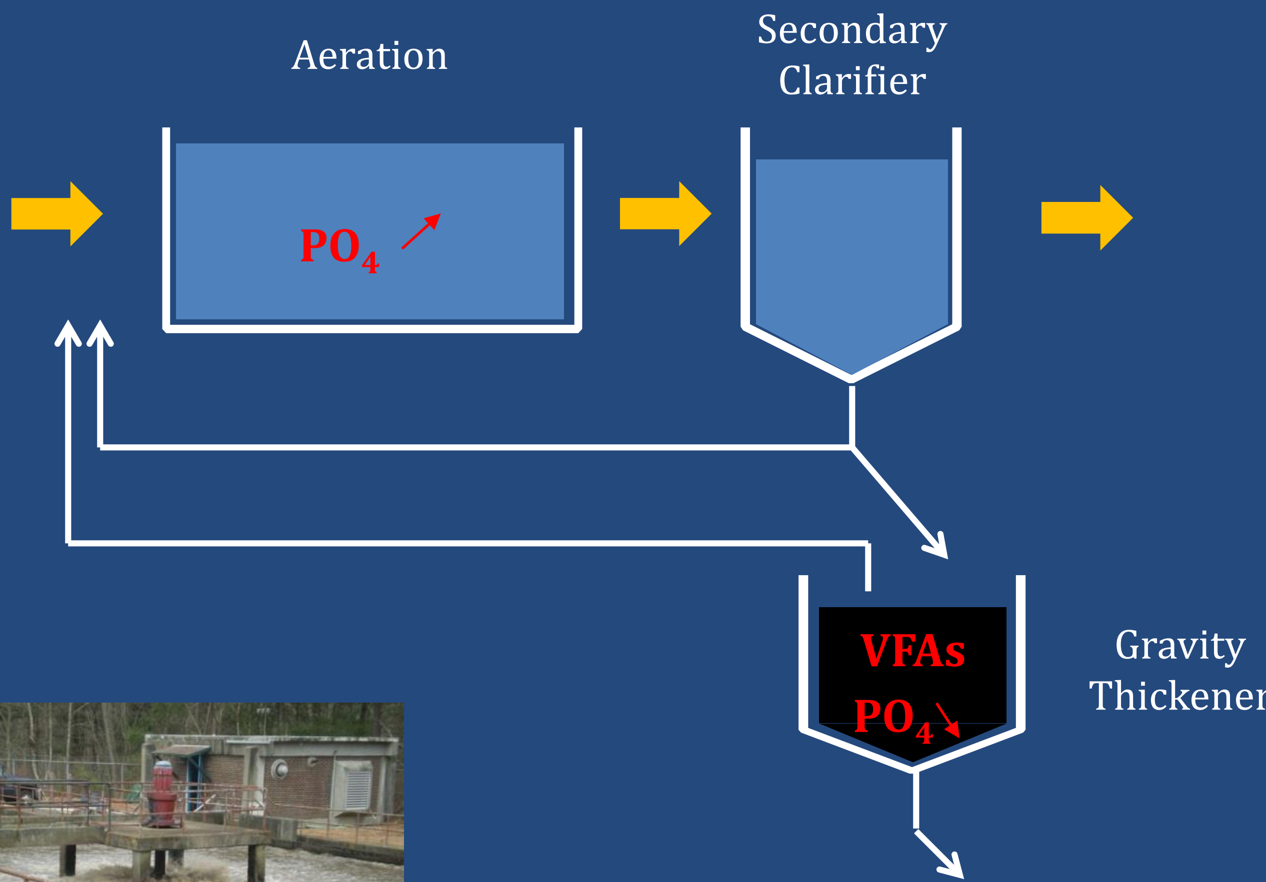

Conrad, Montana
(0.5 MGD: 2,600 people)

