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Treating Contaminants of Emerging Concern

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Disclaimer

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Overview

1) **Nitrate / Perchlorate**
    1) Anion exchange
    2) 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

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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)

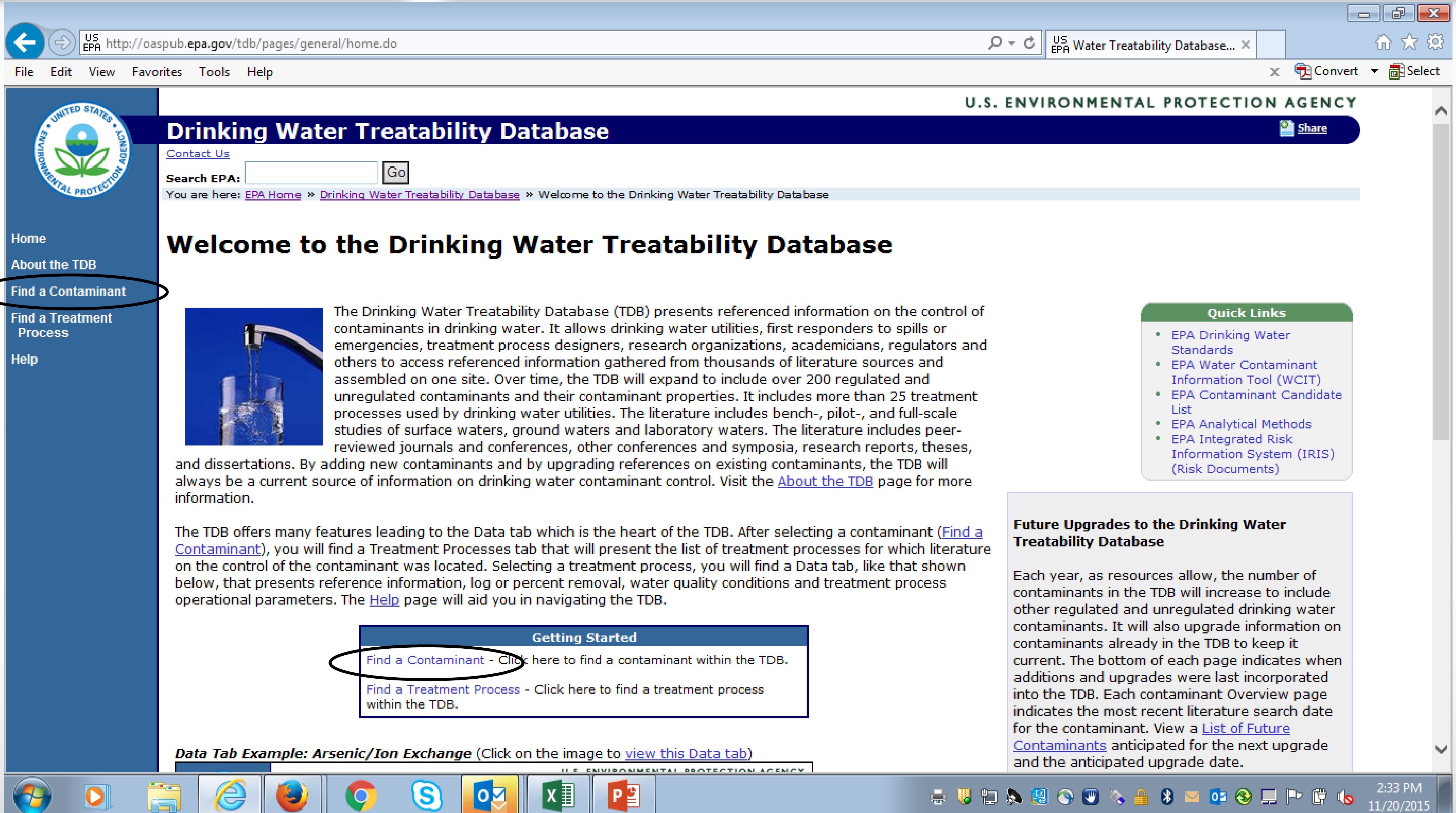
Currently available:

- **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



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#**
- 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

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Nitrate and Perchlorate

Why Nitrate and Perchlorate?

- A number of utilities exceed the nitrate MCL, particularly small system
- Both are fully oxidized – oxidation processes including aerobic biotreatment will not work
- New state regulations and federal regulation consideration for perchlorate
- The treatment processes that will work are pretty much the same
  - Anion exchange resin
  - Reverse osmosis / nanofiltration membranes
  - Anaerobic biological treatment (novel technology)

