Fate & Removal of PPCPs within WWTFs discharging upstream from the Great Bay Estuary

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Outline

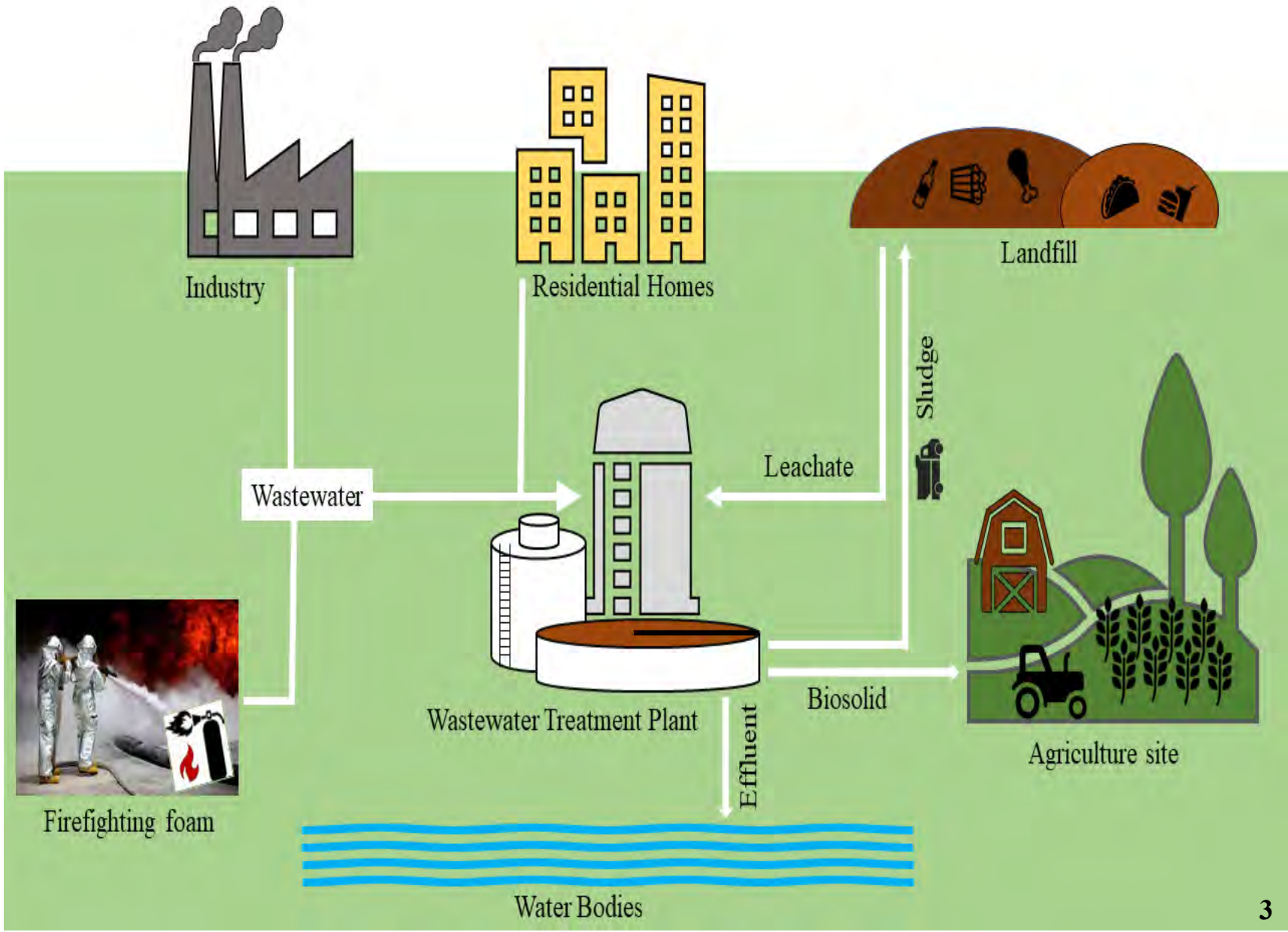
1. **PPCP Background & Knowledge Gaps**
2. Research Goals
3. Methods & Sampling Plan
4. PPCP Results & Preliminary Conclusions
5. Next Steps
6. References

PPCP Background

Simplified Definition

Contaminants of Emerging Concern

1) Chemical and non-chemical materials that have a possible pathway into the environment.
2) Present potential unacceptable human health and environmental risk.
3) Not federally regulated or regulations are currently being developed.



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10,000+ PPCPs Constituents

- 15 Pharmaceuticals
- 6 Personal care products

Source: Integral Corp.

Source: Google Images

CEC Background: 21 PPCP Analytes

15 Pharmaceuticals

ANALYTES			
Analgesic		**B-blocker**	
Acetaminophen	*	Atenolol	*
Antibiotic		**Narcotic**	
Amoxicillin		Methadone	
Azithromycin		**Sedative**	
Ciprofloxacin	*	Diazepam	*
Sulfamethoxazole	*	Meprobamate	
Trimethoprim	*	**SSRI**	
Anti-convulsant		Fluoxetine	*
Carbamazepine	*	**Statin**	
Phenytoin		Atorvastatin	
Primidone			

6 Personal Care Products

ANALYTES	
Flame retardants	
TCEP	*
TCPP	*
TDCPP	
Insecticide	
DEET	*
Stimulant	
Caffeine	*
Tobacco metabolite	
Cotinine	*

* Frequently Detected in the environment

PPCP Knowledge and Gaps

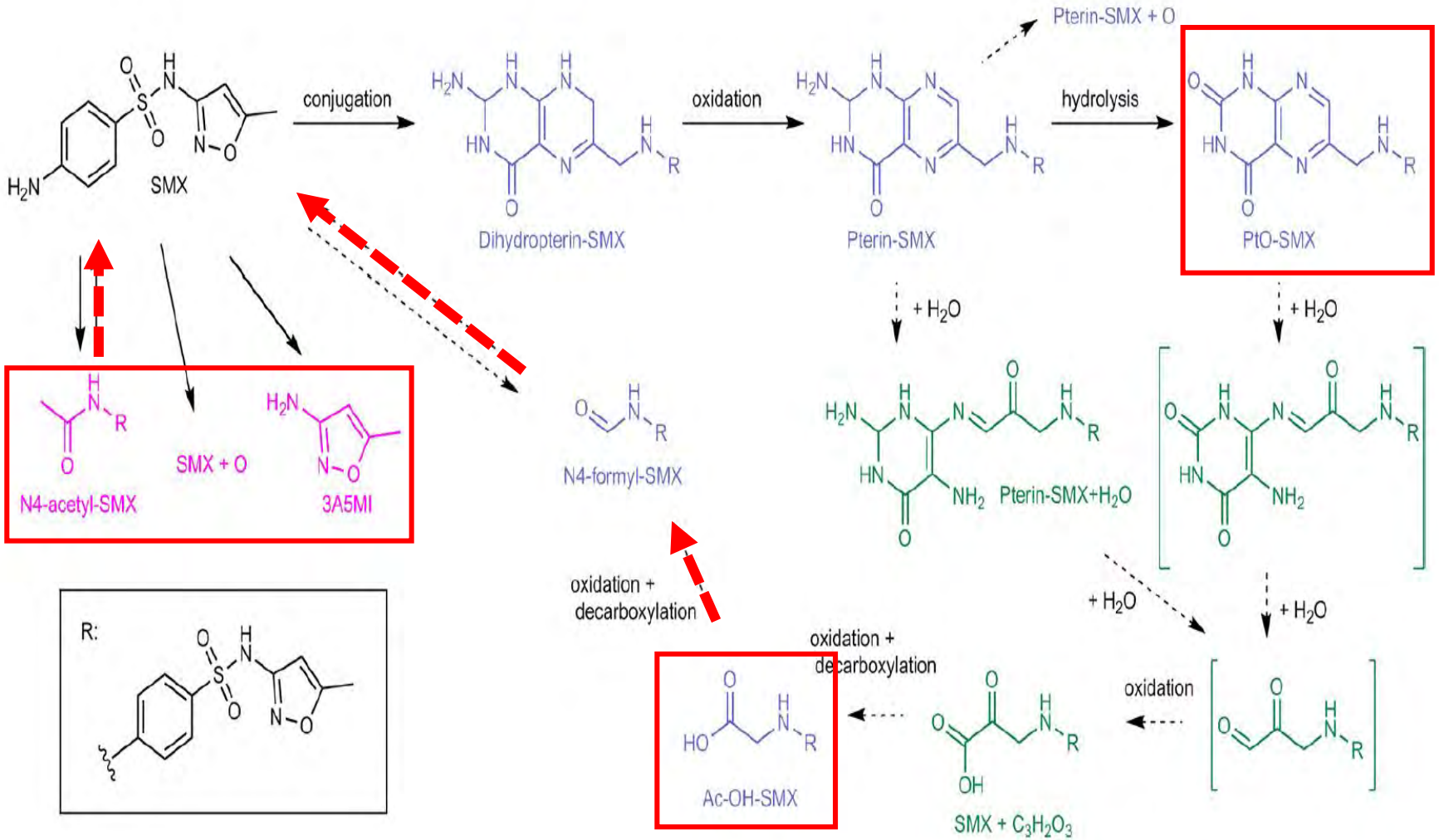
What We 'Know'

1. Biodegradation is one of the main pathway of PPCP removal in WWTFs

Current Gaps

- Fate of PPCPs within secondary treatment
- Removal in Aerobic vs Anoxic vs Anaerobic Zones

Proposed biotransformation pathway for **Sulfamethoxazole**



Major Metabolites

Pathway converting back into parent compound

(Achermann et al., 2018)

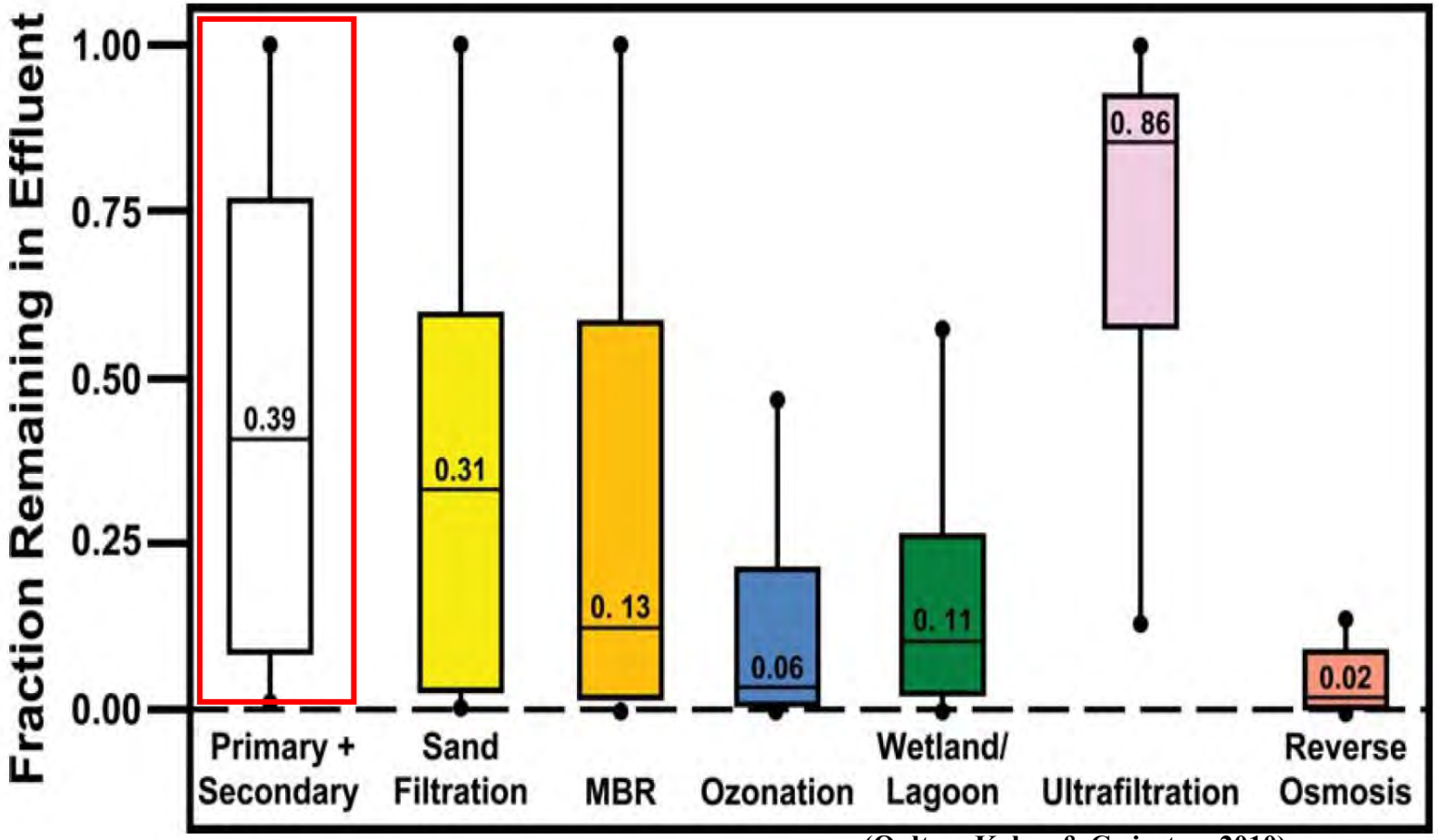
PPCP Knowledge and Gaps

What We 'Know'

2. PPCPs are NOT completely removed in conventional WWTFs

Current Gaps

- What is the Best Available Technology (BAT)?
- Future regulations??



