Jar Testing Procedures and Practical Applications for Water Treatment Processes - Part 1

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OTCO Water Laboratory Webinar

May 11, 2021

Agenda

- Uses for jar testing
- Jar test procedures
- Stock solutions and Test solutions
- Dosage selection
- G values interpretations
- Mixer speed selection
- Settling time determination
- Other analyses

Jar Test Uses

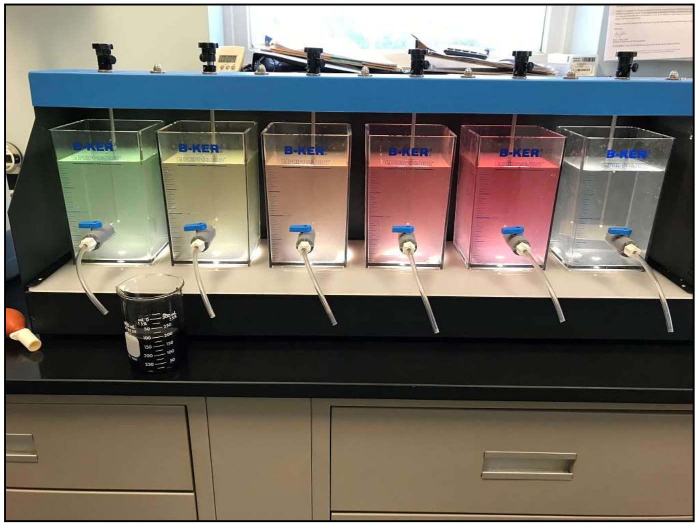
- Determine chemical dosages
- Determine chemical sequencing
- Optimize plant performance
- Troubleshoot operating problems
- Evaluate different treatment schemes
  - Turbidity control
  - Softening treatment control
  - DBP control
  - Disinfection treatment and demand
  - TOC removals
  - Etc.

Jar Test Procedures

- Simulate plant operations
  - Chemical dosages
  - Mixing
  - Flocculation
  - Settling
  - Detention times
  - Overall performance

Jar Test Procedures

- Treatment operations from special studies
  - Dosing needs and sequencing
  - Optimal mixing and floc development
  - Apparent settling rate
  - Potential treatment performance



Jar Test Procedures

- Prepare chemical solutions
  - Each chemical in sequence
  - Concentrations must be known
  - Take care making dilutions
    - Precision is important

Jar Test Procedures

- Sample collection
  - Representative of water treated
    - If chemical added in pretreatment, get raw water prior to chemical addition
    - OR simulate pretreatment with chemical added as it comes into plant
    - OR filter effluent for disinfection evaluations, etc.
  - 3 gallons to 5 gallons typical per run
    - Dedicated clean 5-gallon bucket

Jar Test Procedures

- Jar labeling
  - Left most jar 1
  - Remaining jars in order (left to right)
  - Sample containers same labeling
    - Container sized for all analyses

Jar Test Procedures

- Chemical addition
  - Calculate volumes for dosages selected
  - Dose jars with stirrer off
  - Start stirrer for rapid mixing (rpm)
    - Same mixing time as process
  - Sequence chemicals same as process during test run

Jar Test Procedures

- Flocculation
  - Same detention time as operations
  - Mixing based on flocculation basin or solids contact operation
    - Define actual G values from plant operations
  - Speeds determined from graph
  - Observe floc formation and record

Jar Test Procedures

- Settling
  - Stirrer off
  - Detention time based on SOR
    - Conversion to vertical settling rate
  - Observe floc settling and record
  - Floc settling rate observation

$$\frac{225}{t_s} = SOR_{MAX}, gpm / ft^2$$

Jar Test Procedures

- Sample collection
  - All samples collected at same time
  - Collect volume needed for all analyses
  - Record results each jar
  - Analyses based on evaluations needed
    - Most common analytical parameters
  - Calculate other parameters as needed
    - Mg, alkalinity species, etc.

Jar Test Procedures

- Clean jars and equipment
  - All jars and paddles
  - All lab equipment
  - Dilute chemicals before discarding
    - Follow current Chemical Hygiene Plan

Jar Test Procedures

- Complete jar test bench sheet
  - All test data
  - All chemical solutions
  - All dosages
  - All mixing speeds and times
  - All observations and analyses
  - Note any other observations

JAR TEST BENCH SHEET

FACILITY NAME				DATE		
CHEMICAL DATA	**ALUM**	**$FeCl_3$**	**$Fe_2(SO_4)_3$**	**POLYMER**	**LIME**	**$KMnO_4$**
Specific gravity						
Percent dry chemical						
Stock volume, mL						
Chemical added, mL or grams						
Stock concentration, mg/L						
Solution volume, mL						
Stock solution added, mL						
Solution concentration, mg/L						

TEST CONDITIONS	STIRRER RPM	DURATION	Simulated Conditions
Rapid Mixing		seconds	G - sec^{-1}
Flocculation		minutes	G - sec^{-1}
Settling	0	minutes	Coag. gpm/f
Filtered distilled water time		seconds	Soft. gpm/

RAW WATER CHARACTERISTICS

Temperature °C	pH	Alkalinity	Hardness	Turbidity	Color	TOC	DOC	POC
Filterability Index	Calcium	Magnesium	Iron	Manganese	THMFP	UV_{254}	SUVA	

JAR NUMBER	1	2	3	4	5	6
Raw water volume, mL	2,000	2,000	2,000	2,000	2,000	2,000
Alum solution added, mL						
Alum dosage, mg/L						
Ferric solution added, mL						
Ferric dosage, mg/L						
Polymer solution added, mL						
Polymer dosage, mg/L						
$KMnO_4$ solution added, mL						
$KMnO_4$ dosage, mg/L						
Lime solution added, mL						
Lime dosage, mg/L						
FLOC FORMATION OBSERVATIONS						
5 minutes						
10 minutes						
15 minutes						
20 minutes						
25 minutes						
SETTLING CHARACTERISTICS OBSERVATIONS						
1 minute						
2 minutes						
3 minutes						
4 minutes						
6 minutes						
SETTLED WATER RESULTS						
Turbidity, NTU						
Water pH						
Alkalinity, mg/L						
Hardness, mg/L						
TOC, mg/L						
UV_{254}, cm^{-1}						
Filtered water time						
Filterability Index						

NOTES:

Operator Training Committee of Ohio, Inc.

Particle Settling Rates

Particle	Diameter, mm	Estimated Time to Settle Per Foot
Gravel	10	0.3 seconds
Coarse sand	1	3 seconds
Fine Sand	0.1	38 seconds
Silt	0.01	33 minutes
Bacteria	0.001	55 hours
Colloids	0.0001	230 days
Fine colloids	0.00001	6.3 years
Very fine colloids	0.000001	63 years

Chemical Reactions

- Coagulation mechanisms
  - Charge neutralization
  - Sweep coagulation (enmeshment)
  - Interparticle bridging (polymers)
- Oxidative reactions
  - Permanganates, chlorine, ozone, peroxide
  - Iron and manganese oxidation
- Precipitative reactions
  - Lime softening
  - Soda ash or caustic soda softening

Chemical Reactions

- Charge Neutralization

$$Al_2(SO_4)_3 \Rightarrow 2Al^{+3} + 3SO_4^{-2}$$

$$Al^{+3} + H_2O \Rightarrow AlOH^{+2} + H^{+1} at \quad pH < 6.0$$

$$Al^{+3}, Al(OH)_3, Al_2(OH)_2^{+4}, Al_3(OH)_4^{+5},$$

$$Al_{13}O_4(OH)_{24}^{+7}, Al(OH)_2^{-1}$$

Chemical Reactions

- Charge Neutralization

$$FeCl_3 \Rightarrow Fe^{+3} + 3Cl^{-1}$$

$$Fe^{+3} + H_2O \Rightarrow FeOH^{+2} + H^{+1} at\ pH < 6.0$$

$$Fe^{+3}, Fe(OH)_2^{+1}, Fe(OH)_3, FeOOH$$

$$Fe_2(OH)_2^{+4}, Fe(OH)_4^{-1}$$

Chemical Reactions

- Sweep Coagulation

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \Rightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2$$

$$2FeCl_3 + 3Ca(HCO_3)_2 \Rightarrow 2Fe(OH)_3 + 3CaCl_2 + 6CO_2$$

$$Fe_2(SO_4)_3 + 3Ca(HCO_3)_2 \Rightarrow 2Fe(OH)_3 + 3CaSO_4 + 6CO_2$$

$$2Al_2Cl(OH)_5 + Ca(HCO_3)_2 \Rightarrow 4Al(OH)_3 + CaCl_2 + 2CO_2$$

$$2Al_2Cl_3(OH)_3 + 3Ca(HCO_3)_2 \Rightarrow 4Al(OH)_3 + 3CaCl_3 + 6CO_2$$

$$2Al_3Cl_2(OH)_5(SO_4) \cdot 2H_2O + 2Ca(HCO_3)_2 \Rightarrow 6Al(OH)_3 + 2CaCl_3 + 2H_2SO_4 + 6CO_2$$

Chemical Reactions

Coagulant	Alkalinity consumed, mg/L	Solids produced, mg/L	CO_2 added, mg/L
Alum	0.50	0.26	0.44
Ferric chloride	0.55	0.40	0.49
Ferric sulfate	0.53	0.38	0.23
Aluminum chlorohydrate	0.29	0.89	0.25
Polyaluminum chloride	0.71	0.74	0.62
Polyaluminum chlorosulfate	0.35	0.54	0.20

Chemical Reactions

- Oxidative Reactions

$$KMnO_4 + 3Fe^{+2} + 7H_2O \Rightarrow K^+ + MnO_2 + 3Fe(OH)_2 + 5H^+$$

$$2KMnO_4 + 3Mn^{+2} + 2H_2O \Rightarrow K^+ + 5MnO_2 + 4H^+$$

$$HOCl + Mn^{+2} + H_2O \Rightarrow MnO_2 + Cl^- + 3H^+$$

Chemical Reactions

- Lime Softening

$$Ca(OH)_2 + \mathrm{Ca(HC}O)_3 \Rightarrow 2CaCO_3 + 2H_2O$$

$$Ca(OH)_2 + \mathrm{Mg(HC}O)_3 \Rightarrow MgCO_3 + CaCO_3 + 2H_2O$$

$$Ca(OH)_2 + Mg\mathrm{C}O_3 \Rightarrow Mg(OH)_2 + CaCO_3$$

$$Ca(OH)_2 + \mathrm{Mg}Cl_2 \Rightarrow Mg(OH)_2 + CaCl_2$$

Stock Solutions

- Precise concentrations important
- 1% = 10,000 mg/L
- Dry chemicals weighed
  - Adjust for chemical purity
- Liquid chemicals volumetrically measured
  - Adjust for chemical purity and specific gravity

Stock Solutions

Dry chemicals

- 1 liter = 1,000 mL
- 1,000 mL * 0.01 = 10 mL
- 1 mL water weighs 1 gram
- 10 mL = 10 grams dry chemical

Stock Solutions

Dry chemicals

- Dry weight adjustment
  - Hydrated lime 88% purity

$$\frac{10 \text{ grams lime}}{(0.88)} = 11.3636 \text{ grams lime}$$

Stock Solutions

Liquid chemicals

- Calculations more difficult
- 1 liter = 1,000 mL
- 1,000 mL * 0.01 = 10 mL
- Specific gravity and dry weight adjustments needed
- Polymers adjust only for specific gravity
  - Industry standard is 100% active

Stock Solutions

Liquid chemicals

- Liquid alum SG 1.336, 48% purity

$$\frac{10 \text{ mL}}{(1.336 * 0.48)} = 15.4 \text{ mL alum needed}$$

Stock Solutions

- Make 250 mL of 1% alum from dry alum
- Chemical purity 98%
- 250 mL = 250 grams
- 250 grams * 0.01 = 2.5 grams dry
- 2.5 grams/0.98 = 2.551 grams needed

Stock Solutions

- Make 100 mL of 1% polymer
- Specific gravity 1.16
- 100 mL = 100 grams
- 100 grams * 0.01 = 3.0 mLs polymer
- 3.0 mLs/1.16 = 2.6 mLs needed

Stock Solutions

- Make 500 mL of 1% lime from dry lime
- Chemical purity 88%
- 500 mL = 500 grams
- 500 grams * 0.01 = 5.0 grams dry
- 5.0 grams/0.88 = 5.6818 grams needed

Test Solutions

- Stock solutions generally too strong for effective dosing
- Prepare test solution from stock solution
- Test solutions generally 0.1% - 0.5% (1,000 - 5,000 mg/L)

$$\frac{\text{test strength}}{\text{stock strength}} * \text{mL needed} = \text{mL diluted}$$

Test Solutions

- Make 500 mL of 0.3% lime from stock
- Stock 10,000 mg/L
- Test 3,000 mg/L

$$\frac{3{,}000\ \text{mg/L}}{10{,}000\ \text{mg/L}} * 500\ \text{mL} = 150\ \text{mL to dilute}$$

- 150 mL stock diluted to 500 mL is 3,000 mg/L test solution

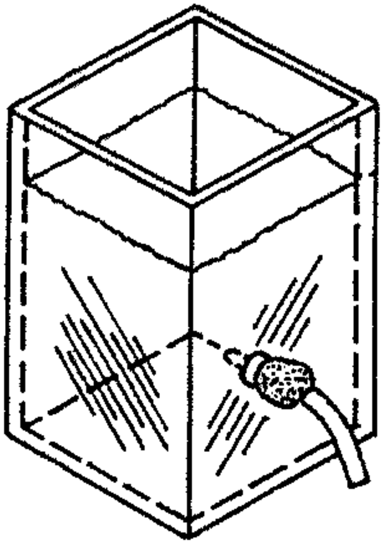
Dosing the Jars

- Dosages are simply dilutions of test solutions into a jar
- Equal intervals or increments
- Known dosage, use 5 mg/L increments
  - 5 mg/L, 10 mg/L, 15 mg/L, etc.
- Unknown dosage, use 10 mg/L increments
  - 10 mg/L, 20 mg/L, 30, mg/L, etc.
  - Second series can tighten dosage ranges

Dosing the Jars

- Use 2,000 mL for jar tests
- Gator jars - 2 liter or 2,000 mL

$$\frac{\text{Dosage, mg/L}}{\text{Test sol., mg/L}} * 2{,}000 = \text{mL test solution added}$$



Dosing the Jars

- Lime dosage needed 100 mg/L
- Test solution concentration 3,000 mg/L

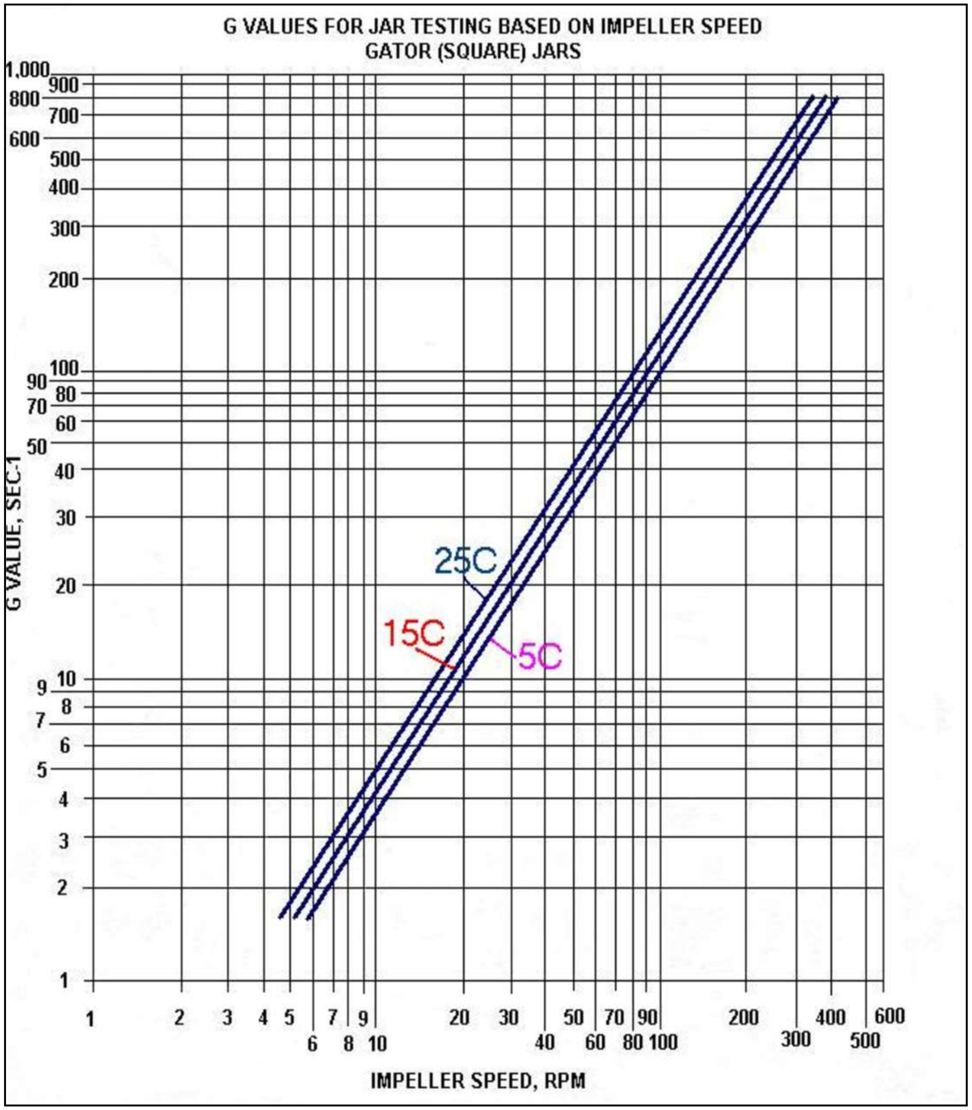
$$\frac{100\ \text{mg/L}}{3{,}000\ \text{mg/L}} * 2{,}000 = 67\ \text{mL added to jar}$$

