Spokane Regional Wastewater Phosphorus Bio-availability Study Final Report

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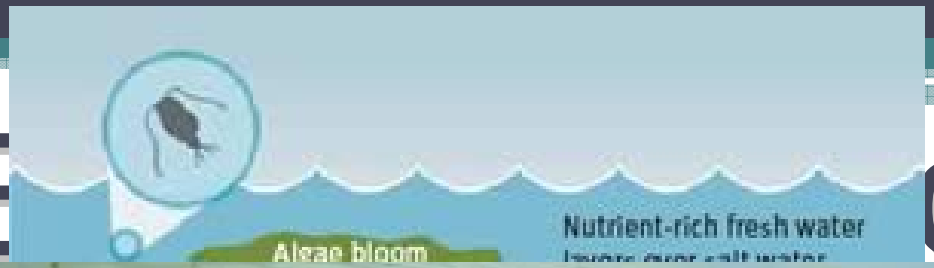
OUTLINE:

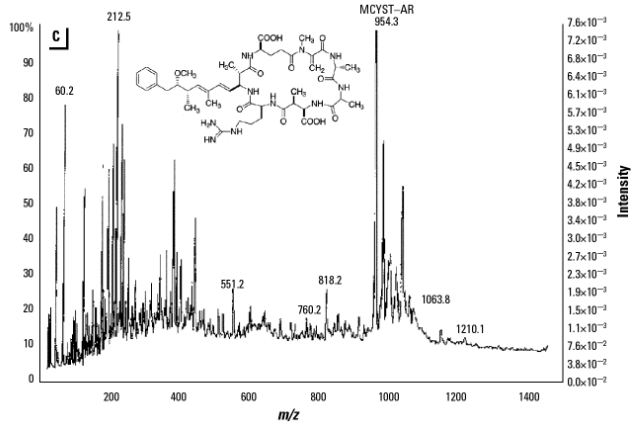
- Bio-available Phosphorus
- Background of Project
- Experimental Section
- QA/QC
- Spokane Pilot Plant
- City of Coeur d'Alene
- Post Fall
- Liberty Lake
- Hayden Area Regional Sewer Board
- Inland Empire Paper
- Spokane River

E on


Nutrient-rich fresh water
Algae bloom


Pea soup. Hans Paerl samples

Cyanobacteria
Cyanotoxins
TOXIC
No swimming
No drinking


MCYST-AR
954.3
212.5
60.2
551.2
760.2
818.2
1063.8
1210.1
Intensity
m/z

Phosphorus

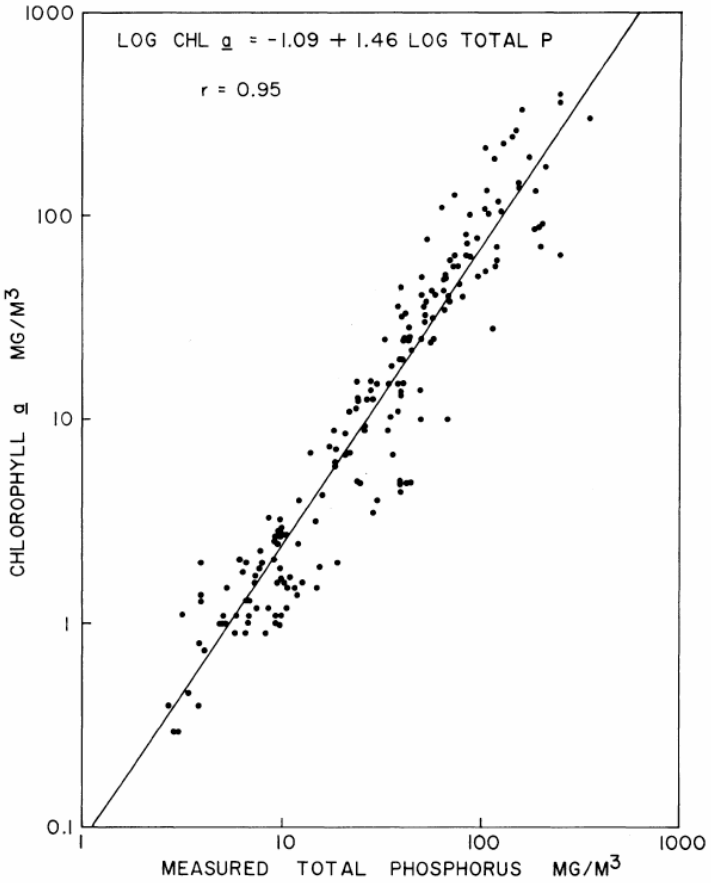
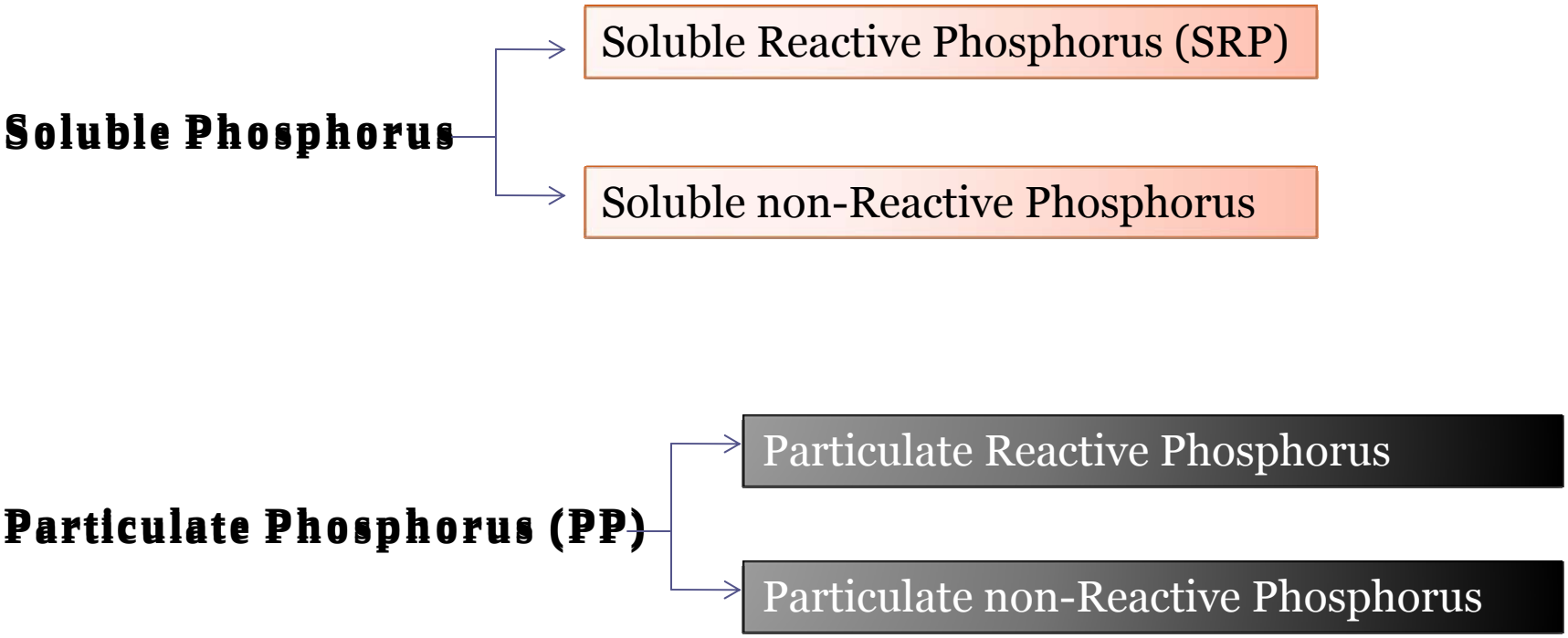


FIGURE 1.—Relationship between summer levels of chlorophyll *a* and measured total phosphorus concentration for 143 lakes.

Phosphorus

Operational Categories



Phosphorus

Operational Categories

≠

Bioavailability

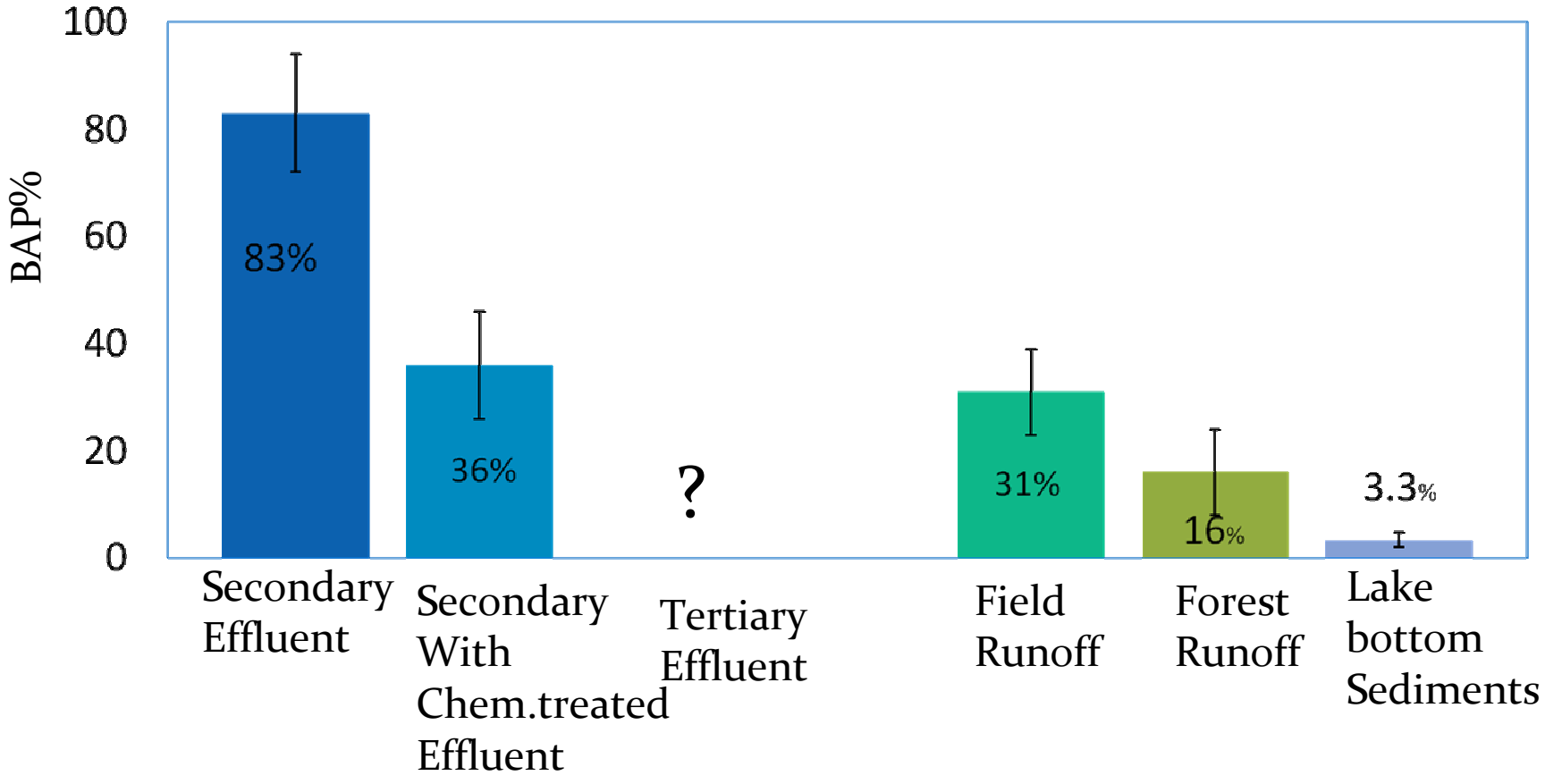
SRP ≠ phosphate = 100% bioavailable ?

BAP

- Bio-available Phosphorus
- phosphorus that can be utilized by plants and bacteria

BAP

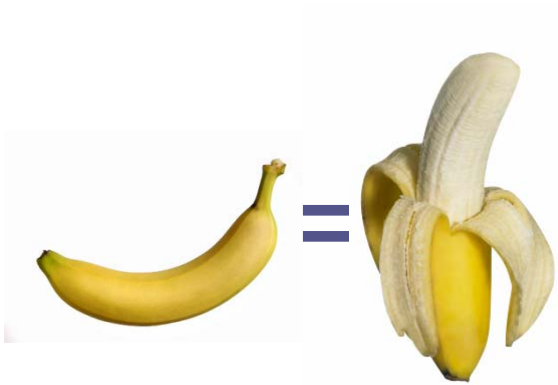
BAP% of TP in different P Source



Source: Petri Ekholm (2003), Determining algal-available phosphorus of differing origin:routine phosphorus analyses versus algal assays

Phosphorus Speciation

- Phosphate (PO_4^{-3})



Recalcitrant Phosphorus

Inorganic P
- Apatite
- ($Ca_3(PO_4)_2$)
- $AlPO_4$
- $FePO_4$

Organic P
- Polyphosphate
- Inositol hexakisphophate
- L-α-phosphatidyl choline
- phosphoenol pyruvate
- glycerophosphate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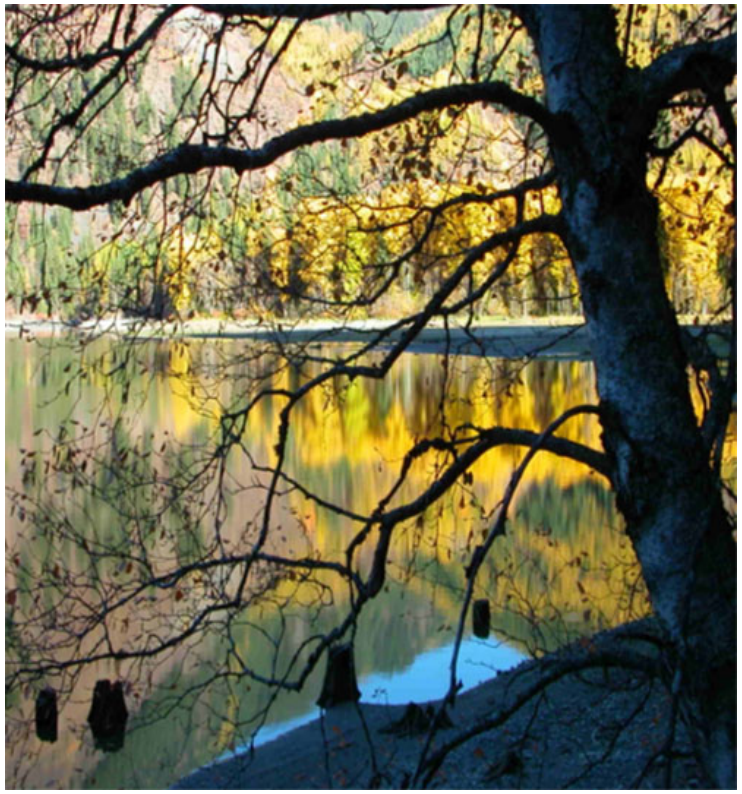
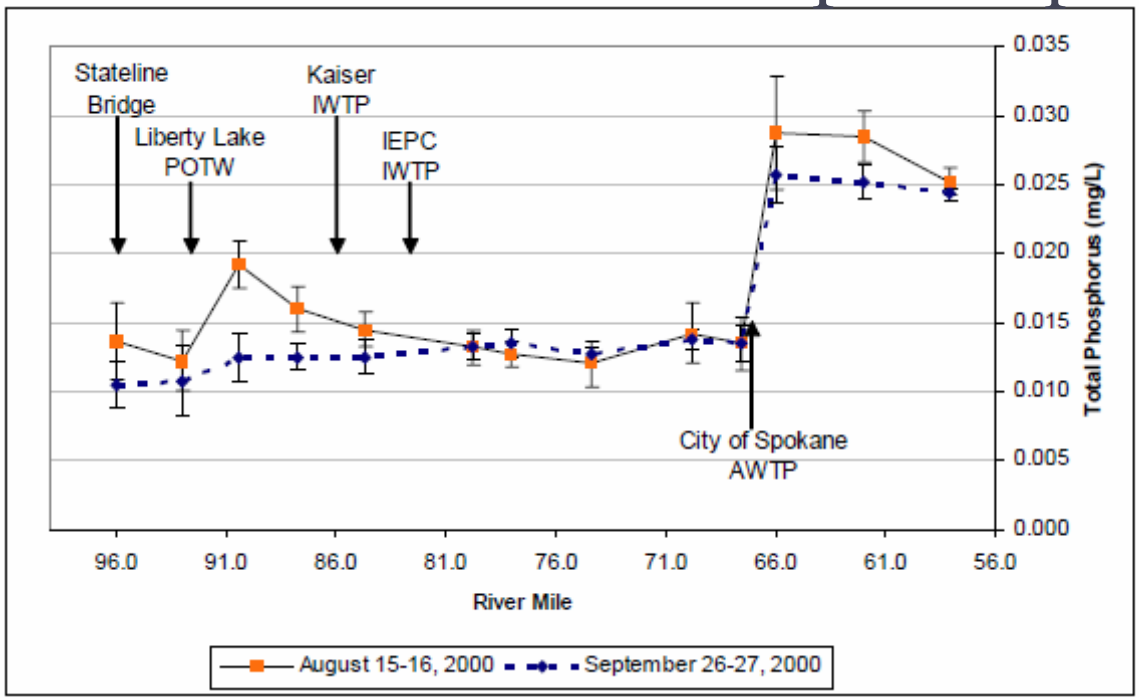
http://lifesohappy.blogspot.com/

