EPA Tools and Resources Webinar: Treating Contaminants of Emerging Concern

Tom Speth, Ph.D.
EPA Office of Research and Development

March 21, 2019

Overview

1) **Nitrate/Perchlorate**
    1) Anion exchange
    2) Point of Use (POU) membranes
    3) Biological treatment (anaerobic)
2) **Microcystins**
    1) Cell removal
    2) Powdered activated carbon
    3) Disinfection/Oxidation
3) **PFAS**
    1) Activated carbon
    2) Anion exchange
    3) Reverse osmosis

Research: Treatment

Publically Available Drinking Water Treatability Database

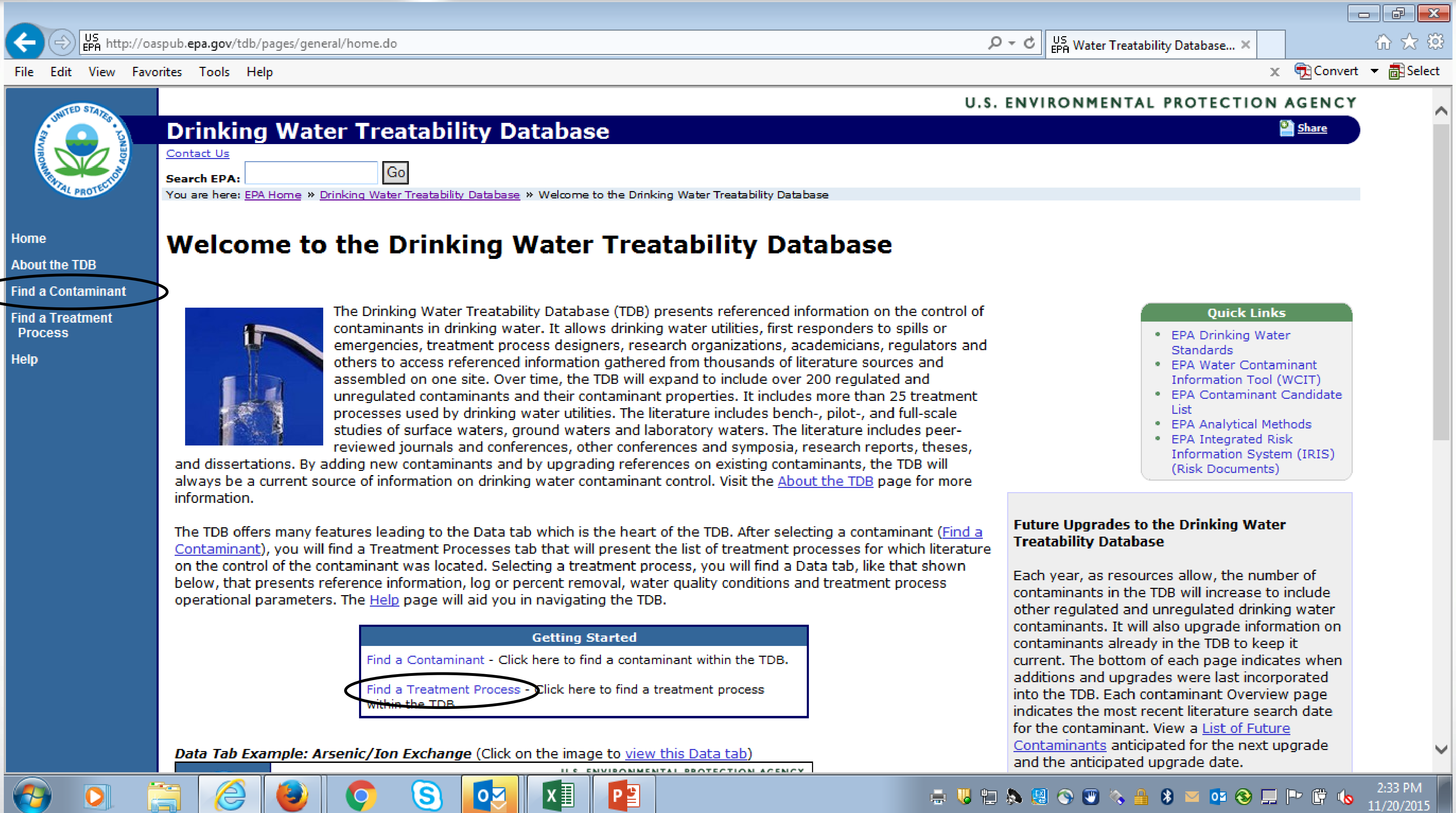
Interactive literature review database that contains over 65 regulated and unregulated contaminants and covers 34 treatment processes commonly employed or known to be effective (thousands of sources assembled on one site)

Currently available:

- **Nitrate**
- **Perchlorate**
- **Microcystins**
- **PFOA, PFOS, PFNA, PFHxA, PFHxS, PFBS, Gen-X**

http://iaspub.epa.gov/tdb/pages/general/home.do
Search: EPA TDB

Treatability Database



Treatability Database

U.S. ENVIRONMENTAL PROTECTION AGENCY

Drinking Water Treatability Database

Share

Contact Us

Search EPA: Go

You are here: EPA Home » Drinking Water Treatability Database » Perfluorooctanoic Acid

Home
About the TDB
Find a Contaminant
Find a Treatment Process
Help

Perfluorooctanoic Acid

Overview | Treatment Processes | Properties | Fate and Transport | References

The following processes were found to be effective for the removal of perfluorooctanoic acid: GAC (up to 99 percent removal), membrane separation (up to > 98 percent), powdered activated carbon (88 percent), and ion exchange (73 to 95 percent). UV irradiation at wavelengths in the 185-220 nm range and/or at long irradiation times (up to 72 hours) could potentially be effective (62 to 90 percent). Membrane filtration varied in effectiveness (22 to 56 percent).

Based on the available literature, the following are not considered effective for the removal of perfluorooctanoic acid: conventional treatment (no removal) and UV at wavelengths outside of the 185-220 nm range (4 percent to 10 percent removal). UV/hydrogen peroxide treatment (35 percent removal) was less effective in comparison to UV alone (45 percent) after 24 hours of irradiation.

Studies were identified evaluating the following treatment technologies for the removal of perfluorooctanoic acid:

Conventional Treatment - Multiple full-scale studies reported insignificant removal of PFOA by conventional treatment. PFOA levels after conventional drinking water treatment were found to correlate to the PFOA levels detected in their surface waters sourc...

GAC Isotherm - Adsorption was observed for PFOA detected in a contaminated groundwater. It was found to be nonlinear.

Granular Activated Carbon - Removal of PFOA by GAC can be effective. Bench scale tests, including rapid small scale column tests, showed removals from less than zero to 95 percent, depending on carbon type and background TOC concentrations [1700, 2423, 2441]. At one full sca...

Ion Exchange - Removal of PFOA using anion exchange resins was found to be effective (73 to 95 percent removal) in a bench study [2427], and in a full scale application [2424; 2441] that used a resin designed for arsenic removal.

What is a Work Breakdown?

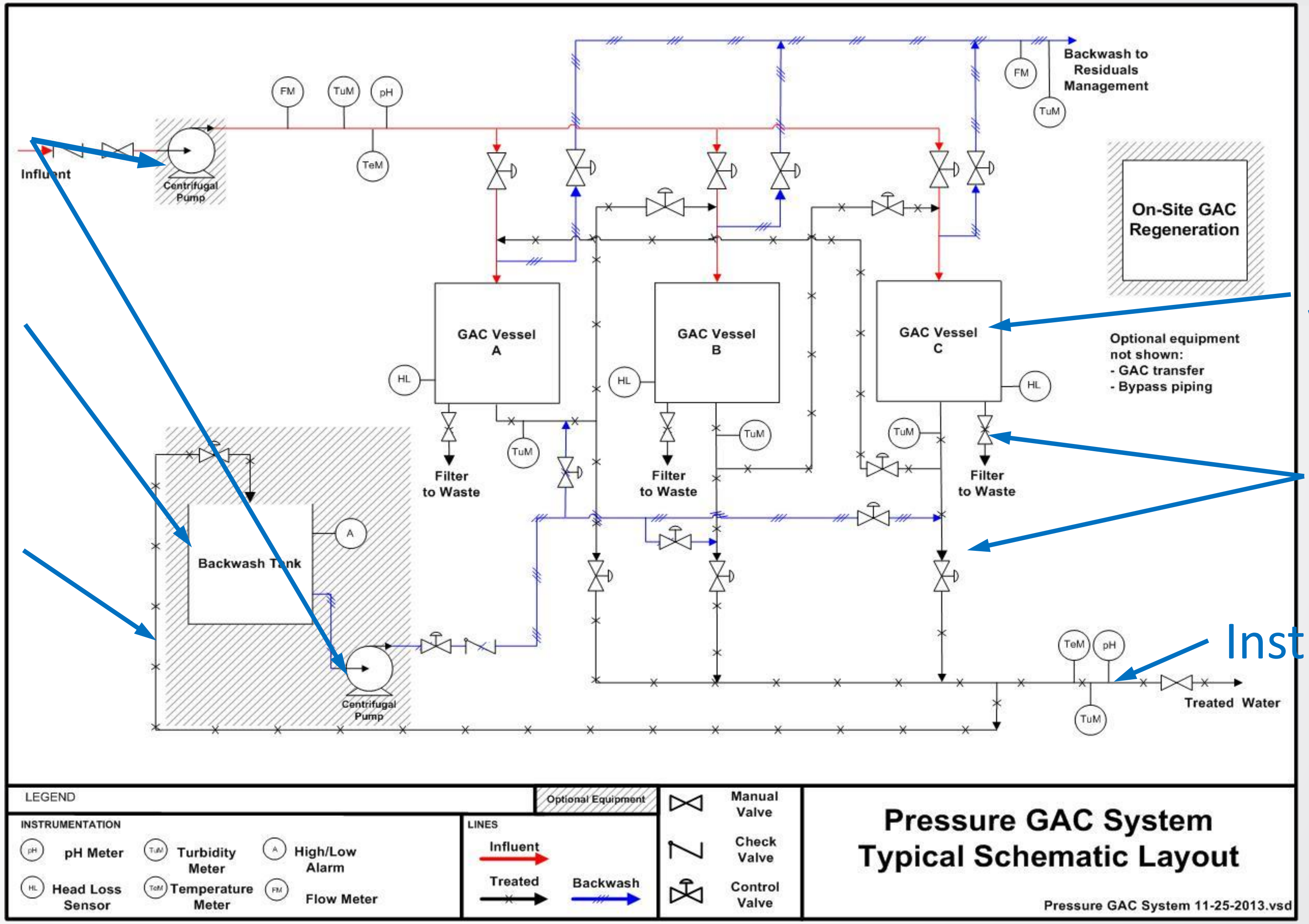
Work Breakdown Structure (WBS) Approach?

A treatment technology is broken down into discrete components that can be measured to estimate costs. Components include specific equipment (e.g., tanks, vessels, pipes, instruments) and identifiable cost elements such as annual labor expenses, chemicals, and energy.

Pumps

Tanks

Pipes



Pressure Vessels

Valves

Instruments

What Costs Do the WBS Models Estimate?

