Evaluation of Distribution System Chemical Water Quality During a Free Chlorine Conversion

Presenter:

David G. Wahman[1]

Co-authors:

Matthew T. Alexander[2], Peyton Woodruff[1], Jatin H. Mistry[3], Helen Y. Buse[1], Christy Muhlen[1], Darren A. Lytle[1], and Jonathan G. Pressman[1]

[1]Office of Research & Development, [2]Office of Water, [3]Region 6

20th Annual EPA Drinking Water Workshop: Small System Challenges and Solutions
September 13, 2023

2020 EPA Regional Applied Research Effort (RARE) Project

- Monitoring **Microbial** and **Chemical** Drinking Water Quality During a Chlorine Maintenance Period

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- Additional EPA project team members:

Chemical	Microbial
Matthew Alexander	Maura Donohue
Darren Lytle	Chelsea Hintz
Christy Muhlen	Dawn King
Jonathan Pressman	Jingrang Lu
David Wahman	Nathan Sienkiewicz
Peyton Woodruff	Ian Struewing

Background

- Chloramines (free chlorine + free ammonia)
  - 2nd most used secondary disinfectant
  - Reduce ***regulated*** disinfection byproducts (DBPs)
  - Greater stabilty than free chlorine?
  - Add ammonia in excess to form & ammonia releases during decay/demand

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  - Ammonia oxidizing microorganisms (competition of growth versus disinfection)
- Free chlorine conversion (FCC)
  - Control nitrification (planned or operational response)
  - Chloramines → free chlorine (~1–2 months) → chloramines
  - Regulated DBP formation ⇧ (compliance sampling outside FCC → implications?)
  - Other unintended consequences (e.g., Δ pH or metals)

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- Understand chemical water quality before, during, & after FCC
  - Greater spatial & temporal coverage than published studies
  - Distribution system & residential sample locations
  - Provide chemical water quality data for microbial papers

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5. Metals (orthophosphate, copper, lead, iron, & zinc)

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Previous RARE (SW-2)

ASCE Journal of Environmental Engineering (2023)

https://doi.org/10.1061/(ASCE)EE.1943-7870.0002062

Investigation of Chloramines, Disinfection Byproducts, and Nitrification in Chloraminated Drinking Water Distribution Systems

Gulizhaer Abulikemu[1]; Jatin H. Mistry[2]; David G. Wahman[3]; Matthew T. Alexander[4]; Alison R. Kennicutt[5]; Jacob D. Bollman[6]; and Jonathan G. Pressman[7]

Water Research (2021)

https://doi.org/10.1016/j.watres.2021.117689

Chloramine Concentrations within Distribution Systems and Their Effect on Heterotrophic Bacteria, Mycobacterial Species, and Disinfection Byproducts

Stacy Pfaller[a], Dawn King[a], Jatin H. Mistry[c], Matthew Alexander[b], Gulizhaer Abulikemu[d], Jonathan G. Pressman[a], David G. Wahman[a], Maura J. Donohue[a,*]

Water Research (2021)

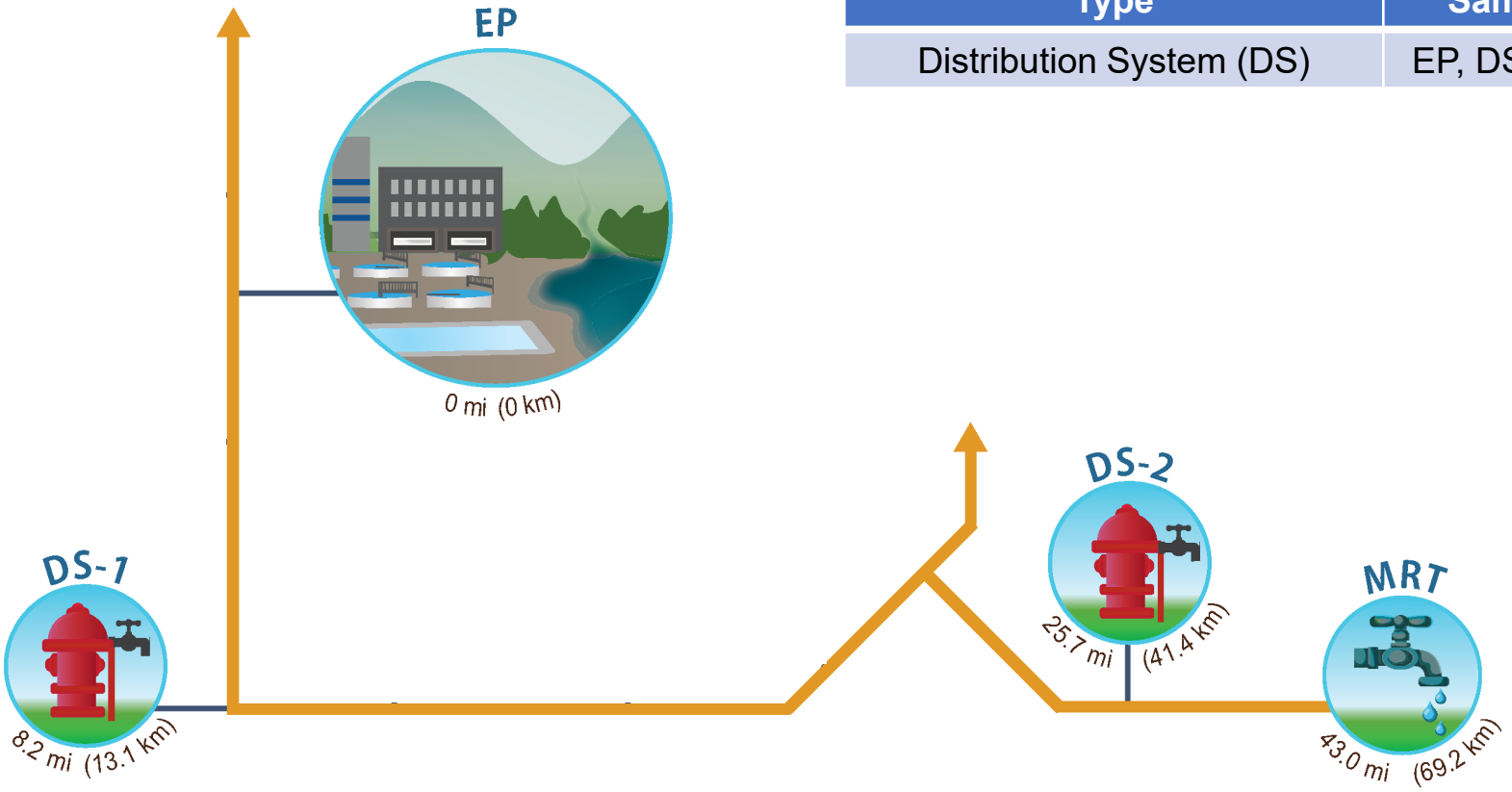
https://doi.org/10.1016/j.watres.2021.117571

Legionella and other opportunistic pathogens in full-scale chloraminated municipal drinking water distribution systems

Chiqian Zhang[a], Ian Struewing[b], Jatin H. Mistry[c], David G. Wahman[b], Jonathan Pressman[b], Jingrang Lu[b,*]

Sample Locations

Type	Sample Locations
Distribution System (DS)	EP, DS-1, DS-2, & MRT



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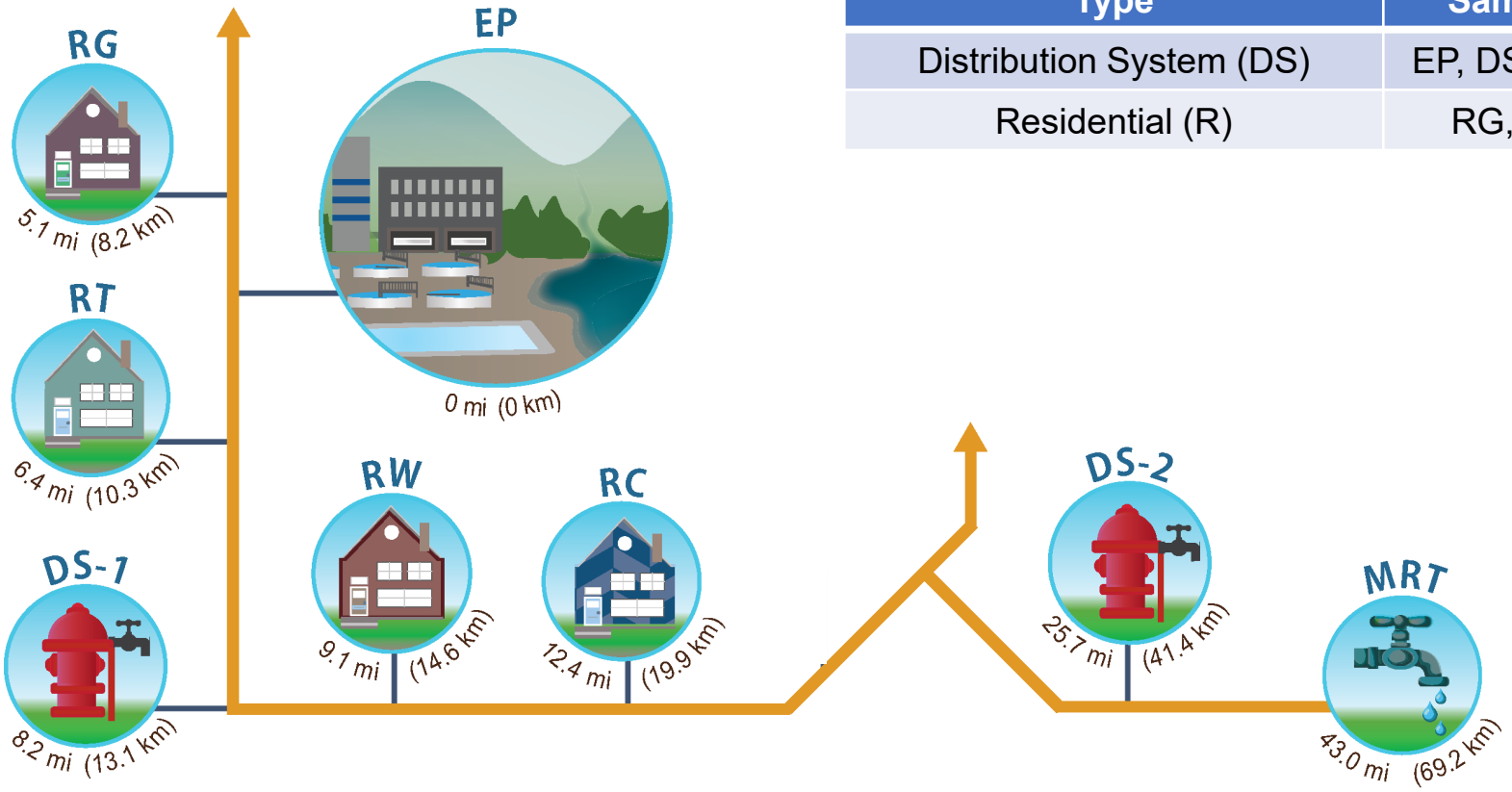

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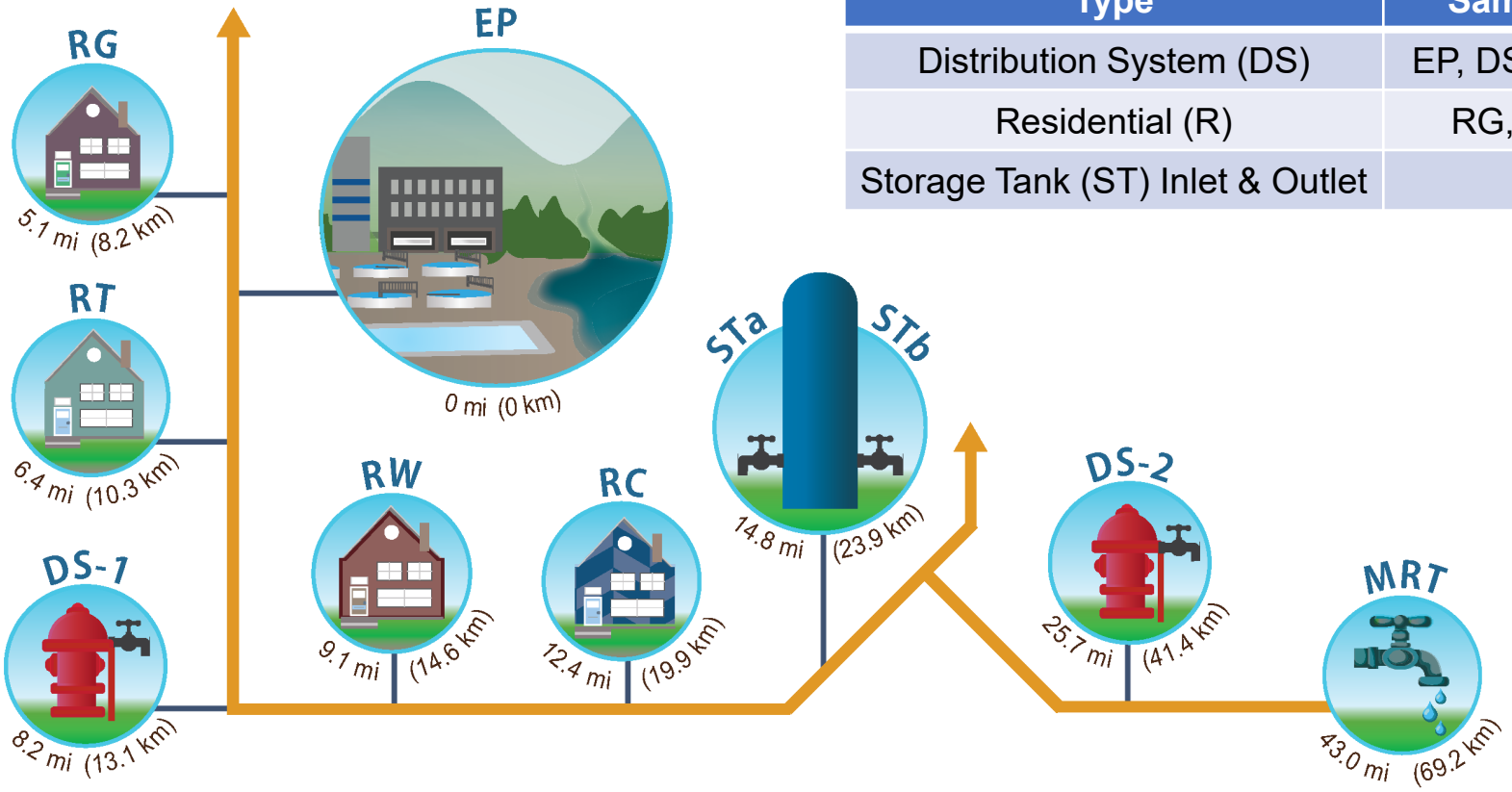
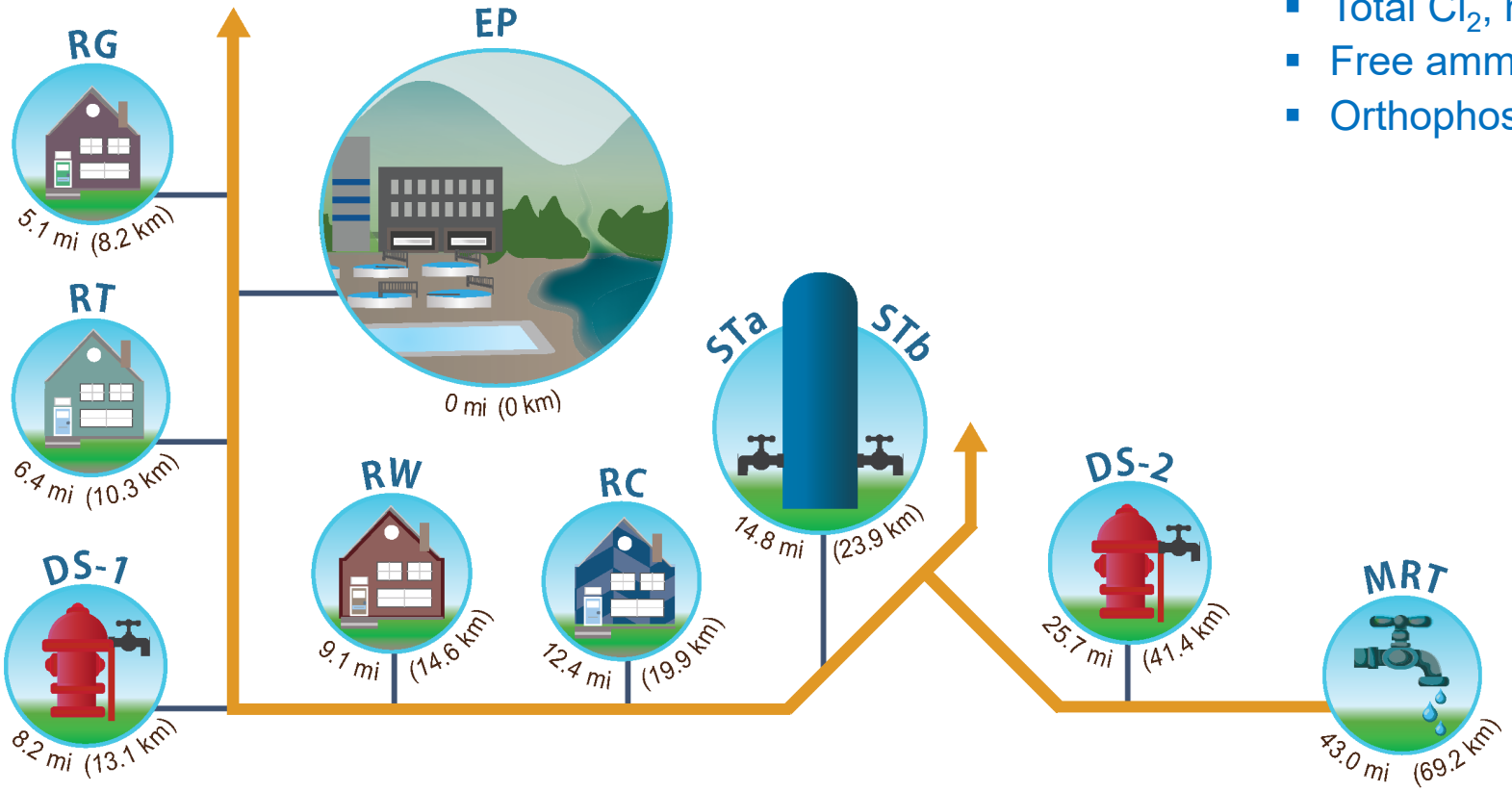
Storage Tank (ST) Inlet & Outlet	STa & STb



Sample Activities

- All samples (field)
  - Temperature & pH
  - Total Cl_2, mono, & free Cl_2
  - Free ammonia & nitrite
  - Orthophosphate



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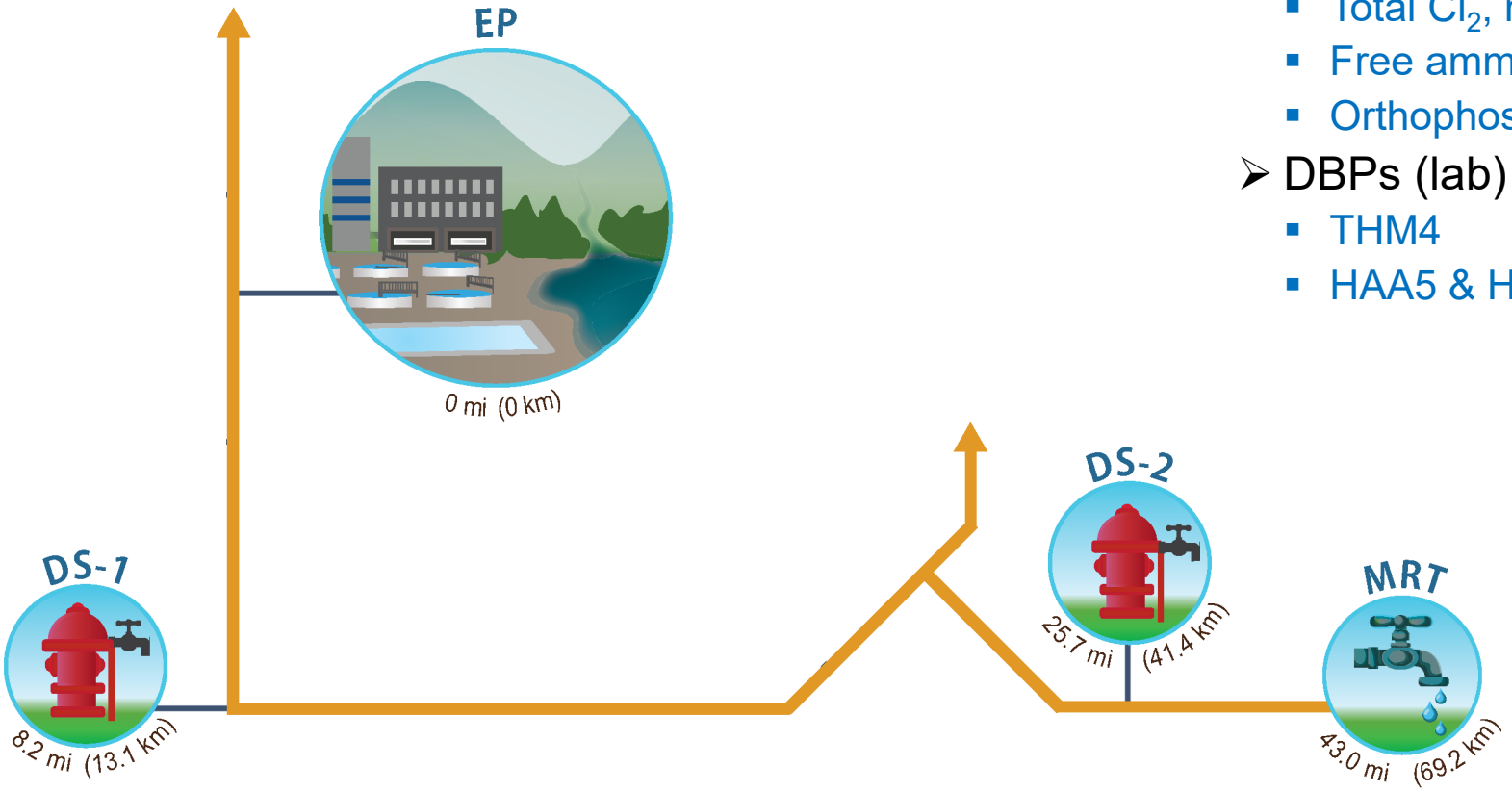

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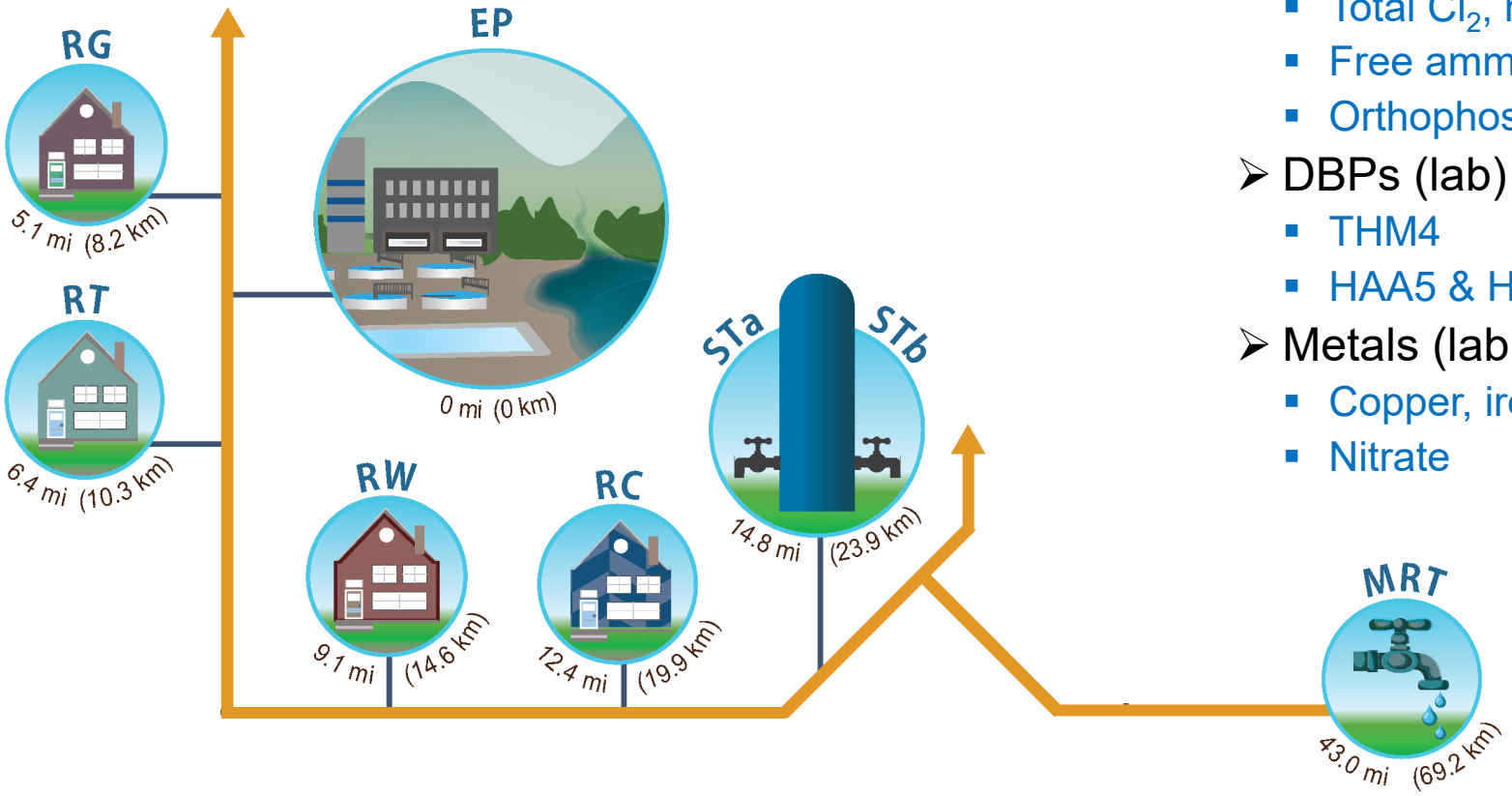

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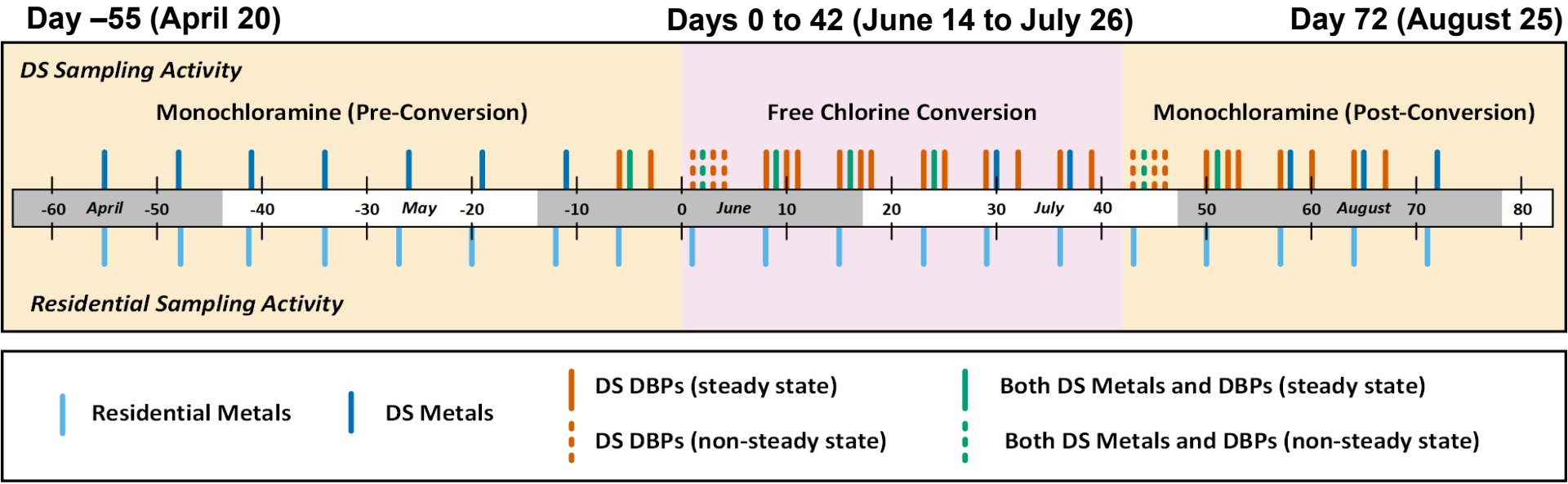
  - Copper, iron, lead, & zinc
  - Nitrate

Sample Timeline (April to August 2021)



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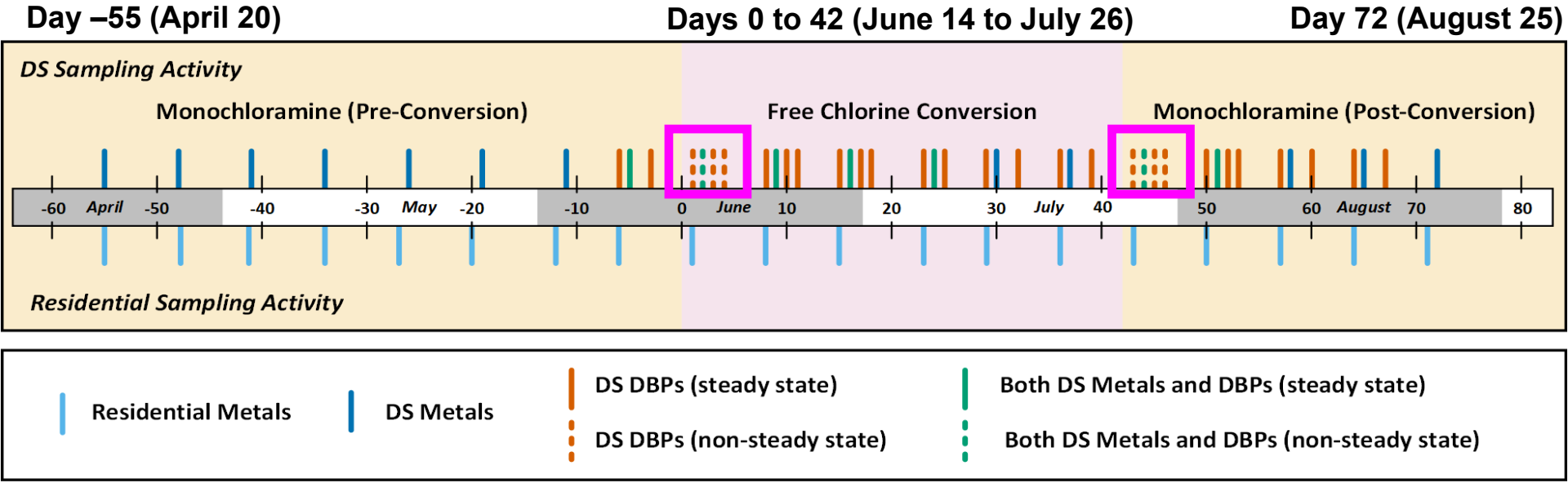

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  - Temporally variable data
  - Shows temporal transients
  - 4 days immediately after conversions

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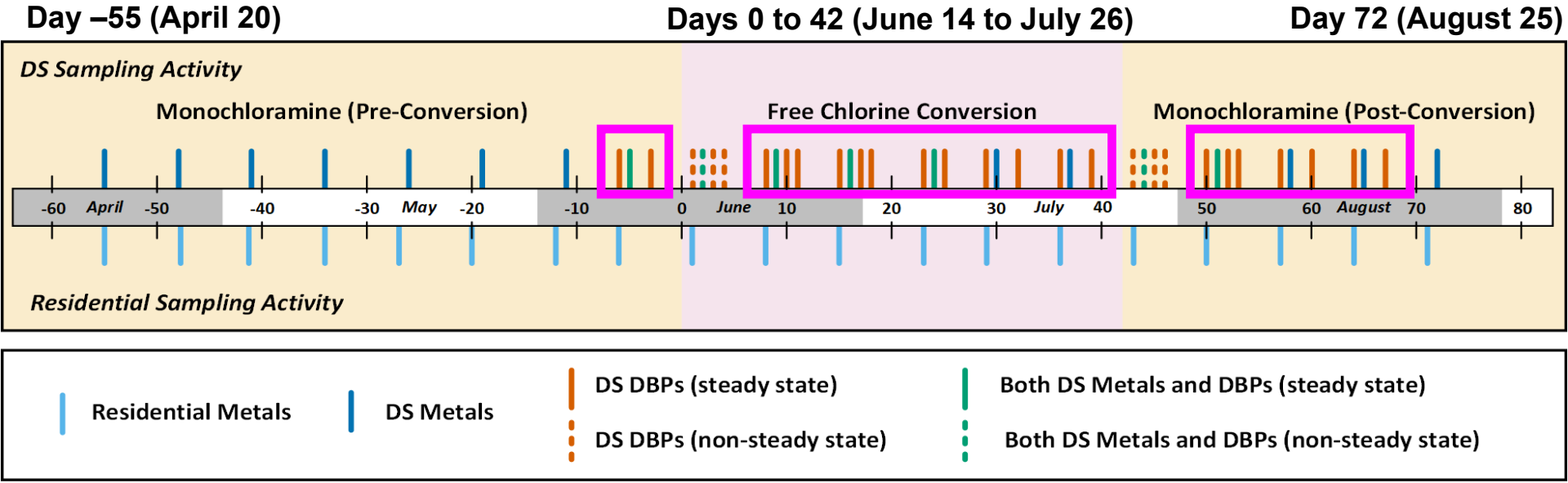
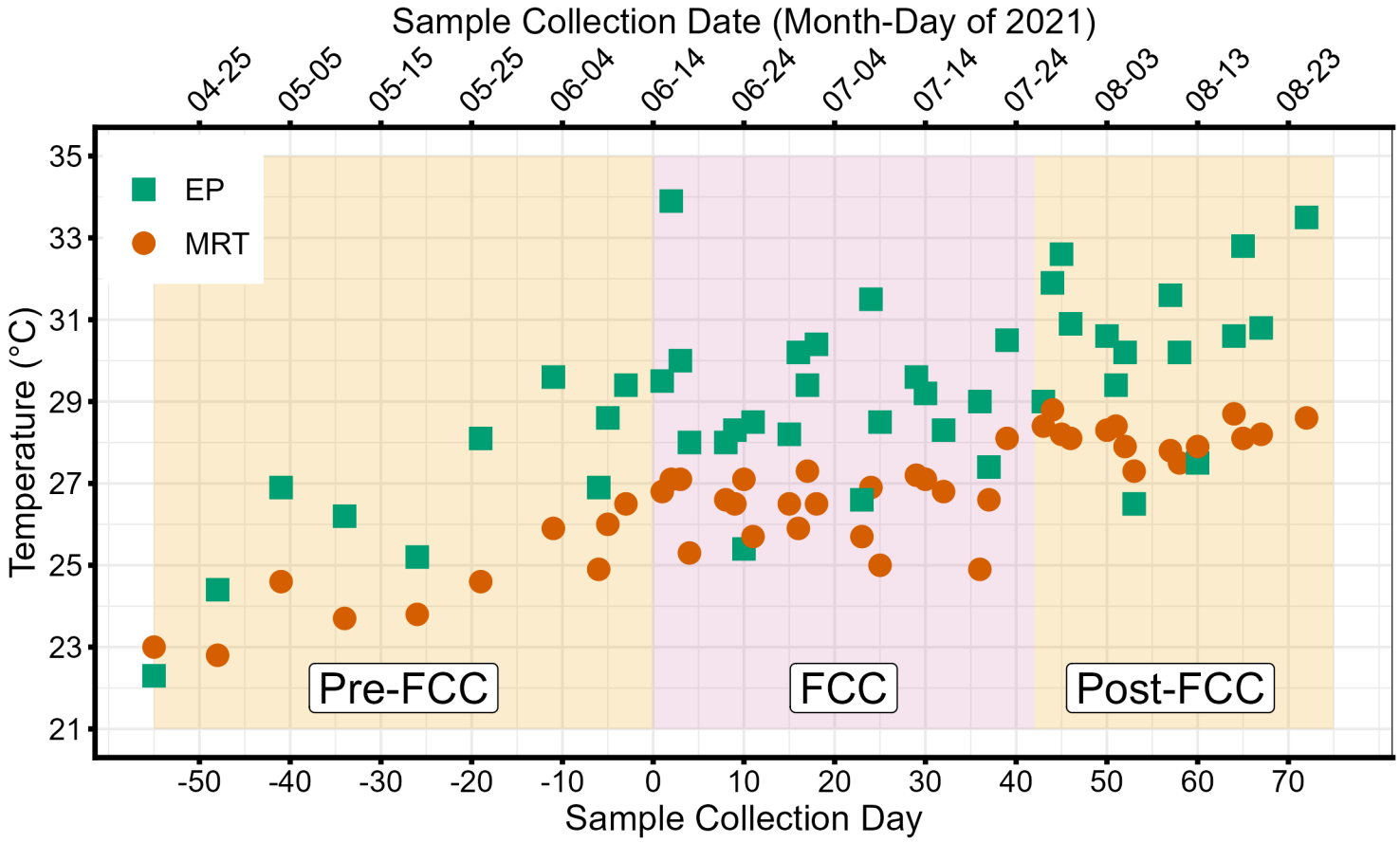