Background of Project



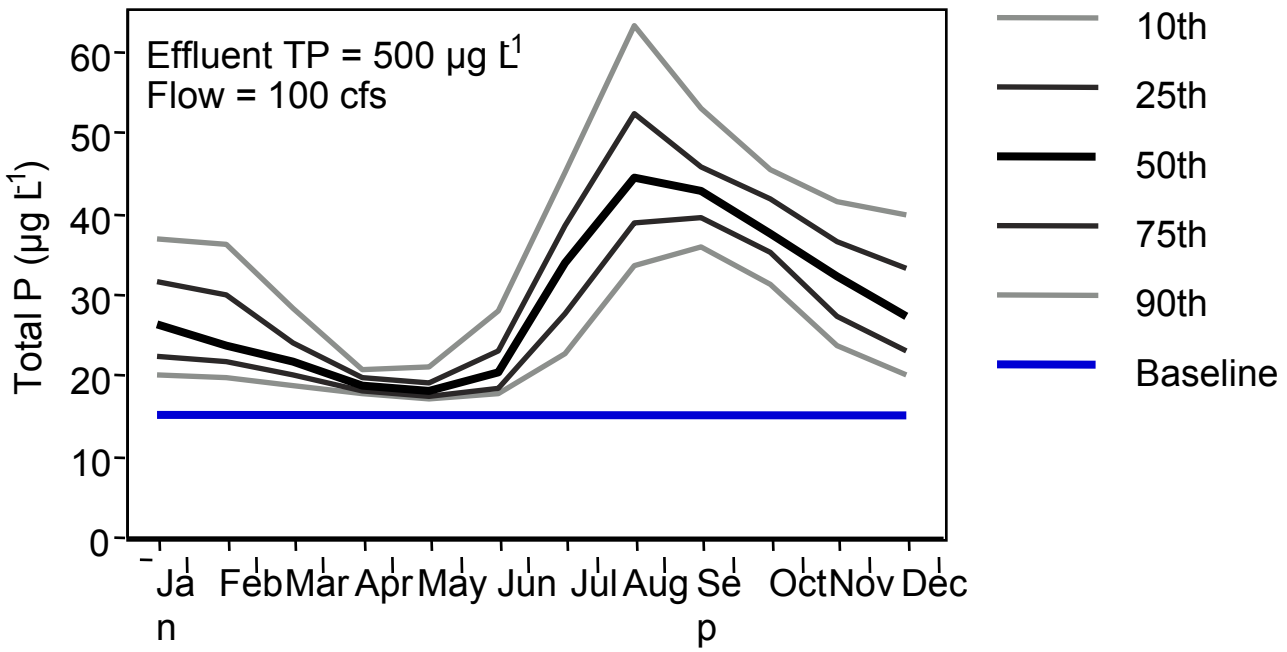
Background of Project

City of Spokane AWTP effluent impacts Spokane Lake



Average total phosphorus concentrations data (n = 4) ± standard deviation by RM for Ecology river surveys conducted on August 15-16 and September 26-27, 2000.

Background of Project



Background of Project

Solution?

Alum + Filtration

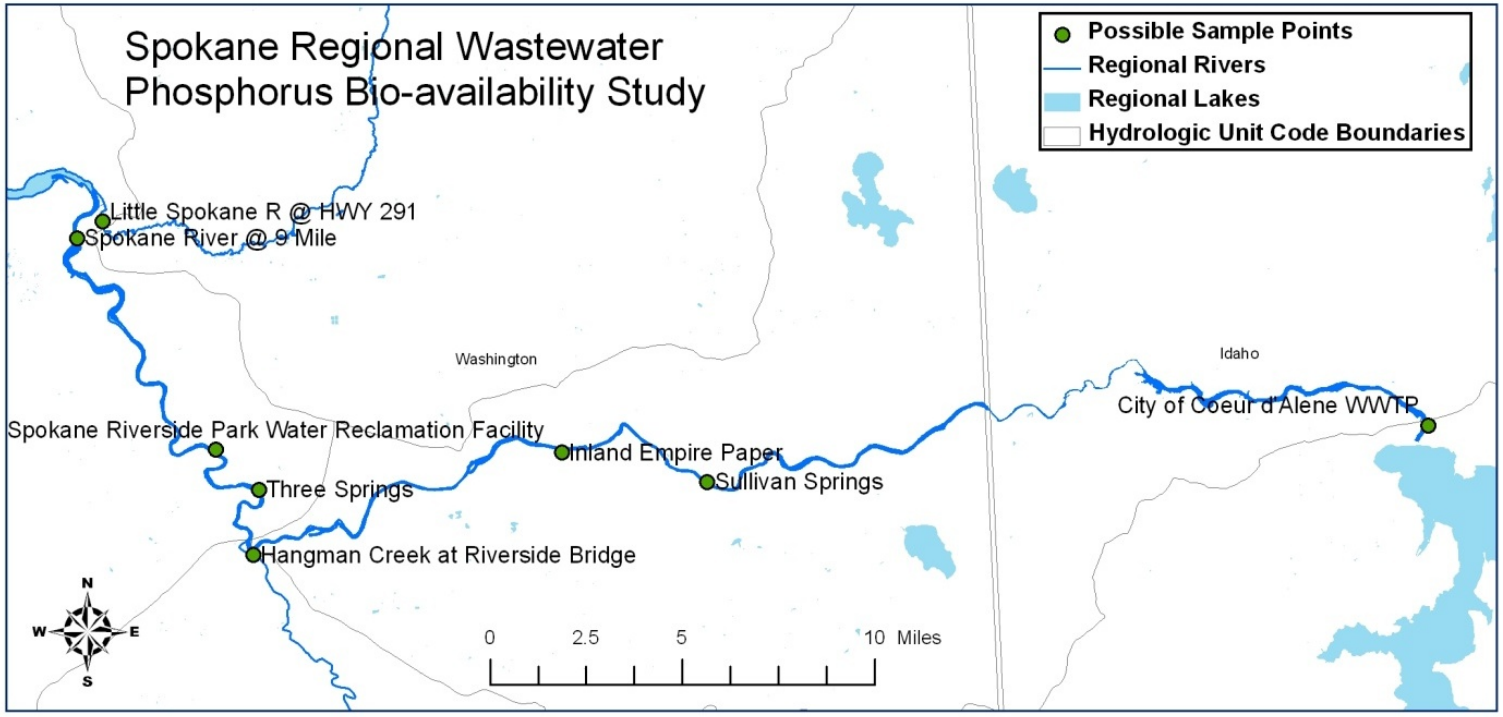
Background of Project

Effluent Phosphorus concentration Goal is based on Total P.

- How does the BAP compare to Total Phosphorus (TP)?
- How does the BAP compare to Total Reactive Phosphorus (TRP)?
- Can TRP be used as a surrogate measure of BAP?

Background of Project

- Study area



Objectives

- How does %BAP vary with the level of P removal?
- How does %BAP vary for effluents from other plants with different removal technologies?
- Can TRP be a surrogate measure for BAP?

Chemical Analysis

Standard Methods 4500-P

- **Total Reactive Phosphorus (TRP):**
Without filtering samples

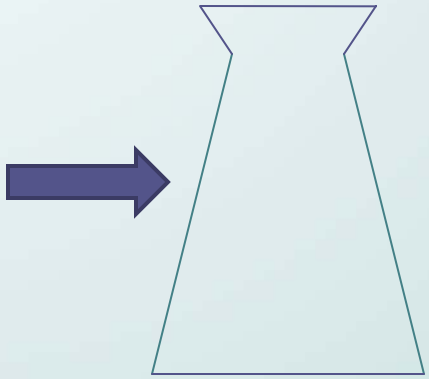
- **Total Phosphorus (TP) :**
Following persulfate digestion.

Bioassay Method

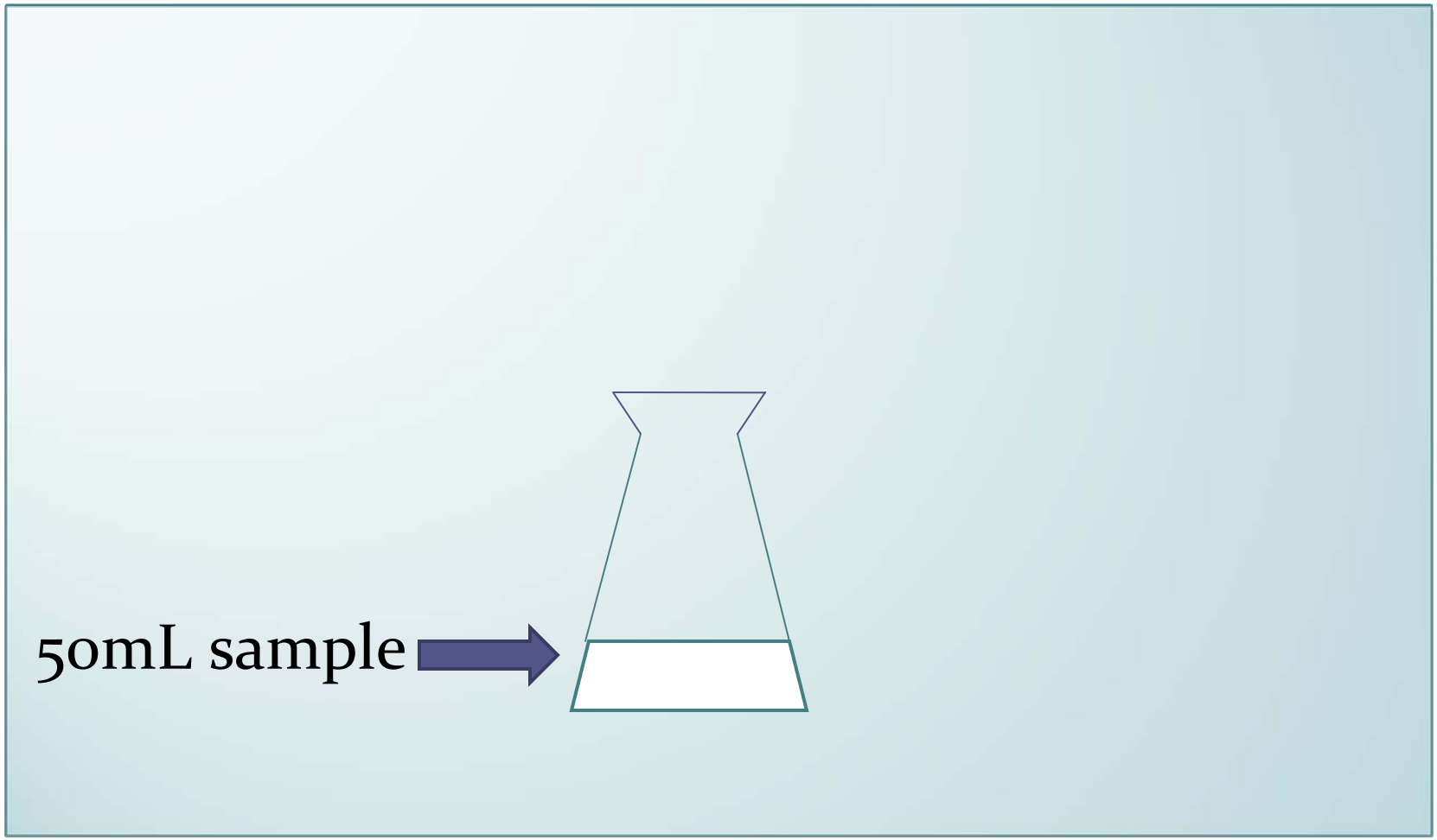
Selenastrum capricornutum

Bioassay Method

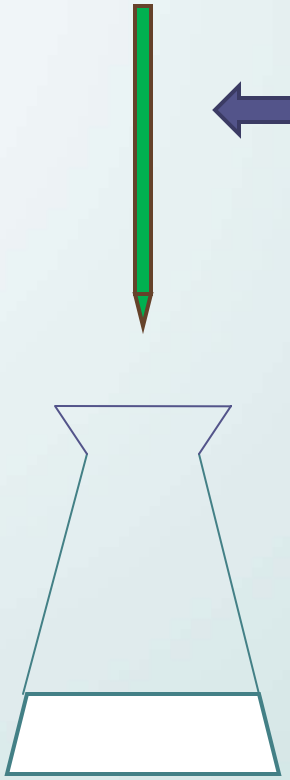
125mL flask



Bioassay Method

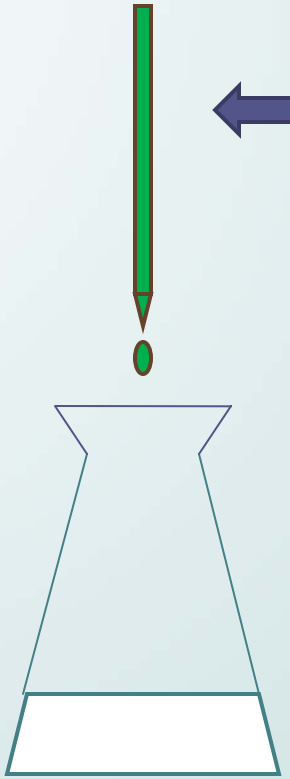


Bioassay Method



0.2mL P-starved S. Cap ($2.5*10^6$cell/mL).

Bioassay Method



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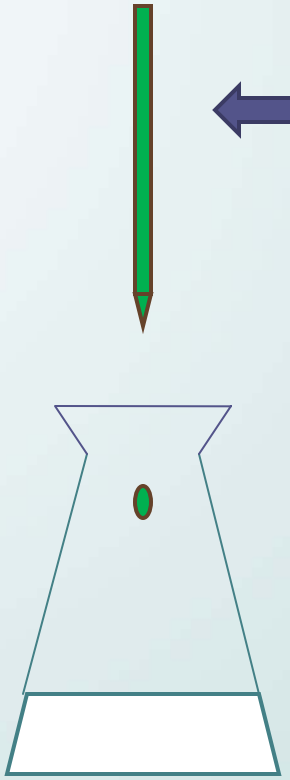
Bioassay Method



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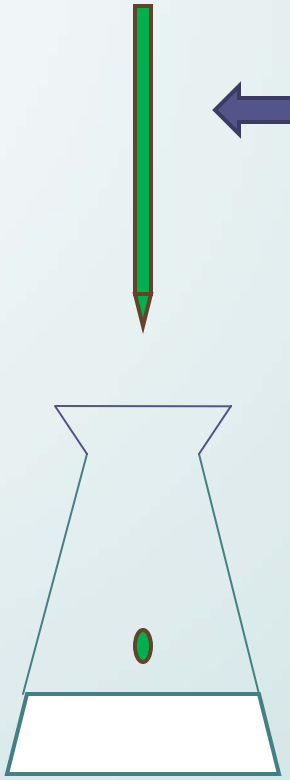
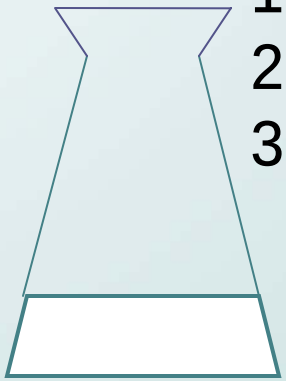
Bioassay Method



0.2mL P-starved S. Cap ($2.5*10^6$cell/mL).

Bioassay Method

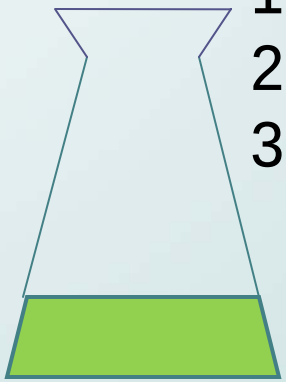
Initial concentration:10,000 cells/ml
Incubate for 14 days.



Culturing condition:
1.Illumination:4300 lumens
2.Temperature: 24 ± 2ºC
3. shake at 110 rpm.

Bioassay Method

Initial concentration:10,000 cells/ml
Incubate for 14 days.



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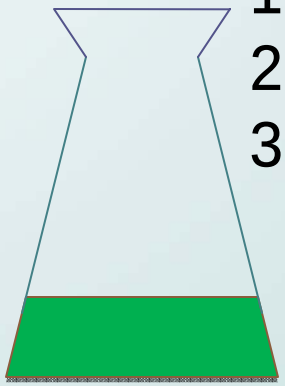

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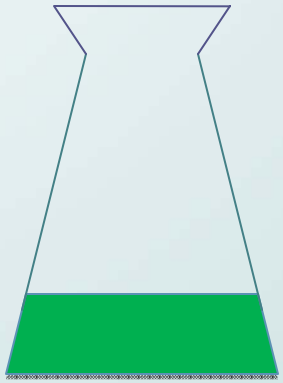
3. shake at 110 rpm.