(Oulton, Kohn, & Cwiertny, 2010)

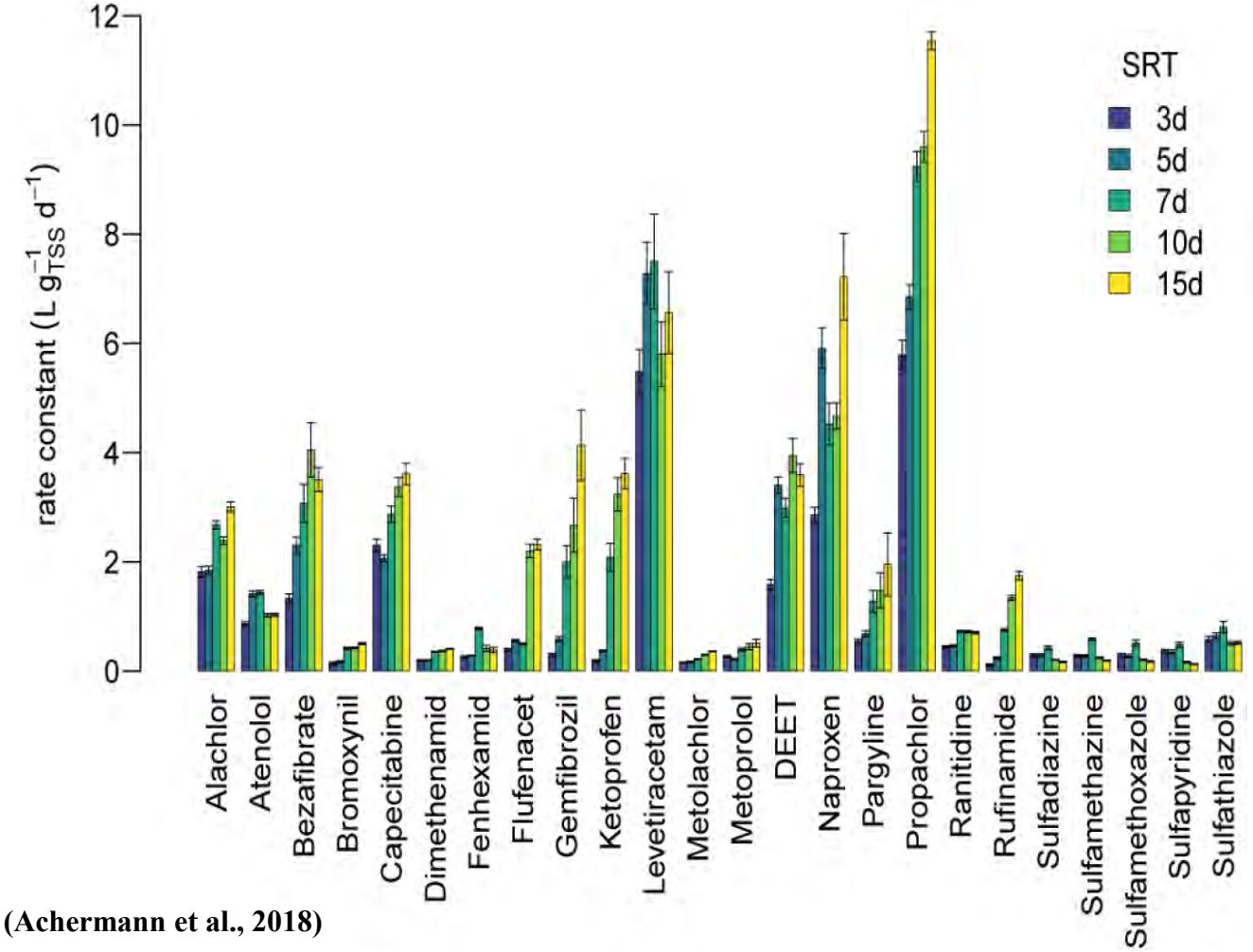
PPCP Knowledge and Gaps

What We 'Know'

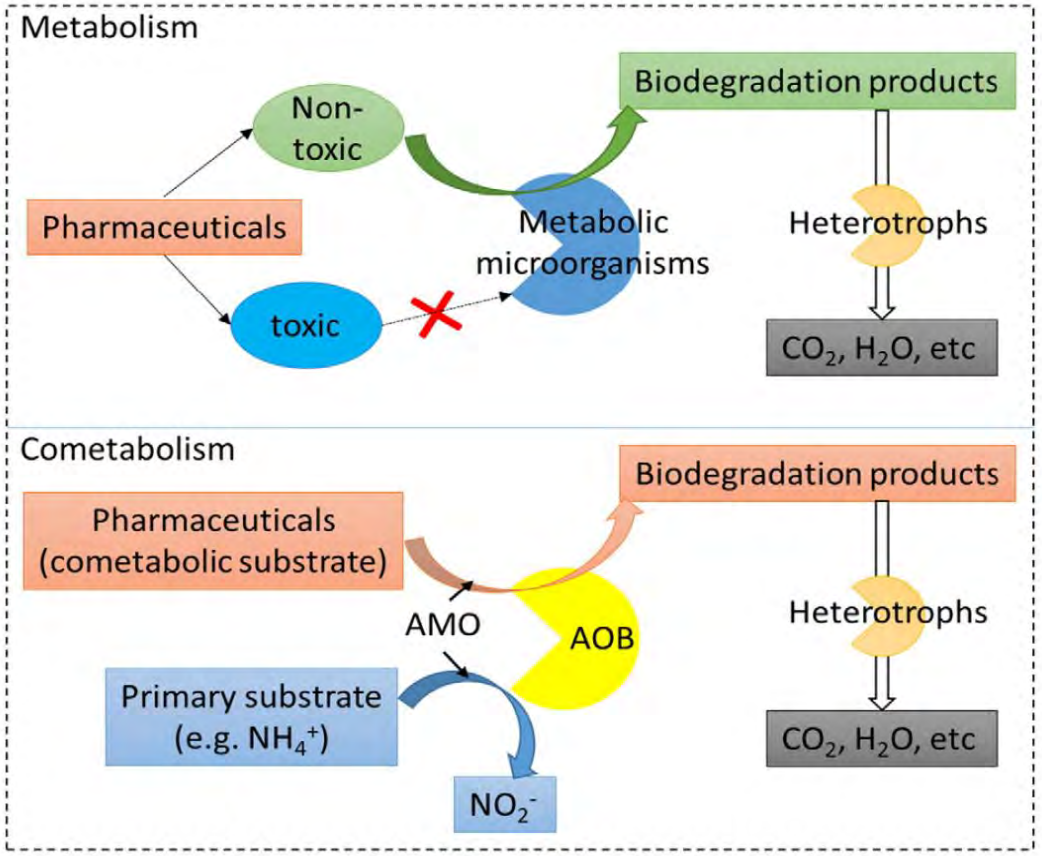
3. PPCP removal is correlated to sludge retention time (SRT) & nutrient removal

Current Gaps

- Is there a 'Sweet Spot'?
- What microbes are responsible for PPCP degradation?



(Achermann et al., 2018)



(Xu, Yuan, & Ni, 2016)

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2. **Research Goals**
3. Methods & Sampling Plan
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Research Goals

Aim

Investigate removal of **21 PPCPs** from **six WWTFs** discharging into the Great Bay in NH based on **(a) treatment process design** and **(b) solids retention time (SRT).**

Hypothesis

There will be a **positive correlation** between the **increase** in overall **PPCP removal** with WWTF's that have **(a) alternating biological treatment zones** (aerobic, anoxic, anaerobic) and **(b) longer SRTs.**

Specific Questions

Detection → 1. What PPCPs are being detected within local WWTFs?

Design → 2. How does WWTF design influence PPCP removal efficiency?

Seasonal Change → 3. Are PPCP concentrations influenced by season?

Occurrence → 4. What is the distribution of PPCP in receiving water bodies (Great Bay Estuary)?

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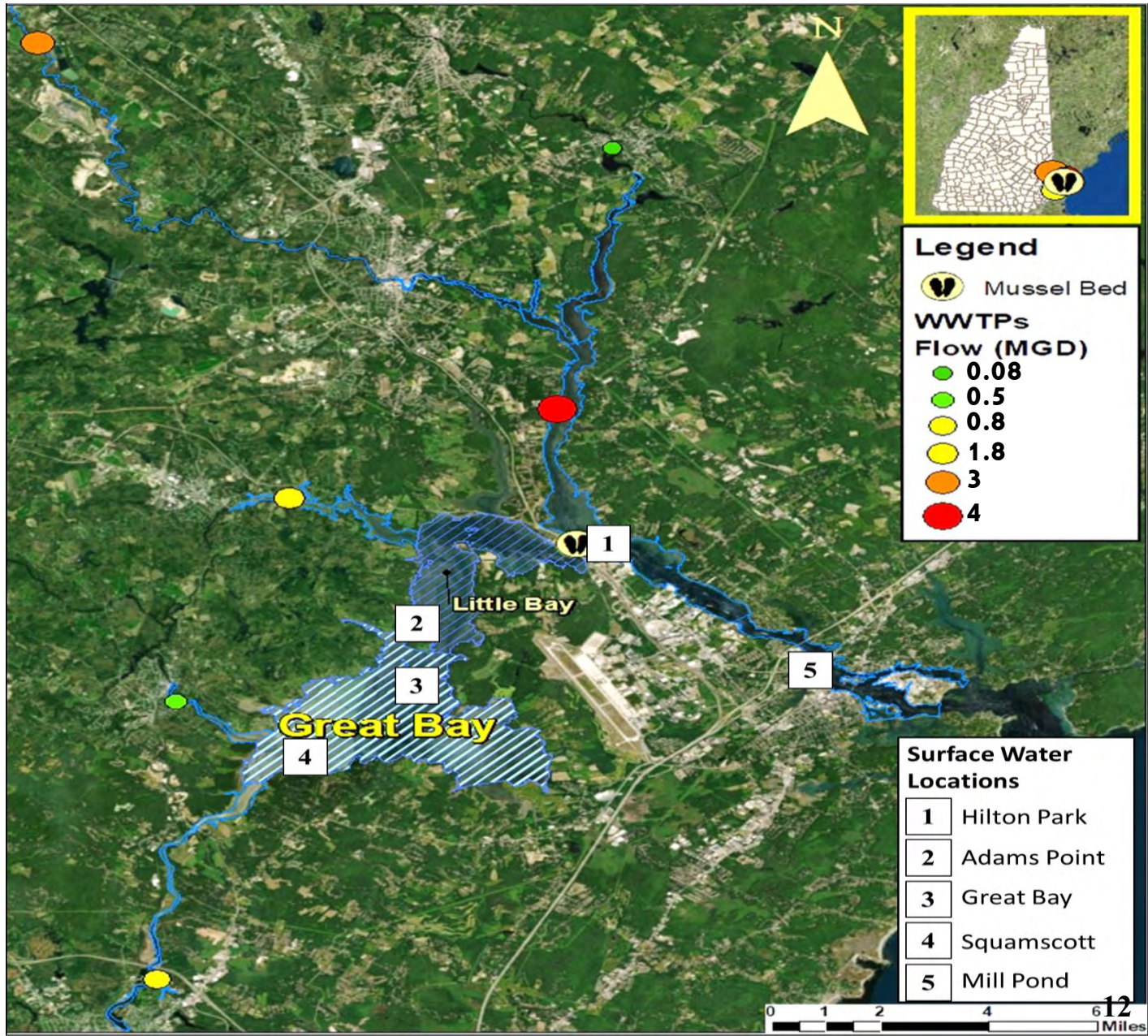
Methods & Sampling Plan

