2

Physical Chemical Phosphorous Removal

KRÜGER

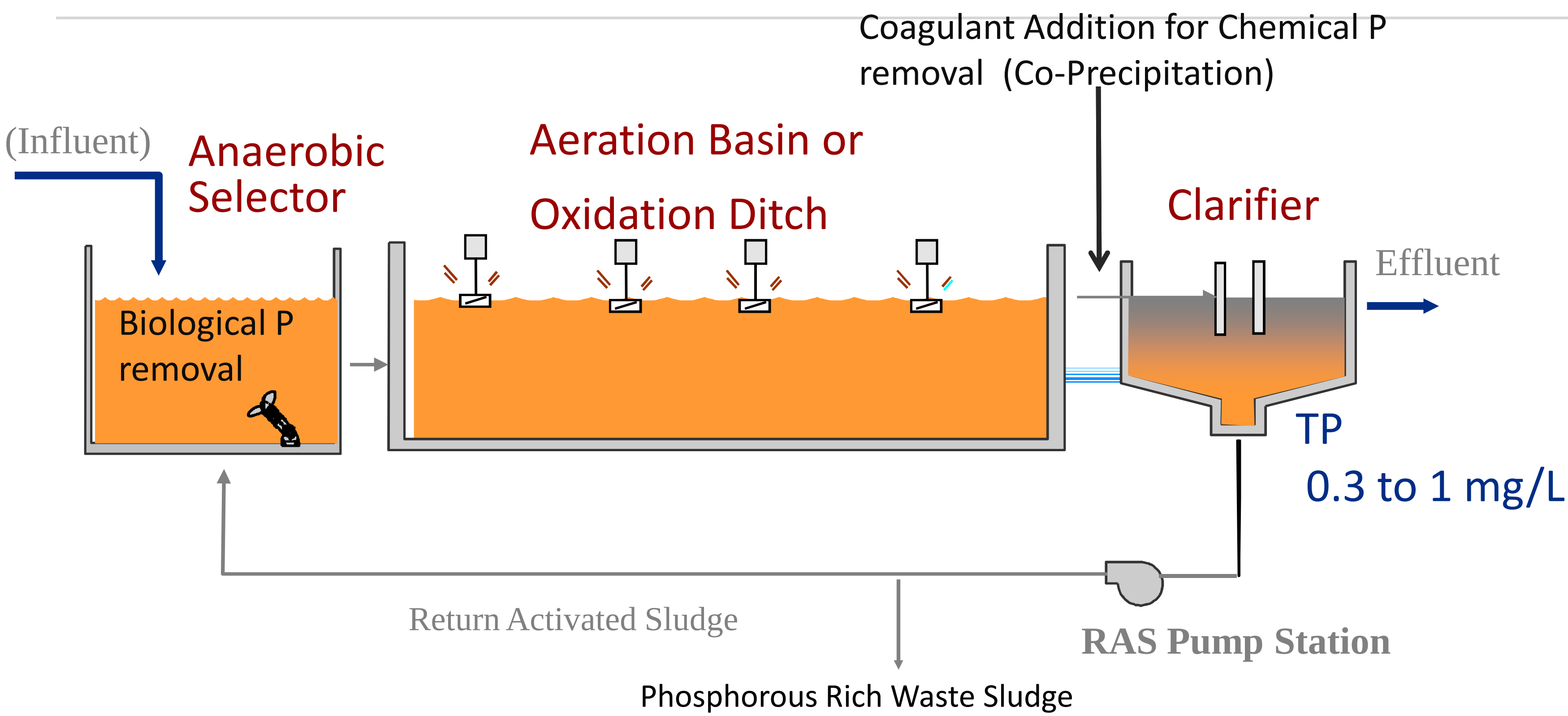
VEOLIA WATER

Solutions & Technologies

Effluent Phosphorous Requirements

Location	Start-up	Capacity (MGD)	TP Limit in mg/l (Future Limit)
West Palm Beach, FL	2003	20	0.1
South Lyon, MI	2004	4	0.07
Syracuse, NY	2005	126	0.12 (0.02)
Danbury Township, OH	2005	4	0.8
Ithaca, NY	2006	13	0.2
Webster, MA	2010	15	0.2 (0.05)
Leominster, MA	2010	28	0.2 (0.05)
Jaffrey, NH	2010	4	0.1
Westborough, MA	2011	38	0.1 (0.05)

Phosphorous Removal



To get below 0.3 mg/L, some form tertiary treatment typically required

Phosphorus Removal

- Tertiary treatment solutions

  - **> 0.3 mg/L** : Bio-P removal and/or Co-precipitation
  - **0.2 to 0.5 mg/L** : add tertiary Filtration
  - **0.1 to 0.3 mg/L:** coagulation upstream of tertiary filtration
  - **< 0.1 mg/L**

    →Coagulation/flocculation upstream of tertiary filtration
    →High Rate Coagulation/flocculation
    →Multi-point coagulation with Multi-stage filtration

Chemical Phosphorous Removal

Alum: $Al_2(SO4)_3*14H_2O$

Ferric Chloride: $FeCl_3$

Theoretically to remove 1 mg/L of PO_4-P you need

- 9.6 mg/L of Alum
- 5.2 mg/L of Ferric Chloride

- Real life requires 0.5 to 15 times as much
- Competing reaction forms $Al(OH)_3$ or $Fe(OH)_3$
- Consumes alkalinity

For low P effluent

Rapid Mixing critical to efficiency

Chemical Dosage

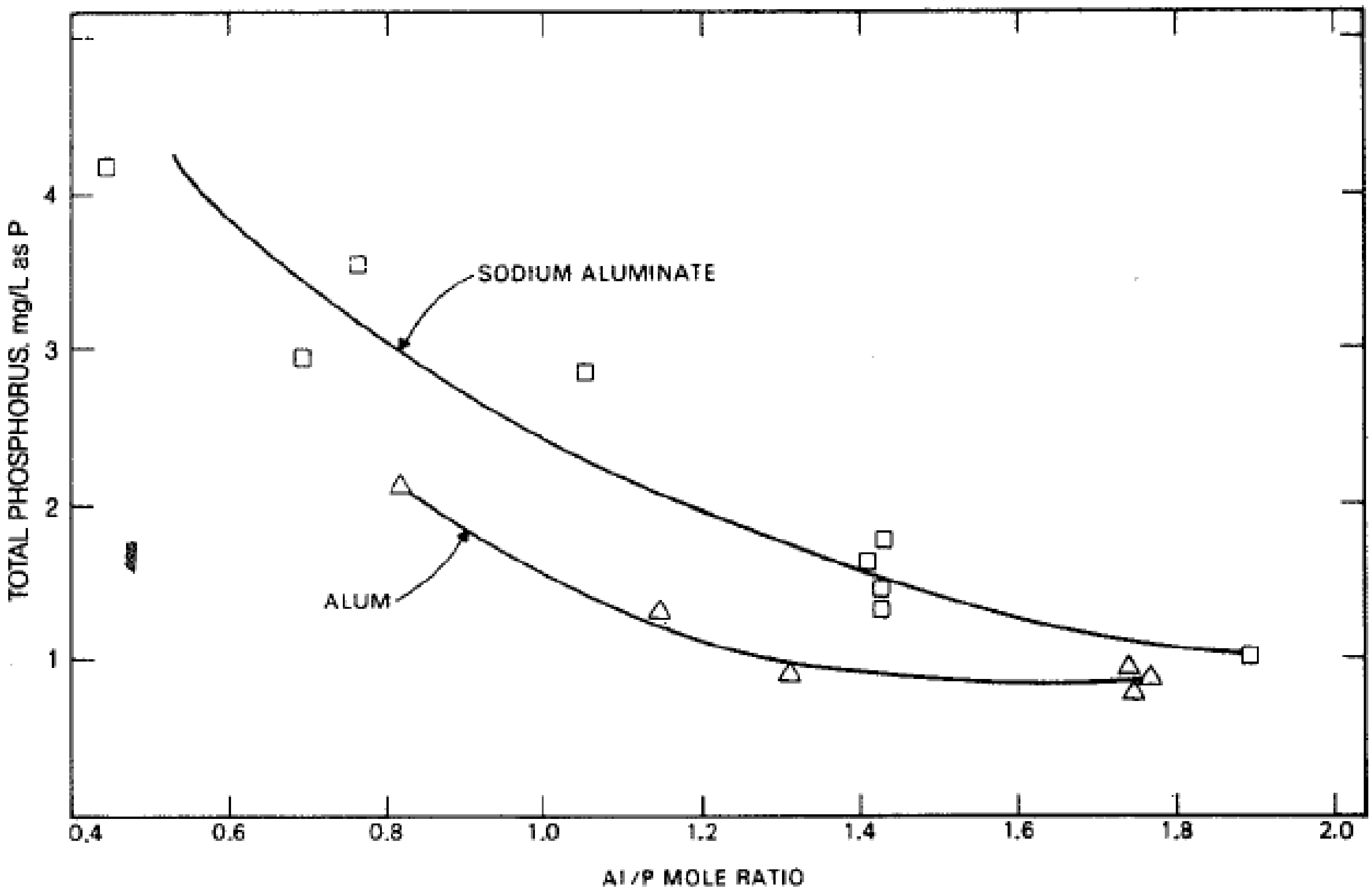
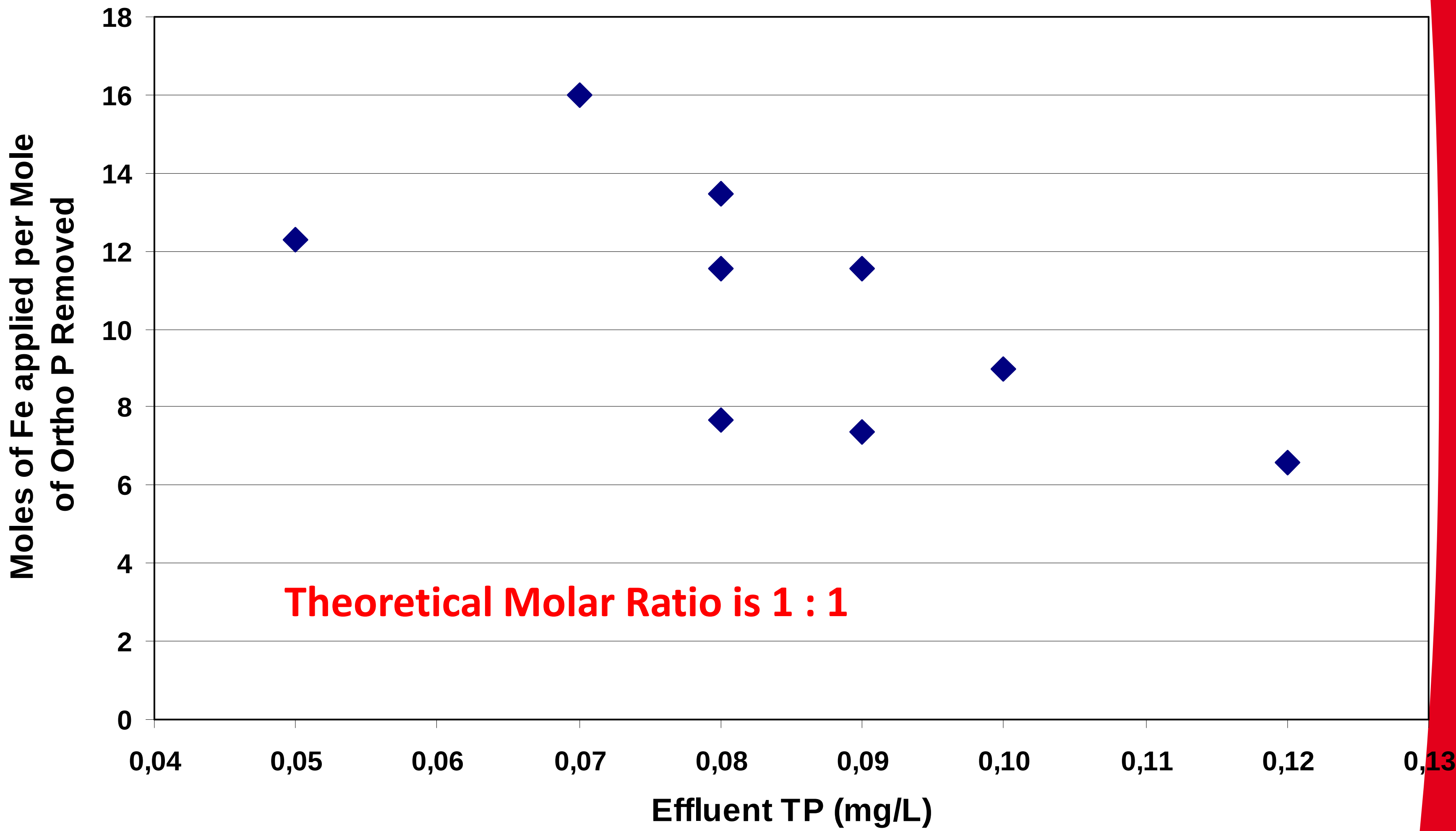