Anion Exchange Design Considerations

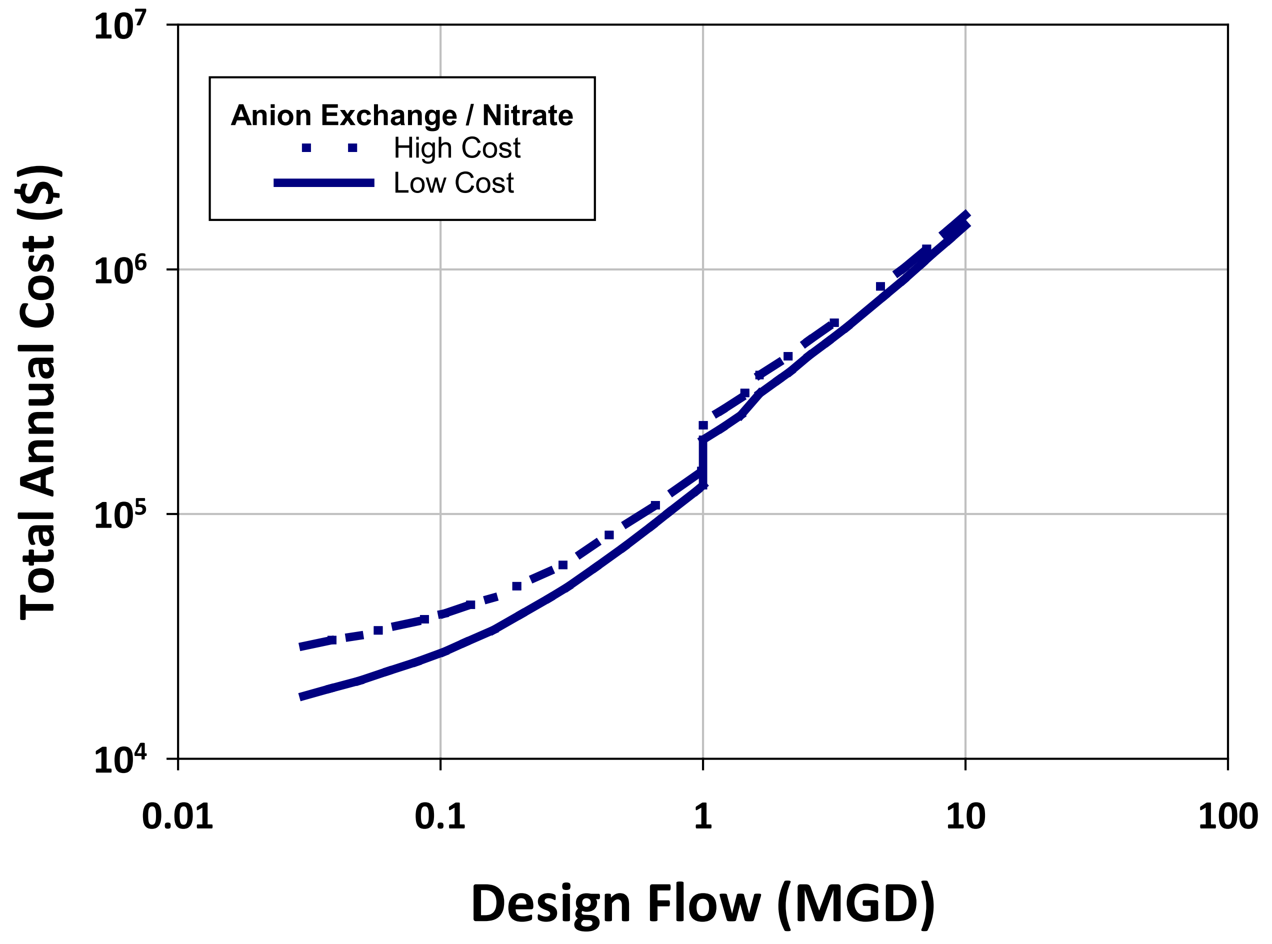
Given for All Technologies

- Design and average flow
- Contaminant (Nitrate)
- Influent Concentration (20.3 mg N/L)
- *AEX Specific*
- Resin type (performance and cost) (Nitrate selective)
- EBCT (2 min) / Superficial velocity / Bed depth / Column diameter
- Vessels in series / parallel (2)
- Bed volumes before regeneration/replacement ***

General Other

- Brine delivery method
- Residual management options (POTW)
- Redundant vessels
- Number of booster pumps
- Backwash pump design and backwash storage
- Corrosion control

Annual Cost: Anion Exchange / Nitrate



Primary Assumptions

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

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

POU Design Considerations

Given for All Technologies

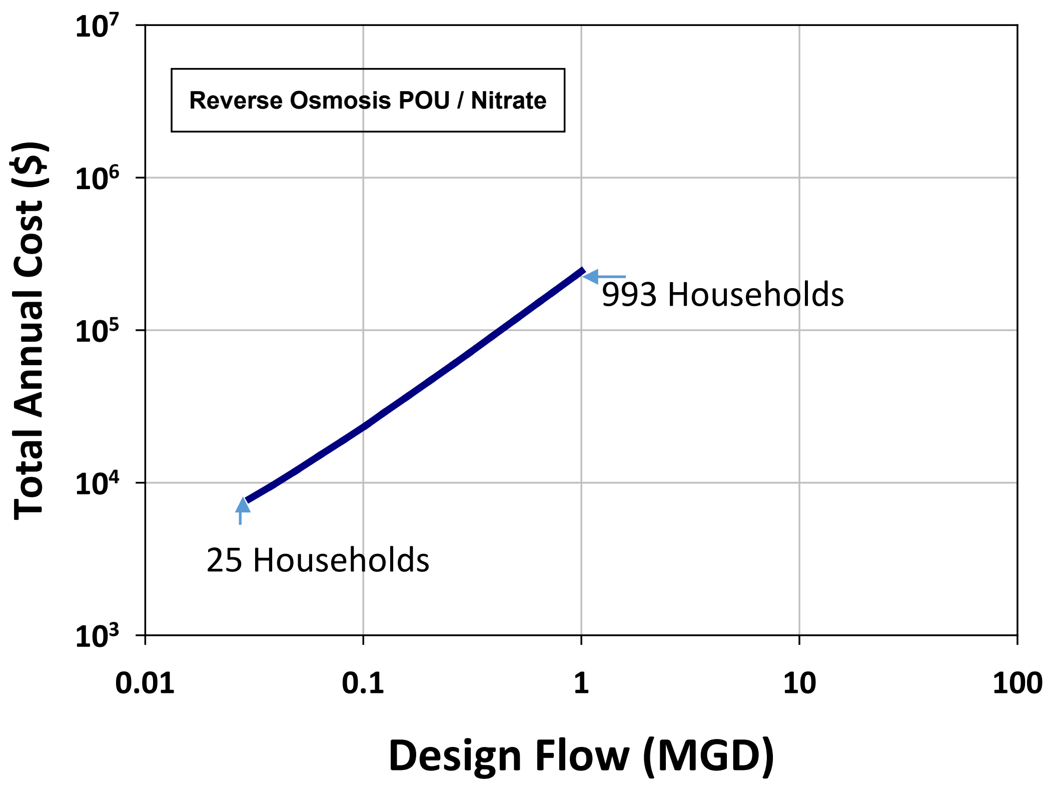
- Design and average flow
- Contaminant (Nitrate)
- Influent Concentration (20.3 mg N/L)

POU Specific

- Technology (RO)
- Replacement frequency (3 years, etc.)
- UV Post disinfection? (No)
- Groundwater versus surface water

Annual Cost: Point of Use - Nitrate

Only for 1 MGD design flow and below



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

Biotreatment Design Considerations

Given for All Technologies

- Design and average flow
- Contaminant (Nitrate)
- Influent Concentration (20.3 mg N/L)

