Nutrient Optimization: Why? How? What?

Operator Training Committee of Ohio
Compliance Workshop
Columbus, OH
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President
CleanWaterOps.com, an ERG subcontractor

Nutrient Optimization: Why, How & What

Why

- Facility Planning solutions can be very expensive
- Optimizing existing facilities is often quicker and more sustainable

How

- Create optimal habitats for N&P removal

What: Case Studies

- Chinook, Montana
- Conrad, Montana
- Cookeville, Tennessee
- Palmer, Massachusetts

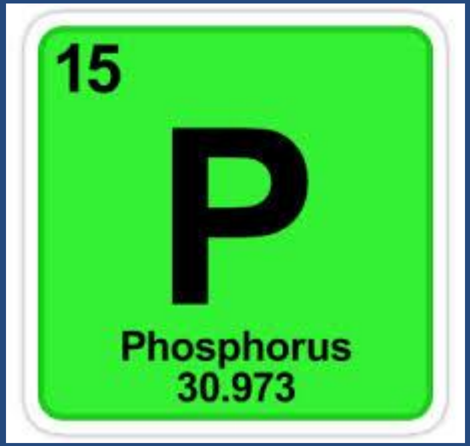
Cost of Nutrient Removal

	Effluent Concentration	Capital Cost ($/MGD)	O&M Cost ($/yr/MGD)
Nitrogen	3-8 mg/L	0-$98 million	0-$1.8 million
Phosphorus	1 mg/L or less	$30,000-$22 million	$40,000-$2.3 million
	1 mg/L +	$50,000-$13 million	0-$1.5 million

Source: EPA 2015 "A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution"

OPERATIONS CHALLENGE™

Change day-to-day operations to create ideal habitats for bacteria to remove Nitrogen & Phosphorus


15
P
Phosphorus
30.973

Phosphorus Removal:
What an Operator needs to know

ONE. Convert soluble phosphorus to TSS …

Biologically

Chemically

TWO. Remove TSS

Biological Phosphorus Removal

Step 1: prepare "dinner"

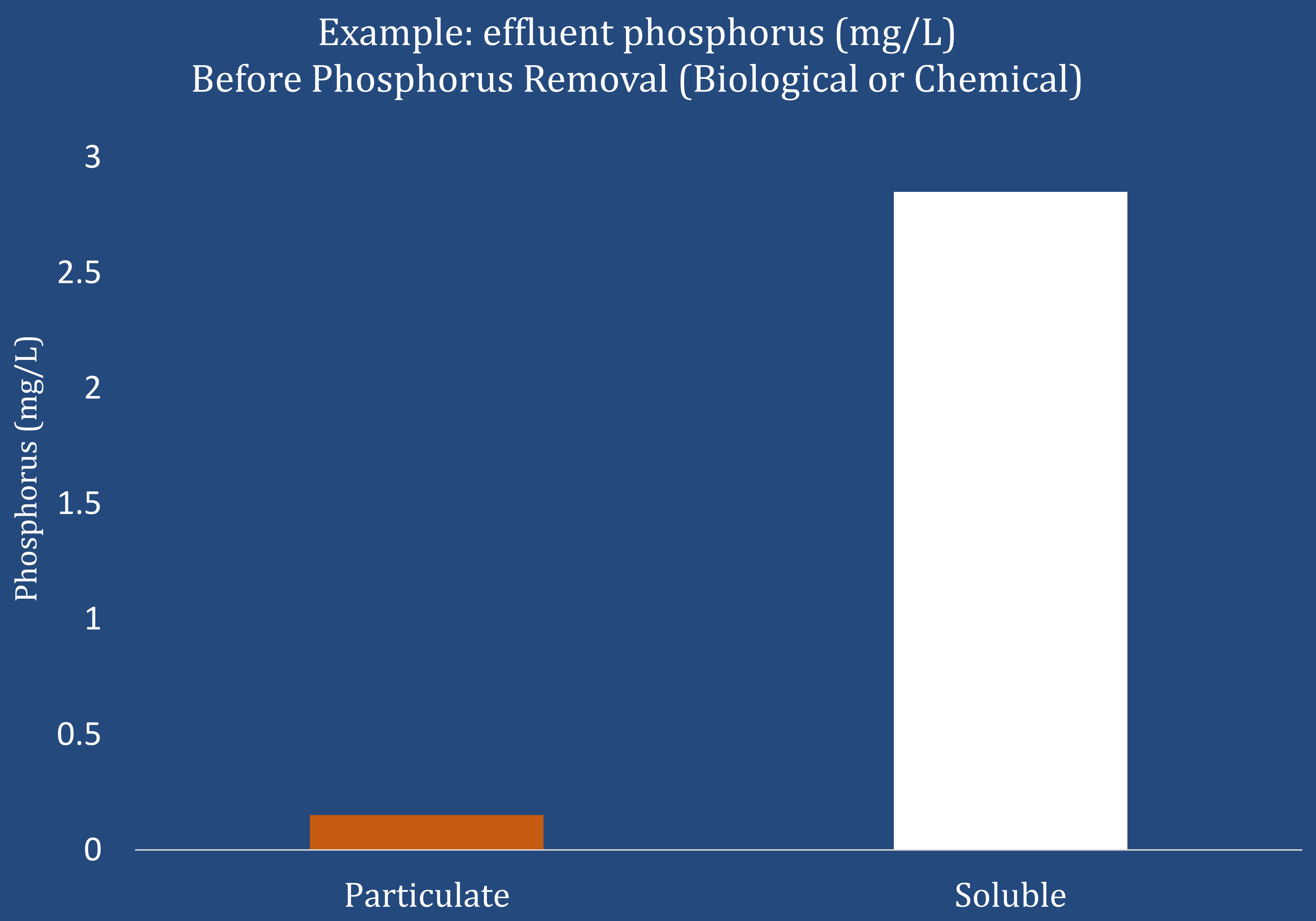
VFA (volatile fatty acids) production in anaerobic/fermentive conditions

Step 2: "eat"

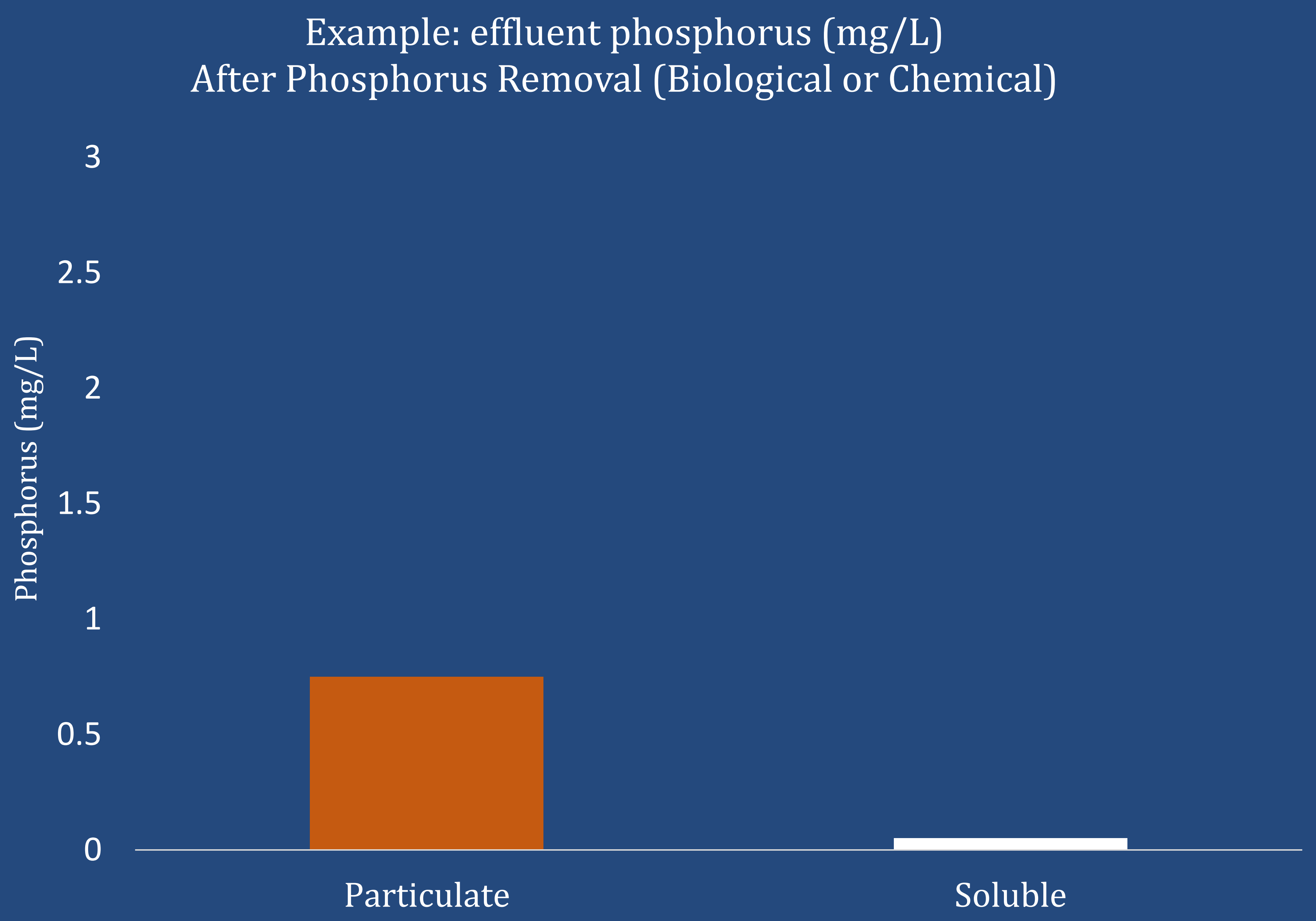
Bio-P bugs (PAOs) eat VFAs in anaerobic/fermentive conditions … temporarily releasing more P into the water

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



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


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

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

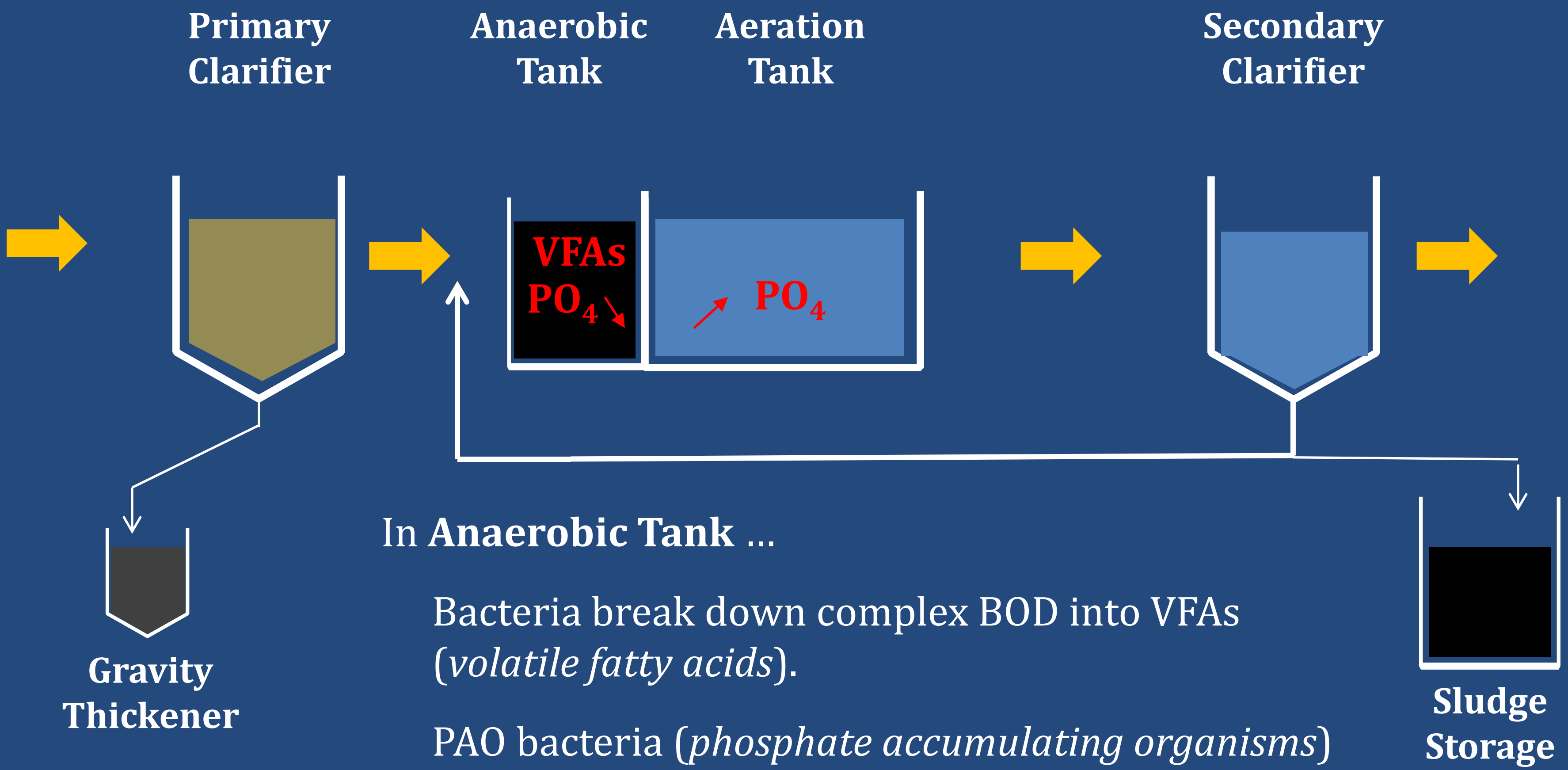
Phosphorus Removal without Facility Upgrades

	t-P Before	t-P After
Conrad, MT	2.1	0.2
Chinook, MT	2.8	0.3
Westfield, MA	1.0	0.5*
Palmer, MA	0.65	0.65*
Cookeville, TN	3	0.8
Montague, MA	3	0.9
Athens, TN	3	1.8*

*chemical reduction of 50% or more

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*).

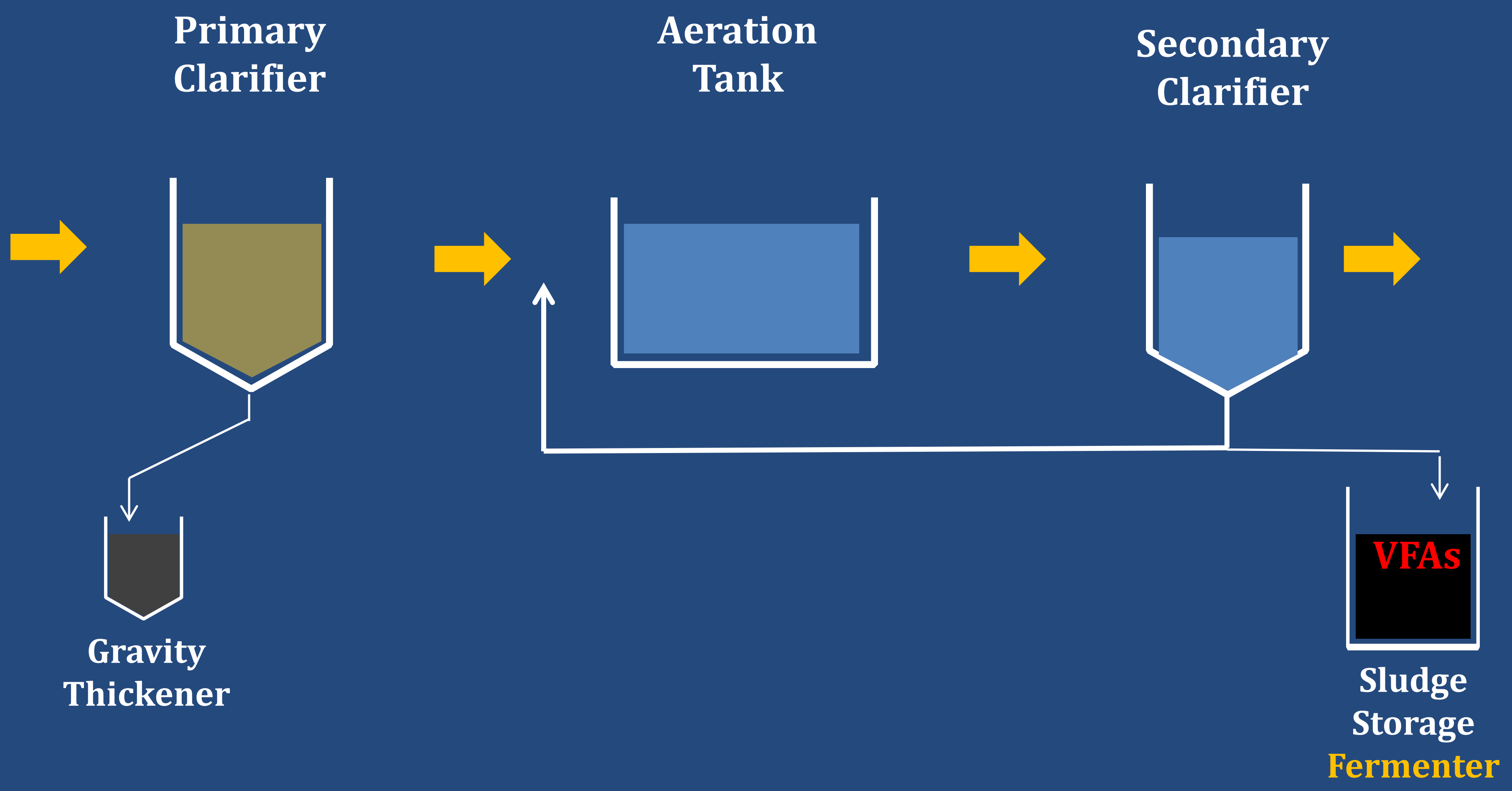
PAO bacteria (*phosphate accumulating organisms*) take in VFAs as energy source & temporarily release PO_4 (*phosphate*) into solution.

In **Aeration Tank** ...

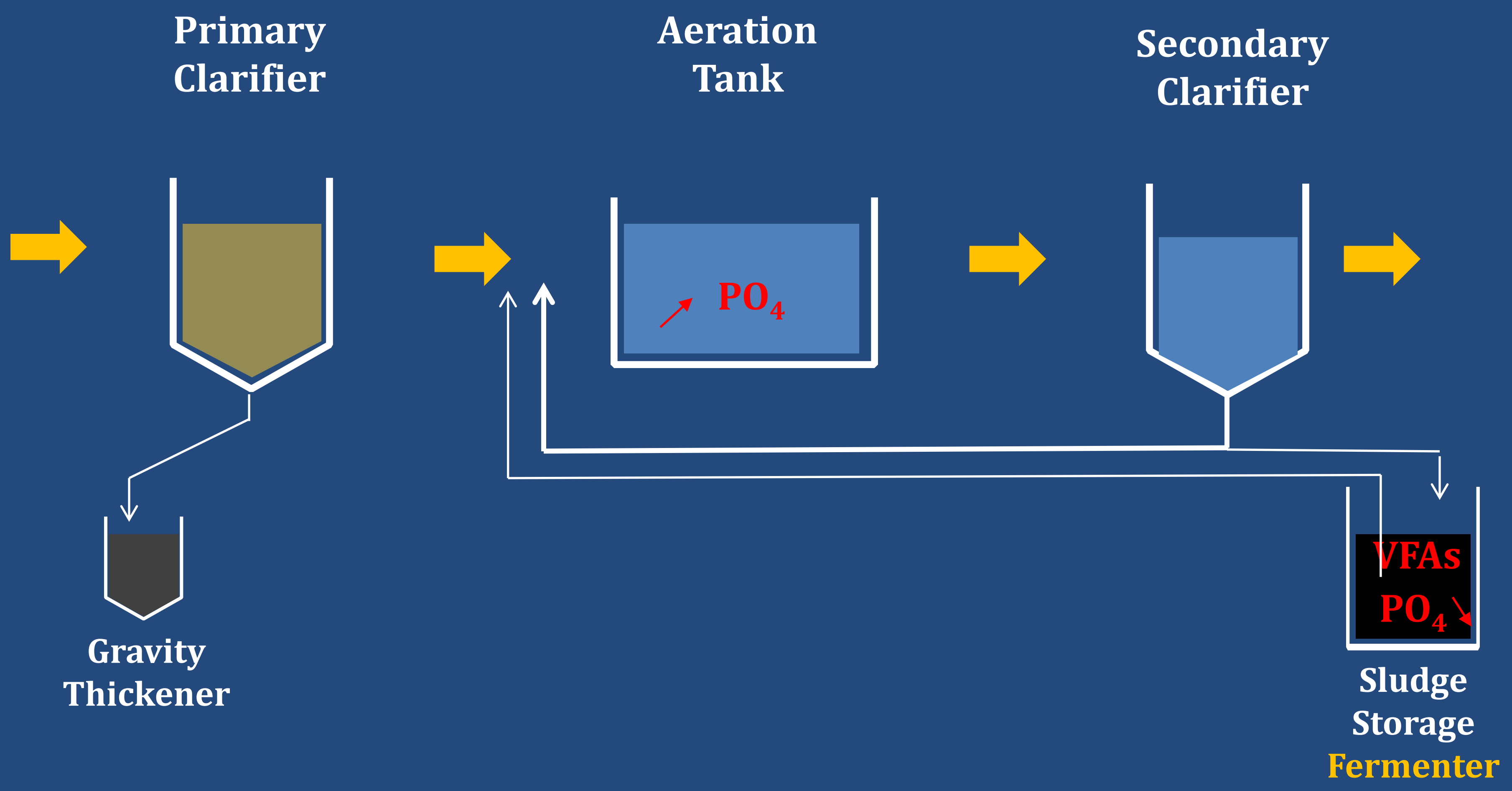
Energized PAO bacteria take PO_4 out of solution.

