PFAS in the Engineered Water Cycle:
The Science and Limitations of Treatment Processes

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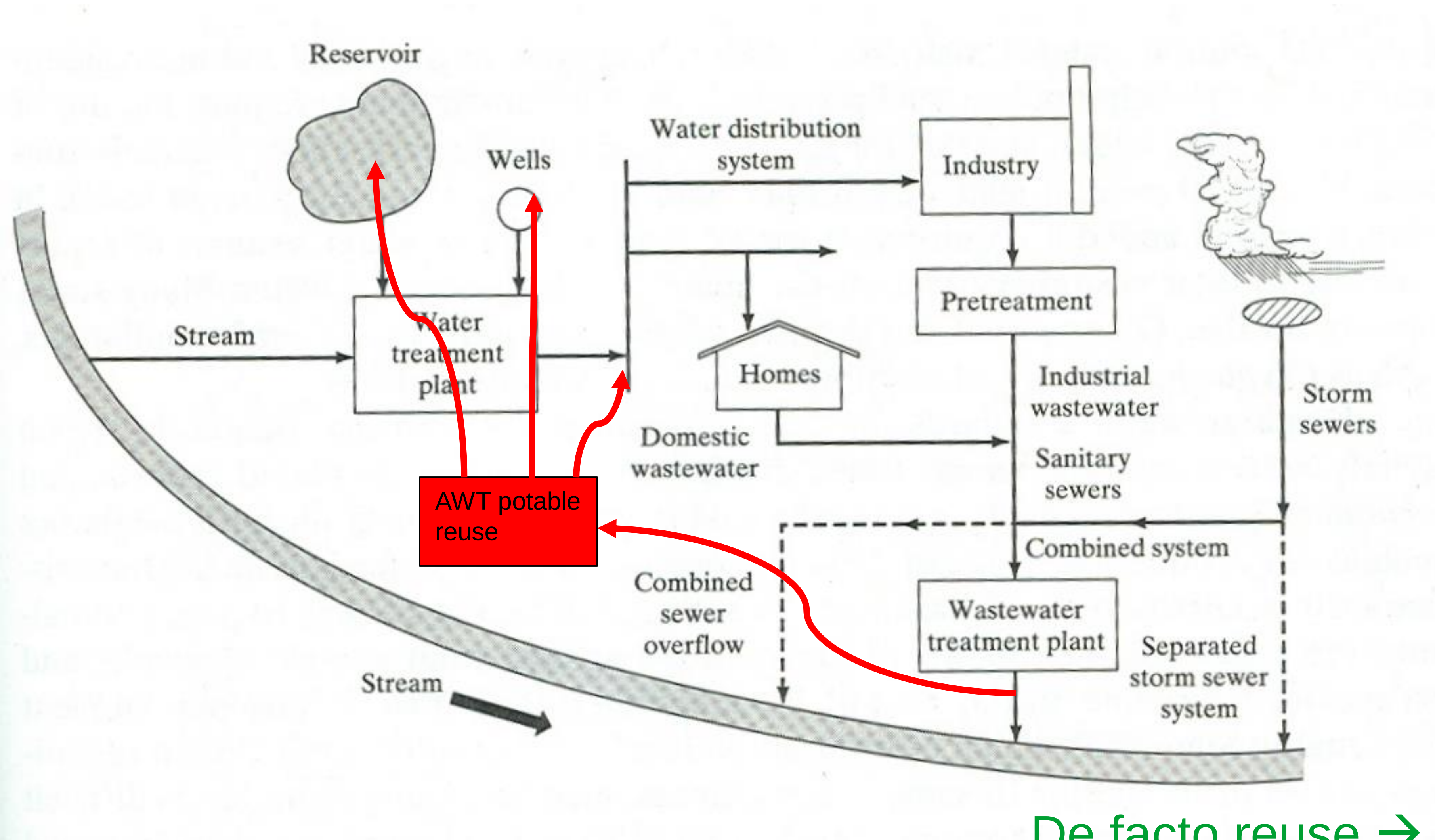
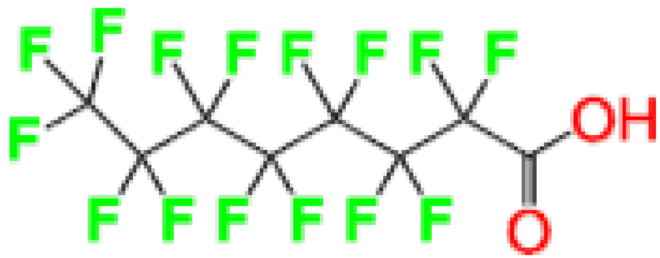
Our Engineered Water Cycle



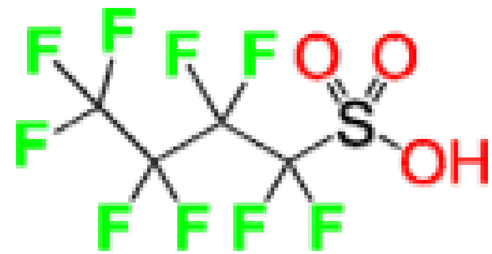
De facto reuse →

A Little PFAS Chemistry…

8 C



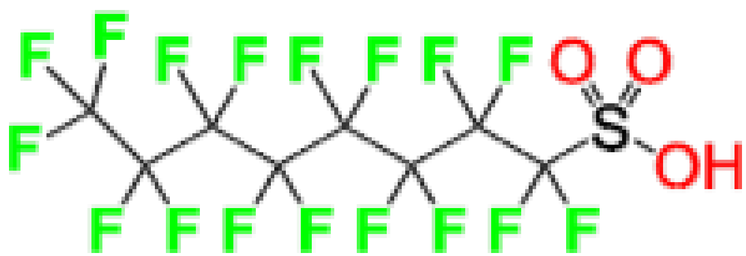
PFOA
(Perfluorooctanoic Acid)



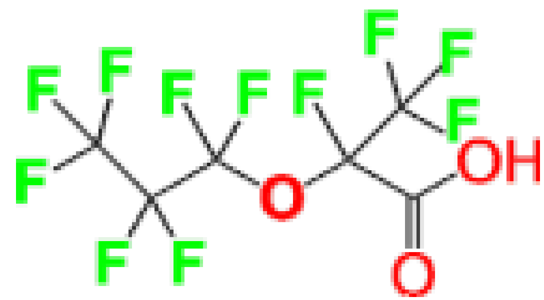
PFBS
(Perfluorobutane Sulfonic Acid)

4 C

8 C



PFOS
(Perfluorooctane Sulfonic Acid)



