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Emerging Contaminants Update - What lies ahead beyond PFAS in Drinking Water:

Microplastics in Drinking Water & PFAS in Wastewater/Biosolids

In The kNOW Webinar
December 8, 2022

Agenda

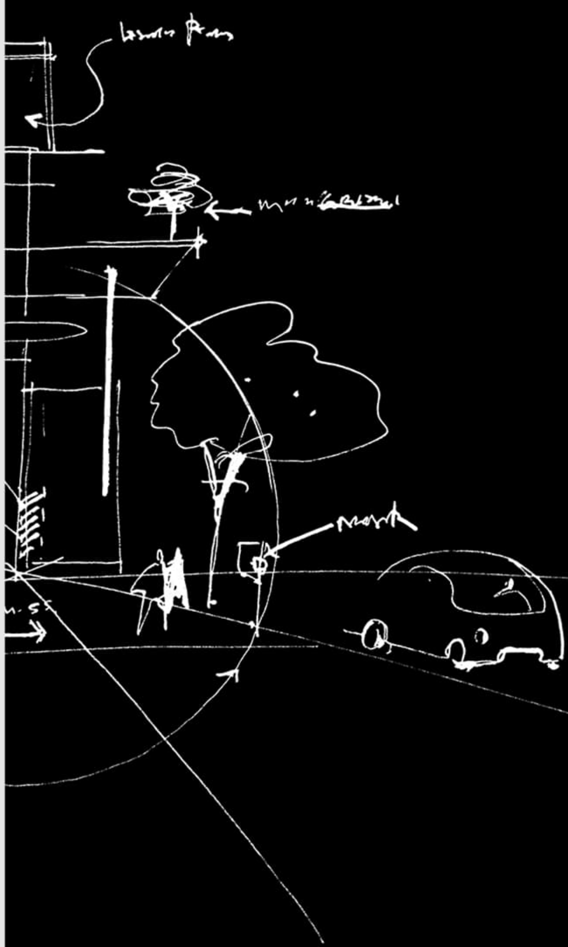
- Introduction
- Microplastics in Drinking Water
- PFAS in Wastewater & Biosolids
- Question/Answer

Moderator:

- Dr. Scott Grieco, Drinking Water Global Technology Leader – Jacobs

Speakers:

- Dr. Rajat Chakraborti, Senior Technologist – Jacobs
- Dr. Sanjay Mohanty, Assistant Professor Department of Civil and Environmental Engineering - University of California Los Angeles (UCLA)
- Todd Williams, Residuals Global Technology Leader – Jacobs



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Scott Grieco

Poll Question

- What prompted you to attend this webinar?

a. To learn more about microplastics impacts to human health and mitigation?
b. To learn more about PFAS in biosolids?
c. Both

Contaminants of Emerging Concern (CECs)

- Source: chemicals that are used widely
  - Manufacturing, Pharmaceuticals, Pesticides, Flame retardants, Detergents, Personal Care Products
  - Many end up in wastewater
- Do not degrade easily
  - Many not removed effectively by conventional wastewater treatment
  - Subsequently found in the environment
- Hard to detect
  - Typically low (ug/L to ng/L) concentrations
  - Improvements in analytical technologies in last 20 years has revealed widespread detections
- Actual human/environmental health impacts sometimes difficult to determine
  - Often difficult to correlate laboratory analysis with actual human health or wildlife health impacts
  - Continued development of Toxicological and Epidemiological studies
  - Evidence of human and environmental impacts
- Concerns of health impacts
  - Some are suspected carcinogen (e.g., NDMA, 1,4-dioxane, PFOA)
  - Many are suspected to affect endocrine/hormonal system
  - Some will bio-accumulate
  - Some are found to have impacts at extremely low concentrations
  - Unknown impacts on humans for many of the chemicals of concern – molecular-level impacts are confirmed; dose-response in highly developed animals are not clear

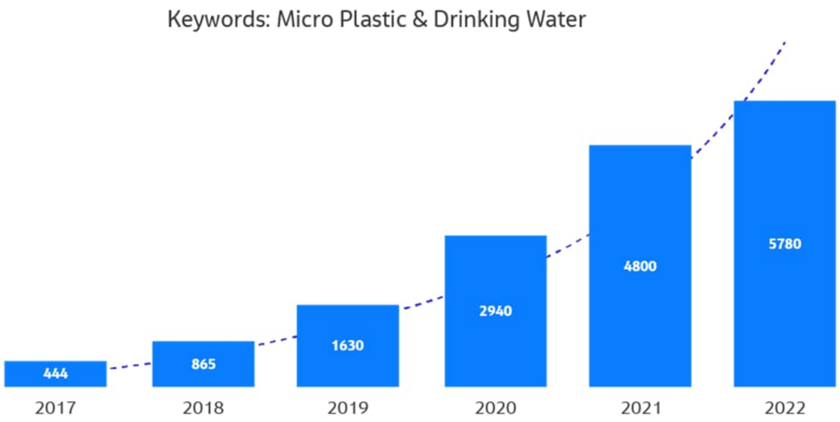
Contaminant Candidate Lists

- Established under Safe Drinking Water Act (SDWA)
- CCL5 – Finalized November 14, 2022
  - 66 chemicals
    - ✓ more PFAS
    - ✓ pharmaceuticals
    - ✓ Antibiotics / antifungals
    - ✓ Pesticides / herbicides / fungicides
    - ✓ cyanotoxins
    - ✓ disinfection byproducts
    - ✓ flame retardants
    - ✓ 1,4-dioxane
    - ✓ 1,2,3-trichloropropane
    - ✓ Inorganics
  - 12 microbes

Microplastics

- Wide range of materials:
  - different substances
  - different densities, shapes, and sizes
- Microplastics are ubiquitous in the environment
  - Have been detected in both bottled and tap water
- Concerns with multiple hazards:
  - physical particles
  - chemicals releases
  - chemical and microbial substrates
- Limited toxicological data exist
  - Better understanding on uptake & fate following ingestion is needed

Google Scholar Output



PFAS – EPA Actions beyond drinking water

- PFAS incorporated into National Pollution Discharge Elimination System (NPDES)
- Comprehensive Environmental Response & Liability Act (CERCLA)
- Biosolids Risk Assessment
- Regional Screening Level (RSL) for PFAS in soils
  - Human exposure
  - Impact to groundwater
- Draft Aquatic Life Ambient Water Quality Criteria (AWQC)

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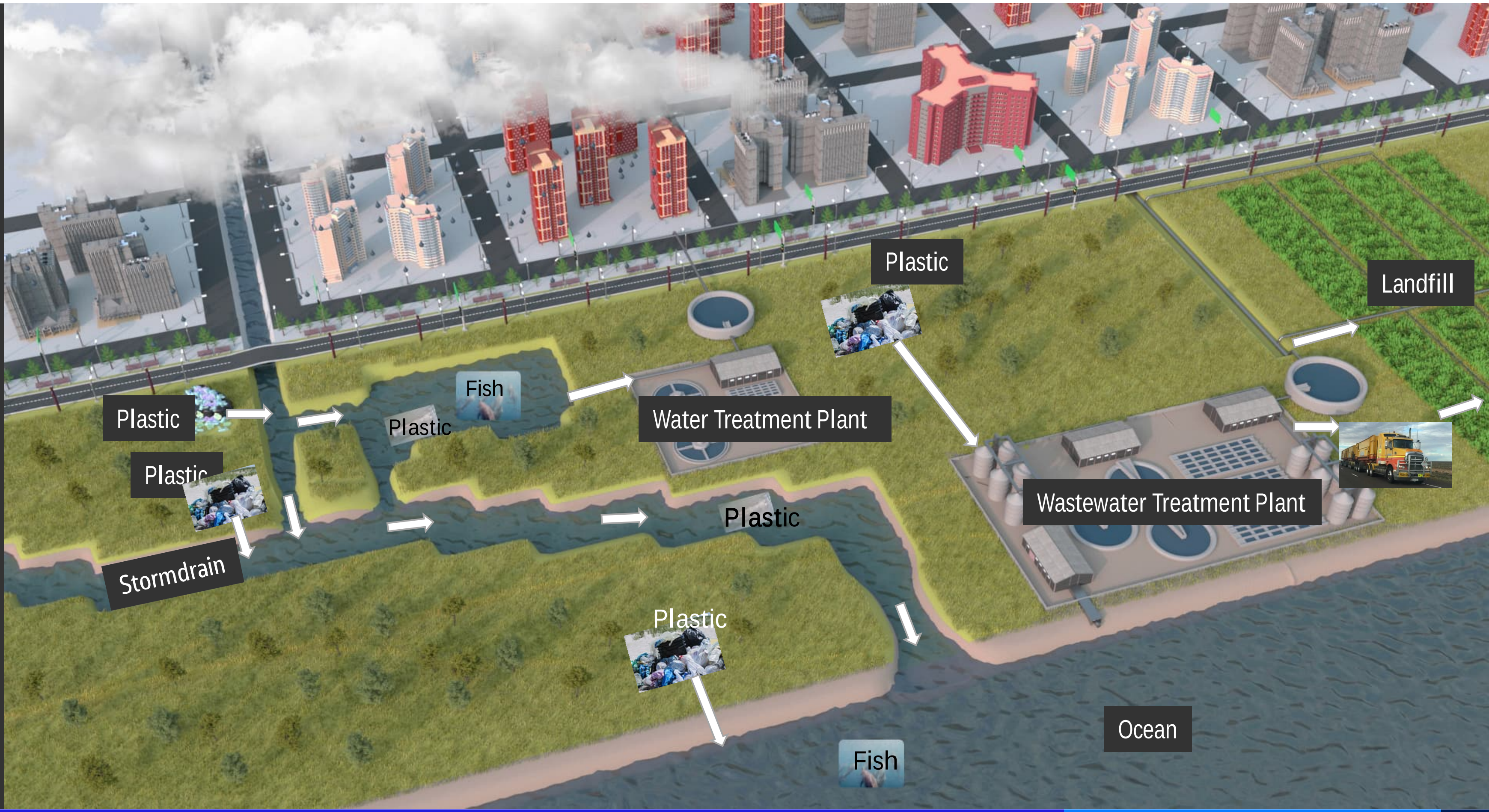
Potential Risks of Microplastics in Water Resources

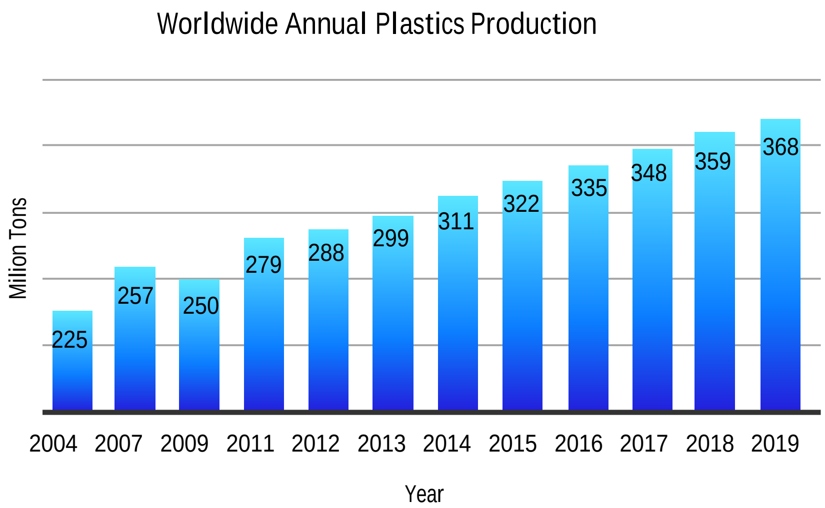
Rajat Chakraborti, Ph.D.
Senior Technologist
Jacobs

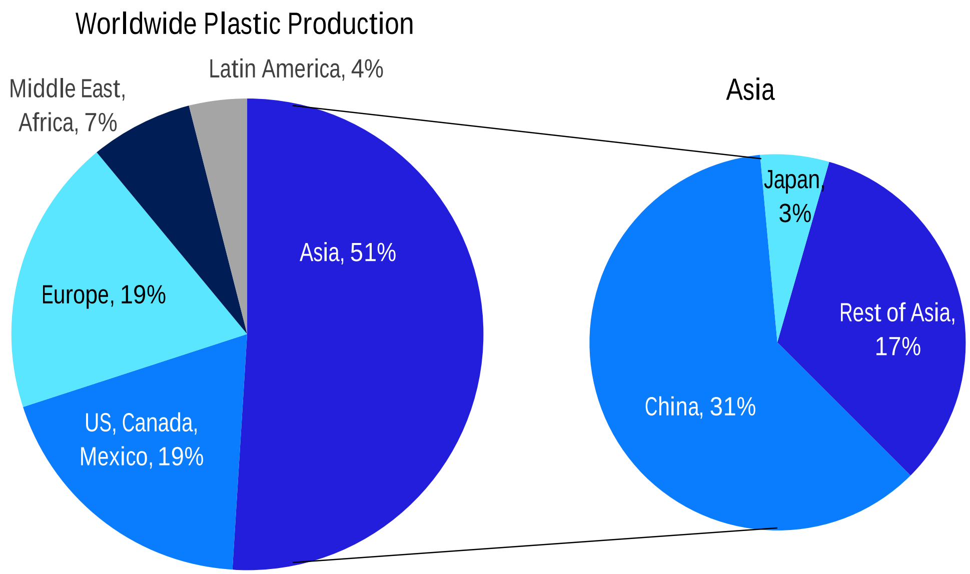
Transfer pathways of plastics through watershed

- Plastic products
- Personal hygiene products
- Microbeads
- Nurdles
- Clothing
- Tire wear
- Dusts
- Marine coatings



Worldwide annual plastics production





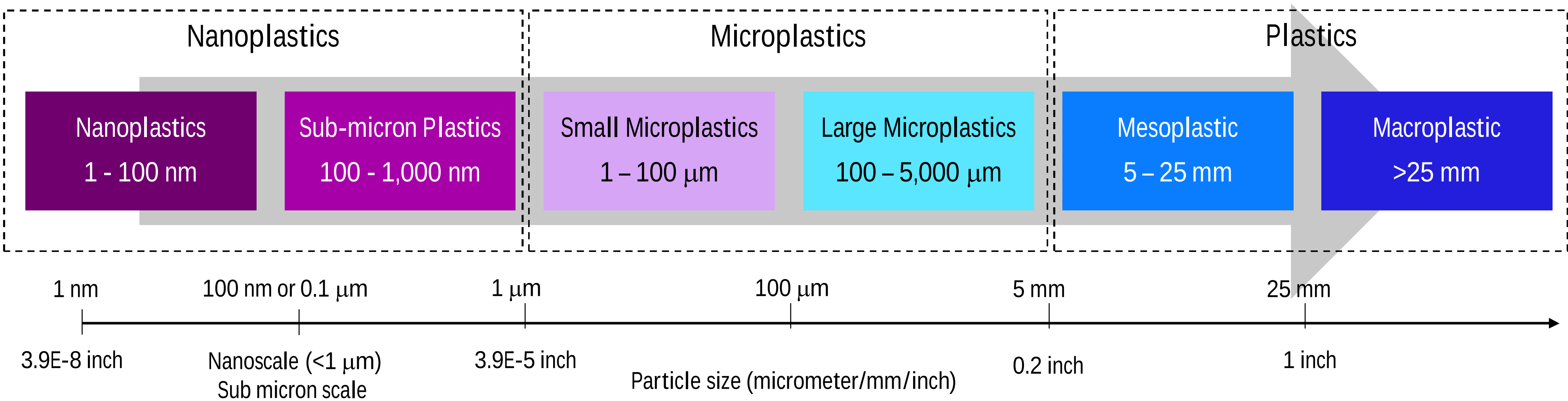
- Worldwide plastics production has been gradually increasing (on average, about 10 Million Tons/year increment in the last 10 years)
- Asia contributes more than half of worldwide plastics production

Population size and the quality of waste management systems largely determine which countries contribute the greatest mass of uncaptured waste available to become plastic marine debris