Biological Phosphorus Removal:
Sidestream Flow Fermentation Processes

Sidestream Biological-P Removal: Sludge Storage

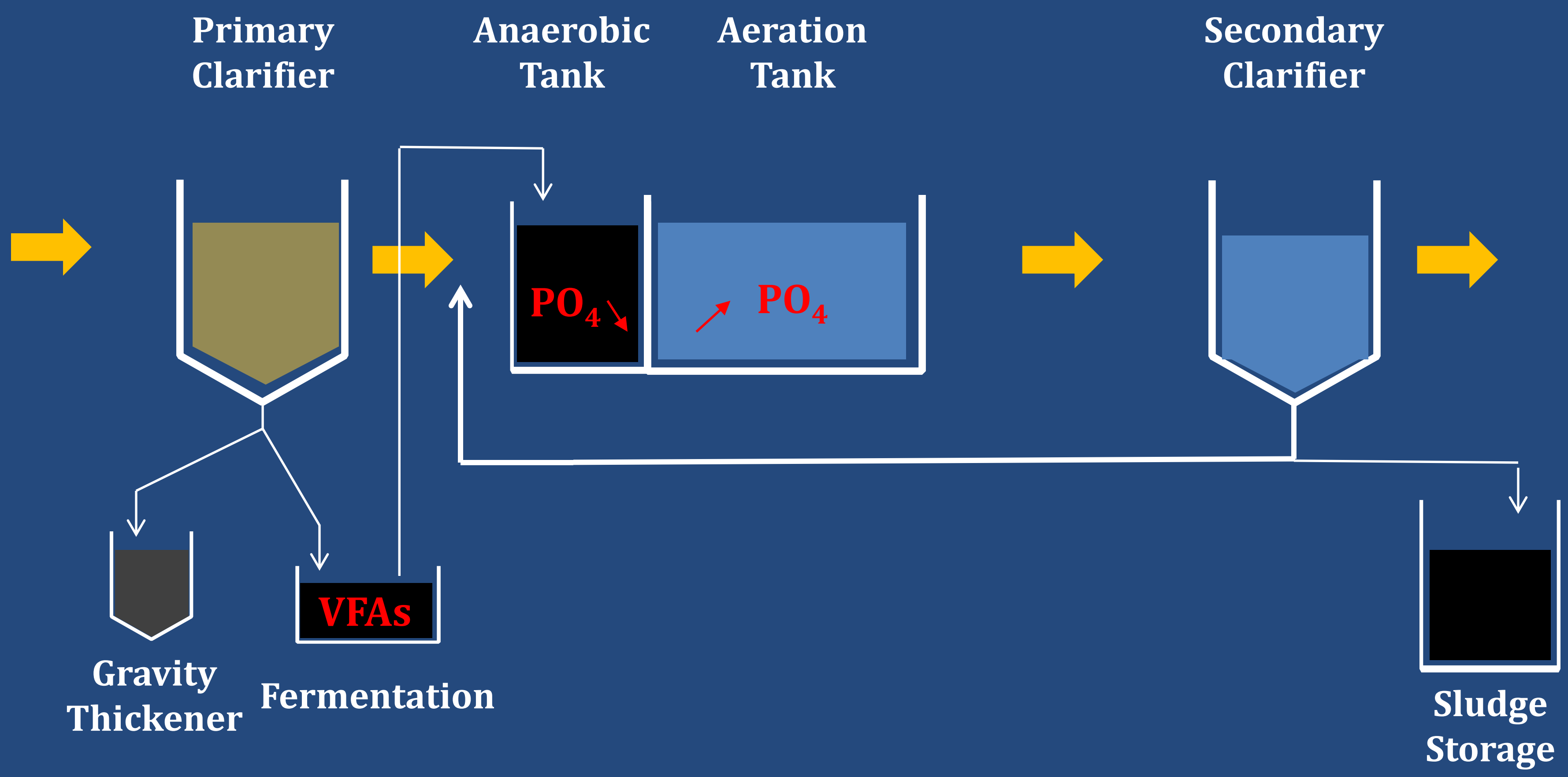


Sidestream Biological-P Removal: Sludge Storage



Biological Phosphorus Removal: Combined Sidestream & Mainstream Fermentation

Bio-P Removal: Sidestream & Mainstream Fermentation



Optimizing Bio-P Removal: Mainstream, Sidestream or Combination Fermentation

Anaerobic Tank

~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)*

Aeration Tank

High DO / High ORP

pH of 6.8+*

Ortho-P concentration of 0.05 mg/L*

*Approximate: Every Plant is Different

7

N

Nitrogen

Ammonia Removal

Ammonia (NH_4) is converted to Nitrate (NO_3)

Ammonia

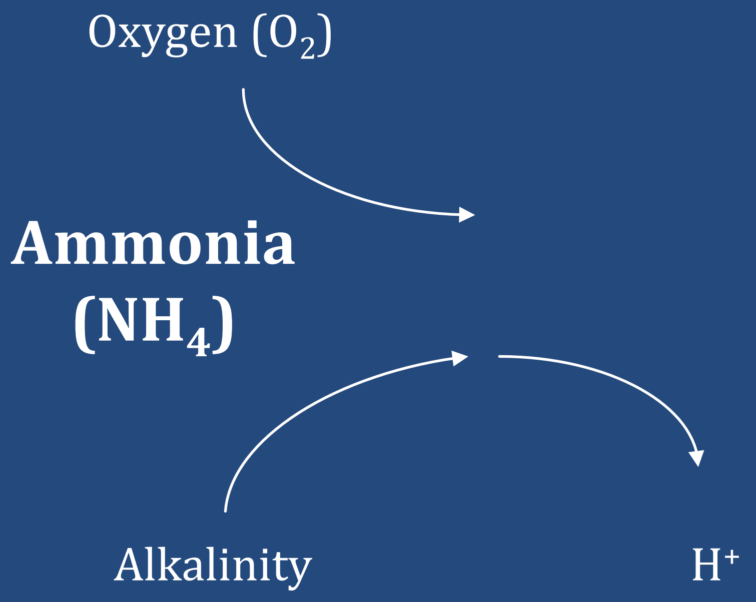
(NH_4)

Ammonia Removal

Oxygen (O_2)

Ammonia
(NH_4)

Ammonia Removal



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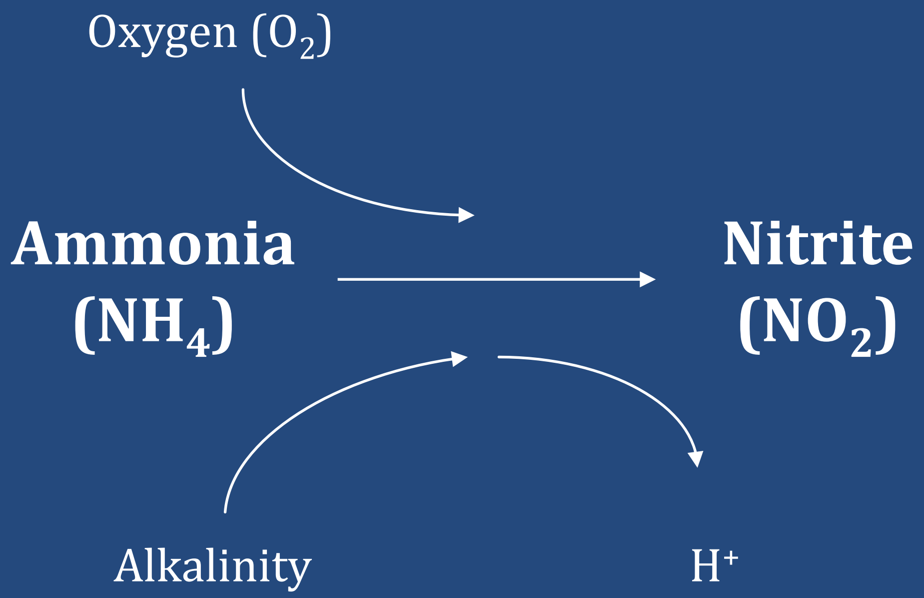

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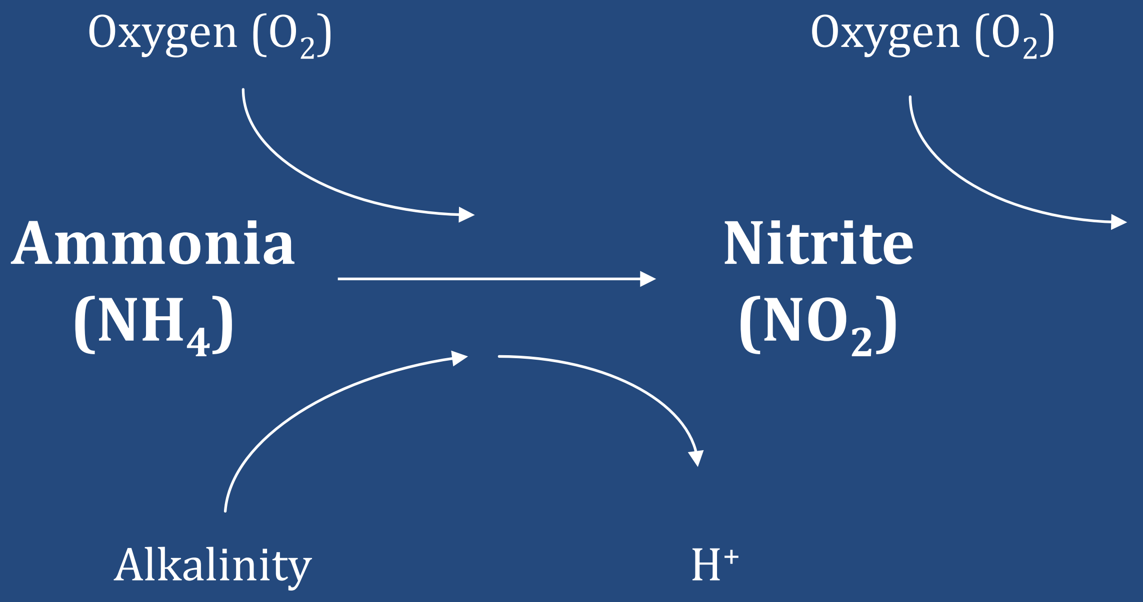

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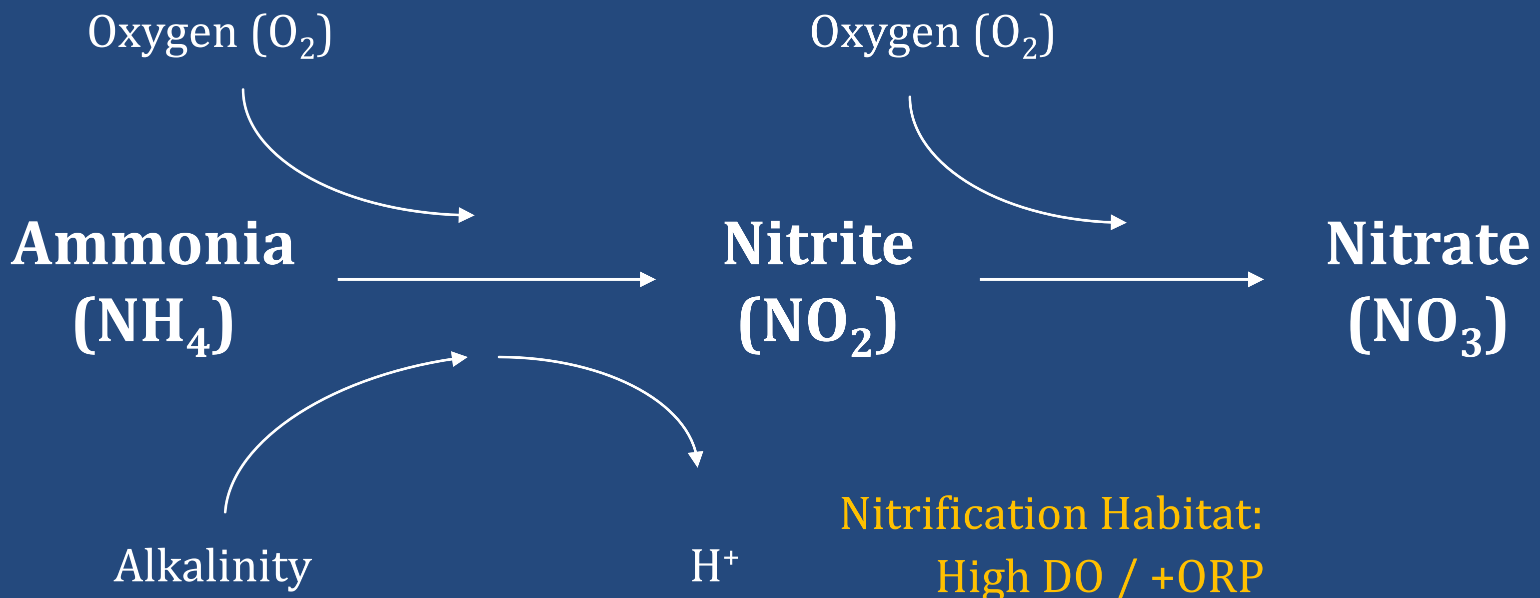


Nitrification Habitat:

- High DO / +ORP
- Low BOD
- High MLSS/MCRT
- High HRT

Consumes oxygen
Consumes alkalinity: lowers pH

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

<u>Oxygen Rich Habitat</u>

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.

Biological Nitrogen Removal:
Next,
The Nitrate (NO_3) created during Nitrification …
is converted to Nitrogen Gas (N_2)

Nitrate Removal

Nitrate
(NO_3)

Nitrate Removal

BOD

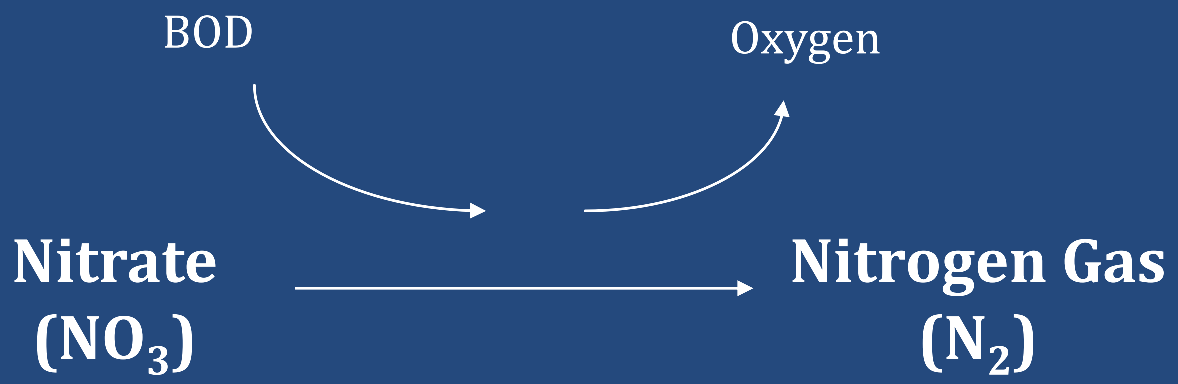
Nitrate
(NO_3)

Nitrate Removal

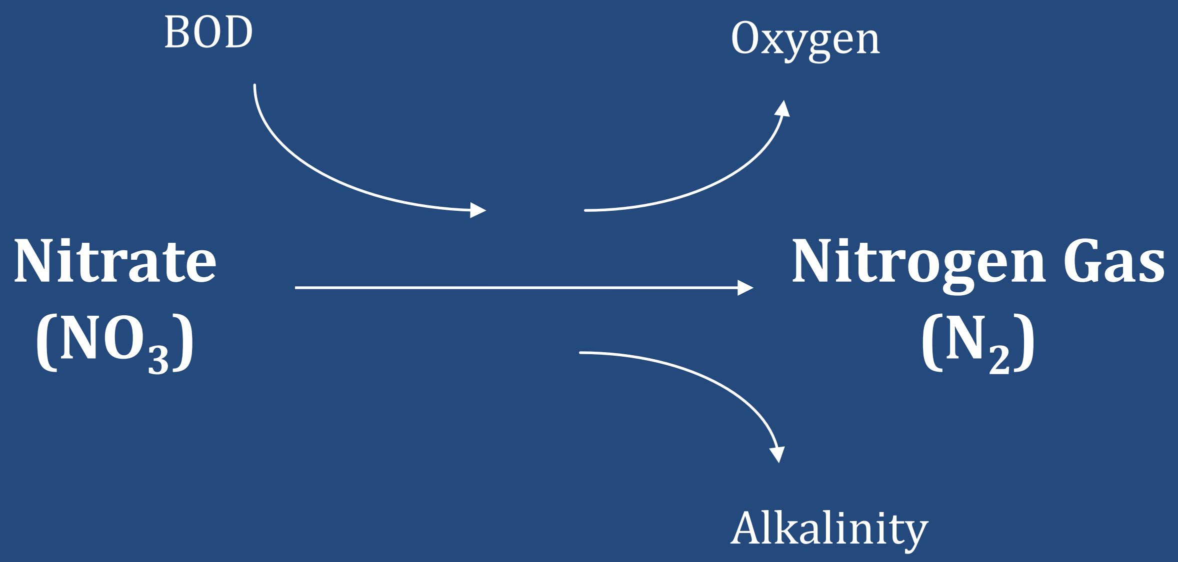
BOD

Nitrate (NO_3) → **Nitrogen Gas (N_2)**

Nitrate Removal



Nitrate Removal



Denitrification Habitat:

- Low DO / -ORP
- High BOD

Adds DO

Gives back ½ the alkalinity: beneficially raises pH

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

<u>Oxygen Poor Habitat</u>

ORP* of -100 mV or less (DO < 0.3 mg/L)

Surplus BOD* (100-250 mg/L: 5-10 times as much as NO_3)

Retention Time* of 45-90 minutes

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	**1. Nitrification** Ammonia Removal $NH_4 \rightarrow NO_3$	**2. Denitrification** Nitrate Removal $NO_3 \rightarrow N_2$
DO: Dissolved Oxygen	>1 mg/L	<0.3 mg/L
ORP: Oxygen Reduction Potential	>+100 mV	<-100 mV
MLSS	>2500 mg/L	>2500 mg/L
HRT (Hydraulic Retention Time)	>6 hr	~1 hr
BOD: Biochemical Oxygen Demand	<20 mg/L	>100 mg/L
Alkalinity	>60 mg/L	NA
	Alkalinity is lost	Alkalinity is gained

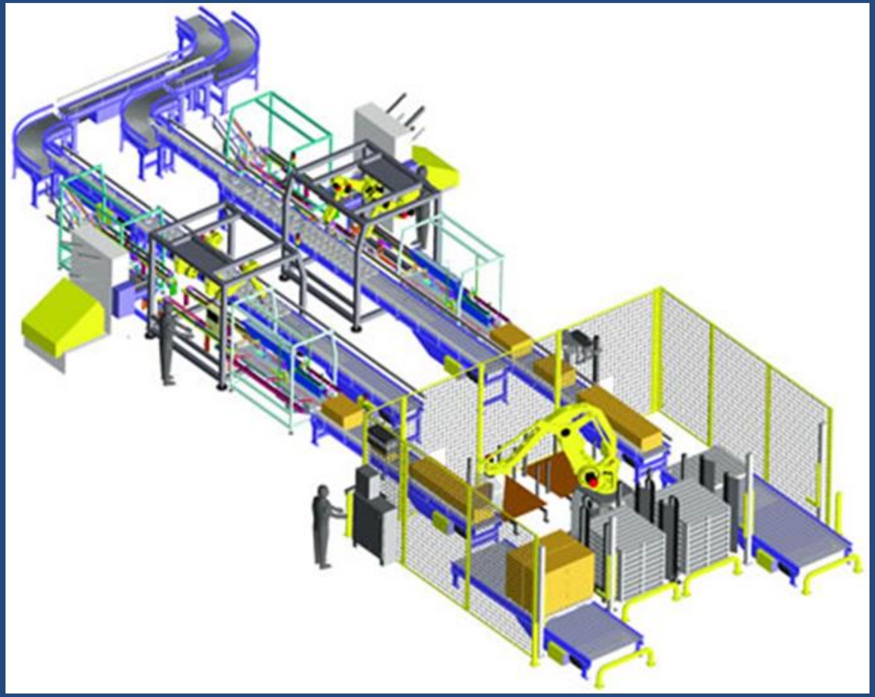
Notes:

> means "greater than"
< means "less than"
~ means "approximately“
All numbers are “rules of thumb”

Nitrogen Removal without Facility Upgrades

	t-N Before	t-N After
Suffield, CT	7	2
Chinook, MT	26	3
Hardin, MT	18	4
Conrad, MT	35	5
Montague, MA	30	5
Cookeville, TN	25	5
Upton, MA	22	6
Plainfield, CT	25	10
Colchester-East Hampton, CT	24	12
Big Sky, MT	25	14
Libby, MT	32	21

Technology!



