Chemical Phosphorus Removal

2017 ORWEF Short School

Clackamas Community College

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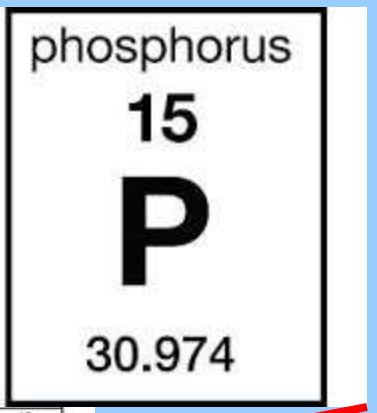
Rock Creek AWTF

Outline

- Phosphorus: Fractions and Forms
- Alum: Reactions and Removal mechanisms
- Practical Application at Rock Creek with the Actiflo Process

Phosphorus



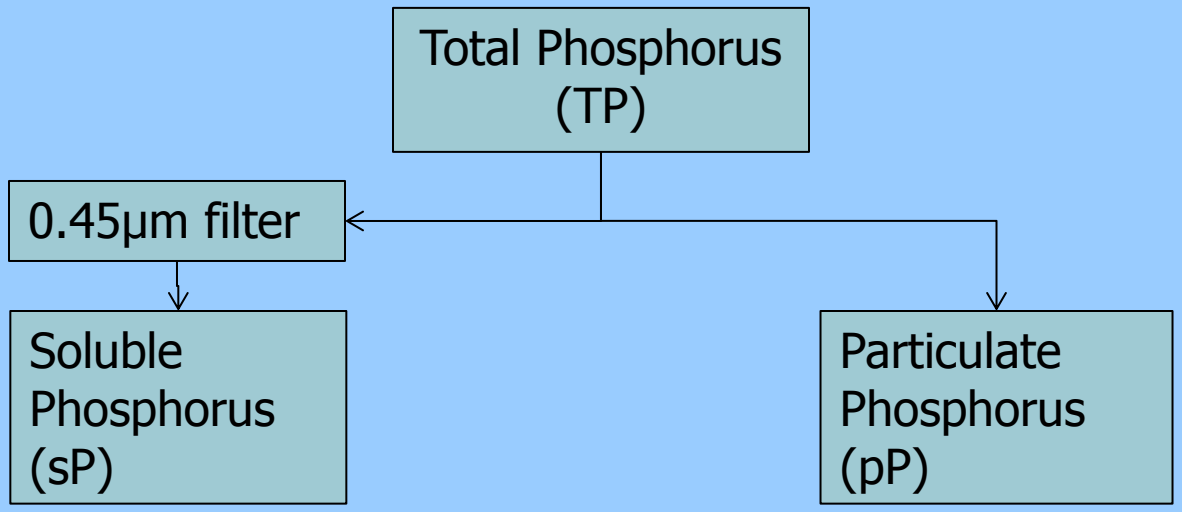
The Periodic Table of the Elements

1 H Hydrogen 1.01																	2 He Helium 4.00
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.61	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57 La Lanthanum 138.91	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium 178.49	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (272)	112 Cn Copernicium (285)						

58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium 168.93	102 No Nobelium (259)	103 Lr Lawrencium (262)

3 Li Lithium 6.94
- Atomic Number
- Element Symbol
- Element Name
- Average Atomic Mass

Phosphorus fractions



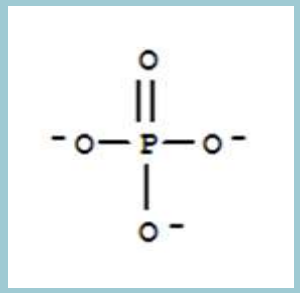
Phosphorus fractions

Soluble Phosphorus
Dissolved + Colloidal

H_2SO_4

Persulfate Digestion

Phosphate = Orthophosphate (OP)
= Reactive Phosphorus (RP)= PO_4^{3-}



(sRP)

