Optimizing for Biological Phosphorus Removal

Operator Training Committee of Ohio

April 13, 2021

Presented by:

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Ohio EPA – Compliance Assistance Unit

Troubleshooting Noncompliance
in
Small Communities

And maybe save some cash as well…..

Troubleshooting BNR Systems in Small Communities

Causes of Noncompliance in Small BNR Systems:

1) Small system operators are not trained very well to run BNR systems
2) Small systems typically do not have their own labs to run process control tests
3) Small systems are designed using textbook characteristics for influent waste streams
4) Small systems often suffer from inadequate soluble carbon that drives denitrification and orthophosphate release reactions

Troubleshooting BNR Systems in Small Communities

How BNR is supposed to work:

Most Important – A good soluble influent $cBOD_5$

Second Most Important – Low nitrates in Anaerobic Zone

Third Most Important – Low nitrates in Anoxic Zone

Fourth Most Important – Process Control so you know!

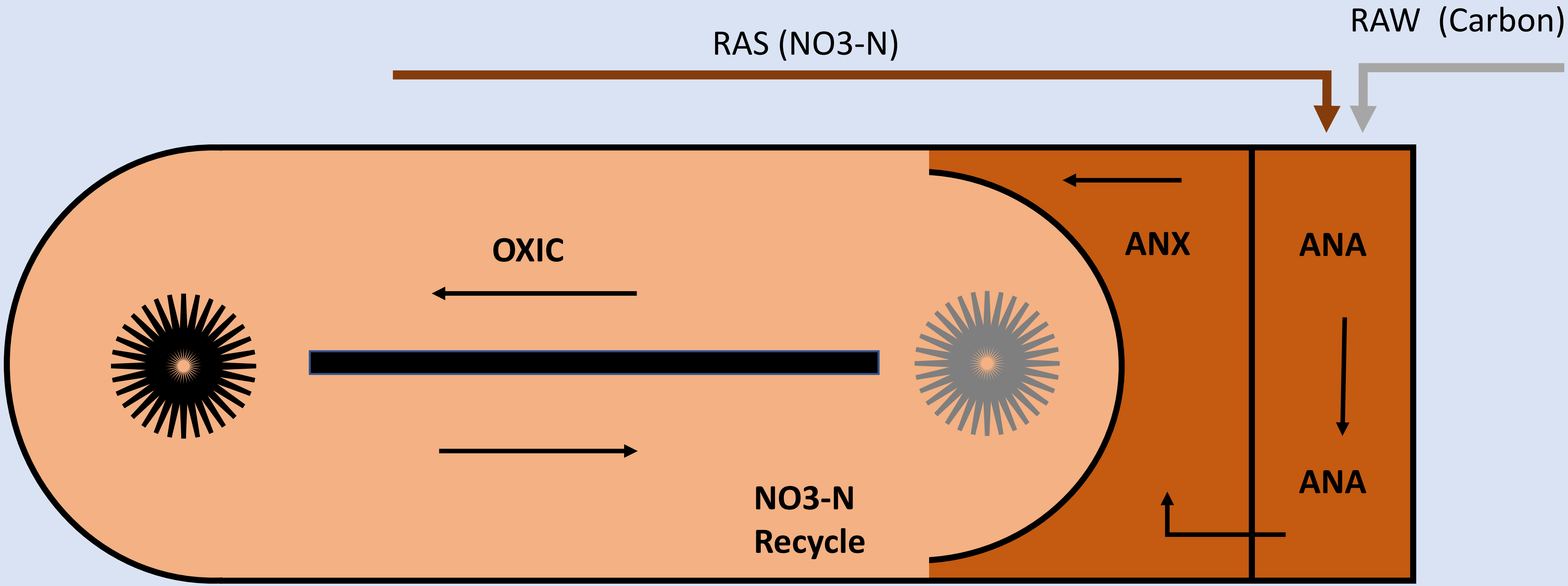
Troubleshooting BNR Systems in Small Communities

First, we will look at a small community:

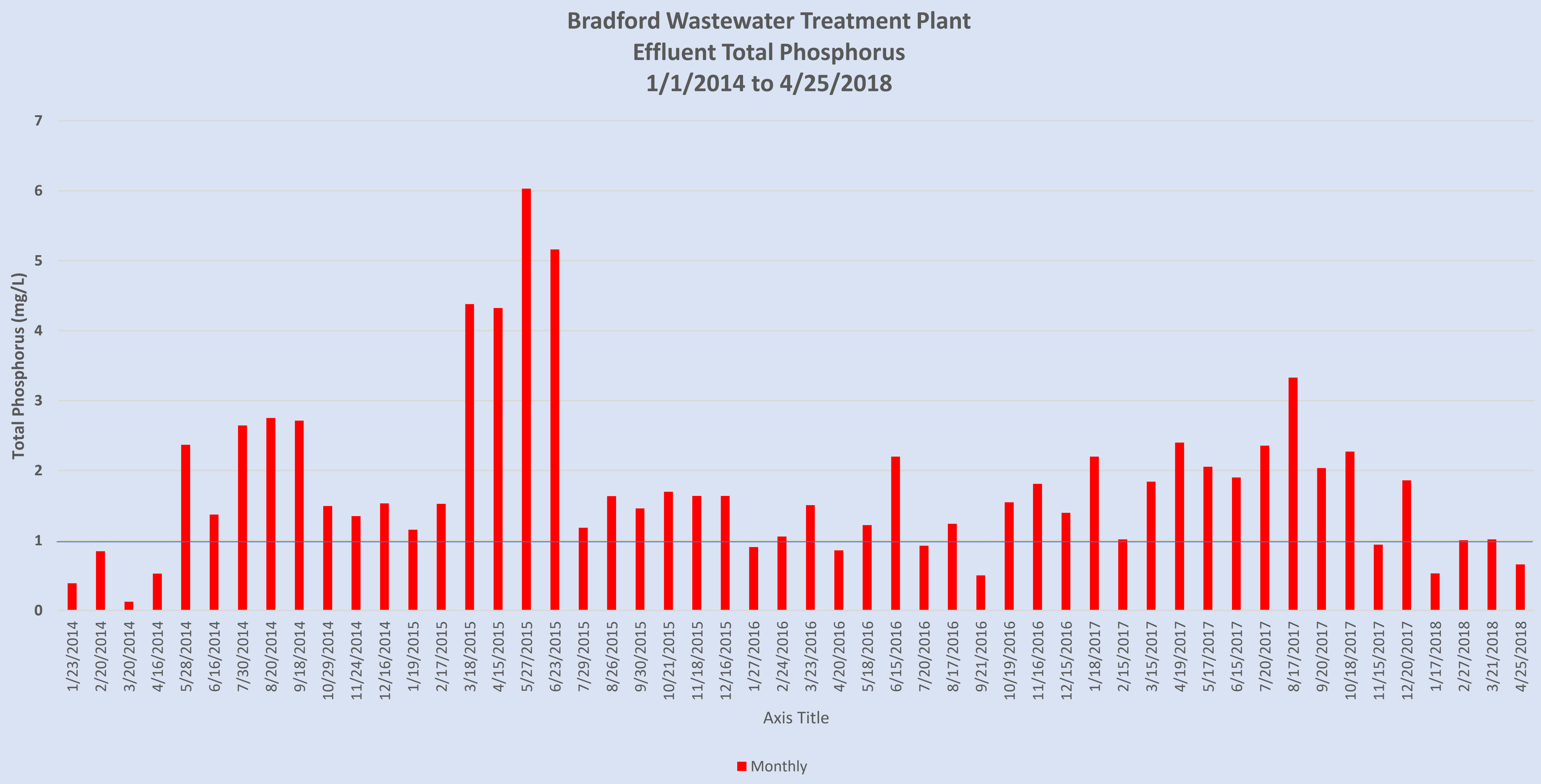
- **That abandoned one wastewater treatment plant**
- **Constructed a new BNR wastewater treatment plant**
- **Suffered from nearly random compliance for 4 years**
- **Then reached out to the Compliance Assistance Unit to visit their BNR system.**

Troubleshooting BNR Systems in Small Communities

BNR (Carrousel type)




WesTech


Bradford Wastewater Treatment Plant
Effluent Total Phosphorus
1/1/2014 to 4/25/2018
Total Phosphorus (mg/L)
0
1
2
3
4
5
6
7
1/23/2014
2/20/2014
3/20/2014
4/16/2014
5/28/2014
6/16/2014
7/30/2014
8/20/2014
9/18/2014
10/29/2014
11/24/2014
12/16/2014
1/19/2015
2/17/2015
3/18/2015
4/15/2015
5/27/2015
6/23/2015
7/29/2015
8/26/2015
9/30/2015
10/21/2015
11/18/2015
12/16/2015
1/27/2016
2/24/2016
3/23/2016
4/20/2016
5/18/2016
6/15/2016
7/20/2016
8/17/2016
9/21/2016
10/19/2016
11/16/2016
12/15/2016
1/18/2017
2/15/2017
3/15/2017
4/19/2017
5/17/2017
6/15/2017
7/20/2017
8/17/2017
9/20/2017
10/18/2017
11/15/2017
12/20/2017
1/17/2018
2/27/2018
3/21/2018
4/25/2018
Axis Title
Monthly

Troubleshooting BNR Systems in Small Communities

Date Range	Monthly Average Reported	Compliant	% Compliant	Noncompliant	% Noncompliant
Jan 2014 to Mar 2018	51	10	19.6	41	80.4

Troubleshooting BNR Systems in Small Communities

Location	COD	NH3-N	N03-N	P04-P
Standard (300 mg/L)	299			
Influent	190	19.0		1.27
Anaerobic Tank	119	4.5	11.9	1.01
Anoxic Tank	113	0.1	14.6	0.99
Oxic Tank		0.02	14.7	0.99
Final Effluent	99	0.09	13.9	0.79
RAS			14.2	
Note all samples are grab samples (Samples run on 3/15)				

Troubleshooting BNR Systems in Small Communities

Nitrate Profile (mg/L)			
	RAS	Anaerobic	Anoxic
3/15/2018	14.3	11.9	14.6
→ 3/19/2018	8.7	12.5	11.9
3/20/2018	11.6	7.9	11.8
3/21/2018	11.5	7.5	12.0
3/22/2018	8.6	8.2	11.1

