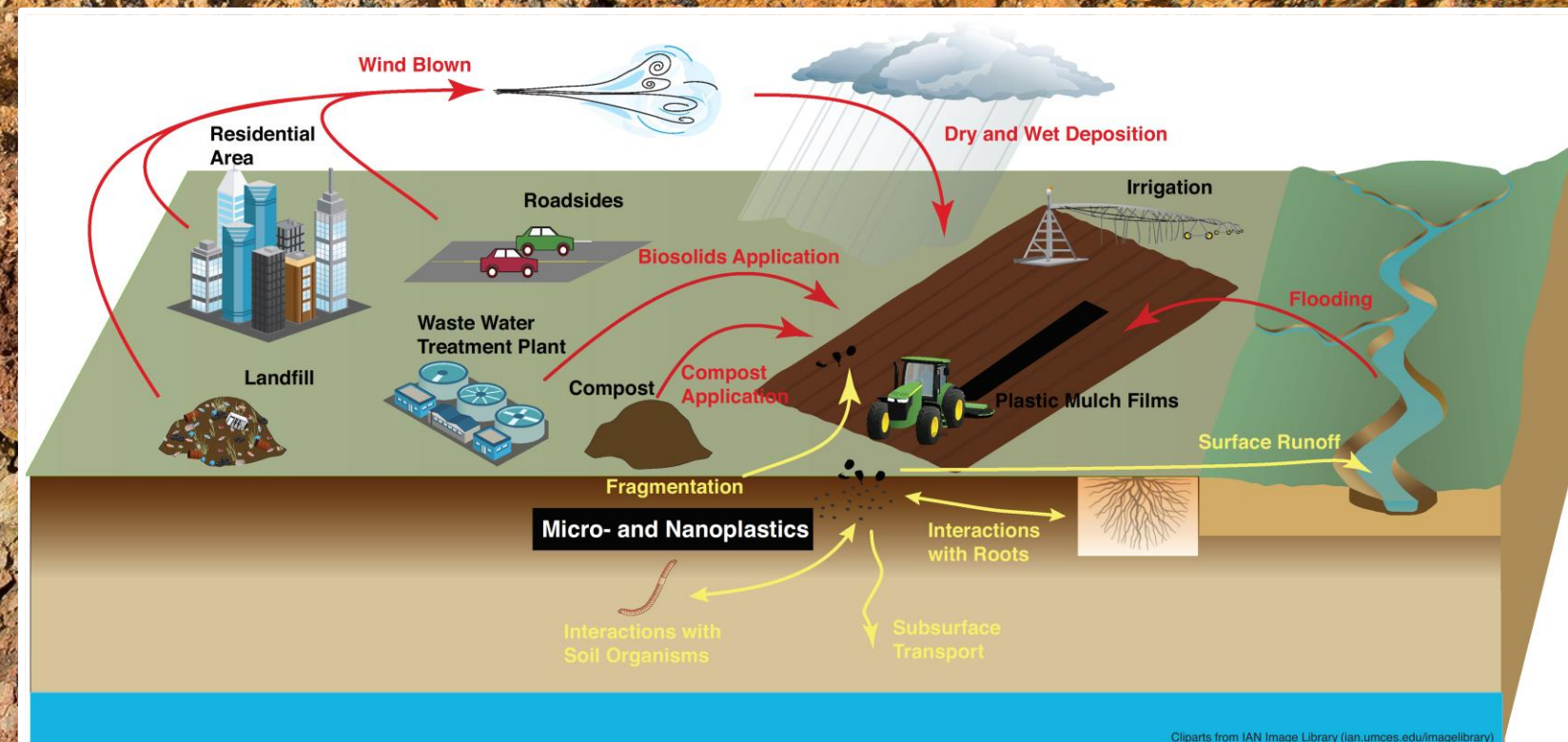
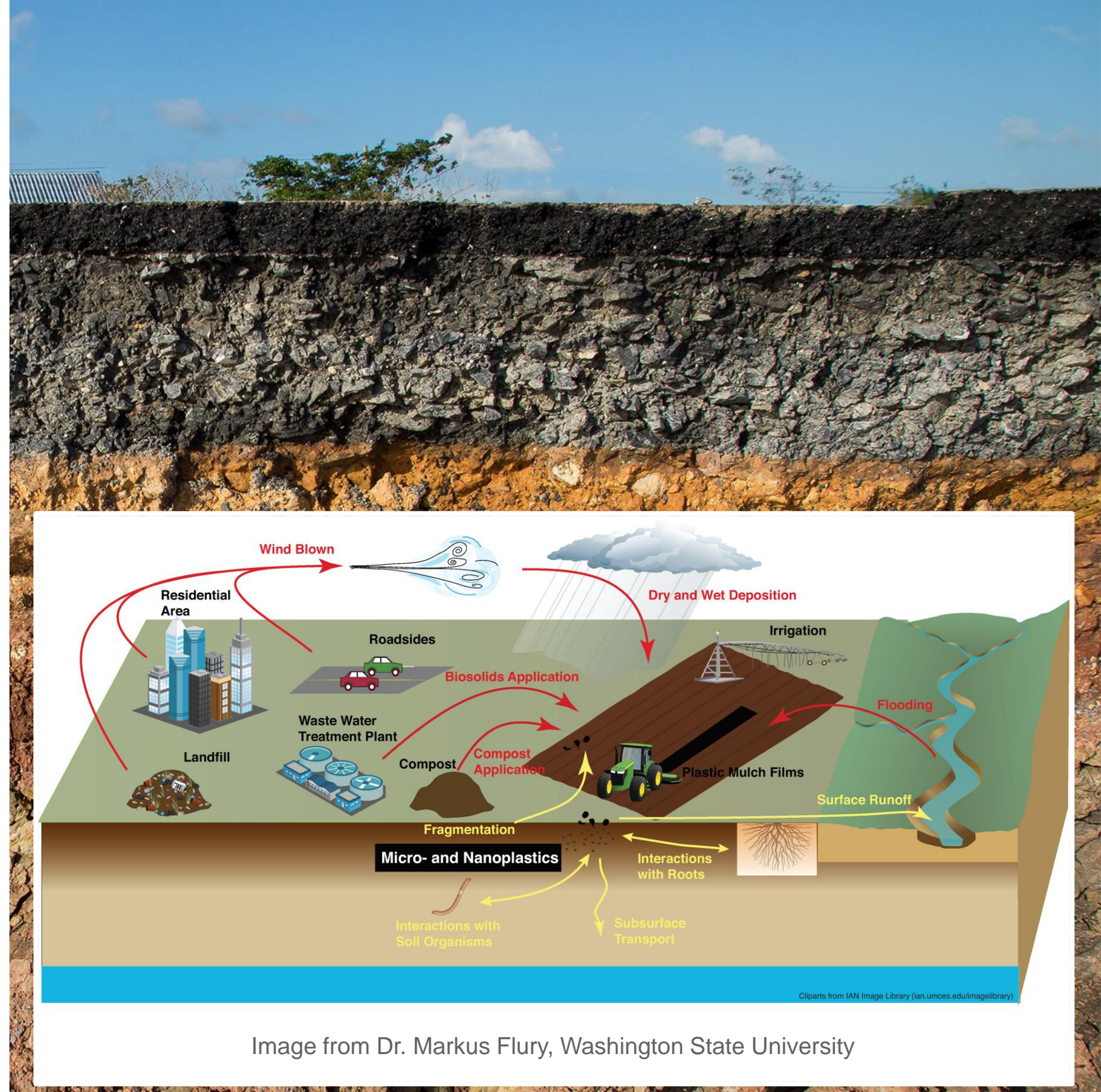


Forever chemicals: How plastic and PFAS get to, and move through, our soils

September 25, 2020

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Image from Dr. Markus Flury, Washington State University