Figure 16.37 **Comparison of phosphorus removal effectiveness of alum and sodium aluminate.**

Chemical Dosage: Discfilter Study



Sludge from chemical P removal

- 1 lb Alum produces about 0.4 lbs sludge
- 1 lb $FeCL_3$ produces about 0.6 lbs sludge

Phosphorous removal by coagulant addition

Three principle removal mechanisms

1. Chemical precipitation of PO_4^{-3}
2. Coagulation/flocculation of particulate forms
3. Adsorption of PO_4^{-3} onto chemical flocs of $Fe(OH)_3$ & $Al(OH)_3$

Phosphorus species in water

Table 1: Phosphorus Species in Water

Category	Species	Solid/Liquid	Comment
I - Orthophosphate	PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^{-}$, H_3PO_4	Liquid	Weak acid (pKa's ~ 2.15, 7.2, 12.35), most dominant form, reactive.
II - Polyphosphates / Condensed Phosphate	Pyrophosphate, tripoly-phosphate, metaphosphate	Liquid	Complex large molecule. Precipitate in condensed form or hydrolysis to orthophosphate. Hydrolysis rates high in presence of microorganisms (sludge).
III - Organic Phosphorus	Cell material, intracellular phosphate, intracellular granules	Solid	Linked to biological growth, enhanced biological phosphorus removal, etc.
IV – Chemical Phosphorus	Phosphorus precipitants, typically Fe, Al, Ca. Struvite and other compounds also contribute to chemical phosphorus.	Solid	Particle size important. Reactions slower and could change with time.
V - Adsorbed Phosphorus	Adsorption to sorbant or to metal hydroxides, form complex	Solid	

Non-Reactive P

- Portion of soluble TP that cannot be precipitated and removed by coagulation/flocculation.
- Typically < 0.01 to 0.02 mg/L but several sites encountered with values ranging from 0.05 to 0.07 mg/L.
- Can be an important contribution to risk assessment when guarantee is 0.1 mg/L or less

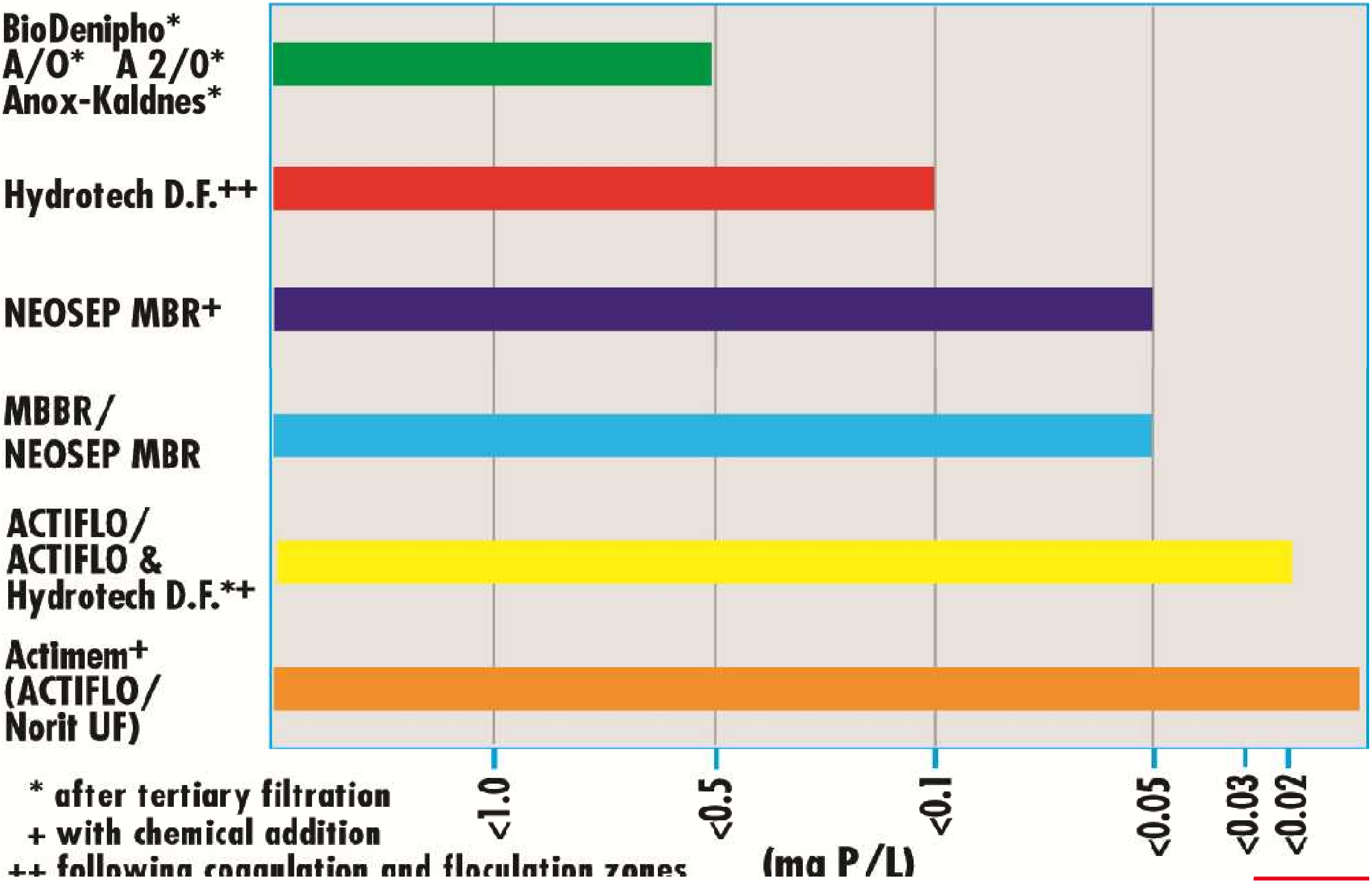
Tertiary P Removal Processes for Low P

- Cloth Media Filters with upstream coagulation/flocculation
  - Kruger Hydrotech
- High Rate Coagulation/Flocculation
  - Kruger Actiflo
  - Infilco AquaDaf
  - CoMag
- Media Filtration
  - BluePro
  - Parkson DynaSand
  - Others