Too much Nitrate everywhere

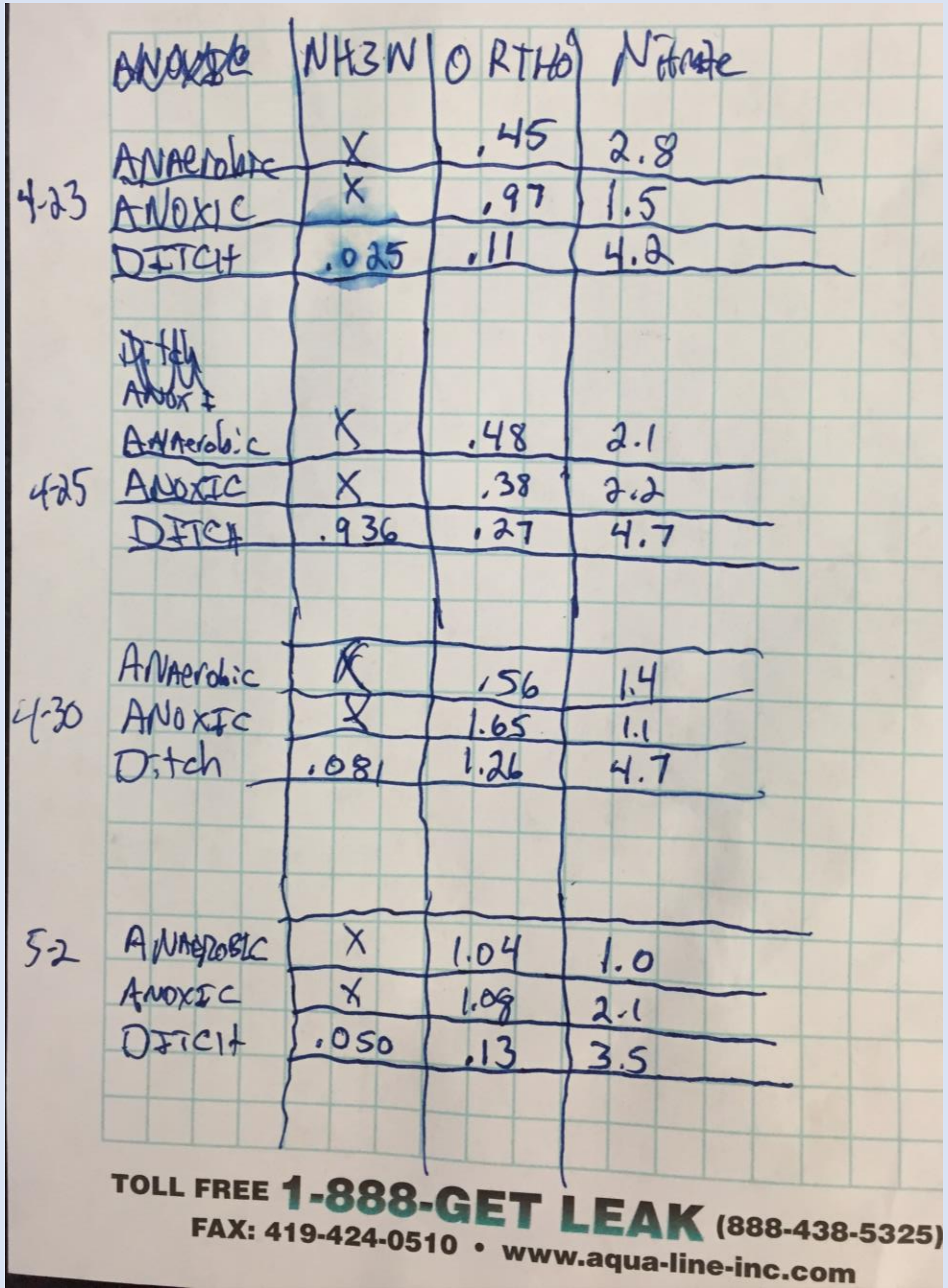
Solution: Manage the Nitrates

Troubleshooting BNR Systems in Small Communities

Solution: Manage the Nitrates

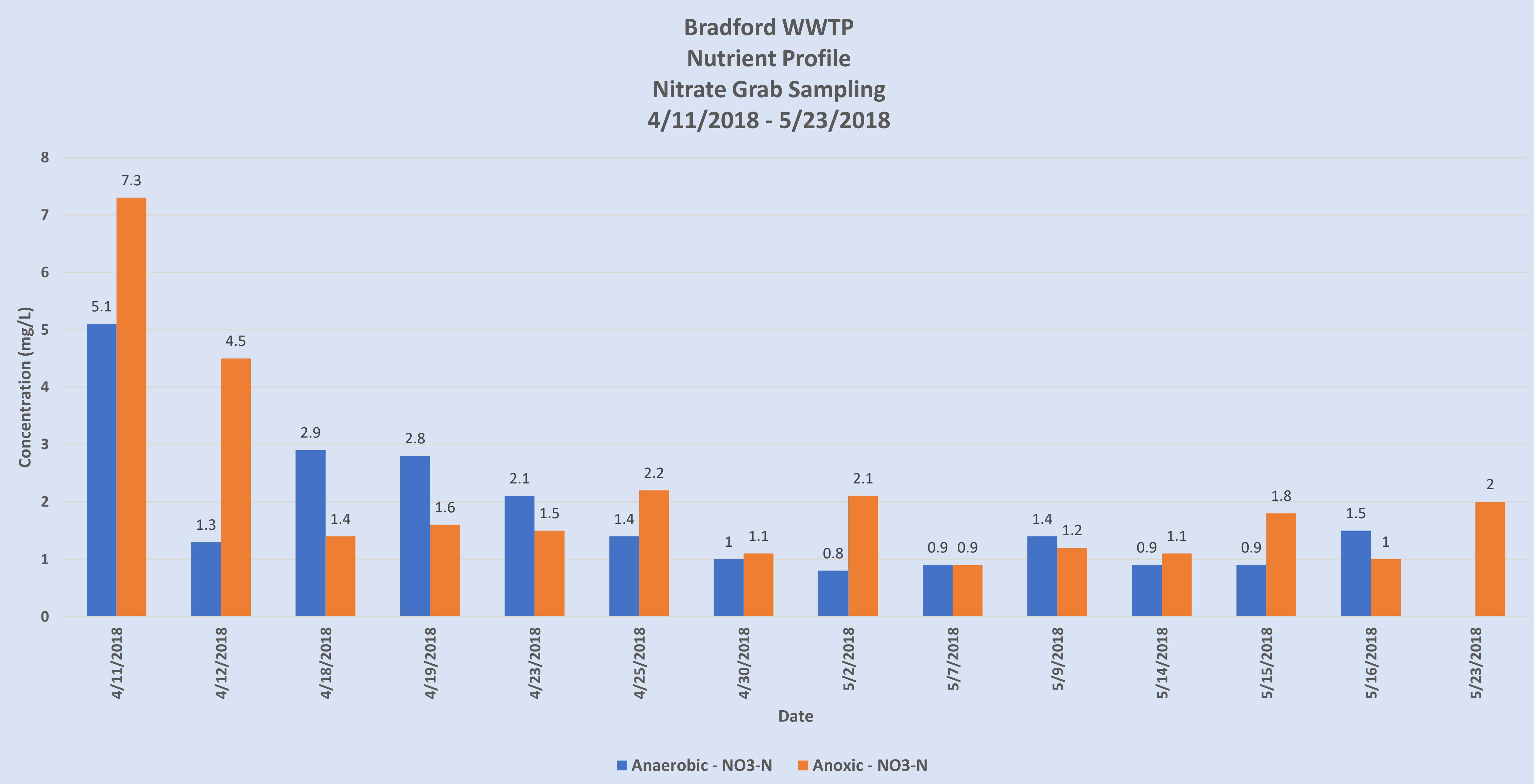
1) Closed the nitrate recycle gate completely
2) Run vertical rotor at 38 Hertz
3) Turned 2nd Anaerobic Zone Mixer OFF for 3.5 hours, ON for 30 minutes
4) Turned Anoxic Zone Mixer OFF for 3.5 hours, ON for 30 minutes
5) Profile Ammonia, Nitrate, and Orthophosphate in each zone

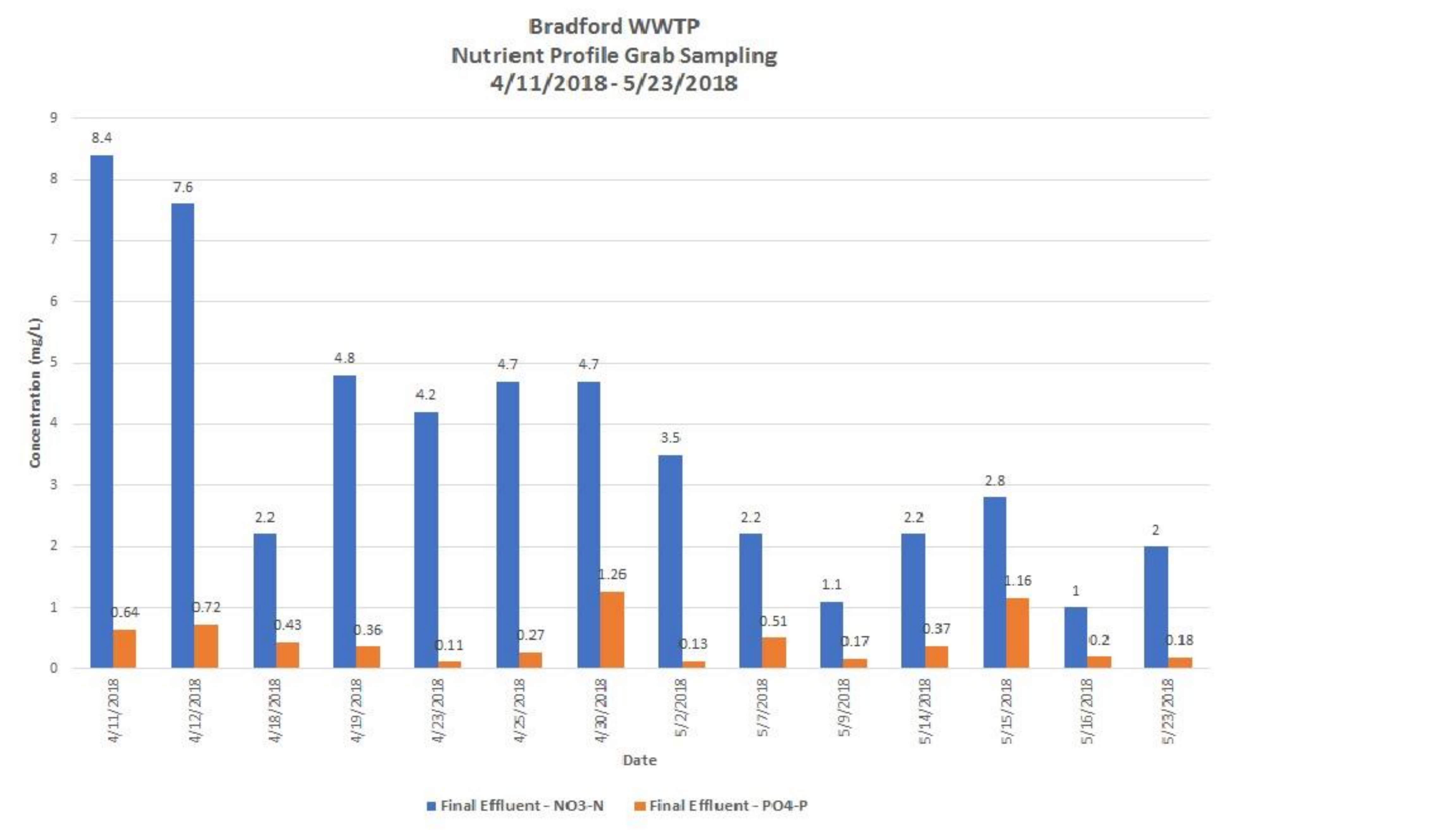
Troubleshooting BNR Systems in Small Communities