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(Micro)plastic

U.S. DEPARTMENT OF
ENERGY **BATTELLE**

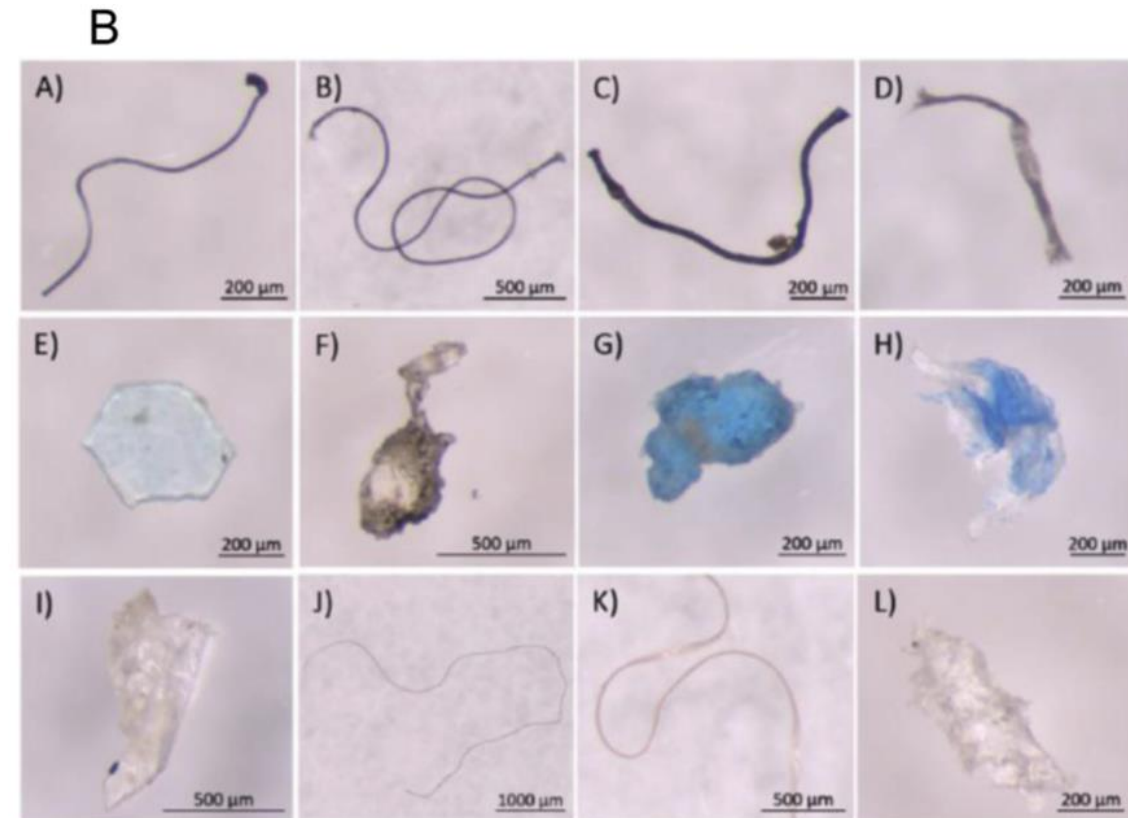
PNNL is operated by Battelle for the U.S. Department of Energy



Forever Chemicals: What are they?

(Micro)plastic

- Plastics are synthetic long carbon chain molecules
- Microplastic < 5mm
- Shapes include spheres, films, fibers, fragments



- Working definition is plastic < 5mm
- Particles observed down to 20μm and even nanometer sized
- Most common polymers in environment are polyethylene, PET, polypropylene, polystyrene, and nylon

Figure 4 from Sun, et al, 2019.

Forever Chemicals: Where do they come from?

Plastic

- Largest producer is packaging industry, followed by construction and textiles

Global plastic production 1950 to 2015

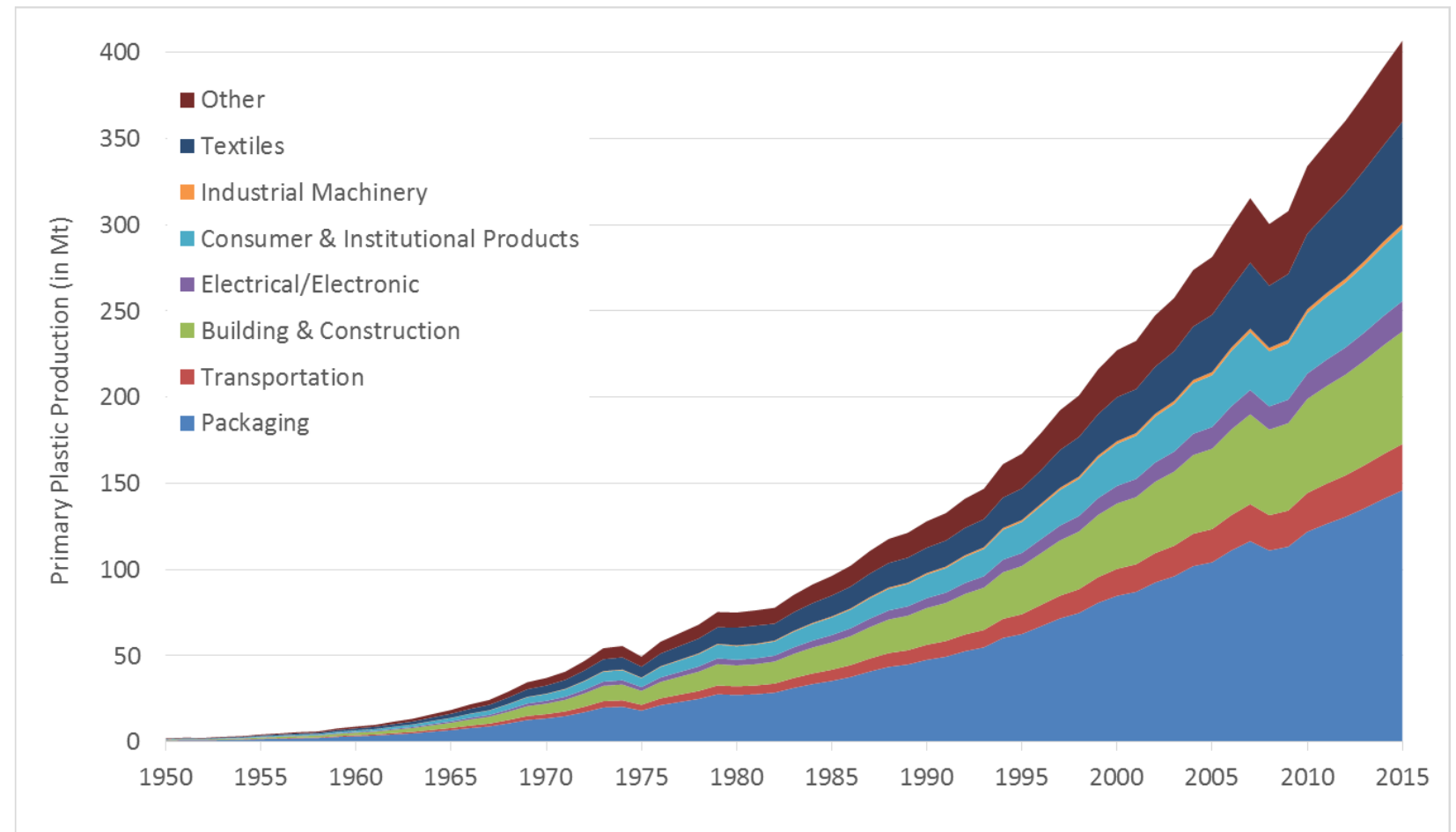
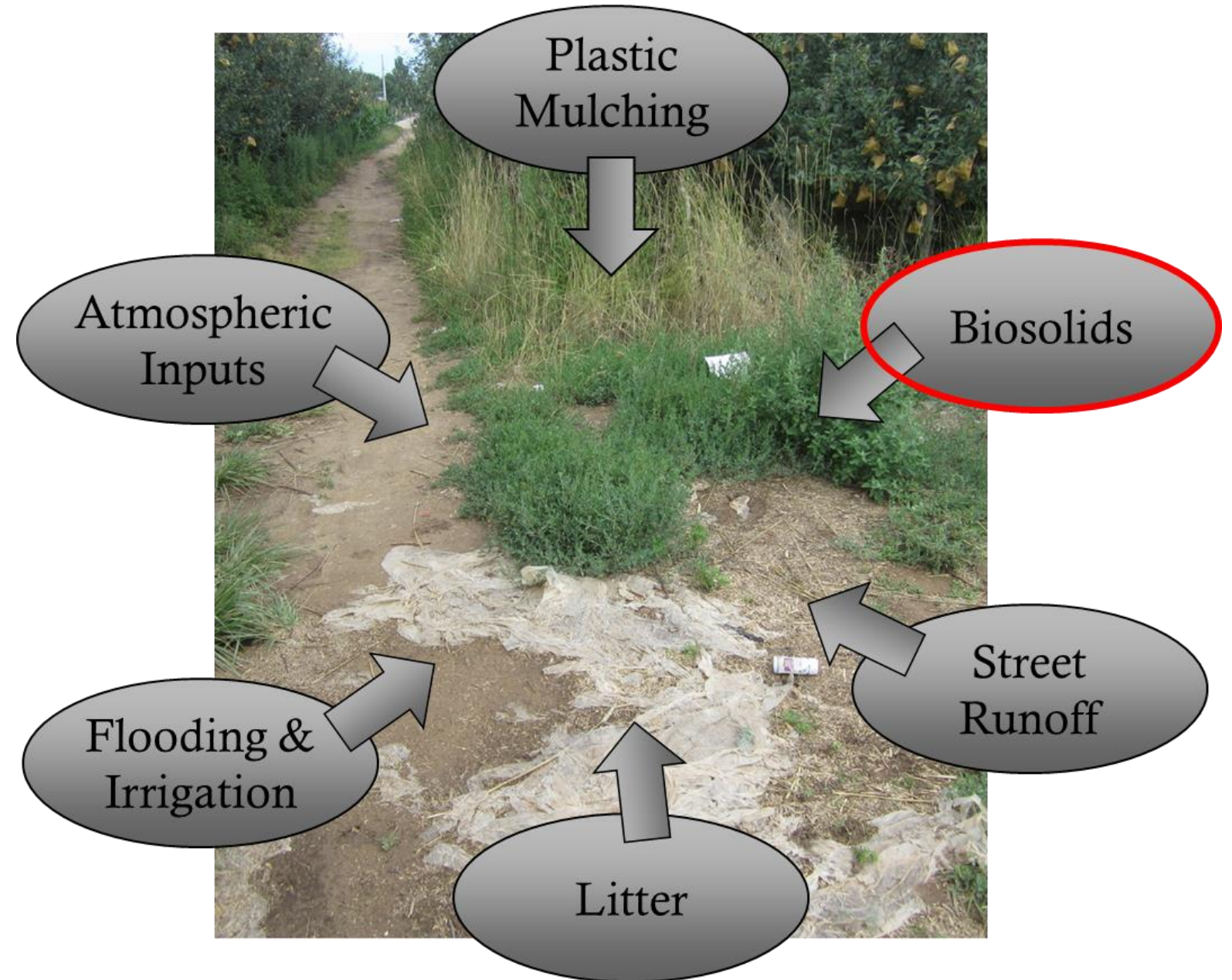


