

Case Studies in Biofiltration from the Pacific Northwest: Characterizing Performance and Water Quality Benefits



Agenda

- Introduction to Biological Filtration
- Case Study #1: Lake Oswego-Tigard Water Treatment Plant
- Case Study #2: Tacoma Public Utilities Green River Filtration Facility
- Case Study #3: Eugene Water and Electric Board Hayden Bridge Water Treatment Plant
- Case Study #4: City of Salem Geren Island Water Treatment Facility
- Summary of Results and Conclusions



Introduction to Biological Filtration

Biofiltration is an operational practice to improve treatment of organic and inorganic constituents



Managing, maintaining, and promoting biological activity on granular media in the filter to enhance the removal of organic and inorganic constituents before treated water is introduced into the distribution system.

Non-chlorinated filters will become biologically active

Bacteria oxidize and reduce contaminants to generate energy and grow

Electron Acceptors

O_2
 NO_3^-
 ClO_4^-
 $Cr(VI)$
VOCs

Nutrients (P, N)

Electron Donors

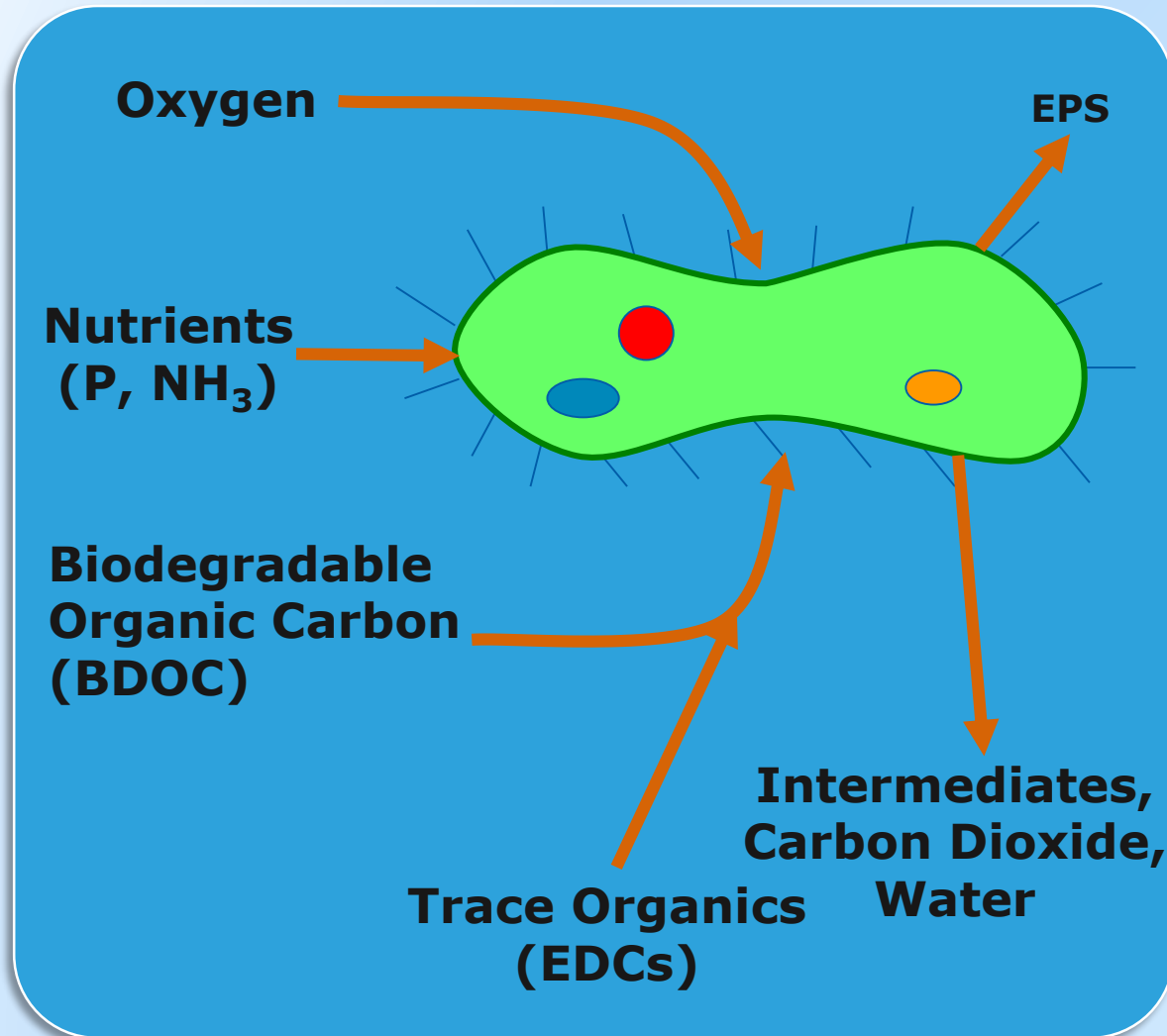
Organic carbon
 NH_3
 Mn^{2+}
 Fe^{2+}

EPS (Biofilm)

$CO_2, N_2, Cl^-, Cr(III)_s$
 NO_3^-, Mn^{4+}, Fe^{3+}

- Reduce T&O
- Reduce DBPs
- Reduce algal toxins
- Reduce ammonia, iron, manganese
- Reduce regrowth potential
- Reduced corrosion potential
- Improved disinfectant stability

Effective biofiltration requires an environmental and nutritional balance



Typical PNW surface waters are:

- Low in nutrients
 - All 4 case studies typically <2mg/L
- Low in total organic carbon
 - All 4 case studies typically <15°C
- Seasonally cold
 - All 4 case studies typically <15°C

However....

- Ozone upstream of filters can convert DOC to BDOC
- Filter media type, media depth, and empty bed contact time can increase biological activity

Common metrics for measuring biofiltration

Table 1-1. Monitoring Parameter Groupings and Tool Overviews.

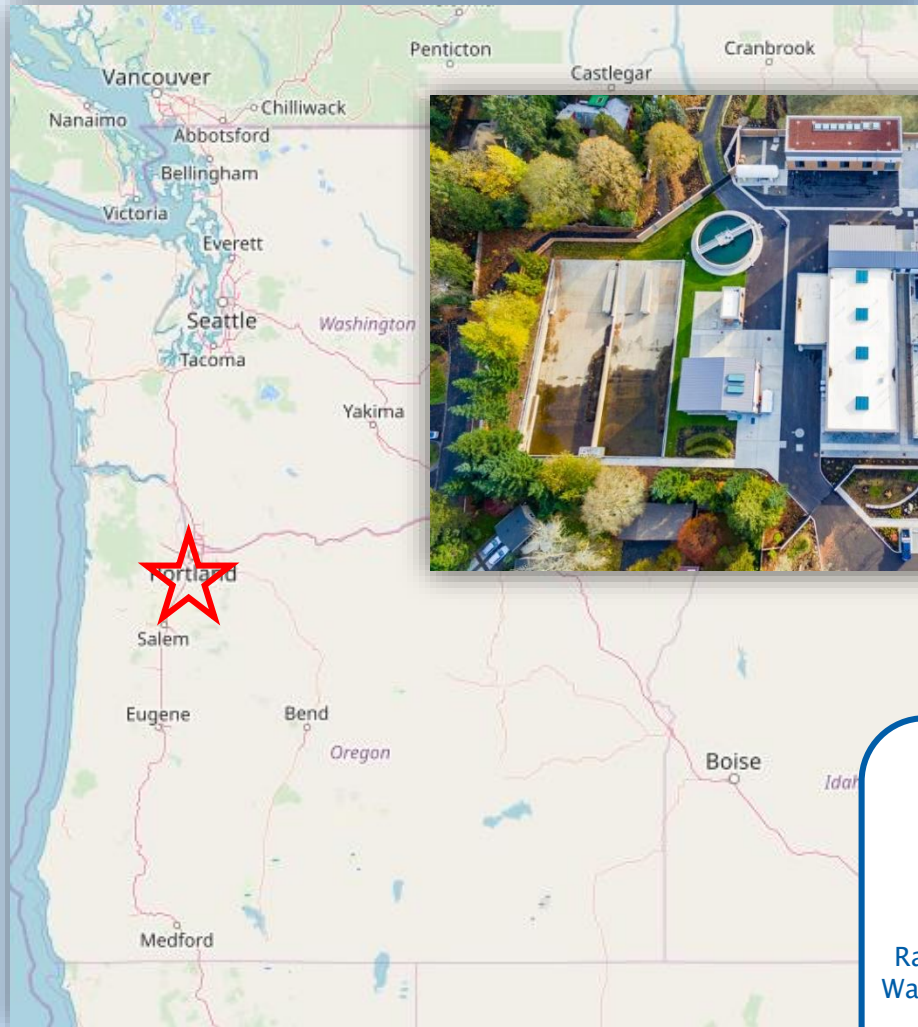
| Group | | Tool | | Importance |
|---------------|------------------------|------------------------------|--|--|
| Biological | Biofilm Formation Rate | | | Sacrificial coupons are installed in a pipe loop at the filter influent and effluent. Bacteria attach and grow on the coupon during a two-week incubation period. The coupon is removed, and ATP is measured on the coupon surface. The rate of biofilm formation is an indicator of biological activity. When measured at the filter influent, biofilm formation rate is an indicator of the potential for biological growth on filter media. When measured at the filter effluent, biofilm formation rate is an indicator of the biological stability of treated water. The change in biofilm formation rate from the filter influent to effluent is a direct measure of the filter biological activity. |
| | Water Quality | Adenosine Triphosphate (ATP) | Photoelectrochemical oxygen demand (peCOD) | peCOD is a recently developed method that does not use mercury and provides an alternate estimate of COD. peCOD has a lower detection limit than the SM for COD. peCOD is measured in water samples. Orthophosphate can be used to indicate bioavailable phosphorus. Phosphorus is an important macronutrient. Phosphorus deficiency has been shown to generate excess EPS, which may impact filter hydraulics. |
| | | | Phosphorus | Nitrogen is an important macronutrient. Ammonia is the most readily available form of nitrogen, but nitrate and nitrite may also be used by bacteria. Nitrogen deficiency may lower the ability for biofilters to degrade organic carbon. |
| | | | Nitrogen species | Temperature influences biological activity and the rate of biological degradation of contaminants. |
| | | | Temperature | pH influences particle charge, floc stability, and speciation of compounds. The pH must be between 6 and 9.5 to maintain biological activity. |
| | | | pH | Turbidity is used to characterize changes in influent water quality and biofilter effectiveness for removal of pathogens. |
| | | | Turbidity | Headloss accumulation rate is a measure of the change in headloss over time. Long-term tracking of the profile can indicate when and where excess biomass or solids have accumulated, changes to filter media size distribution, and other characteristics. |
| | Filter Hydraulics | | Headloss accumulation rate | Differential pressure profiling includes measuring pressure at various depths through the filter bed. This can be used to determine where within the filter fouling occurs. |
| | | | Clean Bed and Terminal Headloss | The FRT is the number of run hours the filter is online between backwashing. |
| | | | Differential Pressure Profiling | The FRTV is the quantity of water filtered through each square foot of filter media between backwashes. |
| Water Quality | Carbon | | Filter Run Time (FRT) | The backwash pump pressure at the beginning of a backwashing cycle can be an indicator of changes to filter fouling between backwashes. |
| | | | Unit Filter Run Volume (UFRV) | The backwash pump pressure at the beginning of a backwashing cycle can be an indicator of changes to filter fouling between backwashes. |
| | | | Backwash pump pressure | EBCT is calculated as the volume of the empty filter bed divided by the flow rate. Contaminant removal has been shown to be influenced by the amount of time water is in contact with biofilm on the filter surface. |
| | | | Empty Bed Contact Time (EBCT) | The concentration of oxidant residual can negatively impact biological activity. Biological filtration may impact the oxidant demand in downstream processes (e.g., chlorine demand for disinfection). |
| | | | Oxidant Residual | |
| | Other Operational | | Oxidant Demand | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | Carbon | | | expressed as carbon equivalents can be used as an indicator of biodegradable NOM. |
| | | | | UV ₂₅₄ is measured in water samples at the filter influent and effluent and provides information on the quality of organic carbon, specifically regarding the degree of aromaticity. UV ₂₅₄ has also been shown to be an indicator of DBP-FP (Archer and Singer 2006, Kingsbury 2010). |
| | | | | FEEM is used to measure fluorescent compounds (those capable of fluorescence at various light wavelengths) such as humic and fulvic acids, amino acids, and proteins. FEEM is measured in water samples. |
| | | | | DBP-FP can be measured at the influent and effluent or just the filter effluent as an indication of how effectively the biofilter removes organic carbon compounds that can form into disinfection byproducts (DBPs). |
| | | | | |

