# Crafting a Predictive TOC Treatability Model by Combining Multiple Removal Strategies

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OTCO Water Workshop – Quest Conference Center

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# Agenda

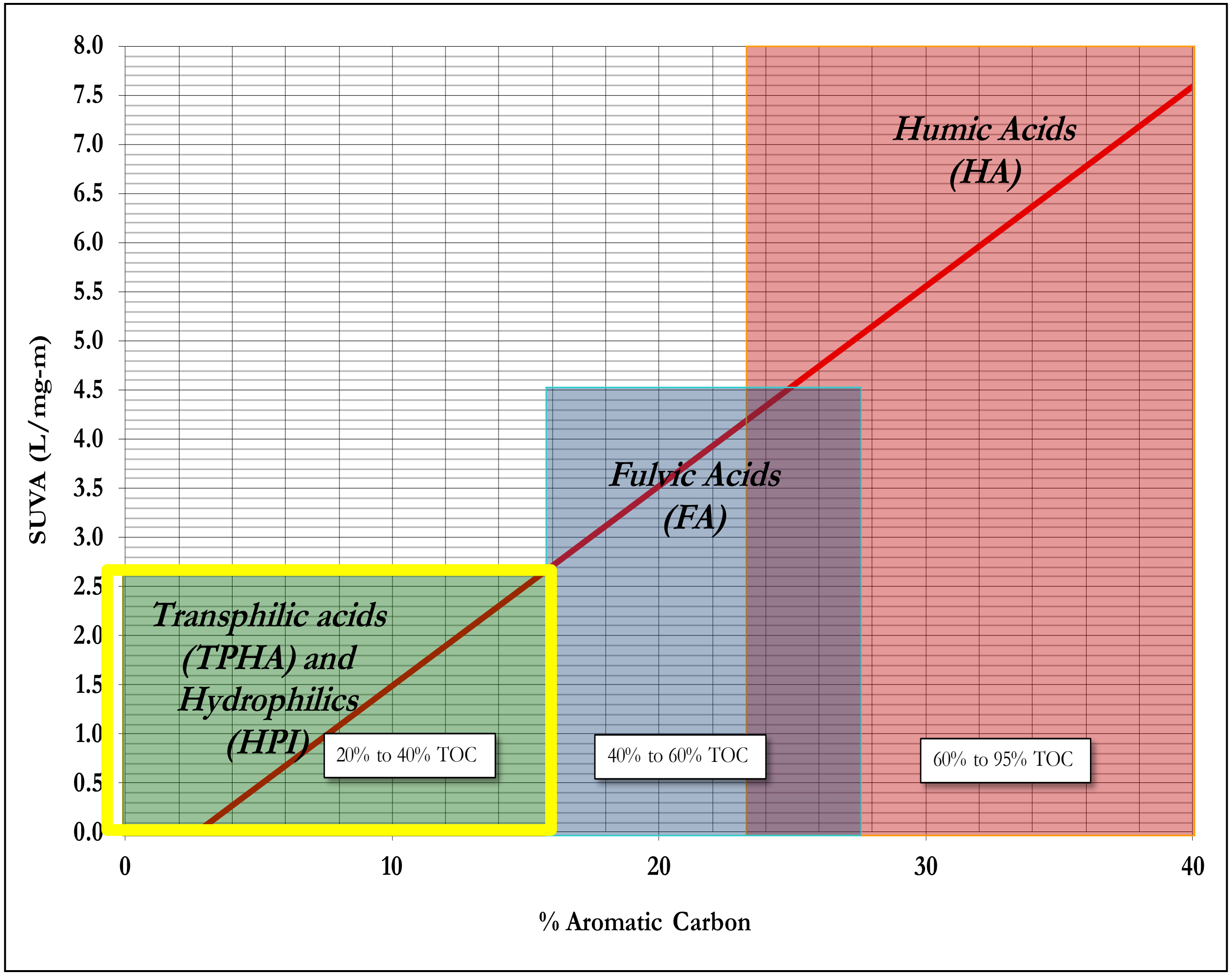
- What we knew about organics removal in water
- What we've learned about organic removal in water
- Crafting a predictive TOC treatability model
- Case study to verify predicted TOC removal in full-scale treatment applications
- Questions

# What We Knew About Organics Removal

- Organic character
  - Consists generally of humic acids, fulvic acids, transphilic acids, and other hydrophilic matter (NOM)
  - SUVA values commonly used to depict TOC removal capability
    - > 3 L/mg-m suggests easier TOC removal
    - < 3 L/mg-m more difficult TOC removal
  - SUVA values suggest general TOC treatability based on organic characterization

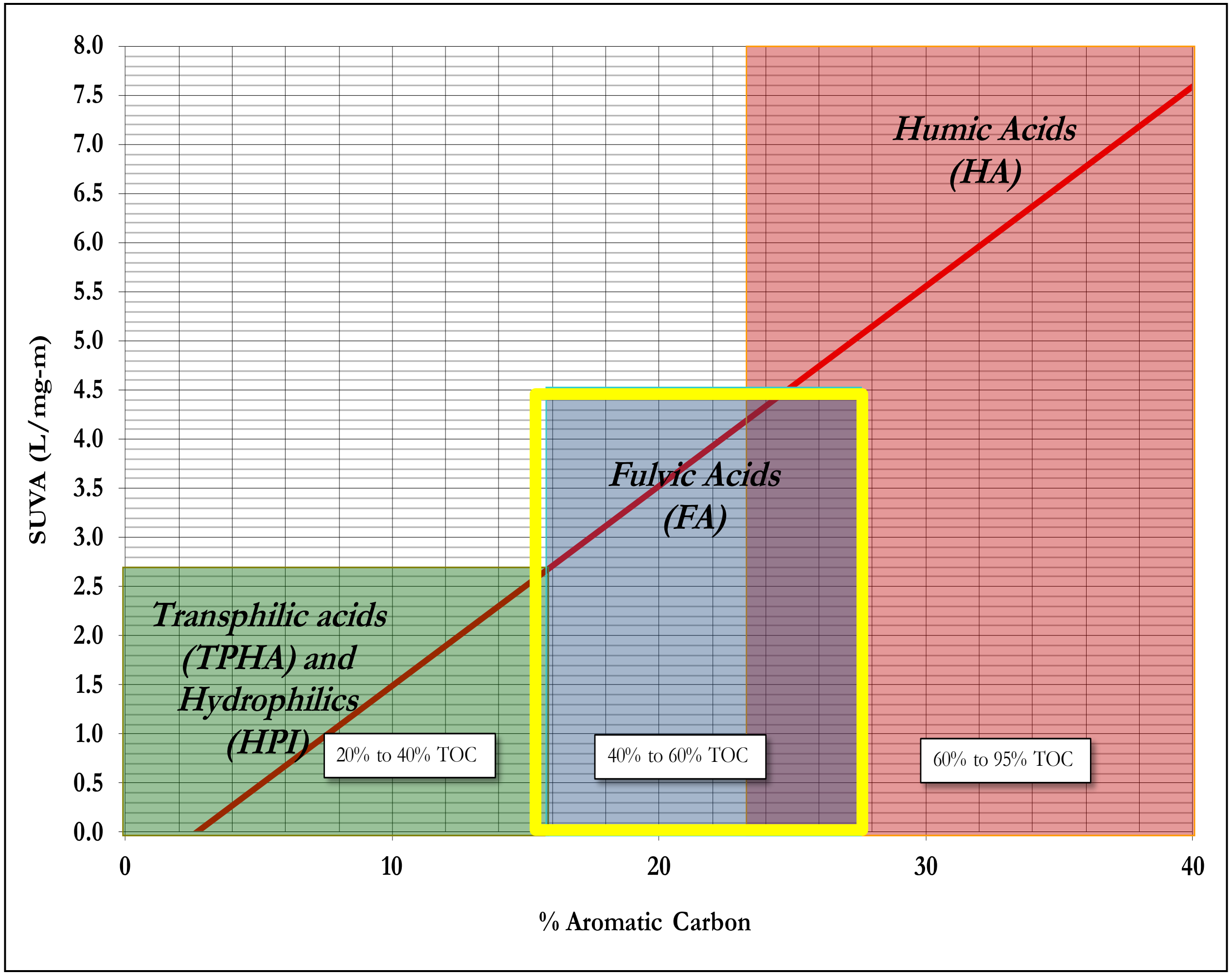
# What We Knew About Organics Removal

- Low SUVA values (up to 2.5 L/mg-m) suggest hydrophilic matter and transphilic acid (THPA) content
  - 20% to 40% TOC removal expected



# What We Knew About Organics Removal

- Low SUVA values(up to 2.5 L/mg-m) suggest hydrophilic matter and transphilic acid (THPA) content
  - 20% to 40% TOC removal expected
- Moderate SUVA values (2.5 L/mg-m to 4.2 L/mg-m) suggest fulvic acid presence
  - 40% to 60% TOC removal expected



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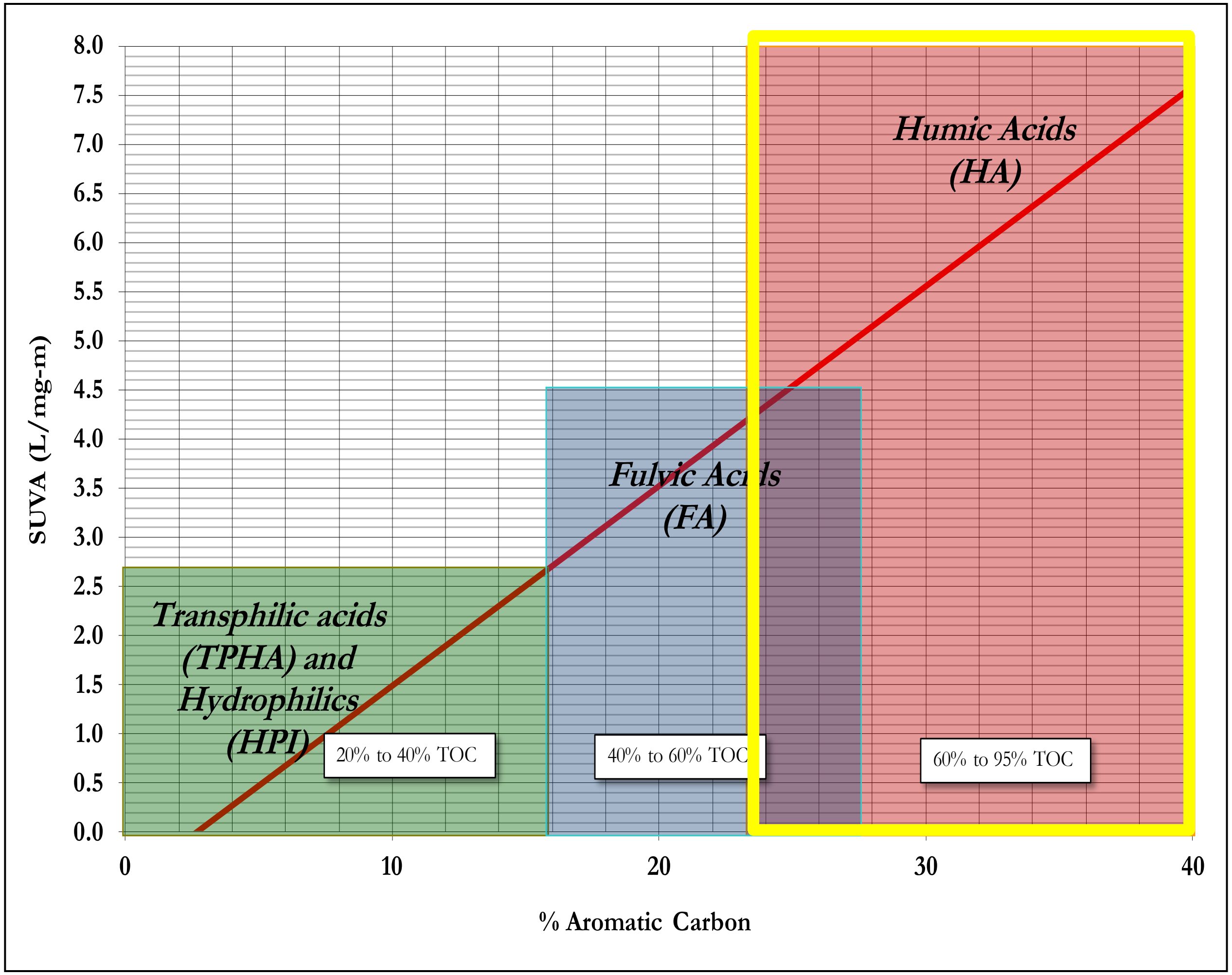
- Moderate SUVA values (2.5 L/mg-m to 4.2 L/mg-m) suggest fulvic acid presence
  - 40% to 60% TOC removal expected
- High SUVA values (greater than 4.2 L/mg-m) suggest humic acid presence
  - 60% to 95% TOC removal expected



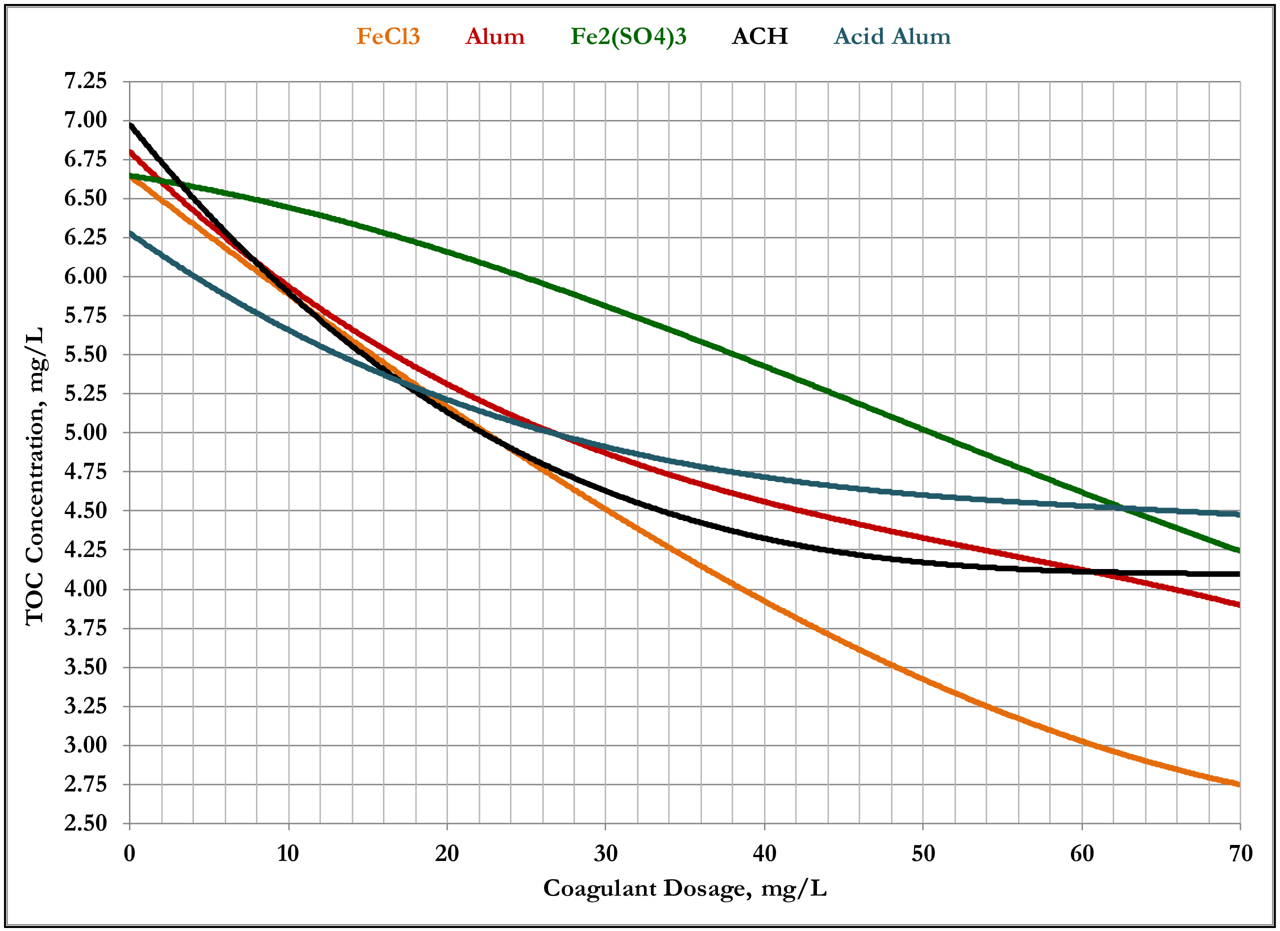
# What We Knew About Organics Removal

| Organic Matter | SUVA Range, L/mg-m | Chlorine Demand mg/L |
|---|---|---|
| Humic acids | 4.2 and greater | 3.0 ±0.2 |
| Fulvic Acids | 3.1 to 4.5 | 1.4 ±0.12 |
| Transphilic acids | 2.0 to 2.7 | 1.2 ±0.2 |
| Other hydrophilics | 1.2 to 1.8 | 0.3 ±0.1 |