Figure S1 from Geyer, et al, 2017. Global primary plastics production (in million metric tons) according to industrial use sector from 1950 to 2015.

Forever Chemicals: How do they get to soil?

(Micro)plastic

- Multiple pathways including flooding, atmospheric inputs, and biosolids or compost soil amendments
- Breakdown of larger pieces leads to micro-size



Forever Chemicals: Where are they?

(Micro)plastic

- Publicity and research is focused on water
- Amount of plastic in soil rivals that of water
- BUT soil to water transport can't be ignored
- Can't compartmentalize!

Plastic (fiber) emissions to land rivals' water

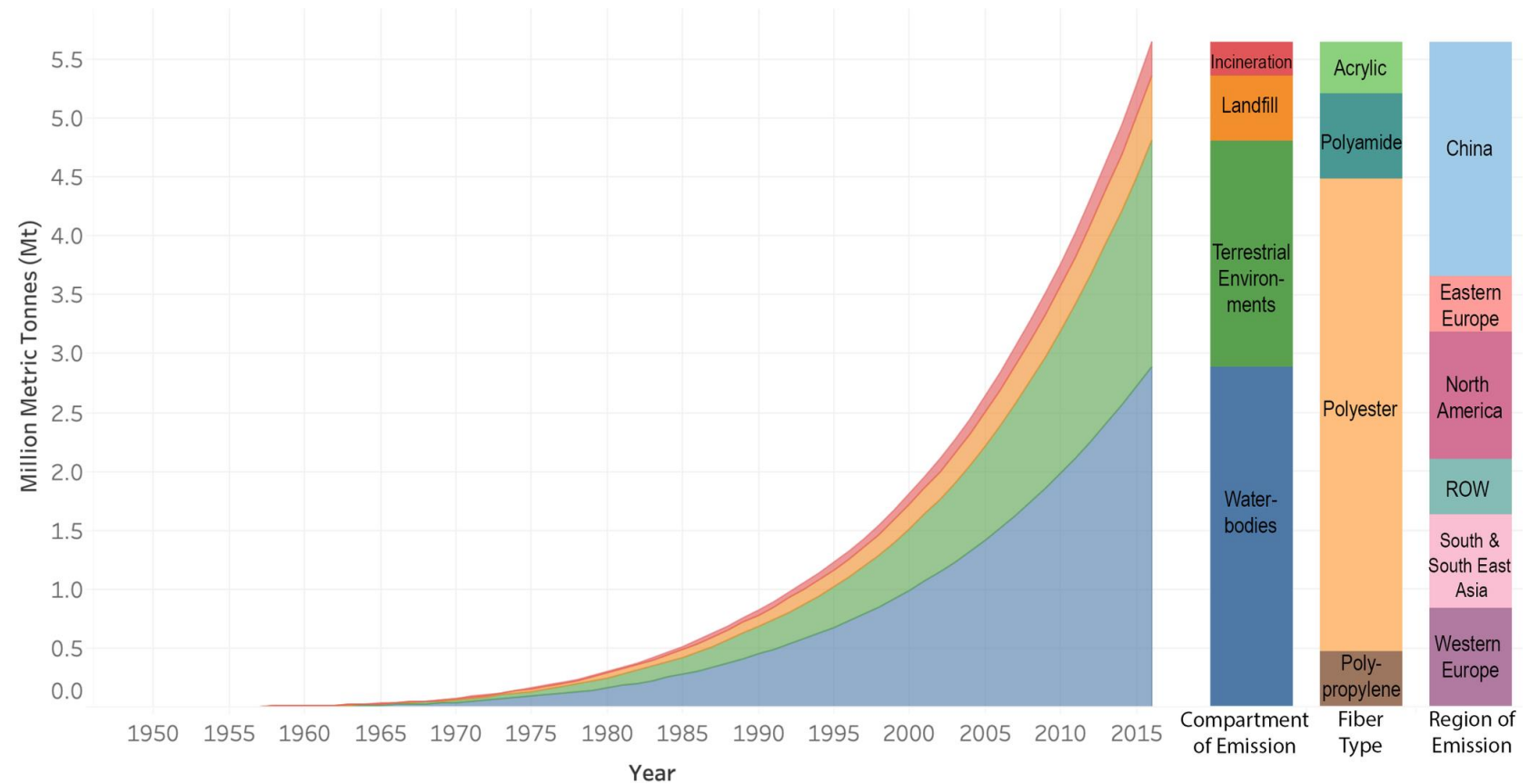


Figure from Gavigan et al., 2020

Forever Chemicals: Why do we care?