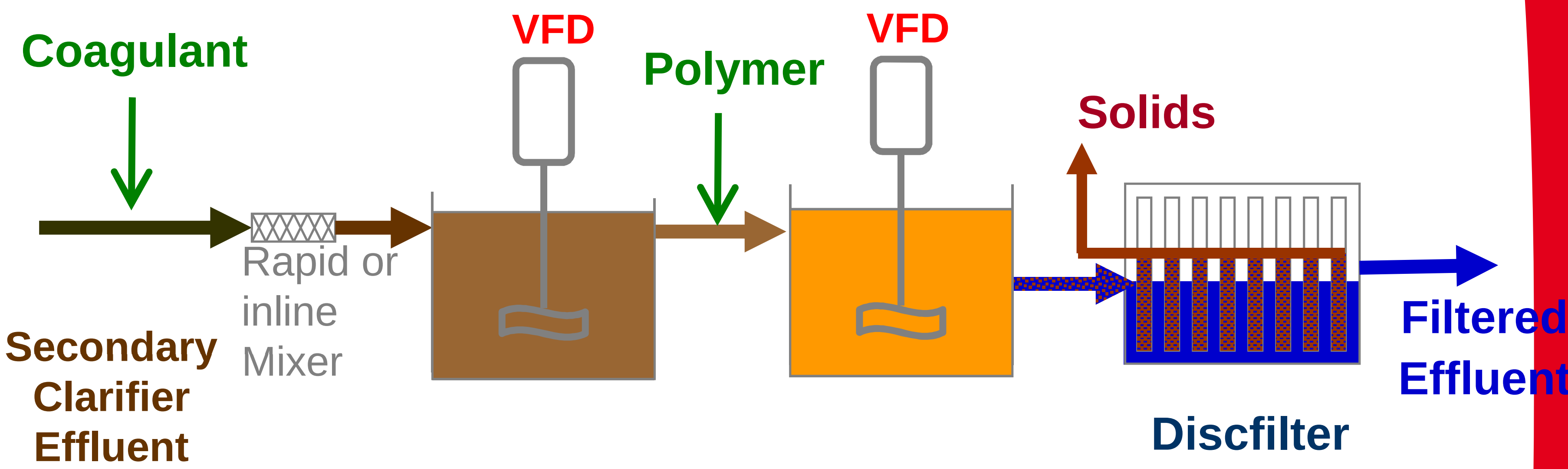
Phosphorus Removal

- Tertiary treatment solutions :
  - **>0.5:** Co-precipitation
  - **0.3 mg/L** : Tertiary filtration with upstream co-precipitation
  - **0.1 to 0.5 mg/L** : Tertiary Filtration with tertiary coagulation/flocculation
  - **< 0.1 mg/L** :
    - → Actiflo or other ballasted floccultiion
    - → (possible with Discfilter and tertiary coag/flocc sytstem if secondary effluent TP < 0.5)
    - → Deep Bed or Multi-stage granular media filters wither tertiary coagulation and filter aid if secondary effluent TP < 0.5

Phosphorous Removal

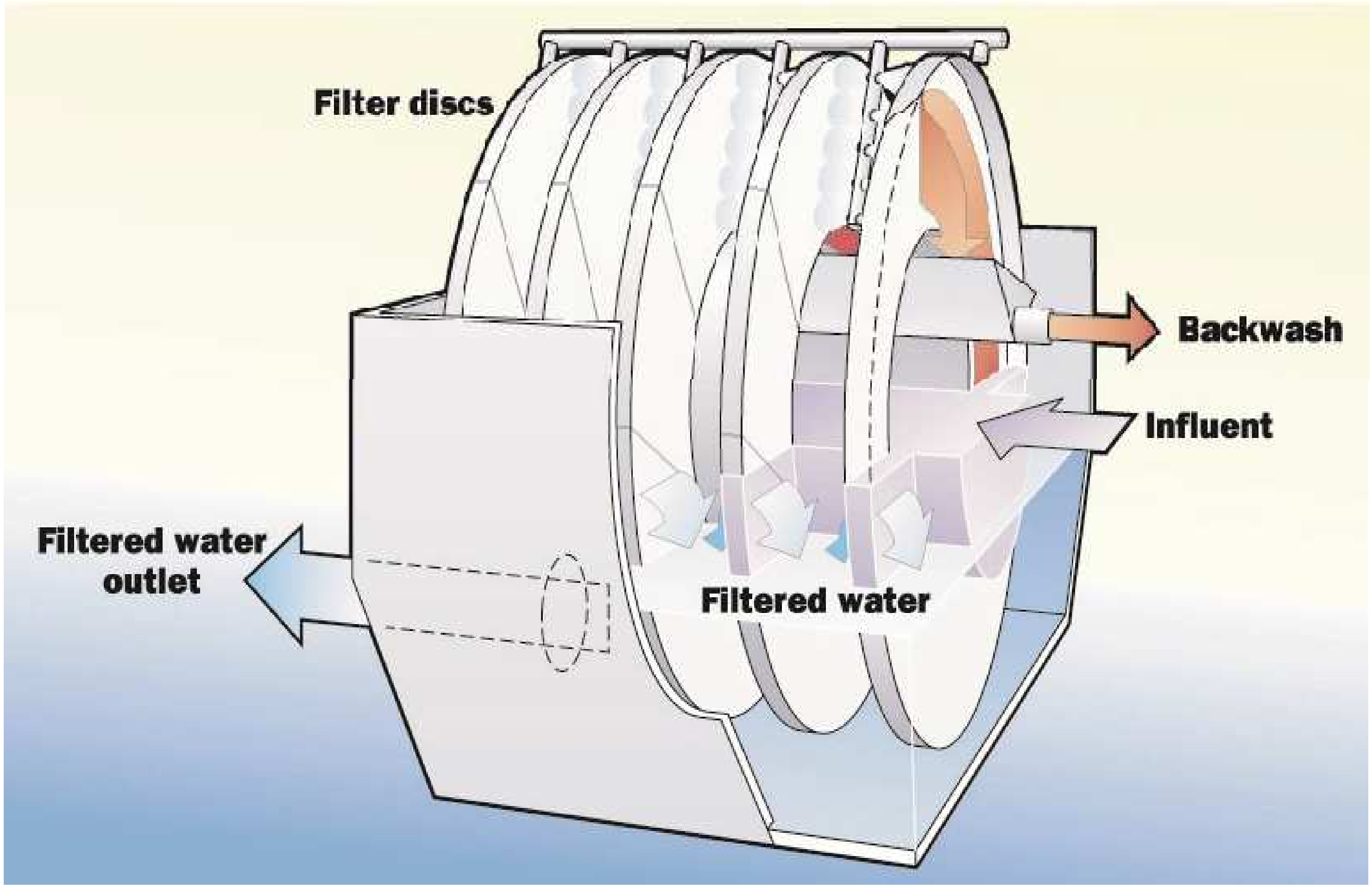


Tertiary Coagulation ahead of the Cloth Media Filter

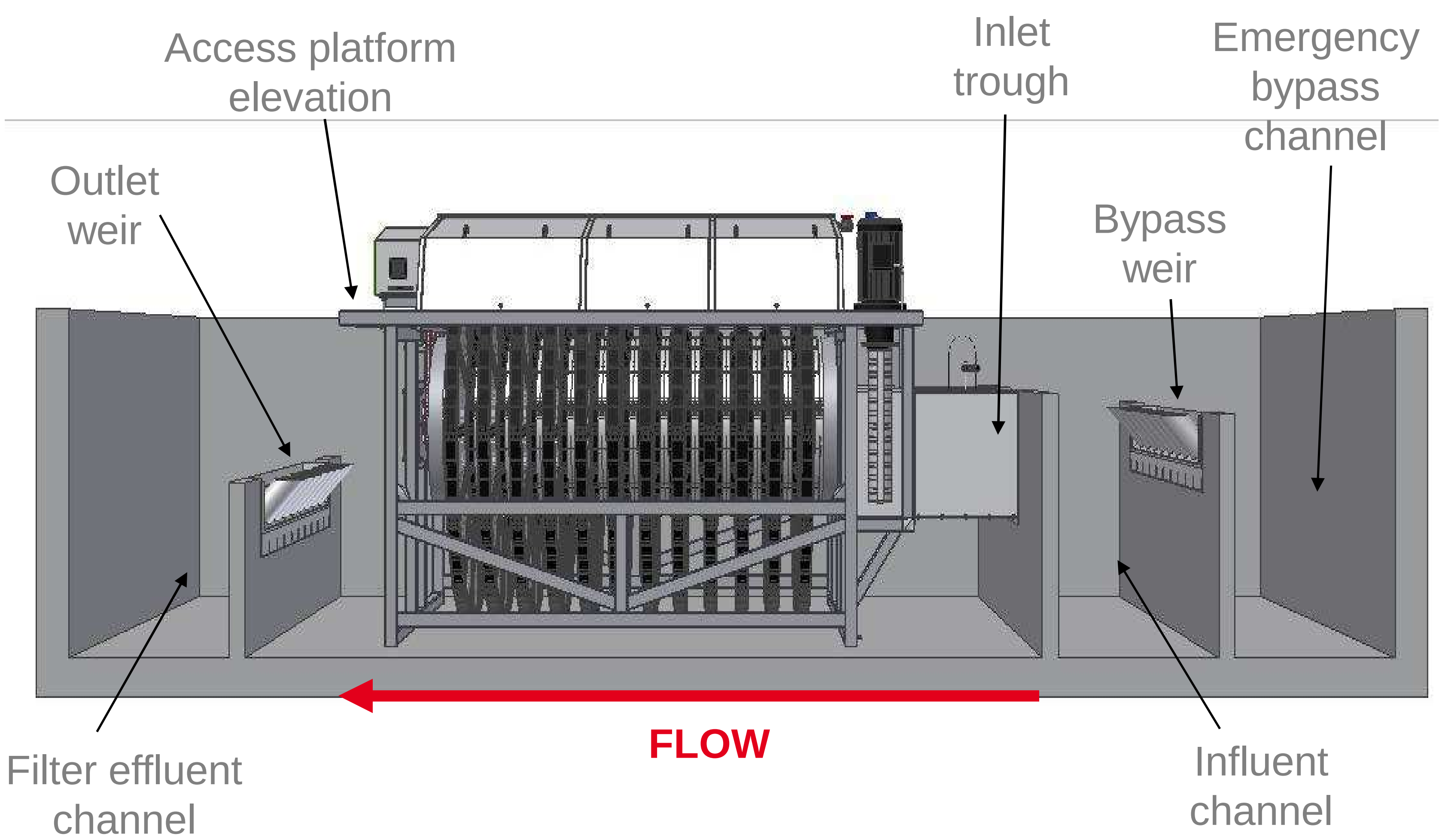


- Can Target TP <0.1 mg/L
- An Automated Chemical Cleaning (ACS) system is recommended to minimize operator maintenance