# What We Knew About Organics Removal

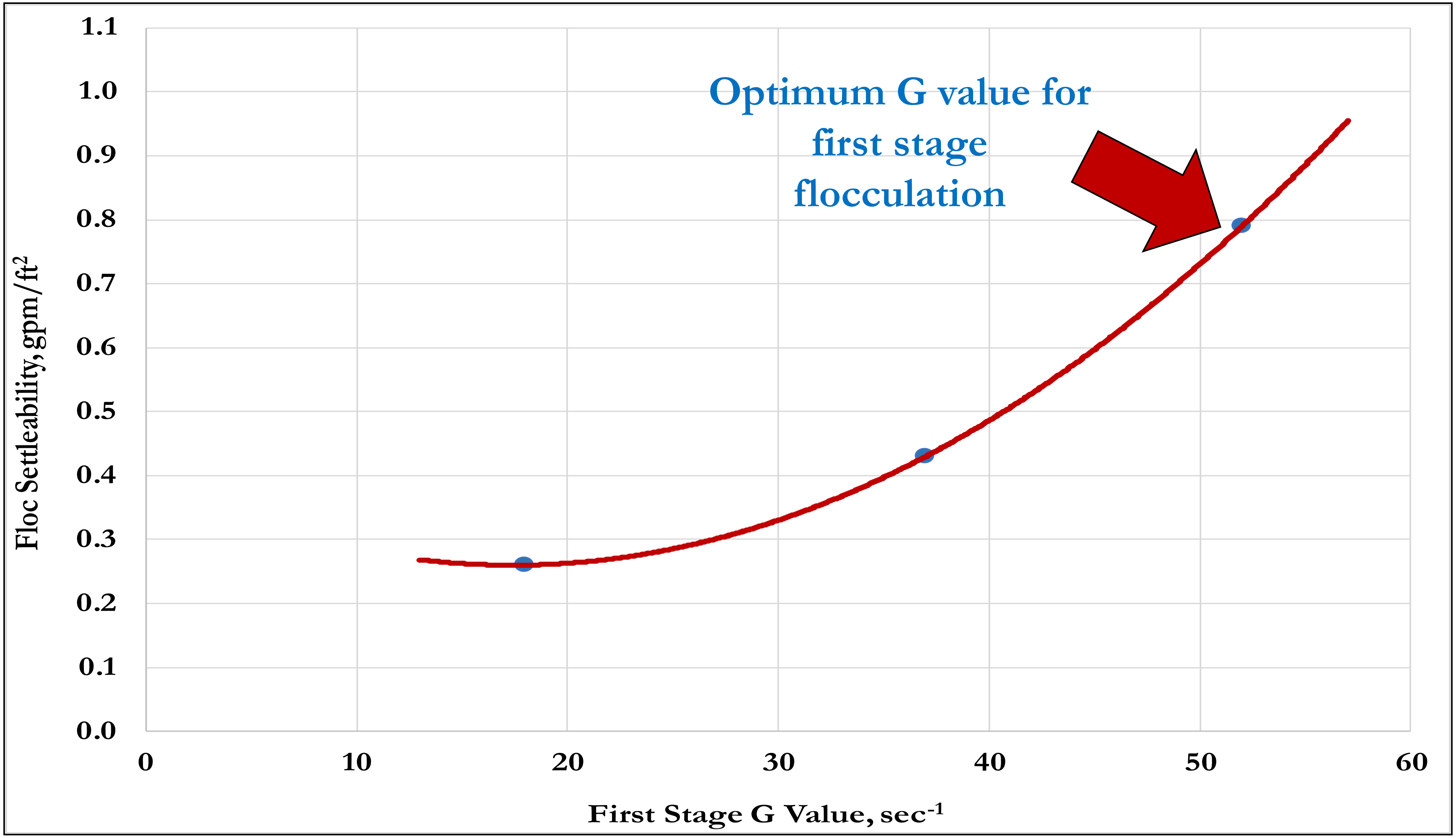
- Jar testing can predict mixing conditions and coagulant dosing to optimize TOC reductions in water
  - Optimal mixing intensity for floc development and settleability
  - Most effective coagulant type and dosage
  - Enhanced coagulation dosing
  - TOC removal capability from chemical treatments
  - Oxidative conditioning strategy to enhance TOC reductions
  - TOC reduction capabilities from PAC treatment

# What We Knew About Organics Removal




- Increased coagulant dosage can improve TOC removal
- High coagulant dosages consume significant amounts of alkalinity
  - Check OCCT needs
- Enhanced coagulation may not remove sufficient TOC for DBP control
  - Depending on organic character and treatability

# What We Knew About Organics Removal



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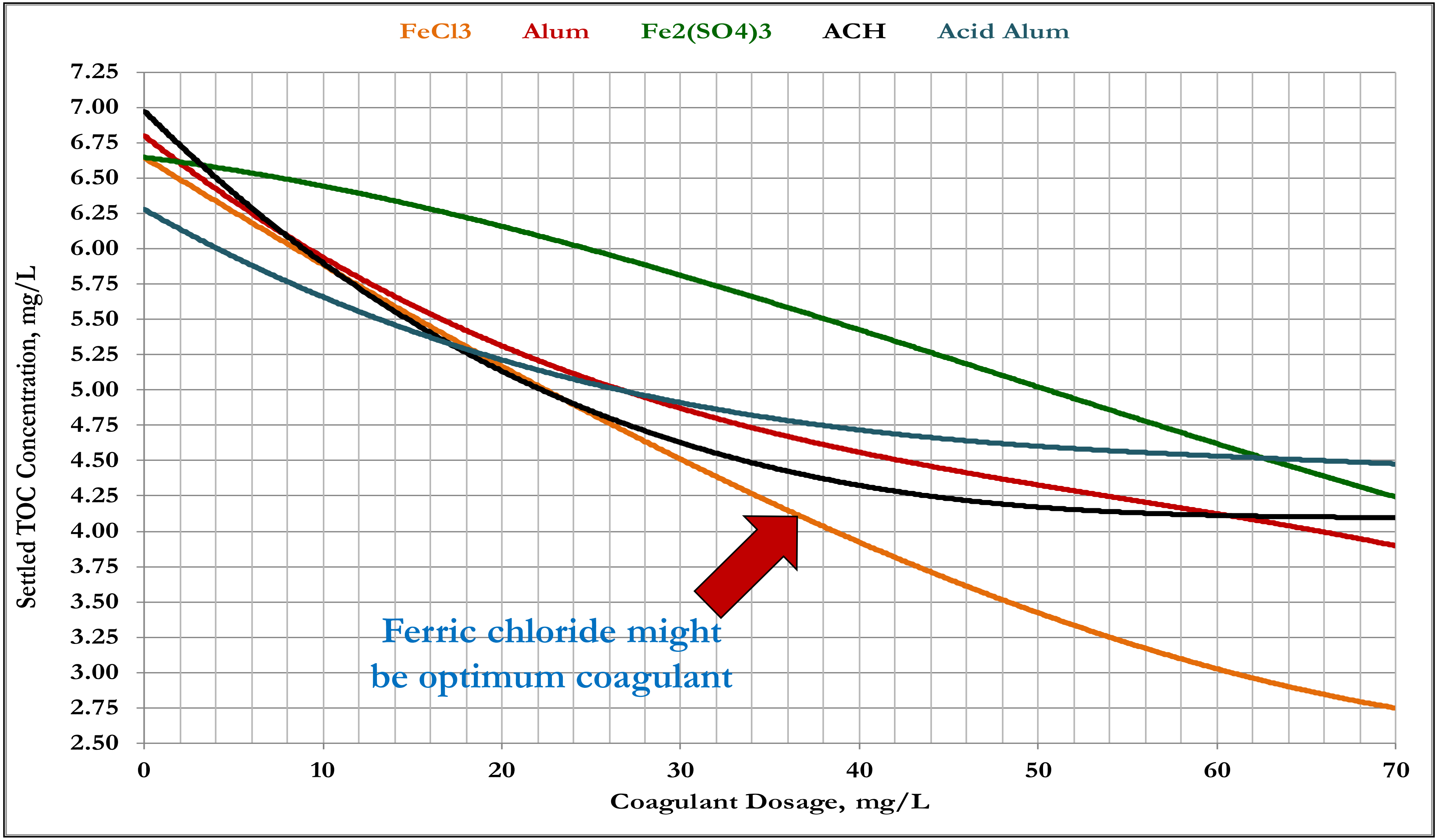

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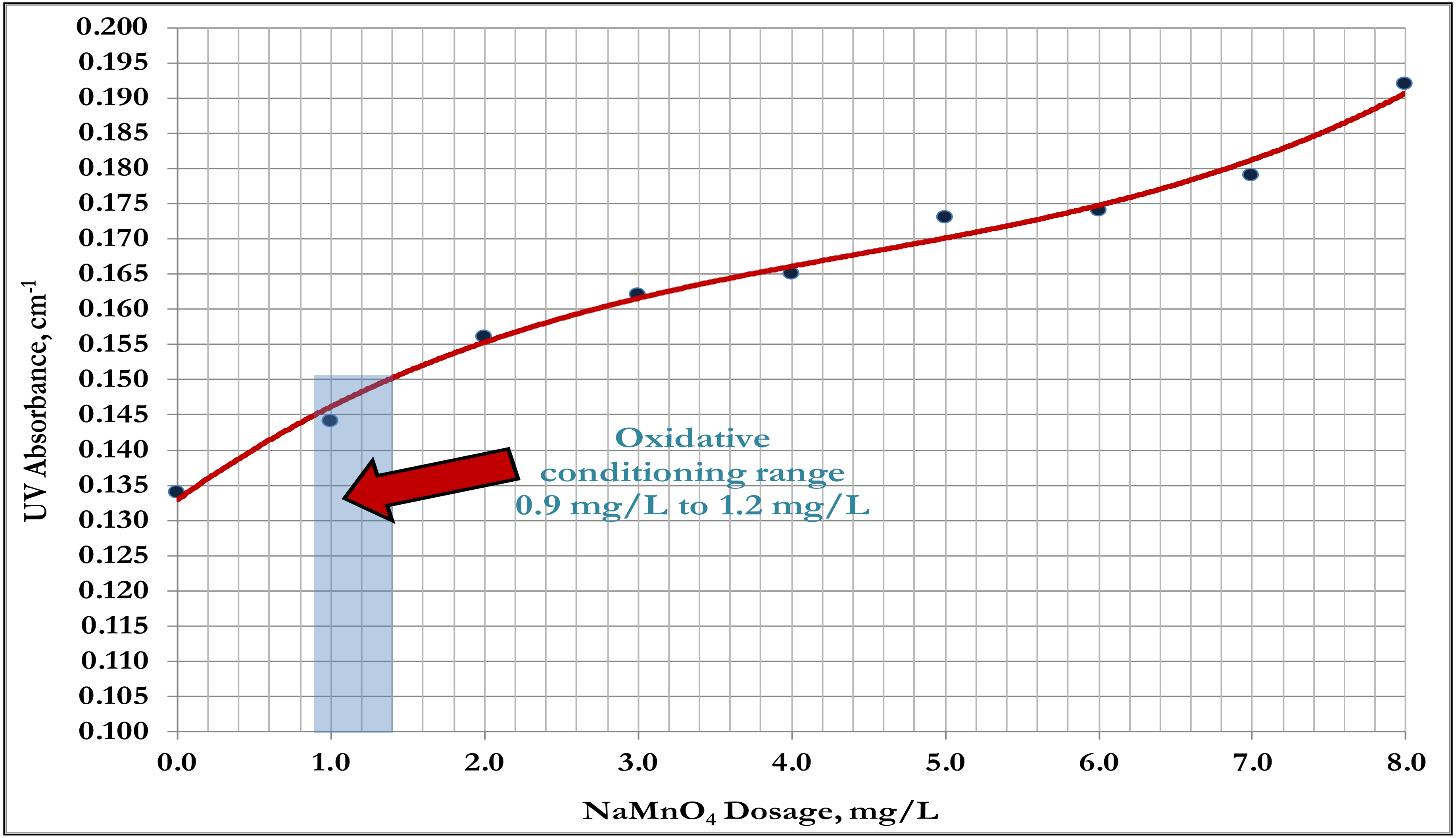