Gen X

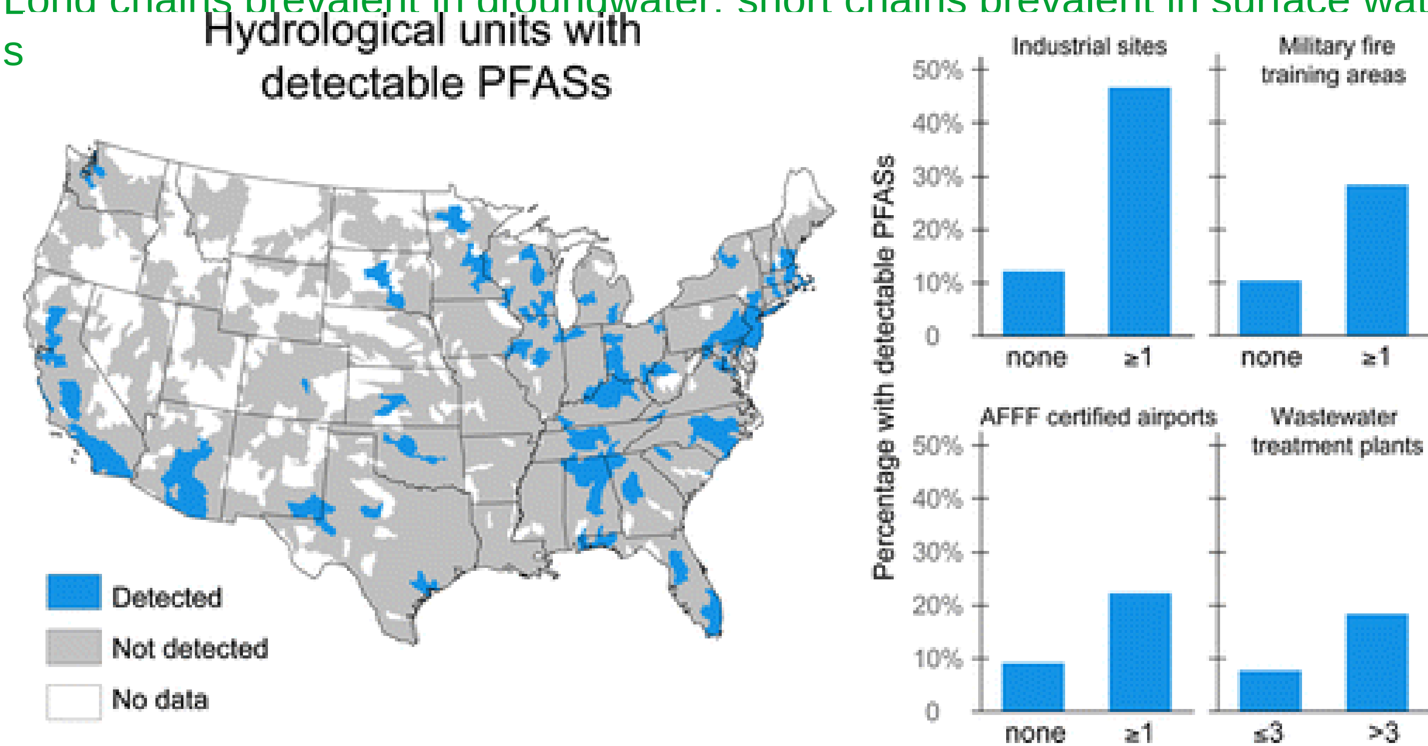
3+3 C

Long chain
High molecular weight (MW)
≥ 8 carbons

Short chain
Low molecular weight (MW)
≤ 5 to 6 carbons

Occurrence in Drinking Water and Sources (UCMR3)

- Six PFAS monitored in public water supplies— 194 detections (of 4,864 monitored)
- Majority of positive detections (76%) used groundwater sources
- Long chains prevalent in groundwater, short chains prevalent in surface waters



Hu, X.C., Andrews, D.Q., Lindstrom, A.B., Bruton, T.A., Schaider, L.A., Grandjean, P., Lohmann, R., Carignan, C.C., Blum, A., Balan, S.A. and Higgins, C.P., 2016. Detection of poly-and perfluoroalkyl substances (PFASs) in US drinking water linked to industrial sites, military fire training areas, and wastewater treatment plants. *Environmental science & technology letters*, *3*(10), pp.344-350.

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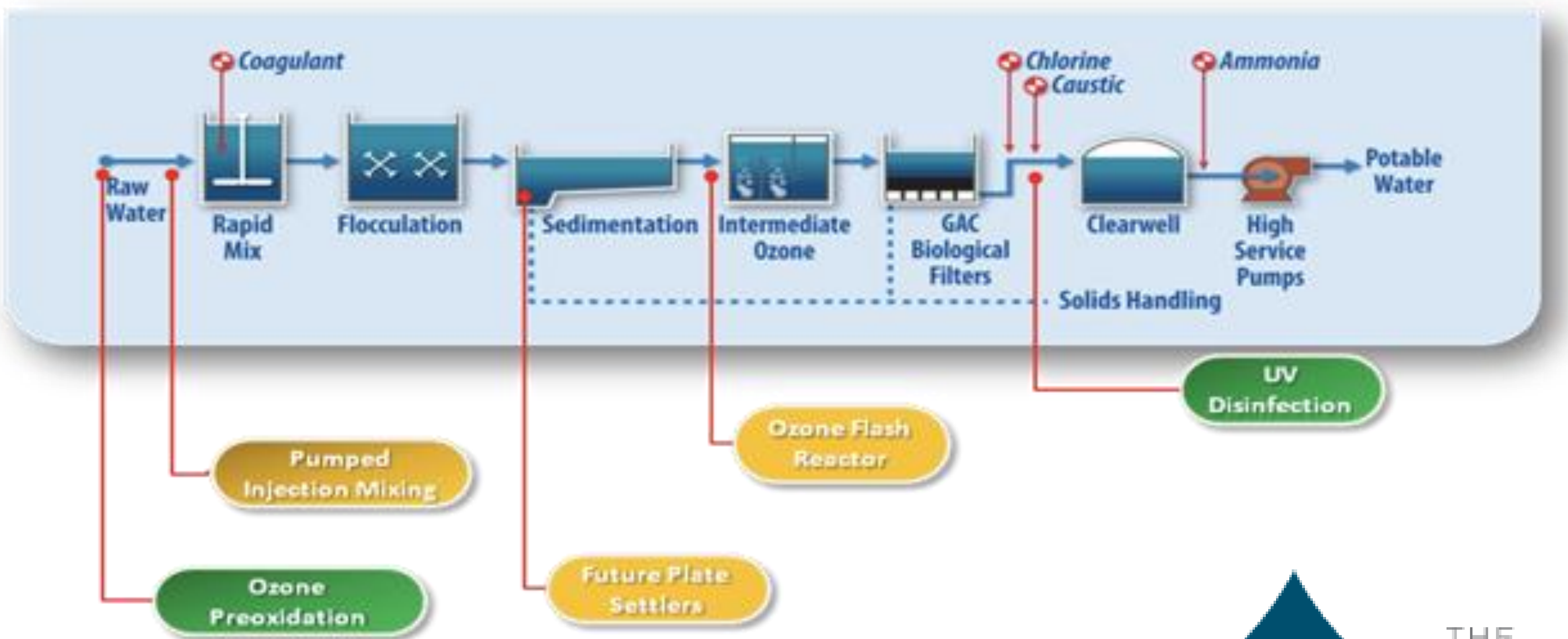
PFAS and Drinking Water Treatment