Capital Costs

- Equipment costs
  - Pumps
  - Tanks/vessels
  - Pipes
  - Instruments
- Buildings
- Add-on costs
  - Pilot study
  - Permits
  - Land
- Indirect costs
  - Engineering
  - Construction management
  - Sitework/electrical

Annual Operating Costs

- Labor
  - Technical
  - Managerial
  - Administrative
- Materials and supplies
  - Chemicals
  - Equipment maintenance
- Residuals management
  - Publicly owned treatment work (POTW)
  - Granular Activated Carbon (GAC) regeneration
  - RCRA Subtitle D or C landfill
- Energy
  - Operating (e.g., pumps, blowers)
  - Heating, ventilation, and air conditioning (HVAC)

EPA's Drinking Water Cost Models

- Adsorptive media
- **Anion exchange***
- **Biological treatment***
- Cation exchange
- **GAC***
- Greensand filtration
- Microfiltration/ultrafiltration
- Multi-stage bubble aeration*

- Non-treatment
- Packed tower aeration
- **POU/POE (Point of Entry)** #
- Reverse Osmosis/Nanofiltration
- UV disinfection
- UV Advanced Oxidation

*** Search: EPA WBS** http://www2.epa.gov/dwregdev/drinking-water-treatment-technology-unit-cost-models-and-overview-technologies

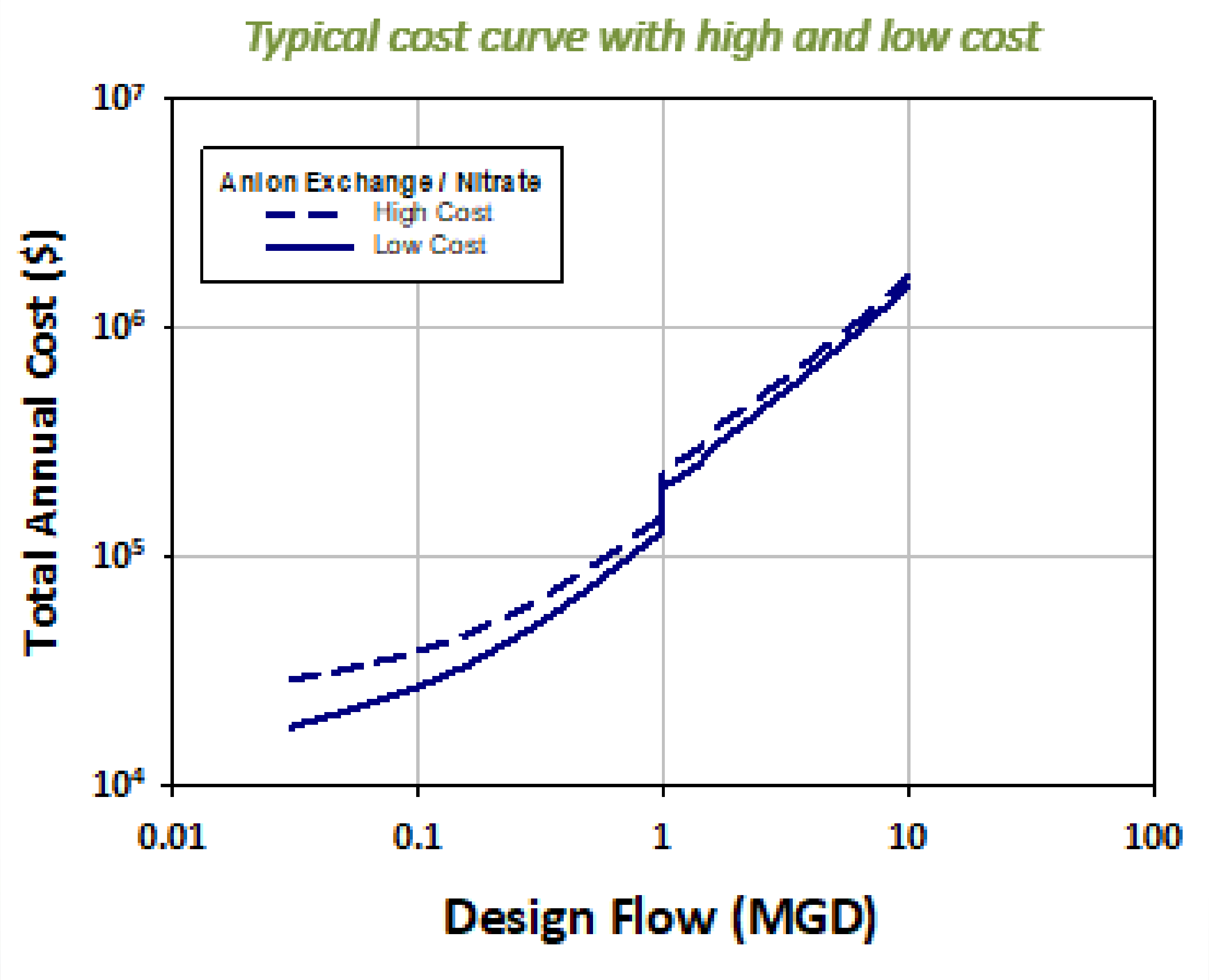
 # For POU/POE search: EPA small system compliance help
http://water.epa.gov/type/drink/pws/smallsystems/compliancehelp.cfm

Nitrate and Perchlorate

Why Nitrate and Perchlorate?

- Nitrate: A number of utilities exceed the nitrate Maximum Contaminant Level (MCL), particularly small systems
- Perchlorate: New state regulations and federal regulation consideration
- Both are fully oxidized – oxidation processes including aerobic biotreatment will not work
- The treatment processes that will work are pretty much the same
  - Anion exchange resin
  - High pressure membranes: reverse osmosis or nanofiltration
  - Anaerobic biological treatment (novel technology)

Cost: Nitrate/Anion Exchange



Primary Assumptions

- 20.3 mg N/L Influent
- Nitrate selective resin
- 420 Bed volumes before regeneration
- 2 minute Empty Bed Contact Time (EBCT)
- Parallel contactors
- Brine discharge to POTW

*Million Gallons Per Day (MGD)

Cost Savings for Small Systems under 1 MGD

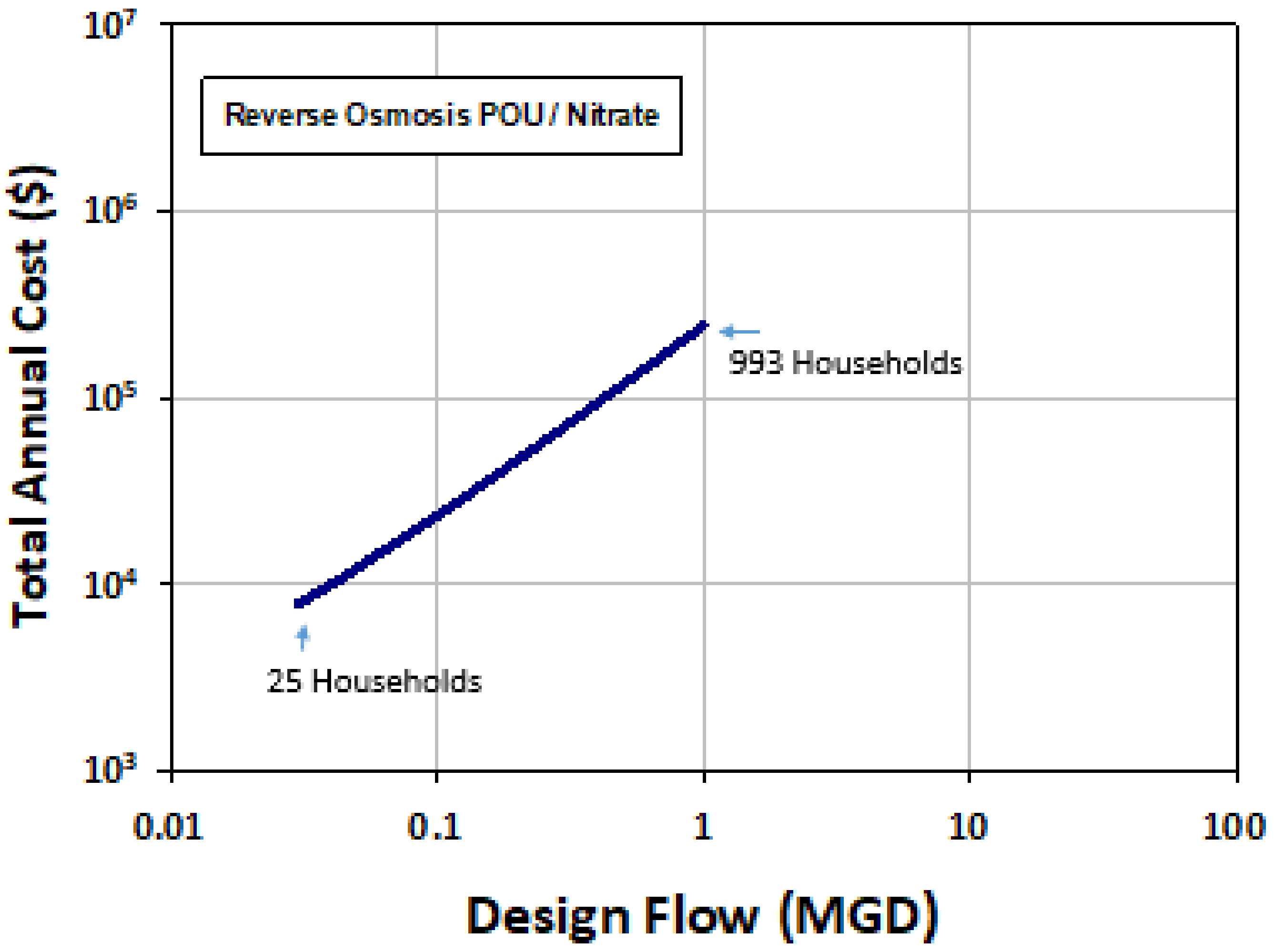
Specific Design Modifications for Smaller Systems within the Cost Model

(Considers flows under 1 MGD)

- Construction issues (building)
- Residual handling flexibility
- Reduced spacing between vessels
- Smaller and no redundant vessels
- Reduced instrumentation
- No booster pumps
- No backwash pumps
- Reduced concrete pad thickness
- Reduced indirect costs

Cost: Nitrate / Point of Use

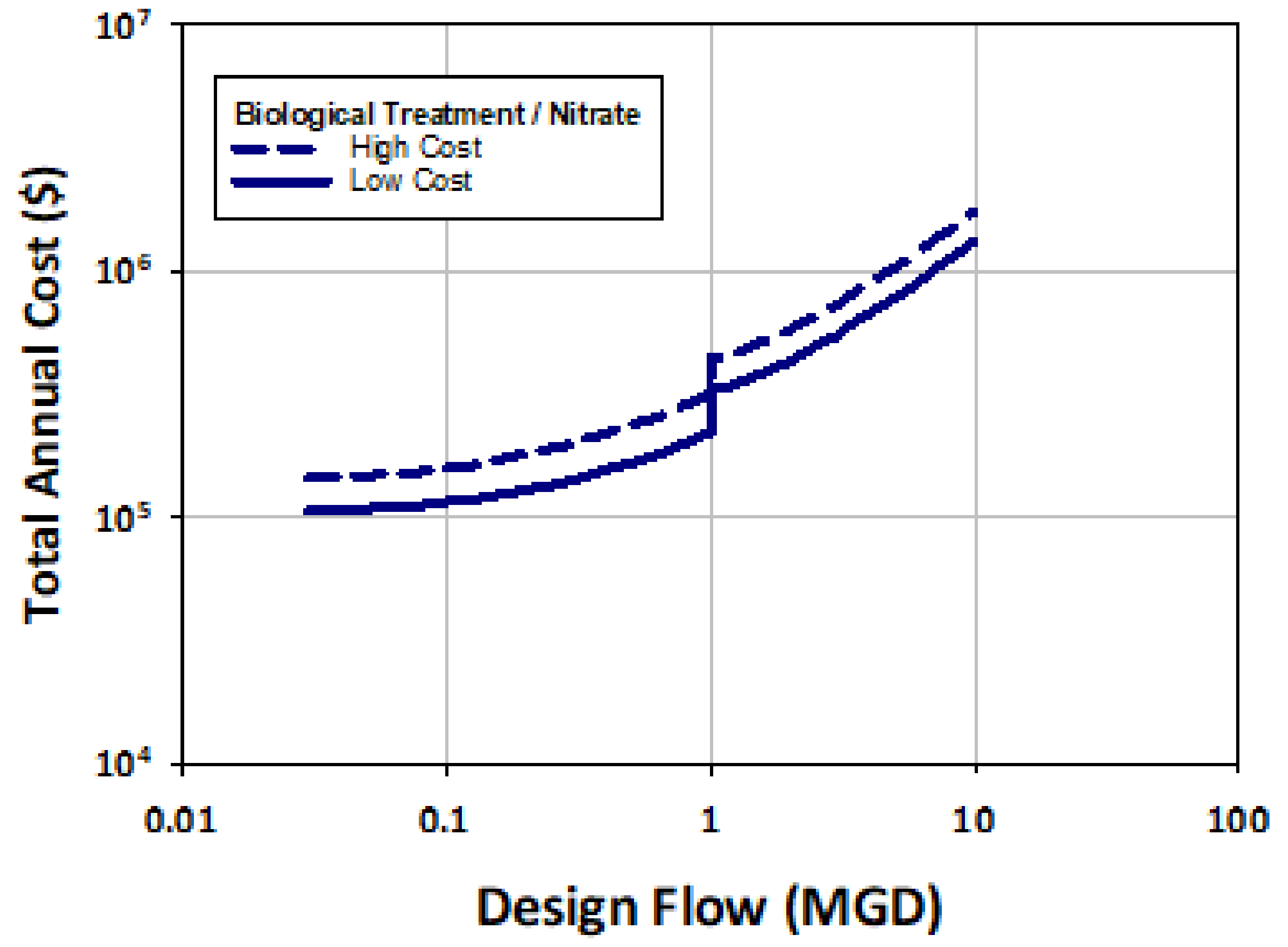
Only for 1 MGD design flow and below



Primary Assumptions

- 20.3 mg N/L Influent
- Reverse osmosis (RO) treatment
- Replacement frequency:
  - RO membrane: 3 years
  - Pre filters: 9 months
  - Post filter: 12 months
- Groundwater
- No post UV disinfection