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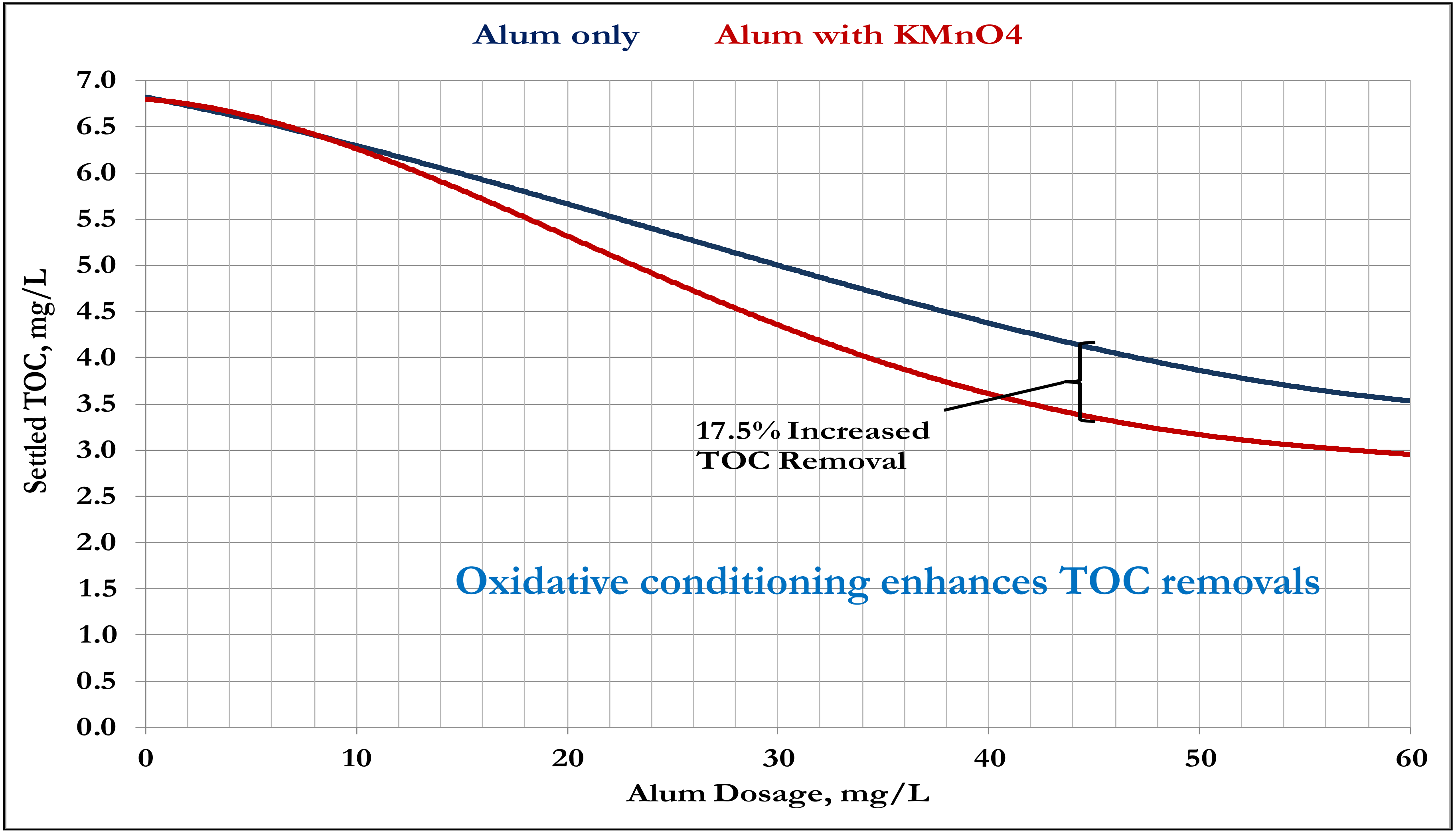

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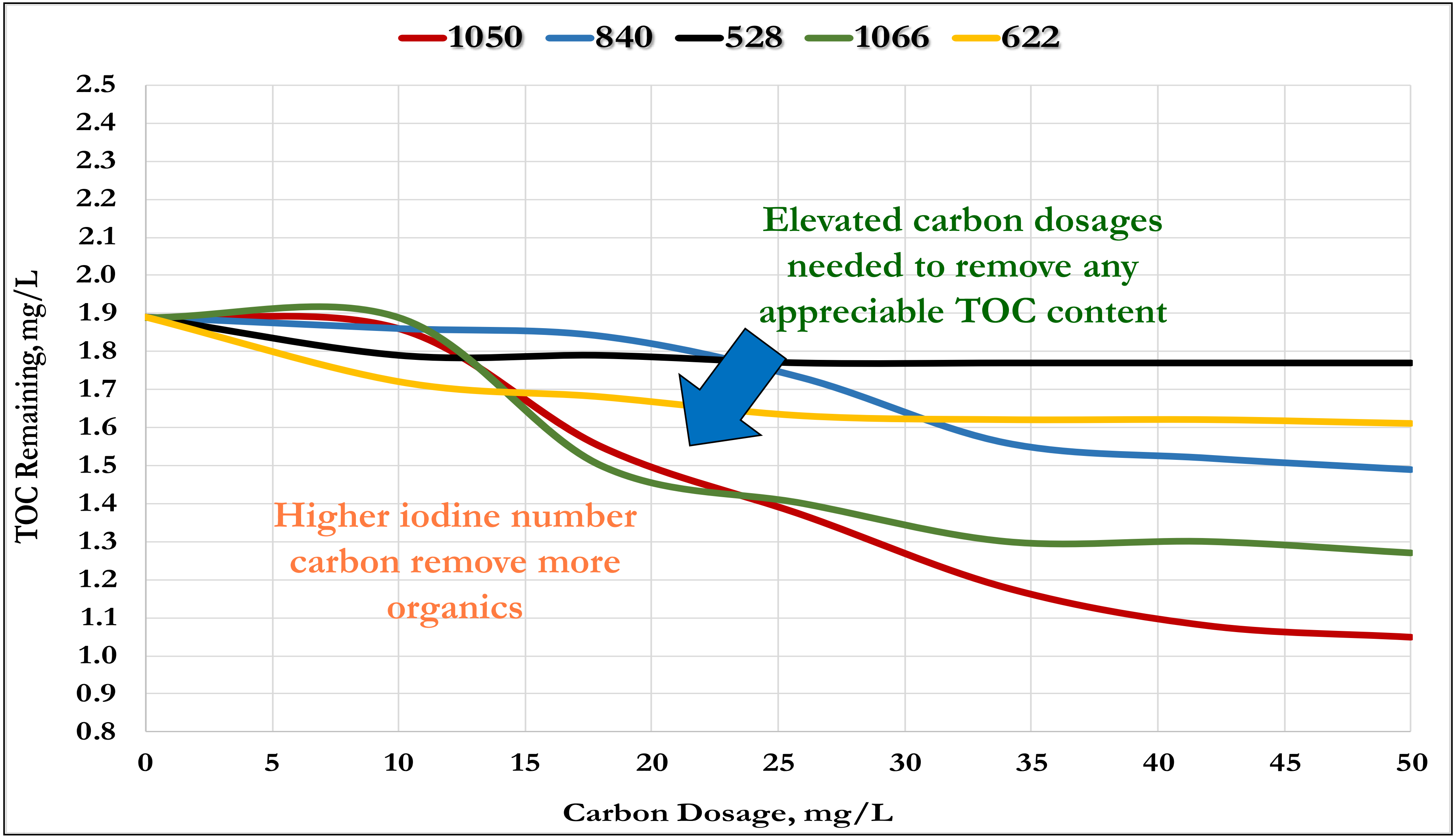
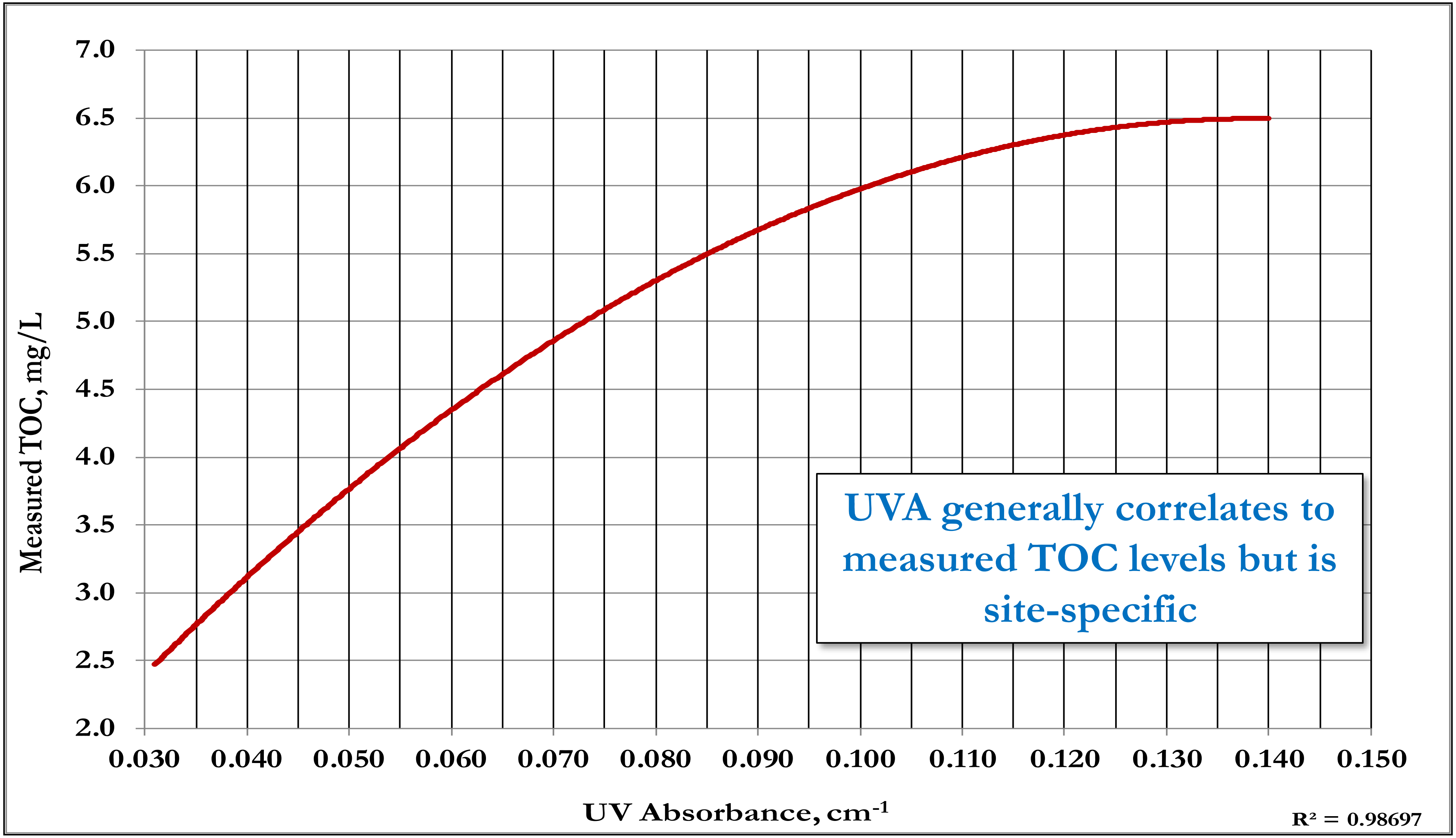


# What We Knew About Organics Removal

- UV absorbance monitoring is very useful for organics removals and process control
  - Simple test procedure
  - UVA is more sensitive to changes than TOC testing
  - UVA can be correlated to TOC for individual treatment plants
  - UVA can be used to predict relative TOC in water

# What We Knew About Organics Removal



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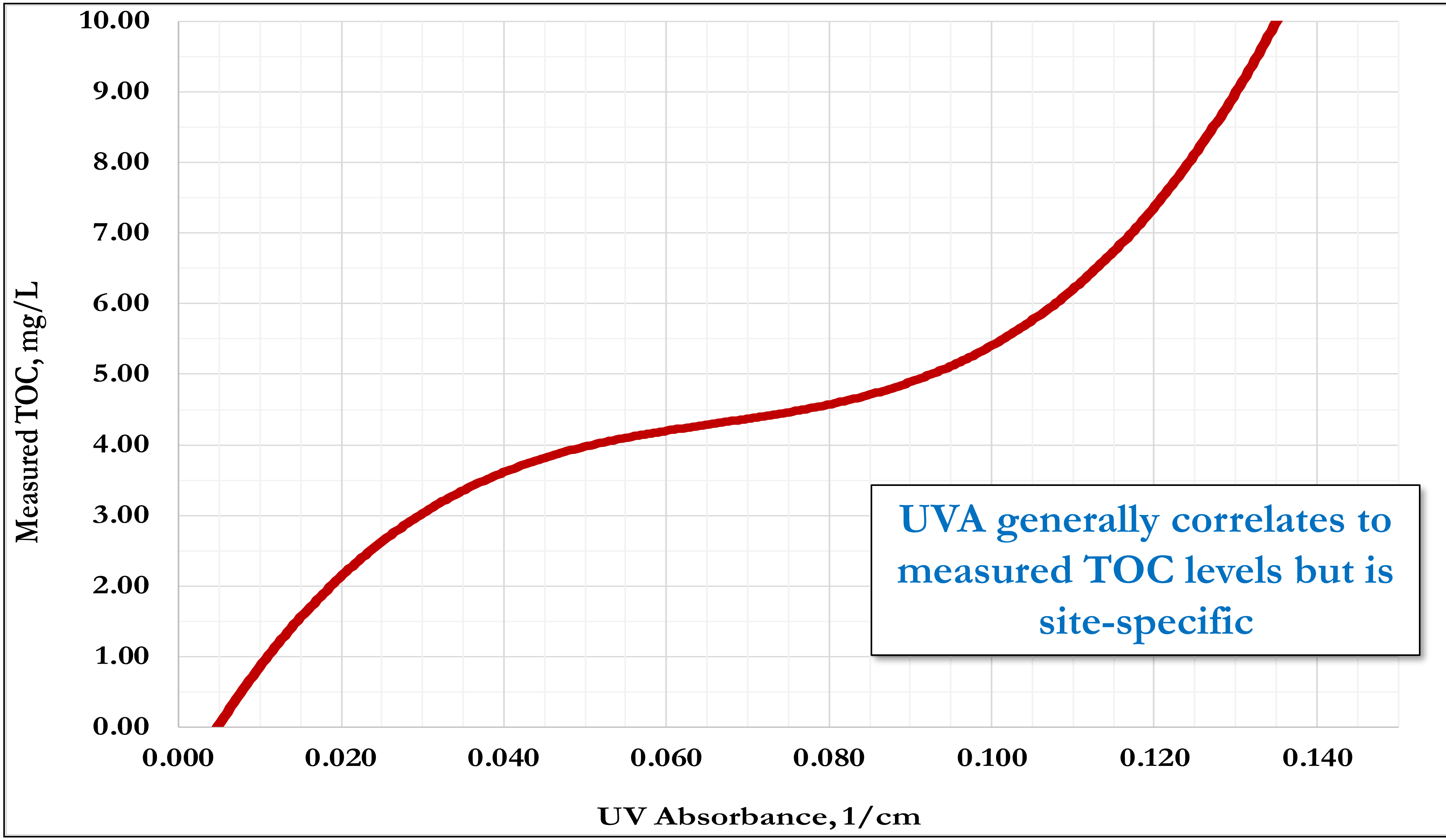
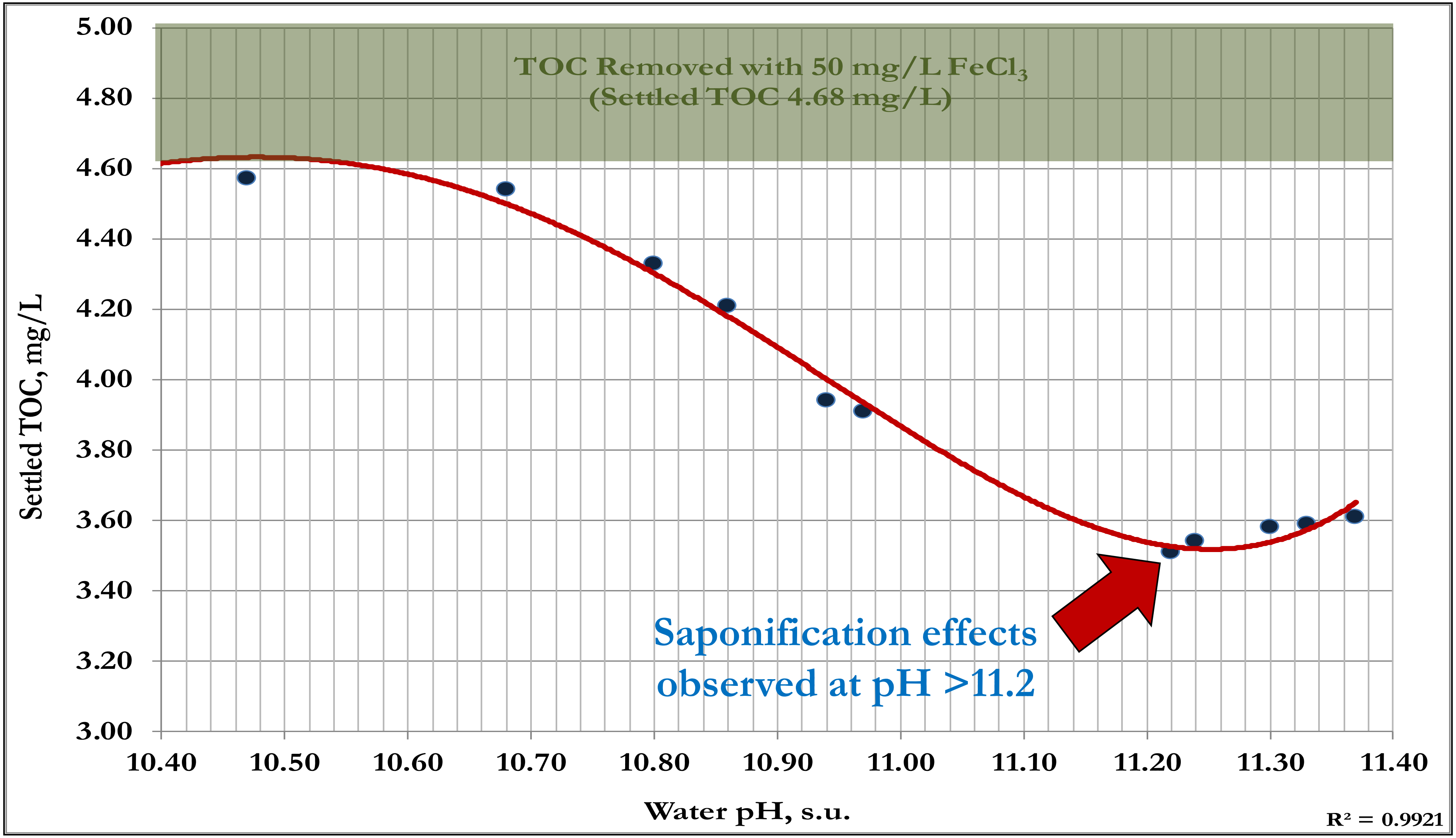