- DS non-steady state
  - Temporally variable data
  - Shows temporal transients
  - 4 days immediately after conversions
- DS steady-state
  - Relatively consistent data
  - Averaged data
    - Pre-FCC (Days –6 to 0)
    - FCC (Days 8 to 39)
    - Post-FCC (Days to 50 to 67)

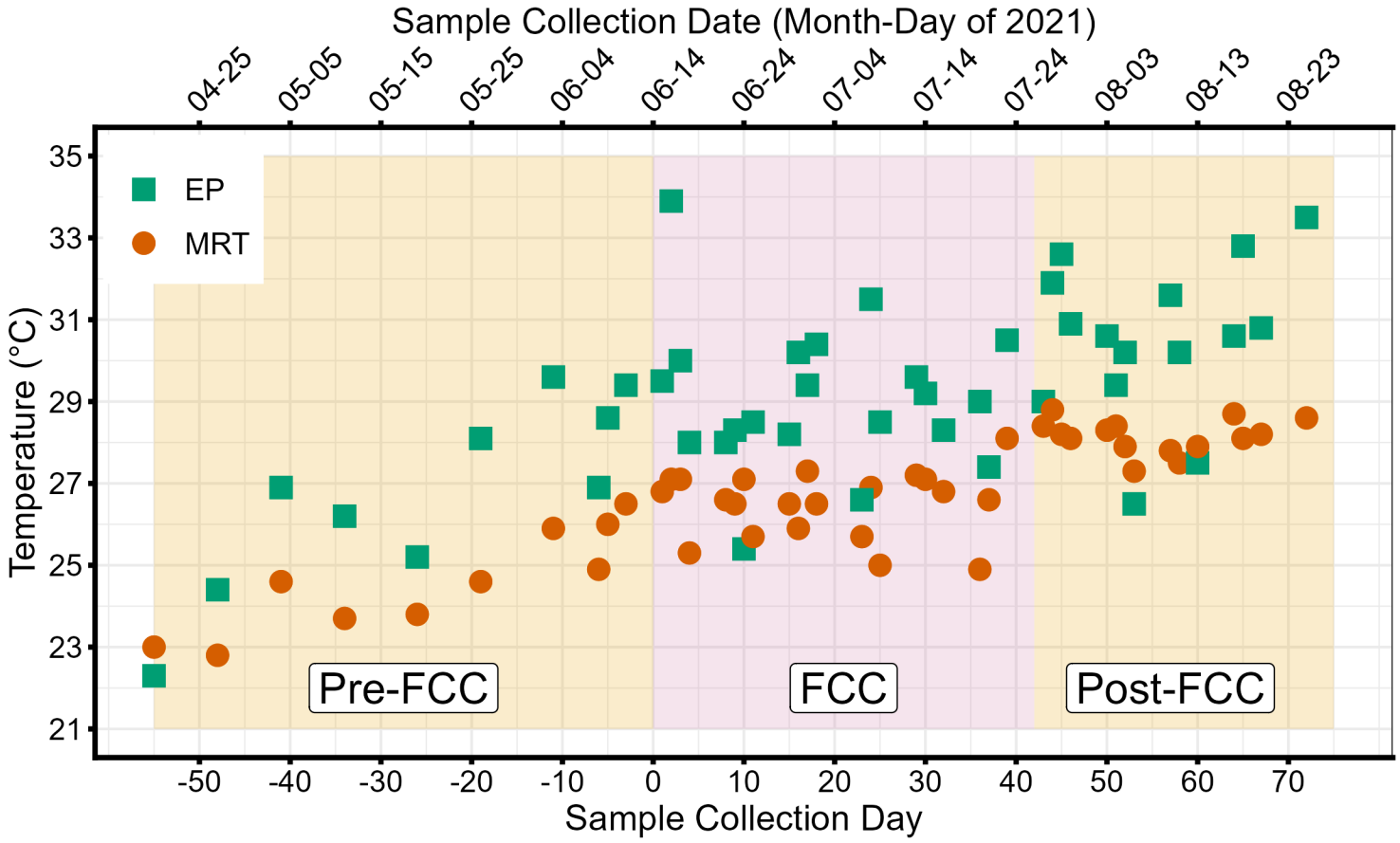
Temperature (All Samples)

- Seasonal ⇧



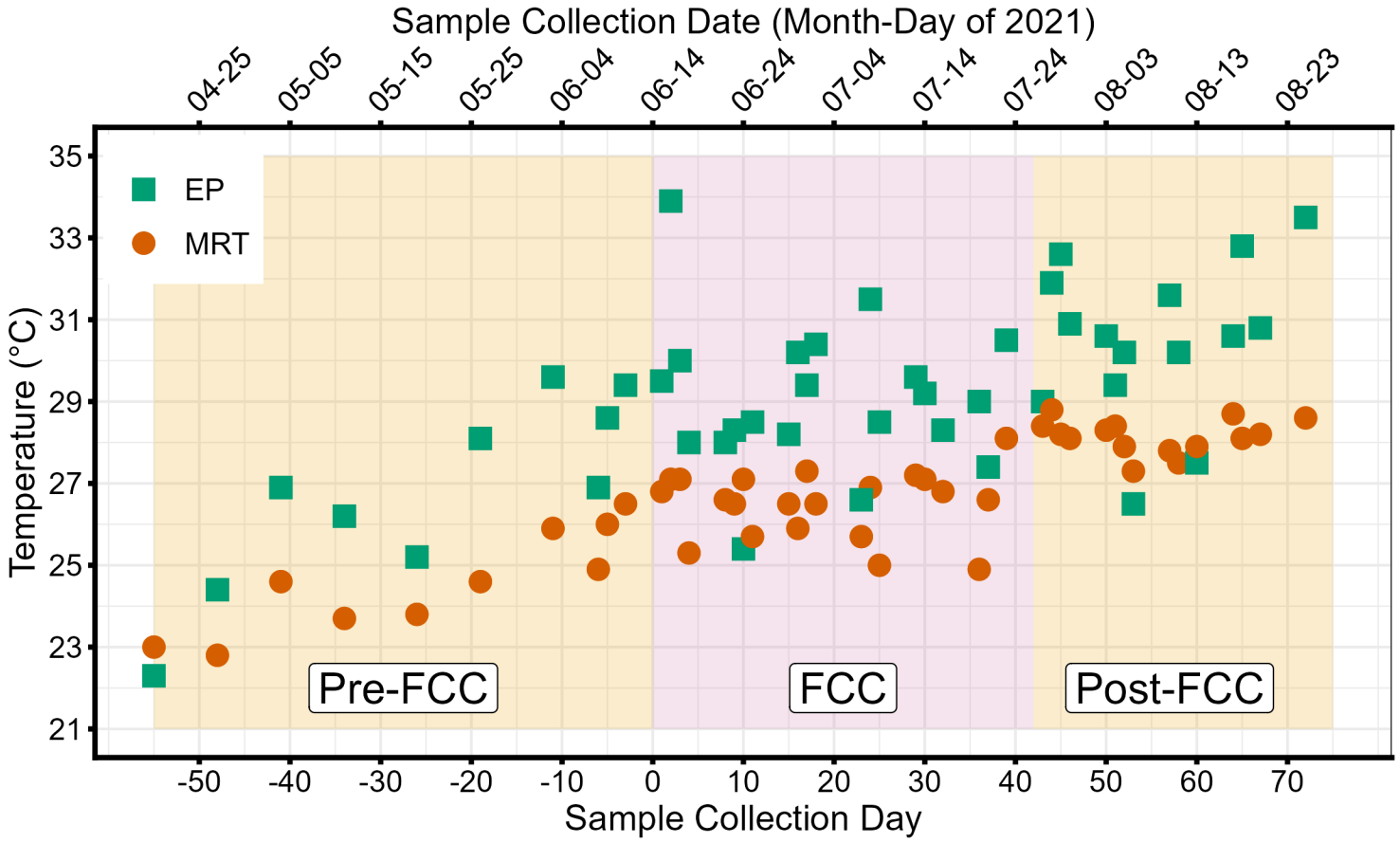
Temperature (All Samples)

- Seasonal ⇧
- EP
  - 11°C ⇧
  - More scatter



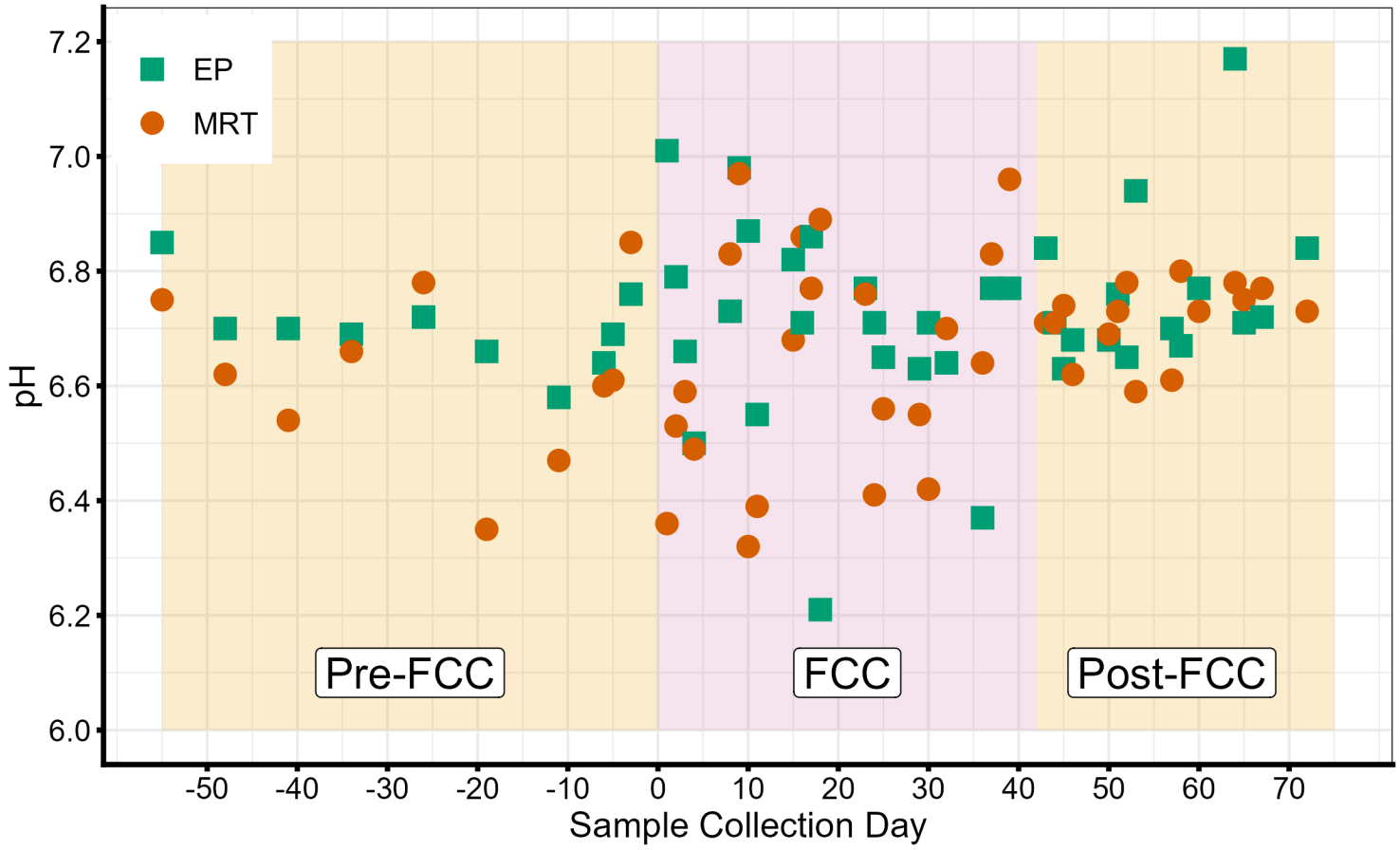
Temperature (All Samples)

- Seasonal ⇧
- EP
  - 11°C ⇧
  - More scatter
- MRT
  - 6°C ⇧
  - Less scatter
  - General ⇩ from EP



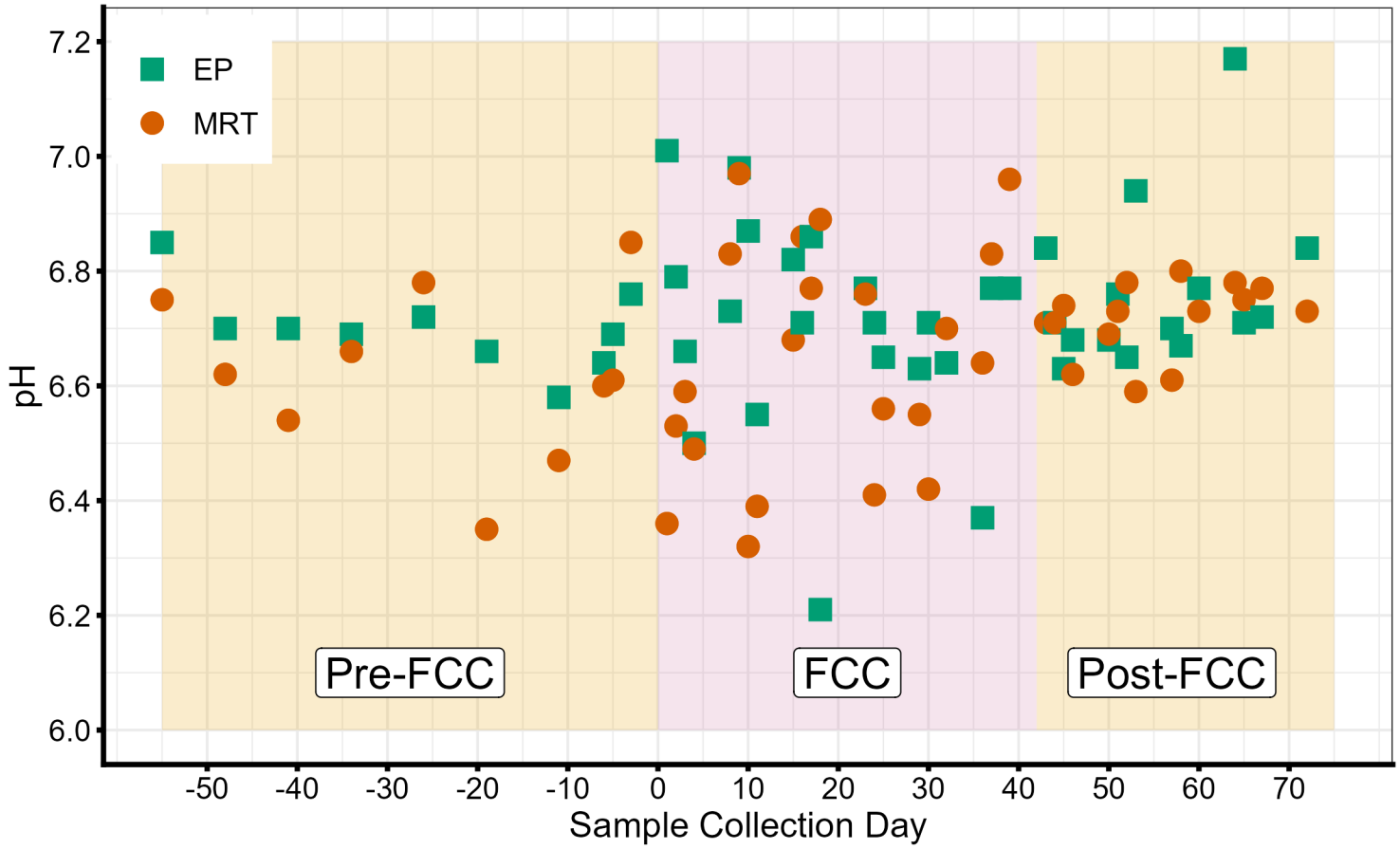
pH (All Samples)

- No trends (scatter)



pH (All Samples)

- No trends (scatter)
- EP
  - pH 6.5–7.0
  - Less variable
  - FCC ⇧ variability



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- EP
  - pH 6.5–7.0
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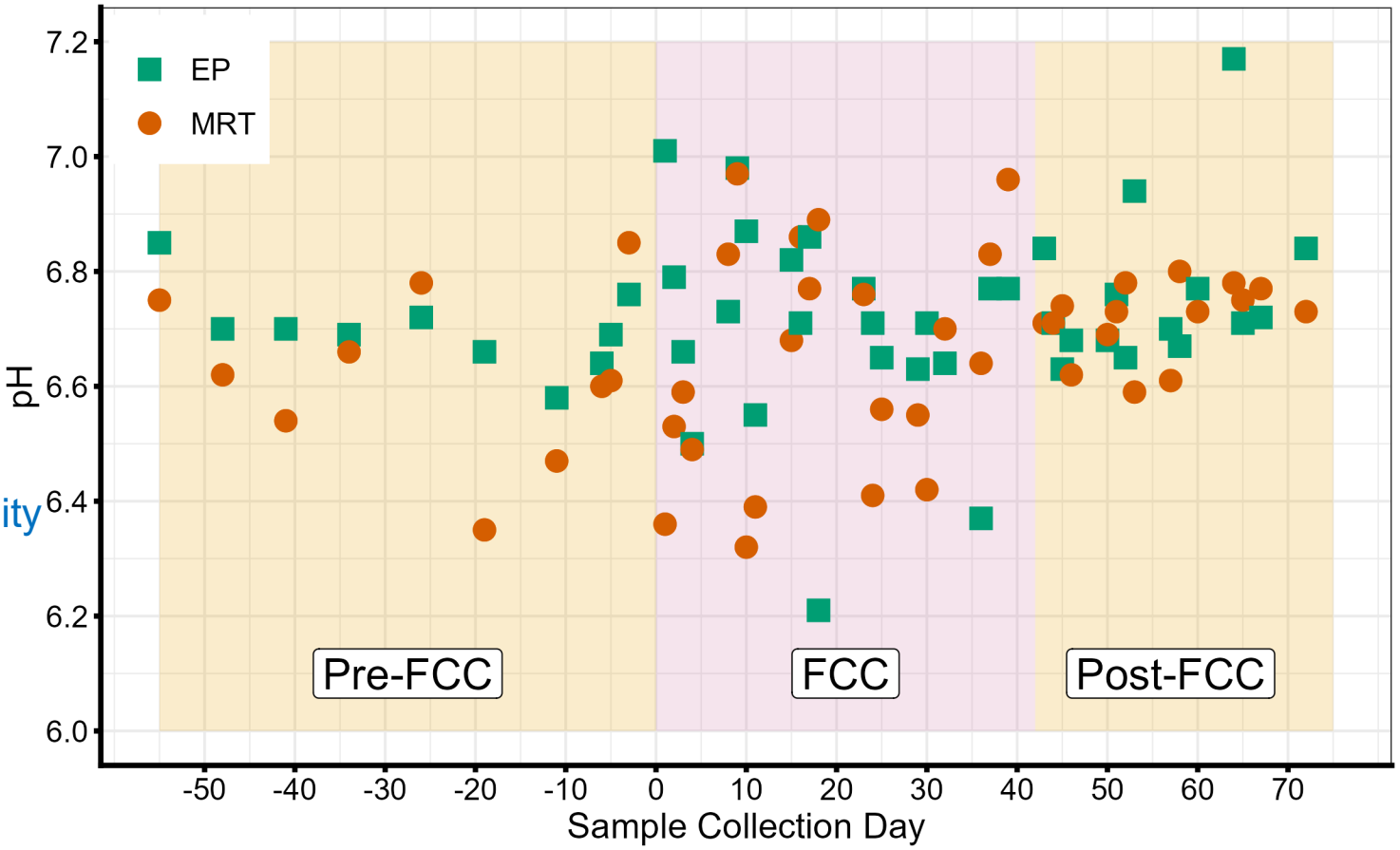
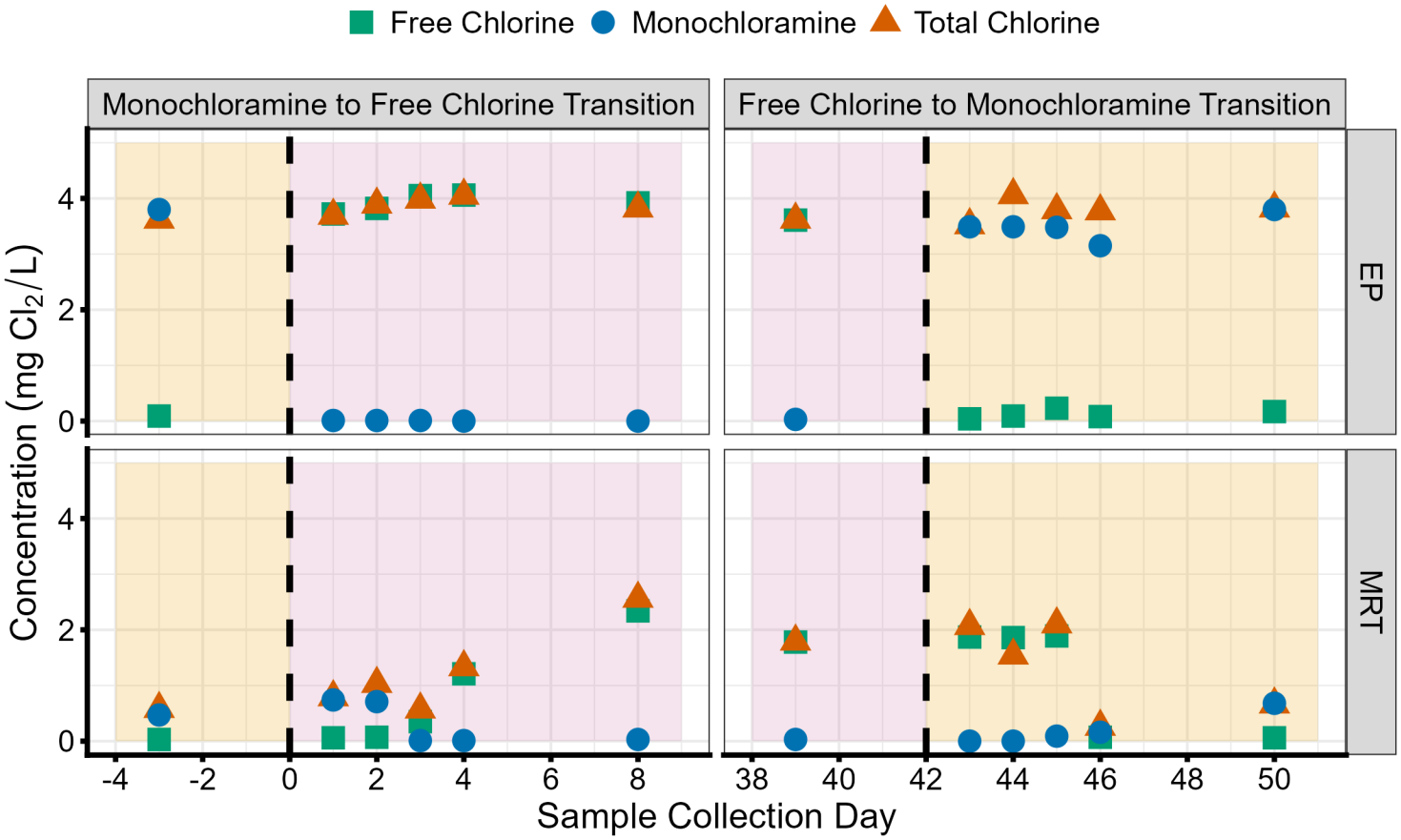
- MRT
  - pH 6.3–7.0
  - More variable
  - Post-FCC ⇩ variability



Disinfectants (Non-Steady State)



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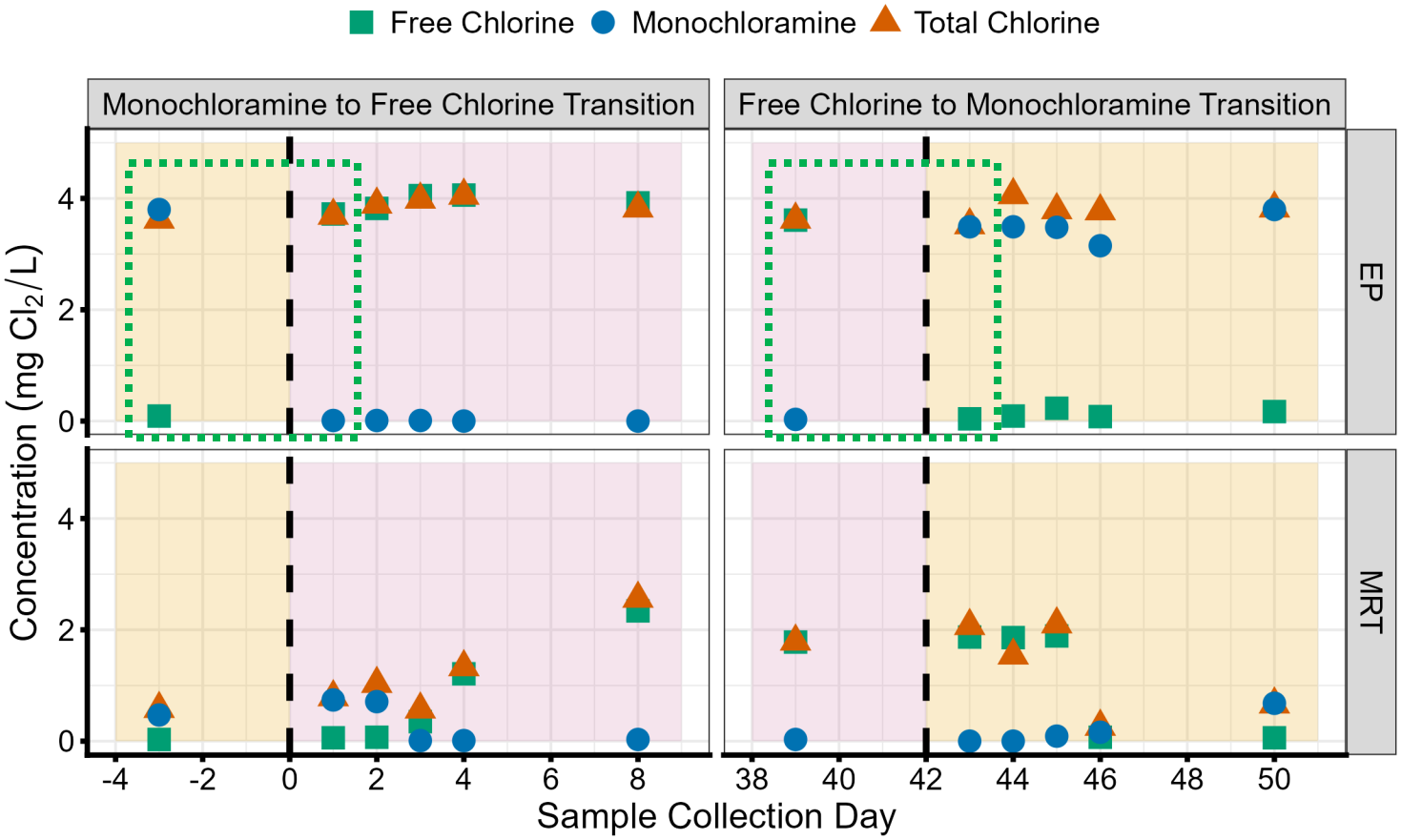
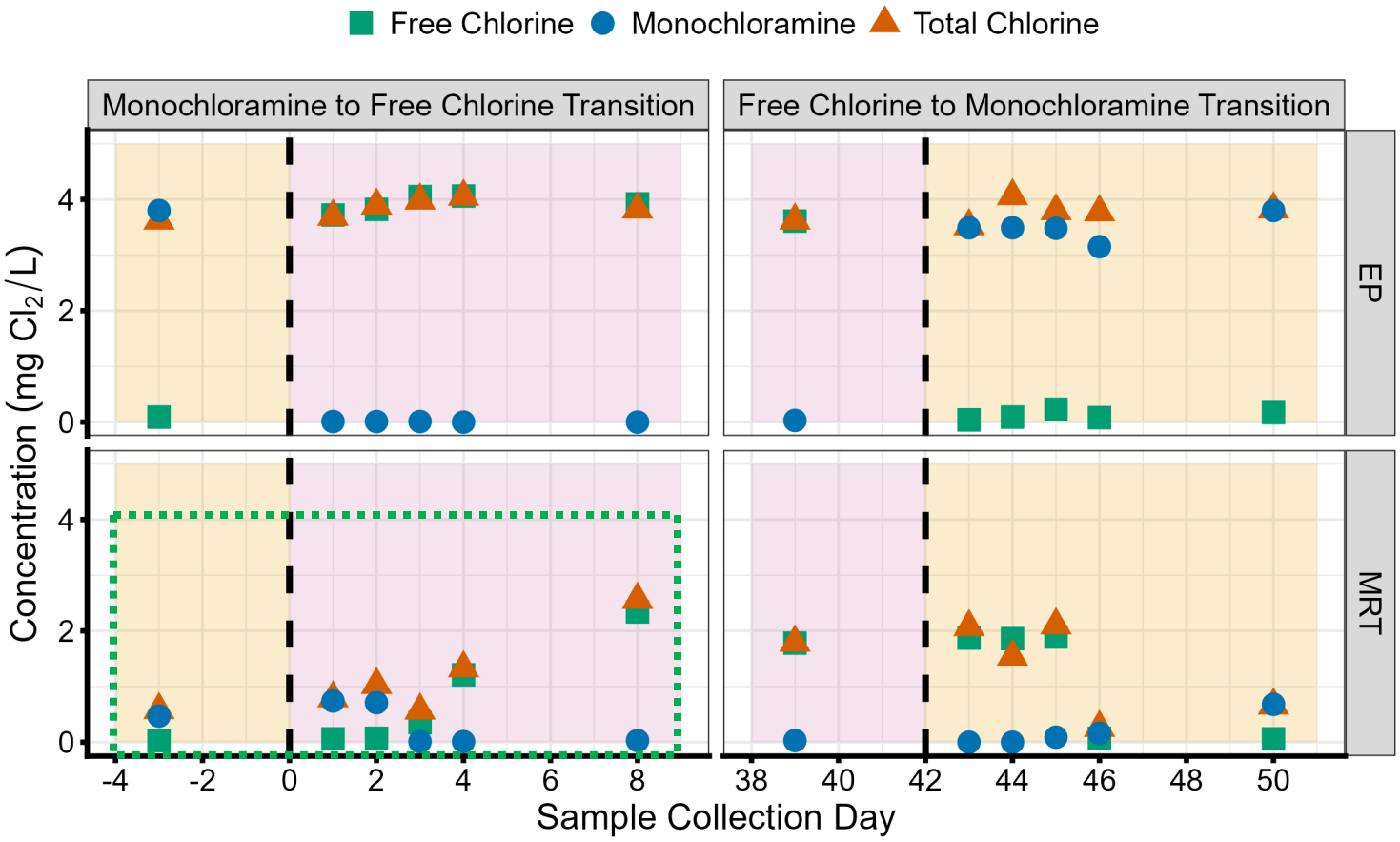


Disinfectants (Non-Steady State)

- EP → immediate Δ
- MRT (mono to free)
  - free (3–4 days)
  - stable (8 days)
  - free > mono