Cloth Media Filter



Cloth media Filter for concrete basins



Harrison TWP, NJ Pilot (2008)

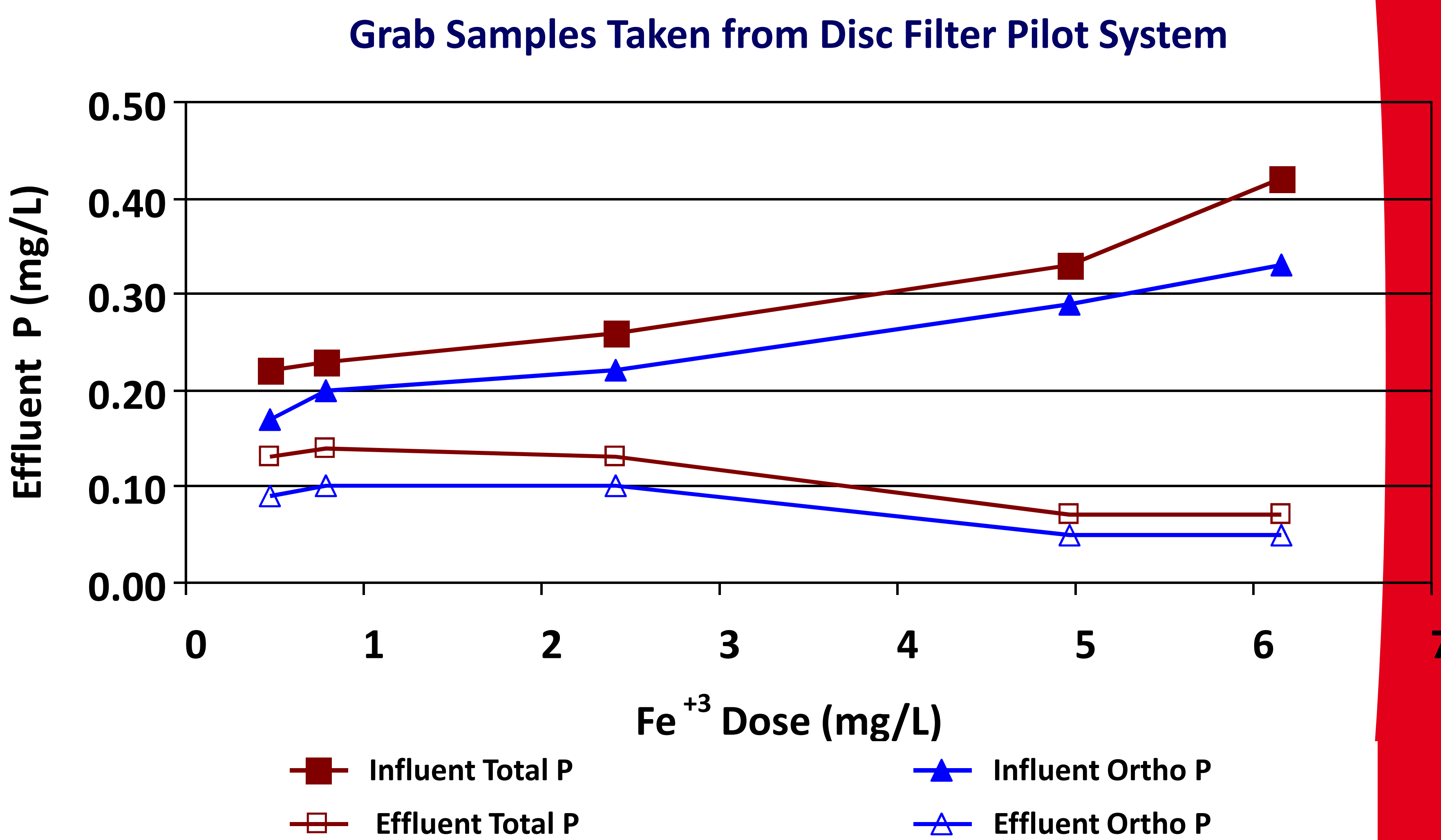
- Treatment goal for Hydrotech Discfilter: TP < 0.1 mg/l
- Since TP of secondary effluent is high (~ 3.8 mg/l), $FeCl_3$ was added prior to the secondary clarifier for upstream co-precipitation to < 0.5 mg/L TP
- Additional 5-15 mg/l $FeCl_3$ added prior to Discfilter for chemical tertiary P precipitation.
- NaOH applied to the Discfilter influent for optimum coagulation pH adjustment (~7)

Harrison Township Pilot Study

Total Phosphorous			
Ferric Dose	Influent	Effluent	% Removal
10	0.174	0.0415	76%
15	0.178	0.0269	85%

Ortho Phosphorous			
Ferric Dose	Influent	Effluent	% Removal
10	0.105	0.0141	87%
15	0.108	0.0081	93%