# What We Knew About Organics Removal

- TOC removal treatments
  - Coagulation can remove significant amounts of TOC, but limitations exist
    - Different coagulants behave differently
    - Some untreatable TOC remains
  - Enhanced coagulation has limitations in TOC removal
    - Coagulation pH important to TOC reductions (lower is better)
  - Enhanced softening has limitations in TOC removal
    - Magnesium removal enhances TOC removal
    - Saponification can occur at high pH levels

# What We Knew About Organics Removal



# Past → Future

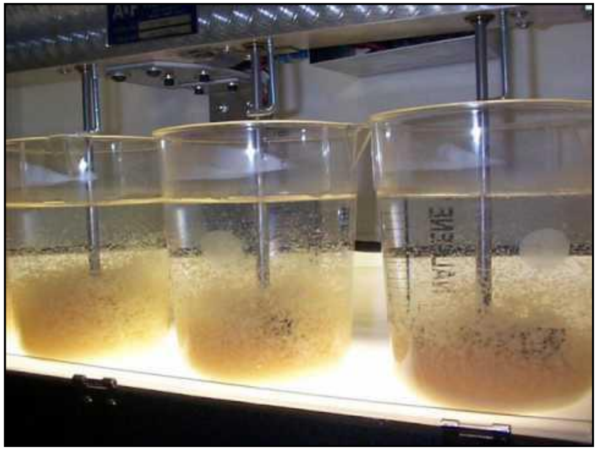
# What We've Learned About Organics Removal

- More recent information obtained and learned by close working relationship with Chris Miller, PhD and the Fontus Blue team

fontusblue

# What We've Learned About Organics Removal

- Tambo & Kamei February 1989 American Chemical Society (ACS) article
- "Evaluation of Extent of Humic-Substance Removal by Coagulation"
  - Increased coagulant dosing improves DOC reductions
  - Non-treatable portion of DOC exists
  - DOC treatability model from coagulation
    - Primarily for high SUVA conditions



# What We've Learned About Organics Removal

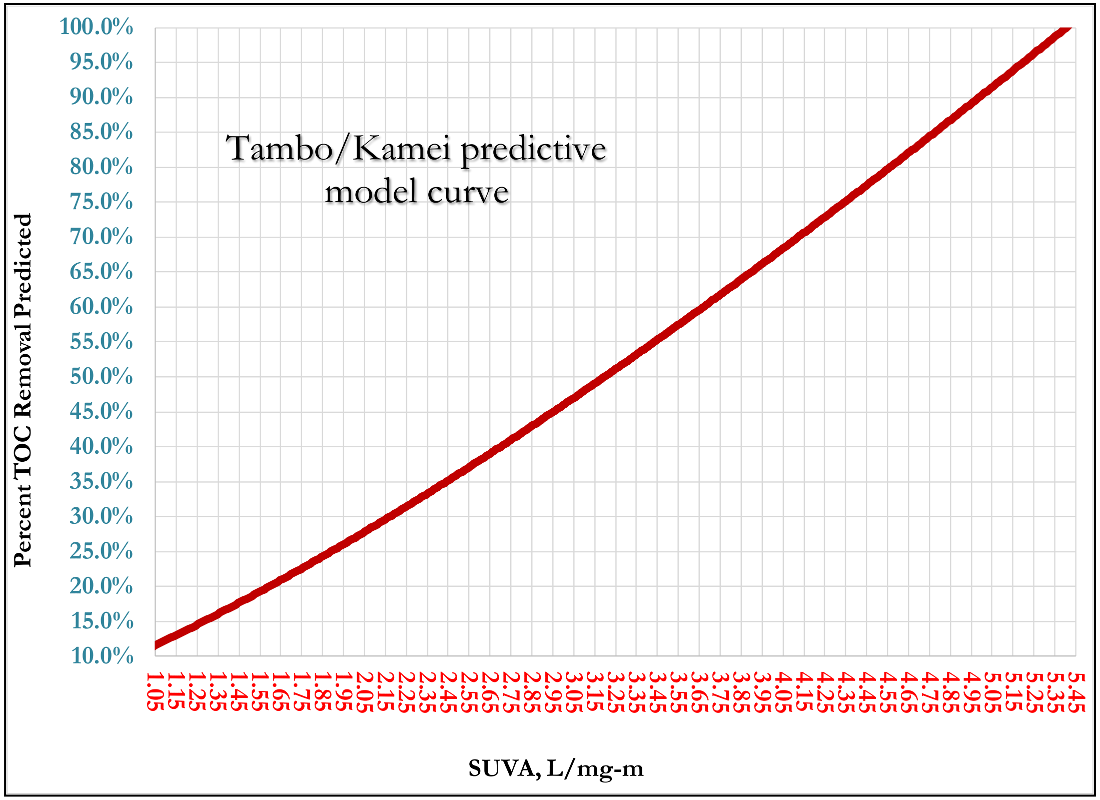
- Tambo, et al predictive DOC equation

$$47.1 * \left(\frac{DOC}{UVA}\right)^{-1.32}$$

Converted for SUVA content

$$10.825 * SUVA^{1.32}$$

- Suggests TOC treatability based on source water SUVA



# What We've Learned About Organics Removal

- Marc Edwards, PhD May 1997 AWWA Journal Article
- "Predicting DOC Removal During Enhanced Coagulation"
  - SUVA, coagulation pH, initial DOC, several constants, applied dosage
  - DOC removal sensitive to coagulant type and pH
    - ≈8.0 pH solubility issues
  - Estimate non-sorbable DOC from SUVA

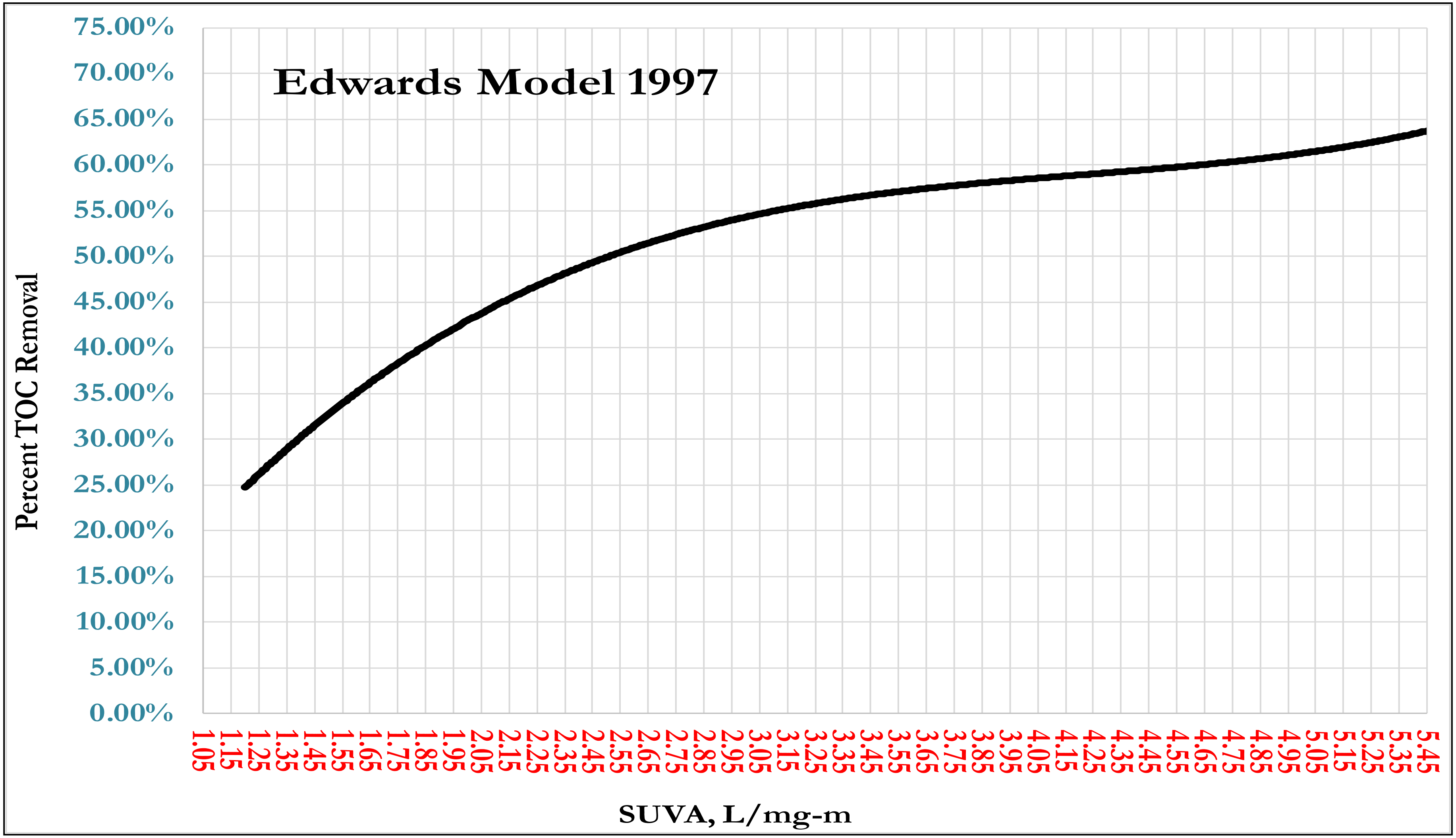
-

$$\frac{\{1 - SUVAK1 - K2\}DOCi - Ceq}{M} = \frac{(x3pH^3 + x2pH^2 + x1pH)bCeq}{1 + bCeq}$$