MLE (Modified Ludzack-Ettinger) Process

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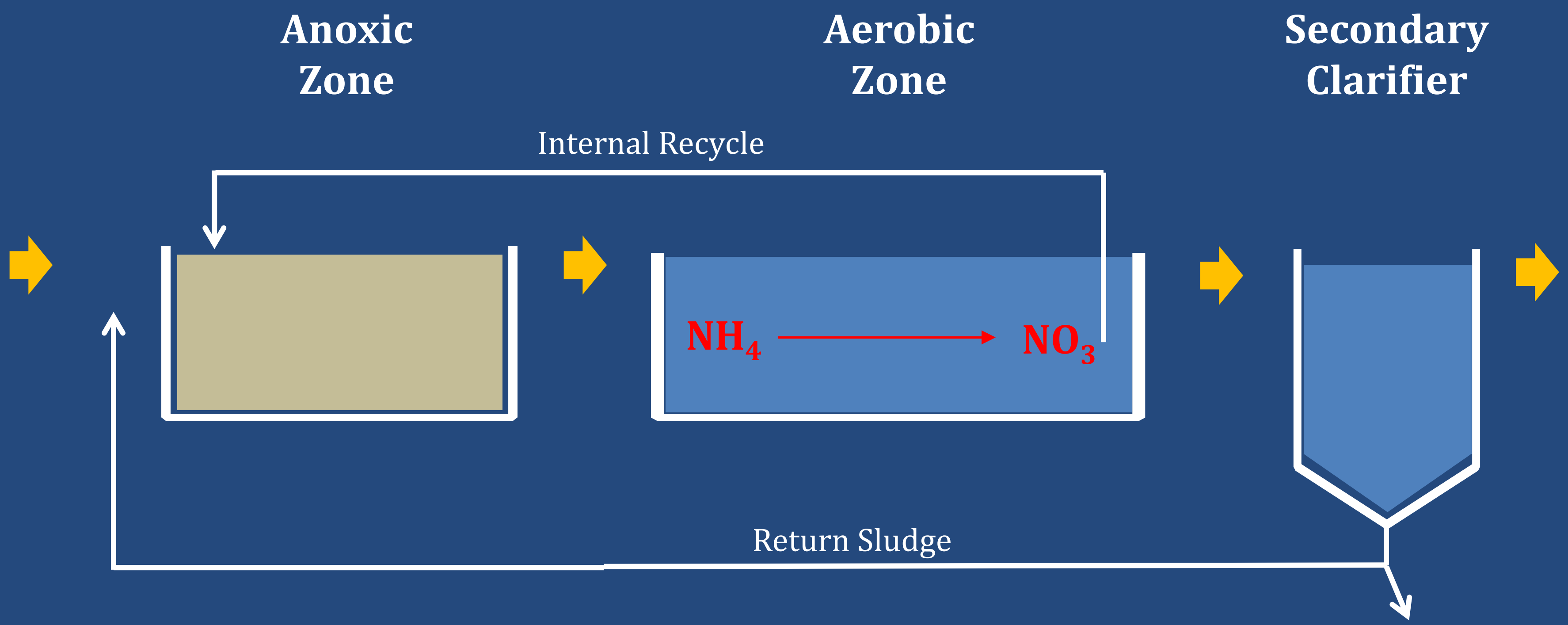

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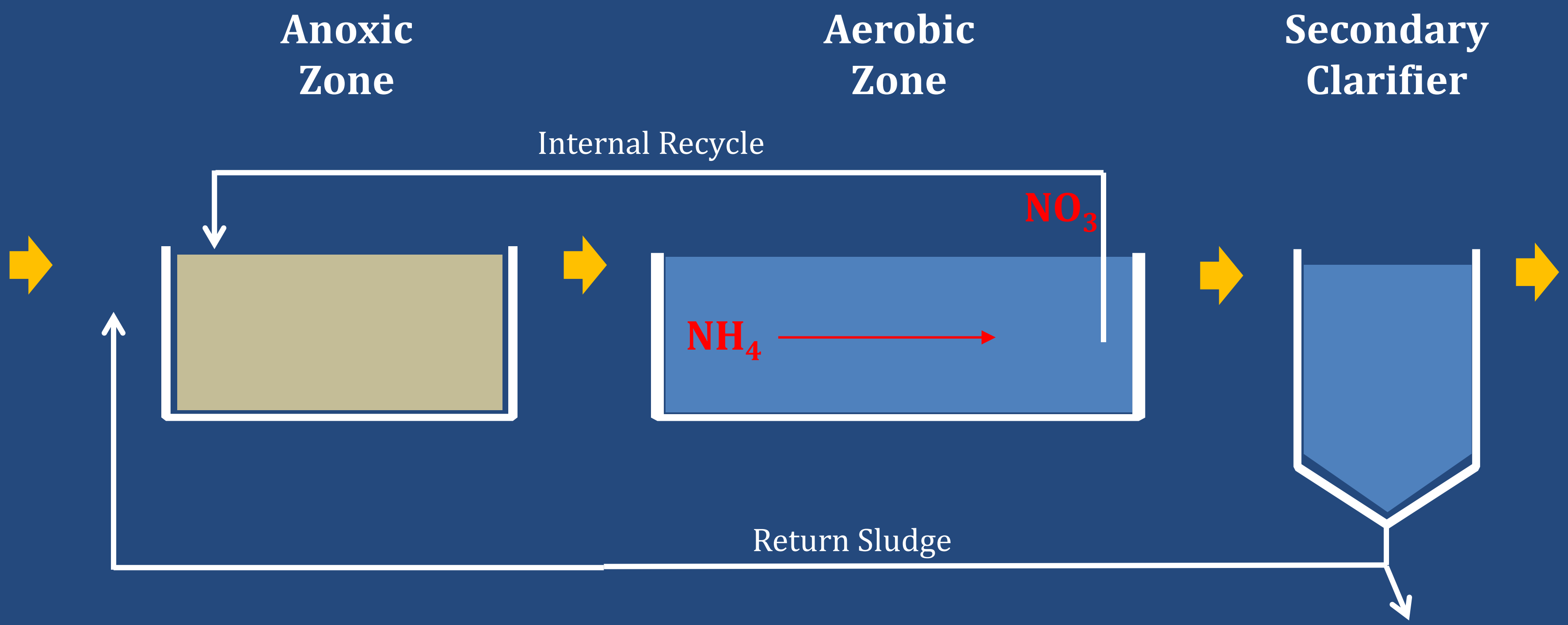

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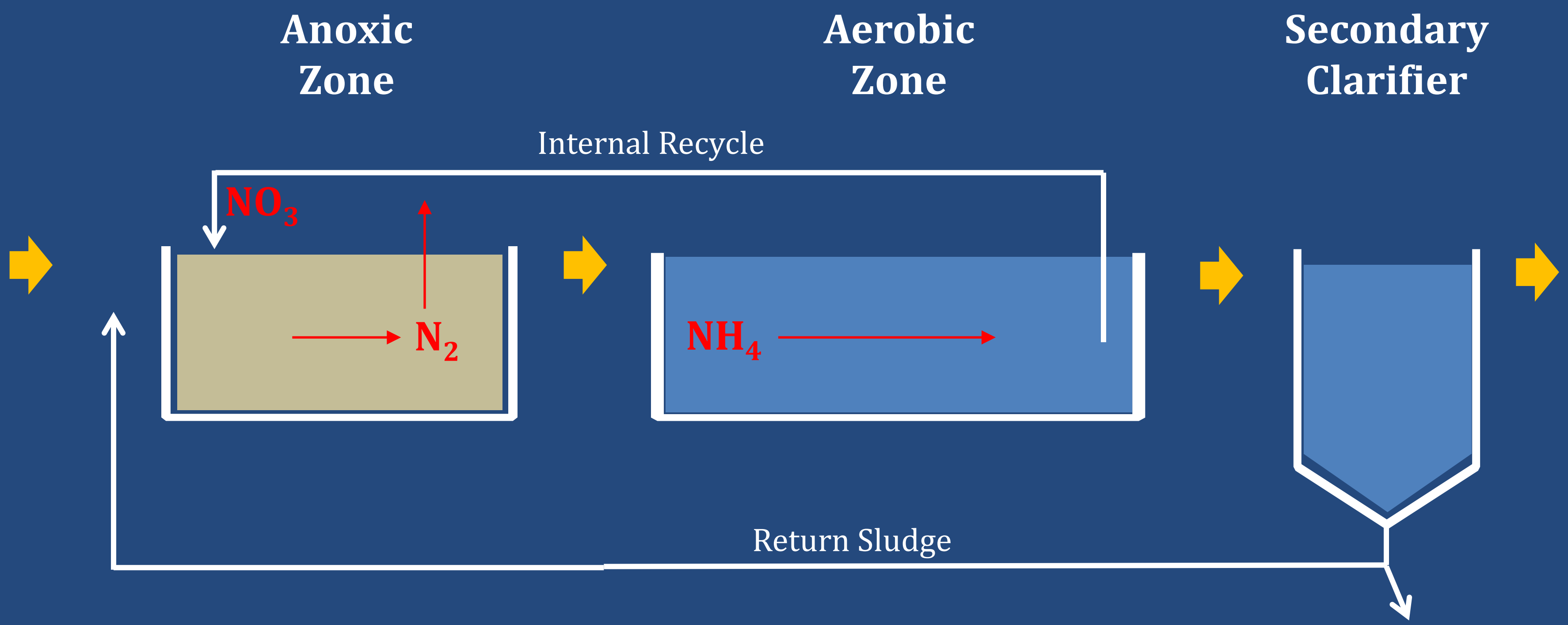


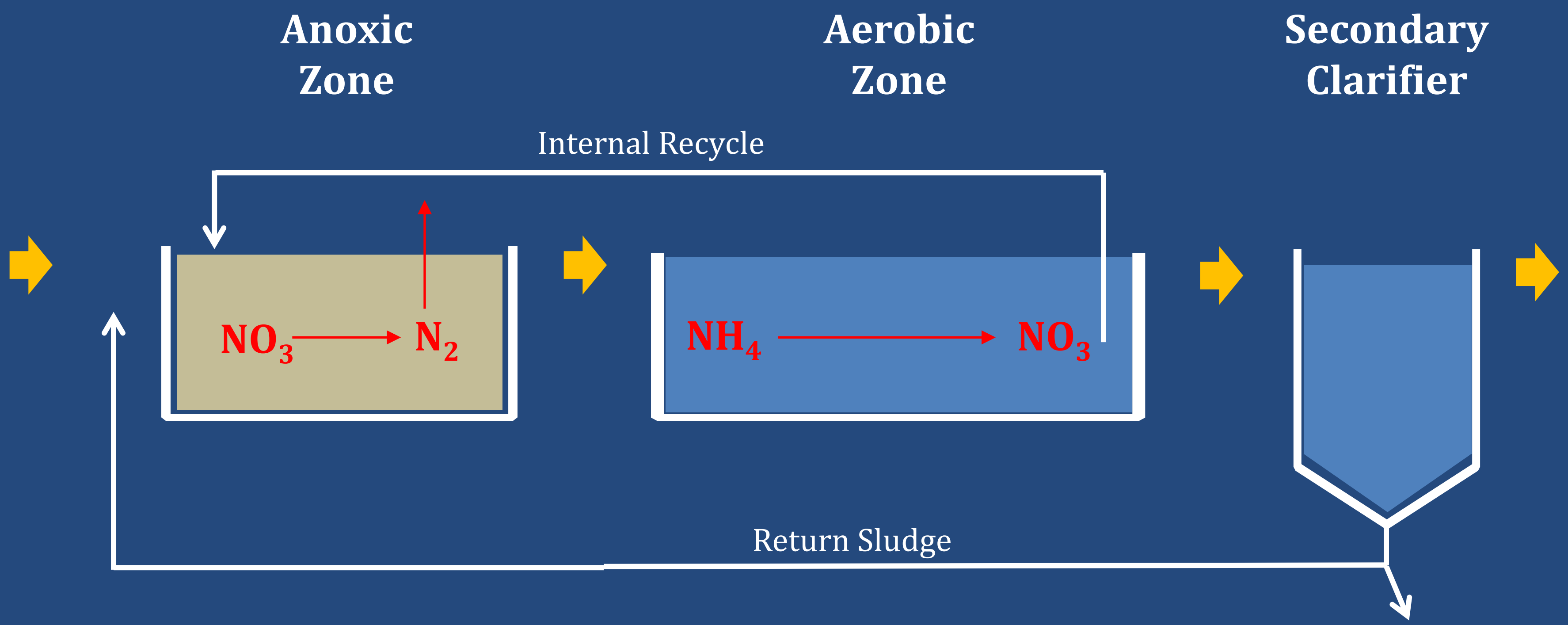
Ammonia (NH_4) Removal

Target: $NH_4 < 0.5$ mg/L

Nitrate (NO_3) Removal

Target NO_3 in Anoxic Tank: 0.5-2 mg/L

MLE (Modified Ludzack-Ettinger) Process



MLE Process Control:

Proper Internal Recycle Rate; not too much / not too little.

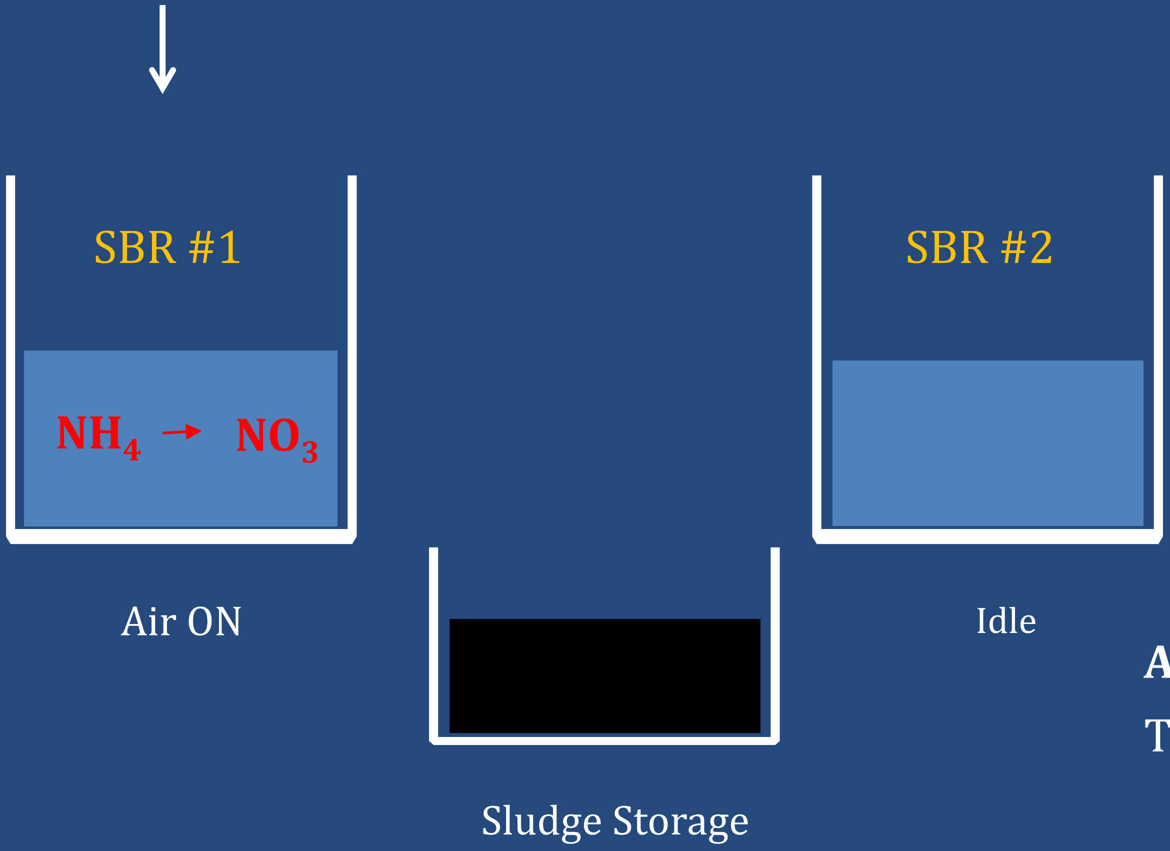
ORP of +100 mV in Aerobic Zone for Ammonia (NH_4) Removal.

ORP of -75 to -150 mV in Anoxic Zone for Nitrate (NO_3) Removal.

Enough BOD to support Nitrate (NO_3) Removal.