(Micro)plastic

- They have a long-lifetime in most environments
- They can bioaccumulate
- Absorption of other contaminants

Mean lifetime of polymers in the environment

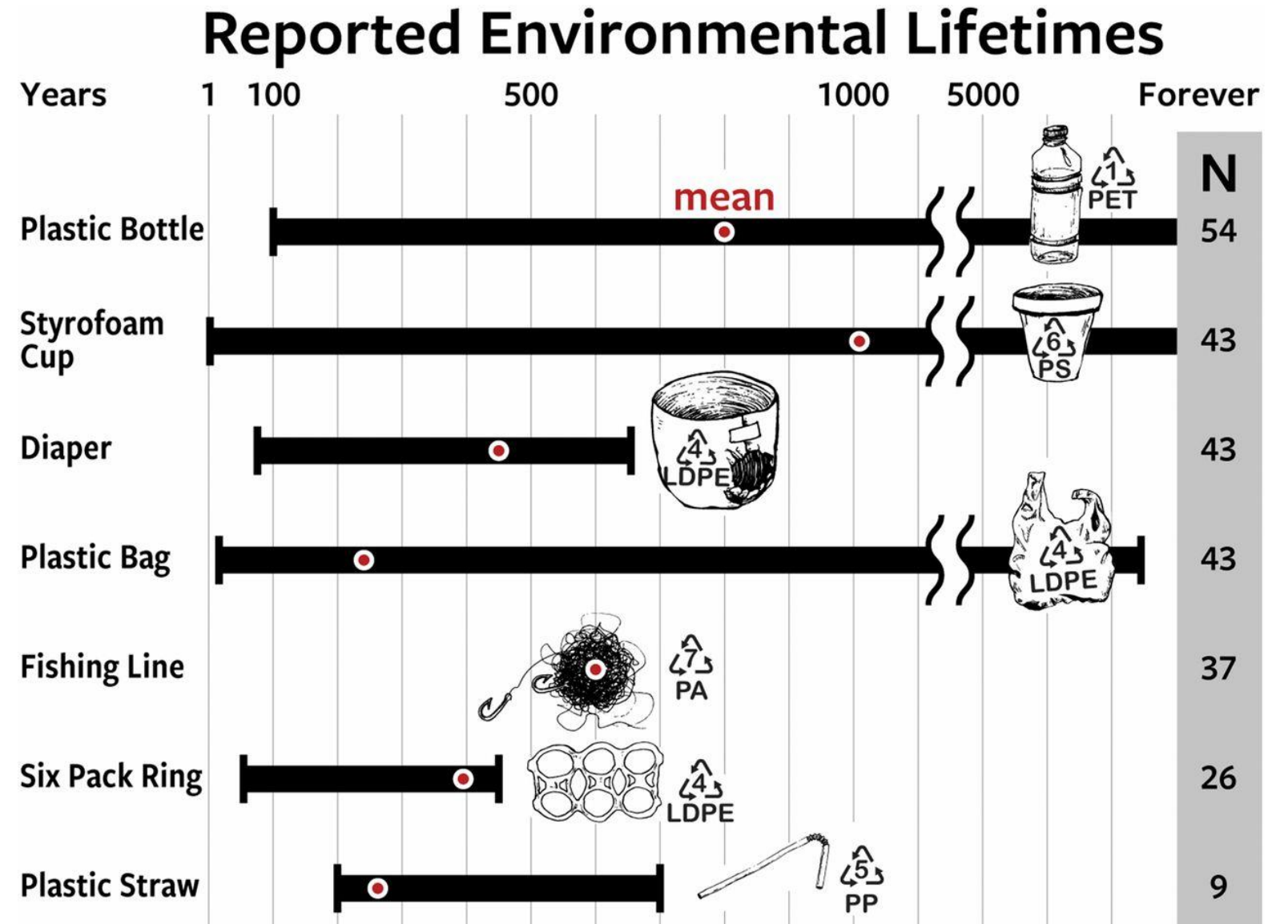


Figure from Ward and Reddy, 2020.

1000 metric tons per year
fall within south and central western U.S.

Forever Chemicals: Why do we care?

(Micro)plastic

- They are ubiquitous

Average Wet + Dry Plastic Deposition in 2018

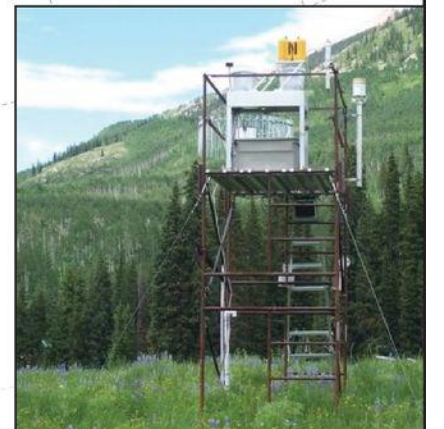
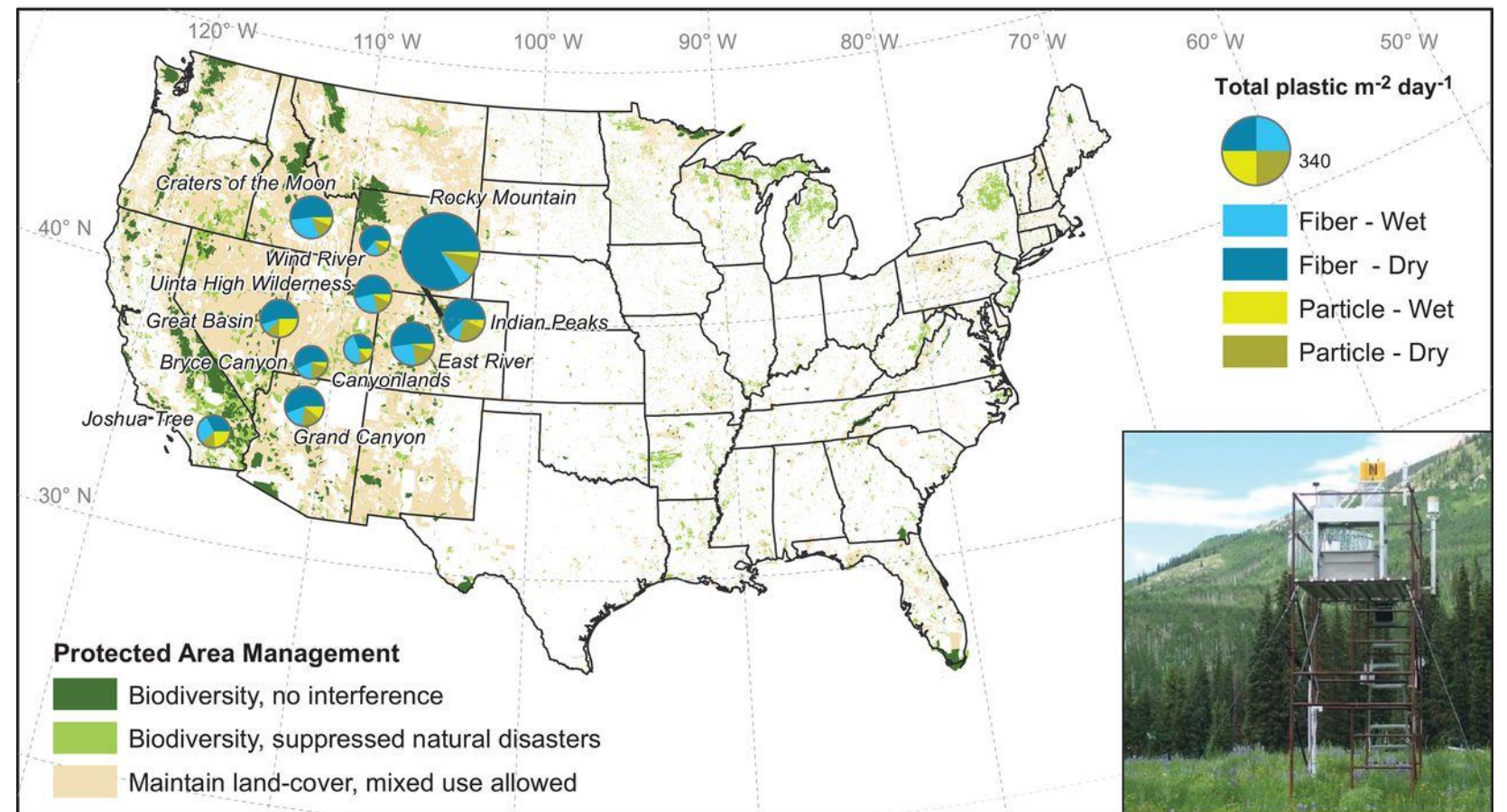