solve for Ceq and final DOC

$$DOCf = Ceq + (K1SUVA + K2)DOCi$$

# What We've Learned About Organics Removal



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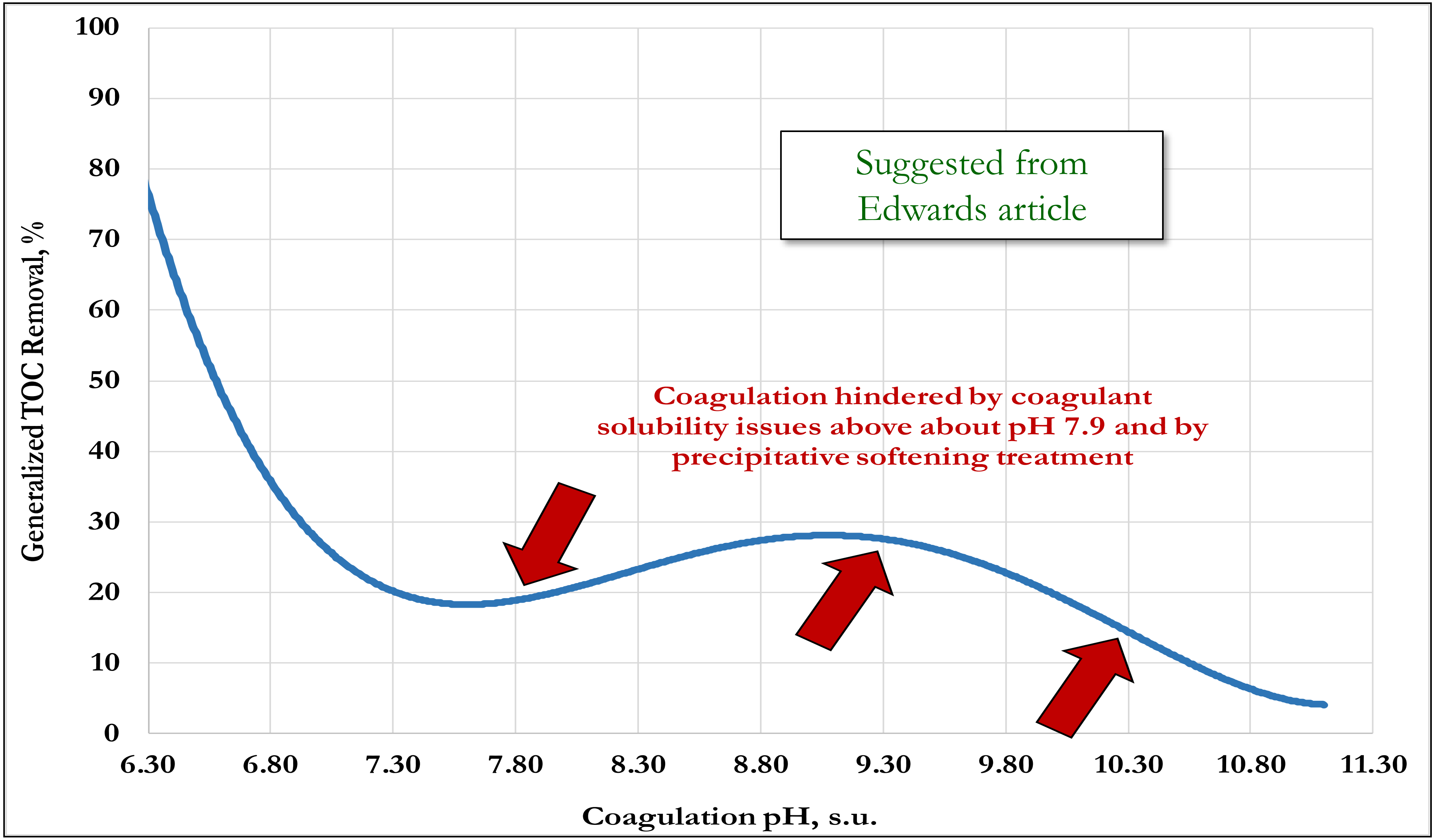
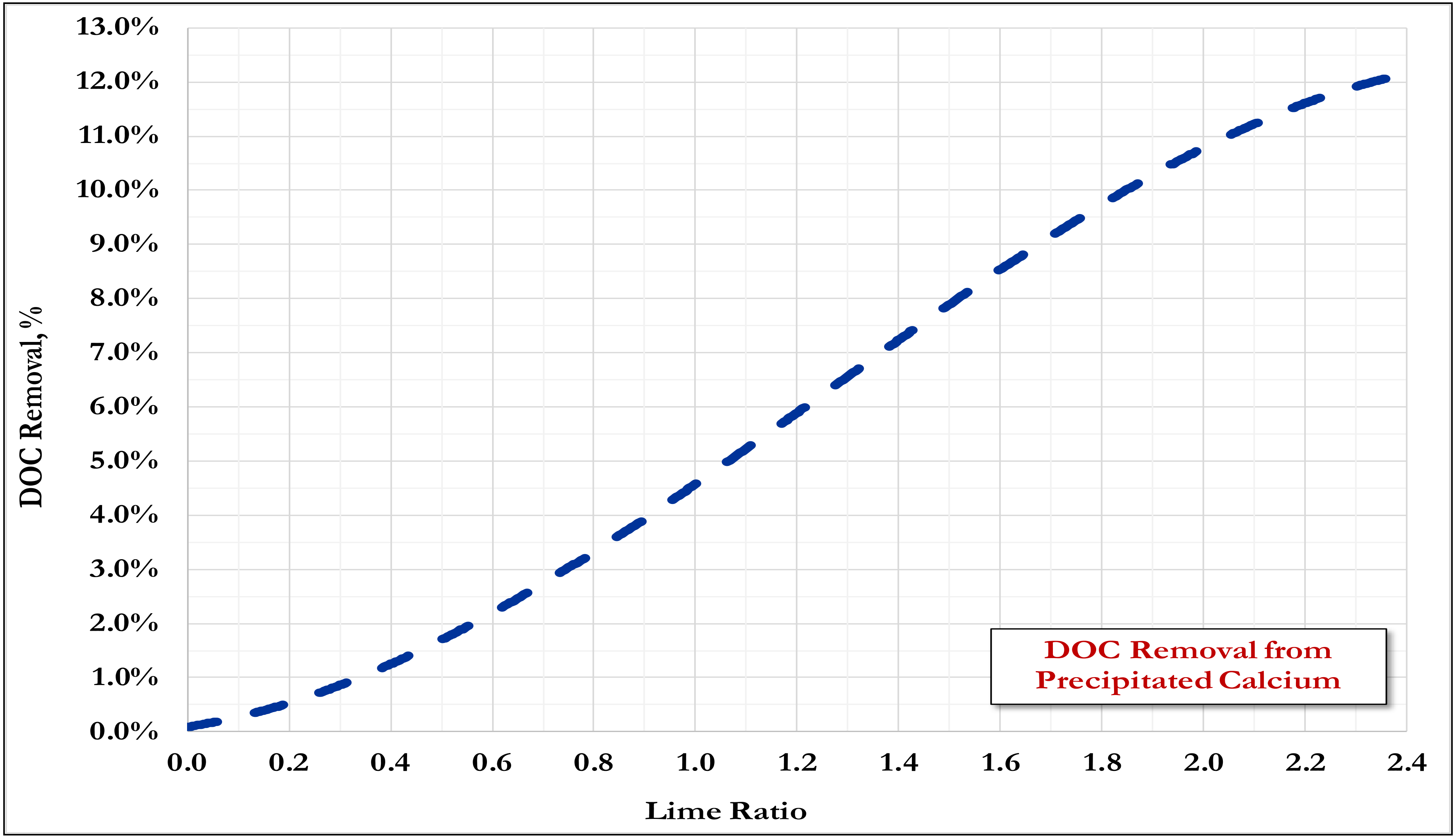


# What We've Learned About Organics Removal

- Kathyrn Kalscheur November 2006 AWWA Journal article
- "Enhanced Softening: Effects of Source Water Quality on NOM Removal…"
  - Introduced lime ratio and relationships to DOC removal in softening
  - Lime ratio is actual dosage divided by required dosage to minimize calcium
    - Calcium removal enhances DOC removal
    - Magnesium removal enhances DOC removal

# What We've Learned About Organics Removal



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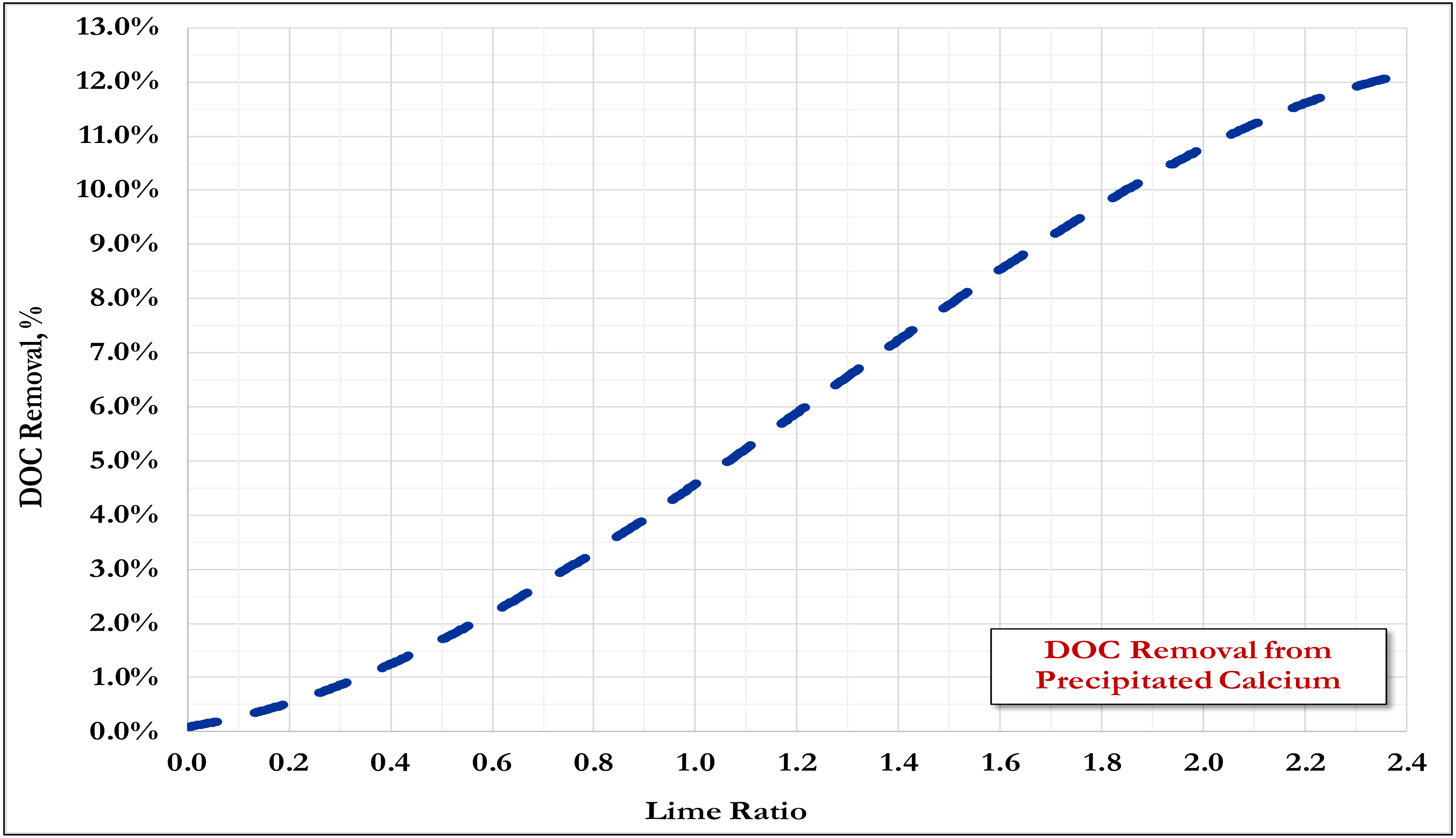

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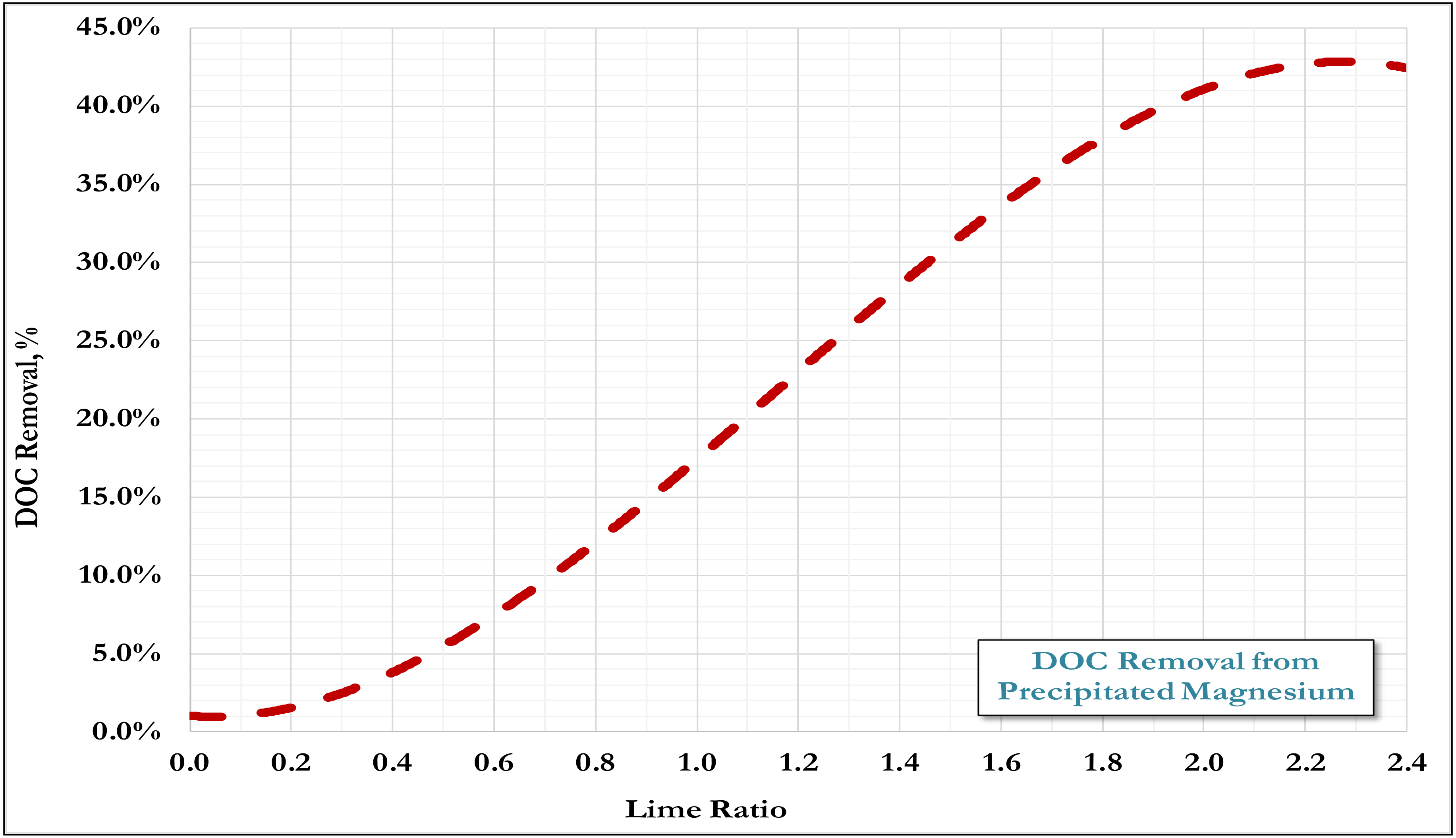