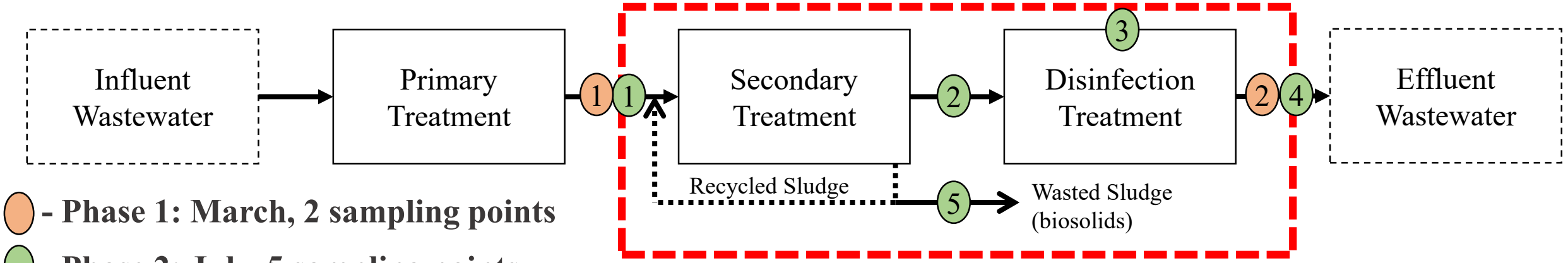
- WWTF approximate locations and flows
- Surface water locations

Phase 1: March
6 WWTF & one surface water

Phase 2: July
4 WWTF & five surface waters



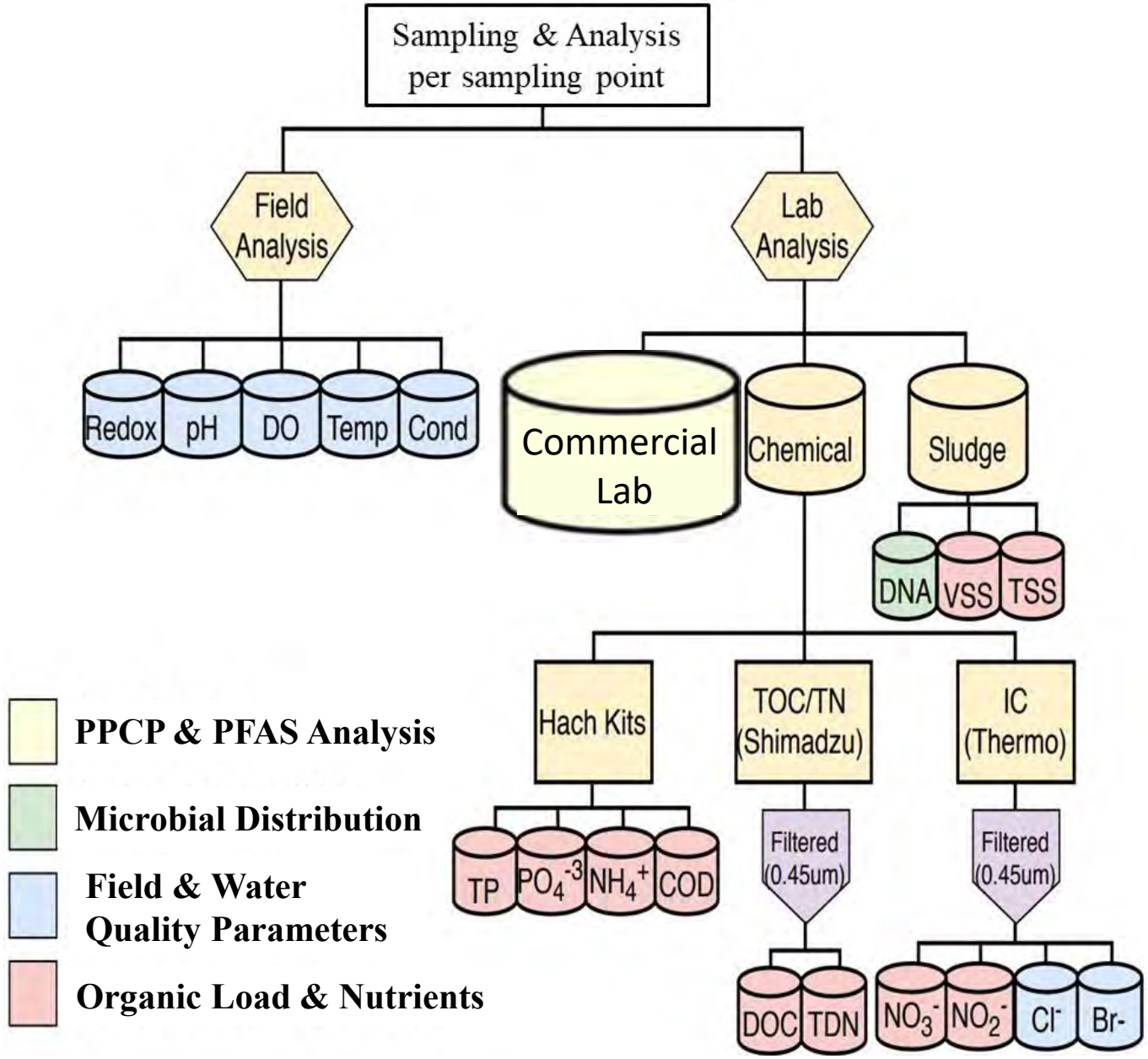
Methods & Sampling Plan



- Phase 1: March, 2 sampling points
- Phase 2: July, 5 sampling points

Methods & Sampling Plan

- Field and Laboratory Analyses Performed
- Commercial Lab used for PPCP analysis: Weck Laboratories, Inc.



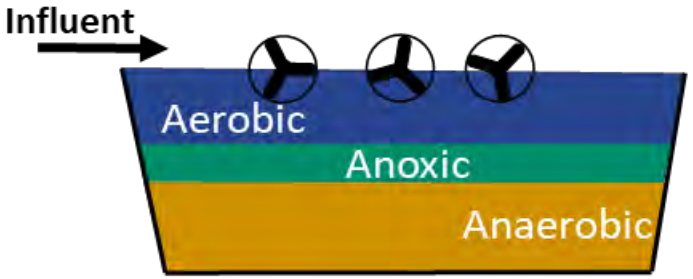
Methods & Sampling Plan

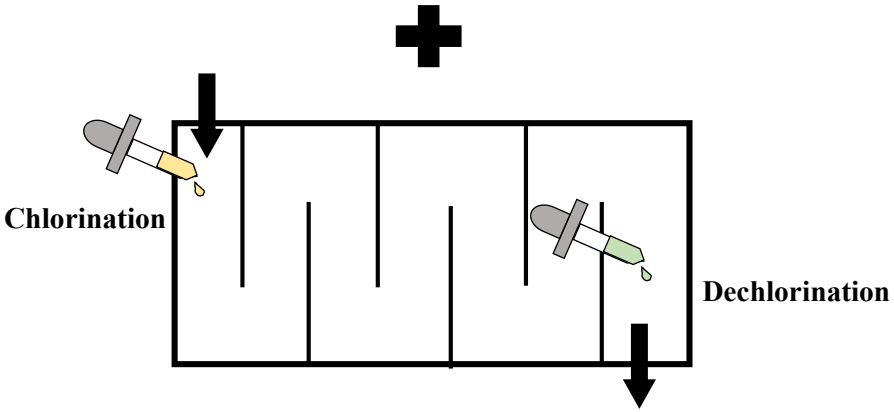
- Acronyms for each WWTF that will be used for the rest of the presentation.
- WWTFs chosen for each season; March vs July.
- Phase – 2 WWTFs were chosen based on having the same disinfection method (acts as a control).

Phase 1 – March	Phase 2 – July
WWTF # 1 → AL + CD	Upgrade* WWTF # 1 → Bar4 + CD (1)
WWTF # 2 → Bar4 + CD (2)	WWTF # 2 → Bar4 + CD (2)
WWTF # 3 → Bar4 + CD (3)	WWTF # 3 → Bar4 + CD (3)
WWTF # 4 → AS + UV (1)	
WWTF # 5 → OD + CD	WWTF # 5 → OD + CD
WWTF # 6 → AS + UV (2)	

Methods & Sampling Plan

Aerated Lagoon (AL)





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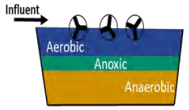
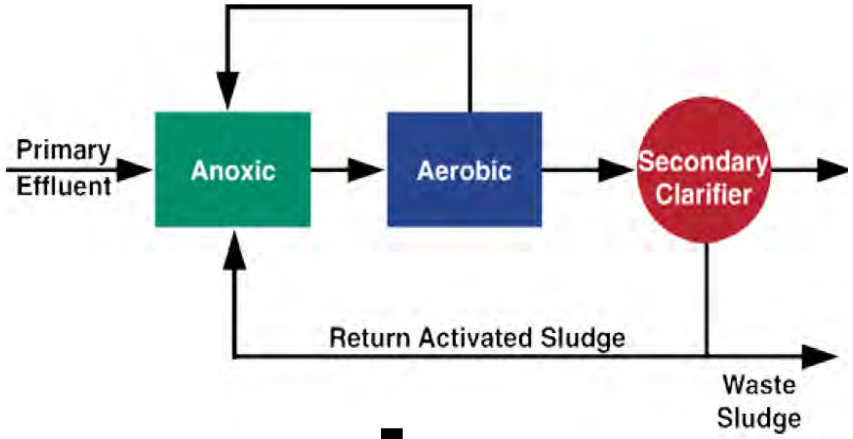
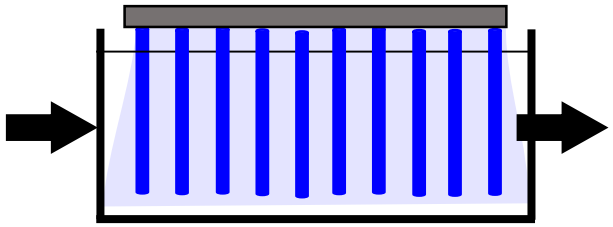
Worst Removal ——— *Assumption* ———→ Best Removal



Methods & Sampling Plan

Activated Sludge (AS)