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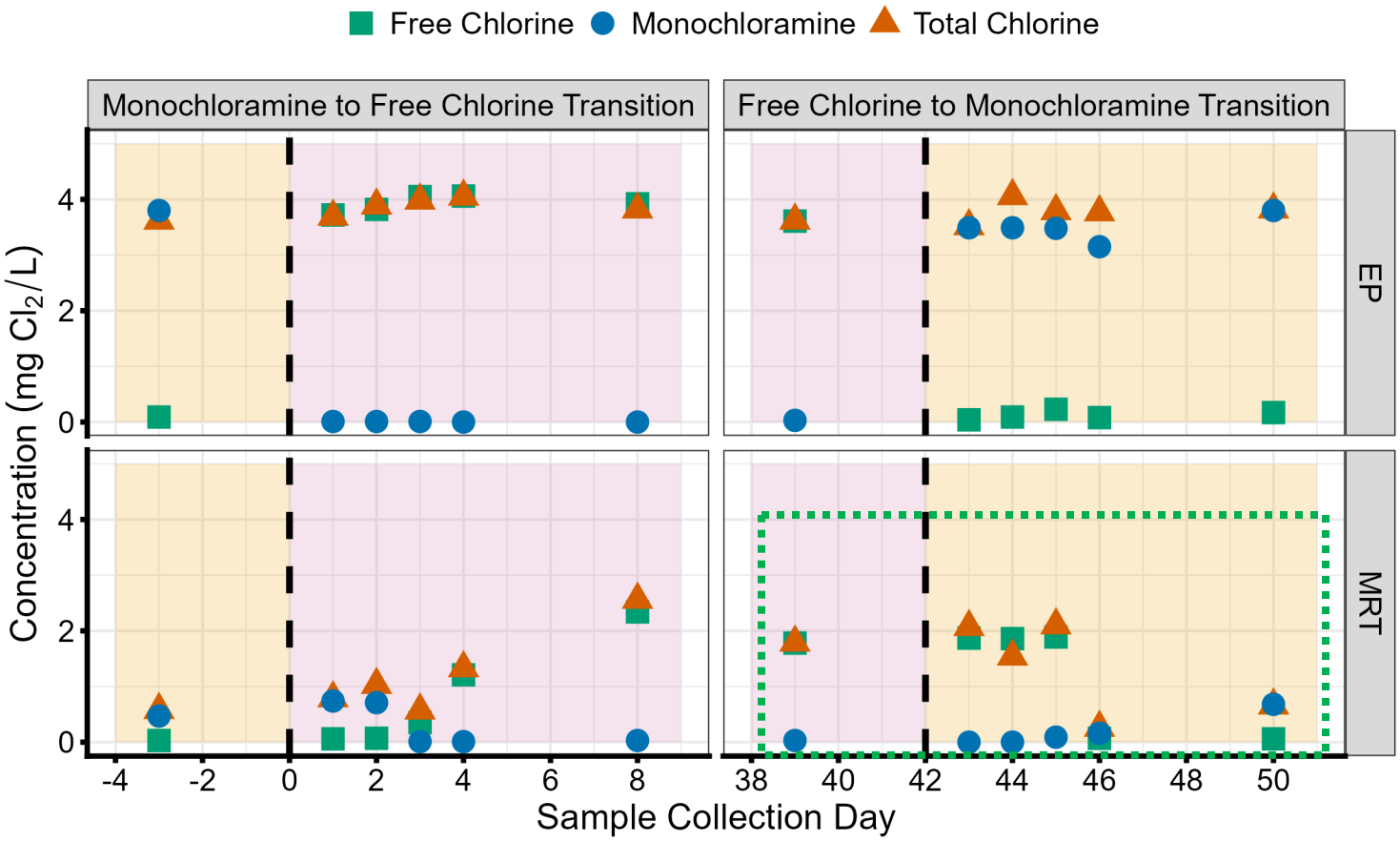
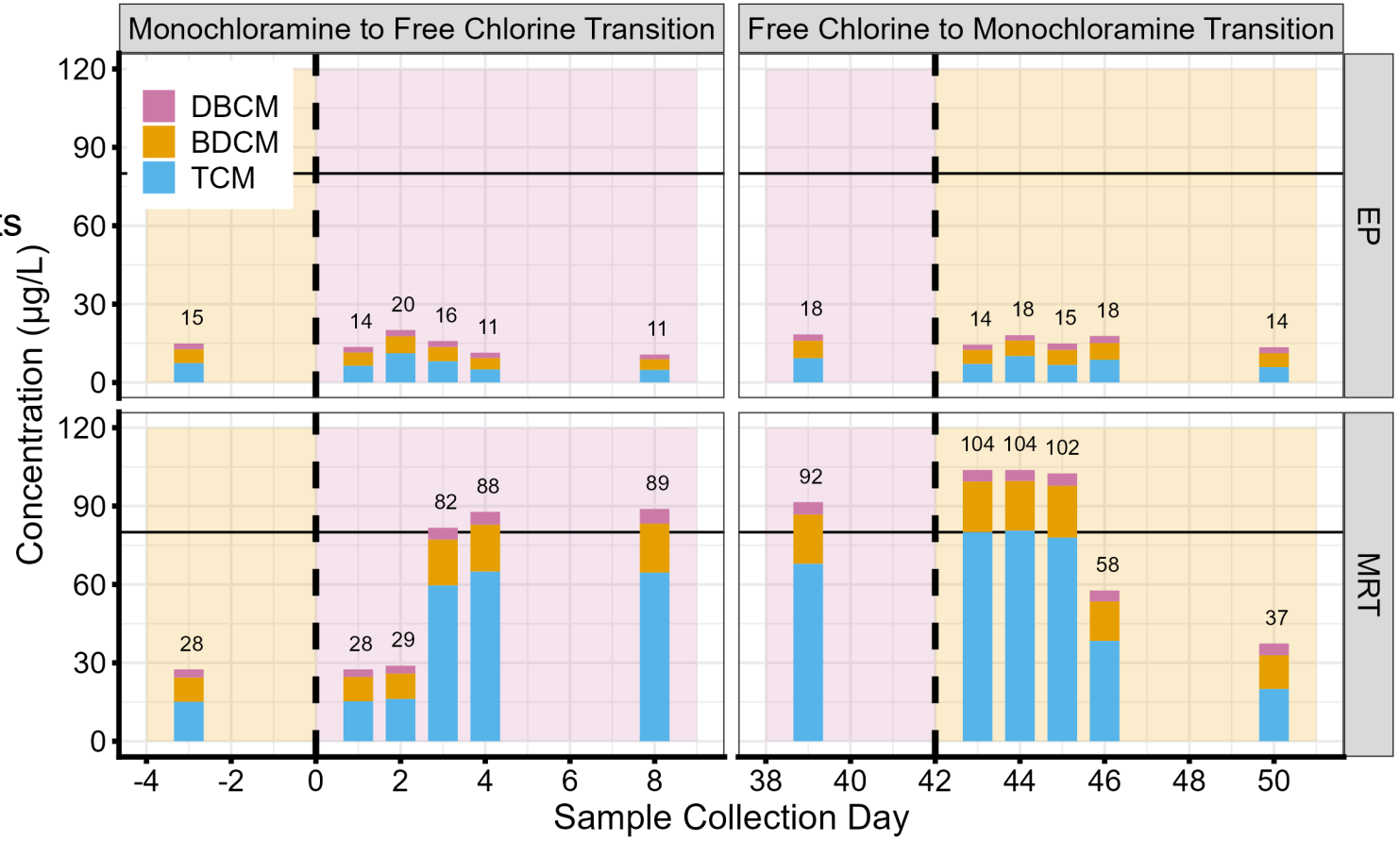


THMs (Non-Steady State)

- No TBM
- Mainly chlorinated
- Parallels disinfectants



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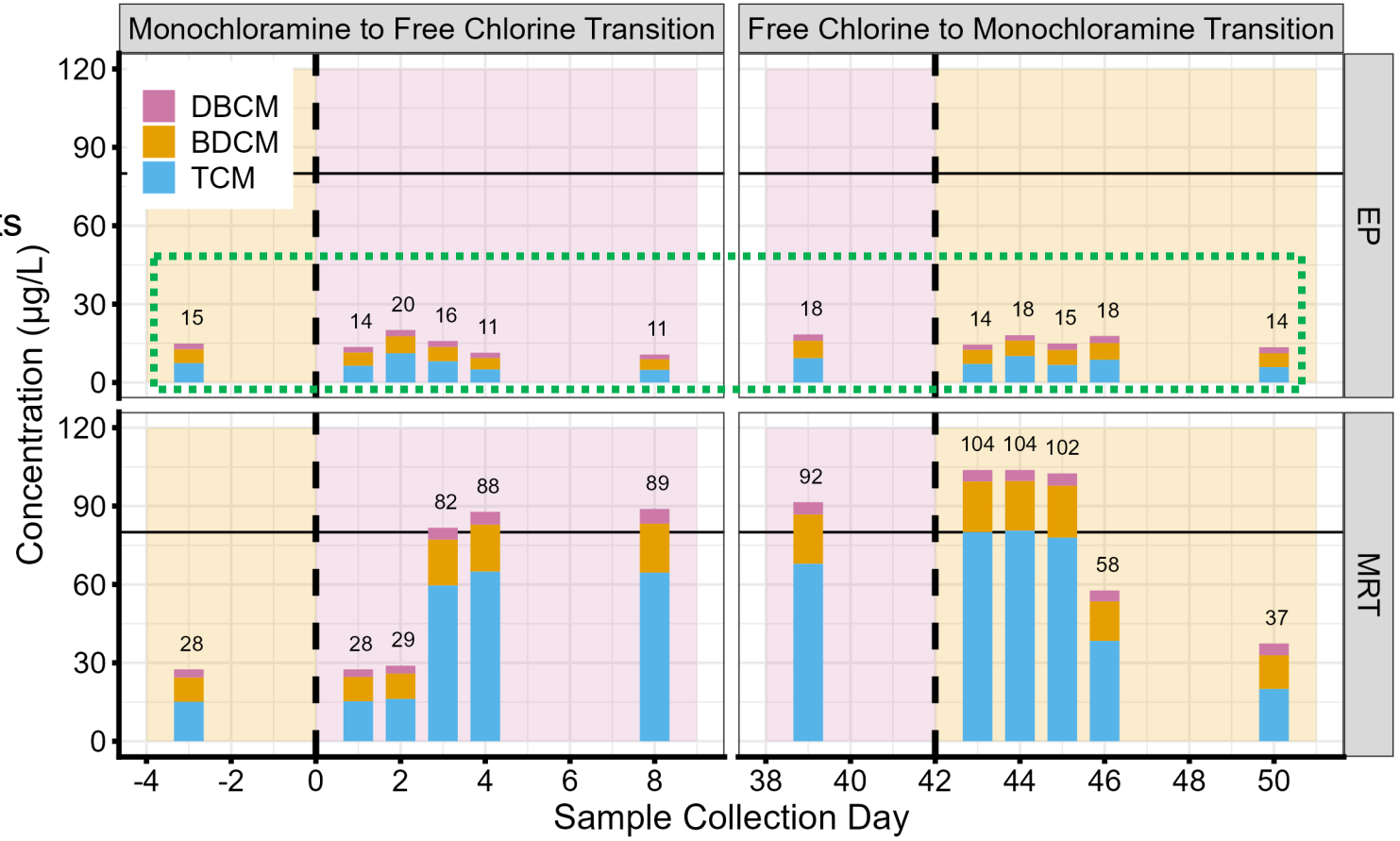

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  - Mainly TCM ⇧
  - Some BDCM ⇧
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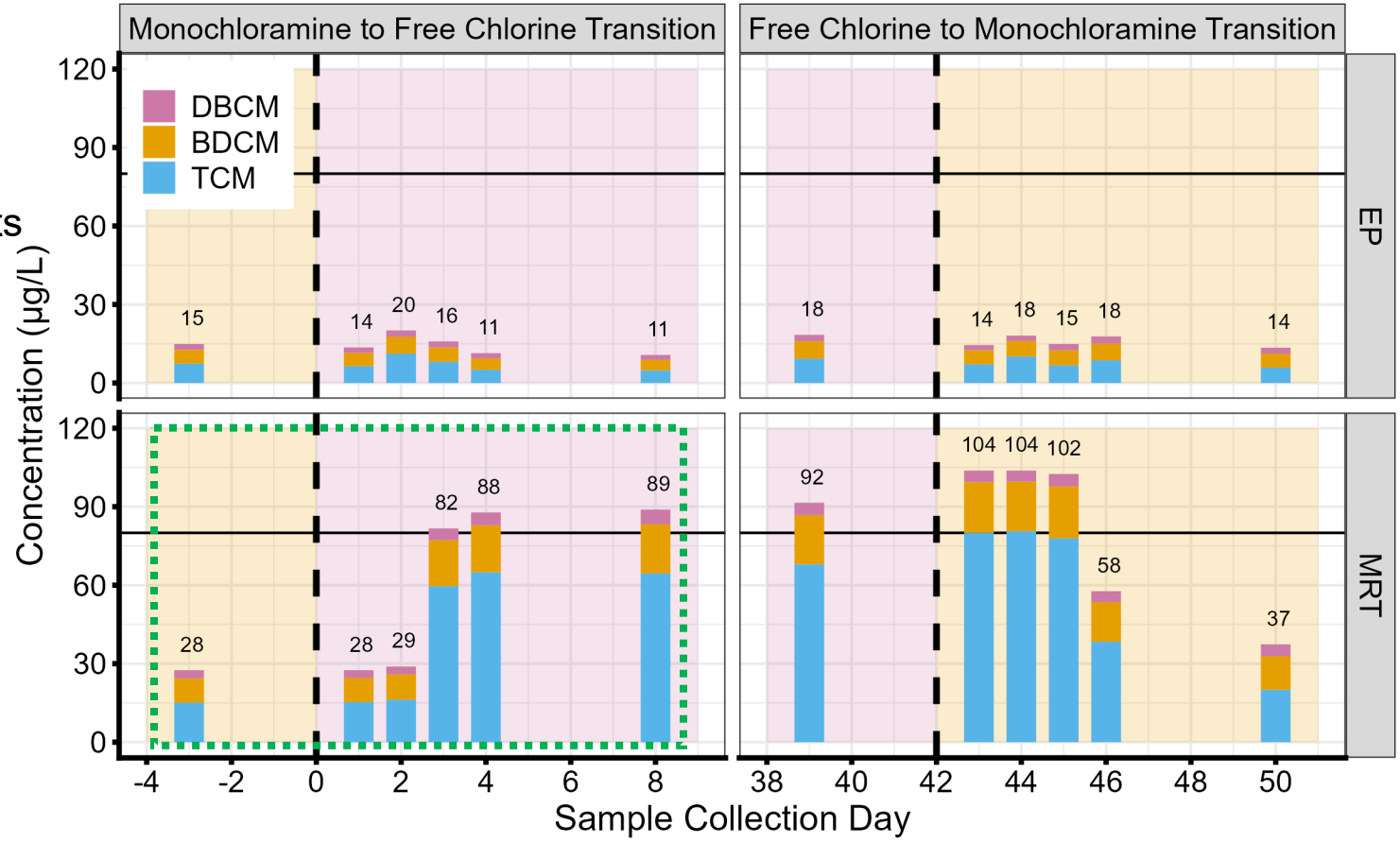

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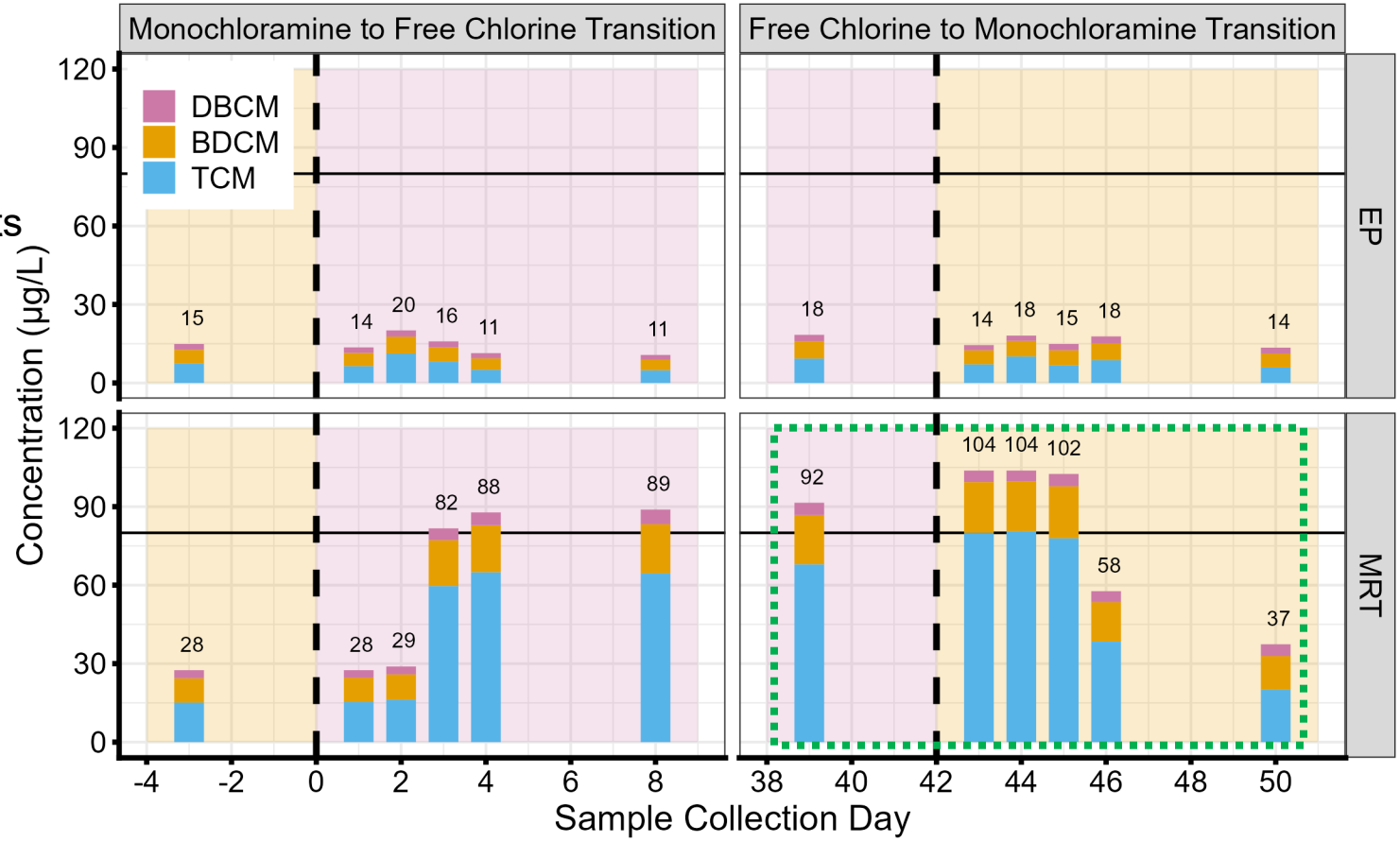

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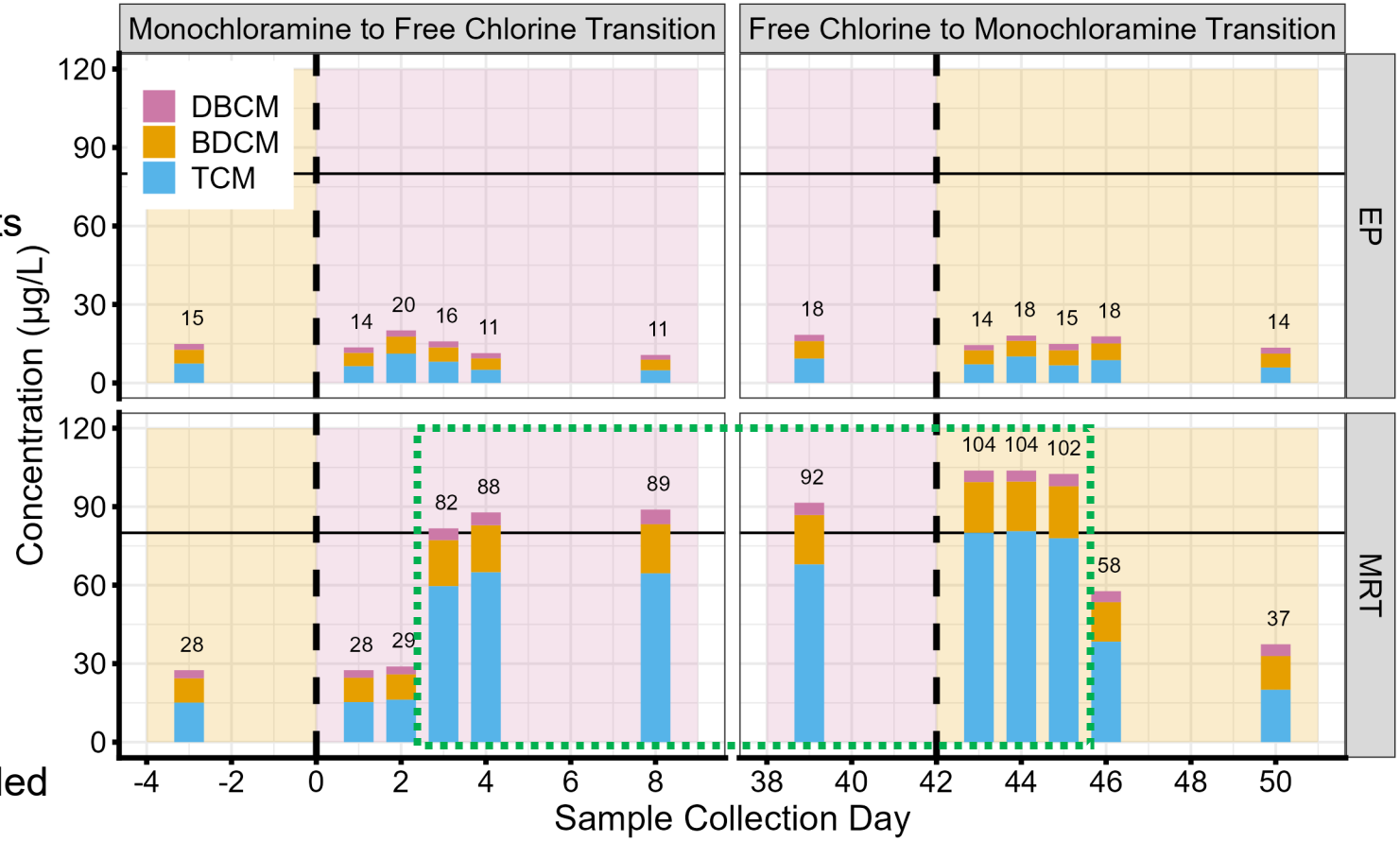

HAAs (Non-Steady State)

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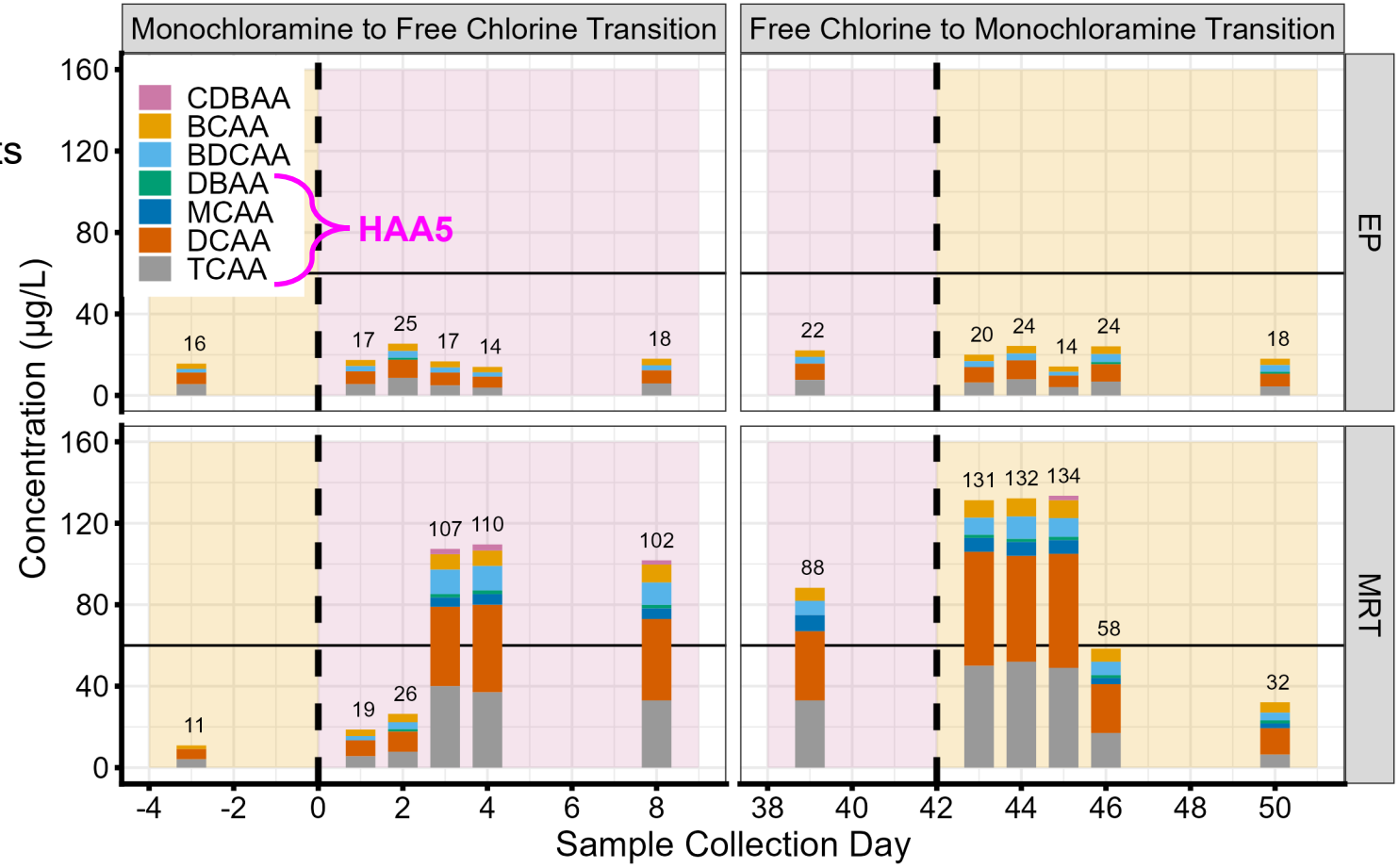
- Parallels disinfectants



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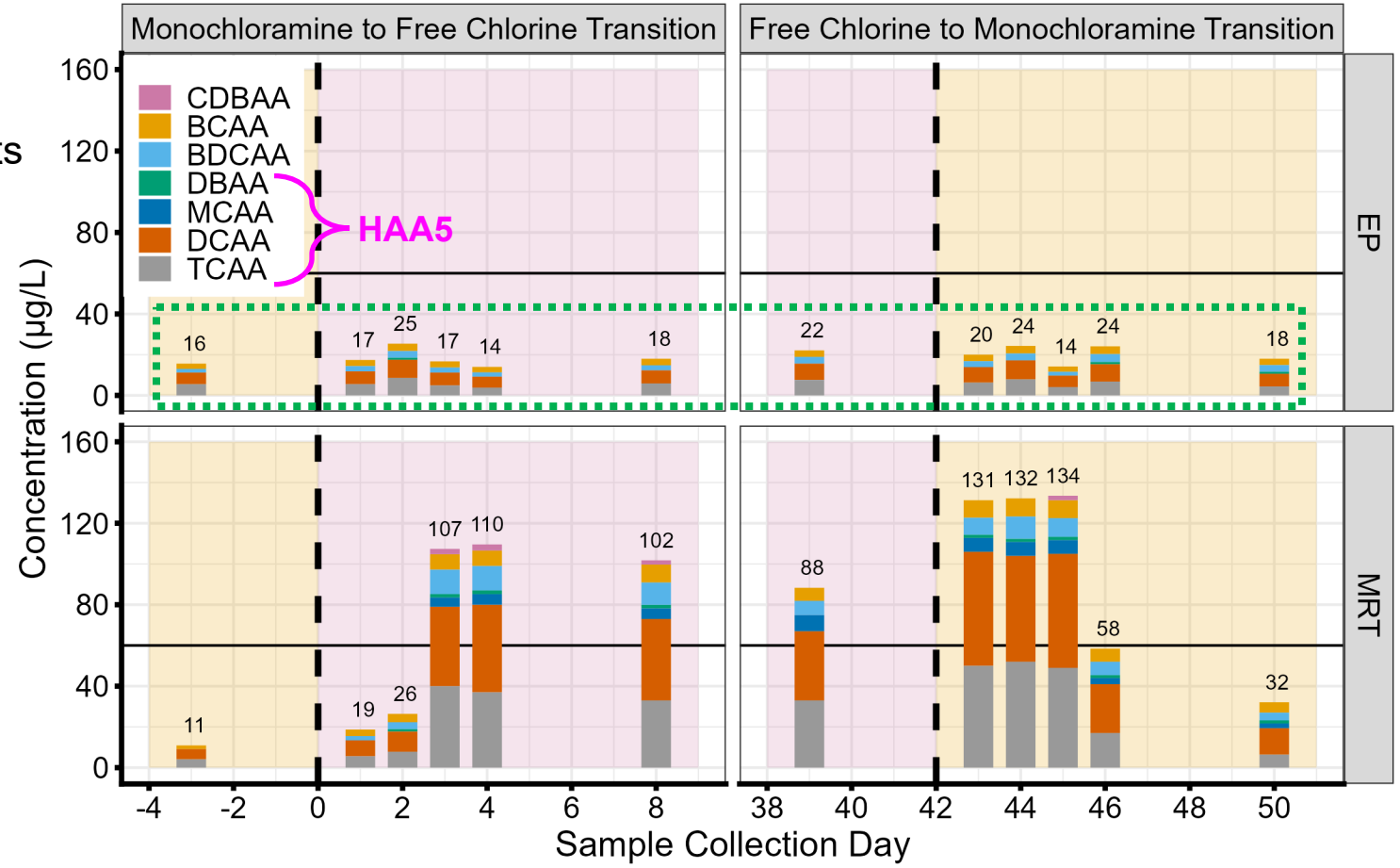

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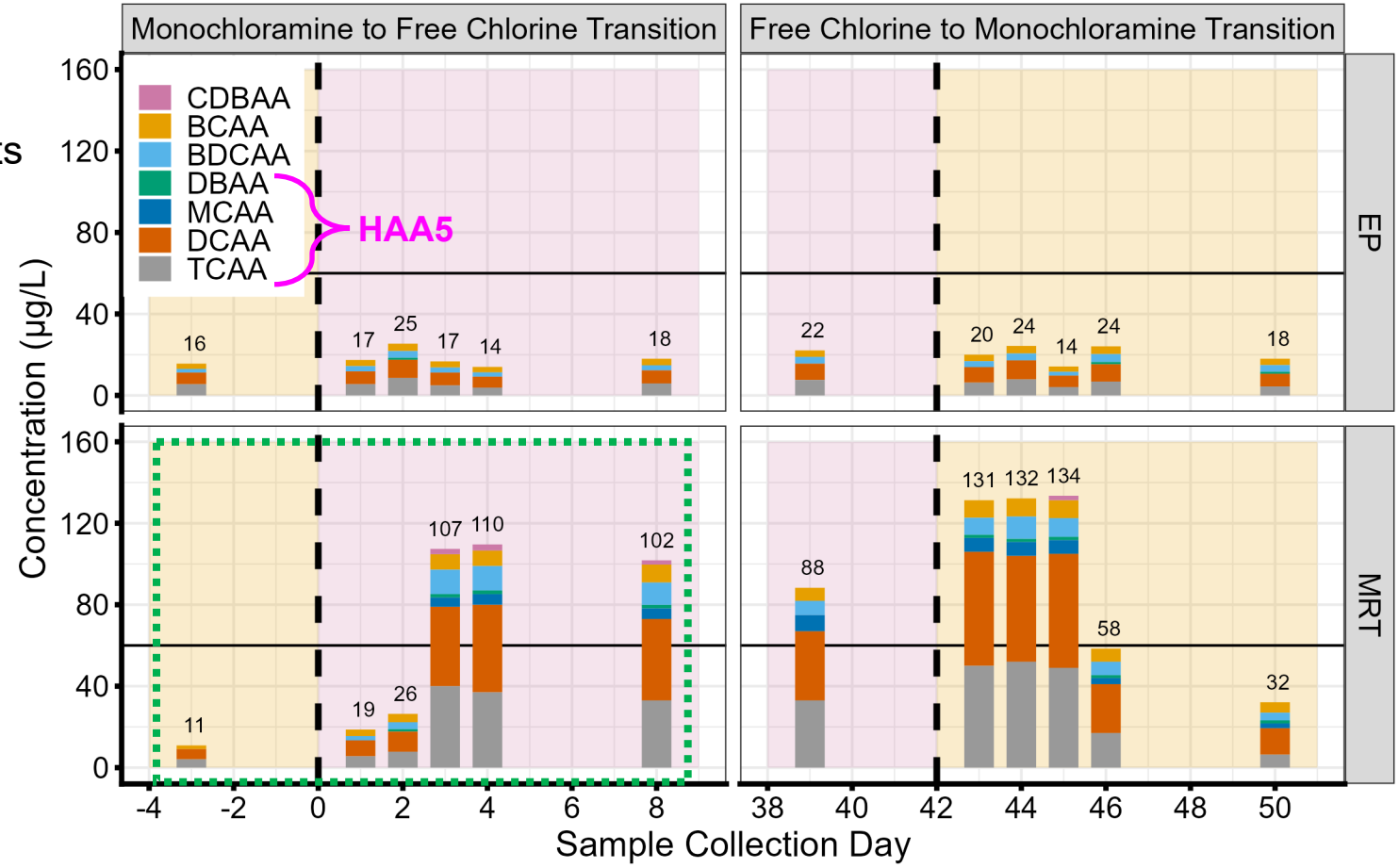
  - HAA9 ⇧ (10x)
  - Mainly chlorinated



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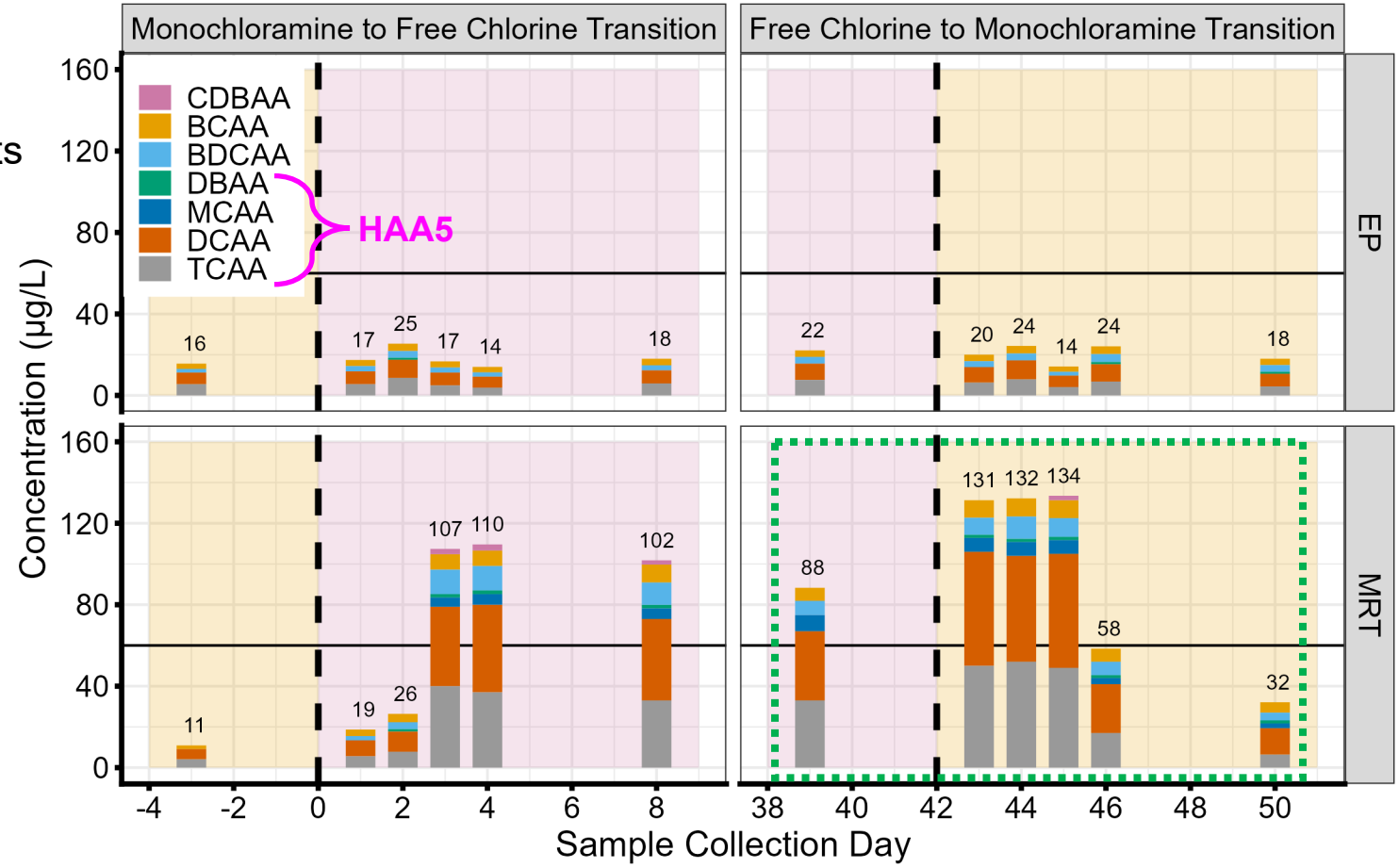
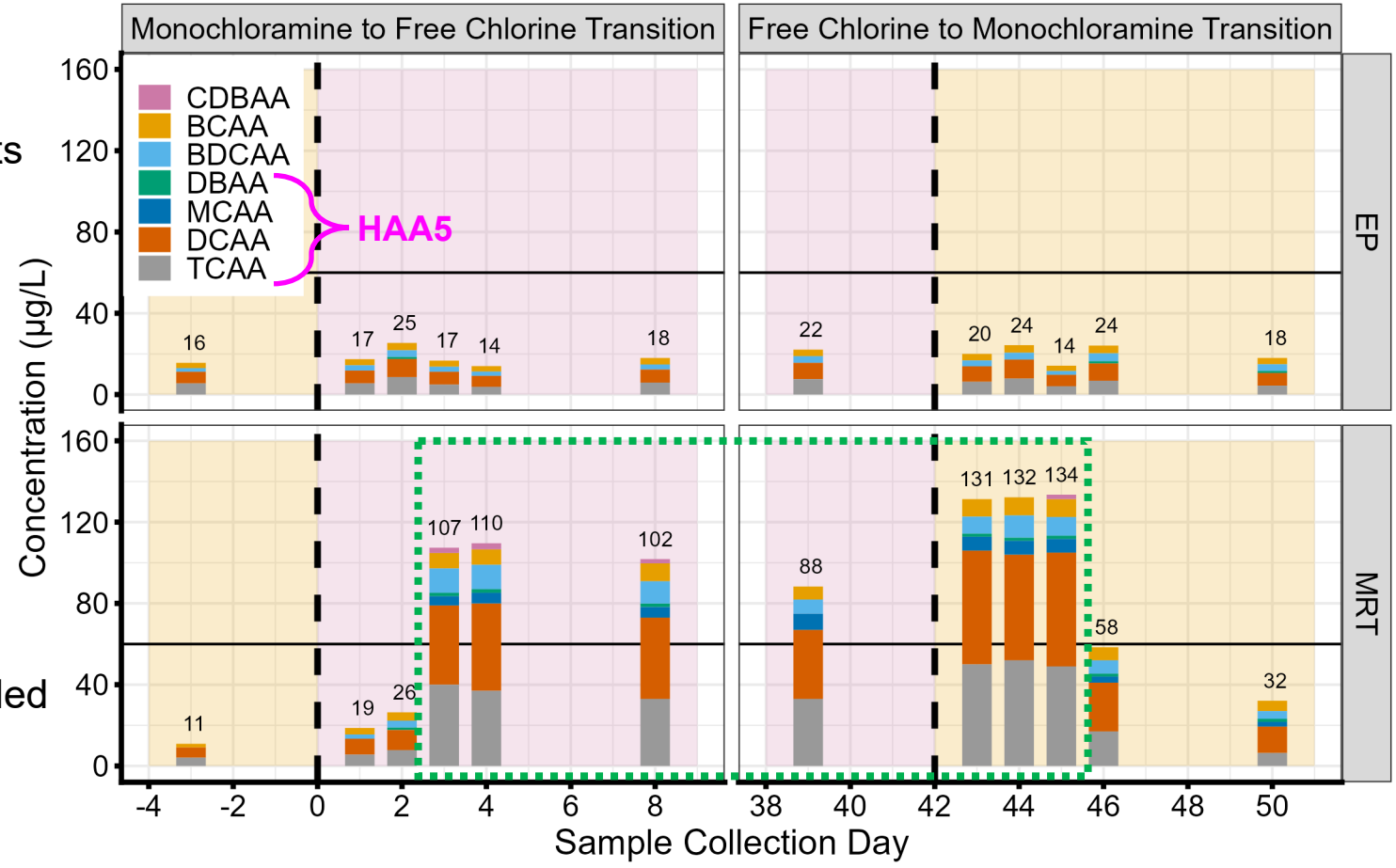
  - Extra HAA9 ⇧ (13x)
  - Mainly chlorinated