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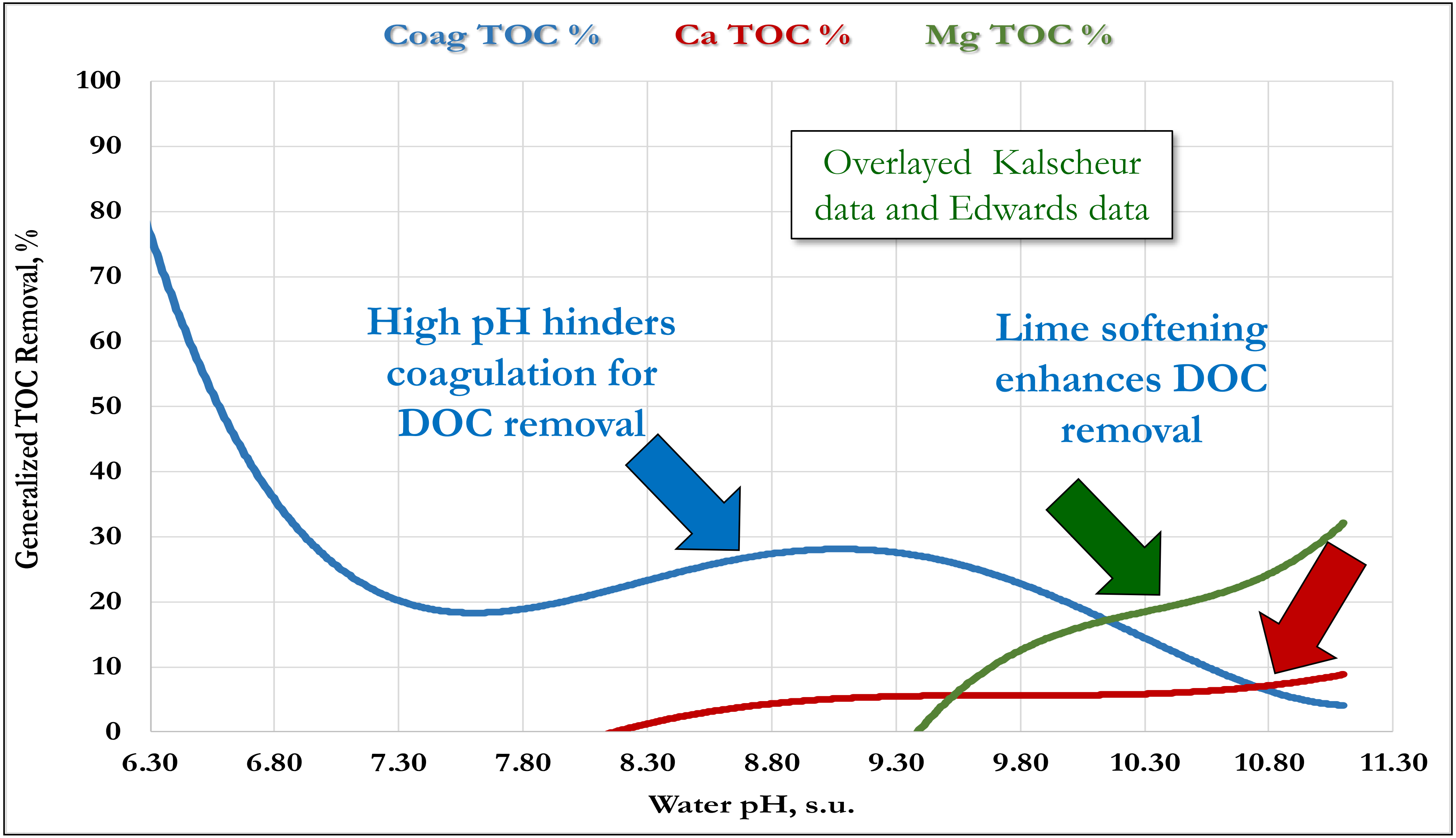
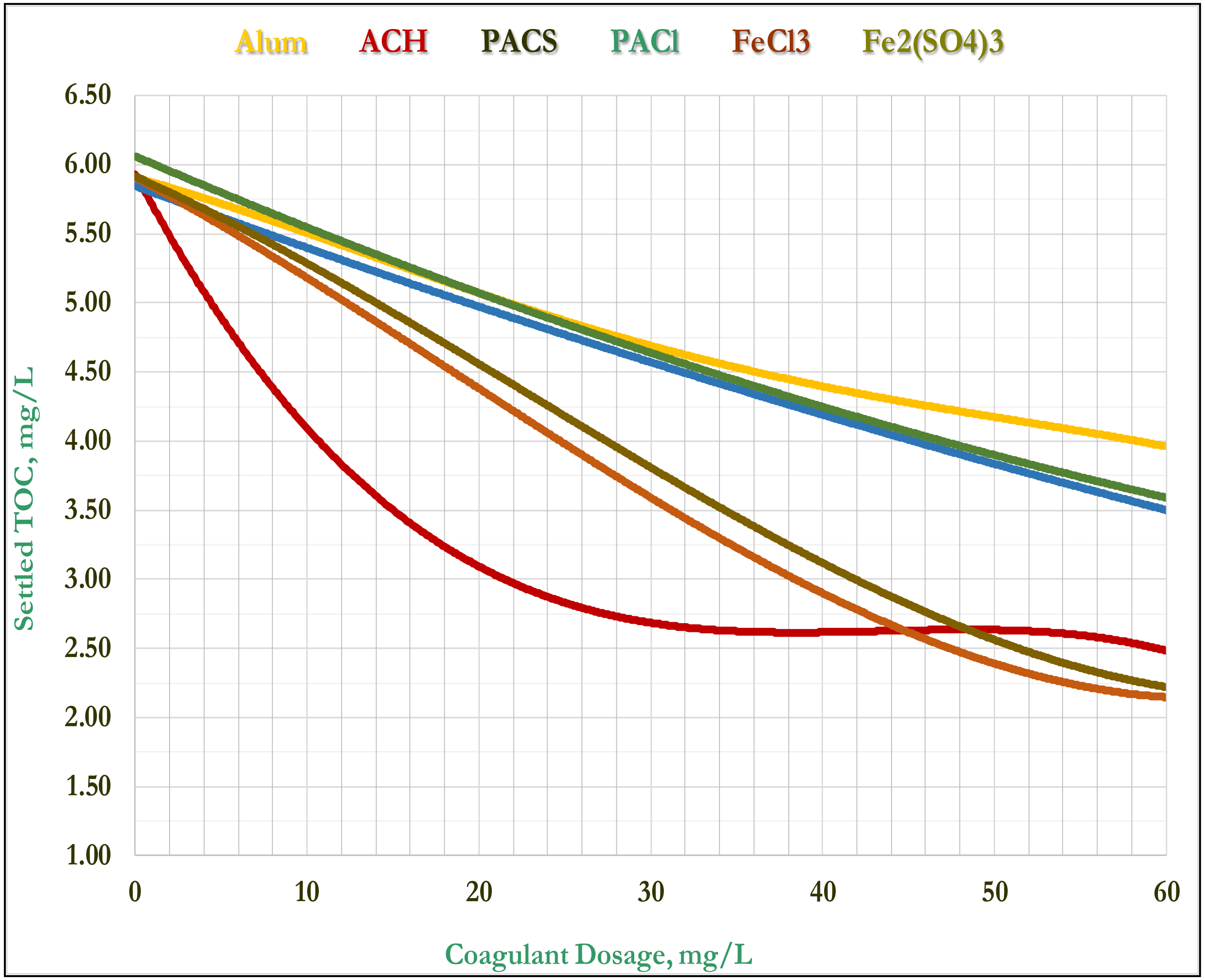


# What We've Learned About Organics Removal

- Optimum coagulant type found in jar testing
  - Dosage and TOC reduction produced
- Optimum coagulant varies with source water
  - SUVA and organic character suggest TOC treatability
- All coagulants exhibit limitations on TOC removal
  - THPA and hydrophilic matter are difficult to remove (low SUVA conditions)



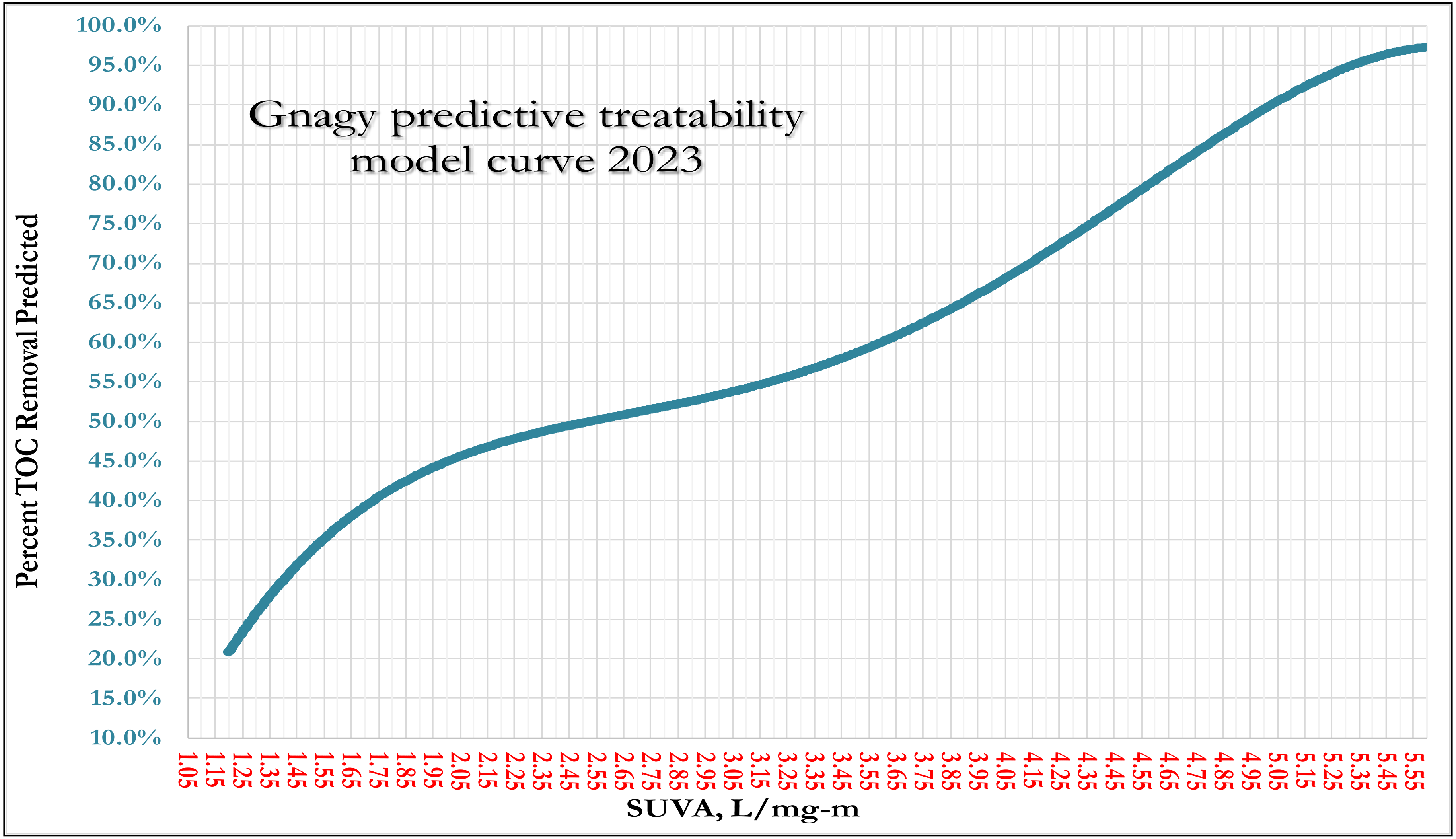
# Crafting a Predictive TOC Treatability Model

- Limitations exist in TOC removal by coagulation
  - Treatability predictions useful for chemical optimization
- Oxidative conditioning techniques and carbon adsorption treatments can enhance TOC removals
- Enhanced softening can simulate TOC removals
  - Saponification impacts due to high pH levels in softening hinder TOC removals
- Predictive model estimating TOC treatability from SUVA values can improve process control
  - Predictive model needs to be verified for accuracy and variability

# Crafting a Predictive TOC Treatability Model

- Reviewed 100's jar test simulations for water quality (1990's to 2023)
  - Recorded source water SUVA values
    - Ranged from 1.30 to more than 7.30
  - Assessed actual TOC removal capability of coagulants, precipitative softening, carbon treatments
  - Developed table of SUVA versus TOC treatability from available data
    - Developed predictive TOC treatability curve from data sources
  - Checked other jar test data against predicted TOC treatability (initial verification)

# Crafting a Predictive TOC Treatability Model



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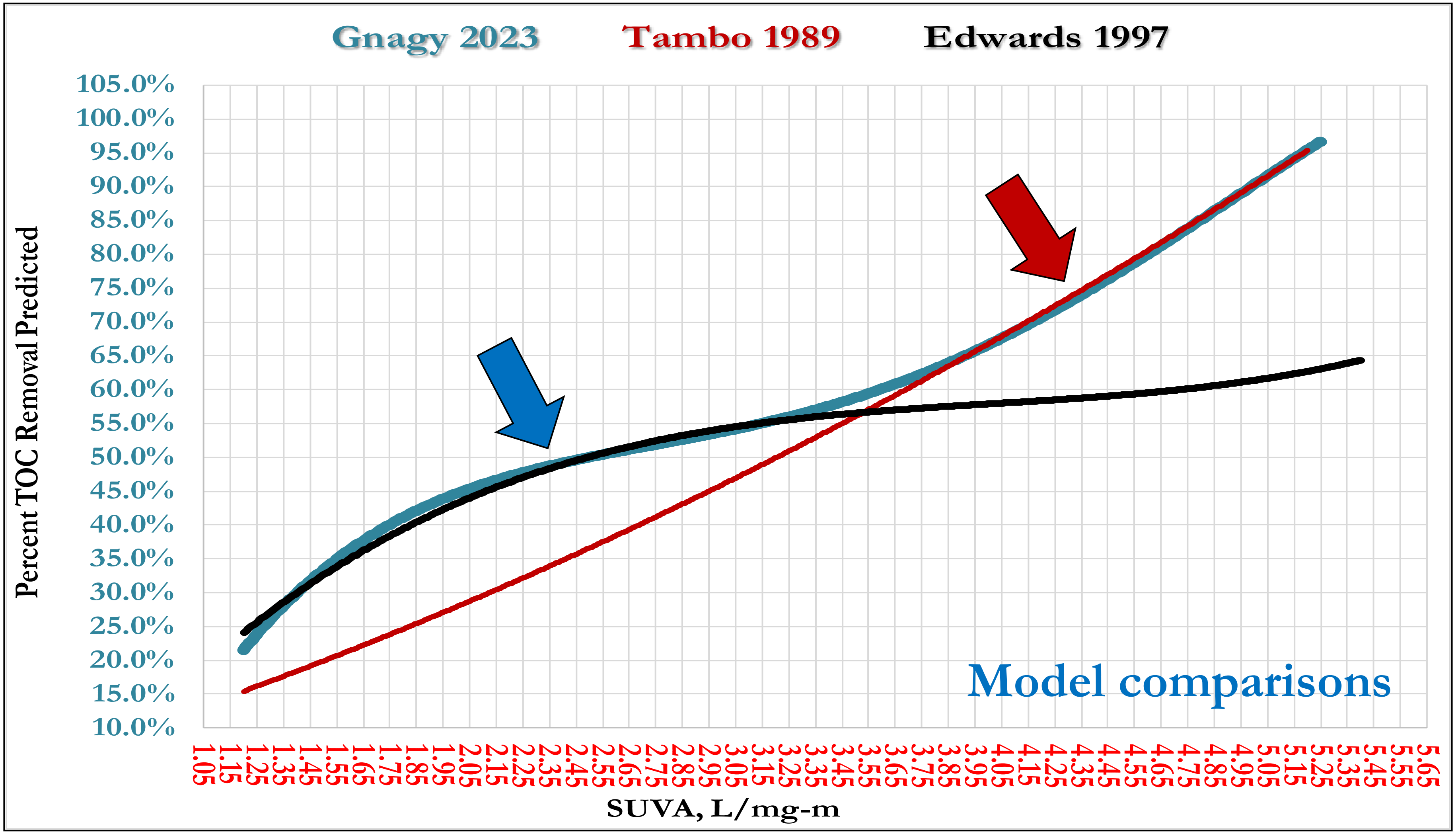


# Full-scale Treatment Verifications

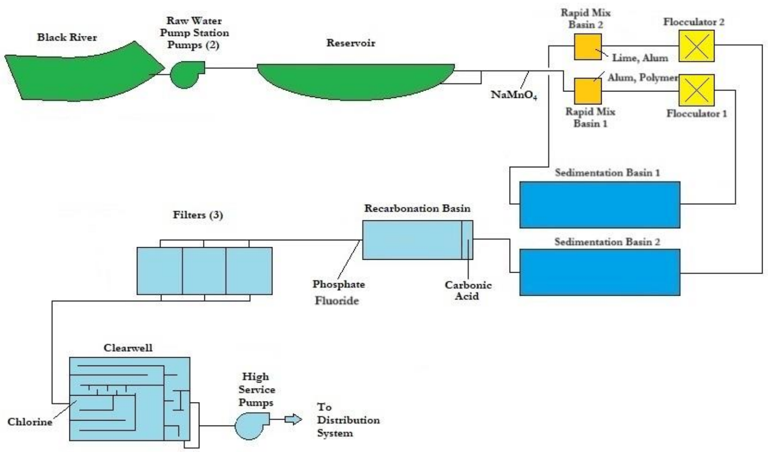
- Oberlin, Ohio
  - 2.25 mgd surface water plant
  - 0.8 mgd average production
  - $NaMnO_4$, alum and polymer, lime, $CO_2$, $PO_4$, $F^-$, $Cl_2$
  - Conventional treatment prior to filtration
  - DBP concerns
    - OEL's Oct. 2022 & Jan. 2023
  - Targeted split (two-stage) treatment alternative after water quality reviews

# Full-scale Treatment Verifications

- $NaMnO_4$ dosing variable
- Alum and lime added together in first basins
  - TOC removal not optimum
  - Optimize alum dosing (maximize TOC reductions at lower pH)
  - Optimize lime softening for additional TOC removal
  - Improve TOC removal before October 2023 THM monitoring

# Full-scale Treatment Verifications

- Initiated split treatment in August 2023
  - $NaMnO_4$ raw water (≈0.3 mg/L)
  - Alum in first stage basins (50 mg/L continued)
  - Lime in second stage basins (140 mg/L continued)
  - Optimized mixing to produce enhanced floc settleability
  - Daily process-based water quality monitoring implemented