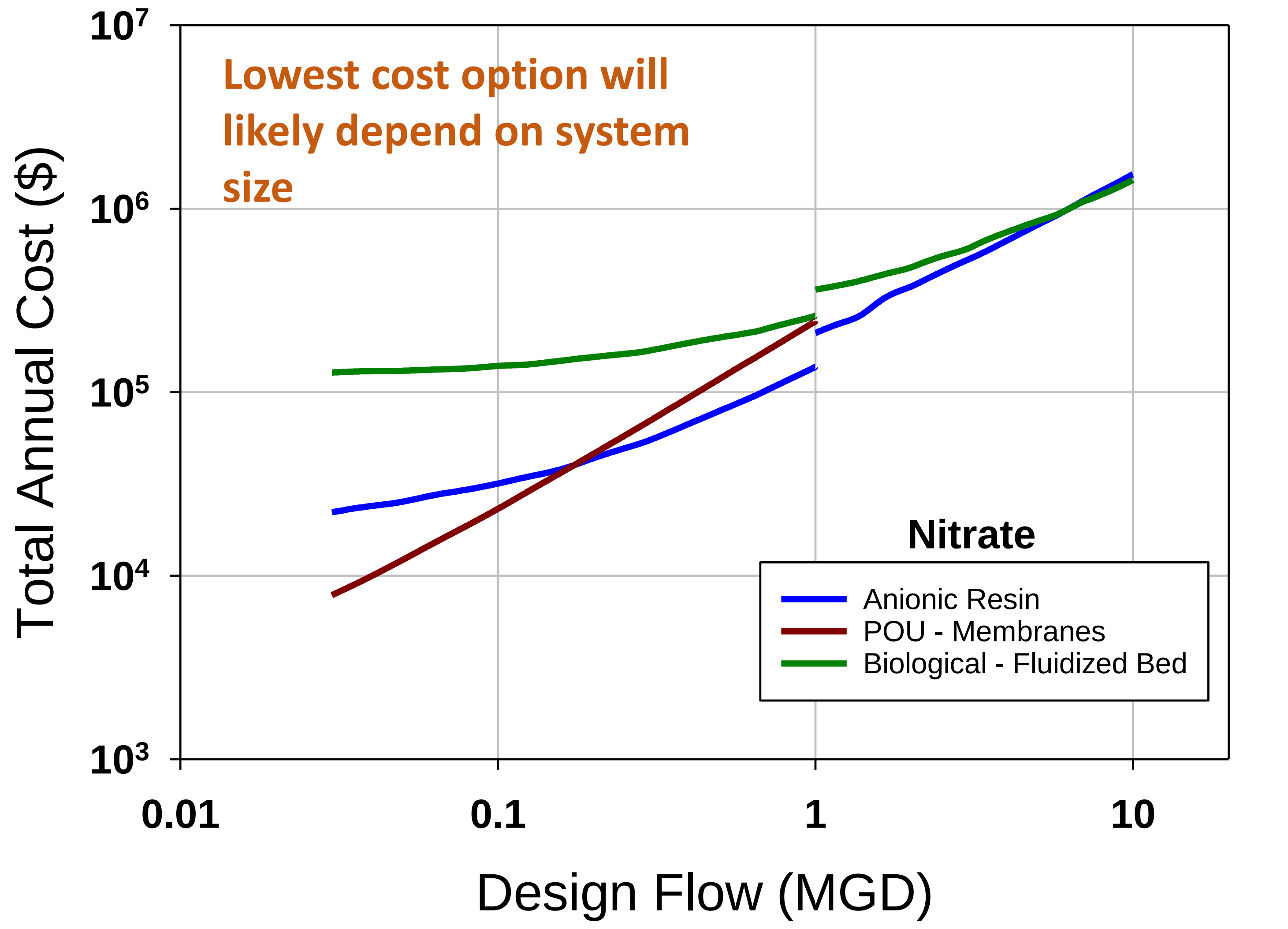
Cost: Nitrate / Anaerobic Biological Treatment



Primary Assumptions

- 20.3 mg N/L
- Fluidized bed reactor
- 28.5 mg/L acetic acid
- 2 mg P/L phosphoric acid
- 10 minute EBCT
- Post treatment aeration
- Post treatment filtration
- Recycle of spent backwash

Cost: Nitrate (combined)

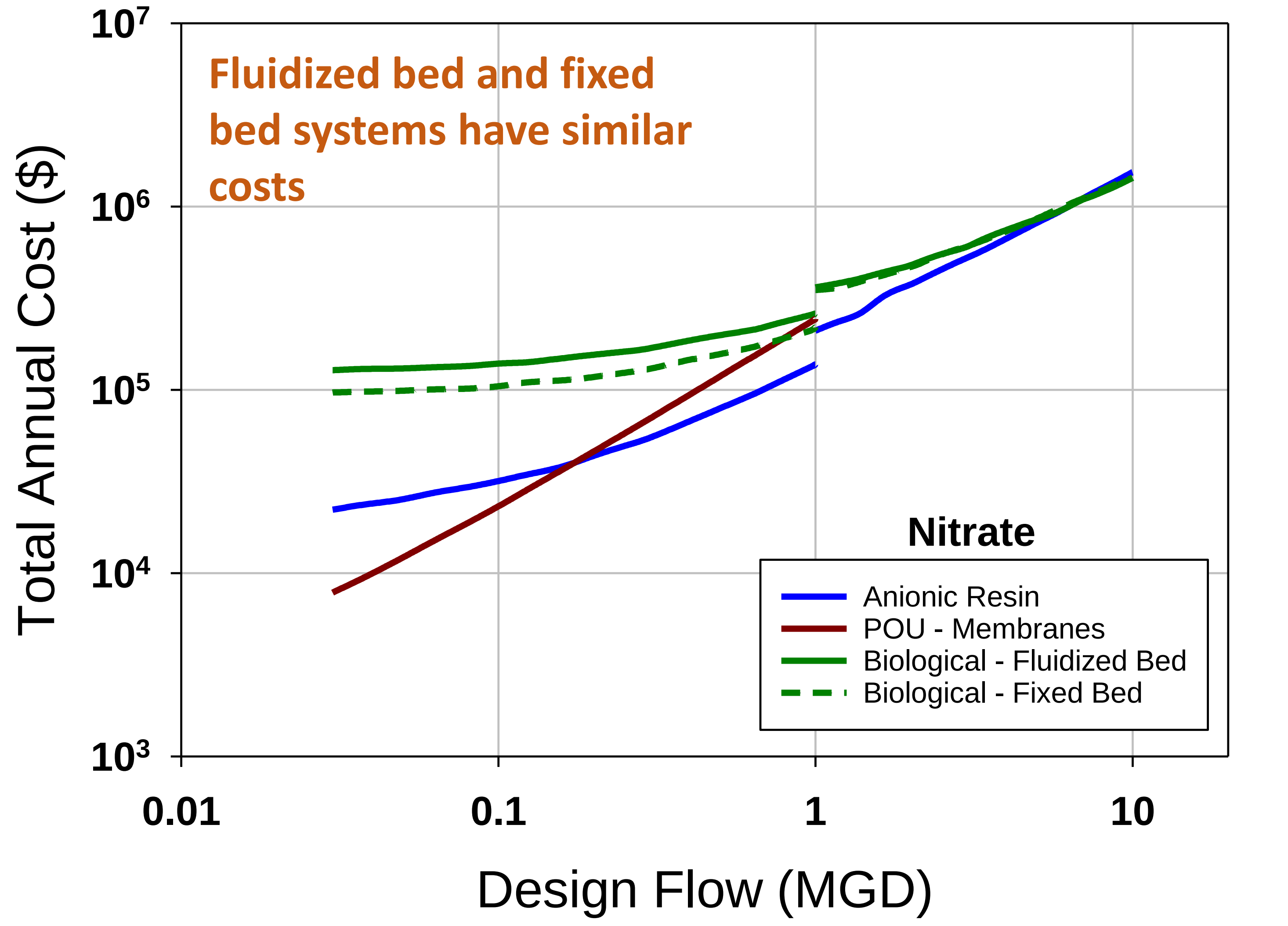


Conditions Same as Previous Slides:

- Medium cost option
- Influent 20.3 mg N/L
- Groundwater
- Ion Exchange (IEX): Nitrate selective
- Biological: Fluidized bed
- POU: Reverse Osmosis

Cost: Nitrate (combined)