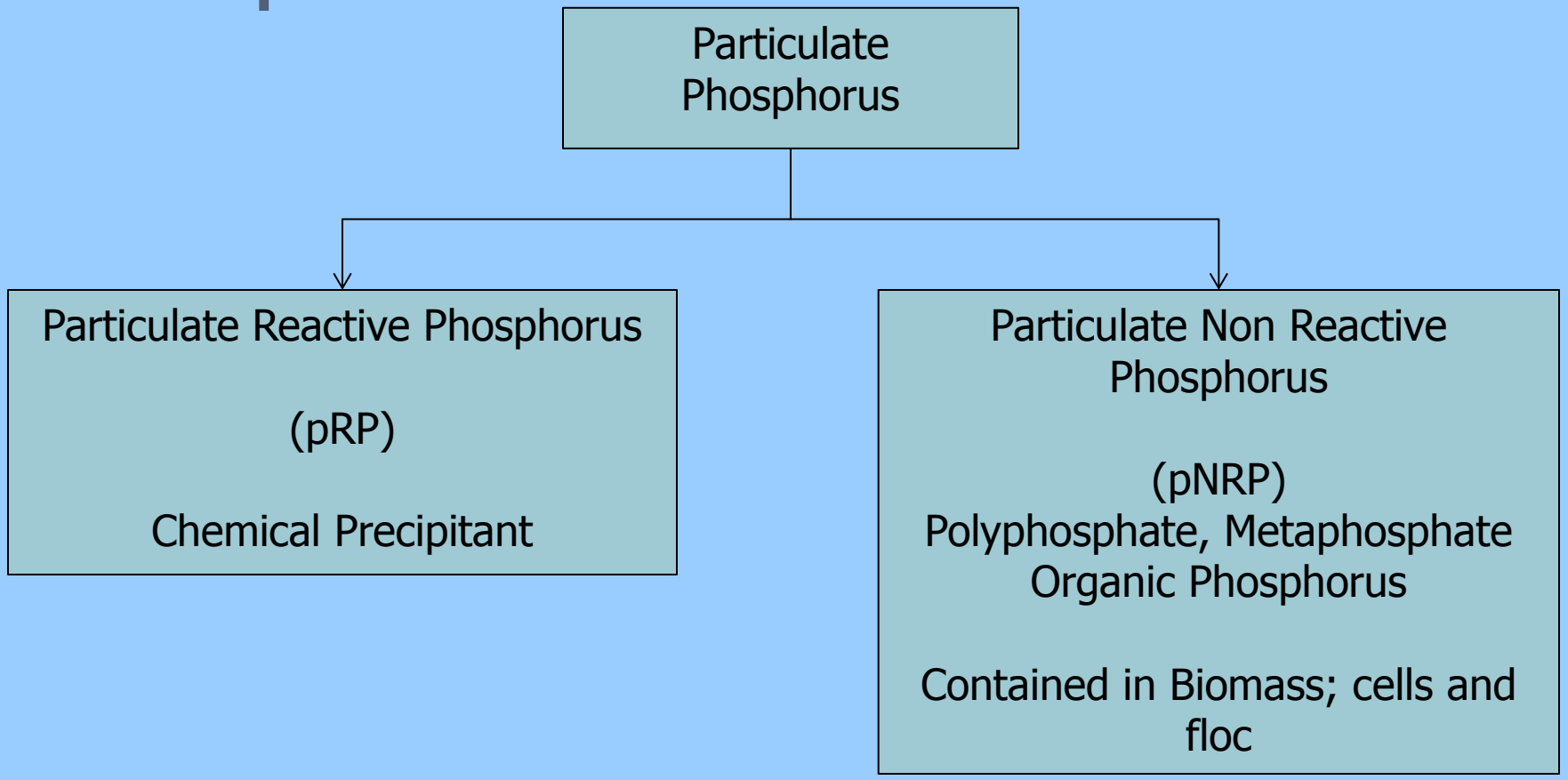
Polyphosphate, Metaphosphate

Organic Phosphorus

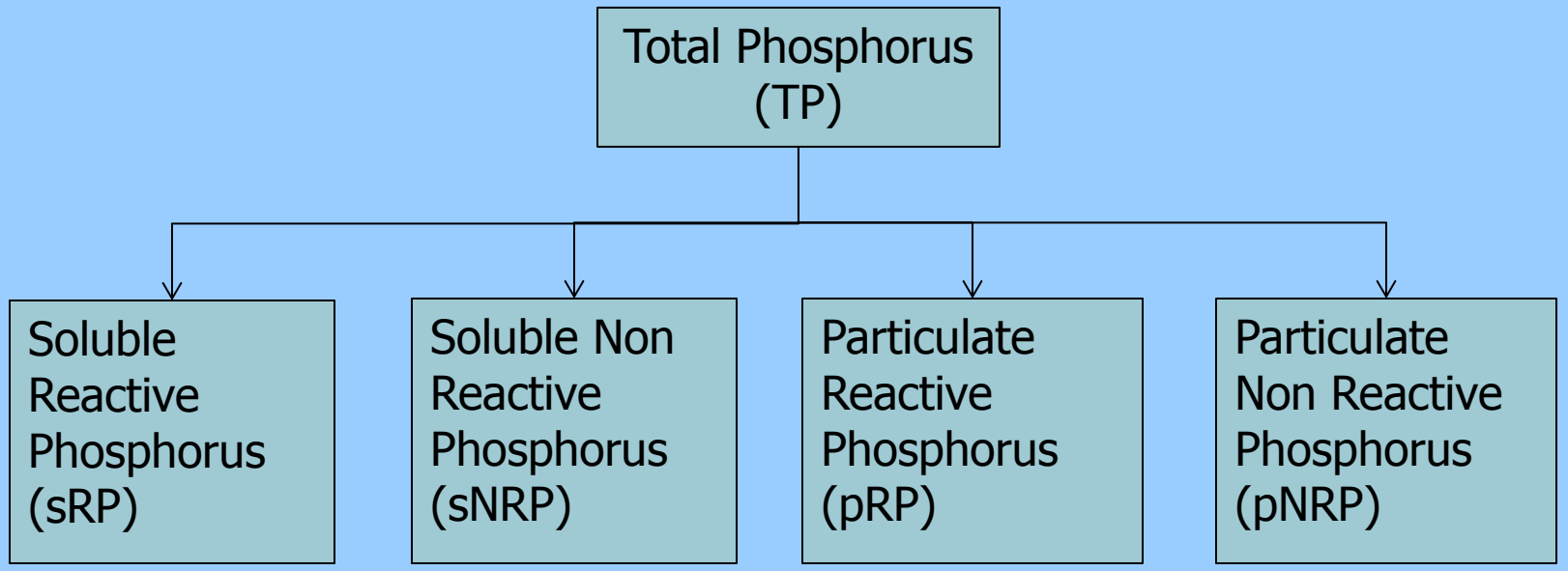
Soluble Non Reactive Phosphorus

(sNRP)

Phosphorus fractions



Phosphorus fractions



Removing the Fractions

Fraction	Removal Mechanism	Ease
sRP	React with something to make a particle, or react with a particle	1
sNRP	Adsorption to a particle (Sticks to the particle surface without a chemical reaction)	4
pRP	Reaction with other particles, adsorption, coagulation, flocculation	2
pNRP	Adsorption, coagulation, flocculation	3

Alum

- Alum is $Al_2(SO_4)_3 \cdot 14\ H_2O$ (Dry Alum)
- Usually supplied as 48.5% wt/wt
- 11.15 lbs/gal
- The aqueous Aluminum ion is trivalent, Al^{3+}

Alum reactions in Secondary Effluent

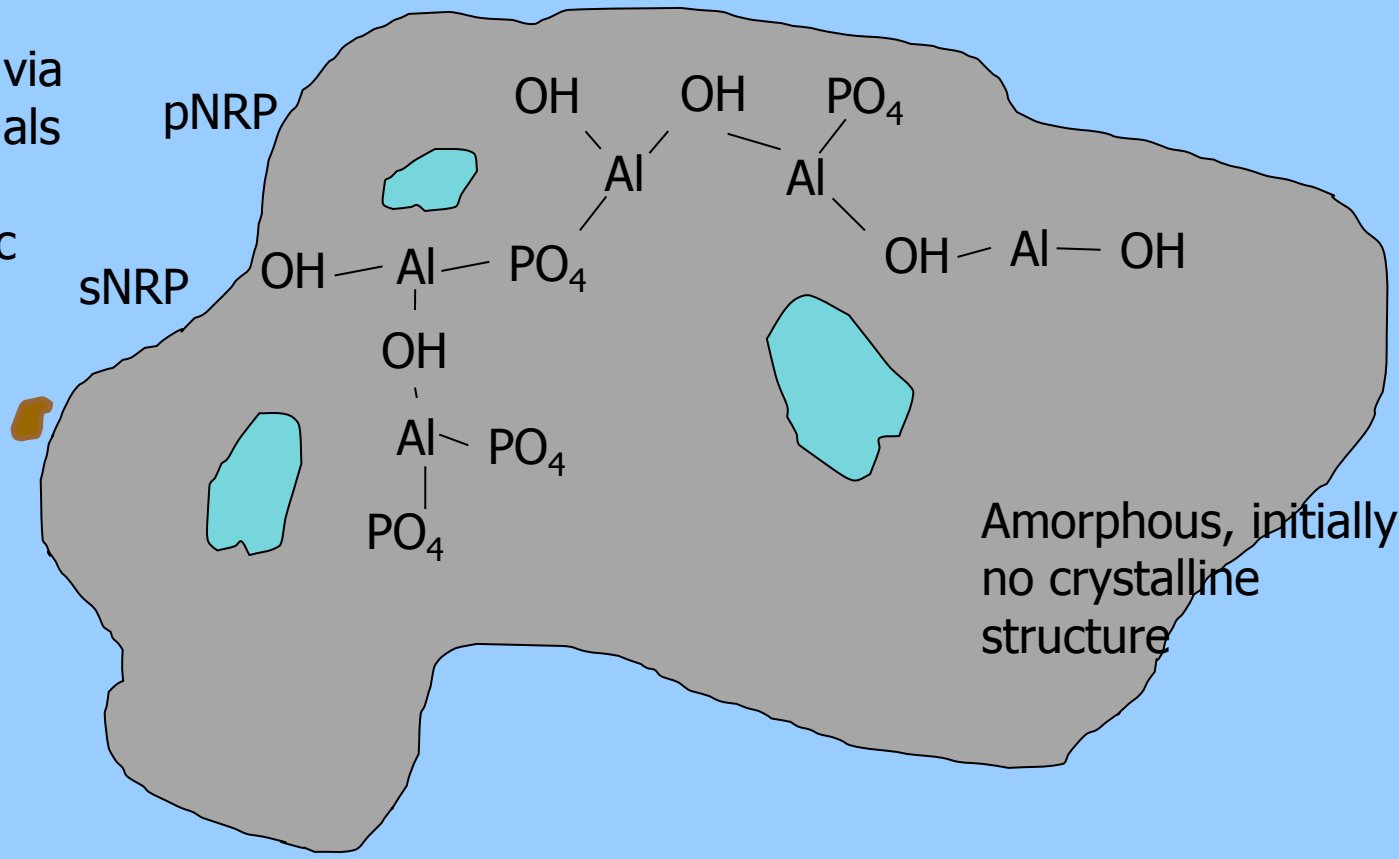
- Direct Precipitation
  - $Al^{3+} + PO_4^{3-} \leftrightarrow AlPO_4$ (s)
- Formation of Aluminum Hydroxides
  - $Al^{3+} + 3OH^- \leftrightarrow Al(OH)_3$ (s)
- Charge Neutralization of particles and colloids

Alum reactions in Secondary Effluent

- Forget about Direct Precipitation
- Consider Co-Precipitation and Complexation with the aluminum hydroxide floc
- Adsorption of non reactive P and colloids to the floc surface

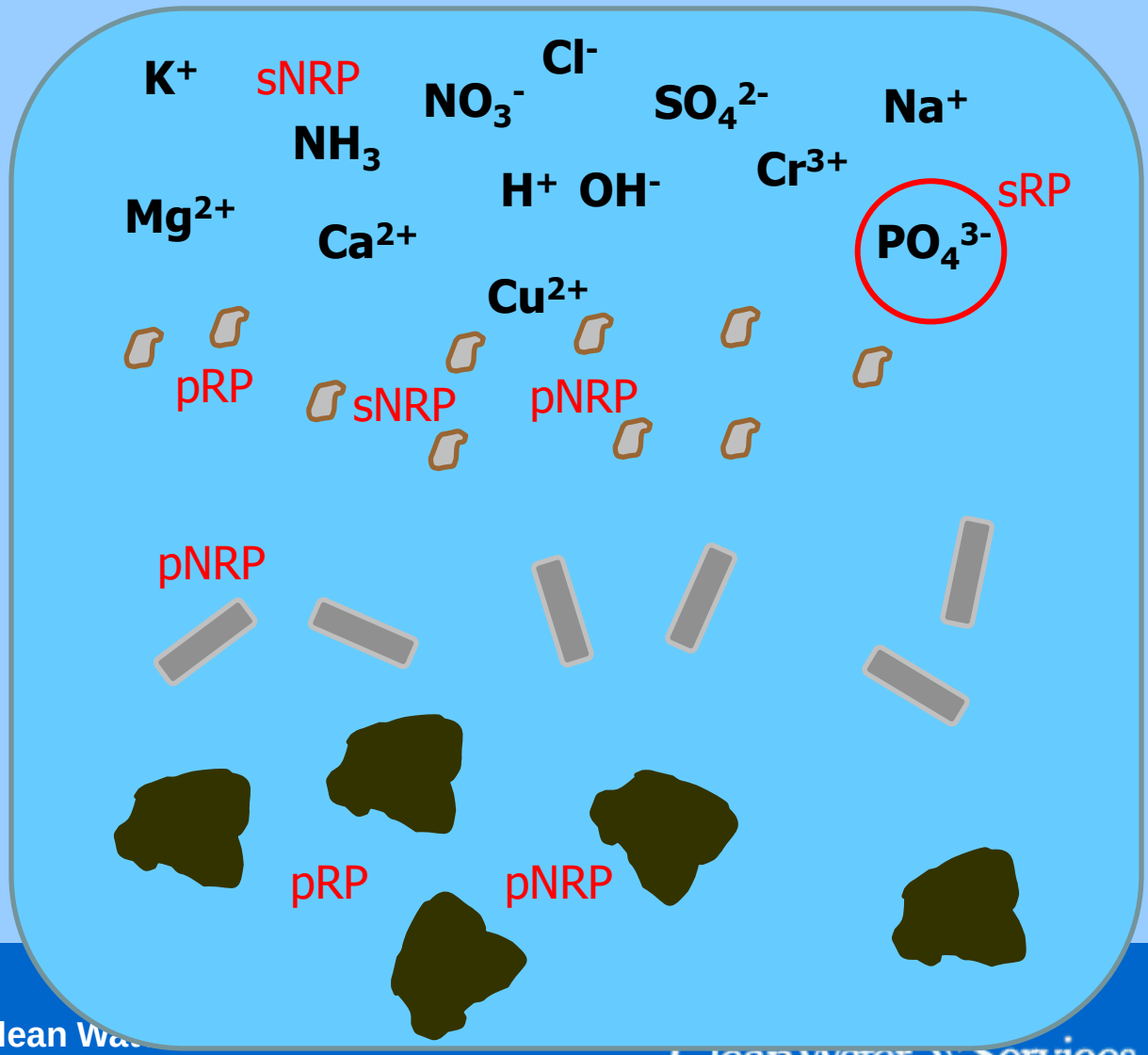
What is Complexation? Well…it's complex

Adsorption via van der Waals forces or electrostatic attraction



What's in Secondary Effluent?