Phosphorus Removal w/ Iron

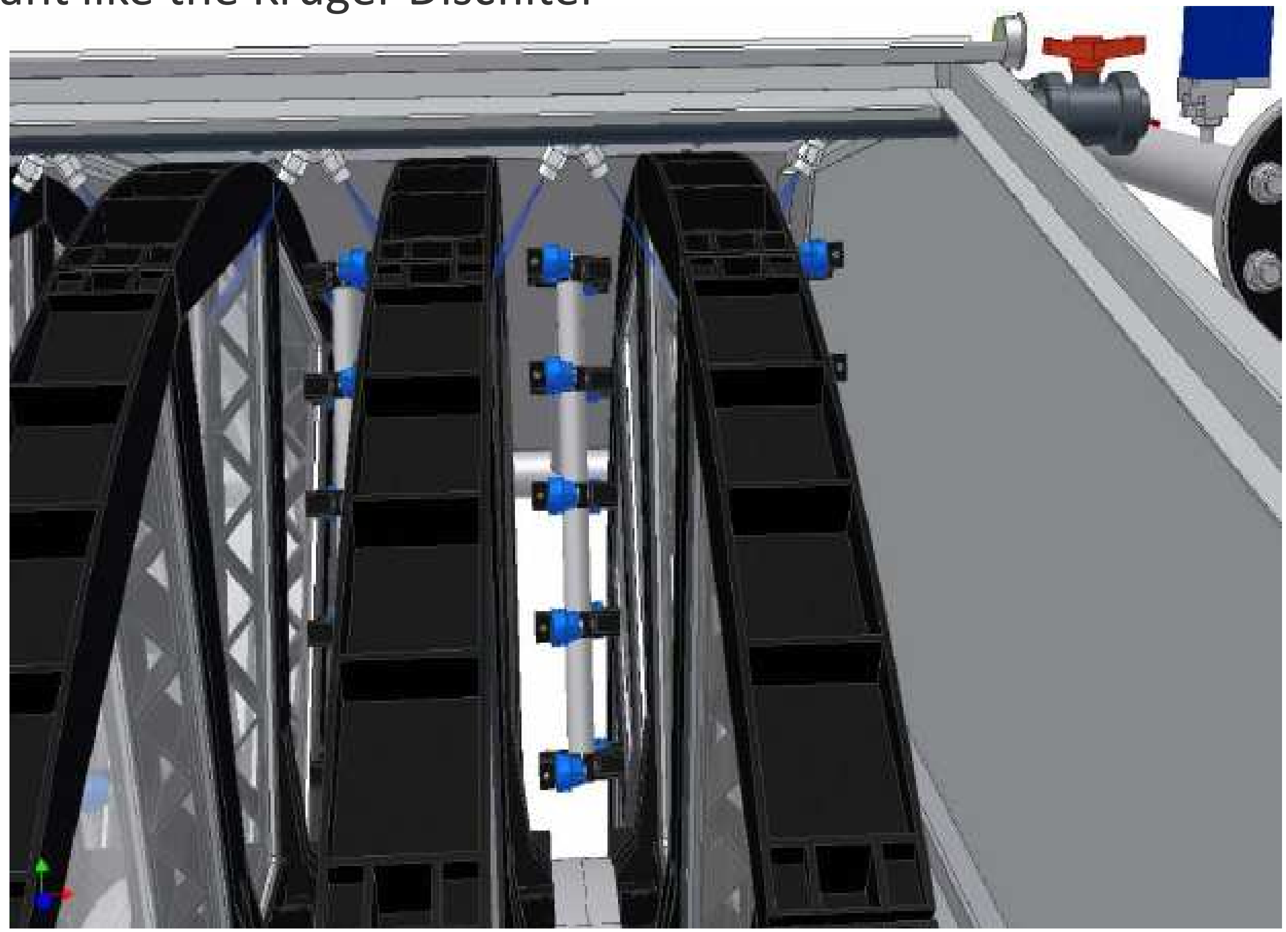


Media Cleaning

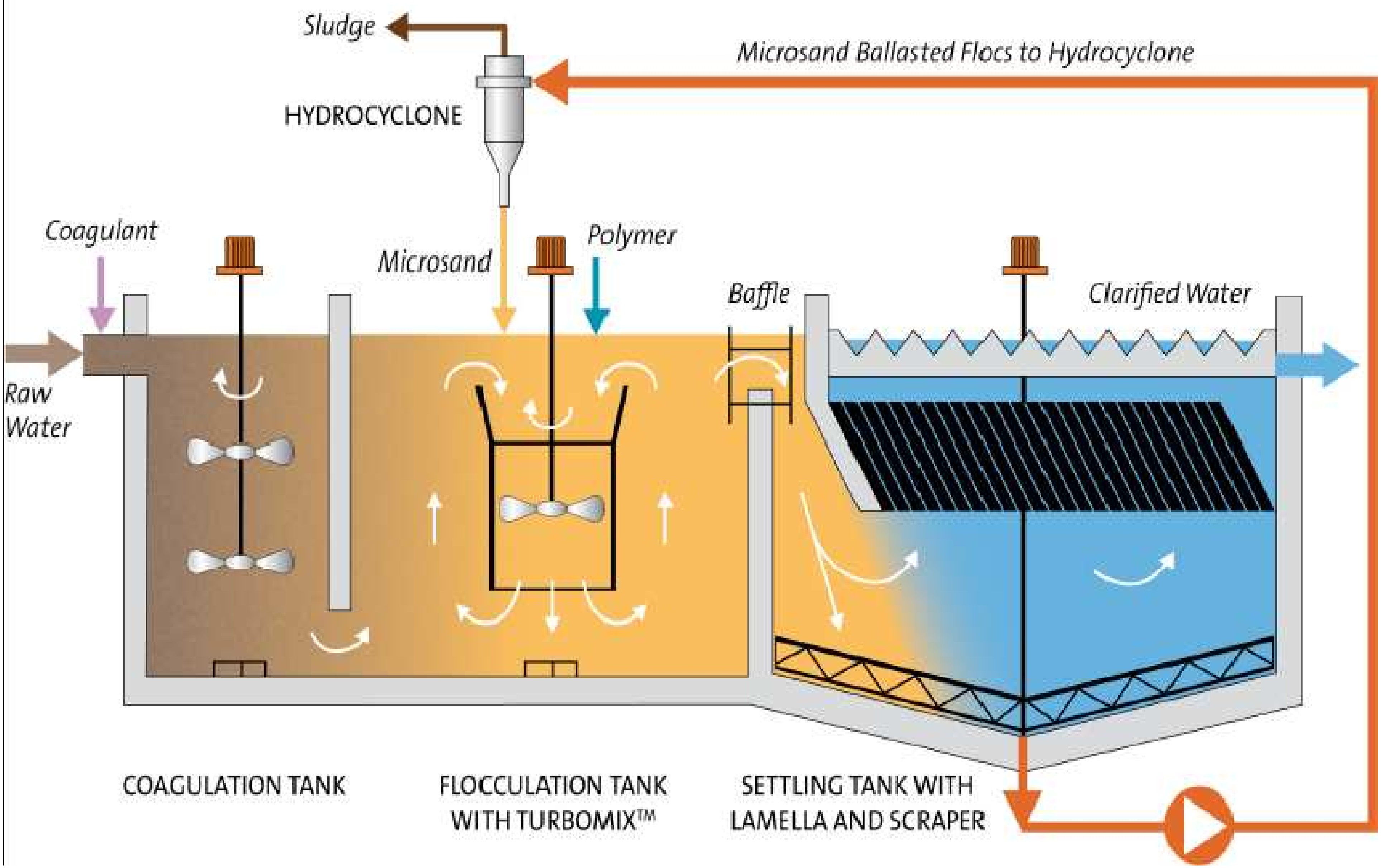
Automated Clean in Place (CIP) system developed by Hydrotech increases hydraulic capacity

Media Fouling Concerns

- An Automated Chemical Cleaning (ACS) system maybe recommended to minimize operator maintenance
- NO OTHER FILTER HAS THIS OPTION and Can Not Take Polymer or Coagulant like the Kruger Discfilter



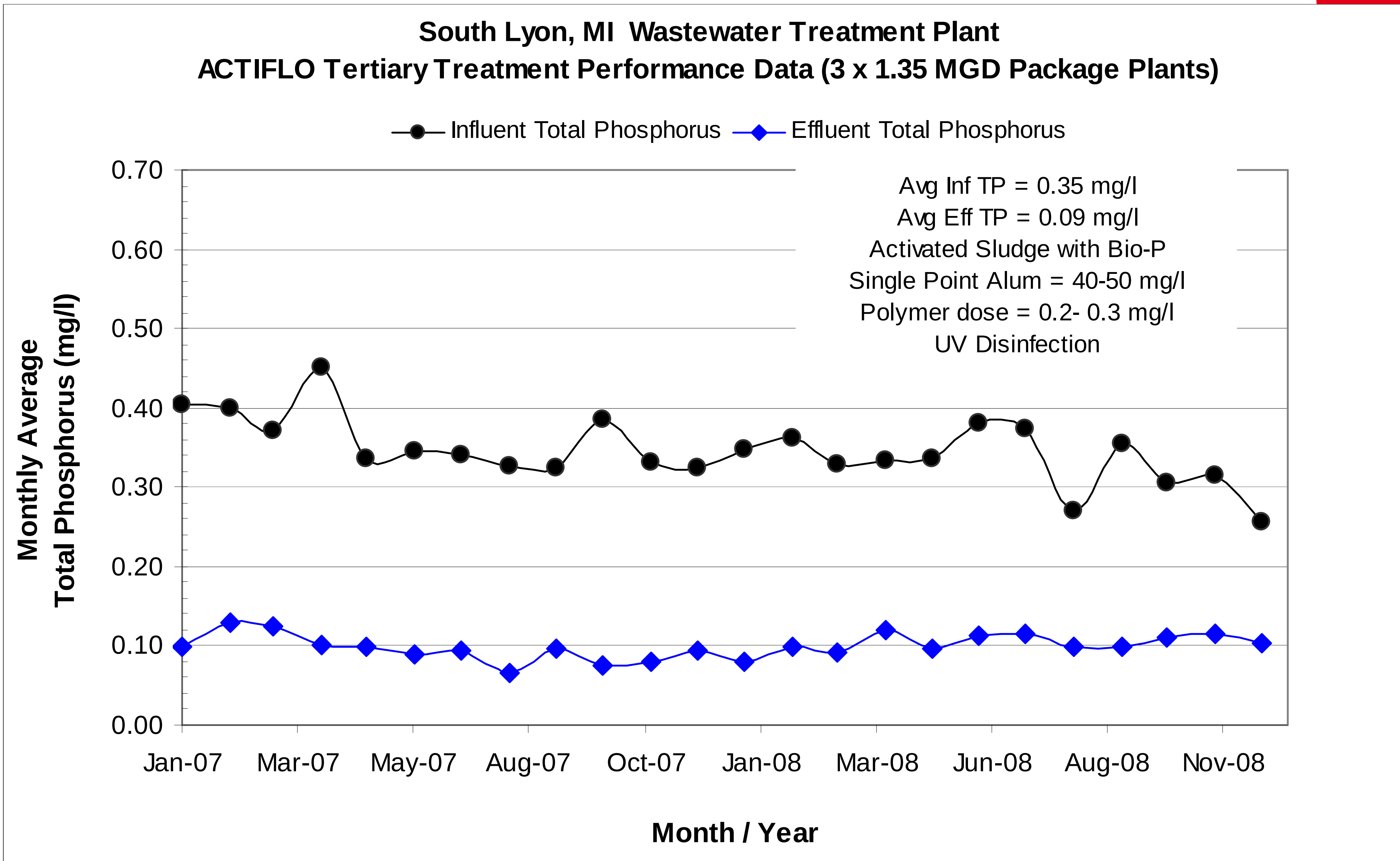
Actiflo (for TP 0.05 to 0.1 mg/L)



South Lyon, MI

- Avg Daily Flow: 1.5 MGD
- Peak Flow: 3 MGD
- ACTIFLO follows an ASP w/ Bio-P
- Eff. TP Limit
  - 0.07 mg/L design flow
  - 0.20 mg/L current flows
- ACTIFLO followed by UV