Ultraviolet light

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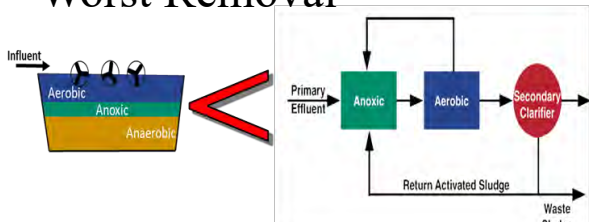
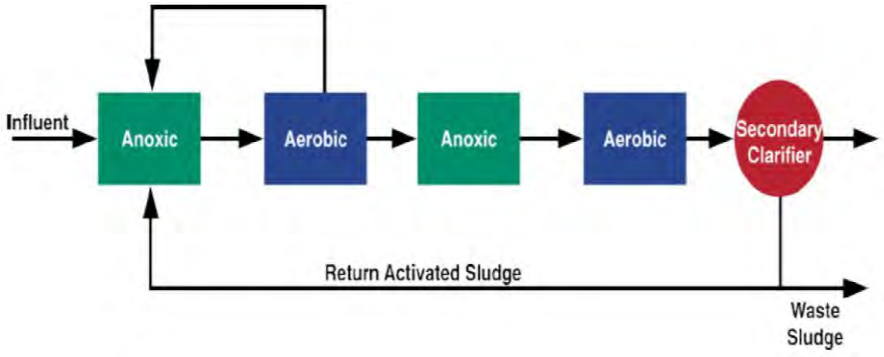
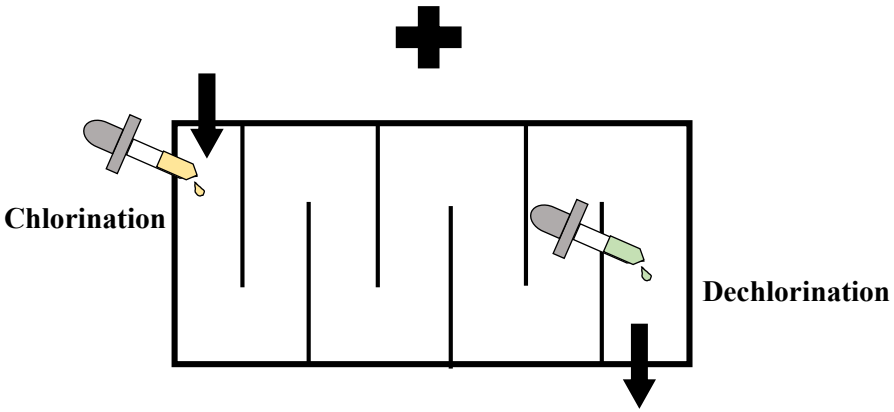
Worst Removal ——— *Assumption* ———→ Best Removal



Methods & Sampling Plan

4-Stage Bardenpho **(Bar4)**





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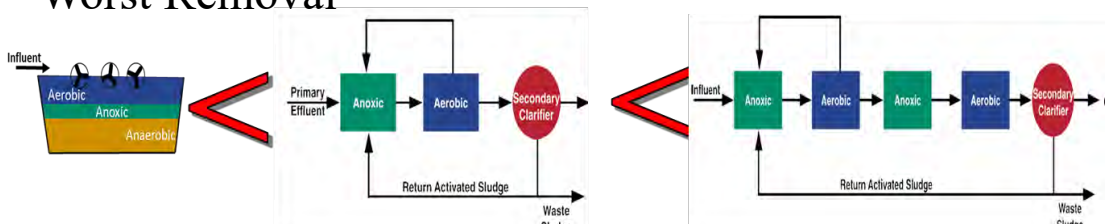
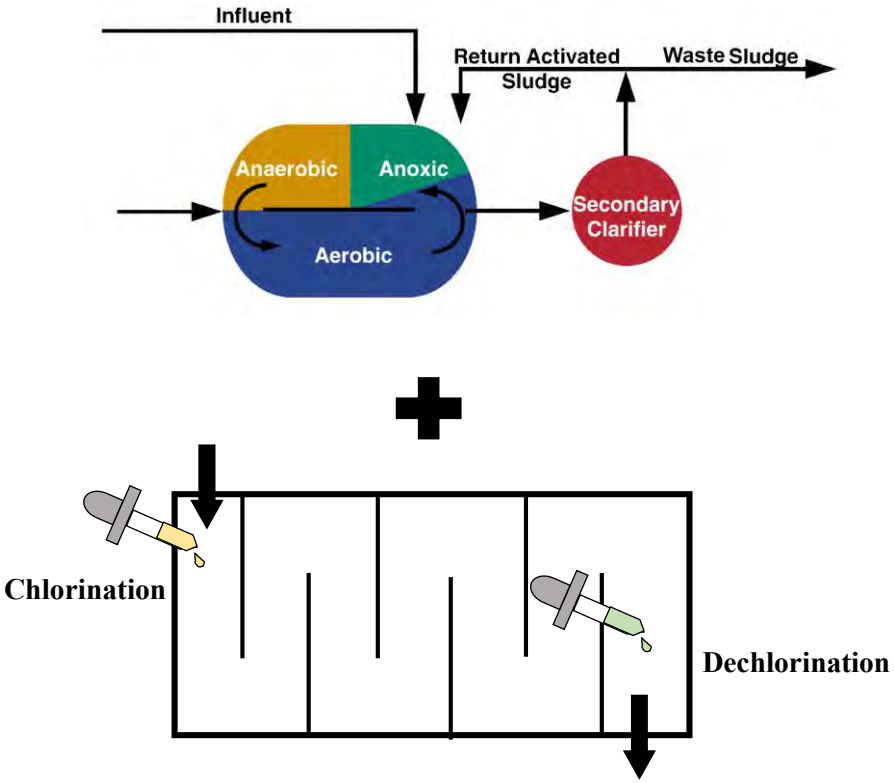


Methods & Sampling Plan

Oxidation Ditch **(OD)**



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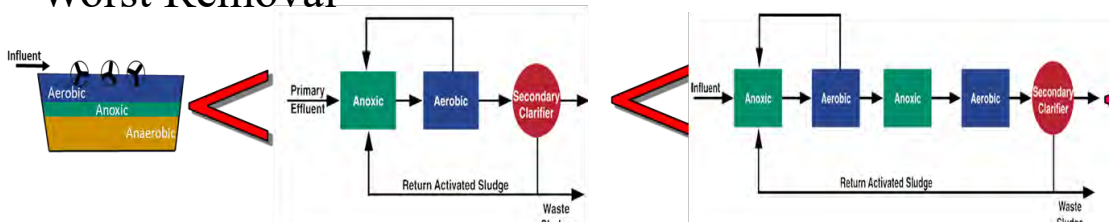
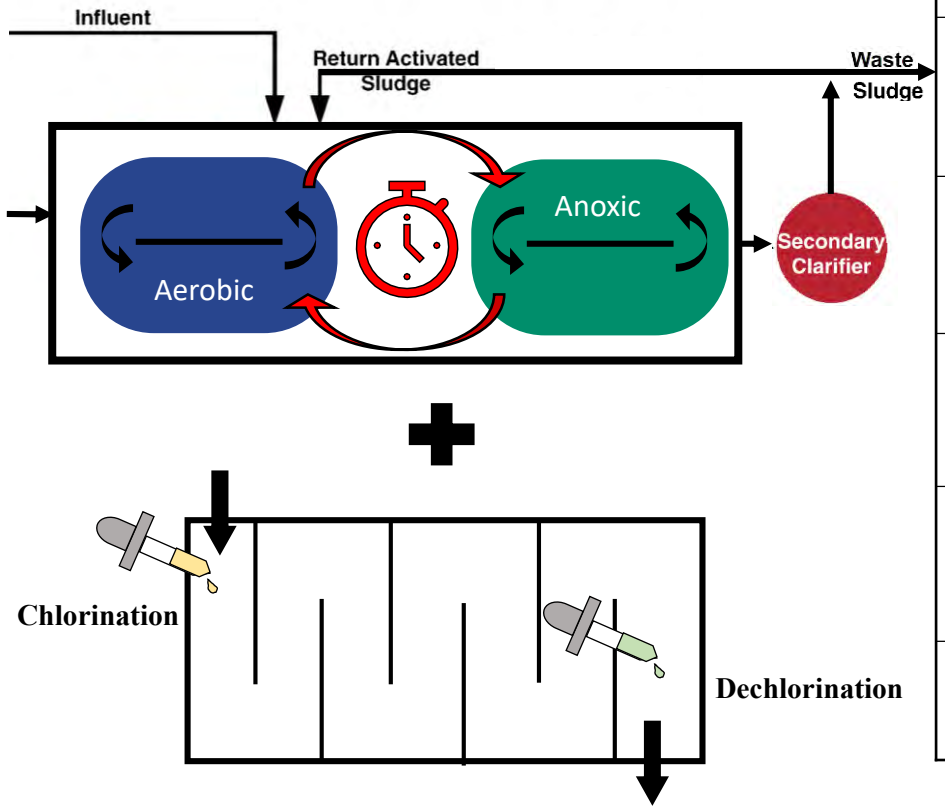


Methods & Sampling Plan

Oxidation Ditch (OD)



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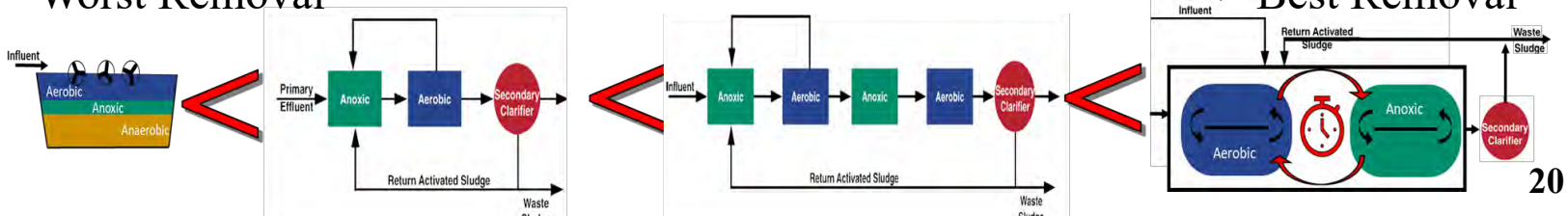
Worst Removal *Assumption* Best Removal



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PPCP Detection

Compound Class		General Name	Removal Trends	AL+CD : March Bar-4 +CD_1 : July				Bar-4 +CD_2				Bar-4 +CD_3				AS + UV_1		OD + CD				AS + UV_2	
				Influent		Effluent		Influent		Effluent		Influent		Effluent		March		Influent		Effluent		March	
				March	July	March	July	March	July	March	July	March	July	March	July	Infl	Effl	March	July	March	July	Infl	Effl
Pharmaceuticals	Analgesic	Acetaminophen*	High																				
	Antibiotic	Amoxicillin	Med.																				
		Azithromycin	Low																				
		Ciprofloxacin*	High																				
		Sulfamethoxazole*	High																				
		Trimethoprim*	Med.																				
	Anti-convulsant	Carbamazepine*	Low																				
		Phenytoin	Low																				
		Primidone	Low																				
	B-blocker	Atenolol*	Med.																				
	Narcotic	Methadone	Low																				
	Sedative	Diazepam*	Low																				
		Meprobamate	Low																				
	SSRI	Fluoxetine*	Med.																				
	Statin	Atorvastatin	Med.																				
Personal Care Products	Flame retardants	TCEP*	High																				
		TCPP*	Low																				
		TDCPP	Low																				
	Insecticide	DEET*	High																				
	Stimulant	Caffeine*	High																				
	Tobacco metabolite	Cotinine*	High																				

Detection Legend:

	Non-Detect
	Detected
	In > Eff
	In < Eff

* Frequently Detected in the environment

- **March:** On average detected **19 PPCPs** in Influent and Effluent
- **July:** On average detected **18 PPCPs** in **Influent** and **16** in **Effluent**
- **15 PPCPs increased** from Influent to Effluent at least once

PPCP Detection

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				Influent		Effluent		Influent		Effluent		Influent		Effluent		March		Influent		Effluent		March	
				March	July	March	July	March	July	March	July	March	July	March	July	Infl	Effl	March	July	March	July	Infl	Effl
Pharmaceuticals	Analgesic	Acetamin*ophen*	High																				
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	Tobacco metabolite	Cotinine*	High																				

Caveats:

1. **Sampling method (grab samples not very representative)**
2. **Analytical issues (detection limits & laboratory blank contamination)**
3. **Matrix issue ('dirty' influent & 'cleaner' effluent)**

Detection Legend:

	Non-Detect
	Detected
	In > Eff
	In < Eff

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				Influent		Effluent		Influent		Effluent		Influent		Effluent		March		Influent		Effluent		March							
				March	July	March	July	March	July	March	July	March	July	March	July	Infl	Effl	March	July	March	July	Infl	Effl	Hilton Park (Mar.)	Hilton Park (July)	Mill Pond (Aug.)	Adams Point (Aug.)	Great Bay (Aug.)	Squam-scott (Aug.)
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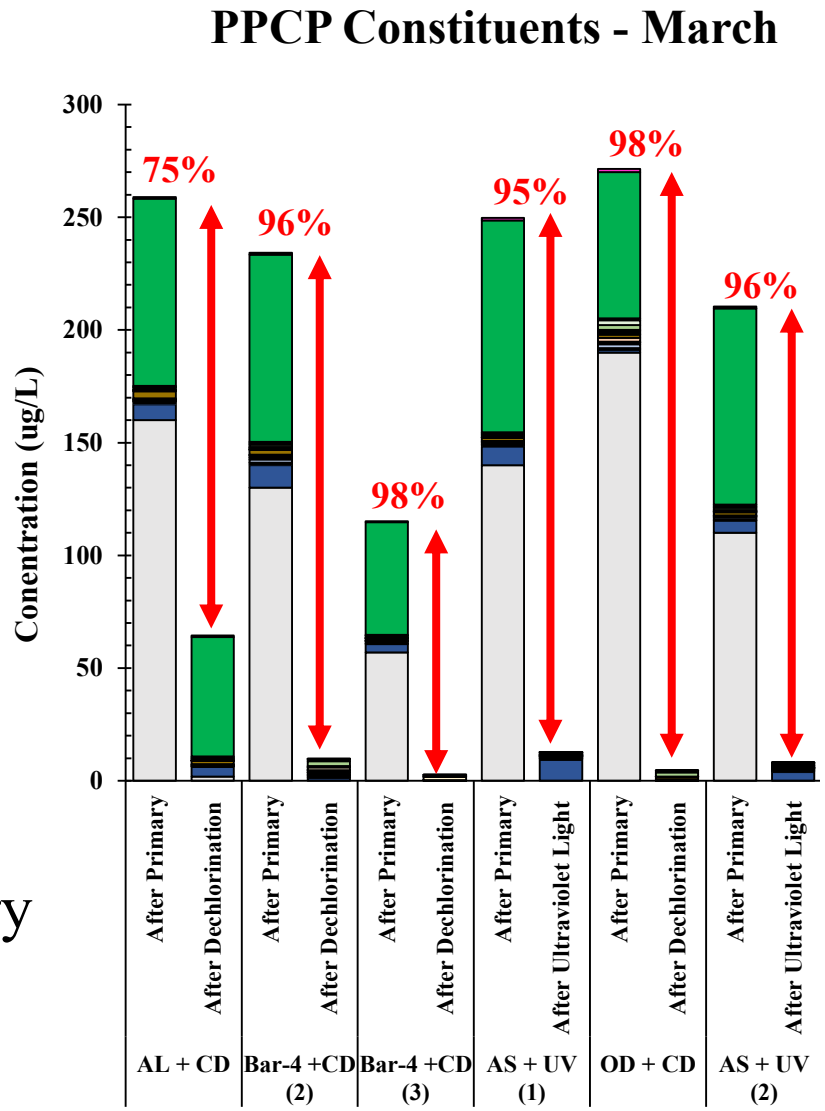
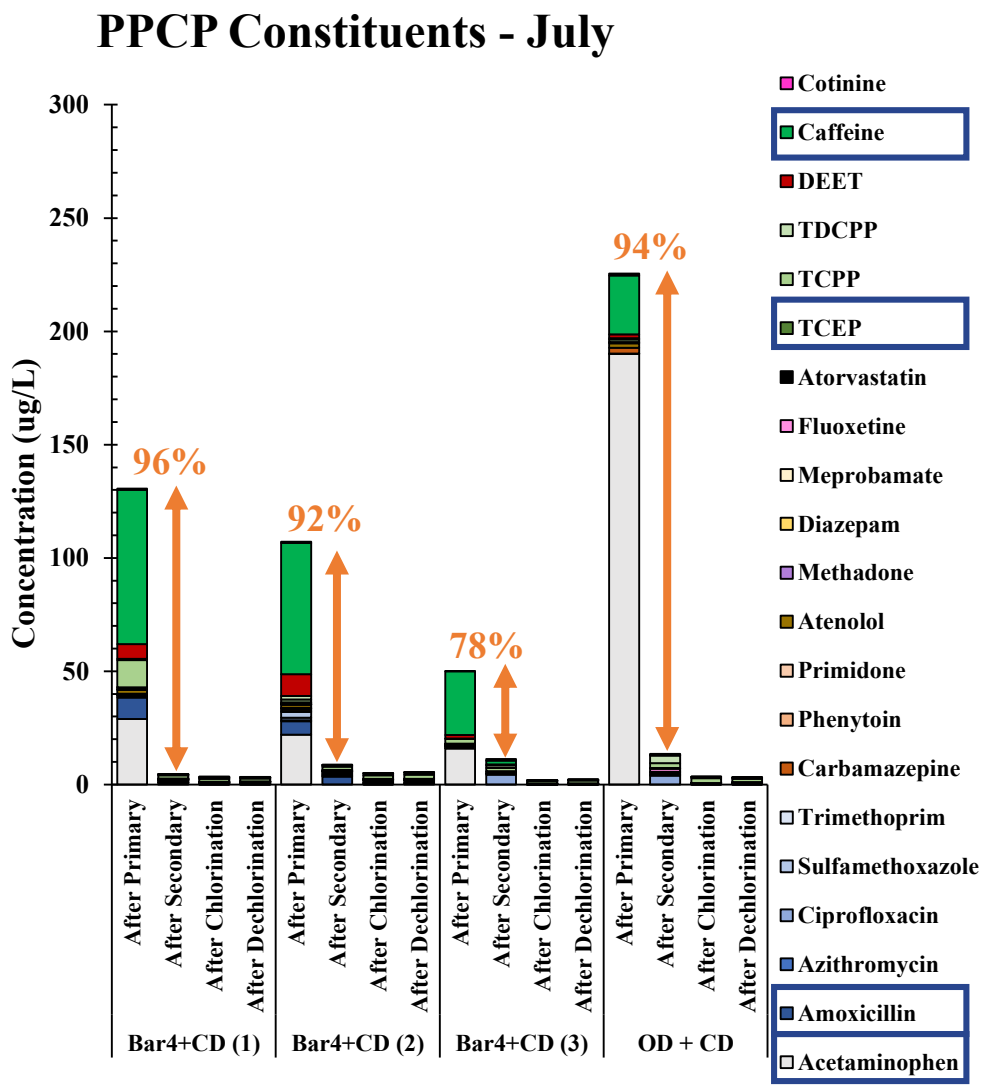
	Stimulant	Caffeine*	High																										
	Tobacco metabolite	Cotinine*	High																						X			X	X

14 PPCPs Detected In Great Bay

PPCP Distribution

- An Analgesic, Antibiotic, Stimulant and Fire retardant were dominant constituents in Influent for both seasons.
- Overall, **good removal** across all WWTFs.
- PPCP concentrations **decreased** after secondary treatment indicating biodegradation as a primary mechanism for removal.

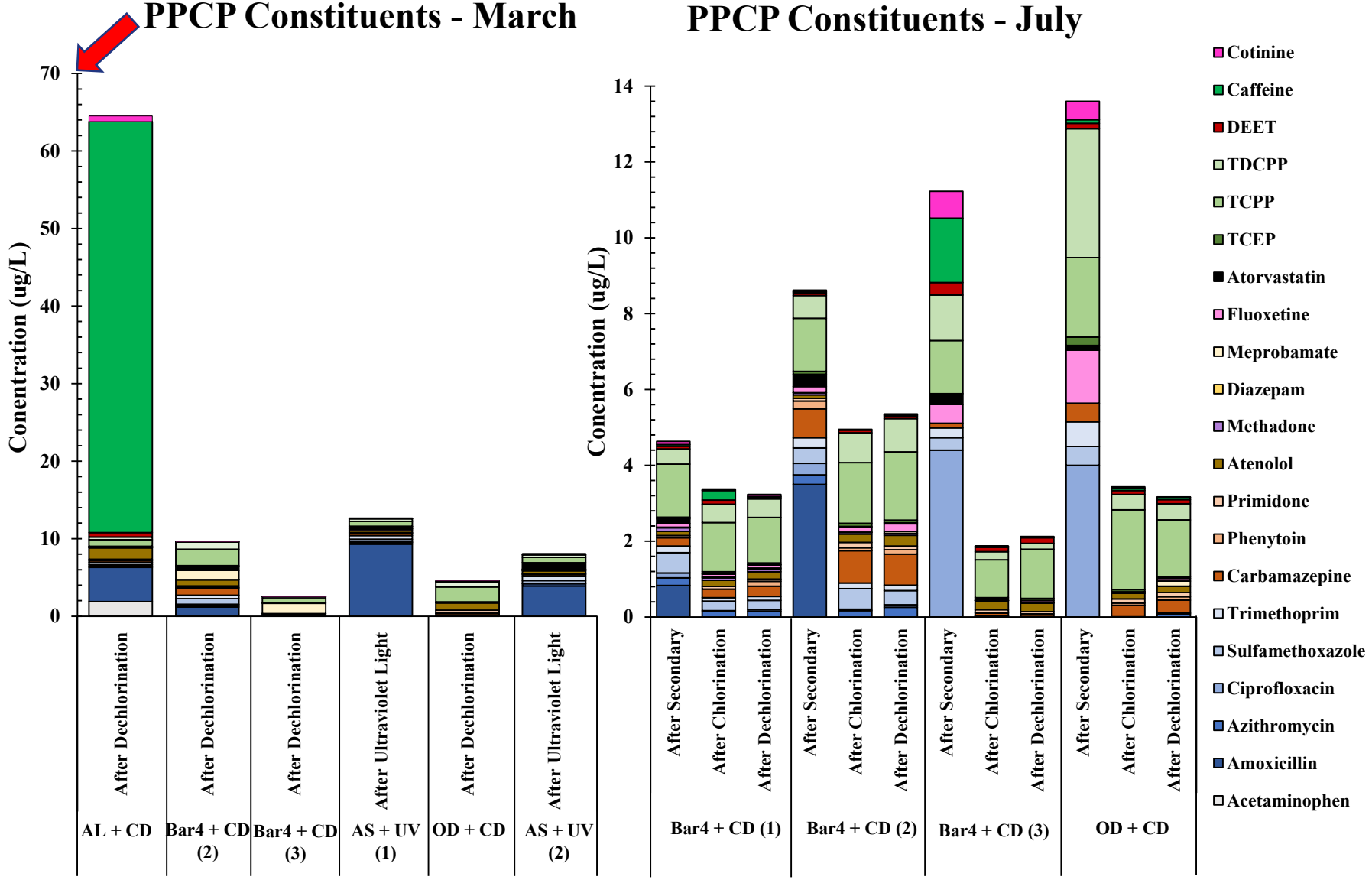




PPCP Distribution

Excluding 'After Primary'