- Soluble Salts, Minerals, Metals and Ions
- Colloids: 1 nanometer to 1 micrometer
- Bacteria: A few micrometers
- Particles: 1 micrometer to 1 millimeter (or larger)

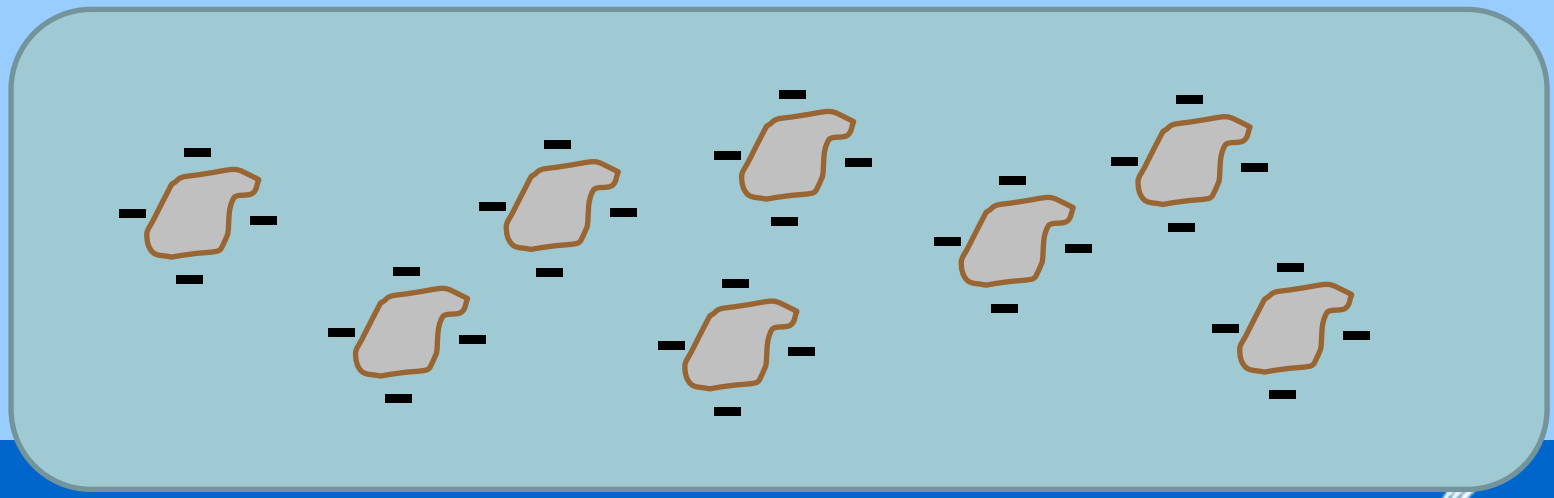


Colloids

- dispersed microscopic insoluble particles
- To qualify as a colloid, the mixture must be one that does not settle or would take a very long time to settle appreciably.
- Milk is a colloidal suspension

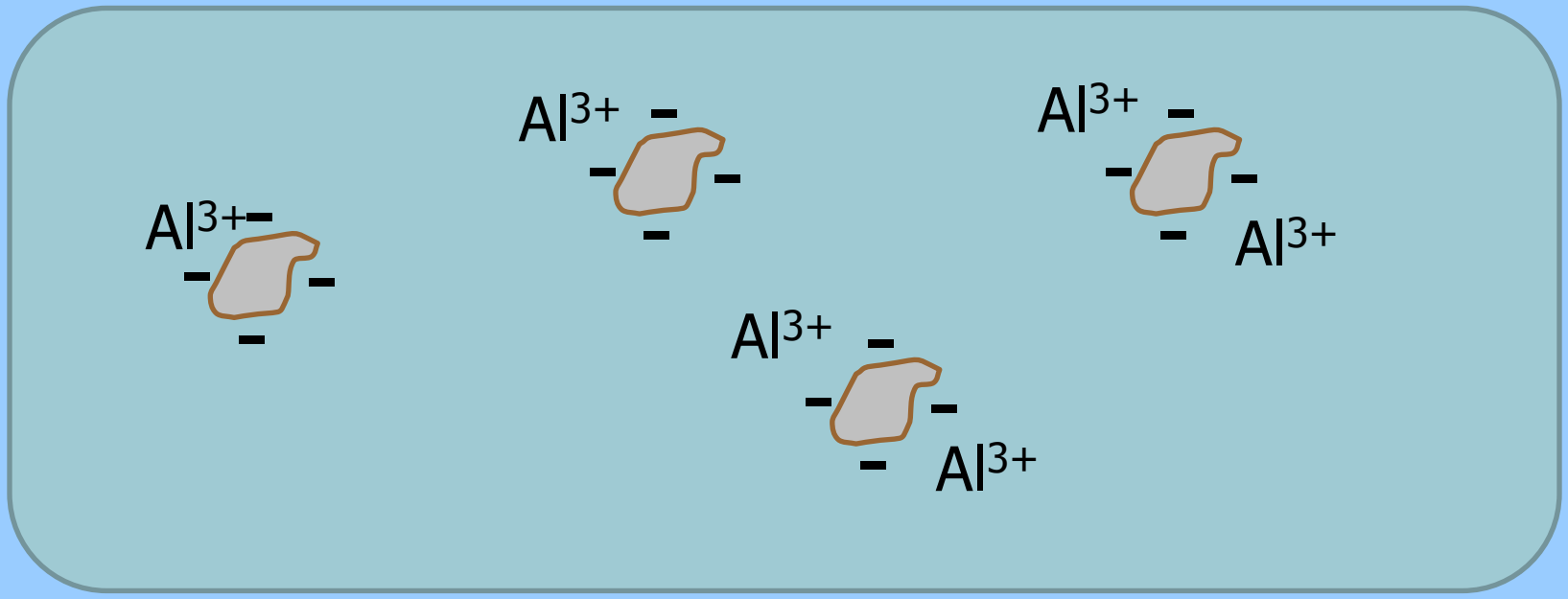
Why didn't the colloids and particles settle out in the secondary clarifier?

- They are to small
- They are to light
- They are stabilized by all having the same charge (mostly negative), and repel each other

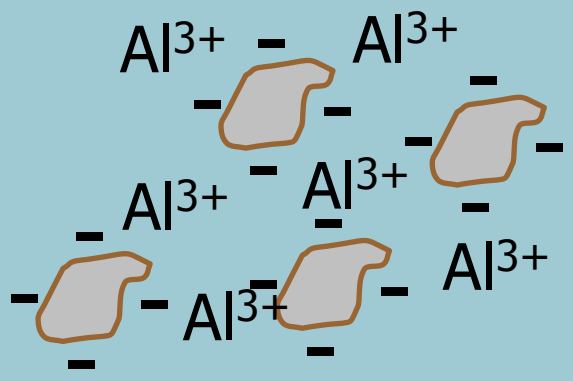


Coagulation by Charge Neutralization

- Neutralize the negative charges so the particles can contact each other.