- **ATP** measurement is used to assess the active biomass.
 - 100 ngATP/cm³ media – 1,000ngATP/cm³ media is typical for biofilters
(Pharand, AWWA, 2014)
- **DOC/BDOC** represents the primary food source for bacteria
 - DOC/BDOC removal across biofilters attributed to biological activity, typically 5%-25%.
(WRF #4459, 2016)



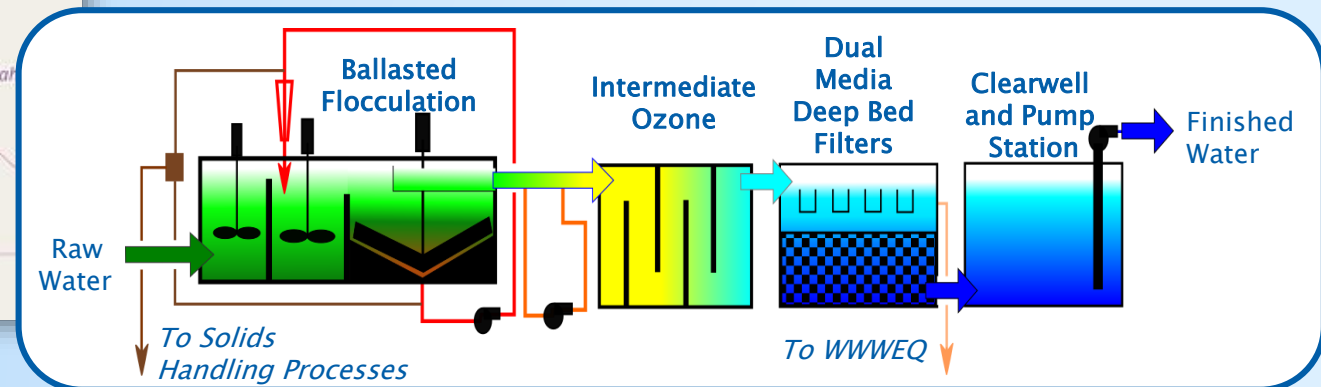
Case Study #1: Lake Oswego-Tigard Water Treatment Plant

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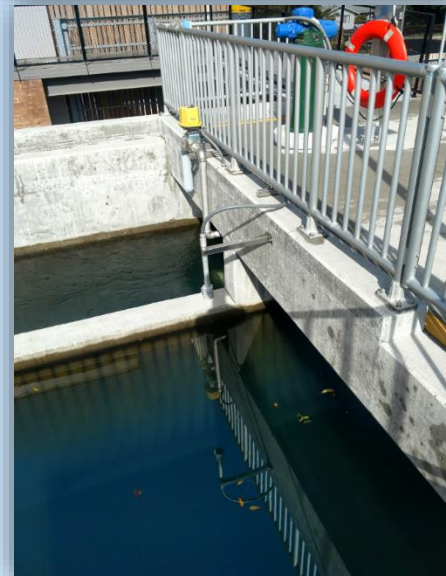
DESIGN CRITERIA:

- 38 MGD Capacity
- Ballasted Flocculation
- Intermediate Ozone
- High-rate GAC Filtration (10 gpm/sf)
 - 4' of GAC over 1' of sand
 - Typical EBCT: 5-10 min

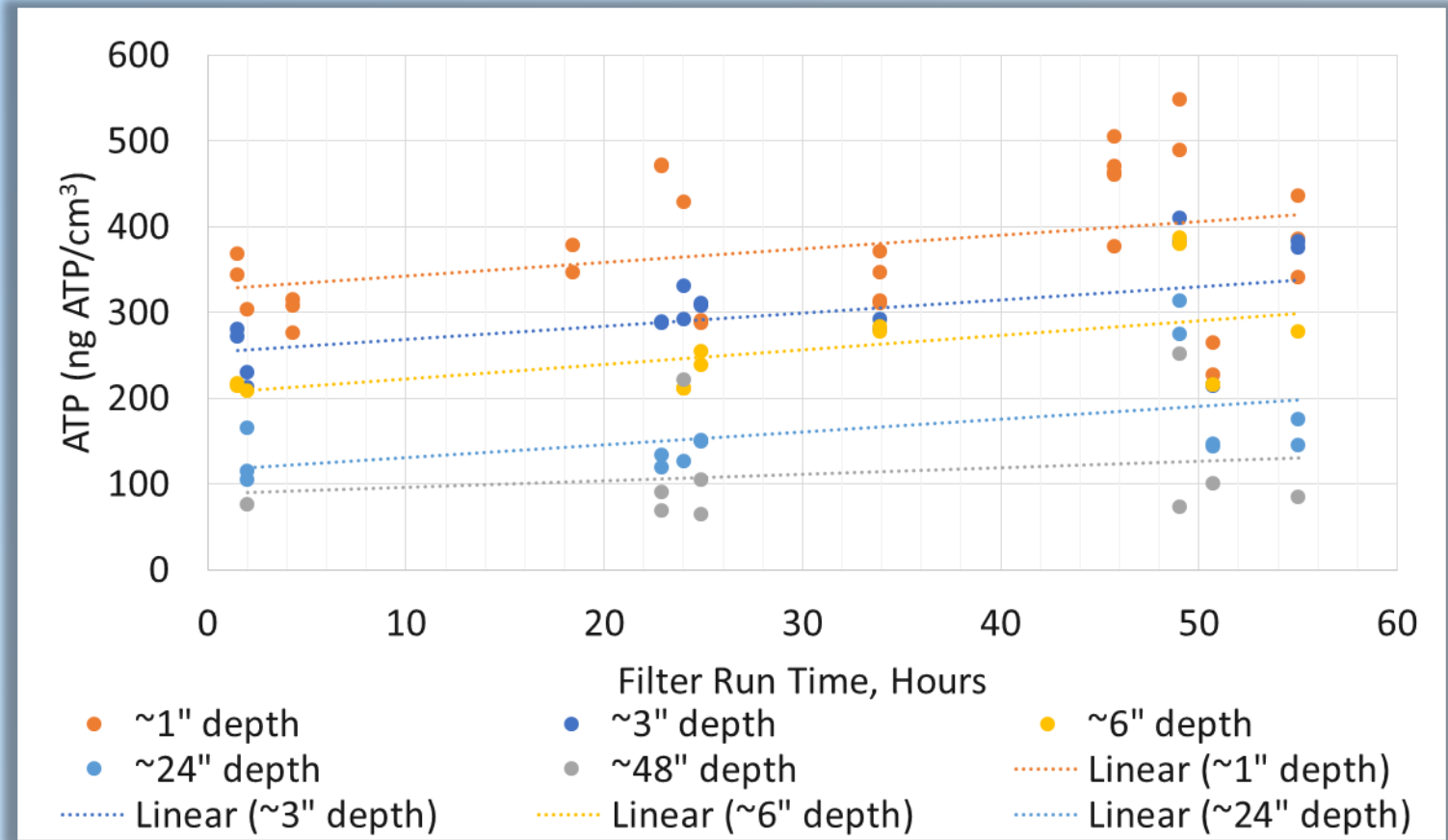
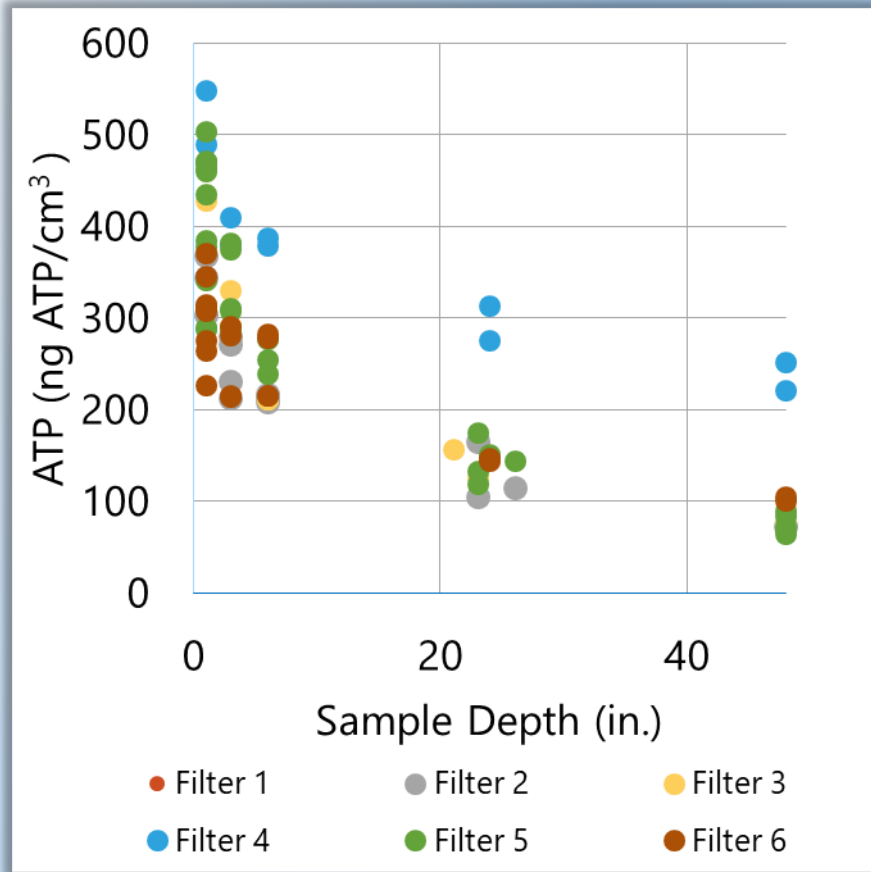