Figure from Brahney et al., 2020



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PFAS

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ENERGY **BATTELLE**

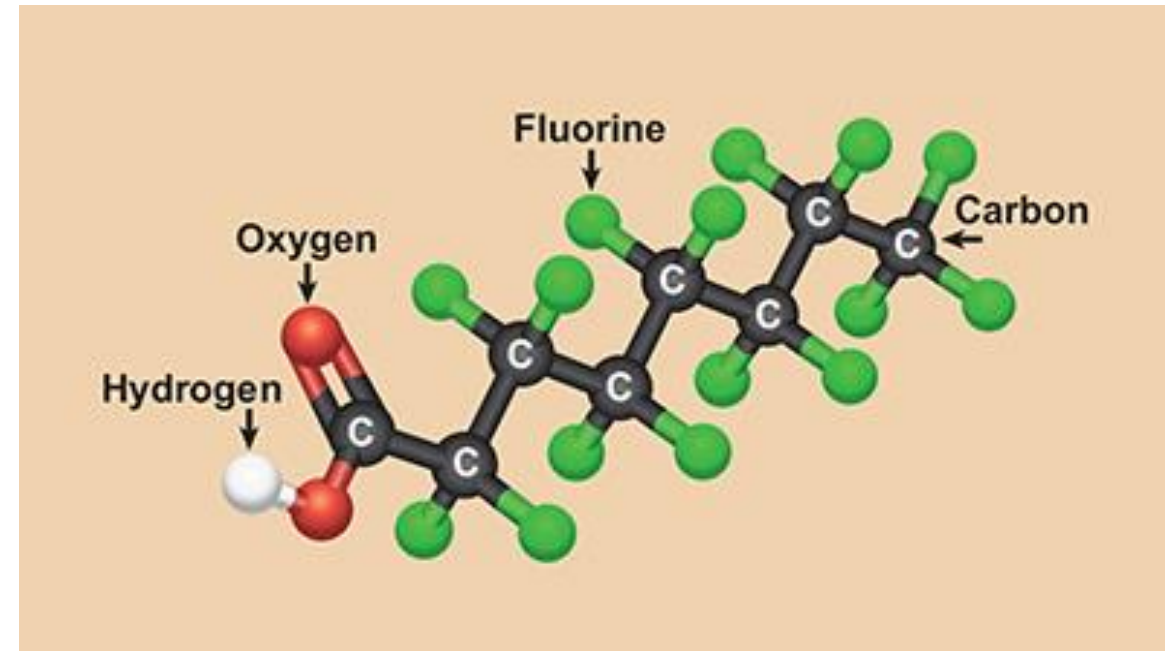
PNNL is operated by Battelle for the U.S. Department of Energy



Forever Chemicals: What are they?

PFAS : Per- and polyfluoroalkyl substances

- There are thousands of PFAS in use by industry



PFAS – per- and polyfluoroalkyl substances

PFOS – perfluorooctane sulfonic acid

PFOA – perfluorooctanoic acid

Differences in length of carbon chain effect toxicity and persistence in the body and environment

Forever Chemicals: Where do they come from?

PFAS

- Used to make coatings and products that resist heat, oil, stains, grease, and water

Sources

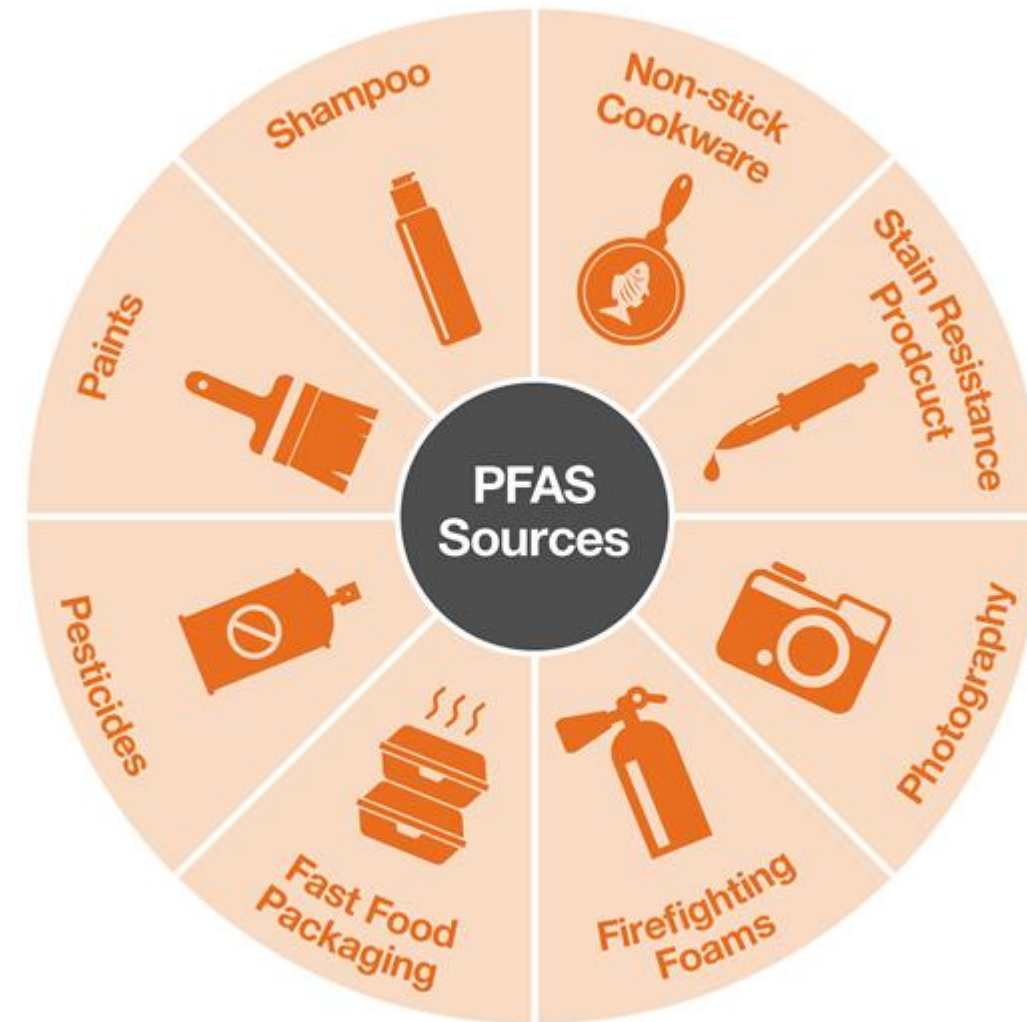


Figure
https://www.navfac.navy.mil/products_and_services/ev/products_and_services/env_restoration/pfas_reading_room.html

Forever Chemicals: How do they get to soil?