Sequencing Batch Reactor
SBR

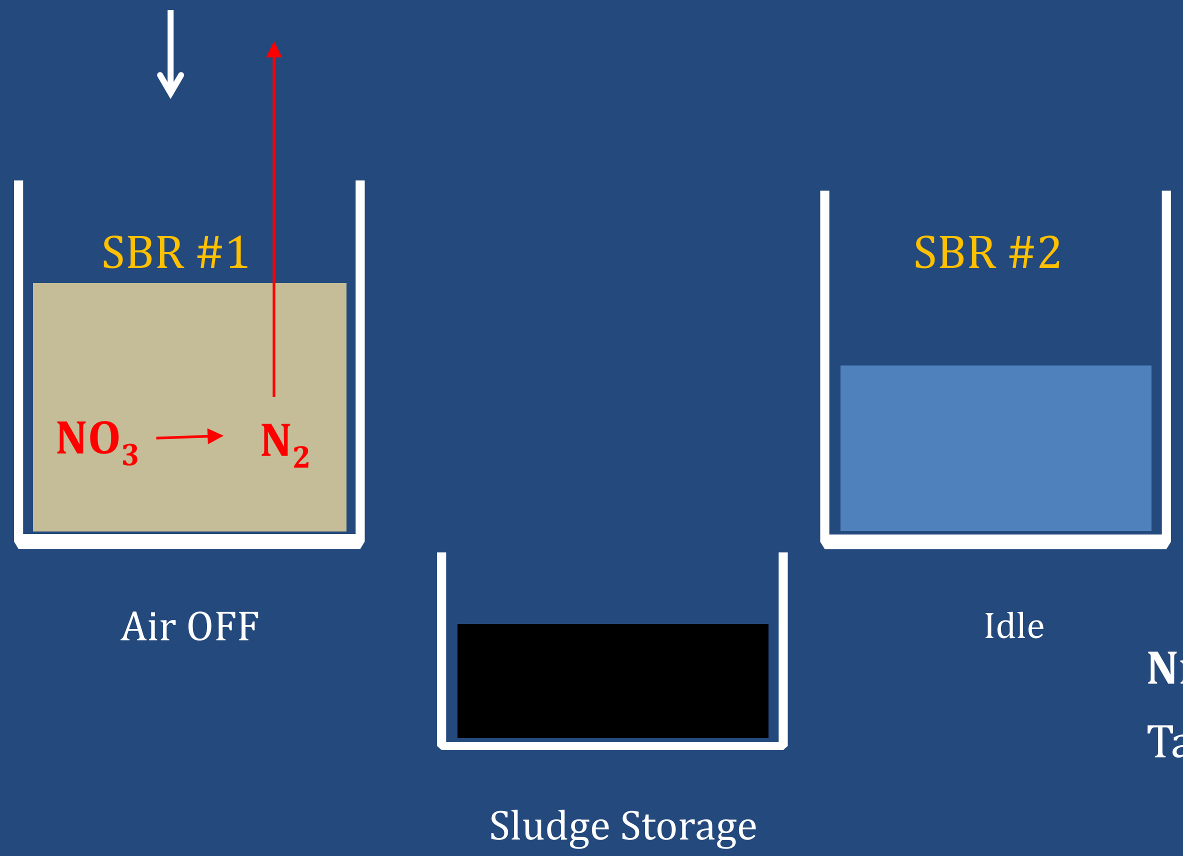
Sequencing Batch Reactor (SBR)
Ammonia (NH_4) Removal: Nitrification



Ammonia (NH_4) Removal

Target: $NH_4 < 0.5$ mg/L

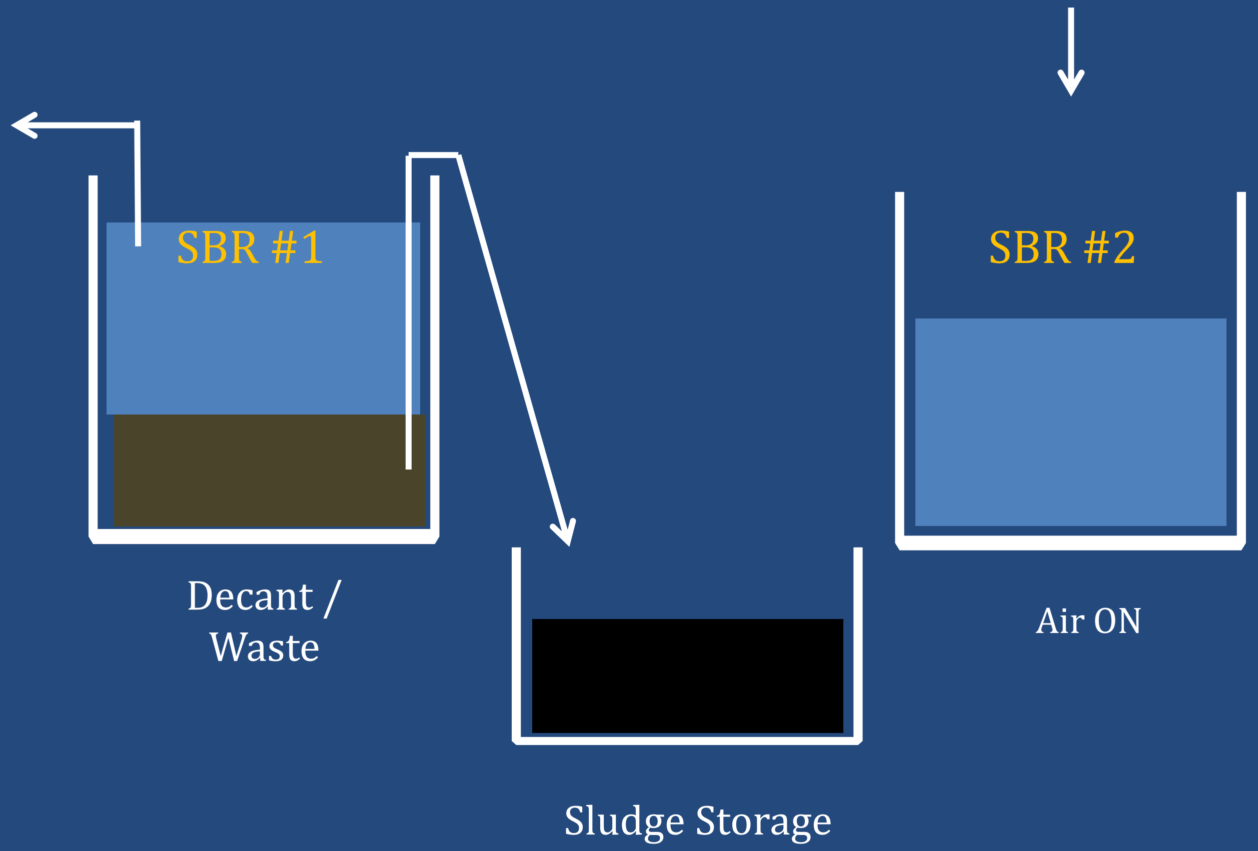
Sequencing Batch Reactor (SBR)
Nitrate (NO_3) Removal: Denitrification



Nitrate (NO_3) Removal

Target: $NO_3 < 4$ mg/L

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



SBR Process Control:

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

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

Optimizing SBR cycle time

Too short

Will not reach +100 mV for Ammonia (NH_4) Removal.

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

Note: Temperature and BOD affect Air OFF cycle.

Too long

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

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

Just right

Good habitats …

- ORP of +100 mV for 60 minutes
- And, ORP of -100 mV for 30 minutes.

Bonus: Changing conditions will serve as a selector.

Case Study
research
case
subject
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cases
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may
thus
focus
Outlier
information
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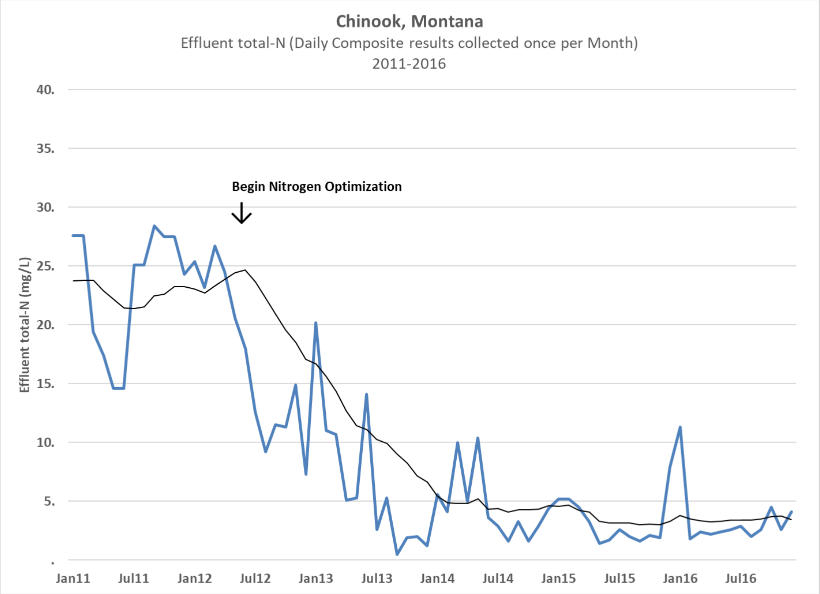
based
criteria
multiple
local
whether
retrospective
evidence
theory-testing
historical
approach
researchers
data
typology
established
in-depth
quantitative
key
offer
sampling
selecting
frame
researcher
become
lines
set


Chinook, Montana


Chinook, Montana
Effluent total-N (Daily Composite results collected once per Month)
2011-2016
Begin Nitrogen Optimization
Effluent total-N (mg/L)
40.
35.
30.
25.
20.
15.
10.
5.
Jan11
Jul11
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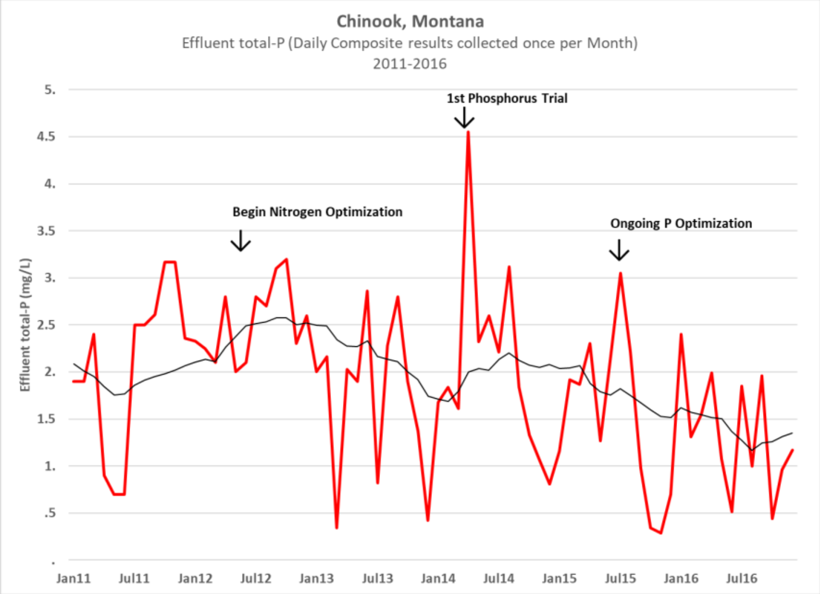
Chinook, Montana
Effluent total-P (Daily Composite results collected once per Month)
2011-2016
1st Phosphorus Trial
Begin Nitrogen Optimization
Ongoing P Optimization
Effluent total-P (mg/L)
5.
4.5
4.
3.5
3.
2.5
2.
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Jan11
Jul11
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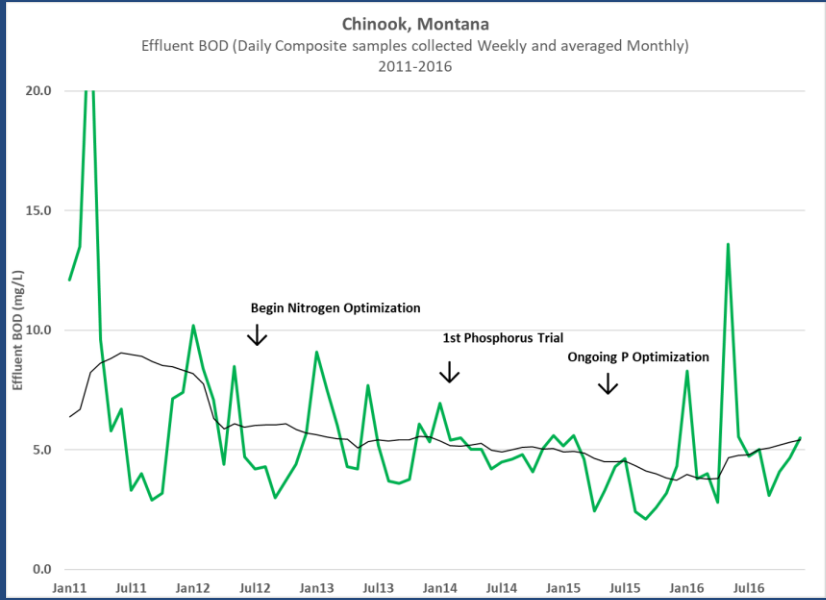
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20.0
15.0
10.0
5.0
0.0
Jan11
Jul11
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Jul12
Jan13
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Jan14
Jul14
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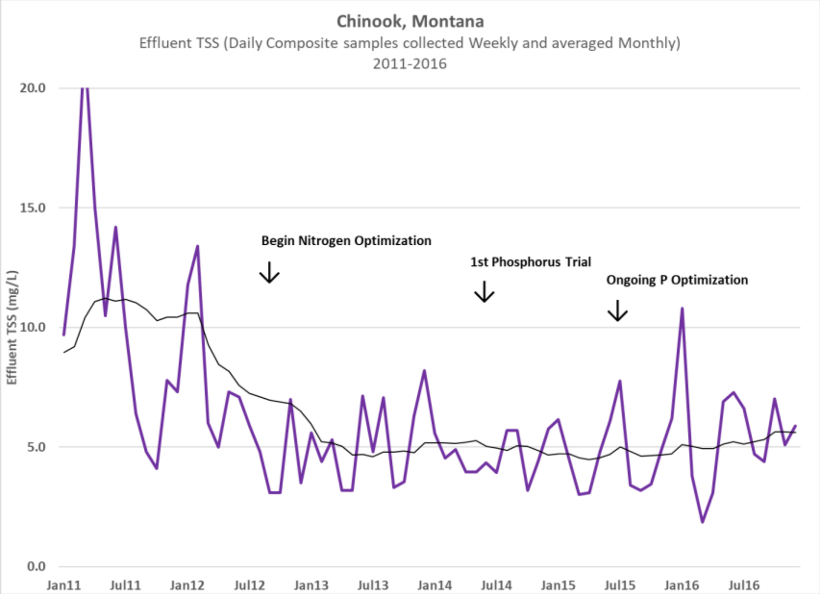
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Effluent TSS (Daily Composite samples collected Weekly and averaged Monthly)
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Effluent TSS (mg/L)
20.0
15.0
10.0
5.0
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Jan11
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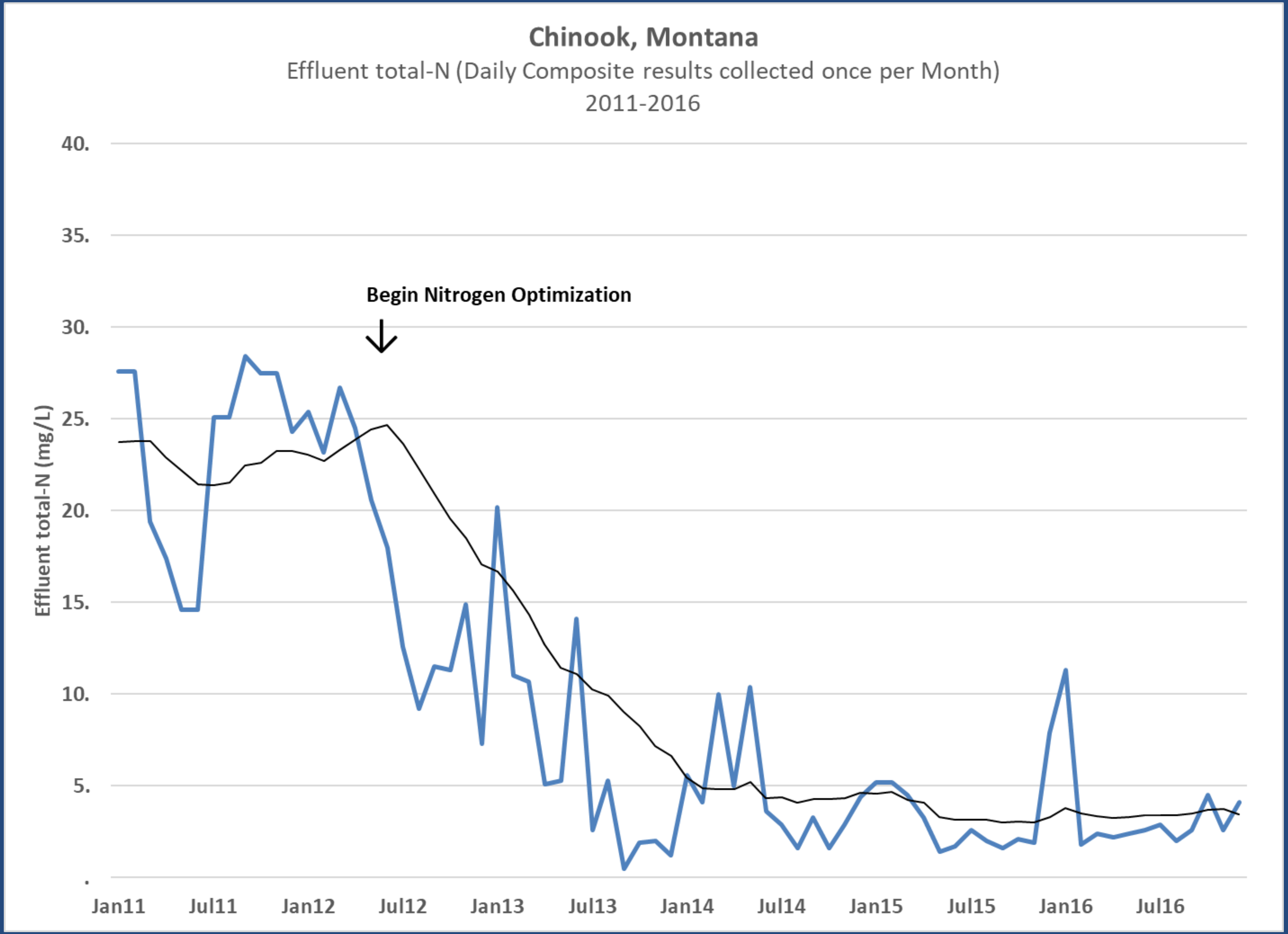

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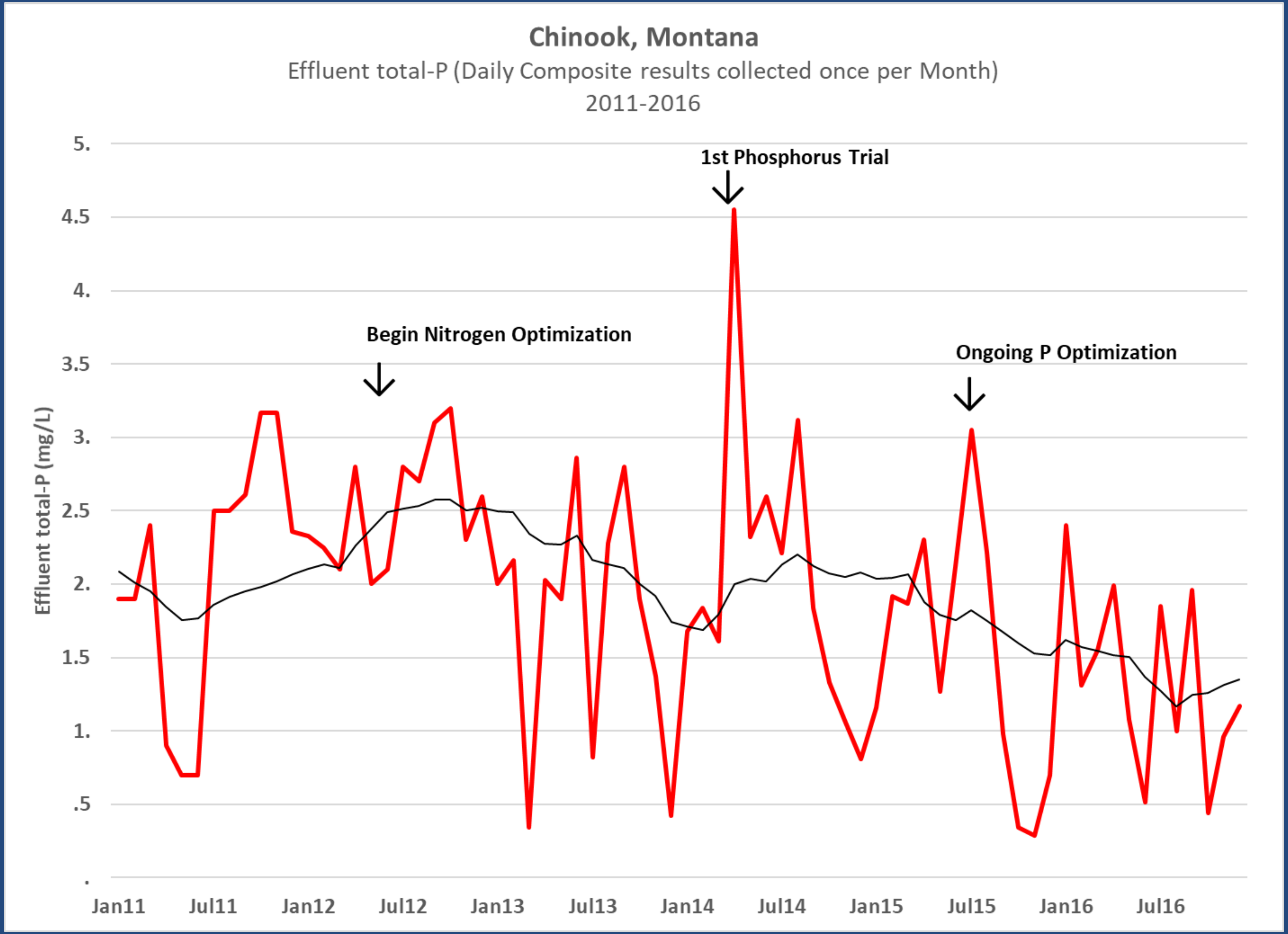