- All other jars dosed same manner

G Values

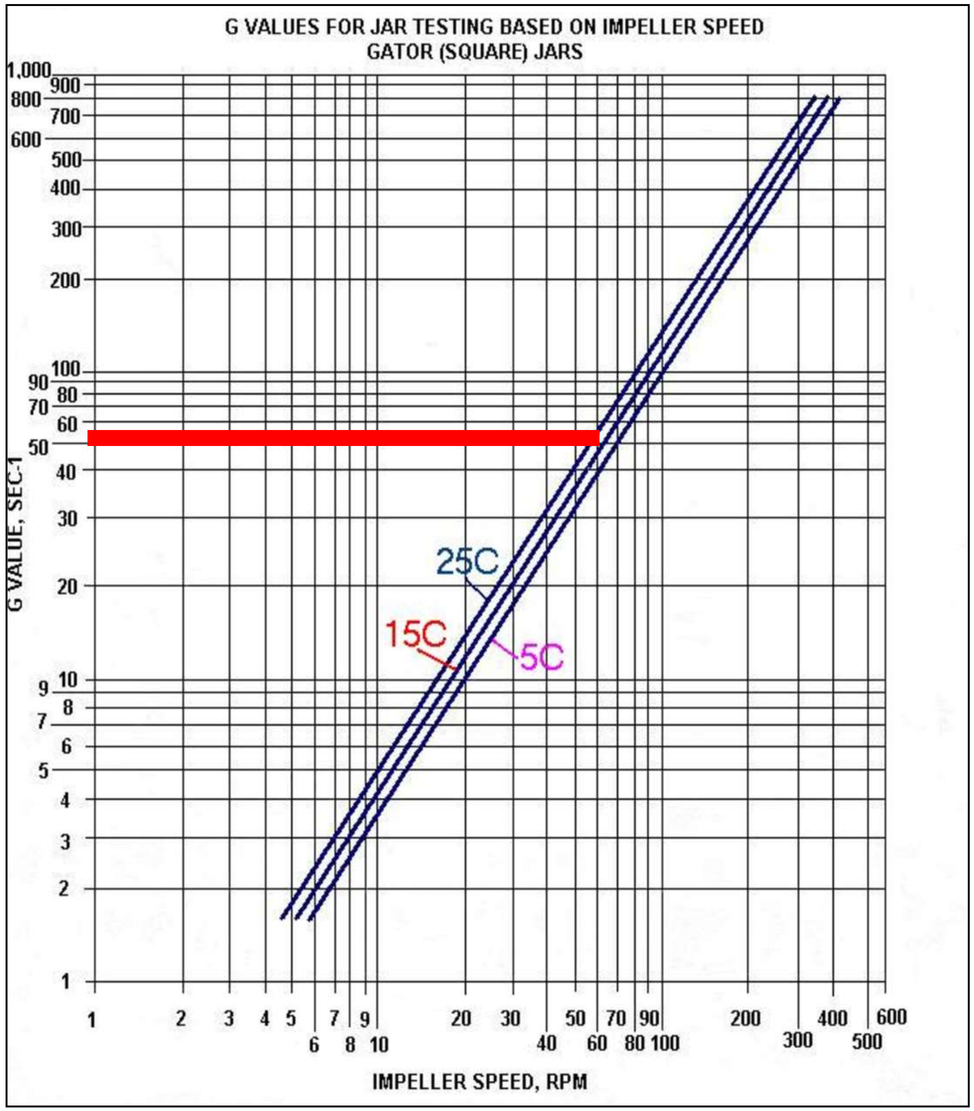
- G values determined for gang stirrers
  - Gator jars or Hudson jars
- G value curve defines mixer operating speeds
  - Identify G value
  - Align with water temperature
  - Read mixer speed

Mixer speeds



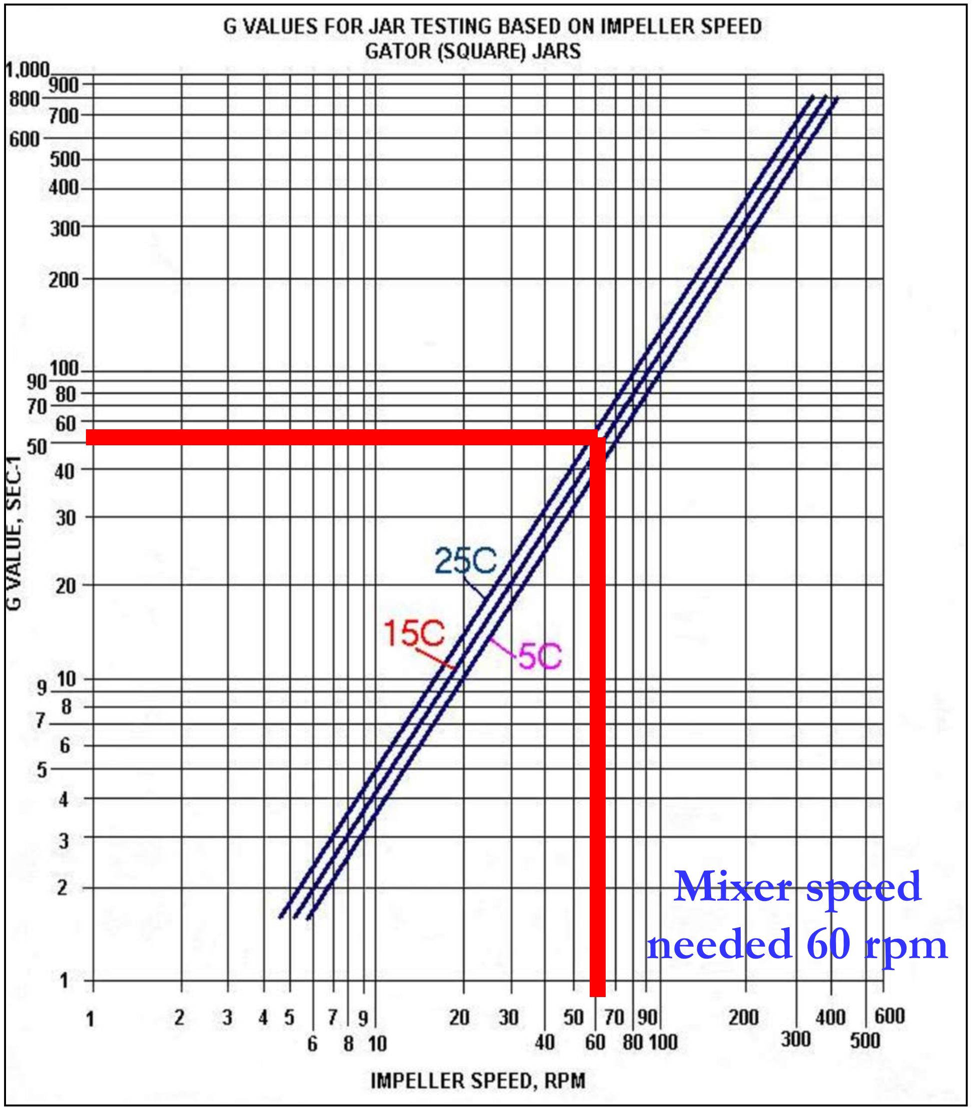
Mixer speeds

G value 50 sec^{-1} needed



Mixer speeds

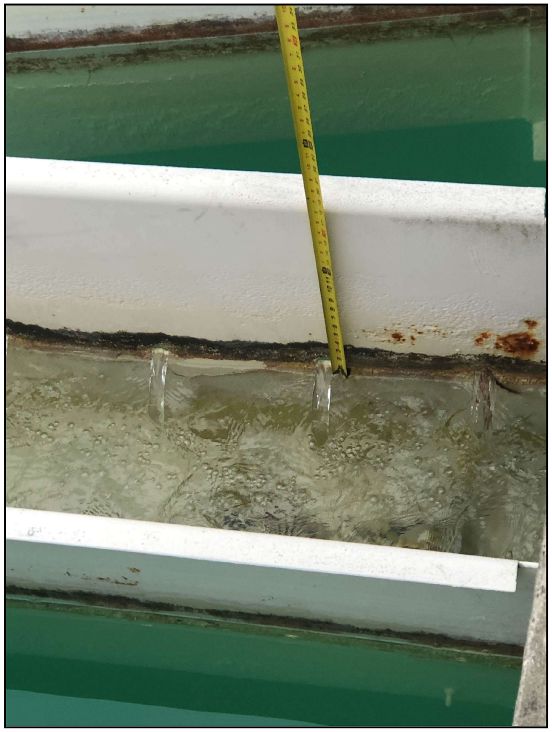
G value 50 sec^{-1} needed



Mixer speed needed 60 rpm

Settling Times

- Sample collection based on vertical floc settling rate
  - Determined from SOR or upflow rate
  - Procedure in AWWA M56
- Graph defines sampling times



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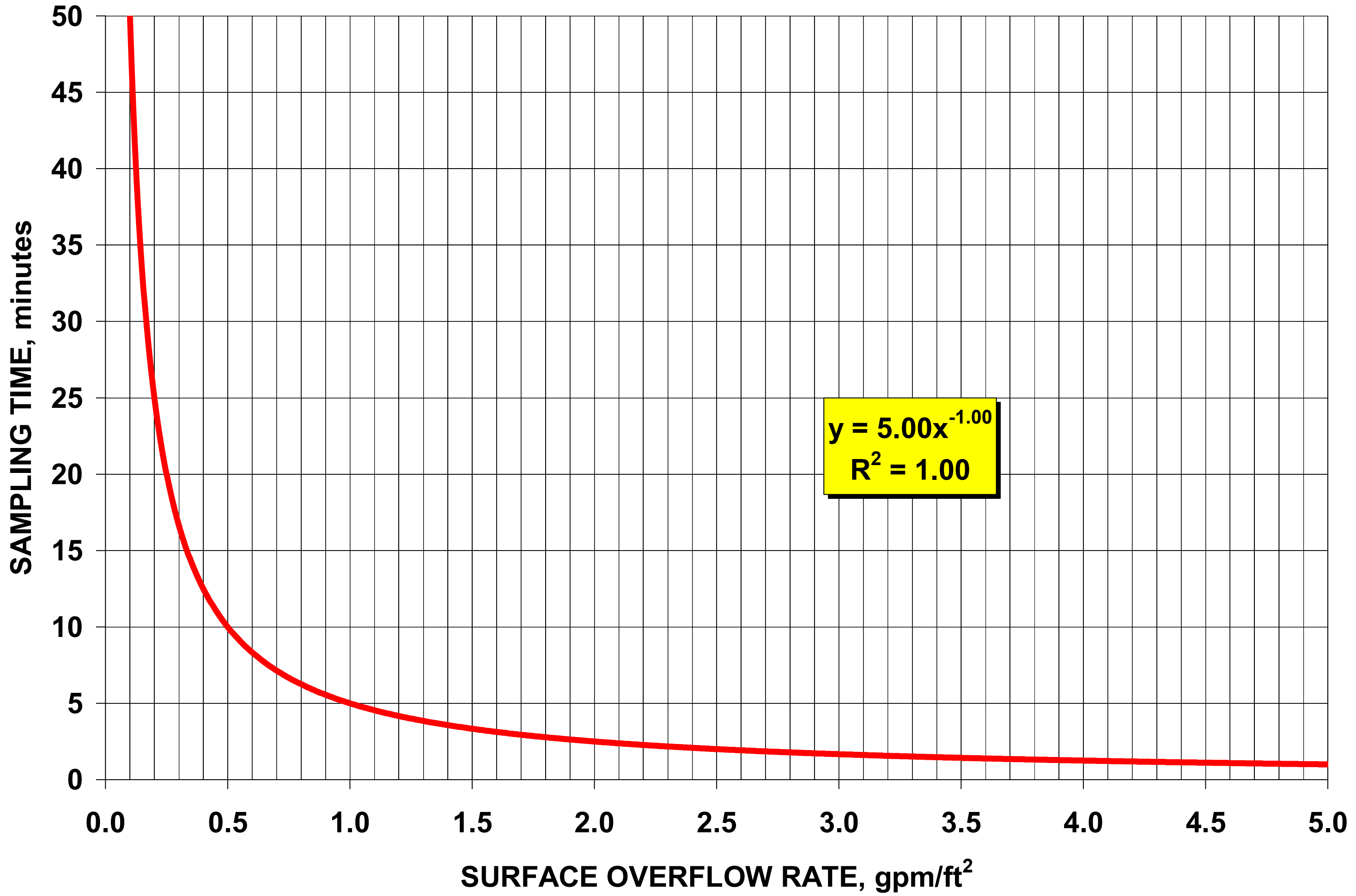


Settling Times

- Upflow rate 0.65 gpm/ft^2
- Sampling time equation

$$Time = \frac{5.0}{upflow}$$

- Sampling time 7 minutes, 42 seconds

Floc Settling Rate

- Estimates maximum upflow rate that allows effective floc settling
- Evaluates floc development for jar testing
- Equation for 100 mL graduated cylinder

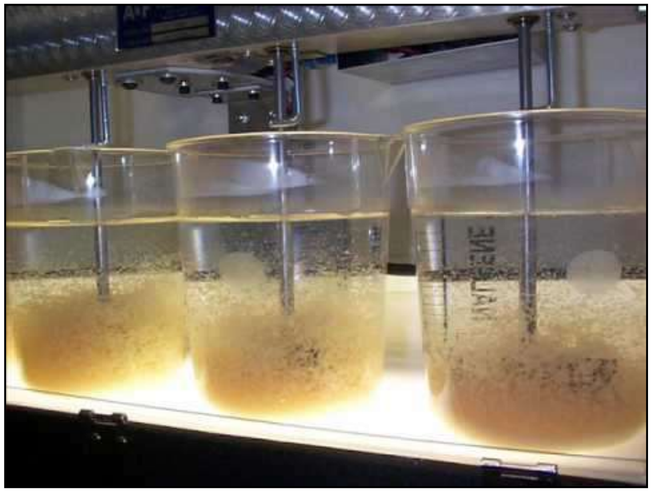
$$\frac{265}{t_s} = SOR_{MAX,}\, gpm/ft^2$$