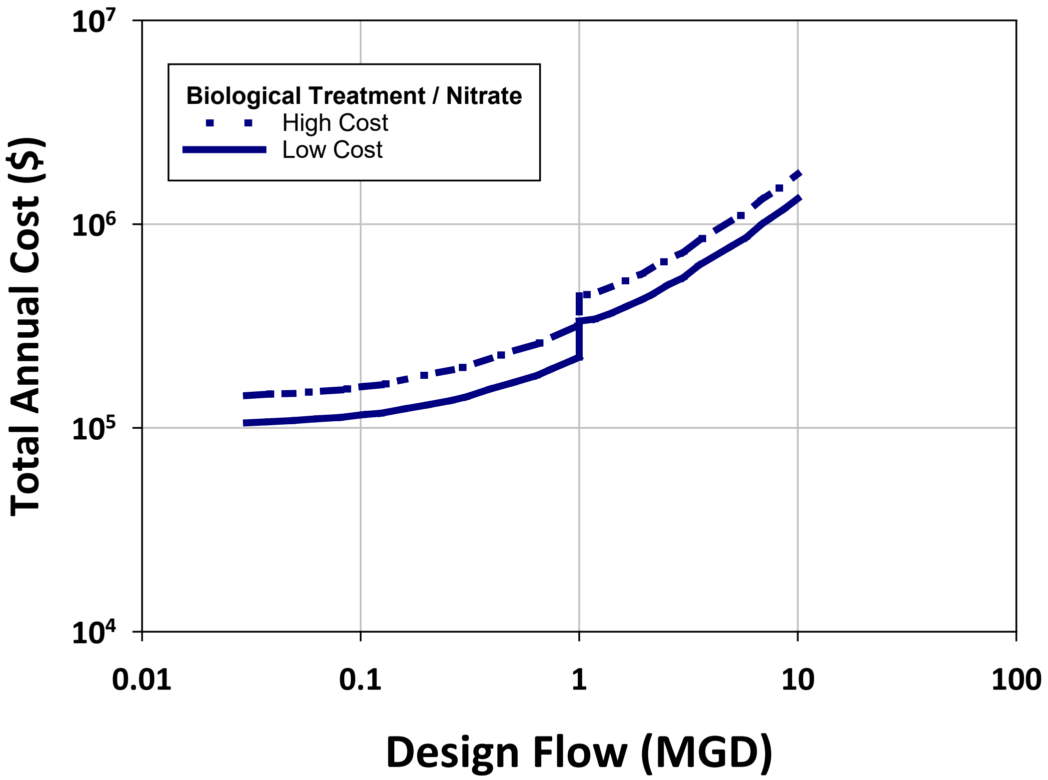
Biotreatment Specific

- Aerobic or Anaerobic (yes)
- Reactor type (fluidized bed (yes), fixed bed gravity or pressure)
- Nutrient and/or electron donor types and doses (phosphoric and acetic acids)
- EBCT (10 min) / Superficial velocity / Bed depth / Column diameter
- Post treatment (aeration and polishing filters)
- Biomass generation (is calculated, if unknown)

General Other

- Brine delivery method
- Residual management options (recycle)
- Number of booster pumps
- Backwash pump design, frequency, and backwash storage
- Corrosion control

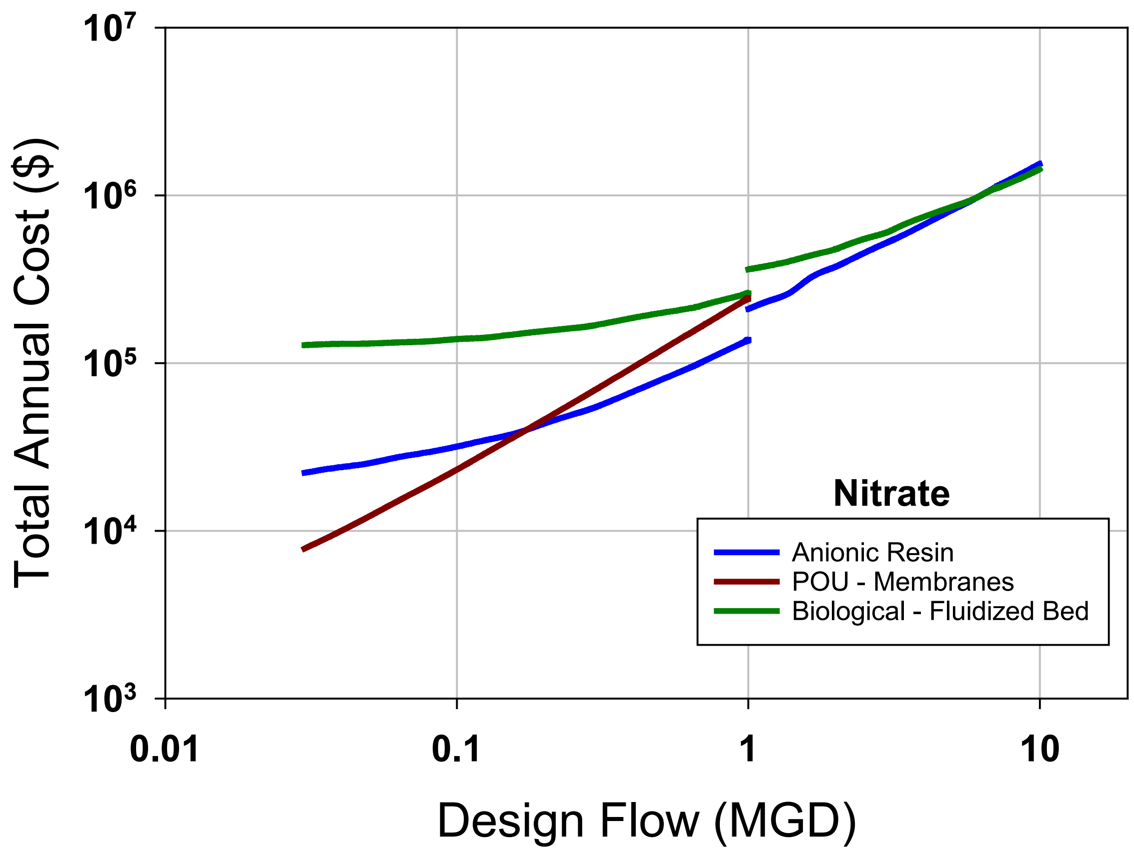
Annual Cost: Anaerobic Biological Treatment - Nitrate



