GET THE MOST BAM FOR YOUR BUCK!

PERFORMANCE ENHANCEMENT OF BIOSORPTION ACTIVATED MEDIA TREATMENT TRAINS BY INCORPORATING SLOUGHED BIOFILM CAPTURE

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BAM

Common Engineering Assumptions:

- Steady State for Bio-Assimilation
  - Biomass growth = Sloughed Biomass discharging
    - Decrease in TP is due to filtration and sorption, not bio-assimilation
- Soluble Reactive Phosphorus (SRP)
  - Decrease in concentration = Removal
  - Decrease in SRP is due to Sorption
    - Commonly used BAM Lifespan calculation:
      - Decrease in Orthophosphate = Consumption of Sorption Capacity

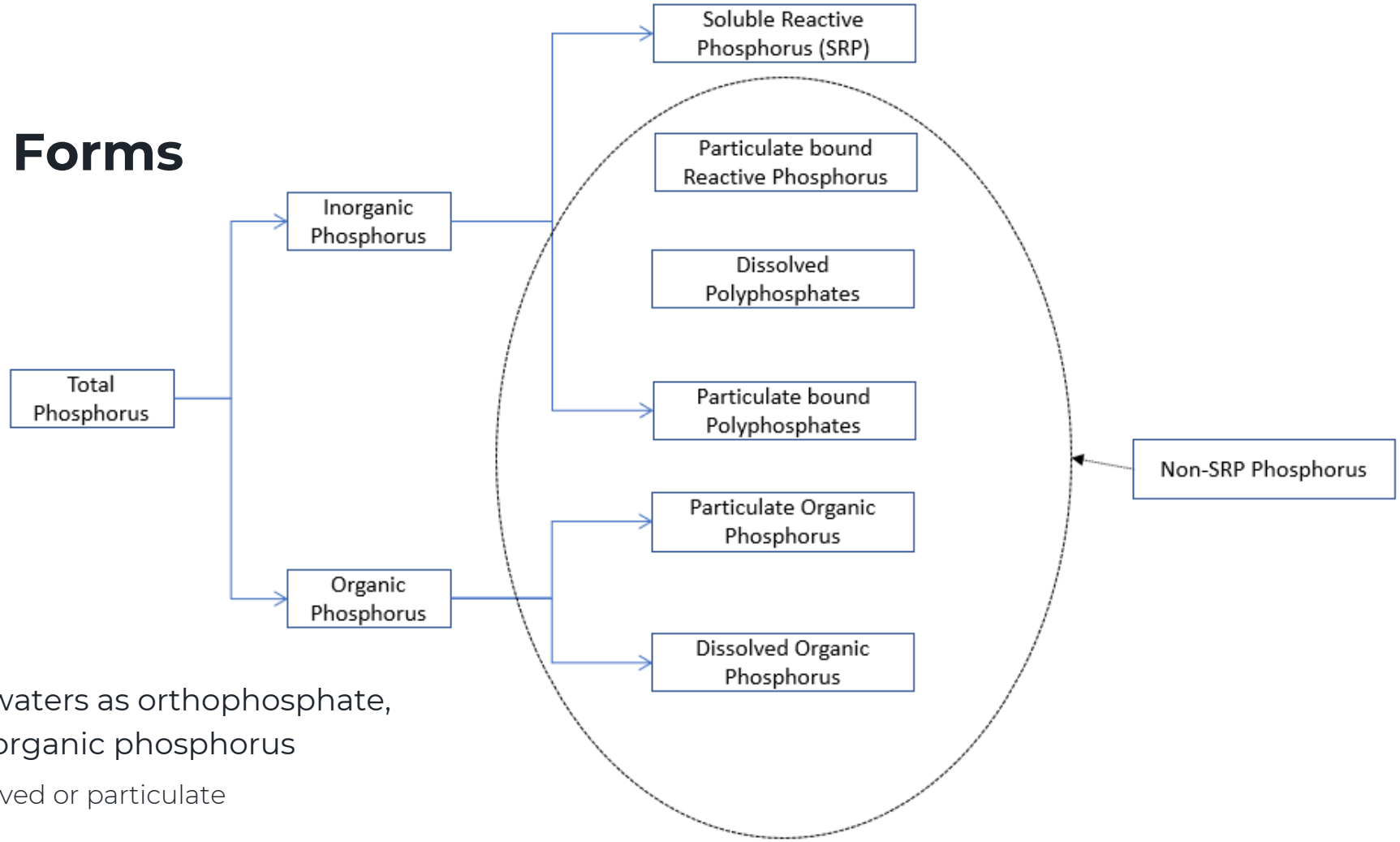
Biosorption

Activated

Media

Familiar brand: Bold & Gold

Phosphorus Forms



- Occurs in natural waters as orthophosphate, polyphosphate, & organic phosphorus
  - All can be dissolved or particulate
- SRP ≈ Dissolved Orthophosphate
- Dissolved Orthophosphate is readily available for biological uptake