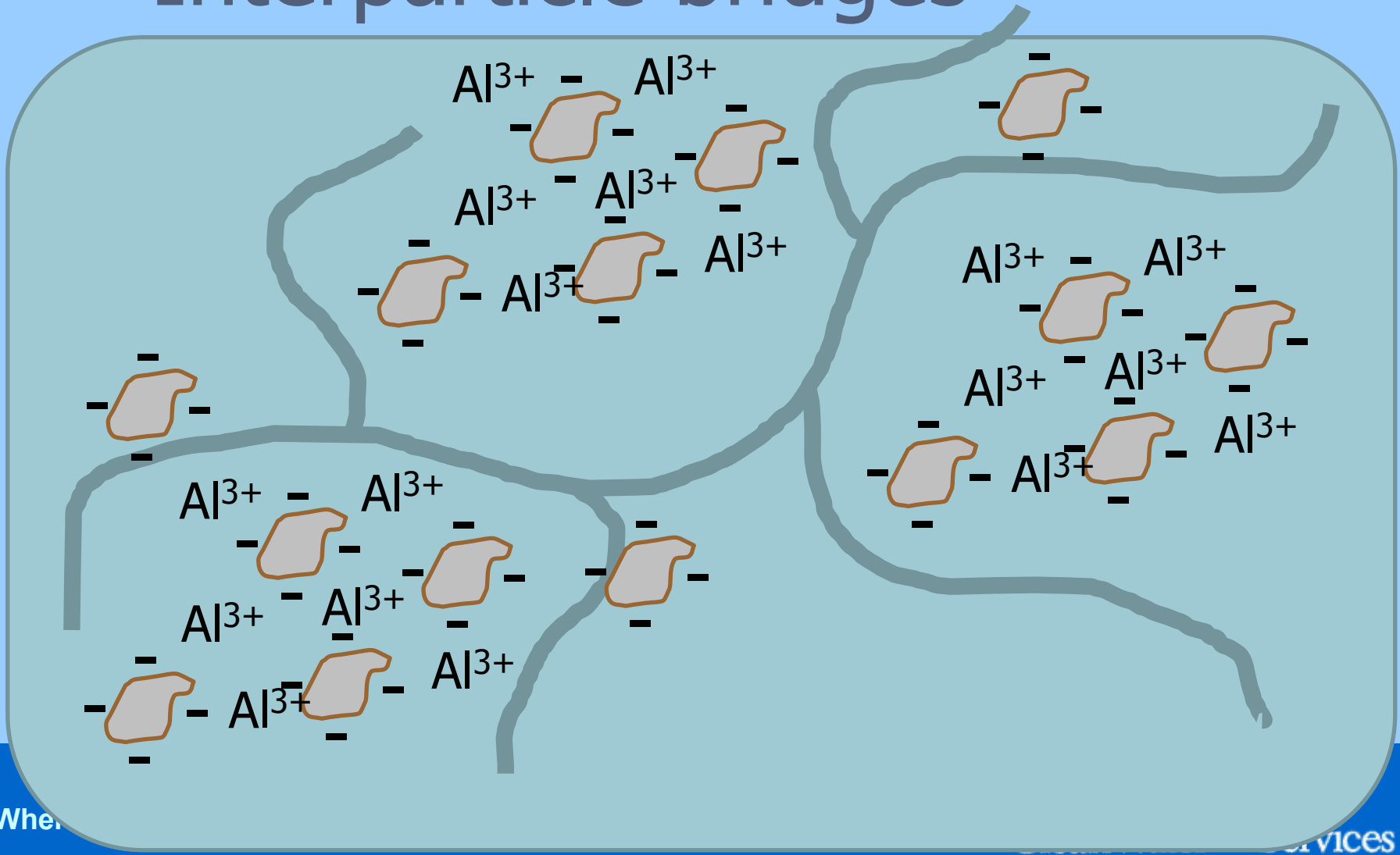
The colloids or particles can now stick together



Step 2: Flocculation

- We now have a few colloidal particles stuck together, still only a few micrometers in diameter
- Needs to grow to a few millimeters to settle
- Stick a bunch of coagulated solids together
- Use polymer as the glue

Flocculation: Adsorption and Interparticle bridges



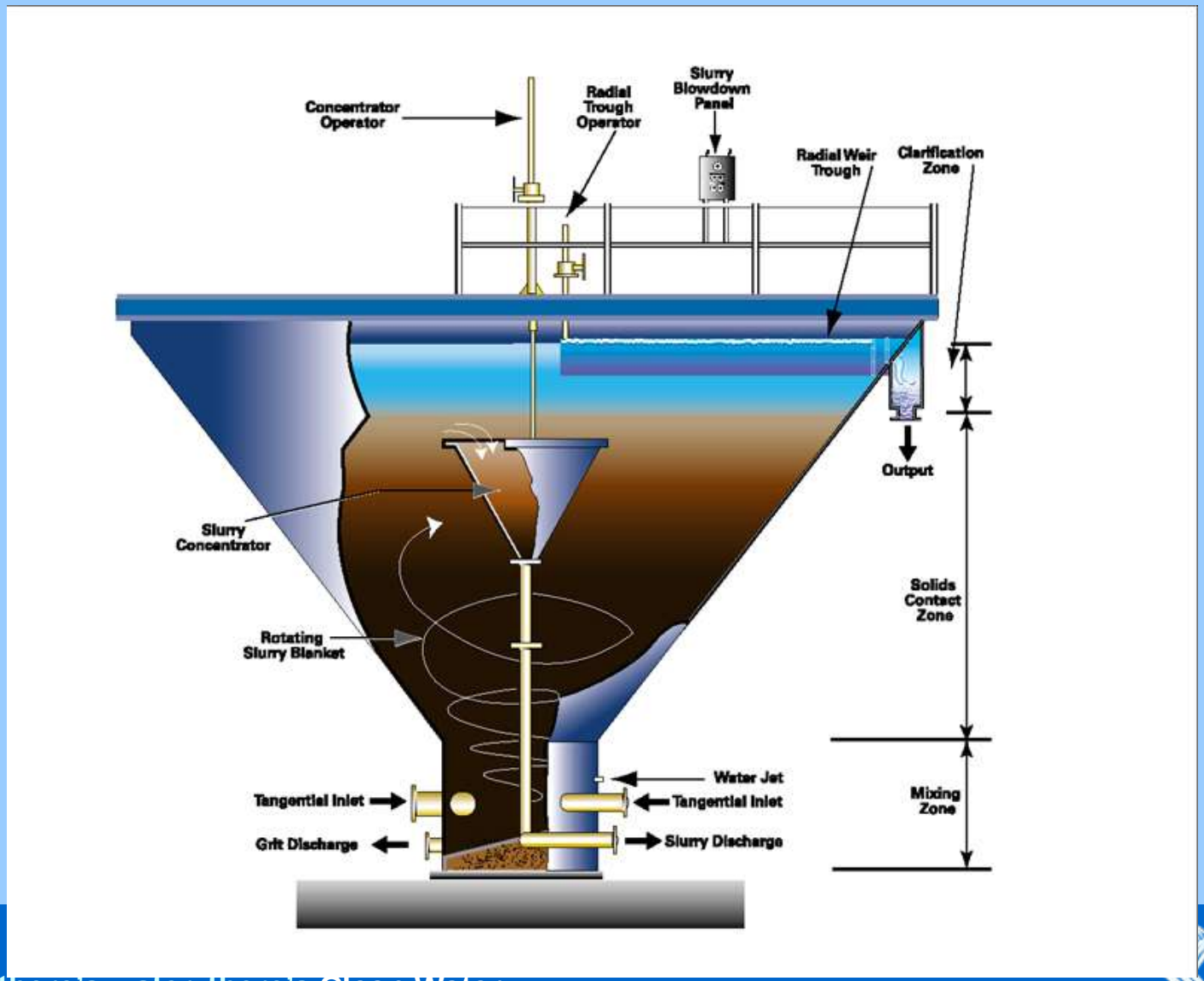
Mixing

- Coagulation – Rapid Mix
  - Need the alum to bump into the colloids so they can interact
  - If all the things are going around at the same speed, will they ever collide?
  - Need "differential" mixing: G, velocity gradient
- Flocculation – Slow mix
  - Need the particles to stick to the poly backbone, but can't break the back

Sweep Floc

- One other mechanism to be aware of, may be important in the Claricone
- Colloids and particles may be physically trapped as they travel up through the sludge blanket
- In Actiflo, may be trapped as the floc settles down over the particles