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

Annual Cost: Nitrate

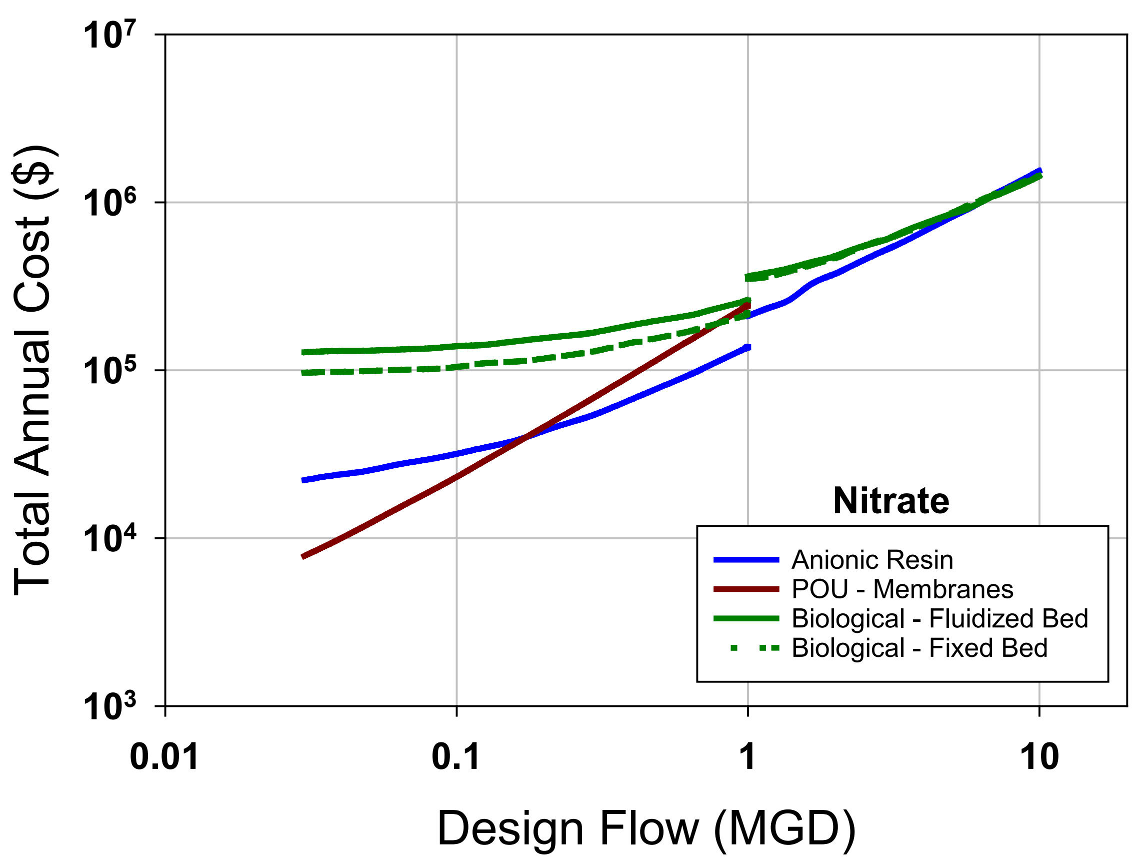


Conditions Same as Previous Slides:

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

Annual Cost: Nitrate

Includes both fluidized bed and fixed bed for anaerobic biological treatment

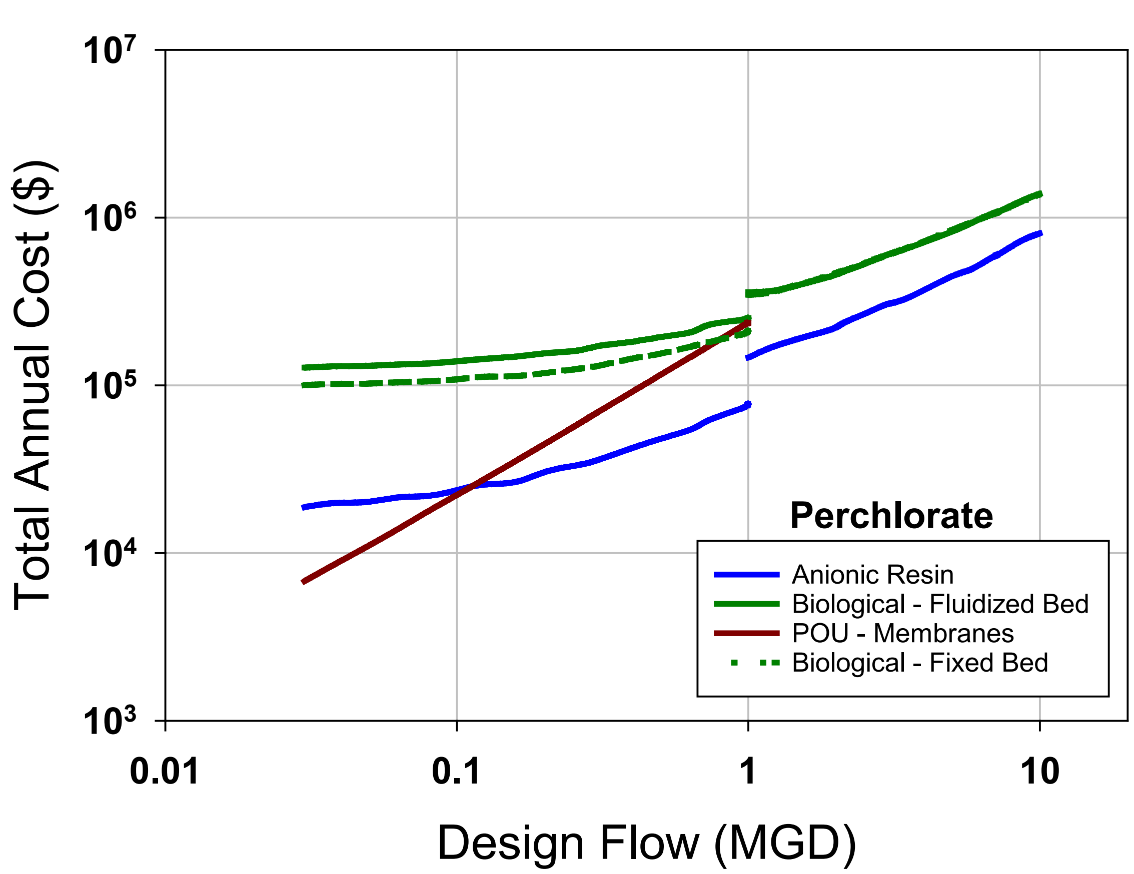


Conditions Same as Previous Slides:

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

Annual Cost: Perchlorate

Includes both fluidized bed and fixed bed for anaerobic biological treatment



Conditions Same as Previous Slides:

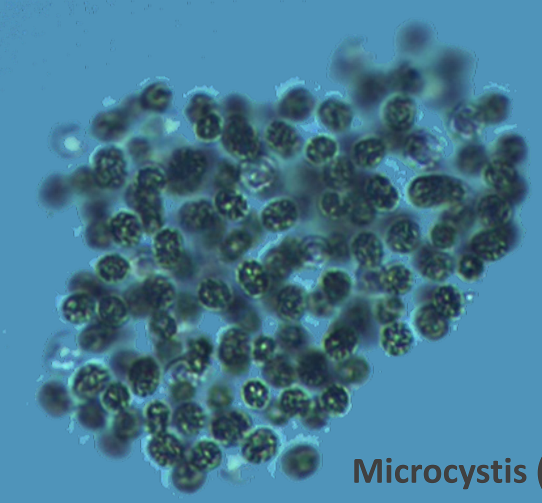
- Medium cost option
- Influent 24 ug/L
- Groundwater
- IEX: Perchlorate selective
- Biological: Fluidized & fixed bed
- POU: Reverse Osmosis

Treatment for Cyanobacteria Toxins

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

Particulates (toxin in cell)

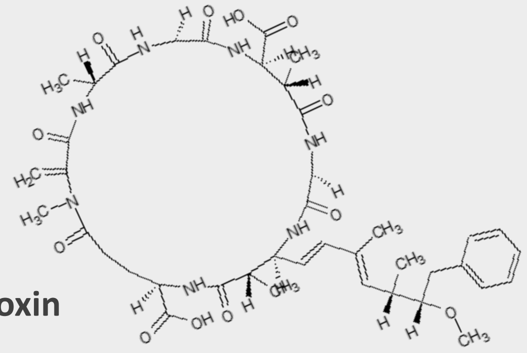
- Solids removal processes effective
- Do not want to lyse cell or toxin will be released