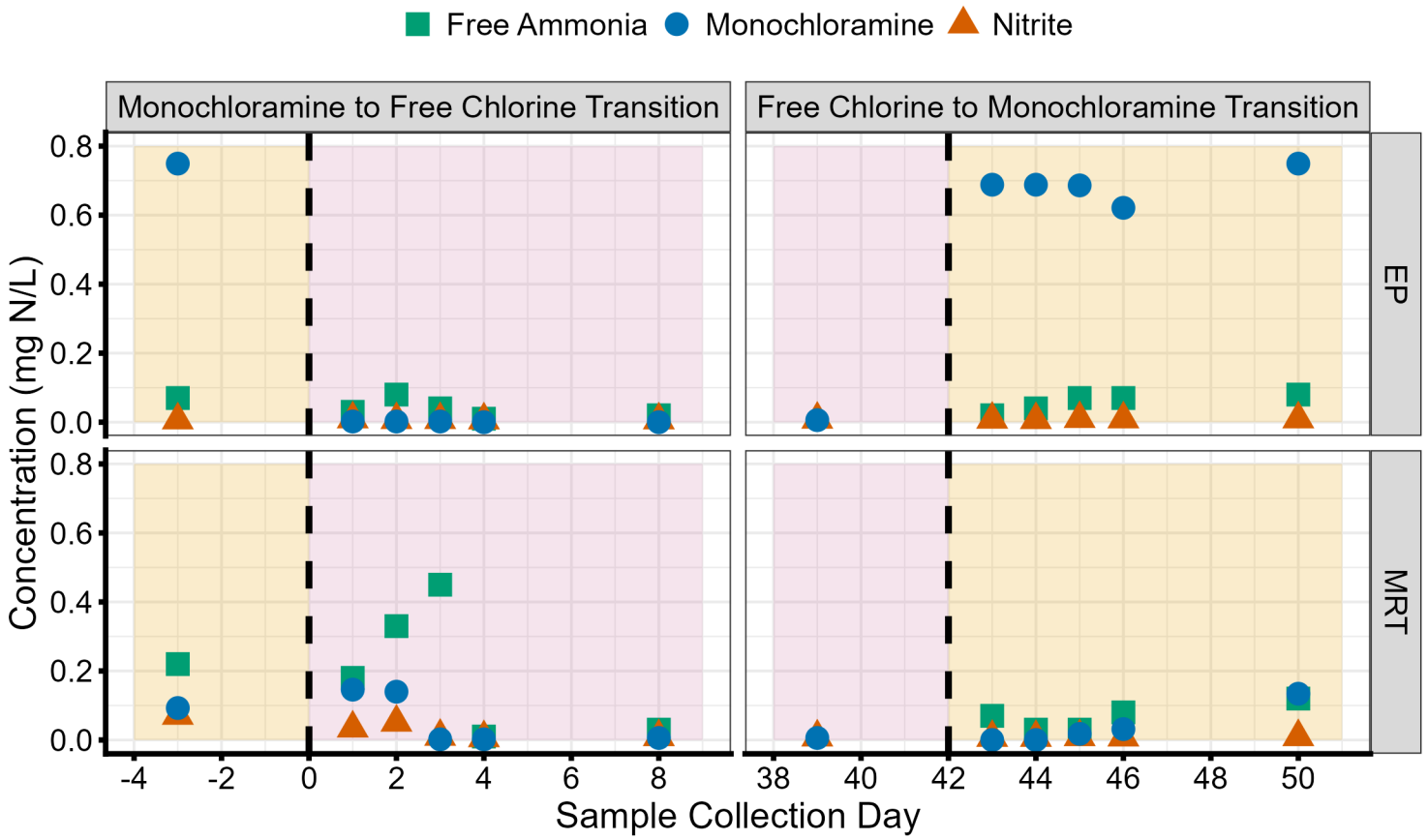
HAAs (Non-Steady State)

- No MBAA or TBAA
- Mainly chlorinated
- Parallels disinfectants
- EP not impacted
- MRT (mono to free)
  - HAA5 ⇧ (8x)
  - HAA9 ⇧ (10x)
  - Mainly chlorinated
- MRT (free to mono)
  - Extra HAA5 ⇧ (10x)
  - Extra HAA9 ⇧ (13x)
  - Mainly chlorinated
- 60 µg/L MCL exceeded



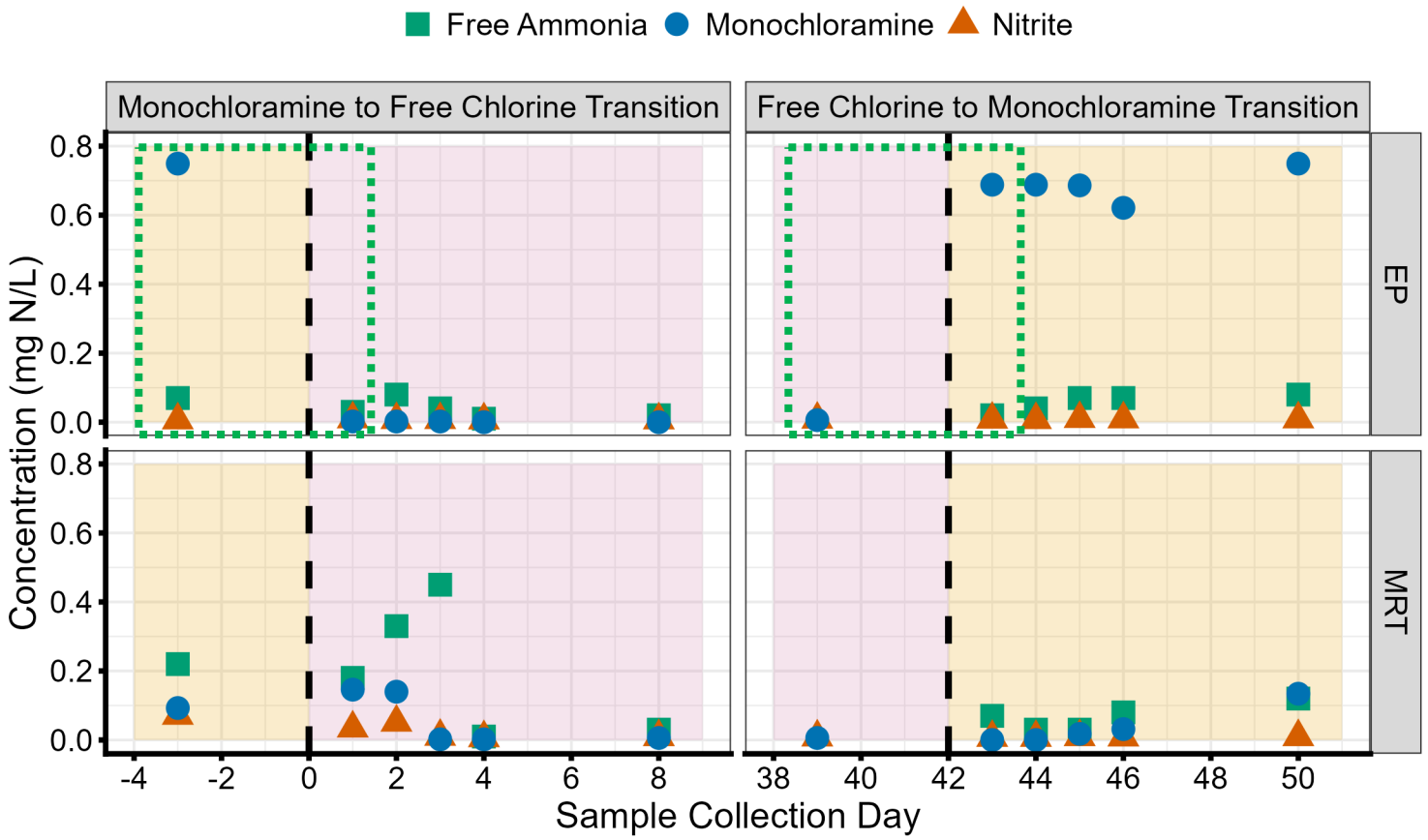
Nitrogen Species (Non-Steady State)

- No field nitrate
- Mono as N



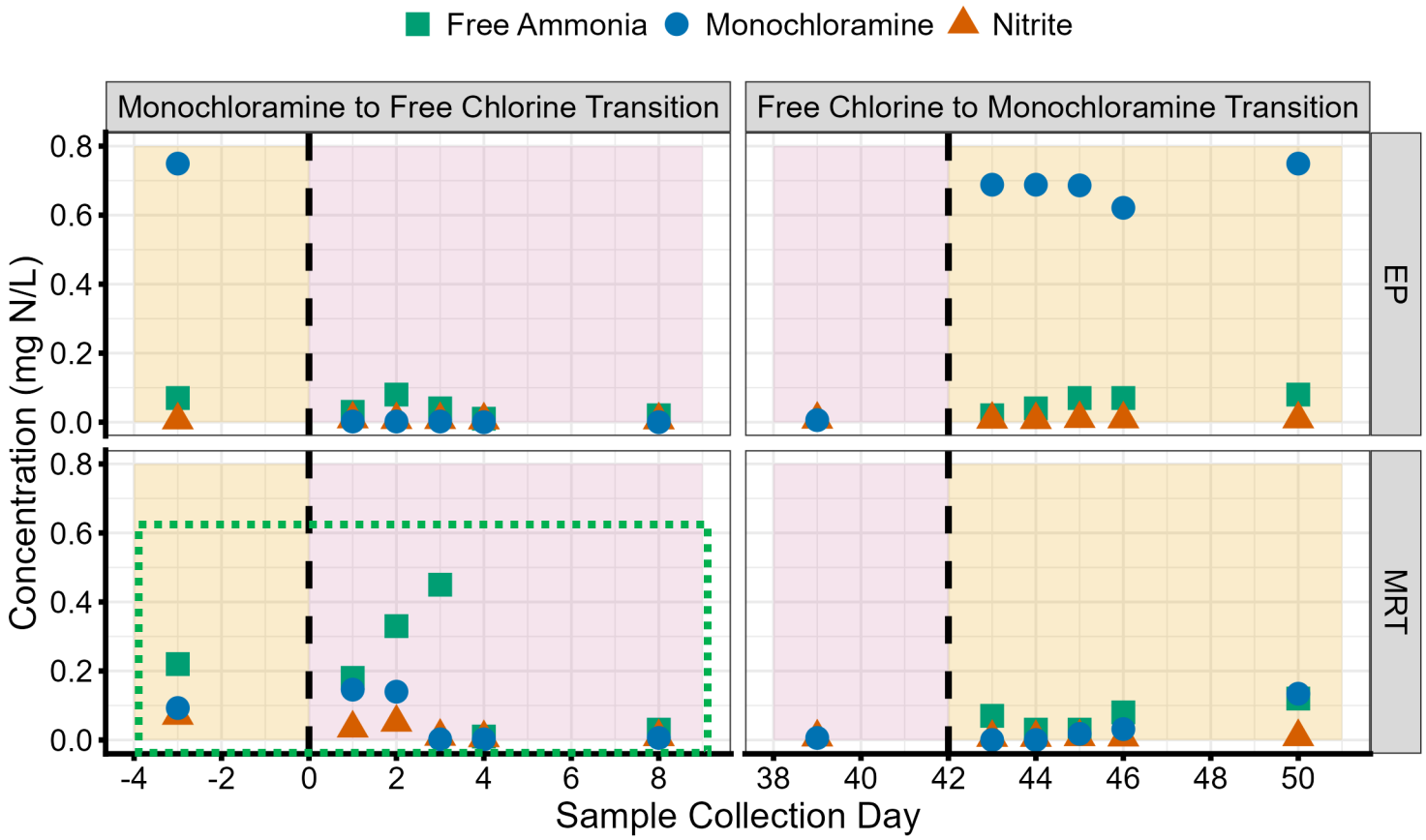
Nitrogen Species (Non-Steady State)

- No field nitrate
- Mono as N
- EP → immediate Δ



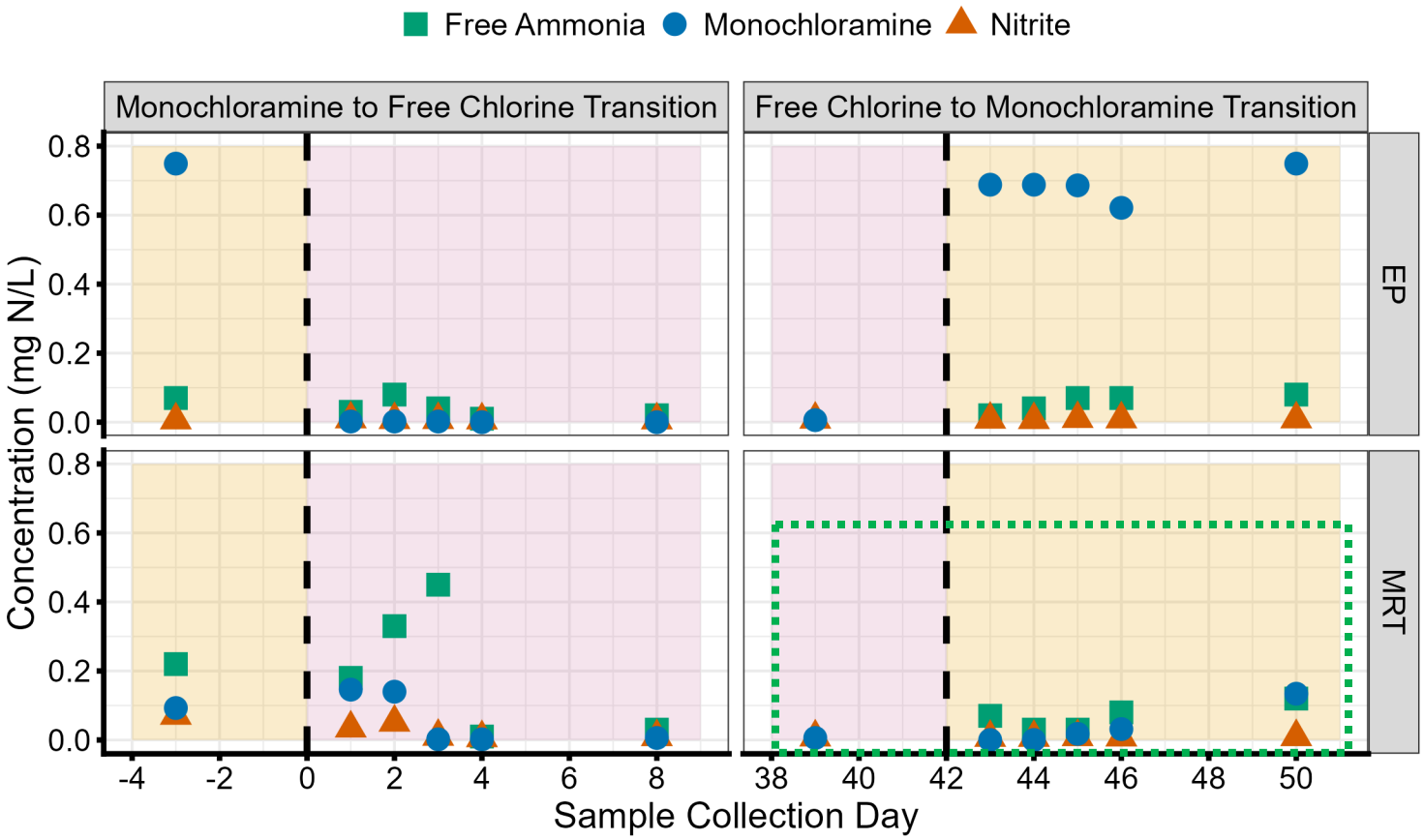
Nitrogen Species (Non-Steady State)

- No field nitrate
- Mono as N
- EP → immediate Δ
- MRT (mono to free)
  - Some nitrite
  - Initial ⇧ ammonia
  - 4 day no ammonia



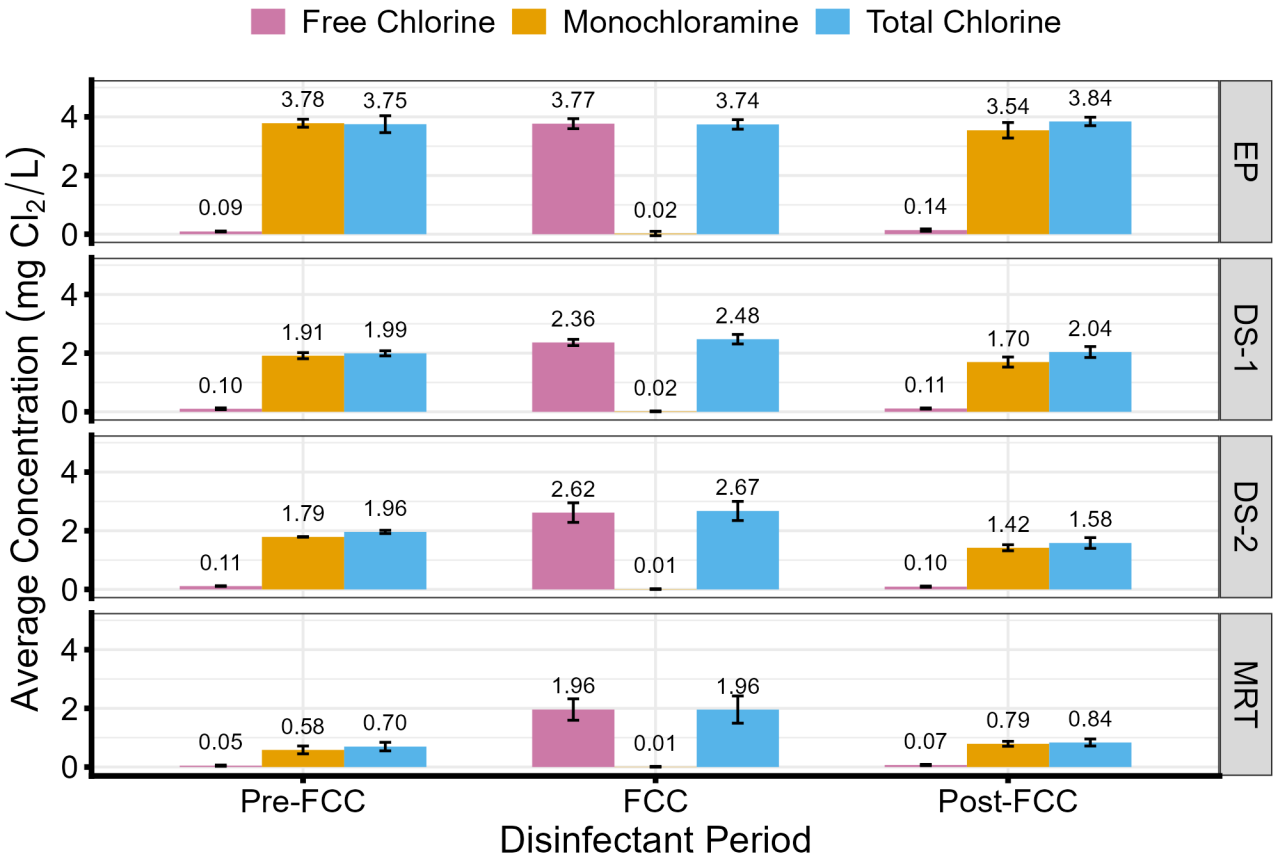
Nitrogen Species (Non-Steady State)

- No field nitrate
- Mono as N
- EP → immediate Δ
- MRT (mono to free)
  - Some nitrite
  - Initial ⇧ ammonia
  - 4 day no ammonia
- MRT (free to mono)
  - No nitrite
  - 4–8 day transition



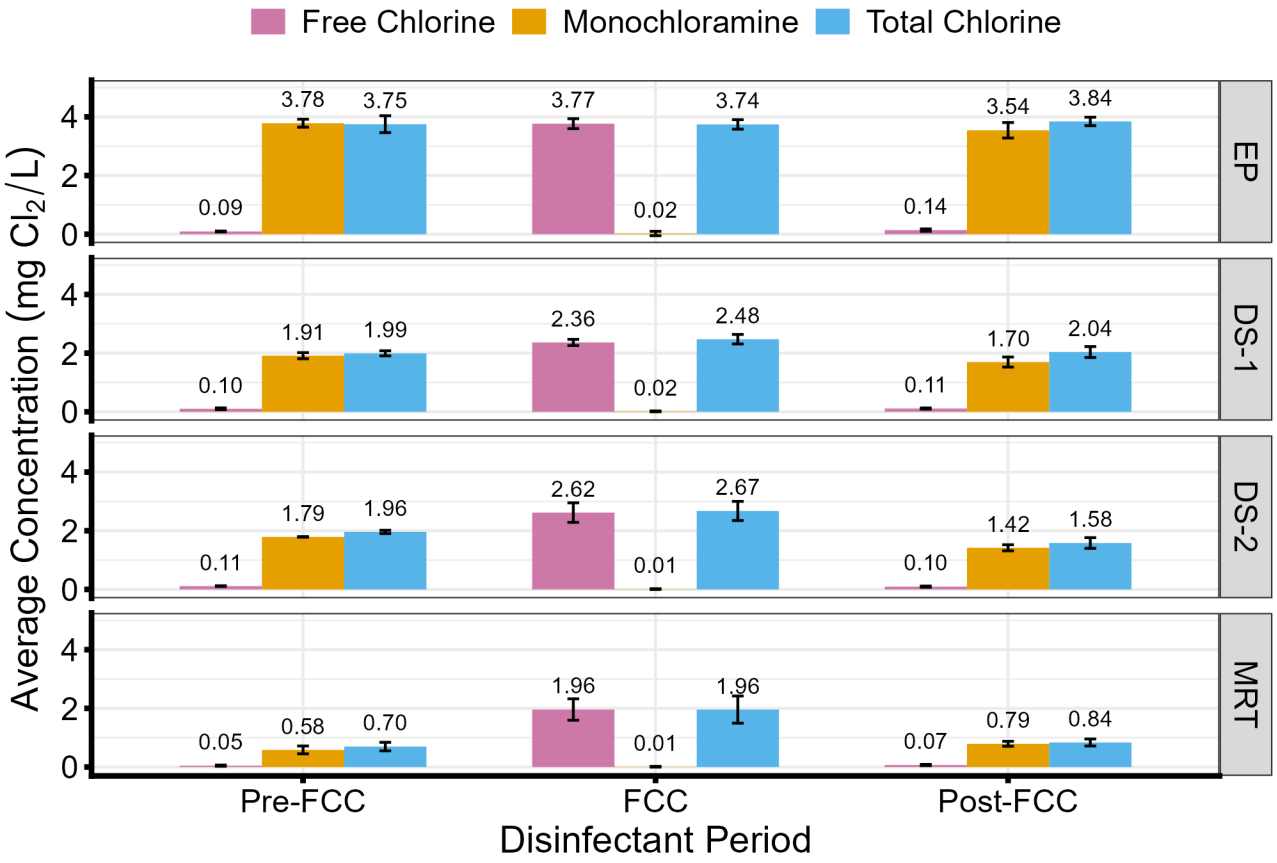
Disinfectants (Steady State)

- Four distribution locations
- EP to MRT = ⇧ water age



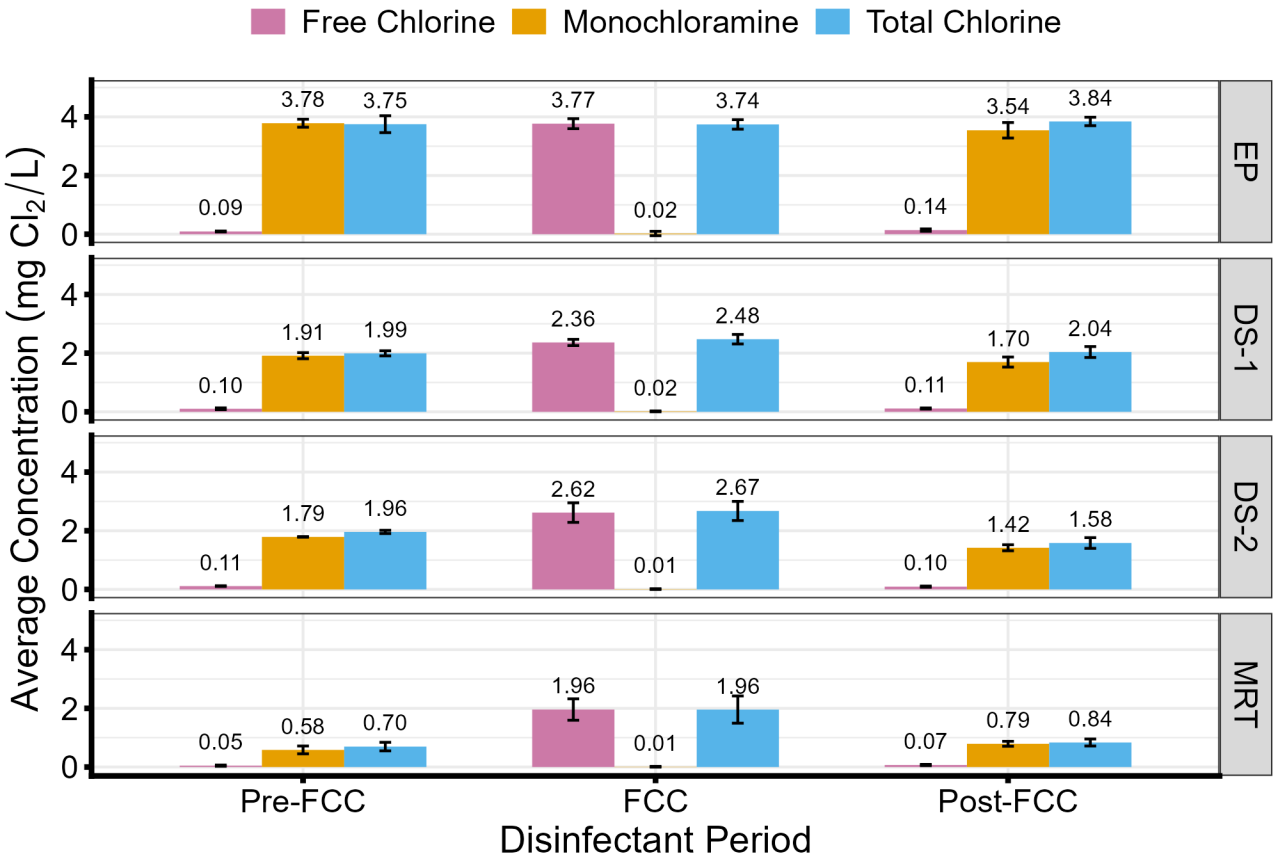
Disinfectants (Steady State)

- Four distribution locations
- EP to MRT = ⇧ water age
- ⇩ with water age



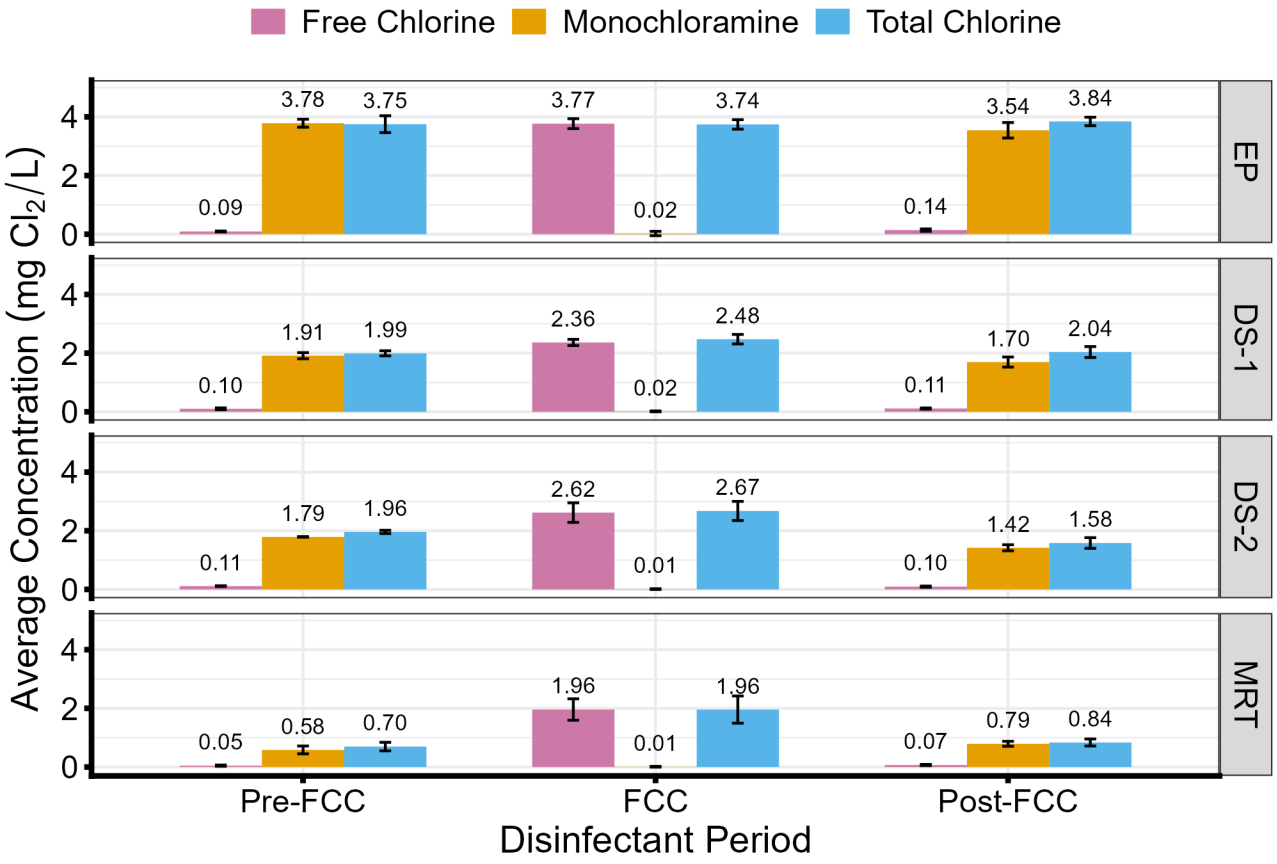
Disinfectants (Steady State)

- Four distribution locations
- EP to MRT = ⇧ water age
- ⇩ with water age
- 0.5 mg Cl_2/L minimum met

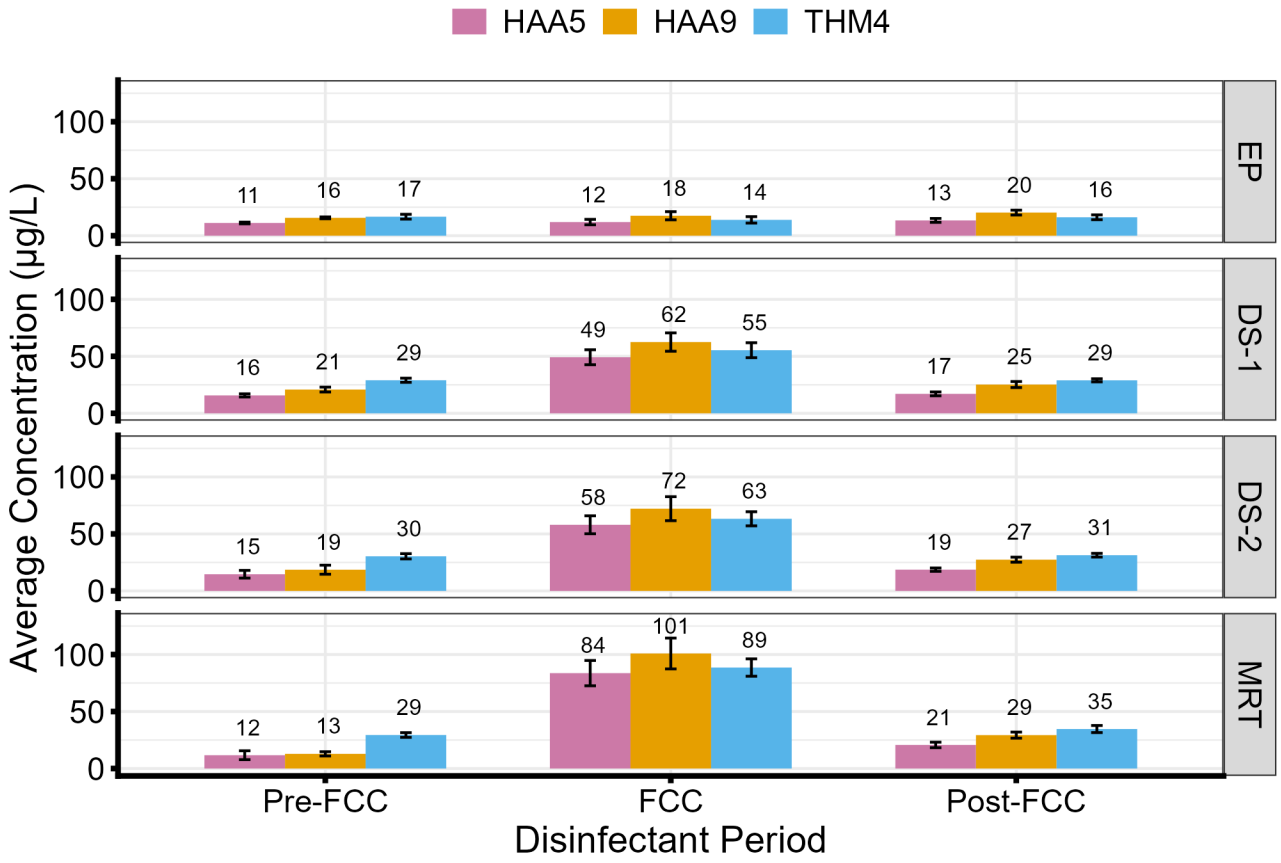


Disinfectants (Steady State)

- Four distribution locations
- EP to MRT = ⇧ water age
- ⇩ with water age
- 0.5 mg Cl_2/L minimum met
- Residual: free > mono (pH)