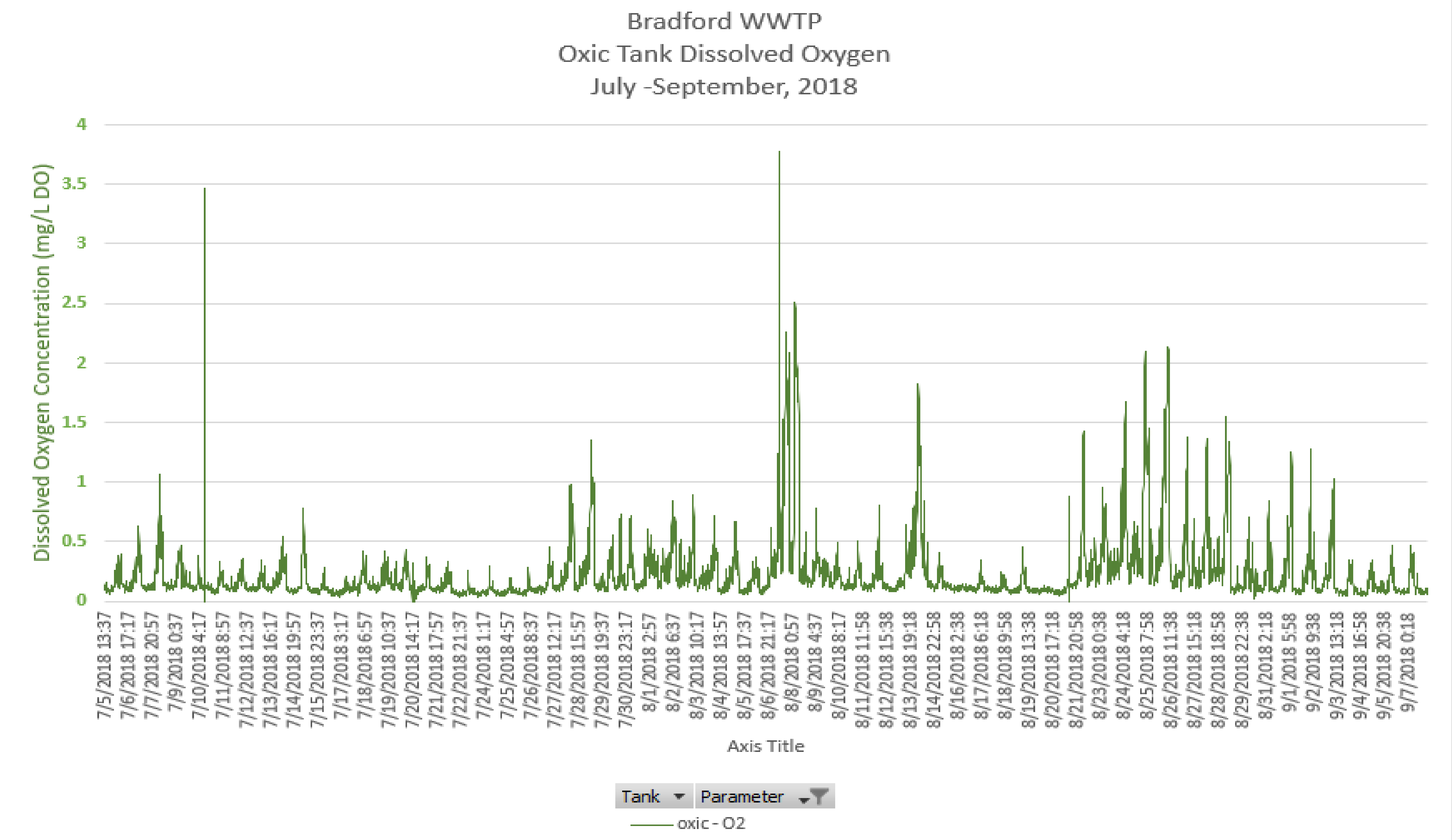


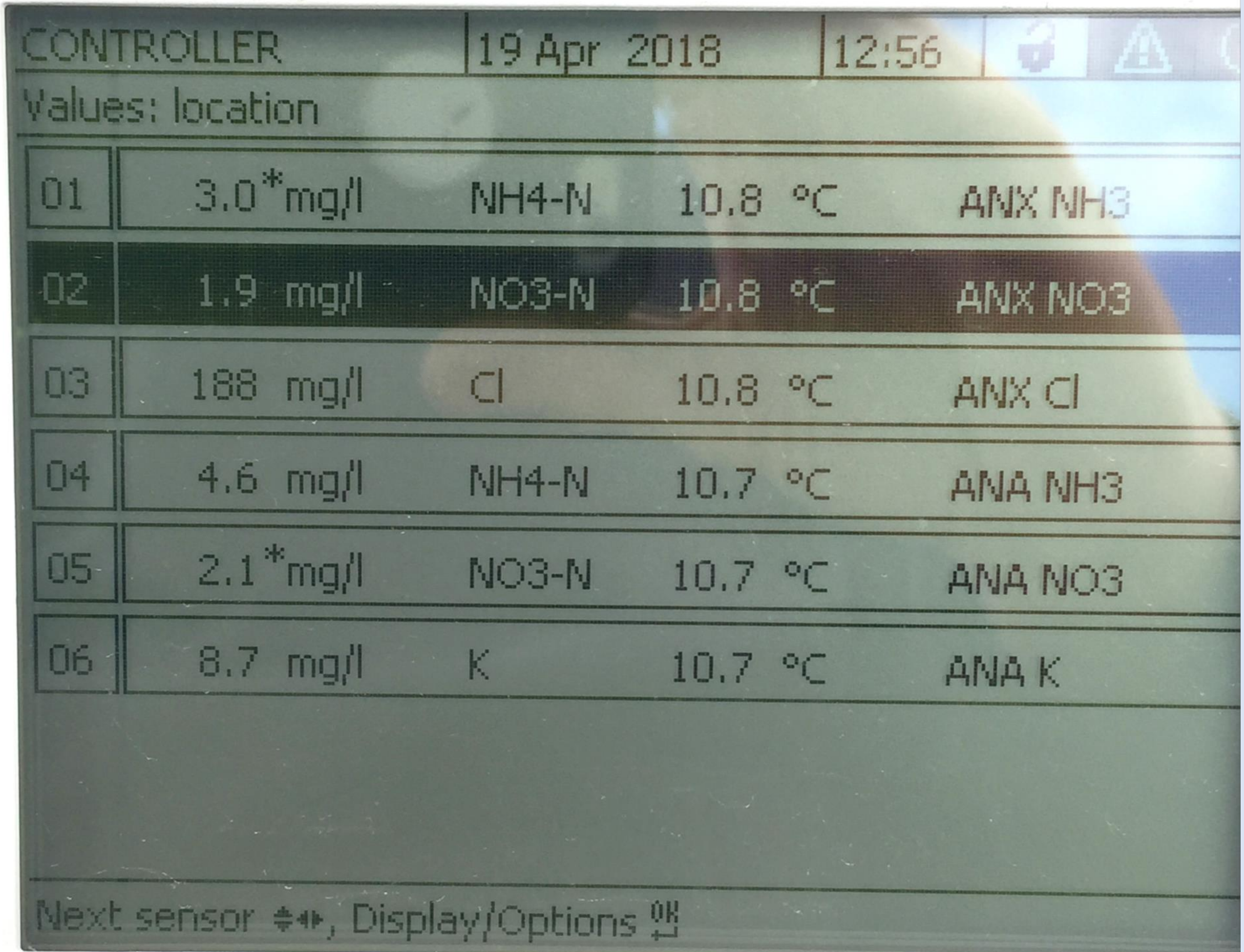
Date	[illegible]	NH3N	ORTHO	Nitrate
4-23	ANAEROBIC	X	.45	2.8
	ANOXIC	X	.97	1.5
	DITCH	.025	.11	4.2
4-25	ANAEROBIC	X	.48	2.1
	ANOXIC	X	.38	2.2
	DITCH	.936	.27	4.7
4-30	ANAEROBIC	X	.56	1.4
	ANOXIC	X	1.65	1.1
	Ditch	.081	1.26	4.7
5-2	ANAEROBIC	X	1.04	1.0
	ANOXIC	X	1.09	2.1
	DITCH	.050	.13	3.5

TOLL FREE 1-888-GET LEAK (888-438-5325)
FAX: 419-424-0510 • www.aqua-line-inc.com

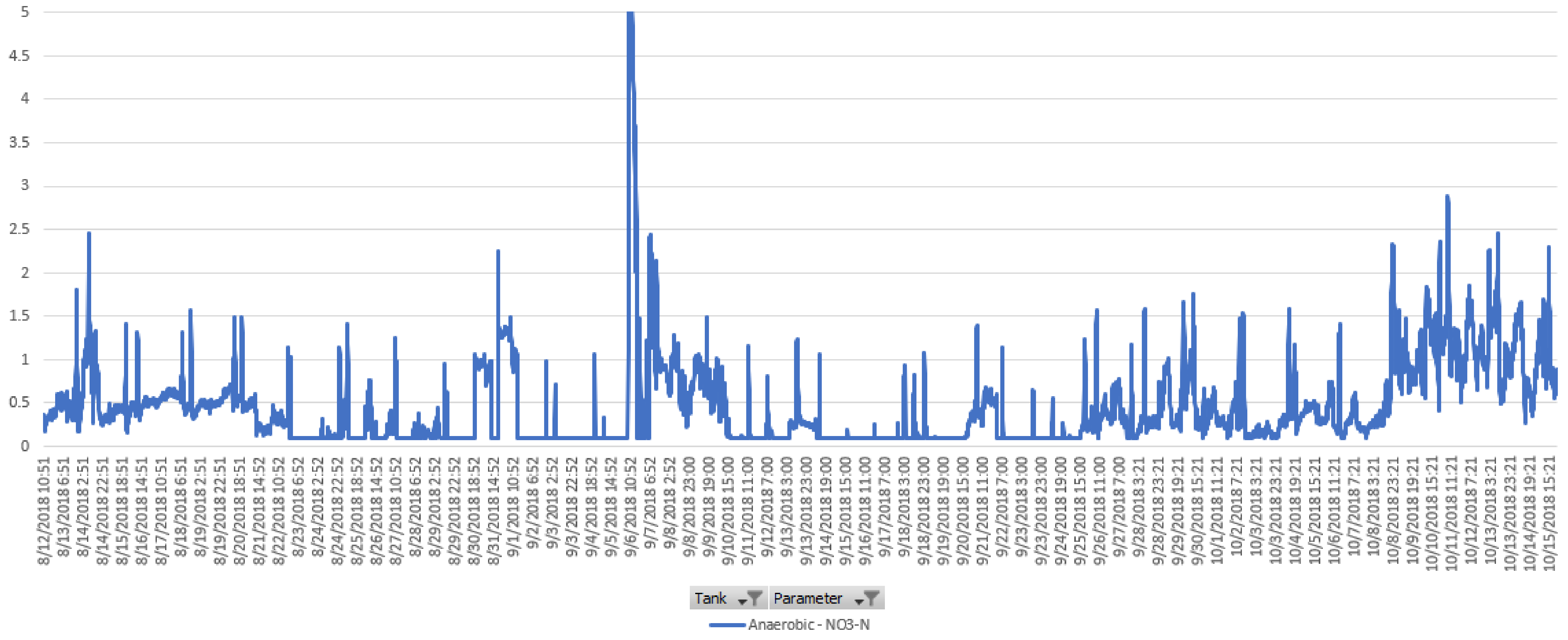

Bradford WWTP
Nutrient Profile
Nitrate Grab Sampling
4/11/2018 - 5/23/2018
Concentration (mg/L)
0
1
2
3
4
5
6
7
8
5.1
7.3
1.3
4.5
2.9
1.4
2.8
1.6
2.1
1.5
1.4
2.2
1
1.1
0.8
2.1
0.9
0.9
1.4
1.2
0.9
1.1
0.9
1.8
1.5
1
2
4/11/2018
4/12/2018
4/18/2018
4/19/2018
4/23/2018
4/25/2018
4/30/2018
5/2/2018
5/7/2018
5/9/2018
5/14/2018
5/15/2018
5/16/2018
5/23/2018
Date
Anaerobic - NO3-N
Anoxic - NO3-N