Bioassay Method

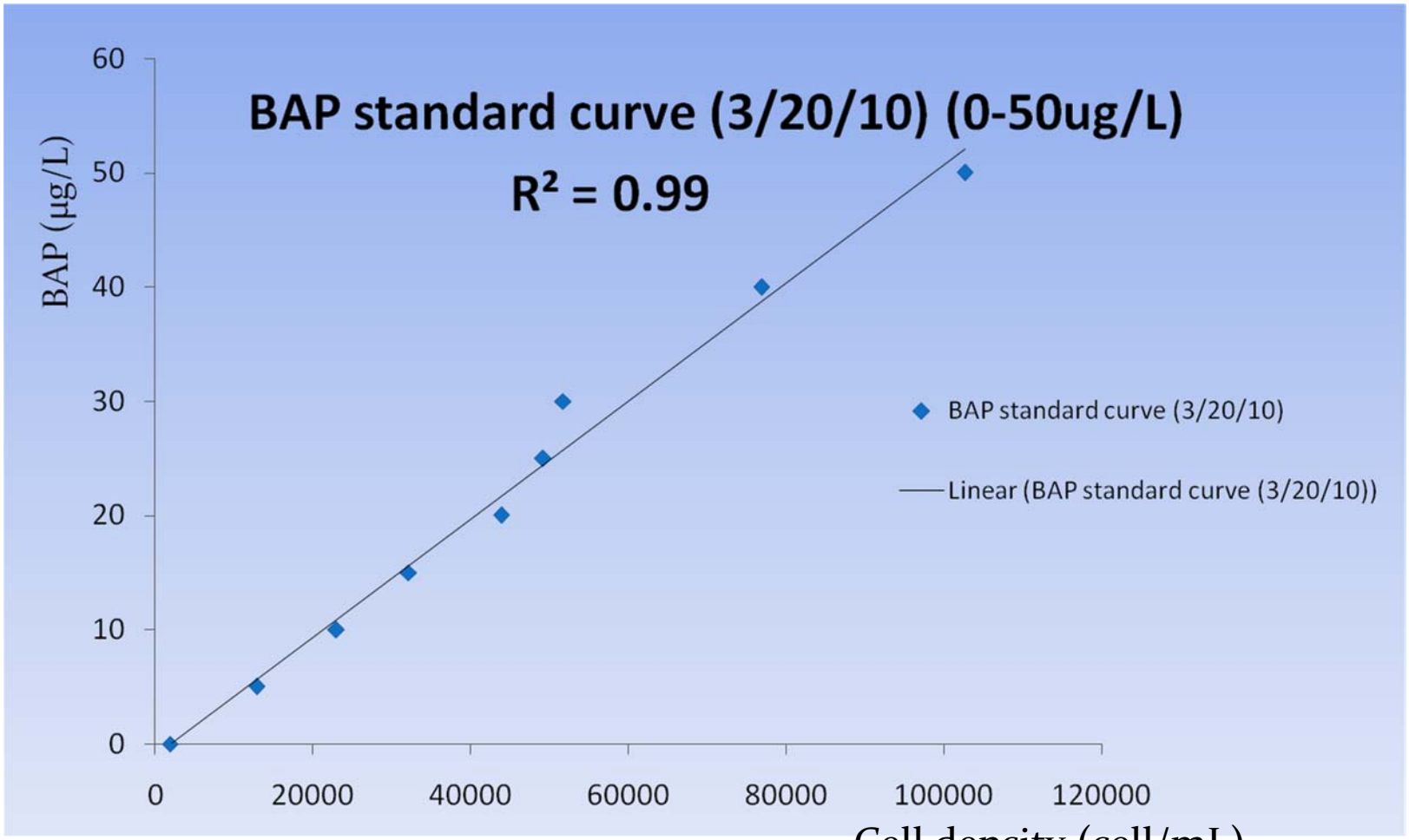


Ten standards containing between 0 and 50 µg P/L

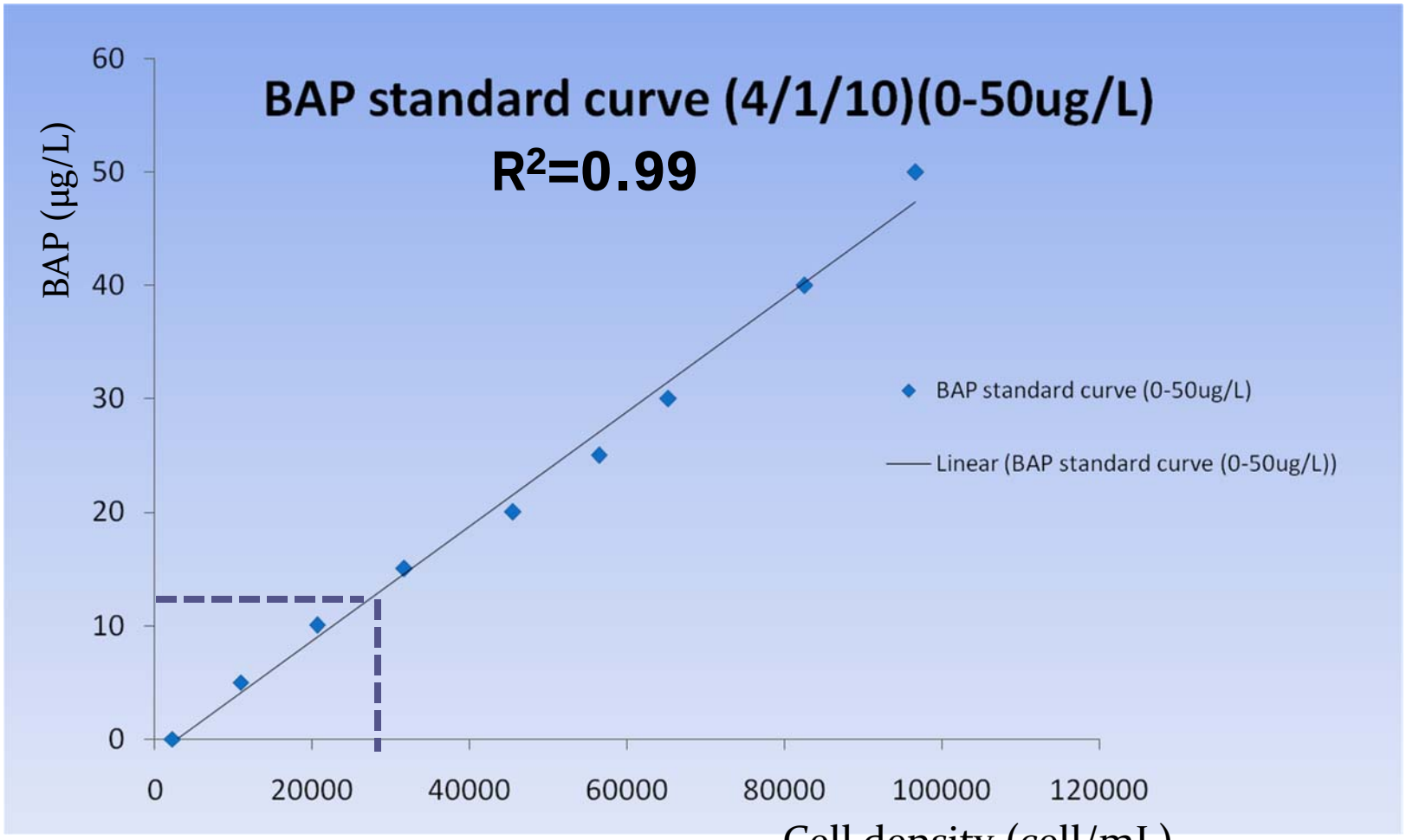
Three reps for each standard

Four reps for each sample

Bioassay Method



Bioassay Method

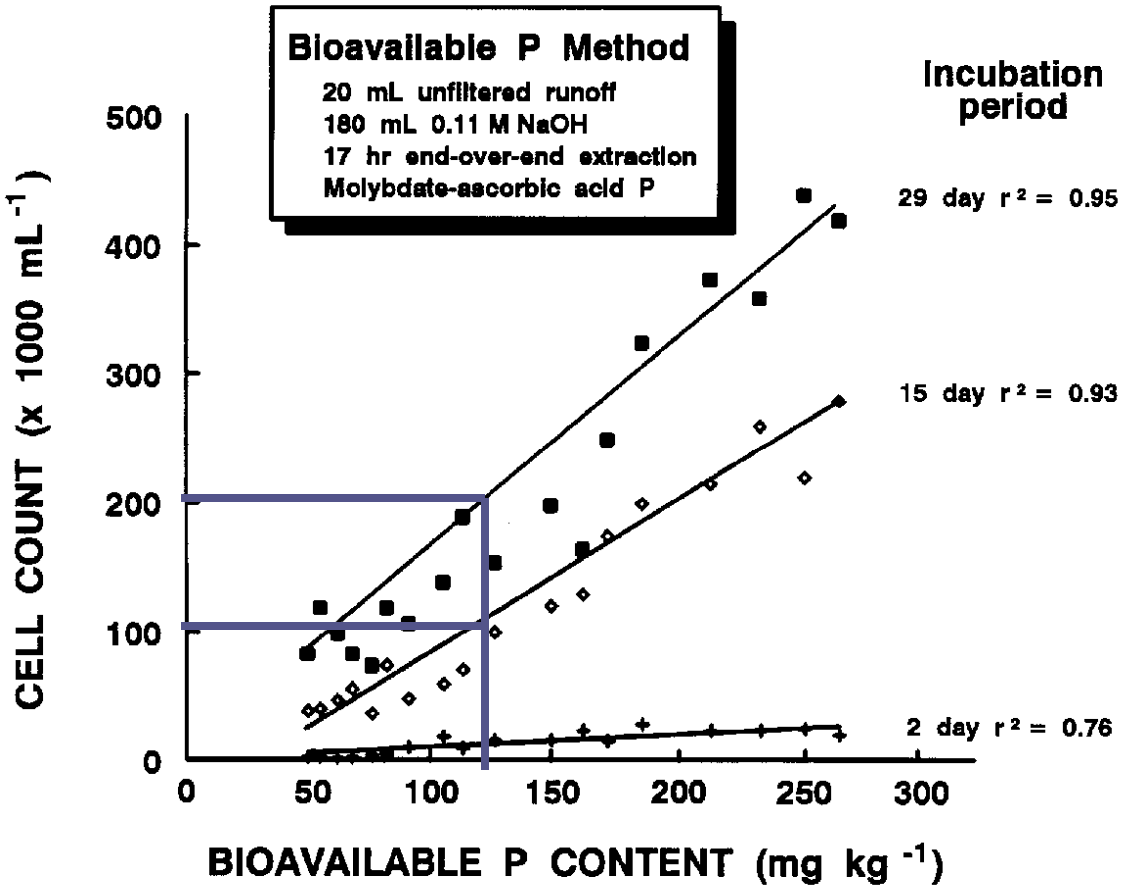


Bioassay Method

Why does the bioassay require a 14 day incubation time?

Because Standard Methods say so!!

Bioassay Method



Consequence: More work & Less data

Bioassay Method

- Day 1

- Day 7

- Day 14

- After 14 Days

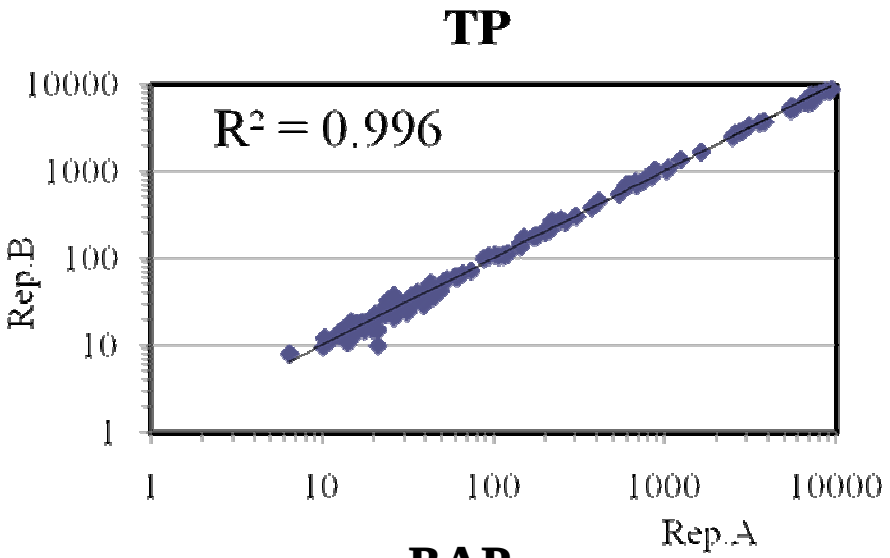
QA/QC

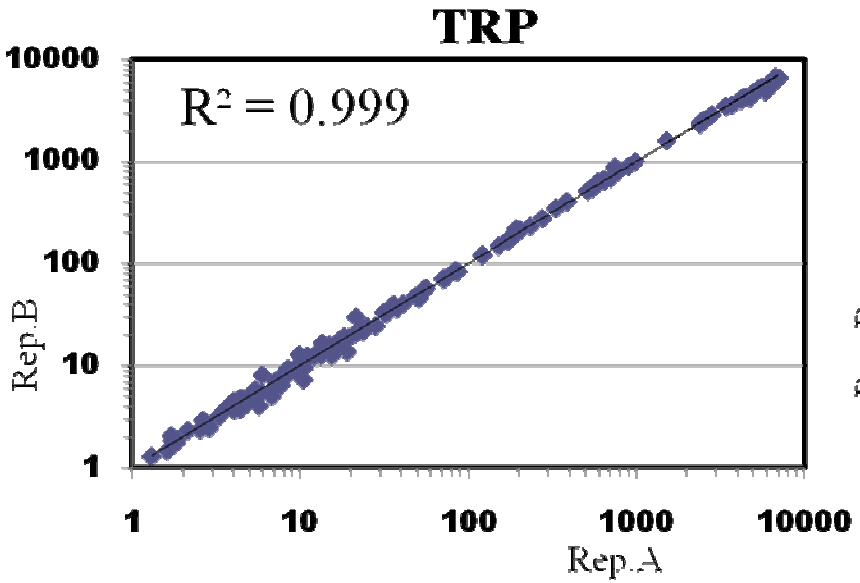
TP			
Replicates	Standard Curve r^2	SD (µg/L)	CV(%)
2	0.9995	±2.6	6

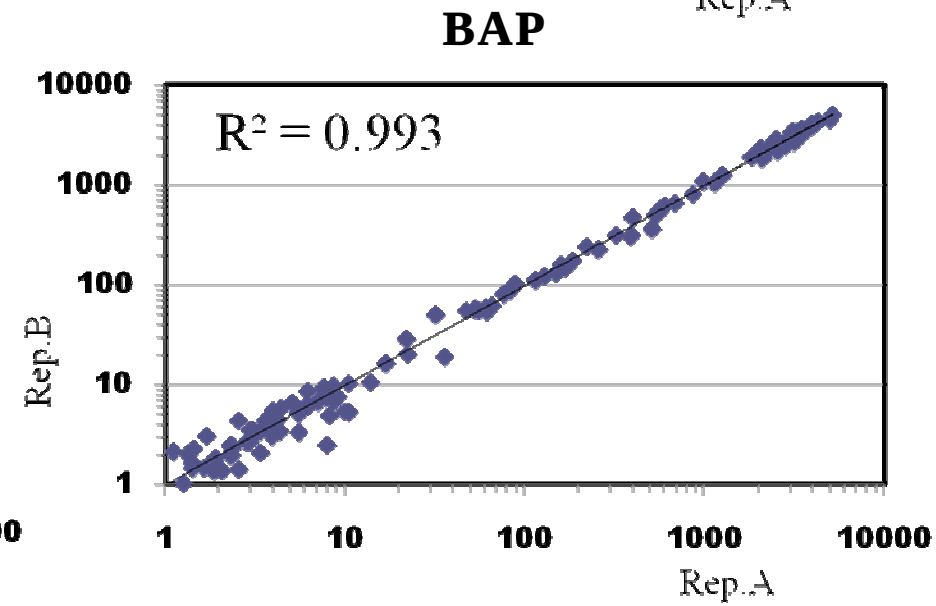
TRP			
Replicates	Standard Curve r^2	SD(µg/L)	CV(%)
2	0.9993	±0.7	4

