Addressing Emerging Contaminants for Water Plants

November 30th, 2023

SEDAC
SMART ENERGY DESIGN ASSISTANCE CENTER

Providing effective energy strategies for buildings and communities

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

Who We Are

We assist buildings and communities in achieving energy efficiency, saving money, and becoming more sustainable.

We are an applied research program at University of Illinois.

Our goal: Reduce the energy footprint of Illinois and beyond.

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About the IEPA PWI Energy Efficiency Program

The Illinois EPA Public Water Infrastructure Energy Assessment Program helps municipalities reduce the cost of water and wastewater treatment.

- **No-cost** energy assessments and technical assistance
- Comprehensive report listing:
  - Potential savings
  - Estimated economics
  - Funding sources
- Operator continuing education

Apply at:
www.smartenergy.Illinois.edu/water

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

Funding provided in whole or in part by the Illinois EPA Office of Energy. This program is in partnership with the U.S. Dept. of Energy Sustainable Wastewater Infrastructure of the Future (SWIFT) Accelerator for energy efficiency in wastewater treatment.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Apply for an Energy Assessment!

Step 1: Initial Application – Pre-Qualification

- Apply at www.smartenergy.Illinois.edu/water
- Be located in Illinois & be publicly-owned
- Allow SEDAC/ISTC to visit site
- Be willing to share facility information
- Share final assessment report with Illinois EPA

Step 2: Data Collection

- Facility information: Process flow, equipment details, etc
- 2 years of utility bills and MORs
- We make this as painless as possible

Step 3: Site Visit Scheduled

Step 4: Report Delivery

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Why Complete an Energy Assessment?

Older Existing System or No Previous Assessments?

Identify missed opportunities

Plan for capital improvements

Uncover what is possible

3rd party support for WTP personnel's ideas

New or Recently Upgraded?

Always more to improve

Plan for future opportunities outside the scope of recent projects

New technologies and processes always in development

Identify opportunities for repairs or upgrades and associated funding!

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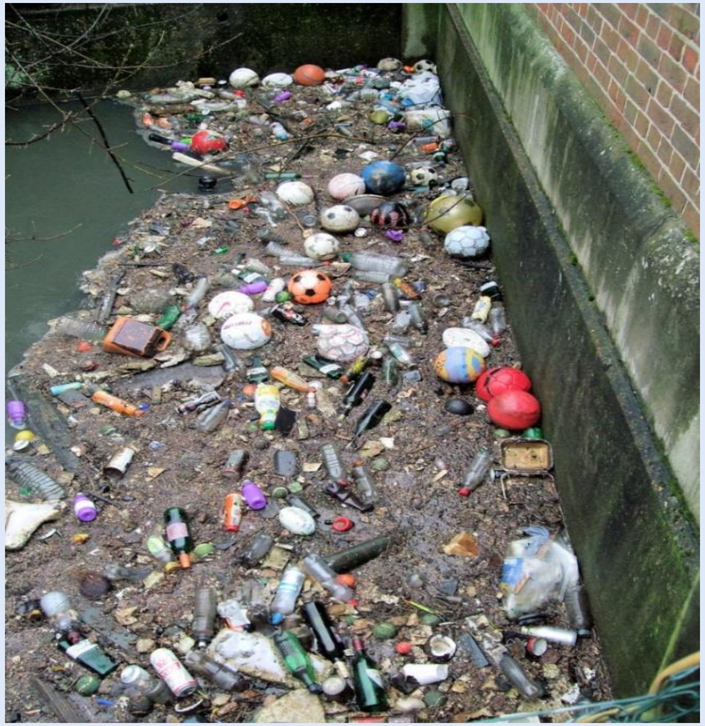
Webinar Outline

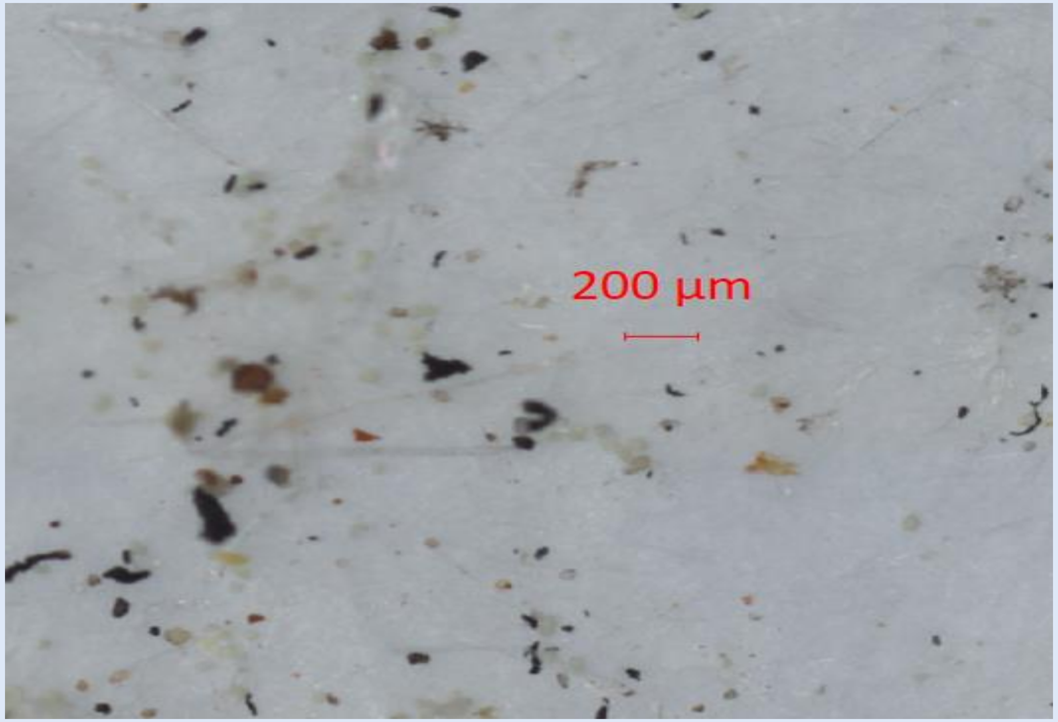
Part 1 – John Scott – ISTC Senior Chemist

Part 2 – Dr. Susan Glassmeyer – USEPA Research Chemist

Part 3 – Shawn Maurer – SEDAC

Plastic Pollution – Smaller the Size, Bigger the Problem

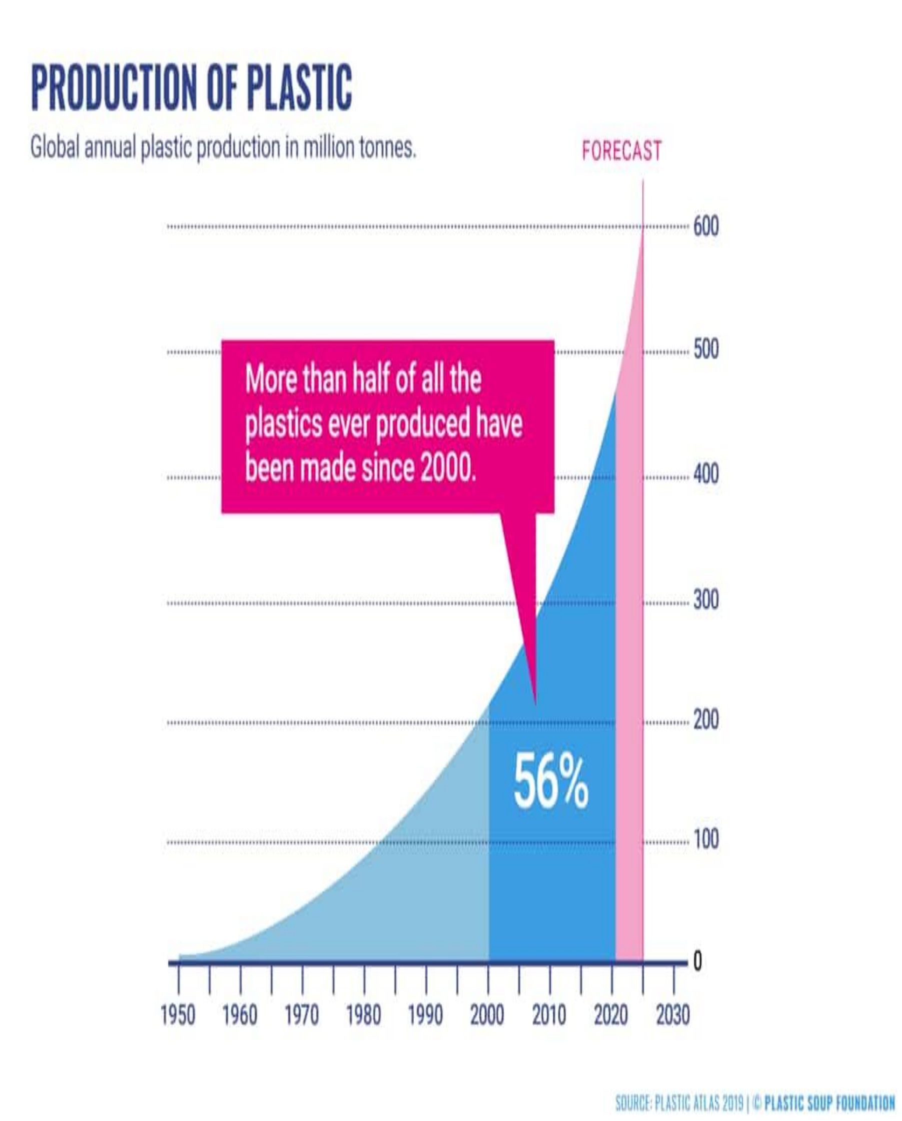




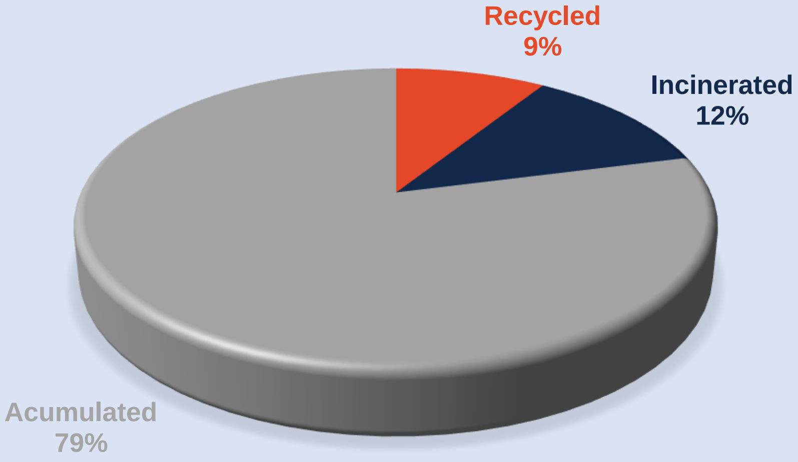
Presented by John Scott - Senior Chemist, University of Illinois

SEDAC November 30, 2023

Living in the Age of Plastics



- Estimated that 8.3 billion metric tons of plastic produced to date.
- Cumulative plastic waste generated is 6.3 billion metric tons.