- Conventional treatment techniques are largely ineffective: coagulation/flocculation, filtration, ozonation, UV, advanced oxidation processes
- Example: Loudoun Water – Trap Rock Drinking Water Treatment Facility



WRF Project Report 4322: Dickenson, E. R., & Higgins, C. 2016. Treatment Mitigation Strategies for Poly-and Perfluoroalk Substances.

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Current Treatment Alternatives

- Technologies that can be implemented at full-scale facilities rely on separation rather than destruction (C-F

Treatment Option	Pros	Cons
Granular Activated Carbon (GAC)	Well-known technology; Carbon can be regenerated (thermal destruction of PFAS?)	Less effective at removing low molecular weight PFAS; potential issues with competitive adsorption
Powdered Activated Carbon (PAC)	Easier application; less efficient removal of PFAS	Same as GAC + cannot regenerate spent carbon
Nanofiltration/ Reverse Osmosis (NF/RO)	Effective removal of low molecular weight PFAS	High cost; Creates concentrated brine
Ion Exchange (IX)	Smaller footprint; Some resins can treat wider array of PFAS compared to GAC	Less effective at removing low molecular weight PFAS; creates regeneration brine and/or resin disposal required

WRF Project Report 4322: Dickenson, E. R., & Higgins, C. 2016. Treatment Mitigation Strategies for Poly-and Perfluoroalkyl Substances.

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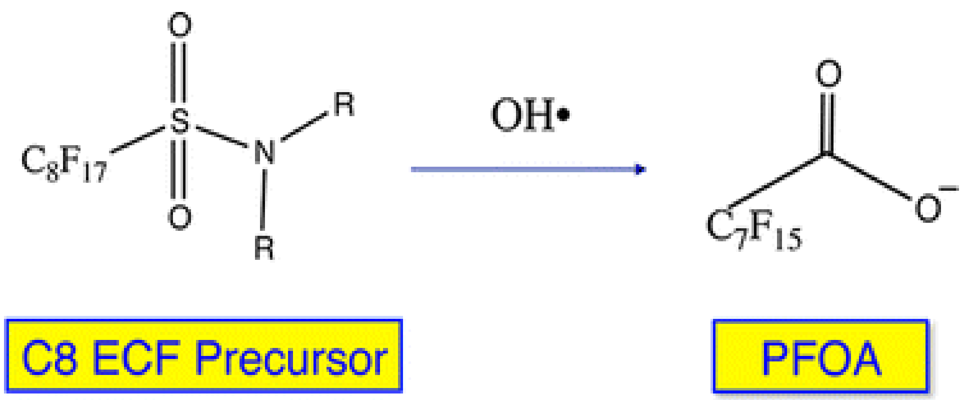
PFAS Precursor Conversion

- Over 4,000 PFAS compounds
  - Can be classified as precursor PFAS or terminal perfluoroalkyl acids (PFAAs)
- C-F bond can**not** be broken biotically (?) — biodegradation will convert precursors to PFAAs
- Total Oxidizable Precursor (TOP) – sample digestion prior to analysis



Modified from: Houtz, E.F. and Sedlak, D.L., 2012. Oxidative conversion as a means of detecting precursors to perfluoroalkyl acids in urban runoff. *Environmental science & technology*, *46*(17), pp.9342-9349.

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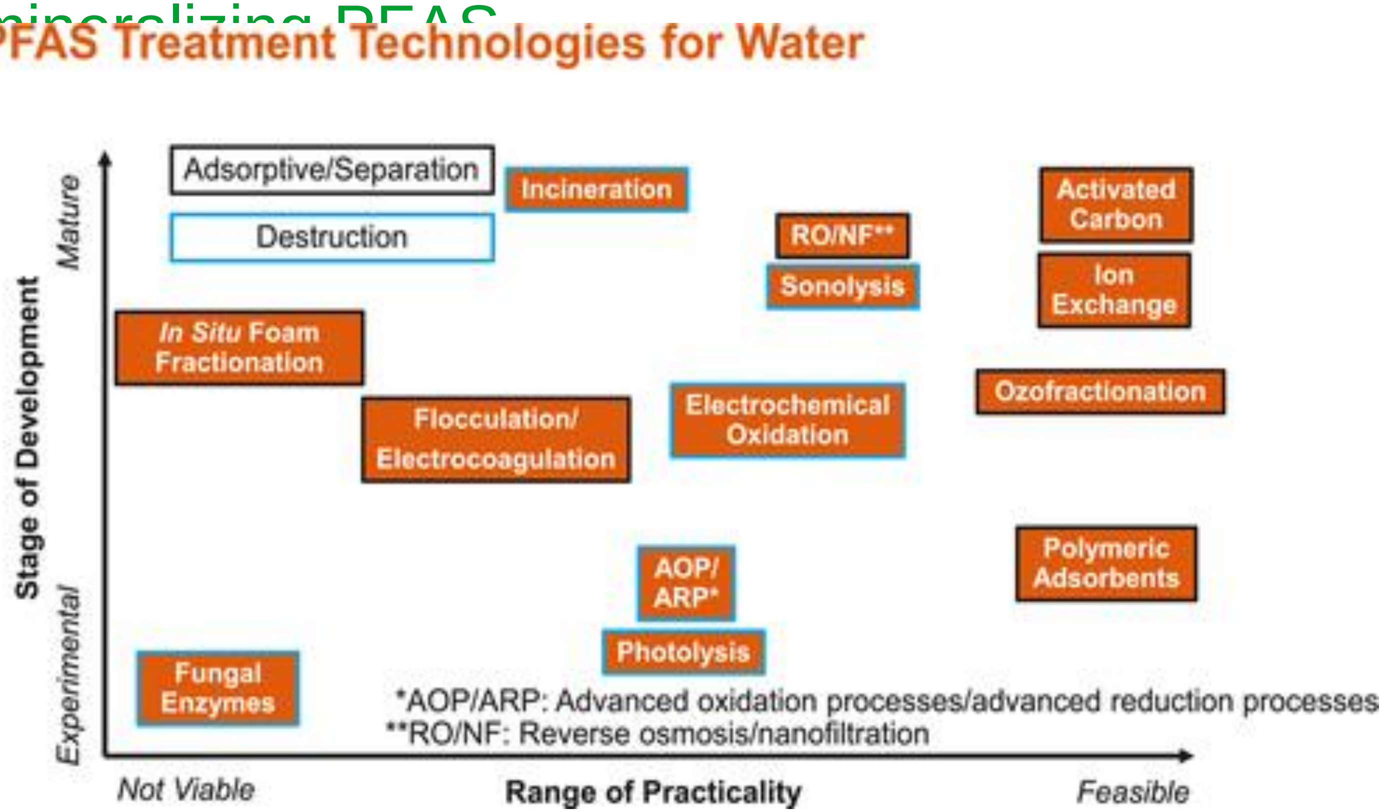
Emerging Technology for PFAS Treatment