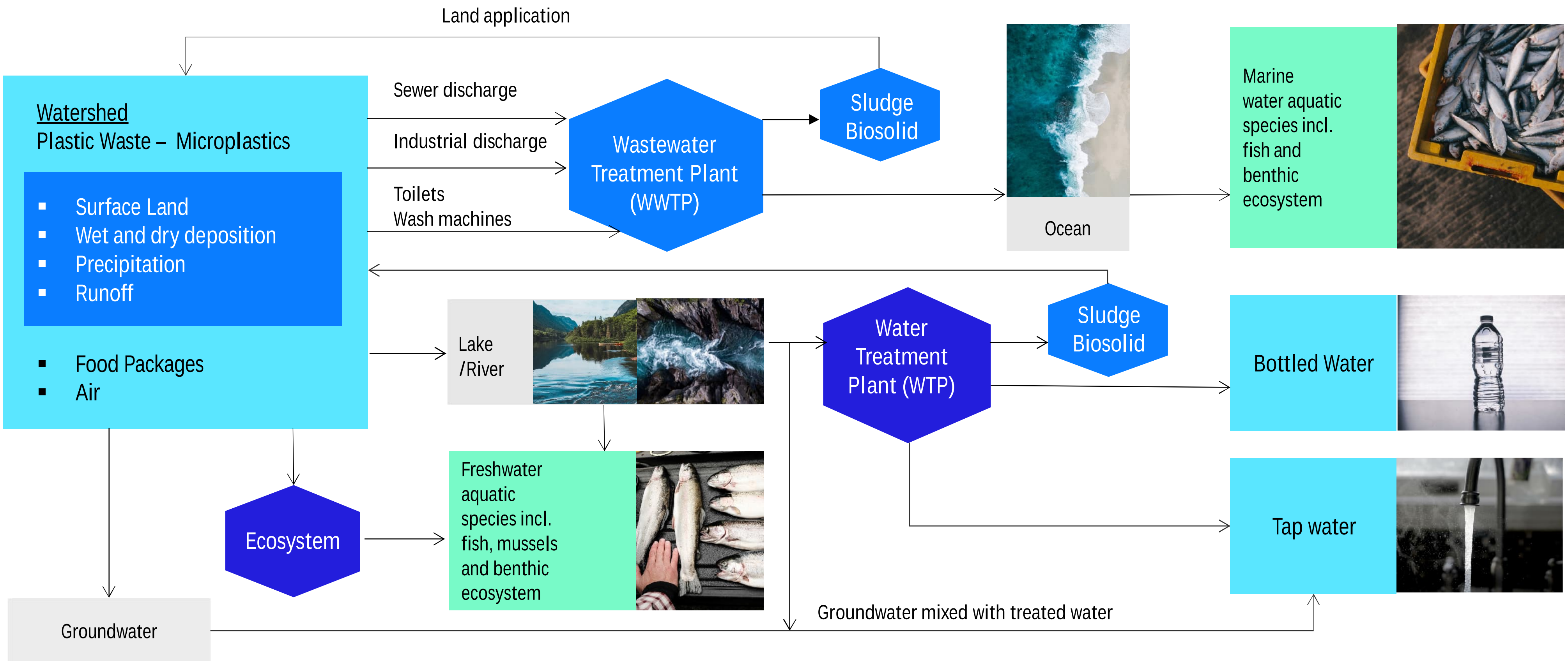
Plastics – the Facts 2020: An analysis of European plastics production, demand and waste data; Plastics_the_facts-WEB-2020_versionJun21_final.pdf

What is microplastics and how to characterize

- Microplastics are solid polymeric materials to which chemical additives or other substances may have been added.
- Microplastics size ranges between 1 micron and 5,000 micron (5 mm). The shape varied widely.
- Nanoplastics are less than 1 micron size.
- Fourier-transform Infrared Spectroscopy (FTIR) and Raman Spectroscopy are used to characterize microplastics

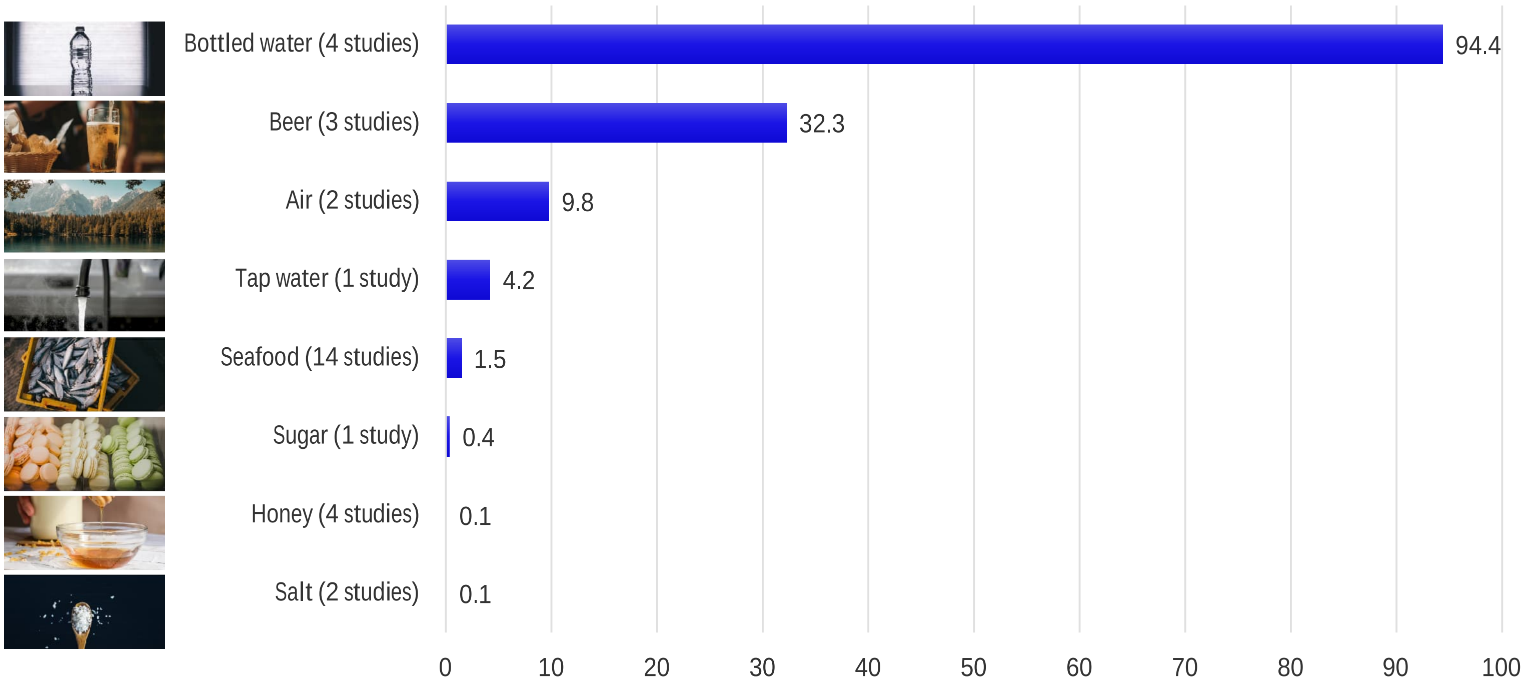


Transport pathways of microplastics in watershed



We have been eating, drinking and breathing microplastic

Average number of microplastics found per gram/liter/m^3 of consumables

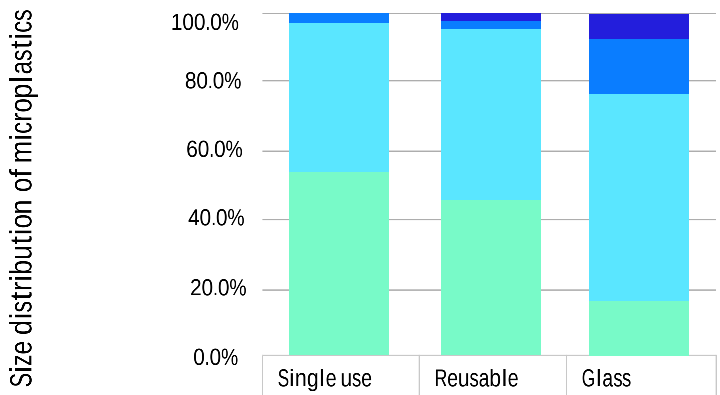


Estimated annual microplastic particles consumed per person is between 74,000 and 121,000 (including via inhalation)

Cox, K. D., Garth A. Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F., and Dudas, S. E. 2019. Human Consumption of Microplastics, Environ. Sci. Technol. 2019, 53, 12, 7068–7074

Jambeck, J.R., Geyer, R, Wilcox, C., Siegler, T.R., Perryman, M. Andrady, A., Narayan, R., and Law, K.L. 2015. Plastic waste inputs from land into the ocean, Science, (347) 6223, 768-771. DOI: 10.1126/science.1260352

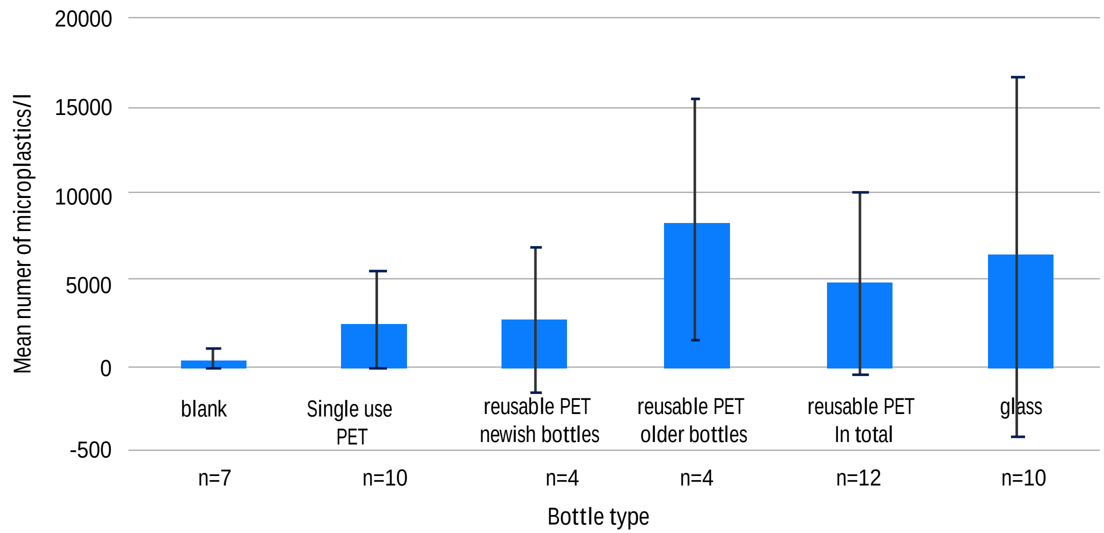
Microplastics in plastic bottles



	Single use PET	Reusable PET	Glass
> 10µm	0.0%	1.7%	6.9%
> 5µm to ≤ 10 µm	1.7%	2.9%	15.4%
> 1.5µm to ≤ 5 µm	44.7%	48.4%	61.4%
≤ 1.5µm	53.6%	47.0%	16.4%

Bottle type

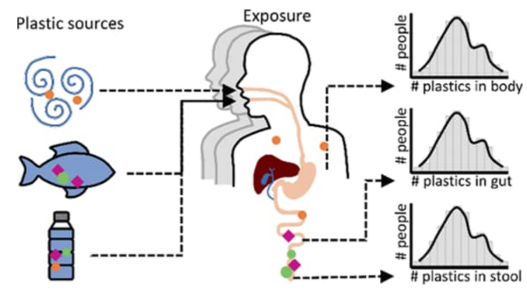
Size distribution of the detected microplastics depending on the bottle material type (PET: Polyethylene Terephthalate)



Mean number of microplastics depending on the bottle material type for 1L sample (Error: Std. Dev., n = number)

Oßmann, B.E., Sarau G, Holtmannspotter, H., Pischetsrieder, M., Christiansen, S.H., Dicke, W. 2018. Small-sized microplastics and pigmented particles in bottled mineral Water, Water Research 141 (2018) 307e316 https://doi.org/10.1016/j.watres.2018.05.027

Exposure pathways to human health risk



Pathways

Media

Plastics (5-25 mm)

Microplastics (MPs)
(1 µm – 5 mm)
Shapes: Filament, fragment, fiber, granular, film, flake, pellets, foam;
Types: PES, PET, PUR, PA, PS, PVC, PP

Nanoplastics (NPs)
(1 nm – 1 µm)

Pathways

Watershed, Atmosphere
River, Creek, Ocean, Land, Rainfall, Soil, Sediment, Biota

Industrial Sources
Wastewater Treatment, Plant, Sludge, Landfill, Agriculture

Other
Cleaning Products, Coatings, Cosmetics, Microbeads, Textiles, Tires, Packaging

Media

Food
Fish, Meat (Pork, Beef, Chicken), Salt
Tea, Honey

Water/Beverage
Bottled Water, Beer, Sea Salt

Air (PM2.5)
Indoor
Outdoor

Hazard x Exposure = Health Risk (probability to cause harm)

Human Exposure Pathway
- Ingestion
- Inhalation
- Dermal Absorption

Human Organs
- Gastro-intestine
- Lungs
- Liver and spleen
- Neurologic
- Immune system
- Endocrine disruption

MPs Identified
- Feces
- Urine
- Gut
- Breast milk
- Placenta
- Meconium

PVC, plastisol ➜ Phthalate esters ➜ Birth defect, Carcinogen, Abnormal sexual development

PC, epoxy resin ➜ Bisphenol A ➜ Obesity, Cardio-vascular diseases, Hormone disruption, Damage to fetal development

Primary source Plastic $\xrightarrow{\text{UV radiation, thermal, physical, biological degradation}}$ Fragmented Plastics (MPs, NPs) → Pathway of MPs $\xrightarrow{\text{Fate and transport}}$ Media for human consumption → Exposure pathways → Toxicity exchange → Potential human body impact → MPs identified in human body

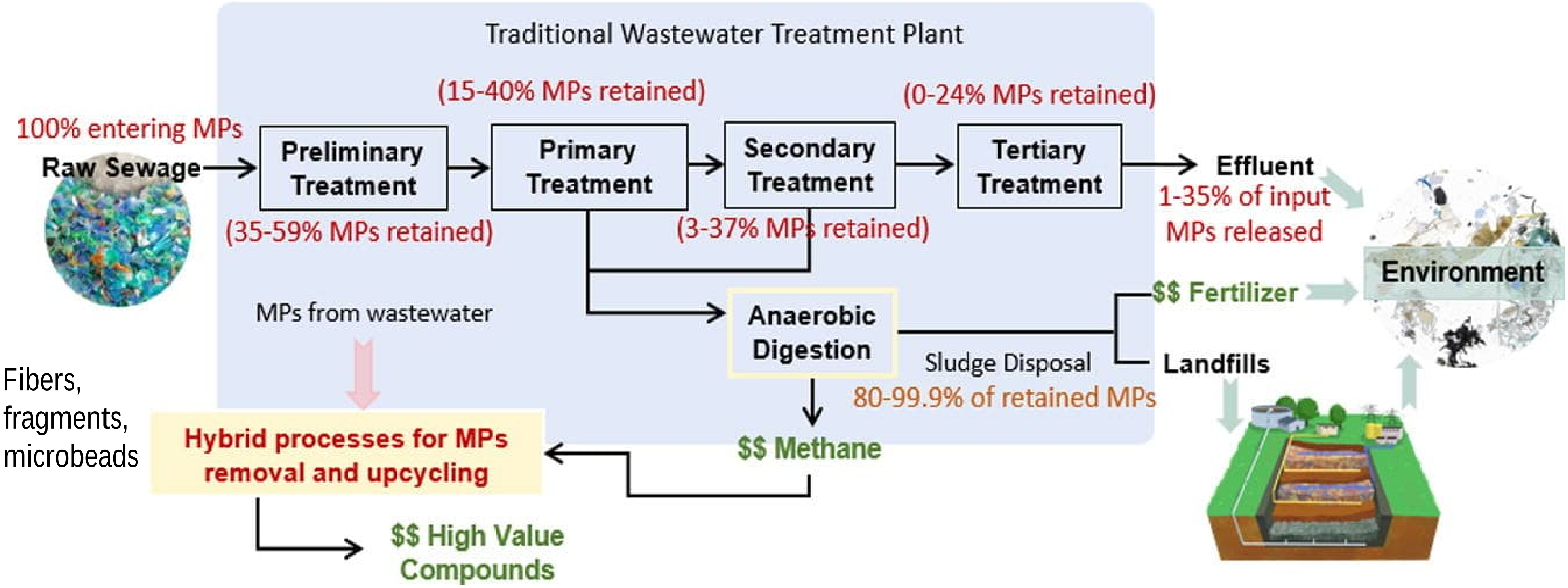
PM2.5 = Particulate matter 2.5 µm

Nur Hazimah Mohamed Nor, Merel Kooi, Noël J. Diepens, and Albert A. Koelmans.2021. Lifetime Accumulation of Microplastic in Children and Adults, Environ. Sci. Technol. 2021, 55, 8, 5084–5096

Polymers/density (gm/cm3): PES = Polyester (1.23-1.38), PET = Polyethylene Terephthalate (1.33-1.4), PE = Polyethylene (0.92-0.96), PA = Polyamide (1.15), PP = Polypropylene (0.9), PS = Polystyrene (1.04-1.07), PUR = Polyurethane (0.05-1.7), PVC = Polyvinyl Chloride (1.4), PC = polycarbonate (1.2)