Source- Geyer, Roland, Jenna R. Jambeck, and Kara Lavender Law. "Production, use, and fate of all plastics ever made." Science advances 3, no. 7 (2017): e1700782.

Where Do We Find Microplastics ?

- Surface water
- Sediments and soil
- Air and dust
- Food and beverages
- Cosmetics
- Wastewater
- Wildlife
- Karst groundwater

- And everywhere else we look

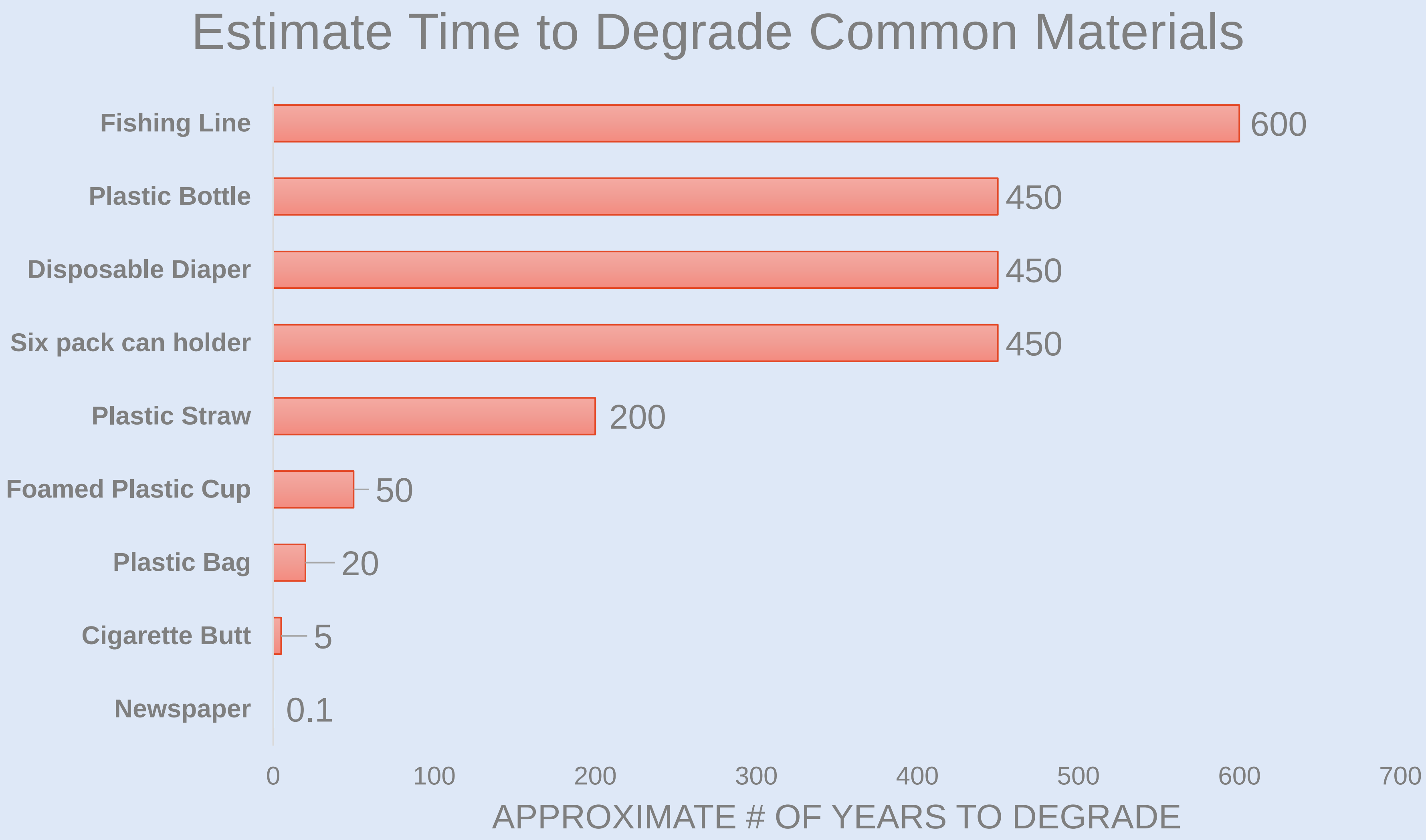
Our team first to discover microplastics in karst groundwater

Project Partners
- Illinois State Water Survey
- Loyola University Chicago

Health Effects and Environmental Impacts

?

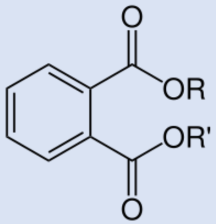
The Problem of Persistence



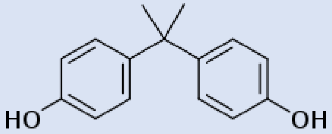
Sources: NOAA/WOODS HOLE SEA Grant & http://environment.about.com/

It’s More Than Just Plastic

Chemical Additives



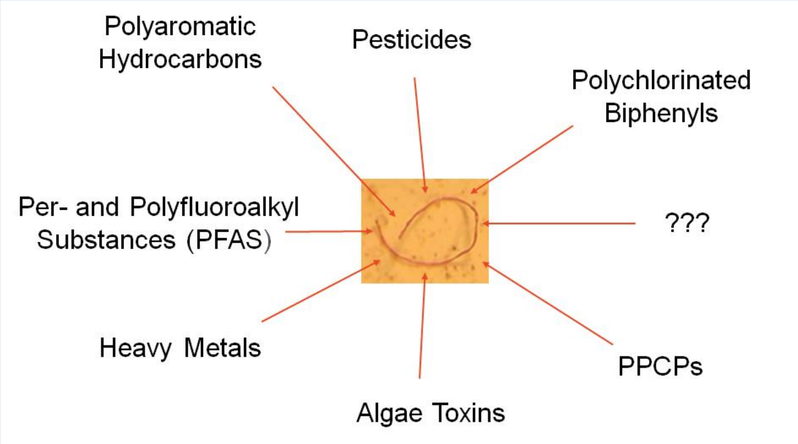
Phthalates



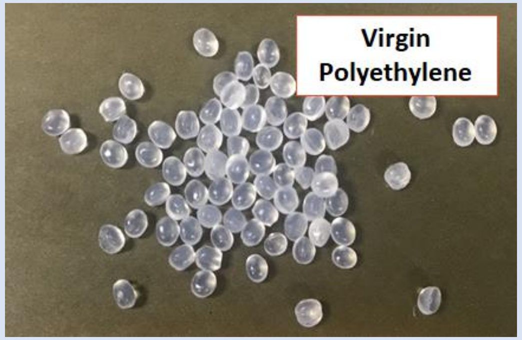
Bisphenol A

Heavy Metals such as Lead, Cadmium, Chromium, Arsenic, Antimony, etc.

Plastics Sorb Environmental Pollutants

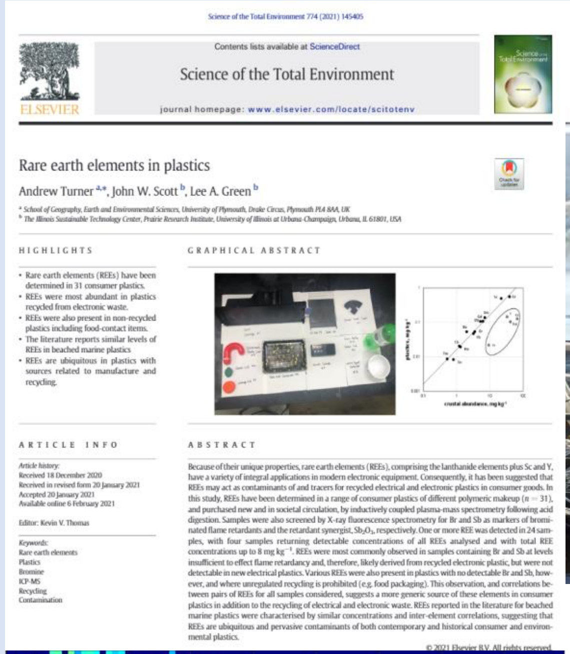


Plastics Sorb Biological Materials



Microplastics Research Portfolio

- Polymer Identification by Mass Spectrometry and Infrared
- Additives & Contaminants in Plastics
- Adsorption of Environmental Pollutants
- Fate and Transport of Microplastics
- Weathering and Degradation of Plastic
- Development of Microplastic Analysis Methods
- Occurrence of Microplastics in Environmental Samples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Rare earth elements in plastics

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HIGHLIGHTS

- Rare earth elements (REEs) have been determined in 31 consumer plastics.
- REEs were most abundant in plastics recycled from electronic waste.
- REEs were also present in non-recycled plastics including food-contact items.
- The literature reports similar levels of REEs in beached marine plastics
- REEs are ubiquitous in plastics with sources related to manufacture and recycling.

GRAPHICAL ABSTRACT

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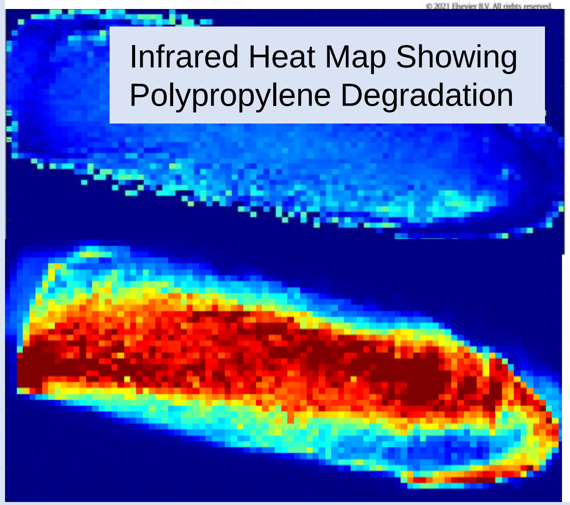
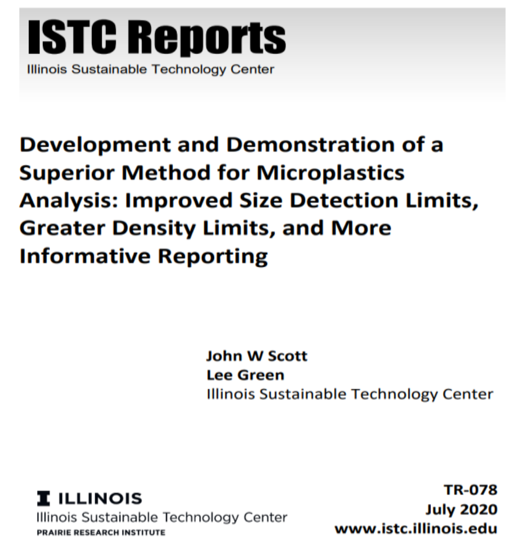
Recycling
Contamination

ABSTRACT

Because of their unique properties, rare earth elements (REEs), comprising the lanthanide elements plus Sc and Y, have a variety of integral applications in modern electronic equipment. Consequently, it has been suggested that REEs may act as contaminants of and tracers for recycled electrical and electronic plastics in consumer goods. In this study, REEs have been determined in a range of consumer plastics of different polymeric makeup ($n = 31$), and purchased new and in societal circulation, by inductively coupled plasma-mass spectrometry following acid digestion. Samples were also screened by X-ray fluorescence spectrometry for Br and Sb as markers of brominated flame retardants and the retardant synergist, Sb_2O_3, respectively. One or more REE was detected in 24 samples, with four samples returning detectable concentrations of all REEs analysed and with total REE concentrations up to 8 mg kg^{-1}. REEs were most commonly observed in samples containing Br and Sb at levels insufficient to effect flame retardancy and, therefore, likely derived from recycled electronic plastic, but were not detectable in new electrical plastics. Various REEs were also present in plastics with no detectable Br and Sb, however, and where unregulated recycling is prohibited (e.g. food packaging). This observation, and correlations between pairs of REEs for all samples considered, suggests a more generic source of these elements in consumer plastics in addition to the recycling of electrical and electronic waste. REEs reported in the literature for beached marine plastics were characterised by similar concentrations and inter-element correlations, suggesting that REEs are ubiquitous and pervasive contaminants of both contemporary and historical consumer and environmental plastics.