- Some promising options for coupling a concentrating step with emerging technology capable of mineralizing PFAS



Ross, I., McDonough, J., Miles, J., Storch, P., Thelakkat Kochunarayanan, P., Kalve, E., Hurst, J., S. Dasgupta, S. and Burdick, J., 2018. A review of emerging technologies for remediation of PFASs. *Remediation Journal*, *28*(2), pp.101-126.

Evidence of Bacterial Reduction of C-F Bond

Environmental Science & Technology

Cite This: Environ. Sci. Technol. XXXX, XXX, XXX−XXX

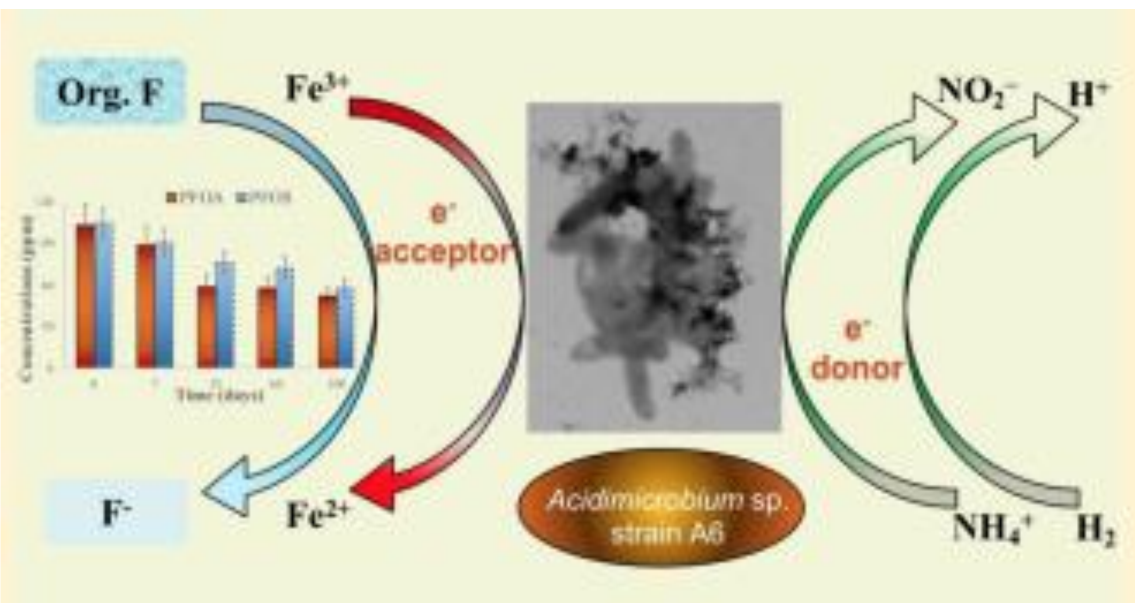
Article

pubs.acs.org/est

Defluorination of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) by *Acidimicrobium* sp. Strain A6

Shan Huang and Peter R. Jaffé*

Department of Civil and Environmental Engineering, Princeton University, Princeton, New Jersey 08544, United States



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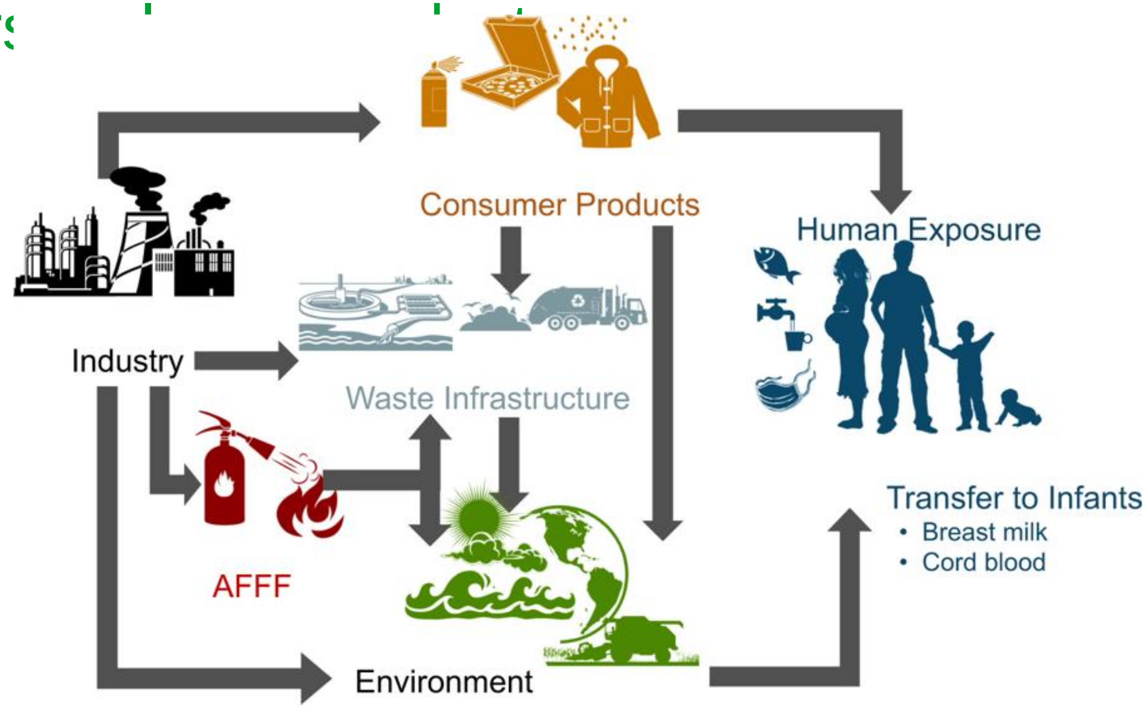
PFAS in Wastewater

- Industrial sources: fire-fighting foams (AFFF), paper and food packaging production, metal plating, landfill leachate
- Residential sources: cleaning products and stain repellants, wash water from PFAS coated clothing, pers



Sunderland, E.M., Hu, X.C., Dassuncao, C., Tokranov, A.K., Wagner, C.C. and Allen, J.G., 2018. A review of the pathways of human exposure to poly-and perfluoroalkyl substances (PFASs) and present understanding of health effects. *Journal of exposure science & environmental epidemiology*, p.1.