LO-T targeted several constituents for biofiltration

- Total Organic Carbon (TOC) removal and reduced disinfection byproducts (DBP's)
- Chlorine residual stability
- Taste and odor removal
- Other treatment benefits

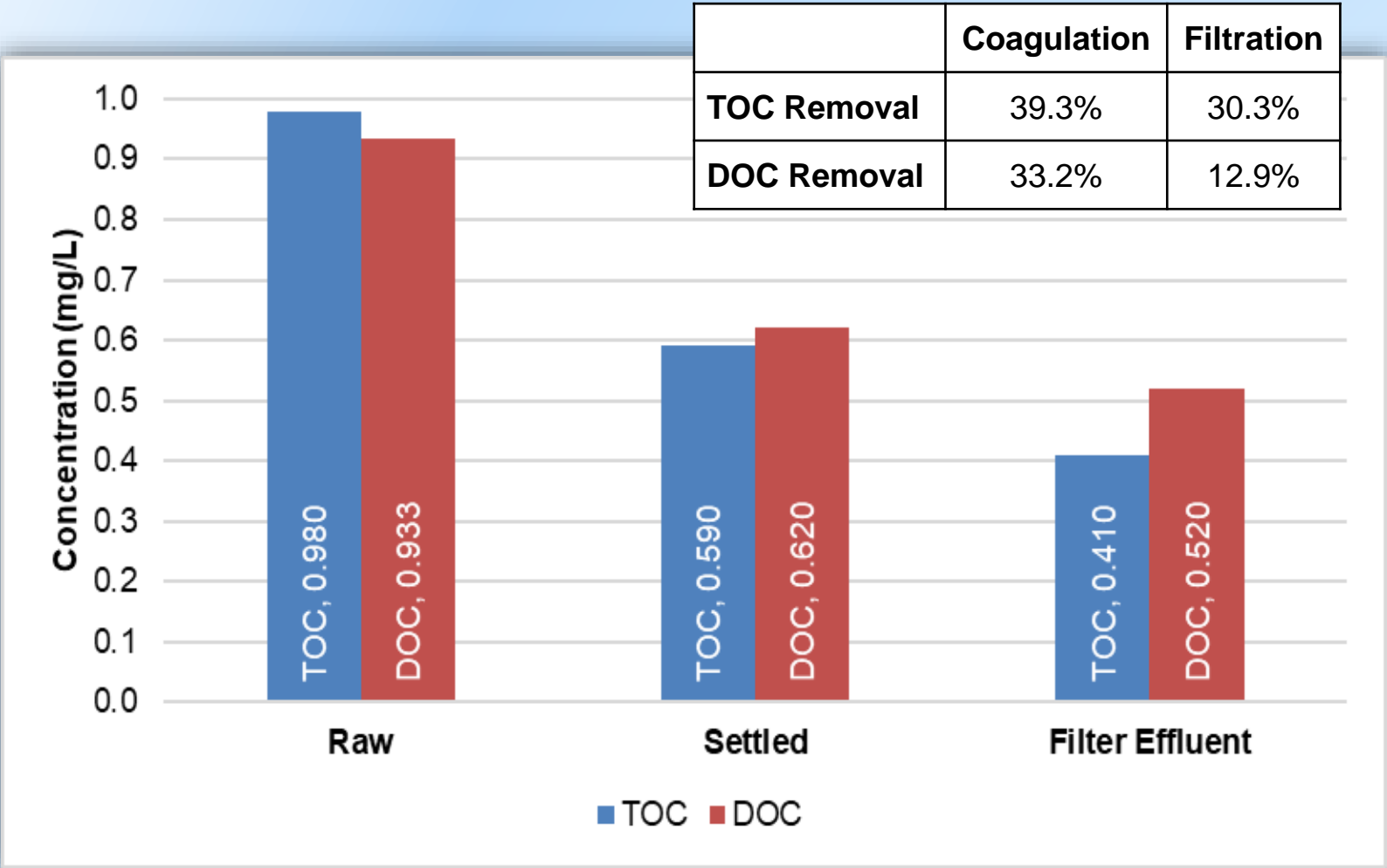


ATP monitoring confirms bioactive filters



- Significant ATP (biomass) measured across all filters throughout media profile
- ATP increases throughout filter run

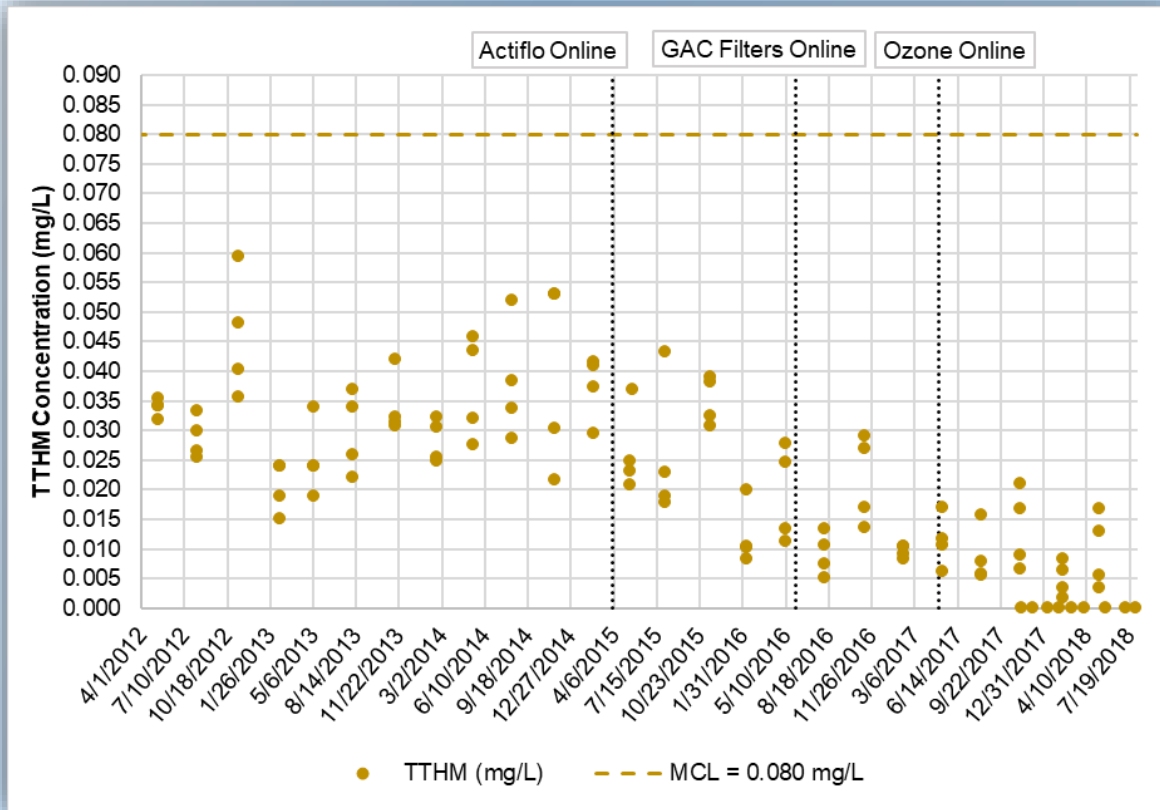
TOC and DOC are reduced through each step of the treatment process



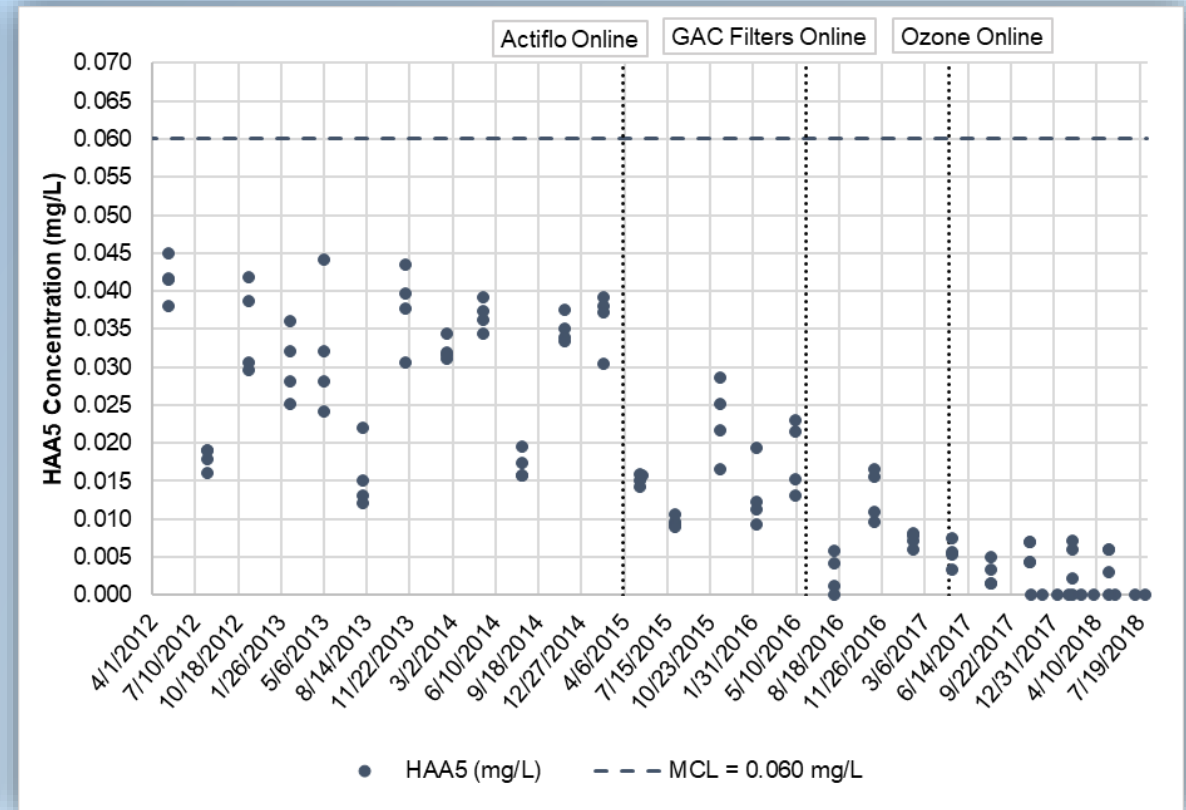
- TOC removal through adsorption on GAC media is likely exhausted
- 13% DOC removal is typical of biofilters
- Reduction in TOC/DOC has real distribution system benefits