Fate of microplastics through wastewater treatment steps

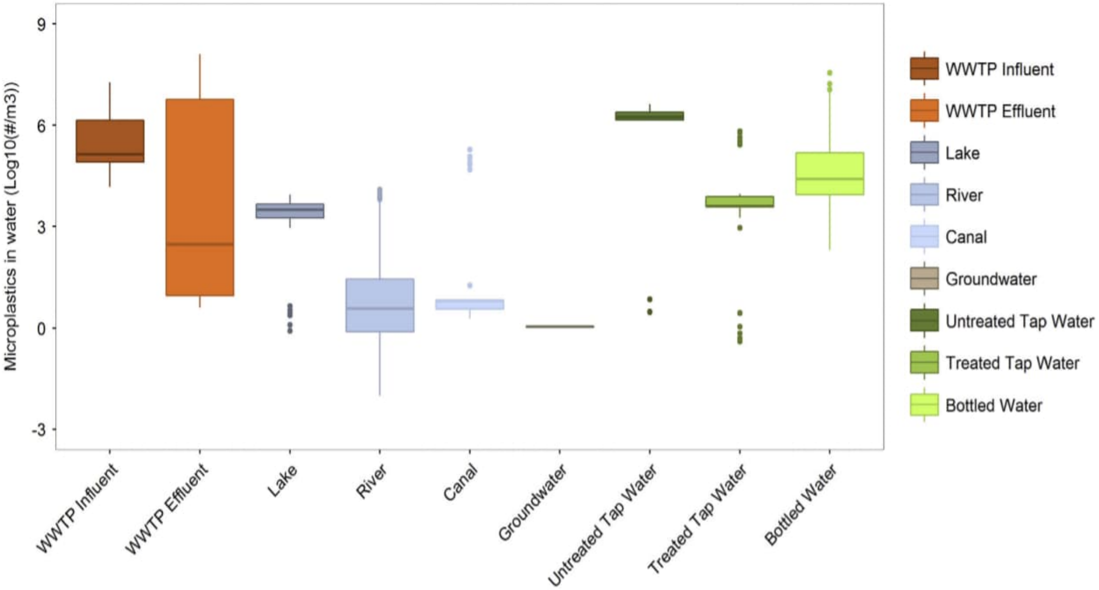
- Fibers,
- fragments,
- microbeads



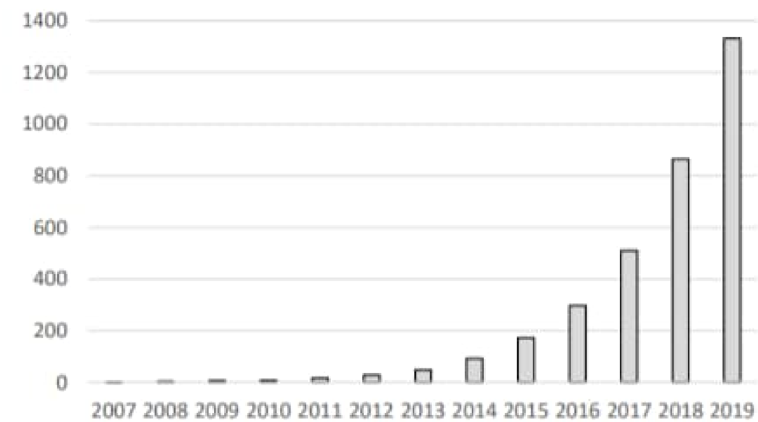
Hou, L., Kumar, D., Yoo, C. G., Gitsov, I., Majumder, E. L. W. 2021. Conversion and removal strategies for microplastics in wastewater treatment plants and landfills, Chem. Eng. J. 406 15 February 2021, 126715, https://doi.org/10.1016/j.cej.2020.126715.

Microplastics in various sources and research

Number of microplastics in water from various sources



Number of peer review publications on microplastics



Koelmans, A.A., Mohamed Nor, N.H., Hermsen, E., Kooi, M., Mintenig, S.M., De France, J., 2019. Microplastics in freshwaters and drinking water: critical review and assessment of data quality. Water Res. 155, 410–422. https://doi.org/10.1016/j. watres.2019.02.054.

Qintong Wang, Carmen Hernández-Crespo, Marcello Santoni , Stijn Van Hulle, Diederik P.L. Rousseau, 2020. Horizontal subsurface flow constructed wetlands as tertiary treatment: can they be an efficient barrier for microplastics pollution? 2020. Science of The Total Environment, DOI: 10.1016/j.scitotenv.2020.137785

Regulation development for microplastics control in California

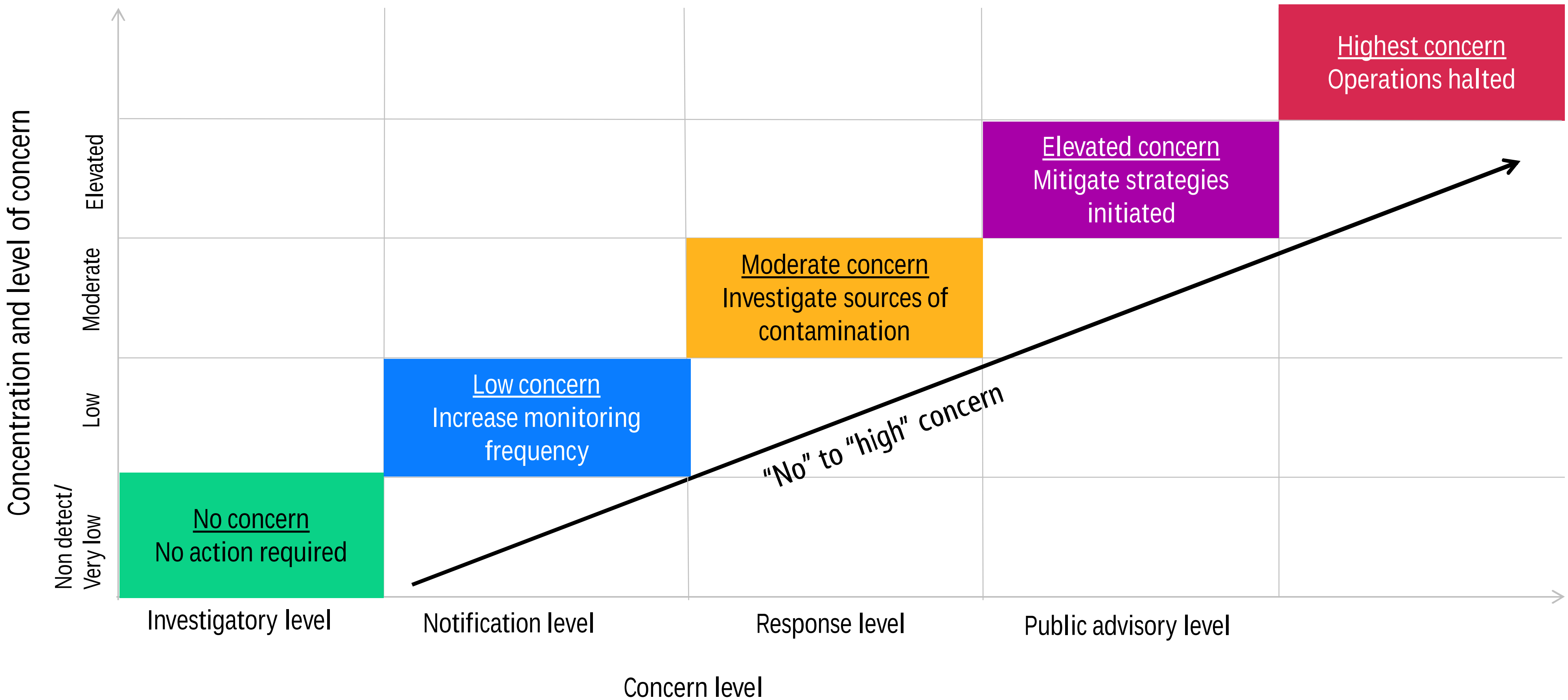
Per California Senate Bill 1422 (2018) – Drinking Water

- 2020-2021:
  - Defined microplastics
  - Developed standard testing method based on four years of inter laboratory (26 labs) testing with FTIR spectroscopy and Raman spectroscopy for drinking water, ocean water, fish tissue and sediment samples; accredit laboratories (Analyte code: SWB-MP1-rev1)

Per California Senate Bill 1263 (2018) – Ecological risk

- 2022 – 2026 Plan:
  - Initiate statewide microplastics strategy
  - Develop risk assessment framework
  - Develop standardized methods
  - Establish baseline occurrence data
  - Investigate sources and pathways
  - Recommend source reduction strategies

Health based threshold decision framework



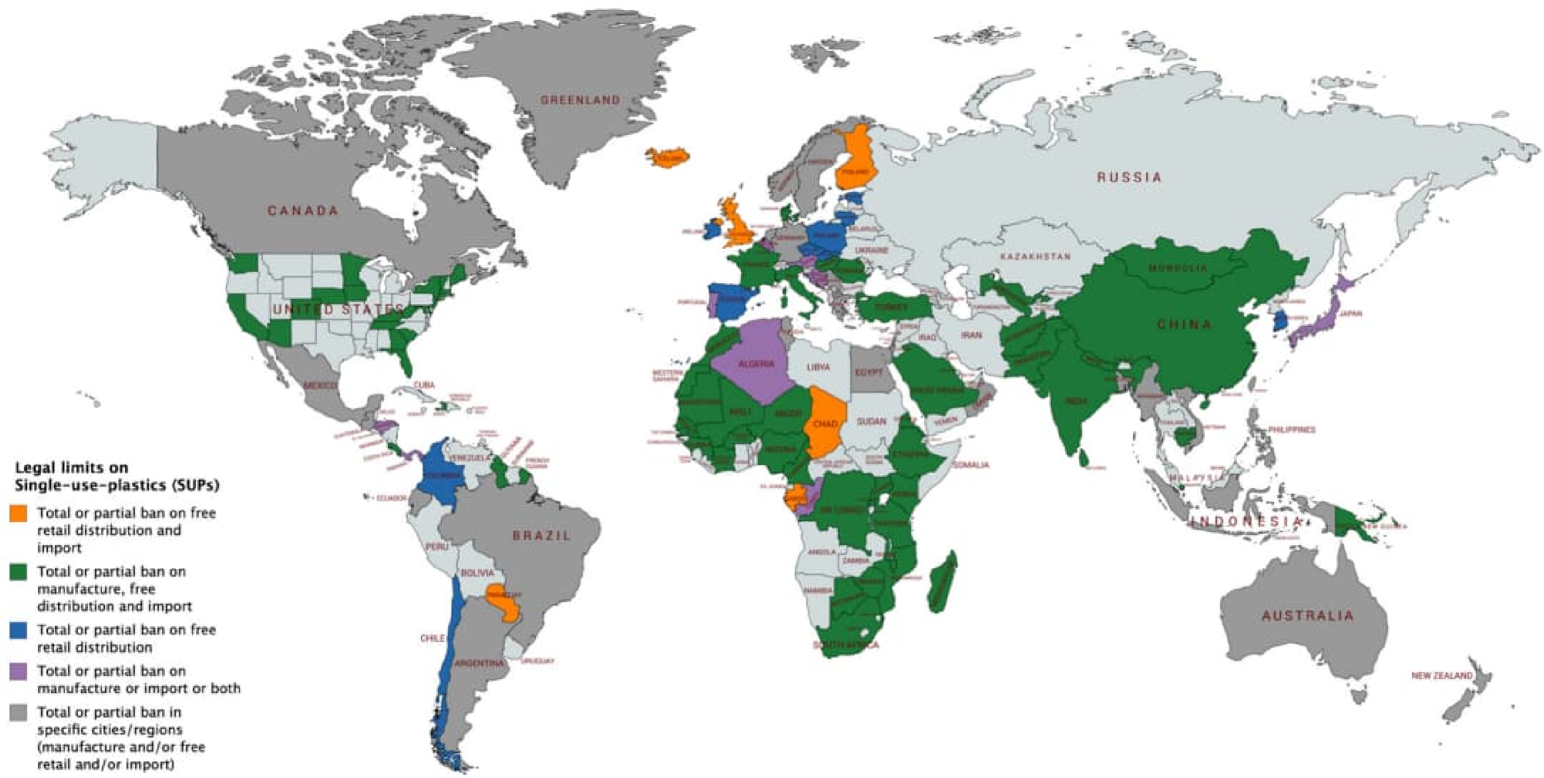
Risk based management of microplastics – aquatic toxicity threshold

Health-based Threshold Stages	Food dilution (particles/L) (mg/L)	Tissue translocation (particles/L) (mg/L)
1. Investigative monitoring	0.3 (0.05)	60 (10)
2. Discharge monitoring	3.0 (0.4)	312 (51)
3. Management planning	5.0 (0.9)	890 (146)
4. Source control measures	34.0 (6.0)	4,100 (676)

- Based on species sensitivity distributions within 26 studies, 14 species, and 6 taxa for all endpoints
- Concentrations aligned food dilution to 1 to 5,000 µm size range and for tissue translocation to 1 to 83 µm size range
- Mass equivalent of food dilution under four categories vary from 0.05 to 6.0 mg/L
- Mass equivalent of tissue translocation under four categories vary from 10 to 676 mg/L

Mehinto et al. Risk-Based Management Framework for Microplastics in Aquatic Ecosystems, *Microplastics and Nanoplastics*, 2022

A global patchwork of policy – example, single use plastic



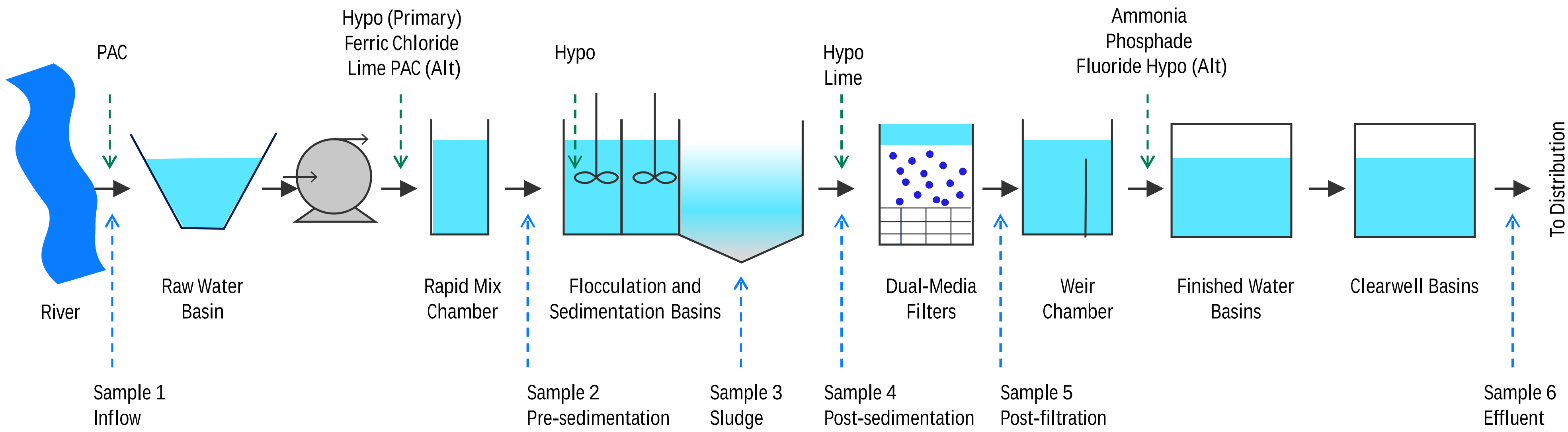
Silva et al. 2020. Science of the Total Environment

USA: Use as scrubbing beads in cosmetics are banned on federal level (“ Microbead Free Waters Act”). Additional regulation(s) at state level is established or under way

CHINA: General plan to prohibit “Microplastic” manufacturing after 31 Dec. 2020, and for sale after 31 Dec. 2022

EU: Proposed REACH restriction, potentially from 2022
REACH: Registration, Evaluation, Authorization and Restriction of Chemicals

Research need: Microplastics in water treatment



Goals

- Track microplastics through the water treatment pathways
- Estimate mass balance of microplastics between influent and effluent
- Target smaller size range, up to 20 μm or lower

Conclusions

- Microplastics transport long distances and degrades slowly
- Microplastics potentially carry harmful chemicals within and on its body
- Difficult to measure smallest plastics, nanoparticles
- Microplastics have been found in water bottles, and effluents of water treatment plant and wastewater treatment plant
- Sludge biosolids produced in wastewater treatment plant is a significant source of microplastic pollution to the environment
- Potential health effects are not well established - but gaining evidence
- Establishment of regulatory limits is under way
- Understanding the risk of microplastic/nanoplastic pollution is in its infancy

Poll Question

- What microplastics pollution issues are of concern to you? (choose all that apply)

a. Microplastics pollute water, air, biota, and ecosystem
b. Microplastics cause human health risk
c. Microplastics will soon be regulated for management
d. Other

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Can stormwater bioinfiltration systems remove emerging stormwater pollutants such as microplastics and PFAS?

Sanjay Mohanty, Ph.D.