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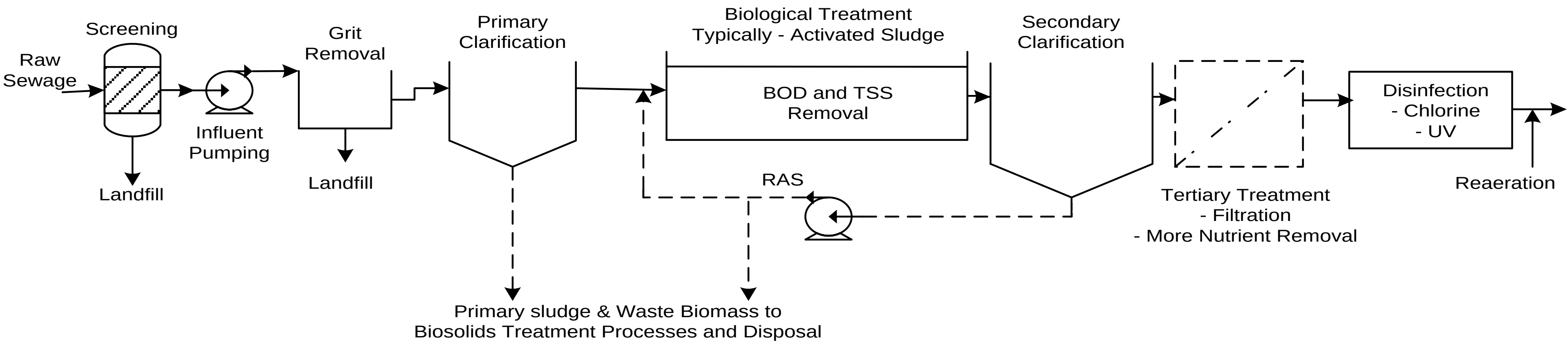
PFAS Fate in Water Resource Recovery Facilities (WRRFs)

- WRRFs do not create PFAS
  - Collect variety of wastes that may contain precursors and terminal PFAAs
  - Biological activity can convert precursors to terminal (and measurable) PFAAs



PFAS Source Control

- Certain known, highly concentrated sources (e.g. AFFF) should be avoided in wastewater influent
  - Protect effective wastewater treatment
  - Protection of pass through to receiving streams, potable reuse, biosolid residuals
- AFFF zero-discharge policy at HRSD since 1970s

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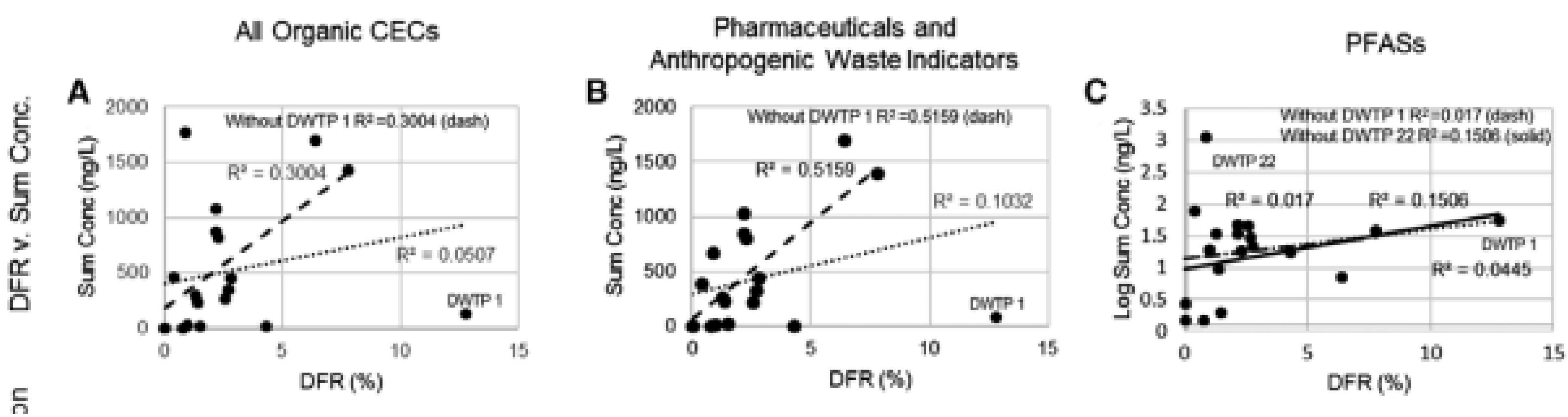
Is De Facto Reuse of Treated Wastewater a Source of PFAS for Downstream Drinking Water Sources?

FIGURE 6 De facto reuse (DFR) at mean streamflow, proximity index (PI), and skewness (SK) index in relation to the summed concentration for all organic contaminants of emerging concern (CECs), and separated by pharmaceuticals and anthropogenic waste indicators and per- and polylfluroalkyl substances (PFASs)



- Probably YES, but….
- Glassmeyer et al – PFAS occurrence in drinking water is not as well correlated with % de facto reuse as pharmaceuticals and other anthropogenic waste indicators

Peer Reviewed

Modeled De Facto Reuse and Contaminants of Emerging Concern in Drinking Water Source Waters