Infrared Heat Map Showing Polypropylene Degradation


ISTC Reports

Illinois Sustainable Technology Center

Development and Demonstration of a Superior Method for Microplastics Analysis: Improved Size Detection Limits, Greater Density Limits, and More Informative Reporting

John W Scott
Lee Green
Illinois Sustainable Technology Center

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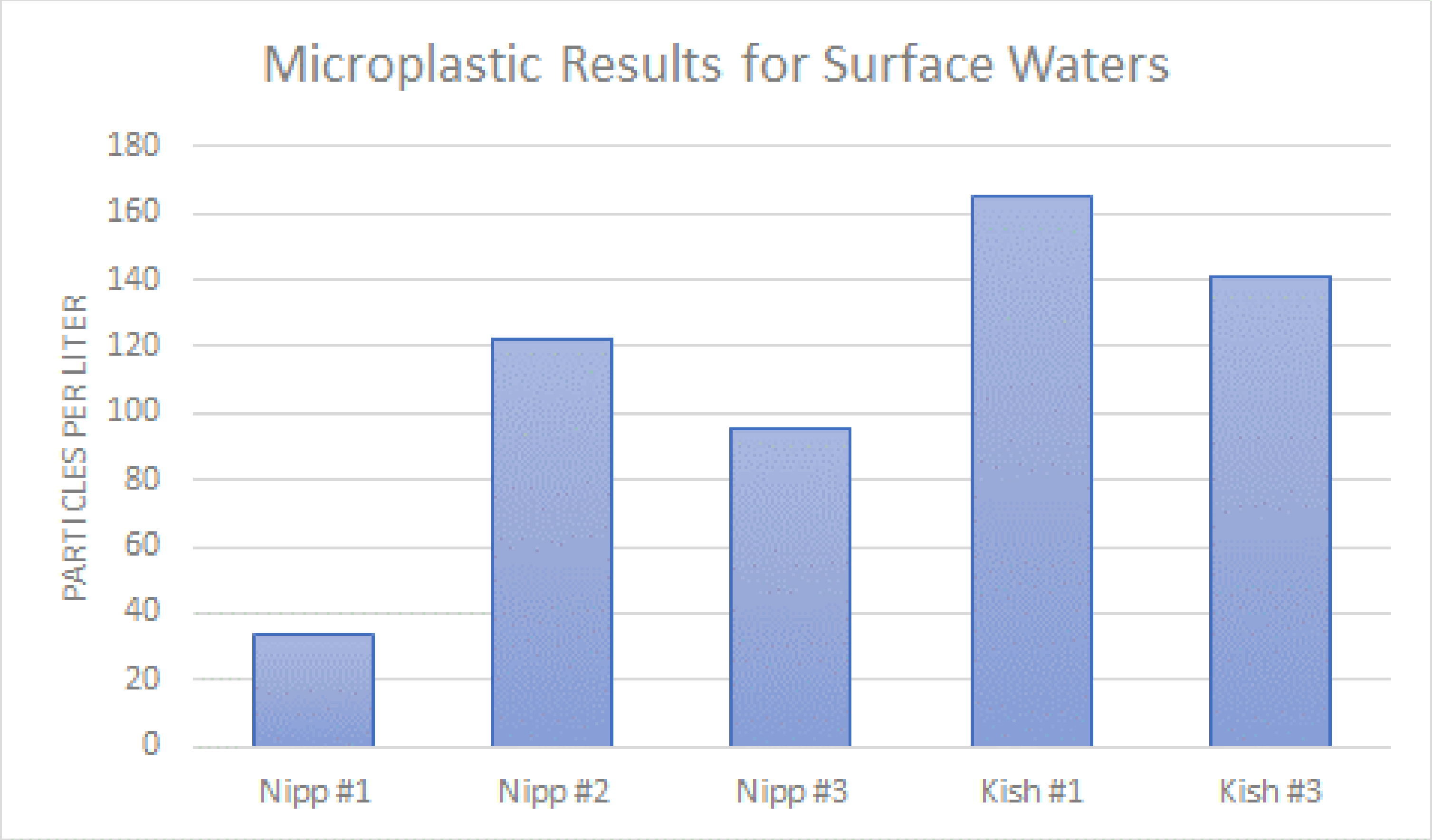
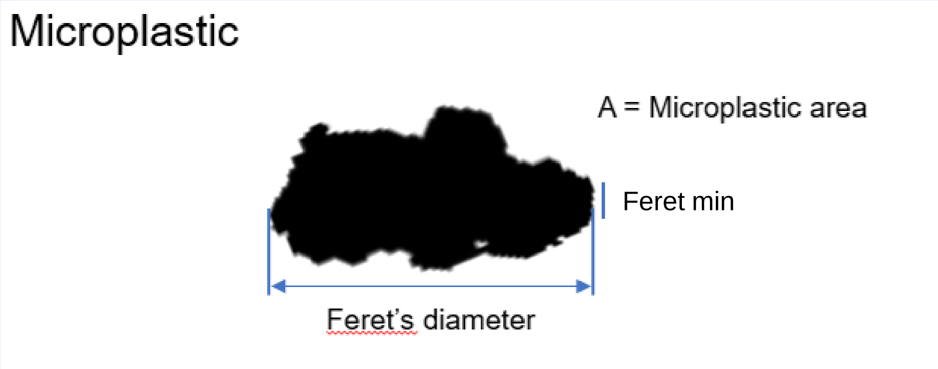
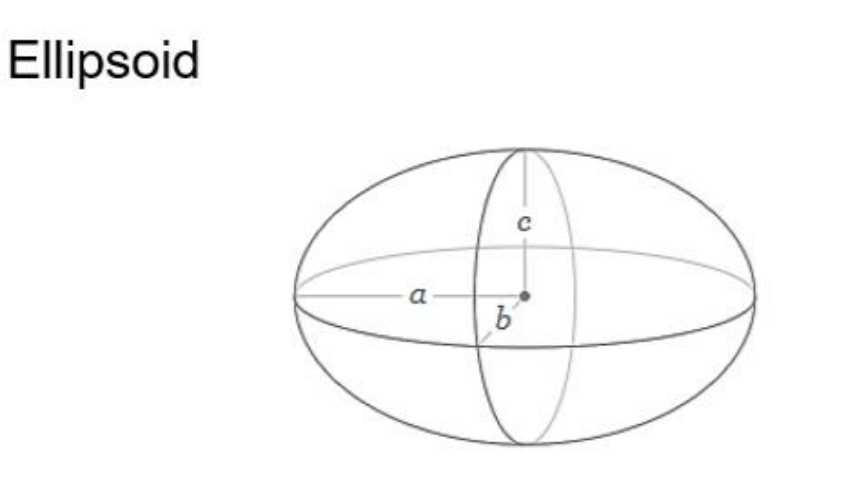
TR-078
July 2020
www.istc.illinois.edu

Reporting of Microplastics, #/L or kg



Estimating Microplastic Mass





Estimate Volume (μm^3)

$$V = (4/3)\ \pi\, a\, b\, c$$

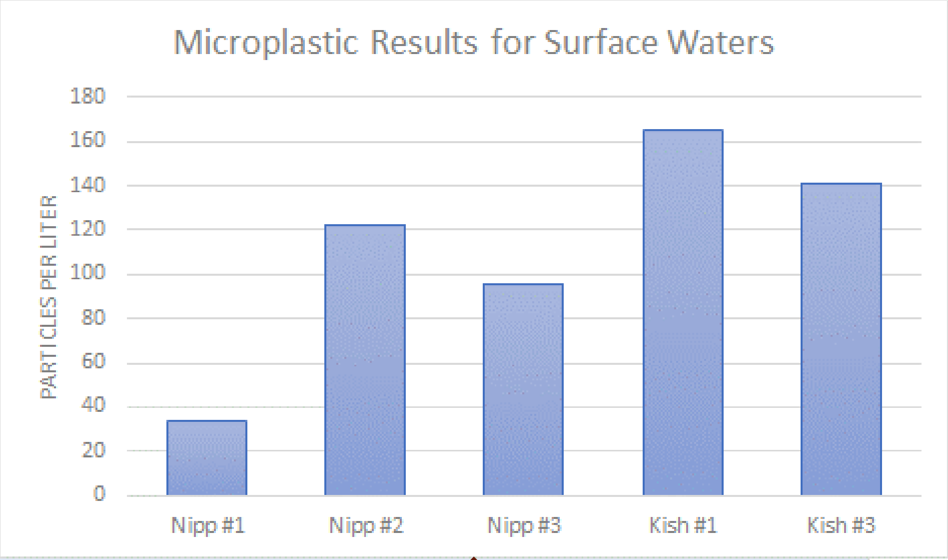
a = Feret's diameter / 2

b = A ÷ (πa)