Includes both fluidized bed and fixed bed for anaerobic biological treatment

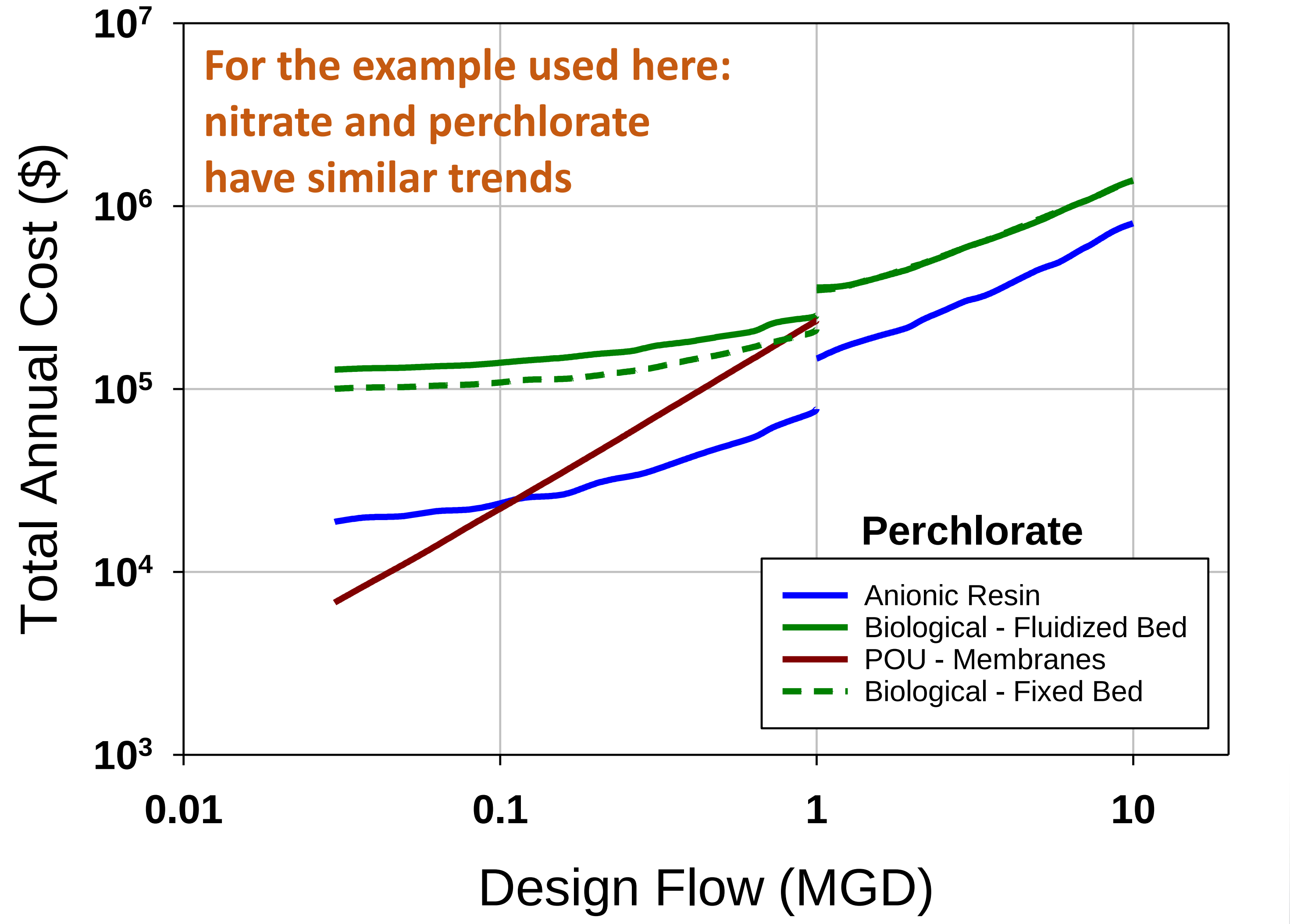


Conditions Same as Previous Slides:

- Medium cost option
- Influent 20.3 mg N/L
- Groundwater
- IEX: Nitrate selective
- Biological: Fluidized bed
- POU: Reverse Osmosis

Cost: Perchlorate (combined)

Includes both fluidized bed and fixed bed for anaerobic biological treatment



Conditions Same as Previous Slides:

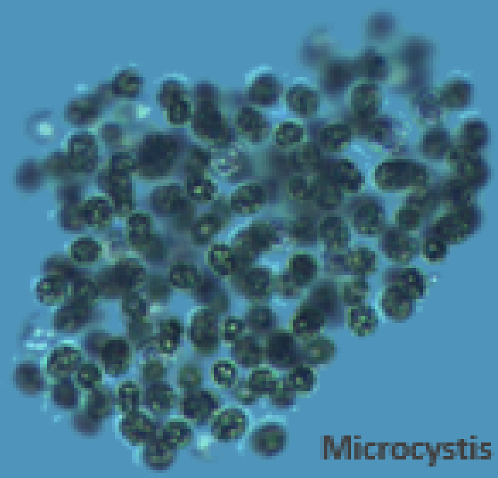
- Medium cost option
- Influent 24 ug/L
- Groundwater
- IEX: Perchlorate selective
- Biological: Fluidized & fixed bed
- POU: Reverse Osmosis

Treatment for Cyanobacteria Toxins

Toxin within the cell and those that are dissolved require different treatment processes

Particulates (toxin in cell)

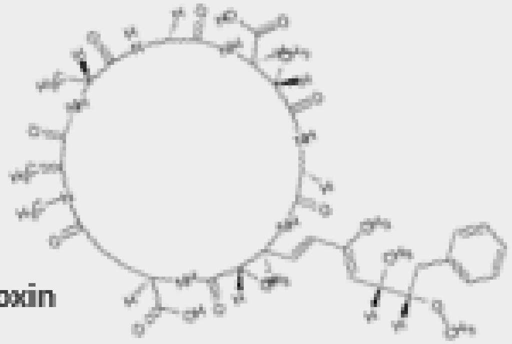
- Solids removal processes effective
- Do not want to lyse cell or toxin will be released



Microcystis (cells)

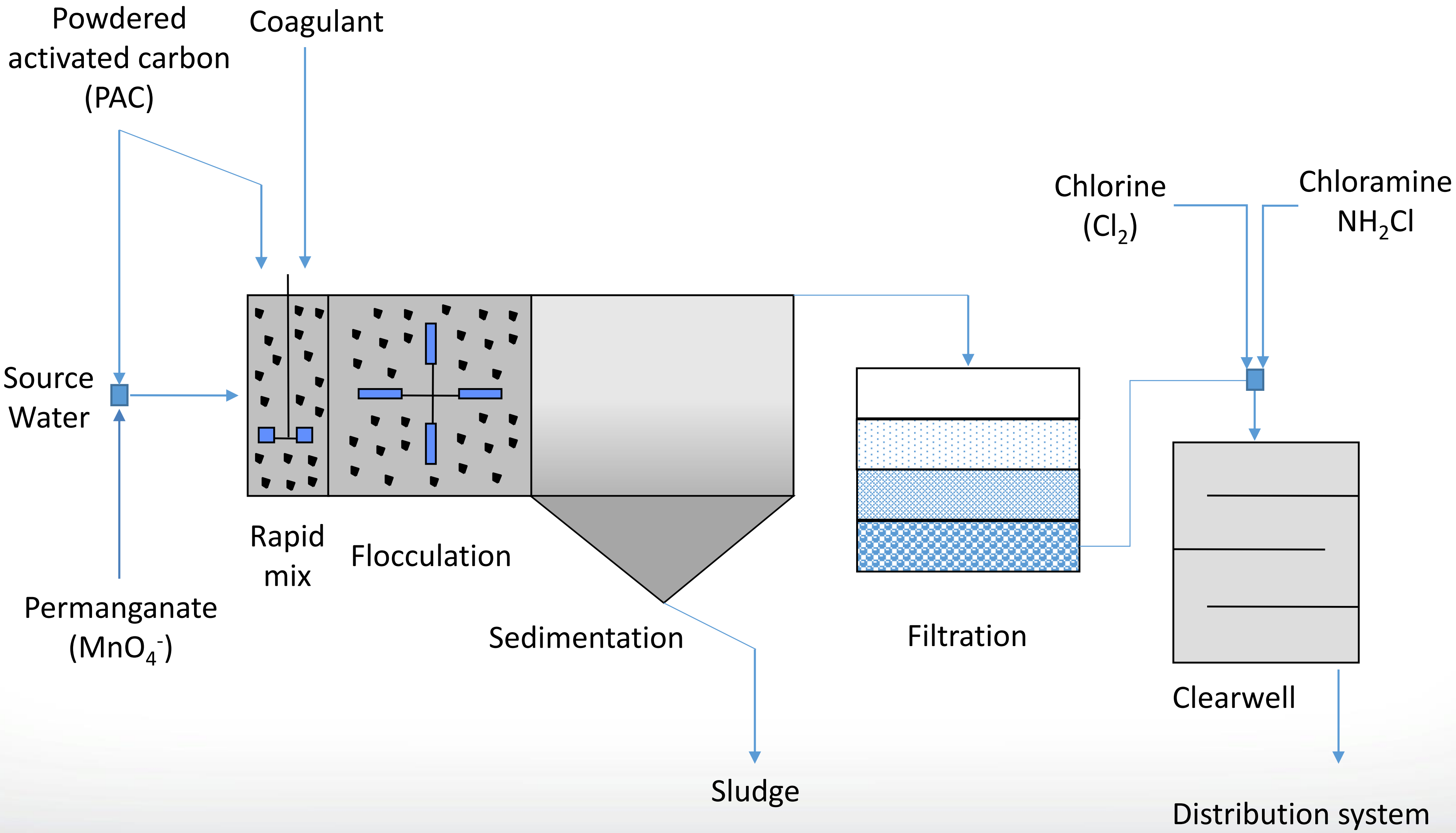
Dissolved (toxin released from cell)

- Solids removal processes ineffective
- Typical disinfectants may not be effective enough (e.g., permanganate, chlorine)
- More effective treatments are expensive and plants typically do not have them in place (e.g., GAC, Ozone)



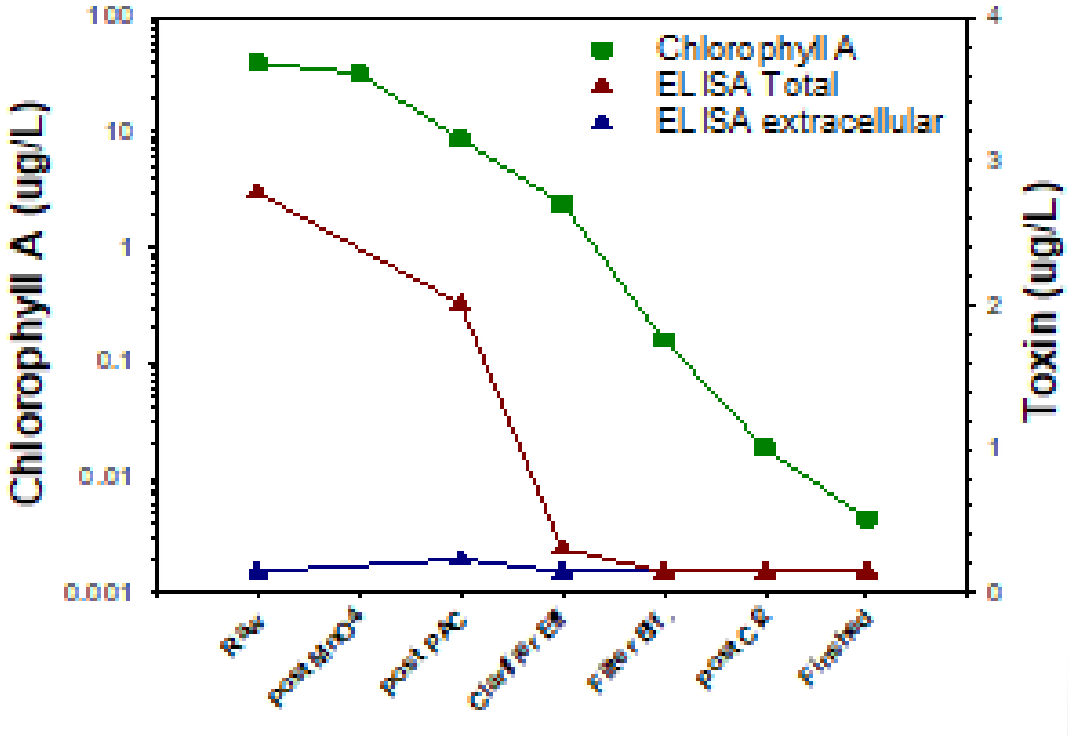
Microcystin Toxin

Typical Treatment Train



Through Treatment (microcystin toxin)

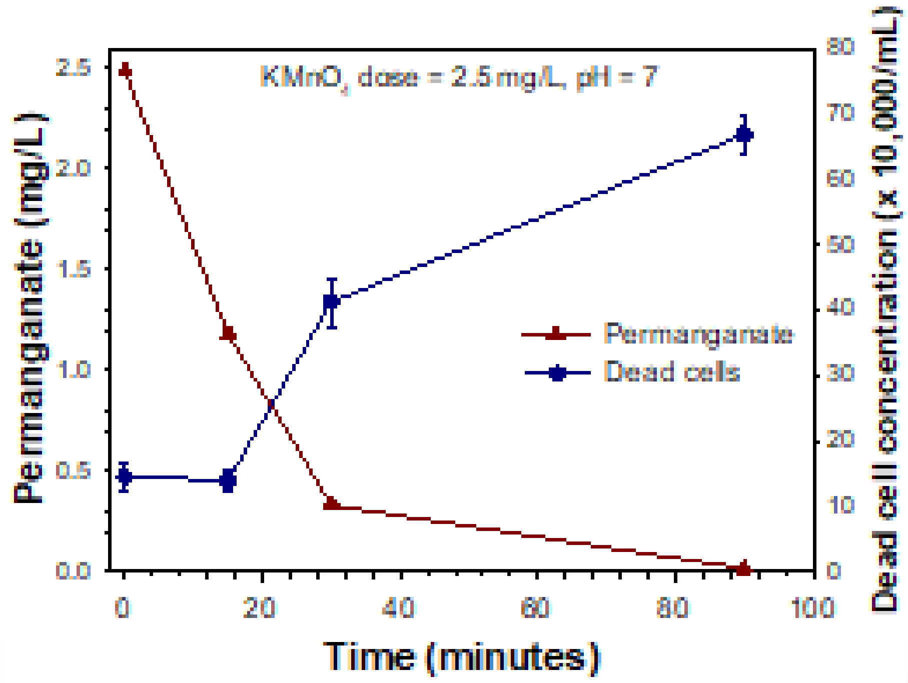
If toxin remains in the cell, most of it is removed before the filter