Reduced TOC leads to lower DBP's in distribution system

70% Lower TTHM



90% Lower HAA5

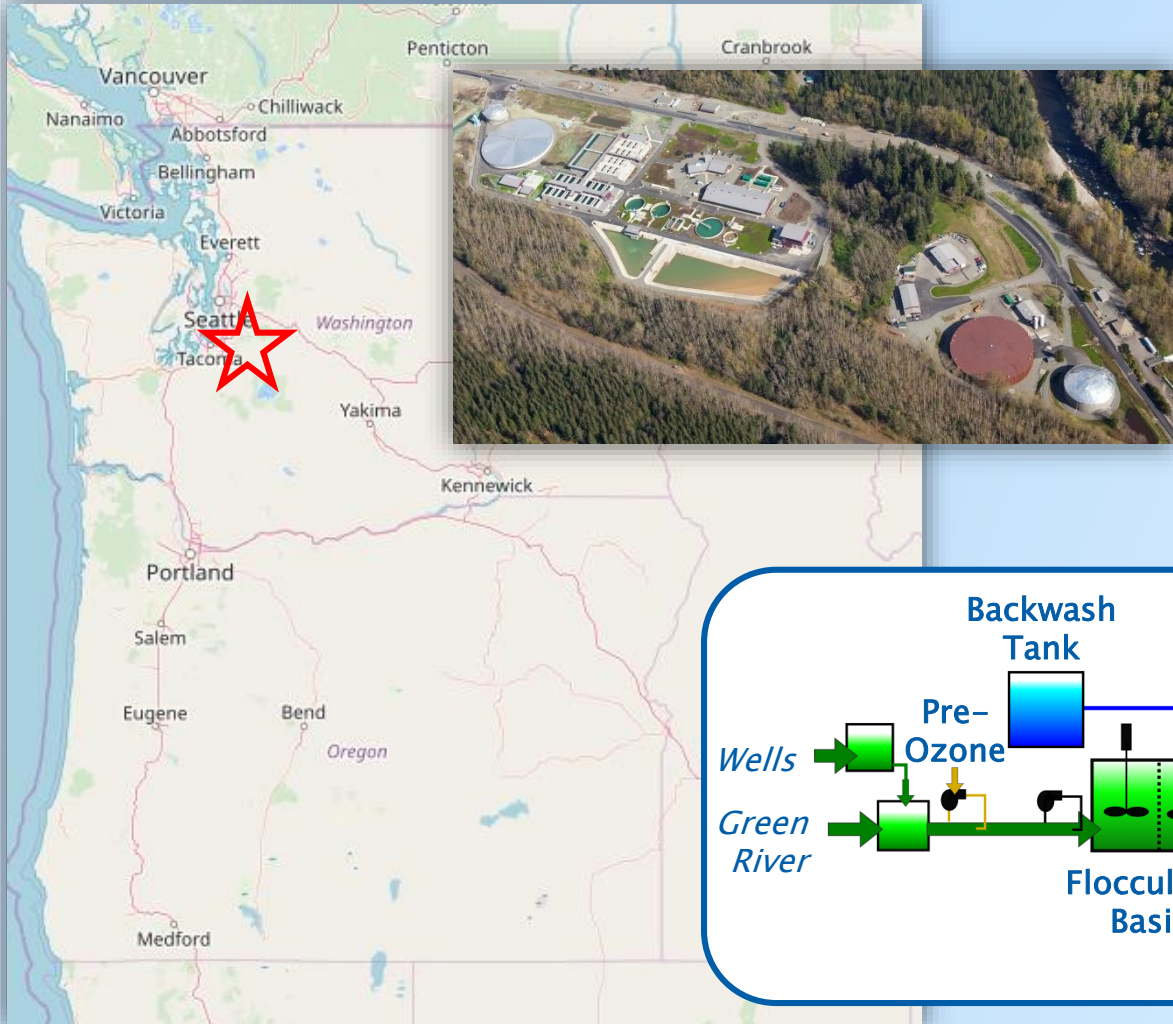


TTHM and HAA5 formation decreased as systems were turned online.



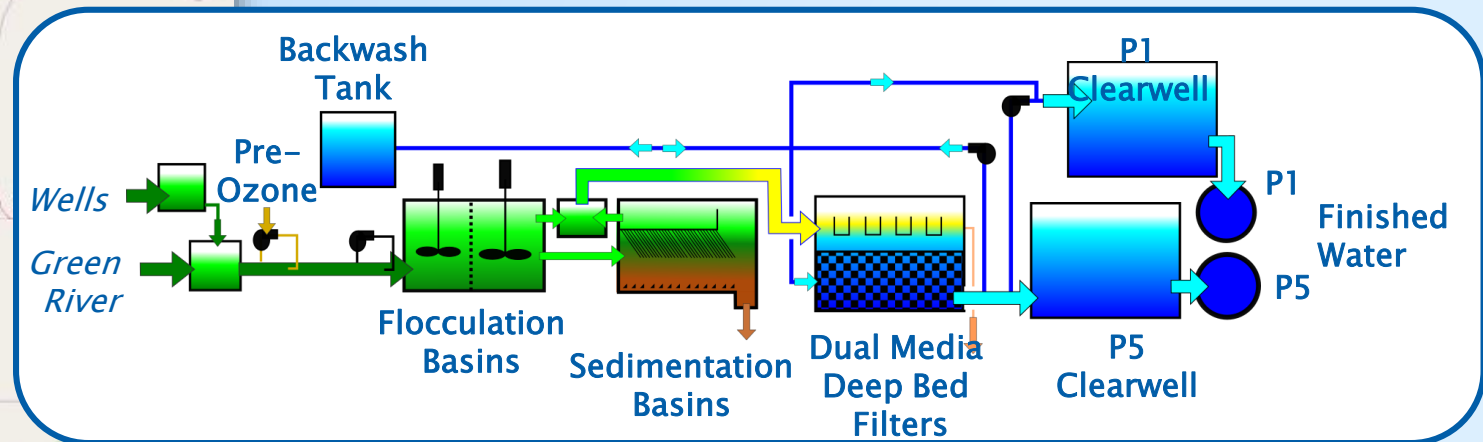
Case Study #2: Tacoma Public Utilities Green River Filtration Facility

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DESIGN CRITERIA:

- 168 MGD Capacity
- Pre-Ozone
- Hybrid Conventional/Direct
- High-rate Filtration (10 gpm/sf)
 - 50" of Anthracite over 20" of sand
 - Typical EBCT: ~5-10 min



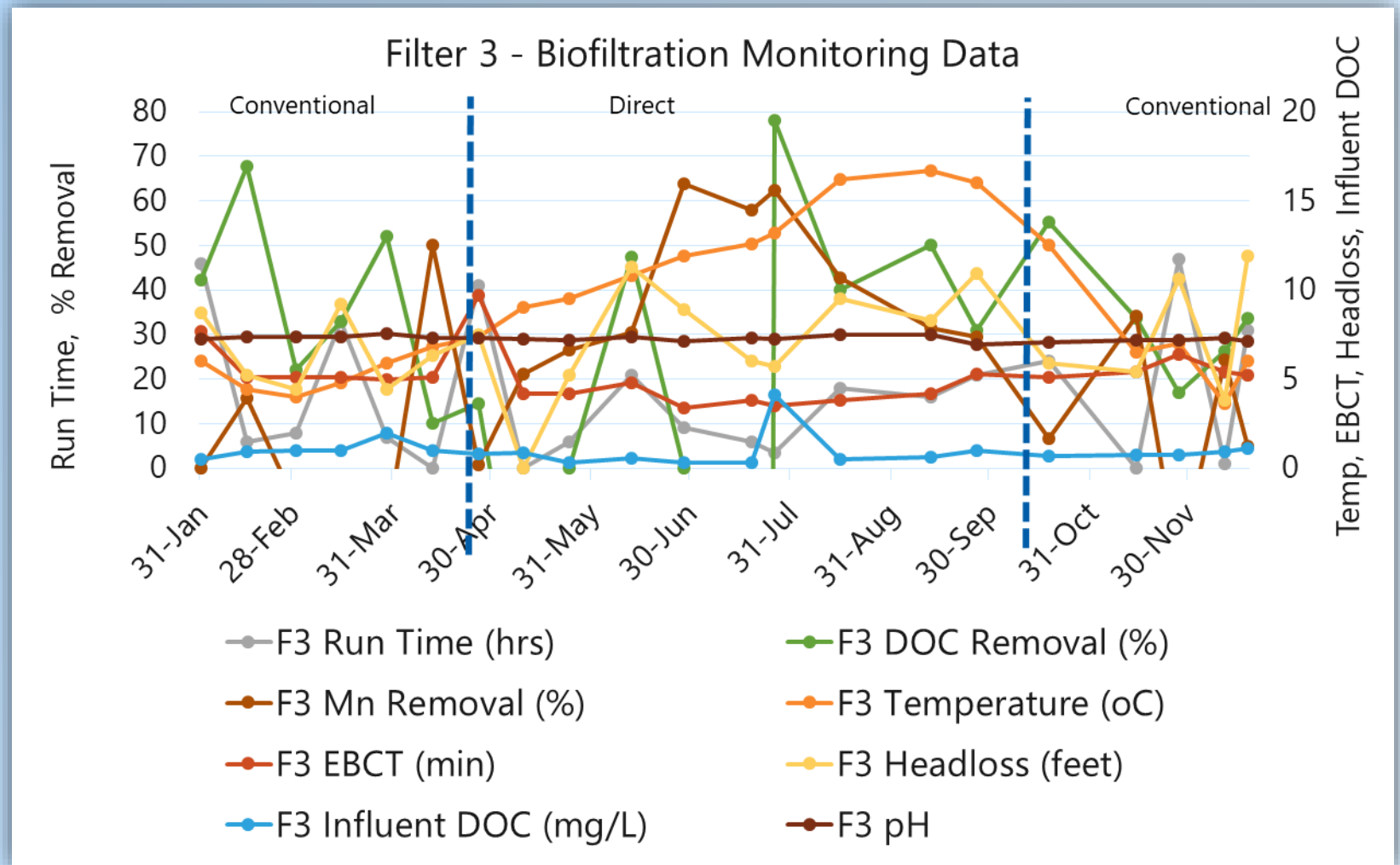
GRFF targeted several constituents for biofiltration

- Total Organic Carbon (TOC) removal and reduced disinfection byproducts (DBP's)
- Chlorine residual stability
- Manganese removal