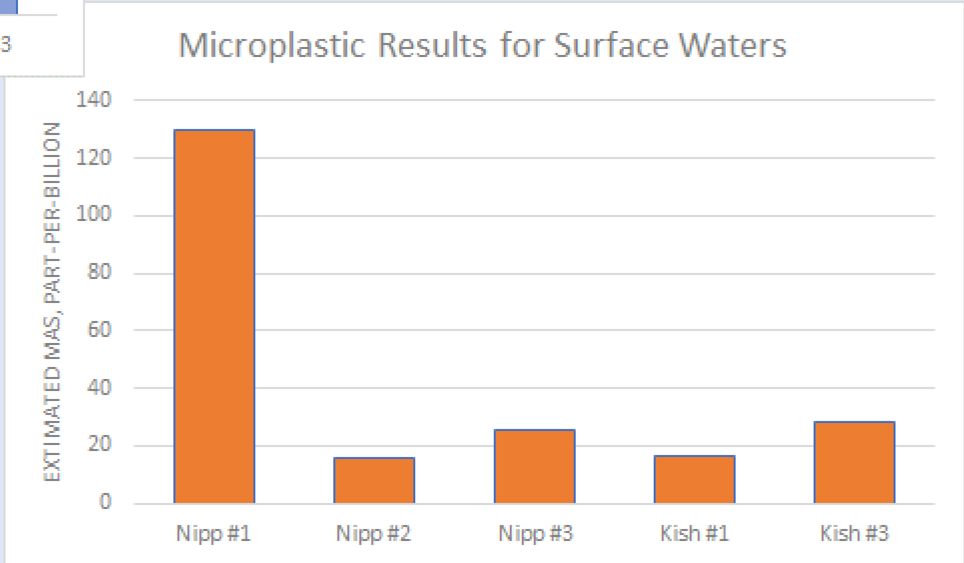
c = 0.72 * *(Feret min / 2)*

Mass = Density x Volume

Microplastics, Counts vs. Mass

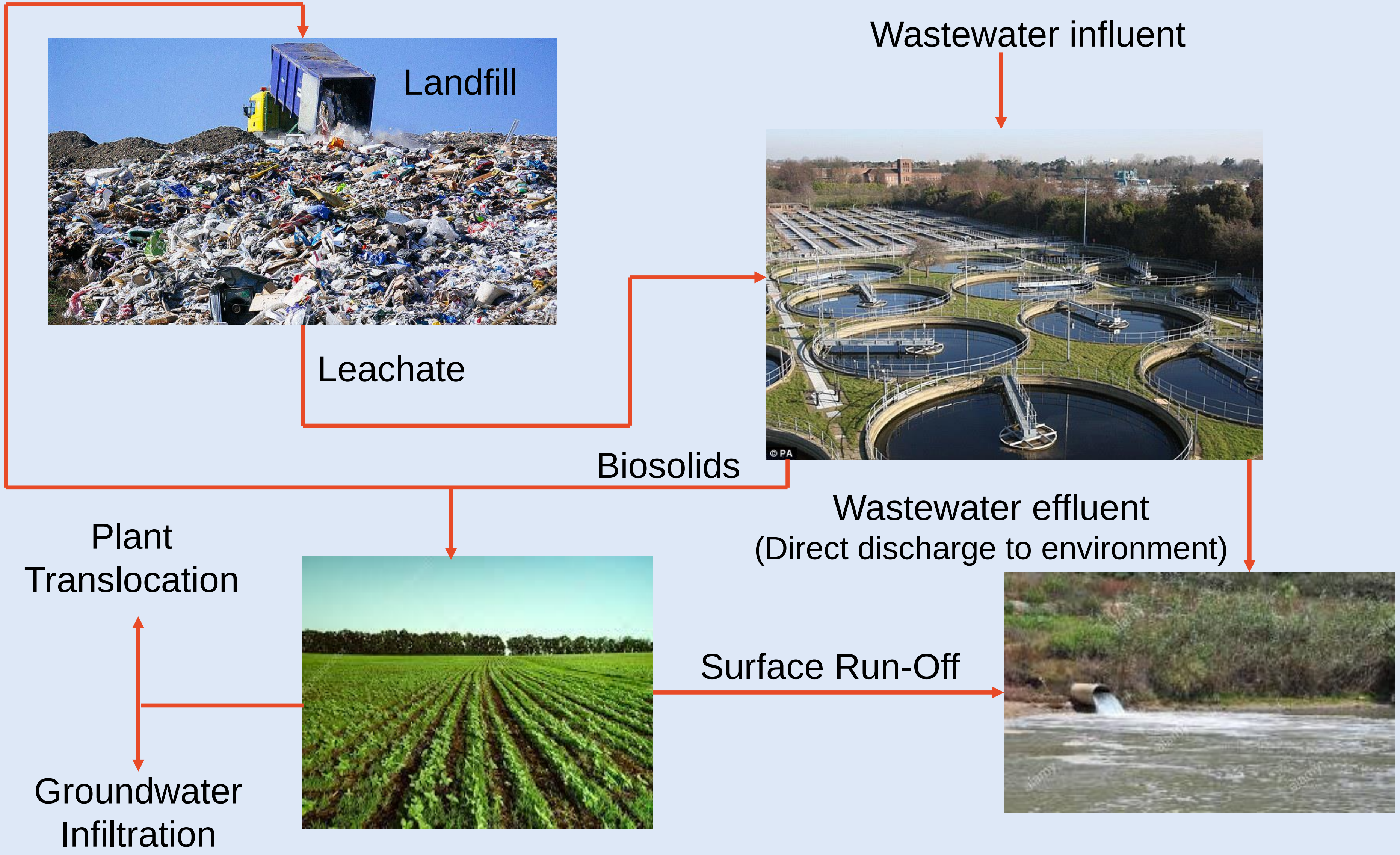


On a mass basis

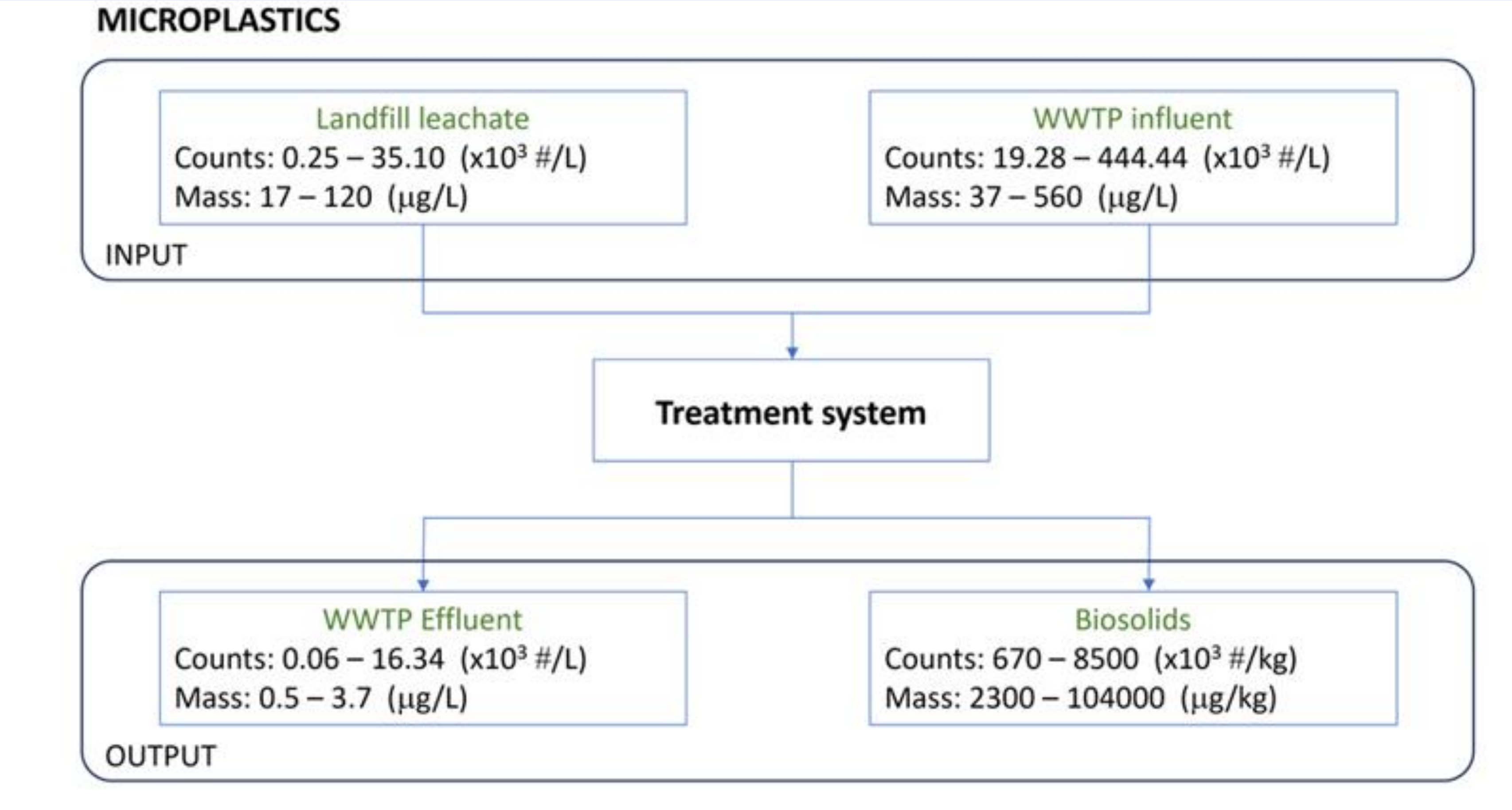


On a count basis

Landfill-WWTP Systems



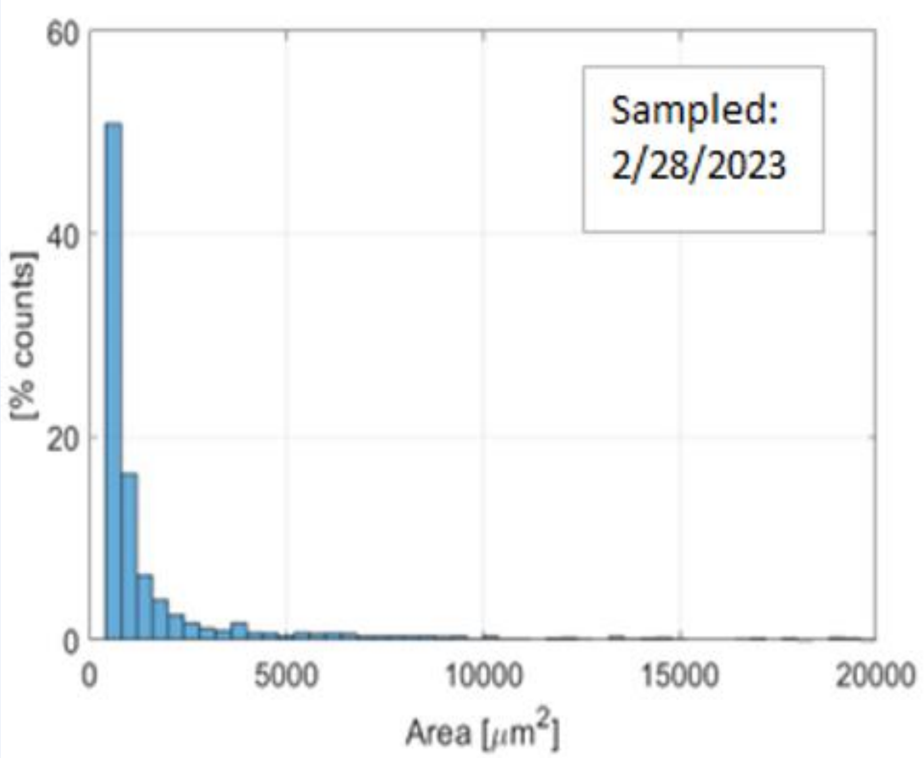
Microplastic in Landfill-WWTP Systems



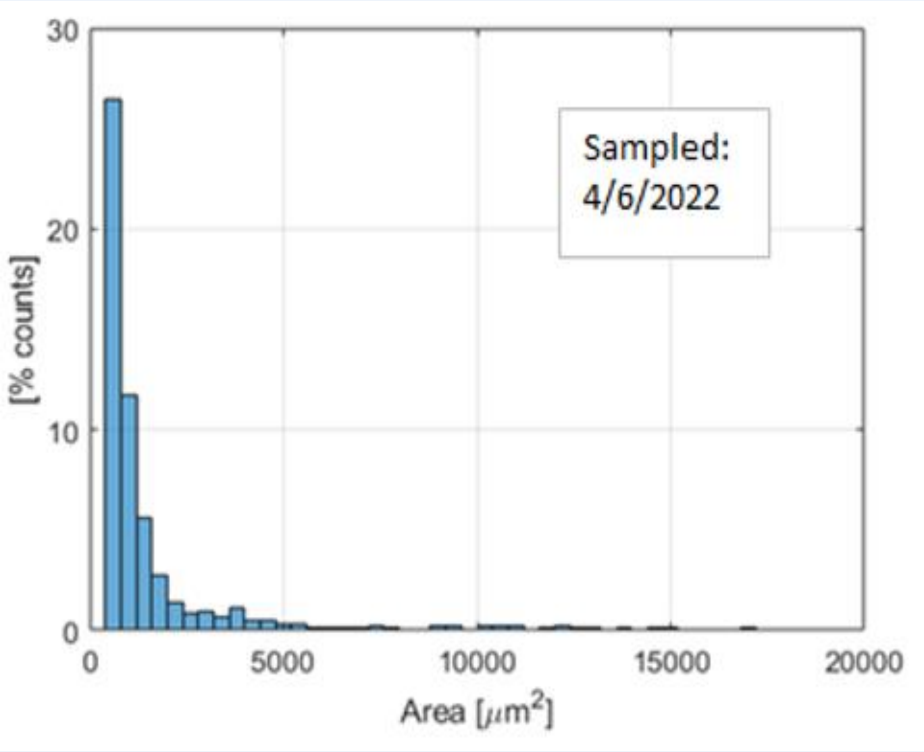
Scott, J., L. Green, A. Prada (2023). "The Transport of Emerging Contaminants (PFAS and Microplastics) in Landfill-Wastewater Treatment Systems." TR Series (Illinois Sustainable Technology Center); in Review.

Pending Review – Do Not Cite

Size Distribution of Microplastics



Landfill Leachate



Biosolids

Greater Occurrence for Smaller Size

Questions?

John W Scott, ISTC Senior Chemist
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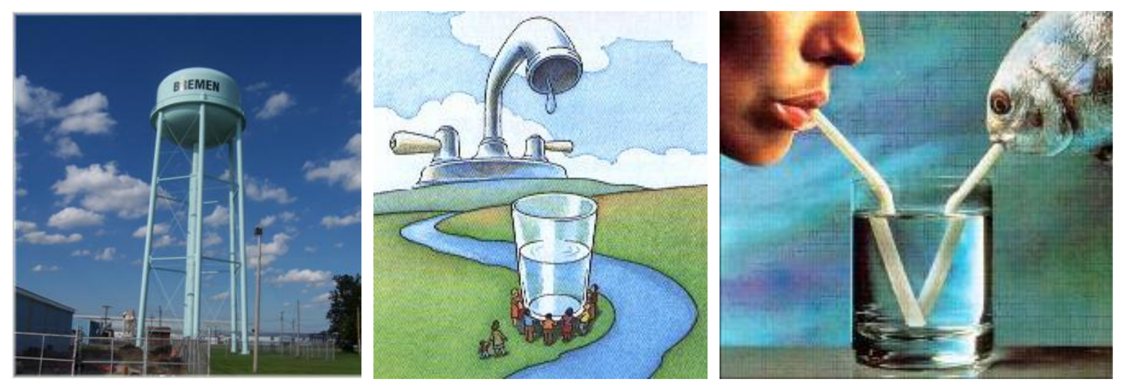
217-333-8407

Still Haven’t Found What You’re Looking For? Integrated Interdisciplinary Analyses May Be the Solution.



United States Environmental Protection Agency

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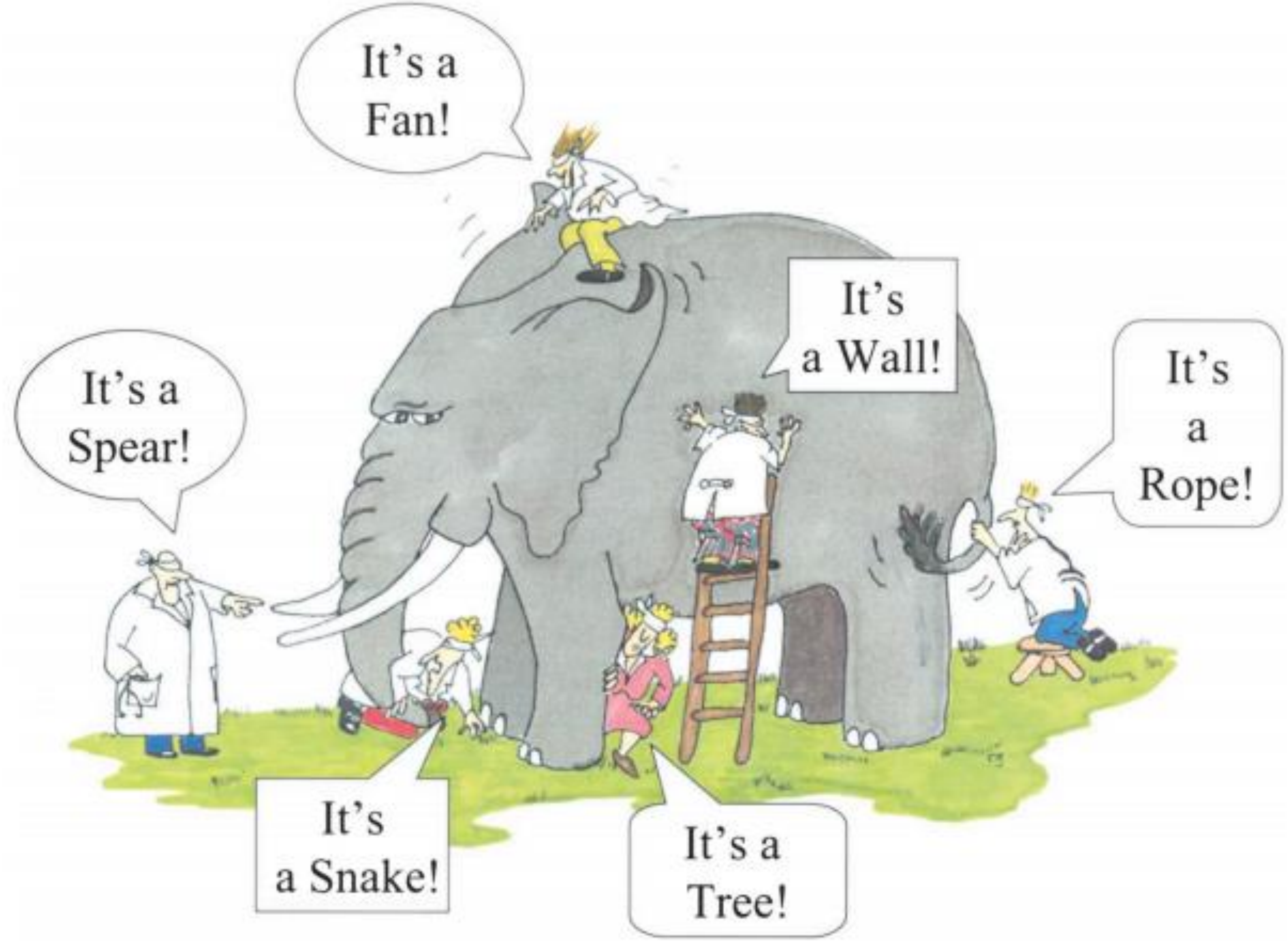
Parable of the Blind Men



Himmelfarb et al., Kidney International 2002

Is Science Blind?
(or maybe just myopic)

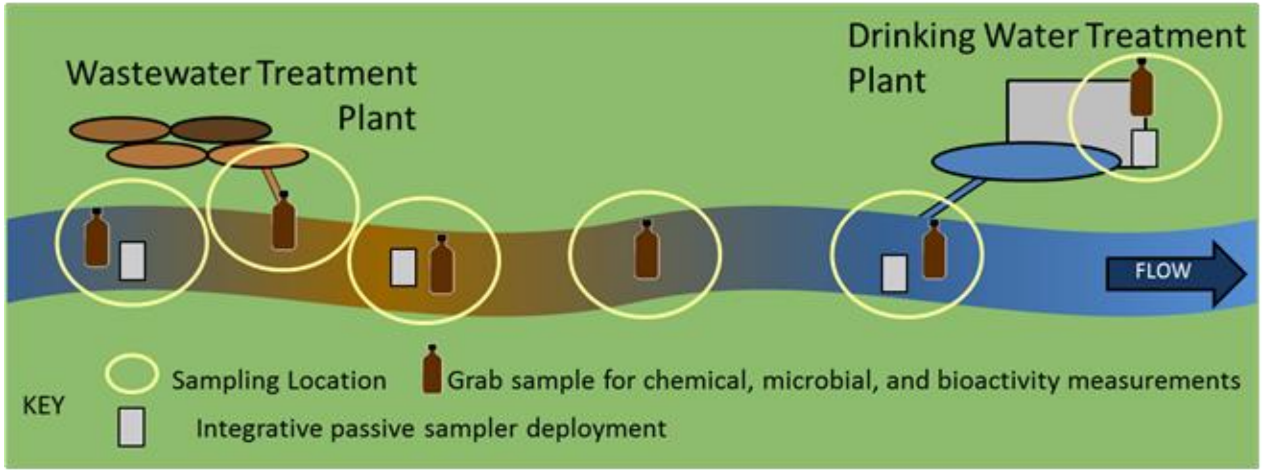
Targeted grab samples: Snapshots of concentration

Integrative samplers: Longer term loads or concentrations