Floc Settling Rate

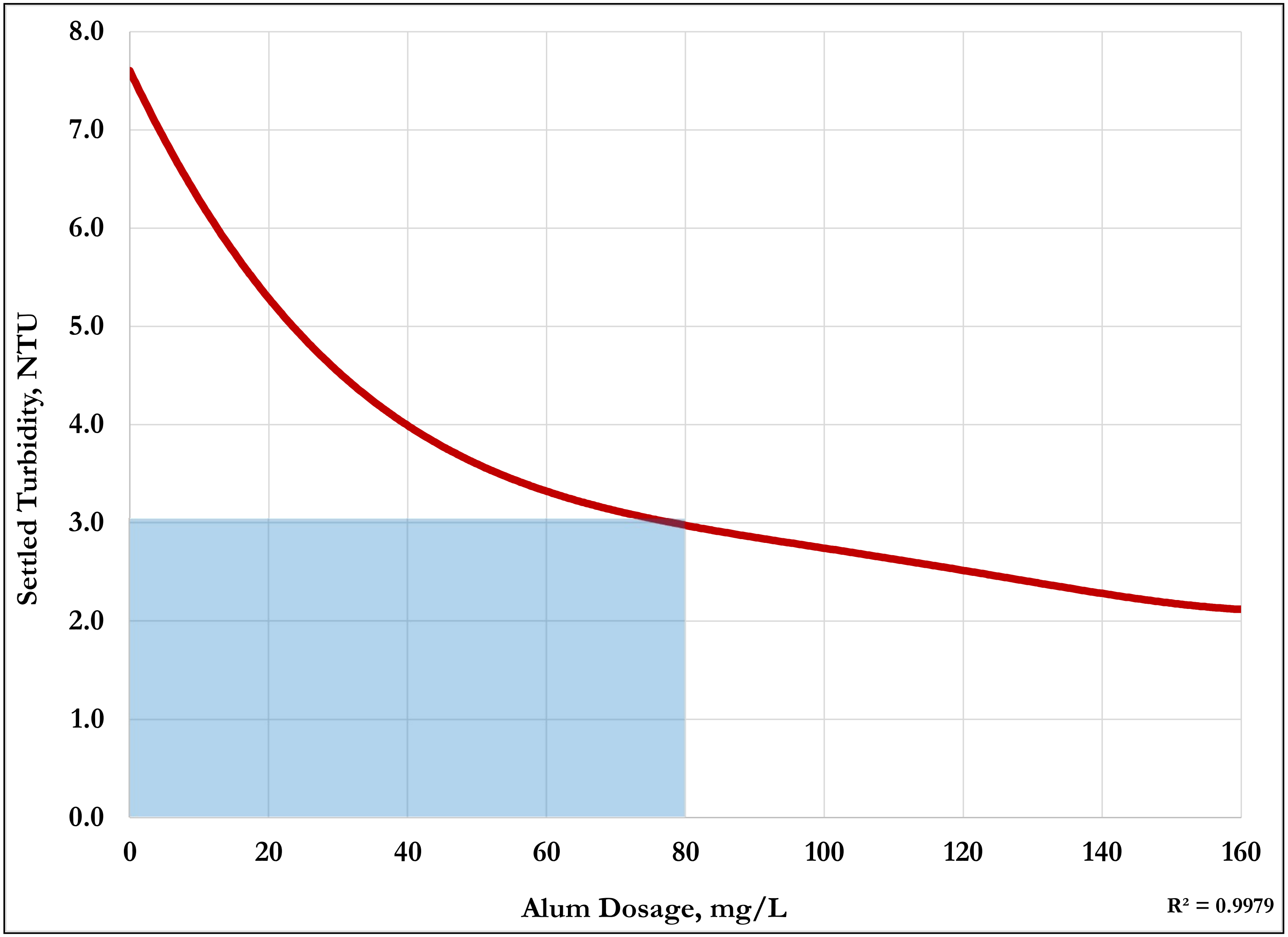
- Floc settling time 4 min. 25 seconds
- Conversion 265 seconds

$$\frac{265}{265\ sec} = 1.0\ gpm/ft^2$$ for graduated cylinder

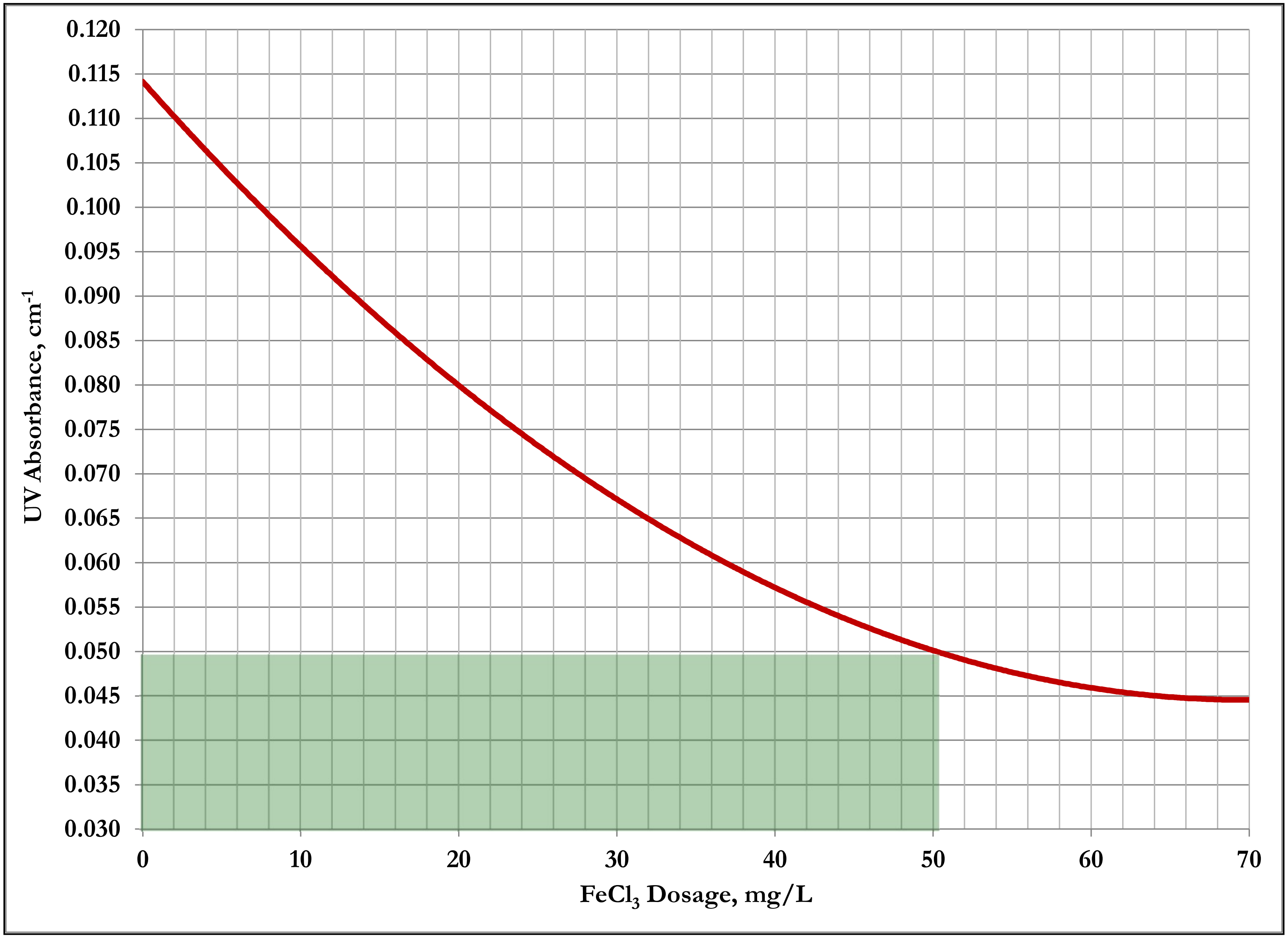
$$\frac{225}{265\ sec} = 0.85\ gpm/ft^2$$ for jars



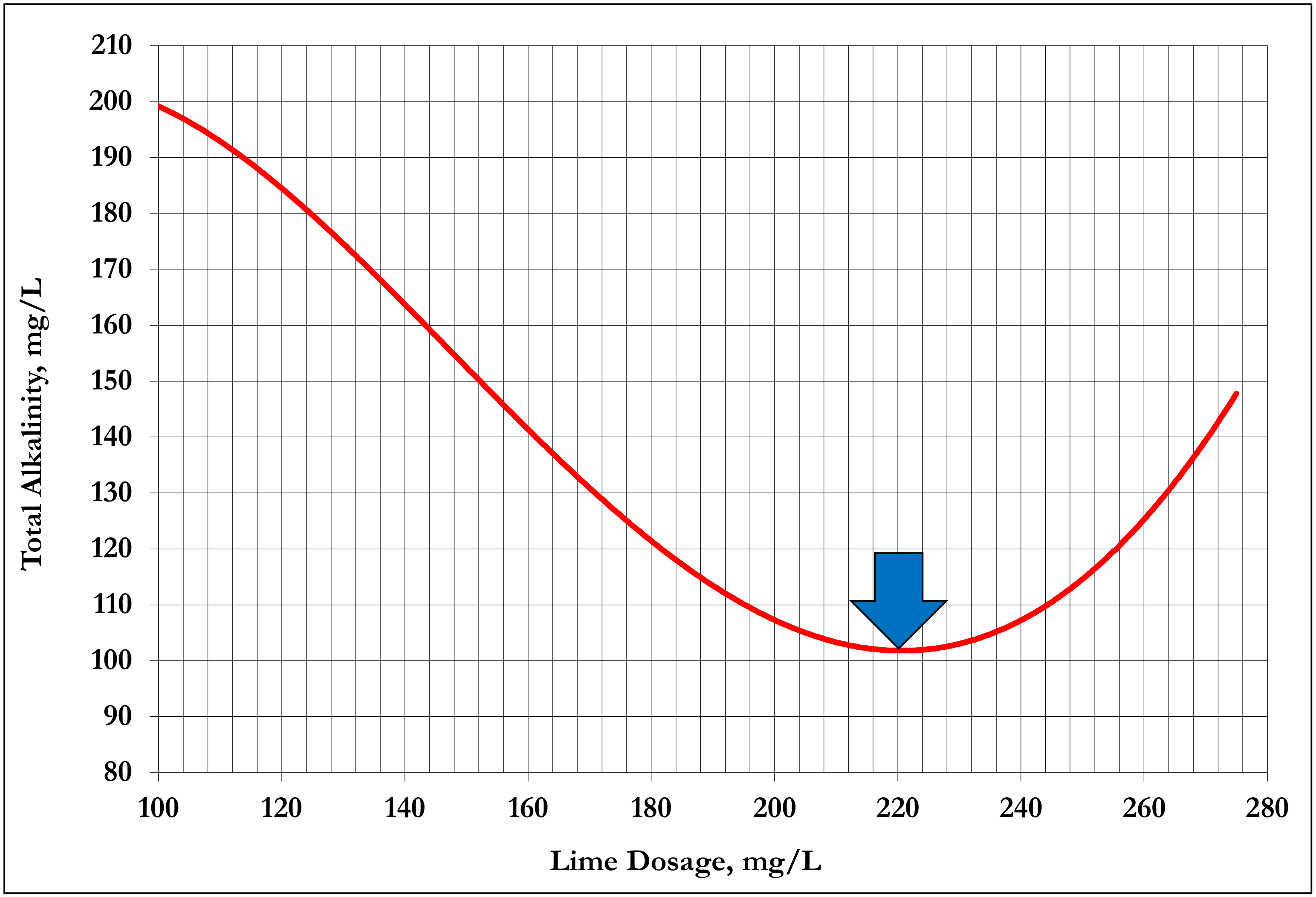
Dosage/Turbidity Curve



Dosage/UVA Curve



Lime Demand Curve



Physical Observations

- Floc Development
  - 0.5 mm to 3 mm diameter
  - Spherical not fluffy, jagged
  - Diameter increases, then decreases
- Floc Settling
  - Density allows rapid settling
- Apparent Clarity
  - More than 4-inches after settling

Questions

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Jar Testing Procedures and Practical Applications for Water Treatment Processes - Part 2

Marvin Gnagy, P.E., President
PMG Consulting, Inc.

OTCO Water Laboratory Webinar

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Agenda

- Practical applications for jar testing
  - Treatments that can be simulated using jar testing techniques
  - Chemical evaluations and assessments
  - Details of various treatment/optimization applications
- Case studies from projects
  - Various treatment optimization or enhanced treatment strategies
  - Examples provided with explanations
  - Specific information related to dosage selection or treatment optimization

Practical Applications

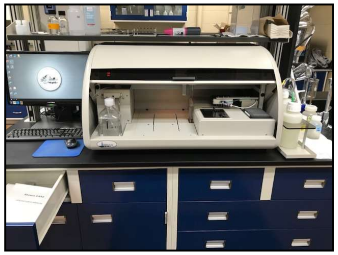
- Jar testing can simulate most pre-treatment processes, mixing processes, and clarification processes
- Cannot simulate filtration operations with jar testing
  - Pilot-scale filters work best
- Evaluation of chemical treatment
  - Effective dosing and sequencing
  - Selection and comparison of chemicals
  - TOC removal and DBP control
  - Cyanotoxin treatments
  - Chemical and process optimization
  - Solids production expectations

Practical Applications

- Numerous applications for chemical treatment and water process operations
  - Use your imagination
  - Develop treatment strategies
  - Define more effective unit process operations
- Optimum application points for chemical addition
  - Mixing intensity
  - Sequence in chemical addition
  - Account for previous chemical treatments
  - Adjust water quality goals

Practical Applications

- Dosage verifications
- Oxidative conditioning studies
- Coagulant comparisons
- High-rate clarification simulations
- Flocculation optimization
- Softening optimization
- Disinfection studies
- Carbon adsorption studies
- Cyanotoxin treatment strategies



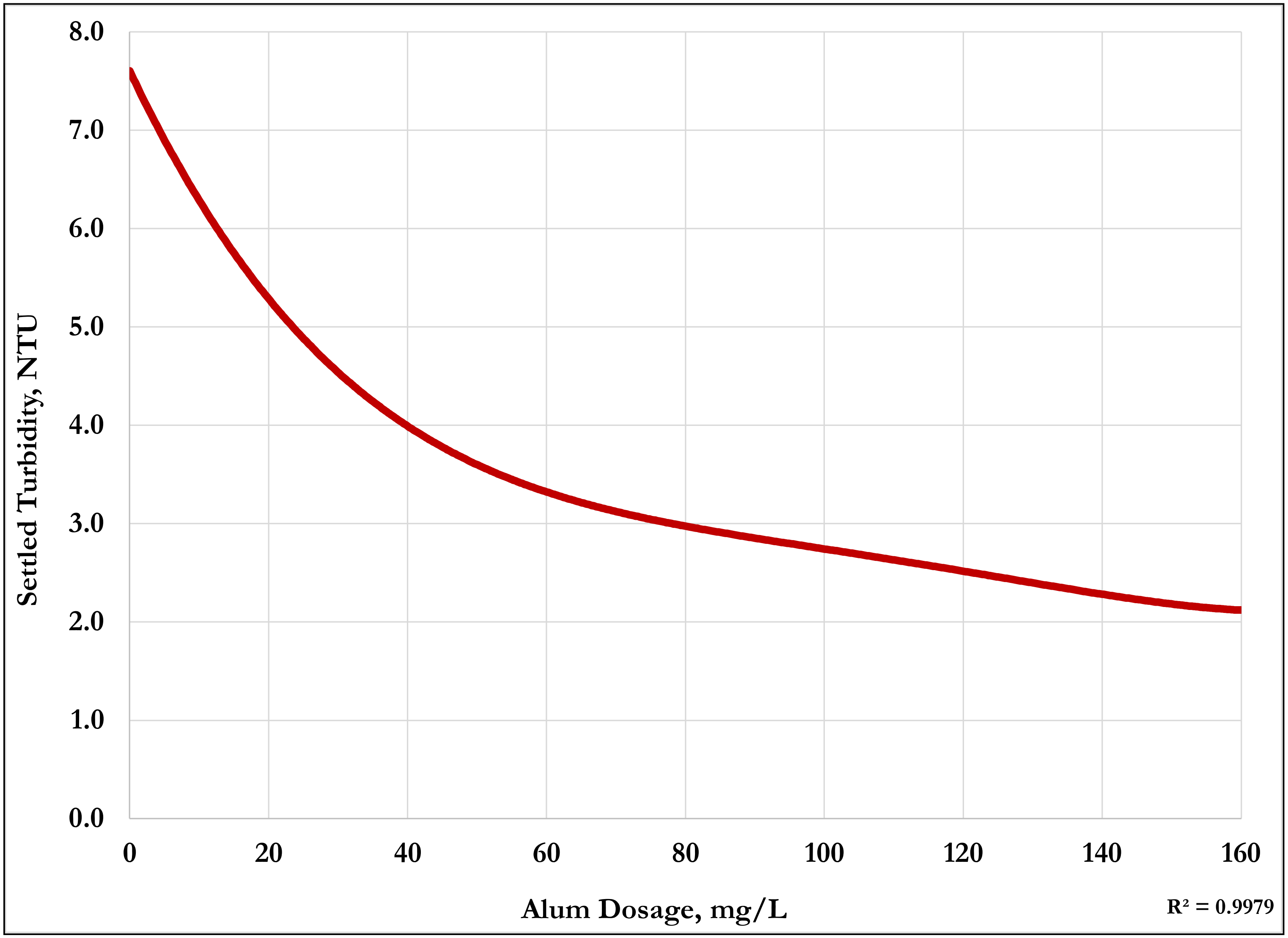
Practical Applications

- Special studies from jar testing evaluations
  - Alternate coagulants and polymers
  - Permanganate oxidation and target residual
  - Enhanced TOC removal
  - Disinfection and chloramination studies
  - Solids production/reduction strategies
  - Cyanotoxin oxidation and adsorption
  - Optimum CT operations
  - Organics conditioning and enhanced removals
  - Iron/manganese removal treatments
  - Taste and odor dosing
  - Activated carbon comparisons