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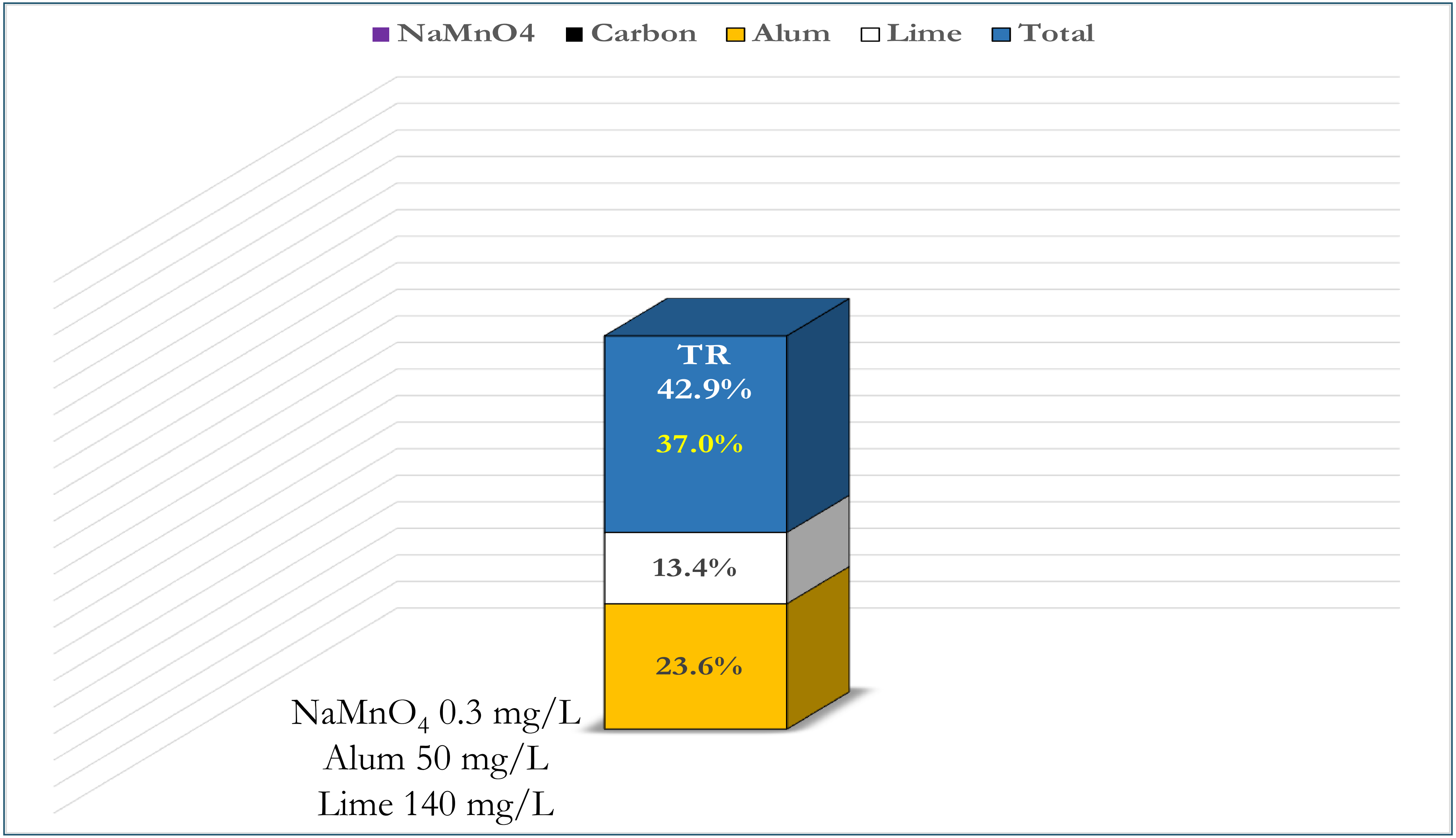
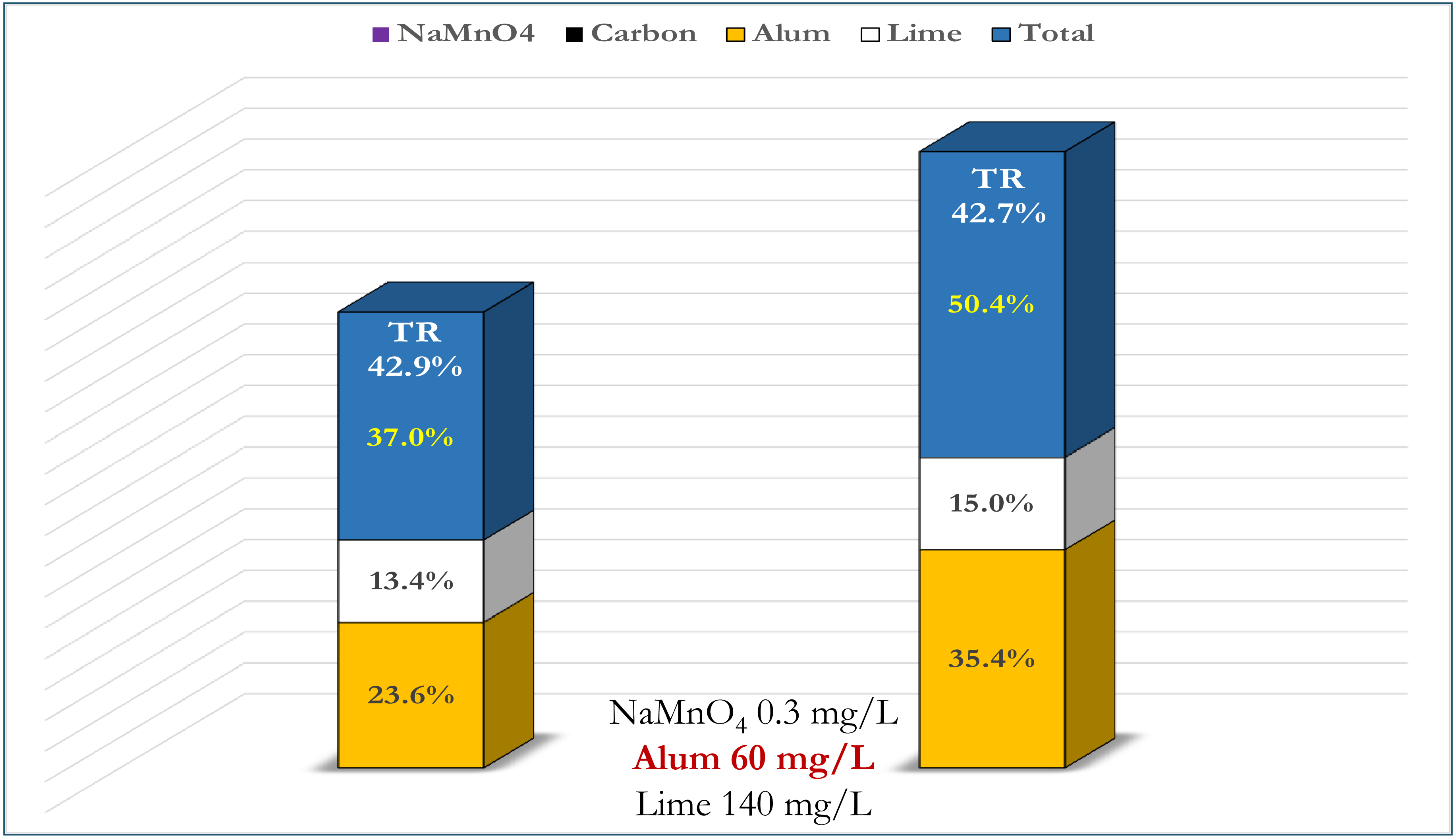


# Full-scale Treatment Verifications

- Alum dosage increased in mid-August
  - $NaMnO_4$ remained 0.3 mg/L
  - Alum in first stage basins (60 mg/L)
  - Lime in second stage basins (maintaining 140 mg/L)
  - Daily water quality monitoring continued

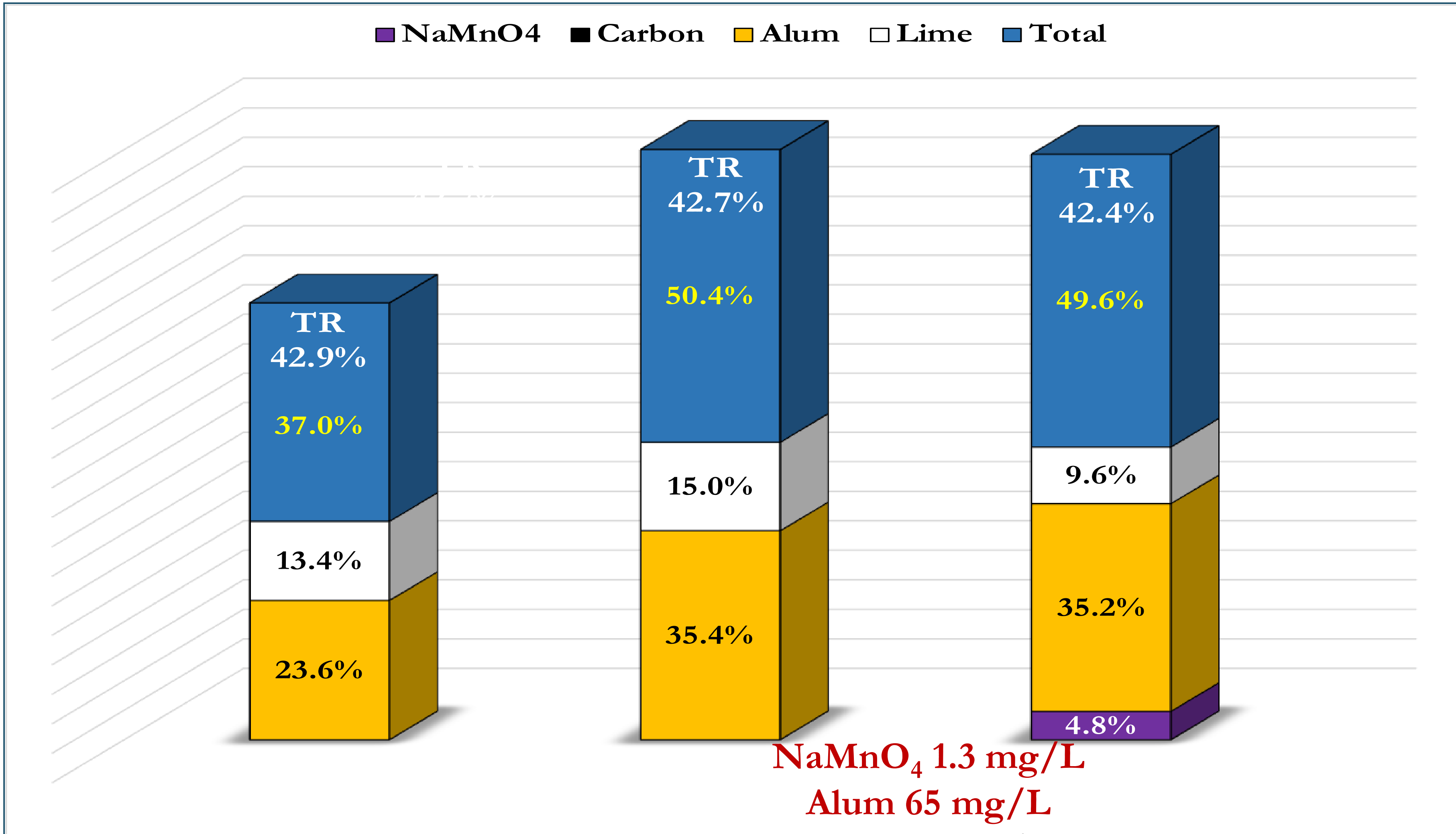
# Full-scale Treatment Verifications



# Full-scale Treatment Verifications

- $NaMnO_4$ dosage increased in early September along with alum
  - $NaMnO_4$ (1.3 mg/L)
  - Alum in first stage basins (65 mg/L)
  - Lime in second stage basins (maintaining 140 mg/L)
  - Daily water quality monitoring continued

# Full-scale Treatment Verifications



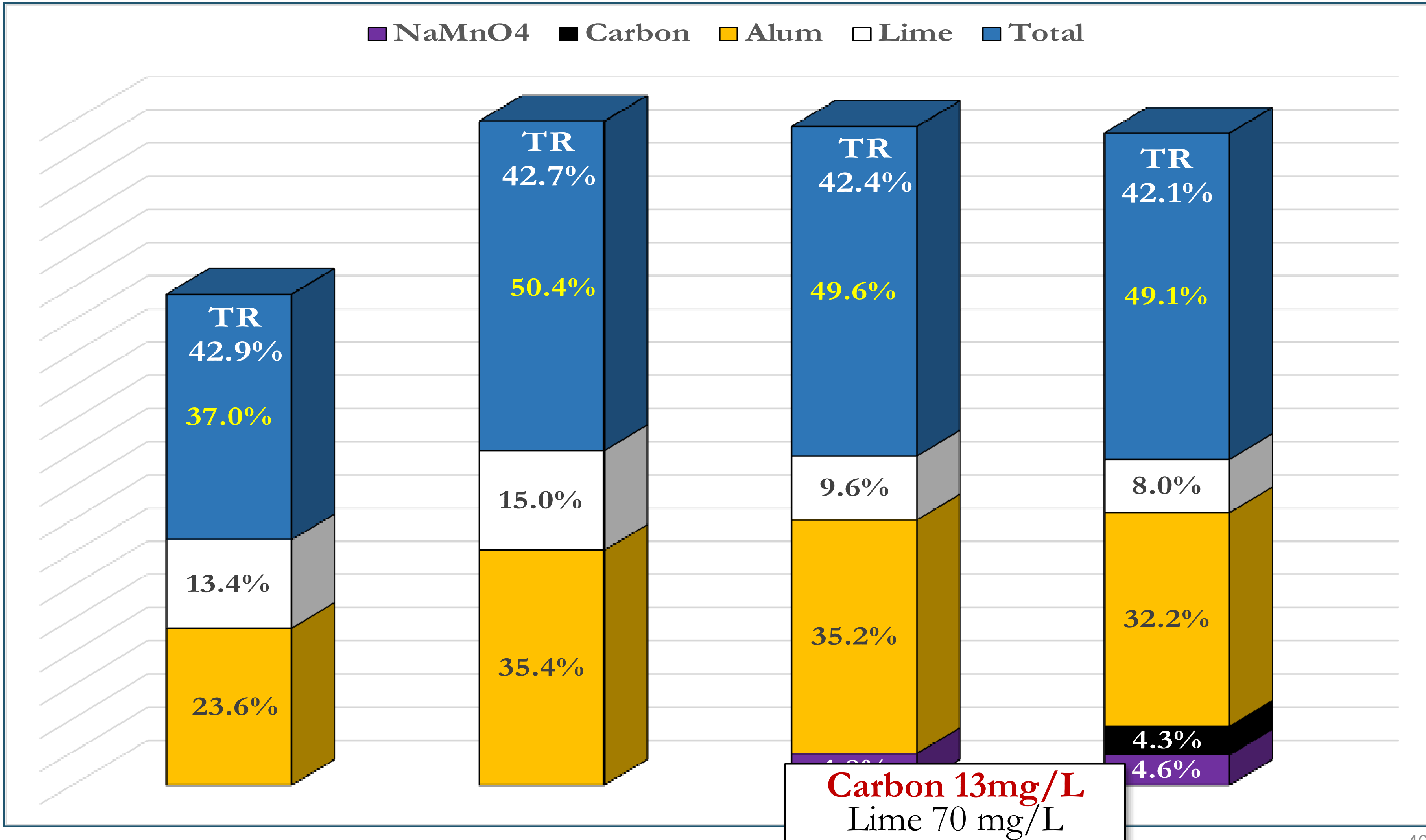

**$NaMnO_4$ 1.3 mg/L**
**Alum 65 mg/L**
Lime 140 mg/L

# Full-scale Treatment Verifications

- Carbon feed initiated late September due to T&O event
  - $NaMnO_4$ (1.3 mg/L)
  - Carbon fed to first stage basins (13 mg/L)
  - Alum in first stage basins (maintaining 65 mg/L)
  - Lime in second stage basins (reduced to 70 mg/L)
  - Daily water quality monitoring continued