BAP			
Replicates	Standard Curve r^2	SD(µg/L)	CV(%)
4	0.98	±1.2	7

QA/QC


TP
R² = 0.996
Rep.B
Rep.A
10000
1000
100
10
1
1
10
100
1000
10000


TRP
R² = 0.999
Rep.B
Rep.A
10000
1000
100
10
1
1
10
100
1000
10000


BAP
R² = 0.993
Rep.B
Rep.A
10000
1000
100
10
1
1
10
100
1000
10000

Sampling location

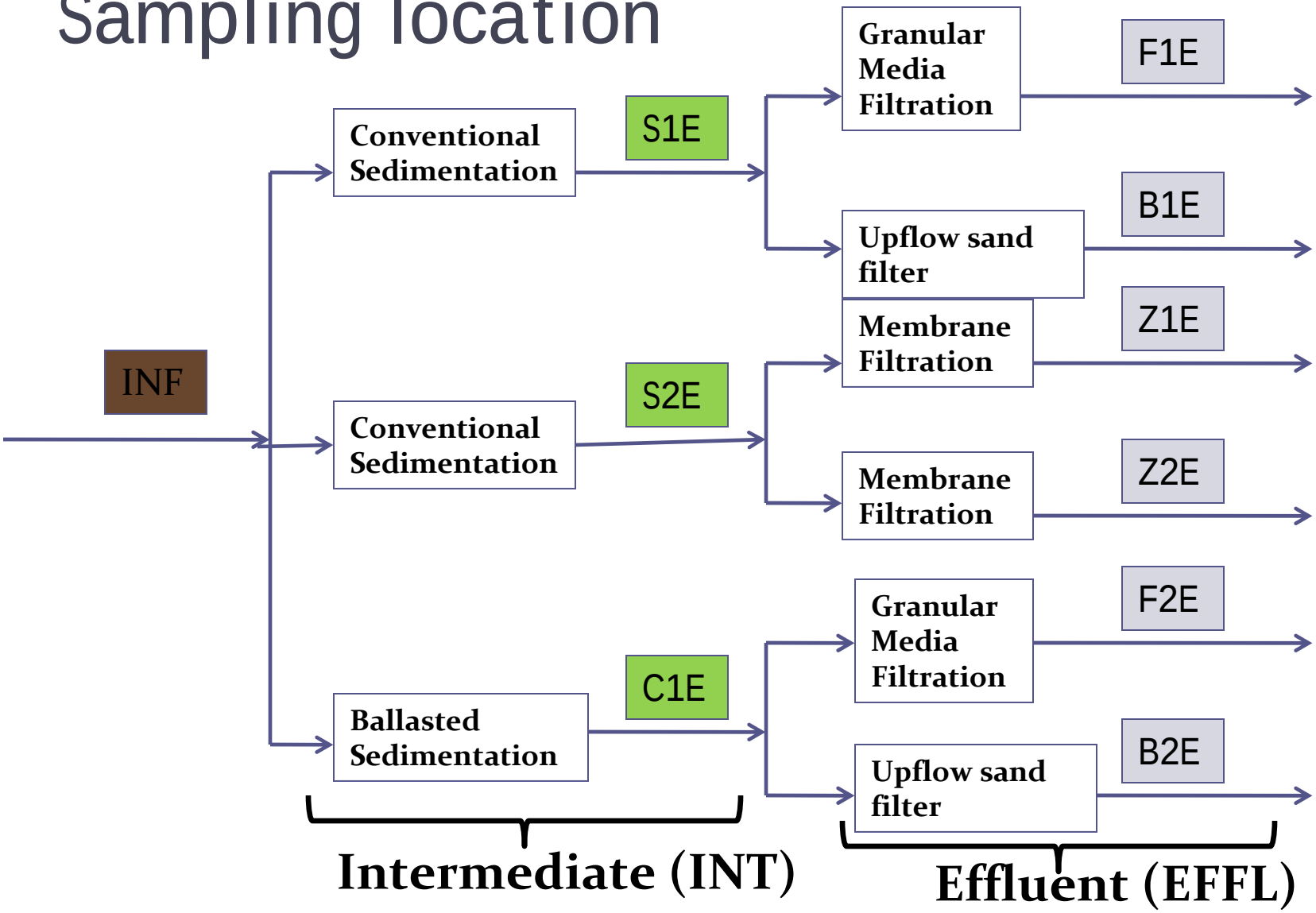
- Spokane Pilot Plant
- City of Coeur d'Alene
- Post Fall
- Liberty Lake
- Hayden Area Regional Sewer Board
- Inland Empire Paper
- Spokane River

City of Spokane Pilot plant

- **Conventional Sedimentation**
- **Ballasted Sedimentation**

- **Granular Media Filtration**
- **Upflow sand filter**
- **Membrane Filtration**

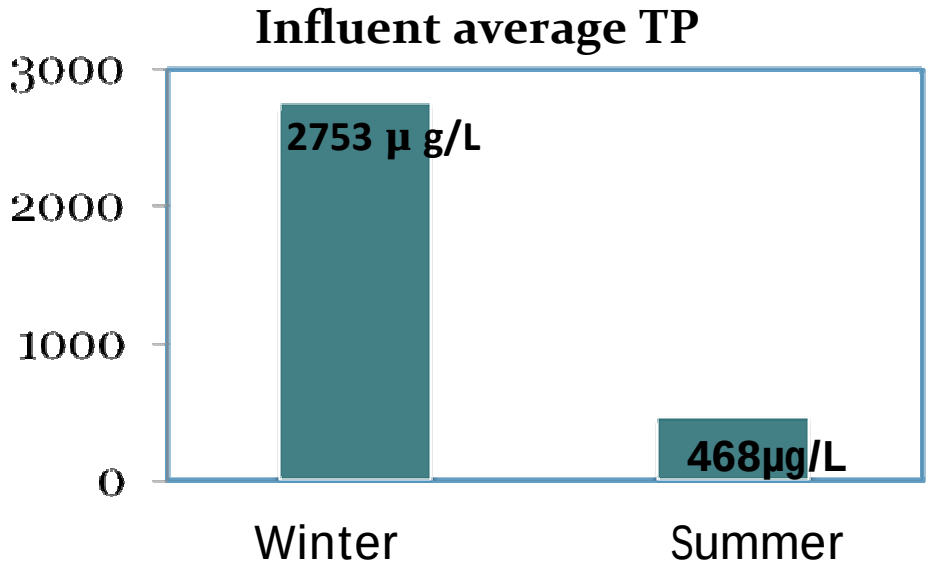
Pilot plant
Sampling location



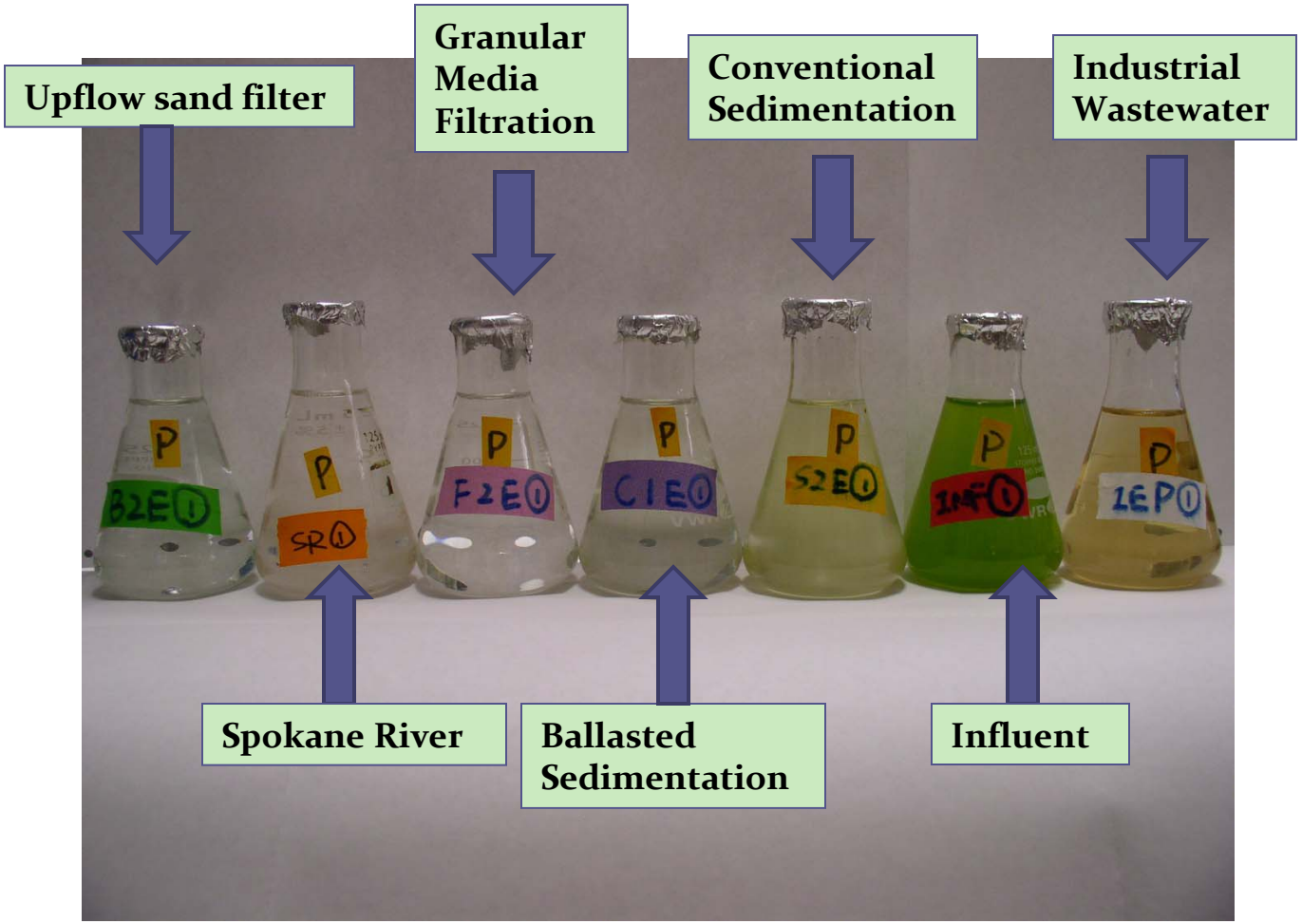
Sampling (from August 2009 to April 2010)

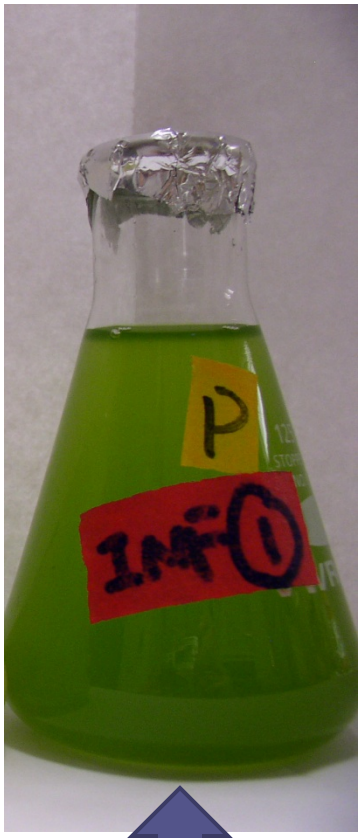
- **Winter Scenario:**
- 3 samples
- *without* alum addition in secondary WWTP

- **Summer Scenario:**
- 5 samples
- *with* alum addition in secondary WWTP

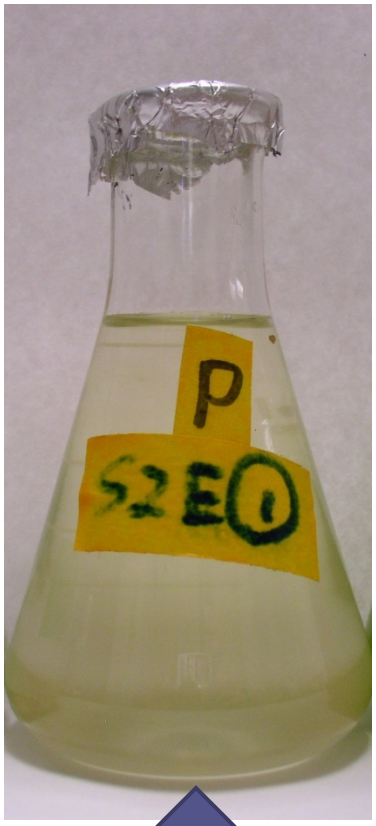


Results


Upflow sand filter
Granular Media Filtration
Conventional Sedimentation
Industrial Wastewater
Spokane River
Ballasted Sedimentation
Influent