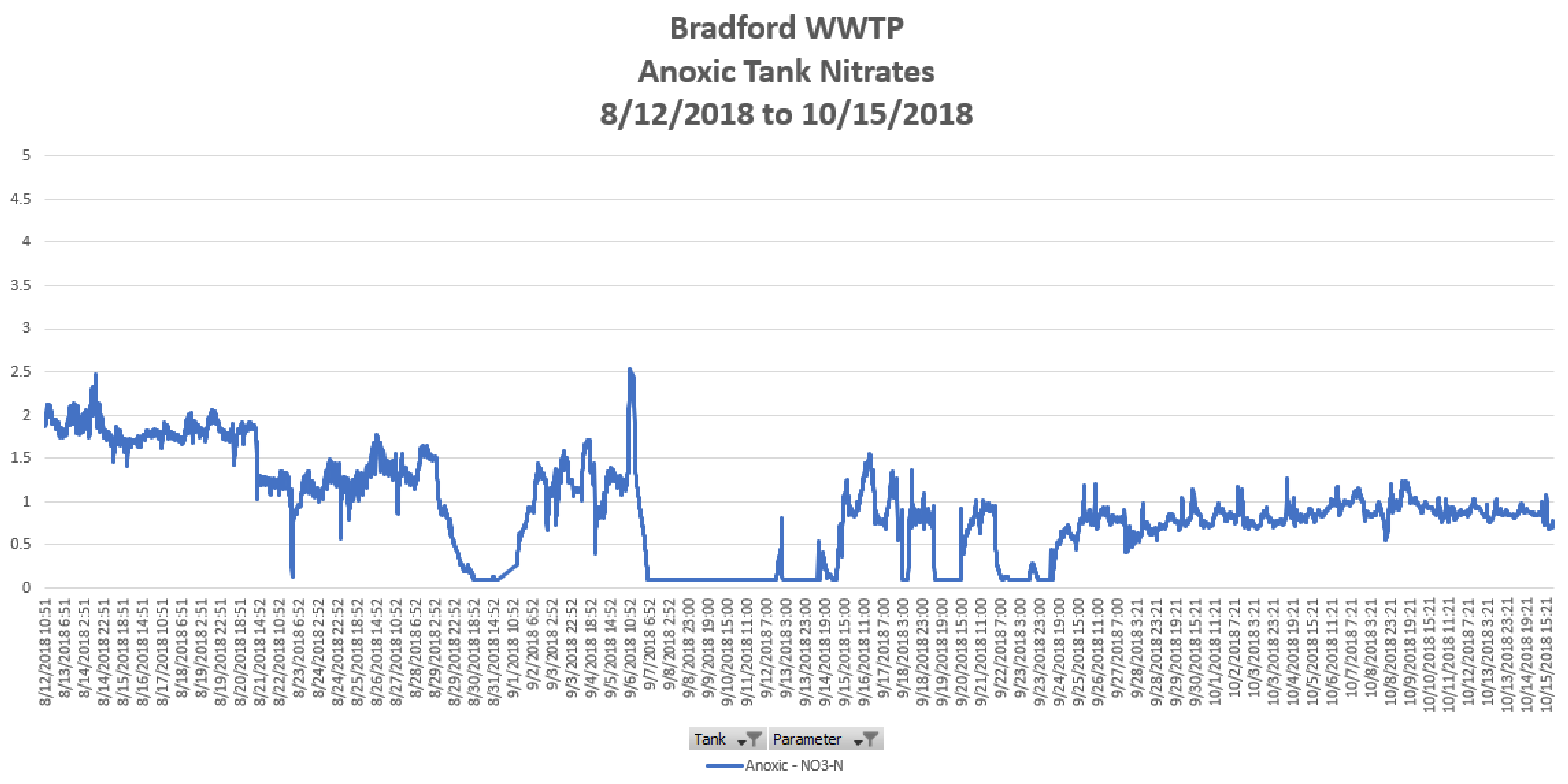

Bradford WWTP
Nutrient Profile Grab Sampling
4/11/2018 - 5/23/2018
Concentration (mg/L)
Date
4/11/2018
4/12/2018
4/18/2018
4/19/2018
4/23/2018
4/25/2018
4/30/2018
5/2/2018
5/7/2018
5/9/2018
5/14/2018
5/15/2018
5/16/2018
5/23/2018
8.4
0.64
7.6
0.72
2.2
0.43
4.8
0.36
4.2
0.11
4.7
0.27
4.7
1.26
3.5
0.13
2.2
0.51
1.1
0.17
2.2
0.37
2.8
1.16
1
0.2
2
0.18
Final Effluent - NO3-N
Final Effluent - PO4-P


Bradford WWTP
Oxic Tank Dissolved Oxygen
July -September, 2018
Dissolved Oxygen Concentration (mg/L DO)
Axis Title
Tank
Parameter
oxic - O2


CONTROLLER
19 Apr 2018
12:56
Values: location
01 3.0*mg/l NH4-N 10.8 °C ANX NH3
02 1.9 mg/l NO3-N 10.8 °C ANX NO3
03 188 mg/l Cl 10.8 °C ANX Cl
04 4.6 mg/l NH4-N 10.7 °C ANA NH3
05 2.1*mg/l NO3-N 10.7 °C ANA NO3
06 8.7 mg/l K 10.7 °C ANA K
Next sensor, Display/Options

Bradford WWTP
Anaerobic Tank Nitrates
8/12/2018 to 10/15/2018





Bradford WWTP
Anoxic Tank Nitrates
8/12/2018 to 10/15/2018
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Tank
Parameter
Anoxic - NO3-N

Troubleshooting BNR Systems in Small Communities

First April sample was high (1.25 mg/L), but the rest of the samples brought the monthly down to 0.66 mg/L

Alum feed was shut down 5/2

May 2018 another consecutive month of compliance for TP

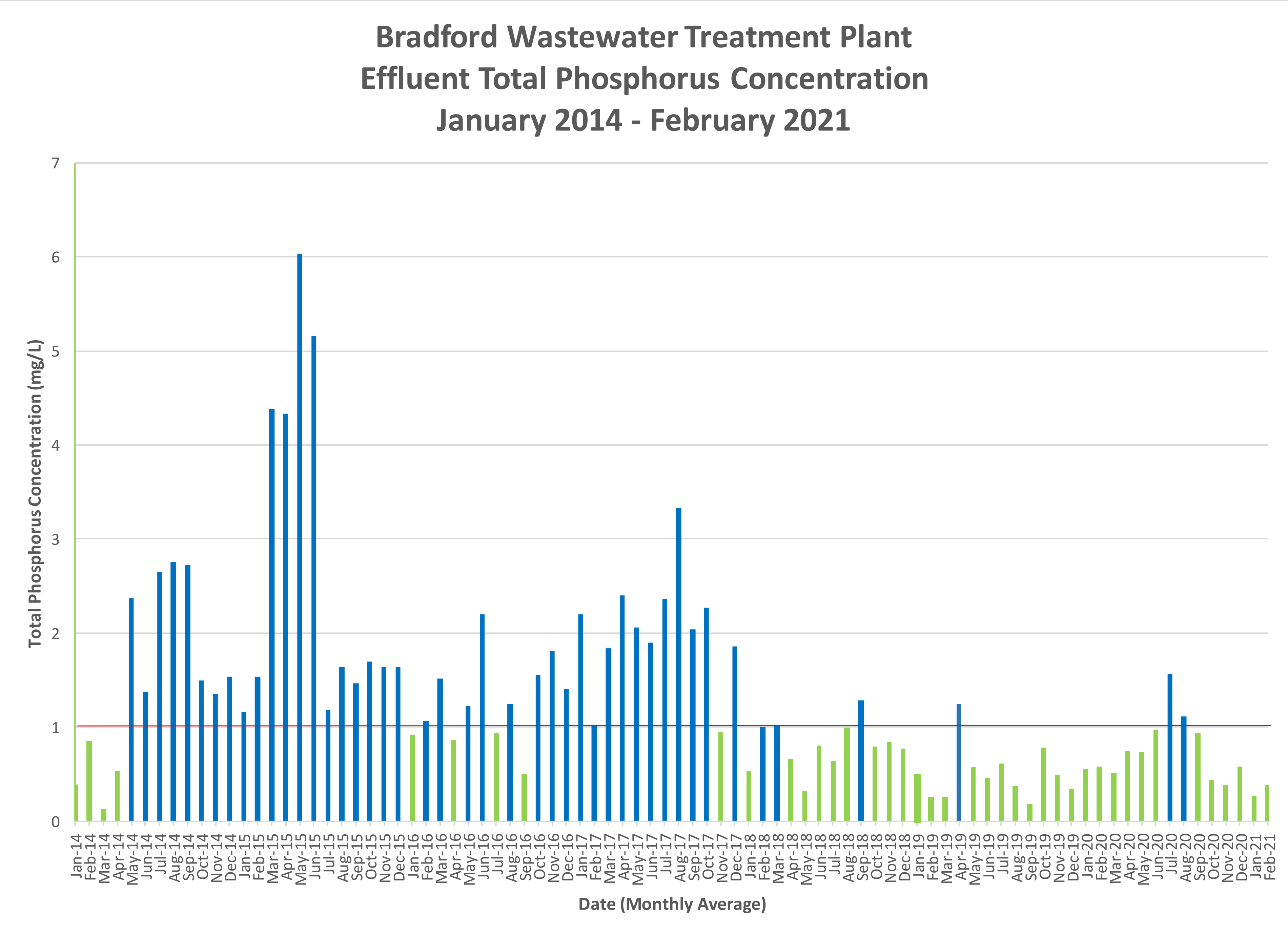
In addition, the village was spending $800 - $1000/month for alum previously.

Electricity demand should also be reduced due to mixer turndown


BLUE RIVER TECHNOLOGIES
NEW CASTLE, INDIANA

Digester Nutrient Profile

Ammonia Nitrogen	Dilution	Nitrate Nitrogen	Dilution	Orthophosphate	Dilution
Nondetect	(1:4)	**504 mg/L**	(1:20)	**220 mg/L**	(1:200)



Bradford Wastewater Treatment Plant
Effluent Total Phosphorus Concentration
January 2014 - February 2021
Total Phosphorus Concentration (mg/L)
Date (Monthly Average)
0
1
2
3
4
5
6
7
Jan-14
Feb-21

Date Range	Monthly Average Reported	Compliant	% Compliant	Noncompliant	% Noncompliant
January 2014 to March 2018	51	10	19.6	41	80.4
April 2018 To February 2021	**35**	**31**	**88.6**	**4**	**11.4**

Troubleshooting BNR Systems in Small Communities

Keys to BNR:

Process Control!

1) Monitor the nutrients in the Inputs to each zone
2) Monitor the nutrients in Internal Recycles (Digester Supernatant)
3) If the Chemistry is correct in the zones, the bacterial response will be compliant.
4) **Know the chemical environment in each zone of the WWTP.**

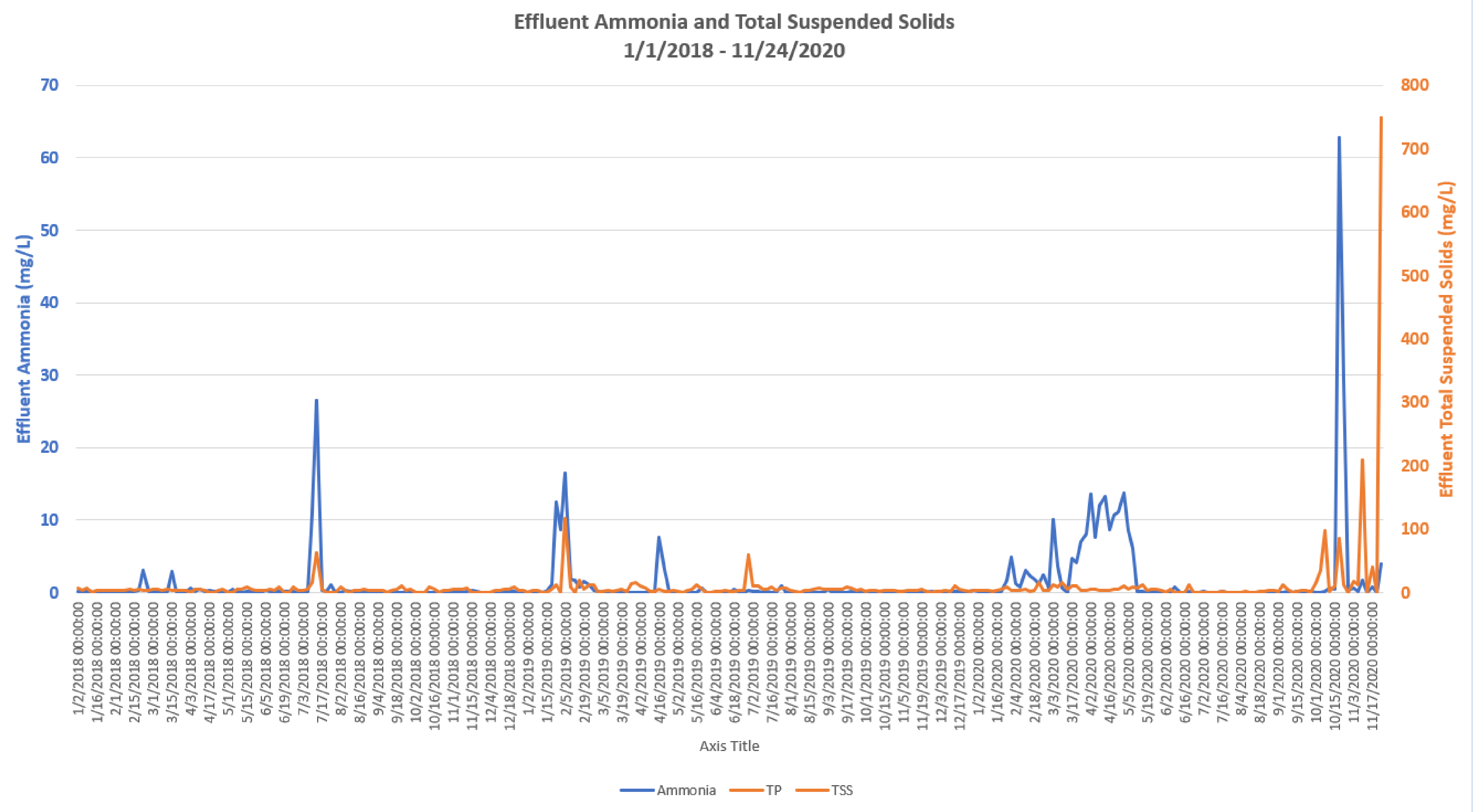
BNR in an SBR?