Nontargeted analyses: Presence of a large number of chemicals

Bioassays: Effects of chemical mixtures

Transport of Wastewater Contaminants



- Goal: examine the occurrence and fate of contaminants of emerging concern (CECs) as they travel from WWTP into DWTP over various seasons and flow conditions.
- Study design: collect residence-time-weighted samples to analyze: chemicals, microorganisms, and bioactivity.
  - One stream reach
  - Three sampling events (Oct 2014, April 2015 and Aug 2015)
  - Six sampling points [Upstream (UP), Effluent Pipe (EFF), Effluent Mixing Zone (EMZ), Downstream (DNS), Drinking Water Intake (DWI), Treated Drinking Water (TDW)]

Utilities

Wastewater Treatment Plant

- –1.2 MGD
- –Serves ~1,700 people
- –Advanced secondary treatment with UV disinfection

Drinking Water Treatment Plant

- –Average 4.5 MGD
- –Serves ~37,000 people
- –Ozone, flocculation, sedimentation, GAC and sand filtration, chloramination (ozone not used in Round 1)

Sample Collection

- **Upstream, Effluent Mixing Zone, Downstream:** sampling device placed ~2 feet below surface, corks pulled and bottle filled.
- **Effluent:** bottle placed in effluent pipe.
- **Drinking Water Intake and Treated Drinking Water:** sampled taps within DWTP.
- Water for all samples decanted into individual bottles except one analytical method required field filtration (direct aqueous injection of pharmaceuticals).