Biofilm – What is it?

Familiar Biofilm examples:

- Slime on a rock
- That feeling on your teeth in the morning

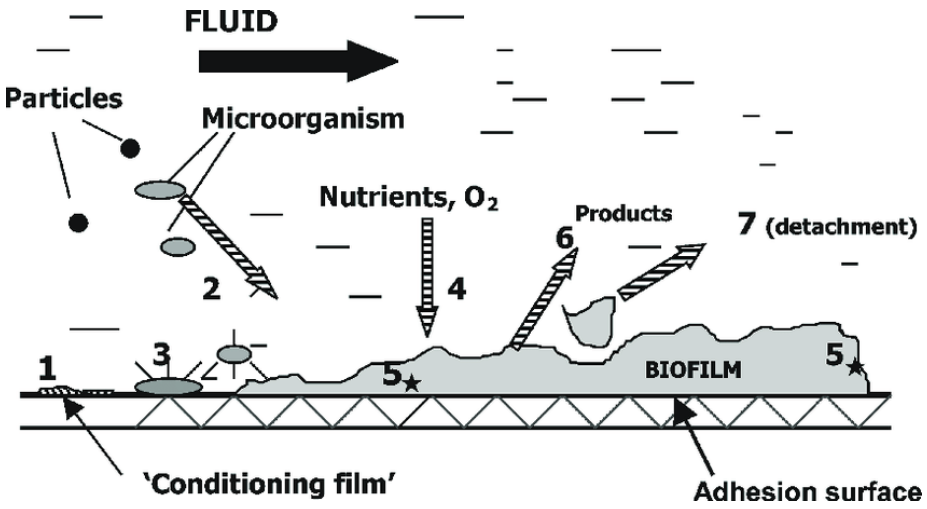


Image Credit:
Biofilm formation and its role in fixed film processes - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Phenomenology-of-biofilm-formation_fig1_285114204 [accessed 11 May, 2023]

Biological Activity

- Microcosms in biofilm due to limitation of diffusion
- Assimilation = new biomass
  - Cell biomass = $C_{12}H_{87}O_{23}N_{12}P$ (Metcalf & Eddy, 2003c)
    - measured as Volatile Suspended Solids (VSS)
- Respiration = energy production

Sloughing/detachment a function of:

- Hydraulic shear
- Heterotrophic Endogenous Respiration occurs in inner layers.
- Nitrogen Bubbles from Denitrification

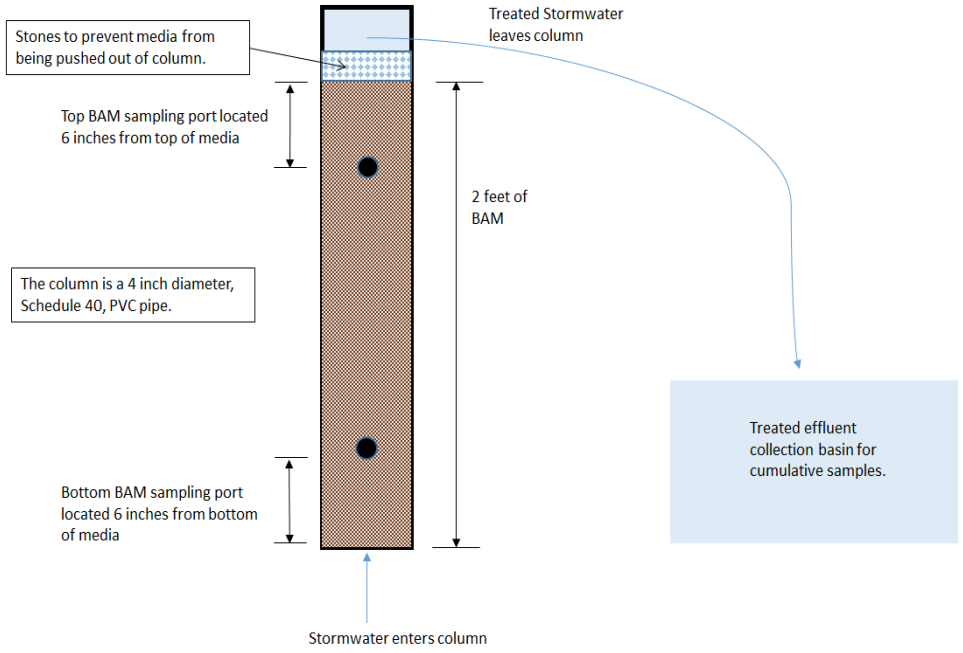
PERFORMANCE ENHANCEMENT OF BAM TREATMENT TRAINS BY INCORPORATING SLOUGHED BIOFILM CAPTURE