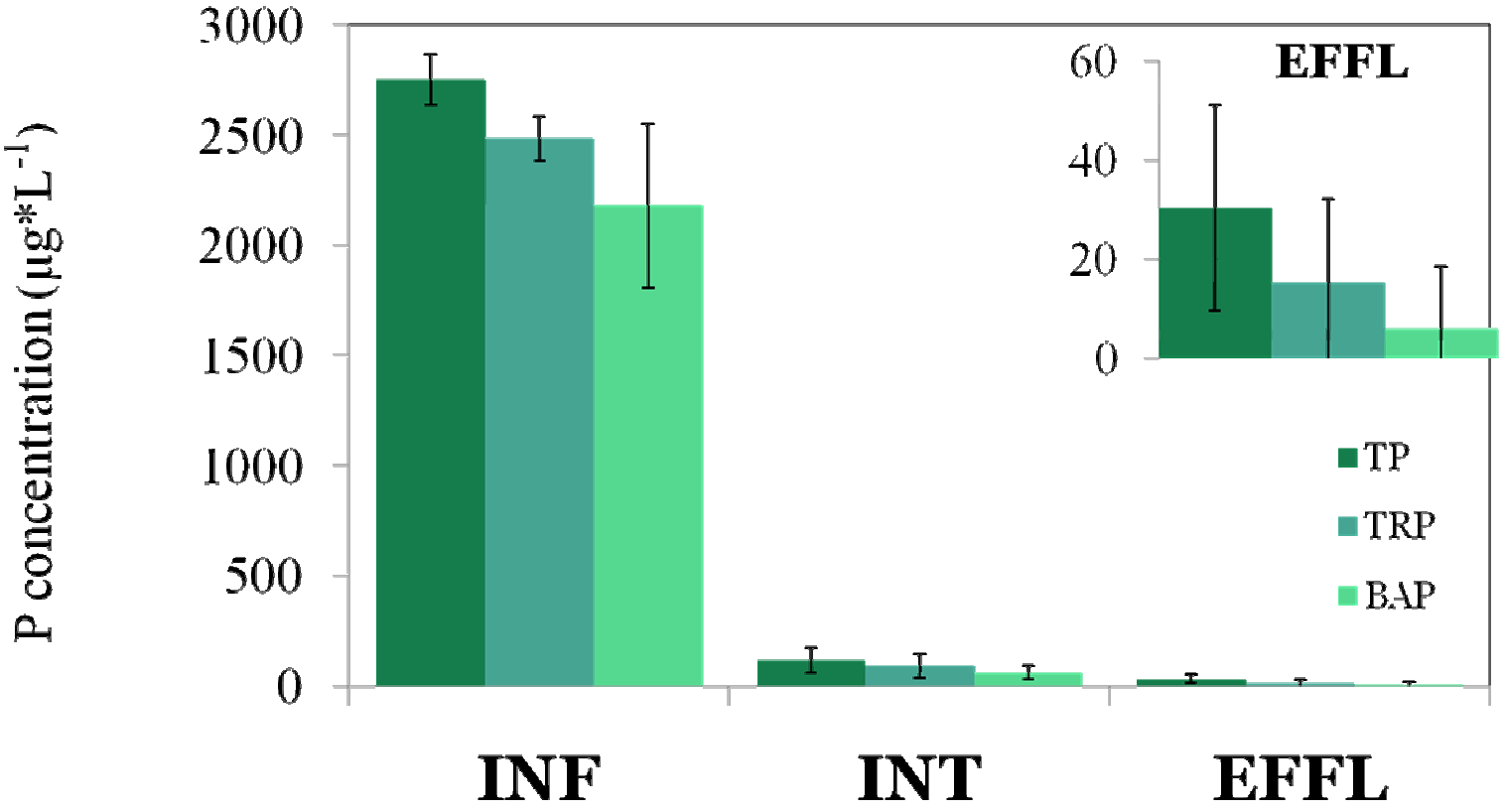
Influent



Intermediate

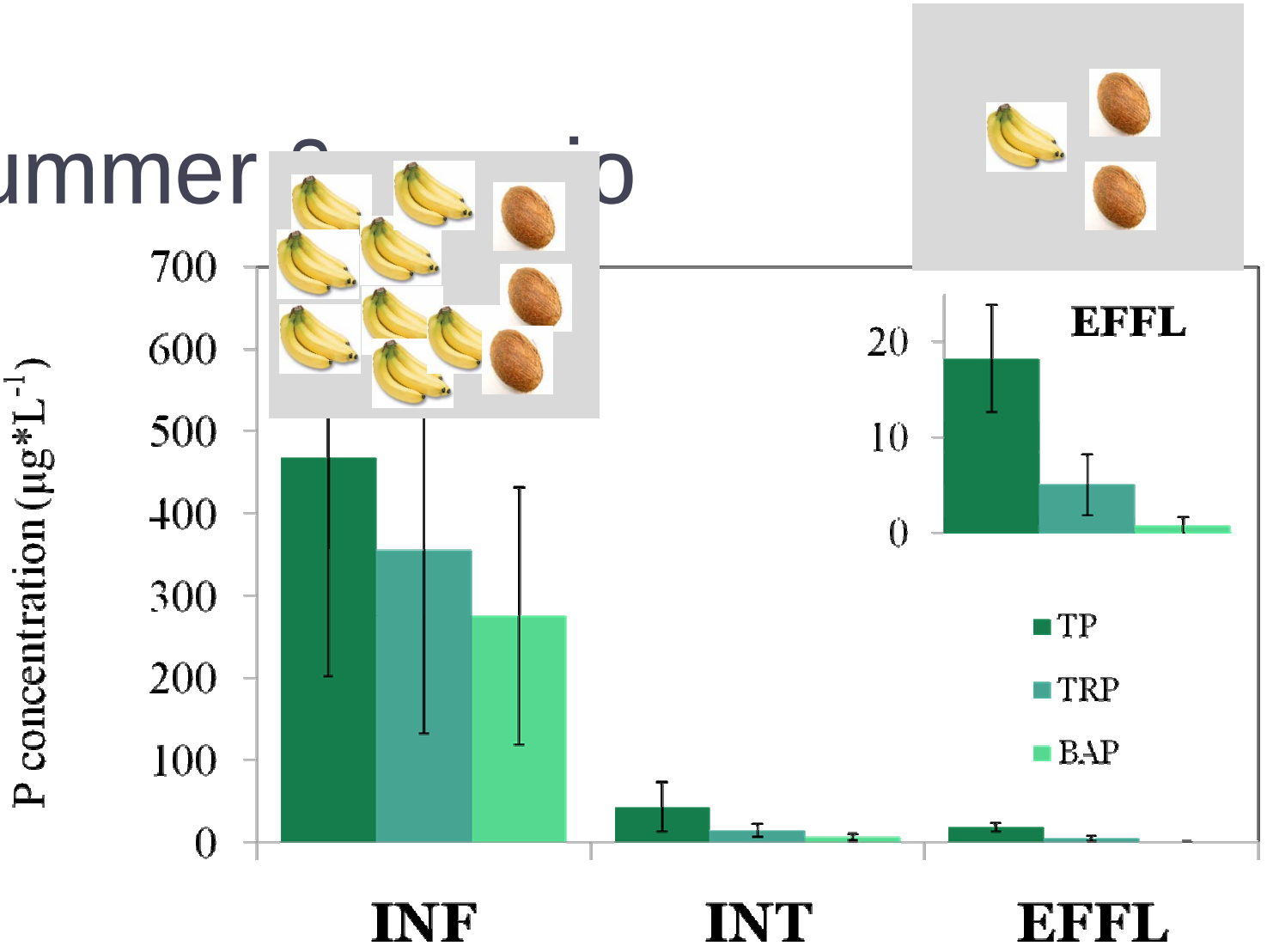
Effluent

Winter Scenario



INF-Inffluent INT-Intermediate EFFL-Effluent

Summer S[illegible]p



INF-Inffluent INT-Intermediate EFFL-Effluent

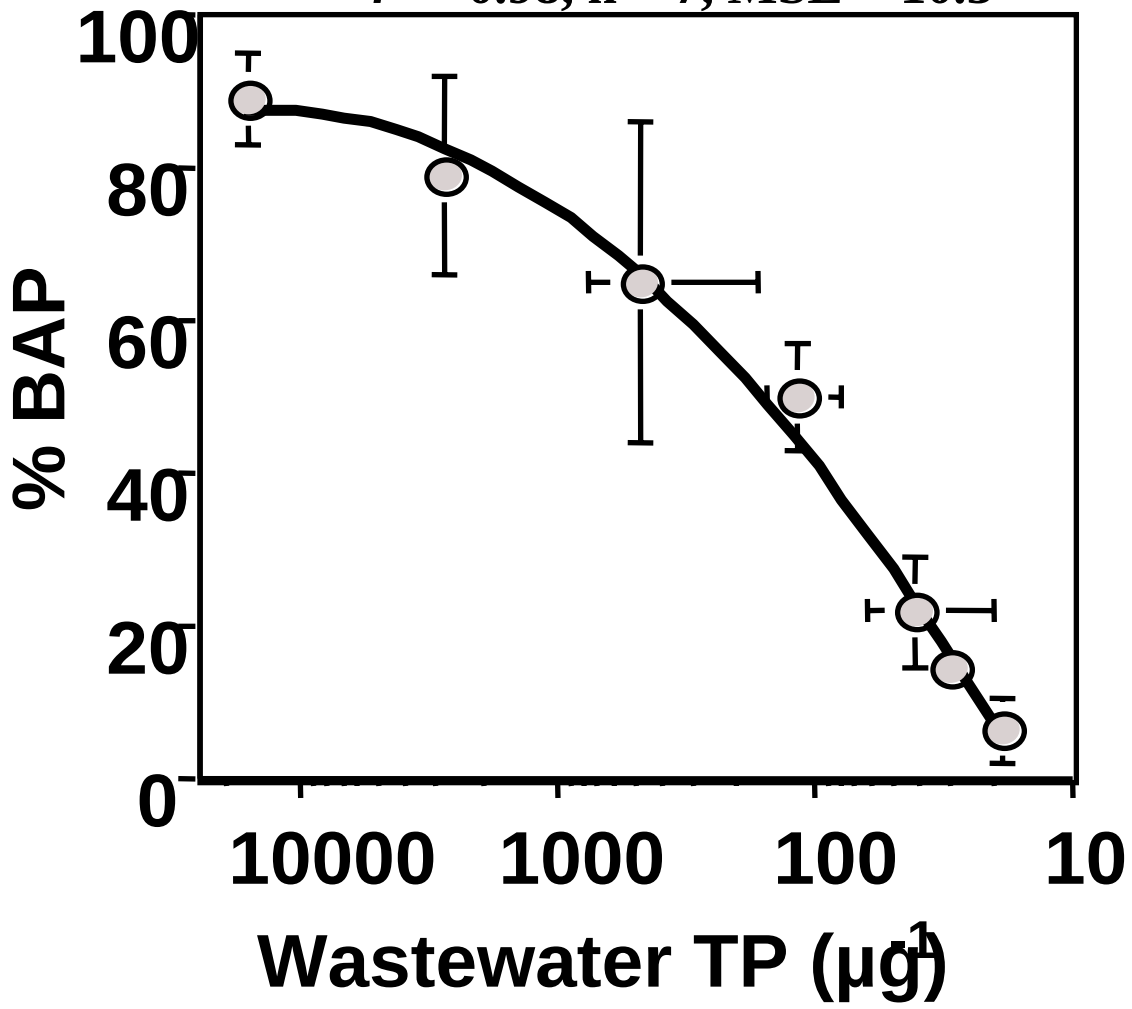
Objectives

- How does %BAP vary with the level of P removal?
- How does %BAP vary for effluents from other plants with different removal technologies?
- Can TRP be a surrogate measure for BAP?

BAP% vs. TP in alum treatment process

%BAP = -12.19*log (TP)^2 + 92.03*log(TP) + 94.17;

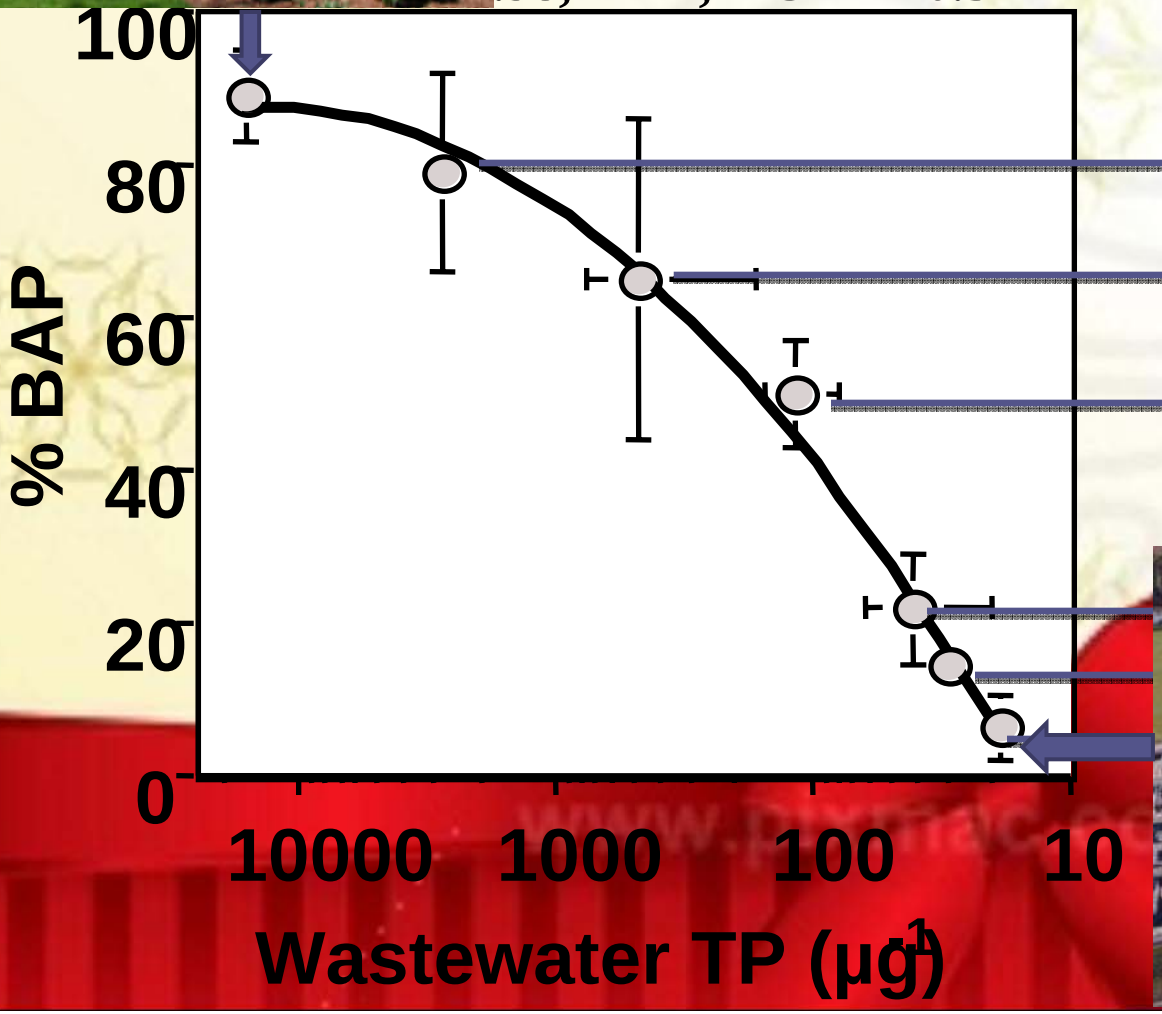
r^2 = 0.98, n = 7, MSE = 10.3



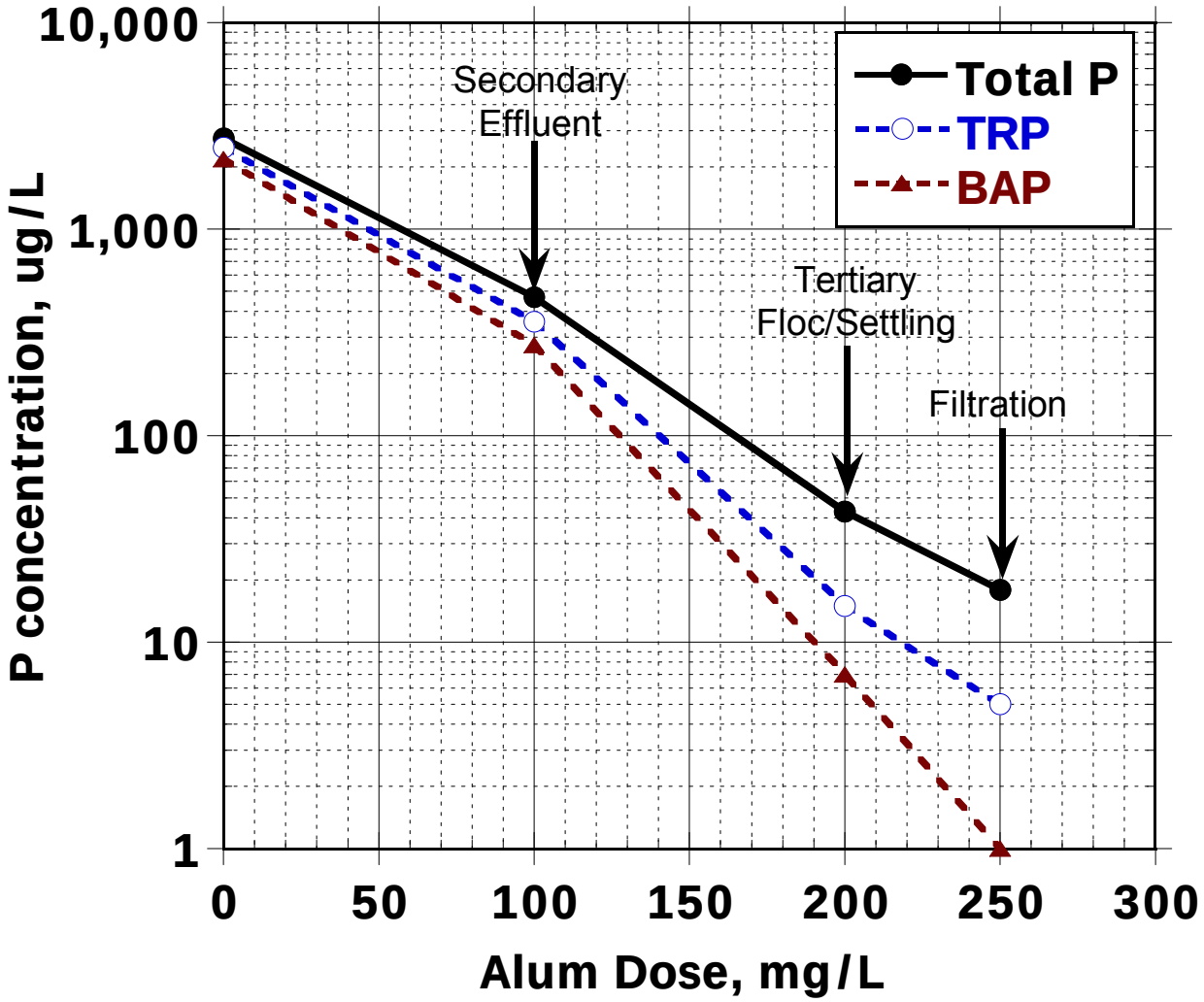
TP in alum treatment process

$P = -12.19*\log(TP)^2 + 92.03*\log(TP) + 94.17;$

$.98, n = 7, MSE = 10.3$



Effect of Chemical Dose and Tertiary Treatment on Effluent P Species

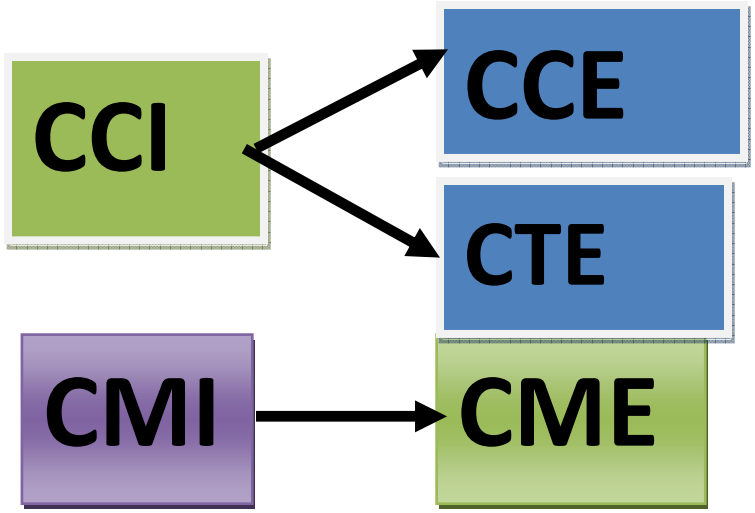


Objectives

- How does %BAP vary with the level of P removal?
- How does %BAP vary for effluents from other plants with different removal technologies?
- Can TRP be a surrogate measure for BAP?

City of Coeur d'Alene

- Blue Water Continuous Upflow filtration, membrane, MBR



CCI--Influent to Tertiary membrane filter (TMF) & Continuous up flow media filter (CUMF – same as blue water), the influent is the same as the plants secondary effluent with alum addition before secondary clarifiers.