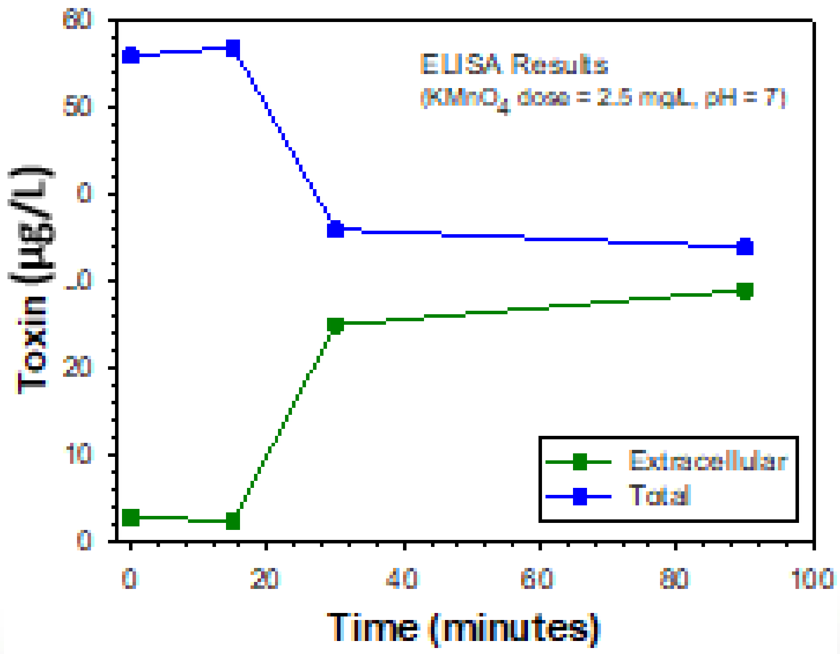


Effect of Permanganate

Inactivates cells

Releases toxins into solution while at the same time destroying them



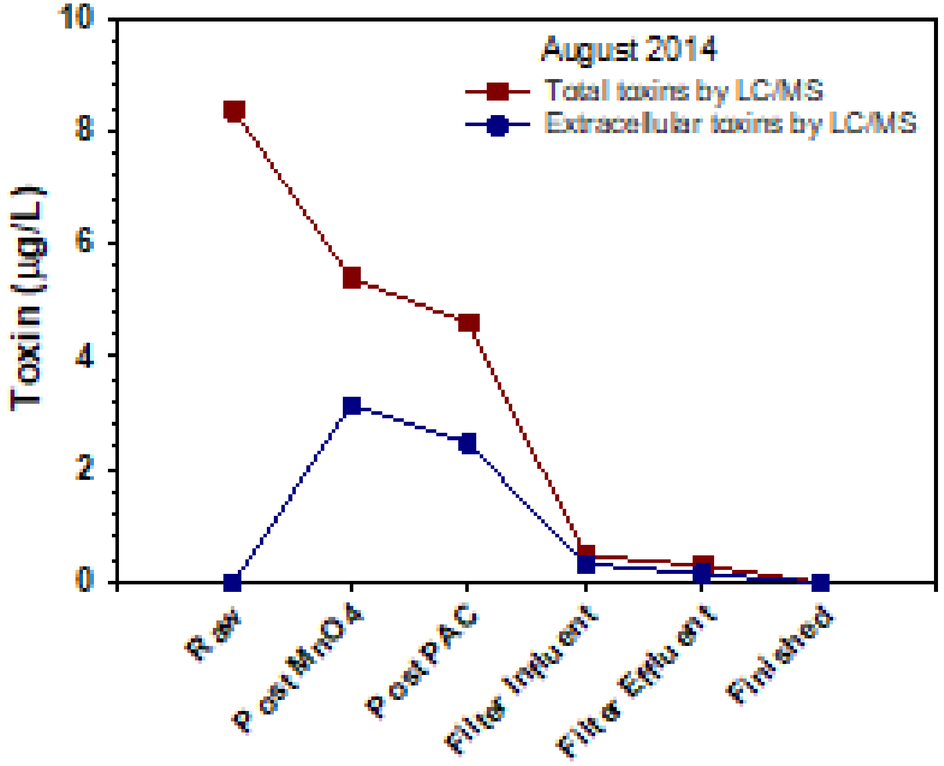


Through Treatment (Microcystin Toxin)

Permangate reducing total and increasing extracellular toxin

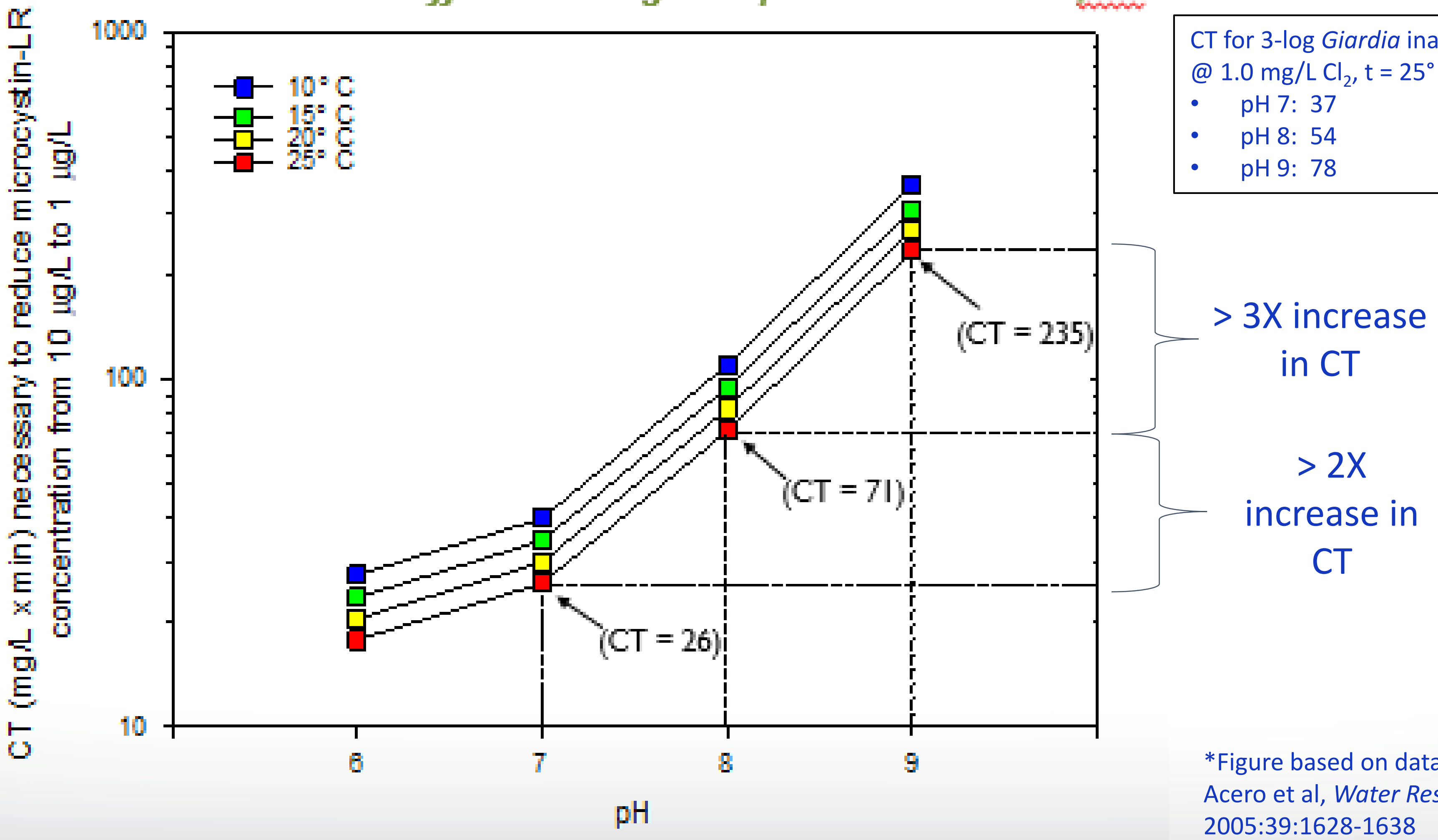
Powdered activated carbon reducing the extracellular toxin

Particulate removal removes the intracellular toxin



Impact of Chlorination

Chlorination most effective at high temperatures and low pHs



CT for 3-log *Giardia* inactivation @ 1.0 mg/L Cl_2, t = 25° C:

- pH 7: 37
- pH 8: 54
- pH 9: 78

*Figure based on data from Acero et al, *Water Research*, 2005:39:1628-1638

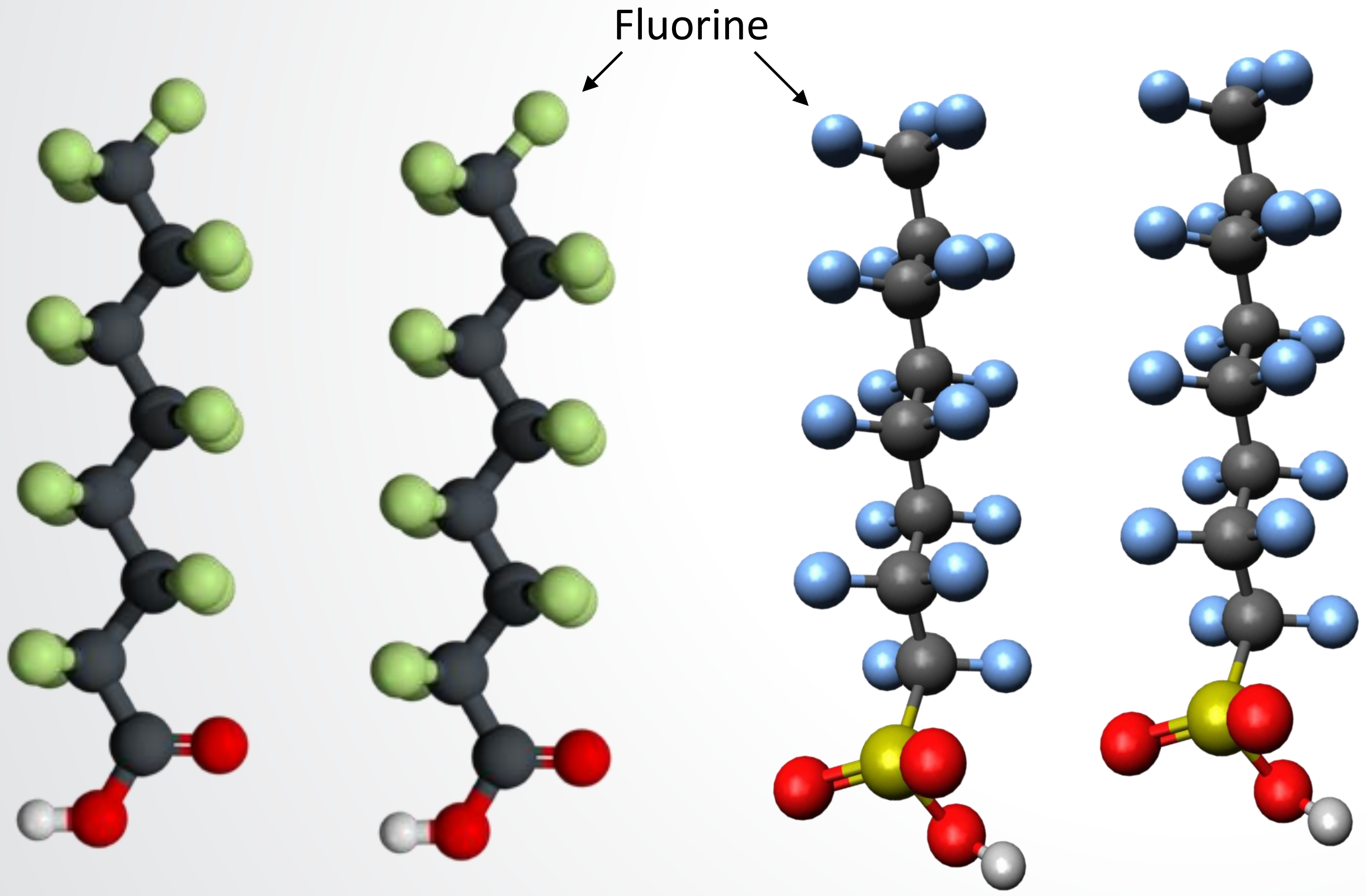
Treatment Issues

Powdered Activated Carbon (PAC)	Removes some harmful algal bloom (HAB) toxins better than others Carbon choice Choosing the correct dose quickly Reduced filter times and sludge disposal
Granular Activated Carbon (GAC)	Removes some HAB toxins better than others Removal depends on amount of preloading High capital cost Reactivation/removal frequency – cost and operation
UV (After treatment)	Needed UV doses are much higher than that required for 2-log disinfection of *Cryptosporidium* = 5.8 mJ/cm^2, *Giardia* = 5.2 mJ/cm^2, viruses = 100 mJ/cm^2.

Treatment Issues

Permanganate	Applied early in the treatment process where concentrations of cyanobacterial cells in are still high – potential to stimulate toxin release
Chlorine	Degradation rate increases significantly with lower pH – need to balance corrosion compliance
Ozone	High capital cost If applied fairly early in treatment - potential for toxin release
Chlorine Dioxide	Not considered effective against microcystins

Per- and Polyfluoroalkyl Substances (PFAS)



Perfluorooctanoic acid (PFOA)

Perfluorooctanesulfonic acid (PFOS)

- **A class of chemicals**
  - Chains of carbon (C) atoms surrounded by fluorine (F) atoms
    - Water-repellent (hydrophobic body)
    - Stable C-F bond
  - Some PFAS include oxygen, hydrogen, sulfur and/or nitrogen atoms, creating a polar end

Thousands of Chemicals: More Than Just PFOA and PFOS

- **PFAS**
  - **Non-polymers**
    - **Perfluoroalkyl acids (PFAAs)** $C_nF_{2n+1}R$
      - Perfluoroalkyl carboxylic acids (PFCAs)
      - Perfluoroalkane sulfonic acids (PFSAs)
      - Perfluoroalkyl phosphonic acids (PFPAs)
      - Perfluoroalkyl phosphinic acids (PFPIAs)
    - **Perfluoroalkane sulfonyl fluoride (PASF)** $C_nF_{2n+1}SO_2F$ → **PASF-based derivatives** $C_nF_{2n+1}SO_2$-R, R = NH, $NHCH_2CH_2OH$, etc.
    - **Perfluoroalkyl iodides (PFAIs)** $C_nF_{2n+1}I$ → **Fluorotelomer iodides (FTIs)** $C_nF_{2n+1}CH_2CH_2I$ → **FT-based derivatives** $C_nF_{2n+1}CH_2CH_2$-R, R = NH, $NHCH_2CH_2OH$, etc.
    - **Per- and polyfluoroalkyl ethers (PFPEs)-based derivatives**
      - Polyfluoroalkyl ether carboxylic acids
  - **Polymers**
    - **Fluoropolymers**
      - Polytetrafluoroethylene (PTFE)
      - Polyvinylidene fluoride (PVDF)
      - Fluorinated ethylene propylene (FEP)
      - Perfluoroalkoxyl polymer (PFA)
      - Others
    - **Side-chain fluorinated polymers**
      - Fluorinated (meth)acrylate polymers
      - Fluorinated urethane polymers
      - Fluorinated oxetane polymers
    - **Perfluoropolyethers**

Overview: EPA Drinking Water Research

- **Problem**: Utilities lack treatment technology cost data for PFAS removal
- **Action**:
  - Gather performance and cost data from available sources (DOD, utilities, industry, etc.)
  - Conduct EPA research on performance of treatment technologies including home treatment systems
  - Update EPA's Treatability Database and Unit Cost Models
  - Connect EPA's Treatability Database to EPA's Unit Cost Models for ease of operation
  - Model performance and cost, and then extrapolate to other scenarios
    - Variable source waters
    - Variable PFAS concentrations in source water
    - Different reactivation/disposal options
    - Document secondary benefits
    - Address treatment impact on corrosion
  - Evaluate reactivation of granular activated carbon
- **Impact**: Enable utilities to make informed decisions about cost-effective treatment strategies for removing PFAS from drinking water

Drinking Water Treatment for PFOS

Ineffective Treatments

Conventional Treatment
Low Pressure Membranes
Biological Treatment (including slow sand filtration)
Disinfection
Oxidation
Advanced oxidation

PAC Dose to Achieve

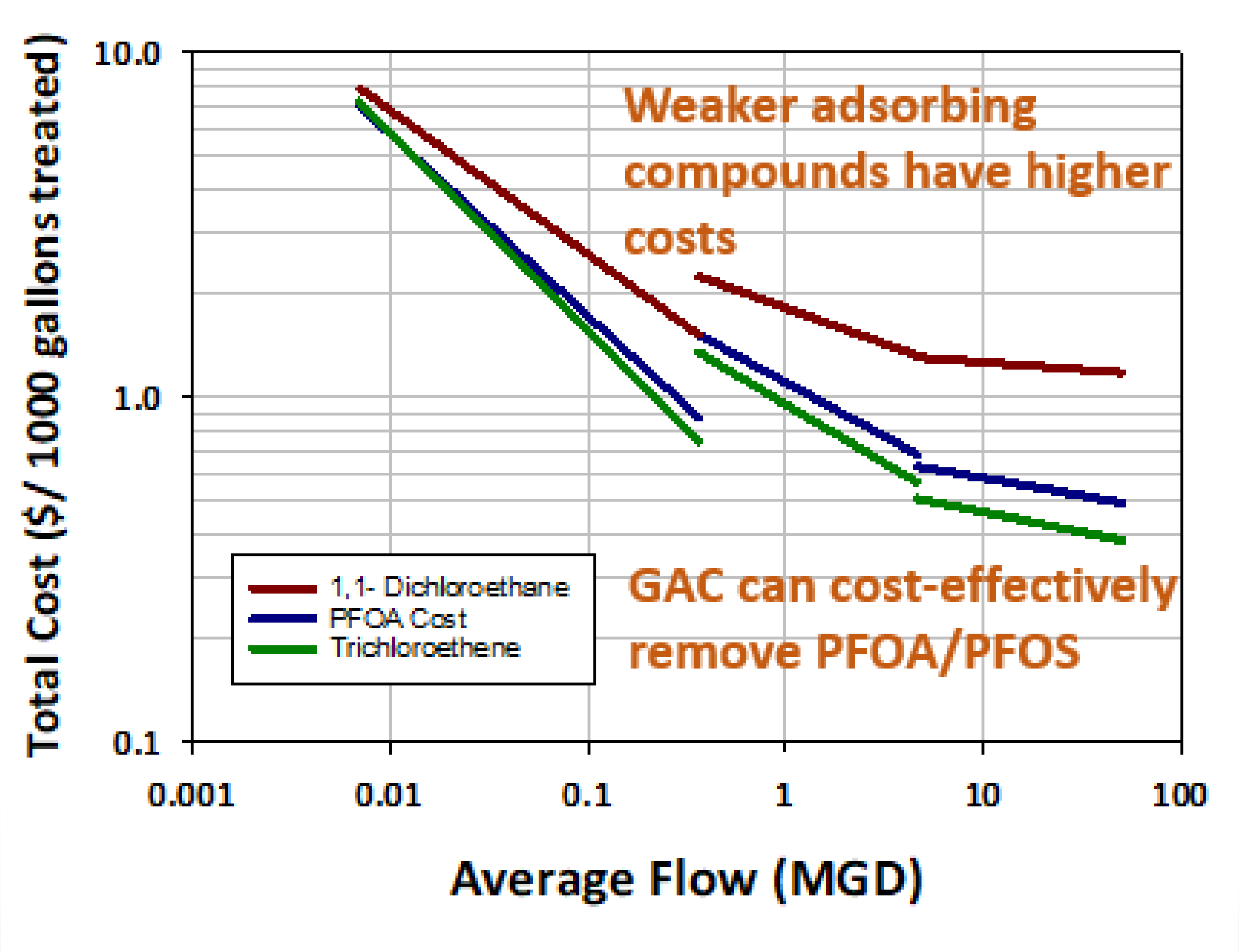
50% Removal	16 mg/l
90% Removal	>50 mg/L

Dudley et al., 2015

Effective Treatments

Effective Treatments	Percent Removal	
Anion Exchange Resin (IEX)	90 to 99	- Effective
High Pressure Membranes	93 to 99	- Effective
Powdered Activated Carbon (PAC)	10 to 97	- Effective for only select applications
Granular Activated Carbon (GAC)		
Extended Run Time	0 to 26	- Ineffective
Designed for PFAS Removal	> 89 to > 98	- Effective