- Biomass is made of nutrients.
- Don’t let biomass just go to the lake, GET THAT ADDITIONAL REMOVAL!
- Boost your BAM BMP TP removal by 20%!!!

Methodology

Experimental Design

3 types of media (1, 2, & 3) with 2 columns for each media; A, B



Source Water

- Simulates stormwater that has prior particulate removal (baffle box, pond, etc.)
- Influent TSS was much lower for this research (3-4.75 mg/L)

Pollutant	NSQD Commercial	NSQD Highways and Freeways	NSQD Industrial	NSQD Institutional	NSQD Open Space	NSQD Residential	This Project: 22 minute EBCT	This Project: 220 minute EBCT
Orthophosphate (mg/L as P)	0.196	0.129	0.273	0.112	0.145	0.264	0.185	0.175
Total Phosphorus (mg/L as P)	0.329	0.398	0.427	0.201	0.392	0.451	0.237	0.206
TSS (mg/L)	119.481	140.766	152.967	144.670	261.948	126.206	4.75	3.0
TN (mg/L as N)	2.858	2.512	2.141	3.092	2.444	3.539	1.600	1.594

Experiment Operation

- Columns run for 8 months
  - Samples were collected during last 5 months
- Column Run types per week:
  - Two unsampled, 2-hr duration events per week (22 minute EBCT)
  - One, 2-hr sampling event per week (22 minute EBCT)
  - One, 24-hr sampling event per week (220 minute EBCT)
- Cumulative effluent samples
  - Samples were taken from the collection basins

Flow Duration (hours)	EBCT (minutes)	Hydraulic Load Rate assuming 2 ft BAM thickness (inches water / minute)
2	22	1.09
24	220	0.11

Results

Change in Total Phosphorus

- BAM #1 & #3 had lower TP removals during longer EBCT
  - P removal should INCREASE with EBCT!
- BAM #1 had highest TP Removal for both EBCTs