CCE-- Effluent from CUMF - Blue Water Continuous Upflow filtration, Iron sand filter

CTE-- Effluent from TMF – Zenon Membrane Filter

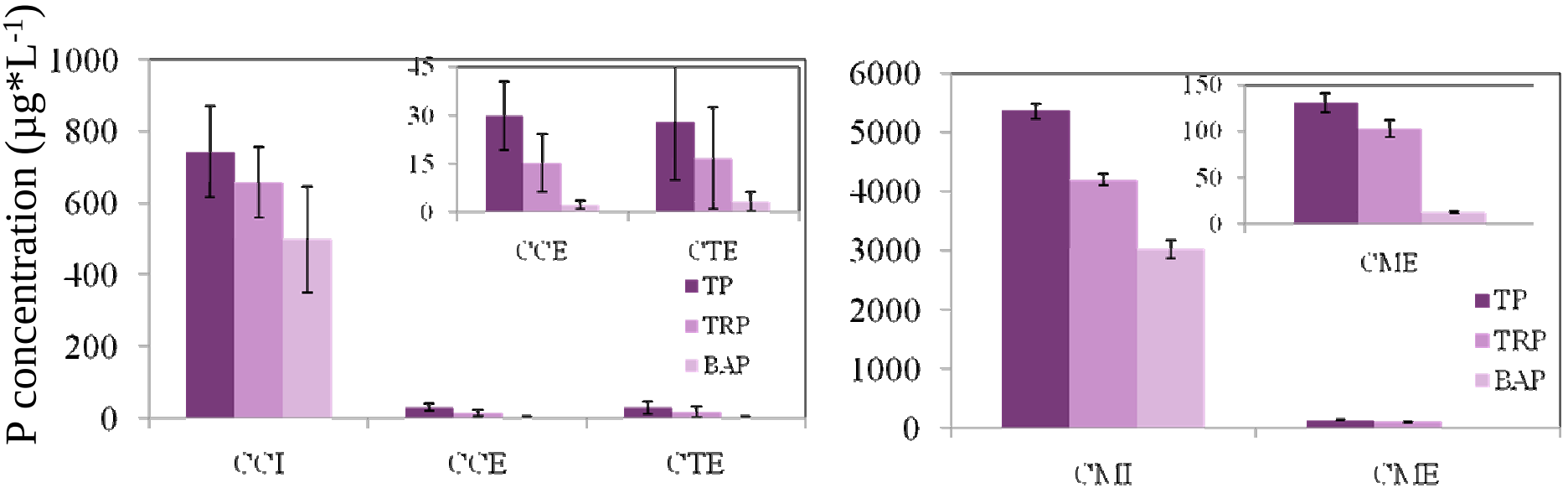
CMI-- Influent to MBR – Zenon Membrane Bio Reactor system, MBR influent is the same as primary effluent (No chemical addition ahead of the primaries) Influent

CME--Effluent from MBR – Zenon Membrane Bio Reactor system

City of Coeur d'Alene

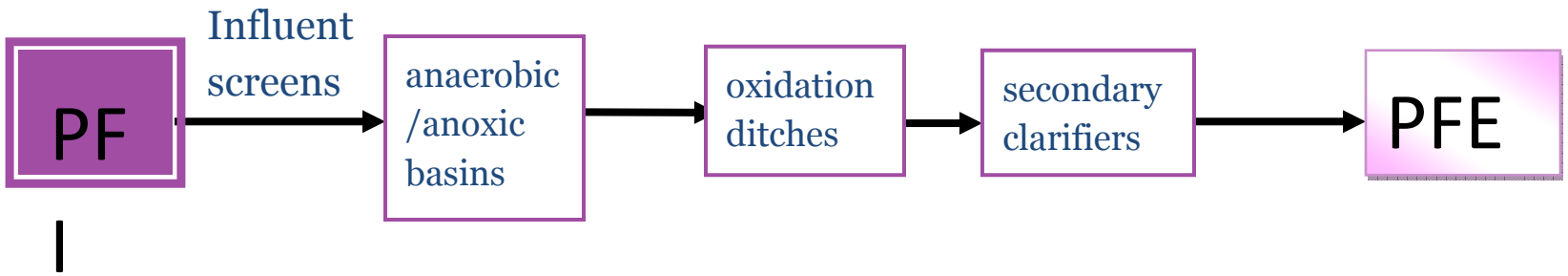
TP									
	1	2	3	4	5				
	5/13	6/10	6/25	7/15	8/10	AVE	SD	Outliers	Optimal performance
CCI	956	662	648	688	758	742	127		
CCE	24	35	41	35	15	30	11		
CTE	27	**545**×	53	20	11	131	232	2	28±18
CMI	5227	**8715**×	**9009**×	5506	5344	6760	1924	2,3	5359±140
CME	261	**7264**×	**3203**×	94	35	2171	3143	2,3	130±117

City of Coeur d'Alene



Post Fall

- Biological Treatment

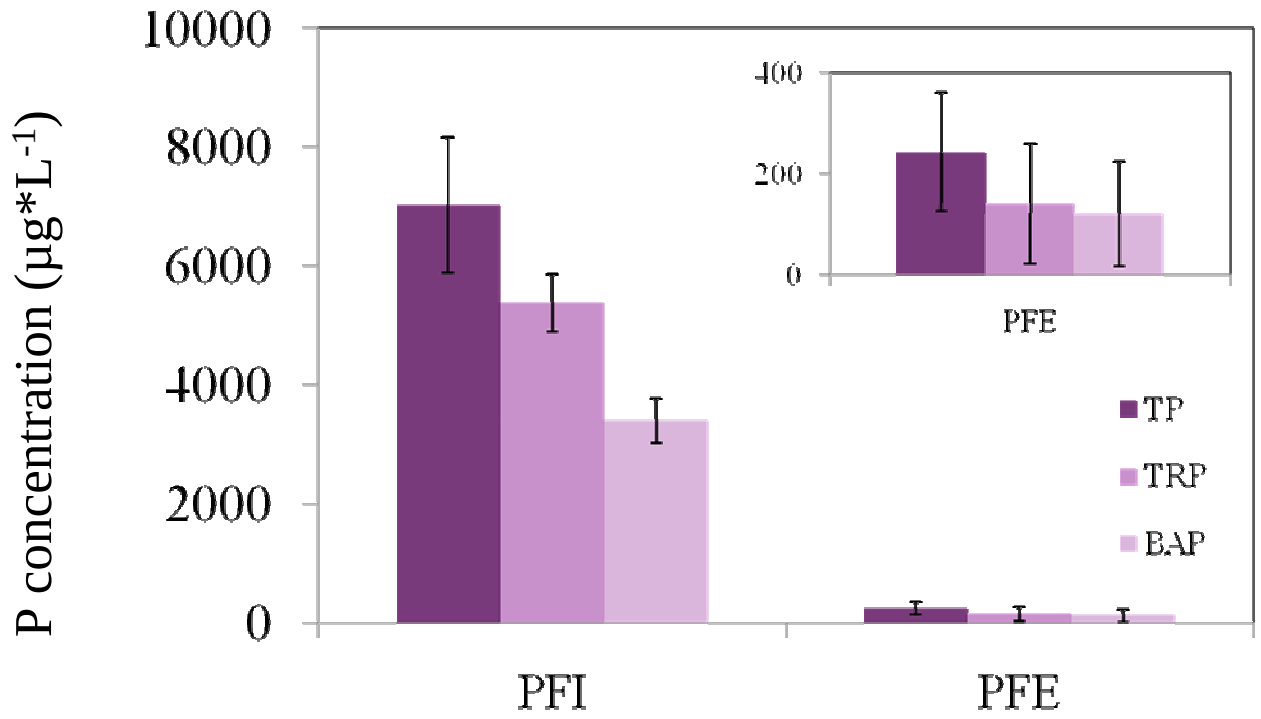


PFI--Post Falls Influent
PFE--Post Falls Effluent - Biological nutrient removal

Post Fall– P removal performance

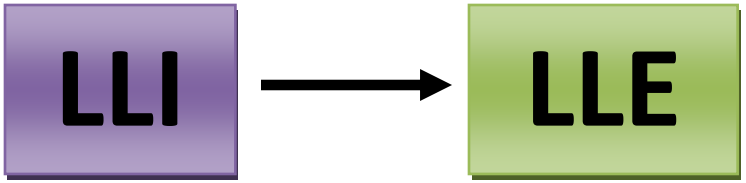
		1	2	3	4	5	AVE	SD	Outliers	Optimal performance
		5/13	6/10	6/25	7/15	8/10				
TP	PFI	5527	8444	7844	6816	6478	7022	1148		
	PFE	176	**852**×	174	379	**1024**×	521	395	2,5	243±118
TRP	PFI	4980	6173	5489	5236	5032	5382	485		
	PFE	72	**652**×	73	279	**788**×	373	332	2,5	141±119
BAP	PFI	3432	3269	2973	3290	4020	3397	386		
	PFE	58	**561**×	64	241	**839**×	352	340	2,5	121±104
%TRP	PFI	90	73	70	77	78	78	8		
	PFE	41	**76**×	42	74	**77**×	62	19	2,5	52±19
%BAP	PFI	62	39	38	48	62	50	12		
	PFE	33	**66**×	37	64	**82**×	56	21	2,5	44±17

Post Fall– P removal performance



Liberty Lake

- Biological Treatment

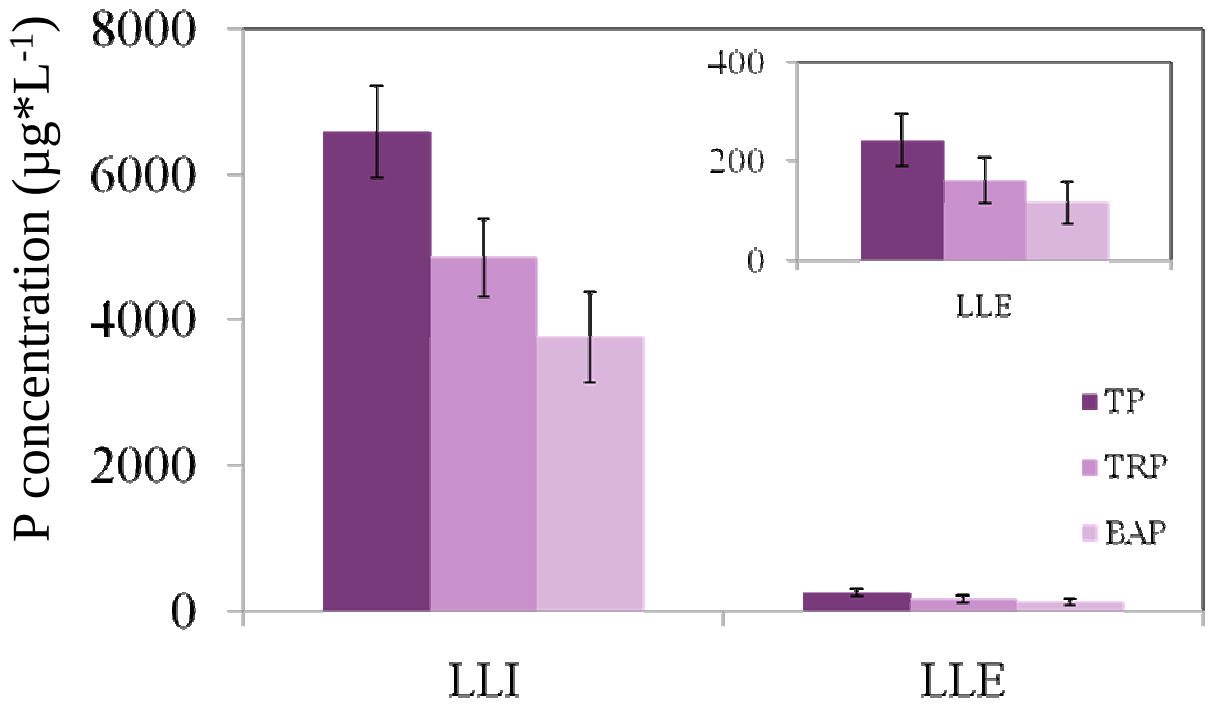


LLI-- LLSWD WWTP - Influent
LLE— LLSWD WWTP - Effluent

Liberty Lake – P removal performance

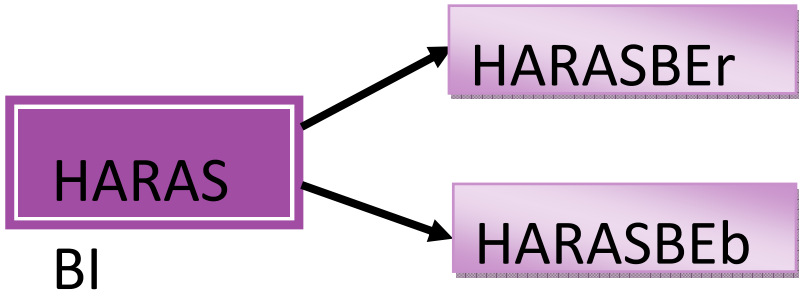
		1	2	3	4	5	6	AVE	SD	Outliers	Optimal performance
		4/15	5/13	6/10	6/25	7/15	8/10				
TP	LLI	6675	5490	6722	7430	6395	6733	6574	632		
	LLE	162	219	263	304	259	**1066**×	379	340	6	241±53
TRP	LLI	4814	4111	4783	5366	4484	5526	4847	531		
	LLE	84	208	152	188	171	**904**×	284	307	6	160±47
BAP	LLI	4046	3176	3529	3096	4751	3929	3755	621		
	LLE	51	96	141	126	161	**1034**×	268	377	6	115±43
%TRP	LLI	72	75	71	72	70	82	74	4		
	LLE	52	95	58	62	66	**85**×	70	17	6	66±17
%BAP	LLI	61	58	53	42	74	58	58	11		
	LLE	32	44	54	42	62	**97**×	55	23	6	47±12