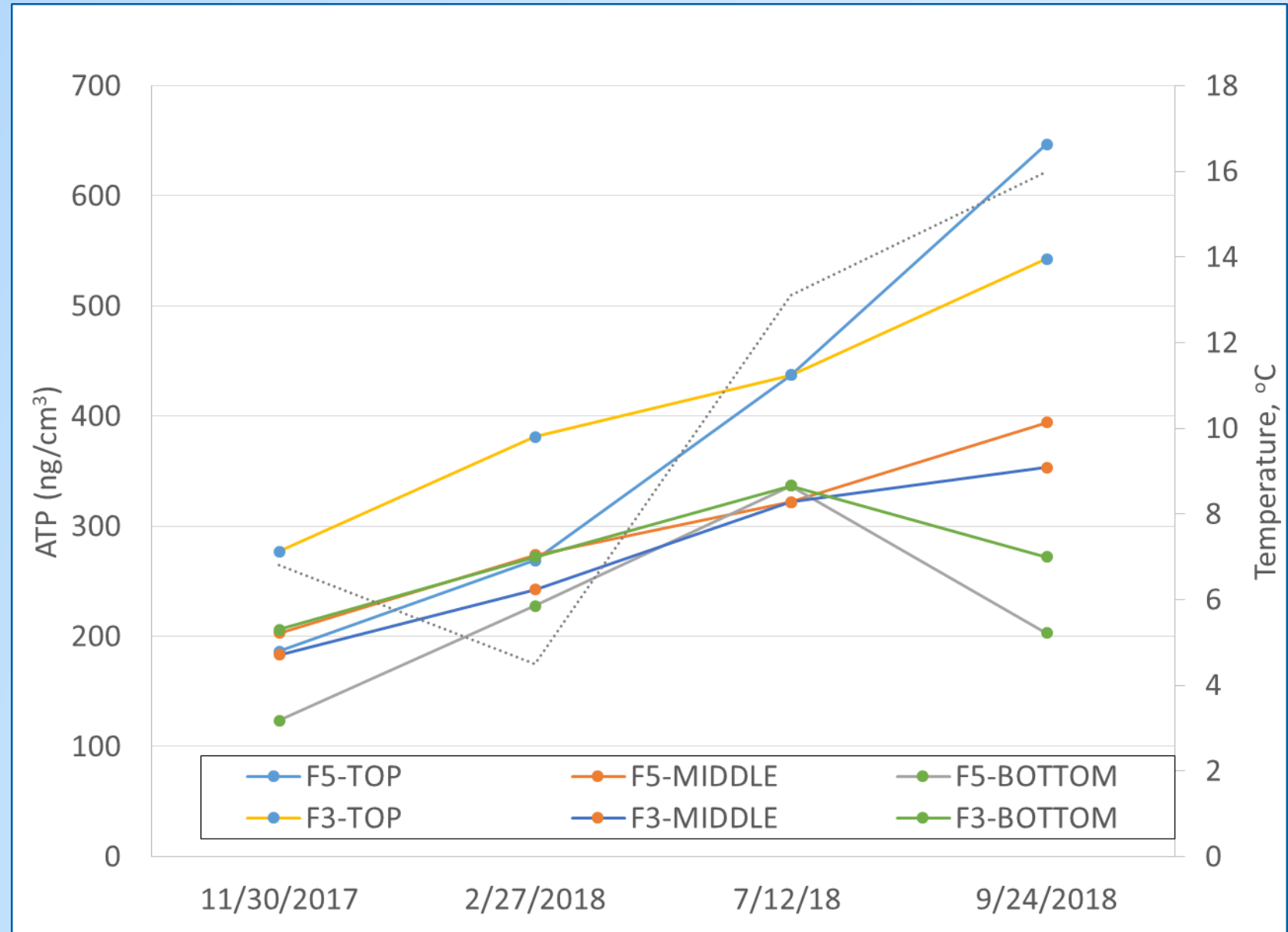
Tacoma Water collected detailed biofiltration monitoring data on two filters over the course of 2018

- Multiple operational parameters and water quality parameters
- ATP, EPS, TOC, BDOC, UV254, Nitrogen, Phosphorous, aldehydes, organic acids, etc.

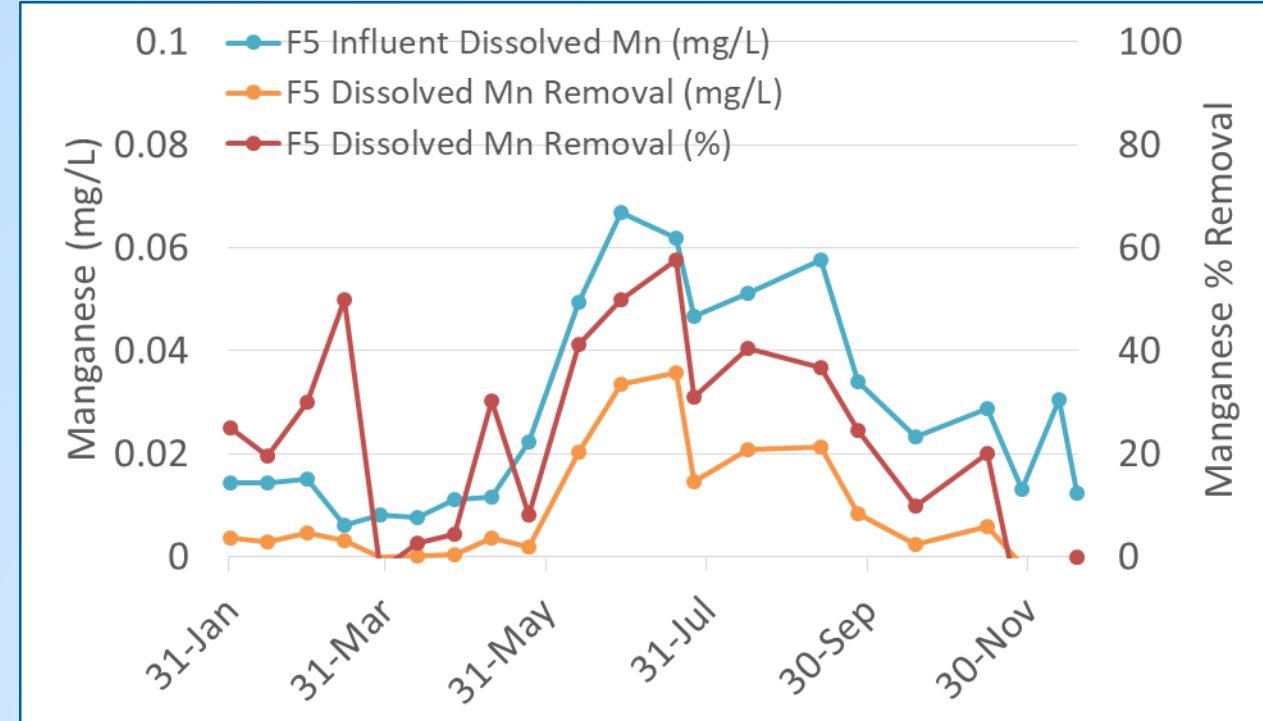
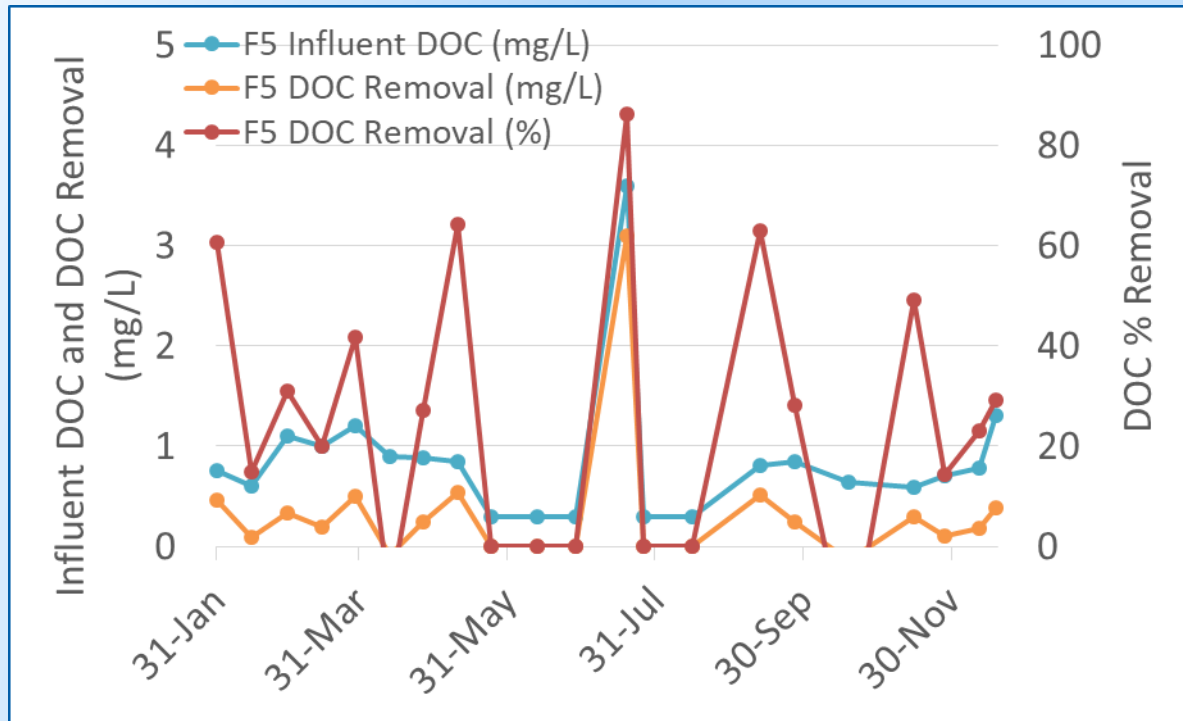


ATP levels were typical of active biofilters

- Lower ATP levels typical of anthracite media
- Temperature does not appear to affect biomass
 - Consistent with other studies