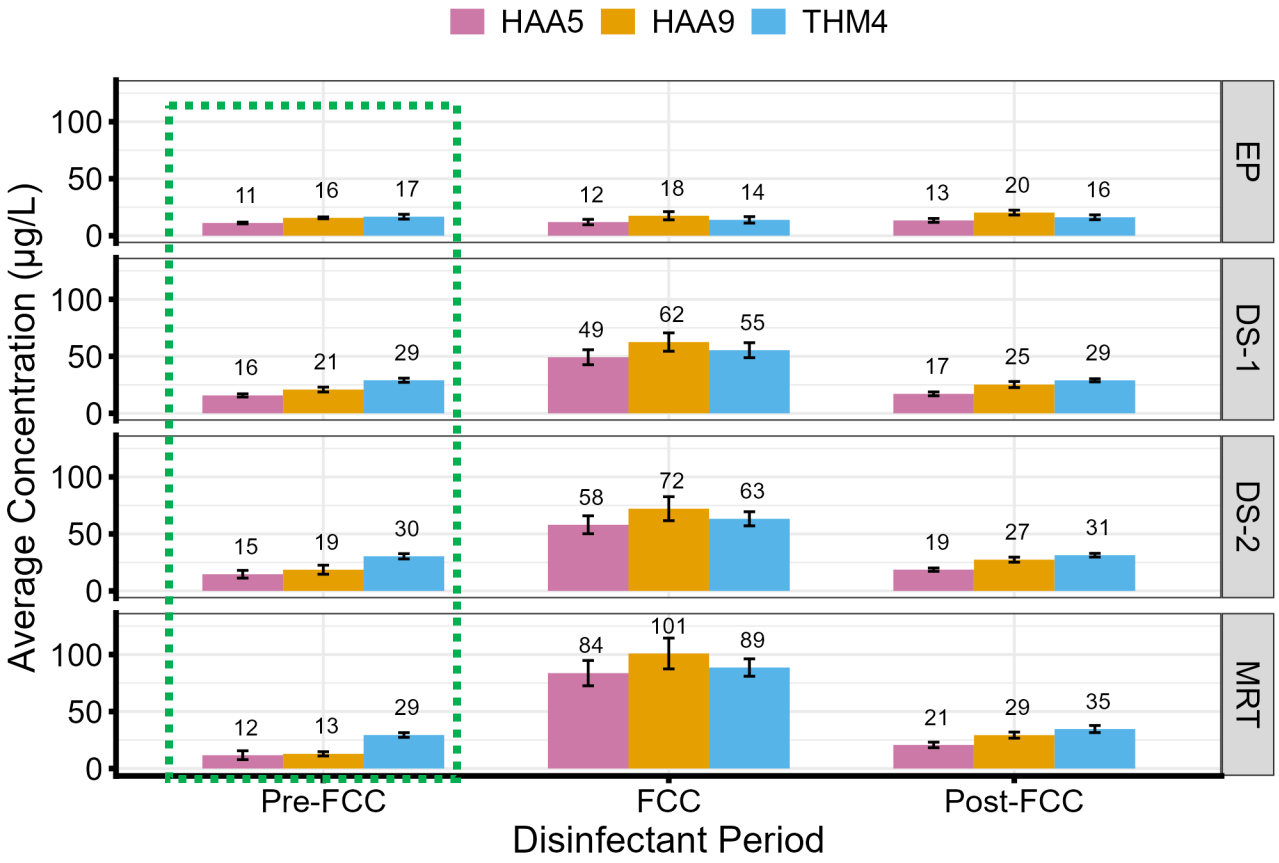


DBPs (Steady State)



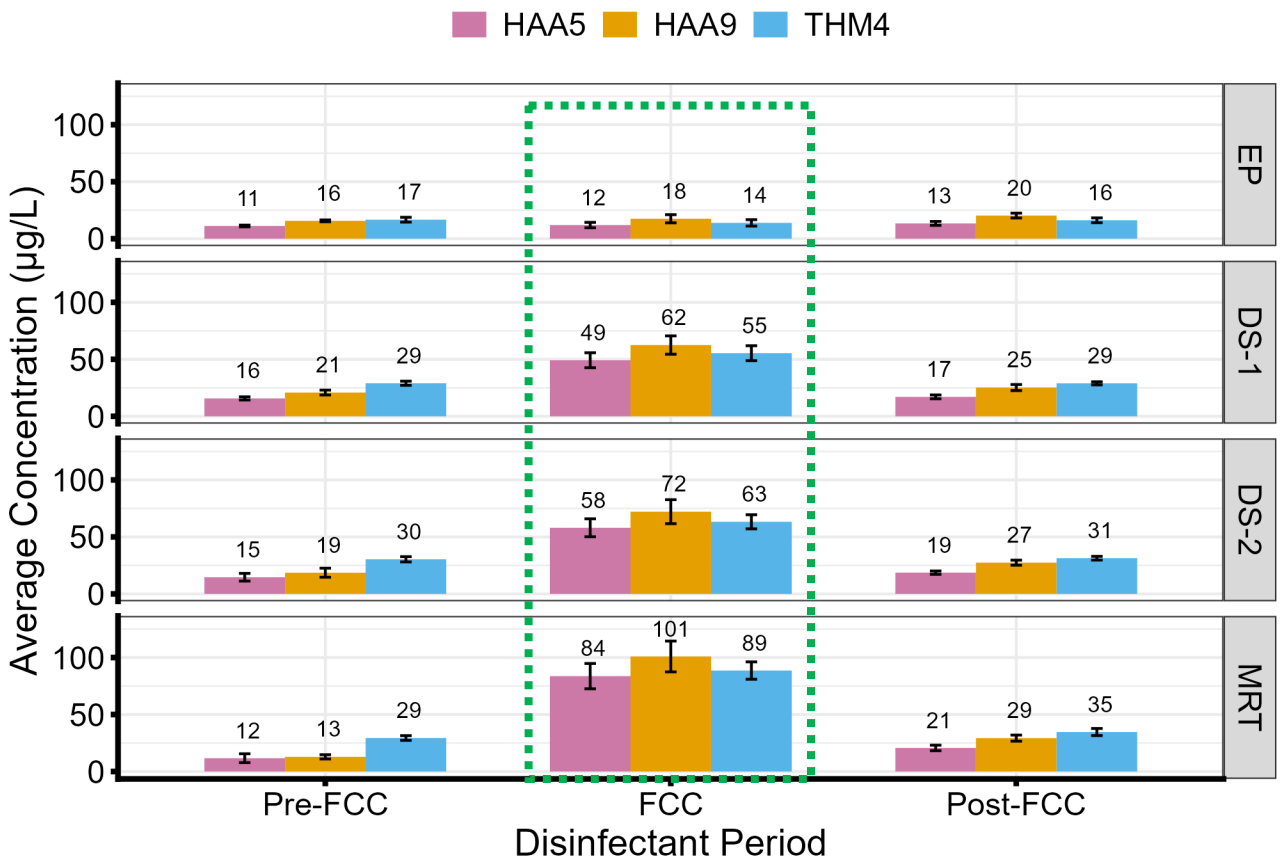
DBPs (Steady State)

- Pre-FCC
  - HAAs: ⇧ DS-1 then ⇩
  - THM4: ⇧ DS-1 then ⇨
  - Biological activity?



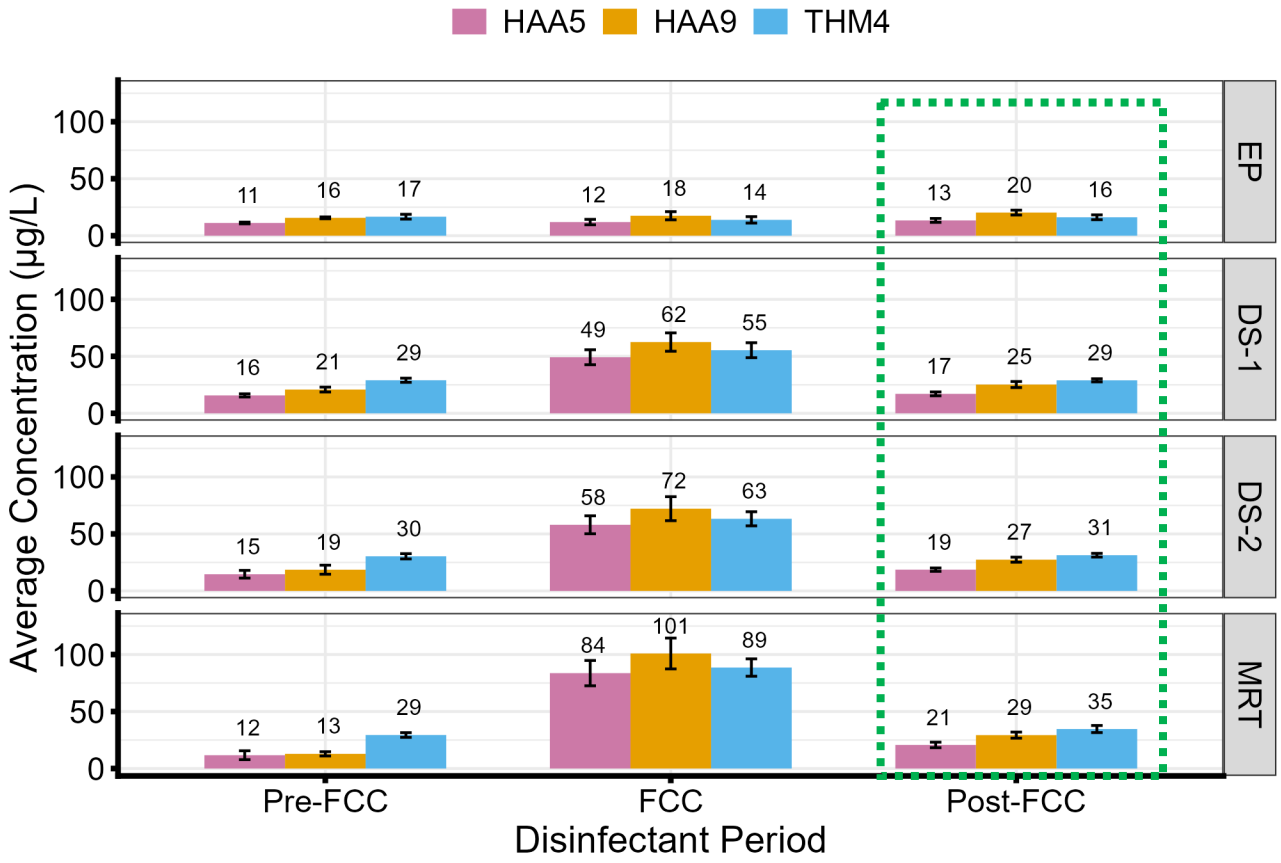
DBPs (Steady State)

- Pre-FCC
  - HAAs: ⇧ DS-1 then ⇩
  - THM4: ⇧ DS-1 then ⇨
  - Biological activity?
- FCC
  - All ⇧ with water age
  - HAAs ⇧ (7-8x MRT)
  - THM4 ⇧ (3x MRT)

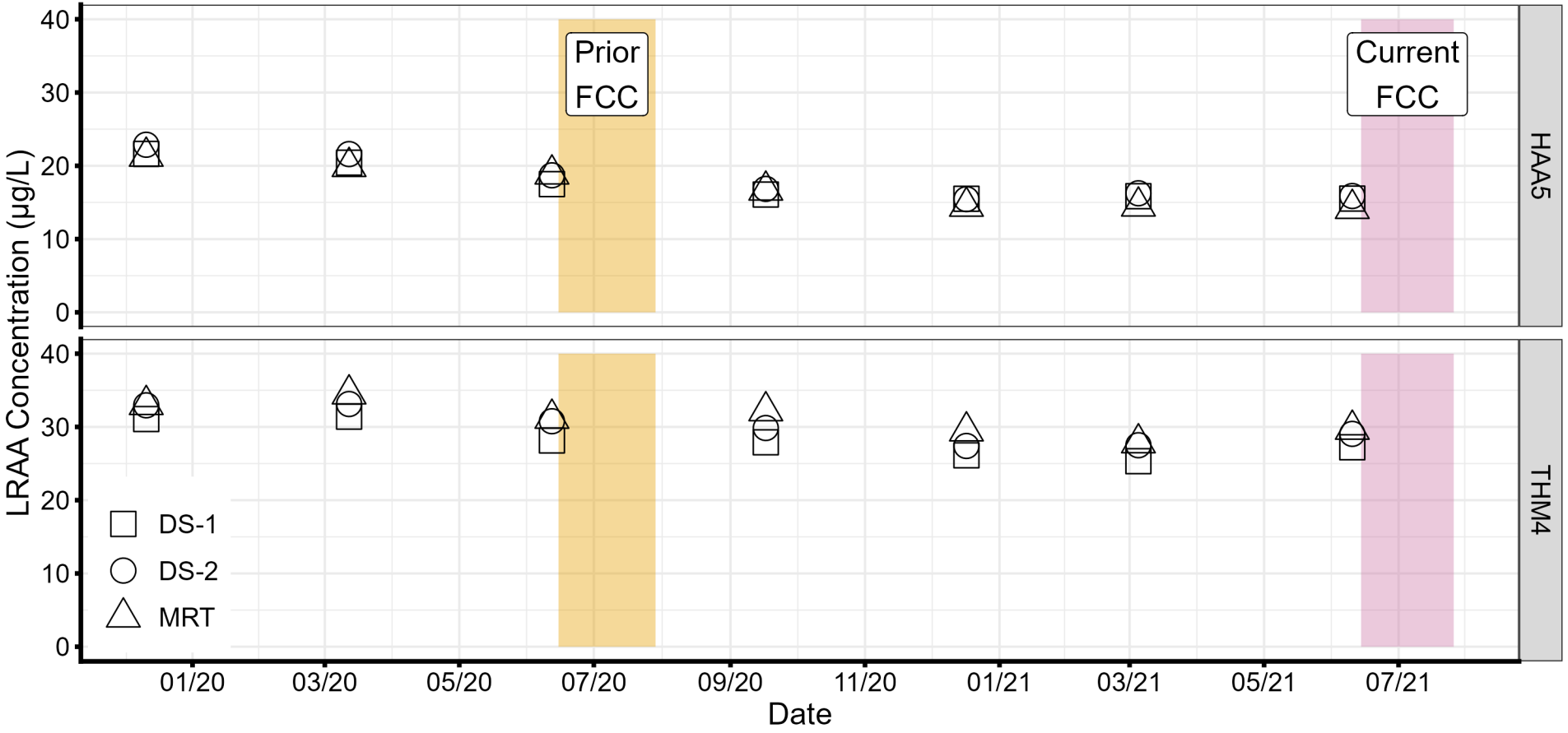


DBPs (Steady State)

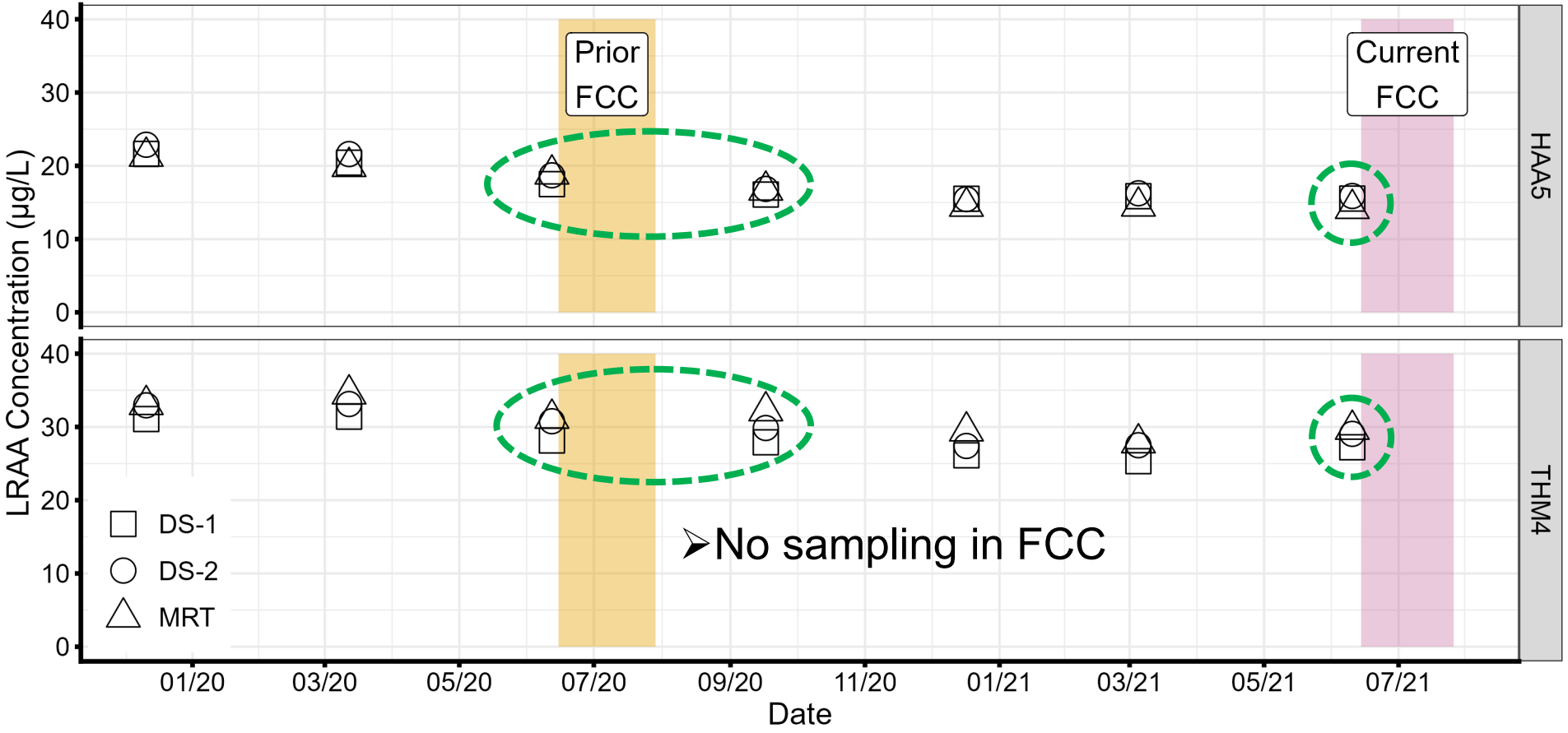
- Pre-FCC
  - HAAs: ⇧ DS-1 then ⇩
  - THM4: ⇧ DS-1 then ⇨
  - Biological activity?
- FCC
  - All ⇧ with water age
  - HAAs ⇧ (7-8x MRT)
  - THM4 ⇧ (3x MRT)
- Post-FCC
  - All ⇧ with water age
  - Most ⇧ vs Pre-FCC
  - Temp ⇧?
  - Biological activity ⇩?



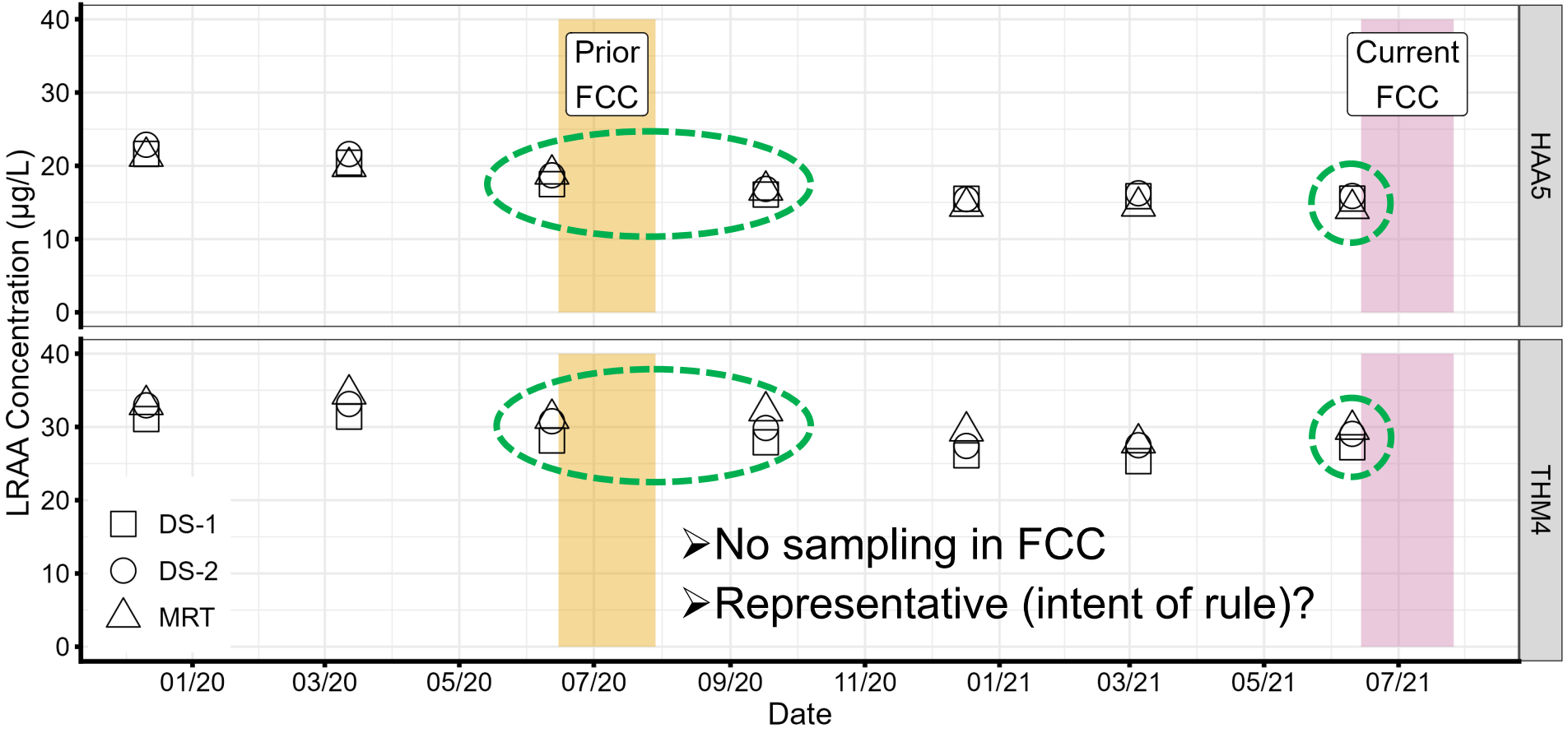
LRAAs & Sampling versus FCCs



LRAAs & Sampling versus FCCs

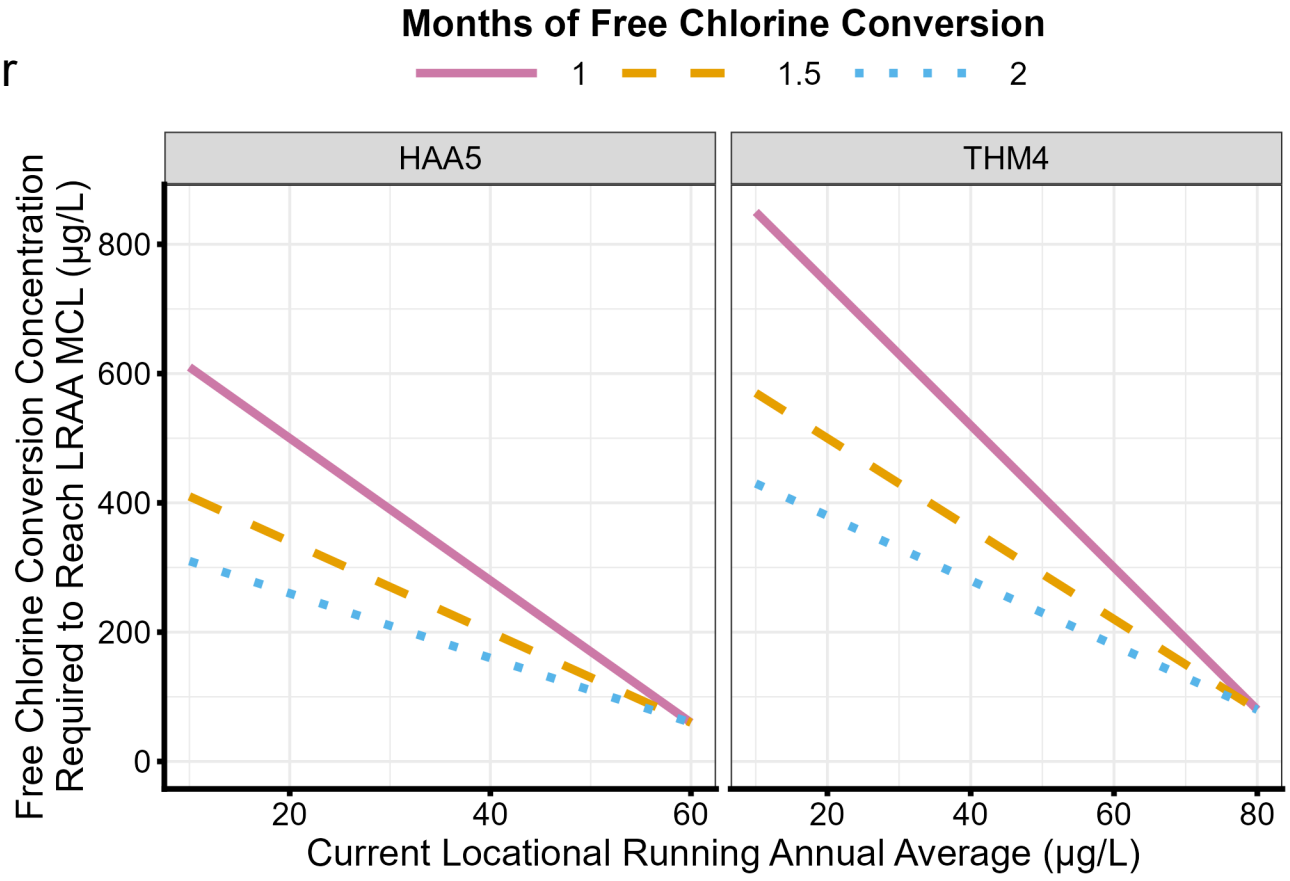


LRAAs & Sampling versus FCCs



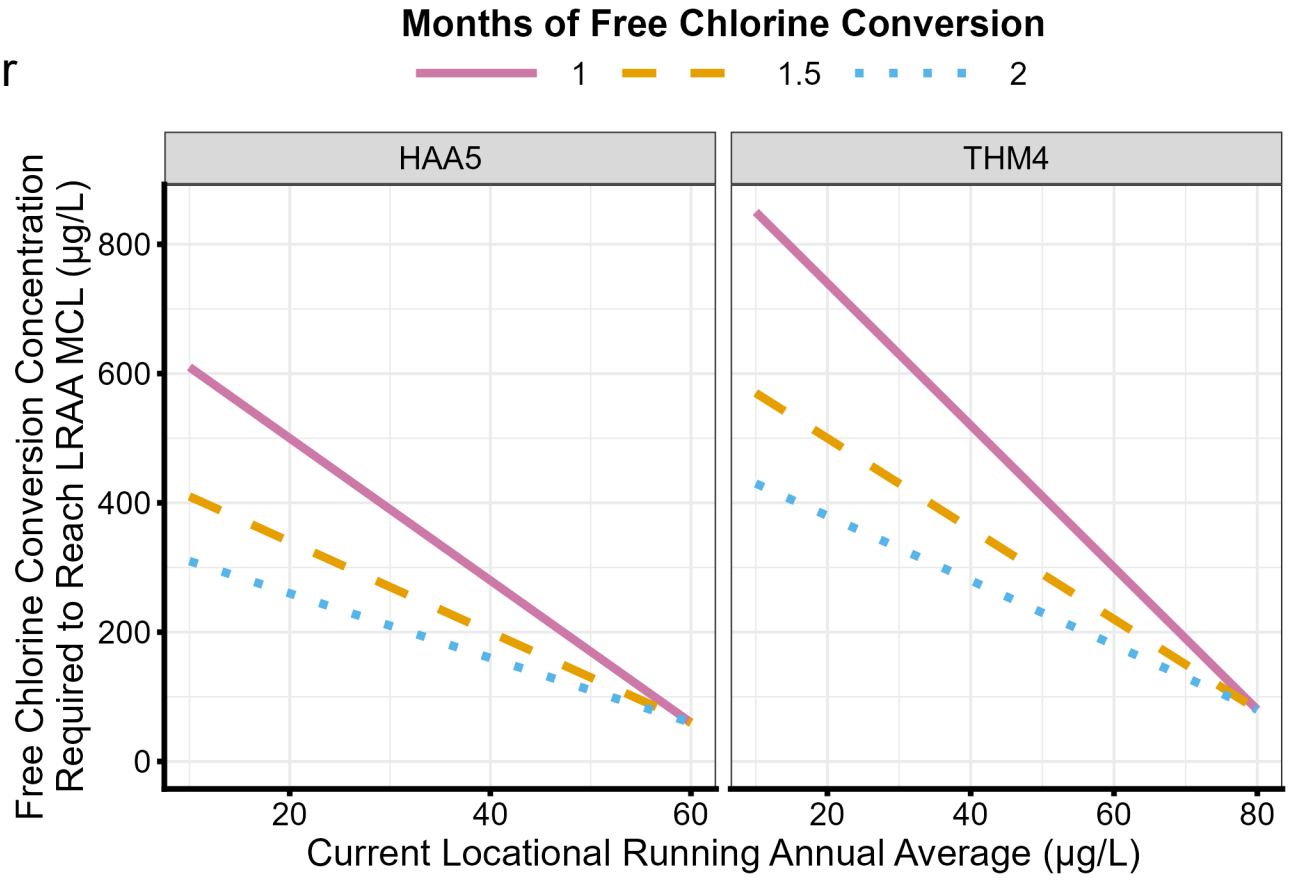
Include FCC (Weighted Average) – MRT?

- modified LRAA (mLRAA)
- Assume one FCC in a year
- Need to know
  - Current LRAA
  - FCC length
  - FCC DBP concentration



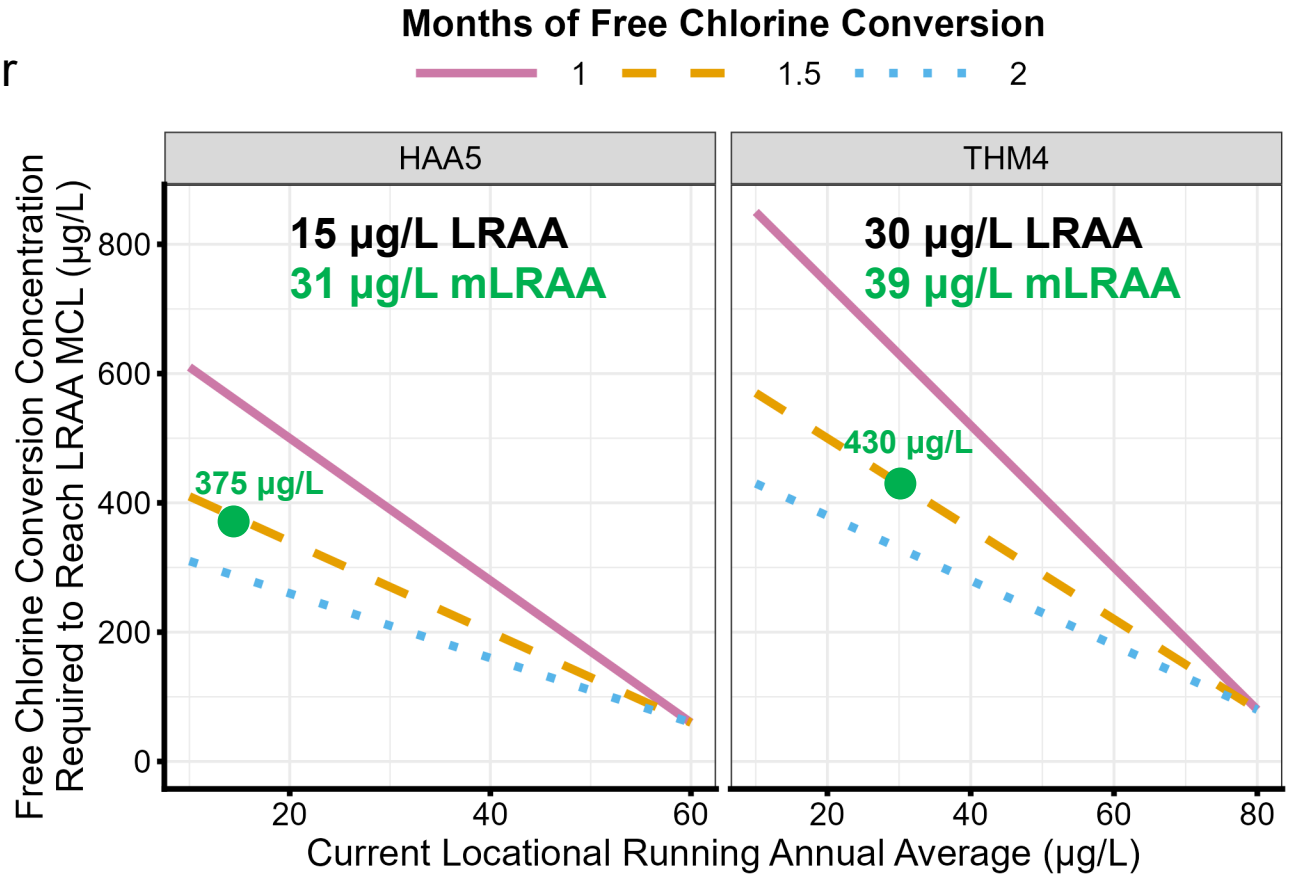
Include FCC (Weighted Average) – MRT?

- modified LRAA (mLRAA)
- Assume one FCC in a year
- Need to know
  - Current LRAA
  - FCC length
  - FCC DBP concentration
- Assess potential impact
  - What is too high?
  - What is too long?
  - mLRAA vs LRAA?



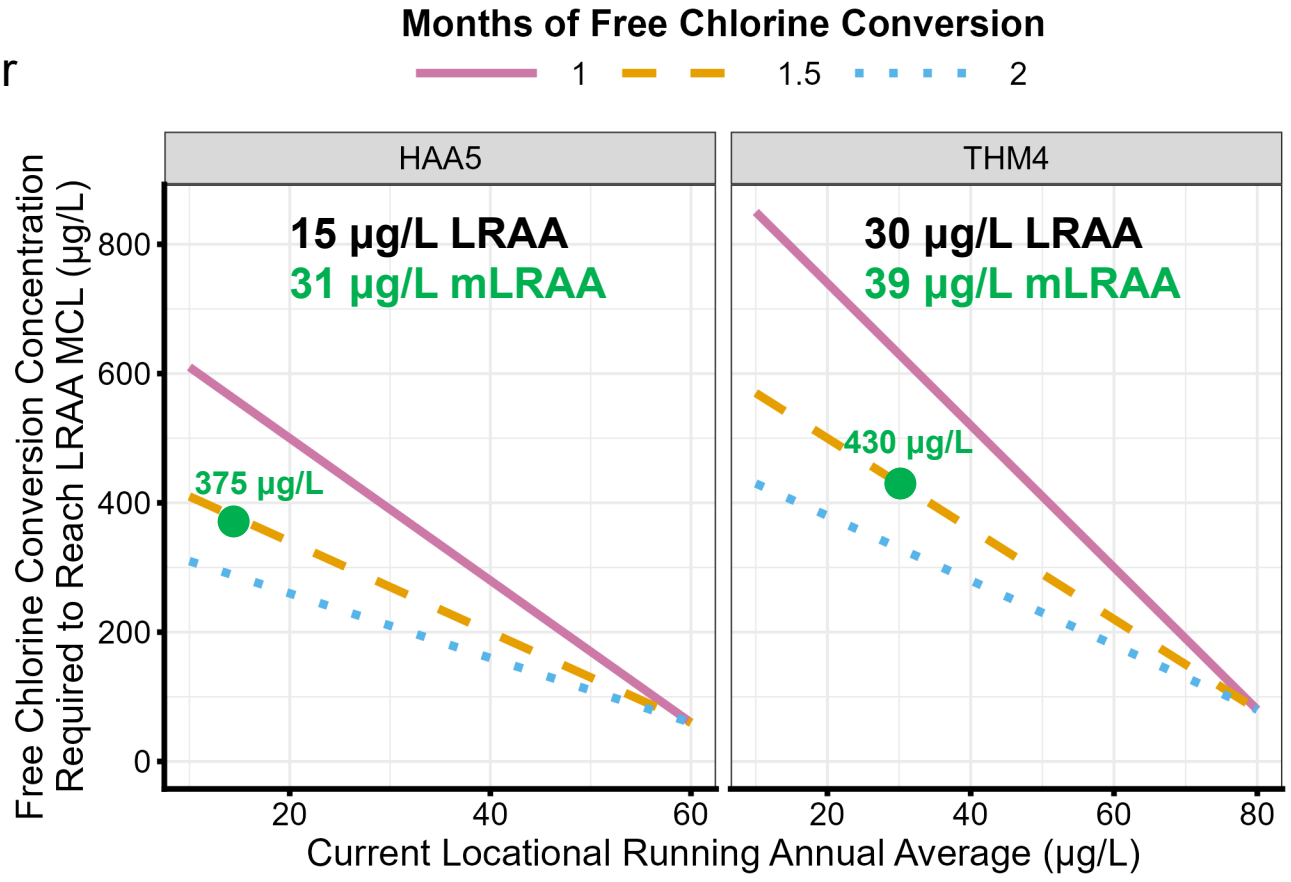
Include FCC (Weighted Average) – MRT?