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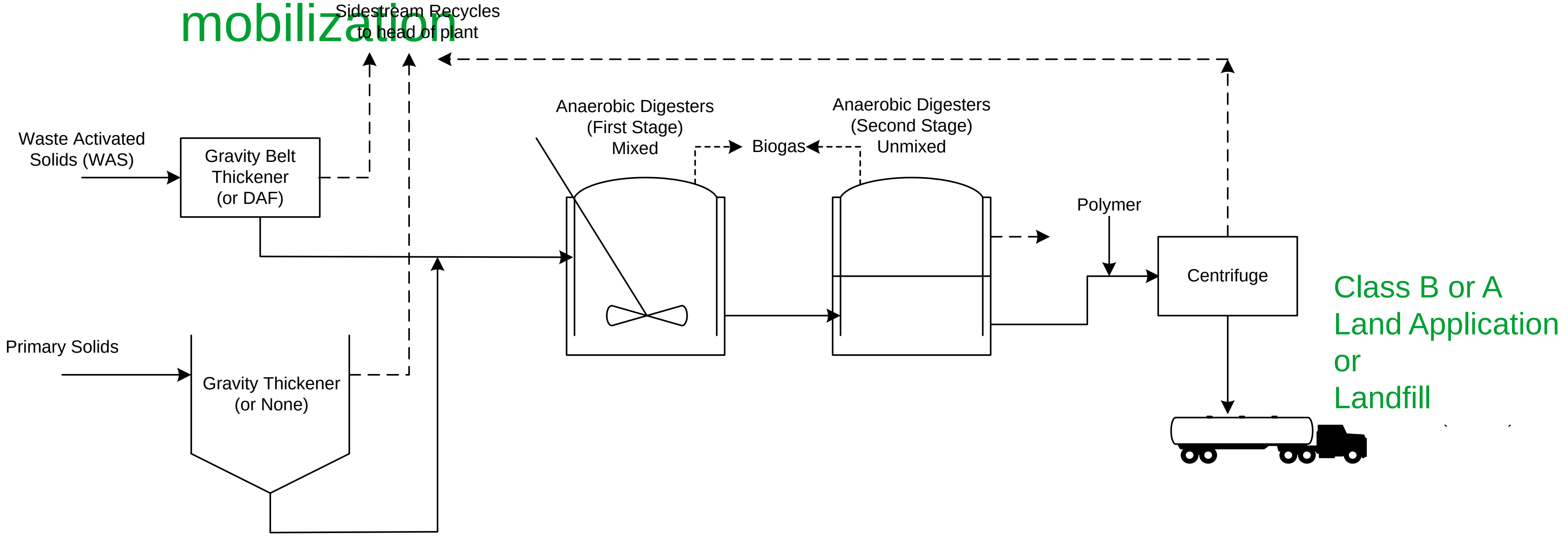
PFAS in WRRF Biosolids

- Longer-chain, hydrophobic compounds preferentially bound to solids
- PFAS content in biosolids can vary greatly depending on sources to WRRF
- Research need: PFAS content & potential for mobilization



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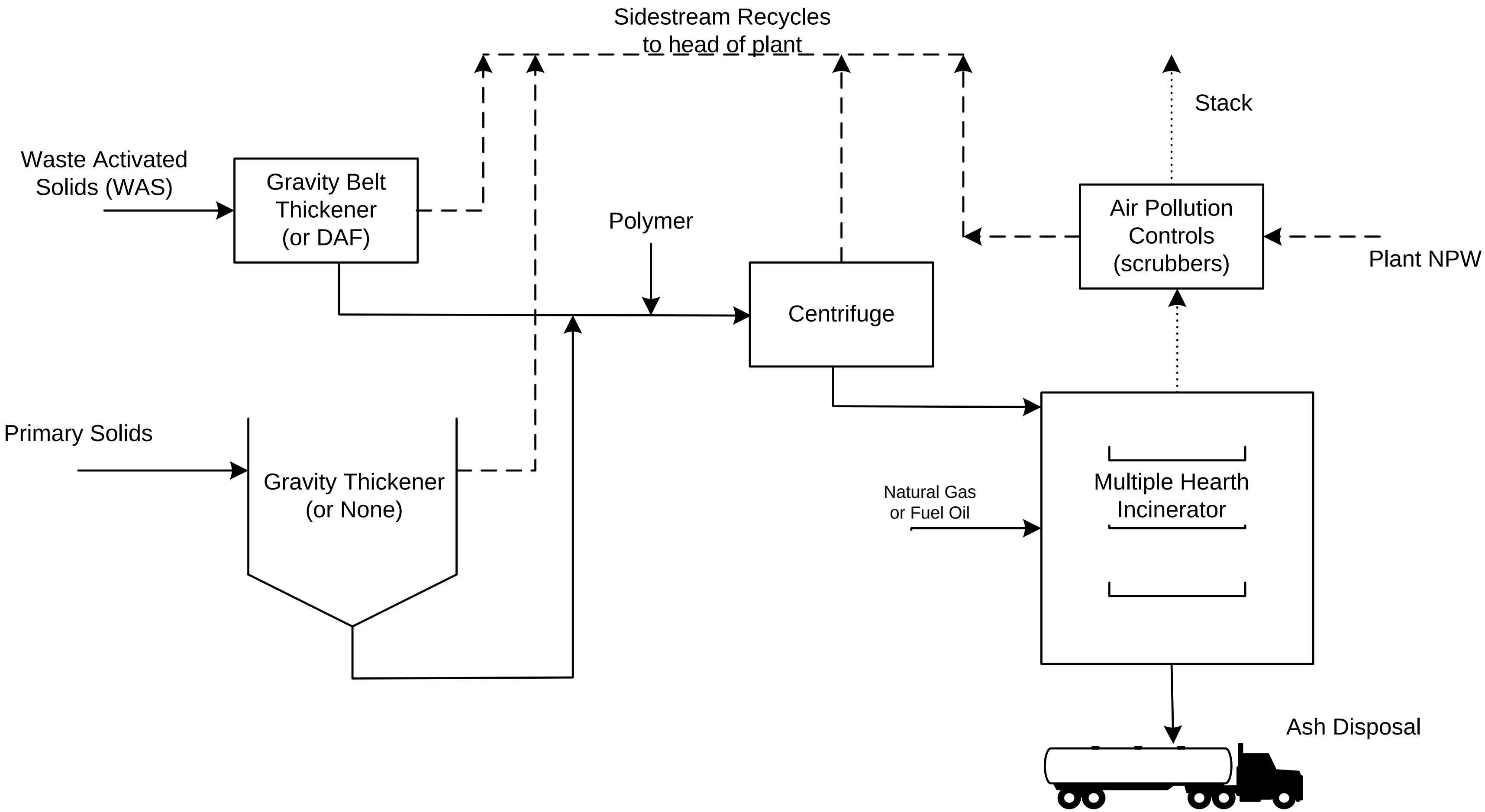
Some Large WRRFs in the US Incinerate Biosolids



S Biosolids Research at WRF & HRSD

- Objectives:
  – Characterize PFAS and other emerging contaminants in Class B and THP Class A biosolids
  – Understand PFAS mobility in soil porewater surrounding biosolids
  – Understand PFAS fate through incineration processes
- HRSD collaboration with Purdue University (Prof. Linda Lee)
- WRF RFP 5031 - Occurrence of PFAS Compounds in US Wastewater Treatment Plants