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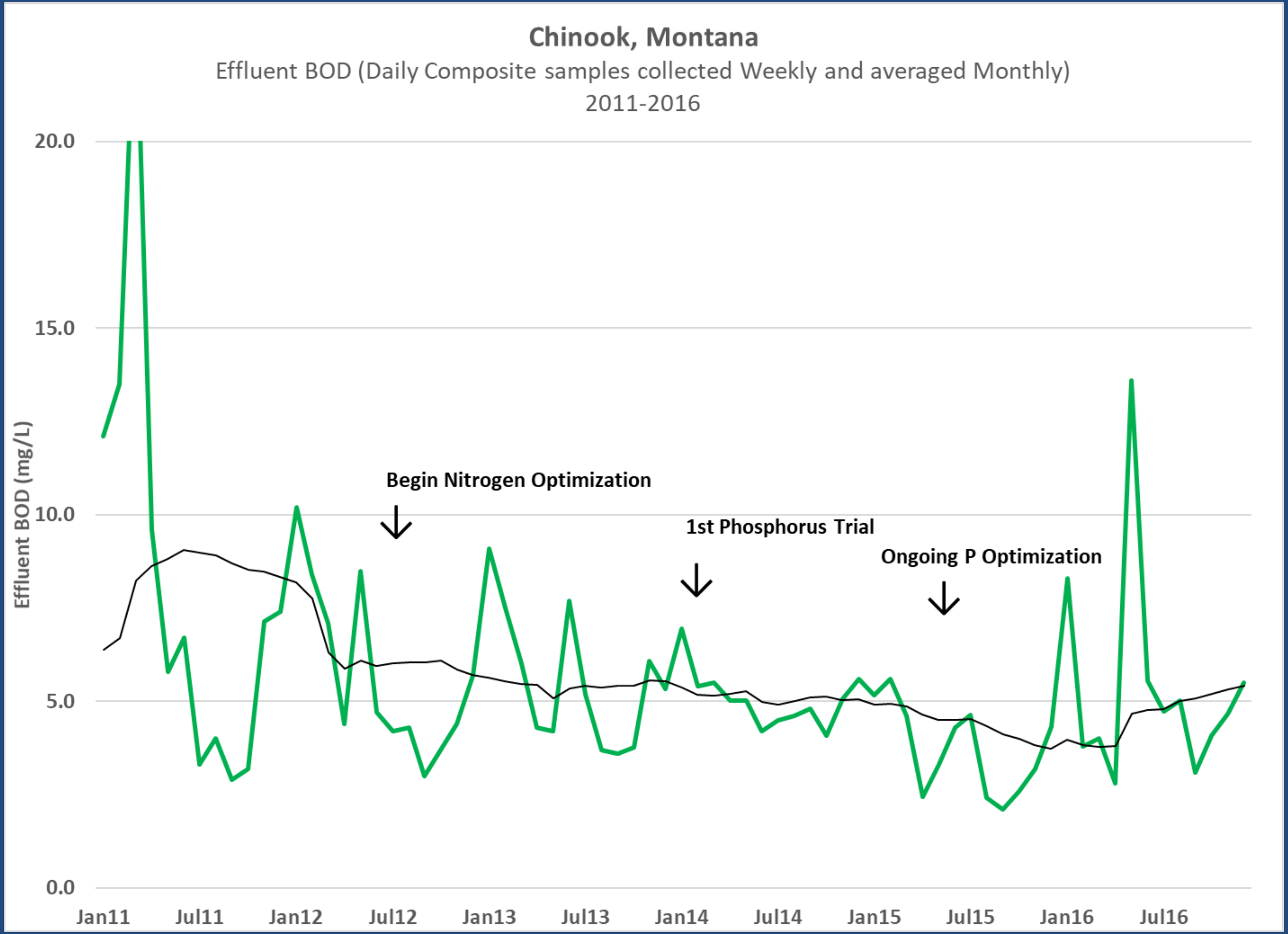
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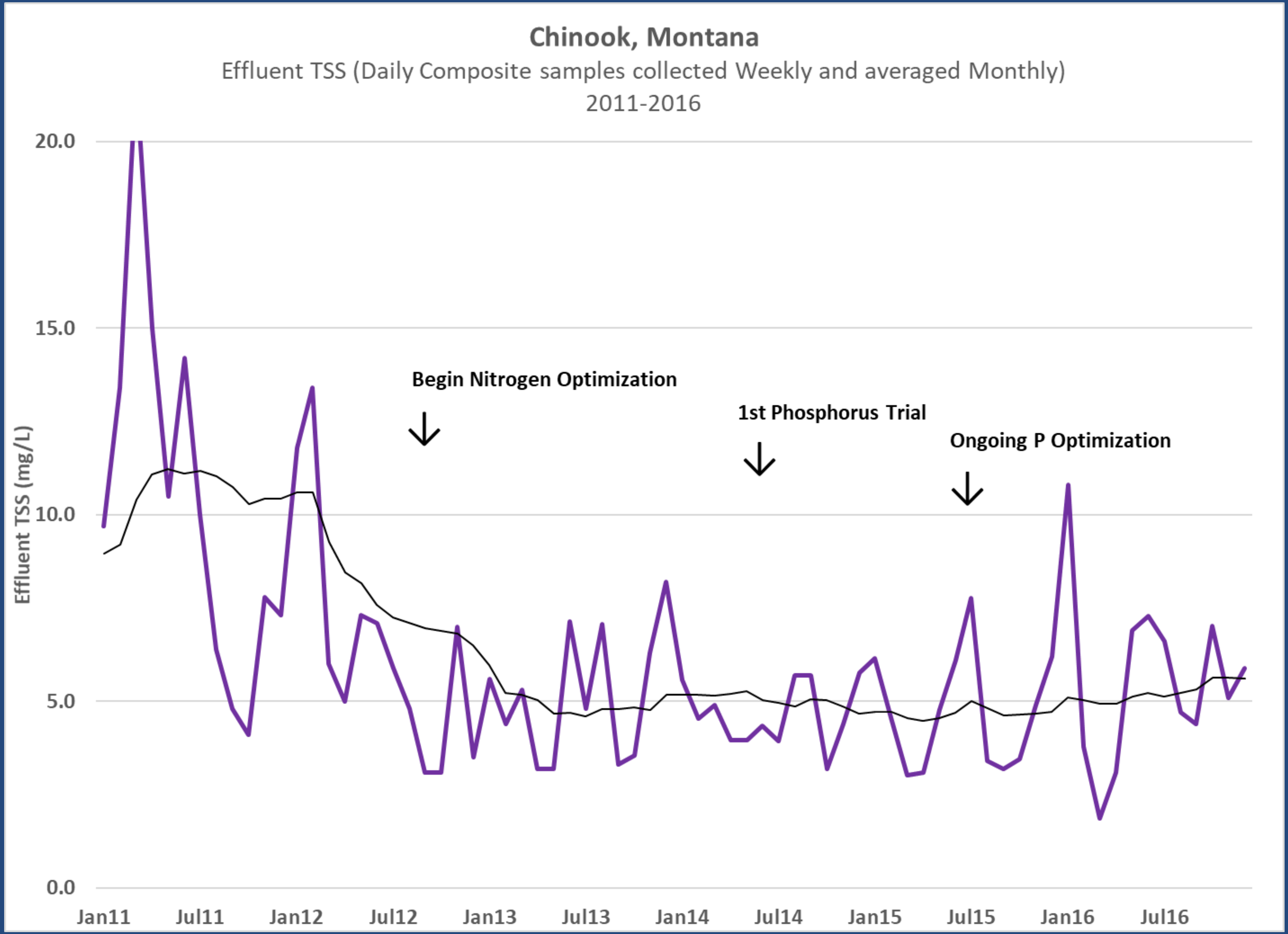
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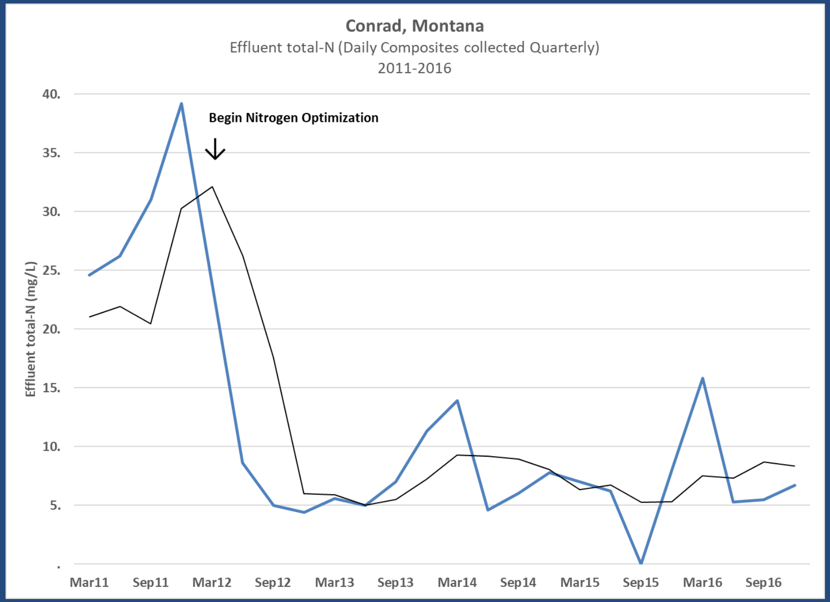
Conrad, Montana



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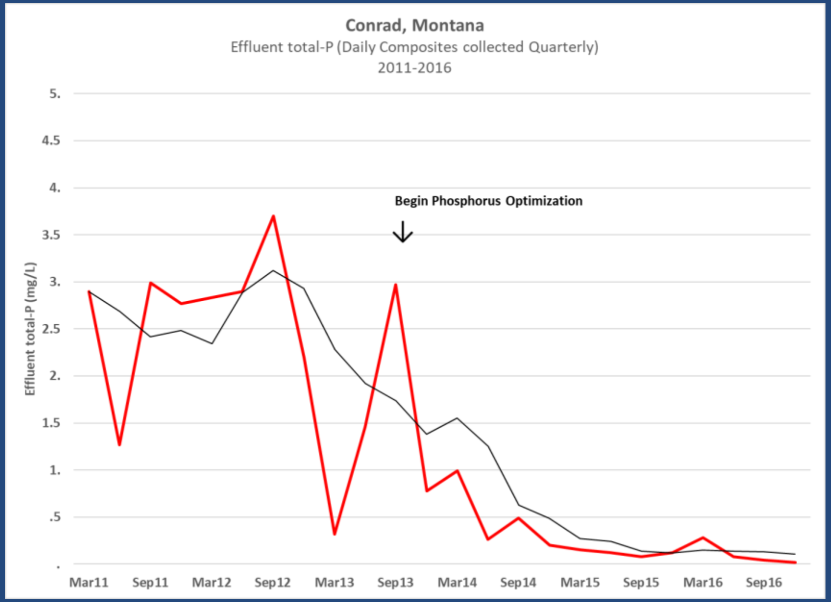

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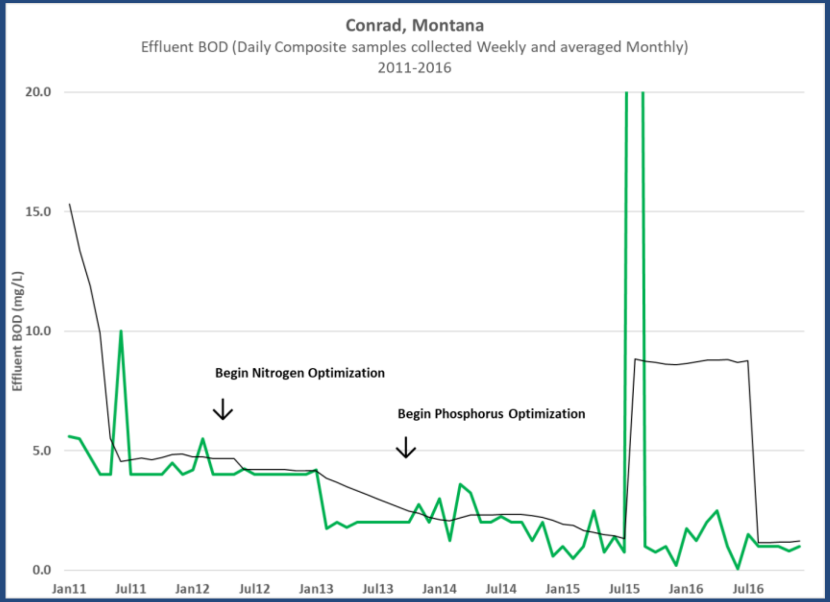

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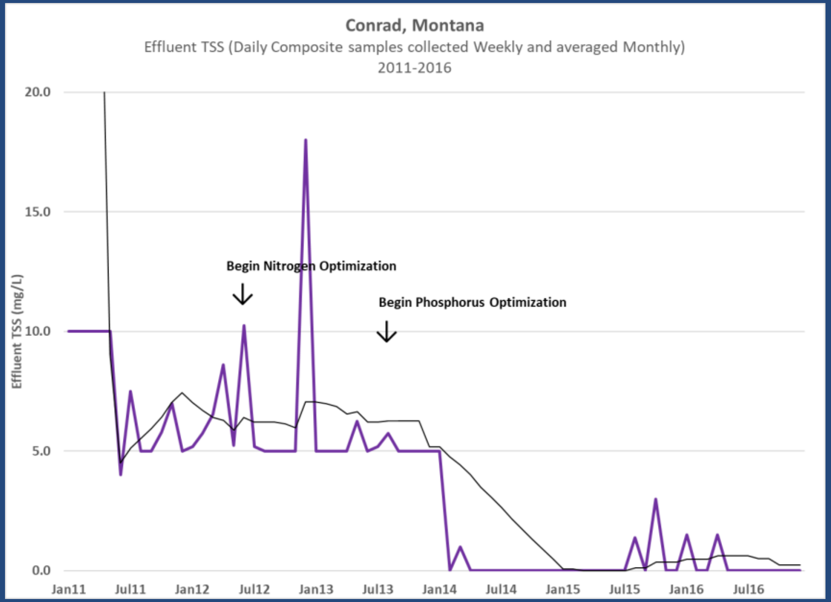