South Lyon, MI



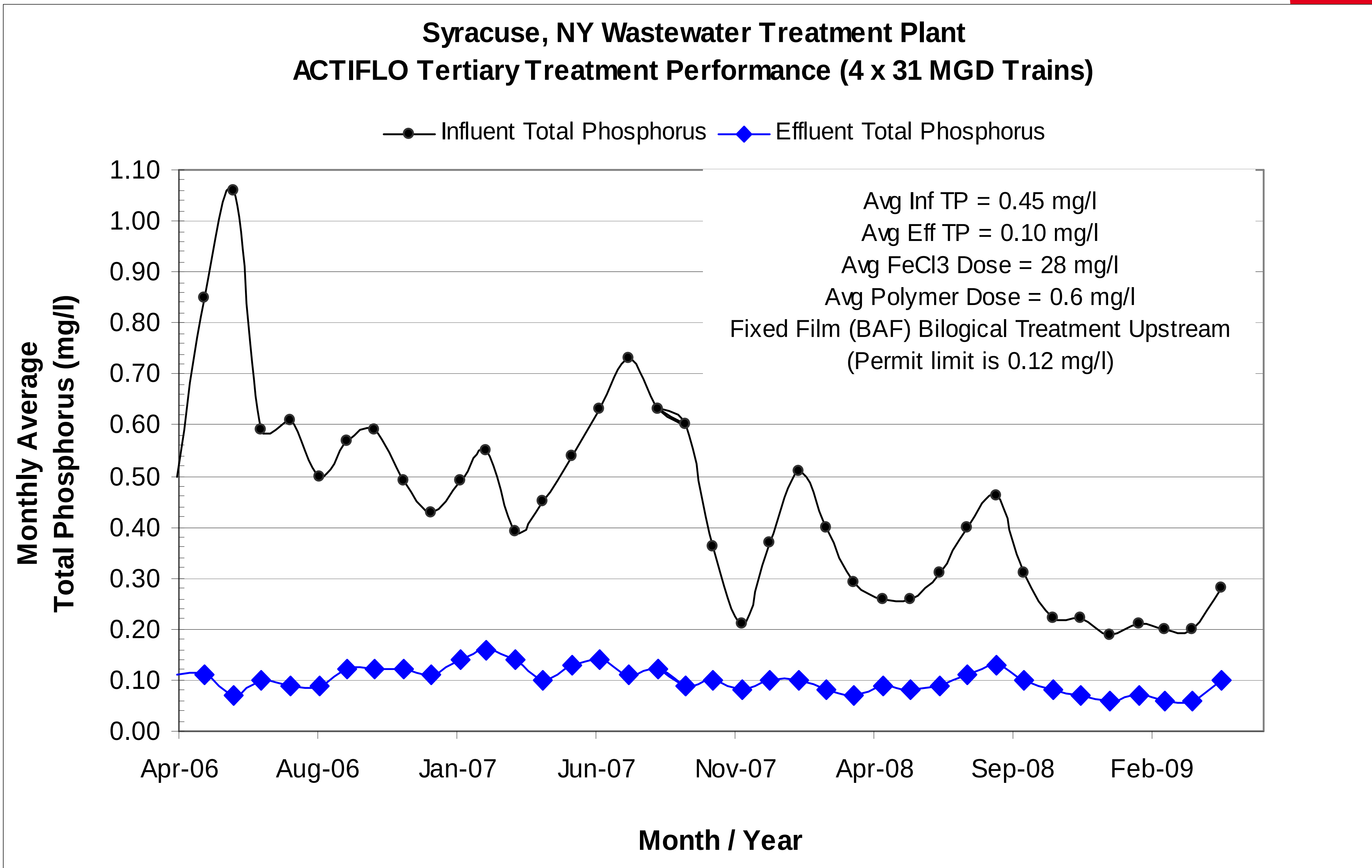
Syracuse, NY

- Secondary treatment completed in 1979
- Combined sewer system w/ treated water discharged into Onondaga lake
- Peak Flow: 126 MGD
- 1997 Consent Order by NY State and USEPA to treat CSOs & to remove Ammonia and Phosphorus:
  - NH_3 limit, 30-day average (2005):
    - → July – September: 1.2 mg/l
    - → October – June: 2.4 mg/l
  - TP limit, 12-month rolling average:
    - → 2006: 0.12 mg/l
    - → 2012: 0.02 mg/l

Syracuse, NY Pilot

- Jar tests & extensive side-by-side pilot testing in 2000
- Reducing BAF TP from 0.75 mg/l to < 0.12 mg/l.
- Processes included various clarification & filtration technologies:
  - Dynasand (Parkson)
  - Supersand (Waterlink)
  - Hydroclear (USFilter)
  - Densadeg (Degremont)
  - ACTIFLO (Krüger Inc.
- ACTIFLO Pilot Testing Results:
  - Inf. TP: 0.38 – 1.06 mg/L
  - Eff. TP: 0.04 – 0.12 mg/L
  - Coagulant: 20-30 gm/L (Ferric)
  - Polymer: 0.4 – 0.6 mg/L

Syracuse Operational Data



Westborough, MA

- Average Flow: 6 MLD
- Design avg. daily flow: 8 MLD
- Design max. daily flow: 16 MLD
- Total phosphorus:
  - Plant Influent TP: ~ 5 mg/l
  - Primary effluent TP: ~ 4 mg/l
  - Secondary effluent TP: ~ 2 mg/l
  - Plant aver. effluent TP: 0.65 mg/l (after filtration)
  - Current discharge limit: 0.75 mg/l P

Westborough, MA Pilot

- 4 different treatment processes were evaluated in a side-by-side 3-week testing period:
  - Blue Pro (Blue Water)
  - CoMag (Cambridge Water Technology CWT)
  - AquaDaf (Degremont)
  - ACTIFLO
- Chemicals were supplied by the Engineer to ensure quality and concentrations
- Test program:
  - Week 1: Optimize coagulants
  - Week 2: Optimize flow & loading rates
  - Week 3: Stress conditions (increased influent TP & TSS conc.)

Westborough, MA Results

- TP removal performance:
  - Influent TP: 0.83 – 1.76 mg/l
  - ACTIFLO effluent TP as low as 0.04 mg/l (up to 97% removal)
  - CoMag TP as low as 0.02 mg/L
- Chemical use:
  - ACTIFLO required the least amount of ferric chloride
  - AquaDAF required the least amount of alum
  - CoMag required the most amount of ferric chloride or alum
- Hydraulic profile:
  - AquaDAF and ACTIFLO fit into the existing hydraulic profile of the plant. Blue Pro & CoMag do not.
- Actiflo selected based on life cycle cost, footprint, and hydraulic profile.

3

CSO and SSO Treatment

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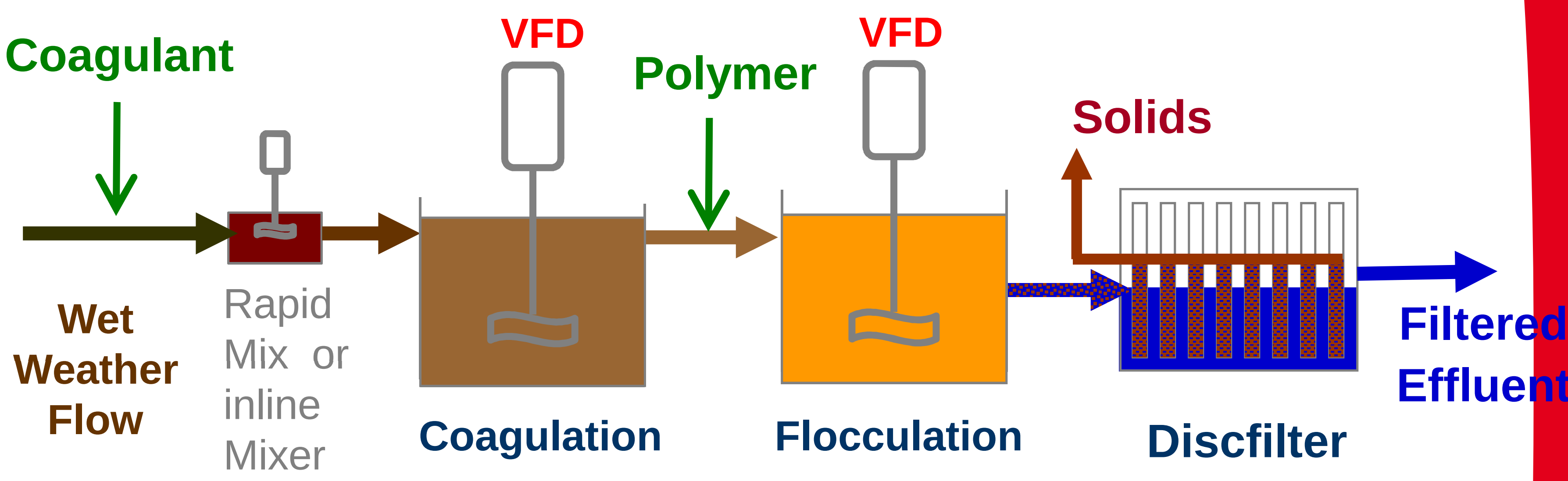
Primary/CSO/SSO Treatment with Discfilter