PFAS

- Concentrate in areas like airports, fire fighting training grounds, or with some soil amendments

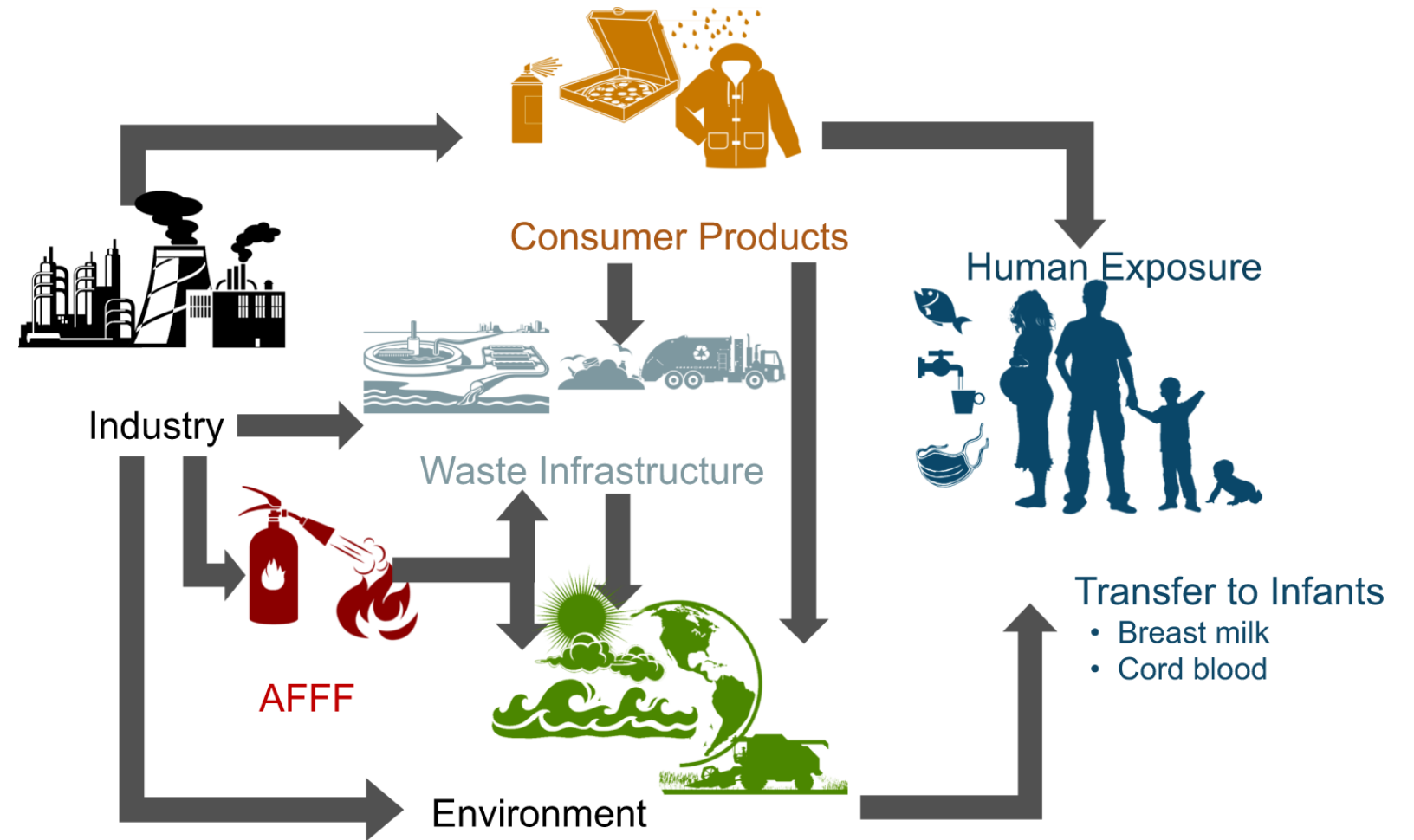


Figure from Sunderland et al., 2018

Forever Chemicals: Why do we care?

PFAS

- Present in most (95%) humans
- Some are highly toxic at very low concentrations
- Persistent in us and in the environment

Blood Levels of the Most Common PFAS in People in the United States from 2000-2014