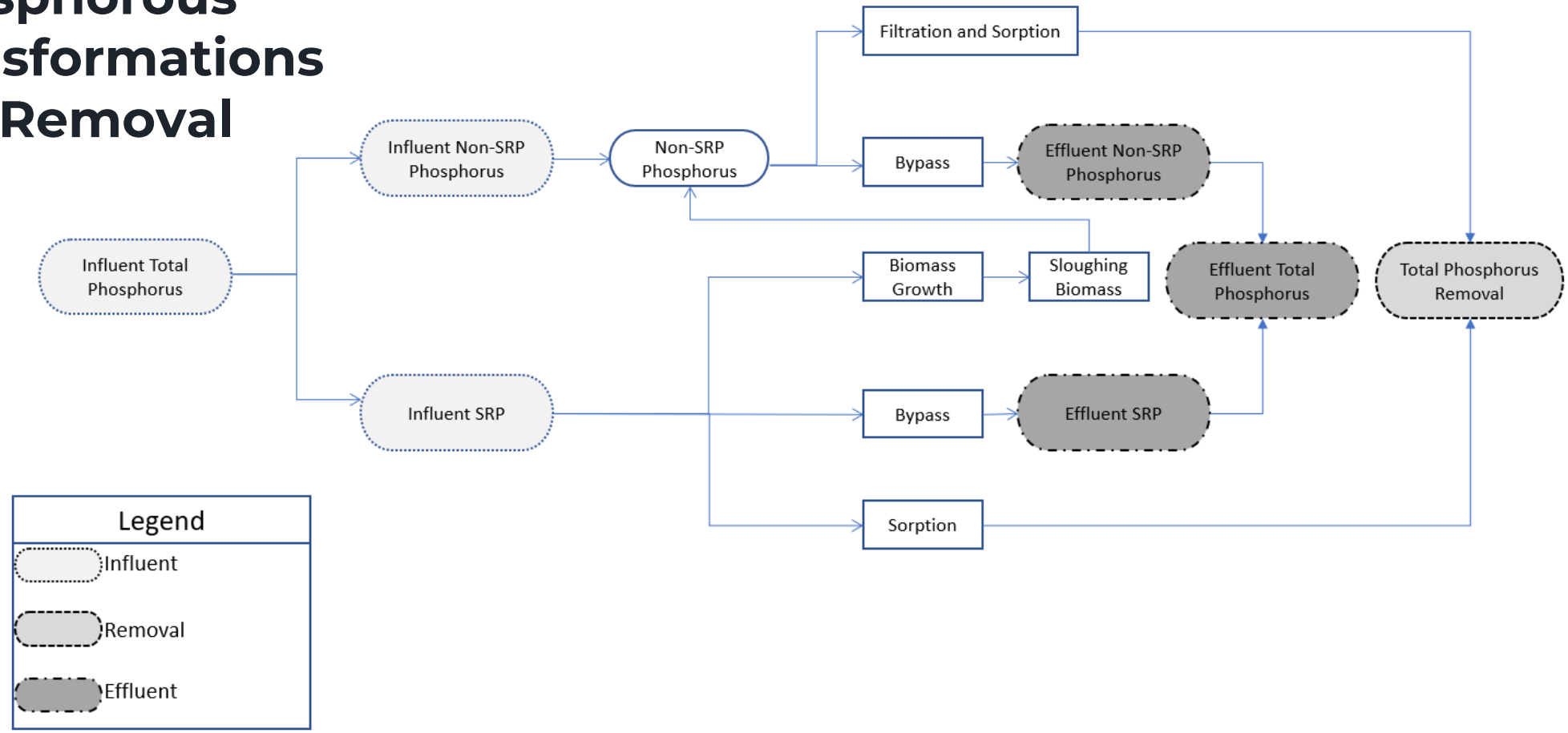
Approximate Flow Duration (hours)	EBCT (minutes)	Column Media #	Average Influent TP (mg/L as P)	Average Effluent TP (mg/L as P)	Δ TP (mg/L as P)	TP % Removal
2	22	1	0.237	0.116	-0.122	51%
		2	0.233	0.180	-0.053	23%
		3	0.233	0.130	-0.103	44%
24	220	1	0.206	0.116	-0.090	44%
		2	0.206	0.142	-0.064	31%
		3	0.206	0.179	-0.027	13%

Changes in Types of Phosphorus

- Greater DECREASE in SRP than TP for all BAM types during 220 minute EBCT
  - Bio-assimilation of SRP into biofilm → Sloughed biofilm in effluent

Approximate Flow Duration (hours)	EBCT (minutes)	BAM #	Type of Phosphorus	Influent (mg/L as P)	Effluent (mg/L as P)	Δ (mg/L as P)	% Reduction
2	22	1	Total Phosphorus	0.237	0.116	-0.122	51%
			SRP	0.185	0.082	-0.103	56%
			Non-SRP Phosphorus	0.052	0.034	-0.019	36%
		2	Total Phosphorus	0.233	0.180	-0.053	23%
			SRP	0.182	0.133	-0.049	27%
			Non-SRP Phosphorus	0.051	0.047	-0.004	8%
		3	Total Phosphorus	0.233	0.130	-0.103	44%
			SRP	0.182	0.110	-0.072	40%
			Non-SRP Phosphorus	0.051	0.020	-0.031	61%
24	220	1	Total Phosphorus	0.206	0.116	-0.090	44%
			SRP	0.175	0.055	-0.120	69%
			Non-SRP Phosphorus	0.031	0.061	0.030	-97%
		2	Total Phosphorus	0.206	0.142	-0.064	31%
			SRP	0.175	0.107	-0.068	39%
			Non-SRP Phosphorus	0.031	0.035	0.004	-13%
		3	Total Phosphorus	0.206	0.179	-0.027	13%
			SRP	0.175	0.136	-0.039	22%
			Non-SRP Phosphorus	0.031	0.043	0.012	-39%