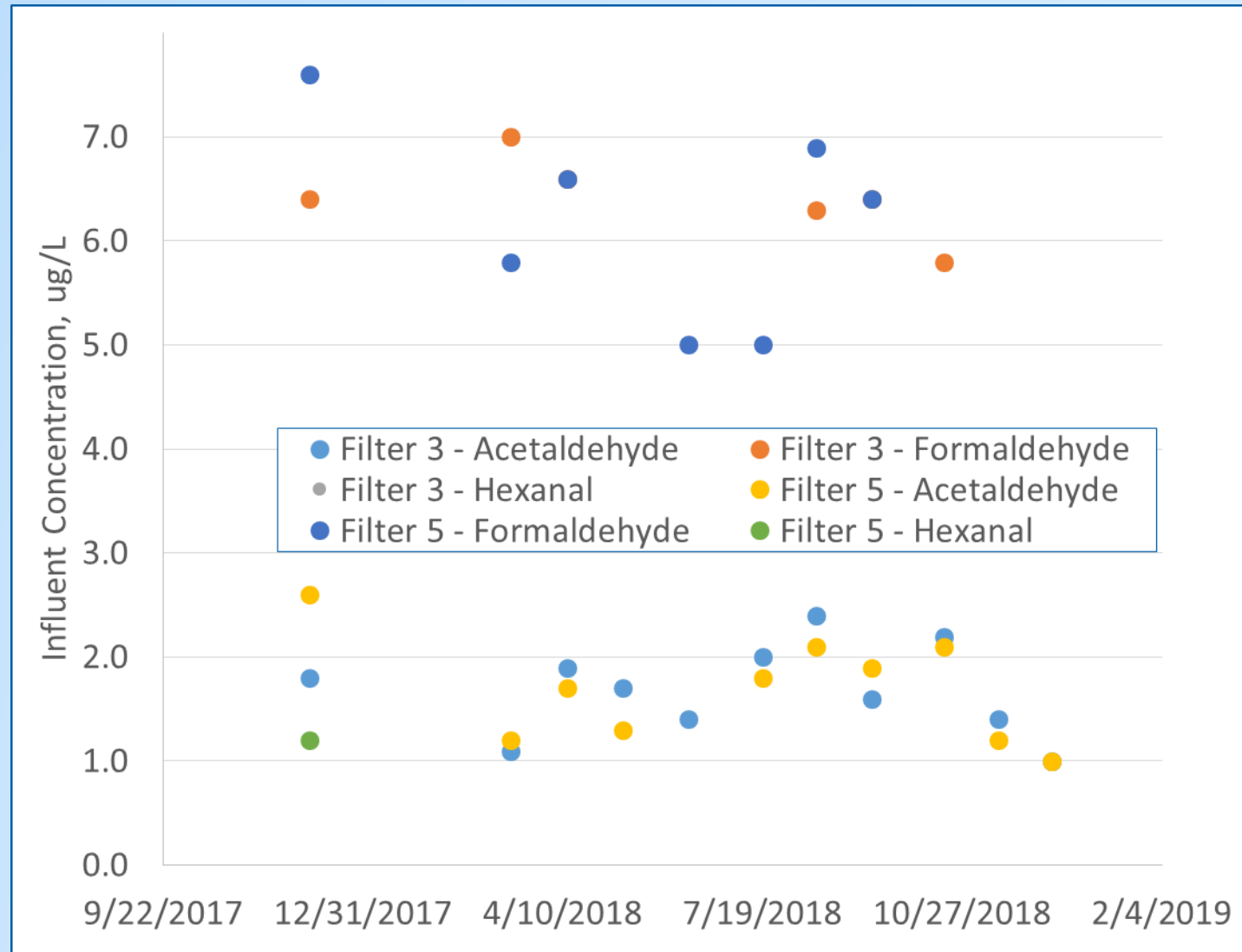
Significant reduction in DOC and Mn when it is most desirable



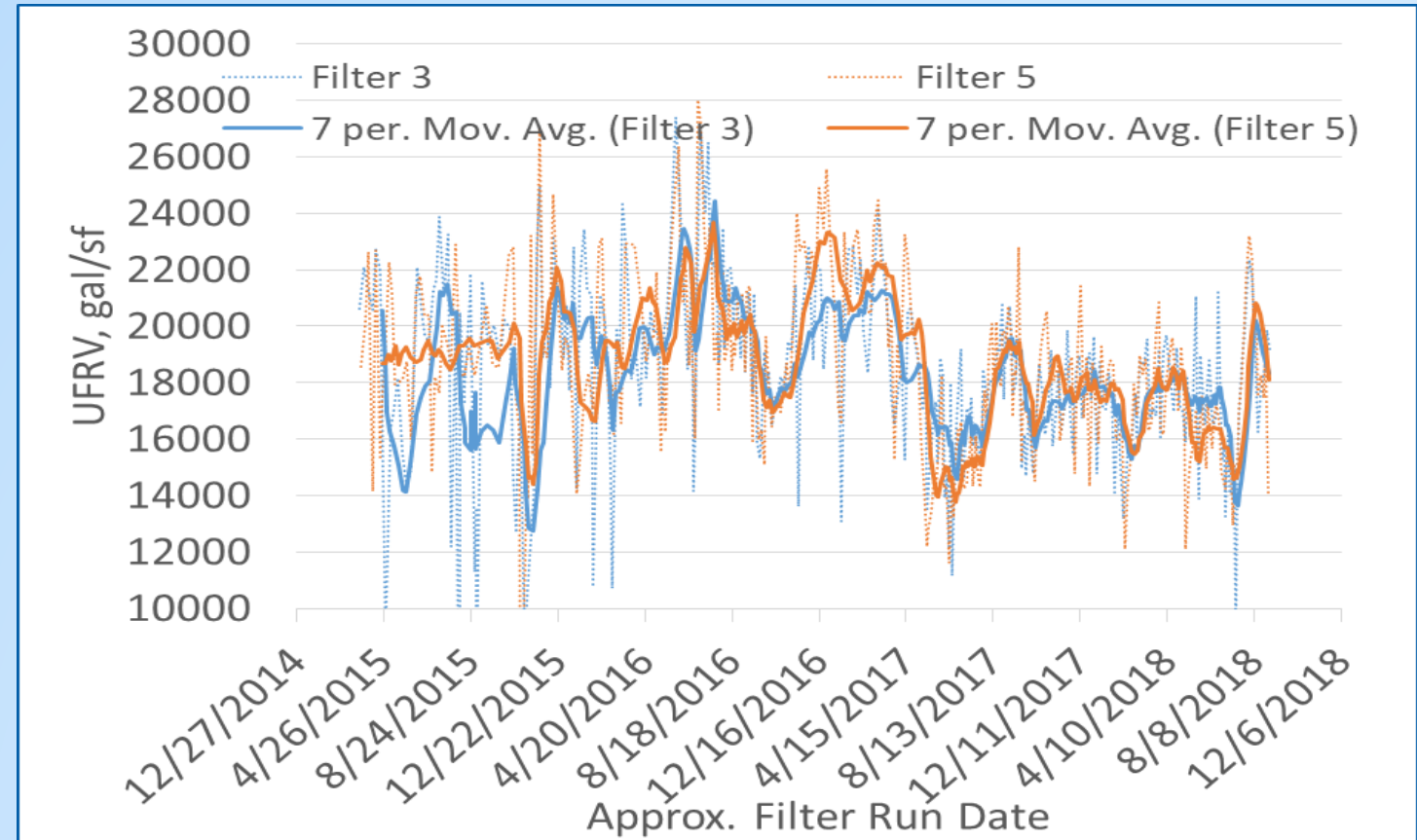
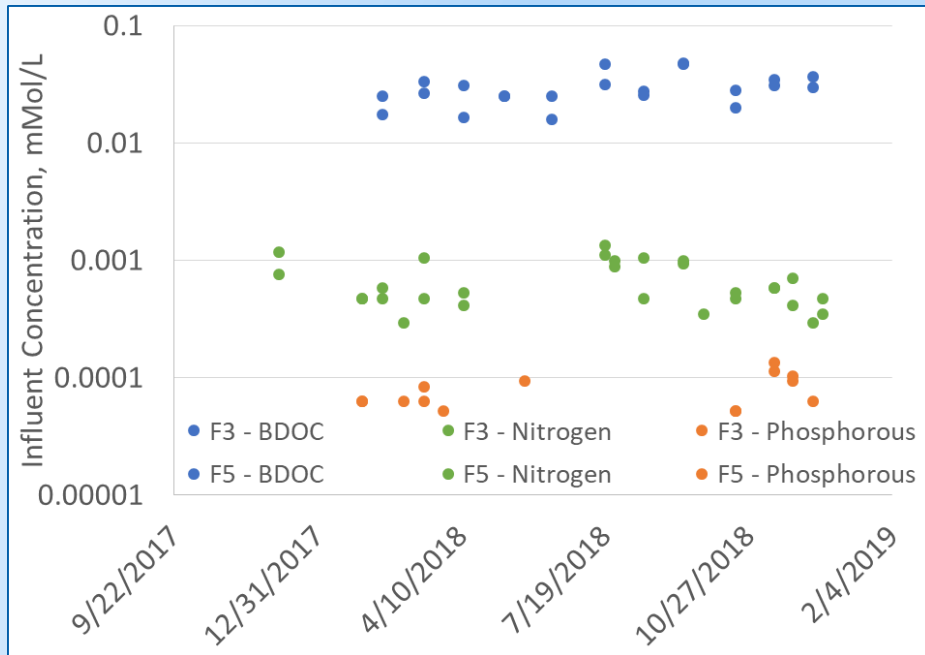
- Influent DOC appears to have the greatest impact on DOC removal
- Influent Mn appears to have the greatest impact on Mn removal
- No correlation found for temperature, EBCT, runtime, pH etc.
- Data suggests non-biological drivers for Mn removal
- Limited nutrients, lower pH may contribute to low biological removal

Very low levels of ozonation byproducts present in filter influent, no detections in filter effluent

- Multiple aldehydes and organic acids tested
- Only a few above detection limits in influent stream
- Typically readily biodegradable and a good food source for biofilters
- Zero detects in effluent



Filter runs not negatively impacted by biological activity in low nutrient water



- Some studies suggest low nutrients responsible for low filter run times in biofilters
- Ratio of C:N:P is good at nearly 100:10:1, but levels are near non-detect
- Filter UFRV's remain consistently above 15,000 gal/sf

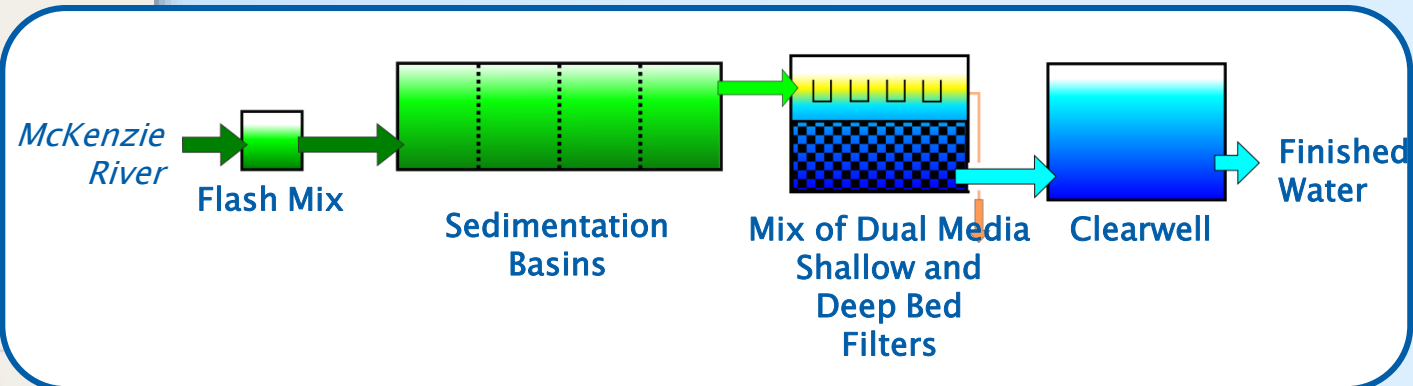


Case Study #3: Eugene Water and Electric Board Hayden Bridge Water Treatment Plant

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DESIGN CRITERIA:

- 88 MGD Capacity
- Direct Filtration
 - 12 filters @ 18" of Anthracite over 10" of sand (6-10 gpm/sf)
 - 2 filters @ 50" of anthracite over 15" of sand (4-8 gpm/sf)
- Typical EBCT: ~2 min