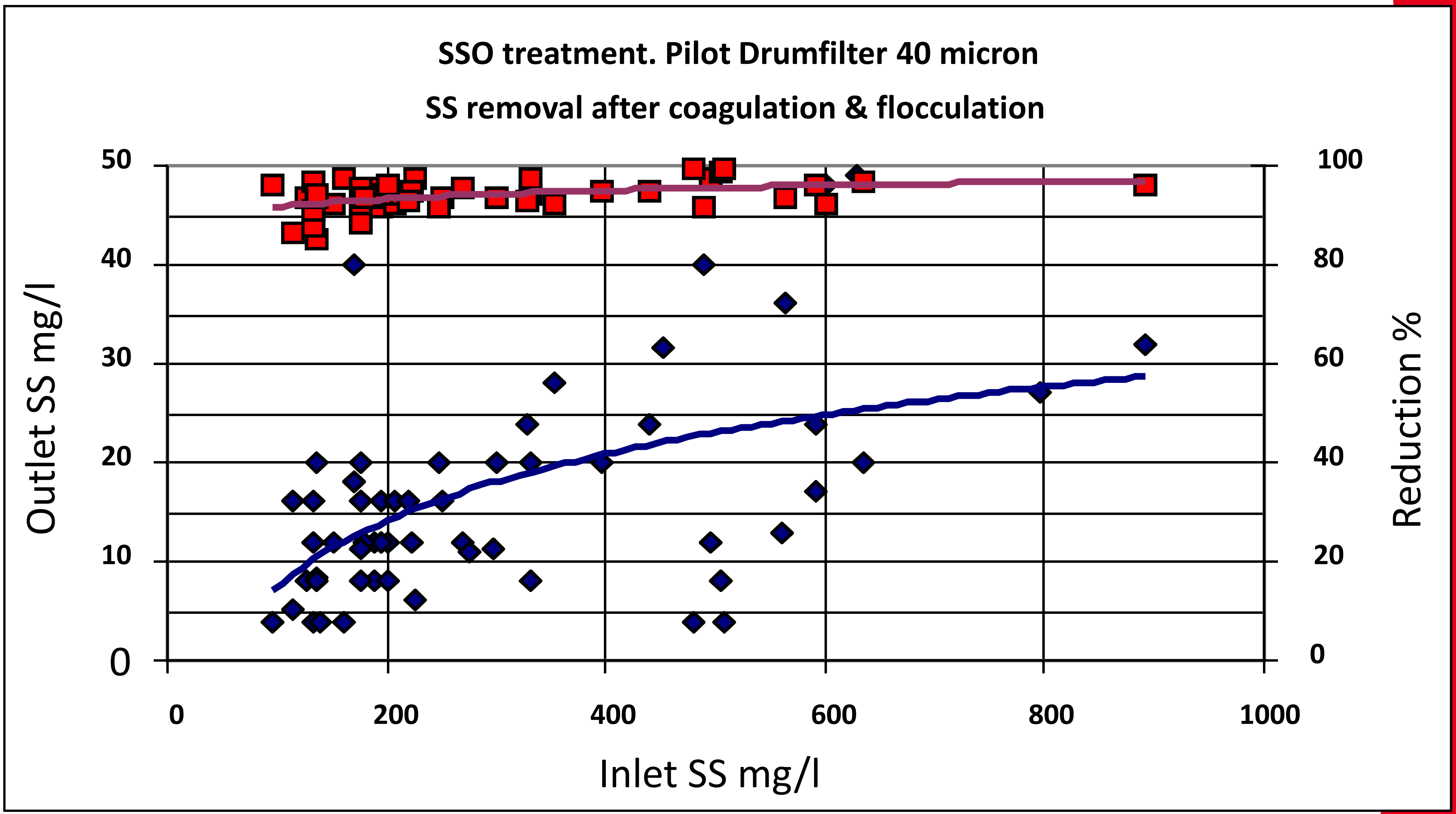


- 90% Removal of TSS and 50 to 70% removal of BOD

Primary/CSO/SSO Treatment w/ Chemicals

Raw wastewater filtration (PIX + anionic polymer)

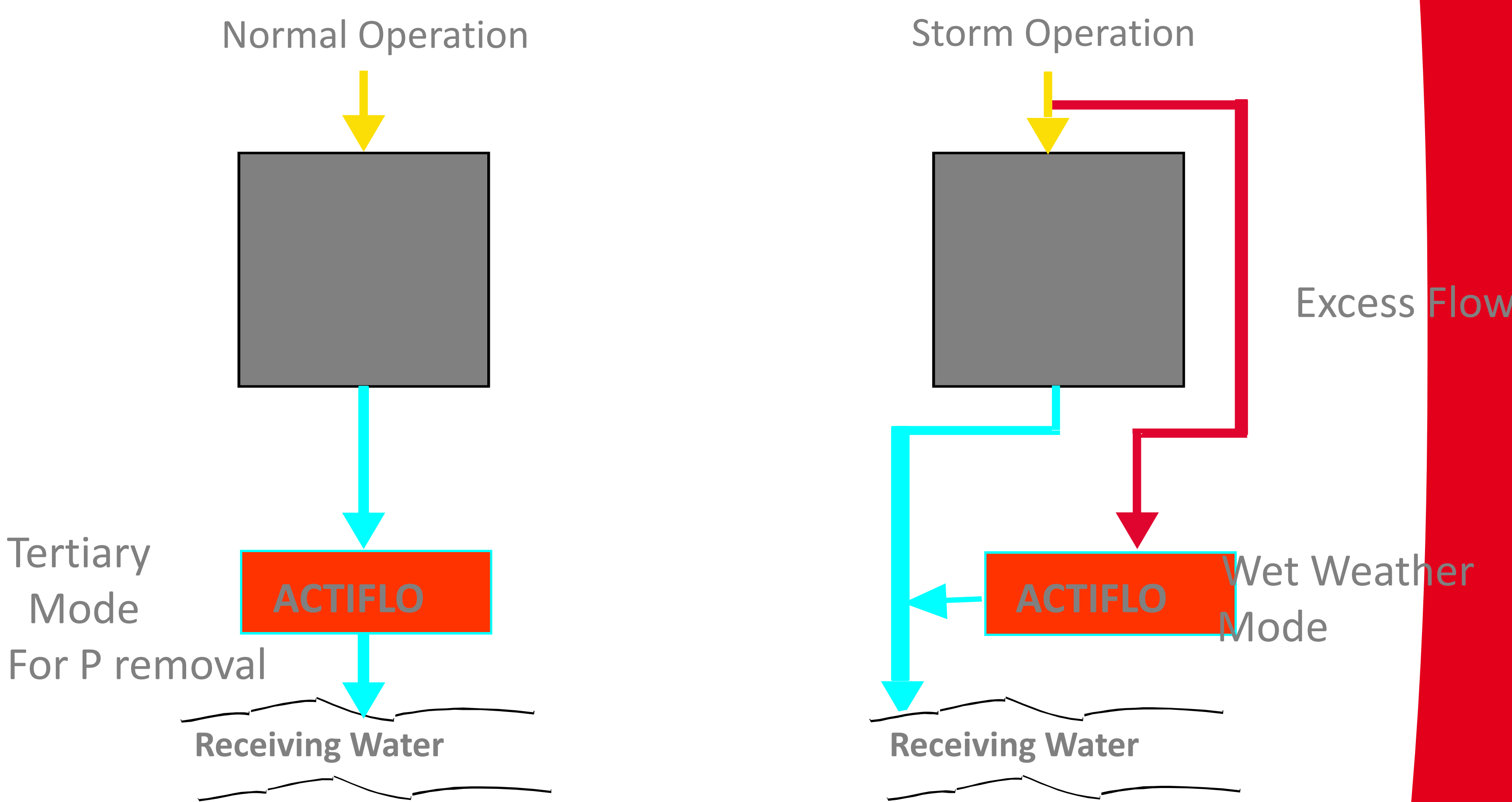
Raw Wastewater (SSO) Pilot Study
Malmo, Sweden



Raw Wastewater (SSO) Pilot Study Malmo, Sweden

SSO treatment 40- 60 micron	Inlet 150-600 mg SS/l	(4-10 mg P/l)	
	coag. + flocc.	polymer only	no chemicals
SS-reduction, %	85 - 95	80 - 90	45 - 60
BOD-reduction%	approx 60	-	-
Total-P reduction, %	65 - 75	-	-
Coagulant (Fe), mg/l	10	-	-
- coagulation time	4 min	-	-
Flocculant (polymer), ppm	2-4	2-4	-
- flocculation time	2-4 min	2-4 min	-

ACTIFLO Overflow Treatment



ACTIFLO® CSO/SSO Facilities

	Plant Location	Start-up	Total Capacity MGD	No. of Trains	Application
1	St. Bernard, LA	2001	10	1	Primary and SSO
2	E. Bremerton, WA	2001	10	1	CSO
3	Lawrence, KS	2003	40	2	SSO
4	Ft. Smith, AR	2004	31	1	SSO
5	Port Clinton, OH	2004	25	2	CSO
6	Fort Worth, TX	2005	80	2	SSO
7	Greenfield, IN	2004	8	2	CSO
8	Port Orchard, WA	2006	6.7	1	CSO
9	Cincinnati SSO 700, OH	2006	15	1	SSO
10	*Cincinnati Sycamore Creek, OH	2007	32	2	SSO
11	*Heart of the Valley MSD, Kaukauna, WI	2007	60	2	SSO
12	**Tacoma, WA	2007	80	2	CSO
13	**Salem, OR	2007	50	2	SSO
14	*Nashua, NH	2008	60	2	CSO

*Under construction

** Under contract

Development Background

Regulatory Climate Regarding SSO Discharges

- Phys/chem treatment is not specifically prohibited for blending of wet weather flows