BNR in an SBR

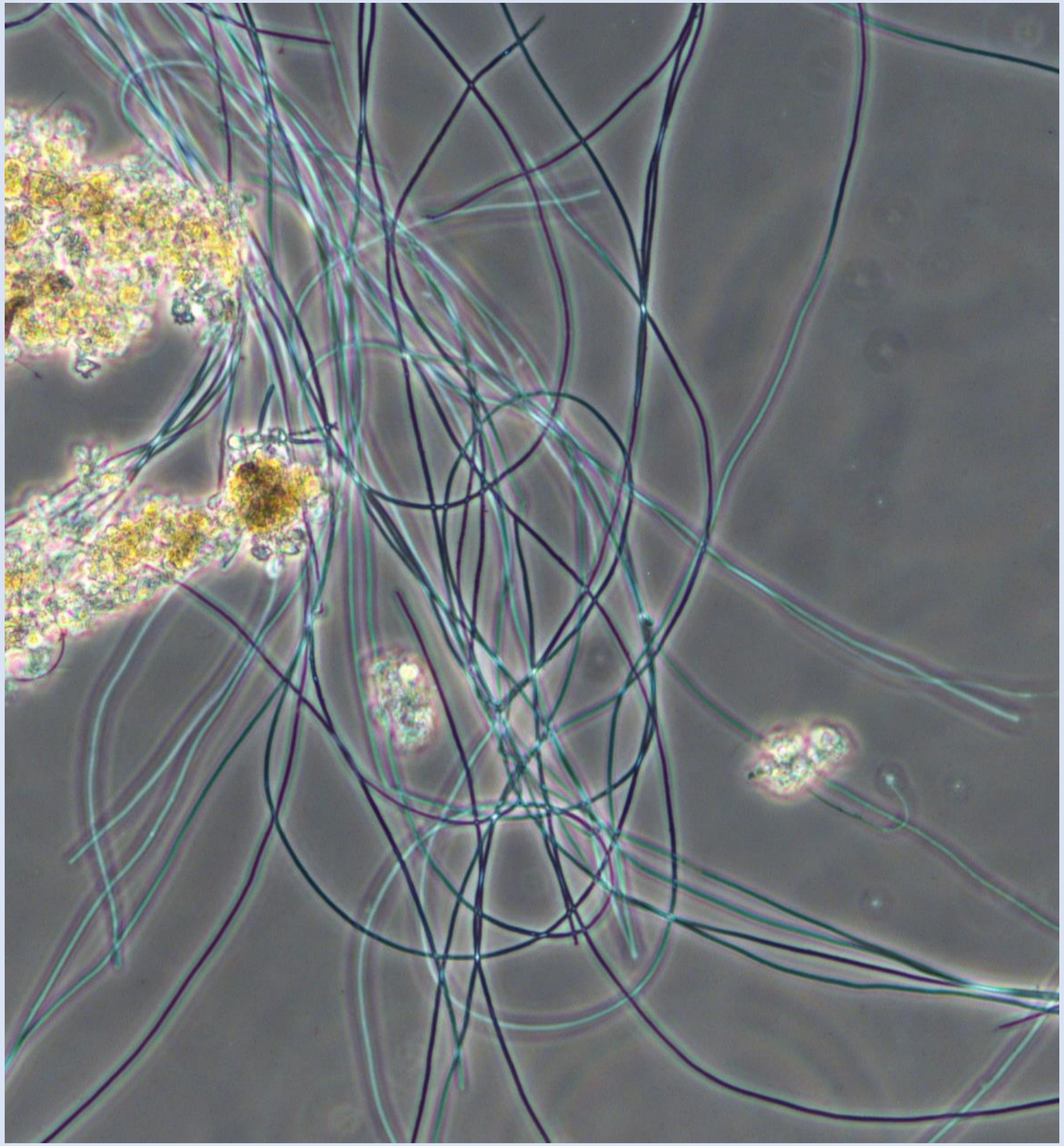
Originally, I was called to diagnose a filament issue.

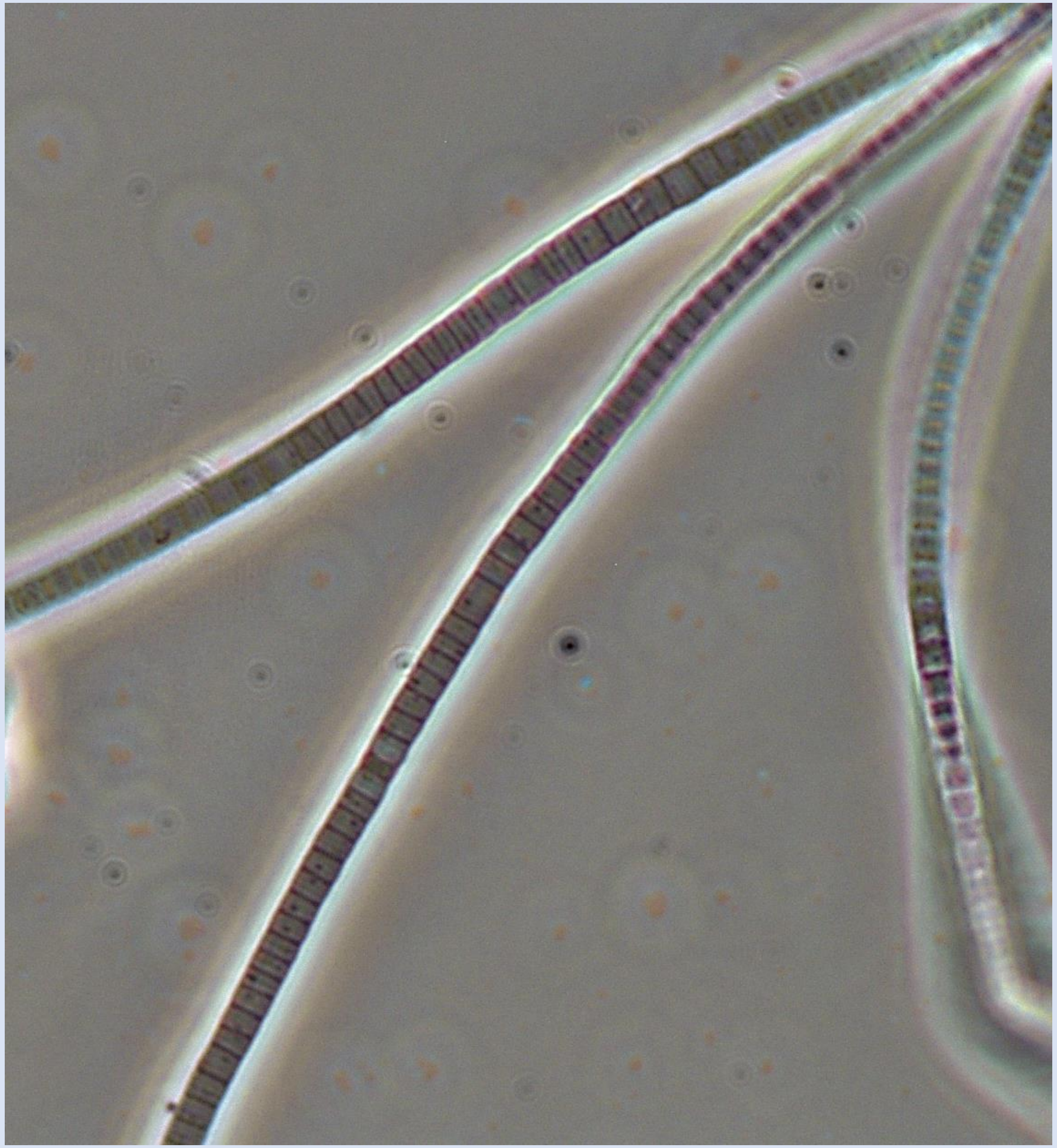
The SBR had Type O21N, EVERYWHERE.

And it was causing severe noncompliance (11/22/2020)



Effluent Ammonia and Total Suspended Solids
1/1/2018 - 11/24/2020
Effluent Ammonia (mg/L)
Effluent Total Suspended Solids (mg/L)
70
60
50
40
30
20
10
0
800
700
600
500
400
300
200
100
0
Axis Title
Ammonia
TP
TSS





BNR in an SBR

There was more filament than floc, and solids were being decanted

Type O21N is a septicity filament

So, the solution was to track down the septicity source:

Long, low flow force mains and solids handling are first to check.


fournier


1
2
3

BNR in an SBR

First Visit to Walnut Creek (12/9/2020):

I realized that the WWTP was feeding **sodium aluminate** in the influent to the SBR

This was how they were meeting their permit concentrations for
Total Phosphorus

But I suspected that they were inadvertently creating a nutrient imbalance for phosphorus

The orthophosphate concentration was less than 0.3 mg/L in the mix/fill cycle

And the influent CBOD was typically around 400 mg/L!

BNR in an SBR

The community did have a low flow force main that has septic wastewater discharge to the WWTP

What was the cause of the Type O21N filament?

Was it septicity? Was it nutrient deficiency?

BNR in an SBR

The Plan:

SBRs are complete mix tanks, which is good for a septic influent.

SBRs can have the cycles adjusted to almost anything as long as the mix/fill and the react/fill cycles match the react, settle and decant cycles.

This SBR was so over designed that they only ran one tank

They could do this because the system was designed to treat 400,000 gpd

But the WWTP only sees around 180,000 gpd.

BNR in an SBR

When we looked at the SBR cycles, we realized that the initial mix-fill cycle was only 5 minutes long

We expanded the mix-fill cycle to 40 minutes to try to stress the phosphorus accumulating bacteria to release OrthoP

We cycled the digester air ON for 3 hours and OFF for 1 hour to try to reduce the Nitrates and OrthoP in dewatering

And on 12/14,

We shut the Sodium Aluminate **OFF**

BNR in an SBR

They could run one tank because they had an influent EQ tank that would store the wastewater during react, settle and decant (actually it could almost store an entire day's flow)

Because the online SBR had so much filament, we switched to the unused tank on 12/15 (with no sodium aluminate added!)

The orthophosphate concentration never missed a beat staying typically below the permit limit of **1.0 mg/L**

But the ammonia crept up slowly settling in at around 10-12 mg/L.

BNR in an SBR

We kept bumping the aeration cycles to ty to oxidize the ammonia

But the ammonia didn’t budge and remained around 10 mg/L

What is going on here?