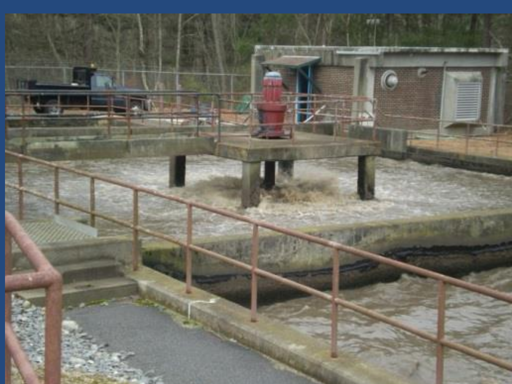


Conrad, Montana
Effluent total-P (Daily Composites collected Quarterly)
2010-2016
Effluent total-P (mg/L)
5.
4.5
4.
3.5
3.
2.5
2.
1.5
1.
.5
.
Begin Phosphorus Optimization
Mar11
Sep11
Mar12
Sep12
Mar13
Sep13
Mar14
Sep14
Mar15
Sep15
Mar16
Sep16


Plainfield, Connecticut – Village Plant
0.5 MGD (15,000 people)

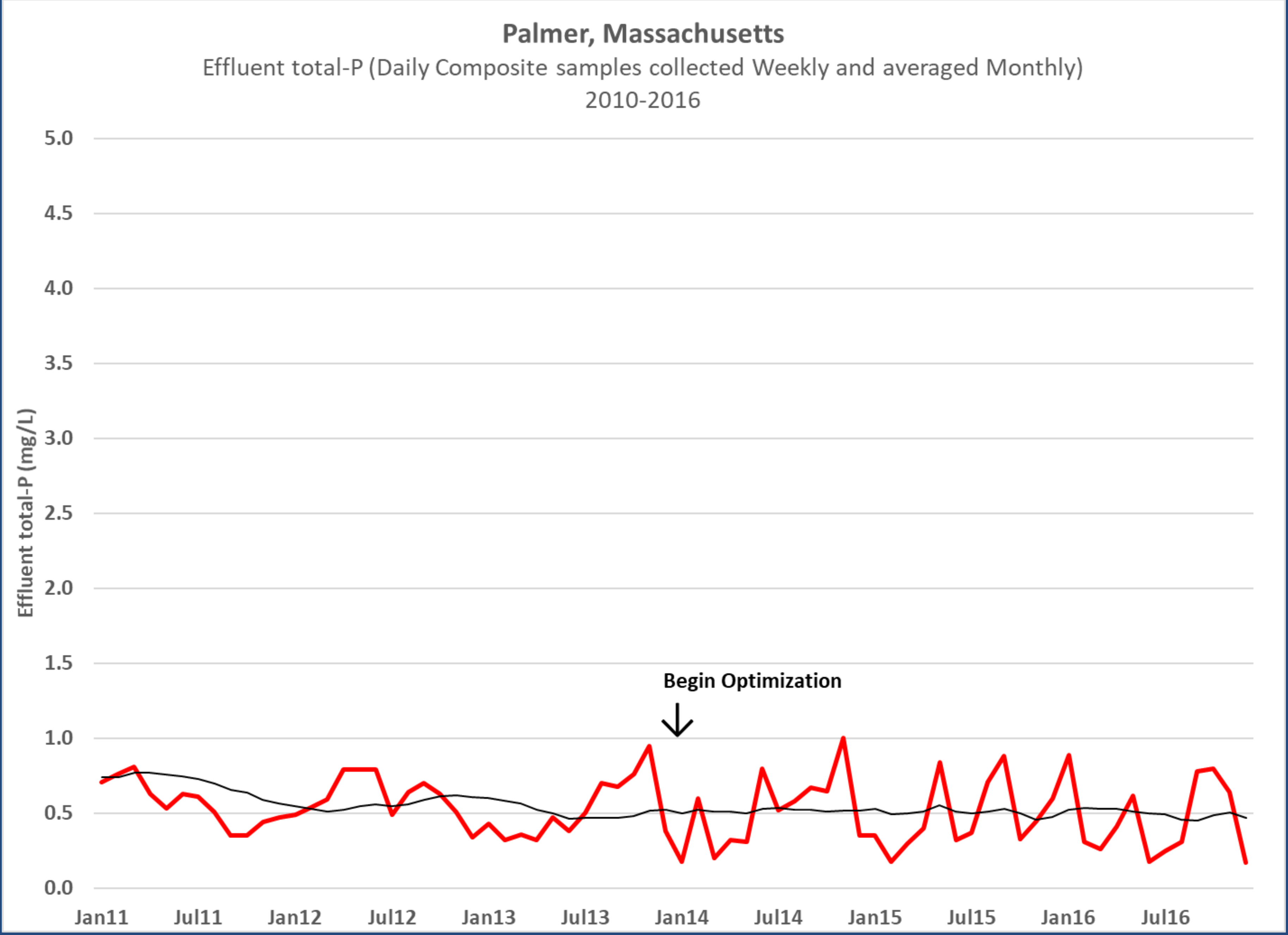
Plainfield Village





Phosphorus Removal

Palmer, Massachusetts