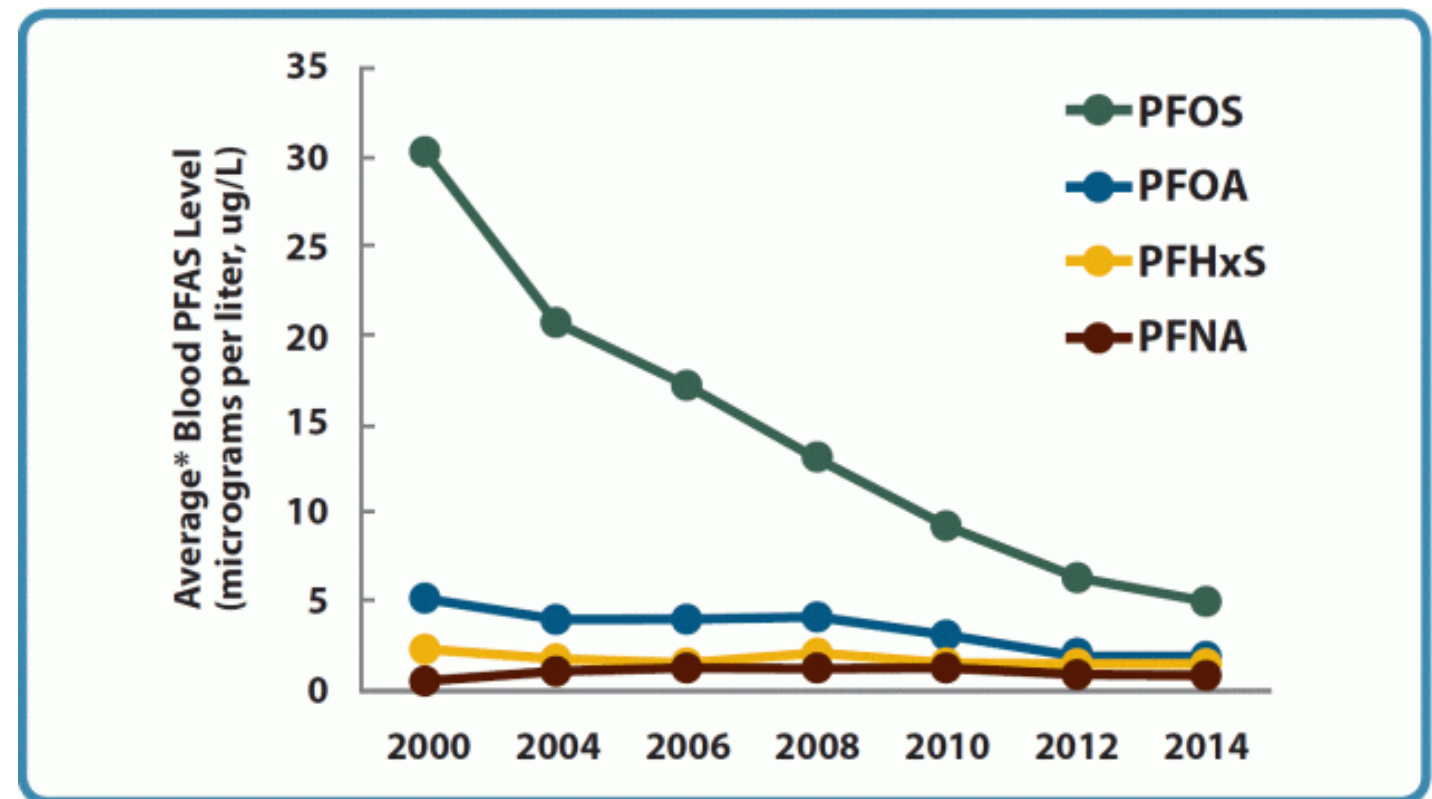


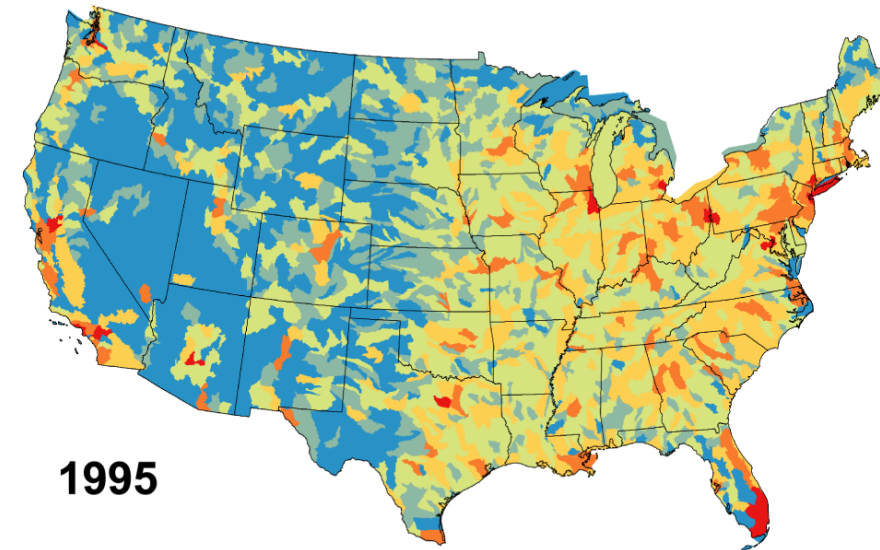
Figure here: <https://www.atsdr.cdc.gov/pfas/health-effects/us-population.html>

Data here: <https://www.cdc.gov/exposurereport/>

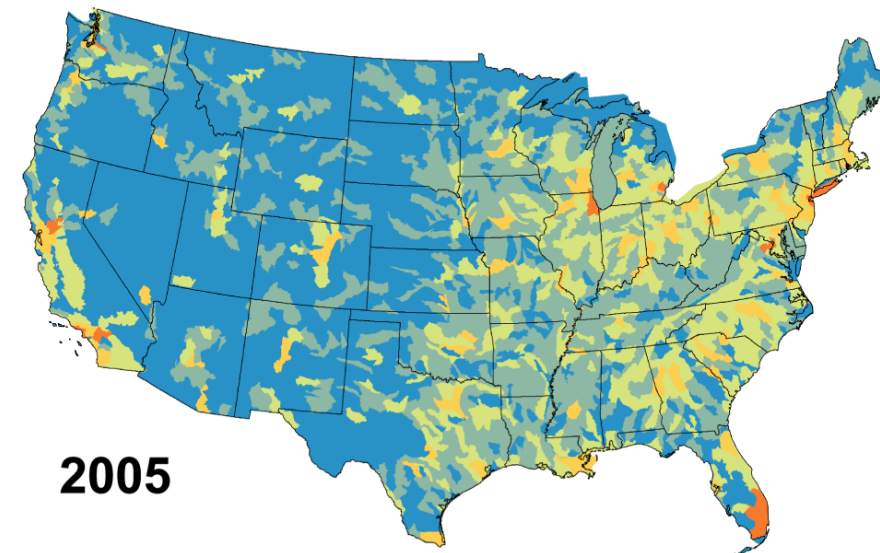
Forever Chemicals: Why do we care?

PFAS

- They are ubiquitous



1995



2005

PFOS discharge (kg yr^{-1})

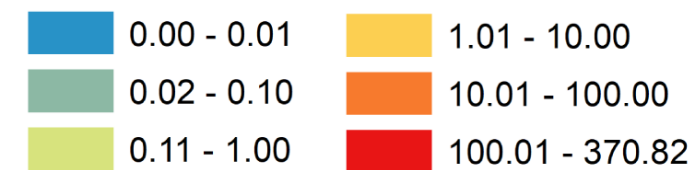


Figure from Sunderland et al., 2018

Environmental Working Group PFAS Contamination Across the US

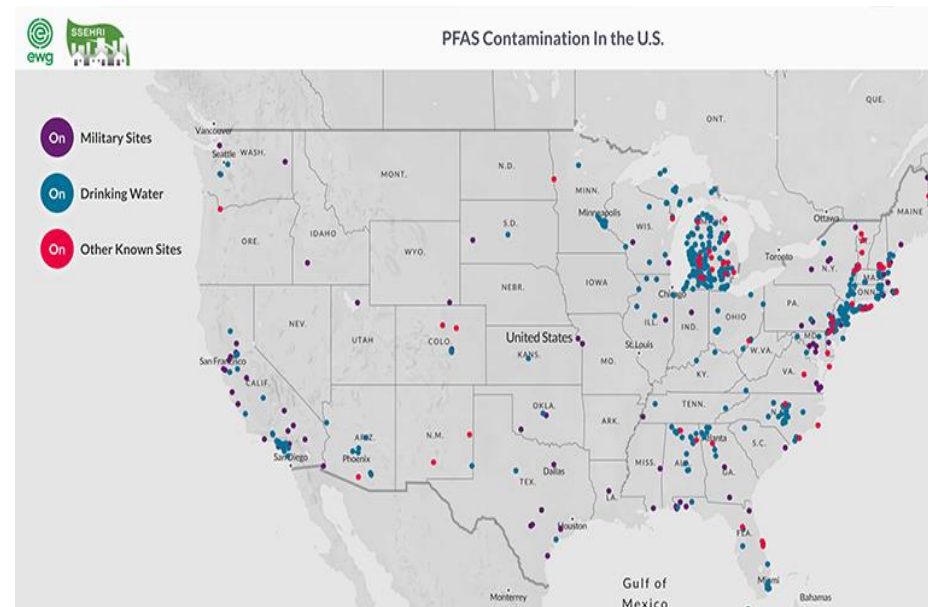
“...EWG scientists now believe PFAS is likely detectable in all major water supplies in the U.S., almost certainly in all that use surface water.”



PFAS Contamination of Drinking Water Far More Prevalent Than Previously Reported

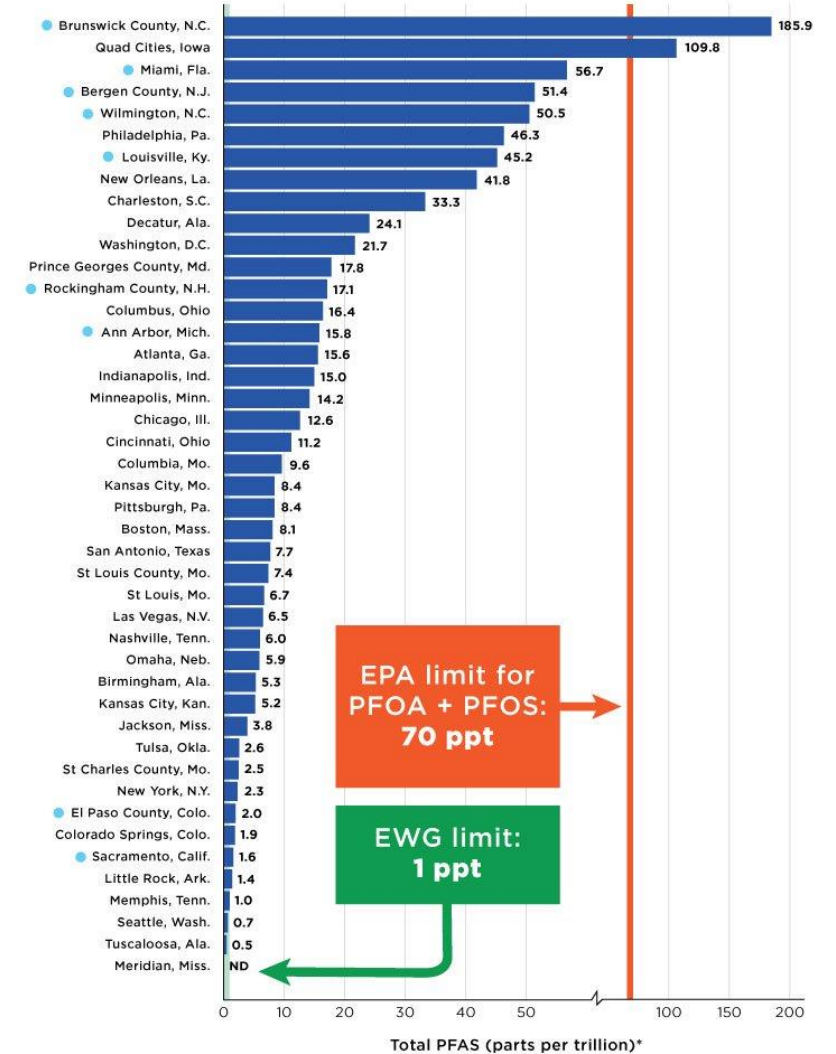
New Detections of ‘Forever Chemicals’ in New York, D.C., Other Major Cities