Assays

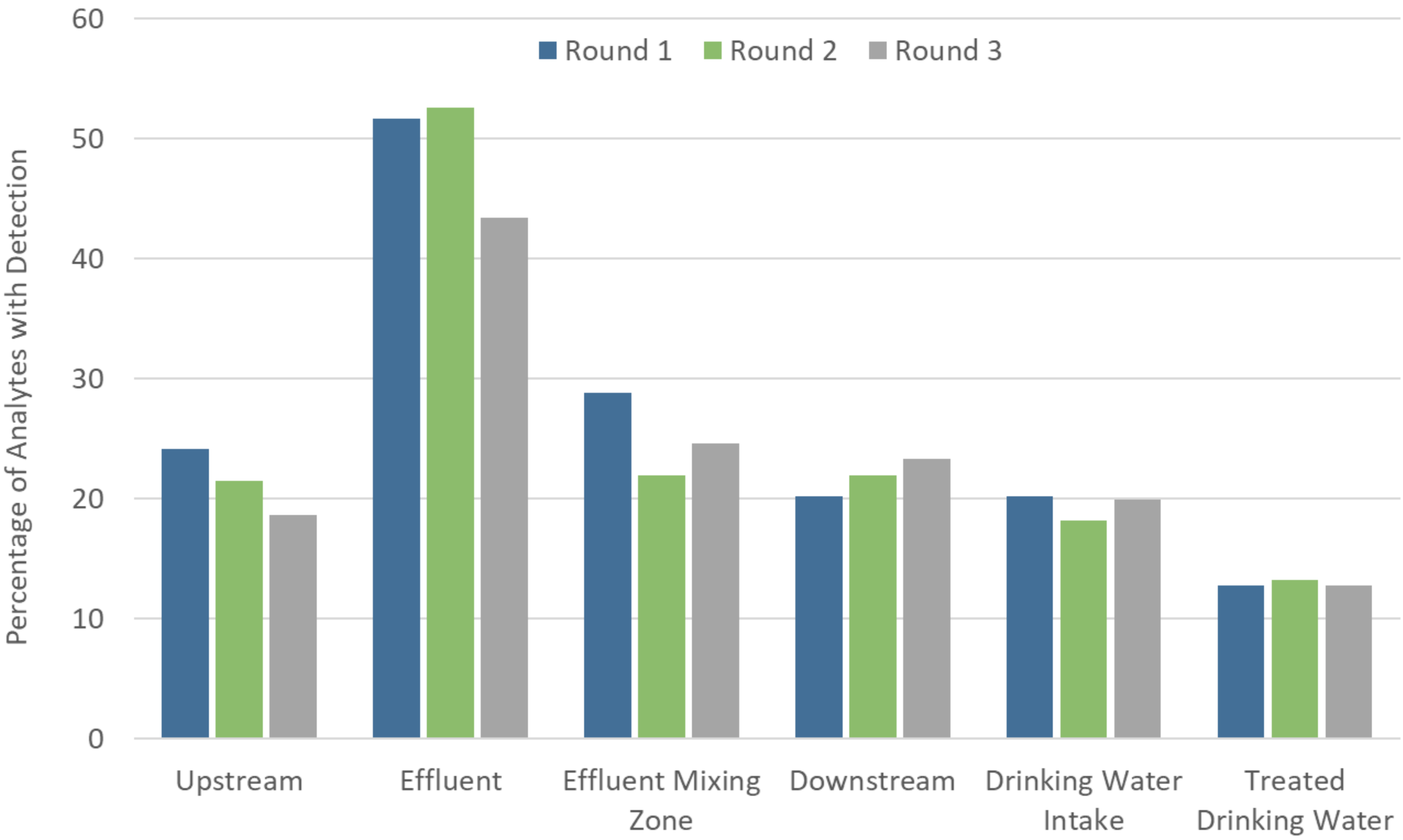
PI	Assay	Number of Analytes
USGS: Ed Furlong	Pharmaceuticals	109
USGS: Mike Meyer	Antibiotics	28
USEPA: Tammy Jones-Lepp	Antibiotics and aromatase inhibitors	16
USEPA: Kathy Schenck	Hormones and other EDCs	9
USEPA: Marc Mills	Hormones	11
USGS: Michelle Hladik	Disinfection Byproducts	29
USEPA: Marc Mills	Contaminants of Emerging Concern	9
FIU: Piero Gardinali	Sucralose	1
NCSU: Detlef Knappe	1,4-Dioxane	1
USEPA: Marc Mills	Per and Polyfluoroalkyl Substances (PFAS)	25
USEPA: Heath Mash	Inorganics	37
USEPA: Vickie Wilson	Estrogens T47D-KBluc	
USEPA: Vickie Wilson	Androgens MDA-kb2	
USEPA: Phill Hartig	Glucocorticoids CV-1 transient GR assay	
USEPA: Quincy Teng/Drew Ekman/Tim Collette	Metabolite profiling Danio rerio	

255 measurements of
236 unique analytes

United States Environmental Protection Agency

Frequency of Detection

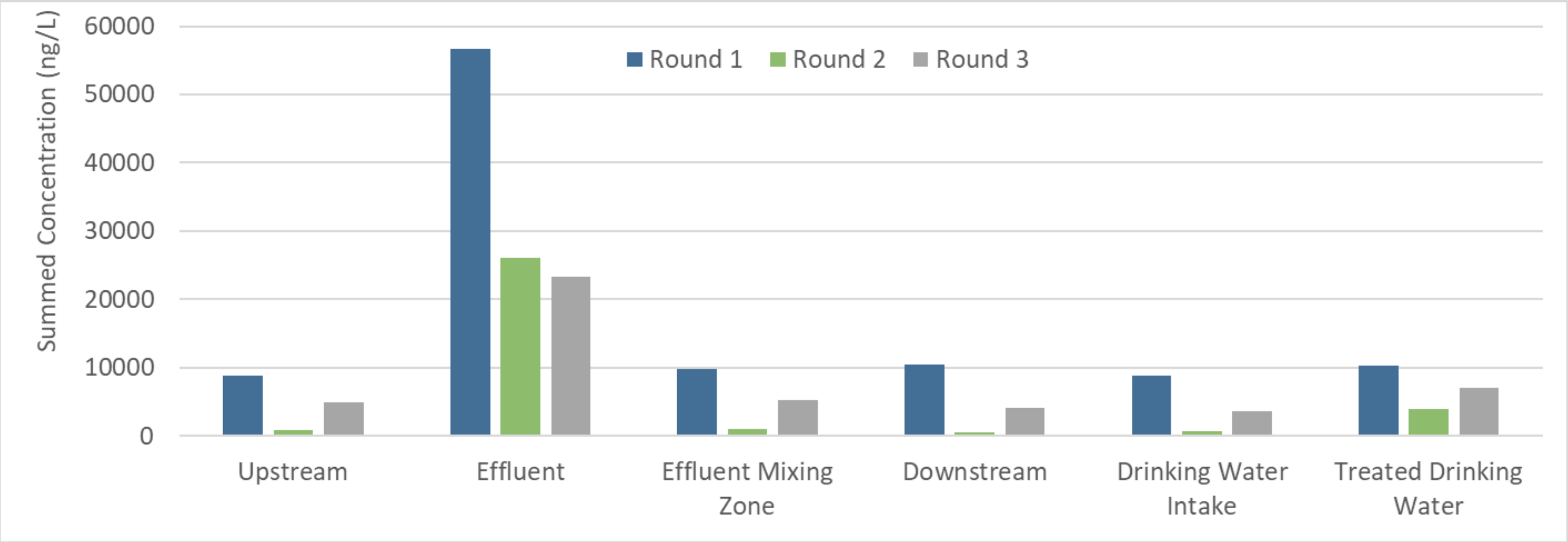
science for a changing world



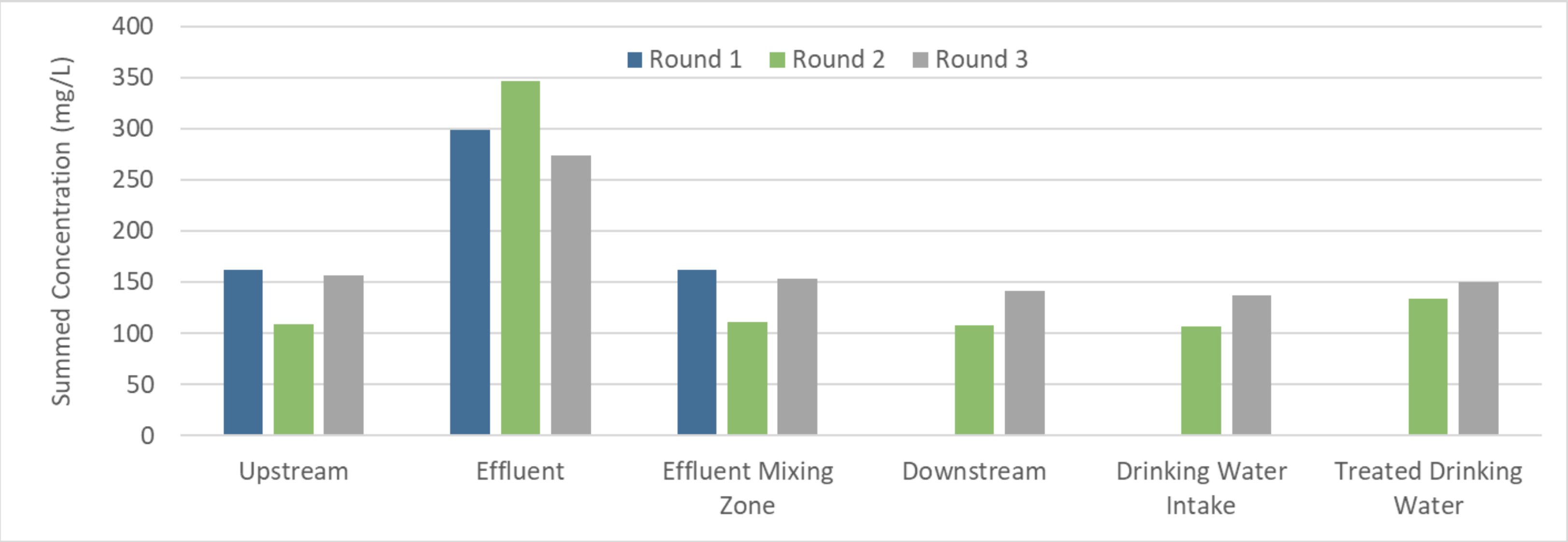
N = 203 to 236 due to missing samples

Concentration

Organic Chemicals



Inorganic Chemicals



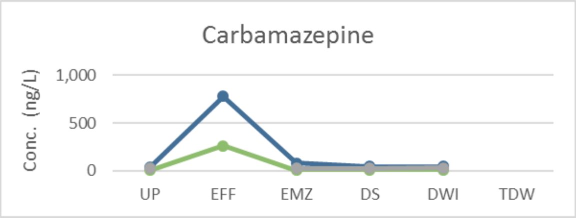
Preliminary Information-Subject to Revision. Not for Citation or Distribution.