Claricone – Practical Considerations

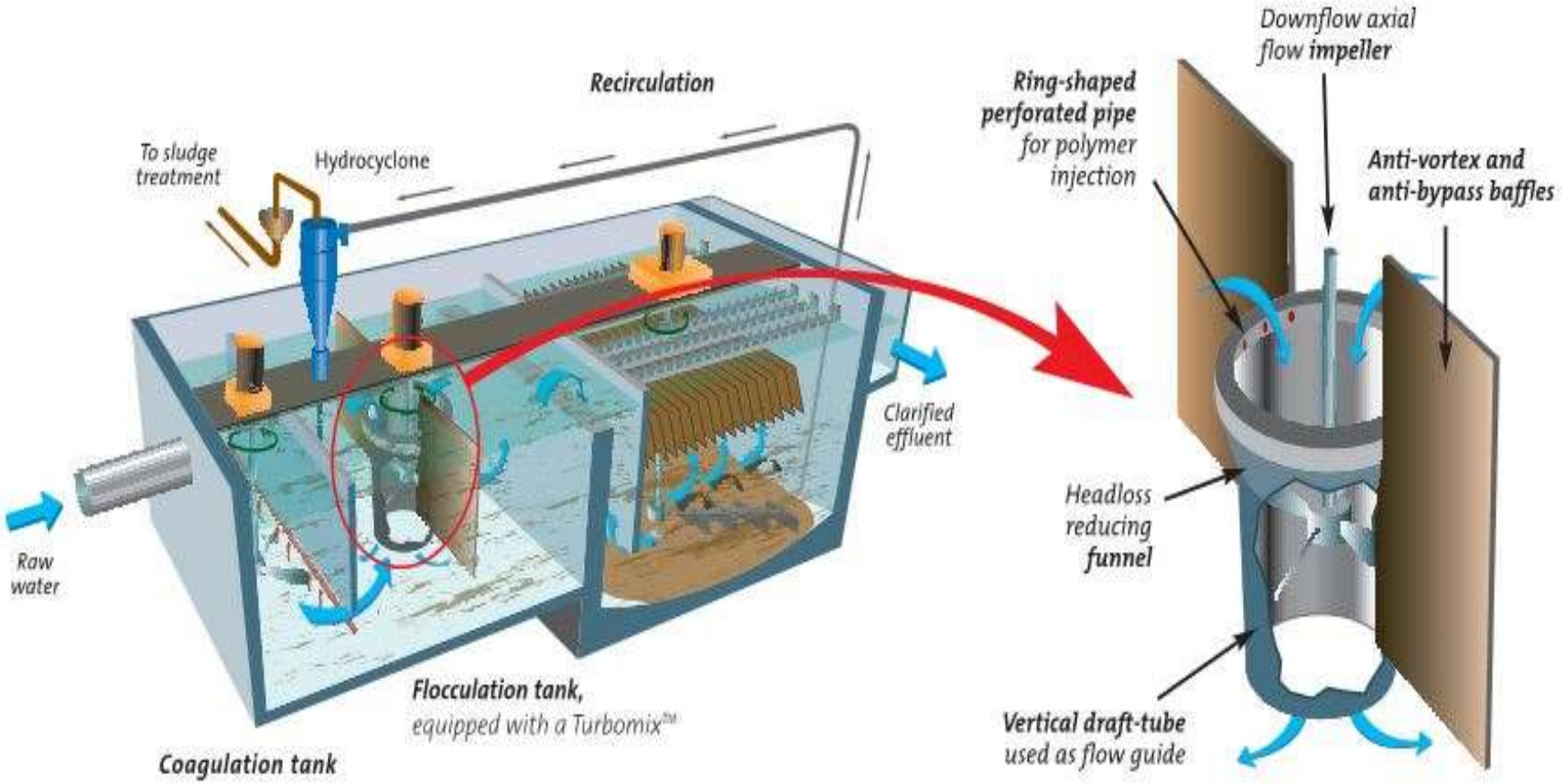



RSPS
Primary
Prelim
WPEPS
EPEPS
West Sec
East Sec
West Tert
West Filters
ETPS
East Tert
East Filters
ACTIFLO

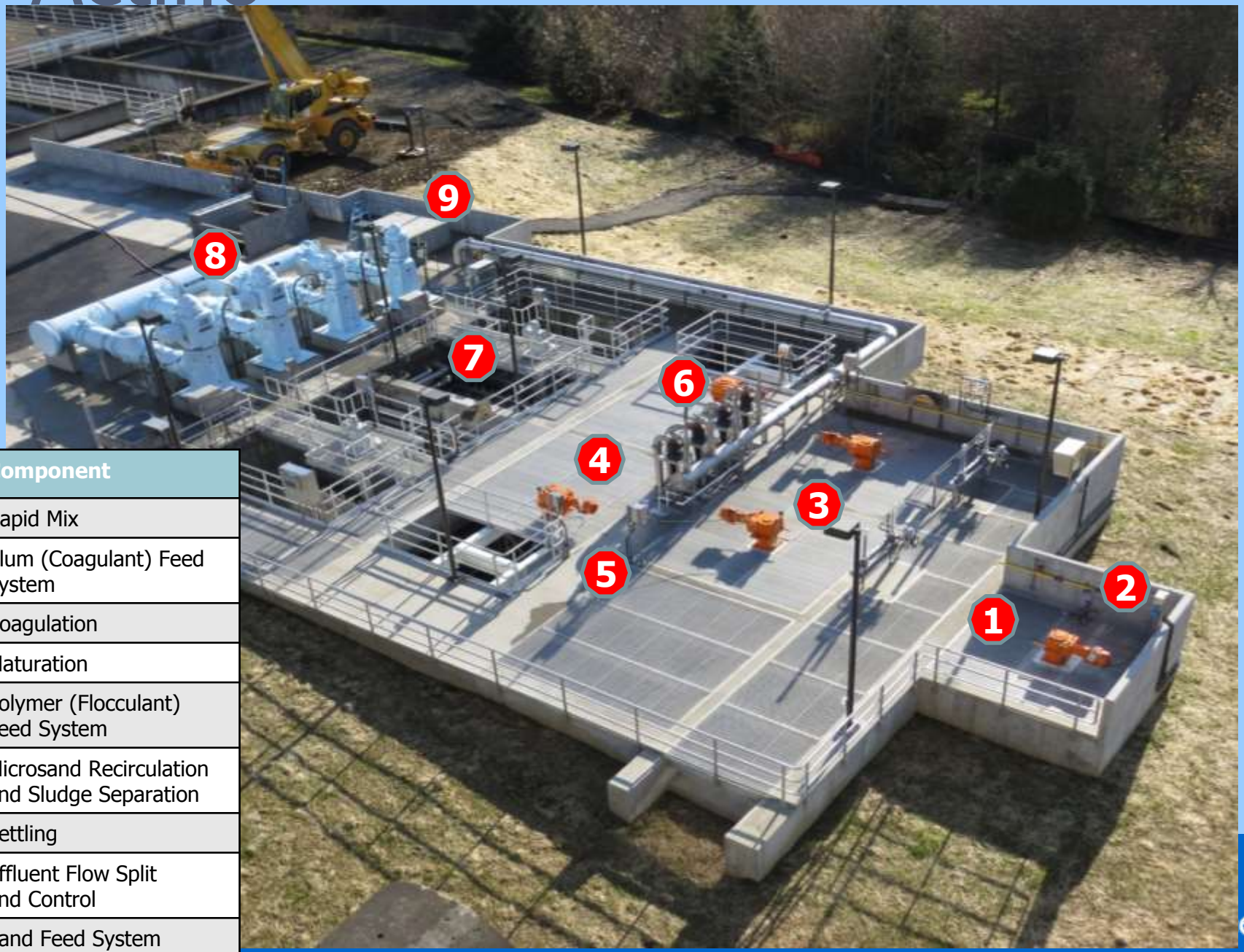
The magic of Actiflo – microsand!

- Our amorphous Al-OH-PO_4 floc and coagulated flocculated colloids and particles can settle, but still have a specific gravity of only about 1.2 – 1.3
- Silica sand has specific gravity of 2.6, so if we embed sand in the floc, it should settle twice as fast

Actiflo Turbo



Actiflo™



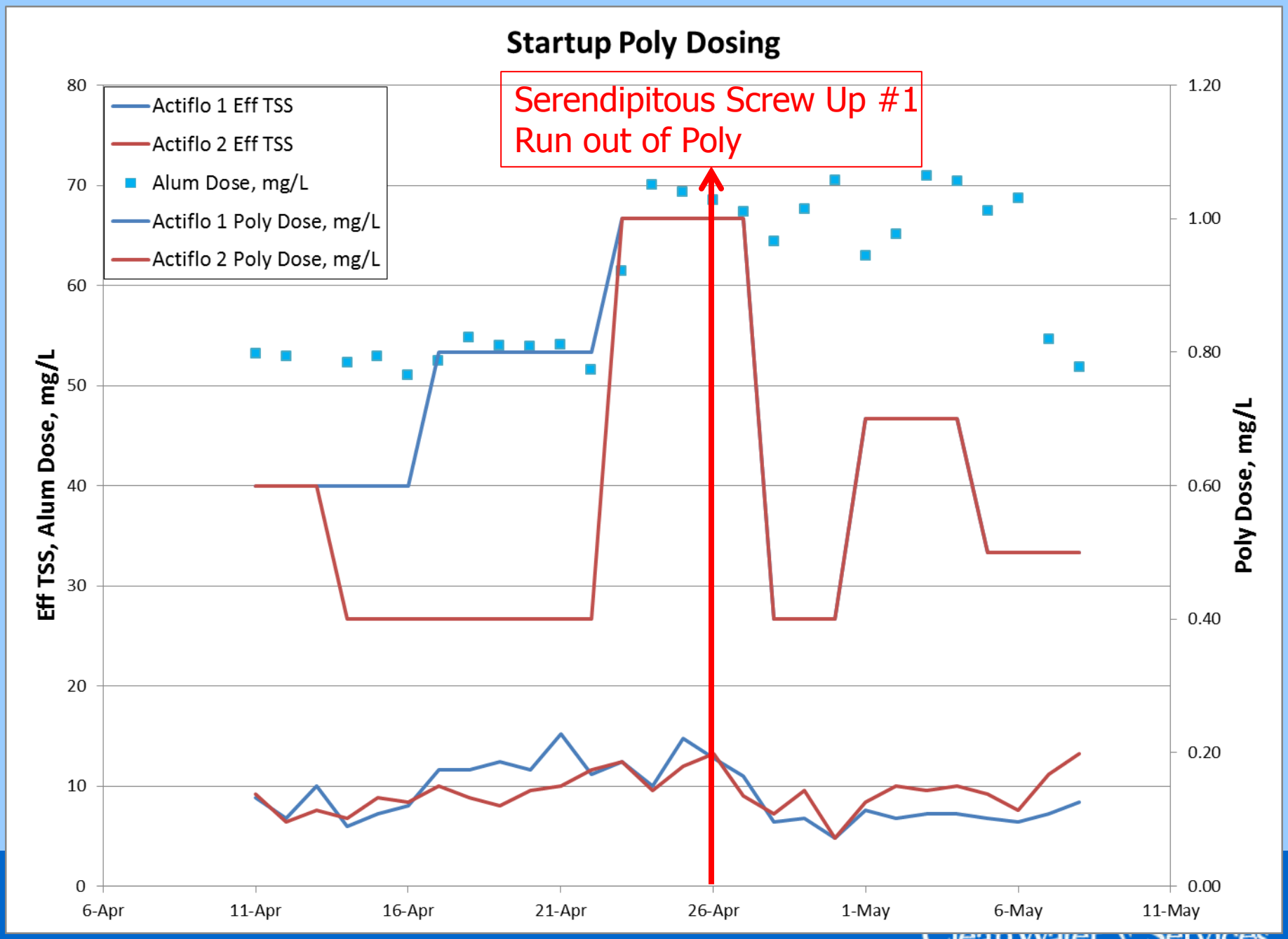
#	Component
1	Rapid Mix
2	Alum (Coagulant) Feed System
3	Coagulation
4	Maturation
5	Polymer (Flocculant) Feed System
6	Microsand Recirculation and Sludge Separation
7	Settling
8	Effluent Flow Split and Control
9	Sand Feed System