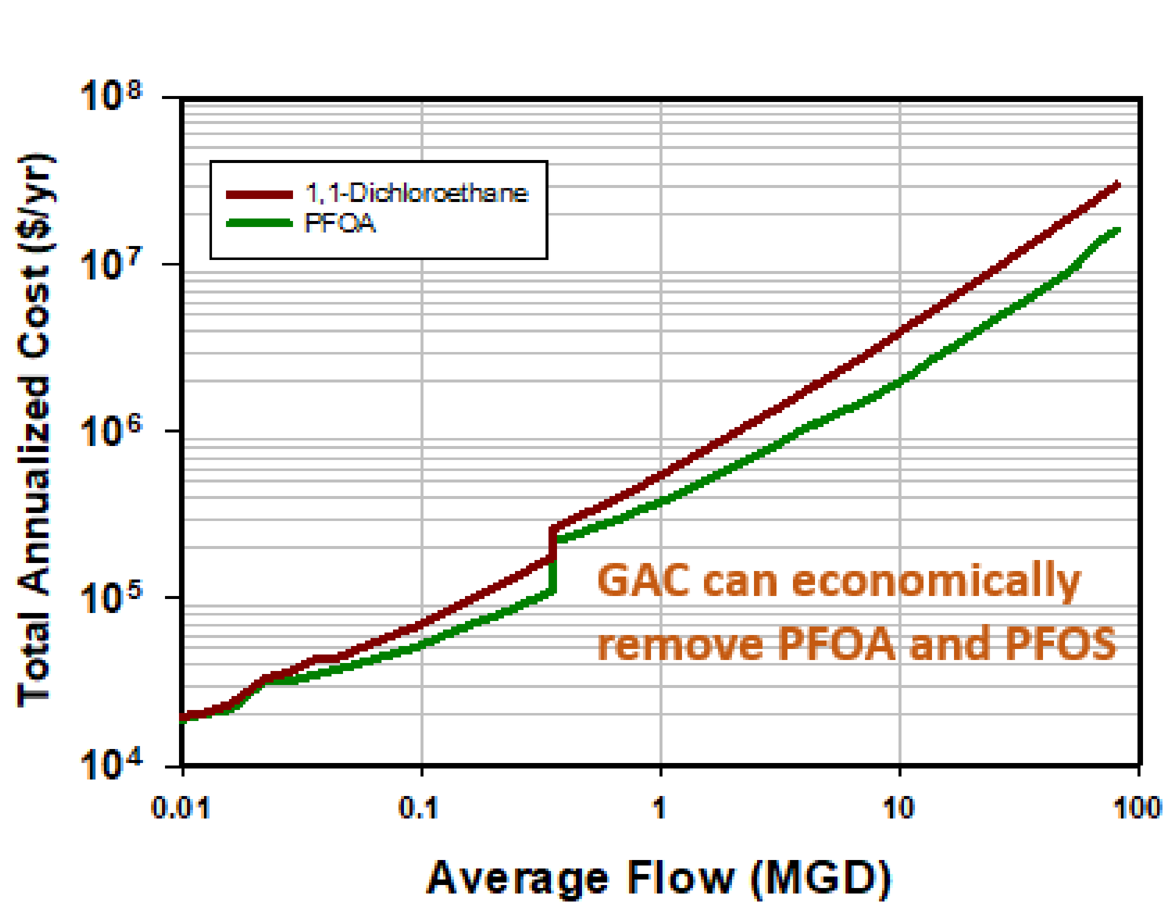
GAC Treatment Cost: PFOA, TCE, 11 DCA



EPA will be evaluating additional water qualities and designs

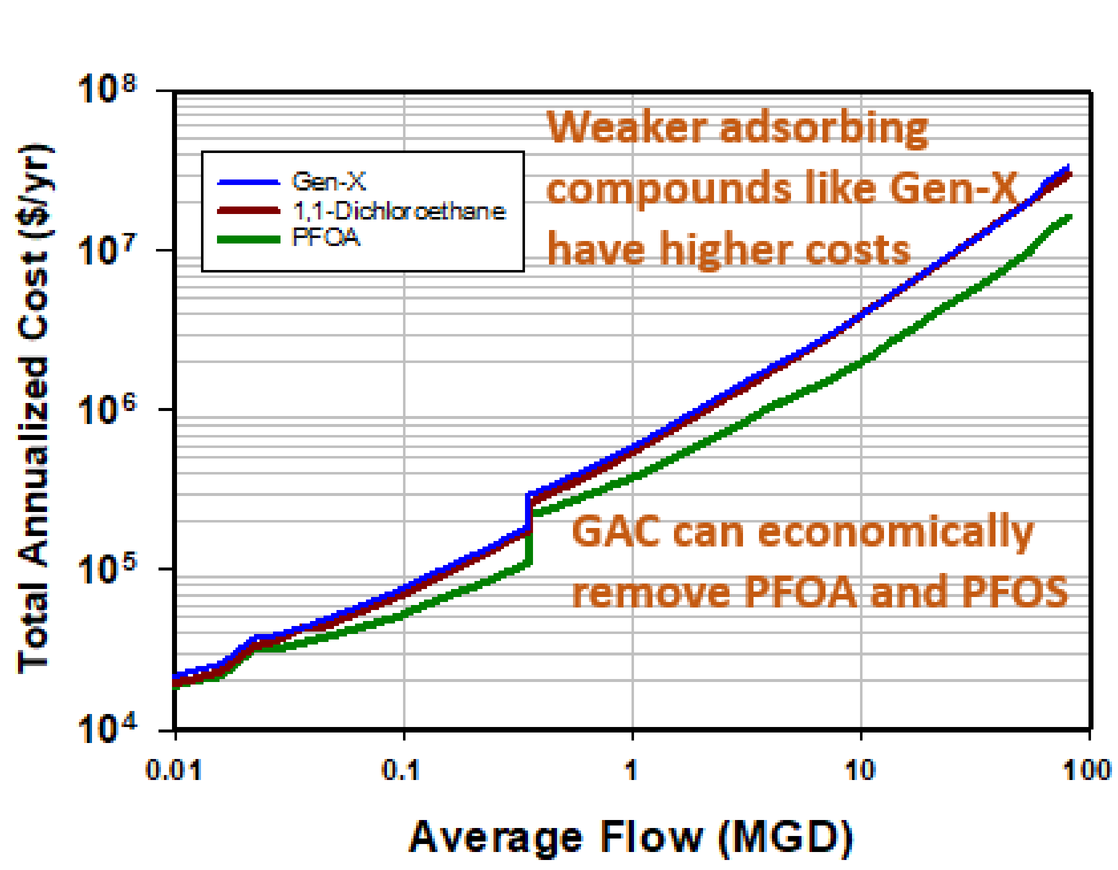
- Full Scale
- 26 min EBCT
- Lead-Lag configuration
- F600 Calgon carbon
- 1.5 m^3/min flow
- Full automation
- POTW residual discharge
- Off site regeneration
- 135,000, 70,000, and 11,000 bed volumes to breakthrough for trichloroethylene (TCE), PFOA, and 11DCA, respectively.

Costs for Additional PFAS



- Pilot Scale Performance Data
- 20 min EBCT
- F400 Calgon carbon
- Full automation
- POTW residual discharge
- Off site regeneration
- 31,000, 7,100, and 5,560 bed volumes to breakthrough for PFOA, Gen-X, and 11-DCA, respectively.

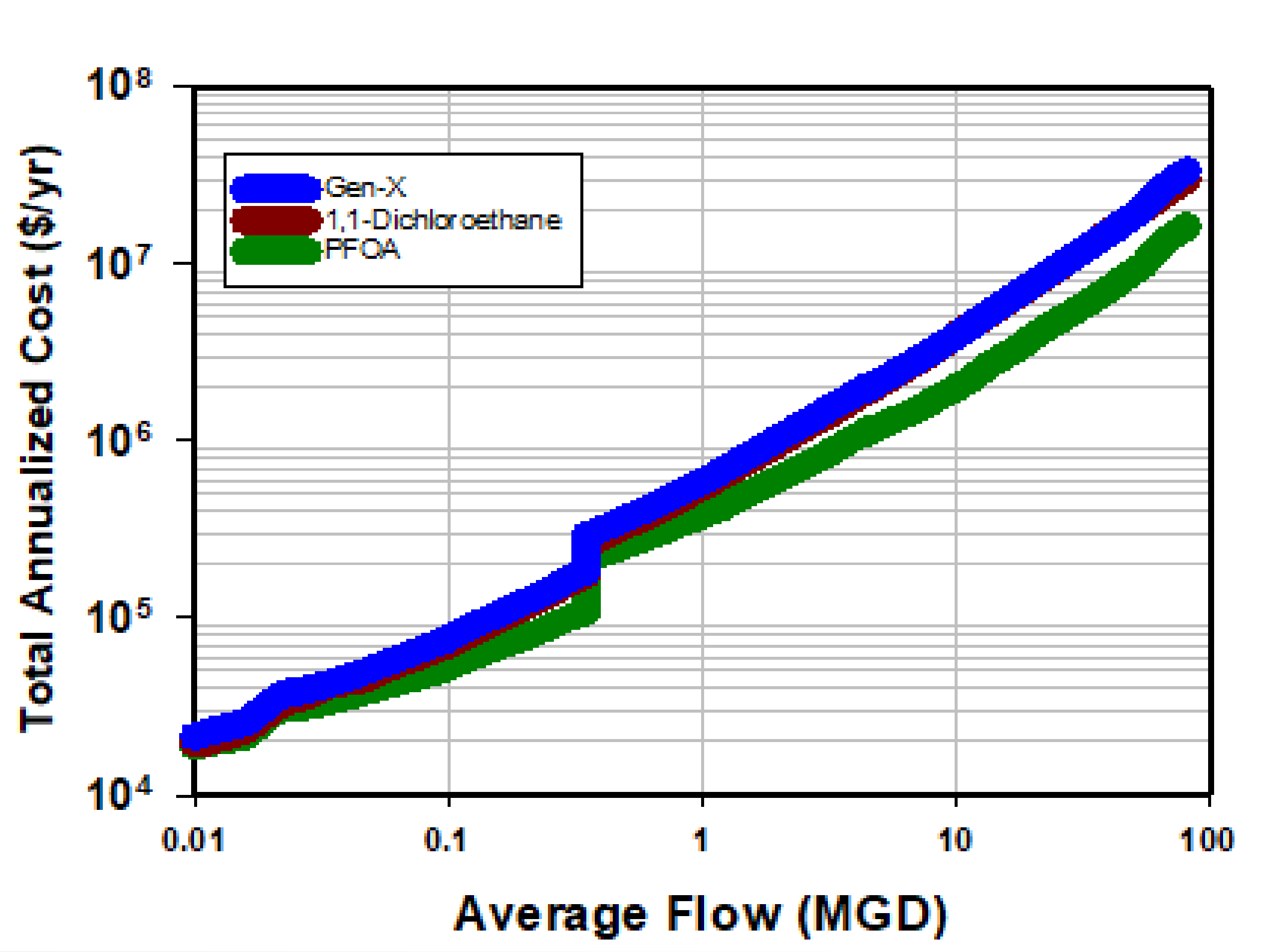
Cost for Additional PFAS



- Pilot Scale Performance Data
- 20 min EBCT
- F400 Calgon carbon
- Full automation
- POTW residual discharge
- Off site regeneration
- 31,000, 7,100, and 5,560 bed volumes to breakthrough for PFOA, Gen-X, and 11-DCA, respectively.

Cost for Additional PFAS

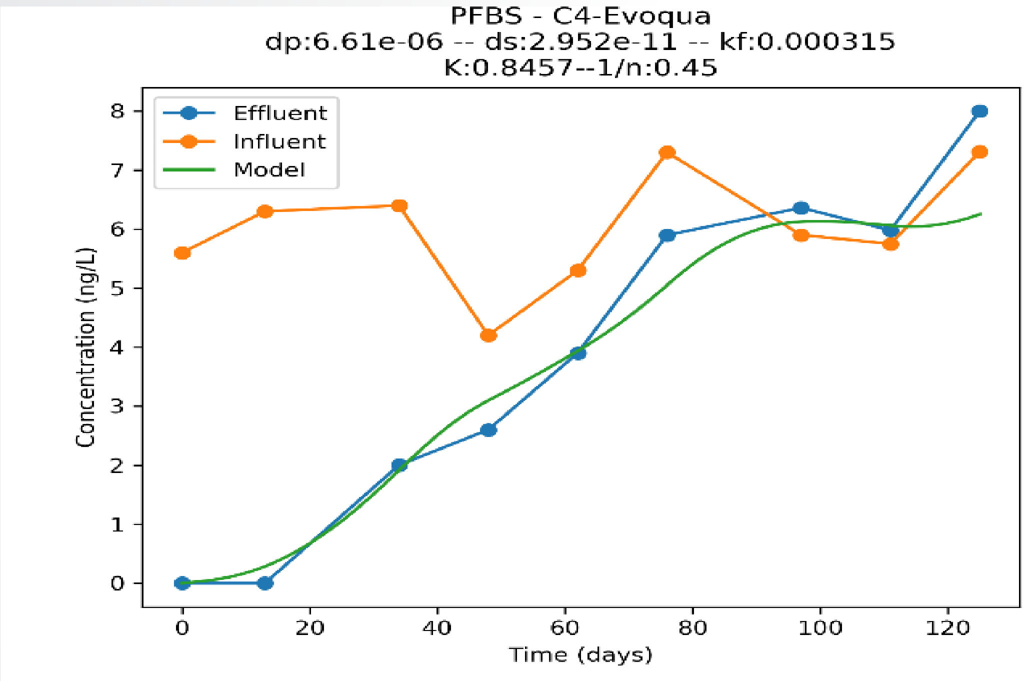
Compounds will have a range of costs depending on water quality and other factors that impact design and operation



- Pilot Scale Performance Data
- 20 min EBCT
- F400 Calgon carbon
- Full automation
- POTW residual discharge
- Off site regeneration
- 31,000, 7,100, and 5,560 bed volumes to breakthrough for PFOA, Gen-X, and 11-DCA, respectively.