Phosphorous Transformations and Removal



- IF: (Removed Influent Biomass) < (Sloughed Biofilm in Effluent)
  - Then: Net increase in stormwater biomass
- With increase in EBCT, there should be an increasing amount of biological activity, and thus an increase in sloughed biofilm in effluent.
  - Biomass measured as VSS
  - Depending on relative magnitude, this may be seen as a decrease in TSS removal as EBCT is increased

Heterotrophic Plate Count

Approximate Flow Duration (hours)	EBCT (minutes)	Media #	Median Influent HPC (CFU/mL)	Median Effluent HPC (CFU/mL)	Δ HPC (CFU/mL)	HPC % Increase
2	22	1	3.86.E+05	4.28.E+05	4.18.E+04	11%
		2	3.86.E+05	4.49.E+05	6.25.E+04	16%
		3	3.98.E+05	3.35.E+05	-6.25.E+04	-16%
24	220	1	2.34.E+05	5.38.E+05	3.04.E+05	130%
		2	2.34.E+05	5.09.E+05	2.75.E+05	117%
		3	2.34.E+05	5.14.E+05	2.80.E+05	120%

- Evidence of Sloughing Biofilm
  - All Increase, except BAM #3 during 22 minute EBCT
  - Higher increase during 220 minute EBCT
  - HPC increased with increased EBCT

TSS

Approximate Flow Duration (hours)	EBCT (minutes)	Column Media #	Median Influent TSS (mg/L)	Median Effluent TSS (mg/L)	Δ TSS (mg/L)	TSS % Removal
2	22	1	4.75	1.75	-3.00	63%
		2	4.75	2.50	-2.25	47%
		3	4.75	1.25	-3.50	74%
24	220	1	3.00	2.25	-0.75	25%
		2	3.00	1.75	-1.25	42%
		3	3.00	1.75	-1.25	42%

- Sorption and Filtration Removal Efficiencies should INCREASE with EBCT
- Exact opposite occurred for ALL BAM types
- Evidence of Sloughed Biofilm in Effluent

22 minute EBCT (2-hour Duration) vs 220 minute EBCT (24-hour Duration)

Why don't we see a greater decrease in SRP than TP for both the 22 minute and 220 minute EBCTs?

- Sloughed biomass, as P **>** Removal of Influent Non-SRP
- Longer EBCT= more time for biological processes
- CUMULATIVE SAMPLE TIME!
    - Biofilm Sloughing can be INTERMITTENT!
        - this is already known for wastewater trickling filters
        - Recall during 22 minute EBCT, both BAM #1 & BAM #2 had an increase in HPC.
            - bio-assimilation and sloughing are occurring during both EBCTs

How much sloughed Biomass is leaving?

Approximate Flow Duration (hours)	EBCT (minutes)	BAM #	Type of Phosphorus	Influent (mg/L as P)	Effluent (mg/L as P)	Δ (mg/L as P)	% Reduction
2	22	1	Total Phosphorus	0.237	0.116	-0.122	51%
			SRP	0.185	0.082	-0.103	56%
			Non-SRP Phosphorus	0.052	0.034	-0.019	36%
24	220	1	Total Phosphorus	0.206	0.116	-0.090	44%
			SRP	0.175	0.055	-0.120	69%
			Non-SRP Phosphorus	0.031	0.061	0.030	-97%

- Use BAM #1 as an example since highest TP removal
- 22-minute EBCT achieves 36% reduction of Influent Non-SRP Phosphorus
  - Conservative: This assumes that no sloughed biomass is present in the effluent, which can not be true.
- Apply 36% removal of influent Non-SRP Phosphorus to 220-minute EBCT
  - Conservative: Removal by Filtration & Sorption should increase with EBCT.
- 220-minute EBCT experiences 97% increase in Non-SRP Phosphorus
- Sloughed Biomass in Effluent is categorized as Non-SRP Phosphorus

$$\text{Sloughed Biomass in Effluent} = (\textit{Removed Influent Non-SRP Phosphorus}) + (\textit{Net Increase in Non-SRP Phosphorus})$$

$$\text{Sloughed Biomass in Effluent} = 36\% * \frac{0.031\ mg\ Non\text{-}SRP\ as\ P}{L} + 97\% * \frac{0.031\ mg\ Non\text{-}SRP\ P\ as\ P}{L} = \frac{0.041\ mg\ Non\text{-}SRP\ as\ P}{L}$$