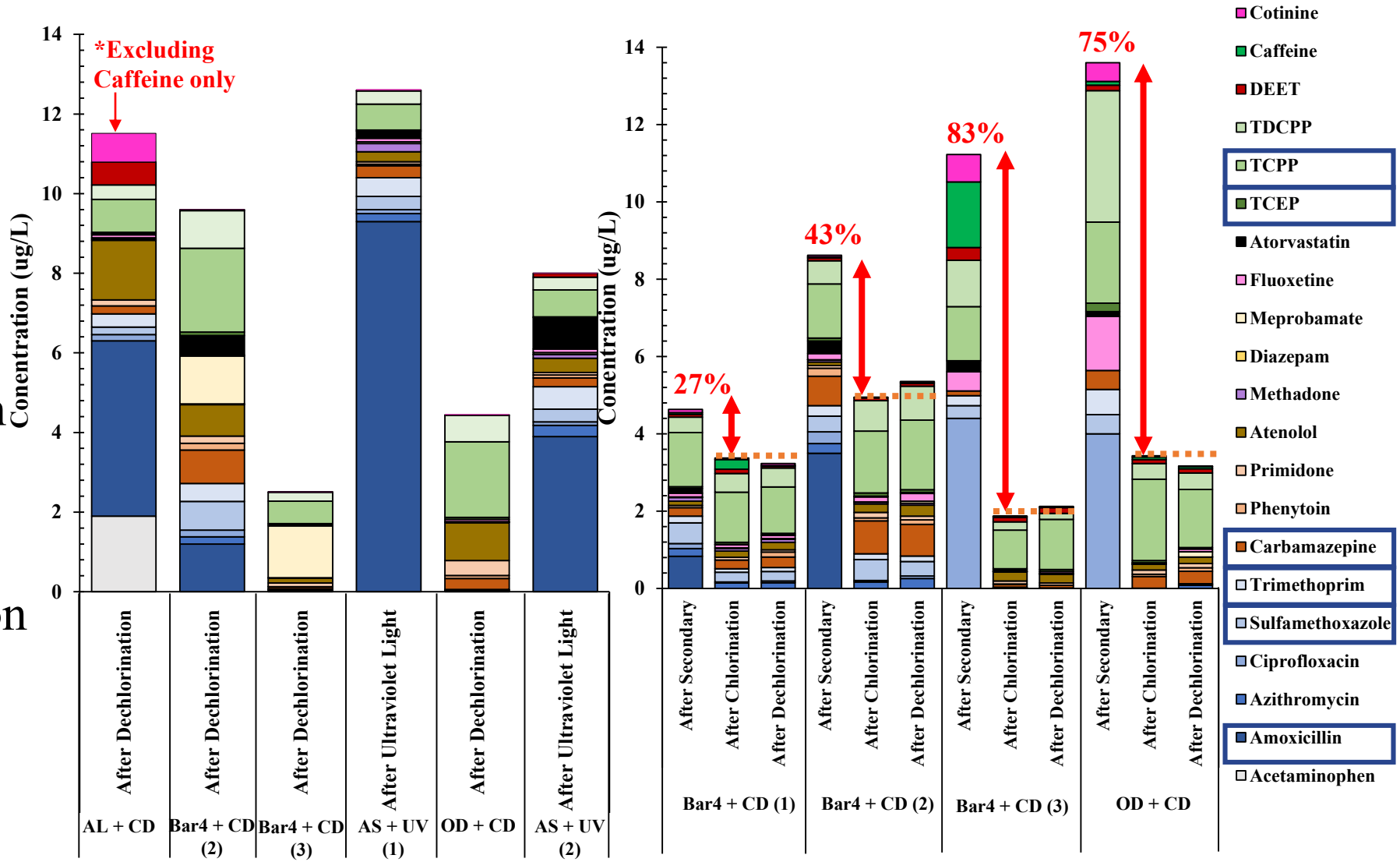
- Caffeine was not well removed from AL which results in a higher y-axis
- Exclude value to visualize bars better.



PPCP Distribution

Excluding 'After Primary'

- Antibiotics, Anticonvulsant and Fire retardants were dominant constituents in Effluent for both seasons.
- PPCP concentrations **decreased** after chlorination indicating further oxidation.
- **Little to no change** from chlorination to dechlorination
- In general, July's **concentrations** were less than March, but it was not **significantly different.**



PPCP Distribution

Sludge Concentrations:

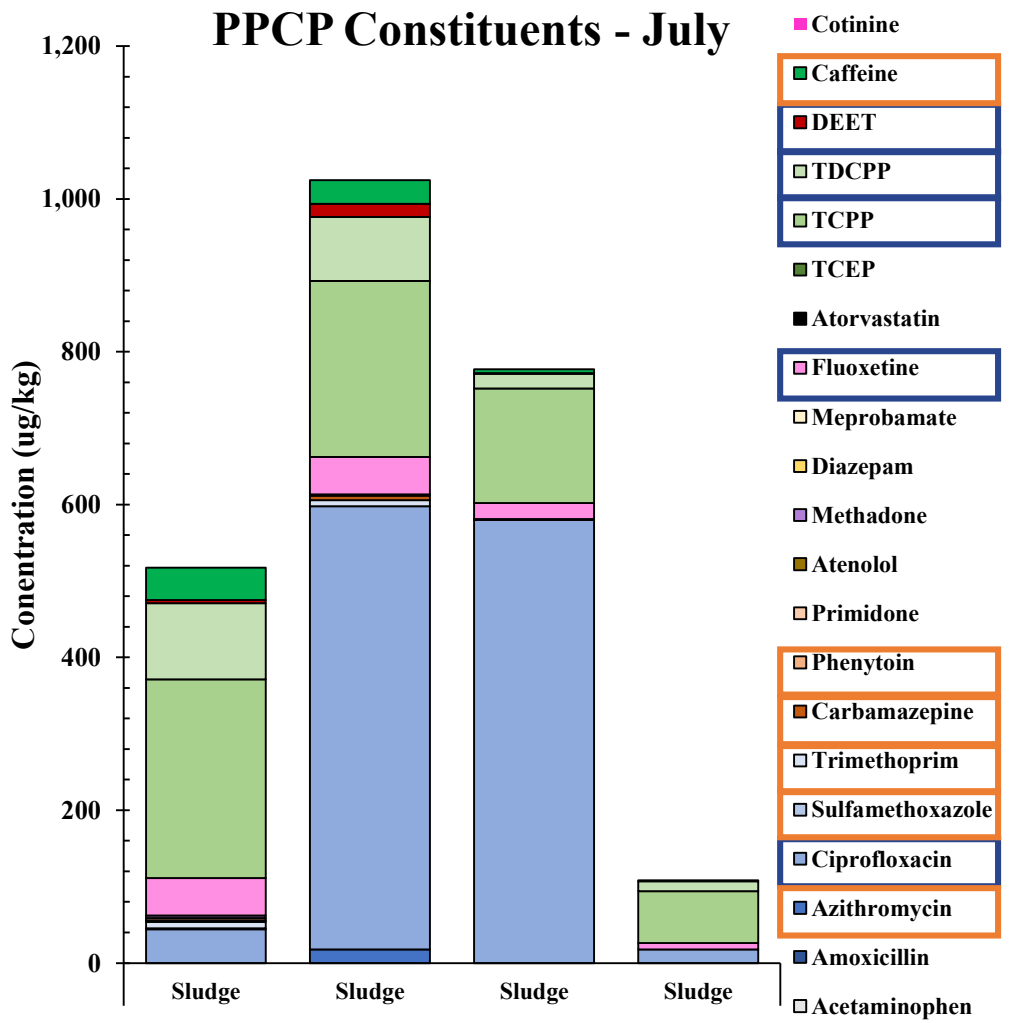
- An Antibiotic, Insecticide, SSRI and Fire retardants were detected within sludge across all 4 WWTFs.
- In general, less PPCP detection within sludge (11of 21)

Detection at each sampling point:

March Sampling	AL + CD	Bar-4 +CD (2)	Bar-4 +CD (3)	AS + UV (1)	OD + CD	AS + UV (2)
After Primary	19	20	17	19	17	19
After Dechlorination	18	20	18	19	18	20

July Sampling	Bar4+CD (1)	Bar4+CD (2)	Bar4+CD (3)		OD + CD	
After Primary	19	20	20		12	
After Secondary	19	19	11		12	
After Chlorination	17	17	17		15	
After Dechlorination	18	18	13		16	
Sludge	11	10	7		5	

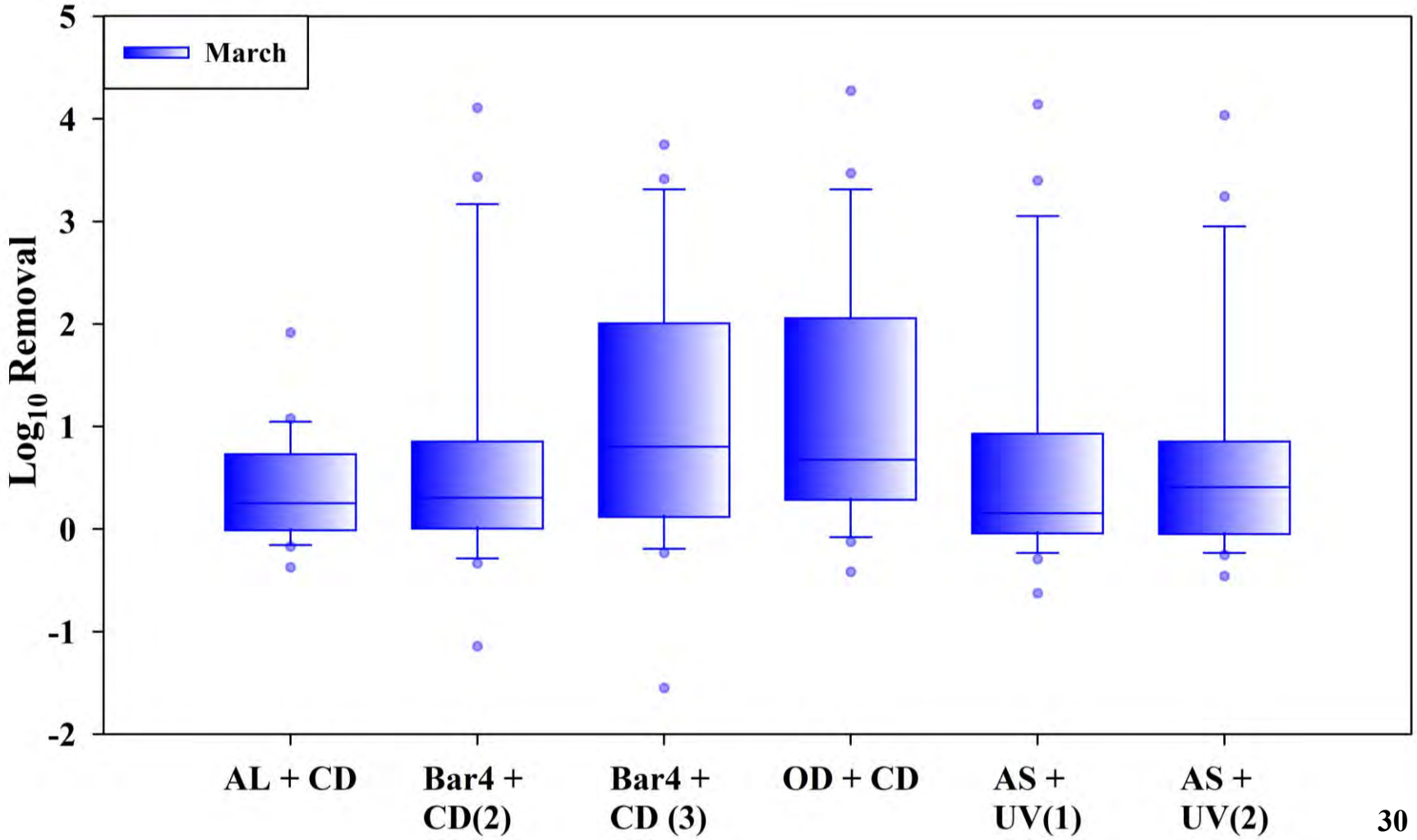
- No clear increasing or decreasing trend for PPCPs detected within each stage of the treatment train.