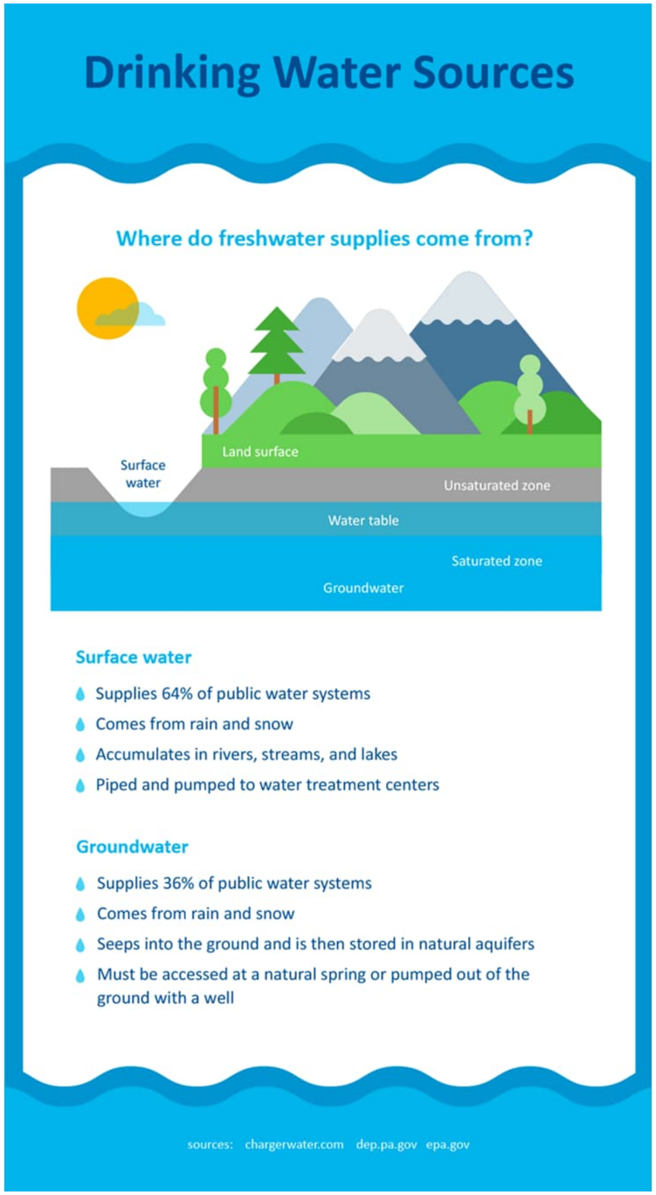
Subsurface Engineering and Analysis Laboratory

UCLA Environmental Engineering

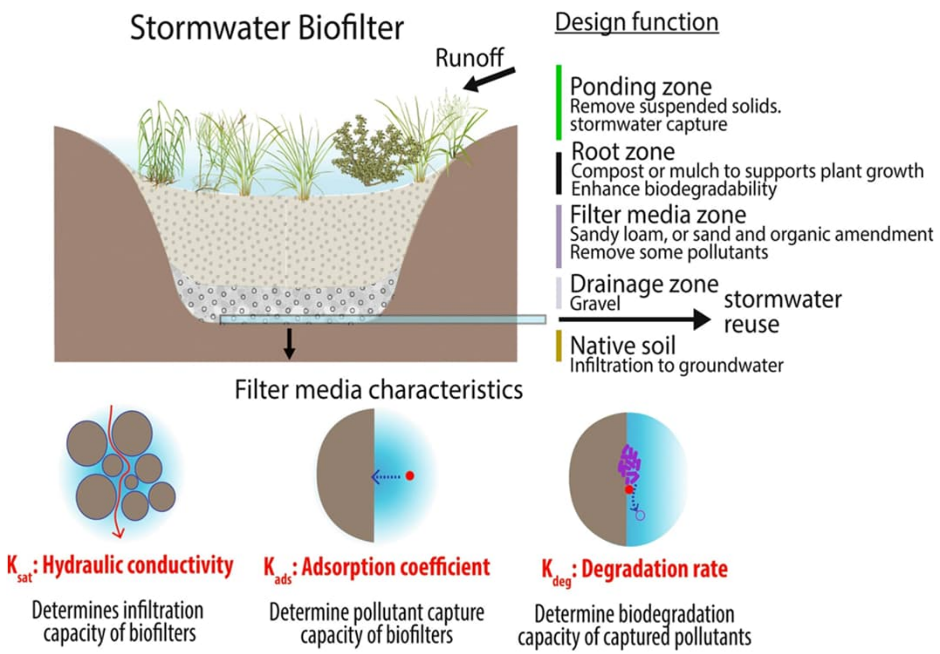
Picture: ecoevoblog

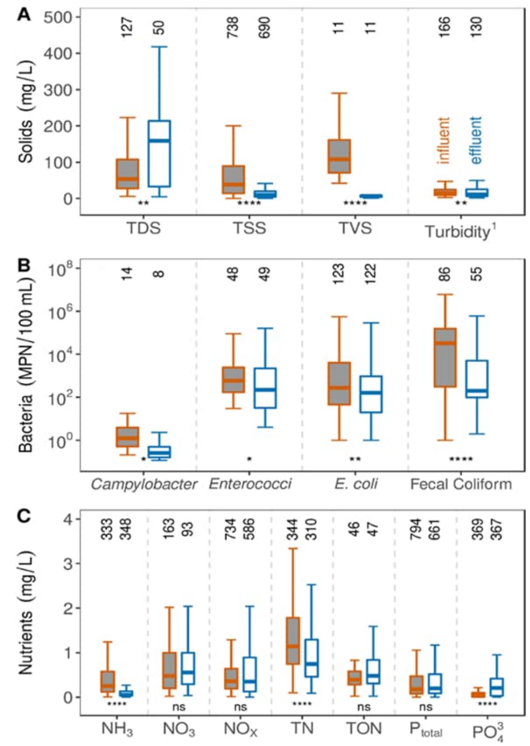
Clean stormwater would save millions of treatment cost for drinking water

- Supply: Surface water supplies 64% and groundwater supplies 34 % of public water systems, and those are replenished by rain via stormwater. Stormwater treatment and reuse are an integral part of urban water sustainability.
- Pollution: Stormwater is increasingly polluted with emerging pollutants such as microplastics and PFAS, both of which can last >100 years in environment.
- Cost: Polluted stormwater means utilities (and the public) have to take the burden to spend hundreds of millions in treatment costs.



Infiltration-based stormwater BMP are typically used to remove more pollutants but their capacity is limited.



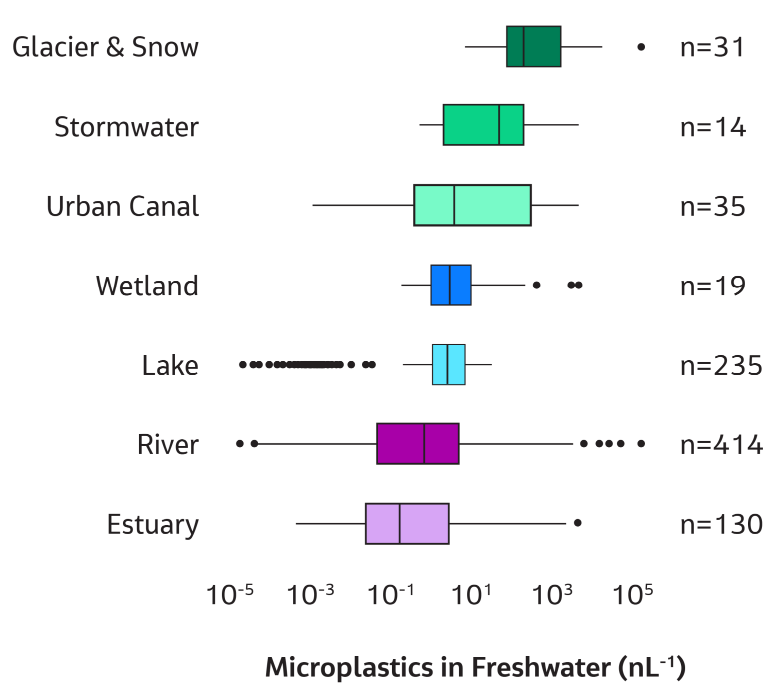


Tirpak, A., Afrooz, N., Winston, R.J., Valenca, R., Schiff, K., Mohanty, S.K. (2021) Conventional and Amended Bioretention Soil Media for Targeted Pollutant Treatment: A Critical Review to Guide the State of the Practice. ***Water Research***. 189, 116648. https://doi.org/10.1016/j.watres.2020.116648.

Question - Microplastics

Can the passive stormwater treatment systems remove emerging pollutants such as microplastics and PFAS, and protect drinking water sources?

Microplastic concentration is the highest in stormwater

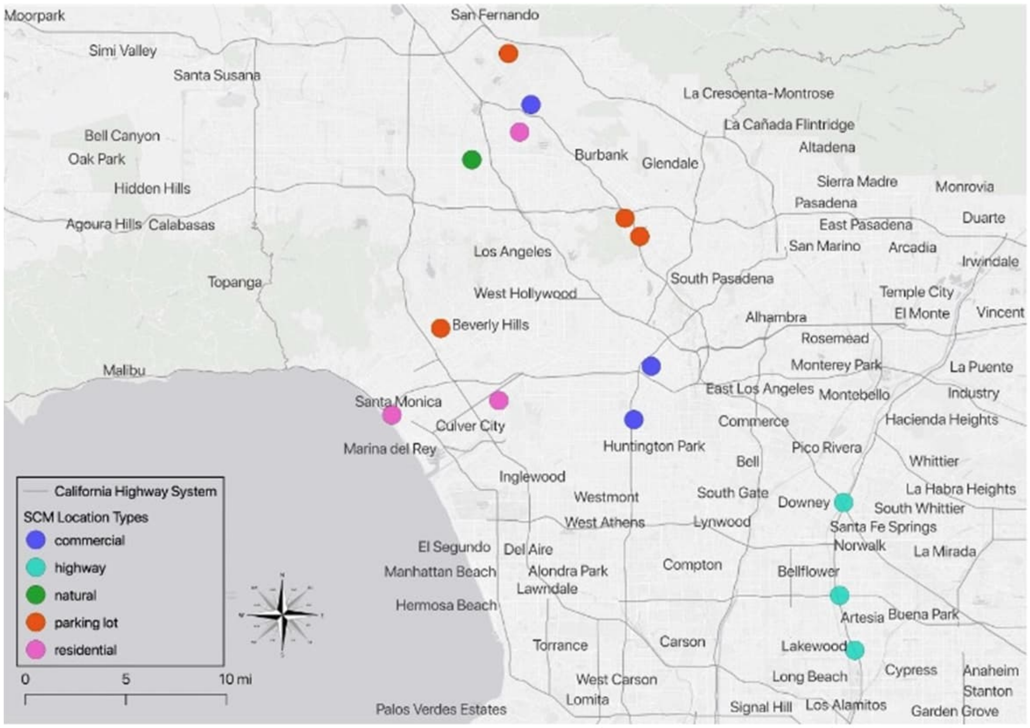


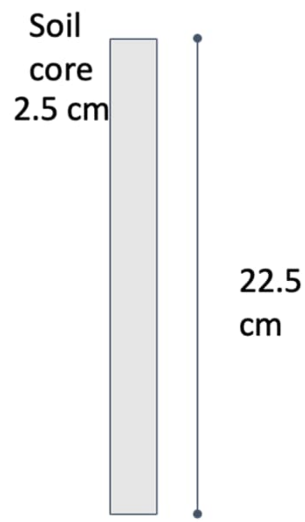
Koutnik, V.S., Leonard, D. J., Alkidim, S., DePrima, F., Ravi, S., Hoek, E., and Mohanty, S.K. (2021) Distribution of microplastics in soil and freshwater environments: Global analysis and framework for transport modeling. ***Environmental Pollution.*** 274, 116552. https://doi.org/10.1016/j.envpol.2021.116552

March 2022 | NY Times

"In a First, California Plans to Clean Up Microplastics - The state has adopted a strategy to monitor and reduce the ubiquitous form of pollution."

We collected filter media core from 14 stormwater control measure (SCM) in Los Angeles to determine if microplastics are migrating towards groundwater

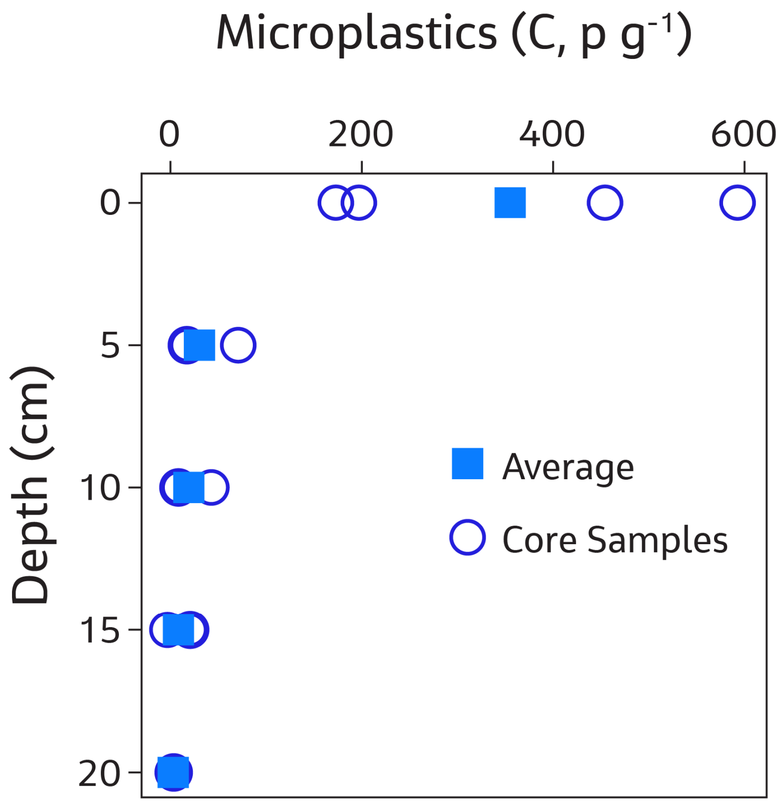




Koutnik, V.S., Leonard, J., Glasman, J.B., Koydemir, H.C., Novoselov, A., Brar, J., Bertel, R., Tseng, D., Ozcan, A., Ravi, S., Mohanty, S.K. (2022) Microplastics retained in stormwater control measures: Where do they come from and where do they go? ***Water Research.*** 118008. https://doi.org/10.1016/j.watres.2021.118008

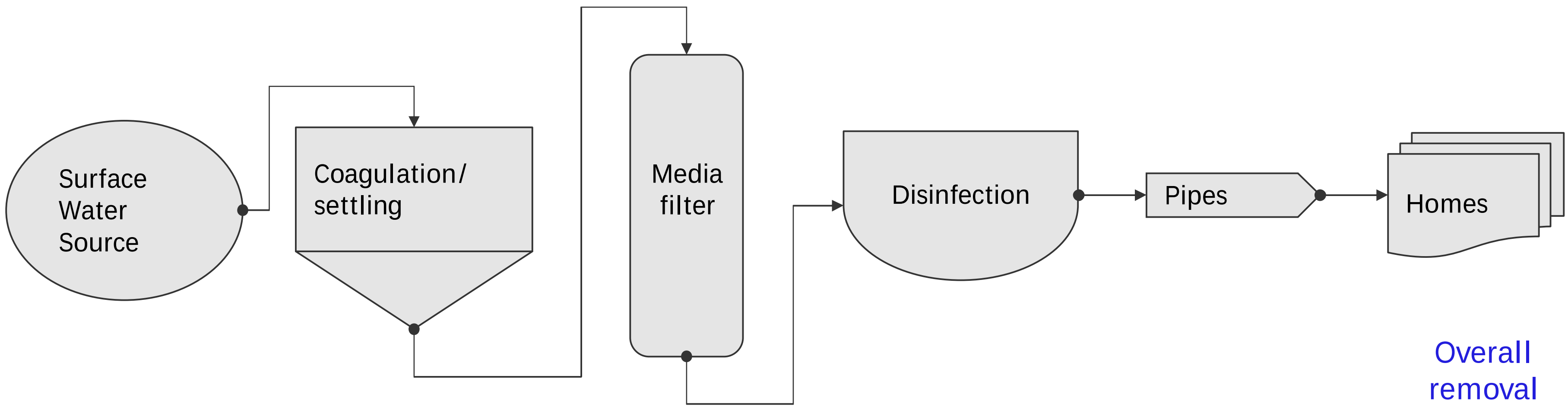
Microplastic concentration decreased with depth.

- Most microplastics are removed within top 5-10 cm of layer.
- Result indicates limited risk for groundwater contamination.
- Drinking water treatment plants with groundwater as source water won't have to deal with microplastic pollution.



Koutnik, V.S., Leonard, J., Glasman, J.B., Koydemir, H.C., Novoselov, A., Brar, J., Bertel, R., Tseng, D., Ozcan, A., Ravi, S., Mohanty, S.K. (2022) Microplastics retained in stormwater control measures: Where do they come from and where do they go? ***Water Research.*** 118008. https://doi.org/10.1016/j.watres.2021.118008

Can drinking water treatment systems remove microplastics?