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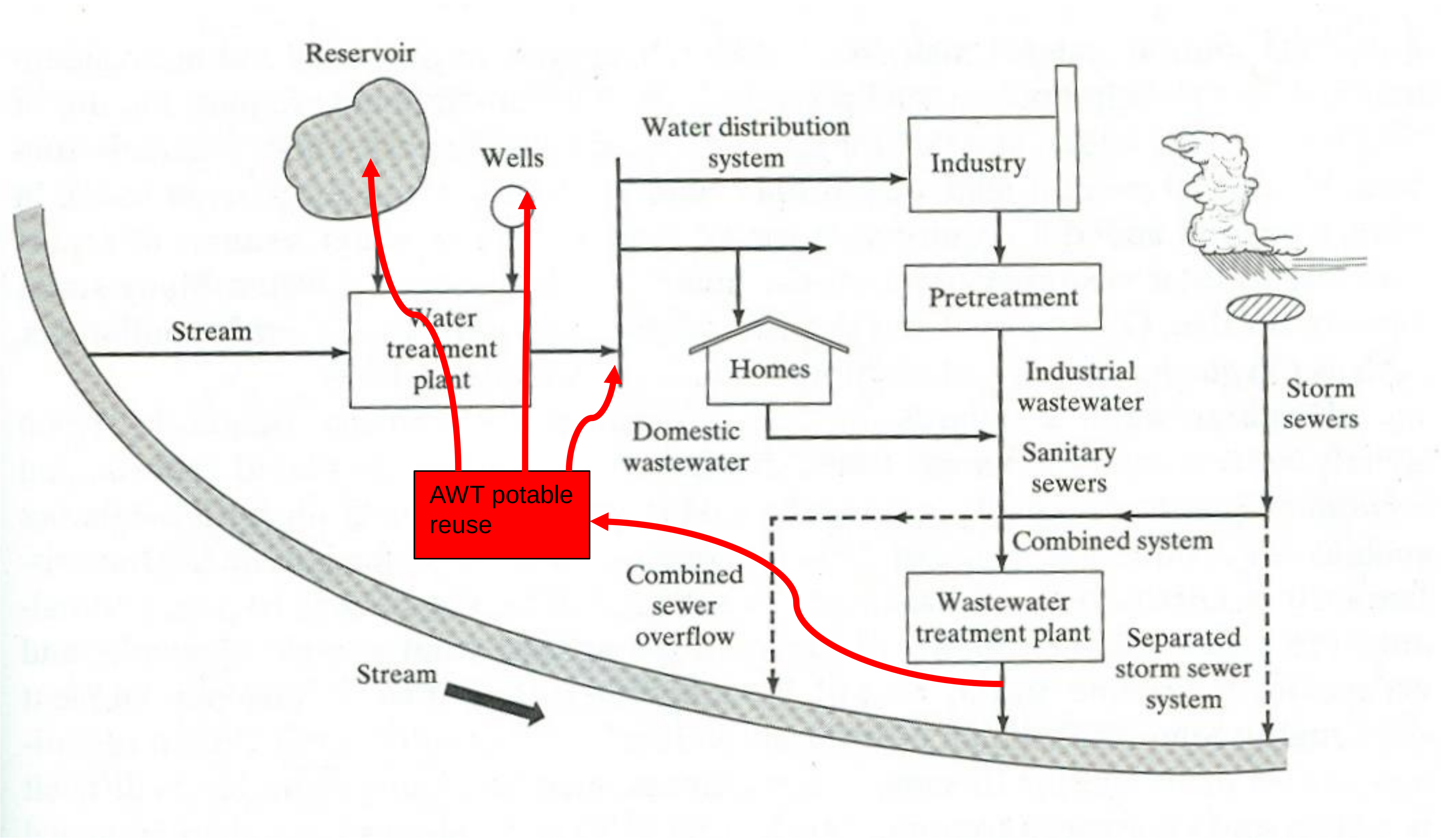


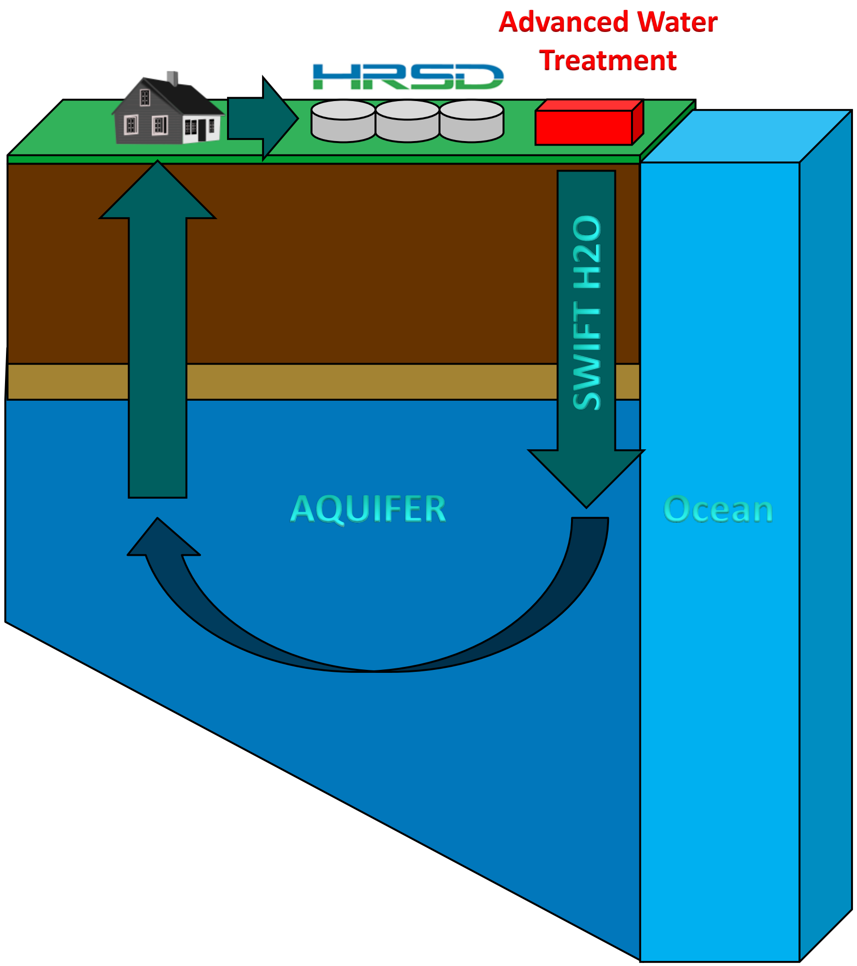
Potable Reuse and PFAS

- Multibarrier approach for potable reuse
- Reverse osmosis (RO)
  - Required by CA as part of full advanced treatment (FAT)
  - Effective for PFAS removal but concentrated brine remaining
- Granular activated carbon (GAC)
  - HRSD's Sustainable Water Initiative for Tomorrow (SWIFT) indirect potable reuse project
  - Less effective at removing low molecular weight PFAS but carbon regeneration possibly(?) mineralizes PFAS
  - PFAS source control coupled with optimizing carbon regeneration times

SWIFT – Sustainable Water Initiative for Tomorrow

Treat water to meet drinking water standards and replenish the aquifer with clean water to:

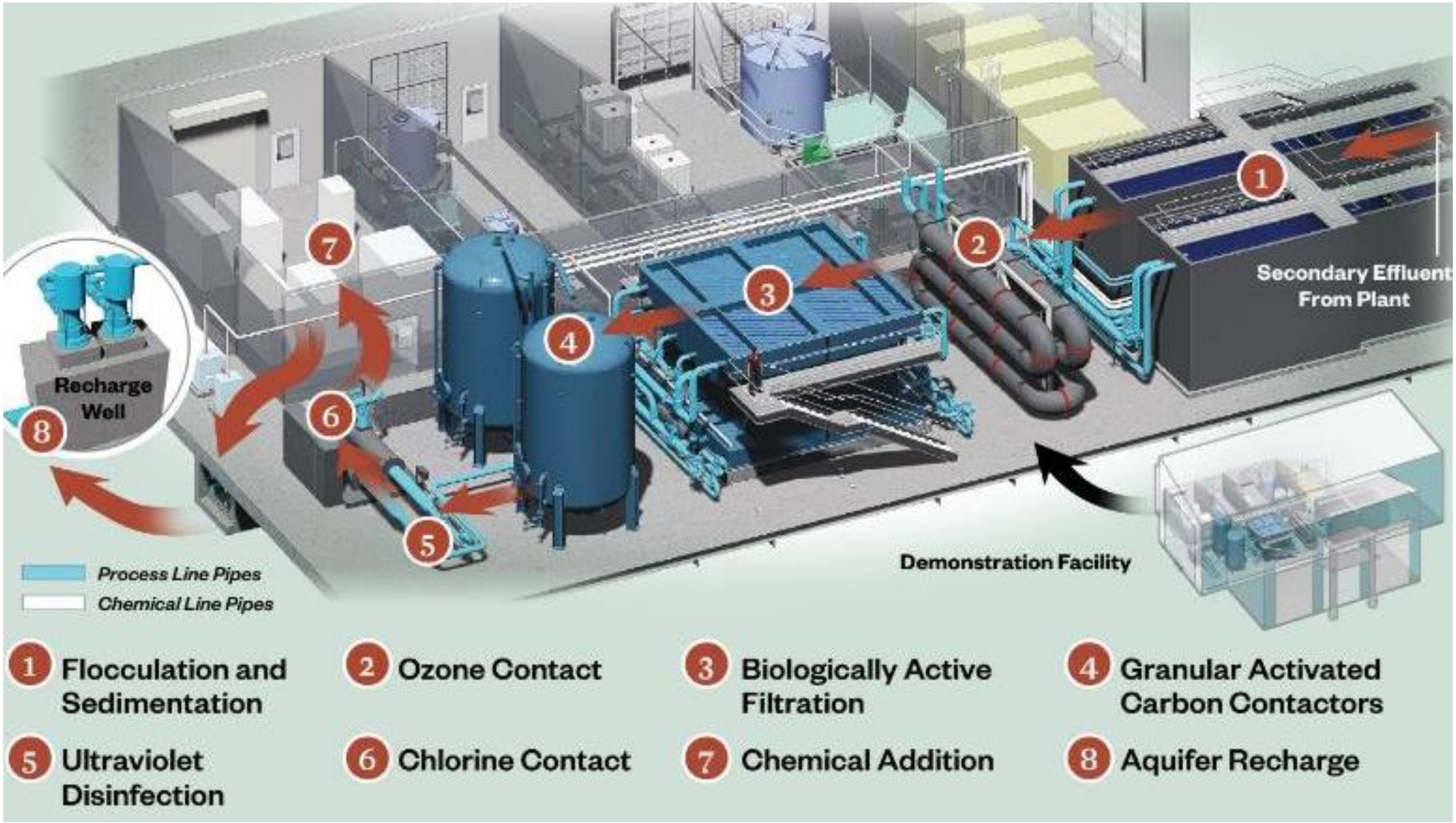
- Provide regulatory stability for wastewater treatment
- Provide a sustainable supply of groundwater
- Reduce nutrient discharges to the Bay
- Reduce the rate of land subsidence



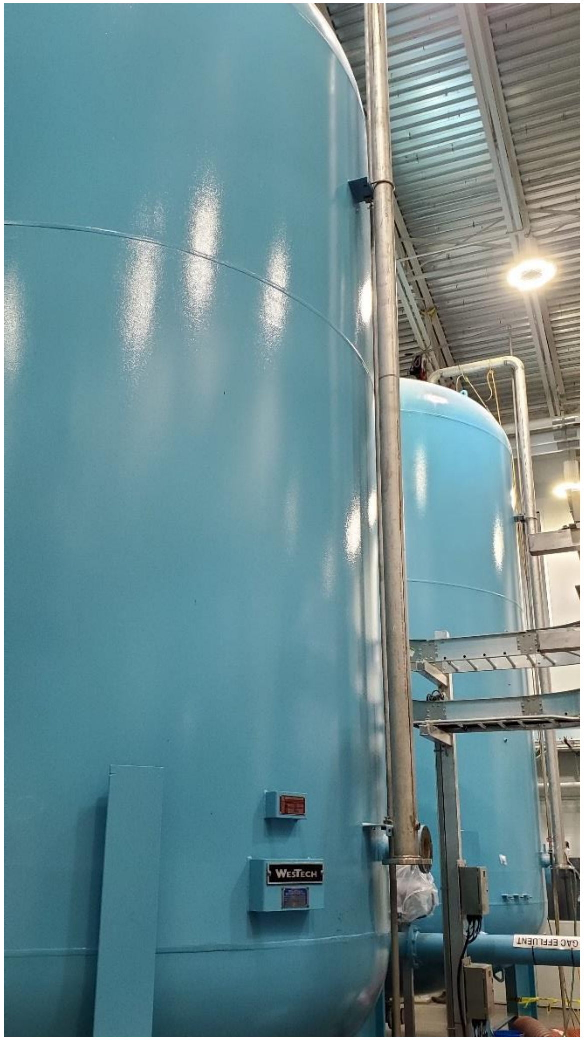
SWIFT Research Center

(1.0 MGD AWT + recharge well + monitoring wells + public outreach and education center + research facilities)

HRSD's SWIFT Program



WRF 4913: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances



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- Collaborative project:
  - NC State University
  - Southern Nevada Water Authority
- Goal: Understand removal of PFAS, particularly low molecular weight compounds across GAC

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Summary

- Treatment technology will continue to develop, but PFAS are difficult
- Research is needed:
  - Toxicology
  - Treatment (separation vs defluorination/mineralization)
  - Occurrence, fate and transport (surface water, drinking water, soil/biosolids, groundwater)
  - How and where should PFAS be managed?
- Meanwhile, control of concentrated sources is probably our best tool