BNR in an SBR

Parameter	Dilution (Sample: DI water)	Meter Read	Multiplier	Concentration
EQ Basin	0.2:9.8	0.66	50	**33 mg/L**
NH3-N (react-fill)	0.2 : 9.8	0.58	50	**29 mg/L**
NH3-N (post EQ)	0.5:9.5	0.61	50	**30.5 mg/L**
NO3-N (react)	1 : 0	0.7	1	**0.7 mg/L**
PO4-P (react)	2.5 : 2.5	0.49	2	**0.98 mg/L**

Grab samples from 12/16/2020

BNR in an SBR

- Interestingly, the nitrate was almost always less than 1 mg/L as well
- But they didn’t have a nitrate limit or at total inorganic nitrogen limit
- To take care of the new ammonia violation, we increased the react/fill and the react cycles.
- But the ammonia didn’t come down

BNR in an SBR

- Prior to turning off the sodium aluminate, ammonia was near nondetect
- But that was in the tank with the filaments. We switched tanks to the unused tank to stop losing solids to the creek.
- The other factor was that the tanks were above ground and out of direct sight.
- We didn’t have good visual cues, only random cues when we collected samples

BNR in an SBR

What we eventually discovered:

The original tank aeration was on a timed cycle

When we switched tanks, the second tank was programed to run aeration with a DO probe

We didn't notice when the air was shut down when it reached a high set point

And the influent pump would pump whenever the EQ floats called for pump cycle

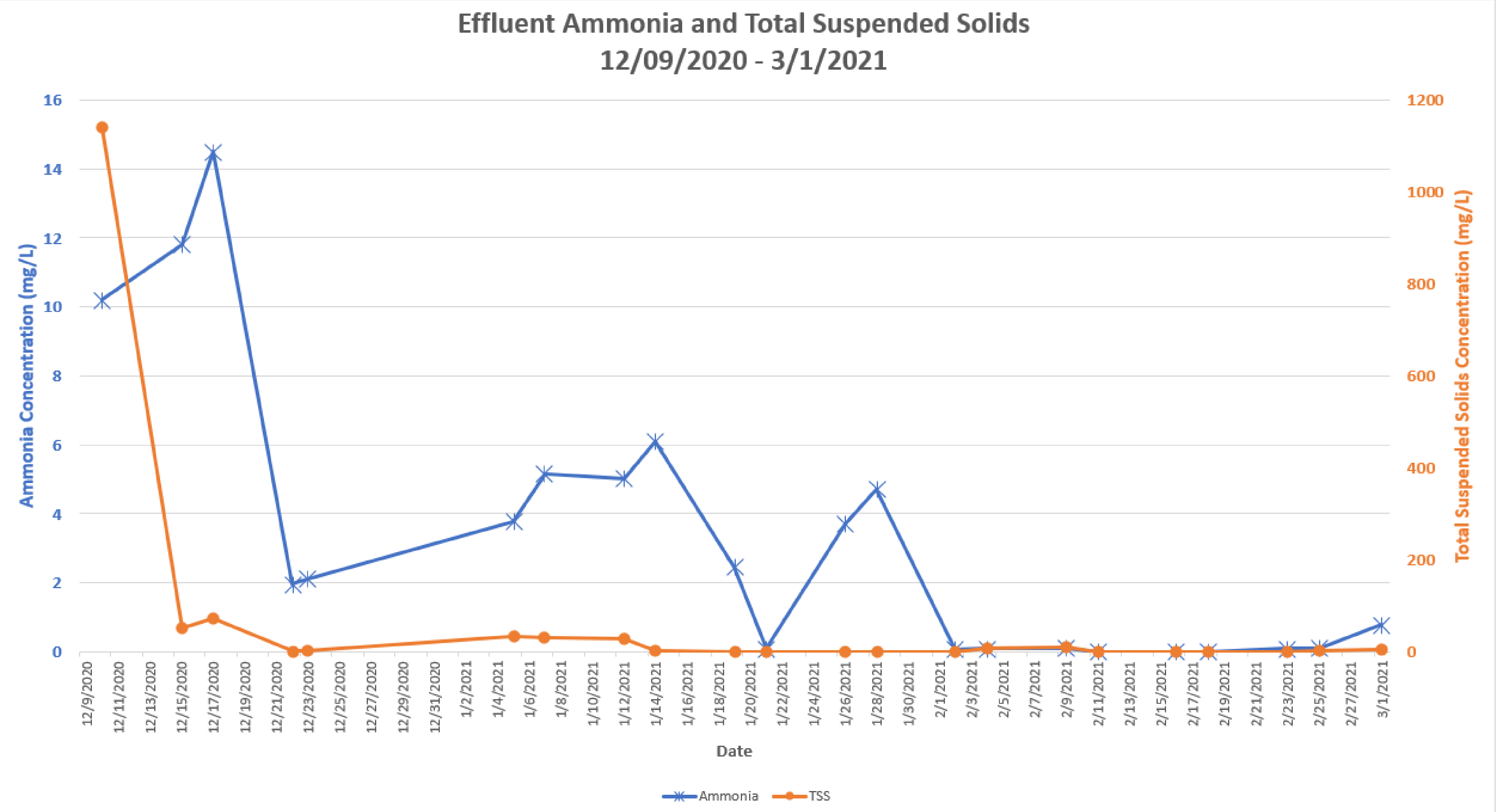
BNR in an SBR

The other thing we discovered much later:

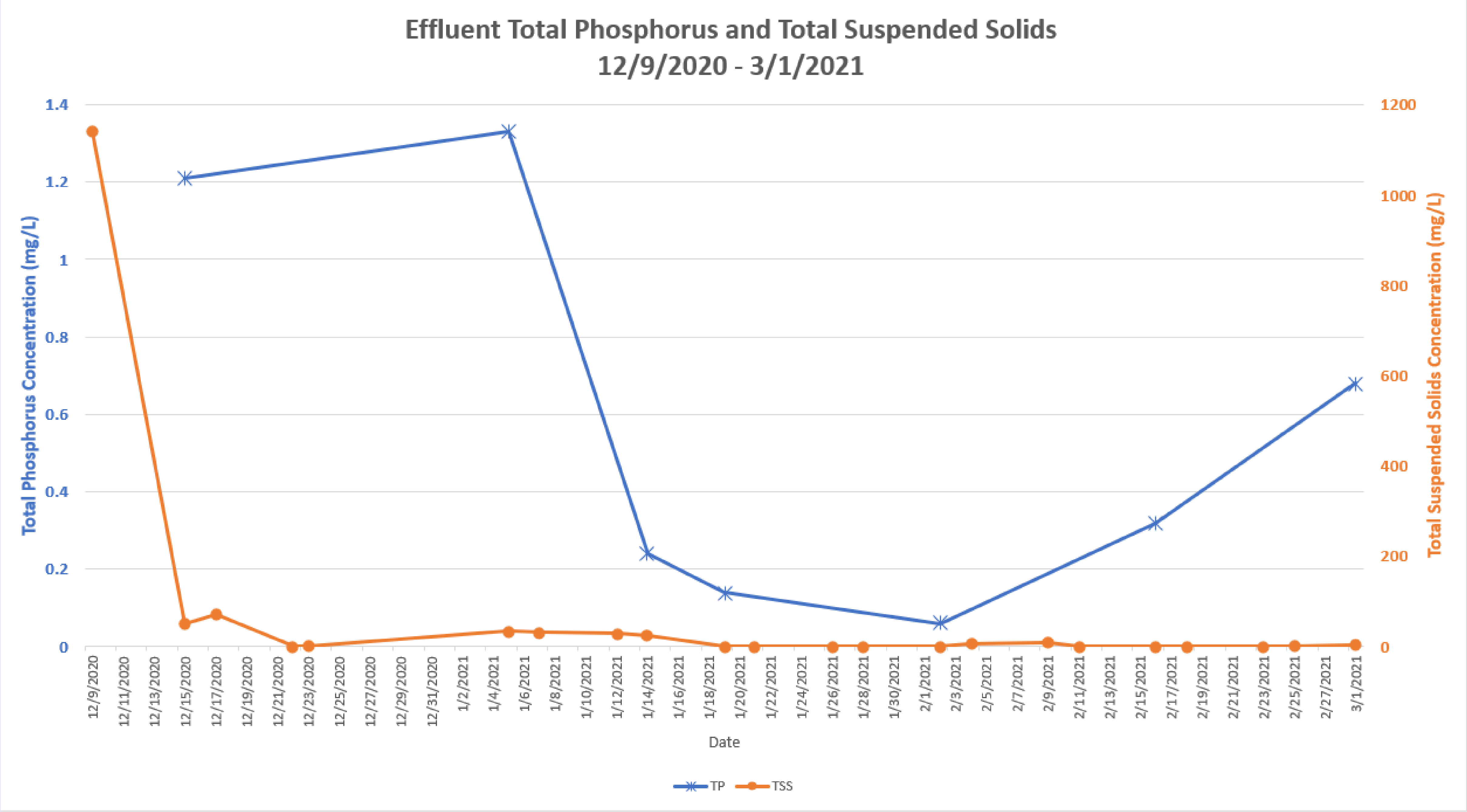
The DO probe was faulty, showing a higher (1-2 mg/L) in the second tank than what my handheld DO probe measured (around 0.5 mg/L)

The tank turned out to be DO limited

And a DO limited MLSS will let the ammonia slip into violation



Effluent Ammonia and Total Suspended Solids
12/09/2020 - 3/1/2021
Ammonia Concentration (mg/L)
Total Suspended Solids Concentration (mg/L)
Date
Ammonia
TSS



Effluent Total Phosphorus and Total Suspended Solids
12/9/2020 - 3/1/2021
Total Phosphorus Concentration (mg/L)
Total Suspended Solids Concentration (mg/L)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1200
1000
800
600
400
200
0
12/9/2020
12/11/2020
12/13/2020
12/15/2020
12/17/2020
12/19/2020
12/21/2020
12/23/2020
12/25/2020
12/27/2020
12/29/2020
12/31/2020
1/2/2021
1/4/2021
1/6/2021
1/8/2021
1/10/2021
1/12/2021
1/14/2021
1/16/2021
1/18/2021
1/20/2021
1/22/2021
1/24/2021
1/26/2021
1/28/2021
1/30/2021
2/1/2021
2/3/2021
2/5/2021
2/7/2021
2/9/2021
2/11/2021
2/13/2021
2/15/2021
2/17/2021
2/19/2021
2/21/2021
2/23/2021
2/25/2021
2/27/2021
3/1/2021
Date
TP
TSS

BNR in an SBR

In summary,

Once we solved the low DO issue, the WWTP ran great

And by increasing the Mix/Fill cycle, we eliminated the chemicals…

…which will result in a huge cost savings

Better effluent water at a cheaper cost.

BNR in an SBR

Questions?

Conventional Activated Sludge Biological Phosphorus Removal

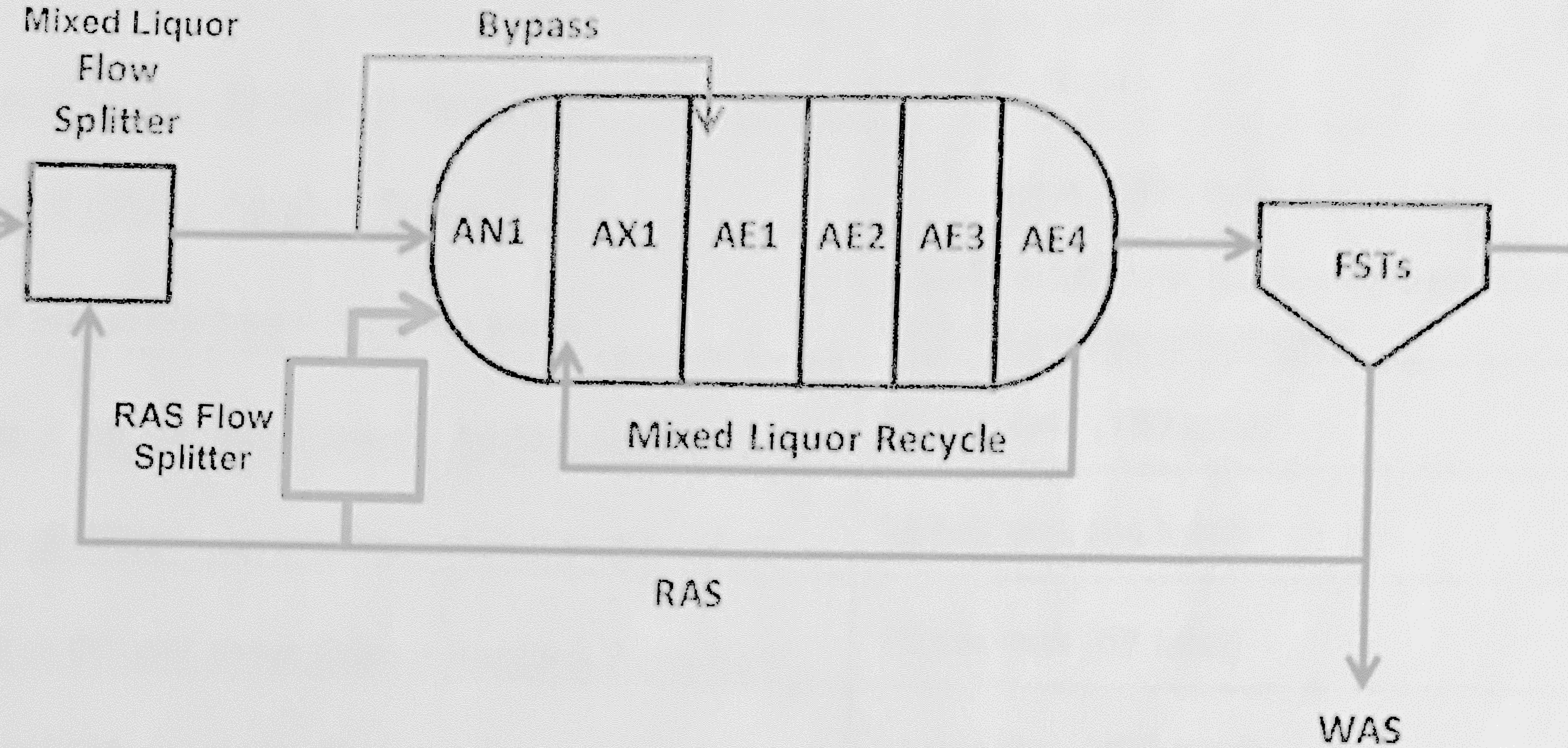
Niles, Ohio Population: 18,500 6.2 MGD design flow

In 2017, the City upgrades their WWTP from a typical extended aeration system to modern Biological Nutrient Removal system.