Liberty Lake – P removal performance



Hayden Area Regional Sewer Board

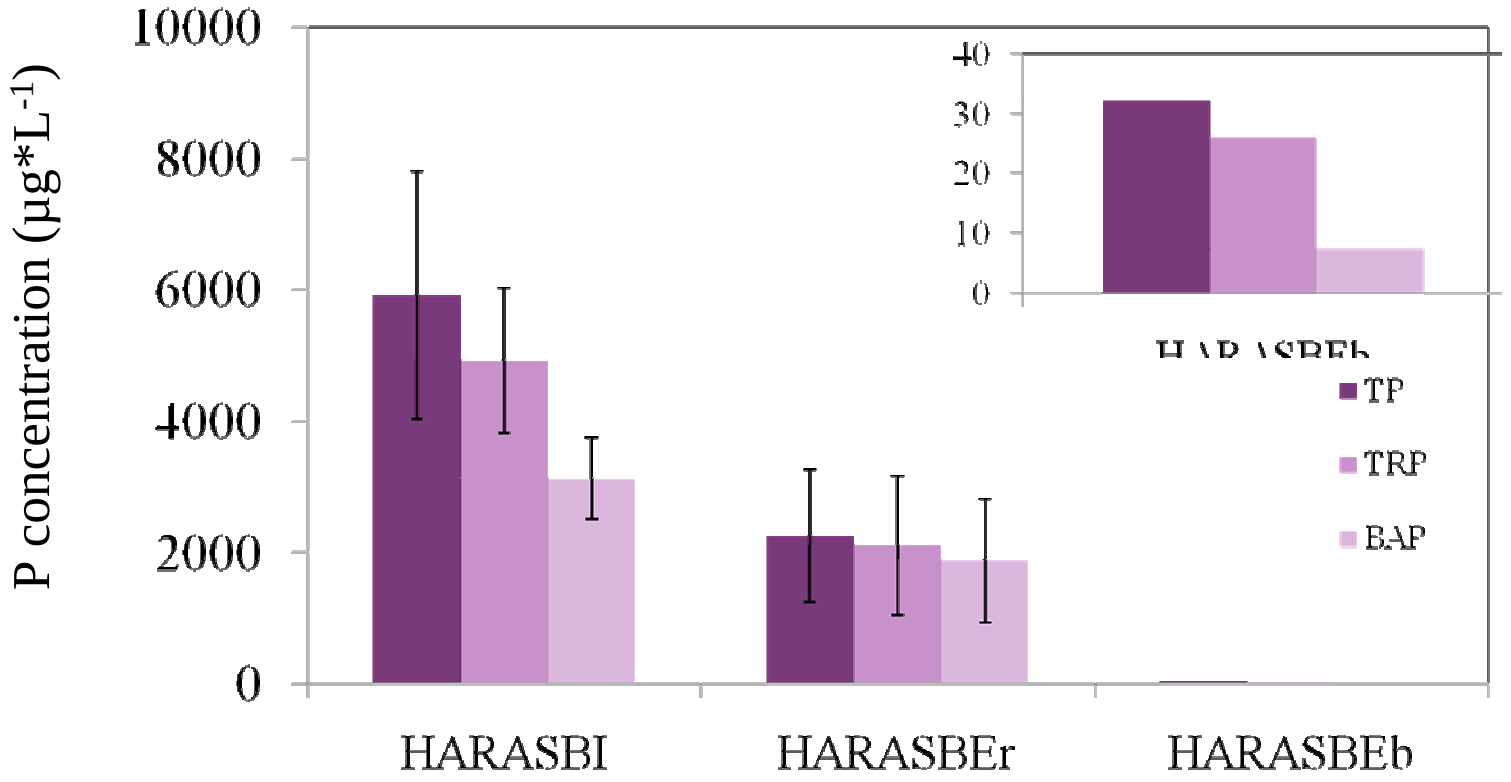
- Upflow sand filter



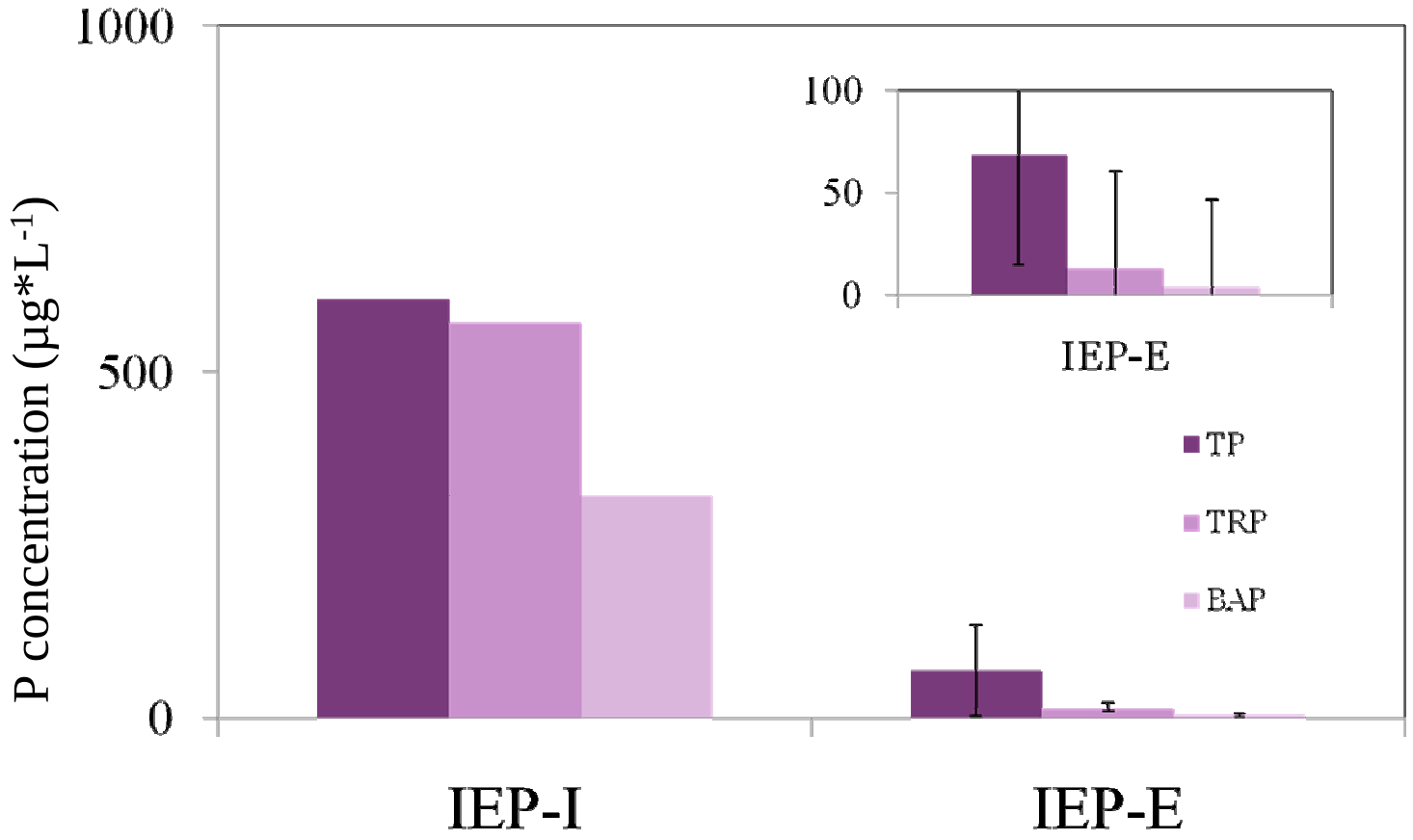
HARASBI--HARSB Influent
HARASBEr--HARSB Tertiary effluent - (Regular Effluent)
HARASBEb--HARSB Tertiary effluent - (Blue Water Effluent)

- 3 Samples from Influent
- 4 Samples from Regular Effluent
- 1 Samples from Blue Water Effluent

HARSB – P removal performance

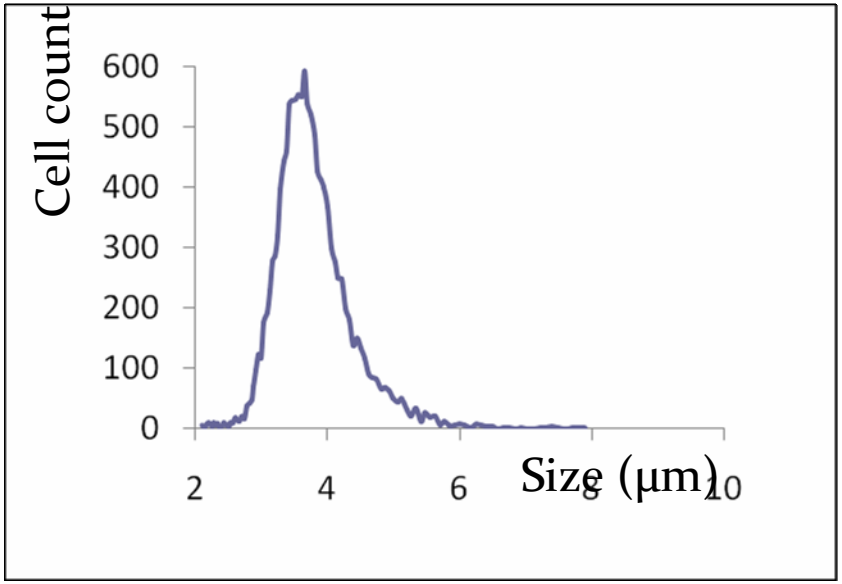


Inland Empire Paper

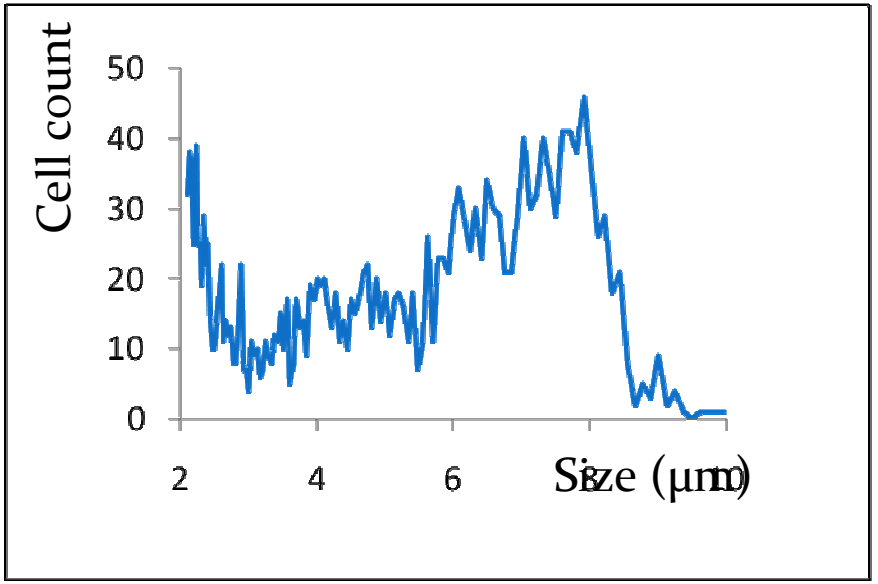


Inland Empire Paper

Expected

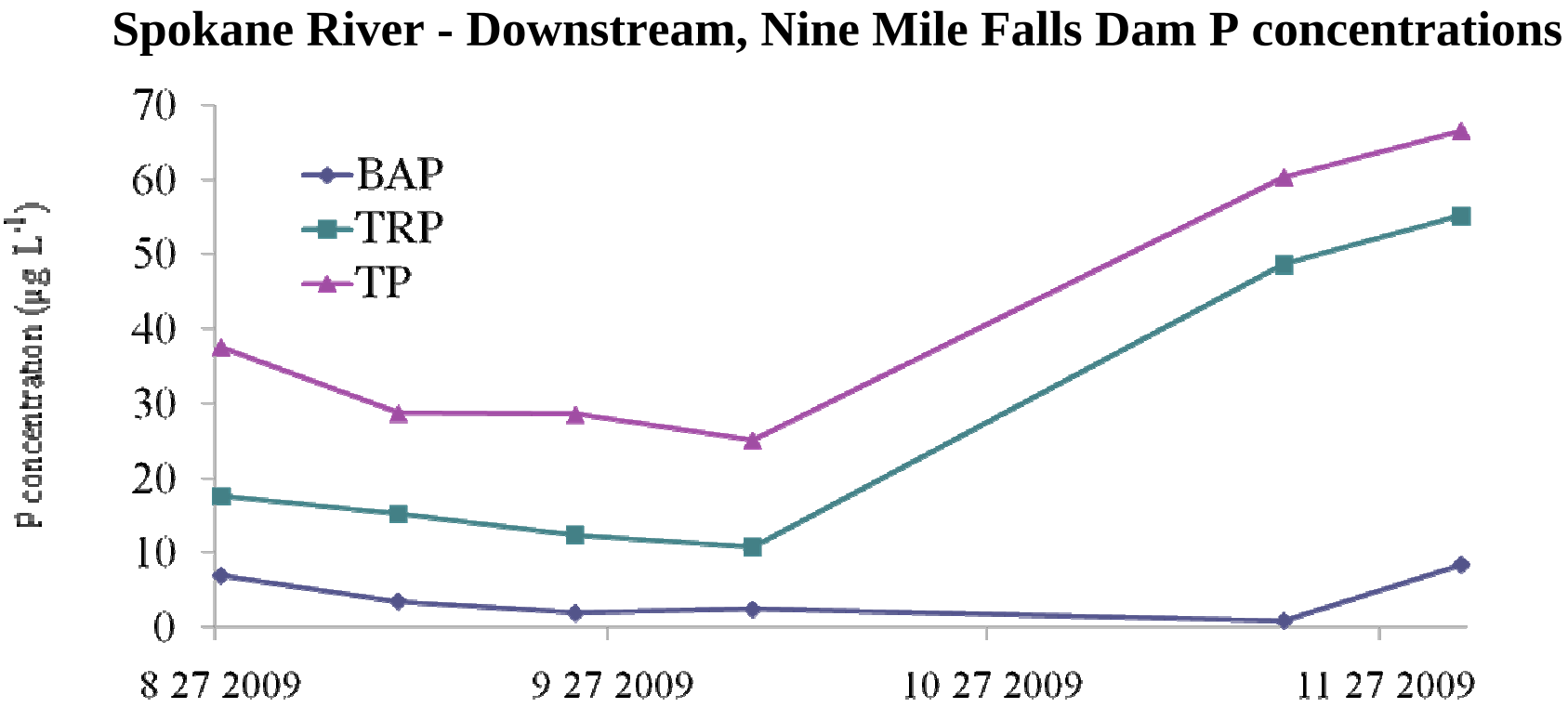


Industrial Wastewater



IEP	Sep. 10	Dec.3rd
Chl-a *(µg/L)*	1.06	1.6

Spokane River

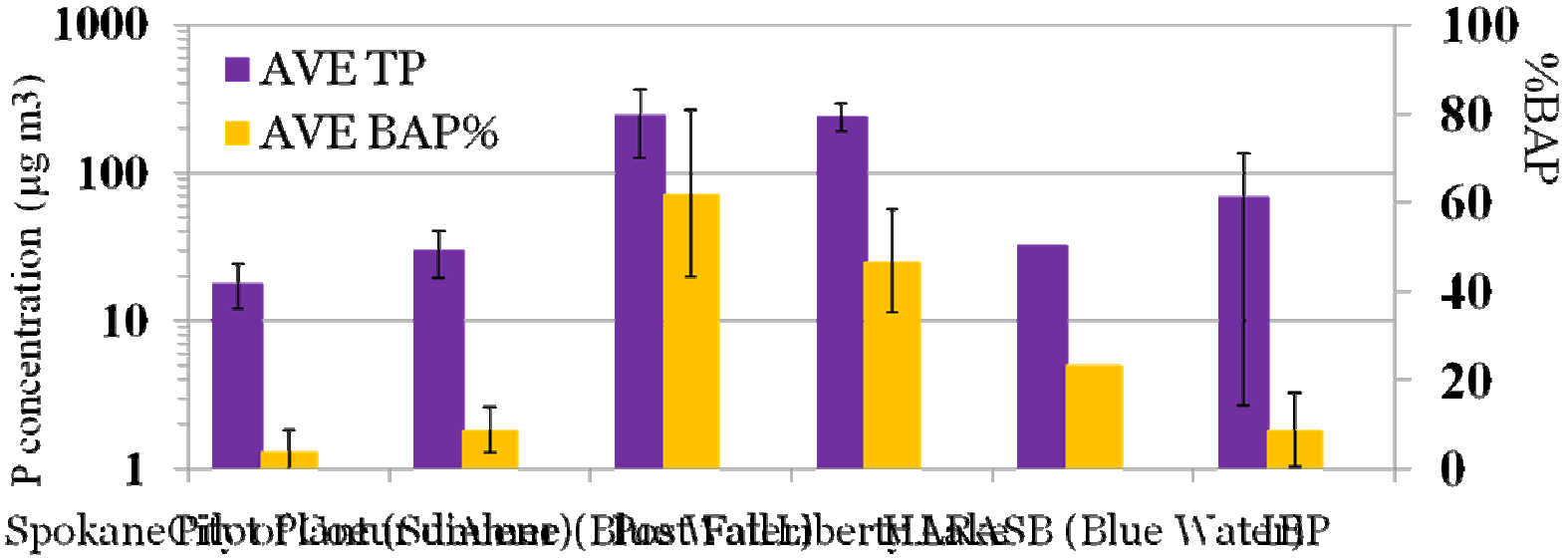


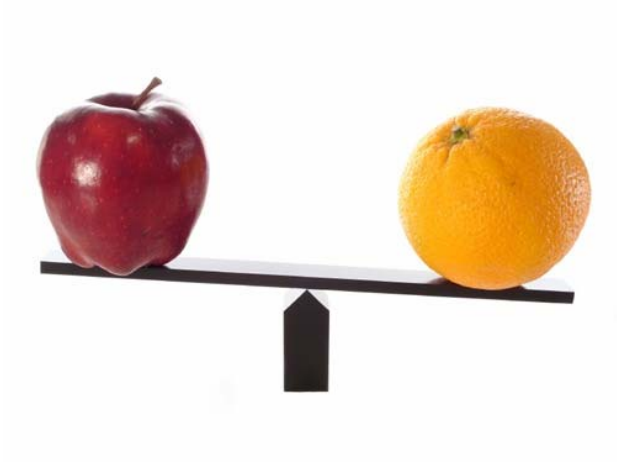
Spokane River

State Line (Washington – Idaho)

Spokane River Upstream	
TP ($\mu g \cdot L^{-1}$)	11
TRP ($\mu g \cdot L^{-1}$)	4
BAP ($\mu g \cdot L^{-1}$)	Non detect
TRP%	39
BAP%	1

Comparison of %BAP and TP





Objectives

- How does %BAP vary with the level of P removal?
- How does %BAP vary for effluents from other plants with different removal technologies?
- Can TRP be a surrogate measure for BAP?

BAP vs TP and SRP?