Dosage Verifications

- Customary verification of effective chemical dosages
- Jar testing reviews dosages below and above current chemical treatment
  - One chemical at a time
  - Bracket existing treatment to verify results and expectations
  - Compare analytical results between dosages
    - Verify current treatment meet objectives
    - Adjust chemical dosing based on most effective treatment

Dosage Verifications



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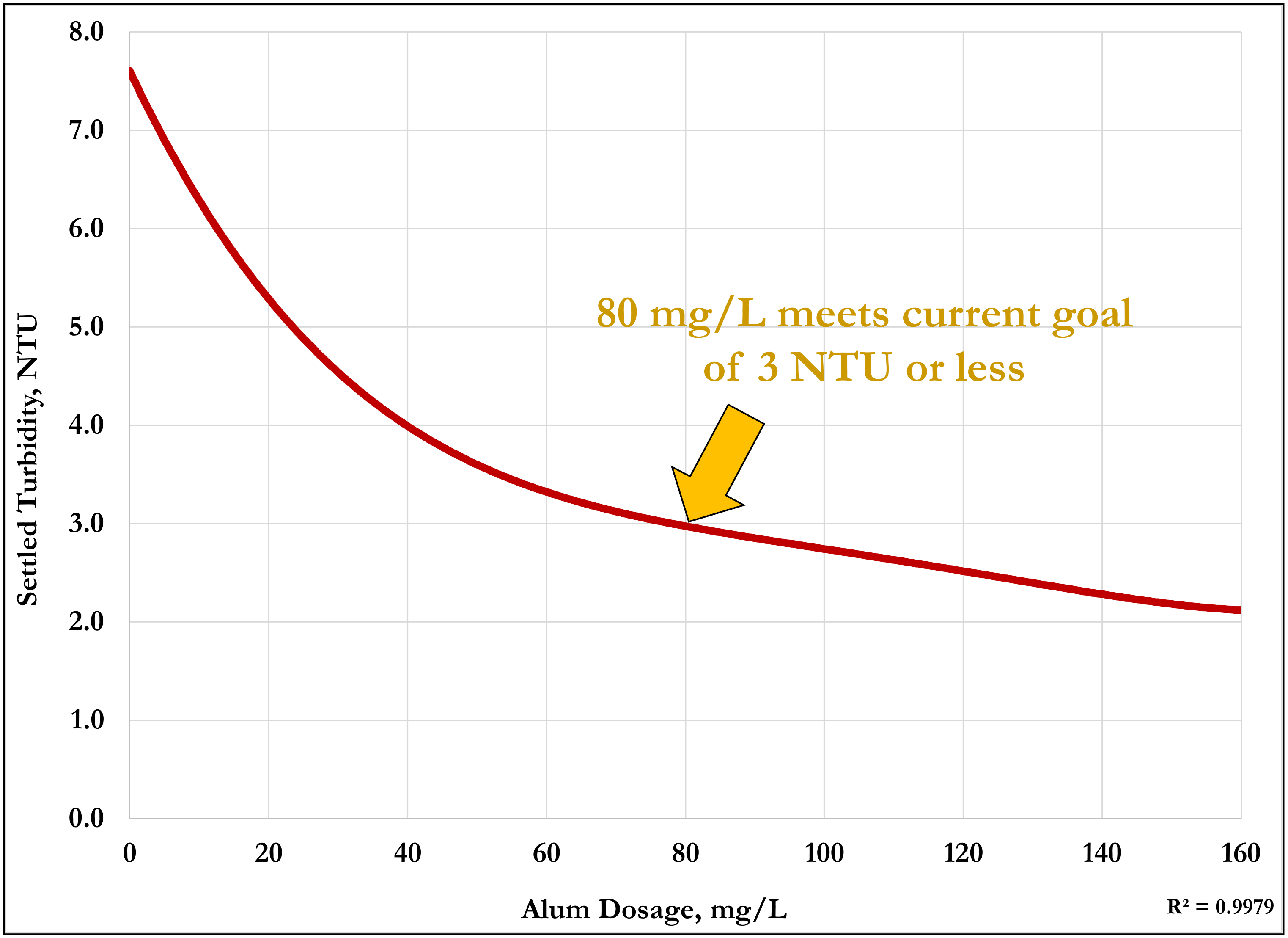

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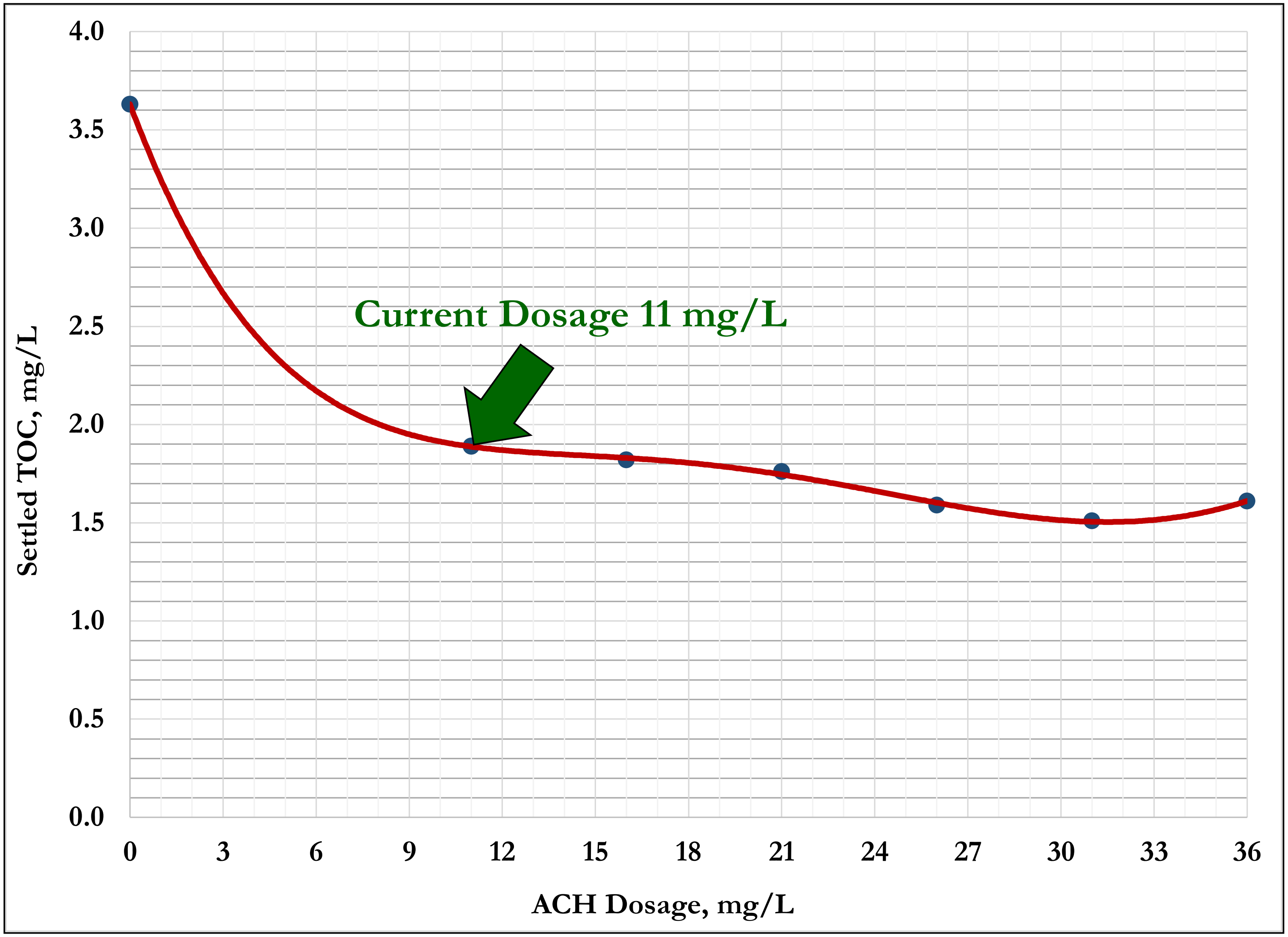

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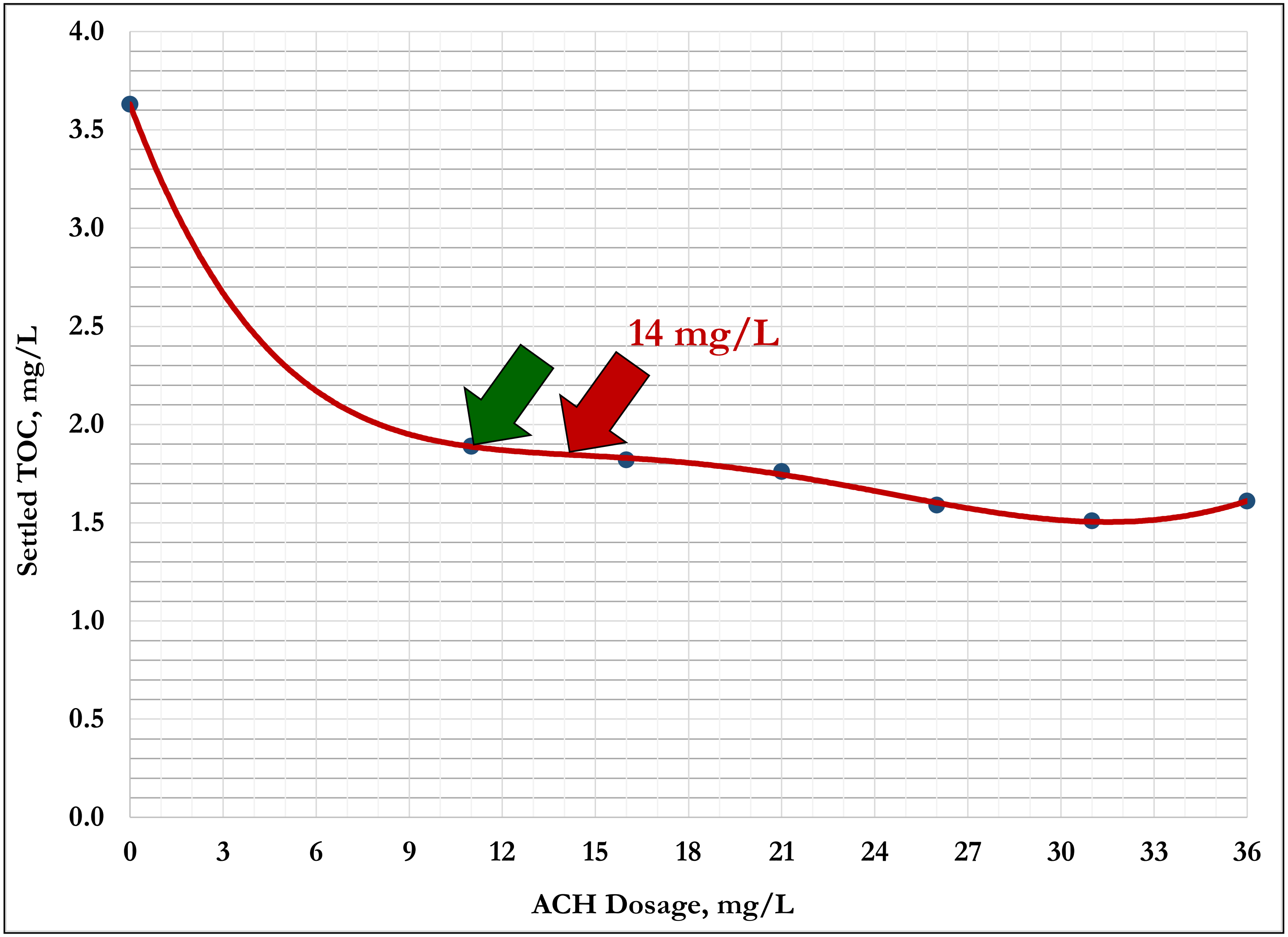

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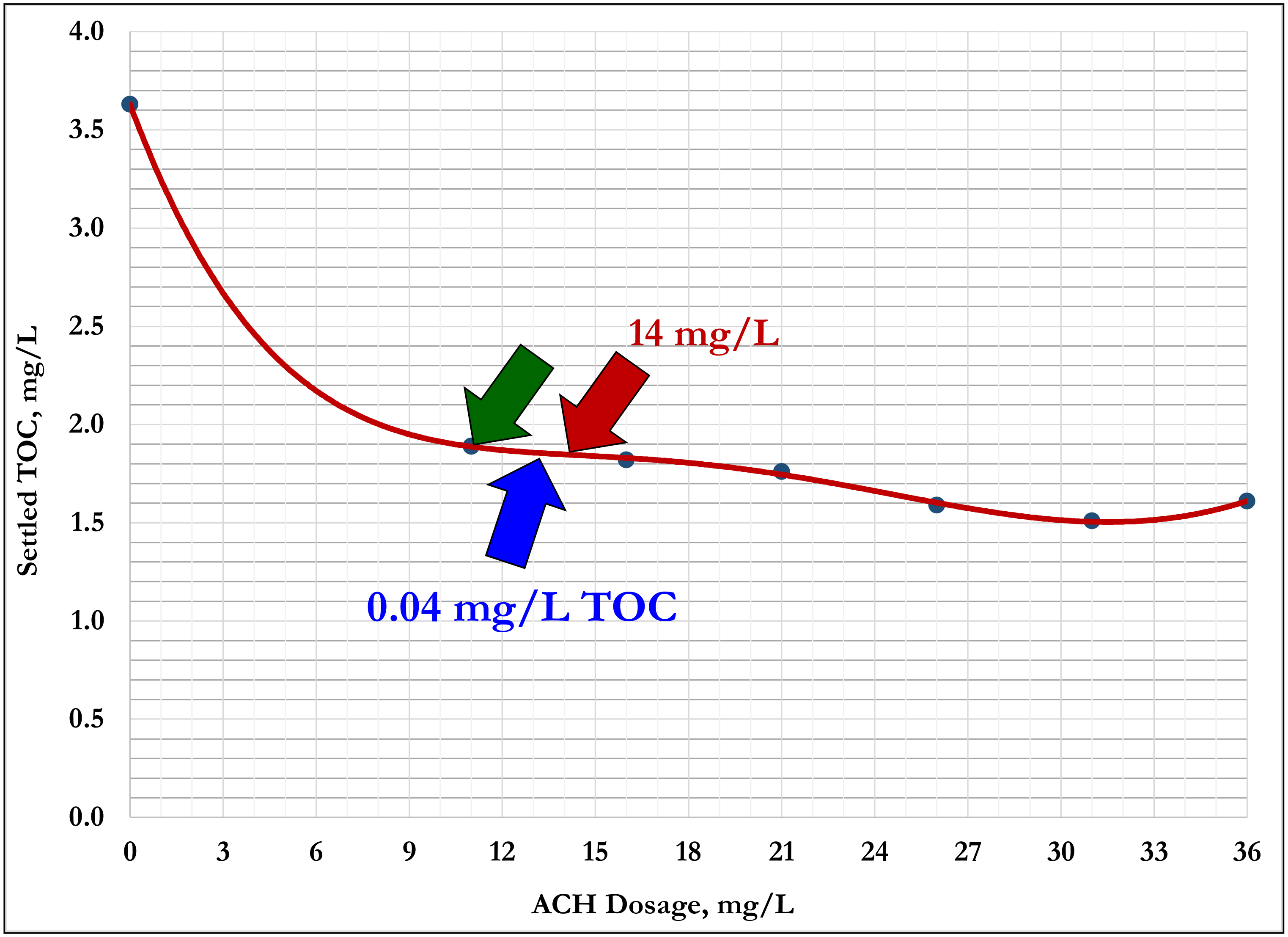