It was a needed rebuild of the heart of the WWTP:

- Converted the diffused aeration ditches into 3 – 3 zone BNR tanks
- Constructed 3 big, new clarifiers
- Converted anaerobic digestion to aerobic digestion
- Constructed a new head works

It was very expensive


Mixed Liquor Flow Splitter
Bypass
AN1
AX1
AE1
AE2
AE3
AE4
FSTs
RAS Flow Splitter
Mixed Liquor Recycle
RAS
WAS

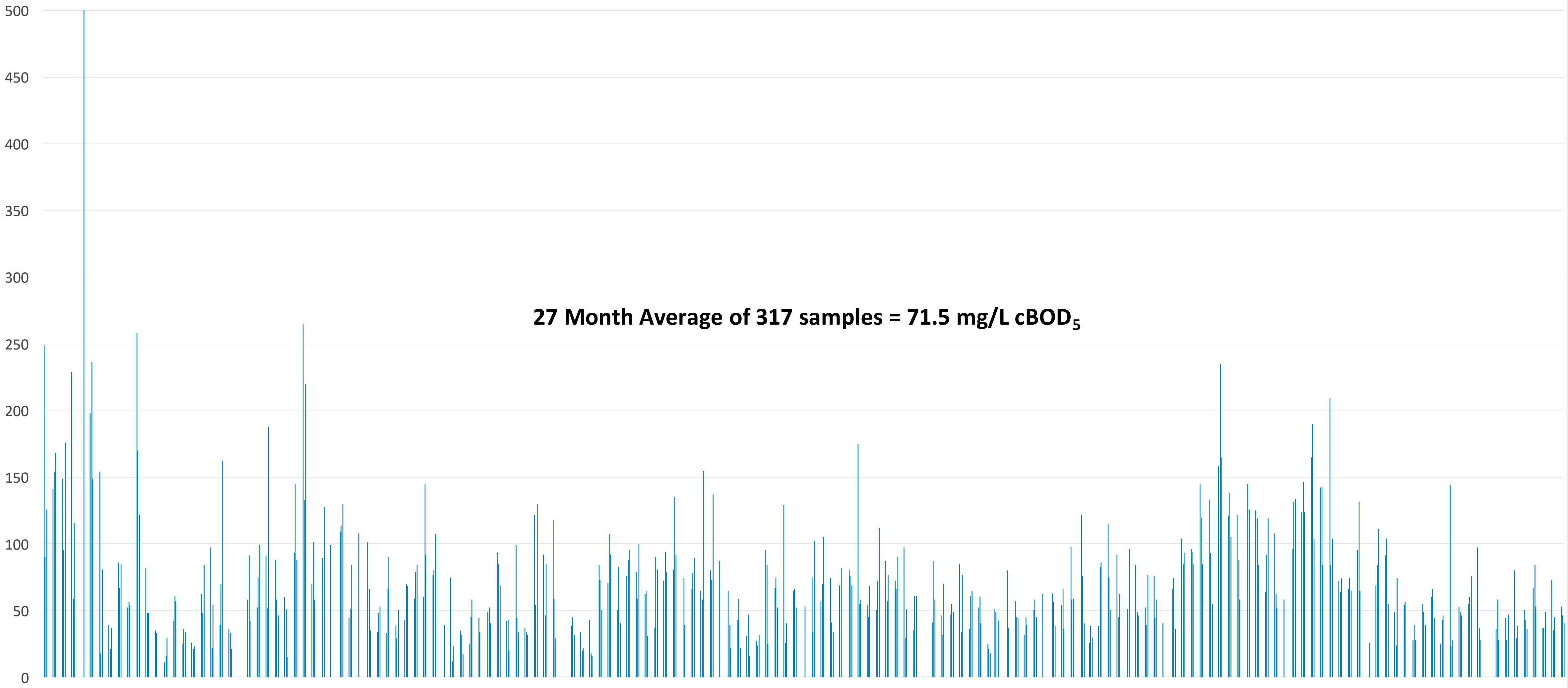
9.76 psi
20.1% M I
19.6% M I
29.8% M I
41.8% M B
ANOXIC
ZONE 1
ZONE 2
ZONE 3
ZONE 4
Setpoints
Setpoints
Setpoints
Setpoints
Setpoints
DO
DO
DO
DO
100.3% M I
ON TANK NO1 IN
-ML-PV-05
PEN MANUAL
MANUAL
I
A
A
A
M
-5.0% L
AERATION TANK NO1 IN
25-ML-PV-06
CLOSED
HAND
ANAEROBIC
pH
NO3
RUNNING

But the design engineers missed one thing:

The WWTP averaged less than 100 mg/L cBOD5 in their influent

There was not enough loading to drive the bacterial reactions that result in effective biological phosphorus removal

Niles WWTP
Influent $cBOD_5$
1/1/2018 - 3/1/2020

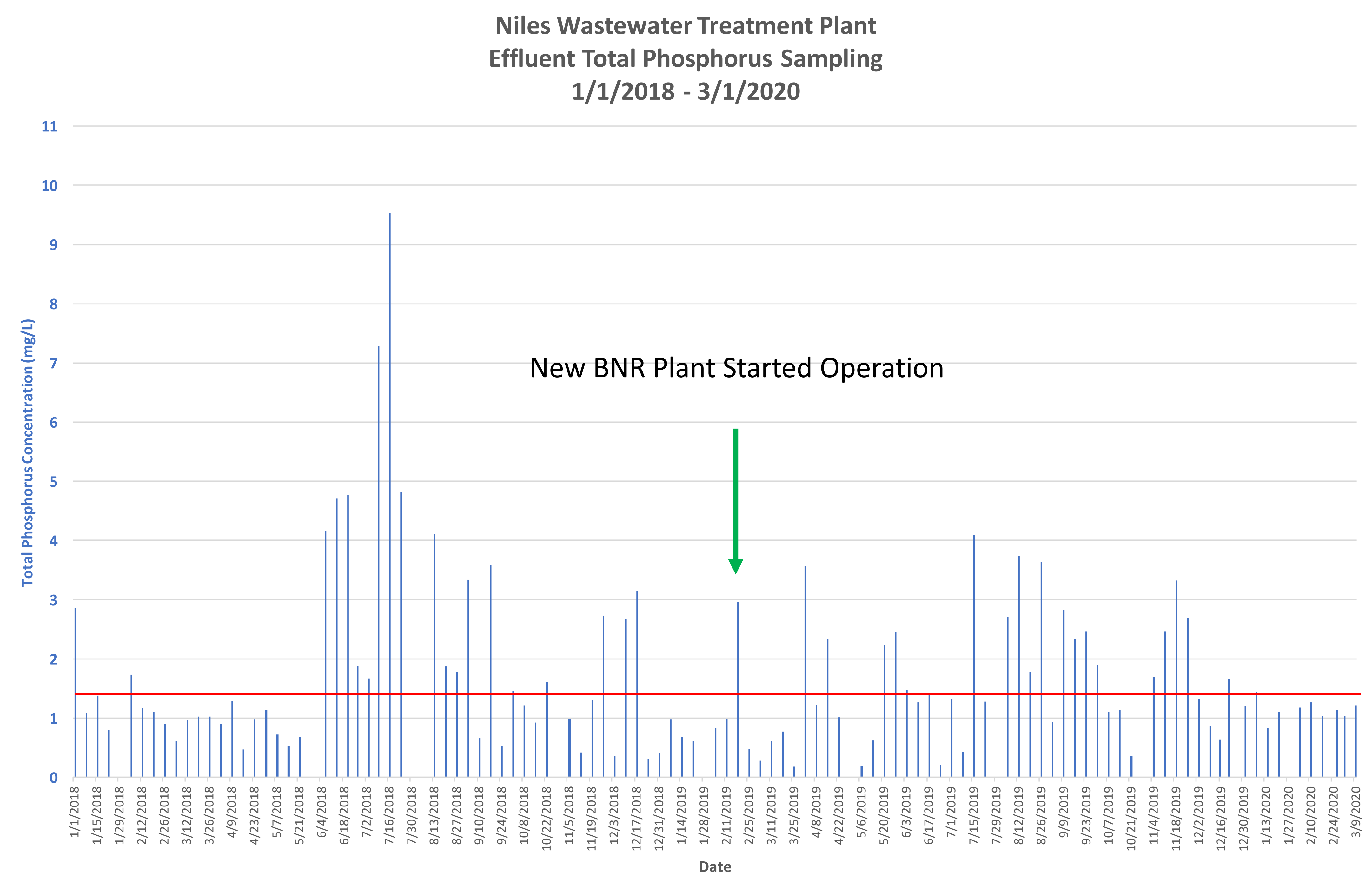


The Construction finished up in 2019.

The one-year SRF Certification Period began.

The only problem was that the new WWTP didn’t reliably remove phosphorus

It met it’s 1 mg/L monthly limit pretty randomly


Niles Wastewater Treatment Plant
Effluent Total Phosphorus Sampling
1/1/2018 - 3/1/2020
New BNR Plant Started Operation
Total Phosphorus Concentration (mg/L)
Date

Since the new WWTP started up, the treatment plant had only:

13 of 49 samples under 1.0 mg/L PO_4-P

The superintendent called me in late February 2020

I drove up, got a tour of the wwtp and then started to tell him about the success we had in Bradford

And what would be involved to implement it in Niles

Then COVID-19 arrived on the scene

And Ohio EPA field staff was grounded (including ME)