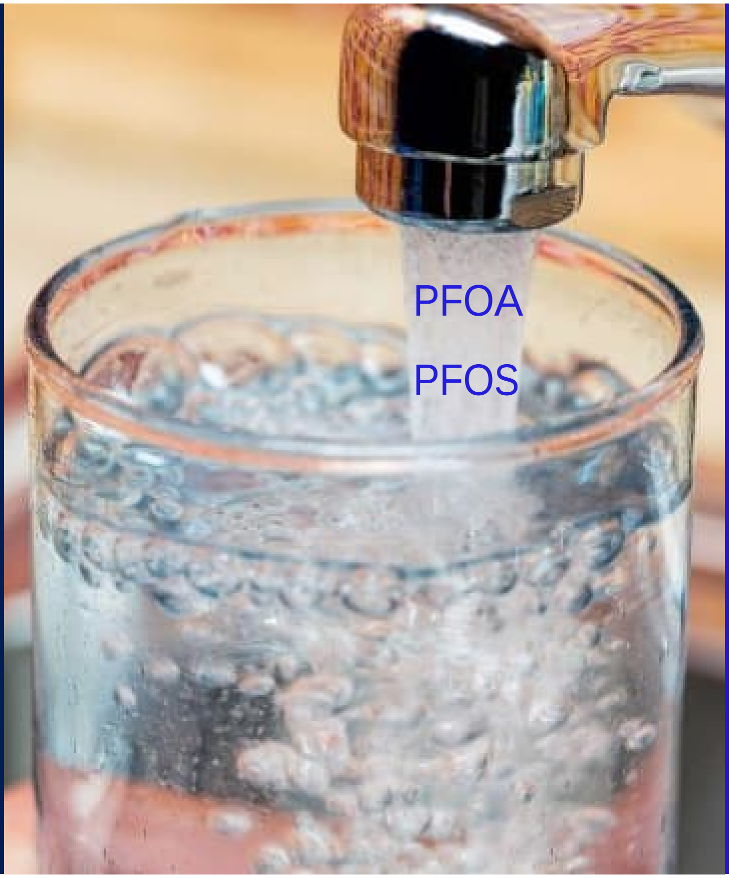
						Overall removal
Wang et al. 2020		40.5–54.5%	56.8–60.9%			81%
Pivokonsky et al. 2018						70-83%
Pivokonsky et al. 2020		62%	+25%	+5%		88%

- Removal of drinking water treatment plants varies between 70-90%
- Most microplastics found in effluents are less than 10 µm.

Microplastics: What we have learned so far?

- Infiltration based treatment systems can remove most microplastics from stormwater and protect groundwater, but surface water sources will continue to be polluted.
- Capacity of drinking water treatment plants to remove microplastics is still unclear.

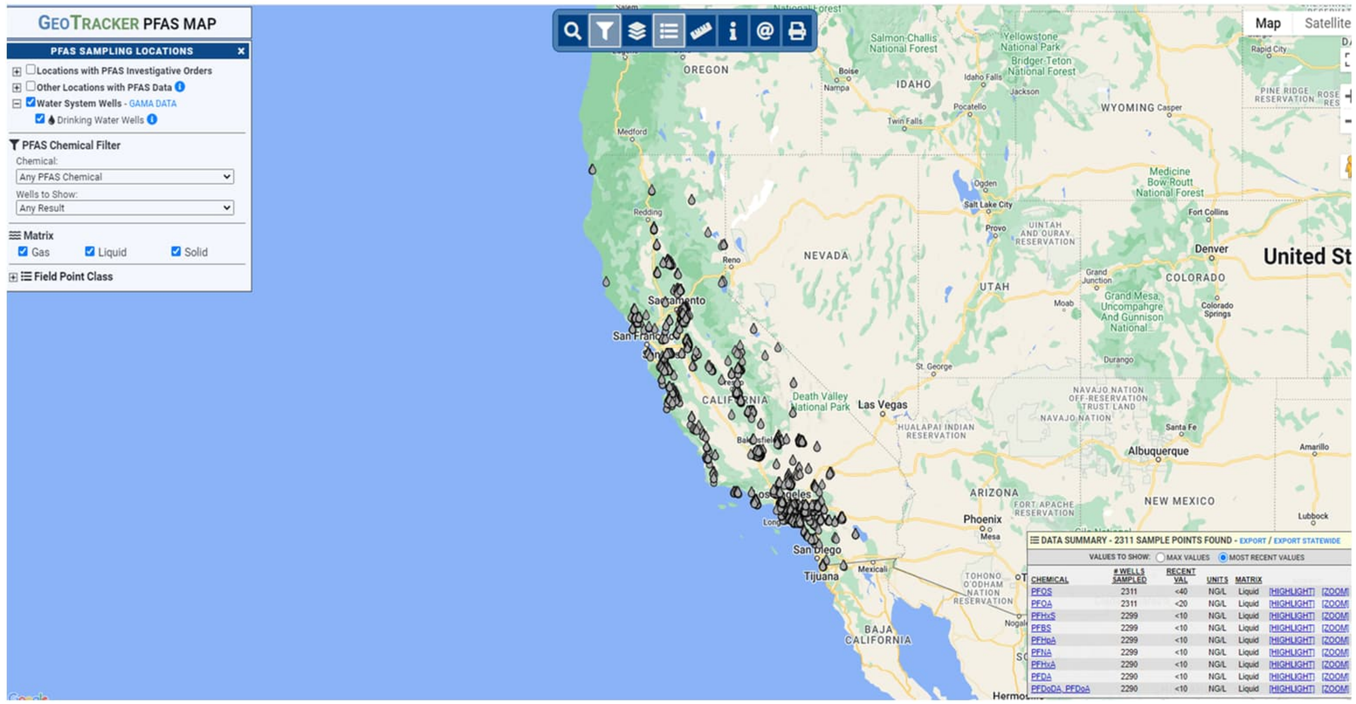
Question - PFAS



- Can bioinfiltration systems remove PFAS?
- How can we improve the design of bioinfiltration systems?

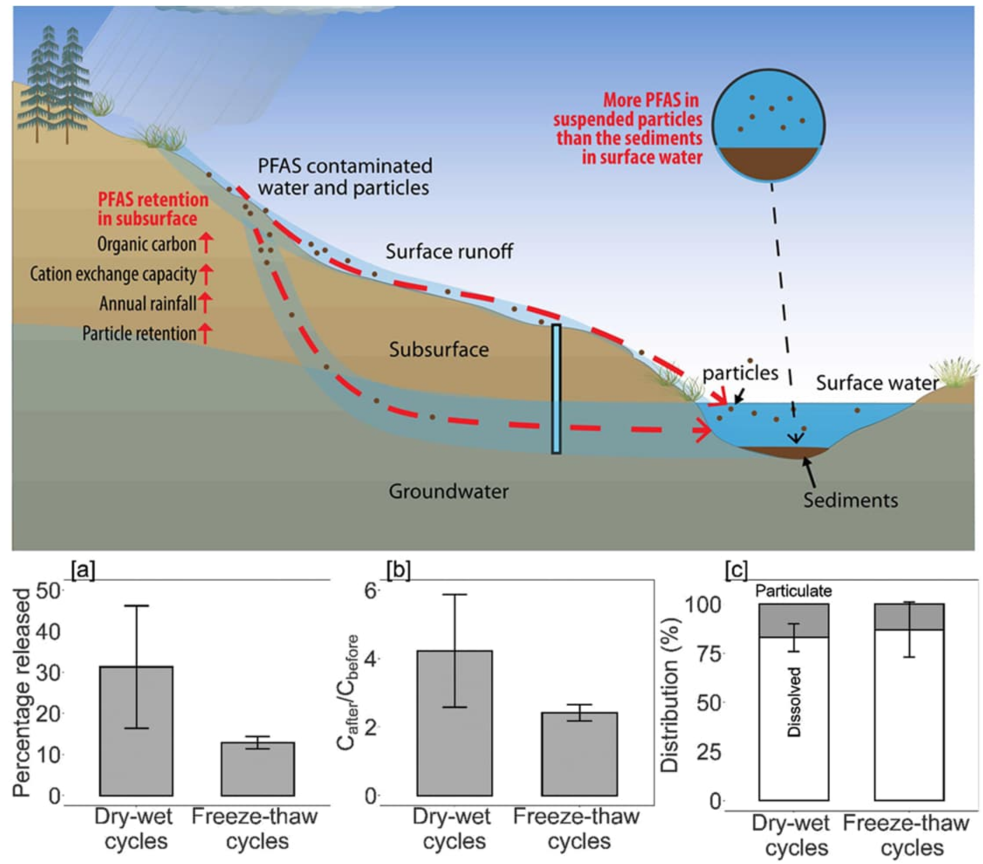
Groundwater wells in CA are polluted with PFAS

- Concentrations exceed EPA's advisory limits.
- Direct stormwater injection could only make things worse in groundwater aquifers.
- Stormwater treatment could minimize the risk.



PFAS release from subsurface into groundwater

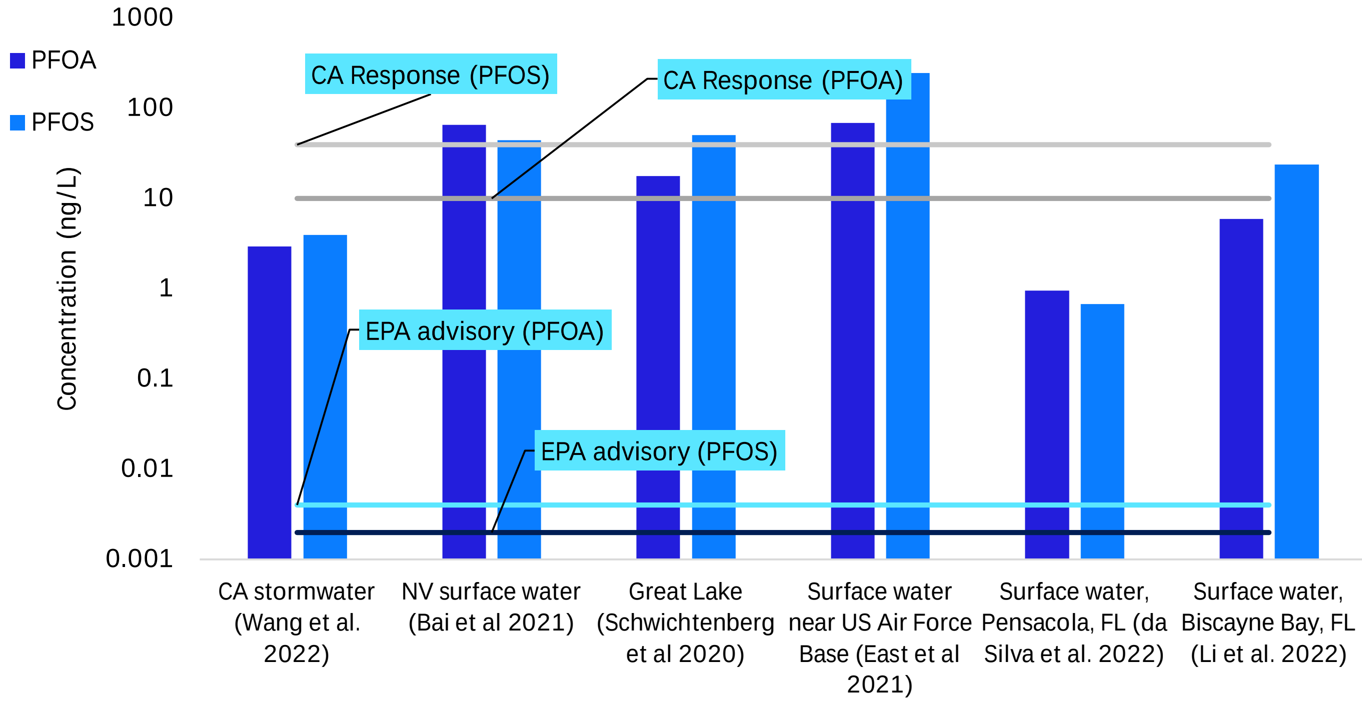
- Subsurface typically removes and contains 90% of influent PFAS in stormwater.
- Natural dry-wet and freeze-thaw cycles could increase the release of PFAS from subsurface soil into groundwater.



Borthakur, A., Olsen, P., Dooley, G., Cranmer, B.K., Rao, U., Hoek, E.M.V., Blotevogel, J., Mahendra, S., and Mohanty, S.K. (2021) Dry-wet and freeze-thaw cycles enhance PFOA leaching from subsurface soils. Journal of Hazardous Materials Letters. 2. 100029. https://doi.org/10.1016/j.hazl.2021.100029

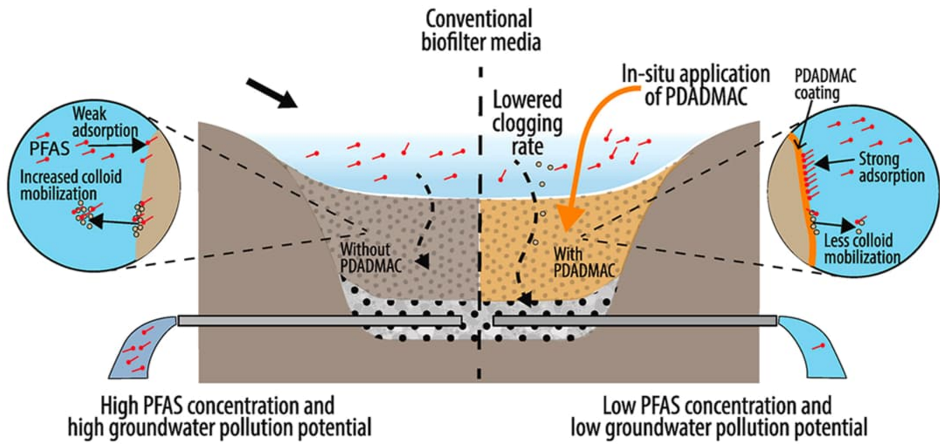
Concentration of PFAS in surface waters

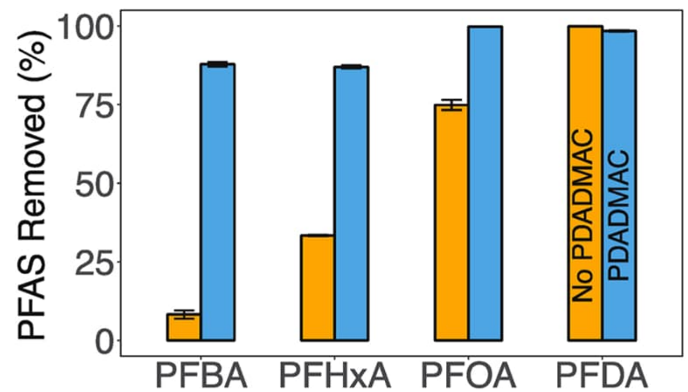
- Stormwater BMP needs to treat surface water at least 2 logs (99%) to meet the EPA advisory limit.
- Most stormwater biofilters, even with amendments, can remove about 90 % of influent PFAS.
- Filter media gets exhausted, and their replacement is expensive.



Potential solution: In situ regeneration of adsorption capacity

- The addition of cationic polymers such as PDADMAC (a drinking water coagulant) could increase the adsorption capacity of filter media.
- The improvement is significant for low-chain PFAS, the types that are difficult to remove in treatment systems.

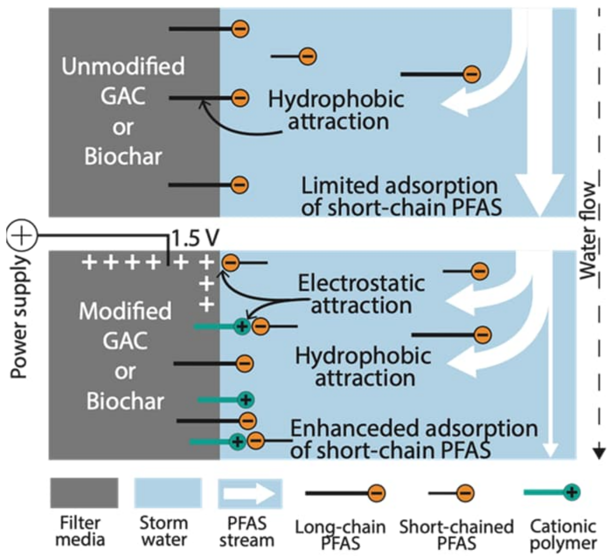


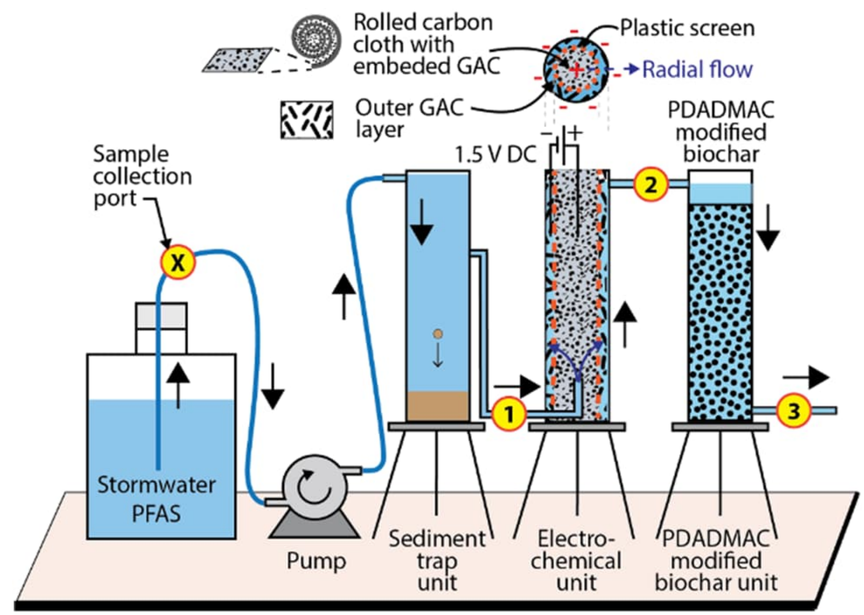


Borthakur, A., Das, T.K., Zhanga, Y., Libbert, S., Prehn, S., Ramos, P., Dooley, G., Blotevogel, J., Mahendra, S., and Mohanty, S.K. (2022) Rechargeable stormwater biofilters: In situ regeneration of PFAS removal capacity by using a cationic polymer, Polydiallyldimethylammonium chloride. Journal of Cleaner Production. 134244. https://doi.org/10.1016/j.jclepro.2022.134244.