<https://www.ewg.org/research/national-pfas-testing/>



https://www.ewg.org/interactive-maps/2019_pfas_contamination/map/?_ga=2.197778607.1497694942.1558632732-844068127.1558632732

EWG TESTS FOUND TOXIC PFAS CHEMICALS IN TAP WATER IN 31 STATES AND D.C.



Source: EWG, from samples taken between May and December 2019.

● PFAS previously reported by EPA or State

*Sum of detections of 30 types of PFAS

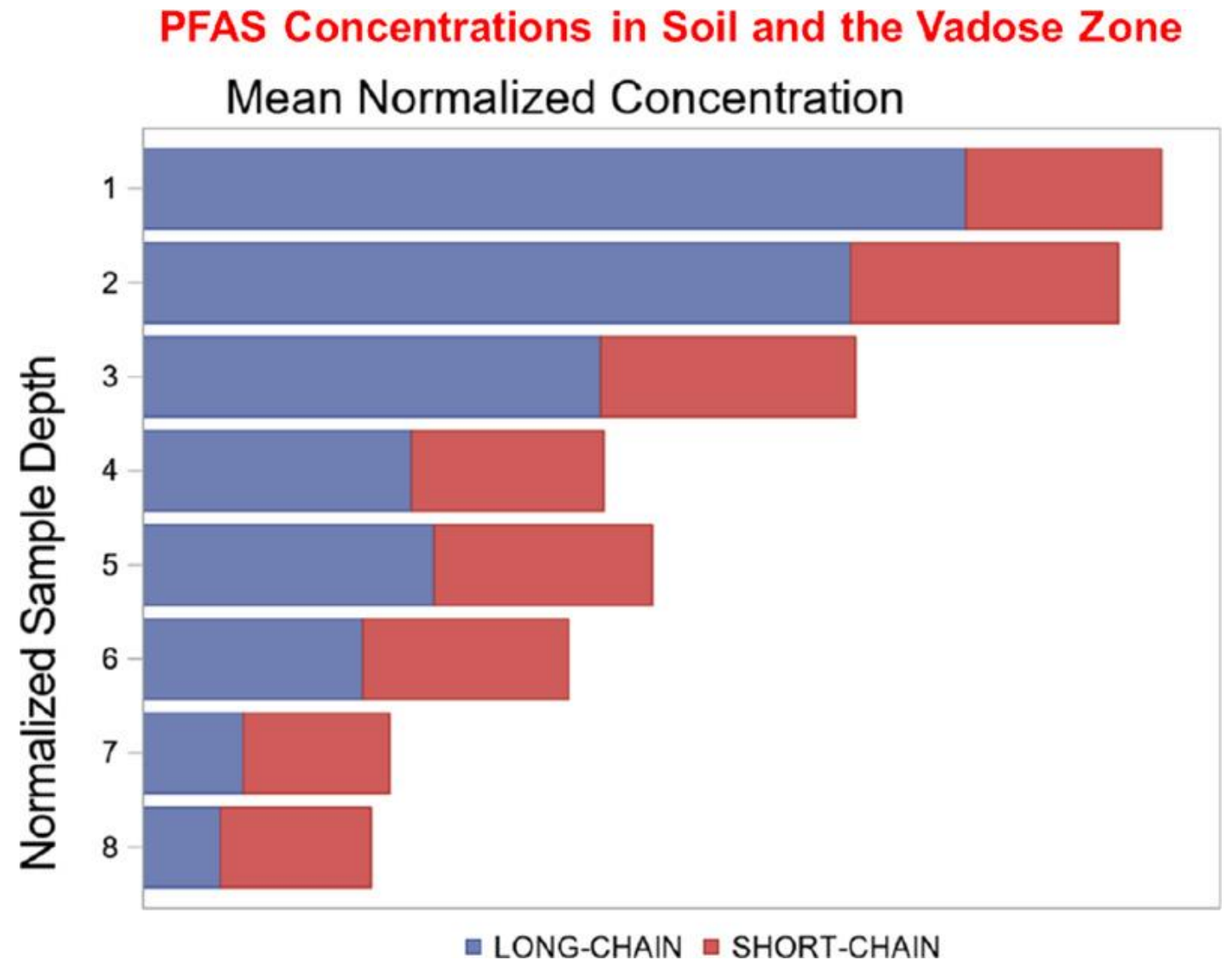
Samples were taken by either EWG staff or local volunteers and analyzed by an independent accredited laboratory using a modified version of EPA Method 537. Details of all samples taken at each site and the precise sampling dates are in the tables in the Appendix.

Forever Chemicals: Why do we care?

PFAS

- They can move through soil

Depth distribution of total PFAS in soil as a function of chain length..



Concentrations range from 0.07 to 2500 $\mu\text{g}/\text{kg}$ soil.

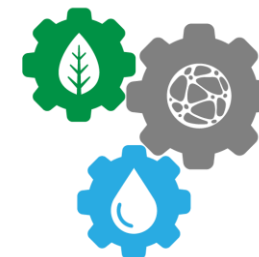
Figure from Brusseau et al., 2020.

Forever Chemicals: What can be done?

Plastic

Per- and
polyfluoroalkyl
substances (PFAS)

- Mitigate the source – develop alternative products with better end-of-life
- Understand and quantify the risk
- Understand behavior, fate, and transport to mitigate risk
- Effective and efficient remediation options
- Efficient sensing and monitoring technologies



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CENTER FOR THE REMEDIATION
OF COMPLEX SITES
@PNNL

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Thank you



Environmental Behavior

- Group of 6000+ Compounds
 - Environmentally stable and bio-persistent anthropogenic compounds
 - 240 compounds belonging to 57 classes have been detected in AFFF
 - 24 have been branded toxic by EPA thus far
 - ✓ Toxicities of the rest are unknown due to limited studies
 - Larger chains can degrade to smaller, more persistent forms with comparable toxicities
- Primarily exists in anionic or zwitterionic forms in groundwater
 - Highly mobile in the environment and in groundwater due to their charge
 - PFAS diffusion and speciation in groundwater and soil depend on
 - ✓ Electrostatic interactions between PFAS and charged soil/mineral surfaces
 - ✓ Hydrophobic partitioning to soil organic matter
 - Shorter chains more water soluble
 - Longer chains adsorb and partition to soil more
 - ✓ pH
 - ✓ Concentration effects (e.g. micelle formation)
 - ✓ PFAS volatility (some PFAS has been demonstrated to be volatile)
 - ✓ Potential degradation and competitive retention of the parent as well as degradation products
 - PFBS has higher toxicity but lower geological retention in soil compared to parent PFOS
 - ✓ Comingled contaminants (mixed plume and multiple influents)