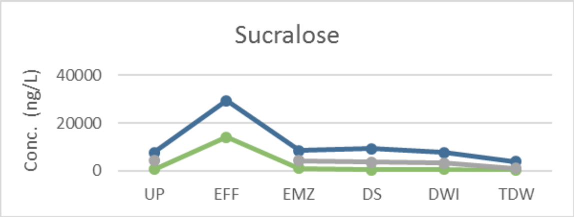
Sources of Chemicals

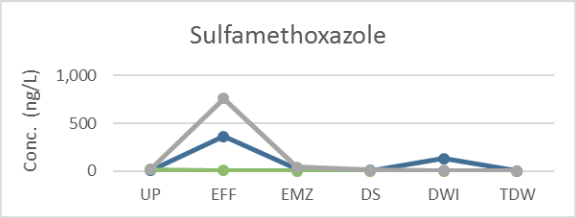
United States Environmental Protection Agency

USGS science for a changing world

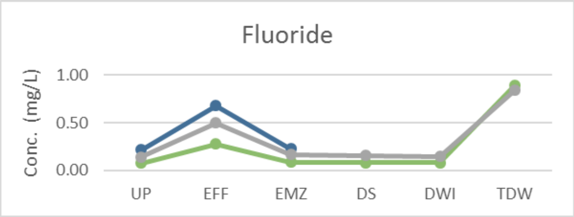
Wastewater Organic Chemicals

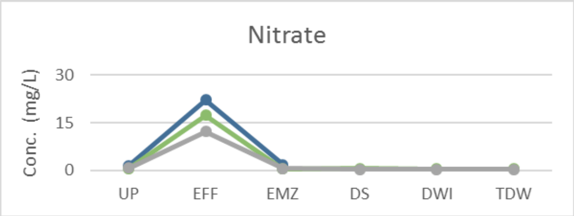


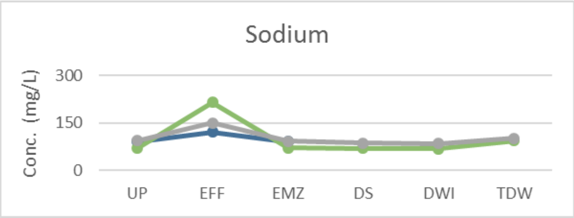




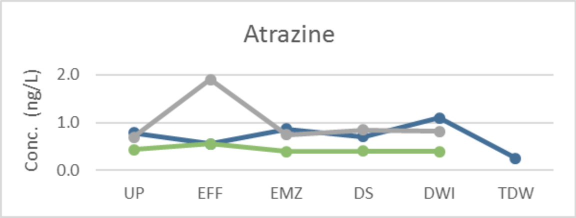
Wastewater Inorganic Chemicals

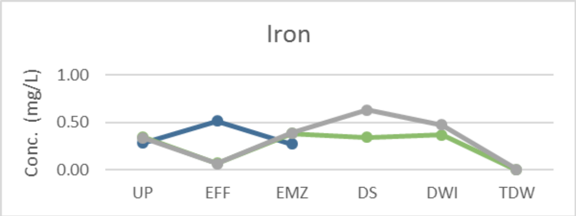


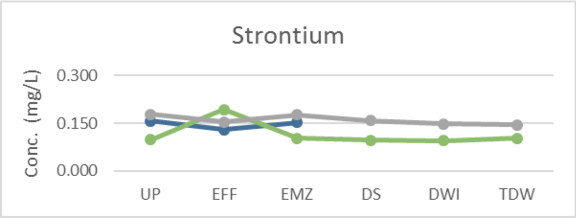




Landscape Chemicals

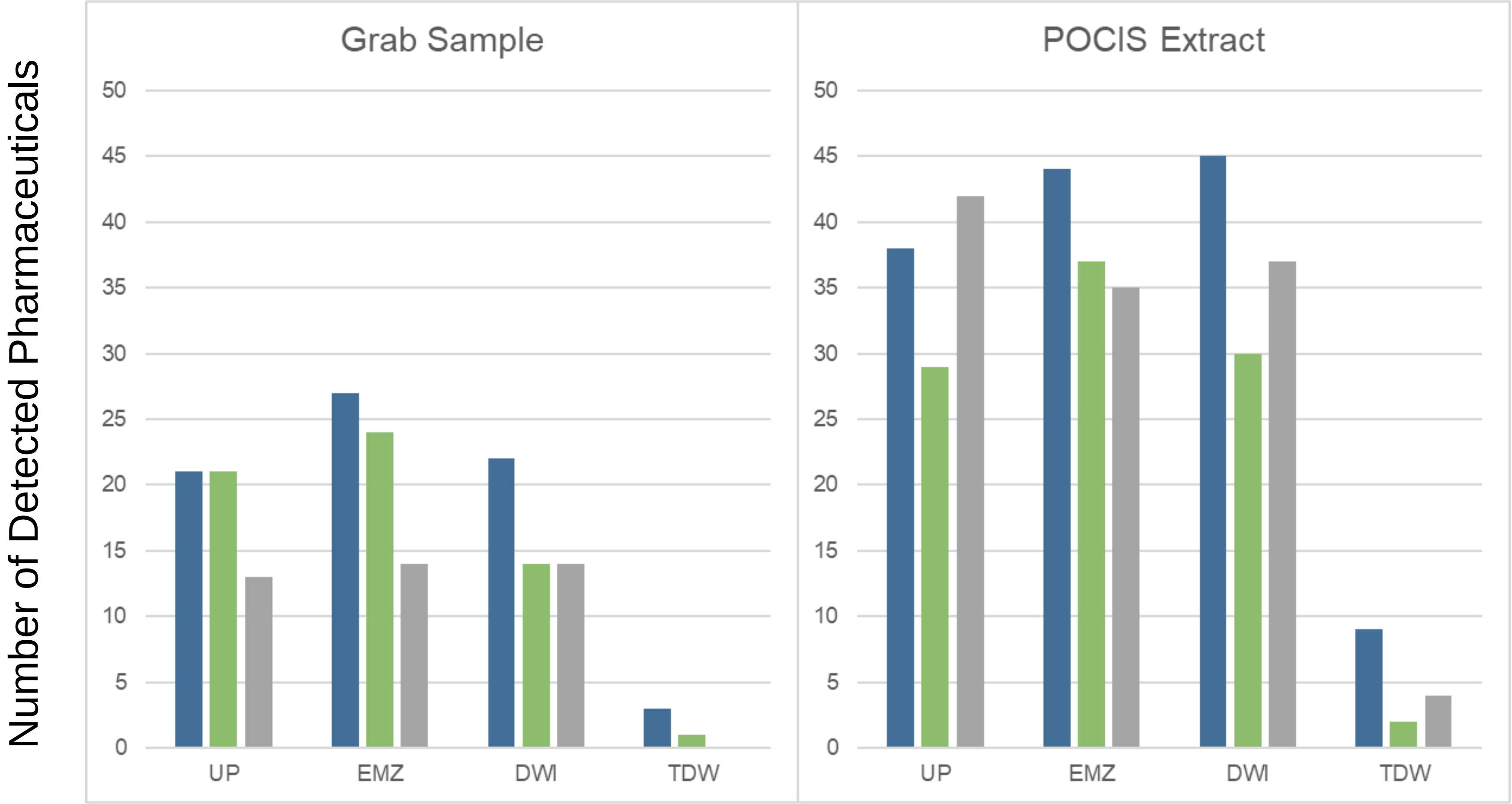






So we know everything about this water system, right?

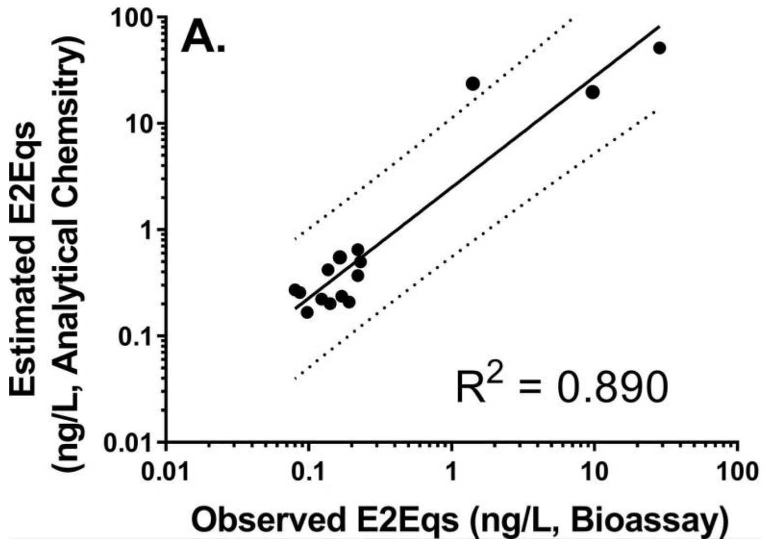
Grab Sample v POCIS

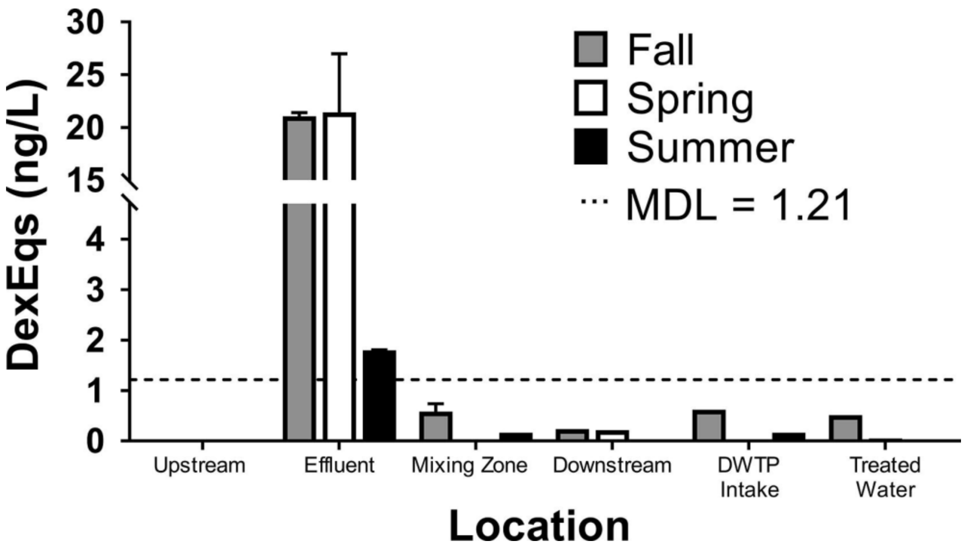


Preliminary Information-Subject to Revision. Not for Citation or Distribution.

That’s all we need, right?