- modified LRAA (mLRAA)
- Assume one FCC in a year
- Need to know
  - Current LRAA
  - FCC length
  - FCC DBP concentration
- Assess potential impact
  - What is too high?
  - What is too long?
  - mLRAA vs LRAA?
- No issue for this system
  - Low current LRAAs
  - HAA5: 114 vs. 375 µg/L
  - THM4: 104 vs. 430 µg/L

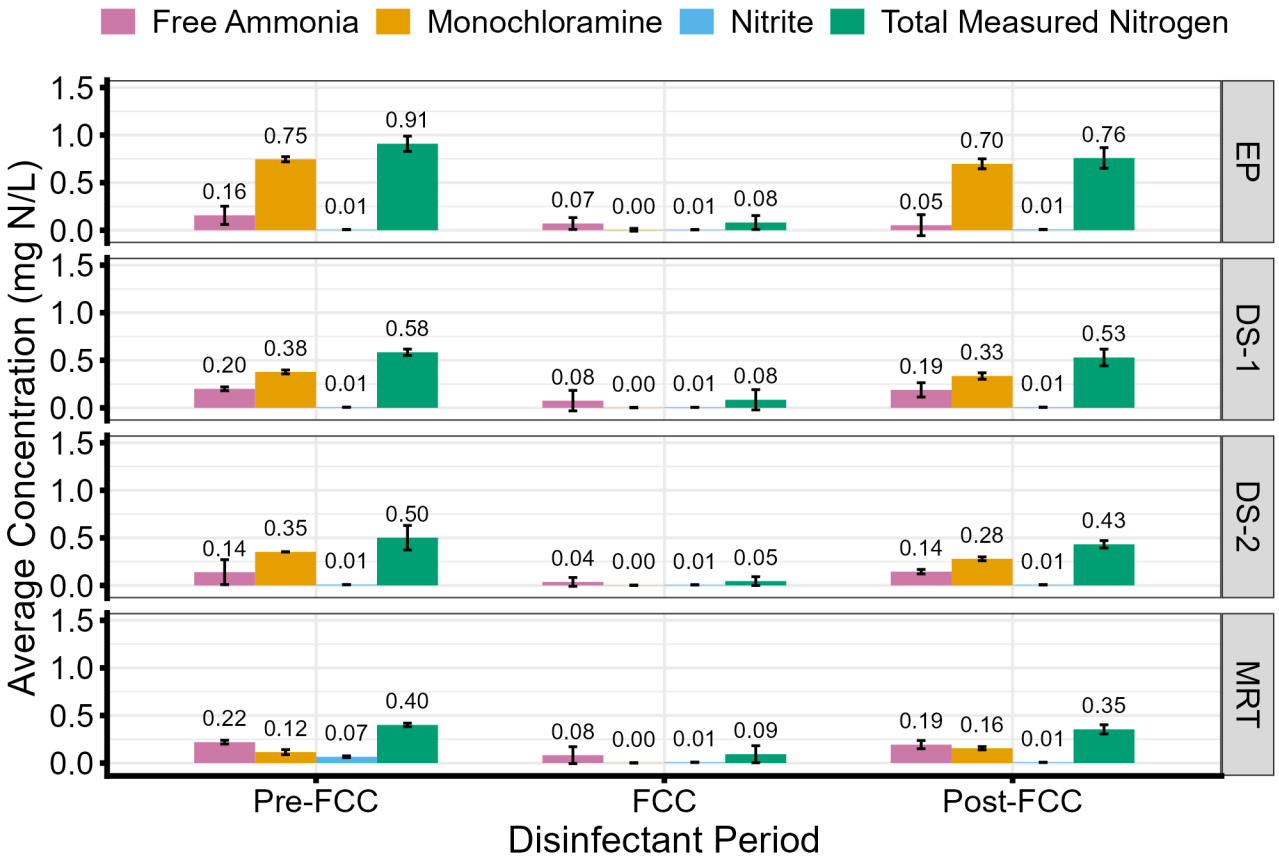


Include FCC (Weighted Average) – MRT?

- modified LRAA (mLRAA)
- Assume one FCC in a year
- Need to know
  - Current LRAA
  - FCC length
  - FCC DBP concentration
- Assess potential impact
  - What is too high?
  - What is too long?
  - mLRAA vs LRAA?
- No issue for this system
  - Low current LRAAs
  - HAA5: 114 vs. 375 µg/L
  - THM4: 104 vs. 430 µg/L
- Other systems?

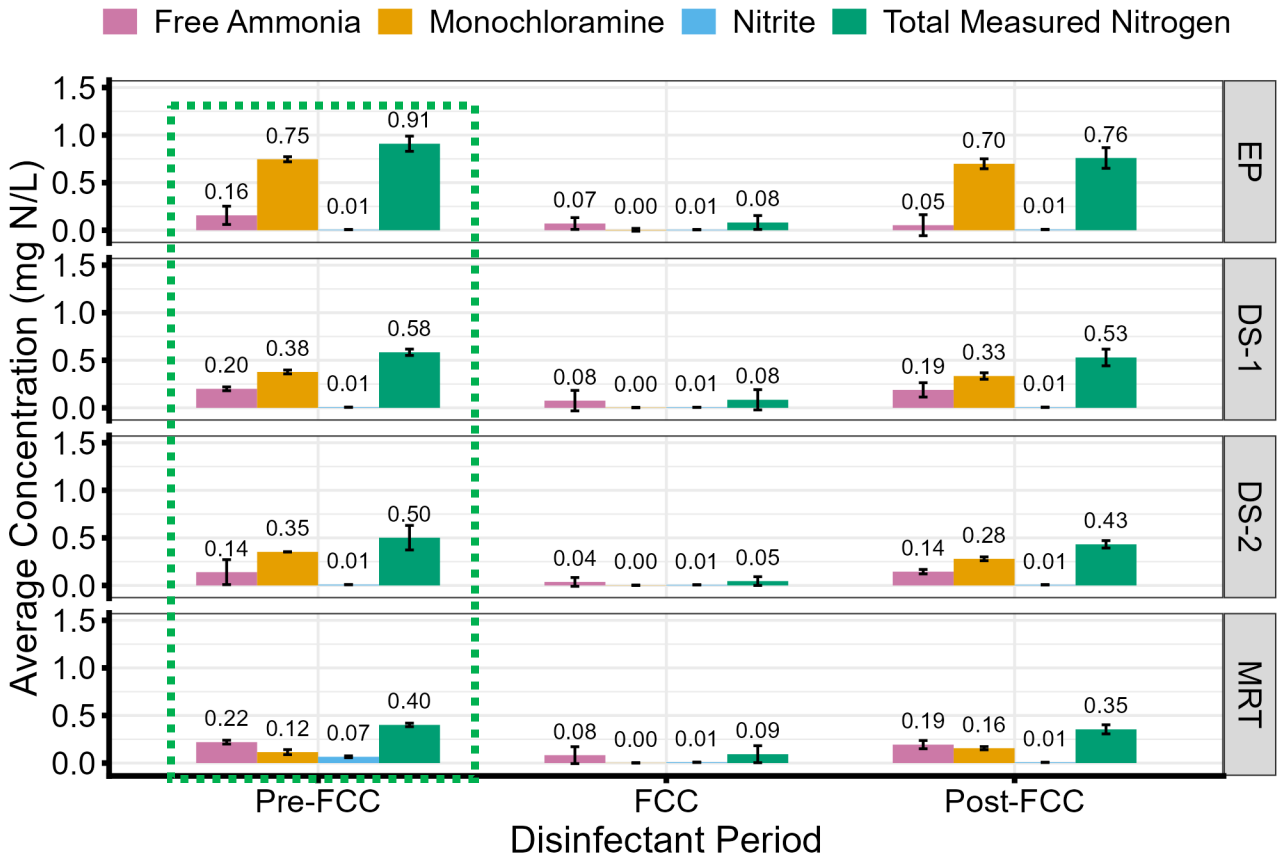


Nitrogen Species (Steady State)



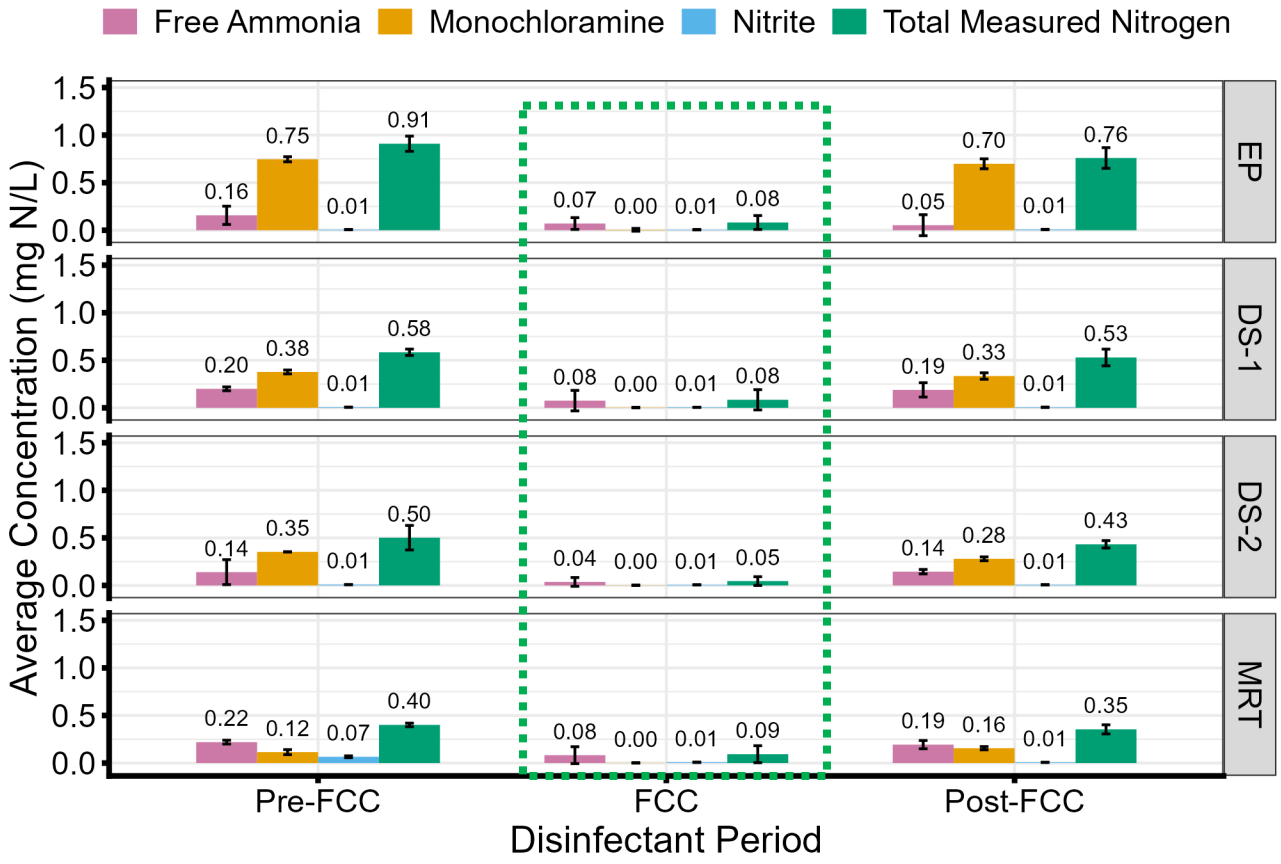
Nitrogen Species (Steady State)

- Pre-FCC
  - Free ammonia > 0.1 mg N/L
  - Nitrite only at MRT (chlorite?)
  - Total measured N ⇩



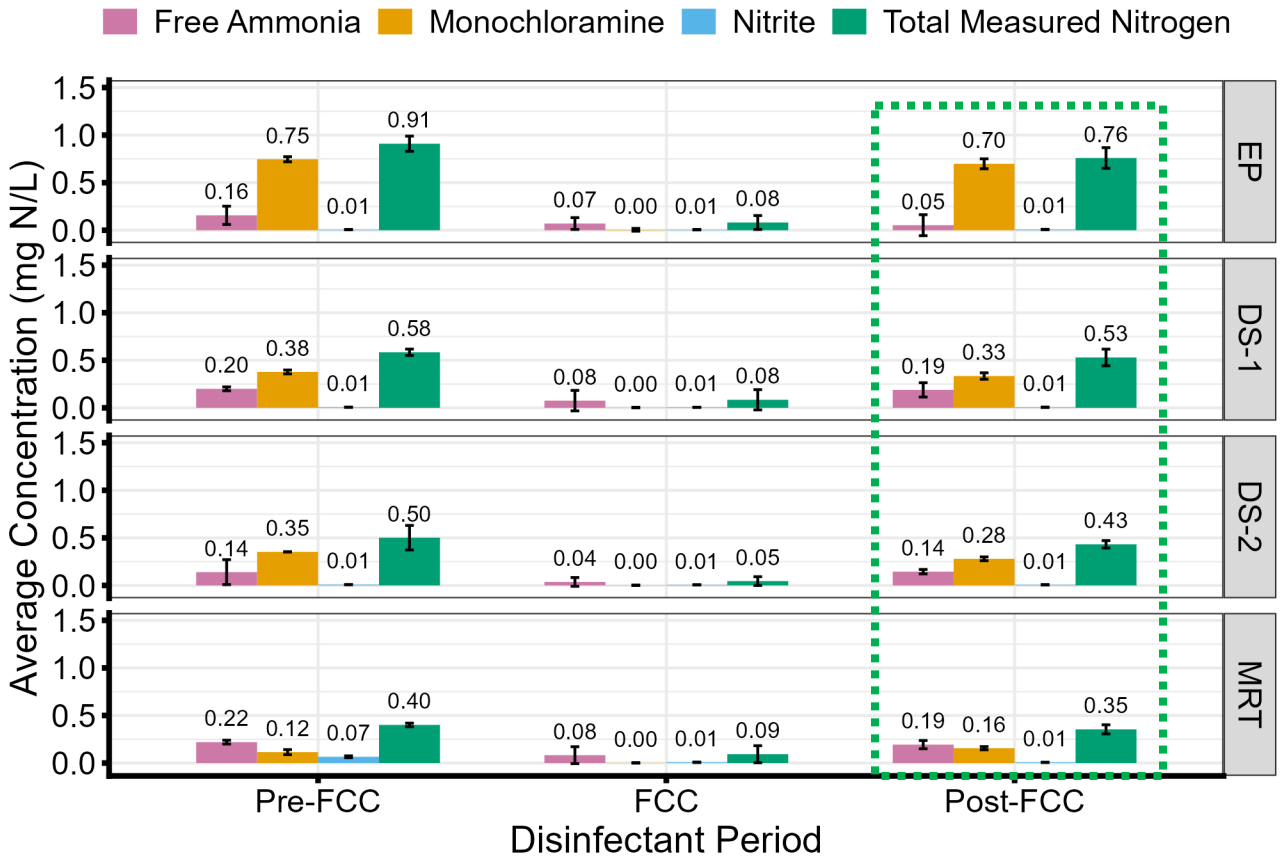
Nitrogen Species (Steady State)

- Pre-FCC
  - Free ammonia > 0.1 mg N/L
  - Nitrite only at MRT (chlorite?)
  - Total measured N ⇩
- FCC removed N



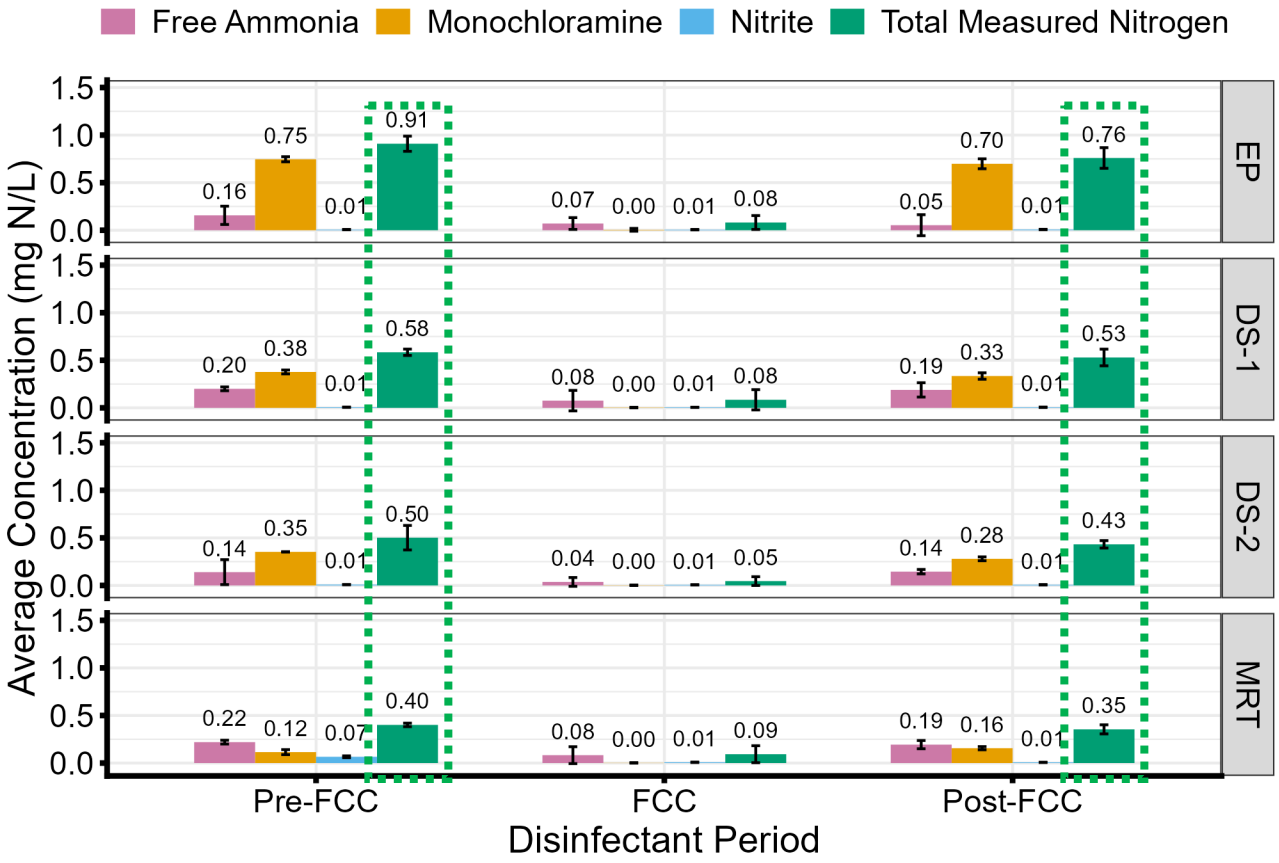
Nitrogen Species (Steady State)

- Pre-FCC
  - Free ammonia > 0.1 mg N/L
  - Nitrite only at MRT (chlorite?)
  - Total measured N ⇩
- FCC removed N
- Post-FCC
  - Like Pre-FCC
  - No nitrite at MRT



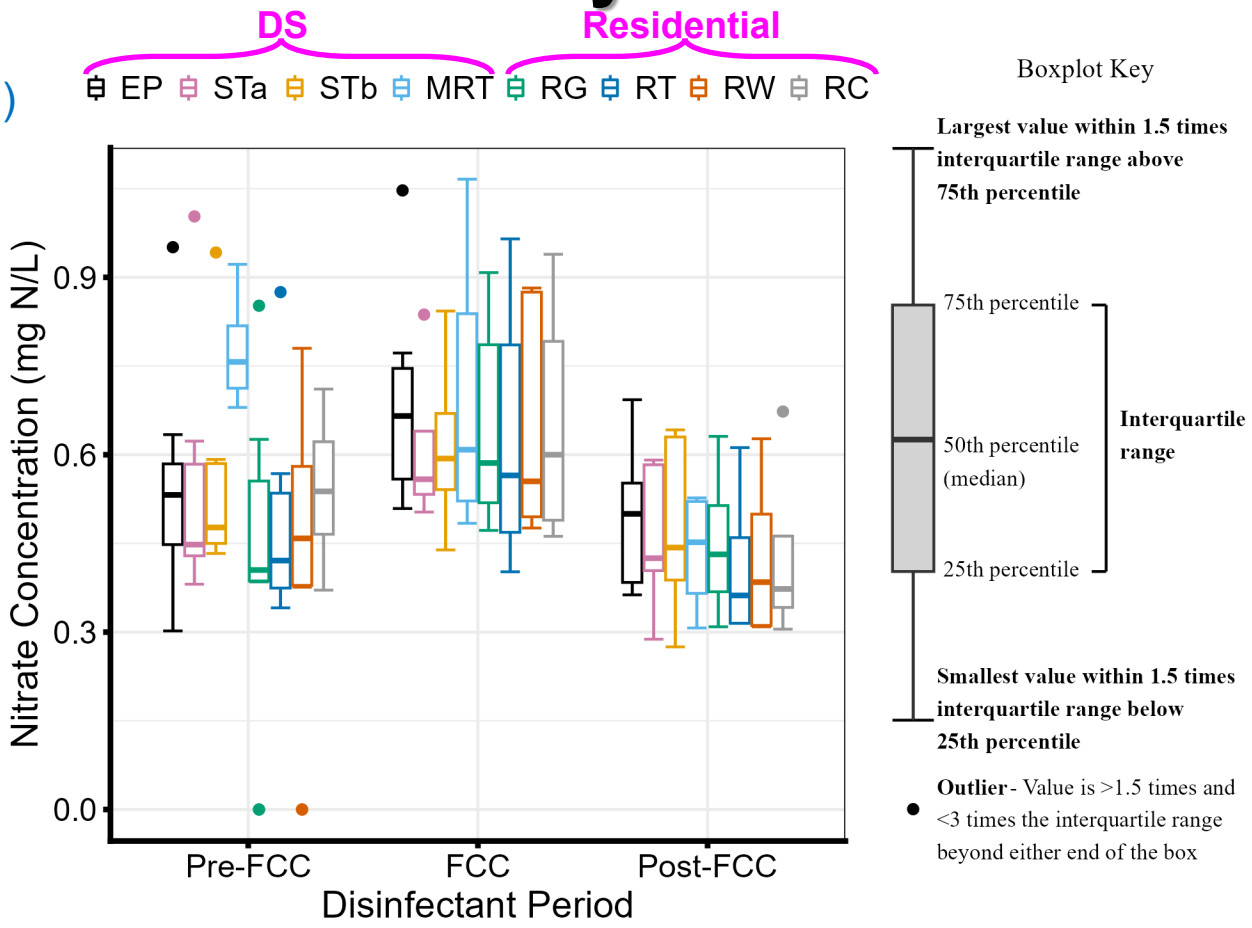
Nitrogen Species (Steady State)

- Pre-FCC
  - Free ammonia > 0.1 mg N/L
  - Nitrite only at MRT (chlorite?)
  - Total measured N ⇩
- FCC removed N
- Post-FCC
  - Like Pre-FCC
  - No nitrite at MRT
- Missing N (0.4–0.5 mg N/L)
  - Nitrate?
    - Complete nitrification?
    - Inorganic nitrite oxidation (pH)?
  - Nitrogen gas (mono decay)?



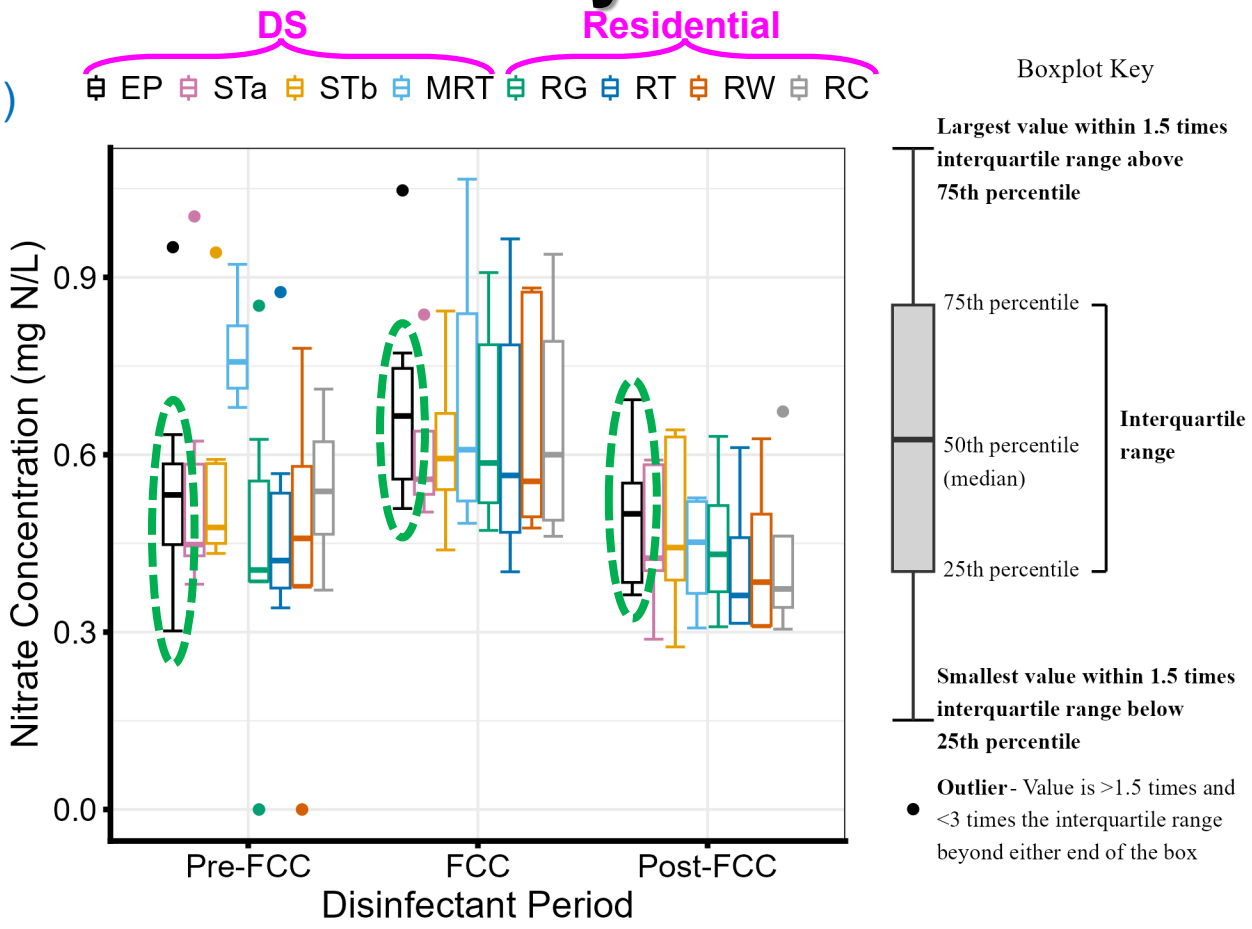
Nitrate Summary

- Holding time
  - Inorganic nitrite oxidation (pH)
  - Nitrite + nitrate?



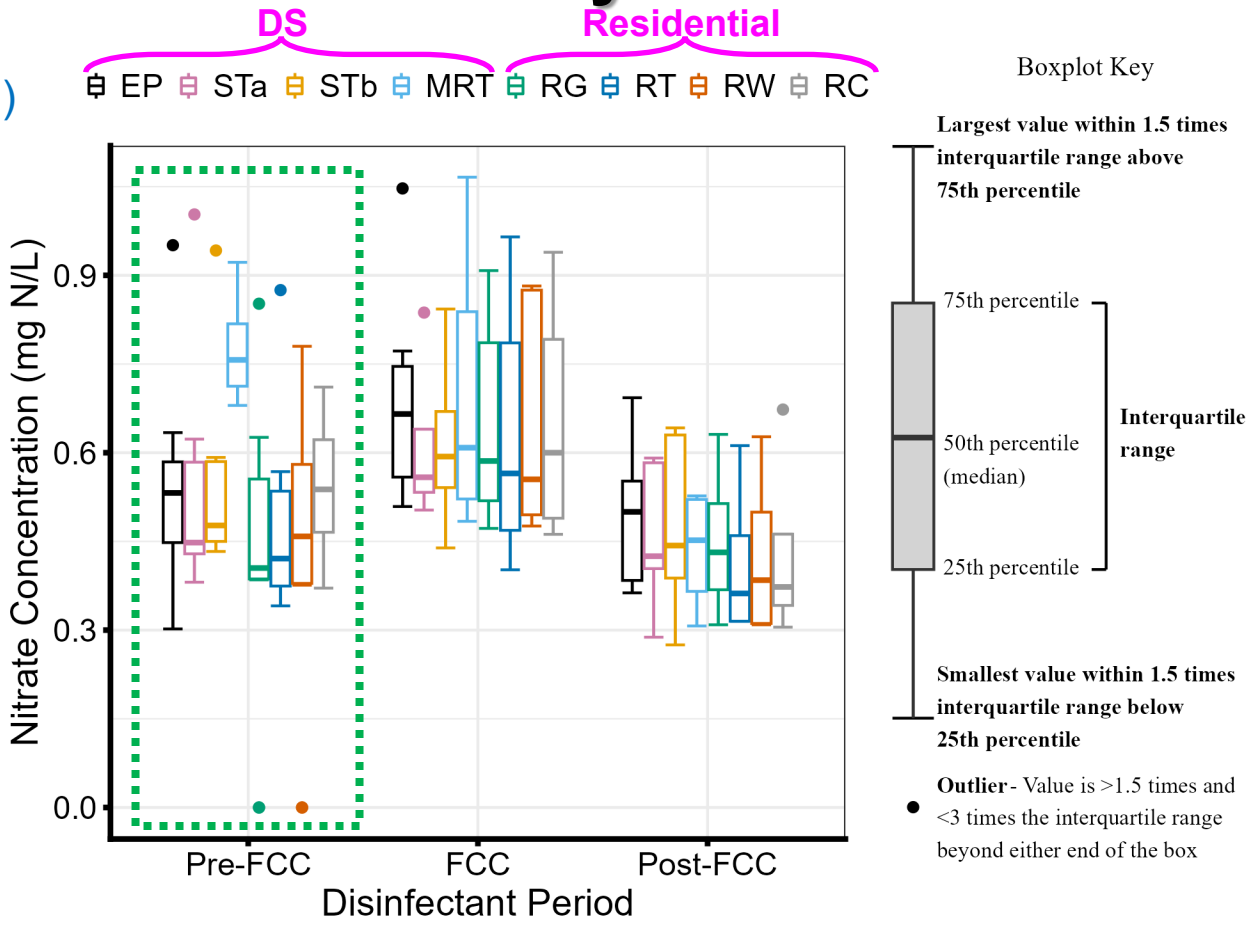
Nitrate Summary

- Holding time
  - Inorganic nitrite oxidation (pH)
  - Nitrite + nitrate?
- Variable at EP (0.3–1 mg N/L)



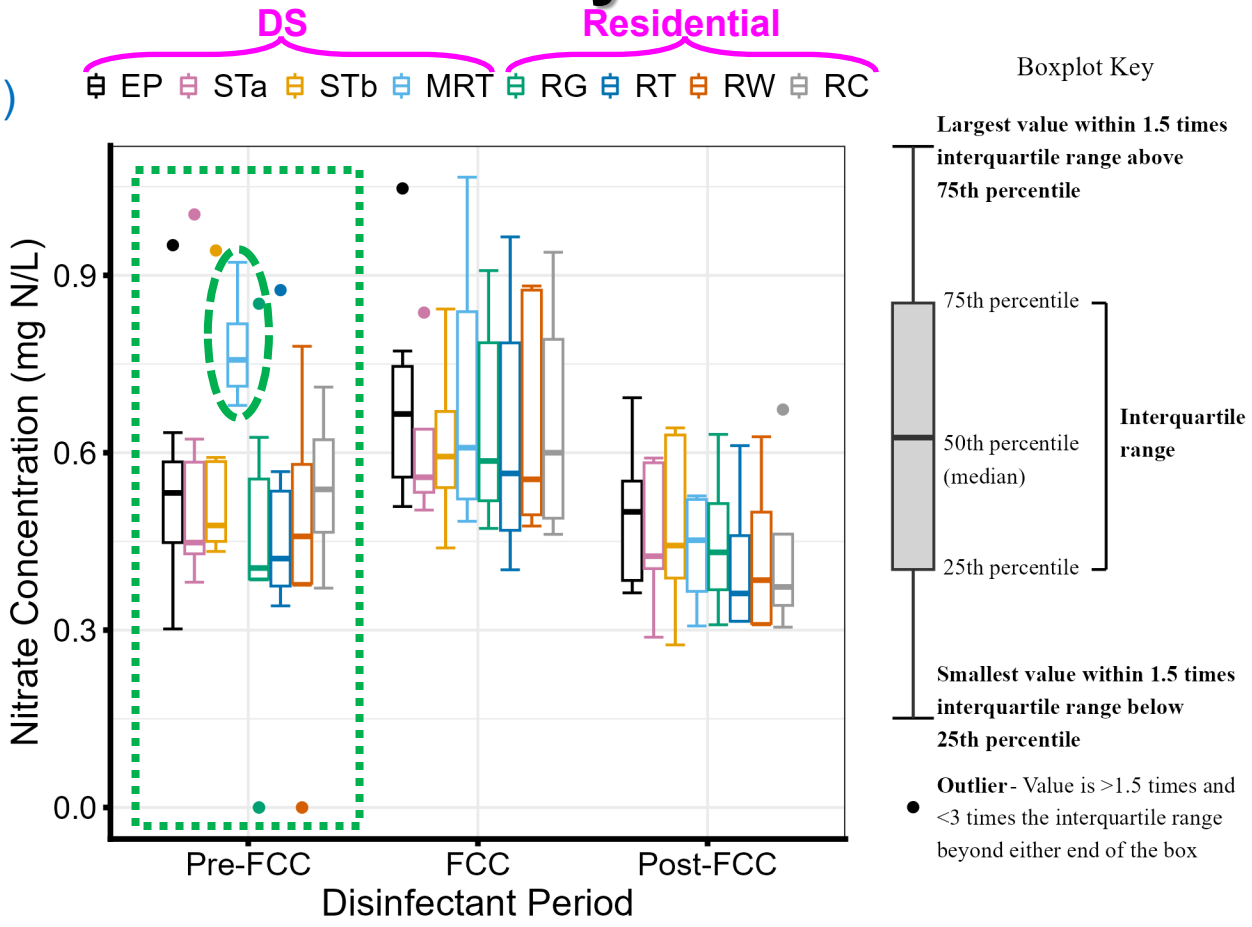
Nitrate Summary

- Holding time
  - Inorganic nitrite oxidation (pH)
  - Nitrite + nitrate?
- Variable at EP (0.3–1 mg N/L)
- Pre-FCC