PPCP Fate

- In general, there is **NO significant difference** in **Log Removal** comparing all the WWTFs.
- Individually, there **IS** a **significantly difference** when comparing **AL** to **Bar4 (3) & OD.**

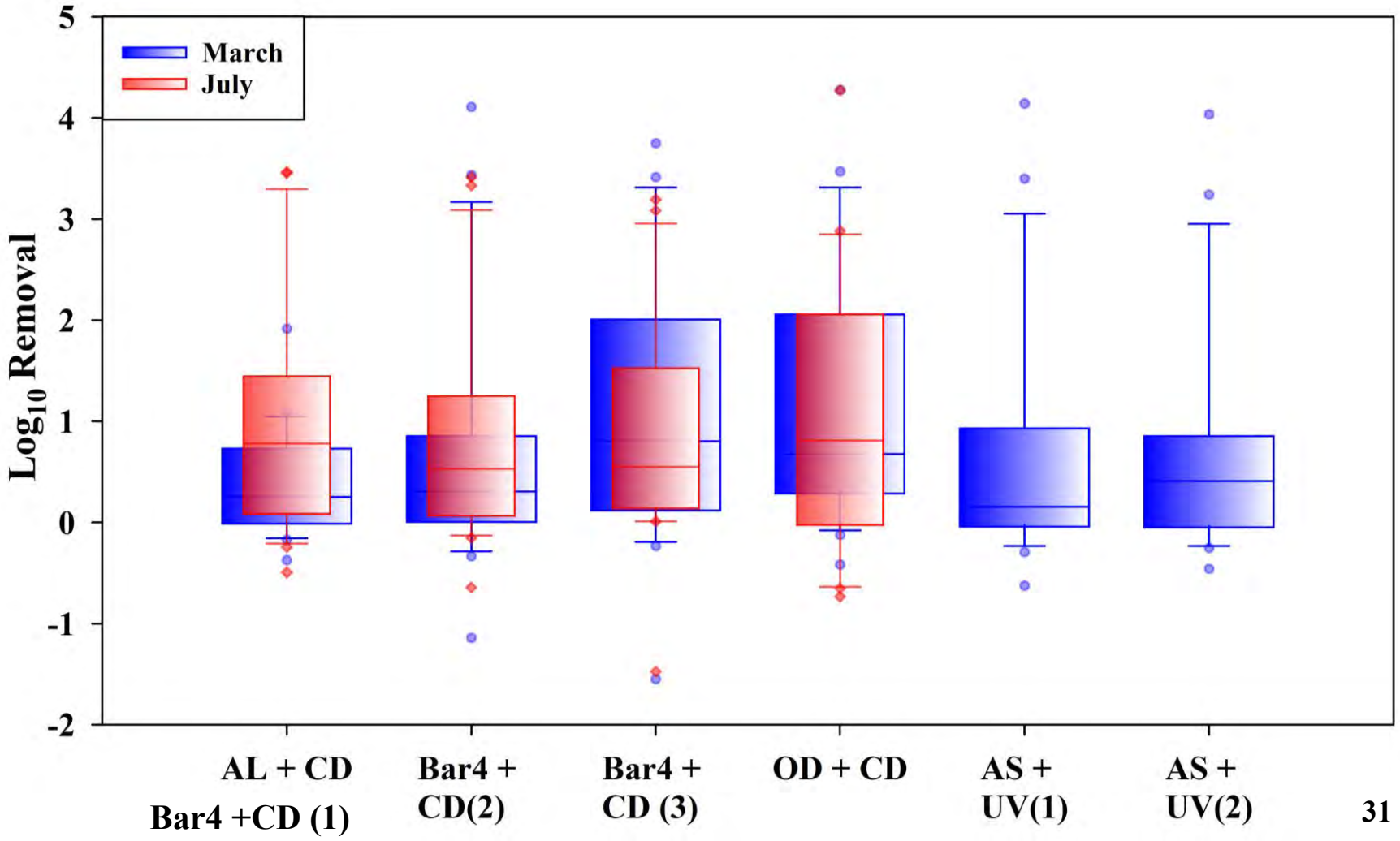
WWTF	March Mean Log Removal
AL + CD	0.37
Bar4 + CD(2)	0.69
Bar4 + CD(3)	1.10
OD + CD	1.25
AS + UV (1)	0.67
AS + UV (2)	0.67



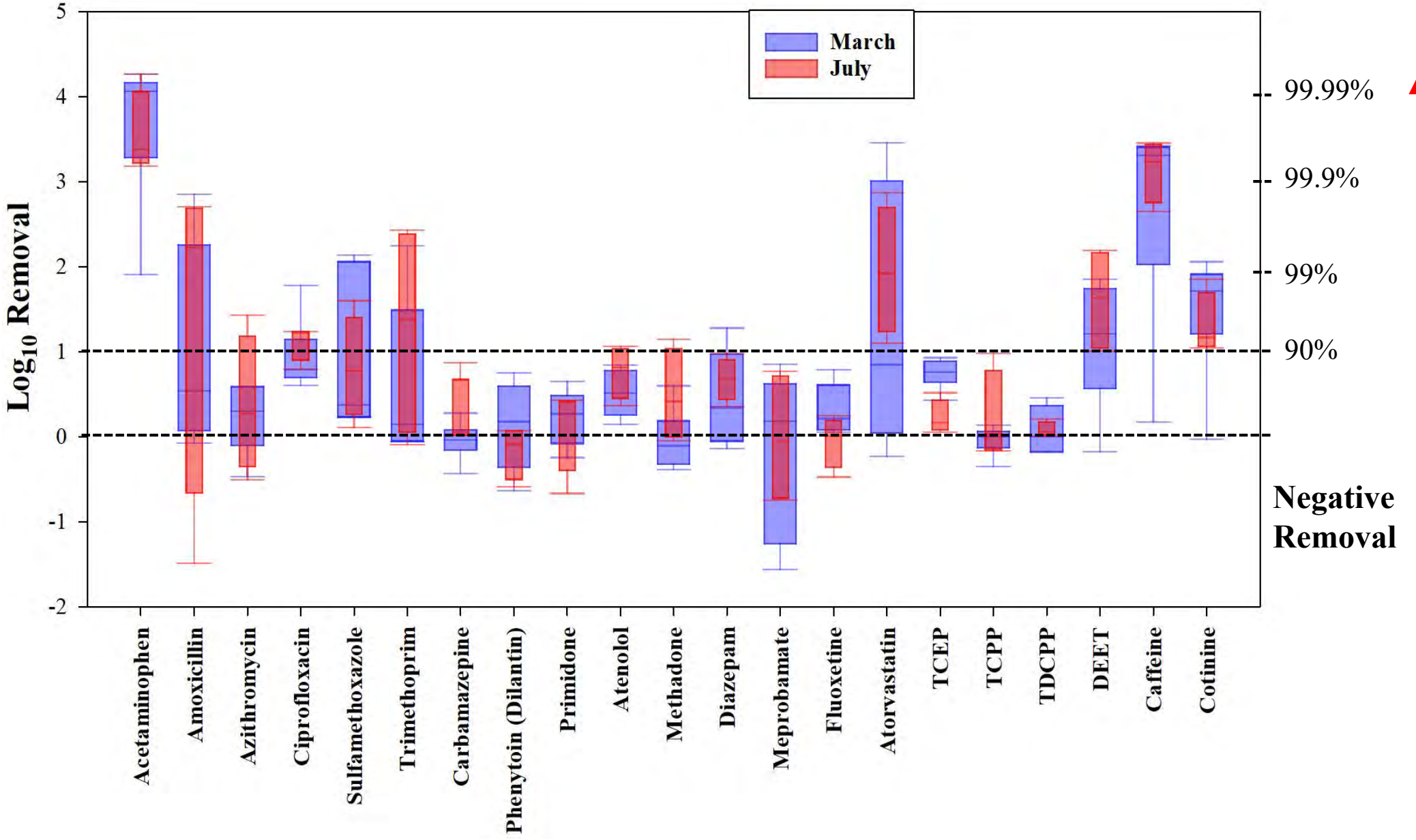
PPCP Fate

- In general, there is **NO significant difference** in **Log Removal** comparing all the WWTFs.
- However, there **IS** a **significantly difference** when comparing the upgrade from **AL to Bar (1).**

WWTF	March Mean Log Removal	July Mean Log Removal
AL + CD Bar4 + CD(1)	0.37	0.95 ↑
Bar4 + CD(2)	0.69	0.85 ↑
Bar4 + CD(3)	1.10	0.91 ↓
OD + CD	1.25	1.03 ↓
AS + UV (1)	0.67	
AS + UV (2)	0.67	



PPCP Fate



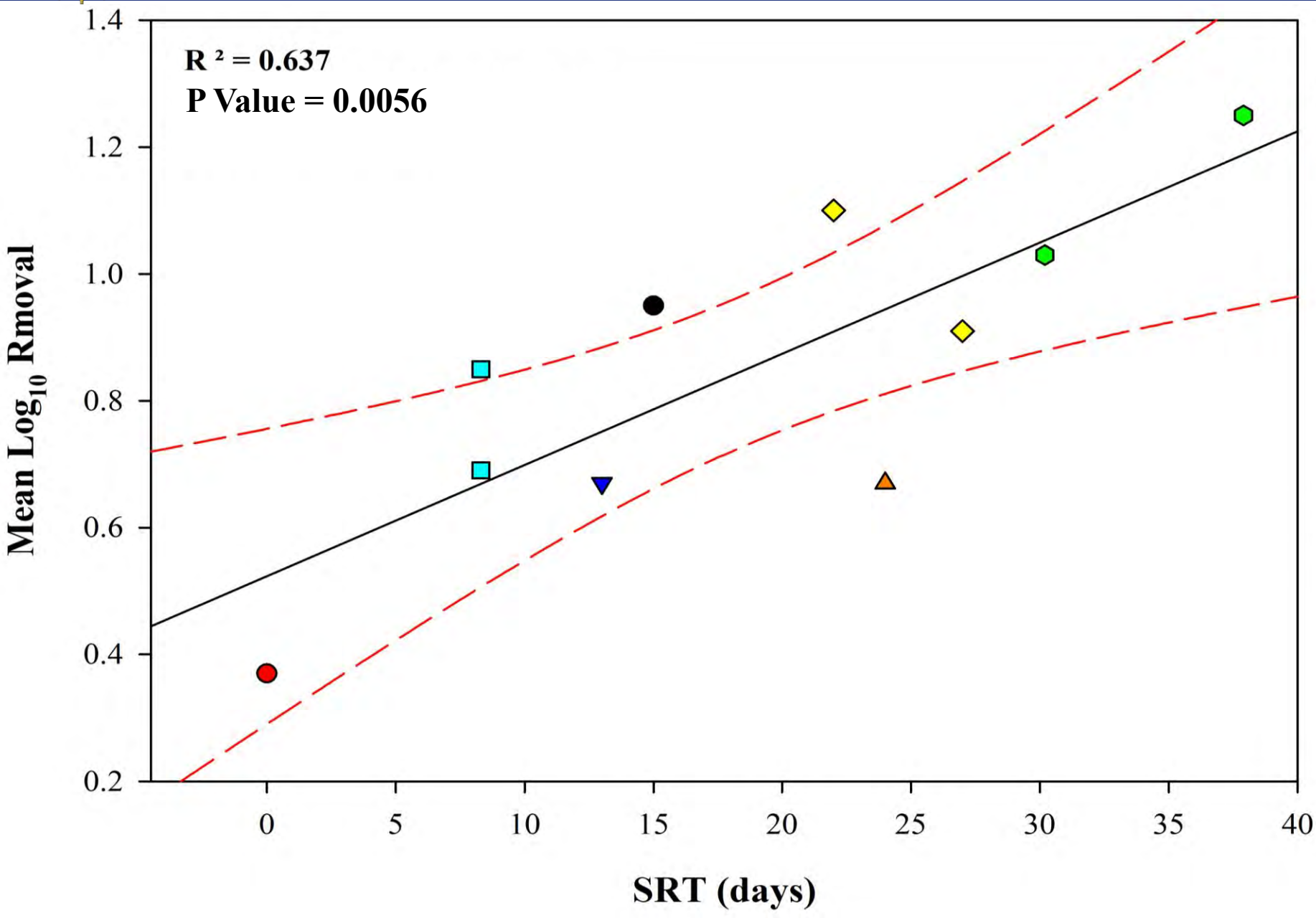
12 PPCPs resulted in **1-log removal+** at least once across the WWTFs.