Disproves common assumptions

- For BAM #1, EBCT 220 minutes
  - Sloughed Biomass in Effluent = 0.041 mg/L as P
  - Decrease in SRP = 0.120 mg/L as P
  - 34% of the decrease in SRP accounted for by sloughed biofilm in effluent

- Disproves SRP Assumptions of:
  - Decrease in SRP concentration = Removal
  - Decrease in SRP is due predominantly to Sorption
  - Commonly used BAM Lifespan calculation:
    - Decrease in Orthophosphate = Consumption of Sorption Capacity

Design and Monitoring Implications

Implications to Sampling protocols & Advertised Removal Efficiencies

- Intermittent Biofilm sloughing = Grab samples aren't representative
  - Sampling During Sloughing event
    - Have you ever had a BAM filter Grab sampling indicate an increase in TP?
  - Sampling Between Sloughing Events
    - BAM TP removal efficiencies might be OVERSTATED
- Composite Sampling for BAM filters should be considered

Implications to Design: Additional TP Removal Potential

- TP is leaving the system as sloughed biomass
  - Categorized as non-SRP Phosphorus
- Use BAM #1, 220 minute EBCT, as example
- Assume all net increase in non-SRP Phosphorus can be captured
- Either an increase in TP removal **OR** now getting what BAM specifications originally claimed

BAM #1, 220 minute EBCT (24-hr duration)								
Type of Phosphorus	**Influent (mg/L as P)**	**Effluent (mg/L as P)**	**Δ (mg/L as P)**	**Measured% Removal**	**Sloughed Biomass in Effluent (mg/L as P)**	**Total Potential TP removal (mg/L as P)**	**Total Potential % Removal**	**Additional % Removal Achieved**
Total Phosphorus	0.206	0.116	-0.090	44%	0.041	0.131	64%	20%

Implications to Design: Additional TN Removal Potential

- Cell biomass is commonly represented by $C_{12}H_{87}O_{23}N_{12}P$ (Metcalf & Eddy, 2003c)
  - $\frac{5.43\ mg\ N}{mg\ P}$
- Use BAM #1, 220 minute EBCT, as example:
  - Recall Sloughed Biomass in Effluent = 0.0412 mg/L as P
  - Thus, Sloughed Biomass in Effluent = 0.224 mg/L as N
    - Assume all sloughed biomass in effluent can be captured
    - Additional 14% TN Removal from treatment train influent.

Is this a One-Off? NOPE!

- Downflow BAM filter project
- Minimum Additional TP Removal:
  - Calculation assumes filter is not removing ANY non-SRP TP from the influent.

Date	ΔTP (ug/L as P)	Δ SRP (ug/L as P)	Minimum Sloughed Biomass in Effluent (ug/L as P)	Minimum Additional TP Removal efficiency if sloughed biofilm captured	Observed TP Removal Efficiency	Minimum Potential TP Removal Efficiency
8/29/2011	-142	-153	11.0	6%	77%	83%
9/7/2011	-145	-173	28.0	14%	73%	87%
9/12/2011	-135	-177	42.0	20%	66%	86%
9/21/2011	-138	-164	26.0	13%	70%	83%
9/26/2011	-144	-156	12.0	6%	73%	79%
10/3/211	-139	-192.1	53.1	26%	68%	94%
Median	-140.5	-168.5	27.0	14%	71%	85%

How to capture the sloughed Biomass?