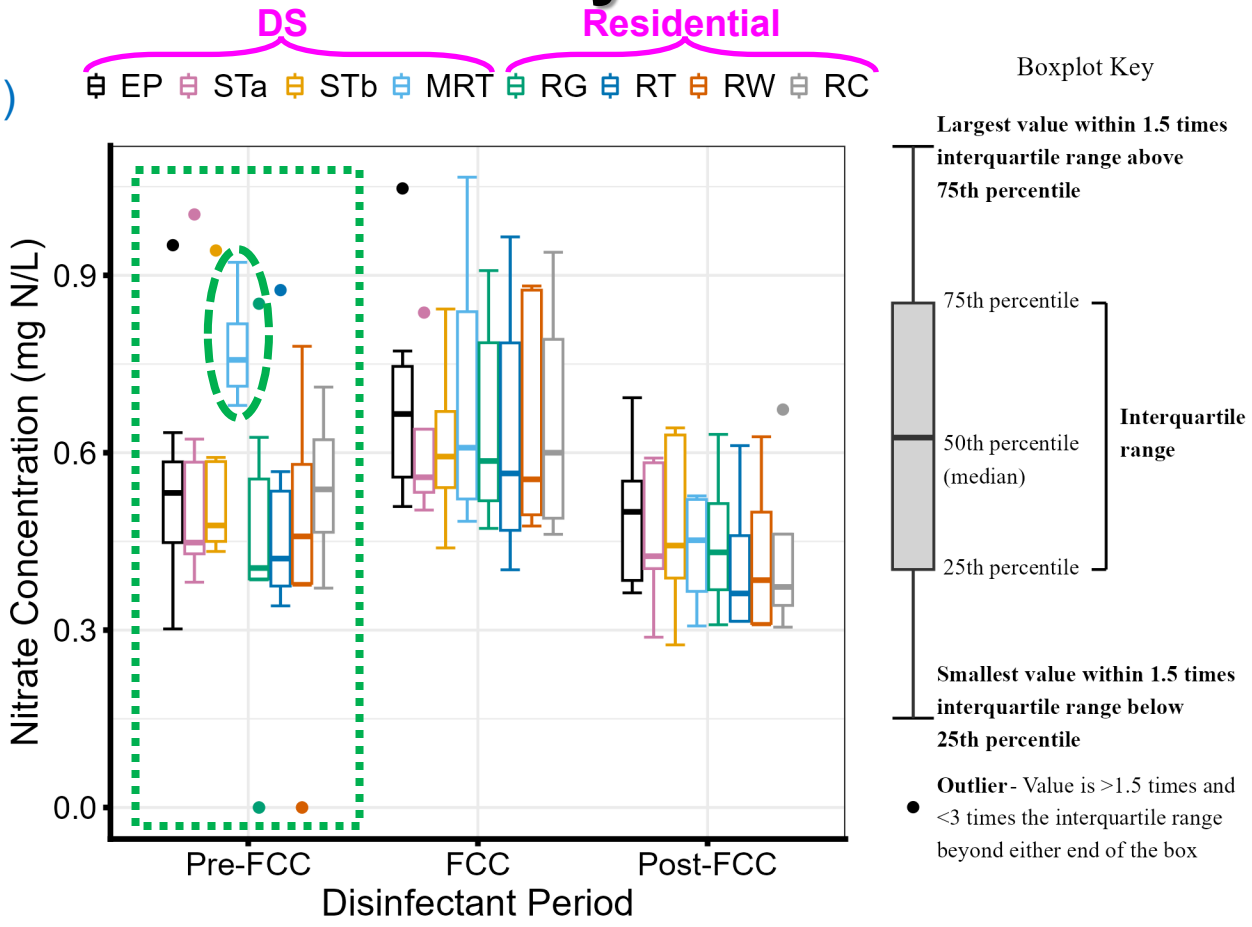
Nitrate Summary

- Holding time
  - Inorganic nitrite oxidation (pH)
  - Nitrite + nitrate?
- Variable at EP (0.3–1 mg N/L)
- Pre-FCC
  - ⇧ at MRT



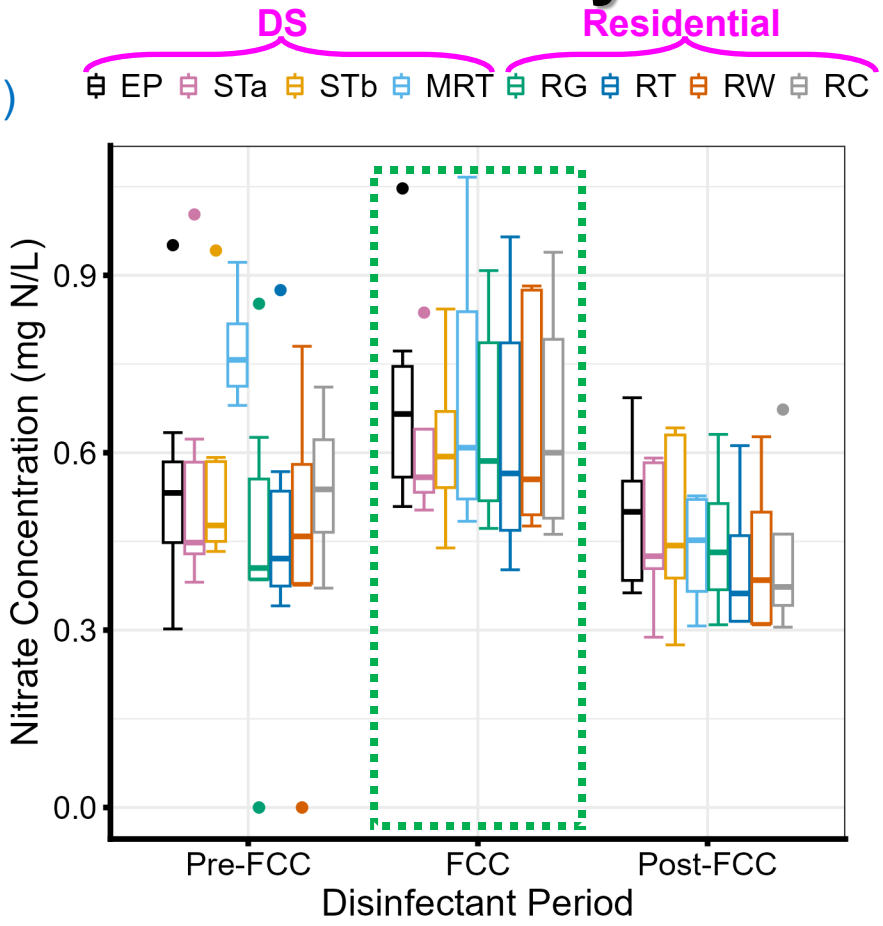
Nitrate Summary

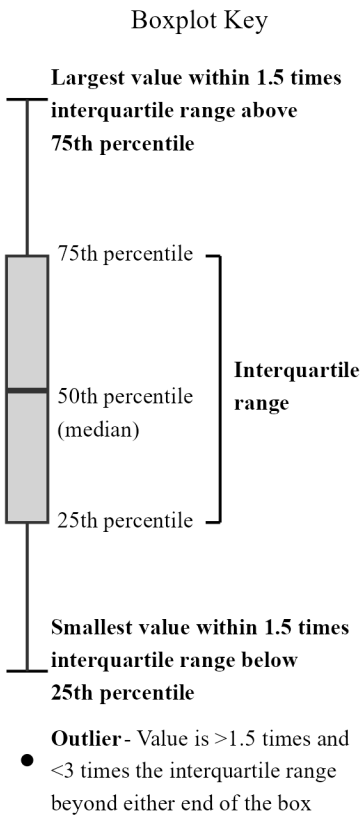
- Holding time
  - Inorganic nitrite oxidation (pH)
  - Nitrite + nitrate?
- Variable at EP (0.3–1 mg N/L)
- Pre-FCC
  - ⇧ at MRT
  - Only site with nitrite (0.1 mg N/L)
  - 0.5 mg N/L gap (without nitrate)
  - 0.1–0.2 mg N/L nitrate Δ
  - 0.3–0.4 mg N/L gap (with nitrate)



Nitrate Summary

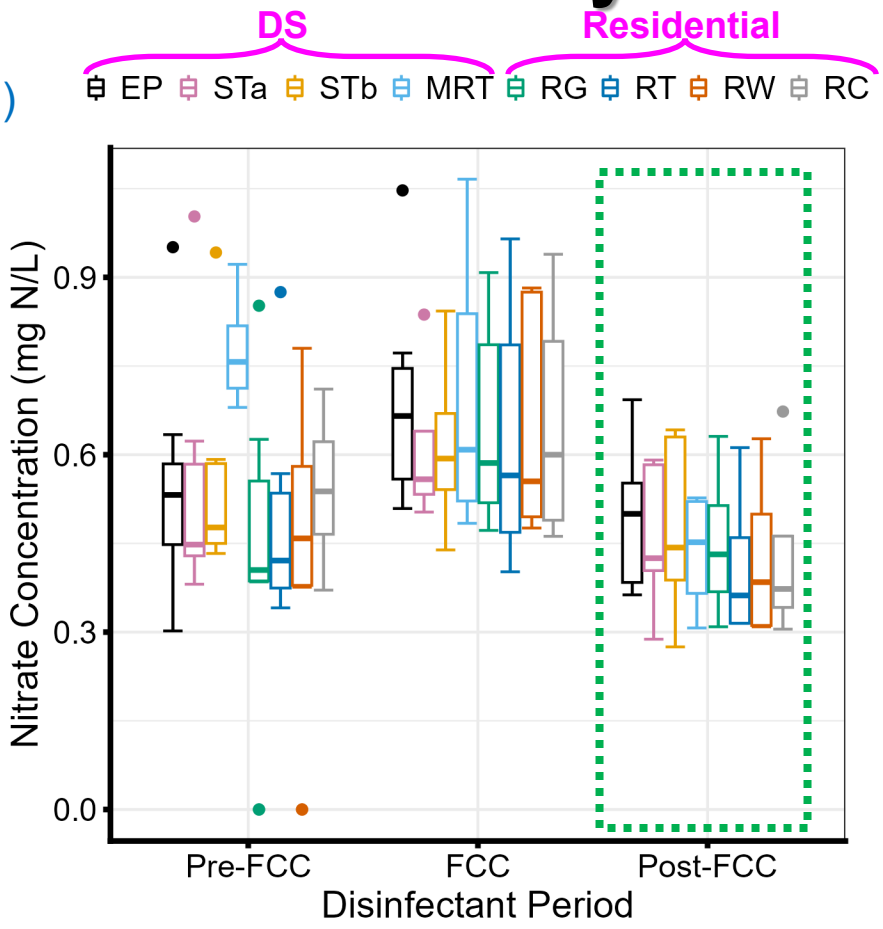
- Holding time
  - Inorganic nitrite oxidation (pH)
  - Nitrite + nitrate?
- Variable at EP (0.3–1 mg N/L)
- Pre-FCC
  - ⇧ at MRT
  - Only site with nitrite (0.1 mg N/L)
  - 0.5 mg N/L gap (without nitrate)
  - 0.1–0.2 mg N/L nitrate Δ
  - 0.3–0.4 mg N/L gap (with nitrate)
- FCC no clear ⇧

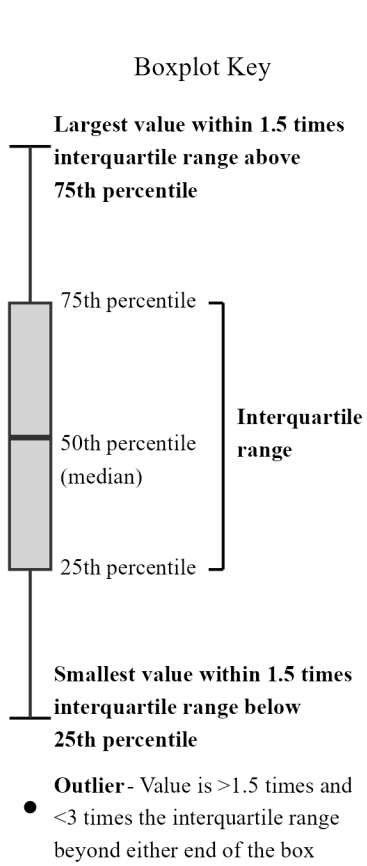




Nitrate Summary

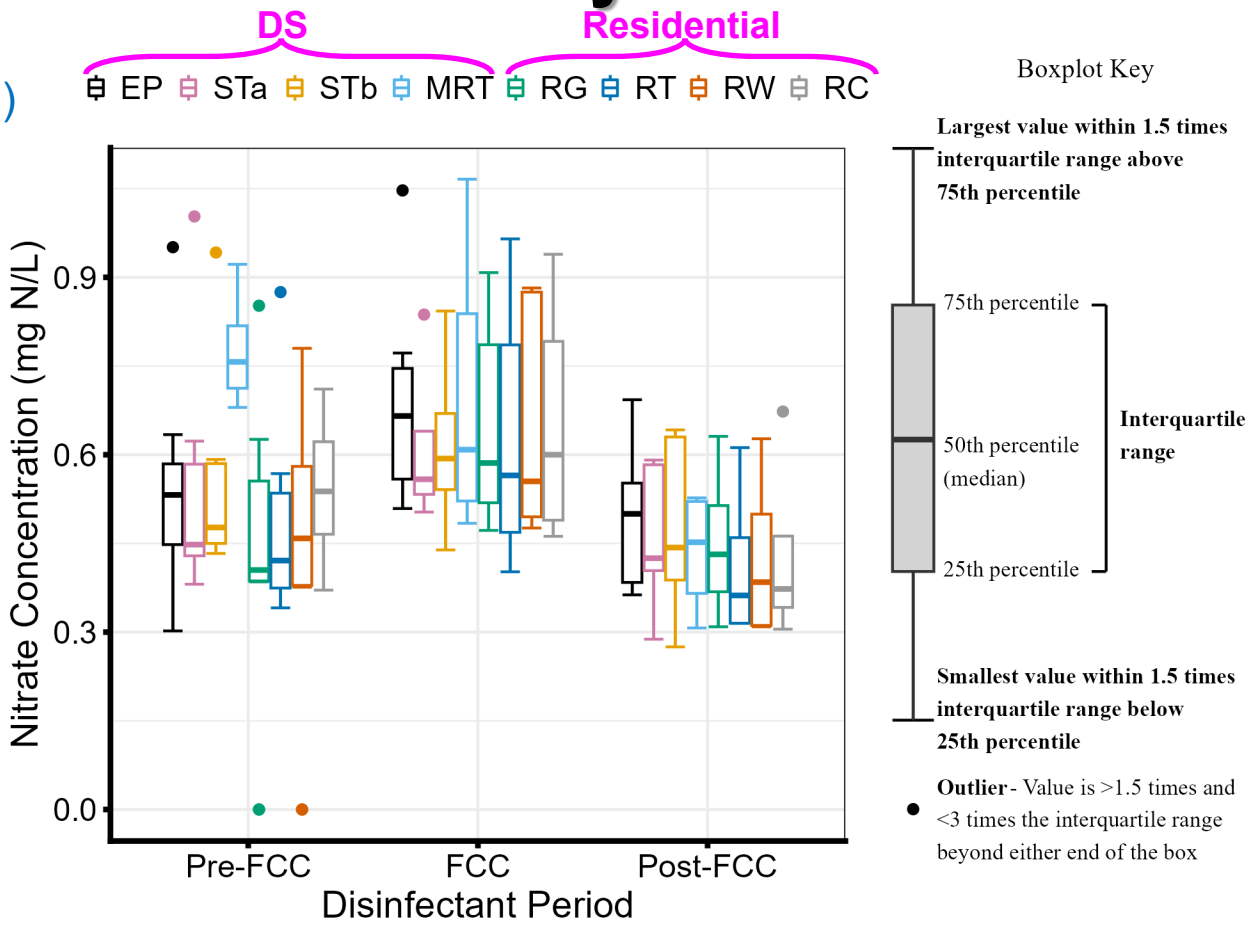
- Holding time
  - Inorganic nitrite oxidation (pH)
  - Nitrite + nitrate?
- Variable at EP (0.3–1 mg N/L)
- Pre-FCC
  - ⇧ at MRT
  - Only site with nitrite (0.1 mg N/L)
  - 0.5 mg N/L gap (without nitrate)
  - 0.1–0.2 mg N/L nitrate Δ
  - 0.3–0.4 mg N/L gap (with nitrate)
- FCC no clear ⇧
- Post-FCC no clear ⇧
  - Like FCC trend
  - 0.4 mg N/L gap (with nitrate)



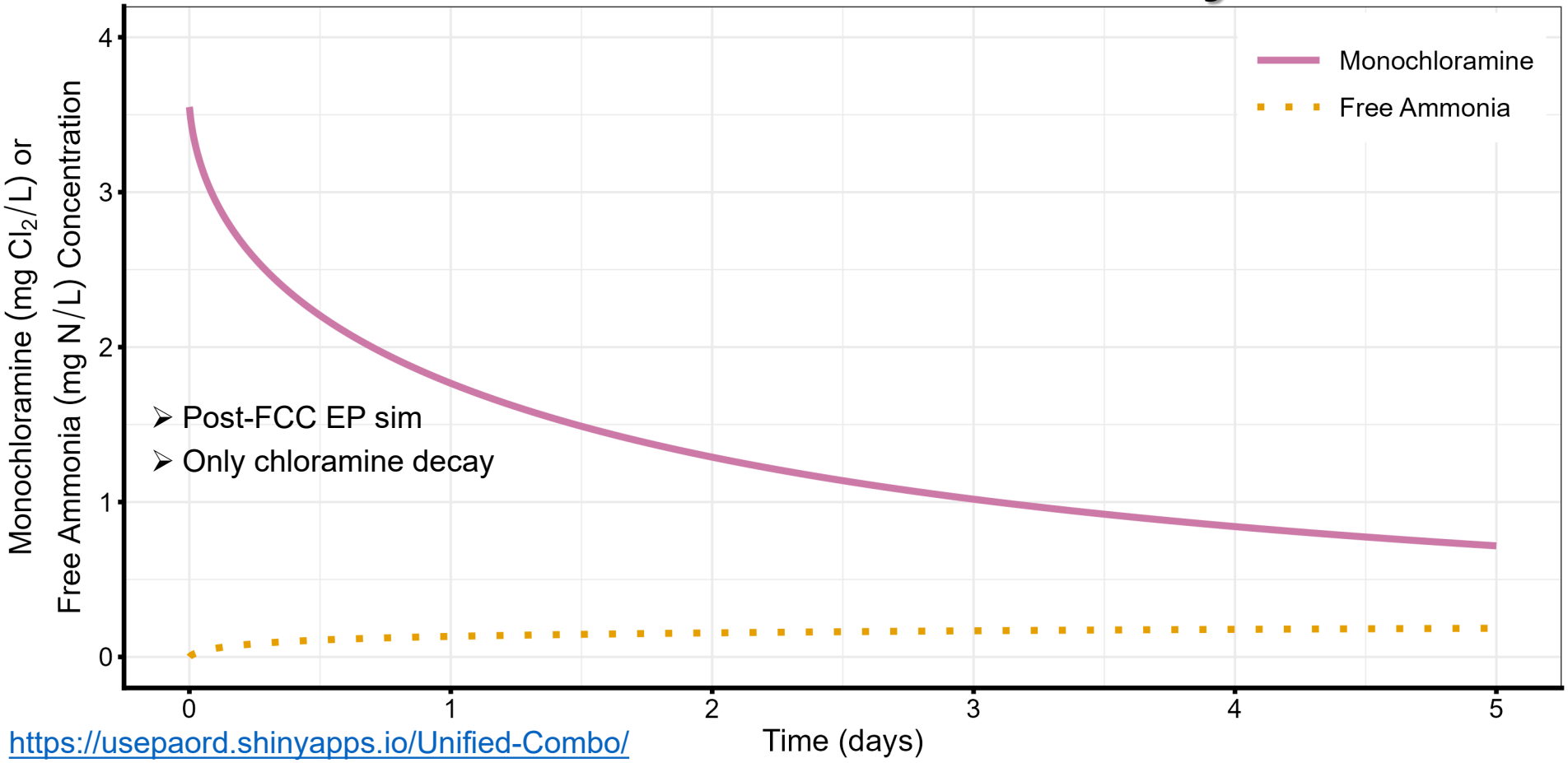


Nitrate Summary

- Holding time
  - Inorganic nitrite oxidation (pH)
  - Nitrite + nitrate?
- Variable at EP (0.3–1 mg N/L)
- Pre-FCC
  - ⇧ at MRT
  - Only site with nitrite (0.1 mg N/L)
  - 0.5 mg N/L gap (without nitrate)
  - 0.1–0.2 mg N/L nitrate Δ
  - 0.3–0.4 mg N/L gap (with nitrate)
- FCC no clear ⇧
- Post-FCC no clear ⇧
  - Like FCC trend
  - 0.4 mg N/L gap (with nitrate)
- Implies nitrogen gas (decay)

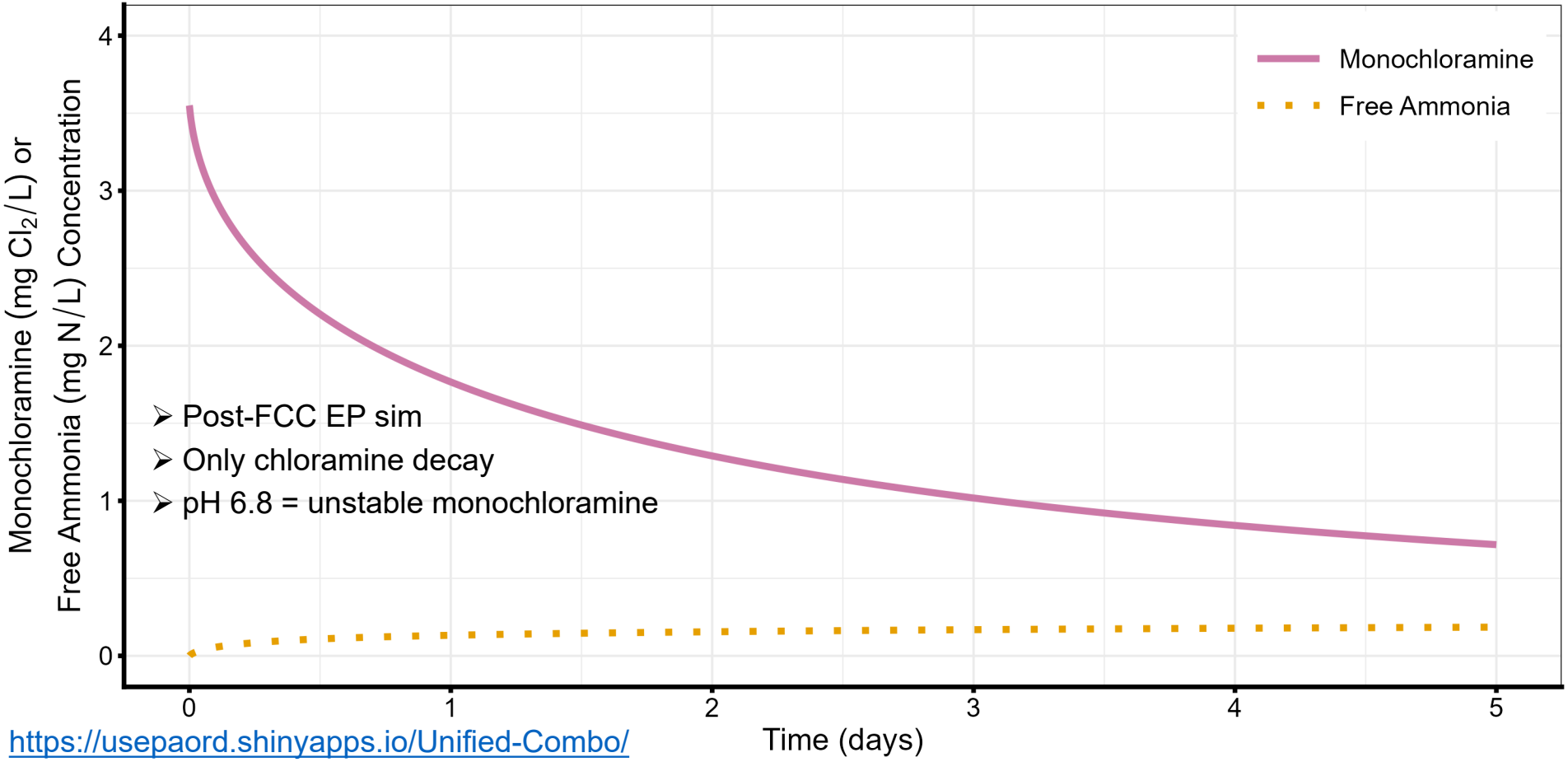


Simulated Chloramine Stability



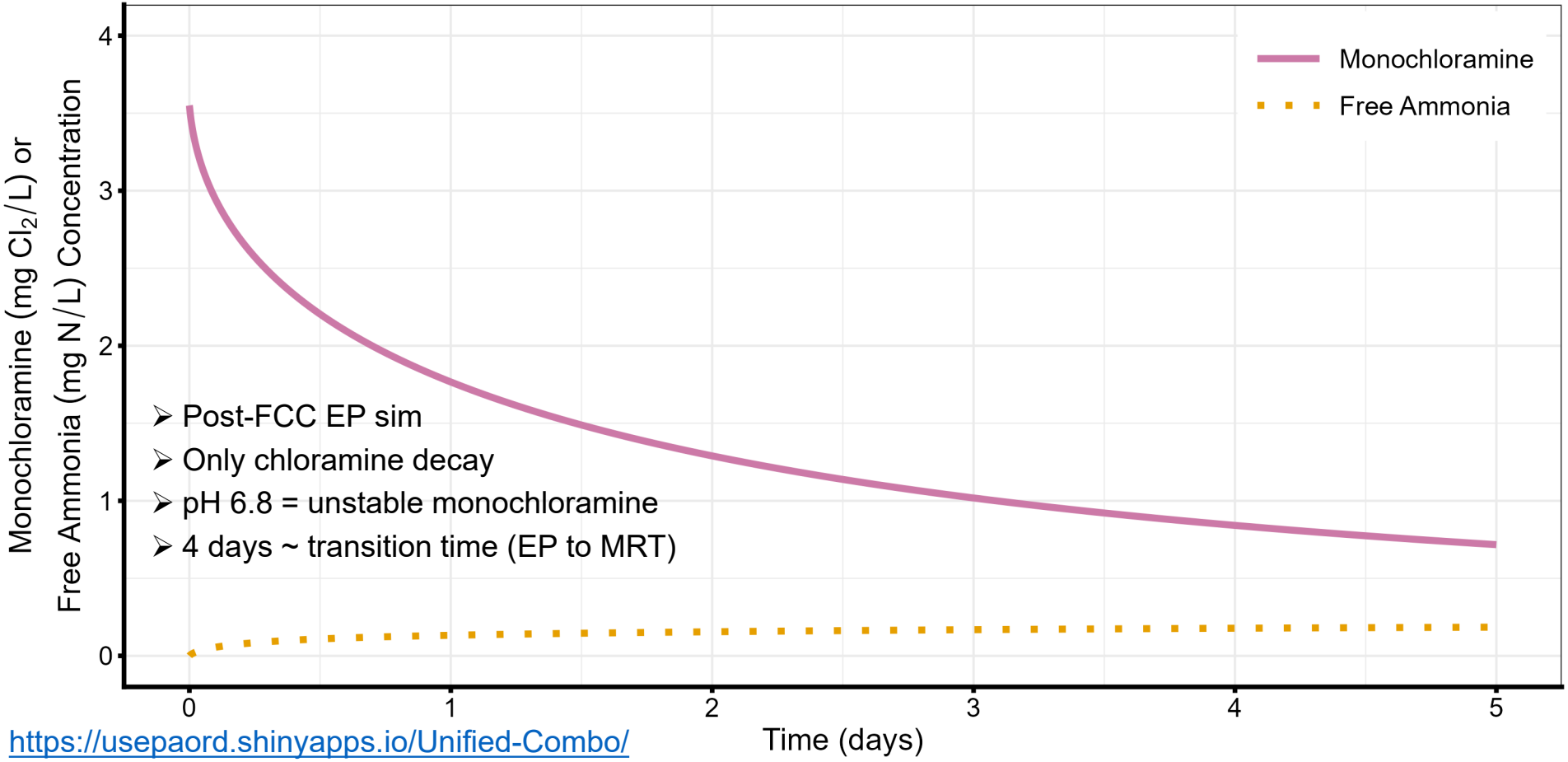
https://usepaord.shinyapps.io/Unified-Combo/

Simulated Chloramine Stability



https://usepaord.shinyapps.io/Unified-Combo/

Simulated Chloramine Stability



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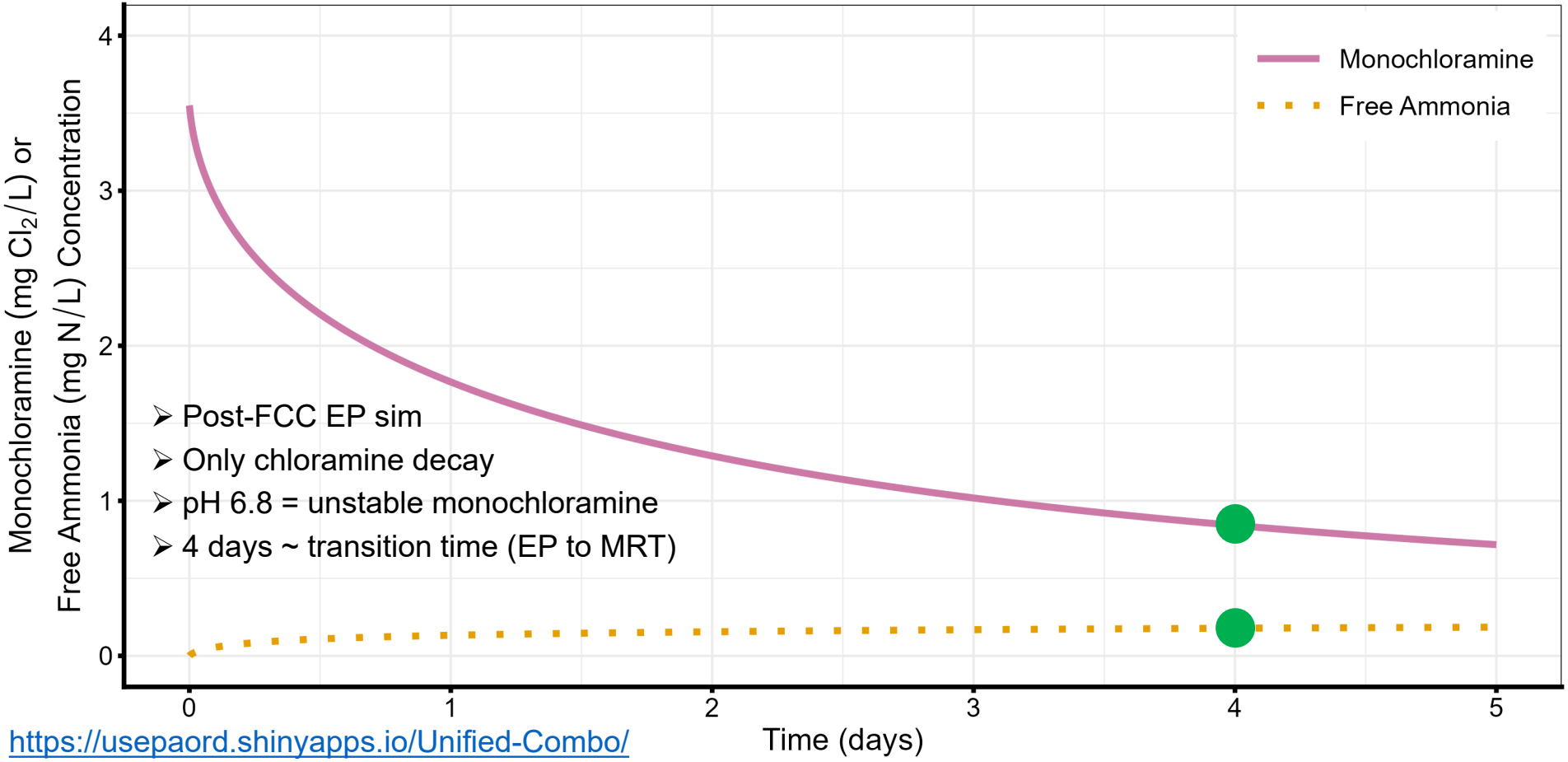
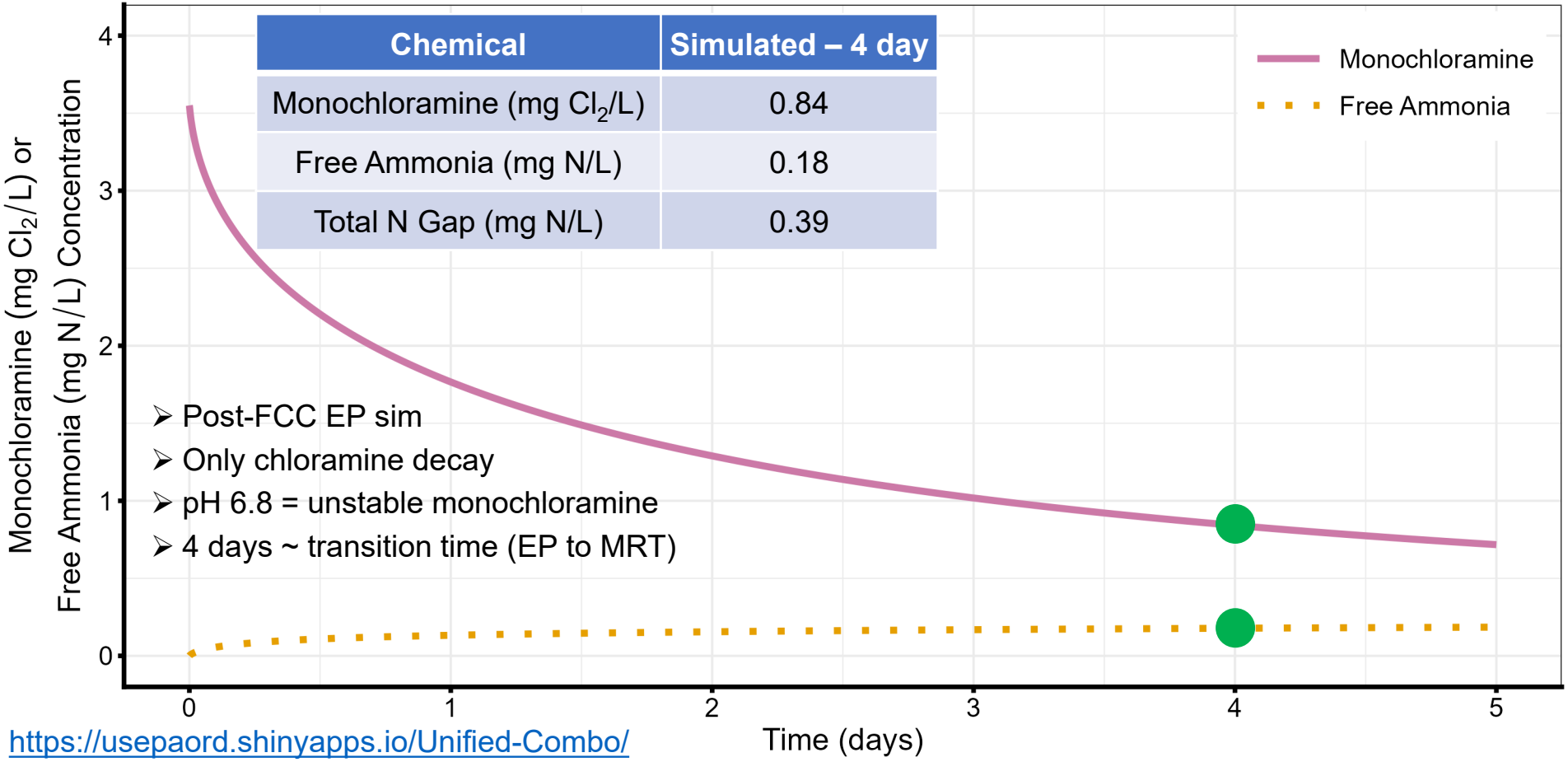
Simulated Chloramine Stability



https://usepaord.shinyapps.io/Unified-Combo/

Simulated Chloramine Stability

Chemical	Simulated – 4 day
Monochloramine (mg Cl_2/L)	0.84
Free Ammonia (mg N/L)	0.18
Total N Gap (mg N/L)	0.39