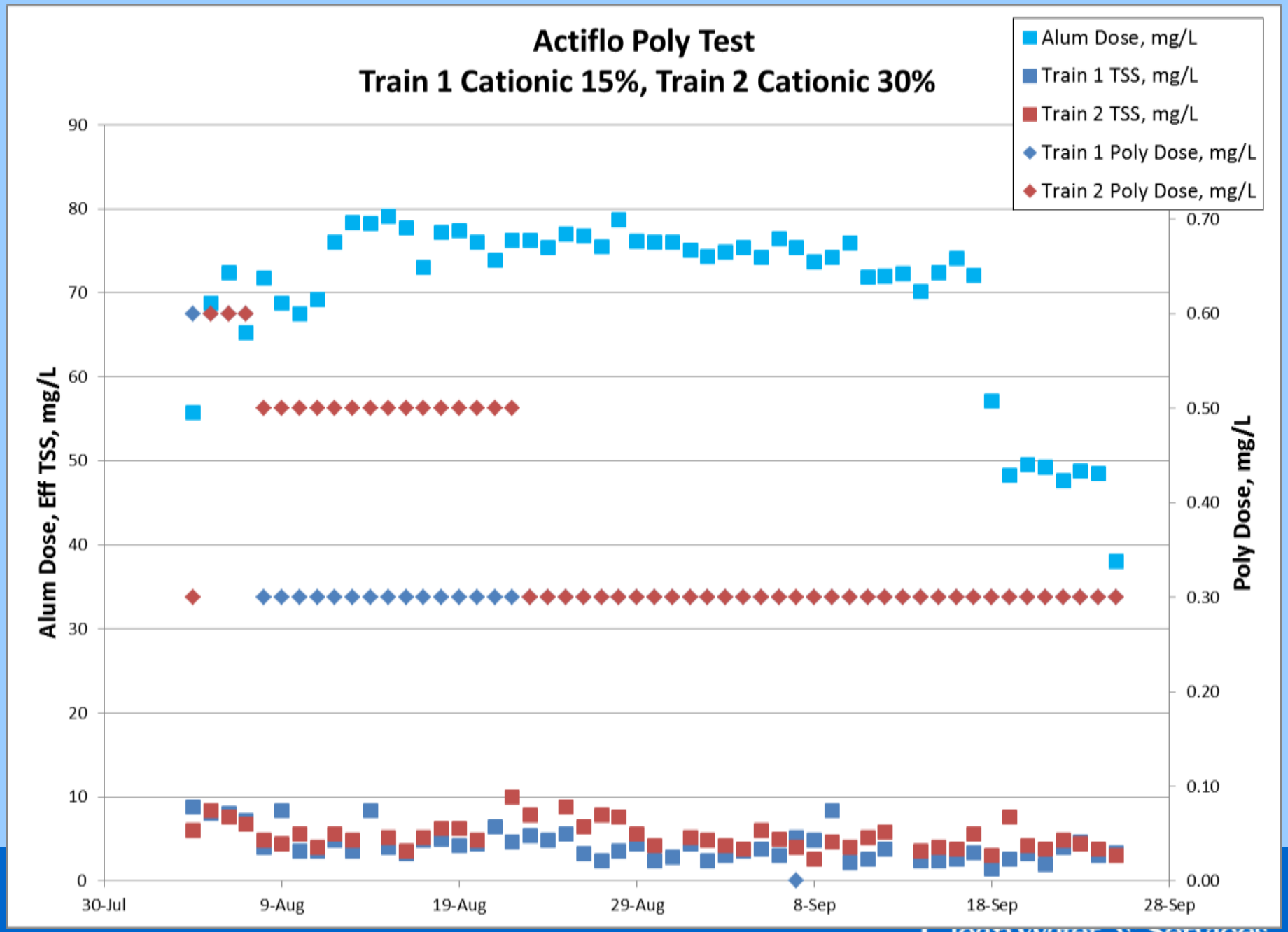
Design and Process Goals

- P and TSS removal: 0.07 mg TP/L, 7 mg TSS/L
- 1. Nutrient Season P removal
- 2. Reduce solids loading on filters, possibly direct discharge
- 3. Wet weather treatment

Startup and Operation

- Although technically a process control variable, let's ignore mixing intensity, leaving three variables to resolve:
- Polymer
  - How much, what kind, filter impacts?
- Sand
  - How much, where will it end up?
- Alum
  - How much?


Startup Poly Dosing
Serendipitous Screw Up #1
Run out of Poly
Actiflo 1 Eff TSS
Actiflo 2 Eff TSS
Alum Dose, mg/L
Actiflo 1 Poly Dose, mg/L
Actiflo 2 Poly Dose, mg/L
Eff TSS, Alum Dose, mg/L
Poly Dose, mg/L
0
10
20
30
40
50
60
70
80
0.00
0.20
0.40
0.60
0.80
1.00
1.20
6-Apr
11-Apr
16-Apr
21-Apr
26-Apr
1-May
6-May
11-May

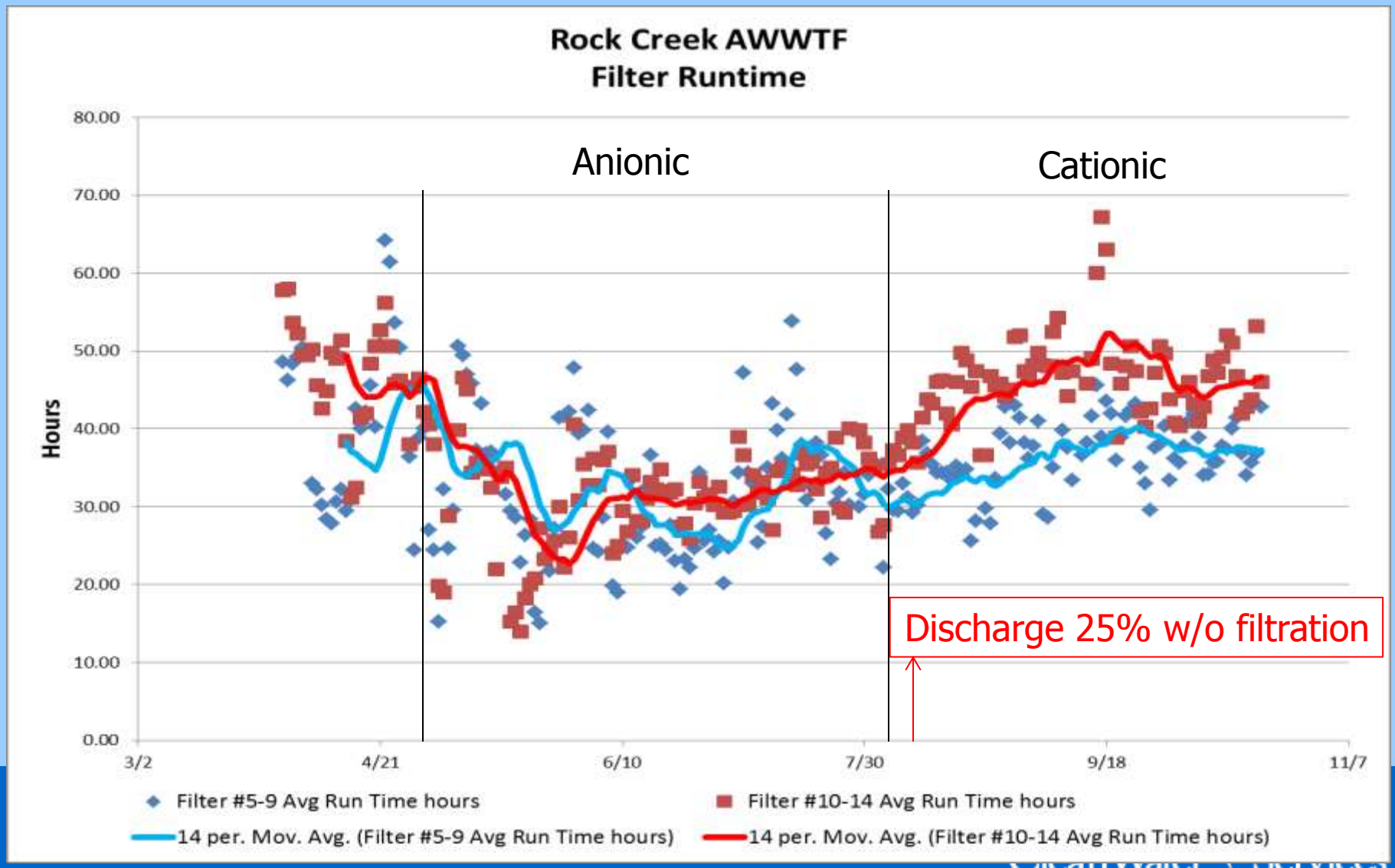

Actiflo Poly Test
Train 1 Cationic 15%, Train 2 Cationic 30%
Alum Dose, mg/L
Train 1 TSS, mg/L
Train 2 TSS, mg/L
Train 1 Poly Dose, mg/L
Train 2 Poly Dose, mg/L
Alum Dose, Eff TSS, mg/L
Poly Dose, mg/L
0
10
20
30
40
50
60
70
80
90
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
30-Jul
9-Aug
19-Aug
29-Aug
8-Sep
18-Sep
28-Sep