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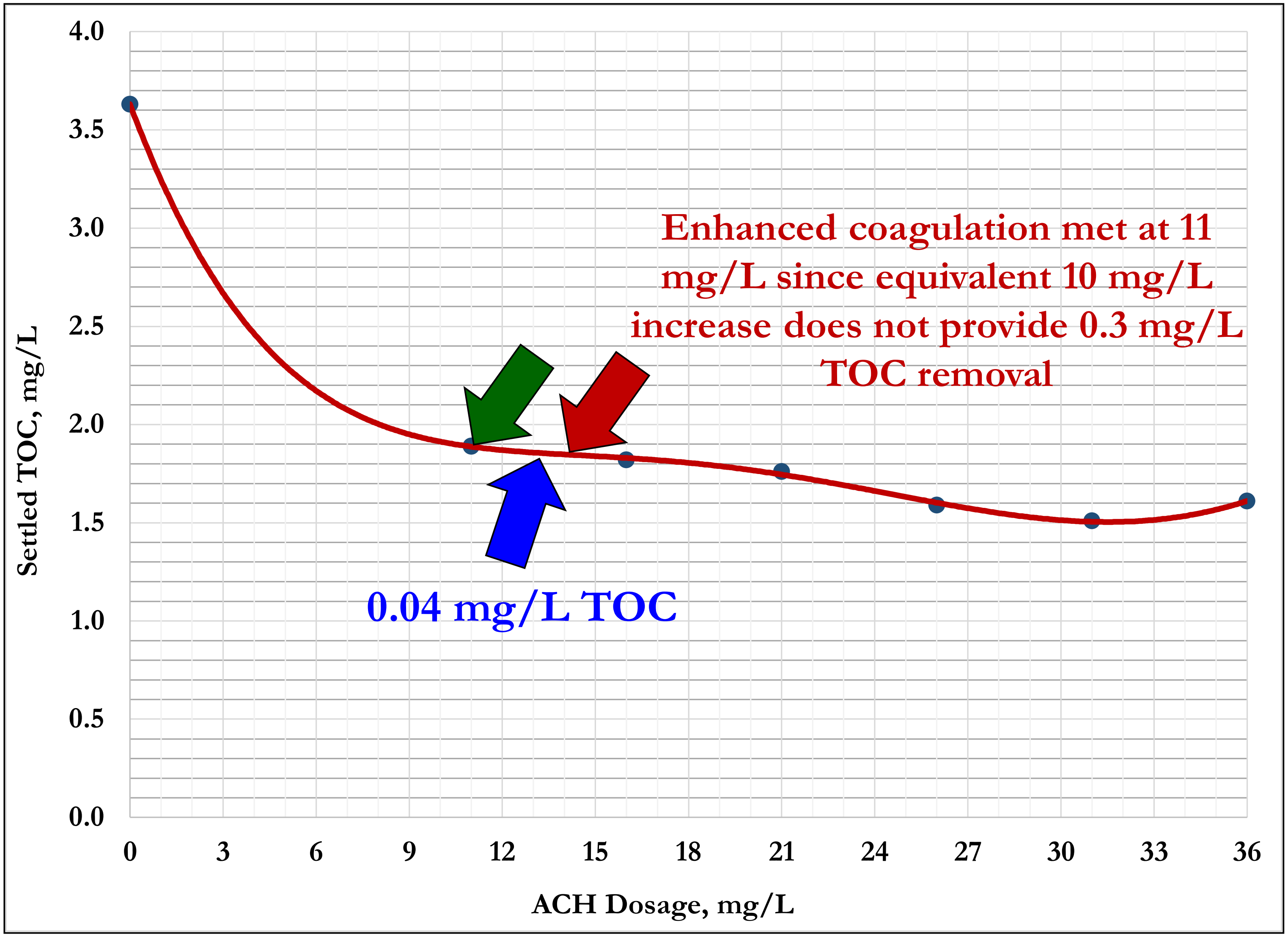
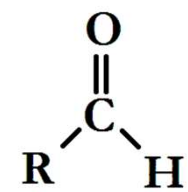
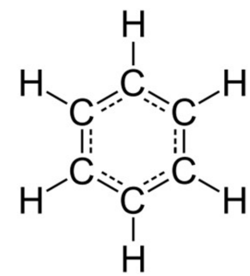
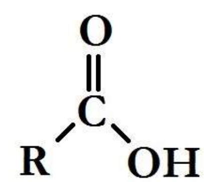


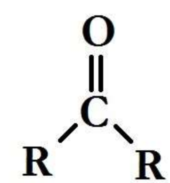
Oxidative Conditioning Studies

- Customary verification of effective chemical dosage
  - Oxidative conditioning of organics for enhanced TOC removal
    - Potassium permanganate or sodium permanganate
    - Chlorine dioxide
  - UV absorbance measured to define optimum dosage range
    - Observed change in UVA
  - Track dosages and residuals from jars
    - Estimated target residual level to control treatment dosing based on variations in source water quality



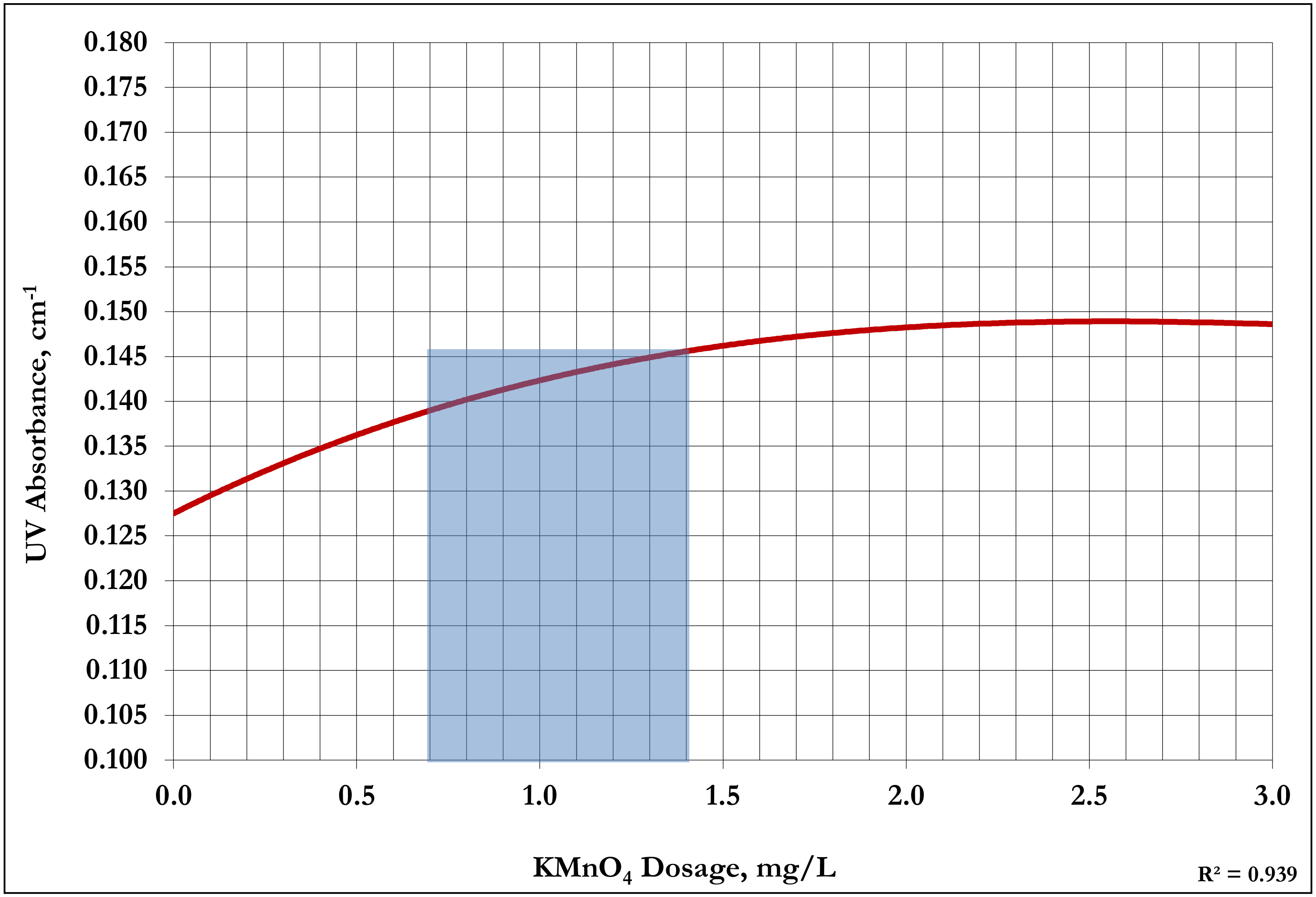






Oxidative Conditioning Studies

- Potassium permanganate



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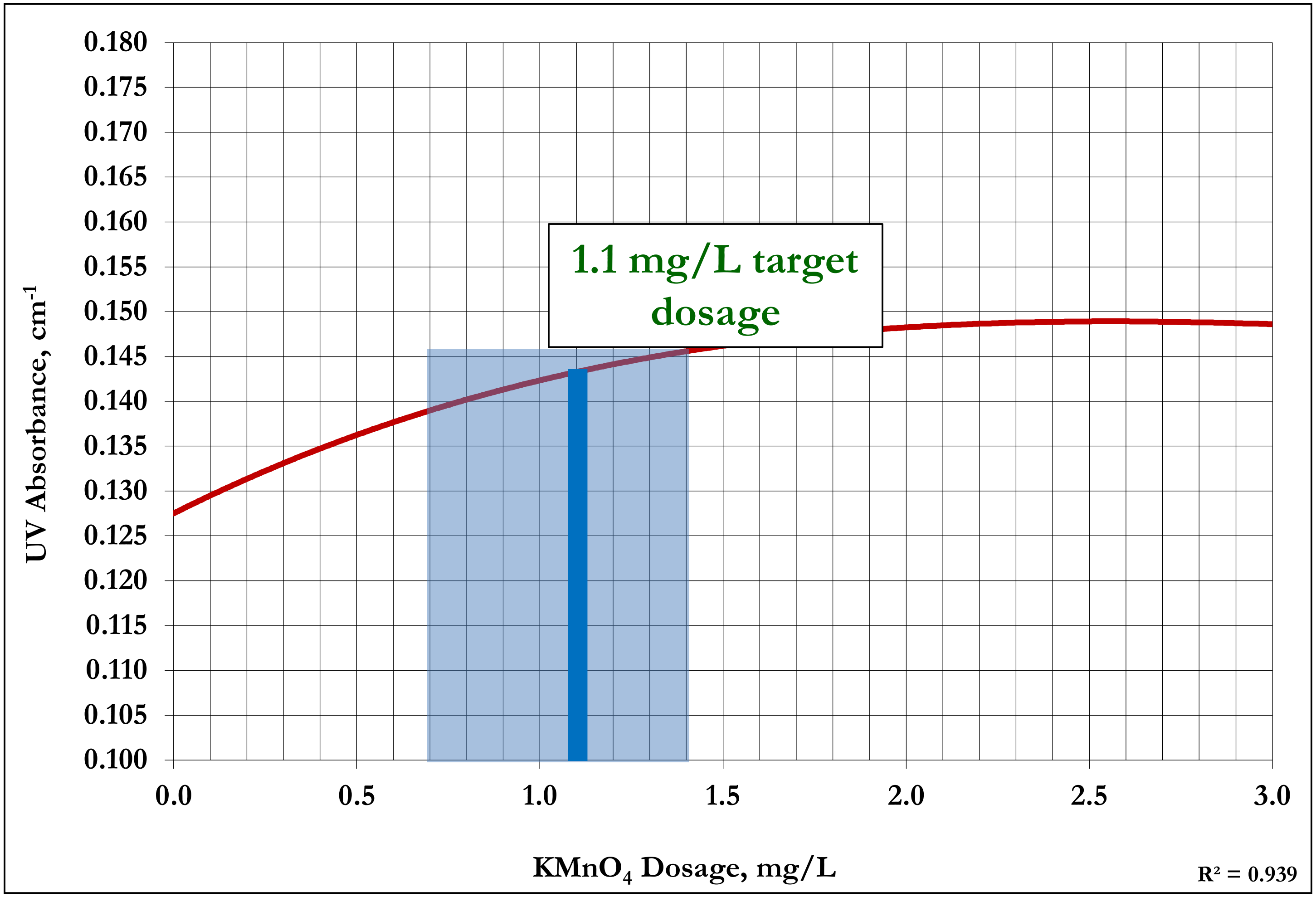

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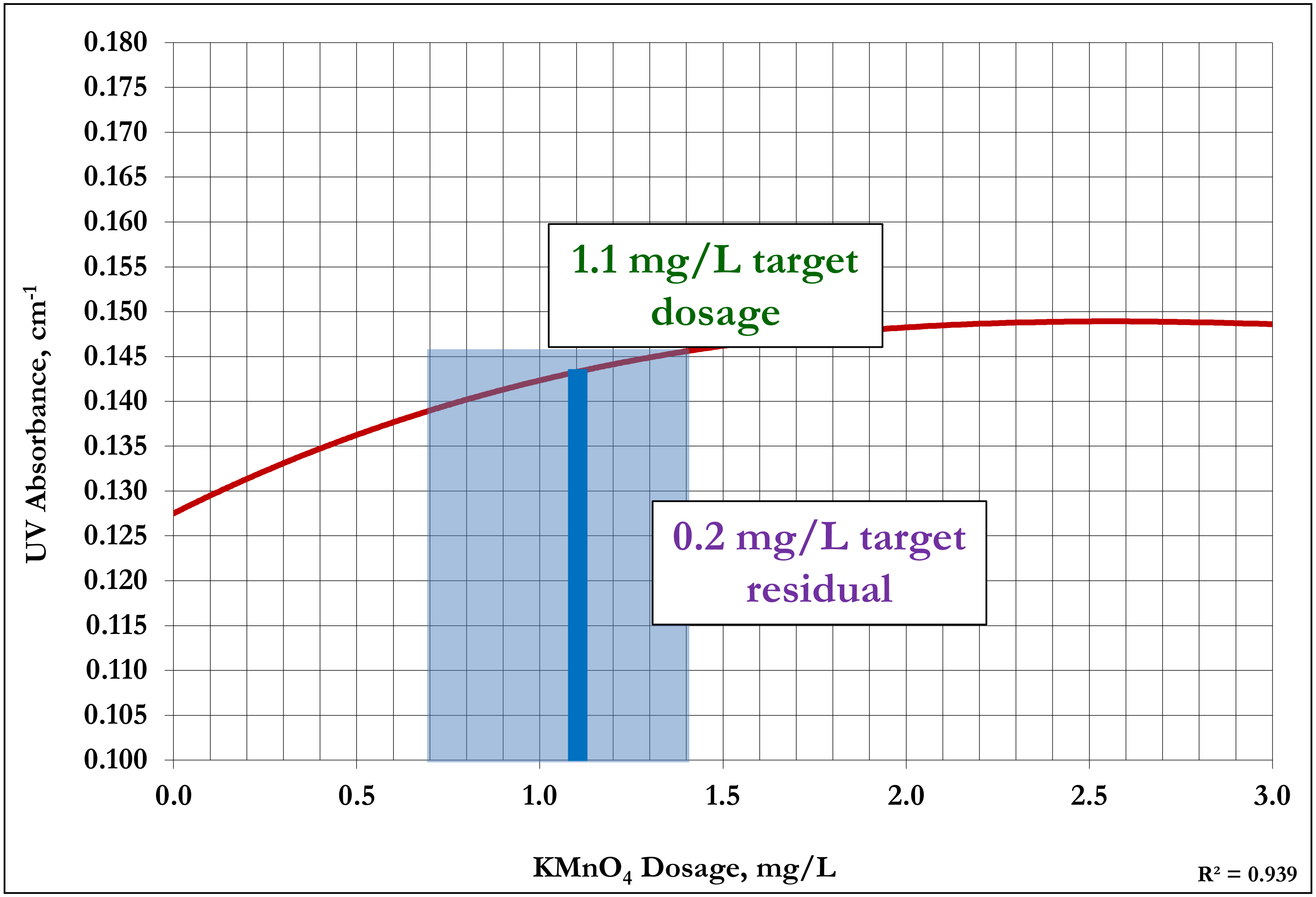