Modeling to Consistent Design Parameters

- Fitting pilot- or full-scale data



- Predicting Results for Consistent Design
  - Allows for comparison across technologies by cost
- Allows for Predicting other Scenarios
  - Other designs: Number of contactors, contactor EBCTs, different treatment goals, etc.
  - Other influent conditions: Changing concentrations of PFAS or background constituents, changing demand, etc.

Advantages of Select Treatments

Granular Activated Carbon (GAC)	**Most studied technology** **Will remove 100% of the contaminants, for a time** **Good capacity for some PFAS** Will remove a significant number of disinfection byproduct precursors Will help with maintaining disinfectant residuals Will remove many co-contaminants Likely positive impact on corrosion (lead, copper, iron)
Anion Exchange Resin (PFAS selective)	**Will remove 100% of the contaminants, for a time** **High capacity for some PFAS** **Smaller beds compared to GAC** Can remove select co-contaminants
High Pressure Membranes (Reverse Osmosis or Nanofiltration)	**High PFAS rejection** Will remove many co-contaminants Will remove a significant number of disinfection byproduct precursors Will help with maintaining disinfectant residuals

Issues to Consider

EPA is evaluating these issues to document where and when they will be an issue

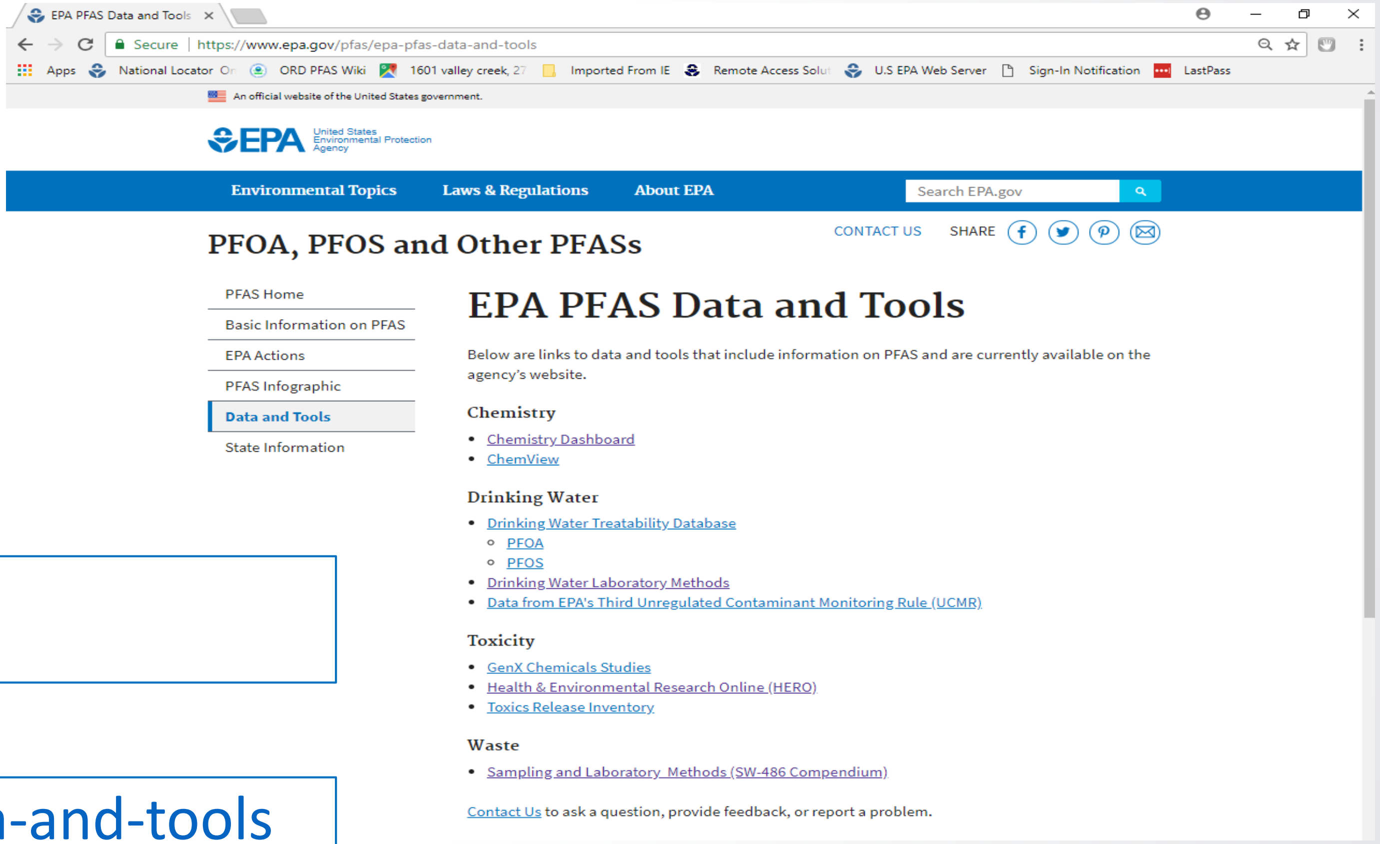
Granular Activated Carbon (GAC)	**GAC run time for short-chained PFAS (shorter run times)** **Potential overshoot of poor adsorbing PFAS, if not designed correctly** **Reactivation/removal frequency** Disposal or reactivation of spent carbon
Anion Exchange Resin (PFAS selective)	**Run time for select PFAS (shorter run times)** **Overshoot of poor adsorbing PFAS, if not designed correctly** Unclear secondary benefits Disposal of resin
High Pressure Membranes (Reverse osmosis or Nanofiltration)	**Capital and operations costs** Membrane fouling Corrosion control Lack of options for concentrate stream treatment or disposal

EPA PFAS Data and Tools

- Links to data and tools that include information related to PFAS and are available on EPA's website:

https://www.epa.gov/pfas

https://www.epa.gov/pfas/epa-pfas-data-and-tools



Drinking Water Goals

For utilities that have a CEC in their source water at concentrations of health concern

1) Eliminate source of the CECs to the source water
2) Either choose a new source of water or choose a **technology, design, and operational scheme** that will reduce the CECs to safe levels at the lowest possible cost in a **robust, reliable, and sustainable manner** that avoids unintended consequences

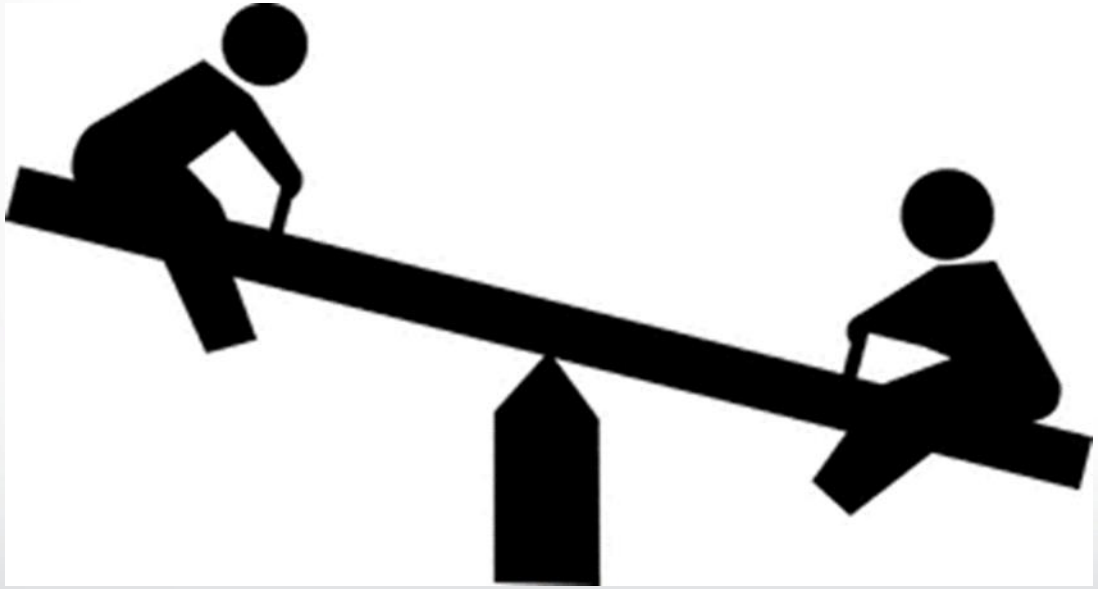
Issues to address (not inclusive)

1) Capital and operating costs are affordable
2) Staff can handle operational scheme over the long term
3) Technology can operate long term under a reasonable maintenance program
4) Technology and treatment train can handle source water quality changes
5) Any waste stream generated can be treated or disposed in a sustainable and cost-effective manner over the long term

Avoiding Unintended Consequences

Choice of technology, design, and operations can lead to…

1) Negative impacts on the performance of the rest of the **treatment system** for other parameters (e.g., decreased control of particulates/pathogens, taste & odor compounds, other source water contaminants)
2) Negative impacts on the **distribution system** (e.g., increased lead, copper, or iron corrosion; disinfection residual maintenance difficulties)

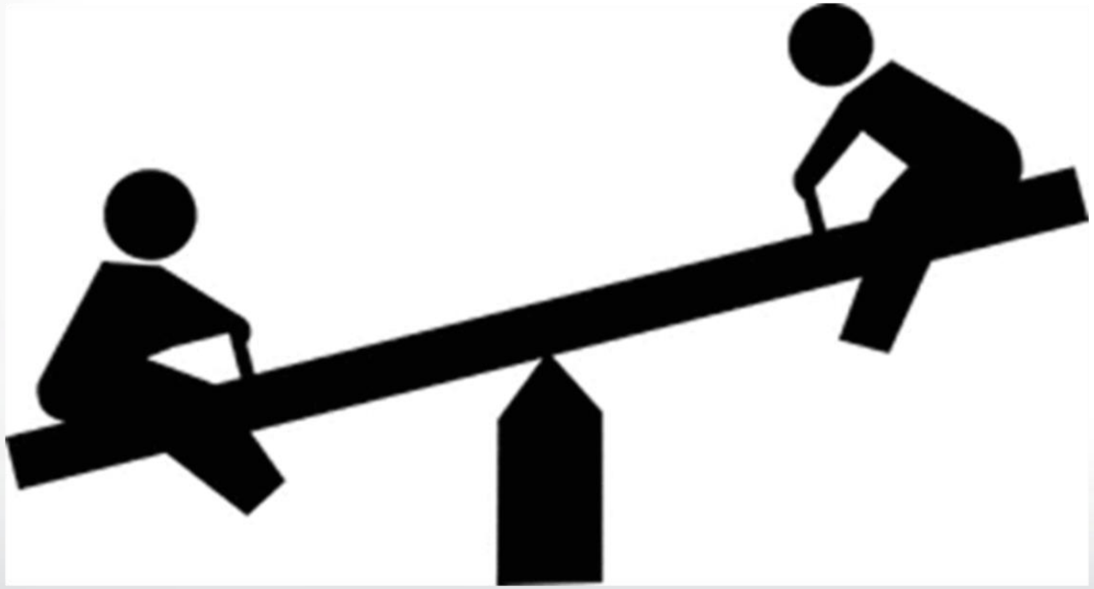


EPA is conducting research on optimizing CEC treatment

To Achieve other Positive Benefits

Choice of technology, design, and operation can have…

1) **Positive impacts** on the performance of the rest of the **treatment system** for other parameters (e.g., improved control of particulates/pathogens, taste & odor compounds, industrial contaminants, pesticides, pharmaceuticals, personal care products, endocrine disruptors)
2) **Positive impacts** on the **distribution system** (e.g., decreased lead, copper, or iron corrosion; better disinfection residual maintenance; fewer disinfection byproducts)



Improved Treatment

Improved Disinfection

Decreased Corrosion

EPA is a resource for communities, states and regions

Contact

Tom Speth, Ph.D., P.E.
Acting Associate Director for Science
National Risk Management Research Laboratory
US EPA Office of Research and Development
(513) 569-7208
Speth.Thomas@epa.gov

Acknowledgements
EPA: Rajiv Khera, Nicholas Dugan, Jonathan Burkhardt, Craig Patterson
ABT Associates: Pat Ransom