SERDP Project: Innovative design to increase PFAS removal capacity

- Use innovative filter design to improve PFAS removal.
- Concept – increase electrostatic attraction on filter media.
- UCLA – Geosyntec partnership.
- $1.2 million research study starting in 2023.





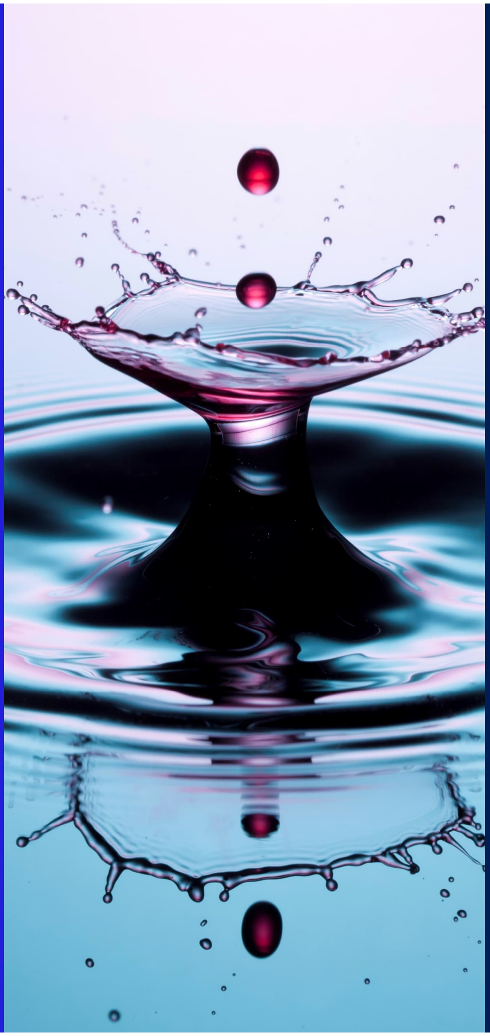
PFAS: What we have learned so far

- Amendments in bioinfiltration systems can be exhausted, limiting their use for sustained PFAS removal.
- Innovative methods to increase adsorption capacity in situ may help

PFAS and Biosolids Management

Todd Williams, PE, BCEE

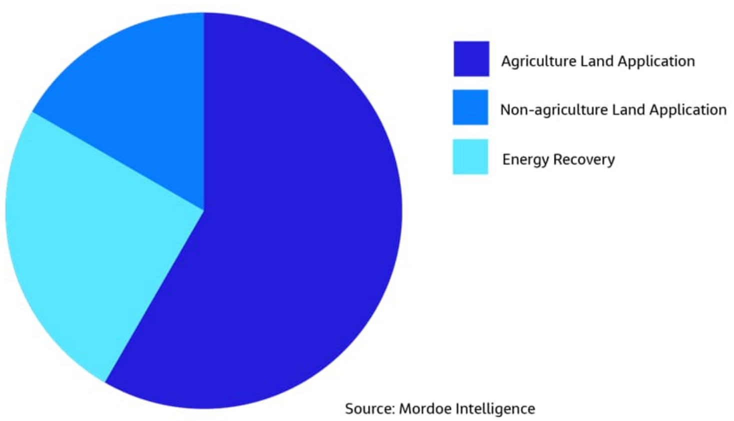
Jacobs Global Technology Leader - Biosolids



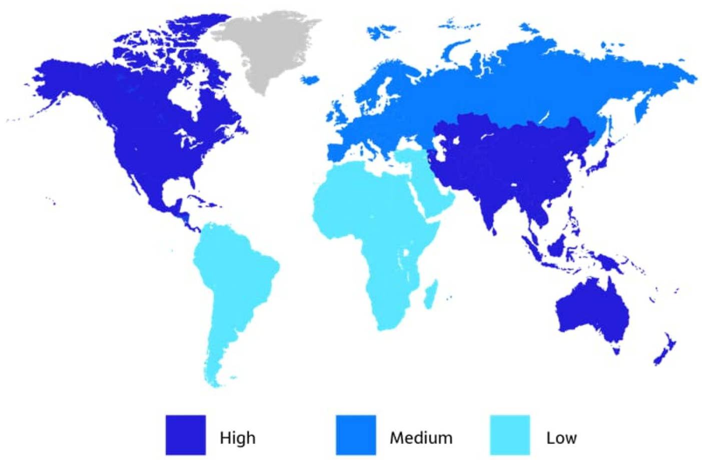
PFAS in Biosolids – Should we care?

- Land application makes up 60% of the global biosolids market
- In the US, half of the 5.8 M dry tons per year of WWTP biosolids are land applied.
- The US biosolids land application market is valued at $600M/year and growing 4% per year or more
- Problems with landfills is forcing even more biosolids to land application
- What are the concerns?
  - Surface water, ground water, plant uptake
- What do farmers and biosolids users think?

Biosolids Market, Volume (%), by Application, Global 2018



Biosolids Market – Growth Rate by Region, 2019-2024



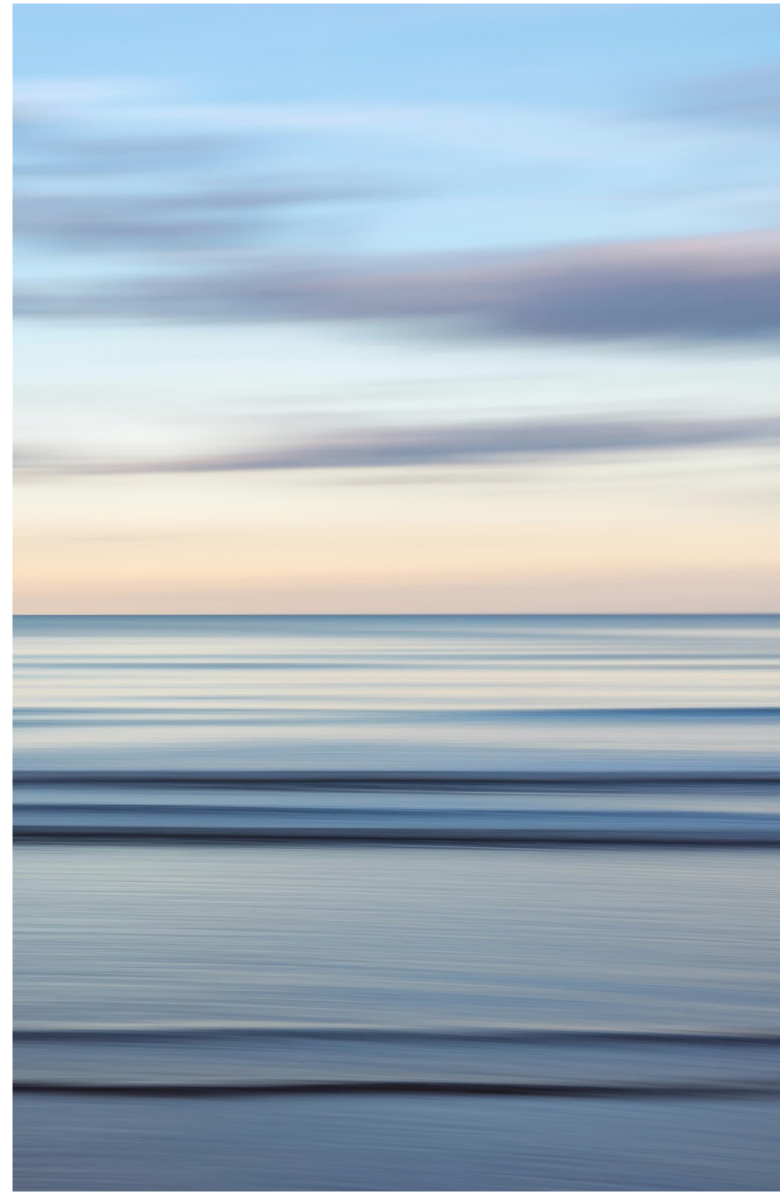
Are there regulations related to PFAS in biosolids?

US EPA Biosolids PFAS Rule-Making Progress

- Focus is on PFOS and PFOA where there is the most data
- PFAS in Biosolids Action Plan Developed February 2020
- Screening and Risk Assessment of Emerging Chemicals of concern including PFOA and PFOS
  - Model development is in progress and to be presented to the Science Advisory Board later this year or early next year
- Laboratory Draft Method 1633 for biosolids is being validated by multiple labs. Expected to be complete early 2023. EPA is pushing this method (40 compounds) instead of 537 modified (24 compounds)
- Risk Assessment to be completed by the end of 2024
  - If there are constituent limits…the 503 rule will be updated
  - Mitigation options will be included
  - Peer review and public comment period will occur
- EPA has informally endorsed Michigan's PFOS concentration approach

States are Approaching Biosolids Land Application Standards Independently

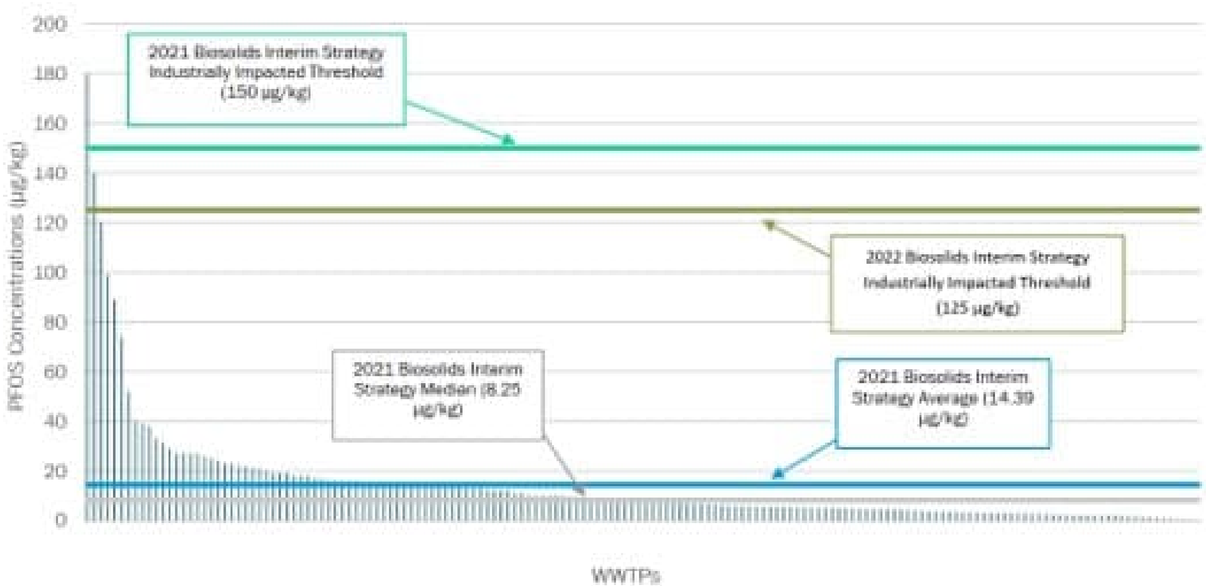
- California
  - PFAS investigation plan (March, 2019)
  - Sampled POTW's and POTW biosolids in 2020 and 2021
  - Wendy Linck of CA Water Control Board stated no issue in biosolids (June 2022)
- Maine
  - Ban on land application and sale and distribution of biosolids and septage products signed into law on April 20, effective July 20, 2022
- Michigan
  - Leveraged IPP program against surface water quality standards
  - Established interim guidance for land application effective July 1, 2021 and updated July 1, 2022



Michigan EGLE Biosolids Land Application Updated Interim Strategy Effective 7/1/2022

- PFOS > 125 µg/Kg, ppb
  - Land application not allowed! Alternative disposal (landfilling) required.
  - Investigate source reduction of PFAS
- PFOS > 50 and <125 µg/Kg, ppb
  - Land application allowed at no more than 1.5 DT/acre
  - Investigate source reduction of PFAS
- PFOS < 50 µg/Kg, ppb
  - Land application is allowed
  - If PFOS > 20 ppb, consider investigating sources

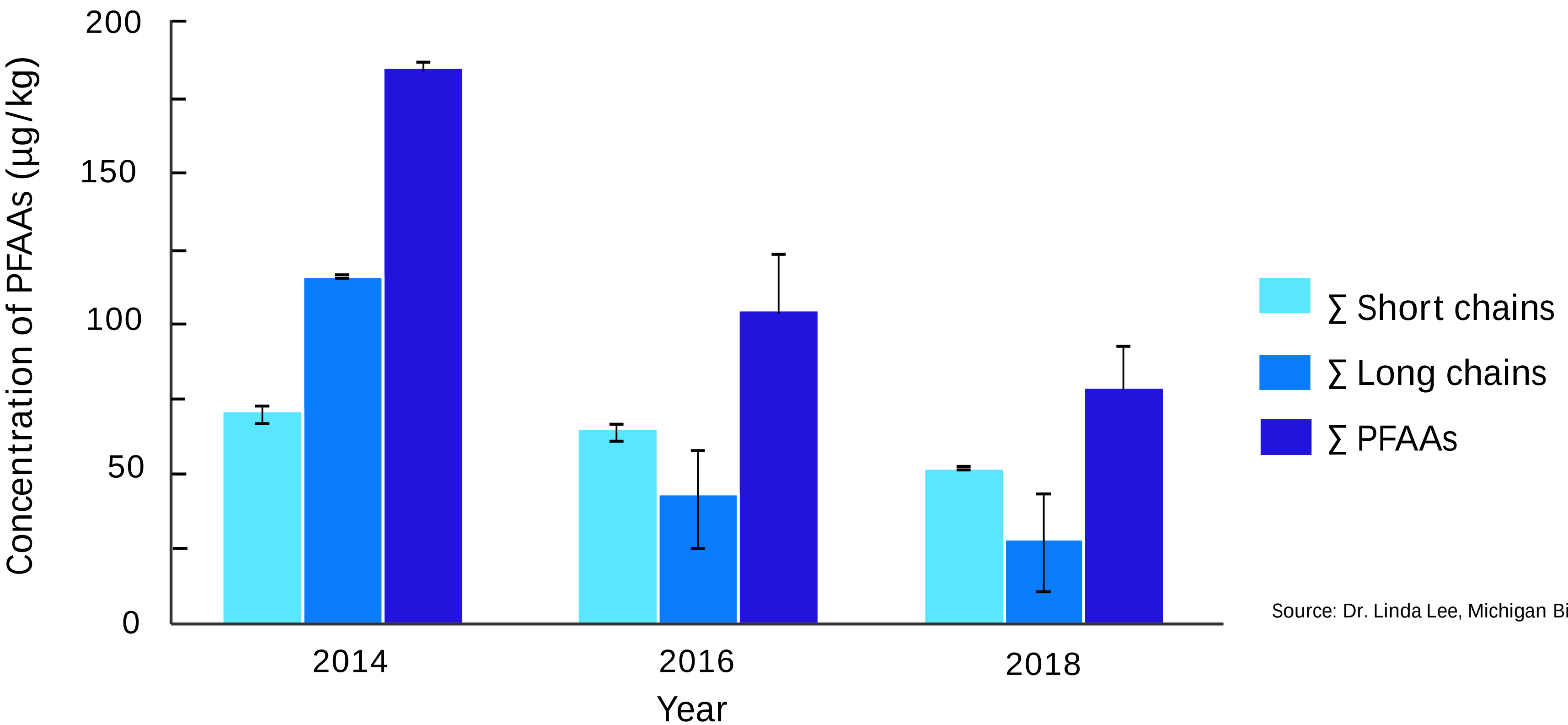
Figure 5. 2022 Industrially Impacted Threshold



Source: Michigan EGLE Land Application of Biosolids Containing PFAS; Updated Interim Strategy, April 2022

How can PFAS in biosolids be treated?