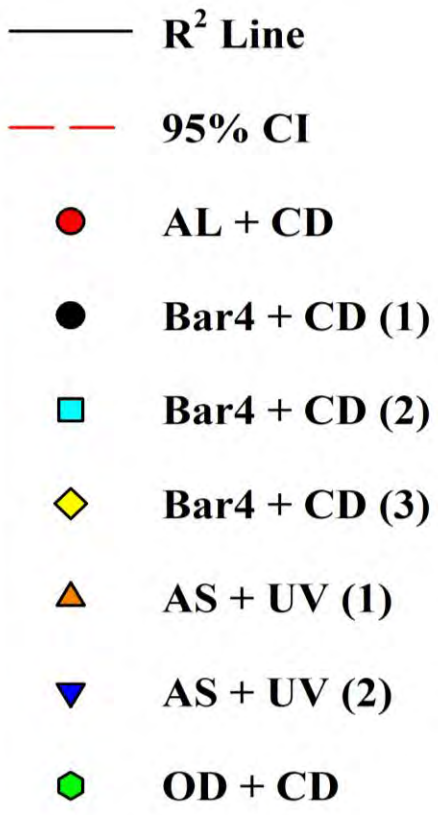
PPCP Fate

Operational Conditions and Water Quality Parameters

WWTFs	BOD Removal	TSS Rmoval	TDN Removal	SRT (days)	pH	Cond. (uS/cm)	DO (mg/L)	REDOX (mV)	Temp (C°)
Phase 1: March									
AL + CD	86.0	81.0	23.3	-	7.4	1,152	8.0	-25.5	7.0
Bar4 + CD (2)	97.5	98.0	74.7	8.3	7.5	1,509	8.5	-27.6	10.3
Bar4 + CD (3)	95.8	95.8	77.8	22.0	7.2	1,388	6.7	-10.8	10.3
AS + UV (1)	98.2	99.7	76.8	24.0	7.4	1,130	7.8	-22.5	9.4
OD + CD	100.0	100.0	95.8	37.9	7.4	1,206	6.4	-26.6	9.7
AS +UV (2)	98.3	98.1	80.6	13.0	7.0	1,470	4.9	-2.5	10.3
Phase 2: July									
Bar4 + CD (1)	96.9	99.4	87.8	15.0	7.0	795.7	4.0	-4.0	22.3
Bar4 + CD (2)	99.1	99.4	94.5	8.3	7.1	897.8	4.7	-7.0	23.5
Bar4 + CD (3)	93.7	99.7	95.1	27.0	6.8	738.1	3.6	6.5	23.8
OD + CD	99.0	100.0	75.6	30.2	7.3	798.6	3.3	-16.9	22.0

PPCP Fate





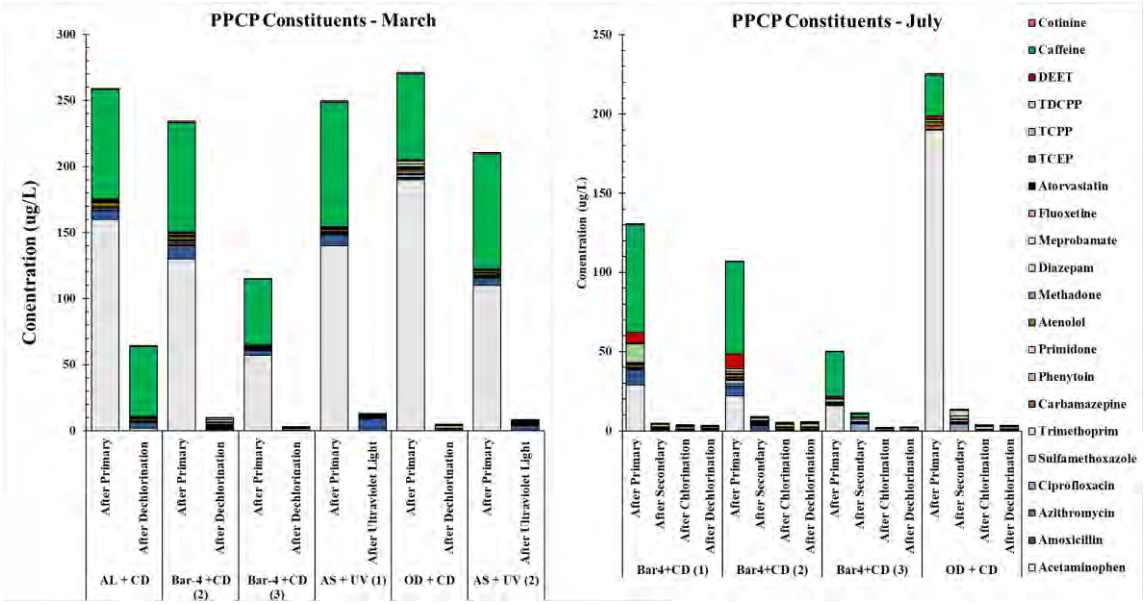
Correlation

Log Removal vs SRT

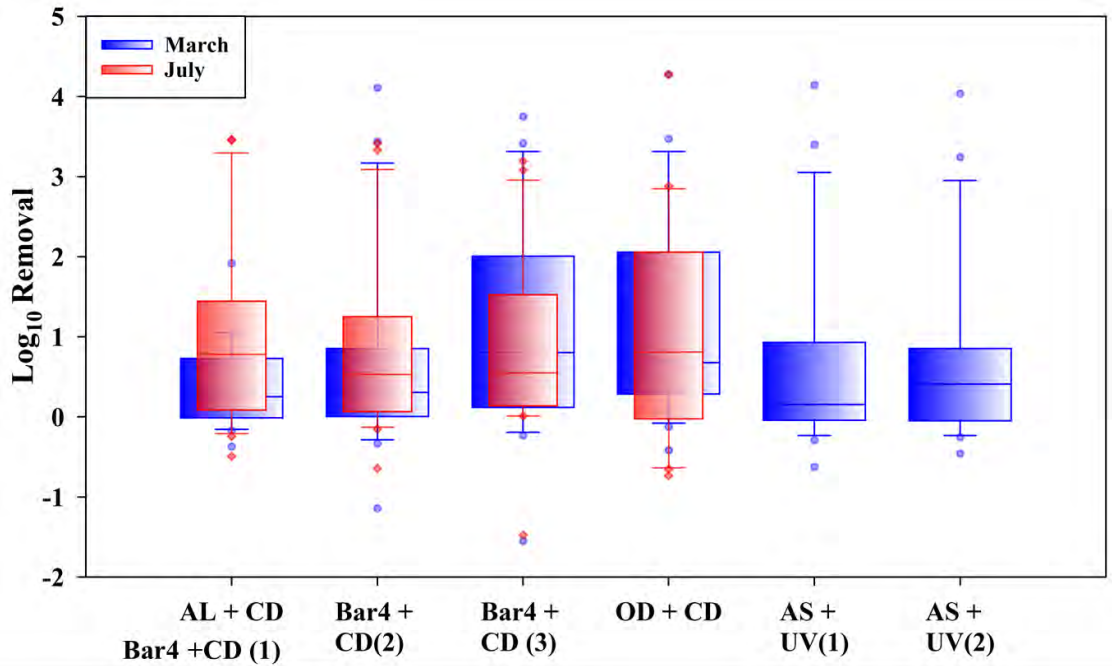
- Positive
- Strong

PPCP Seasonal Variation

- In general, there is **NO significant difference** in for influent and effluent **Concentrations** across both seasons.



- In general, there is **NO significant difference** in overall PPCP **Log Removal** across both seasons except for WWTF#1 that upgraded from an AL to Bar4 system.



Key Points – PPCP

Detection

- **All 21 PPCPs** were detected either in the influent, effluent, or both at each WWTF.
- **Antibiotics** and **Fire retardants** were **dominant** in the influent, effluent, and sludge samples.

Design

- **Enhanced biological** treatment with alternating zones **lead to higher PPCP removal**.
- In this case, a **longer SRT positively correlated** with **higher PPCP removal,** but with this limited data set it is currently unclear if this relationship is holds true.

Seasonal Change

- **No**, influent and effluent **concentrations** and **removal** did not change significantly from March to July (except WWTF#1).

Occurrence

- **9 out of 14 PPCPs detected** within the Great Bay, were listed as 'most frequently detected' in surface waters.
- All **6 personal care products** (3 fire retardants) and all **5 Antibiotics** were detected which relates to the dominant constituents in the effluent.

Outline

1. PPCP Background & Knowledge Gaps
2. Research Goals
3. Methods & Sampling Plan
4. PPCP Results & Preliminary Conclusions
5. **Next Steps**
6. Acknowledgments
7. References

Next Step

1. Determine what parameters could be influence results the most:
    - Operational conditions
    - Water quality parameters
    - PPCP characteristics / properties
    - Analytical / sampling methods

2. Work on mass balance calculations and incorporate sludge data:
    - Most recent sludge produced and wasted data. (In = Out)?

3. Determine the microbial abundance for each facility:
    - Identify the similarities and differences across all facilities

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Sea Grant New Hampshire

NOAA

University of New Hampshire

NSF

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References

1. Achermann, S., Bianco, V., Mansfeldt, C. B., Vogler, B., Kolvenbach, B. A., Corvini, P. F. X., & Fenner, K. (2018). Biotransformation of Sulfonamide Antibiotics in Activated Sludge: The Formation of Pterin-Conjugates Leads to Sustained Risk. *Environmental Science & Technology*, *52*(11), 6265–6274. https://doi.org/10.1021/acs.est.7b06716
2. Achermann, S., Falås, P., Joss, A., Mansfeldt, C. B., Men, Y., Vogler, B., & Fenner, K. (2018). Trends in Micropollutant Biotransformation along a Solids Retention Time Gradient. *Environmental Science & Technology*, *52*(20), 11601–11611. https://doi.org/10.1021/acs.est.8b02763
3. Arpin-Pont, L., Bueno, M. J. M., Gomez, E., & Fenet, H. (2016). Occurrence of PPCPs in the marine environment: A review. *Environmental Science and Pollution Research*, *23*(6), 4978–4991.
4. De Voogt, P., Janex-Habibi, M.-L., Sacher, F., Puijker, L., & Mons, M. (2009). Development of a common priority list of pharmaceuticals relevant for the water cycle. *Water Science and Technology*, *59*(1), 39–46.
5. Ebele, A. J., Abou-Elwafa Abdallah, M., & Harrad, S. (2017). Pharmaceuticals and personal care products (PPCPs) in the freshwater aquatic environment. *Emerging Contaminants*, *3*(1), 1–16. https://doi.org/10.1016/j.emcon.2016.12.004
6. Global Water Microbiome Consortium, Wu, L., Ning, D., Zhang, B., Li, Y., Zhang, P., … Zhou, J. (2019). Global diversity and biogeography of bacterial communities in wastewater treatment plants. *Nature Microbiology*. https://doi.org/10.1038/s41564-019-0426-5
7. Hedgespeth, M. L., Sapozhnikova, Y., Pennington, P., Clum, A., Fairey, A., & Wirth, E. (2012). Pharmaceuticals and personal care products (PPCPs) in treated wastewater discharges into Charleston Harbor, South Carolina. *Science of the Total Environment*, *437*, 1–9.
8. Lubliner, B., Redding, M. B., & Ragsdale, D. (2010). *Pharmaceuticals and personal care products in municipal wastewater and their removal by nutrient treatment technologies* (No. Publication Number: 10-03-004). Washington State Department of Ecology, Olympia, WA.

References

9. Luo, Y., Guo, W., Ngo, H. H., Nghiem, L. D., Hai, F. I., Zhang, J., … Wang, X. C. (2014). A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. *Science of The Total Environment*, *473–474*, 619–641. https://doi.org/10.1016/j.scitotenv.2013.12.065

10. Oulton, R. L., Kohn, T., & Cwiertny, D. M. (2010). Pharmaceuticals and personal care products in effluent matrices: A survey of transformation and removal during wastewater treatment and implications for wastewater management. Journal of Environmental Monitoring, 12(11), 1956–1978. https://doi.org/10.1039/C0EM00068J

11. Sui, Q., Cao, X., Lu, S., Zhao, W., Qiu, Z., & Yu, G. (2015). Occurrence, sources and fate of pharmaceuticals and personal care products in the groundwater: A review. Emerging Contaminants, 1(1), 14–24. https://doi.org/10.1016/j.emcon.2015.07.001

12. Petrie, B., Barden, R., & Kasprzyk-Hordern, B. (2015). A review on emerging contaminants in wastewaters and the environment: Current knowledge, understudied areas and recommendations for future monitoring. Water Research, 72, 3–27. https://doi.org/10.1016/j.watres.2014.08.053

13. Prichard, E., & Granek, E. F. (2016). Effects of pharmaceuticals and personal care products on marine organisms: From single-species studies to an ecosystem-based approach. Environmental Science and Pollution Research, 23(22), 22365–22384. https://doi.org/10.1007/s11356-016-7282-0

14. Water Environment Federation. (2008). Biological Nutrient Removal Processes. In Operation of Municipal Wastewater Treatment Plants: MoP No. 11, Sixth Edition (6th ed.). Retrieved from https://www.accessengineeringlibrary.com/content/book/9780071543675/chapter/chapter22

15. Xu, Y., Yuan, Z., & Ni, B.-J. (2016). Biotransformation of pharmaceuticals by ammonia oxidizing bacteria in wastewater treatment processes. Science of The Total Environment, 566–567, 796–805. https://doi.org/10.1016/j.scitotenv.2016.05.118

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