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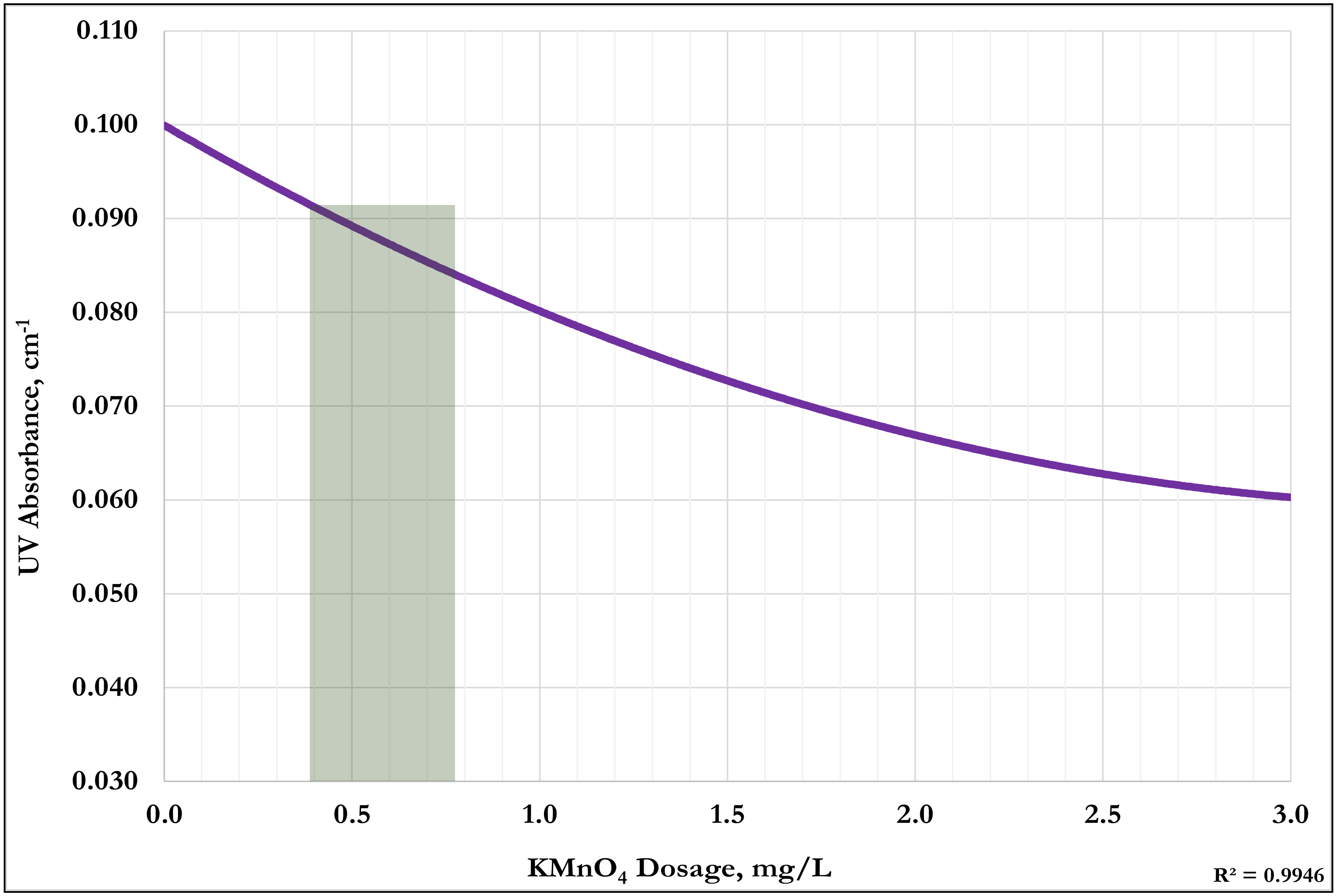

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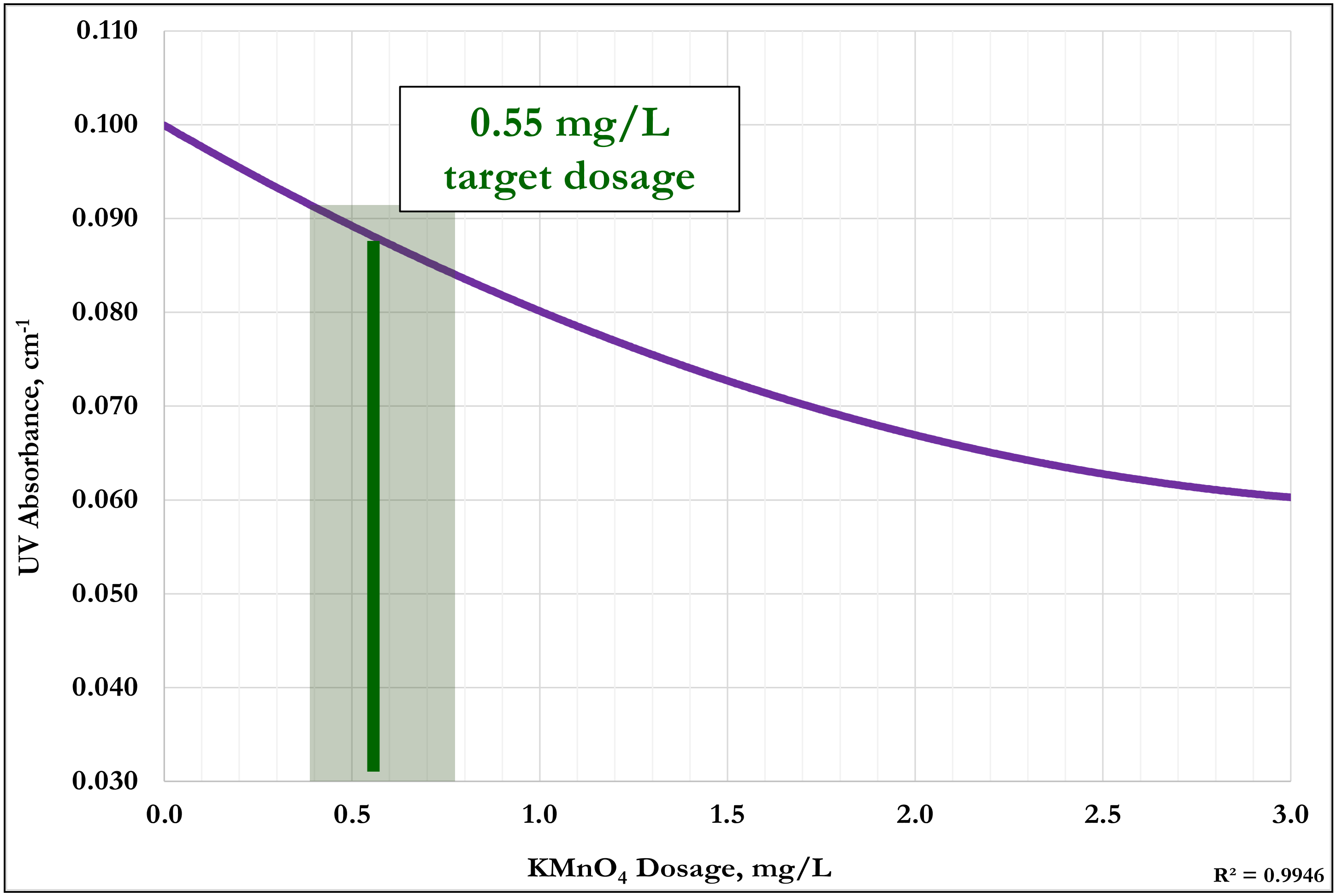

Oxidative Conditioning Studies

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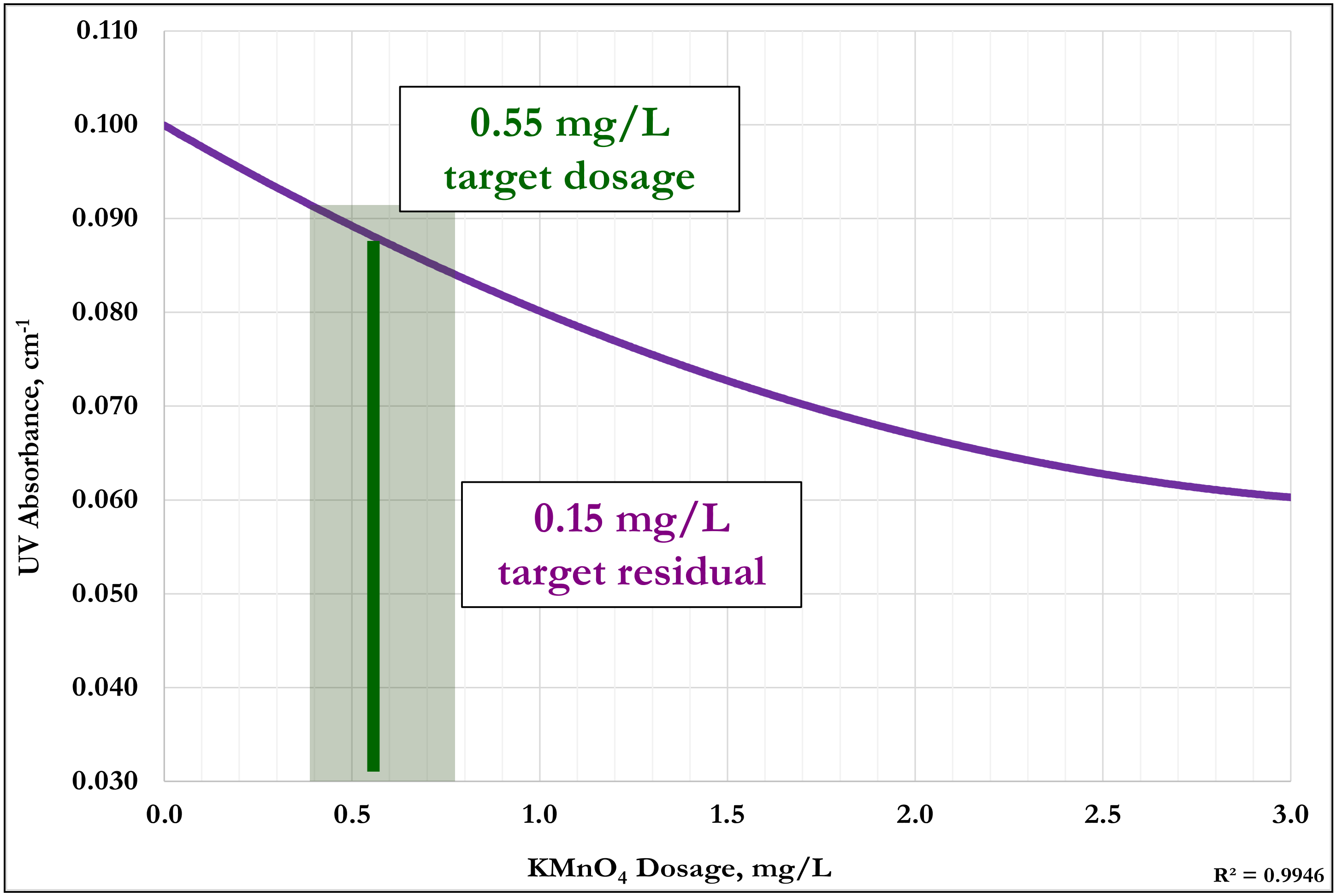
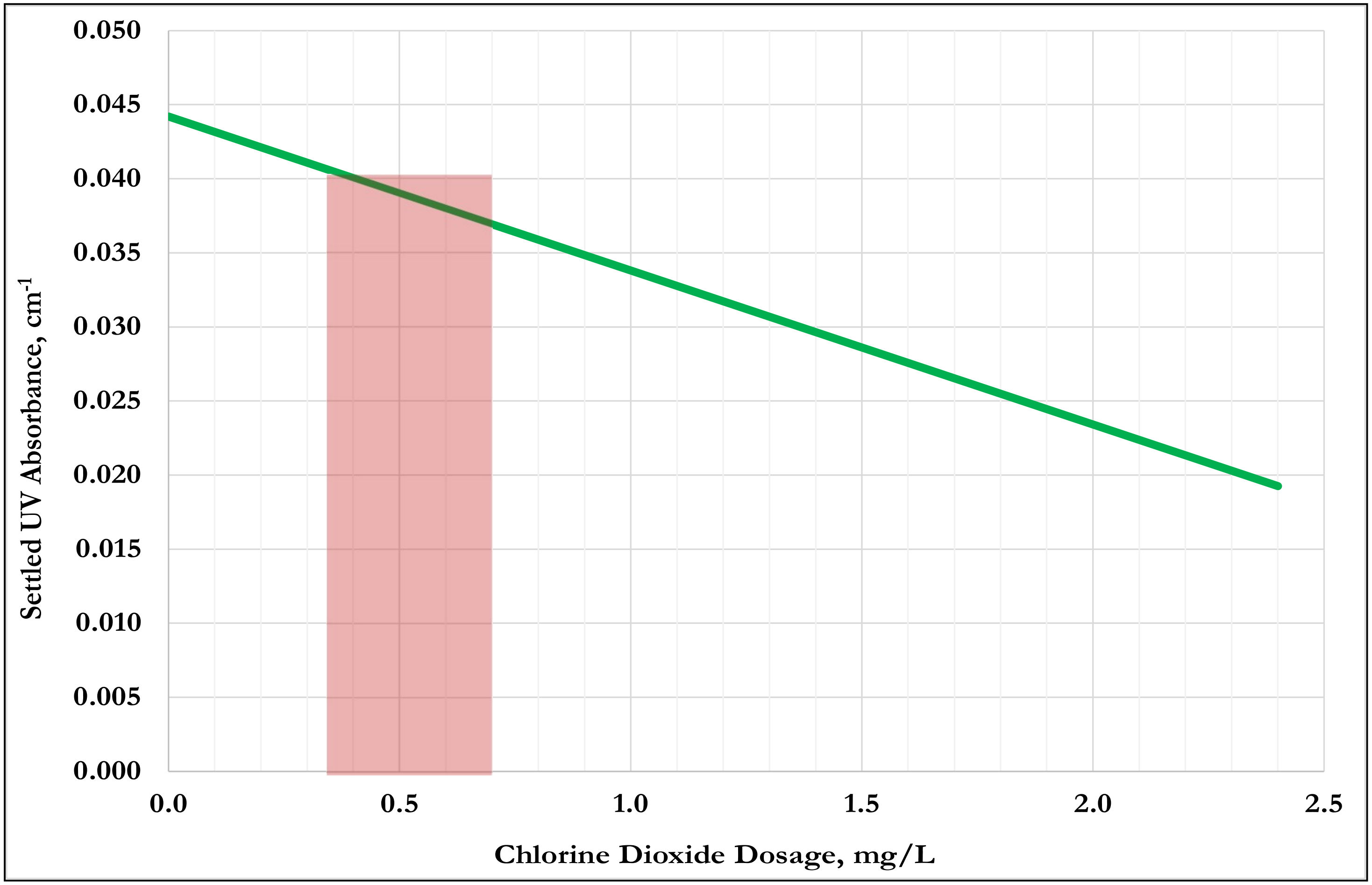