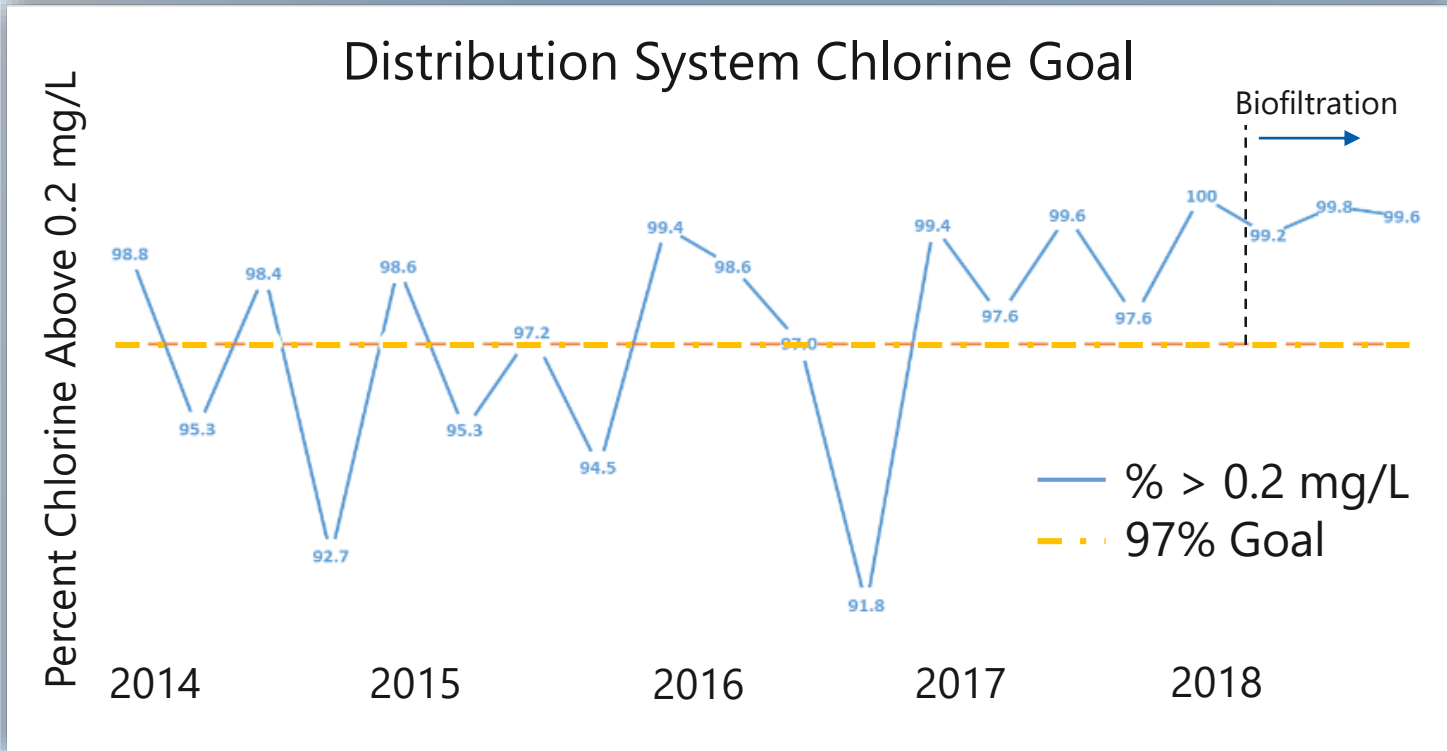


Hayden Bridge targeted several constituents for biofiltration

- Evaluate the impact of eliminating pre-chlorination on filter performance
- Improve treated water quality while reducing costs
 - Reduce DBP's
 - Increase distribution chlorine residuals
 - Decrease chlorine costs

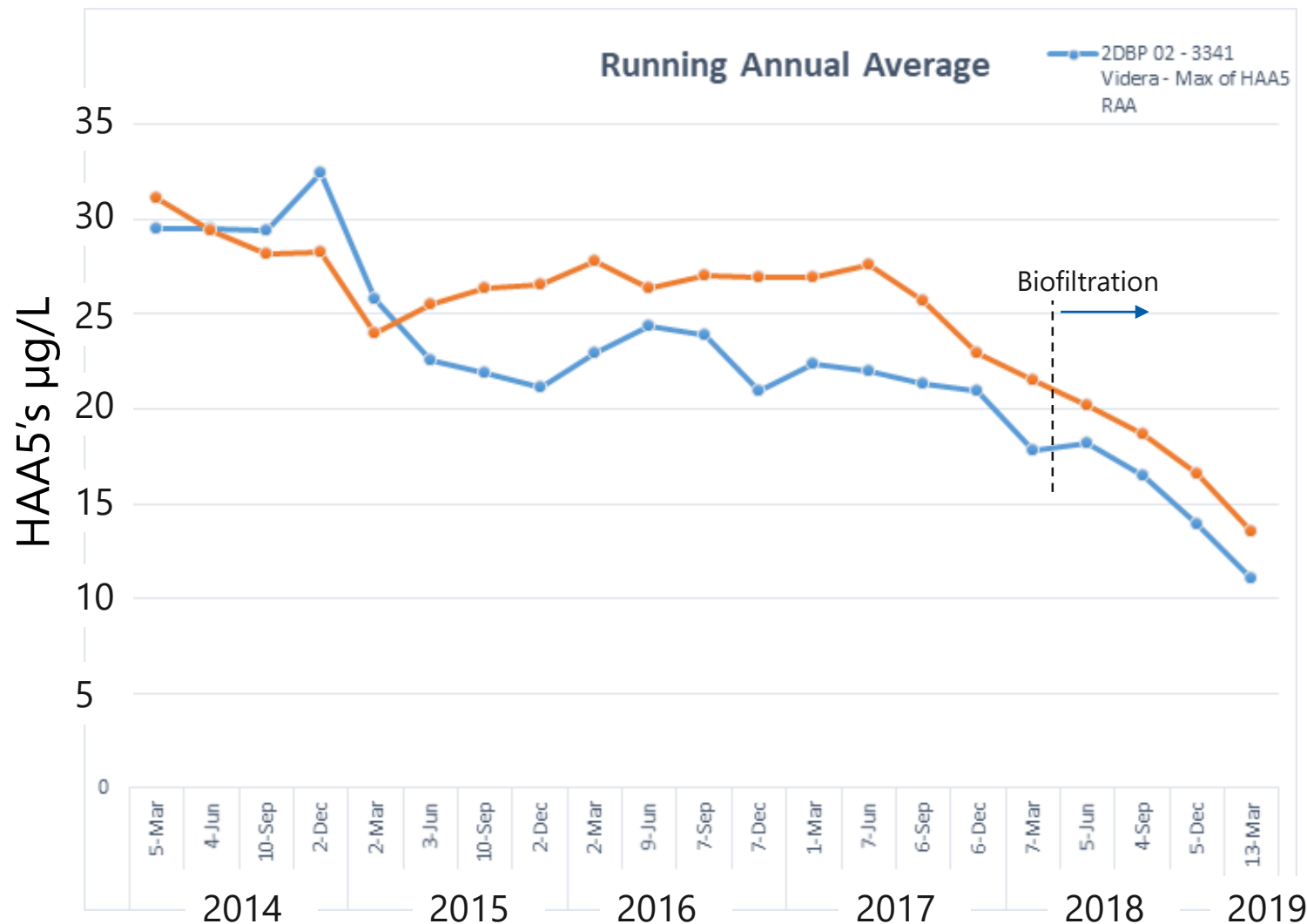


Biofiltration has stabilized chlorine residual throughout the EWEB Distribution system



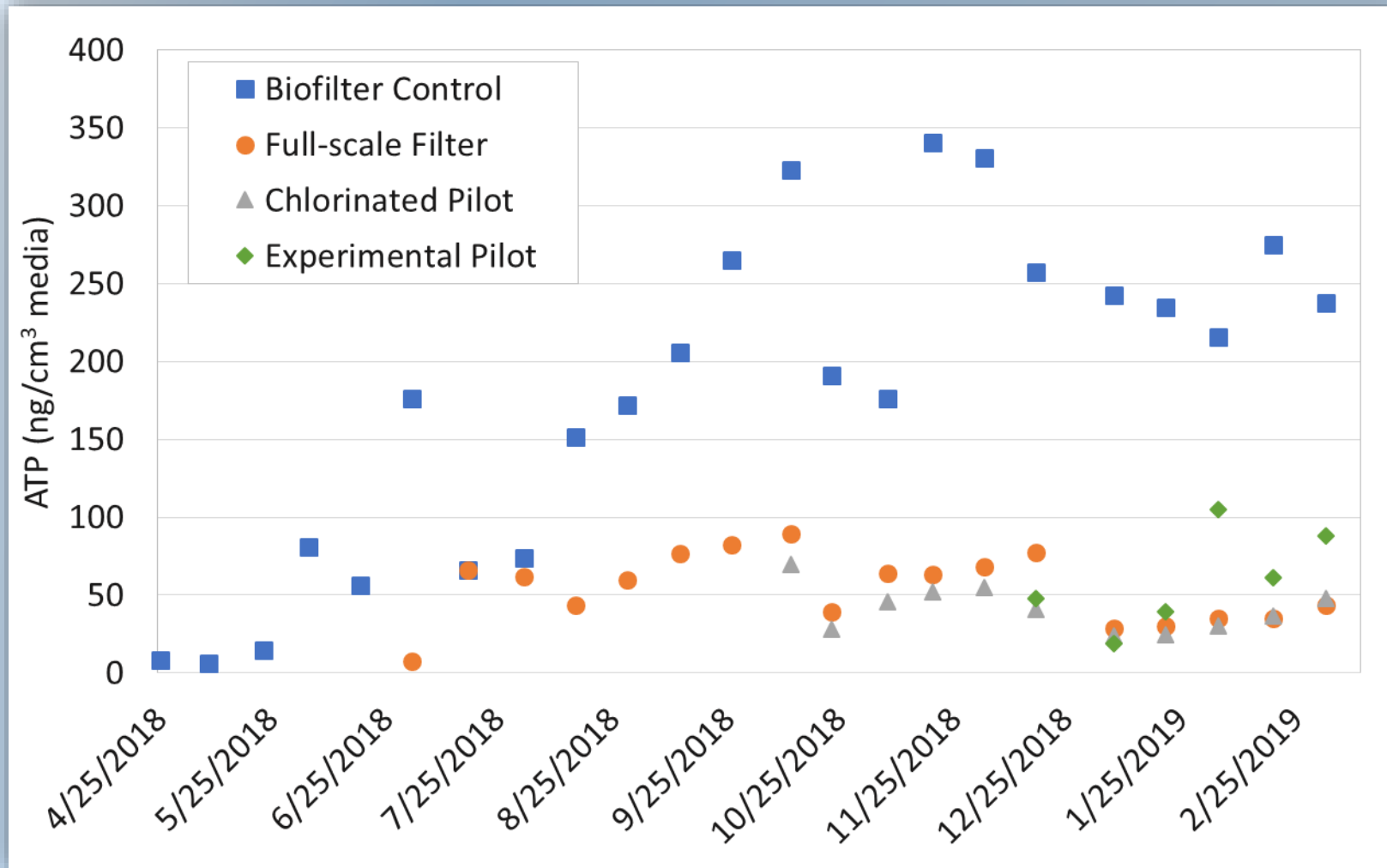
- Previously managed chlorine residual through operations (reservoir levels, flushing, and increased chlorine dose)
- Biofiltration achieves this without special operations
- Chlorine use has decreased by 30% overall

EWEB has seen a significant decrease in DBP's (HAA5's) since going biological



- HAA's already well below 60 µg/L MCL
- Proactive management decreased HAA's
- Biofiltration conversion further decreased HAA's
- Last several samples have been non-detect.