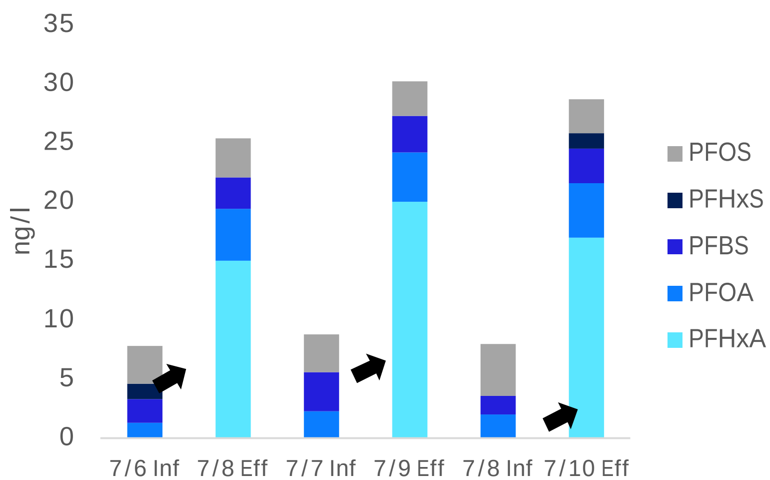
PFAA concentrations in biosolids have dropped as PFOS and PFOA were phased out of production in the US (one dried biosolids case study)



Source: Dr. Linda Lee, Michigan Biosolids Meeting, 2019

A Conventional Wastewater Facility PFAS Concentrations (ng/L)

Sample	Location	PFHxA	PFOA	PFBS	PFHxS	PFOS	Total
7/6 Inf 7/8 Eff	Influent	ND	1.3	2.0	1.3	3.2	7.8
	Effluent	15	4.4	2.7	ND	3.3	26.4
7/7 Inf 7/9 Eff	Influent	ND	2.3	3.3	ND	3.2	8.8
	Effluent	20	4.2	3.1	ND	2.9	30.2
7/8 Inf 7/10 Eff	Influent	ND	2.0	1.6	ND	4.4	8.0
	Effluent	17	4.6	2.9	1.3	2.9	28.7

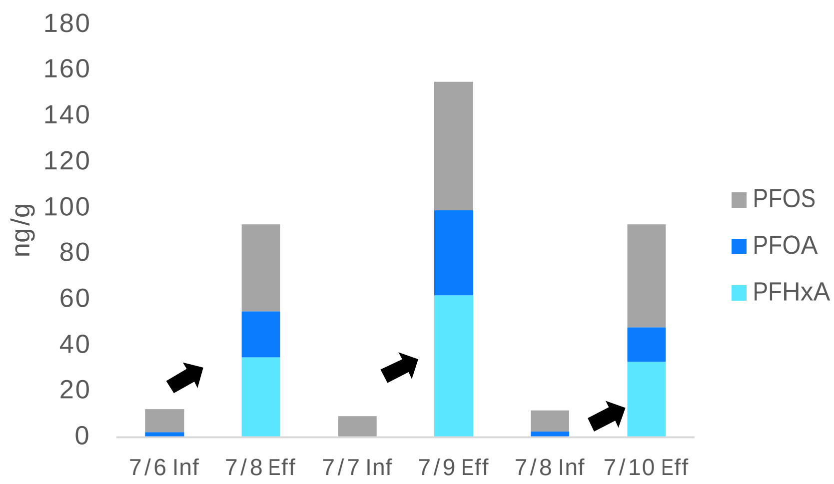


Source: Jacobs, 2019

- Low concentrations of PFAS detected
- Often see detectable concentrations due to wastewater source:
  - Domestic products
  - Landfill leachate
  - Human excretion
- Does not appear to have “significant” industrial contribution
- Increase across aeration commonly observed from “precursor” conversion

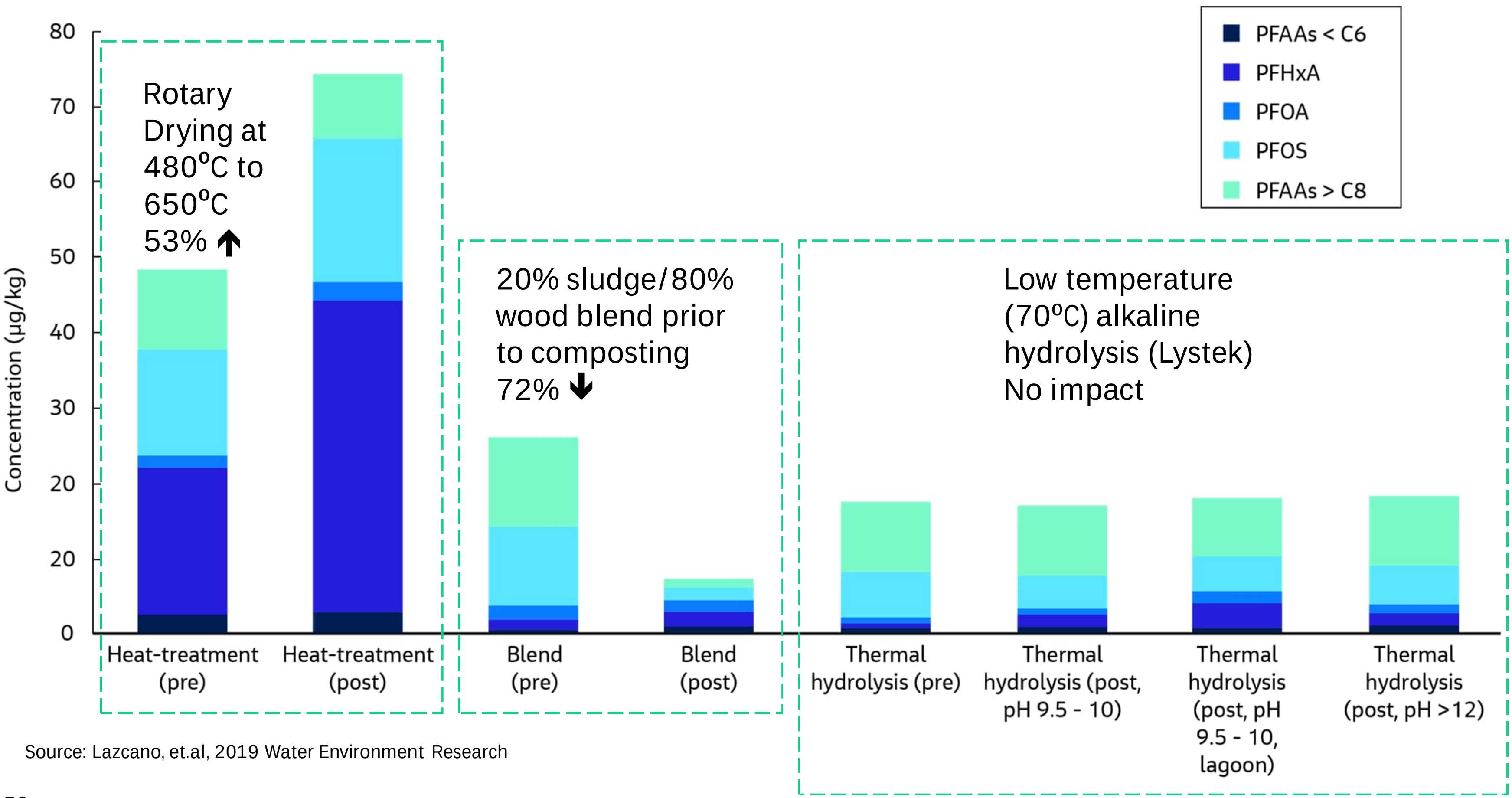
A Conventional Wastewater Facility Biosolids PFAS Concentrations (ng/g)

Sample	Location	PFHxA	PFOA	PFOS	Total
7/11 DI 7/6 BS	Digester Inf	ND	2.3	10	12.3
	Biosolids	35	20	38	93
7/13 DI 7/8 BS	Digester Inf	ND	ND	9.1	9.1
	Biosolids	62	37	56	155
7/15 DI 7/10 Eff	Digester Inf	ND	2.4	9.2	11.6
	Biosolids	33	15	45	93
Average	Digester Inf	ND	2.4	9.4	11.8
	Biosolids	43.3	24	46.3	114



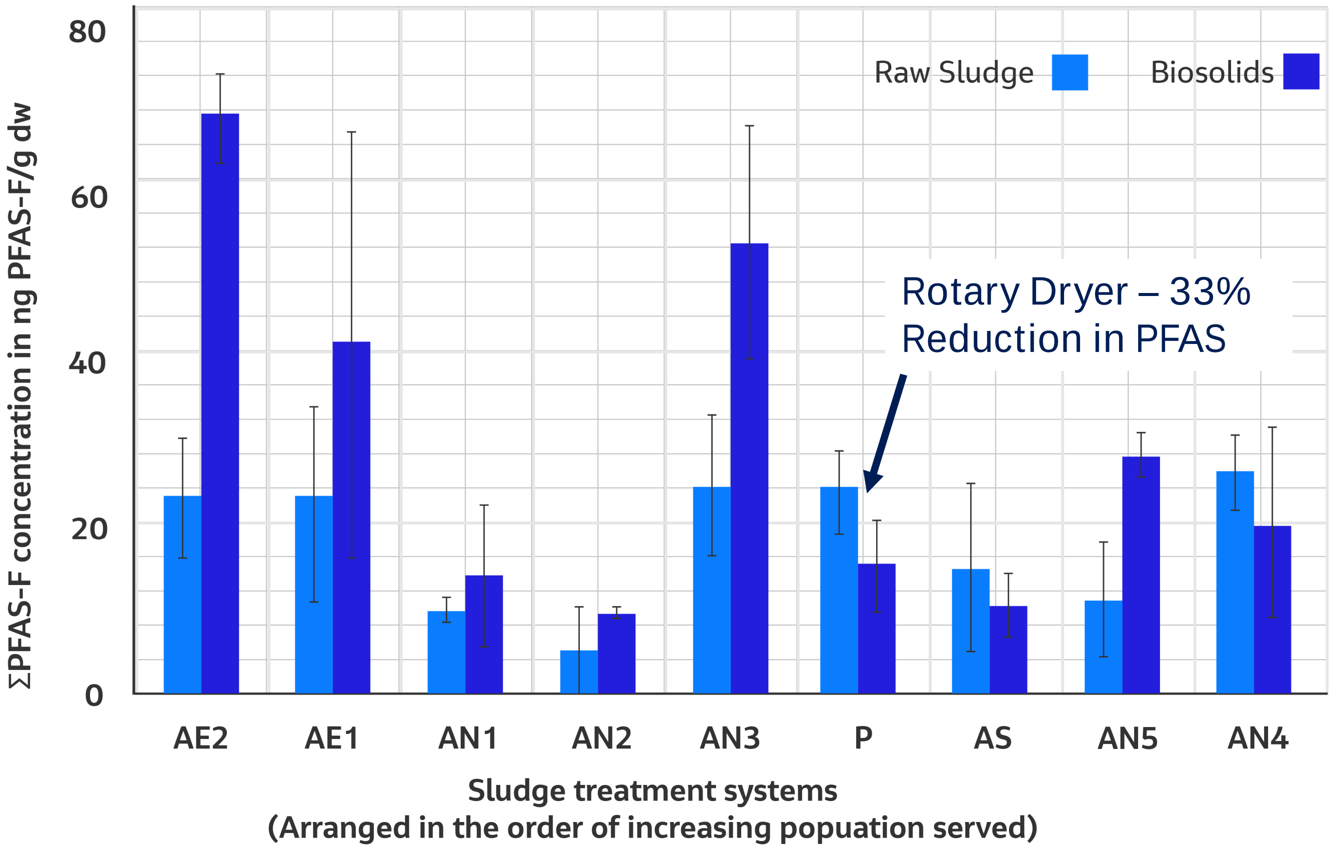
- 100% Waste Activated Solids treated through Autothermal Aerobic Digestion (ATAD) system
- PFBS and PFHxS not detected
- Increase across digestion from aerobic "precursor" conversion and/or changes in % solids

Impact of thermal drying, blending with bulking agent, and chemical/thermal hydrolysis treatment (not THP)



Source: Lazcano, et.al, 2019 Water Environment Research

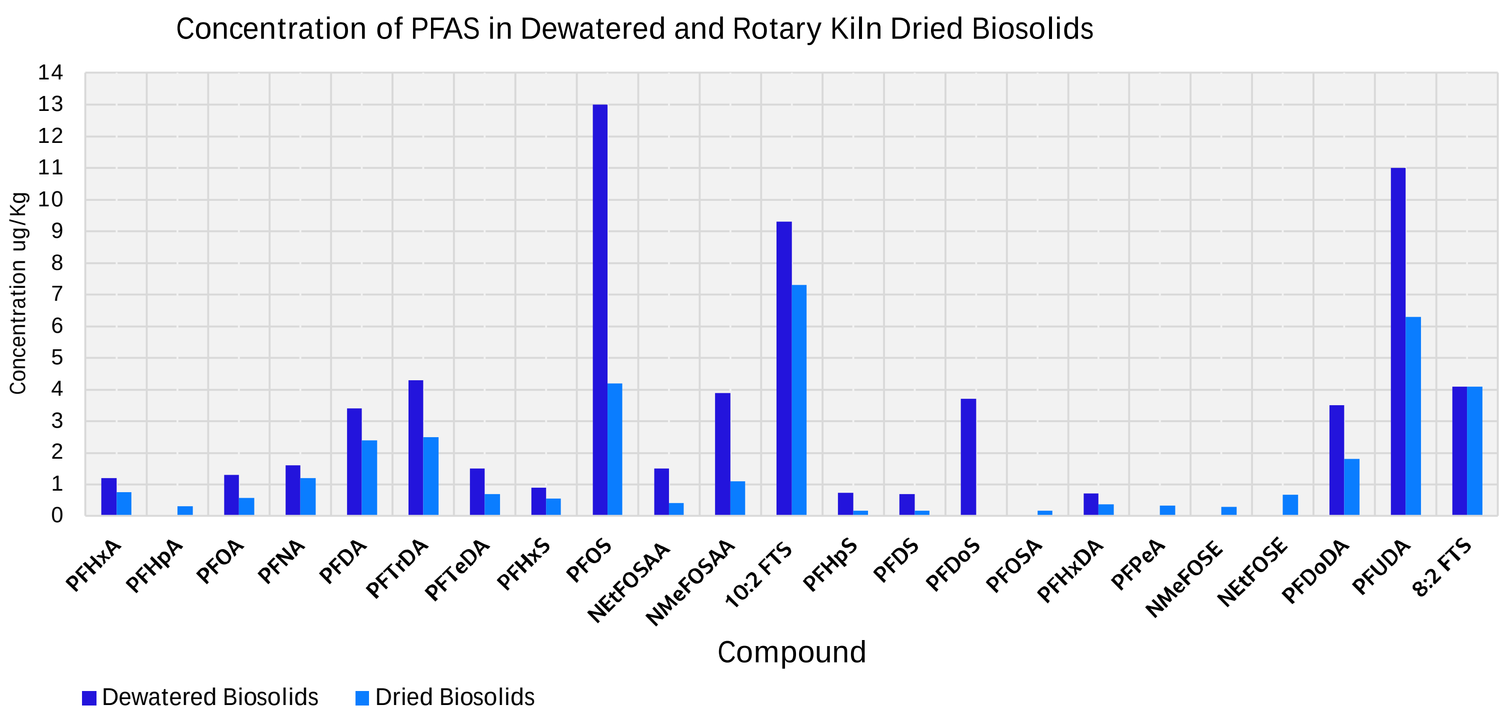
Canadian Sludge Treatment Systems Impact on PFAS



Source: Lakshminarasimman, et.al, 2021 Science of the Total Environment

Rotary Kiln Dried Undigested Biosolids PFAS Testing

45% Reduction of Measured PFAS (Range 25-75% reduction)