Microcystis (cells)

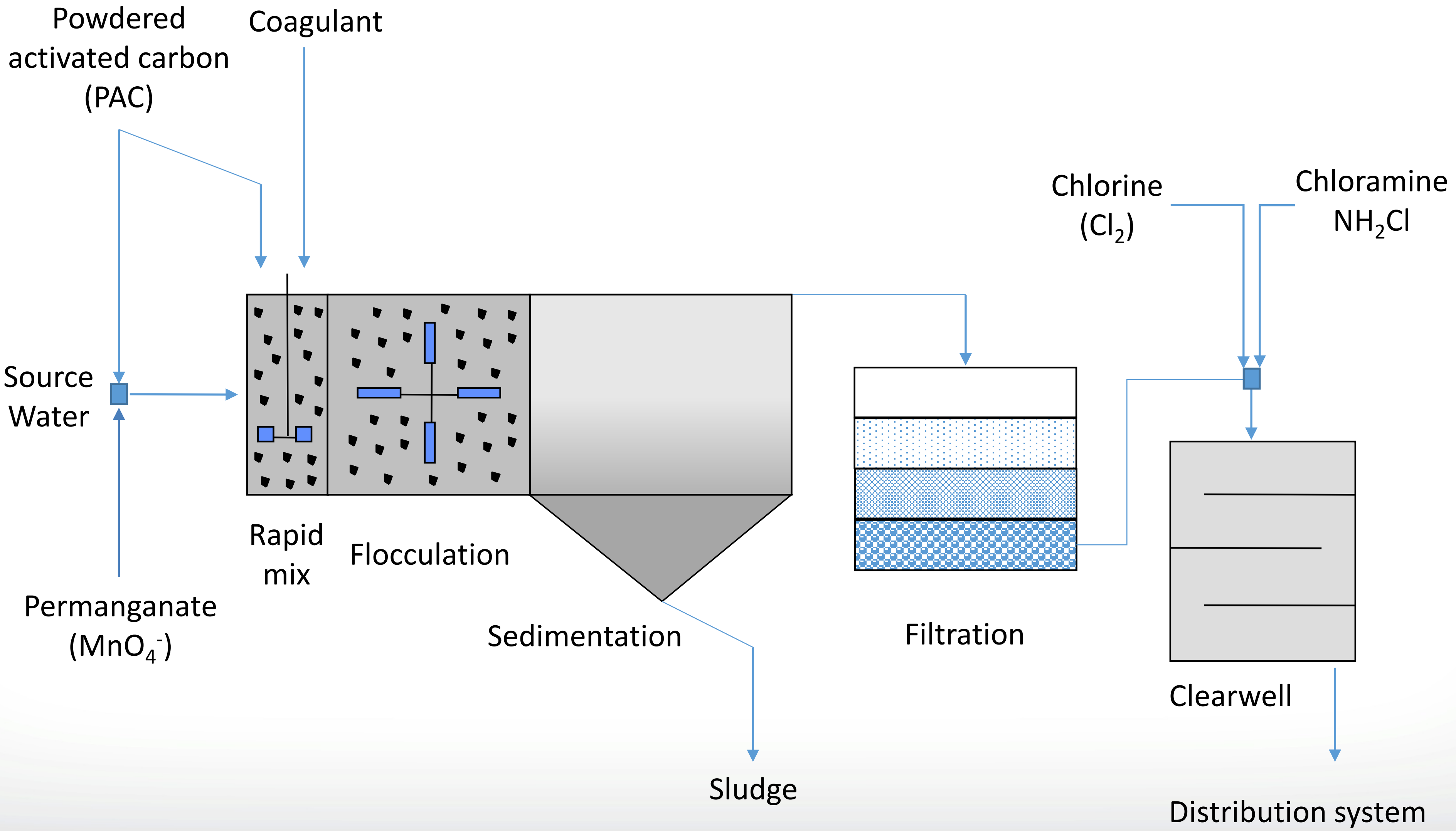
Dissolved (toxin released from cell)

- 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)