(5.6 MGD: 12,000 people)



Palmer, Massachusetts
Effluent total-P (Daily Composite samples collected Weekly and averaged Monthly)
2010-2016
Effluent total-P (mg/L)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Begin Optimization
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15
Jan16
Jul16

Case Study – Phosphorus Removal East Haddam, Connecticut

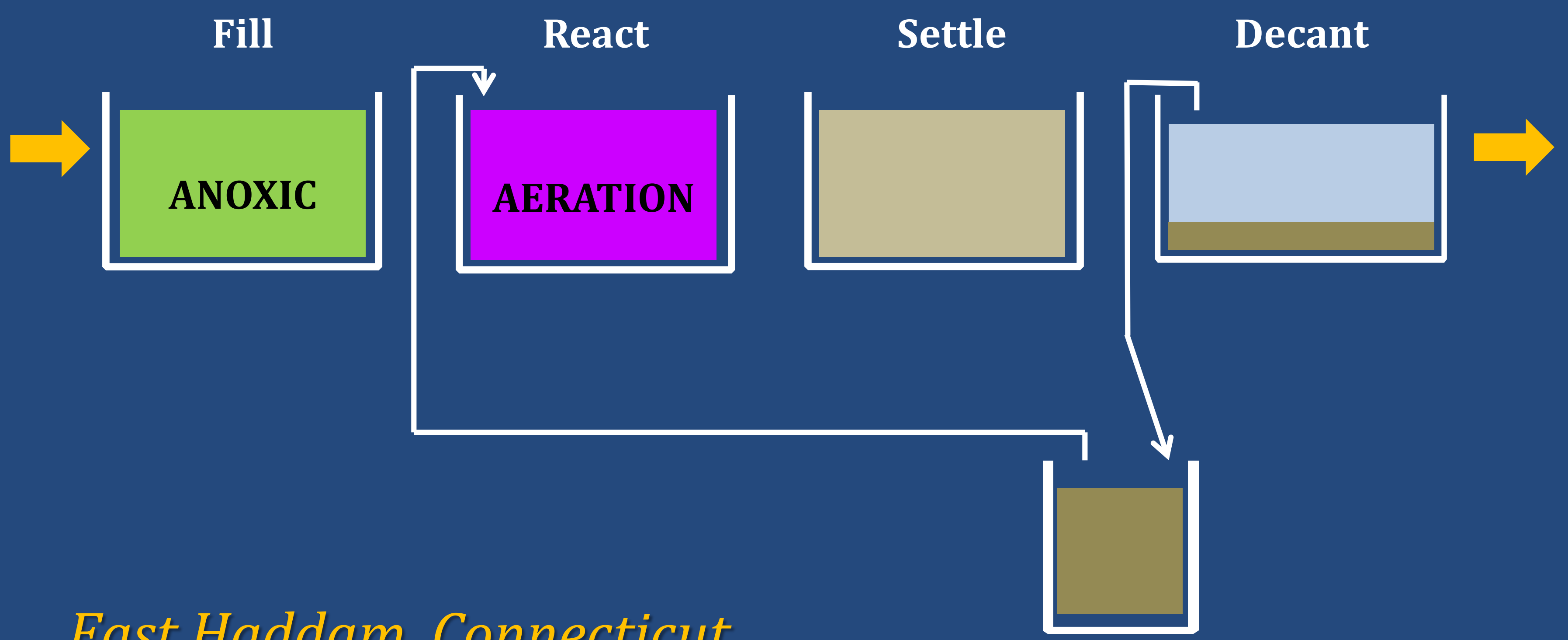
Design Flow: 0.055 MGD
Actual: 0.015 MGD