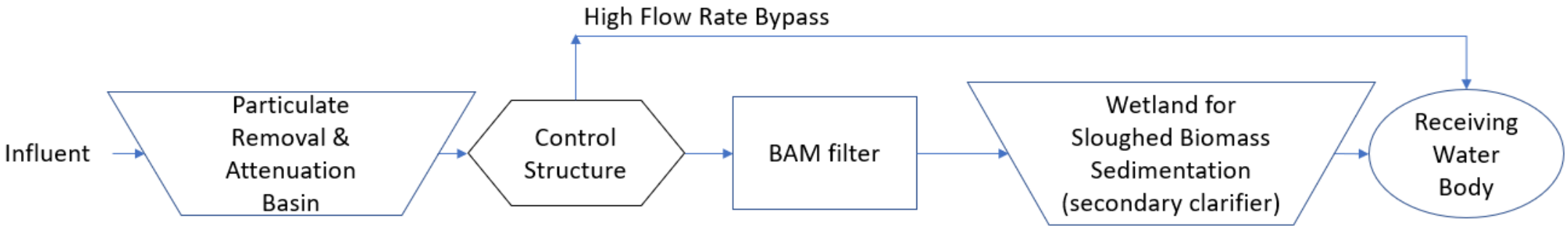
- Wastewater Trickling Filters
  - secondary clarifiers are placed after trickling filters to capture sloughed biomass.

Sizing the secondary clarifier

- Use Wastewater design specifications as a reference
- Surface Area:
  - Design overflow rates (design settling velocities) for wastewater secondary clarifiers following trickling filters
    - For Average flow: 16-24.5 m/day (EPA, 1975; Metcalf & Eddy, 2003a, e; Reynolds, 1995; River, 2004)
    - Use the lower end since wastewater secondary clarifiers likely will have more ideal settling

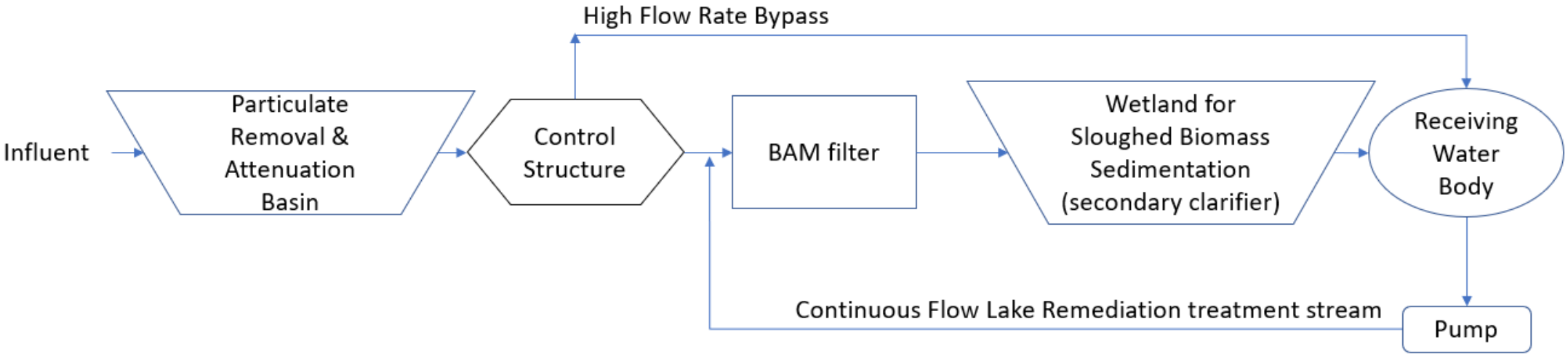
Conceptual Design

- Wetland as secondary clarifier
  - Sloughed Biofilm sedimentation
  - Additional Nitrogen Removal Potential: Denitrification



Even MORE BAM for YOUR BUCK: Don't Let Your BAM Filter Just Sit There & Be LAZY

- Add a Pump for Lake Remediation
- Constant food = Happy Microbes = Higher Biological Performance
- BAM BMPs aren't cheap, don't let it sit there
- Annual TN & TP Removal ⬆ = ⬇ Lifetime Cost per pound removed



Conclusions & Takeaways

- Sampling:
  - Grab samples may lead to overstating removal efficiencies
  - Composite samples
  - Add Volatile Suspended Solids (VSS) to the parameters
    - VSS is used as a measure of the biomass component of TSS
      - An increase in VSS indicates the addition of sloughed biofilm to the water
- Design Implications:
  - Decrease in SRP does NOT necessarily mean removal.
    - BAM lifespan may be significantly longer than predicted by commonly used method of Decrease in Orthophosphate = Consumption of Sorption Capacity.
  - Sloughed Biomass exiting filter is significant
  - Capturing Sloughed Biofilm can greatly increase BAM system TP & TN removal efficiencies
    - Or maybe get what was advertised…. If specs are based on grab samples
  - Consider incorporating Lake Remediation

Questions?

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