Biomass accumulation and biofilter development affected by many factors

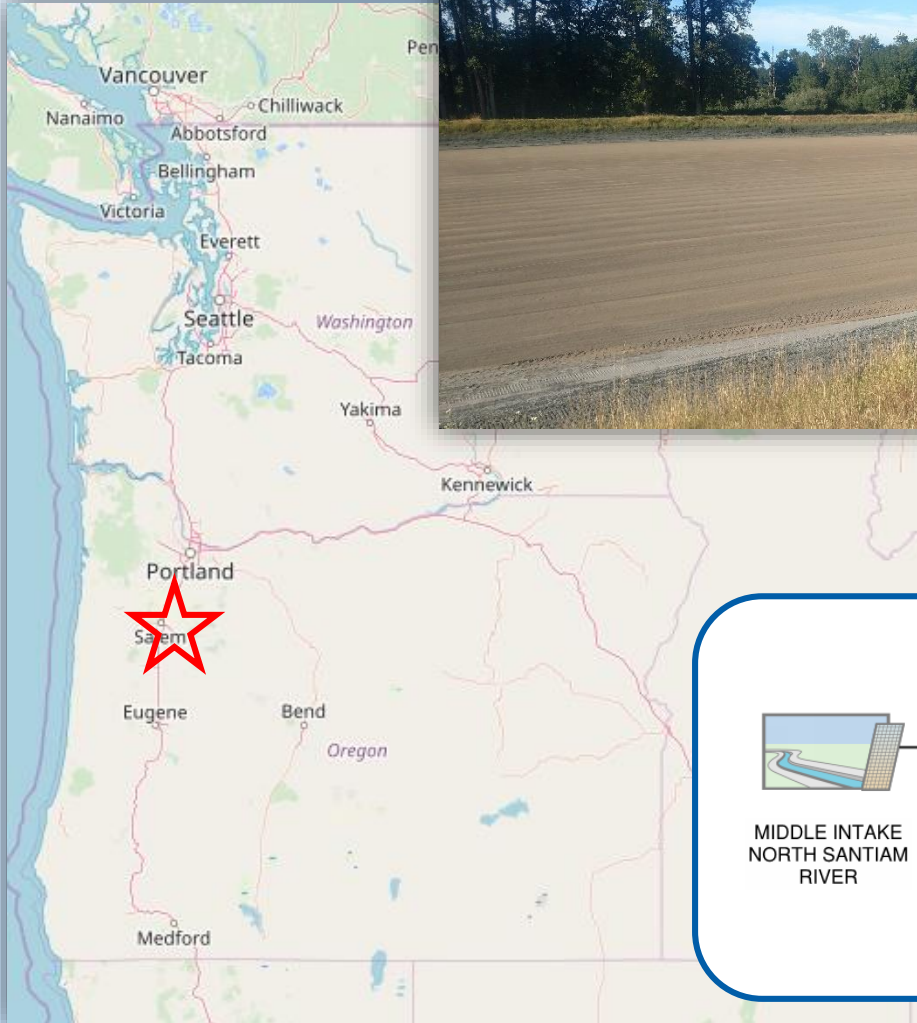


- During winter, filters can sit for a long period of time (3-7 days)
- Chlorinated sweeps may play minor role in ATP reduction
- Colder than usual water in January had large effect on full scale filter



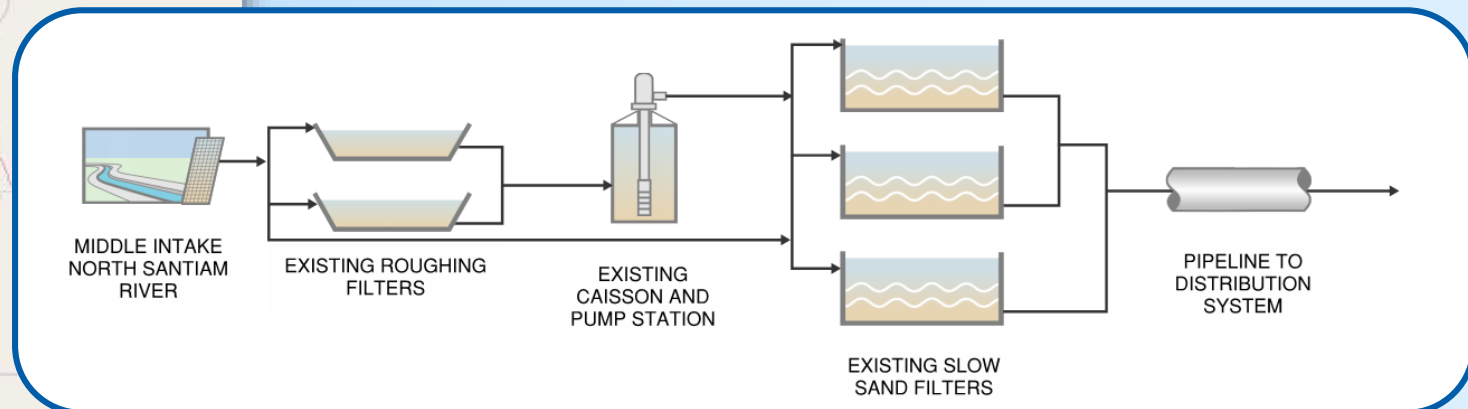
Case Study #4: City of Salem Geren Island Water Treatment Facility

Case Study #3: City of Salem Geren Island Water Treatment Facility



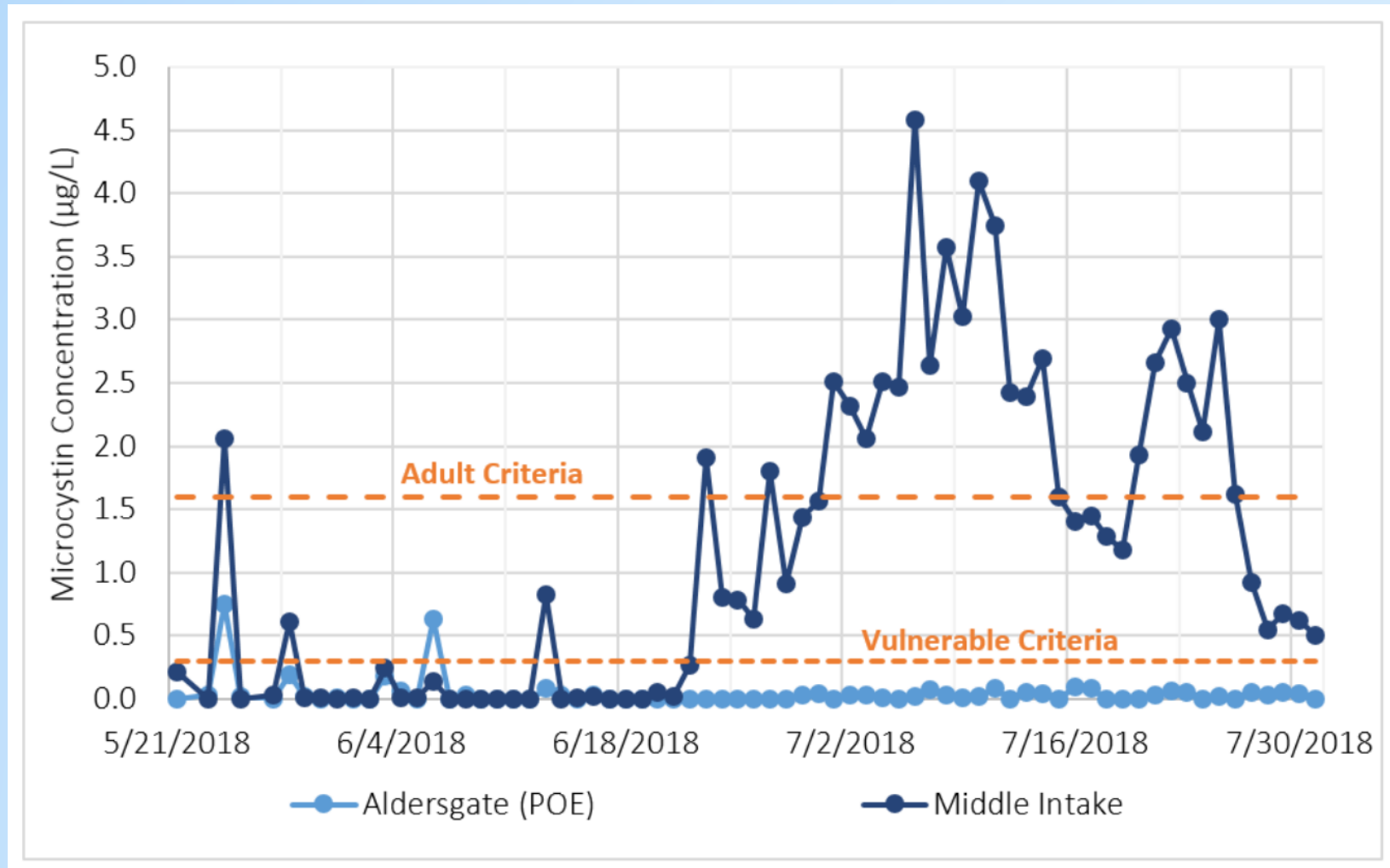
DESIGN CRITERIA:

- 147 MGD Capacity
- Slow Sand Filtration (0.15 gpm/sf, max)
- Roughing filters (sand) used during periods of high turbidity



Geren Island relied on biofiltration to remove algal toxins during the Summer 2018 event

- Development of Microcystin metabolizing biology took several weeks
- Once biology was acclimatized it was highly effective





Summary of Results and Conclusions



Biological filtration practices in the Pacific Northwest have proven water quality benefits



- The operational practice of biofiltration is rising in the PNW
- Distribution system benefits are readily identifiable, in as little as a few months
- Maximized biological treatment may require engineered adjustments (nutrients, pH adjustment, etc.)
- Cold water and low TOC can reduce biological performance, but doesn't eliminate it
- Biofouling or other negative filter performance impacts do not appear to be significant



Contributors and Acknowledgements

Co-Authors:

- Kari Duncan (LO-T)
- Kim DeFolo (Tacoma)
- Ray Leipold (EWEB)
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Thank You