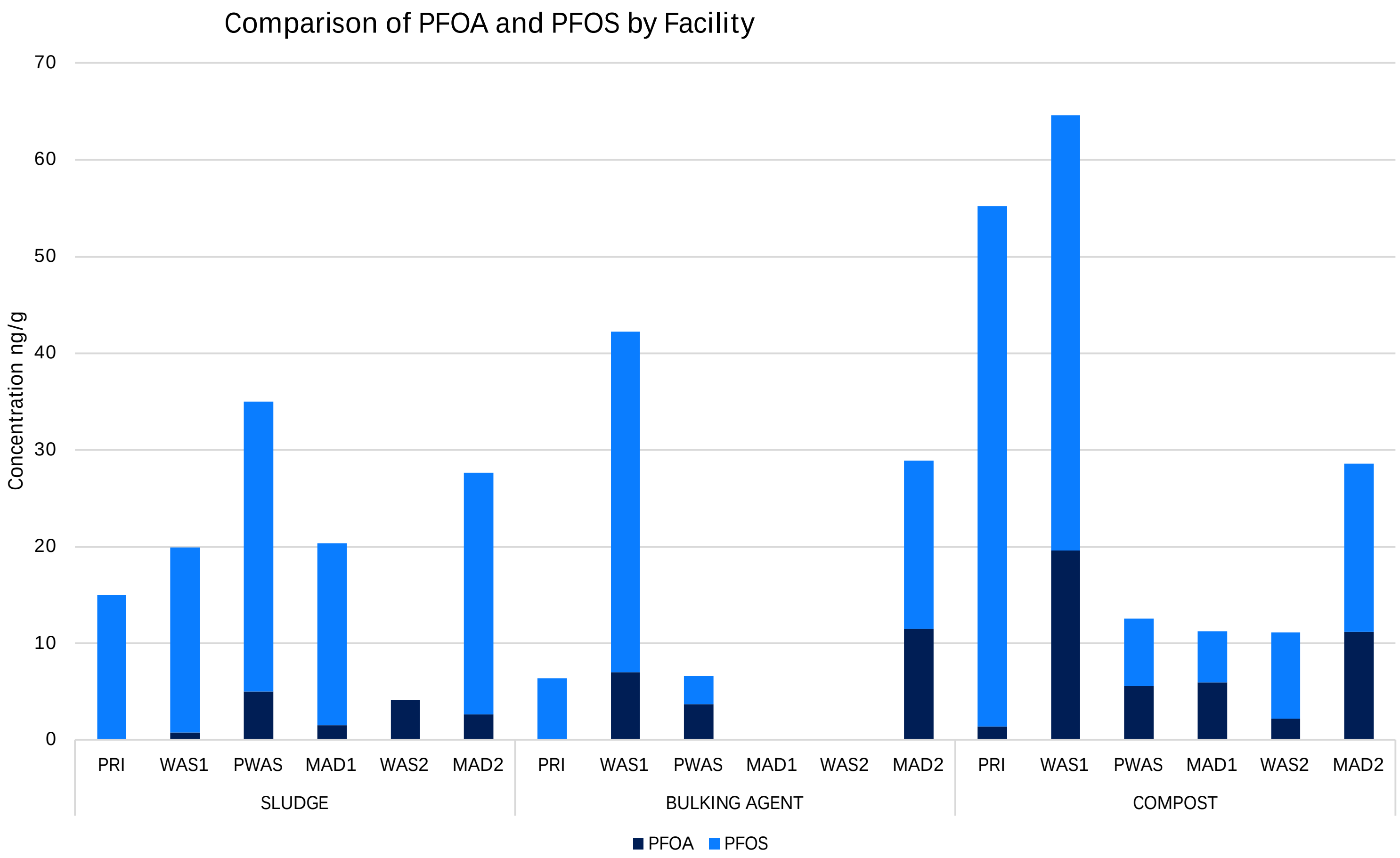


Source: Jacobs confidential client 2022

Biosolids Composting and its Impact on PFAS Concentrations

- Jacobs conducted sampling and testing of six biosolids composts for analysis of 24 PFAS compounds using isotope dilution/LC-MS/MS method (modified 537)
- Wastewater treatment systems where compost sampled have minimal industrial contribution
- Wastewater treatment schemes prior to composting included the following:
  - Primary treatment and primary sludge only (PRI-1)
  - Conventional secondary treatment with nutrient removal, mixture of primary and waste activated sludge (PWAS-1)
  - Conventional secondary treatment with nutrient removal, waste activated sludge only (WAS-2)
  - Conventional secondary treatment, mixture of primary and waste activated sludge, then mesophilic anaerobic digestion (MAD-2)
- All operations sampled utilized the aerated static pile method of composting
  - Meet all EPA 503 time and temperature requirements to achieve Class A and EQ standards

PFOA, PFOS and Total PFAS by Sludge and BA Type



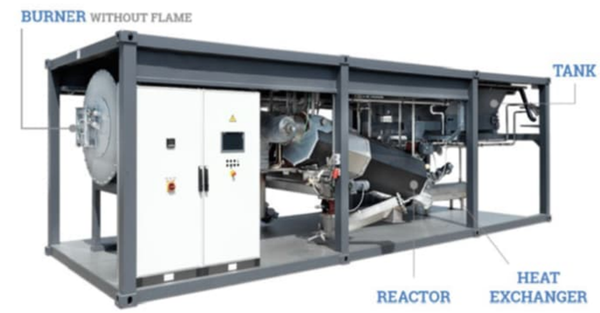
PRI & WAS2

PWAS & MAD1

WAS1 & MAD2

What About Pyrolysis?

- Pyrolysis is a process which occurs by exposing dried biosolids to high temperatures (850°F – 1300°F) without oxygen for ~20 minutes to produce a charcoal type product known as biochar.
- Destruction of contaminants such as estrogens, microplastics, PFAS & pathogens in biosolids
- Biochar is easy to store and handle
- Volume of biochar is ~50% less than dried biosolids
- Biochar is a valuable soil amendment
- Pyrogas can be used as fuel
- Relatively small footprint



(courtesy of BioforceTech)

(courtesy of CharTechnology)

What if PFAS Standards for Biosolids are Developed?
Pyrolysis after Drying will Eliminate Measurable PFAS in Char

- One set of samples 2019, confirmed in 2020, Jacobs independent test confirmed in 2020
- Pyrolysis at 1100^{o}F (600^{o}C)
- We know soil sampling needs to be above 1000^{o}C for destruction of PFAS

PFOA =89.1 &
PFOS = 26.3

All ND
@ 2ppb

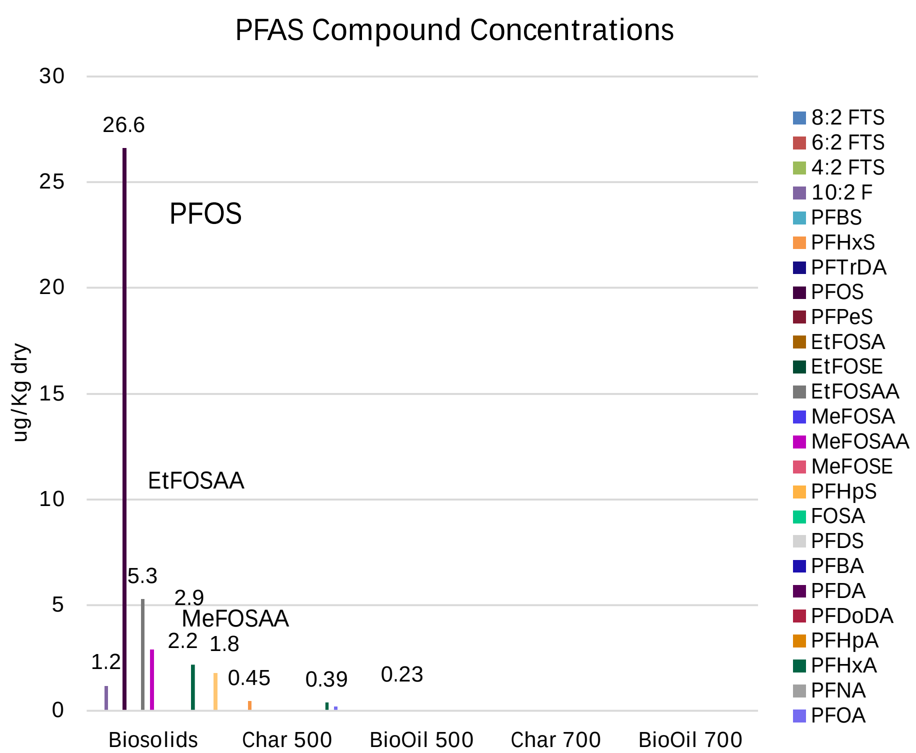
Compound Name	Dry Biosolids (ng/g)	Biochar (ng/g)
PFBA	7.03	Not Detected
3:3 FTCA	ND	Not Detected
PFPeA	5.94	Not Detected
PFBS	2.3	Not Detected
4:2 FTS	ND	Not Detected
PFHxA	33.7	Not Detected
PFPeS	ND	Not Detected
HFPO-DA	ND	Not Detected
5:3 [illegible]	[illegible]	[illegible]
PF[illegible]	[illegible]	[illegible]
AD[illegible]	[illegible]	[illegible]
PF[illegible]	[illegible]	[illegible]
6:[illegible]	[illegible]	[illegible]
PFOA	89.1	Not Detected
PFHpS	ND	Not Detected
7:3 FTCA	40	Not Detected
PFNA	5.3	Not Detected
PFOSA	ND	Not Detected
PFOS	26.3	Not Detected
9Cl-PF3ONS	ND	Not Detected
PFDA	11.3	Not Detected
8:2 FTS	5.68	Not Detected
PFNS	ND	Not Detected
MeFOSAA	23.5	Not Detected
EtFOSAA	19.6	Not Detected
PFUnA	3.39	Not Detected
PFDS	ND	Not Detected
11Cl-PF3OUdS	ND	Not Detected
10:2 FTS	ND	Not Detected
PFDoA	5.85	Not Detected
MeFOSA	ND	Not Detected
PFTrDA	ND	Not Detected
PFTeDA	2.44	Not Detected
EtFOSA	ND	Not Detected
PFHxDA	ND	Not Detected
PFODA	ND	Not Detected
MeFOSE	17.1	Not Detected
EtFOSE	ND	Not Detected

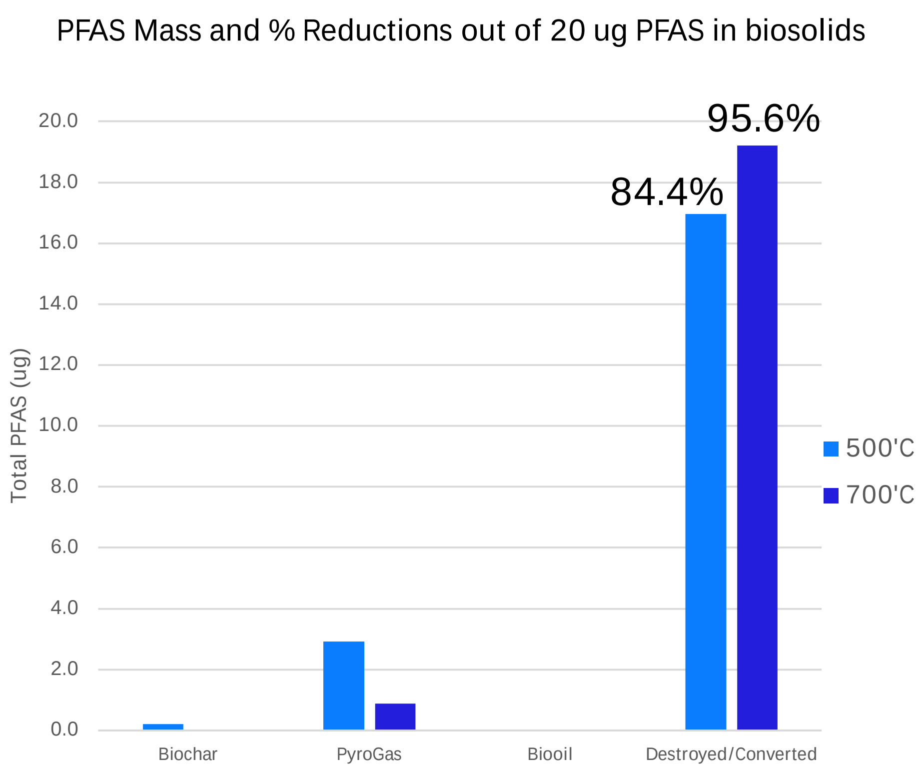
Source: BioForceTech, 2019, retested and confirmed 2020

What about in the Pyrogas?
Jacobs and Char did some of the first PFAS Testing of all Resultant Medias
Biosolids Sources That Were Tested

- 2020
  - Undigested conventional waste activated sludge
  - Dewatered with belt filter presses
  - Thermally dried using batch dryer to 95% total solids (TS)
  - Class A Exceptional Quality Biosolids
- 2022
  - Anaerobically digested conventional waste activated sludge
  - Thermally dried using batch dryer
  - Class A Exceptional Quality Biosolids

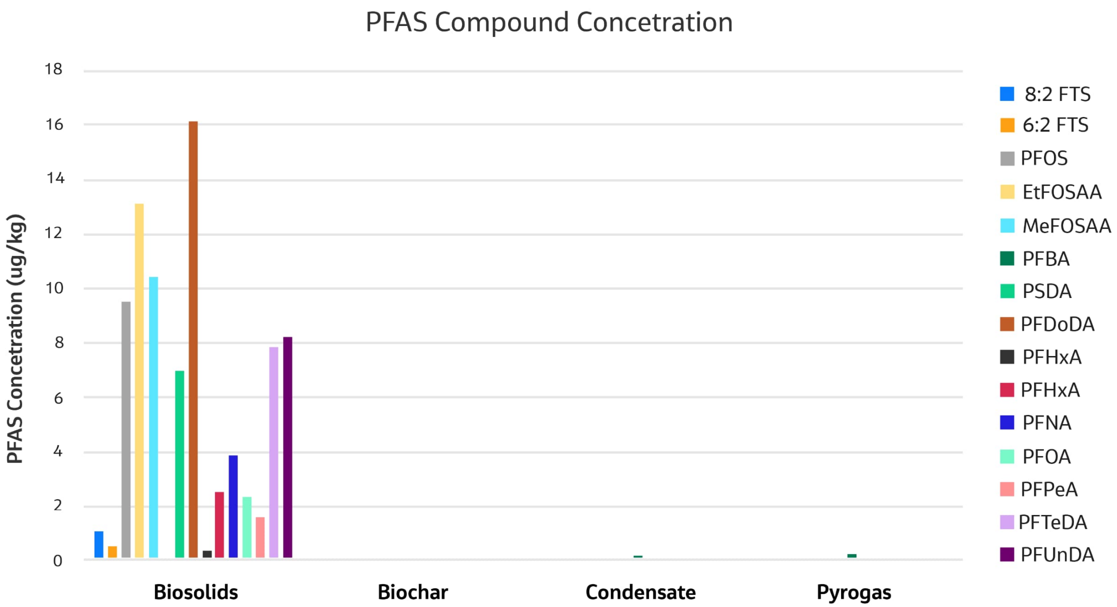
Undigested Dried Biosolids - Results Before and After Pyrolysis

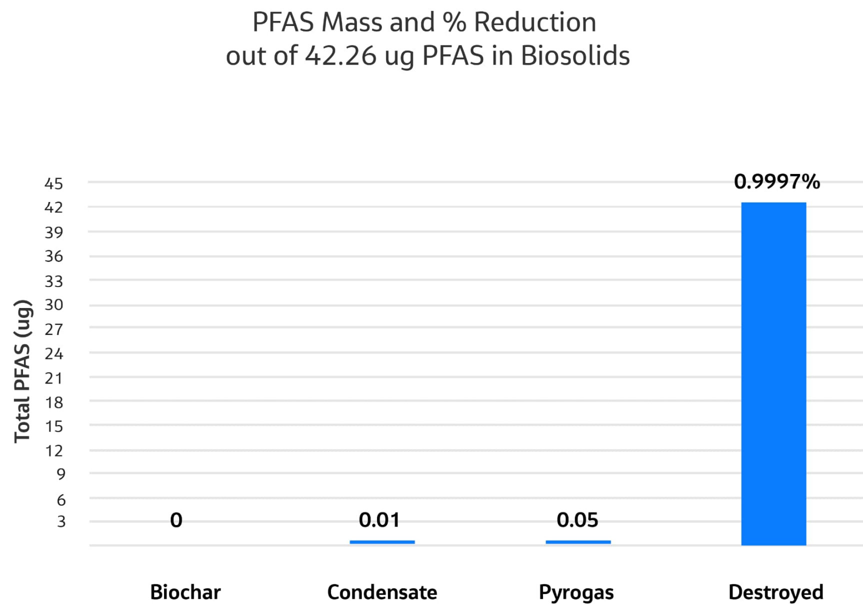




Source: Jacobs, WEF RBC 2021

Digested Dried Biosolids - Results Before and After Pyrolysis





Source: Jacobs, 2022

So what’s the Impact of Biosolids Processes on PFAS?

- Limited data….but…
  - Digestion may change precursors, but does not reduce overall PFAS levels
  - Thermal drying may increase or decrease measured PFAS depending on precursors and dryer technology
  - Composting of some sludges may decrease PFAS concentrations
  - Pyrolysis (and longer duration desorption) can eliminate measurable PFAS

Biosolids PFAS Management Summary Thoughts…

- Follow studies and regulation development
- It is important to update biosolids management plans
- It is important to develop flexible biosolids programs that can be modified as regulations and/or public demand require
- Consider testing biosolids to understand PFAS levels
- Look upstream for industries that may use PFAS (SIC search)
- Prepare for questions from the public as they will come
- Fact sheets are available from several sources
  - https://www.nacwa.org/advocacy-analysis/campaigns/pfas
  - https://pfas-1.itrcweb.org/

Poll Question

- How many times have you tested your biosolids for PFAS?

a. Zero
b. Once
c. Two or more

Questions & Answers

Challenging today.
Reinventing tomorrow.

Thank You!

Jacobs

Challenging today.
Reinventing tomorrow.

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