Temporary carbon feed system

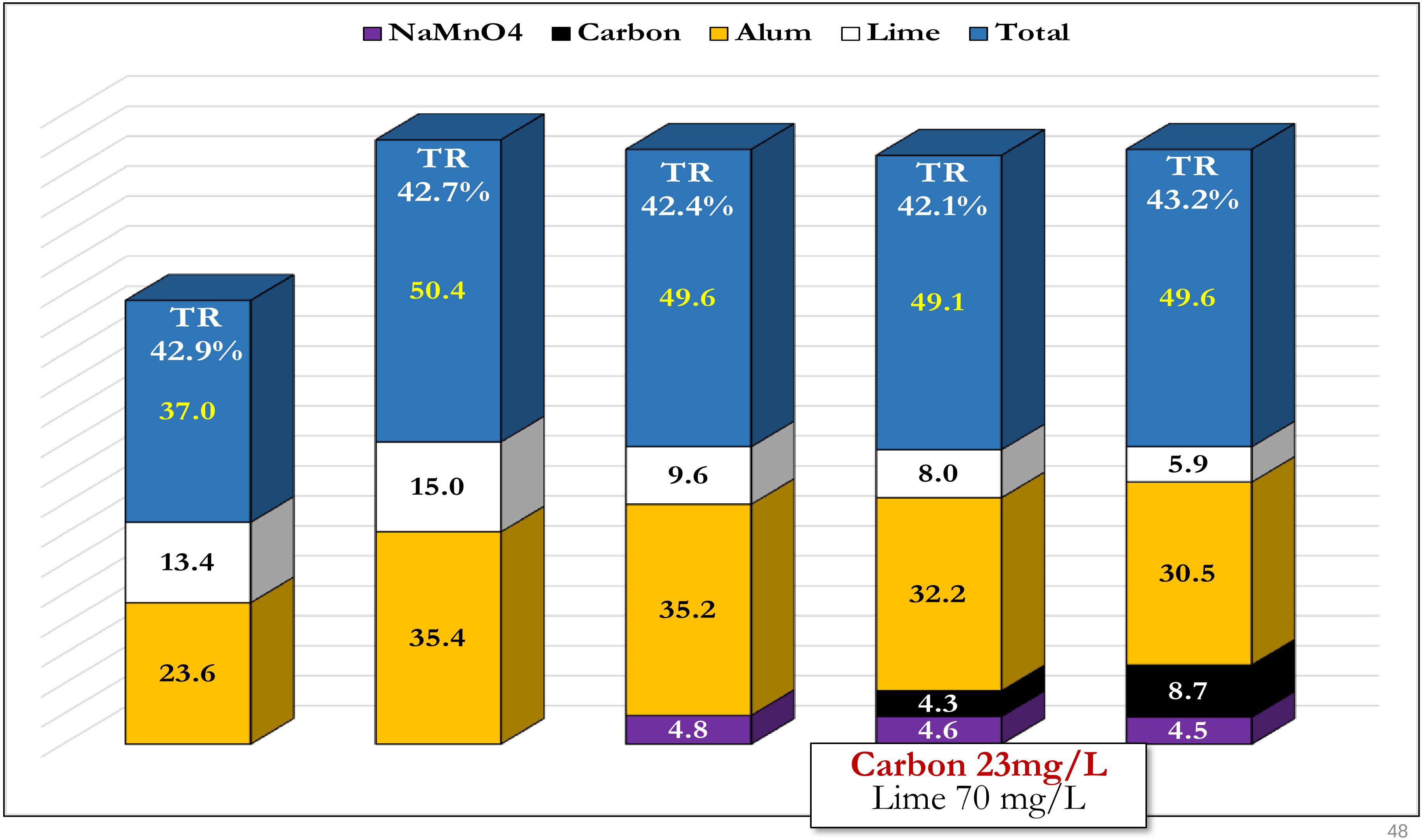
# Full-scale Treatment Verifications



# Full-scale Treatment Verifications

- Carbon increased in October due to T&O event
  - $NaMnO_4$ (1.3 mg/L)
  - Carbon fed to first stage basins (23 mg/L)
  - Alum in first stage basins (maintaining 65 mg/L)
  - Lime in second stage basins (maintaining 70 mg/L)
  - Daily water quality monitoring continued

# Full-scale Treatment Verifications



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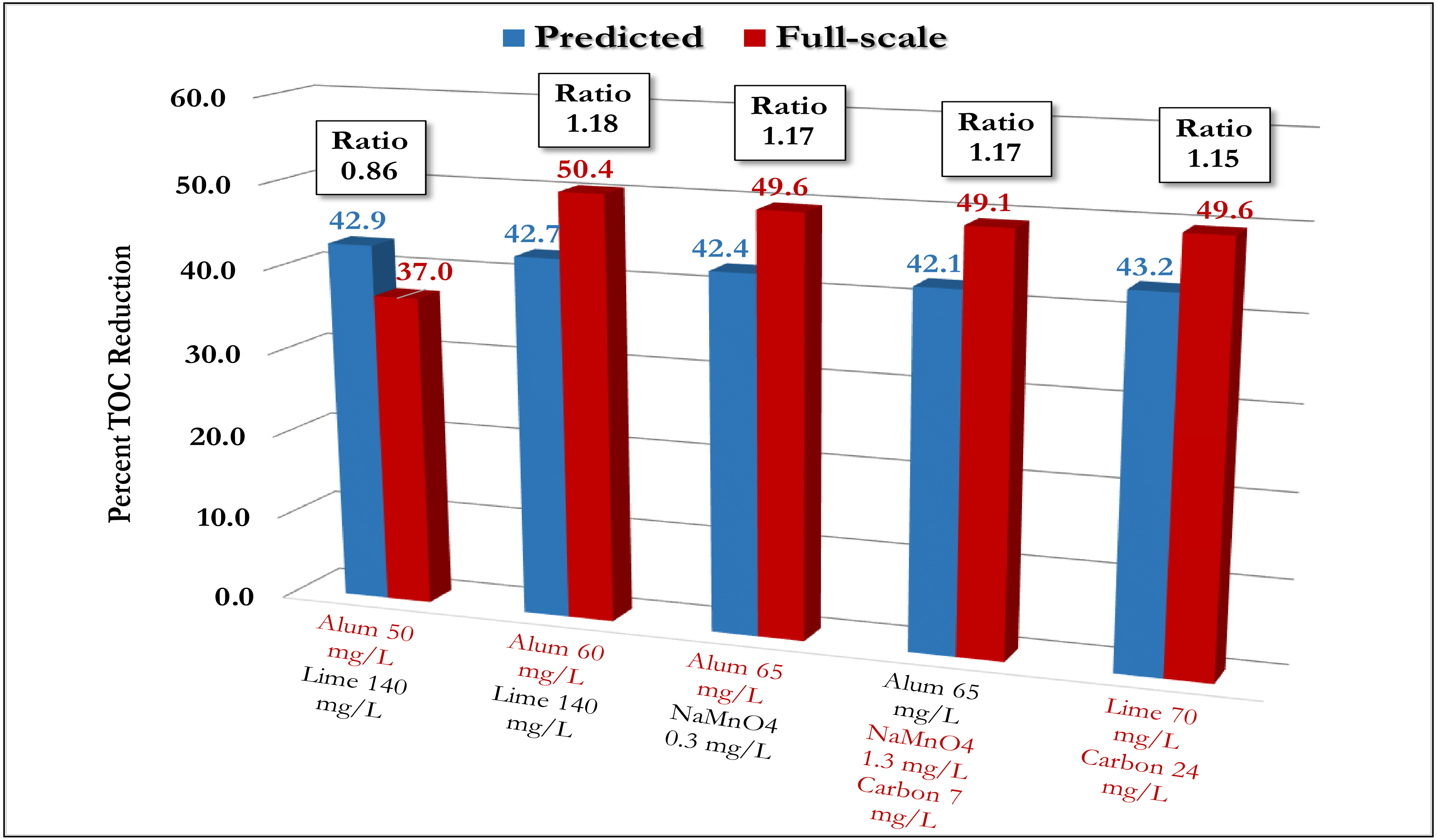

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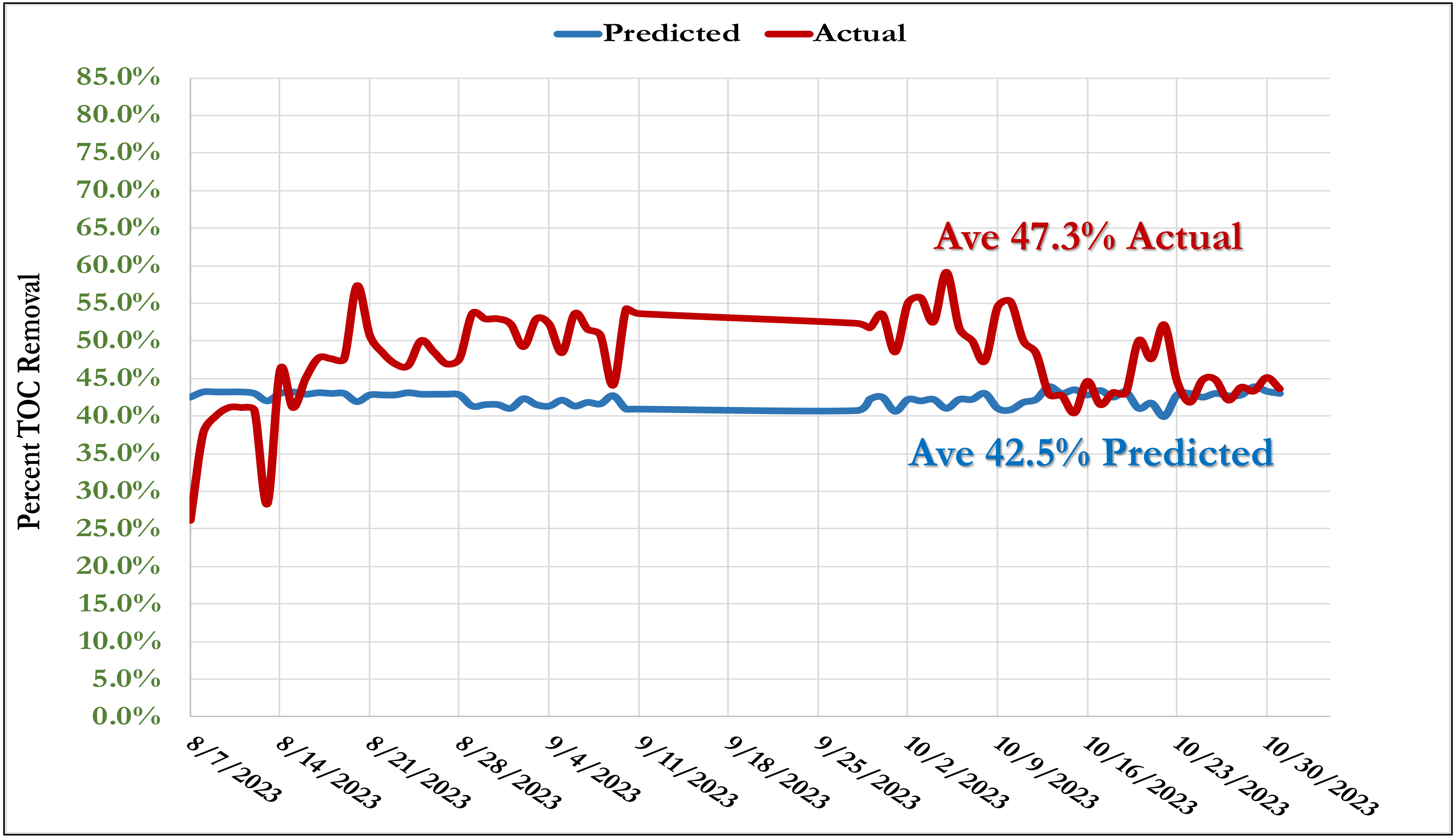
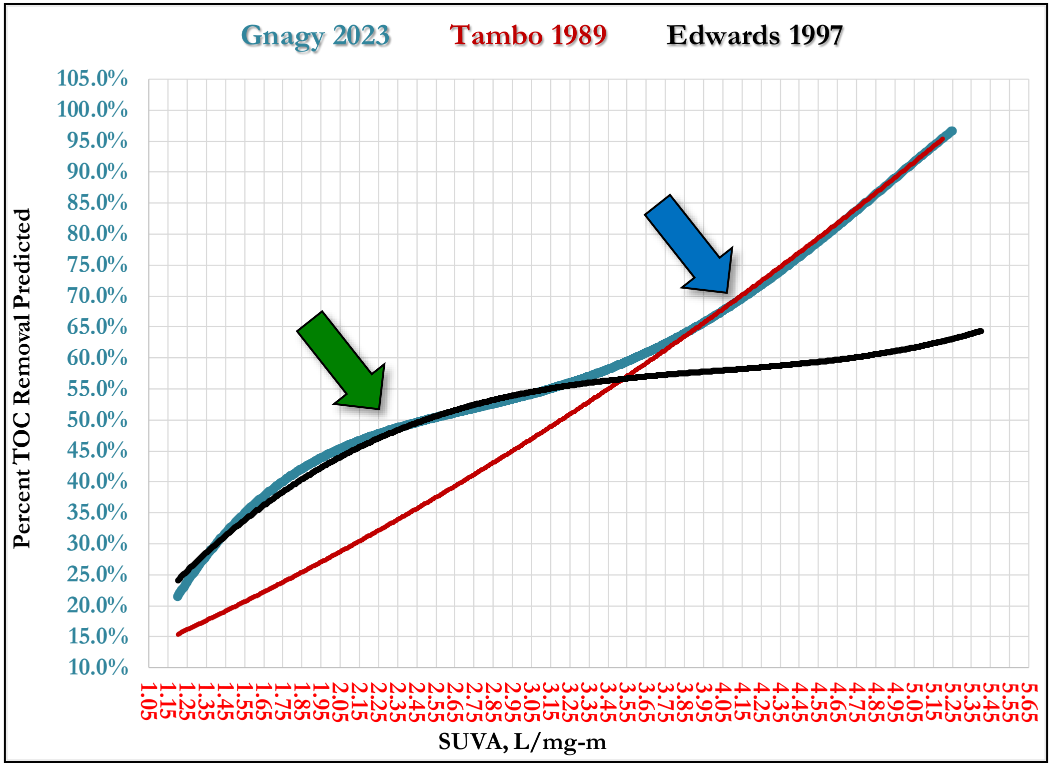


# Summary

- Model curve appears to predict TOC removal close to full-scale treatment (94% confidence level)
  - Aligns with Edwards model at lower SUVA values
  - Aligns with Tambo & Kamei model at higher SUVA values
  - Predicts TOC more precisely (case study proven)



# Summary

- Treatability ratio (TR) appears to be useful for process control and optimal chemical dosing
- TR useful in operations
  - Measures oxidative conditioning enhancements
  - Optimizes coagulation/softening dosages to avoid overfeeding
  - Defines other technologies for TOC/DBP control (nonsorbable DOC removal)

# Questions

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