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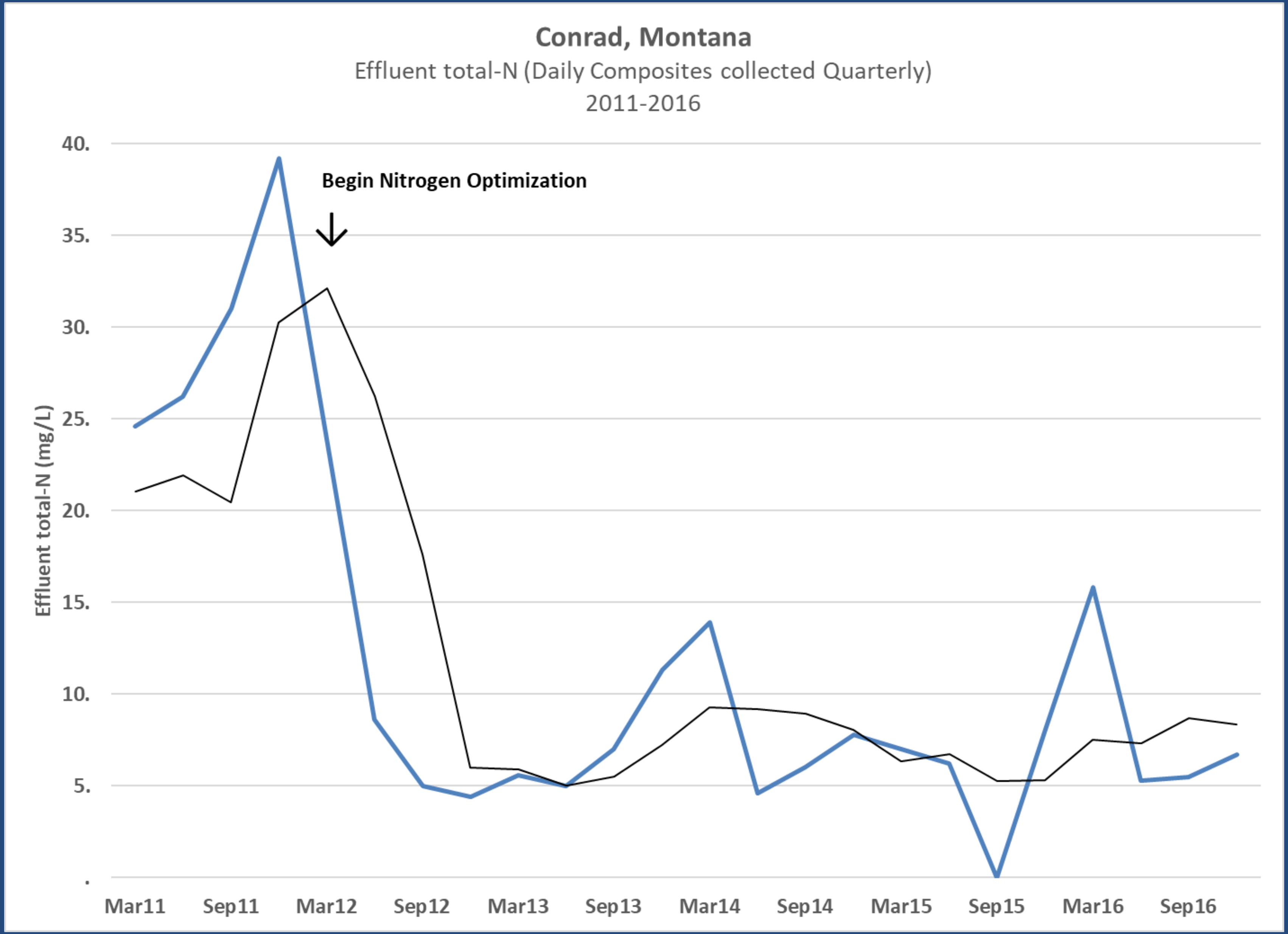
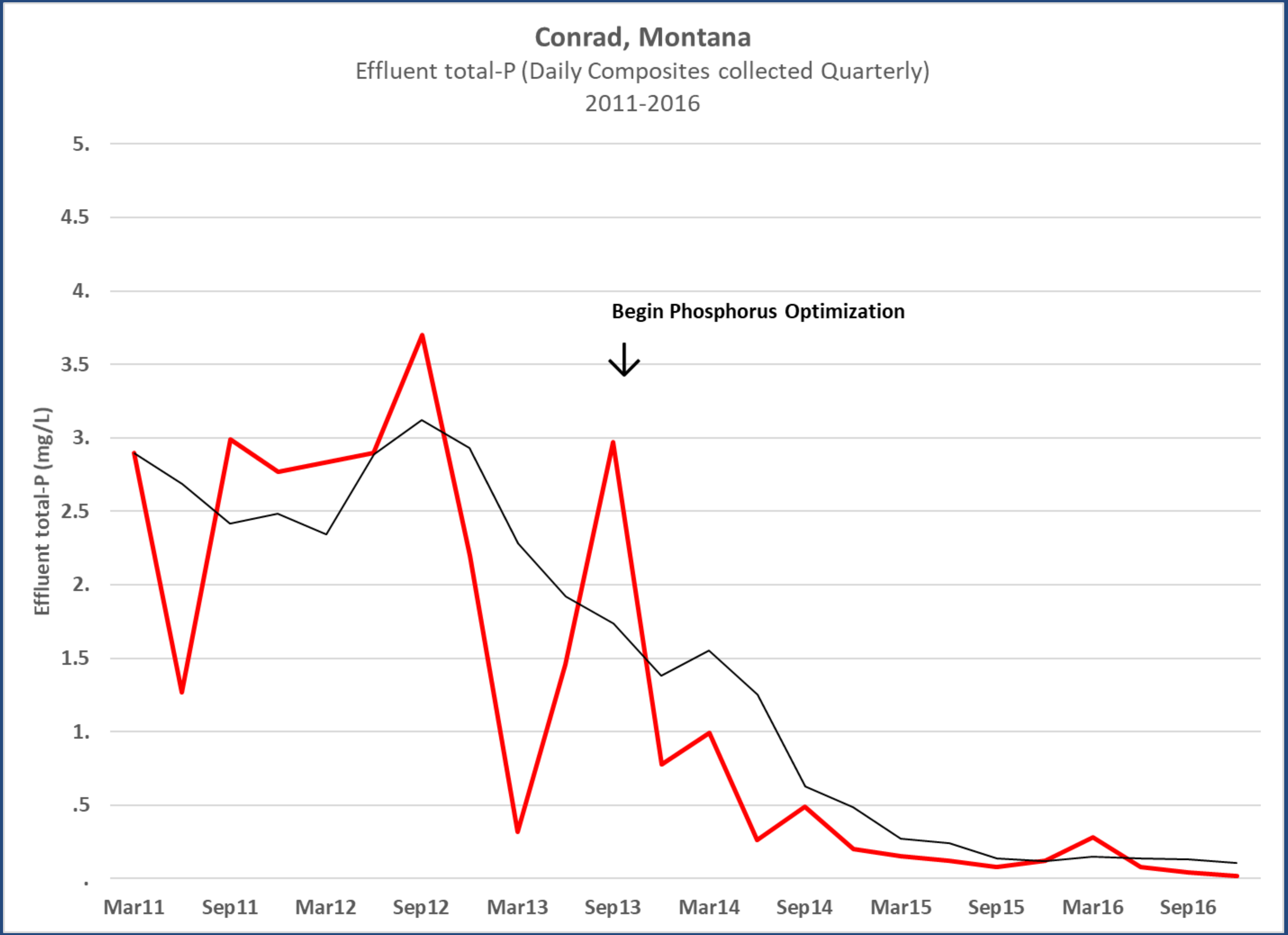
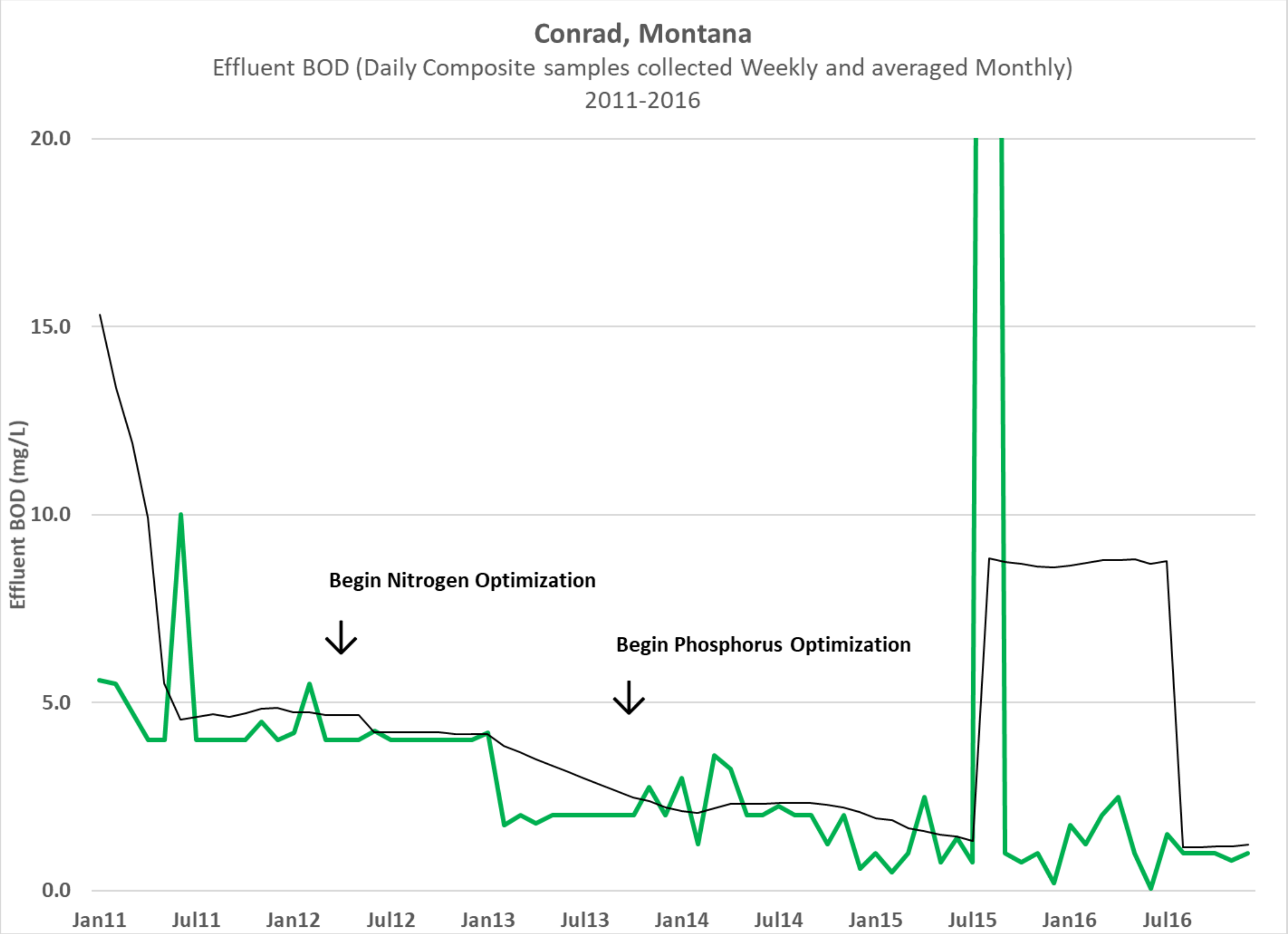
Jan16
Jul16



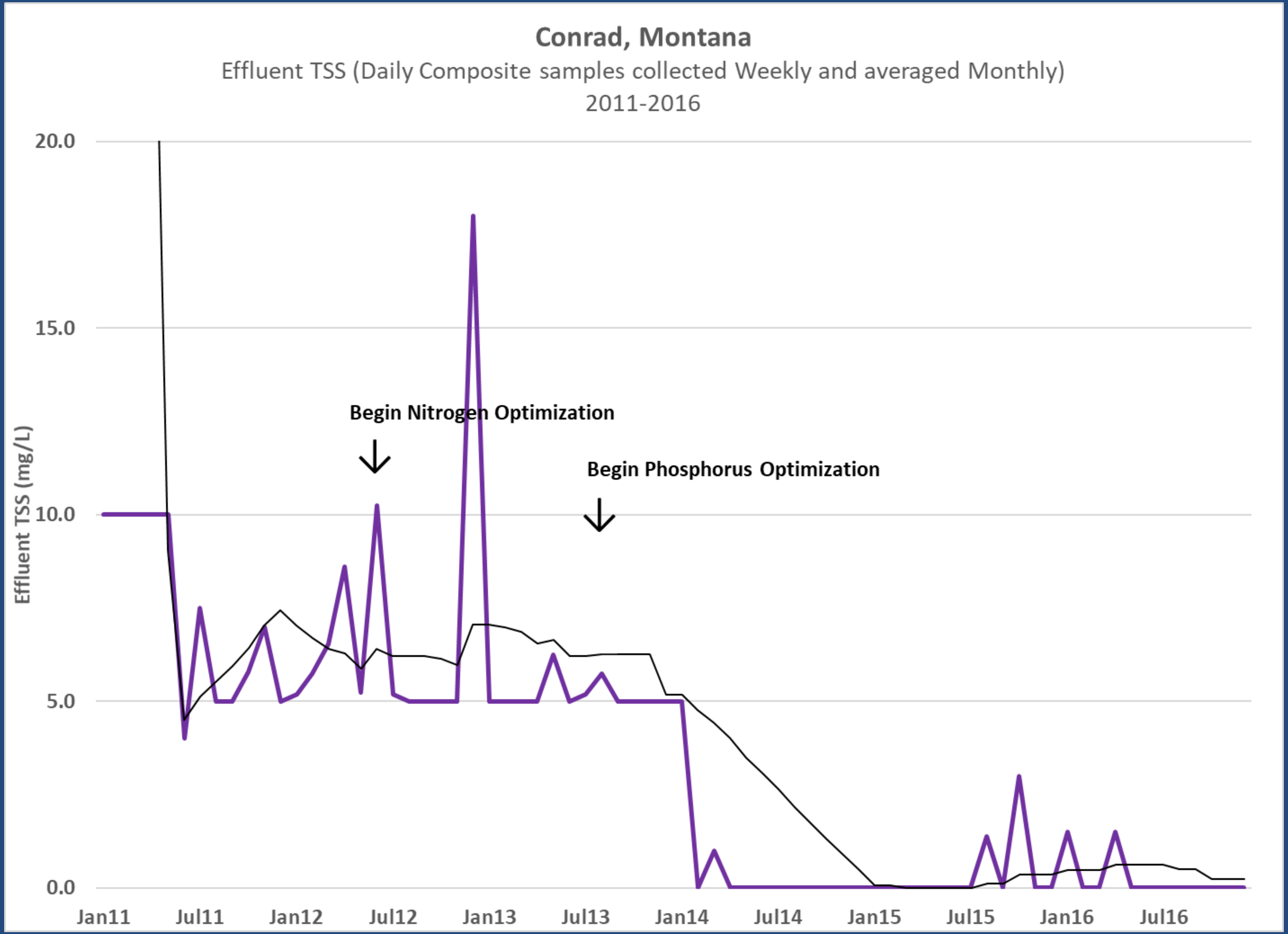
Conrad, Montana
Effluent total-N (Daily Composites collected Quarterly)
2011-2016
Begin Nitrogen Optimization
Effluent total-N (mg/L)
40.
35.
30.
25.
20.
15.
10.
5.
.
Mar11
Sep11
Mar12
Sep12
Mar13
Sep13
Mar14
Sep14
Mar15
Sep15
Mar16
Sep16



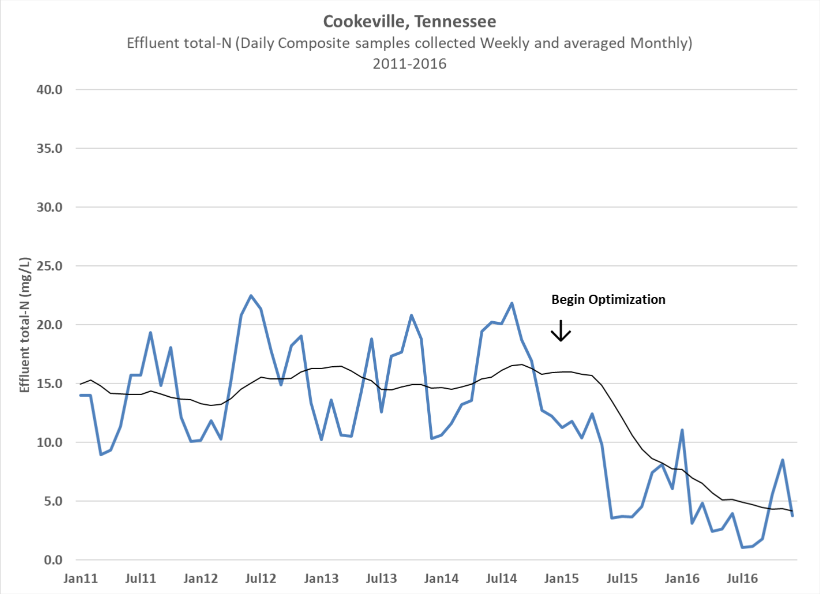
Conrad, Montana
Effluent total-P (Daily Composites collected Quarterly)
2011-2016
Begin Phosphorus Optimization
Effluent total-P (mg/L)
5.
4.5
4.
3.5
3.
2.5
2.
1.5
1.
.5
.
Mar11
Sep11
Mar12
Sep12
Mar13
Sep13
Mar14
Sep14
Mar15
Sep15
Mar16
Sep16

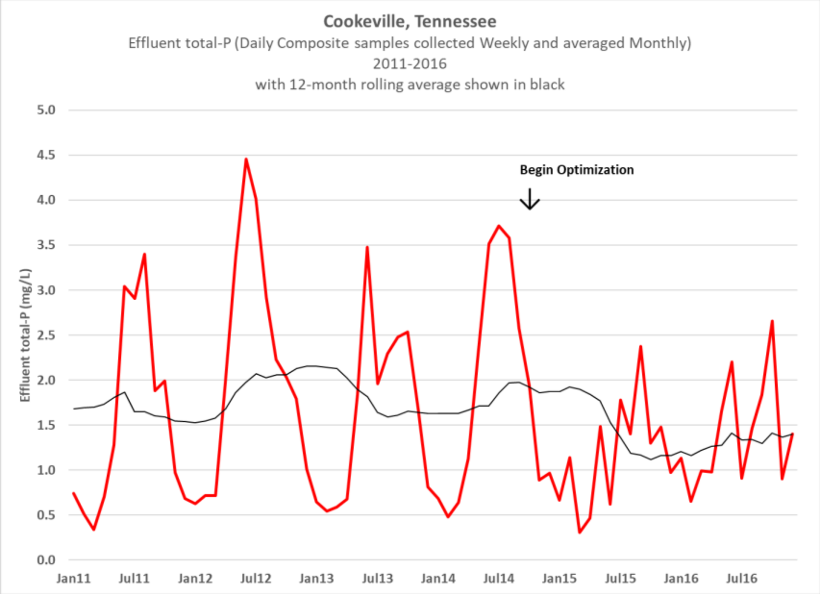


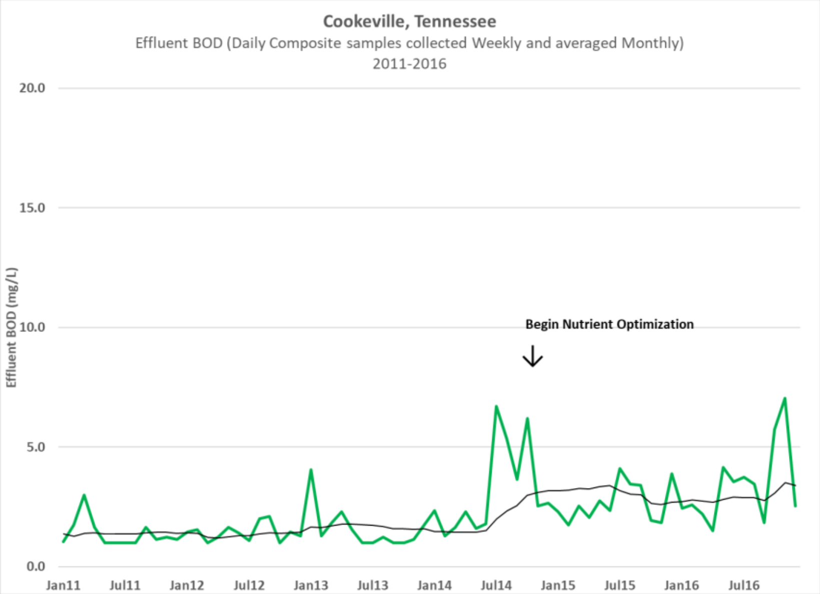
Conrad, Montana
Effluent BOD (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent BOD (mg/L)
20.0
15.0
10.0
5.0
0.0
Begin Nitrogen Optimization
Begin Phosphorus Optimization
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15
Jan16
Jul16

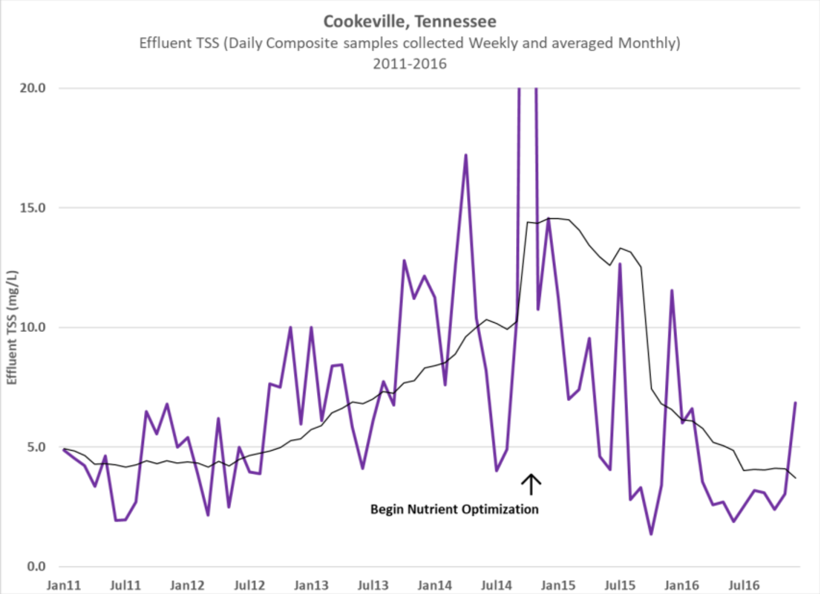

Conrad, Montana
Effluent TSS (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
20.0
15.0
10.0
5.0
0.0
Effluent TSS (mg/L)
Begin Nitrogen Optimization
Begin Phosphorus Optimization
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15
Jan16
Jul16

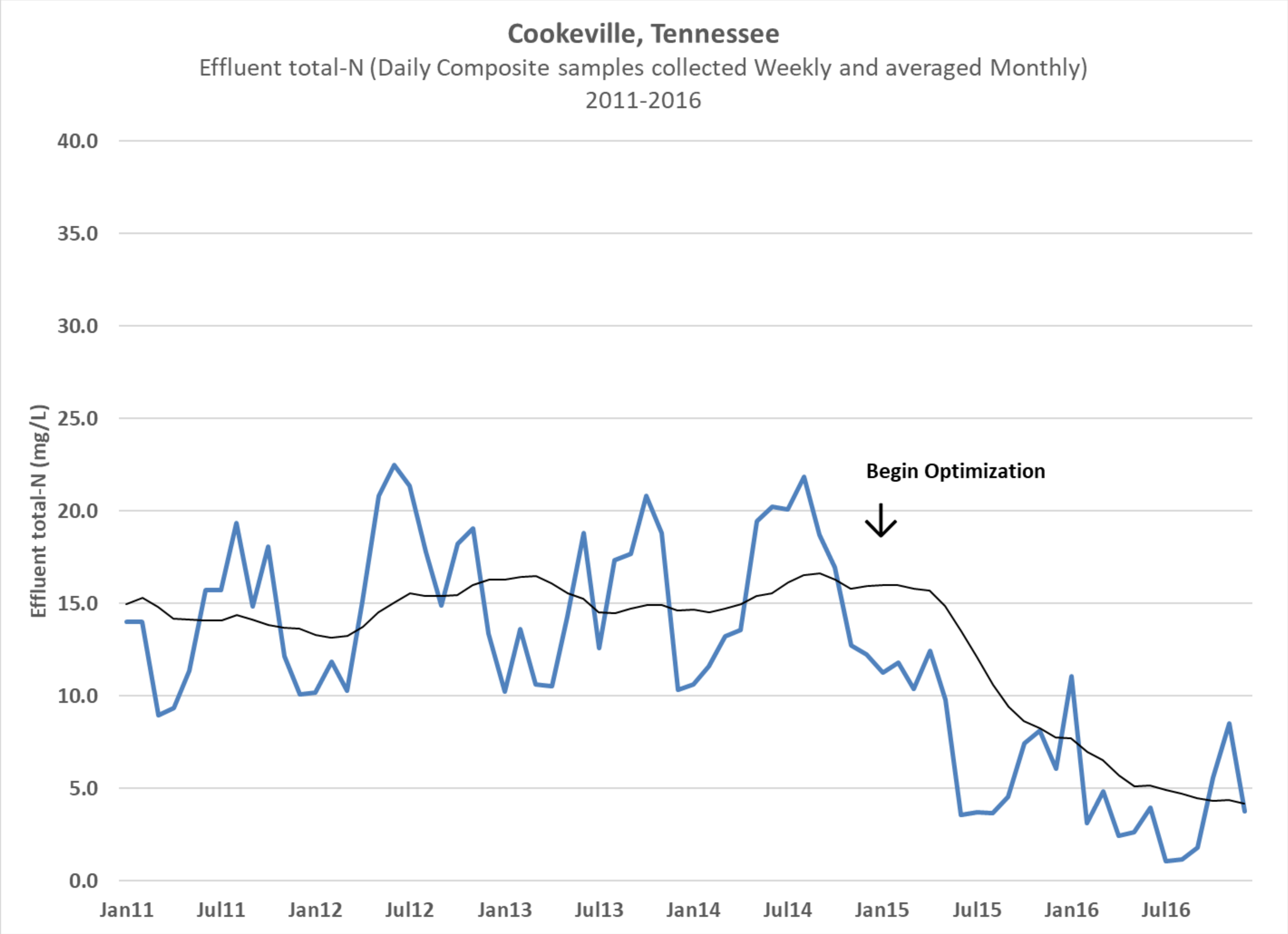

Cookeville, Tennessee


Cookeville, Tennessee
Effluent total-N (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent total-N (mg/L)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Begin Optimization
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15
Jan16
Jul16