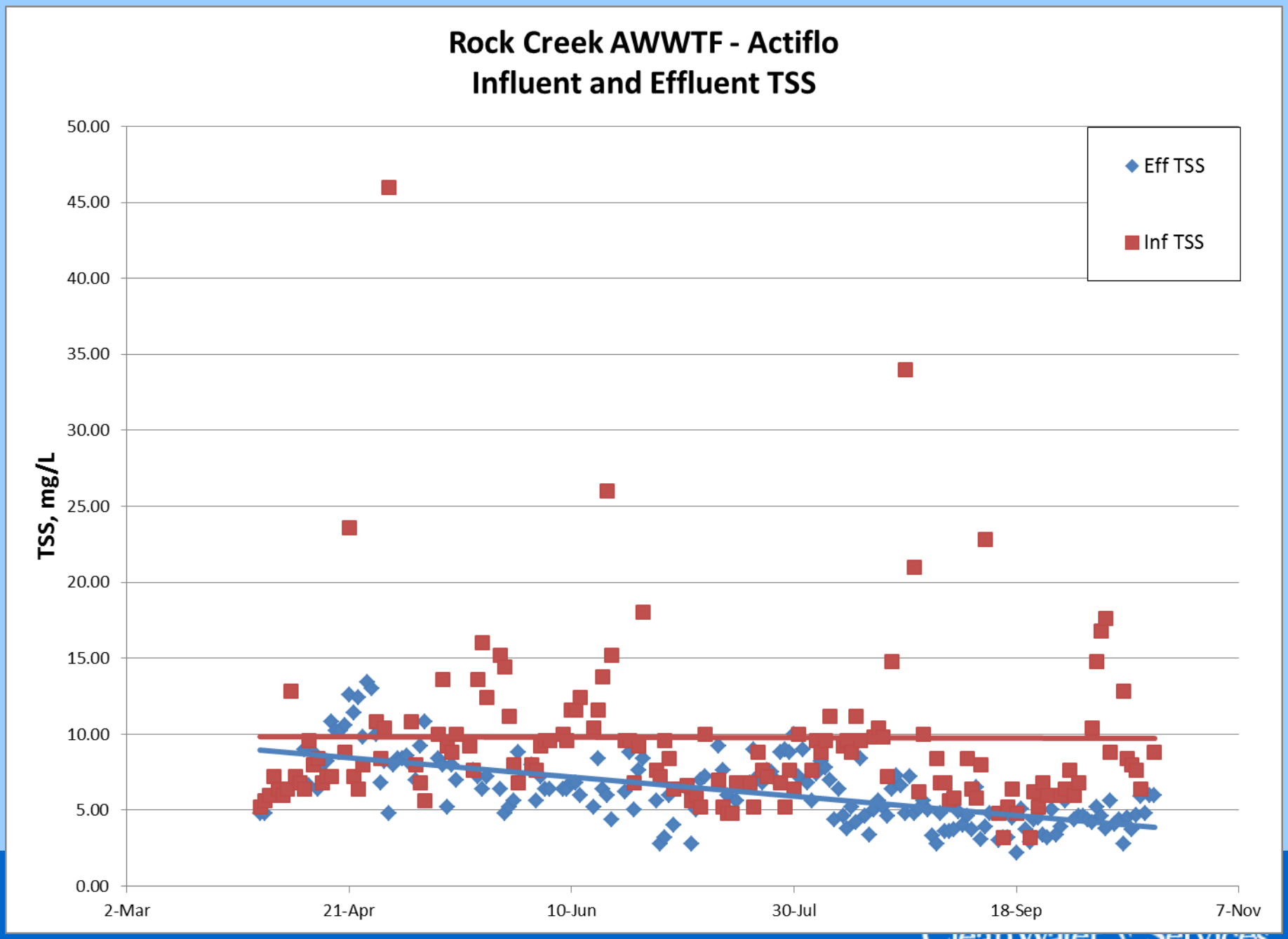
15% or 30%
Other Considerations

15% or 30%
Other Considerations

Filtration?

Cationic Poly produces shorter filter runs




Rock Creek AWWTF - Actiflo
Influent and Effluent TSS
TSS, mg/L
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
2-Mar
21-Apr
10-Jun
30-Jul
18-Sep
7-Nov
Eff TSS
Inf TSS

Microsand System

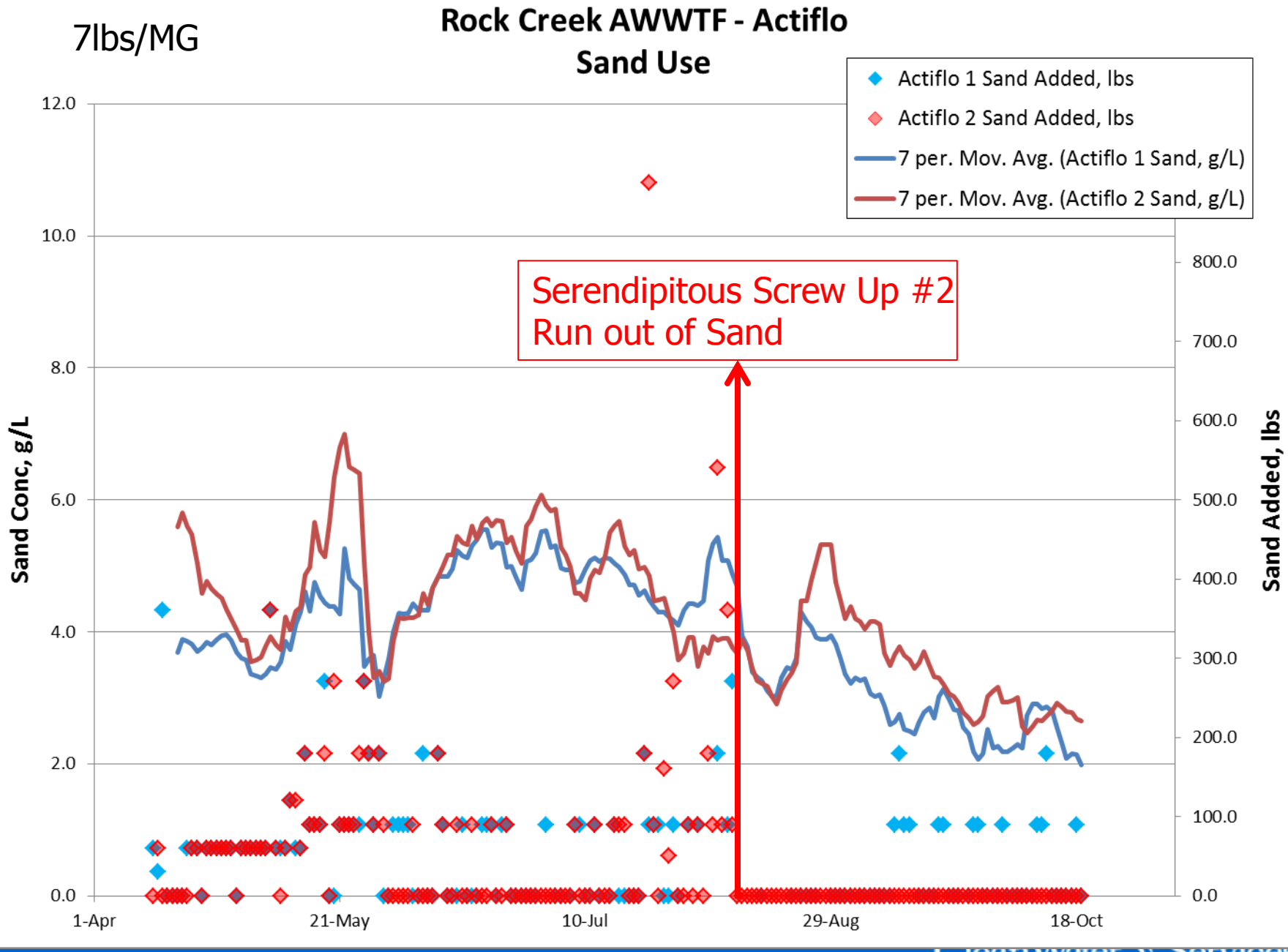
- Recommended range of 3-8 g/L (so we chose 5)
- Check by Imhoff cone (3x/day)
- Add as needed (?)
- Works very well as long as….