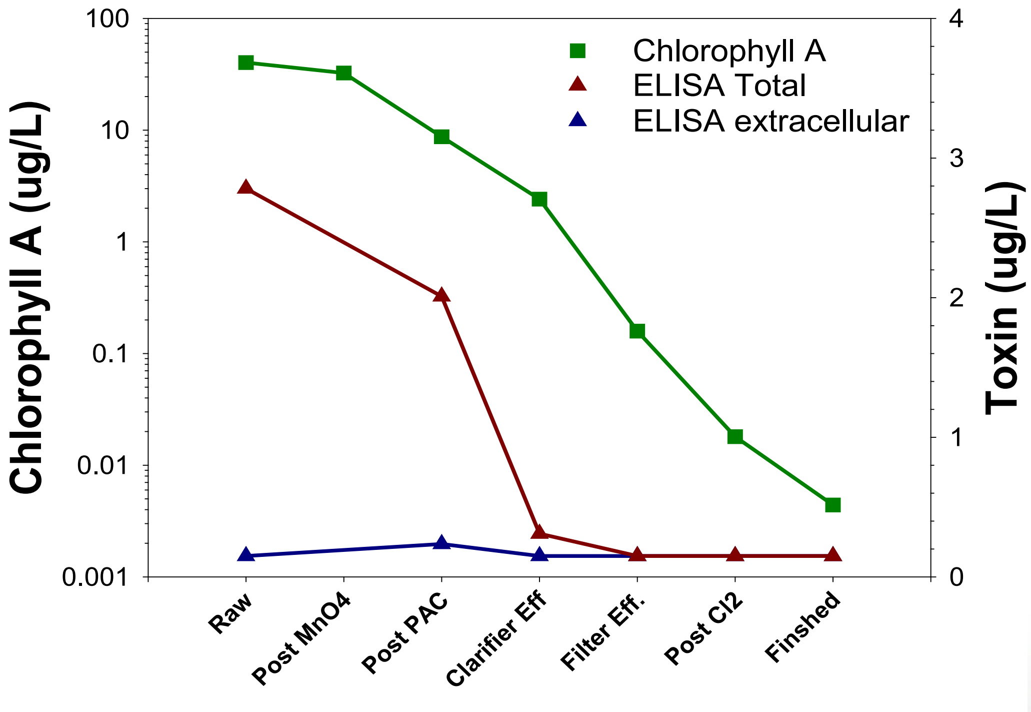
Microcystin Toxin

Typical Treatment Train



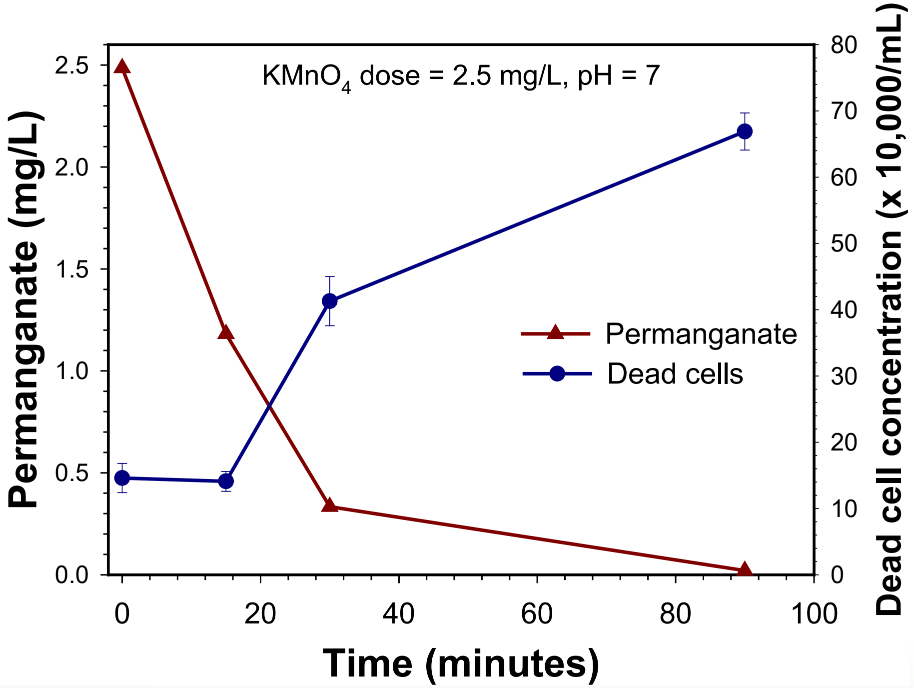
Through Treatment (microcystin toxin)

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

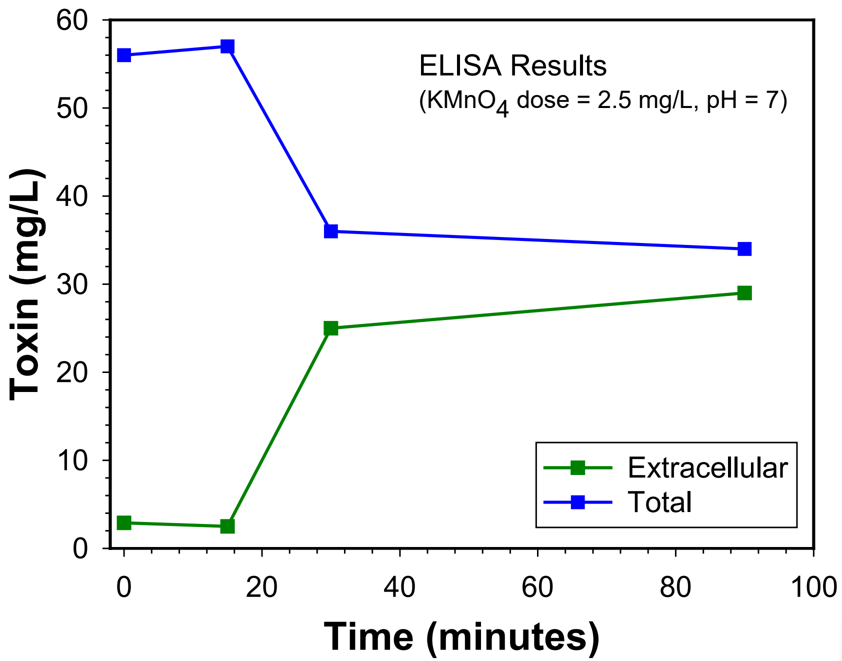


Effect of Permanganate

Inactivates cells



Releases toxins into solution while at the same time destroying them

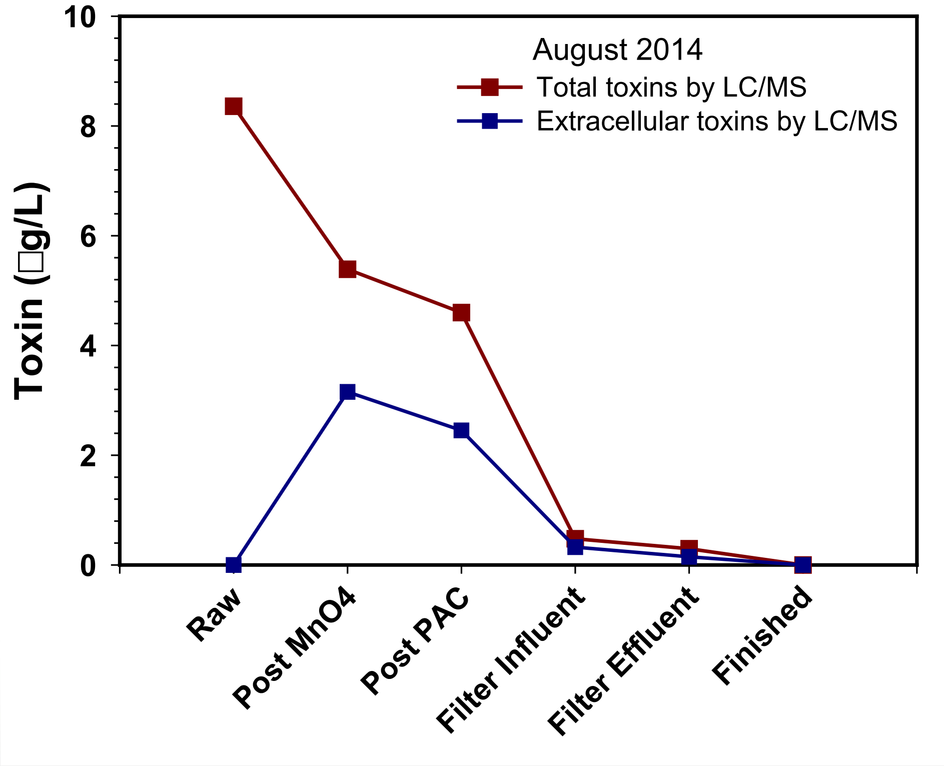


Through Treatment (microcystin toxin)