Oxidative Conditioning Studies

- Chlorine dioxide



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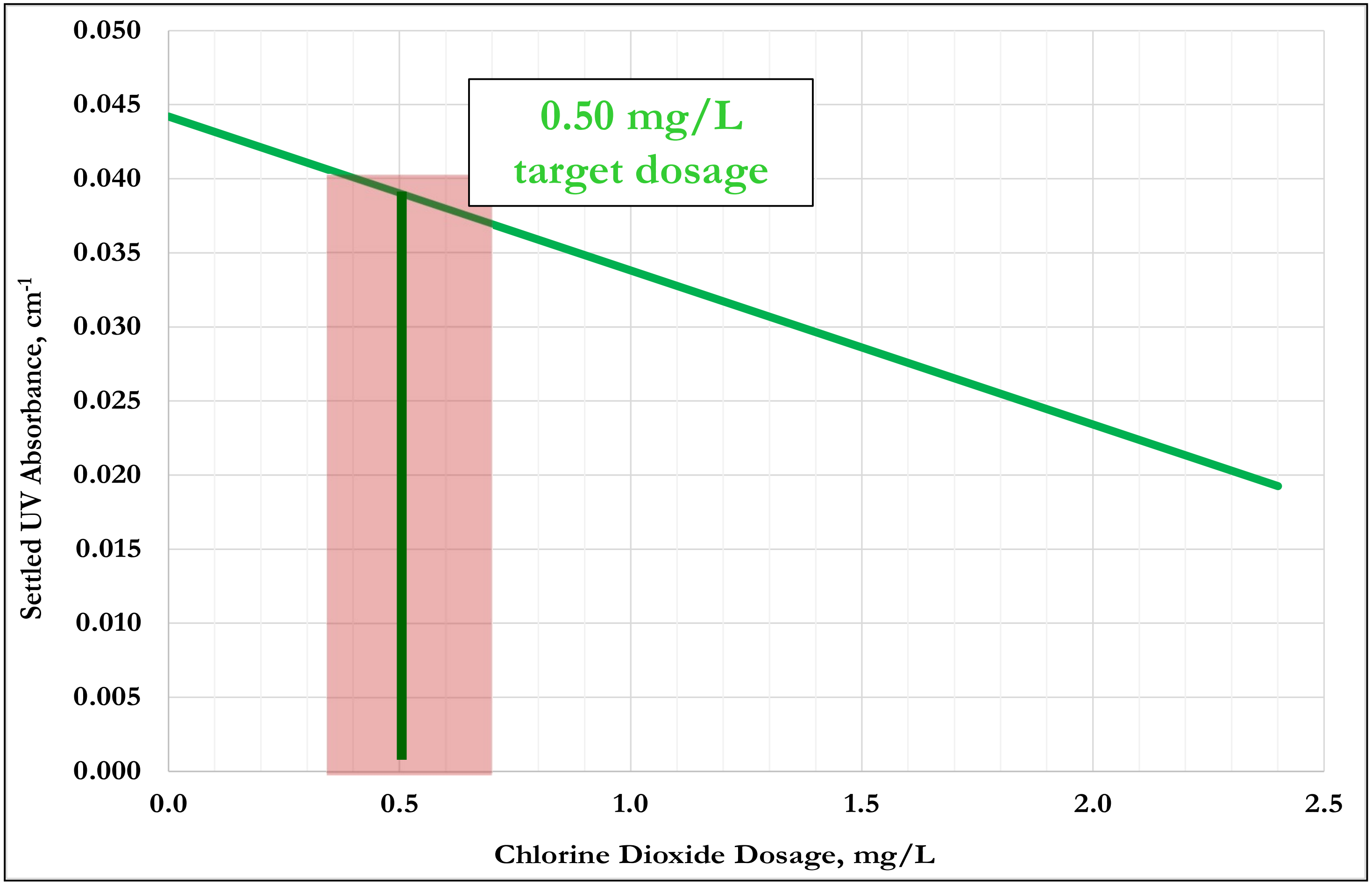
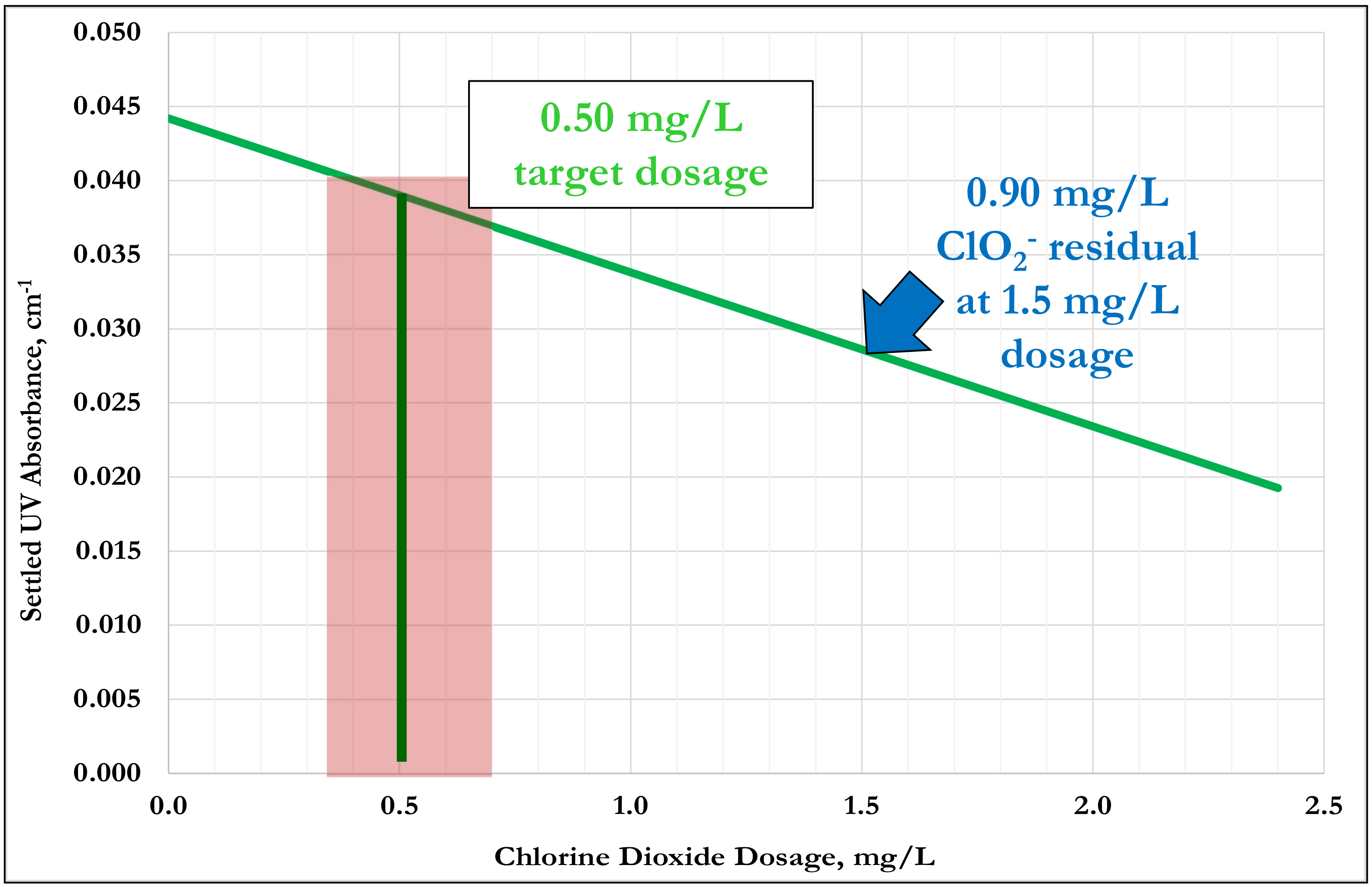


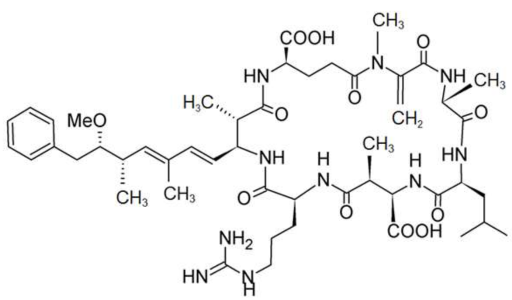
Oxidative Conditioning Studies

- Chlorine dioxide

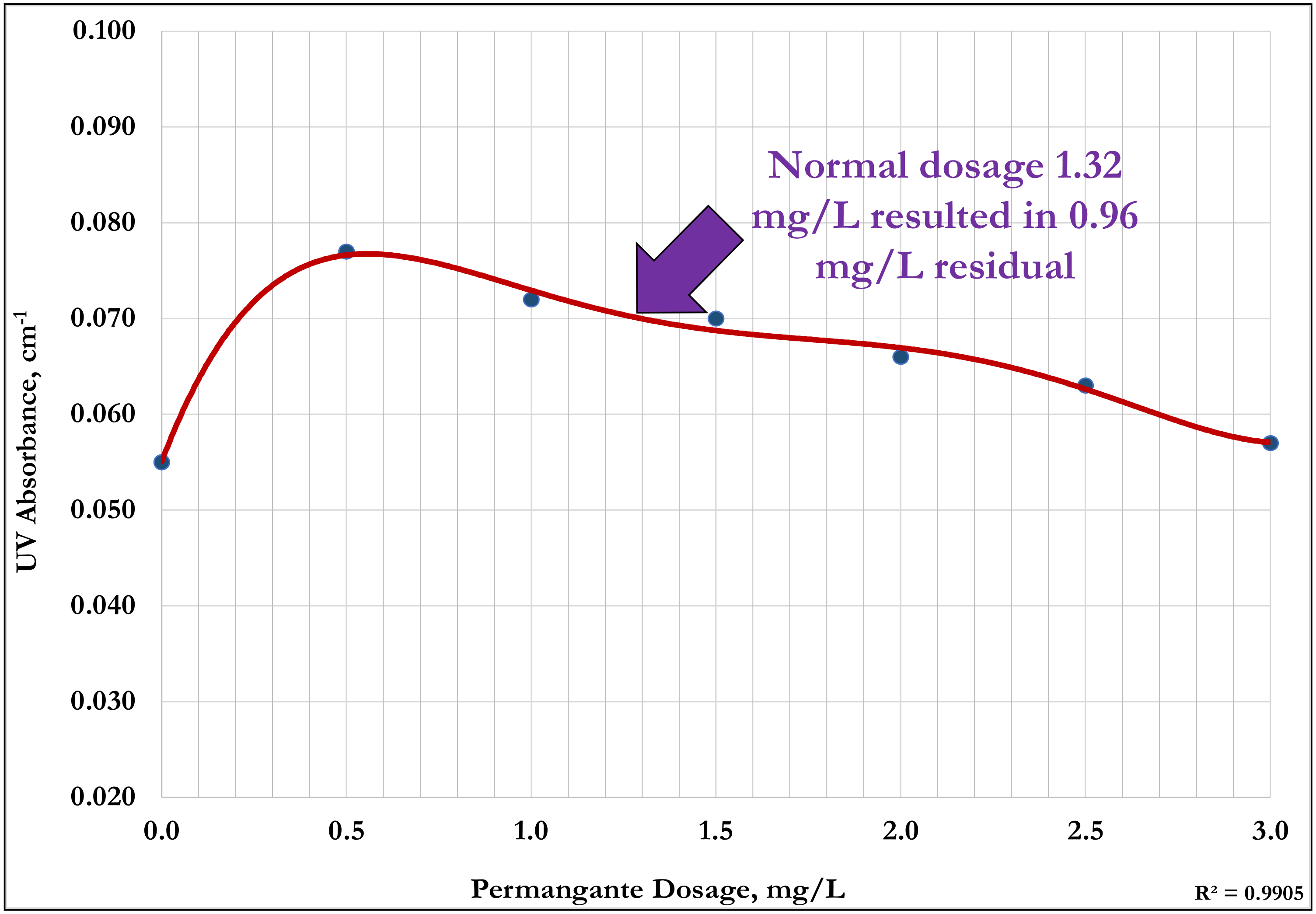


Permanganate Oxidation

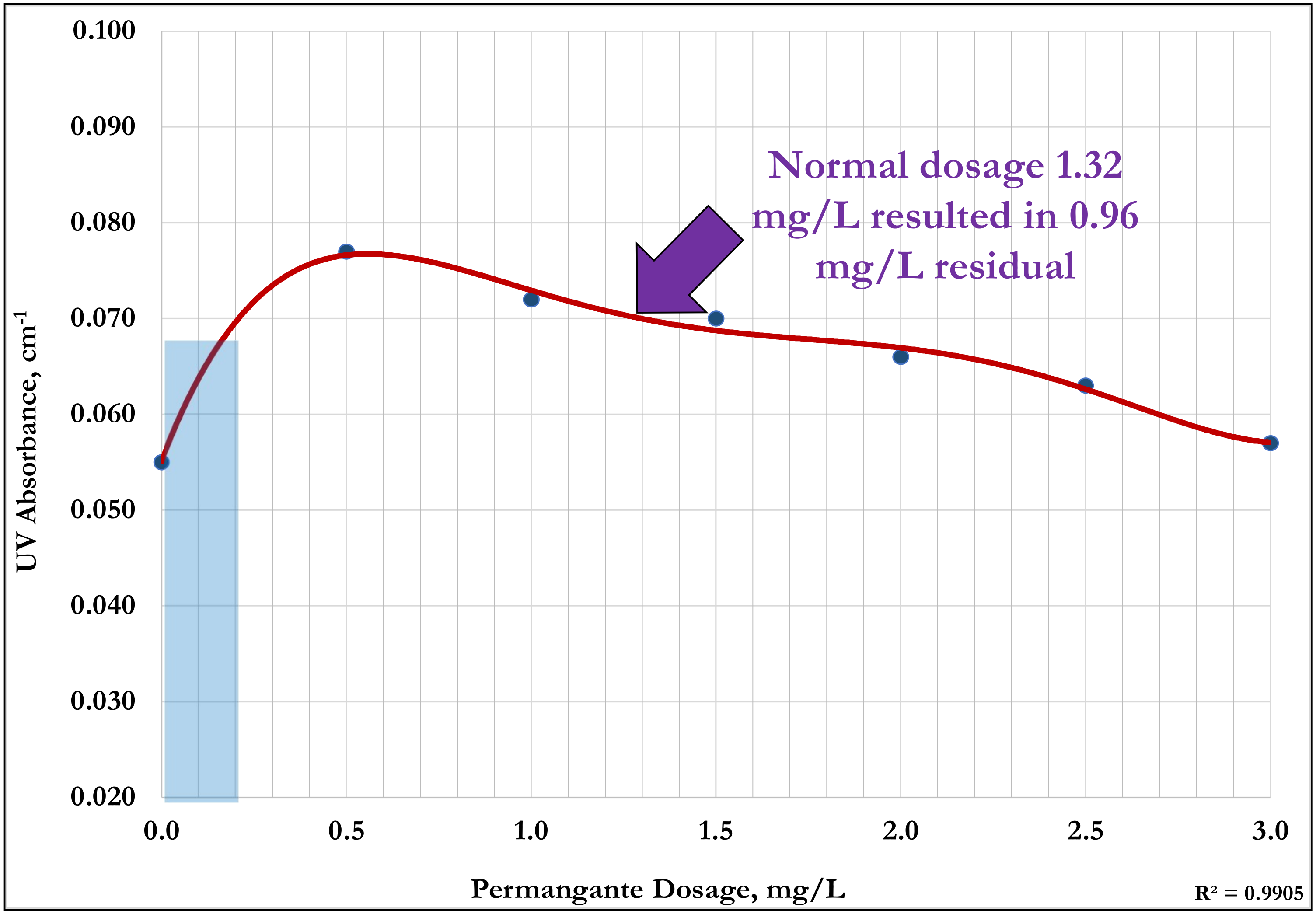
- Demand reactions and residual determinations
  - Enhanced pretreatment techniques
  - Minimize manganese dissolution
  - Maintain effective treatment with seasonal water quality variations
- Microcystin treatment removals
  - Oxidation of microcystin to amino acids
  - Leads to reduction in cyanotoxin levels
  - Target dosage is site-specific