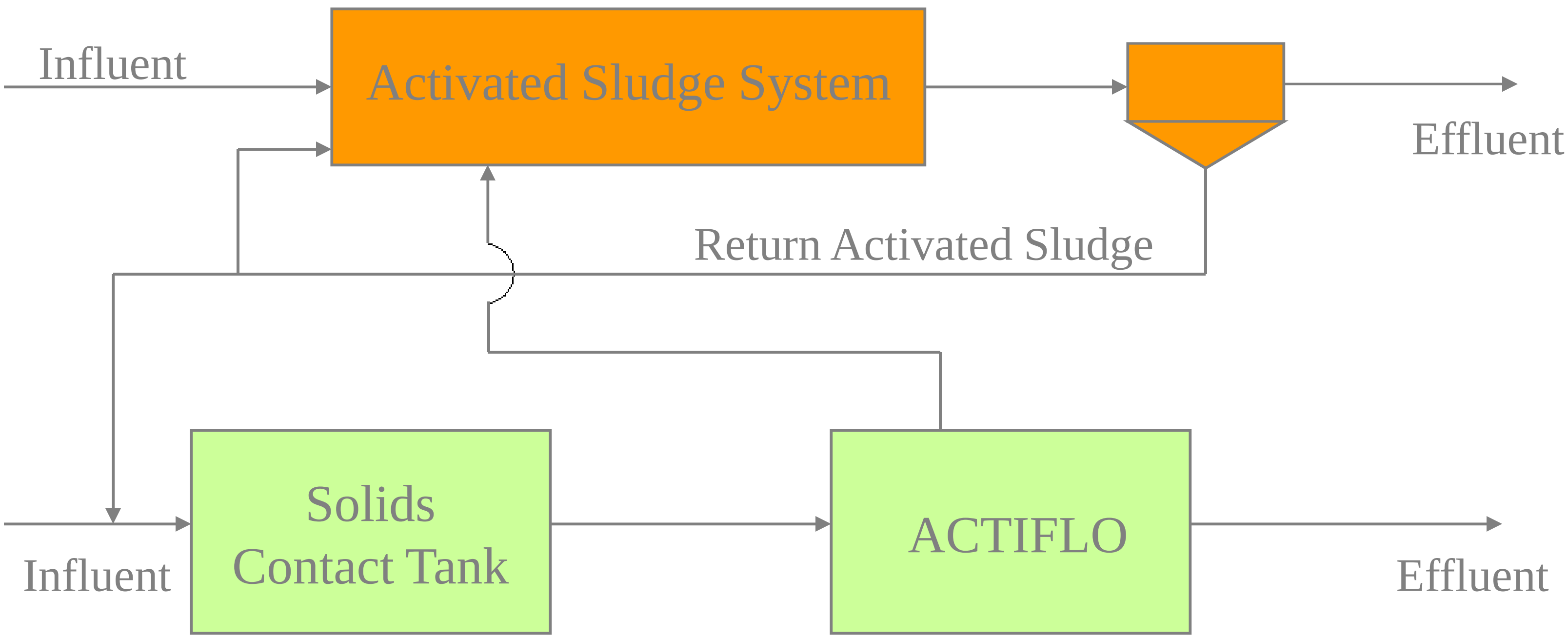
- Environmental groups successfully made the case that while phys/chem treatment (e.g. ACTIFLO) can provide permit compliant discharges (BOD/TSS) they "may" contain higher levels of pathogens

- EPA (NACWA/NRDC) guidelines and policy suggest that the most effective means for compliance is for discharges to meet "secondary treatment requirements"

Wet Weather Treatment

- Theory
  - Exploit “excess” or untapped biological treatment capacity
  - Supplement limited secondary clarification capacity
  - Provide high rate biological secondary treatment (BOD, sBOD, TSS)

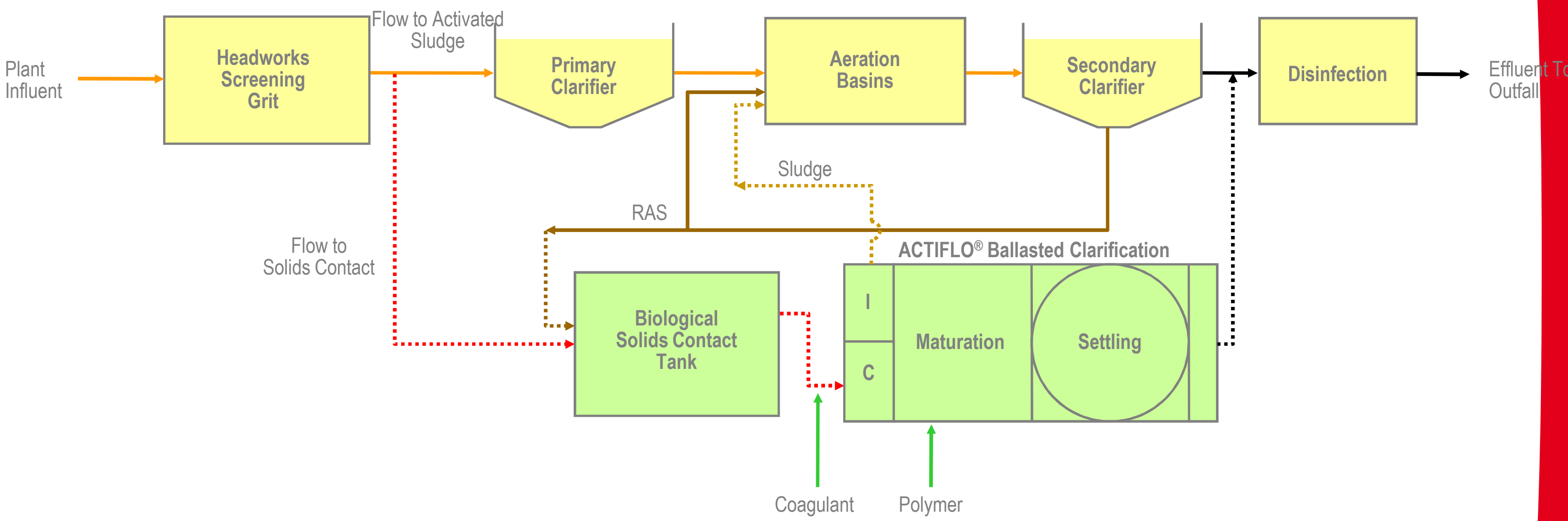
BioACTIFLO Process



BioACTIFLO Design Summary

Solids Contact Tank		
Hydraulic Retention Time	20-30 min.	20
MLSS Concentration	800-1000 mg/L	800
Dissolved Oxygen Level	2 – 4 mg/L	2
High Rate Clarifier		
Hydraulic Retention Time	10-15 min.	1/1/3 min (C/I/M)
Overflow Rate	30-60 gpm/ft2	45
Microsand Recirculation Rate	15%	15
Sludge Production	12%	12
Estimated Performance		
Effluent TSS	<10 mg/L	
Soluble BOD Removal	60-70%	
Total BOD Removal	70-85%	
Estimated Chemical Consumption		
Coagulant Dosage	50-200 mg/L	200
Polymer Dosage	1.5-4.0 mg/L	4
Sand Consumption	17-25 lb/MG	

Plant Schematic



Fort Smith, AR

- Facility Summary
- Pilot Study Results
  - Phase 1
  - Phase 2

Fort Smith, AR

- Facility Summary
- Pilot Study Results
  - Phase 1
  - Phase 2

Ft. Smith, AR SSO Facility 1 x 31 MGD
Full Scale Operating Data

Date	BOD		%	TSS		%
	INF	EFF	Redux	INF	EFF	Redux
	mg/L	mg/L		mg/L	mg/L	
6/10/2004	N/A	N/A	N/A	912	17	98
6/19/2004	65	11	83	255	18	93
6/21/2004	120	32	73	186	10	95
6/22/2004	81	17	79	190	15	97

During this sampling period:

Flows ranged from 8 to 19 MGD

Event duration ranged from 2 to 4 hrs

Dischg. Permit: **30 mg/l BOD, 30 mg/l TSS Monthly Avg**

45 mg/l BOD, 45 mg/l TSS Daily Max

Phase 1: Nov 15, 2004 to Jan 21, 2005

Test Conditions	
MLSS:	100, 200, 300, 400, and 800 mg/L
Contact Basin HRT:	20 and 30 min.
Flow Rate:	200 gpm
Retention Times:	Coagulation: 1.5 min Injection: 1.4 min Maturation: 4.2 min
Rise Rate:	30 gpm/sf
Coagulant (Ferric Sulfate):	Wet Weather: 70 – 90 mg/L Dry Weather: 100 – 135 mg/L
Polymer:	2.0 mg/L

Phase 1 Pilot Data Summary

MLSS Conc.	Contact Tank HRT	Turbidity % Removal	TSS % Removal	BOD % Removal	SBOD % Removal	SCOD % Removal
800 mg/L	30 min	99%	80-95%	70-90%	55-85%	60-85%
800 mg/L	20 min	99%	80-95%	65-85%	50-90%	60-75%
400 mg/L	20 min	99%	40-60%	30-50%	35-60%	75-95%
300 mg/L	30 min	99%	90-95%	50-70%	10-60%	50-65%
200 mg/L	30 min	99%	85-95%	60-80%	45-75%	50-80%
100 mg/L	30 min	98%	70-95%	40-75%	25-50%	40-80%

Phase 2: Nov 15, 2004 to Jan 21, 2005

Test Conditions	
MLSS:	250, 400, 600, 800, 1000, and 1200 mg/L
Contact Basin HRT:	3.9 – 21.7 min.
Rise Rate:	30, 40, 45, and 50 gpm/sf
Coagulant (Ferric Sulfate):	175 – 200 mg/L
Polymer:	2.0 - 4.0 mg/L

Phase 2 Pilot Data Summary

Contact Time (min)	MLSS (mg/l)	Total BOD (mg/l) Primary Effluent	Total BOD (mg/l) Ballasted Floculation Effluent	Percent Removal	Soluble BOD (mg/l) Primary Effluent	Soluble BOD (mg/l) Ballasted Floculation Effluent	Percent Removal	TSS (mg/l) Primary Effluent	TSS (mg/l) Ballasted Floculation Effluent	Percent Removal
30	800	59.4	9.9	83.8	20.1	6.7	66.4	64.6	6.2	89.4
20	800	61.7	16.4	73.1	31.2	11.3	62.9	62.7	7.2	87.5
20	400	114.6	56.7	50.9	81.0	48.0	40.9	60.4	6.6	88.4
30	200	46.7	15.3	70.5	26.4	15.6	52.5	52.3	5.2	89.2
30	300	76.1	29.4	59.8	41.6	25.3	34.3	80.0	5.2	93.3