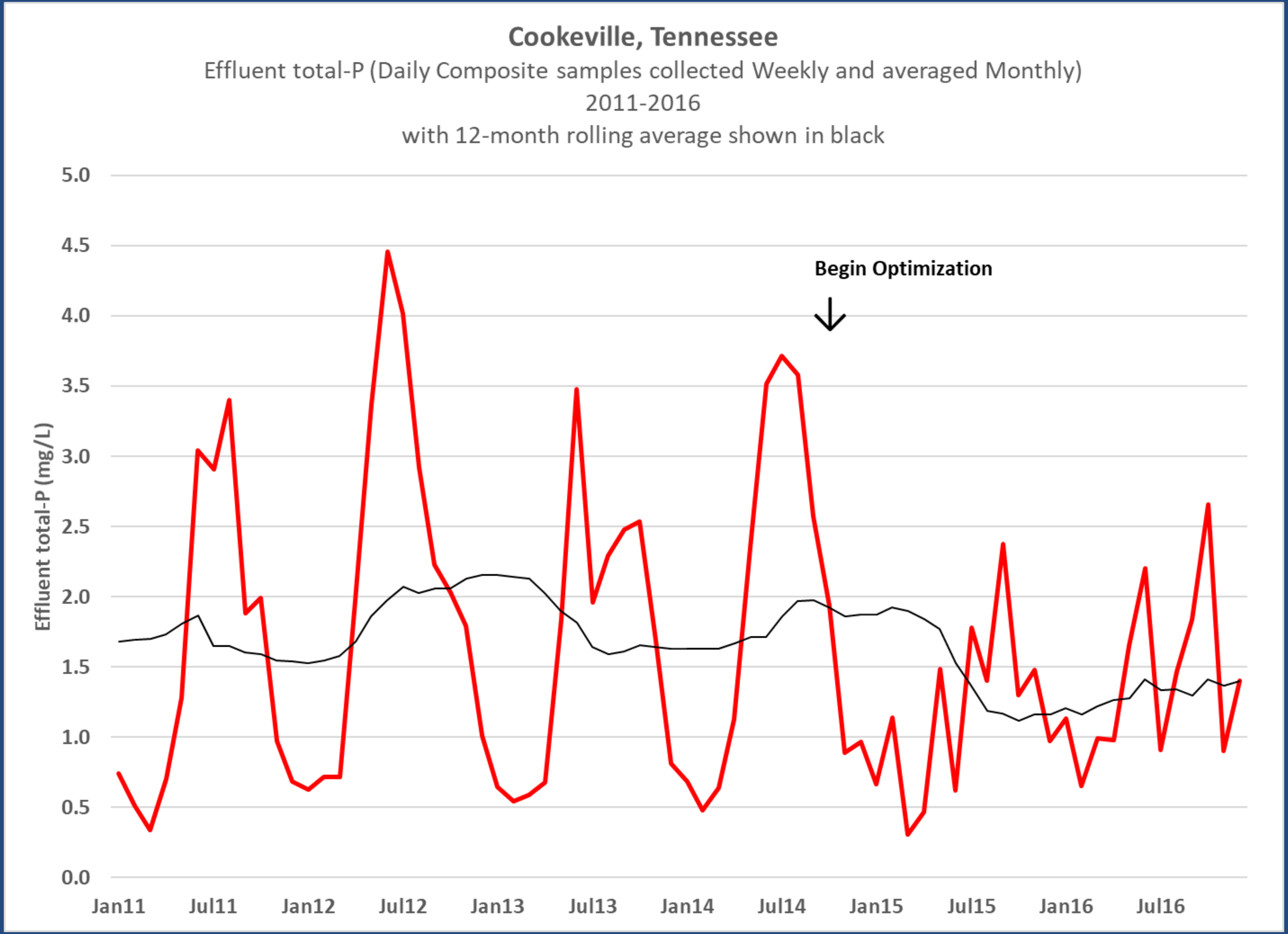

Cookeville, Tennessee
Effluent total-P (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
with 12-month rolling average shown in black
Effluent total-P (mg/L)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Begin Optimization
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15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

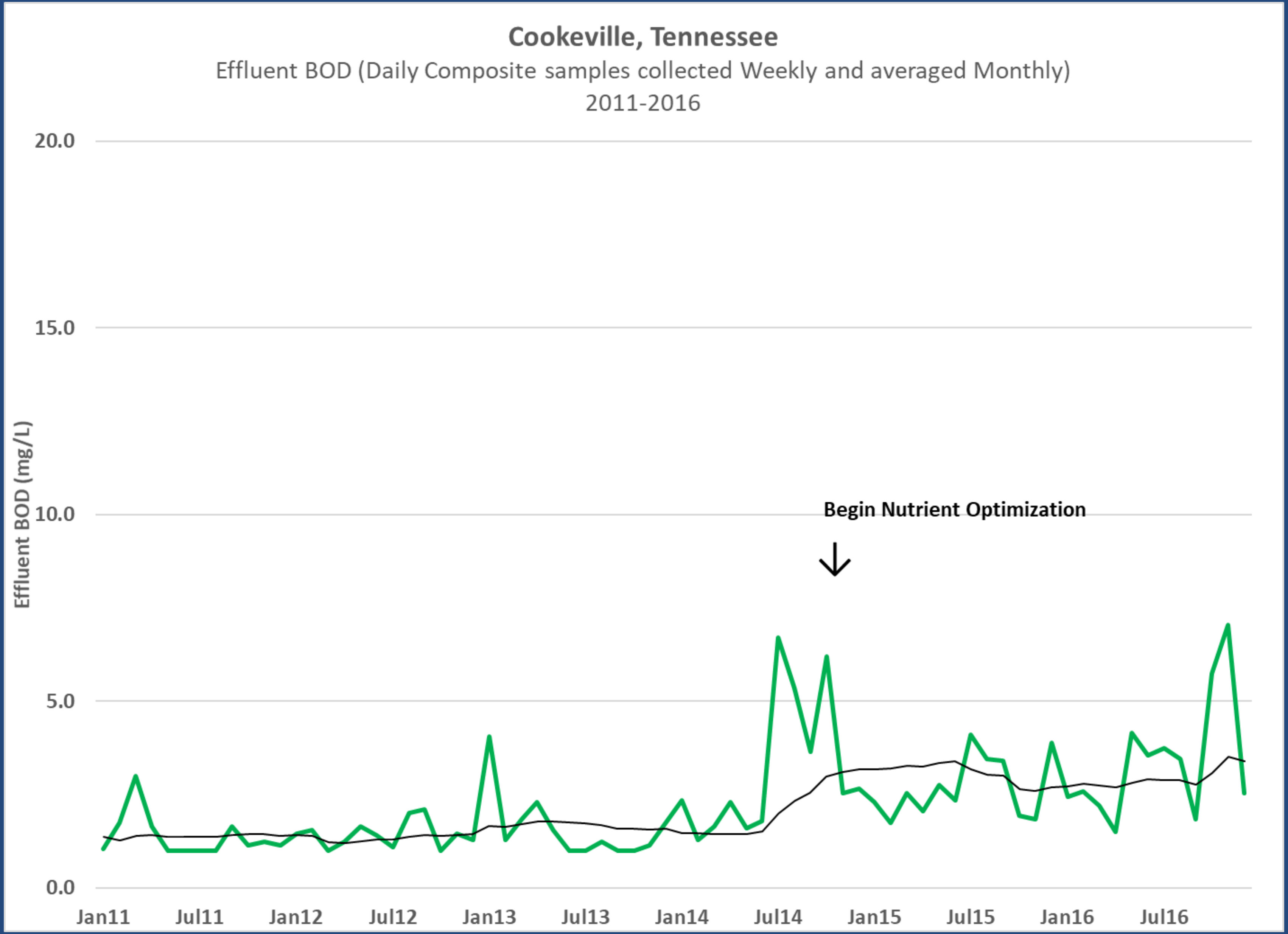

Cookeville, Tennessee
Effluent BOD (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent BOD (mg/L)
20.0
15.0
10.0
5.0
0.0
Begin Nutrient Optimization
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15
Jan16
Jul16


Cookeville, Tennessee
Effluent TSS (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent TSS (mg/L)
20.0
15.0
10.0
5.0
0.0
Begin Nutrient Optimization
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15
Jan16
Jul16



Cookeville, Tennessee
Effluent total-N (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent total-N (mg/L)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Begin Optimization
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15
Jan16
Jul16


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


Cookeville, Tennessee
Effluent BOD (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent BOD (mg/L)
20.0
15.0
10.0
5.0
0.0
Begin Nutrient Optimization
Jan11
Jul11
Jan12
Jul12
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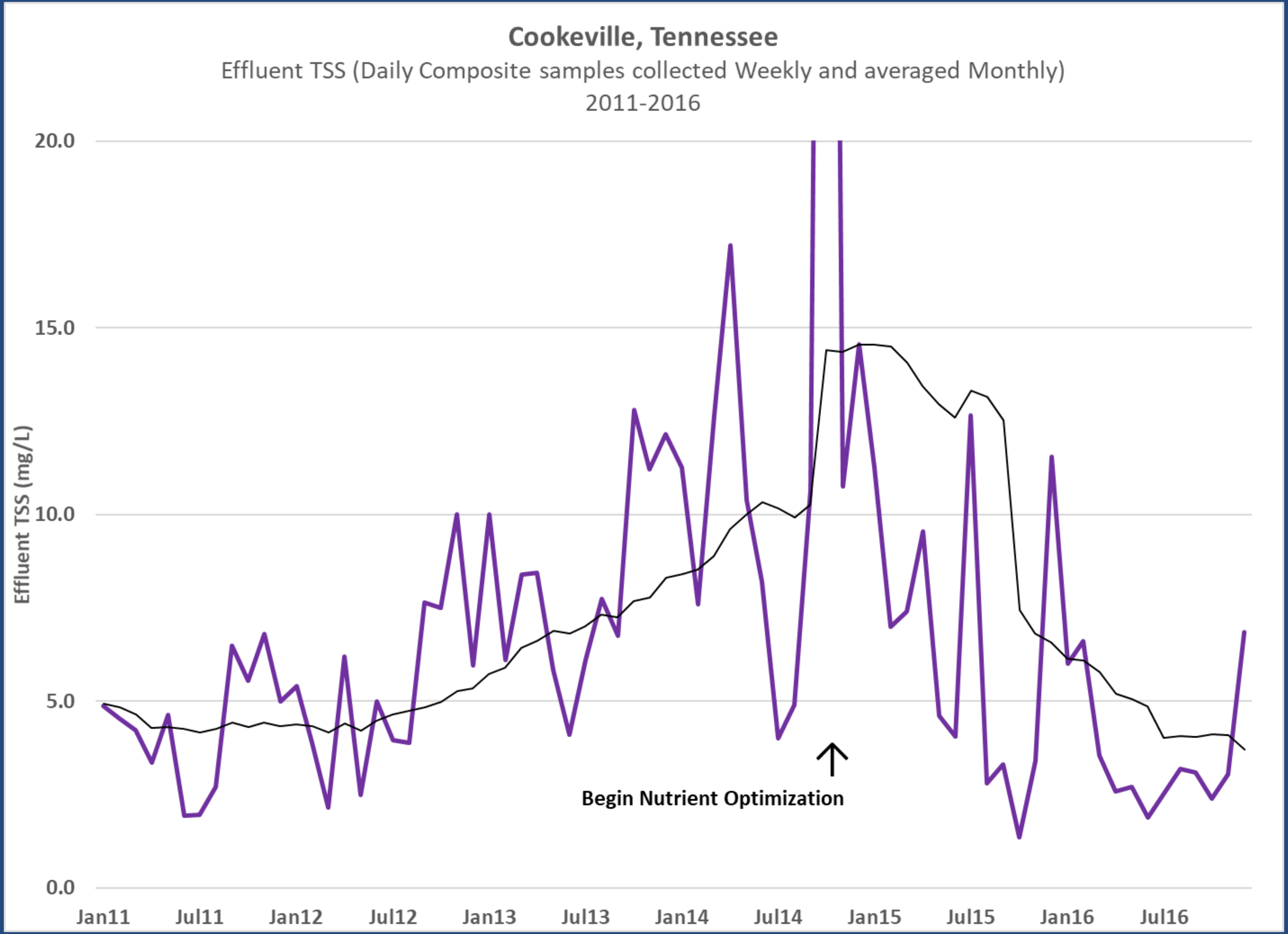
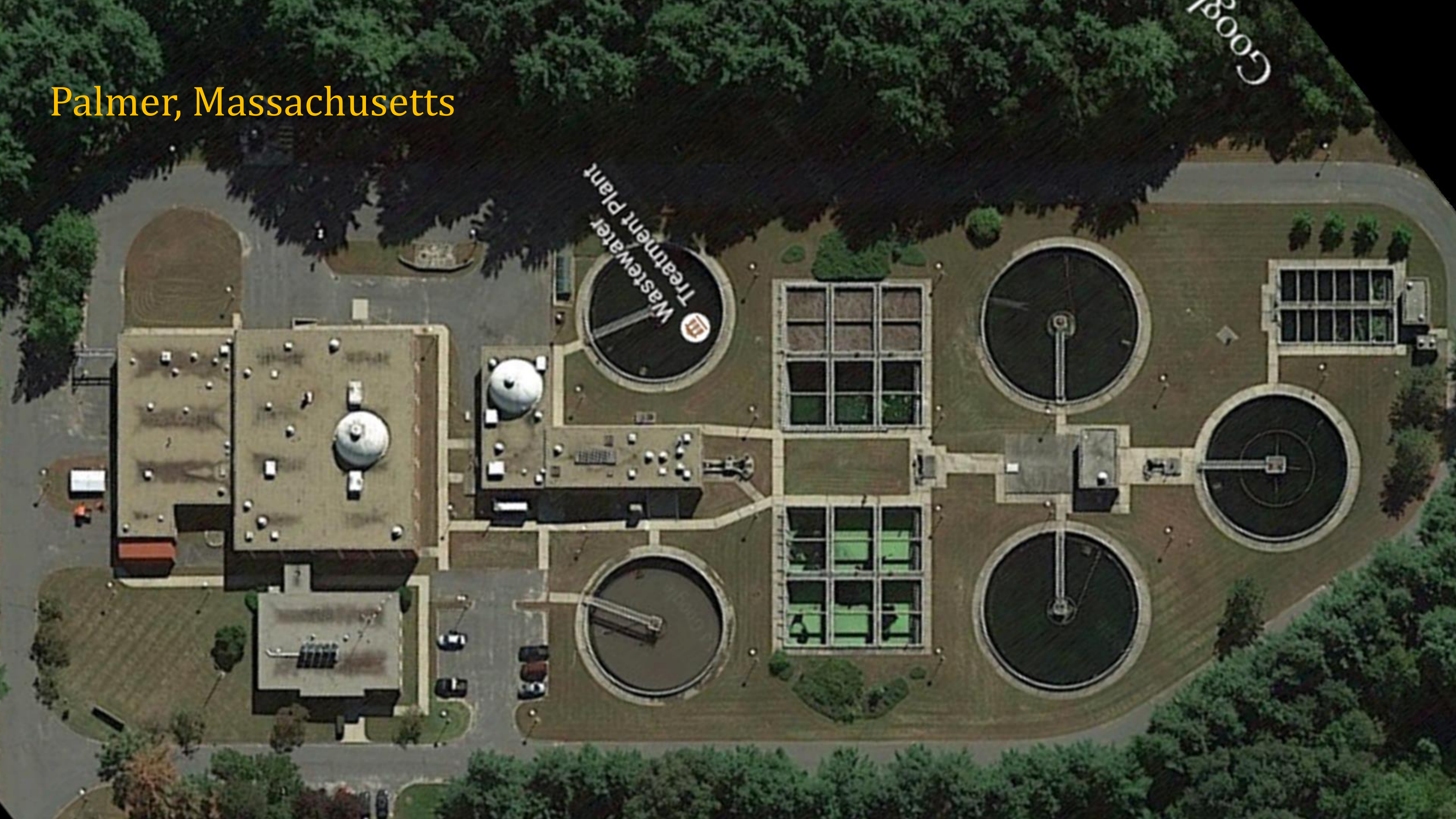
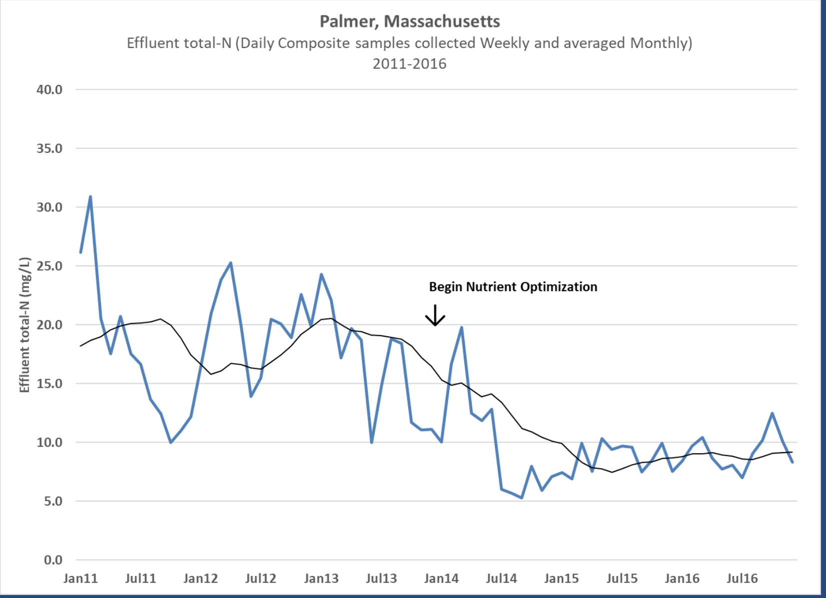
Jan16
Jul16



Cookeville, Tennessee
Effluent TSS (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent TSS (mg/L)
20.0
15.0
10.0
5.0
0.0
Jan11
Jul11
Jan12
Jul12
Jan13
Jul13
Jan14
Jul14
Jan15
Jul15
Jan16
Jul16
Begin Nutrient Optimization

Palmer, Massachusetts





Palmer, Massachusetts
Effluent total-N (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent total-N (mg/L)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Begin Nutrient Optimization
Jan11
Jul11
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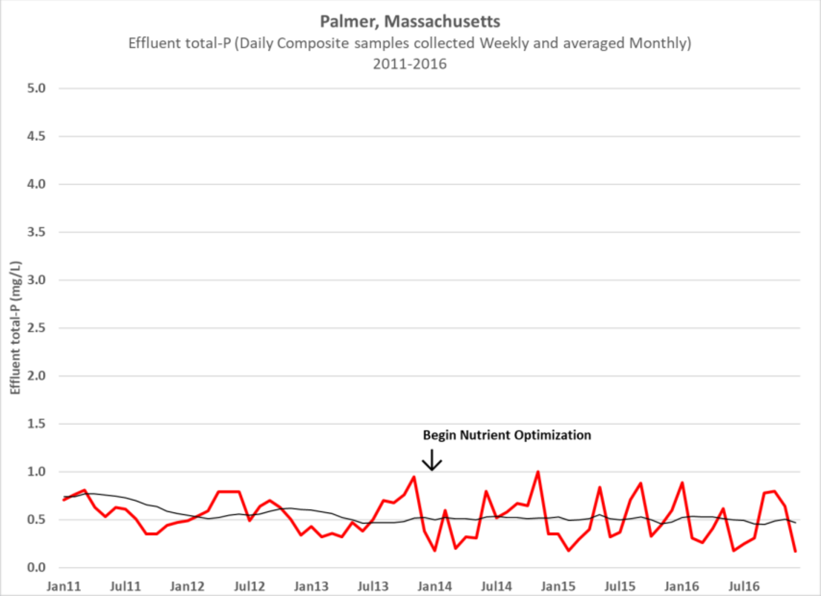
Jul16