Estrogenic and Glucocorticoid Activity

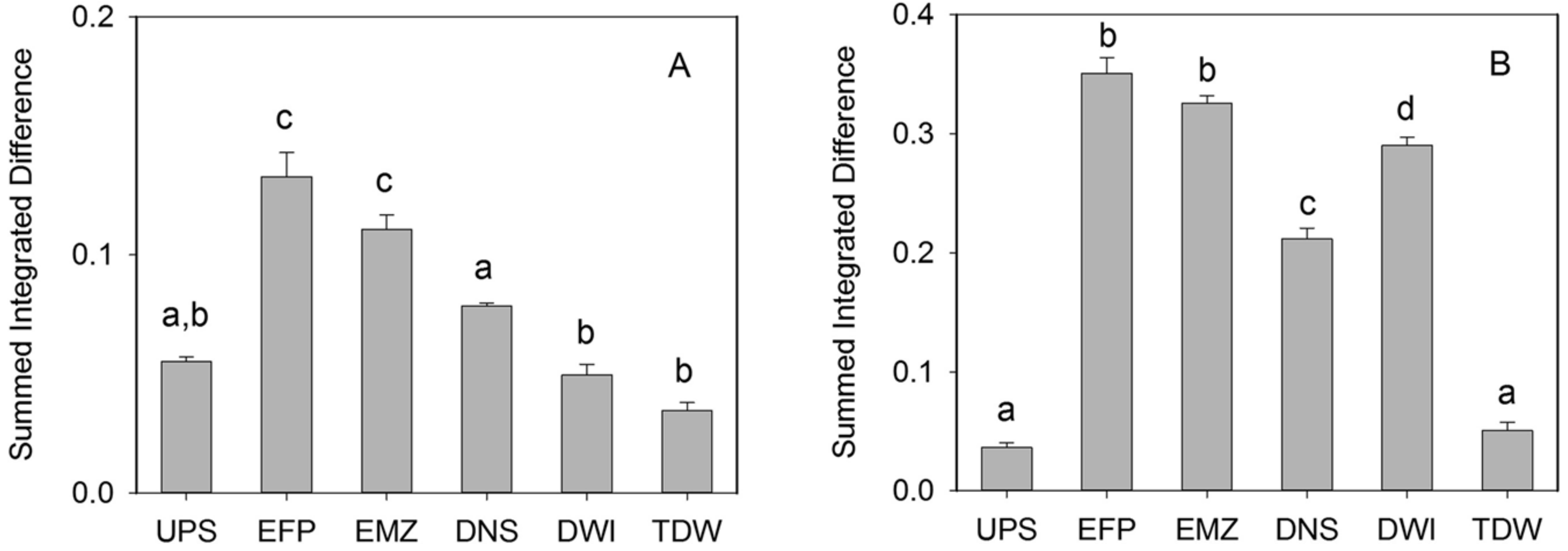




Estrogenic activity agreed well with targeted analyses, but glucocorticoid assay measured activity not captured in the targeted analyte list.

Medlock Kakaley et al., STOTEN 2020

Metabolomics Analysis



Hydrophilic

Lipophilic

Observed increase between DNS and DWI for lipophilic extracts suggests contaminant input between sampling locations.

Zhen et al., Water Research 2018

United States Environmental Protection Agency

Nontargeted Analyses

- Results are forthcoming.
- May explain bioassay results, both for specific chemicals (glucocorticoids) as well as identifying novel chemicals present in the drinking water intake that were not present in the downstream sample.
- May identify chemicals not on our target list that have either wastewater or land-based sources.

Conclusions

- *De facto* reuse of water can result in wastewater-derived chemicals in both DW source waters and in corresponding treated DW.
- Targeted chemical analyses, non-targeted chemical analyses, and bioanalytical tools each provide a unique but incomplete understanding of the contaminant profile.
- Differing sampling techniques provide a way to gain a greater insight to the complex chemical mixtures which are present in water than can be obtained individually.

EPA United States Environmental Protection Agency

Co-PIs

USGS science for a changing world

USGS	USEPA		Academia
Ed Furlong	**Susan Glassmeyer**	Charlita Rosal	Piero Gardinali
Dana Kolpin	**Marc Mills**	Jorge Santo Domingo	Eunha Hoh
Dave Alvarez	Angela Batt	Kathy Schenck	Detlef Knappe
Michelle Hladik	Adam Biales	MJ See	
Mike Meyer	Drew Ekman	Jane Ellen Simmons	
Jason Sorenson	Phill Hartig	Mark Strynar	
Marc Zimmerman	Tammy Jones-Lepp	Quincy Teng	
	Dave Lattier	Dan Villeneuve	
	Jim Lazorchak	Vickie Wilson	
	Andy Lindstrom		
	Heath Mash		
	Stacy Pfaller		

Emerging Contaminant Regulations & Treatment Options

ECOC Determination Process

Items added to the Contaminant Candidate List on 5-yr cycle per the Safe Drinking Water Act.

- New contaminants can be added by public comment

Items on CCL evaluated against 3 criteria for regulatory determination

1. Are there adverse health effects?
2. Is contaminant prevalent enough to occur in public water supplies at levels that cause health concerns?
3. At judgement of Administrator, will regulation have a meaningful opportunity to reduce health risks?

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Regulatory Determinations

Items meeting 3 criteria are submitted for proposed rulemaking

1. Begins a public comment period on proposed rules
2. Sets a maximum contaminant level goal – level at which the contaminant has no health impact
3. Sets a maximum contaminant level – level which is technically feasible with sensing and testing technologies.
    1. If an MCL isn't feasible, EPA sets a "treatment technique" as an enforceable standard

After public comment period, proposed rule is finalized.

3 years after finalizing, regulation becomes effective

PFAS Proposed Regulations

USEPA Actions on PFAS

Proposed adding PFOA and PFOS to Superfund Hazardous Substances designation – public comment period closed Nov 7th and under review

PFAS National Primary Drinking Water Regulation proposed

Compound	Proposed MCL (enforceable)	Proposed MCL Goal (unenforceable)
PFOA & PFOS	4.0 ppt (4.0 ng/L)	0.0 ppt (0.0 ng/L)
PFNA, PFHxS, PFBS, GenX Chemicals (HFPO-DA)	1.0 Hazard Index	1.0 Hazard Index

- Proposed regulations expected to take effect in 2024.

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US EPA Actions on Pharmaceuticals

Some pharmaceuticals on CCL, but not currently under review for proposed regulations.

EPA still gathering data on health impacts and prevalence

- Pharmaceuticals overlap with PFAS and other regulated and CCL chemicals
- Not a specific listing for “PPCP” or “EDC” on CCL since chemicals overlap with other uses

US EPA and Microplastics

Focus on research

- Wide array of types of plastics
- Particle sizes ranging from 5mm to <1nm
- Range of densities

Research will help characterize impacts, sampling protocols, and treatment options to allow for effective regulation development in the future.

Available Treatment Technologies

Mature Removal Technologies - GAC

Image source: Water Online

Granular Activated Carbon

- Used for water purification since 1906
- ~10 minute empty-bed contact time
- Waste GAC thermally destroyed or reactivated
- Good at long-chain capture, poor at short chain capture
- PFAS capture can be reduced by competing compound adsorption

GAC also good for removing many PPCP’s

GAC not good for removing microplastics without pre-treatment

Mature Technologies - IER

Image source: Atlas Scientific

Ion Exchange Resins

- First resins developed in 1905
- Better at short-chain PFAS removal
- Shorter detention time than GAC, longer useful life
  - ~3 minute empty-bed contact time
- Similar interference from ionic compounds possible
- Waste consists of IER regeneration brine, expended IER incinerated

IER good at PPCP removal

IER has little impact on microplastics

Mature Technologies - Membranes

Reverse Osmosis

- Very expensive relative to other methods
- Low-Pressure RO very good for long and short-chain PFAS removal
- Require pre-treatment to prevent fouling (chemical descaling and pre-filtration)
- Waste-stream is highly concentrated

Proven reduction of many PPCP’s from water

Proven reduction of microplastics as well

Image Source: SEDAC Assessment

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Breaking the Contamination Cycle

All previous technologies concentrate ECoCs in waste stream

- Contaminated activated carbon
- Spent resins and/or reactivation brines
- RO reject brine

Incineration of waste is current standard for destruction

- Can release byproducts in flue gases
- Potential residues left in reactivated GAC

Landfilling is common but ineffective at breaking cycle of contamination

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PWS Role in ECoC Removal

ECoC destruction not likely to be performed at small water plants

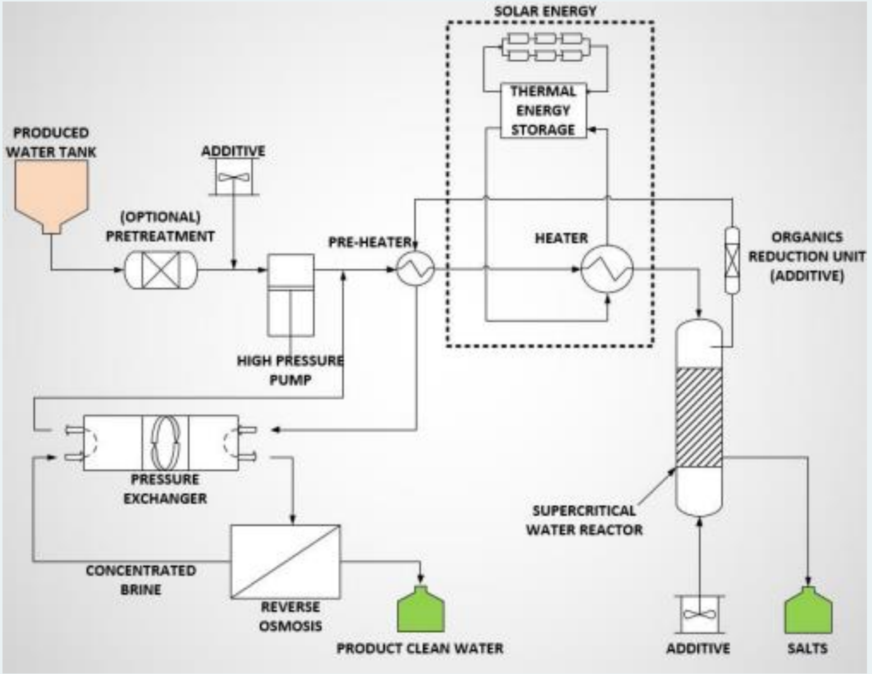
Destruction more likely at large scales, such as wastewater plant sludge and industrial hazardous waste sites

Wastewater treatment may see some ECoC removal regulation in future

- Destruction may be feasible at higher waste stream concentrations
    - Supercritical Water Oxidation – commercially available
    - Plasma Destruction – Research pilots only
    - Electrochemical Oxidation – Research pilots only
    - Photocatalysis/Sonolysis – Research pilots only

Supercritical Water Oxidation

- Pressure & temperature increased to supercritical state
- Organic molecules broken down into H_2O, CO_2, nitrogen, and inorganic mineral salts/acids
- Most installed systems industrial scale, few WWTP applications, no known Public Water Systems
- 374Water, SCFI AquaCritox, Beyond the Dome have plant-ready applications.



[Energy.gov presentation on SCWO processes]

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