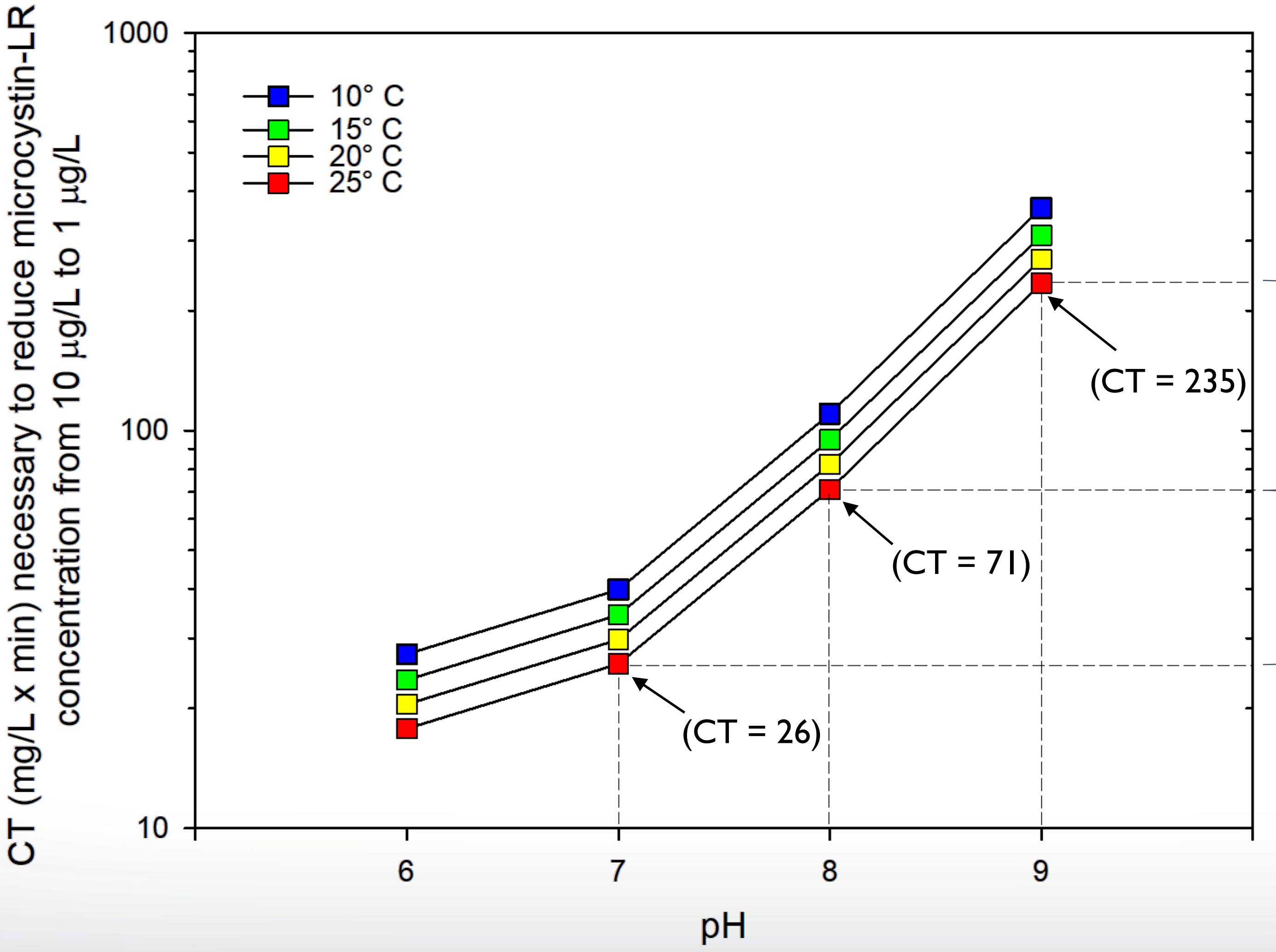
Permangate reducing total and increasing extracellular toxin

Powdered activated carbon reducing the extracellular toxin

Particulate removal removes the intracellular toxin



Impact of Chlorination



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

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

> 3X increase in CT

> 2X increase in CT

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

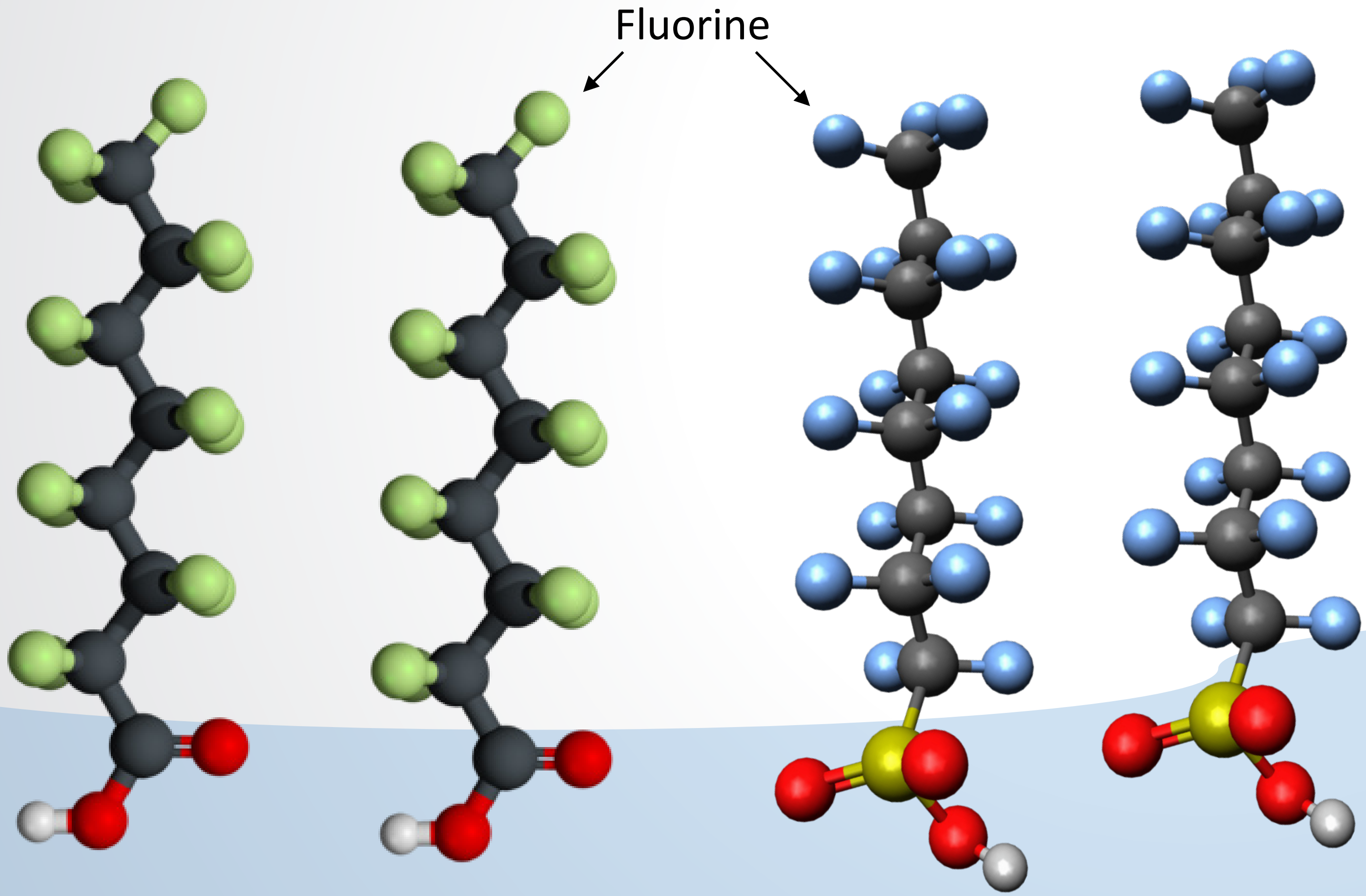
Treatment Issues

Powdered Activated Carbon (PAC)	Removes some 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 Regeneration/removal frequency – Cost
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 – balance corrosion compliance
Ozone	High capital cost 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 man-made 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**