Effluent total-N

Before & After: 6.5 mg/L
(2 TKN, 0.5 Ammonia, 3.5 Nitrite + Nitrate)

Effluent total-P

Before Changes: 3-4 mg/L
After Changes: 0.35 mg/L



East Haddam, Connecticut


Keene, New Hampshire
6.0 MGD (23,000 people)

Optimizing Phosphorus removal in Oxidation Ditches


Suffield, Connecticut
2.0 MGD (16,000 people)

Suffield, Connecticut

Design Flow: 2.0 MGD
Actual: 1.0 MGD

Effluent total-N
Before Changes: 7 mg/L
(3 TKN, 0.5 Ammonia, 4 Nitrite + Nitrate)
After Changes: 1.0-2.0 mg/L
(1 TKN, 0.1 Ammonia, 1 Nitrite + Nitrate)

Effluent total-P
Before Changes: 3.0 mg/L
After Changes: 0.7 mg/L


Bartlett, Tennessee
2.2 MGD (58,000 people)


Athens - North Mouse Creek
1.2 MGD (13,600 people)


LaFollette, Tennessee
1.875 MGD (7,300 people)
La Follette Wastewater Plant

Optimizing Phosphorus removal in Orbal Oxidation Ditches


Athens – Oostanaula
6.0 MGD (13,600 people)

Optimizing Phosphorus removal in Activated Sludge


Helena, Montana
(5.4 MGD: 30,000 people)
Helena Waste Water Treatment Plant
Lewis & Clark Humane Soc
Google
Frontage Rd
Frontage Rd
Frontage Rd


Westfield, Massachusetts
(6.1 MGD: 41,000 people)

Optimizing Phosphorus removal in Sequencing Batch Reactors


Livingston, Tennessee
1.62 MGD (4,100 people)


Livingston, Tennessee
1.62 MGD (4,100 people)
Town Creek

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Making sustainably clean water

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Options for Monitoring Nitrogen and Phosphorus Removal

	Cheapest	Good	Better	Best	Ideal
Environmental conditions					
DO	hand held membrane DO meter	hand held LDO meter	hand held LDO with thumb drive	in-line DO probe	in-line connected to SCADA
ORP	pen/stick measure	hand held ORP meter	hand held ORP meter with thumb drive	in-line ORP probe	in-line connected to SCADA
pH	test strips	pen/stick measure	benchtop pH	in-line pH probe	in-line connected to SCADA
Alkalinity	test strips	test strips	spectrophotometer	benchtop pH w/ titration	benchtop pH w/ titration
Nitrogen					
TKN	estimate: Ammonia + 2.0 mg/L	estimate: Ammonia + 2.0 mg/L	spectrophotometer	spectrophotometer	spectrophotometer
Ammonia	test strips	test strips	spectrophotometer	in-line instrument ($$)	in-line connected to SCADA ($$)
Nitrate	test strips	test strips	spectrophotometer	in-line instrument ($$)	in-line connected to SCADA ($$)
Nitrite	test strips	test strips	spectrophotometer	spectrophotometer	spectrophotometer
Phosphorus					
total-P	estimate: TSSx0.05 + test strips	estimate: TSSx0.05 + test strips	spectrophotometer	spectrophotometer	spectrophotometer
ortho-P	test strips	test strips	spectrophotometer	in-line instrument ($$)	in-line connected to SCADA ($$)

Options for Monitoring Nitrogen and Phosphorus Removal: Small Plants – Less than 1.0 MGD