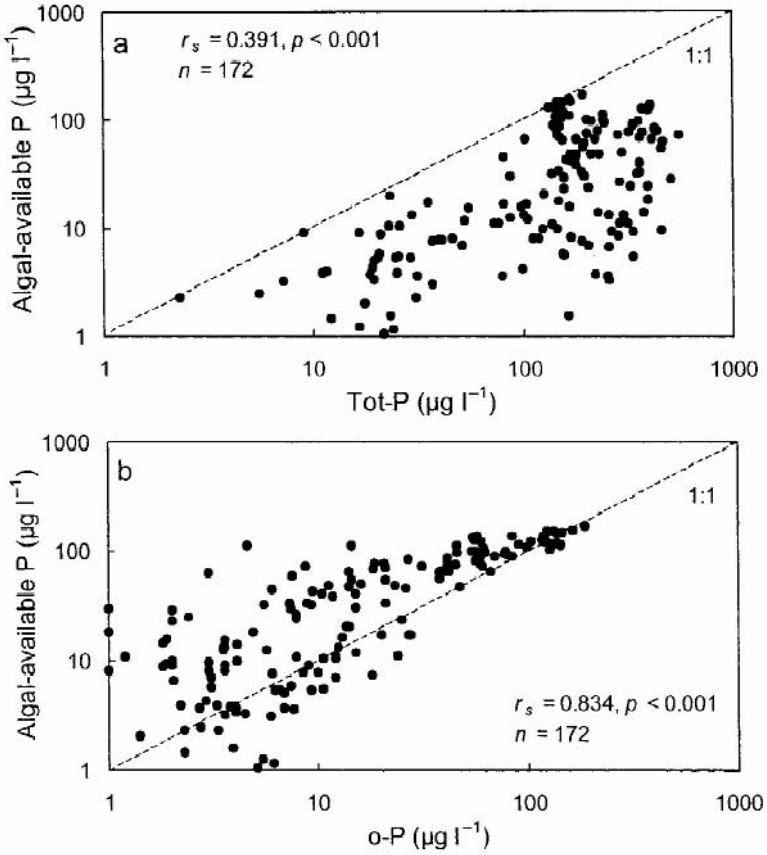
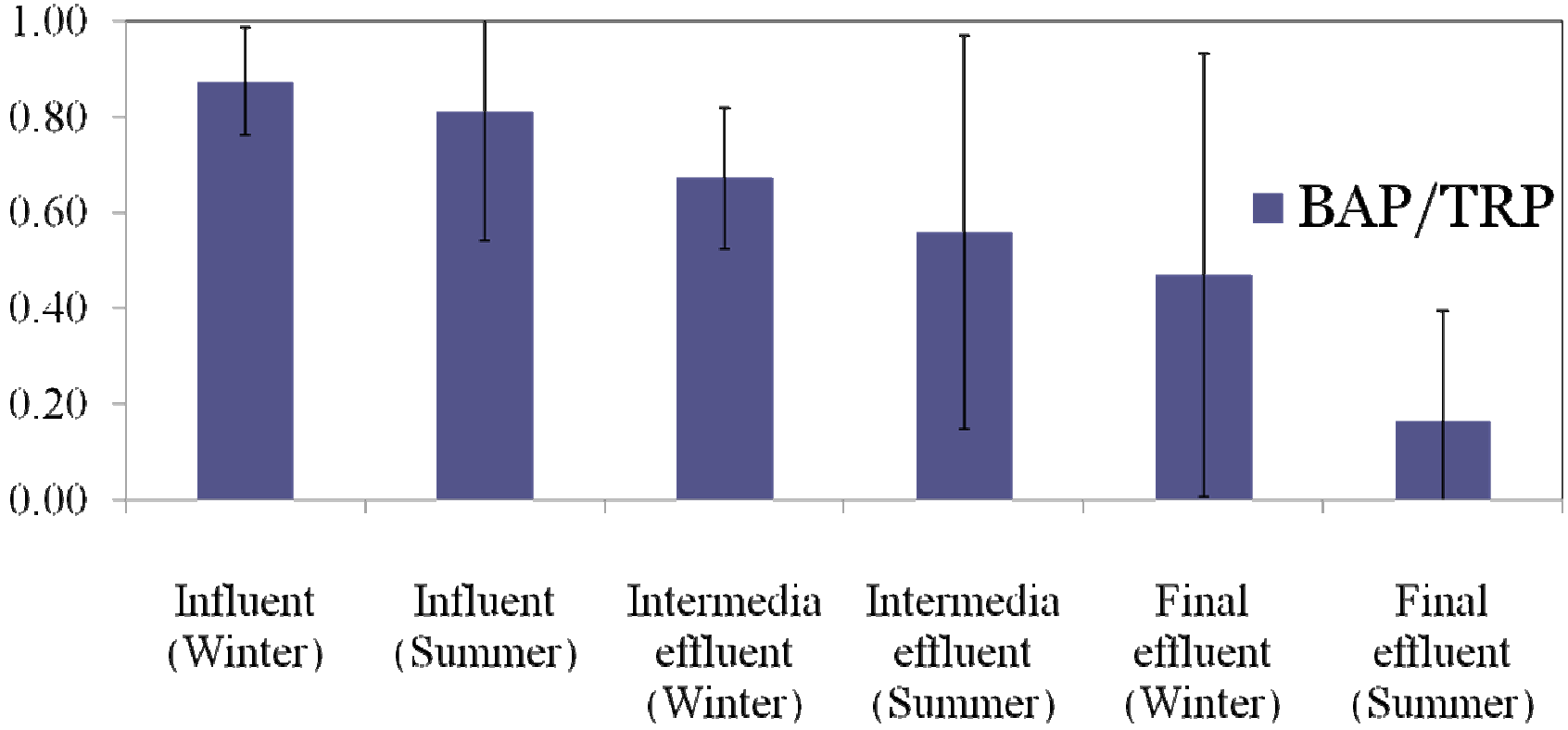


Figure 2. Relationship between algal-available P and tot-P (a) and o-P (b). Note that for P-rich samples, diluted before the assay, the *x*-axis does not represent the P concentration in the original samples. r_S = Spearman's rank correlation coefficient.

Source: Petri Ekholm (2003), Determining algal-available phosphorus of differing origin:routine phosphorus analyses versus algal assays

BAP-TRP?

BAP/TRP=0.44±0.40



BAP vs. TRP

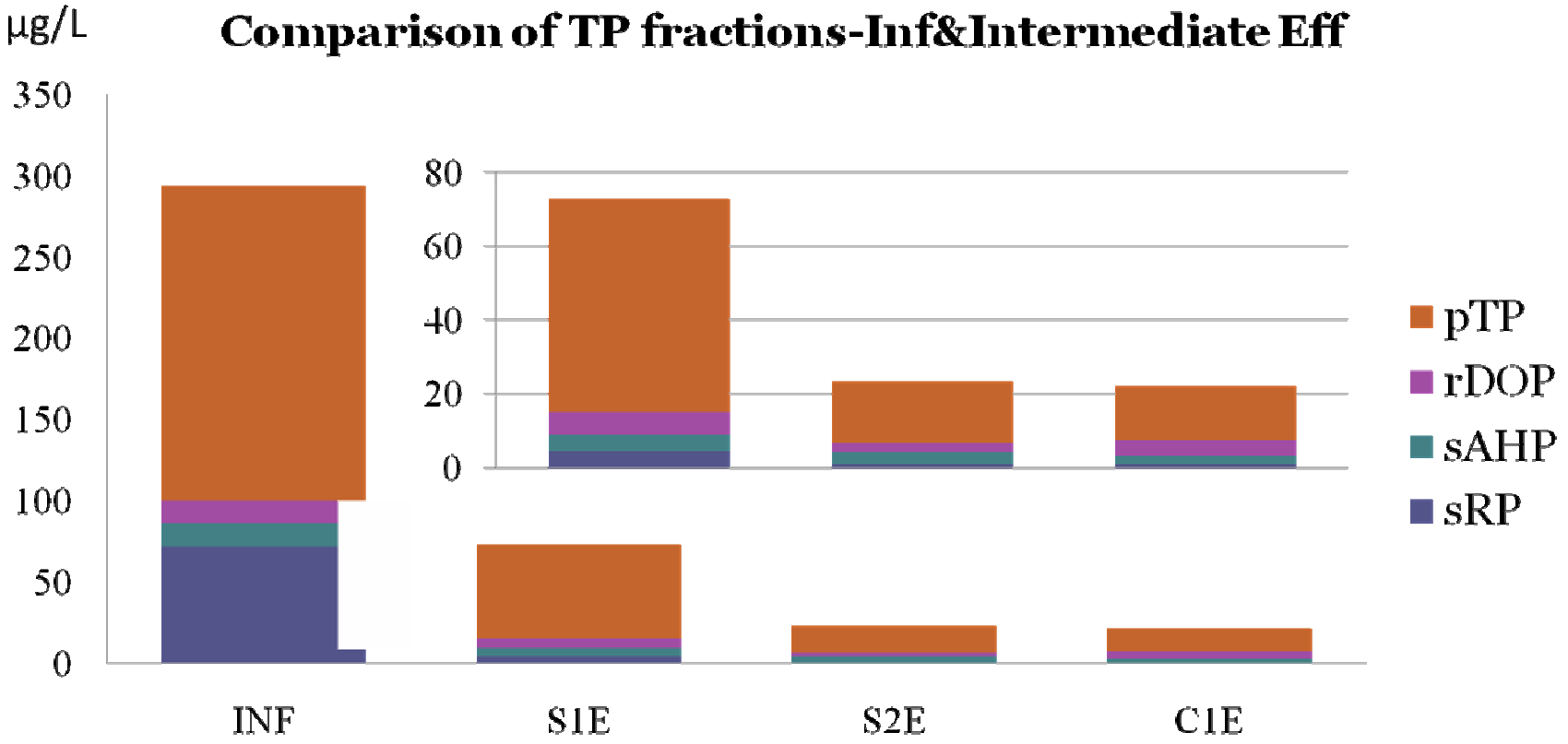
- **BAP is lower than TRP for all the other samples**
- **BAP/TRP=0.54±0.22**

Future Studies

BAP

Chemical species

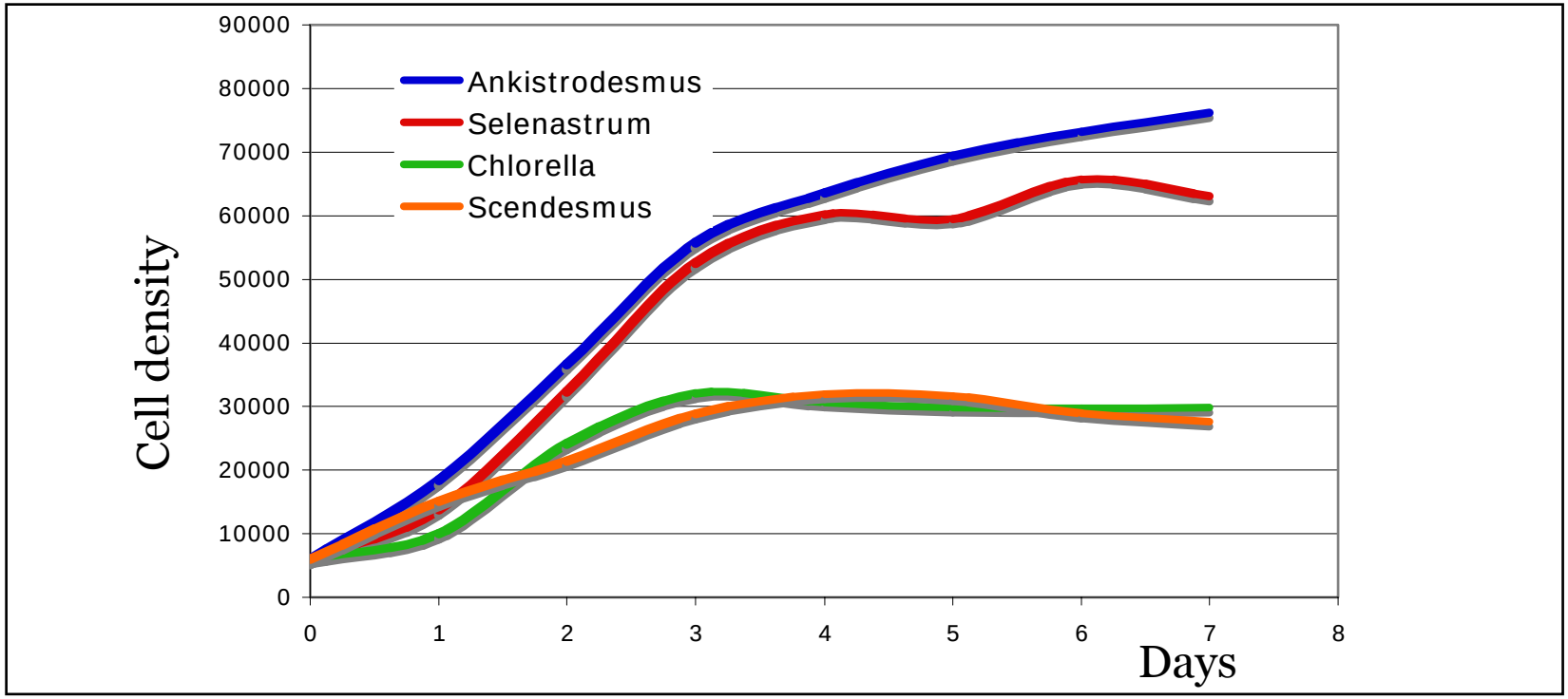
Future Studies



Future Studies

- Dilute pure effluent with P-free media by 50%
- More samples (n≈10) for other plants
- Assess long-term BAP for selected effluent
- Analyze Chl for IEP experiments
- Test for the toxicity (Luxury uptake)

Luxury Uptake



- The growth of four different green algae cultures that were initially P-saturated after being transferred to P-free synthetic media. The X-axis is days after transfer to P-free media and the Y-axis is cell counts. Each treatment had four replicates and within treatment variation averaged ± 12% (i.e. SD/mean).

Conclusions

- %BAP is very low in City of Spokane pilot plant and goes down from the Influent (65%) to Intermediate (27%) to Effluent (4%).
- %BAP in Effluent is always lower than Influent.
- The %BAP vs. TP regression model we derived for the overall alum treatment process will provide an important baseline against which we can compare other processes.
- TRP may be used as a “conservative” measure of BAP.

Acknowledgement

- Washington State Department of Ecology, Spokane County, WA
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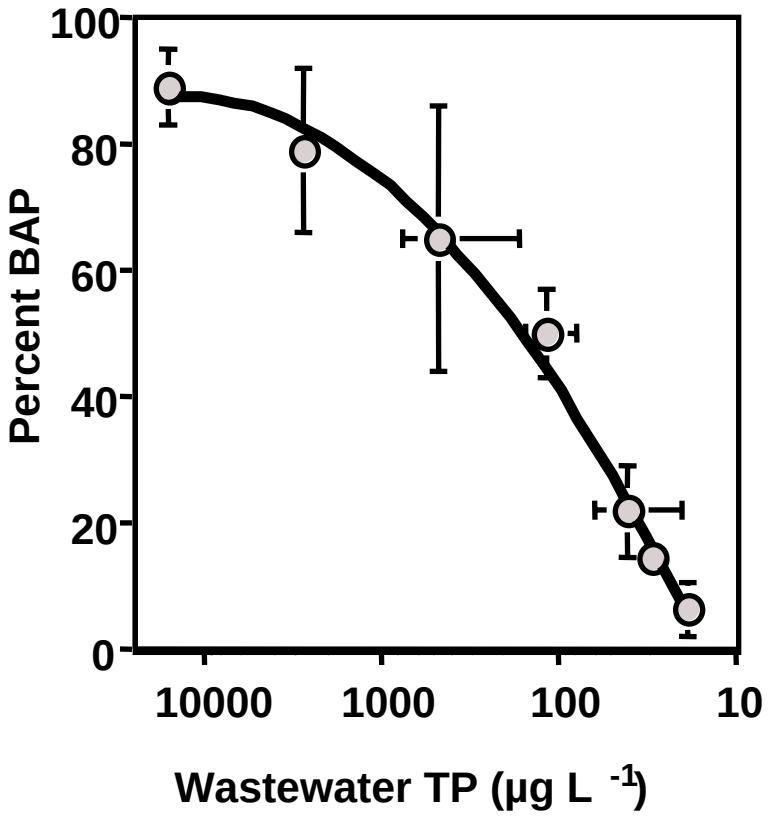
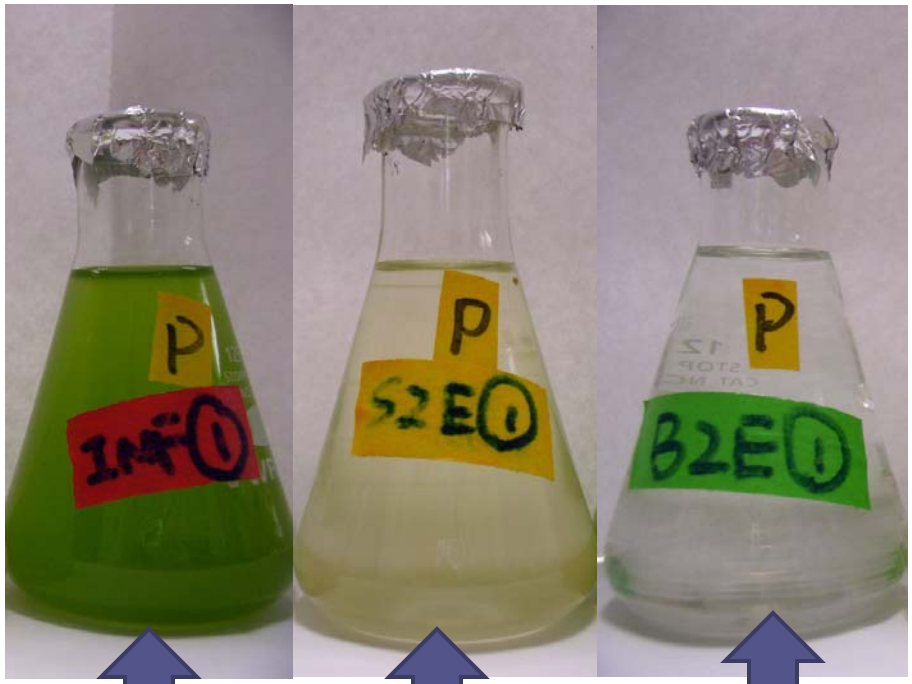
- City of Post Falls, ID
- City of Coeur d'Alene, ID
- Hayden Area Regional Sewer Board, ID
- Kaiser Aluminum
- Inland Empire Paper Company
- Water Environment Research Foundation (WERF)

Questions?





Influent Intermediate Effluent