Sources of PFAS in the Environment

- Direct release of PFAS or PFAS products into the environment
  - Use of aqueous film forming foam (AFFF) in training and emergency response
  - Releases from industrial facility
- Landfills and leachates from disposal of consumer and industrial products containing PFAS
- Land where wastewater treatment plant biosolids were applied

Research: PFOS 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)
- **PFOA & PFOS:** Pages currently available (29 sources)
- **PFNA, PFHxA, PFHxS, PFBS, Gen-X:** Pages were added (June, 2018) from 50 additional literature sources for activated carbon, ion exchange, and membrane separation
- **Other PFAS and technologies to follow**
- Journal papers on literature review on PFAS treatment in agency review

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

PFOS Treatment

Ineffective Treatments

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

Effective Treatments	Percent Removal
Anion Exchange Resin (IEX) #	90 to 99
High Pressure Membranes	93 to 99
Powdered Activated Carbon (PAC)	10 to 97
Granular Activated Carbon (GAC) #	
Extended Run Time	0 to 26
Frequent GAC Replacement	> 89 to > 98

PAC Dose to Achieve	
50% Removal	16 mg/l
90% Removal	>50 mg/L

Dudley et al., 2015

GAC Design Considerations

Given for All Technologies

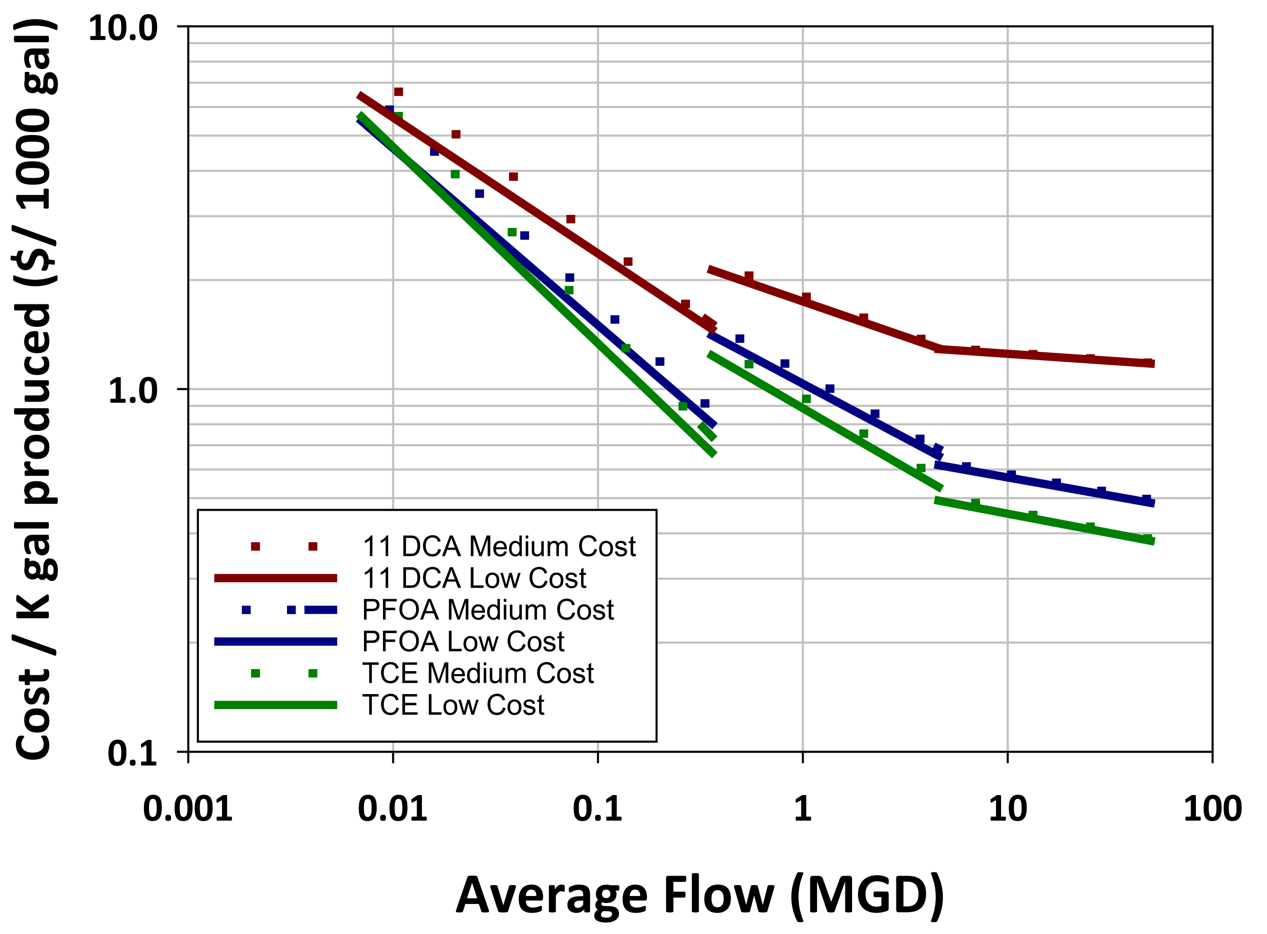
- Design and average flow
- Contaminant
- Influent Concentration

GAC Specific

- Carbon type (performance and cost)
- Vessel type (pressure / gravity)
- EBCT (15 min) / Superficial velocity / Bed depth / Column diameter
- Vessels in series (2) or parallel
- Bed volumes before regeneration/replacement
- Regeneration specifics
- Residual handling

Treatment Cost: PFOA, TCE, 11 DCA

PFOA will break through before PFOS



- 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
- 135K, 70K, and 11K bed volumes to breakthrough for TCE, PFOA, and 11DCA, respectively.

PFAS Treatment Issues

Granular Activated Carbon (GAC)	Poor removal of short-chained PFAS Disposal/reactivation of carbon – potential liability Regeneration/removal frequency
Anion Exchange Resin (selective)	Poor removal of select PFAS Disposal/incineration of resin – potential liability Unclear secondary benefits
High Pressure Membranes	Capital and operations costs Corrosion control Membrane fouling Lack of options for concentrate stream treatment or disposal
Other Novel Technologies	Permitting Issues with ease of operation, Robustness , Reliability Potential unintended consequences High costs Residual streams

Research: PFAS

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

Questions?

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