	Cheapest	Good	Better	Best	Ideal
Environmental conditions					
DO	hand held membrane DO meter	**hand held LDO meter**	hand held LDO with thumb drive	in-line DO probe	in-line connected to SCADA
ORP	pen/stick measure	**hand held ORP meter**	hand held ORP meter with thumb drive	in-line ORP probe	in-line connected to SCADA
pH	test strips	**pen/stick measure**	benchtop pH	in-line pH probe	in-line connected to SCADA
Alkalinity	test strips	**test strips**	spectrophotometer	benchtop pH w/ titration	benchtop pH w/ titration
Nitrogen					
TKN	estimate: Ammonia + 2.0 mg/L	**estimate: Ammonia + 2.0 mg/L**	spectrophotometer	spectrophotometer	spectrophotometer
Ammonia	test strips	**test strips**	spectrophotometer	in-line instrument (\$\$)	in-line connected to SCADA (\$\$)
Nitrate	test strips	**test strips**	spectrophotometer	in-line instrument (\$\$)	in-line connected to SCADA (\$\$)
Nitrite	test strips	**test strips**	spectrophotometer	spectrophotometer	spectrophotometer
Phosphorus					
total-P	estimate: TSSx0.05 + test strips	**estimate: TSSx0.05 + test strips**	spectrophotometer	spectrophotometer	spectrophotometer
ortho-P	test strips	**test strips**	spectrophotometer	in-line instrument (\$\$)	in-line connected to SCADA (\$\$)

Options for Monitoring Nitrogen and Phosphorus Removal: 2-5 MGD

Environmental conditions

	Cheapest	Good	Better	Best	Ideal
DO	hand held membrane DO meter	hand held LDO meter	hand held LDO with thumb drive	in-line DO probe	in-line connected to SCADA
ORP	pen/stick measure	hand held ORP meter	hand held ORP meter with thumb drive	in-line ORP probe	in-line connected to SCADA
pH	test strips	pen/stick measure	benchtop pH	in-line pH probe	in-line connected to SCADA
Alkalinity	test strips	test strips	spectrophotometer	benchtop pH w/ titration	benchtop pH w/ titration

Nitrogen

	Cheapest	Good	Better	Best	Ideal
TKN	estimate: Ammonia + 2.0 mg/L	estimate: Ammonia + 2.0 mg/L	spectrophotometer	spectrophotometer	spectrophotometer
Ammonia	test strips	test strips	spectrophotometer	in-line instrument ($$)	in-line connected to SCADA ($$)
Nitrate	test strips	test strips	spectrophotometer	in-line instrument ($$)	in-line connected to SCADA ($$)
Nitrite	test strips	test strips	spectrophotometer	spectrophotometer	spectrophotometer

Phosphorus

	Cheapest	Good	Better	Best	Ideal
total-P	estimate: TSSx0.05 + test strips	estimate: TSSx0.05 + test strips	spectrophotometer	spectrophotometer	spectrophotometer
ortho-P	test strips	test strips	spectrophotometer	in-line instrument ($$)	in-line connected to SCADA ($$)

Options for Monitoring Nitrogen and Phosphorus Removal: 5+ MGD … or, 6 mg/L tN limit or 0.5 mg/L tP limit

	Cheapest	Good	Better	Best	Ideal
Environmental conditions					
DO	hand held membrane DO meter	hand held LDO meter	hand held LDO with thumb drive	in-line DO probe	in-line connected to SCADA
ORP	pen/stick measure	hand held ORP meter	hand held ORP meter with thumb drive	in-line ORP probe	in-line connected to SCADA
pH	test strips	pen/stick measure	benchtop pH	in-line pH probe	in-line connected to SCADA
Alkalinity	test strips	test strips	spectrophotometer	benchtop pH w/ titration	benchtop pH w/ titration
Nitrogen					
TKN	estimate: Ammonia + 2.0 mg/L	estimate: Ammonia + 2.0 mg/L	spectrophotometer	spectrophotometer	spectrophotometer
Ammonia	test strips	test strips	spectrophotometer	in-line instrument (\$\$)	in-line connected to SCADA (\$\$)
Nitrate	test strips	test strips	spectrophotometer	in-line instrument (\$\$)	in-line connected to SCADA (\$\$)
Nitrite	test strips	test strips	spectrophotometer	spectrophotometer	spectrophotometer
Phosphorus					
total-P	estimate: TSSx0.05 + test strips	estimate: TSSx0.05 + test strips	spectrophotometer	spectrophotometer	spectrophotometer
ortho-P	test strips	test strips	spectrophotometer	in-line instrument (\$\$)	in-line connected to SCADA (\$\$)