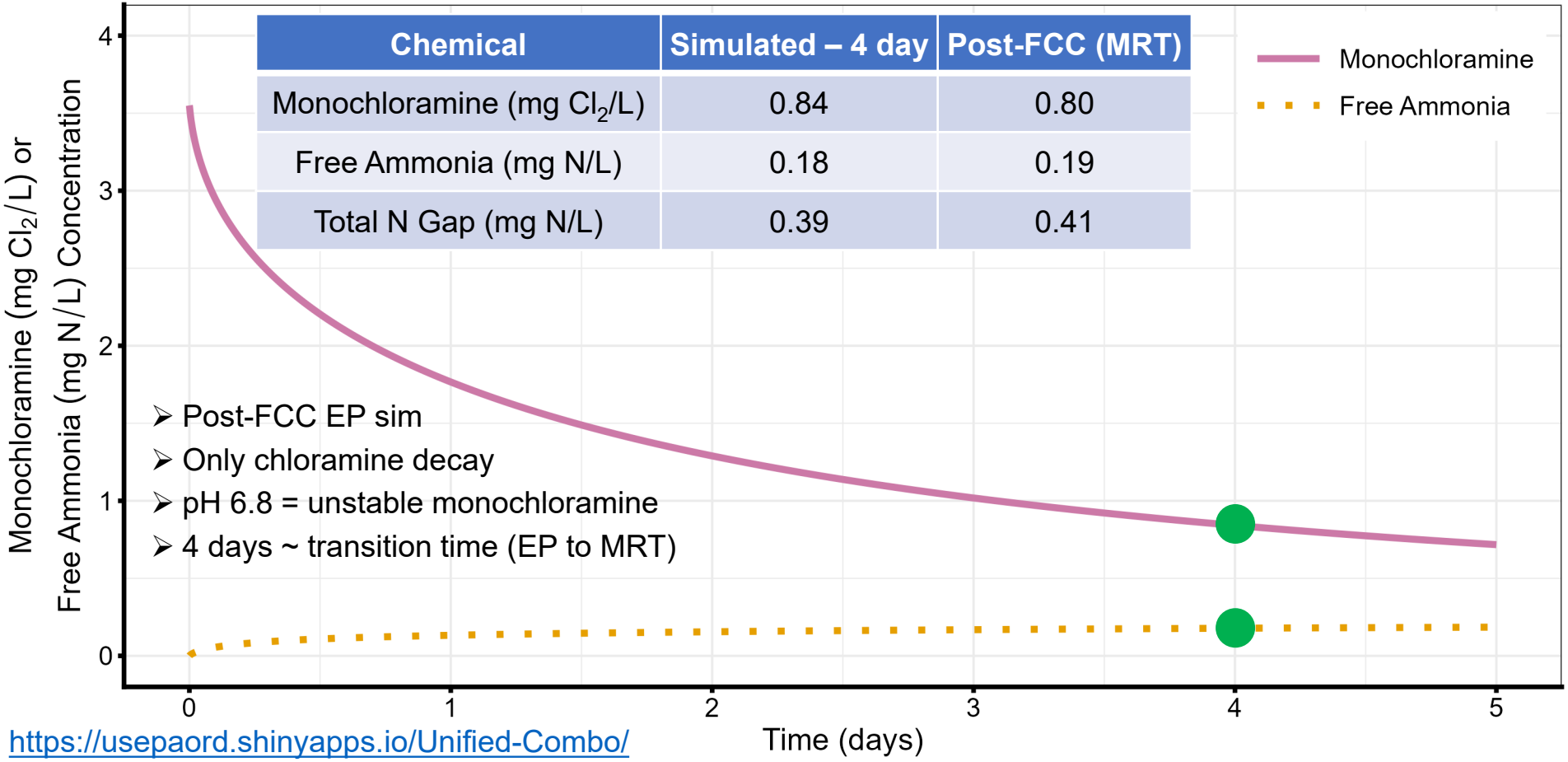


- Post-FCC EP sim
- Only chloramine decay
- pH 6.8 = unstable monochloramine
- 4 days ~ transition time (EP to MRT)

https://usepaord.shinyapps.io/Unified-Combo/

Simulated Chloramine Stability

Chemical	Simulated – 4 day	Post-FCC (MRT)
Monochloramine (mg Cl_2/L)	0.84	0.80
Free Ammonia (mg N/L)	0.18	0.19
Total N Gap (mg N/L)	0.39	0.41



https://usepaord.shinyapps.io/Unified-Combo/

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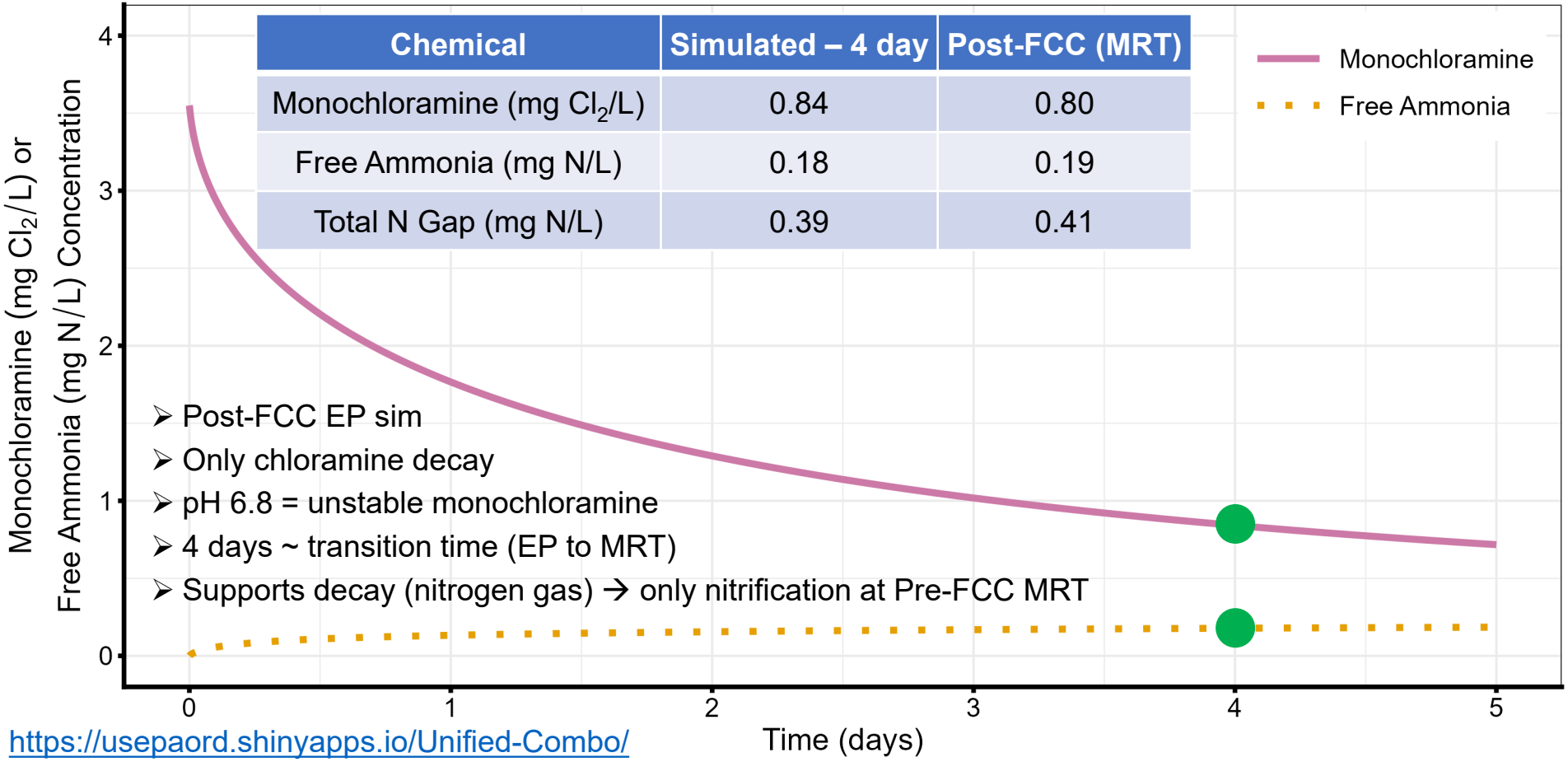

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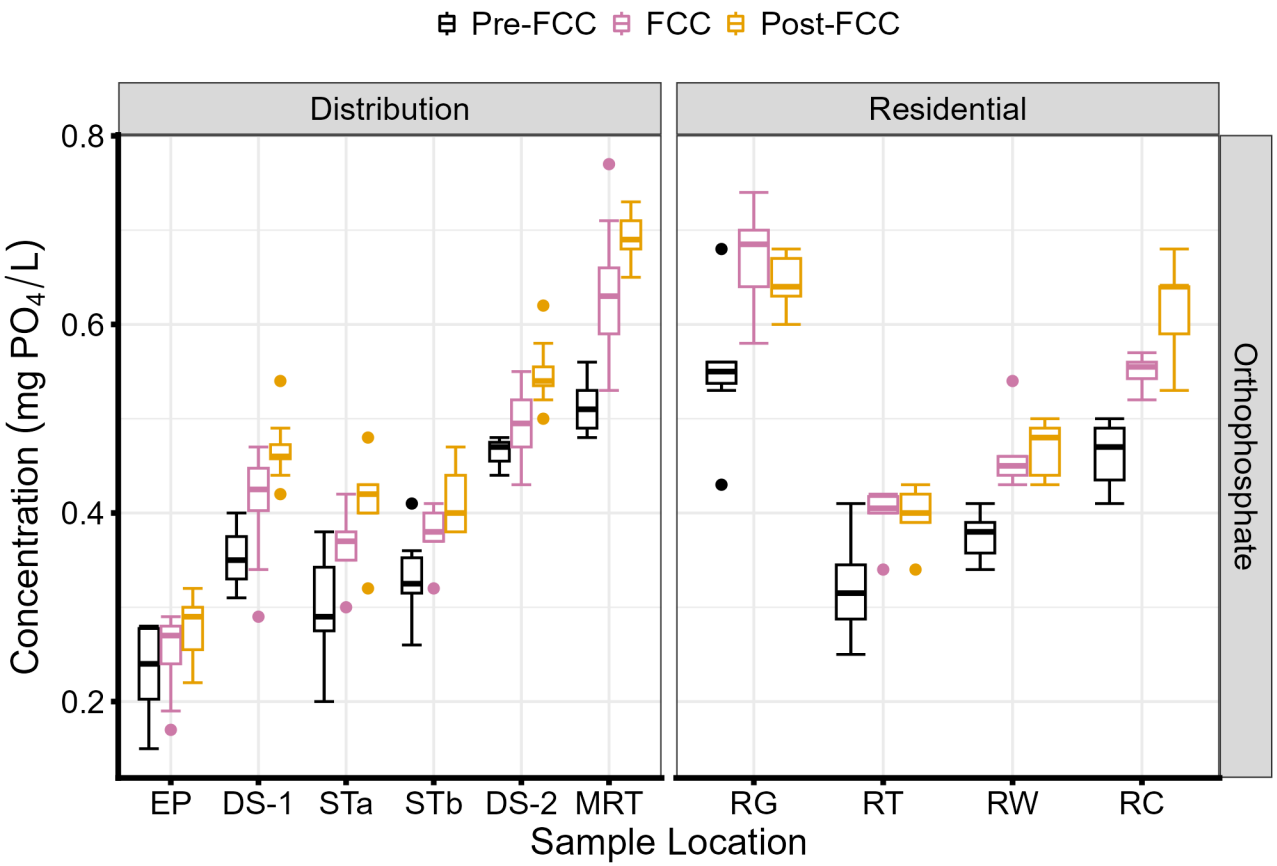
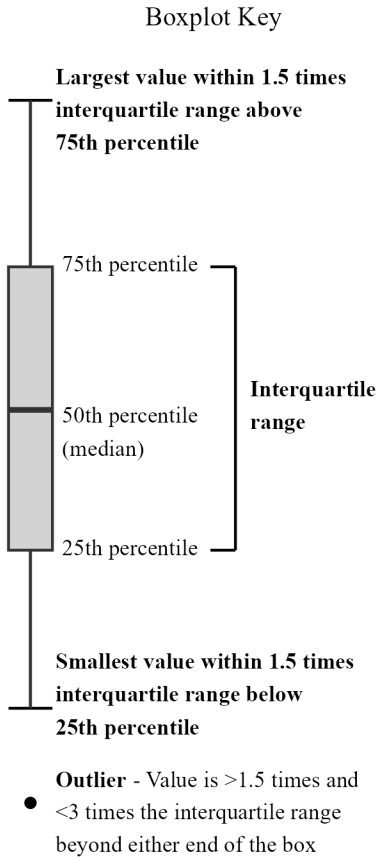
Orthophosphate





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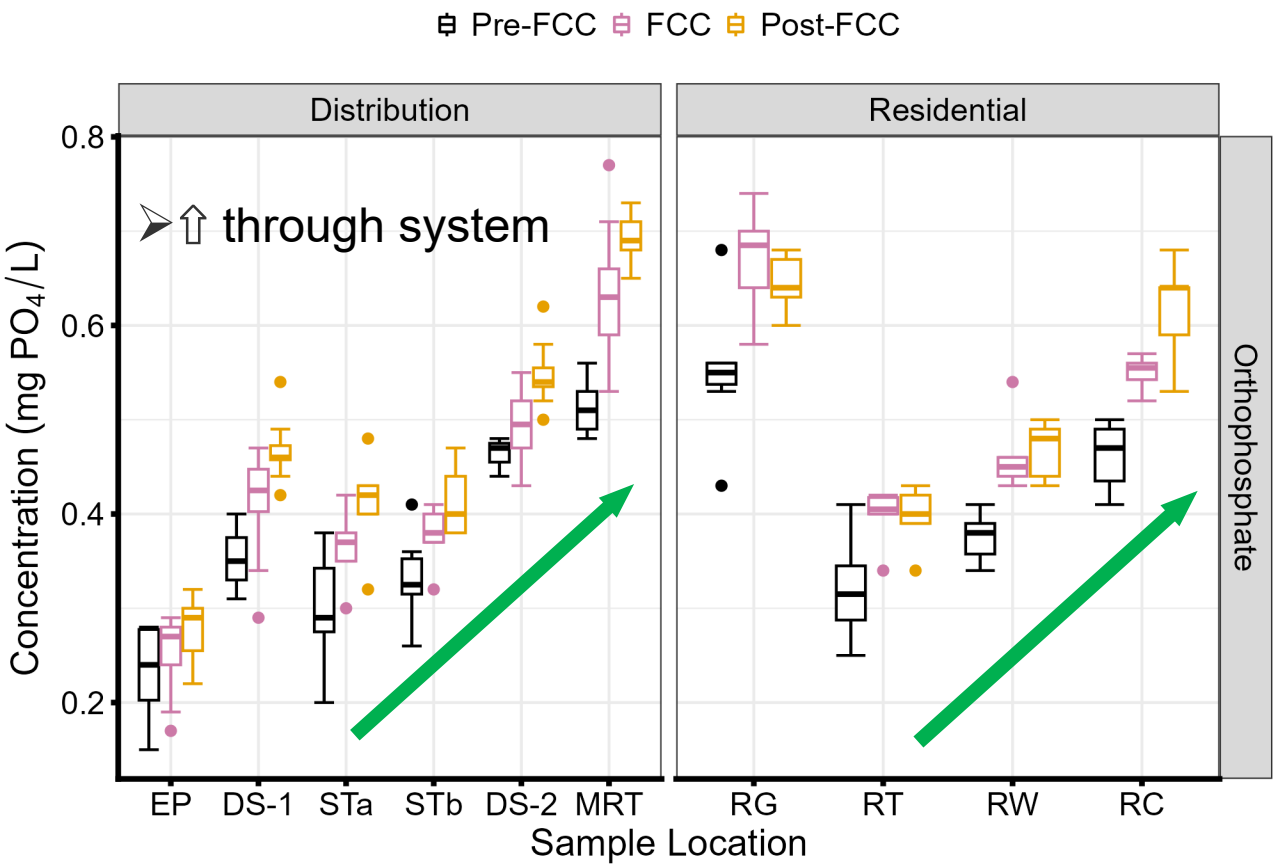


Boxplot Key

Largest value within 1.5 times interquartile range above 75th percentile

75th percentile

50th percentile (median)

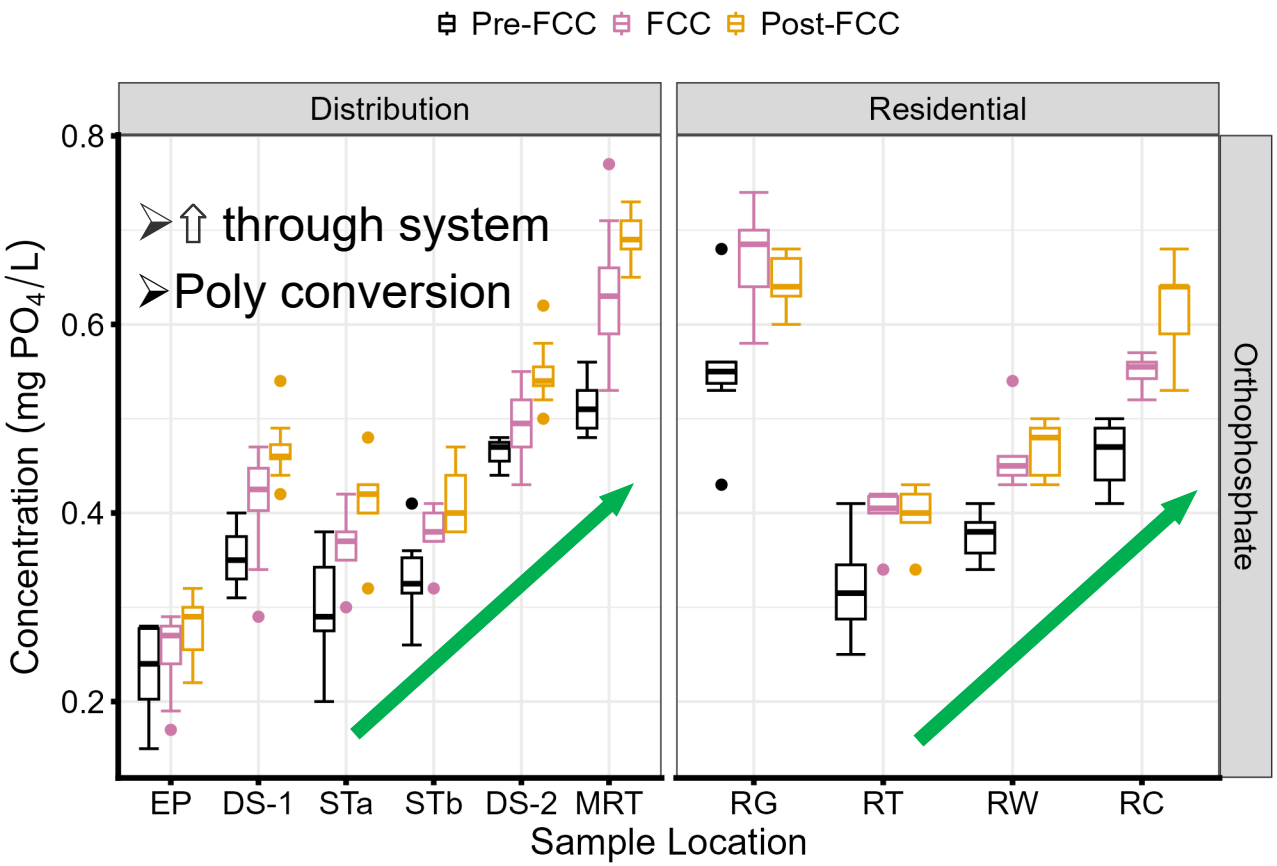
25th percentile

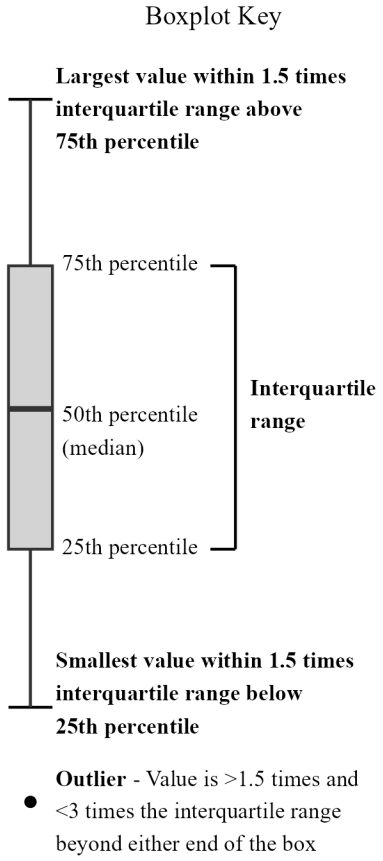
Interquartile range

Smallest value within 1.5 times interquartile range below 25th percentile

Outlier - Value is >1.5 times and <3 times the interquartile range beyond either end of the box

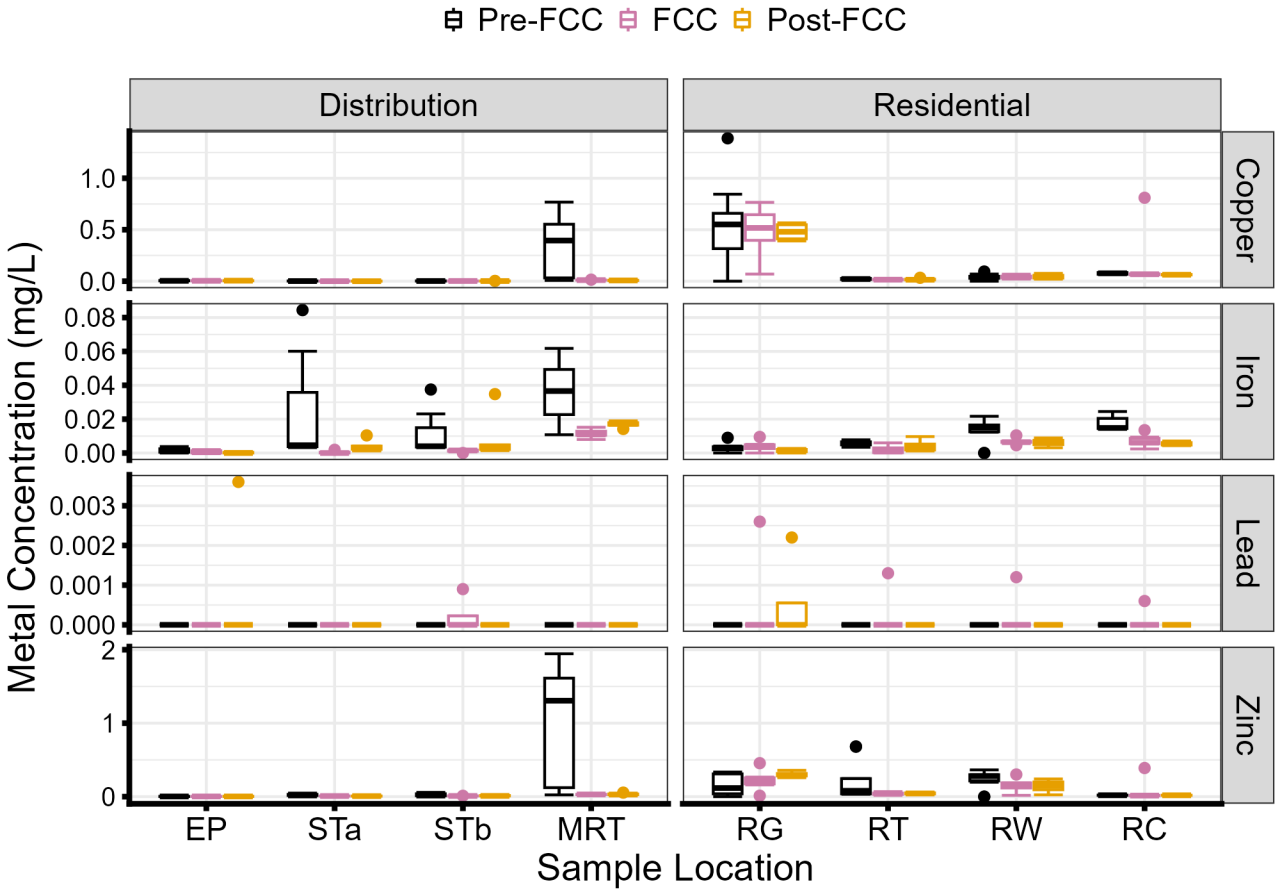
Orthophosphate





Metals

- Generally low metals



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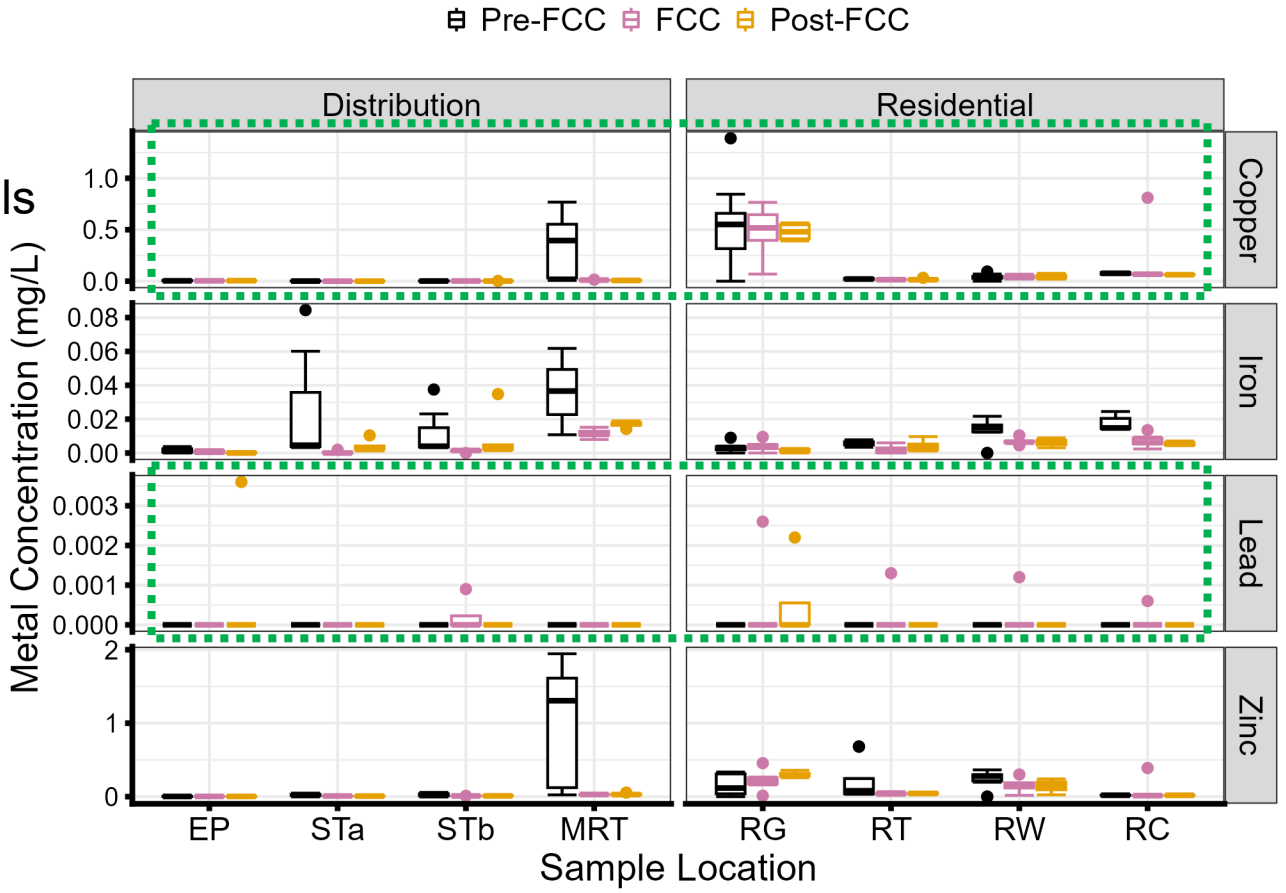

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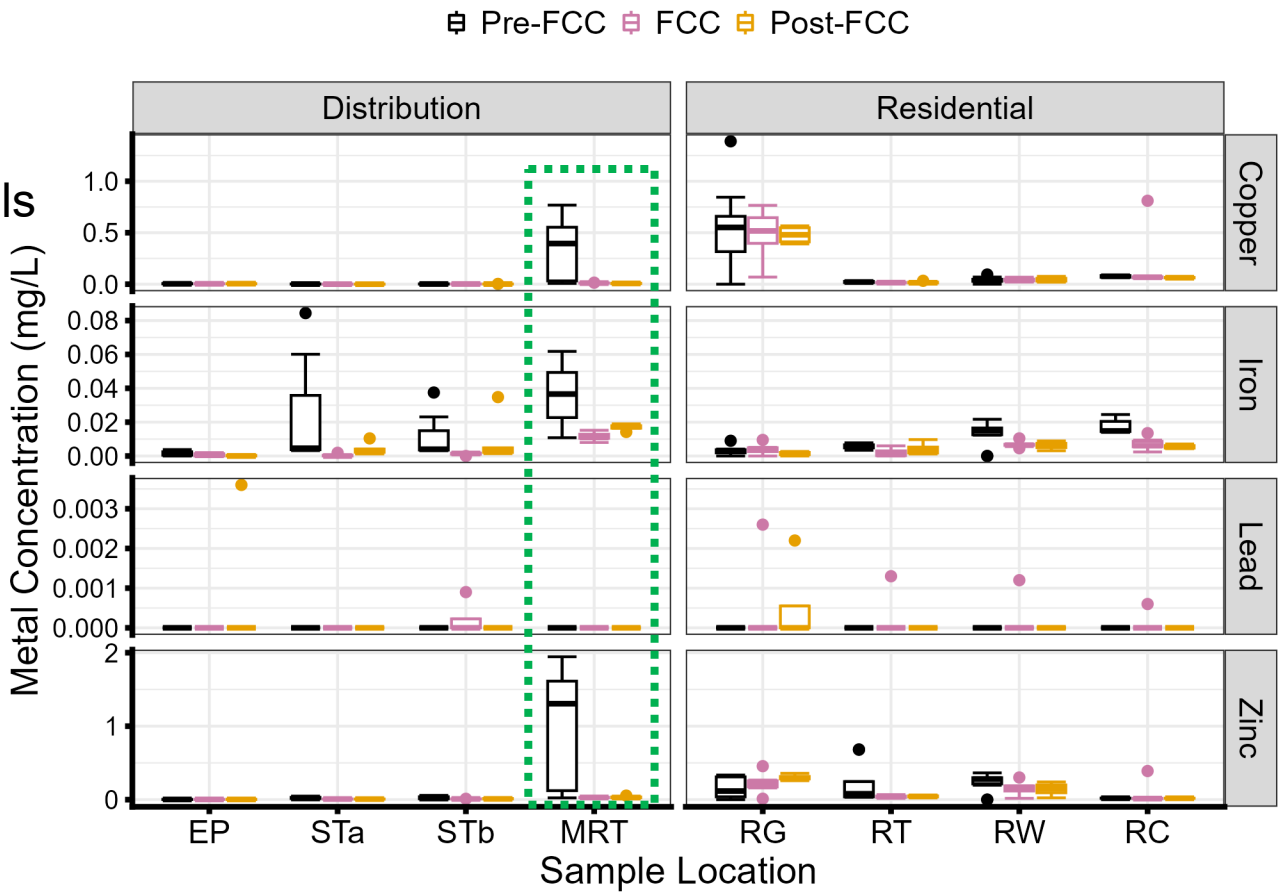

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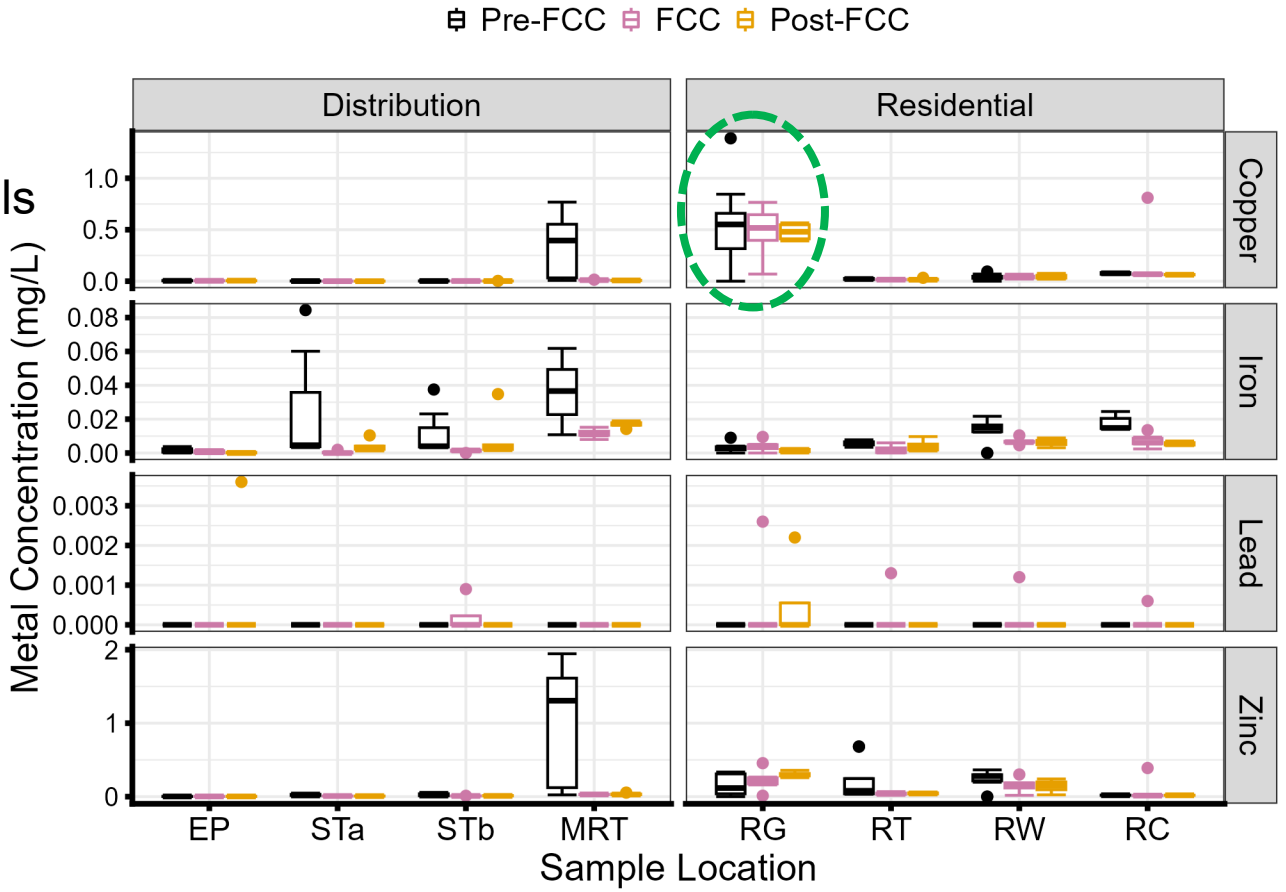

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  - Weighted average that includes FCC
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- Minor impact to metals

Questions?

Acknowledgements

- Anonymous utility
- Anonymous primacy agency

Contact Information

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