Palmer, Massachusetts
Effluent total-P (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
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 Nutrient Optimization
Jan11
Jul11
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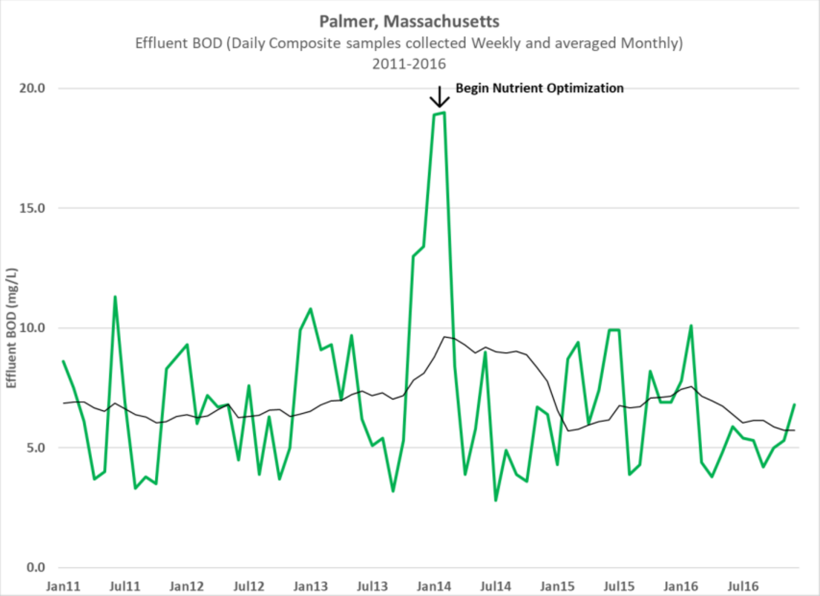
Jul16



Palmer, Massachusetts
Effluent BOD (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent BOD (mg/L)
20.0
15.0
10.0
5.0
0.0
Begin Nutrient Optimization
Jan11
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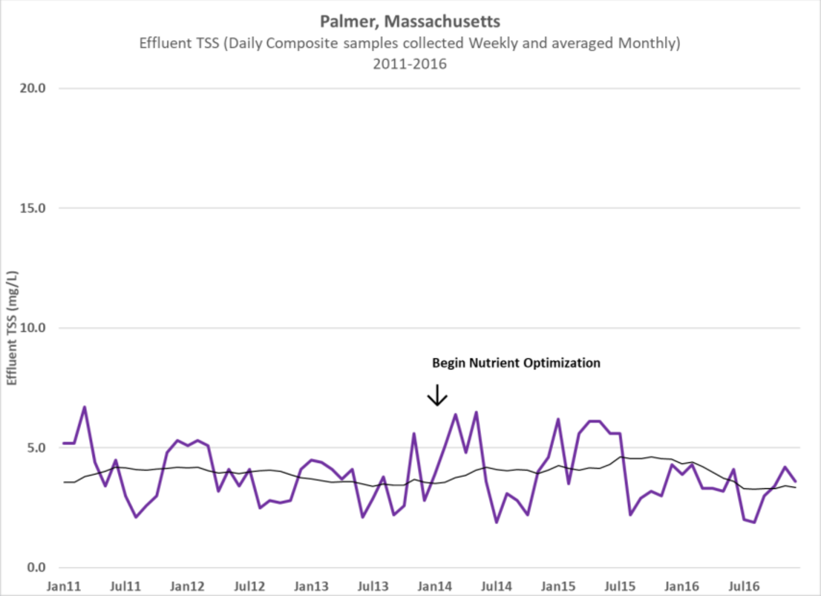

Palmer, Massachusetts
Effluent TSS (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent TSS (mg/L)
20.0
15.0
10.0
5.0
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Begin Nutrient Optimization
Jan11
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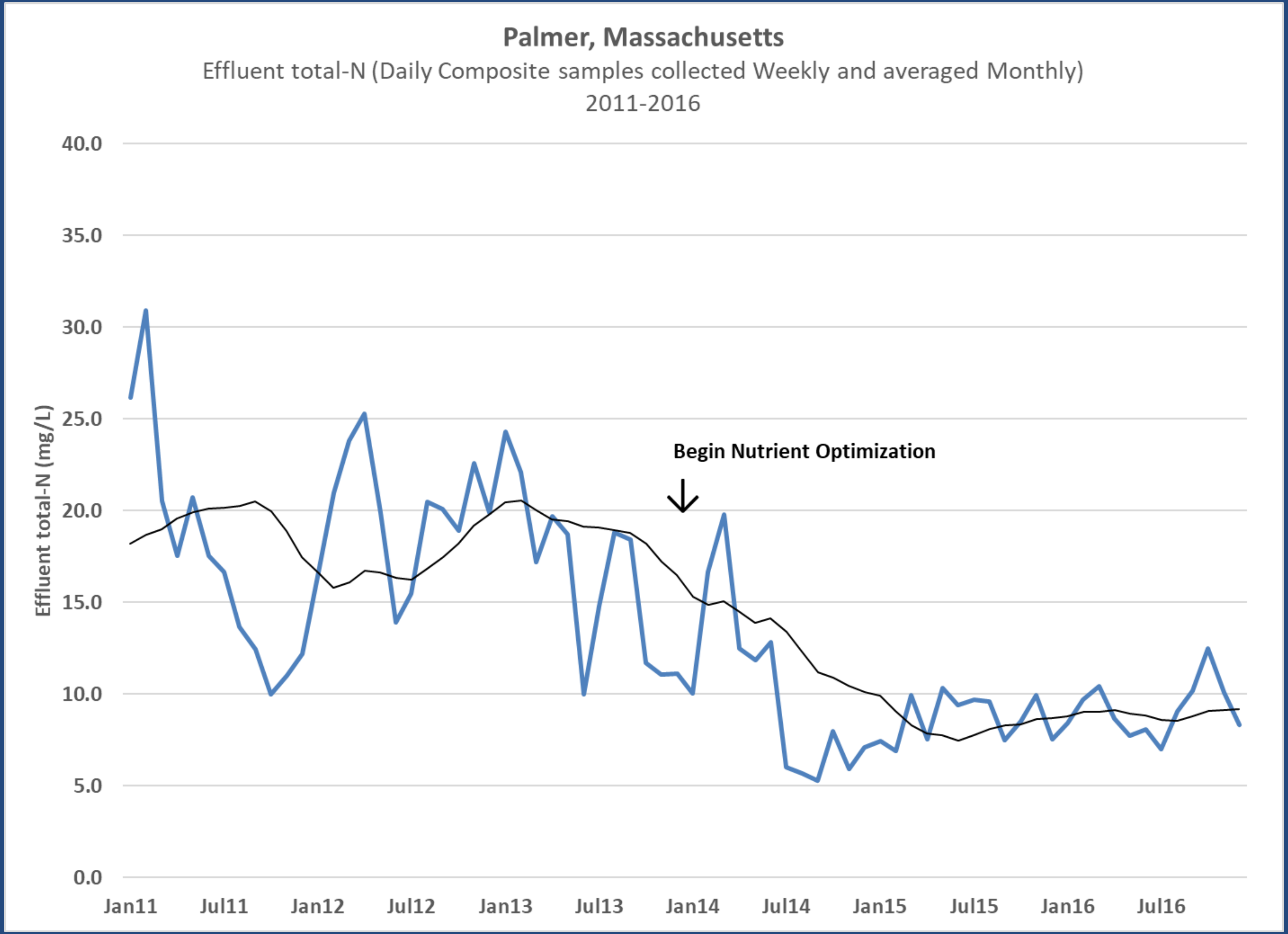
Palmer, Massachusetts
Effluent total-N (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
40.0
35.0
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Effluent total-N (mg/L)
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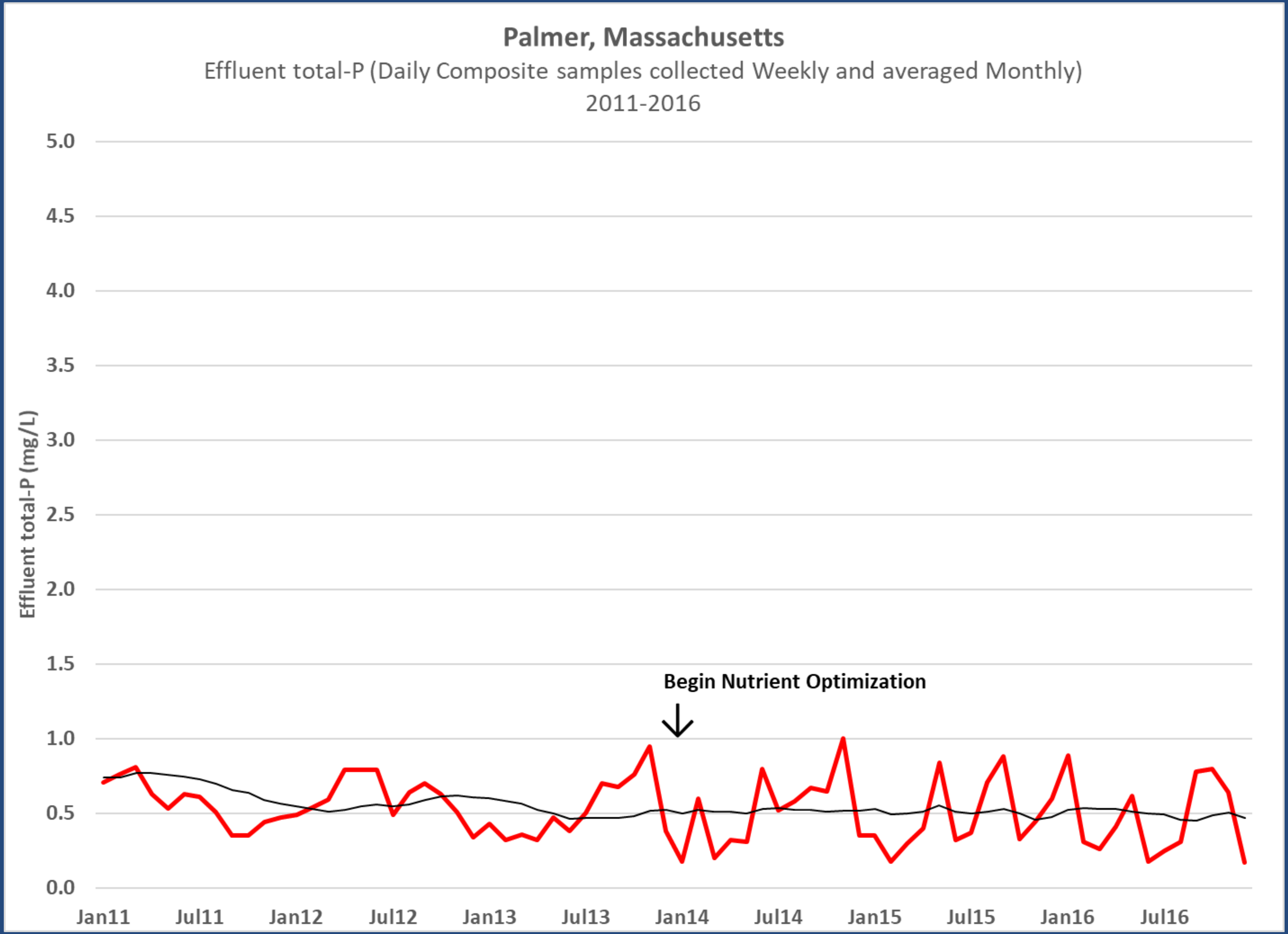
Jul16


Palmer, Massachusetts
Effluent total-P (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent total-P (mg/L)
5.0
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1.5
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Begin Nutrient Optimization
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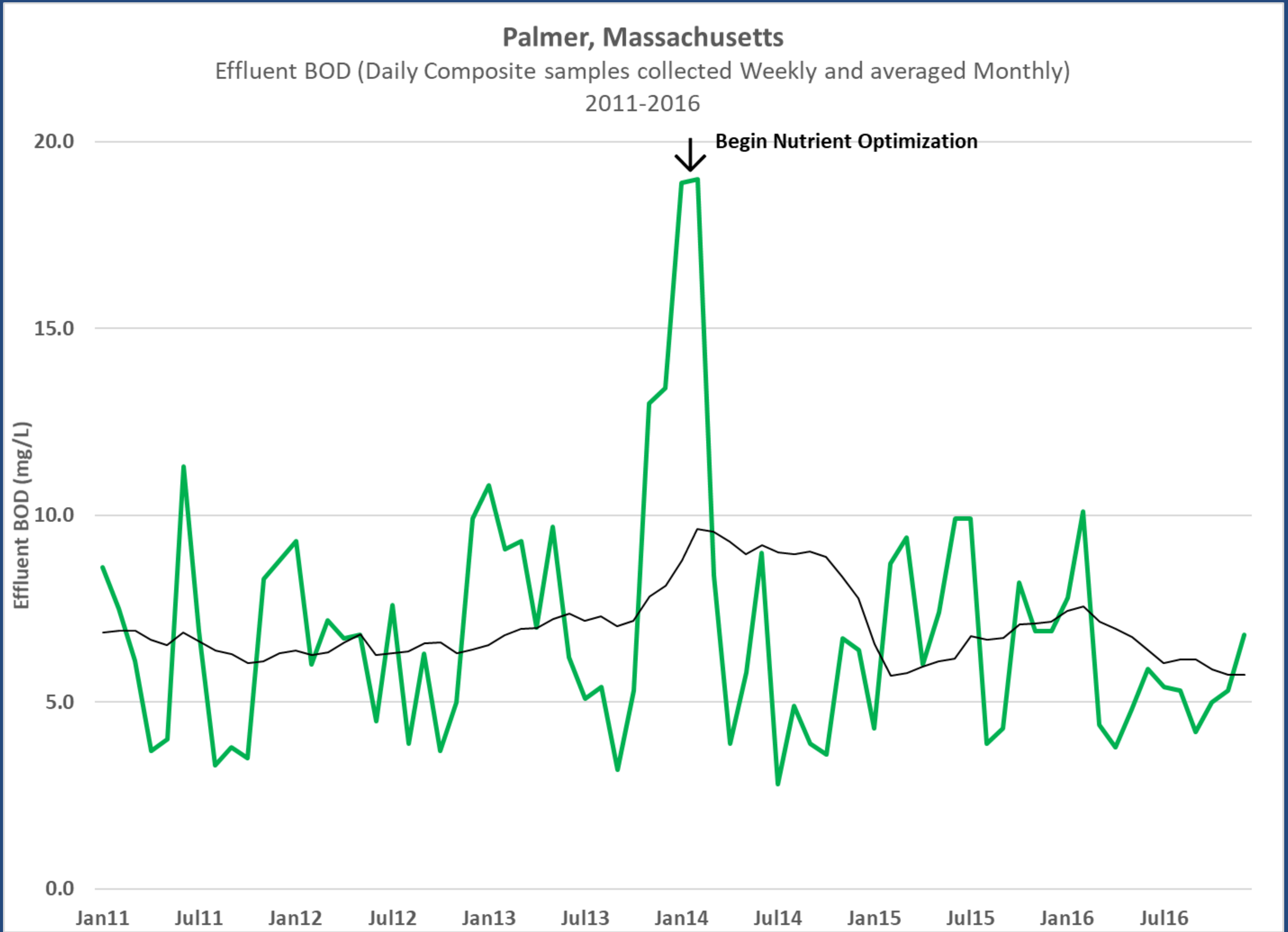

Palmer, Massachusetts
Effluent BOD (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Begin Nutrient Optimization
Effluent BOD (mg/L)
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15.0
10.0
5.0
0.0
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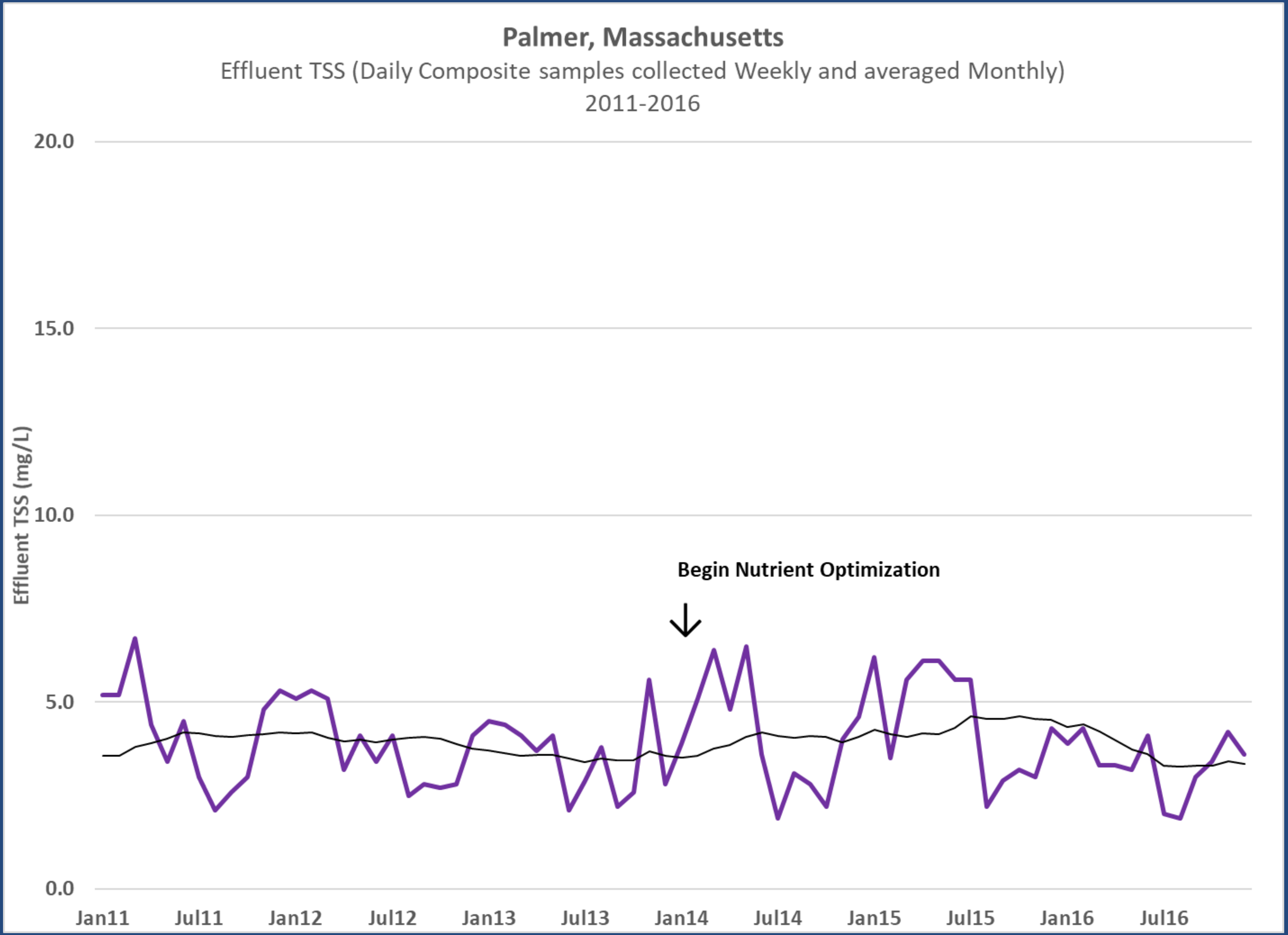

Palmer, Massachusetts
Effluent TSS (Daily Composite samples collected Weekly and averaged Monthly)
2011-2016
Effluent TSS (mg/L)
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Begin Nutrient Optimization
Jan11
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Jul16

Comments & Questions