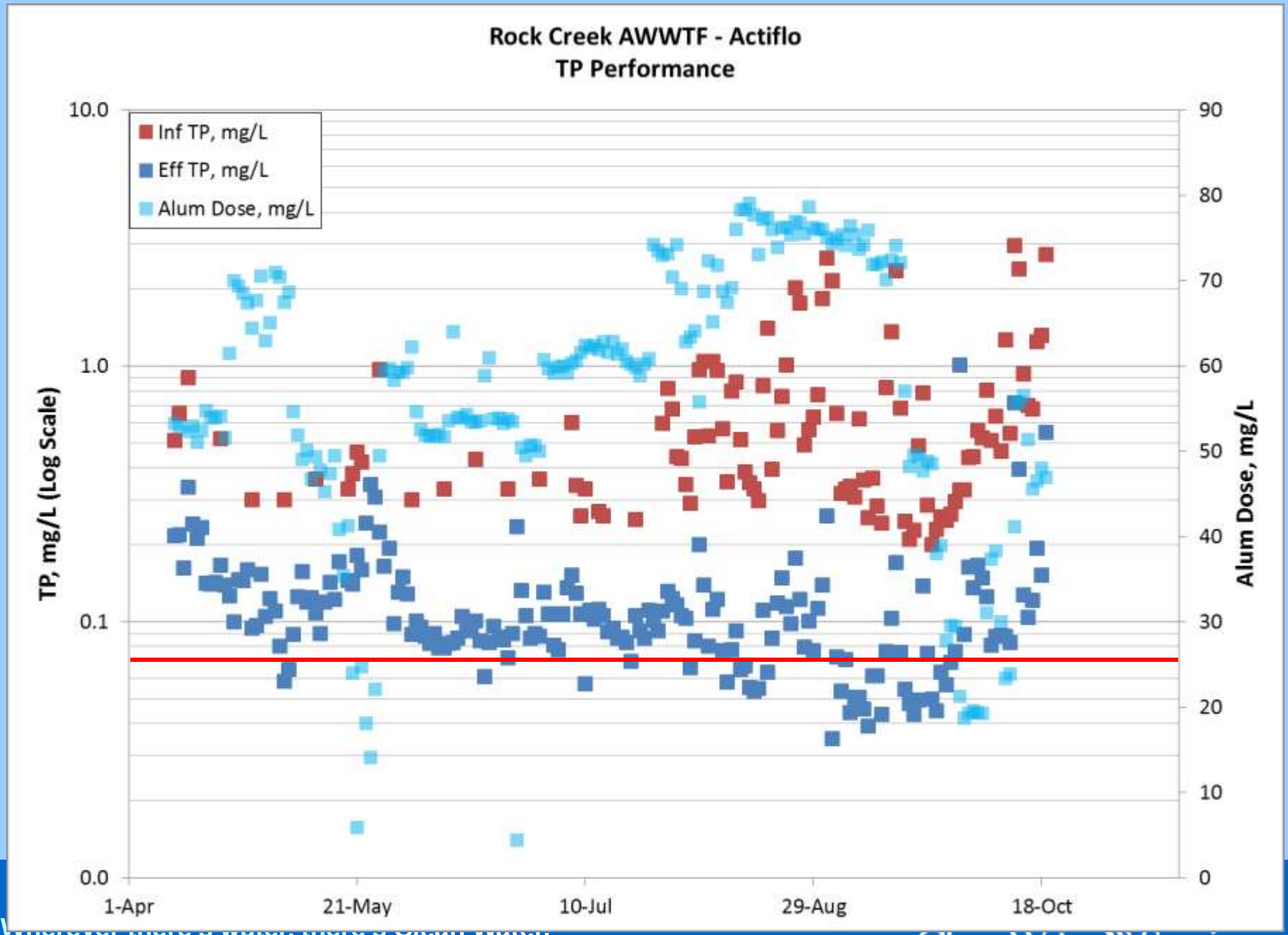
There's not too much construction debris..

And the hydrocyclone holds together…

- 050.MOV

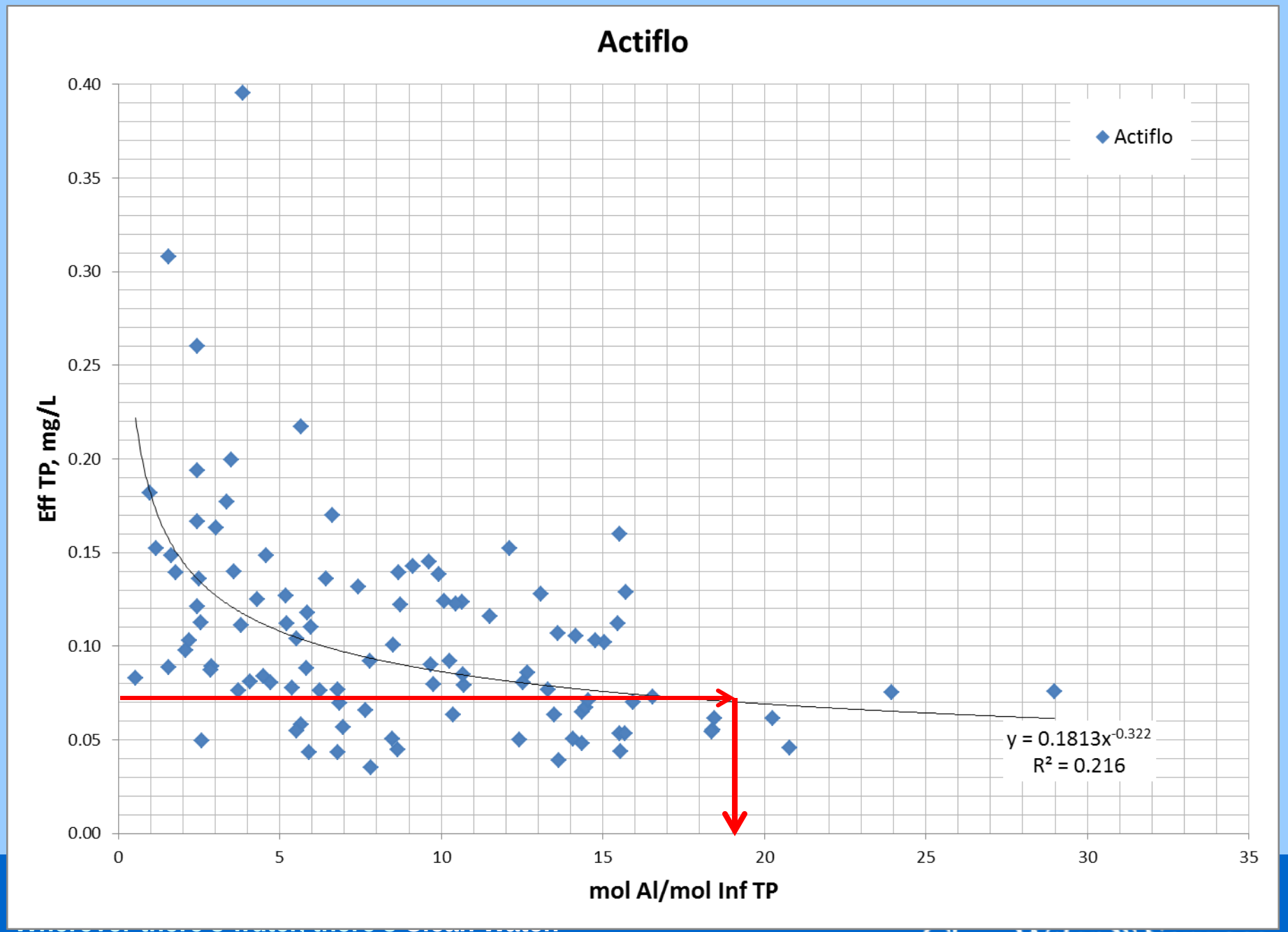
7lbs/MG


Rock Creek AWWTF - Actiflo Sand Use
Actiflo 1 Sand Added, lbs
Actiflo 2 Sand Added, lbs
7 per. Mov. Avg. (Actiflo 1 Sand, g/L)
7 per. Mov. Avg. (Actiflo 2 Sand, g/L)
Serendipitous Screw Up #2
Run out of Sand
Sand Conc, g/L
Sand Added, lbs
12.0
10.0
8.0
6.0
4.0
2.0
0.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
1-Apr
21-May
10-Jul
29-Aug
18-Oct


Rock Creek AWWTF - Actiflo
TP Performance
Inf TP, mg/L
Eff TP, mg/L
Alum Dose, mg/L
TP, mg/L (Log Scale)
Alum Dose, mg/L
10.0
1.0
0.1
0.0
90
80
70
60
50
40
30
20
10
0
1-Apr
21-May
10-Jul
29-Aug
18-Oct

Alum Dose as Molar Ratio

- A pair = 2, Dozen = 12,
- Mol = 6.022×10^{23}
- About a quadrillionth of a mol of people on earth
- Flow pacing can lead to alum wasting
- Feed to influent P


Actiflo
Actiflo
Eff TP, mg/L
mol Al/mol Inf TP
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
30
35
y = 0.1813x-0.322
R² = 0.216

Summary

- P fractions removed through different mechanisms, some are very difficult or impossible to remove
- Alum makes solid phase Al-OH-PO_4 complexes and neutralizes surface charge on colloids and particles
- In Actiflo, silica microsand increases the specific gravity of the floc
- Polymer selection is critical
- Maintaining sand concentration is not a process goal
- Actiflo highly effective in TSS and P removal in small footprint
- Can handle influent TSS flucuations
- Coagulant dose similar to other P removal technologies