So, we started to troubleshoot noncompliance from a distance,

by Phone
by Text
by Email

The Niles upgrade didn’t have VFDs or timers on the mixers

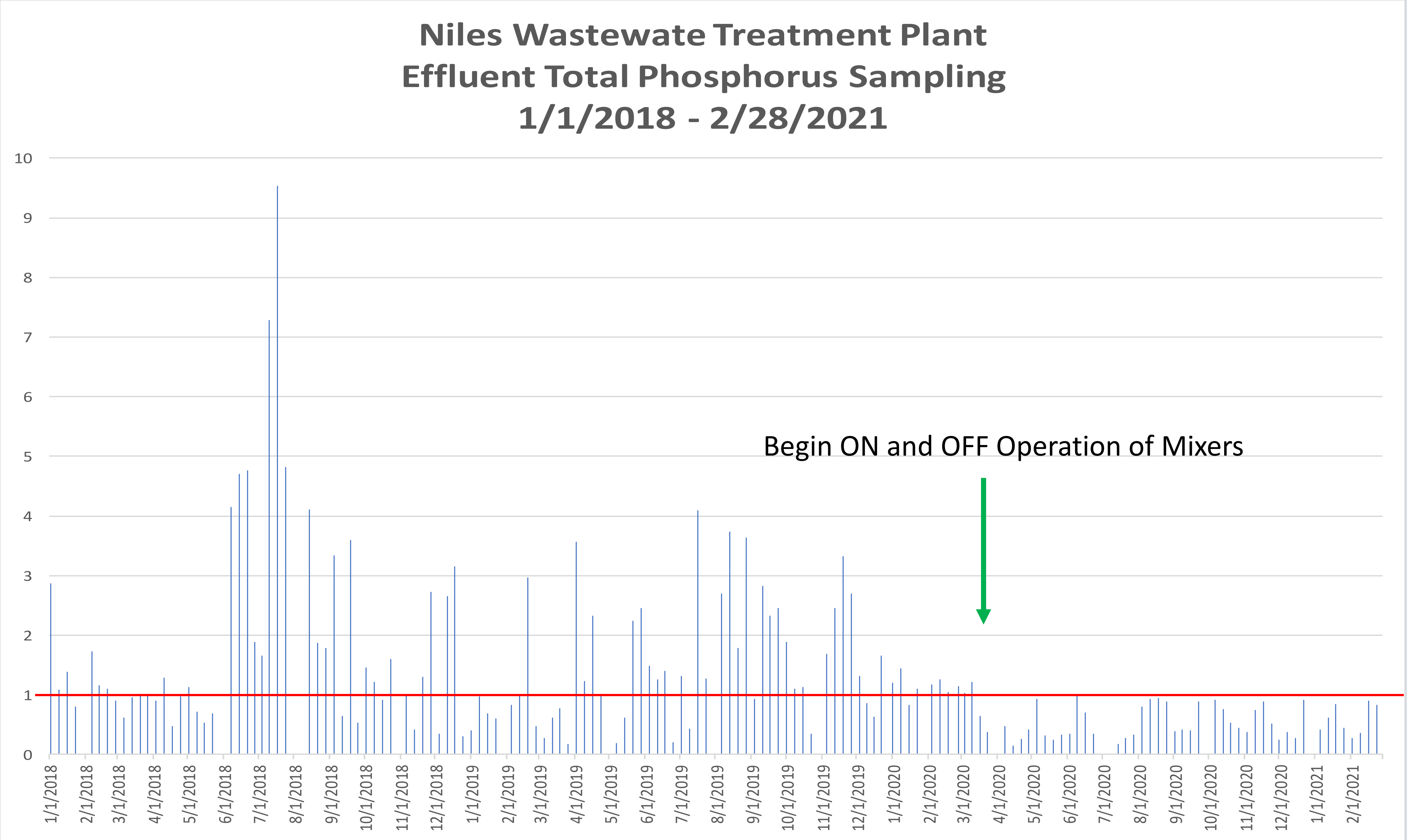
But it was staffed 24/7

So the superintendent assigned treatment plant staff to

Turn Mixers **OFF** for 3 hours

Turn them back **ON** for 30 minutes

Just like Bradford


Niles Wastewate Treatment Plant
Effluent Total Phosphorus Sampling
1/1/2018 - 2/28/2021
10
9
8
7
6
5
4
3
2
1
0
Begin ON and OFF Operation of Mixers
1/1/2018
2/1/2018
3/1/2018
4/1/2018
5/1/2018
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
12/1/2018
1/1/2019
2/1/2019
3/1/2019
4/1/2019
5/1/2019
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
12/1/2019
1/1/2020
2/1/2020
3/1/2020
4/1/2020
5/1/2020
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
12/1/2020
1/1/2021
2/1/2021

In the last year, the WWTP has been under 1.0 mg/L for <u>every</u> Total Phosphorus Sample that has been collected.

Total Phosphorus compliance is no longer a random event

It works, even with an influent $cBOD_5$ of 73 mg/L

No chemicals are fed for phosphorus removal, either

(and they did install timers on the mixers…)

Process Control for Phosphorus Removal

Why do Process Control?

Process control procedures will tell you how well the WWTP is performing

Process control methods do not need to be difficult or complex

Process control methods should not take all day to get results

Process control should be performed at the WWTP, not sent to a outside lab.

The CAU Process Control Tools

These tools are **cheap**, **easy**, and **effective**

1) Multiparameter colorimeter
2) Dissolved Oxygen Meter
3) Alkalinity Test Kit
4) Wastewater Centrifuge
5) Settleometer
6) Core sampler

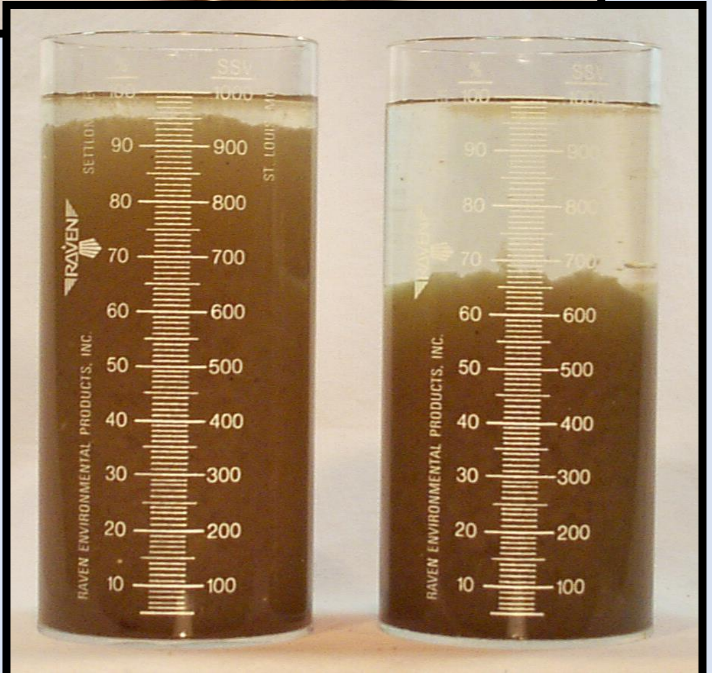

DR 900
535 P React. PV TNT
0.76
mg/L
P
Default 56
10 : 39 : 35
Default
02-26-2021
Options
Zero
Read


HACH


385 N Ammonia Salic.
0.59
mg/L
NH3-N
Default 54
10 : 36 : 55
Default
02-26-2021
Options
Zero


10.19
YSI


TWC#4


RAVEN
RAVEN ENVIRONMENTAL PRODUCTS, INC.
90
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400
300
200
100

The CAU Process Control Tools

These tools are **cheap**, **easy**, and **effective**

Cheap, because most communities do not have a lot cash

Easy, because if it is difficult, then no one will do it

Effective, because if it is not effective, then why bother?

Why do Process Control?

Effective process control will alert you to when your WWTP begins to move toward noncompliance.

It will give you the data that you need to make the process control decisions that will move the WWTP back toward the middle of the Operational Window and stay in compliance.

Process Control is especially important for effective

Biological Phosphorus Removal

Process Control for Effective BioP Removal

Most failures of BioP Removal that I find are:

Too much nitrate in anaerobic environments

Not enough cBOD to drive the orthophosphate release

Not enough DO to drive the orthophosphate uptake

Process Control for Effective BioP Removal

For effective BNR Process Control:

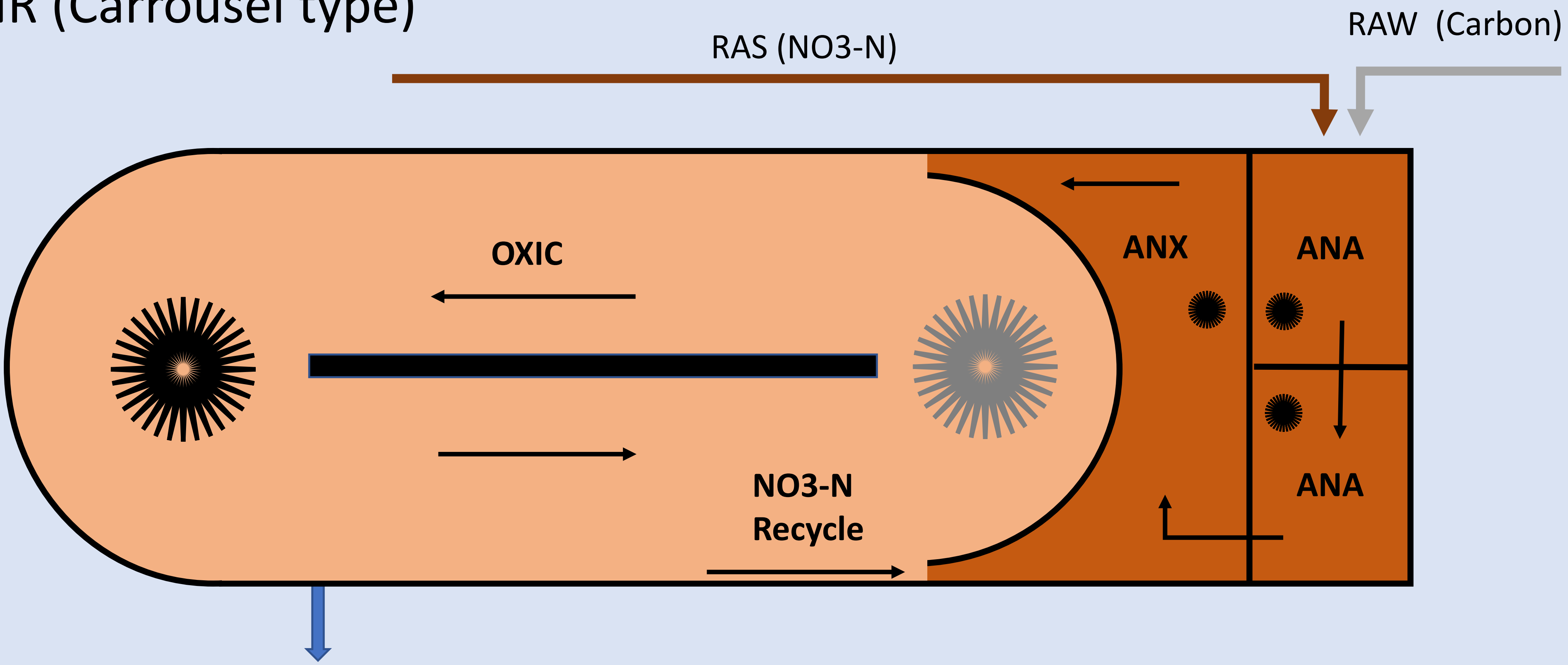
1) Measure nitrate and orthophosphate in the anaerobic environment

2) Measure nitrate and orthophosphate in the anoxic environment

3) Measure ammonia, nitrate and orthophosphate in the oxic environment

Troubleshooting Systems: Bradford WWTP

BNR (Carrousel type)



TP Removal Sample Monday and Wednesday

		NH3N	Ortho	Nitrates
Date 7-23-18	Anaerobic	5.06	.89	.5
	Anoxic	2.22	1.32	.5
	Ditch Outfall	.019	.18	.8
Date 7-25-18	Anaerobic	3.77	1.16	.4
	Anoxic	2.32	1.56	.5
	Ditch Outfall	.045	.32	.3
Date 7-30-18	Anaerobic	4.26	.90	.6
	Anoxic	4.04	1.63	0.0
	Ditch Outfall	AA<.015	.24	1.9
Date 8-1-18	Anaerobic	3.18	1.27	.6
	Anoxic	1.71	1.53	.7
	Ditch Outfall	.033	.47	2.2
Date 8-6-18	Anaerobic	2.51	1.73	1.2
	Anoxic	.142	1.51	1.5
	Ditch Outfall	.018	1.01	1.4
Date 8-8-18	Anaerobic	3.77	1.53	3.5
	Anoxic	2.94	1.43	2.6
	Ditch Outfall	.041	.47	4.6
Date 8-13-18	Anaerobic	3.30	1.68	1.6
	Anoxic	2.42	>3.5	.9
	Ditch Outfall	.039	>3.5	2.6
Date 8-14-18	Anaerobic	4.65	1.67	2.5
	Anoxic	.125	1.46	1.9
	Ditch Outfall	.218	1.57	3.9
Date 8-15-18	Anaerobic	1.70	1.62	1.0
	Anoxic	1.20	1.67	1.1
	Ditch Outfall	AA .015	1.44	2.2
Date 8-20-18	Anaerobic	4.03	1.65	1.1
	Anoxic	3.17	1.62	1.1
	Ditch Outfall	.680	1.19	1.4
Date 8-22-18	Anaerobic	4.66	1.43	.7
	Anoxic	2.08	1.19	1.2
	Ditch Outfall	.046	.73	2.4
Date 8-27-18	Anaerobic	2.76	1.40	1.8
	Anoxic	1.95	1.54	.8
	Ditch Outfall	AA .015	.77	3.2
Date 8-29-18	Anaerobic	4.55	1.33	1.1
	Anoxic	2.14	1.41	1.5
	Ditch Outfall	.032	1.14	3.5
Date 9-5-18	Anaerobic	5.77	1.60	.5
	Anoxic	3.63	1.90	.8
	Ditch Outfall	.025	.89	.5

Questions?

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