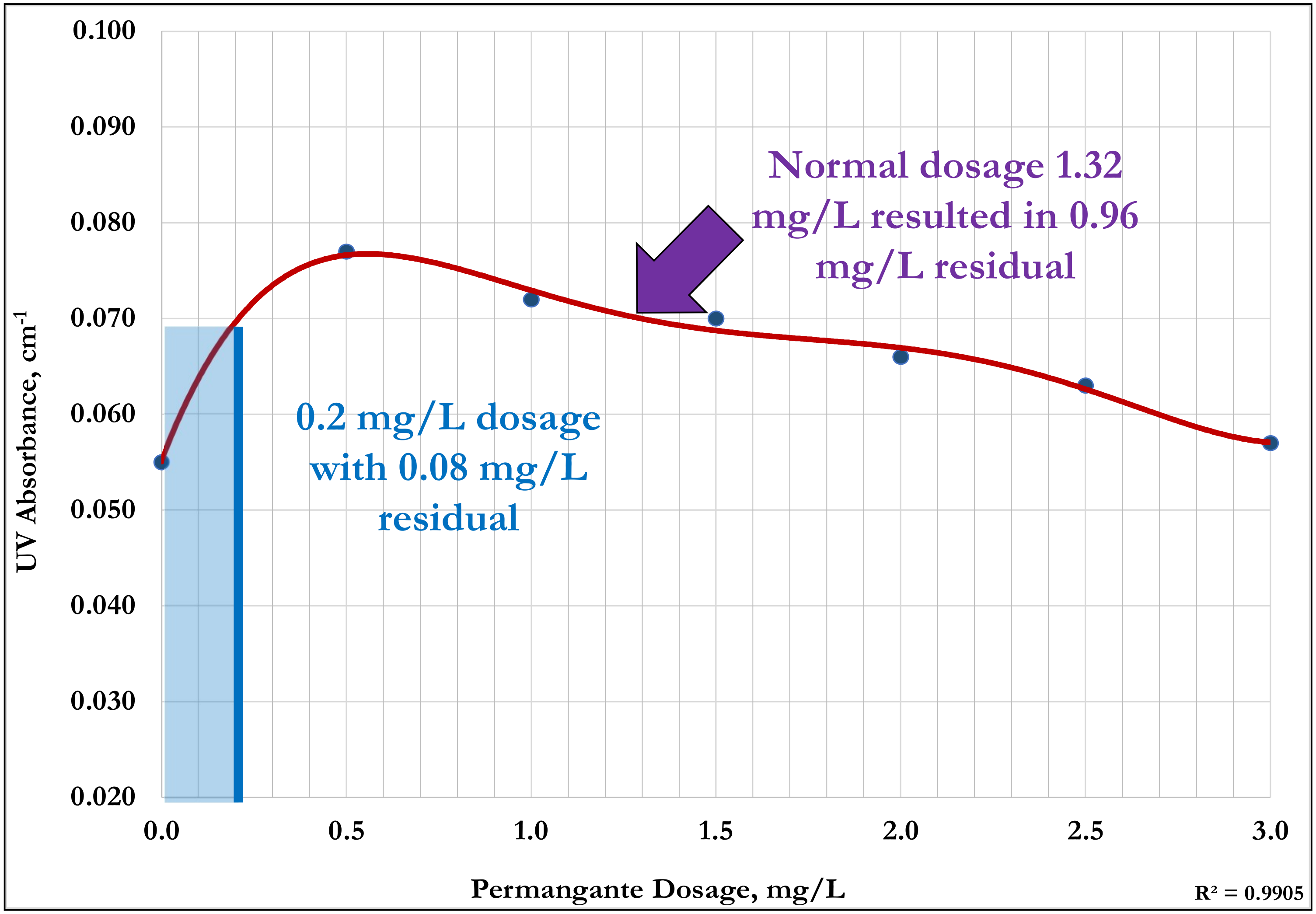
Permanganate Oxidation



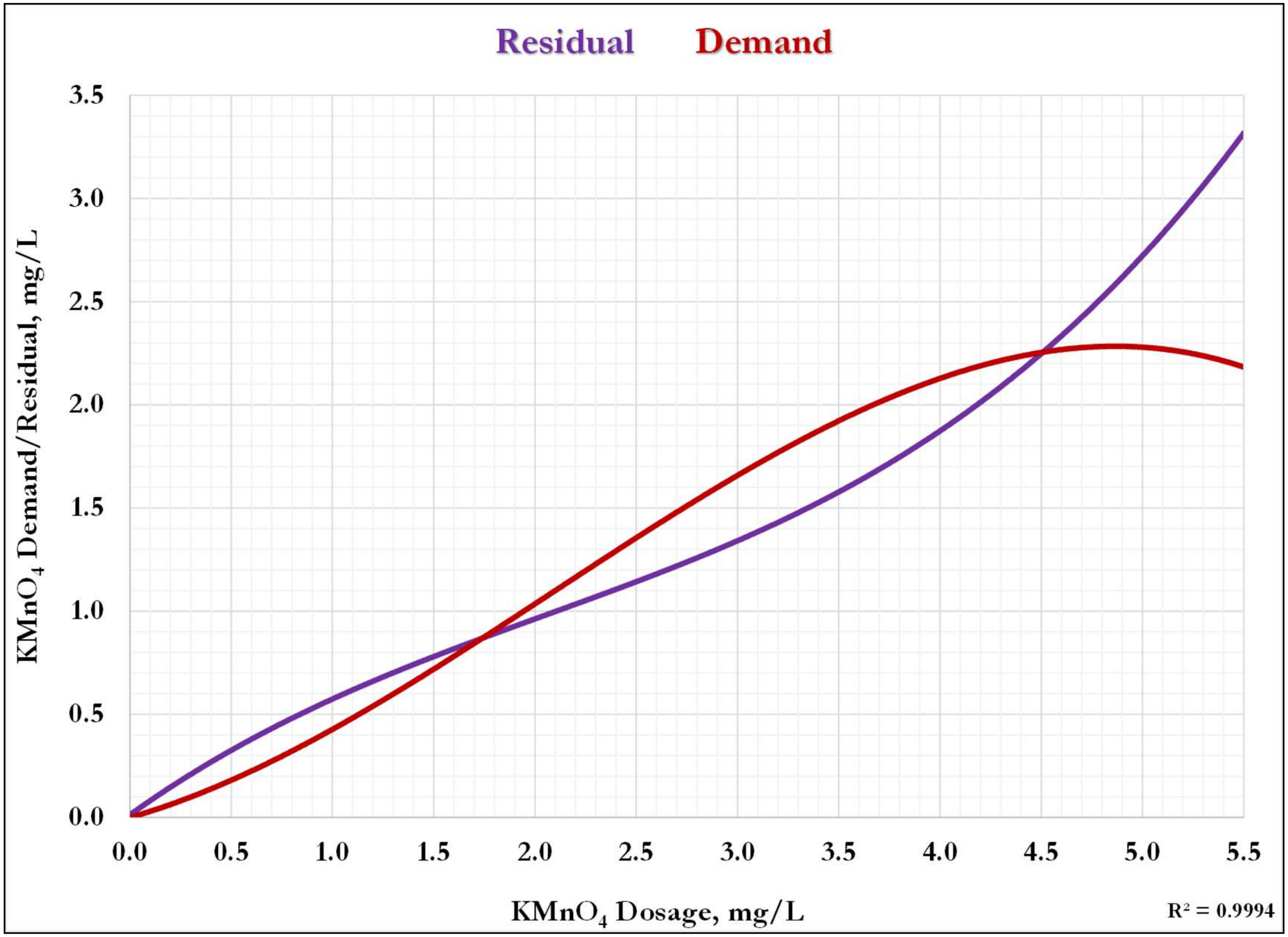
Permanganate Oxidation



Permanganate Oxidation



Permanganate Oxidation



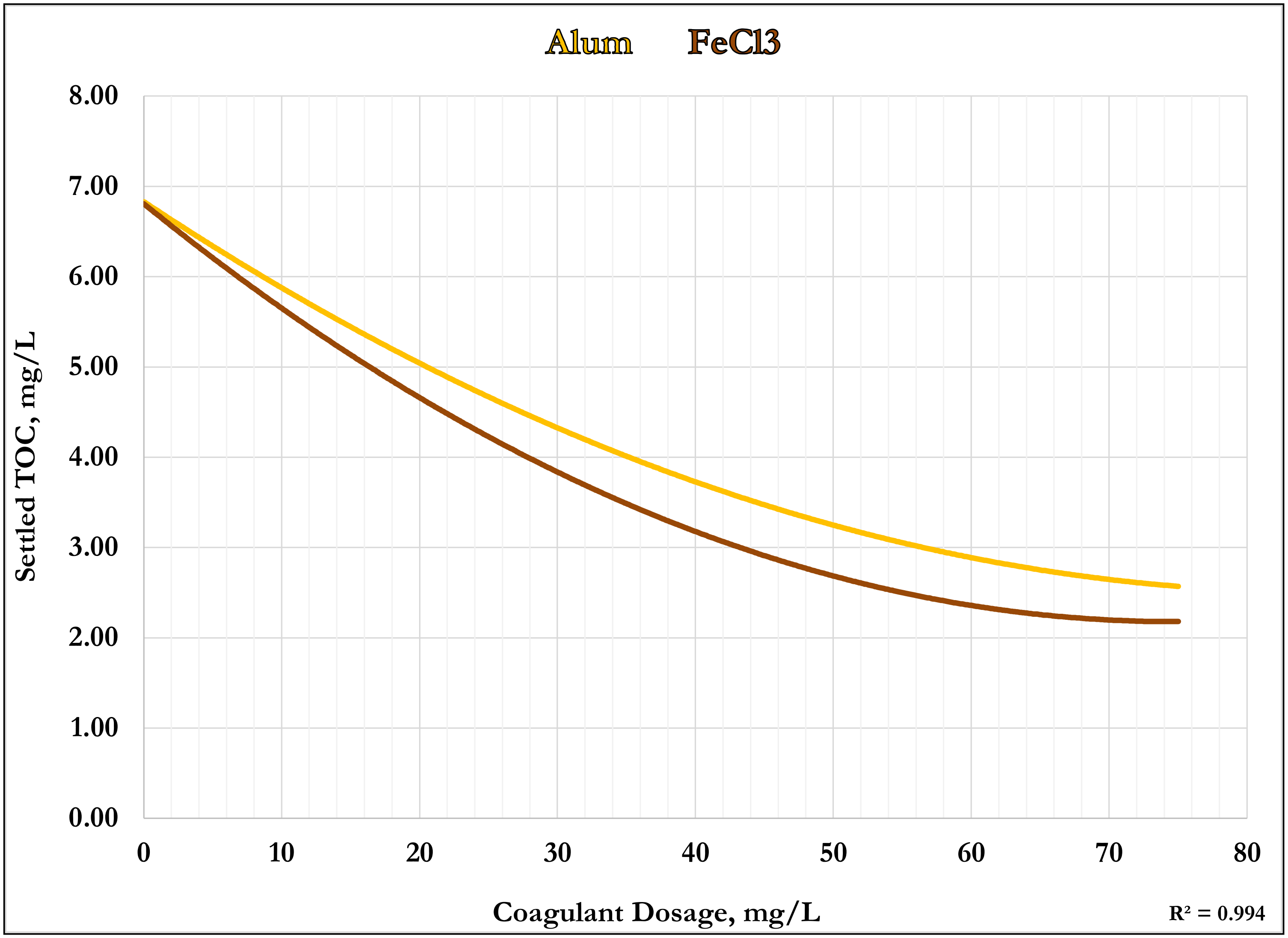
Coagulant Comparisons

- Customary verification of effective chemical dosage
  - Frequency determined by operations experience
  - Meet specific water quality goals
- Alternate coagulants evaluations
  - Compare existing coagulant to alternate coagulant types
    - pH adjustment needs
    - Turbidity control
    - Organics removals
    - DBP formation potentials
    - Solids production

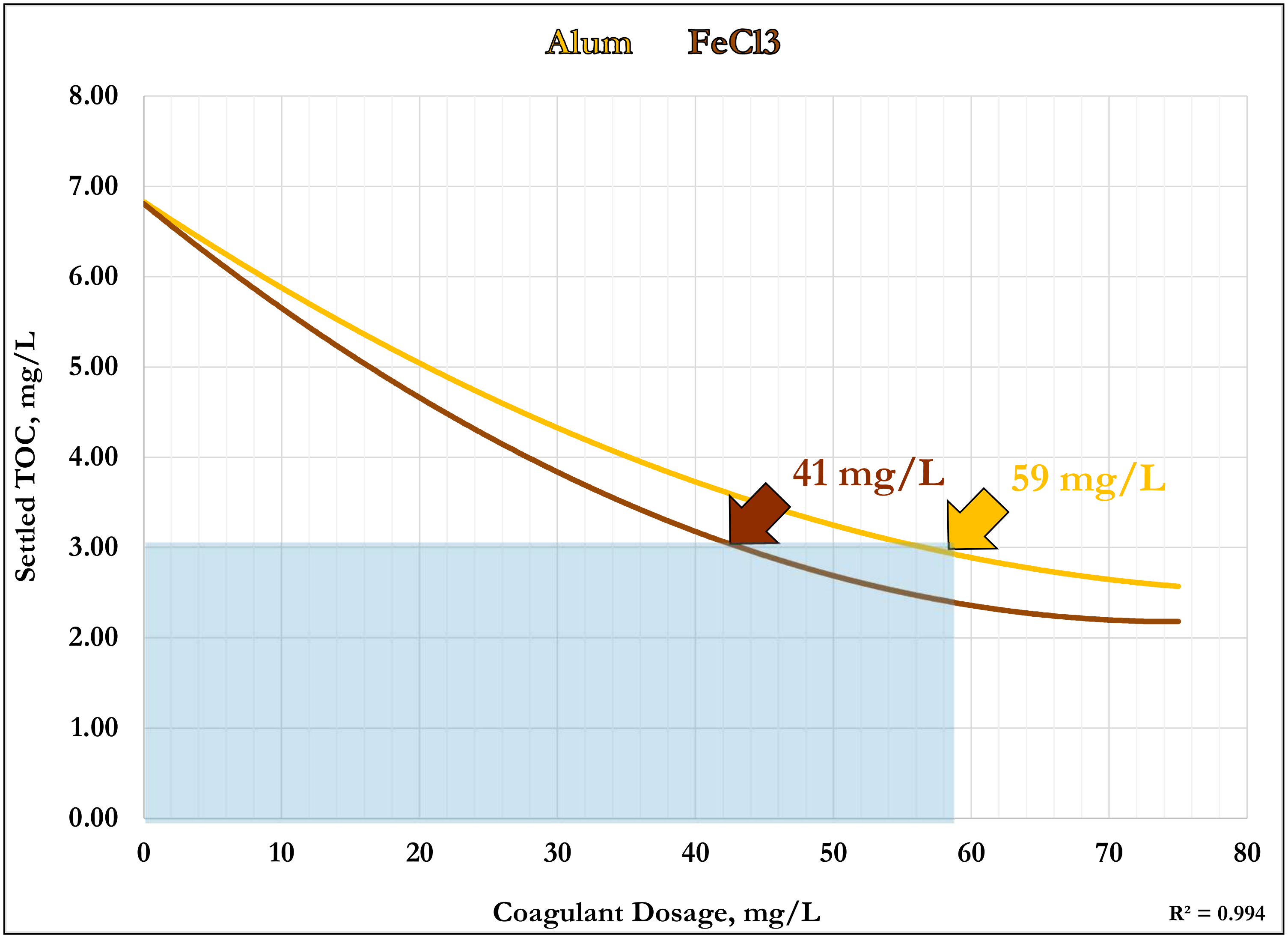

Coagulant Comparisons

- Compare polymer treatment benefits and dosing
  - Check for organics increase or decrease
    - Polymers are generally organic material
    - Wrong polymer can add TOC back into water

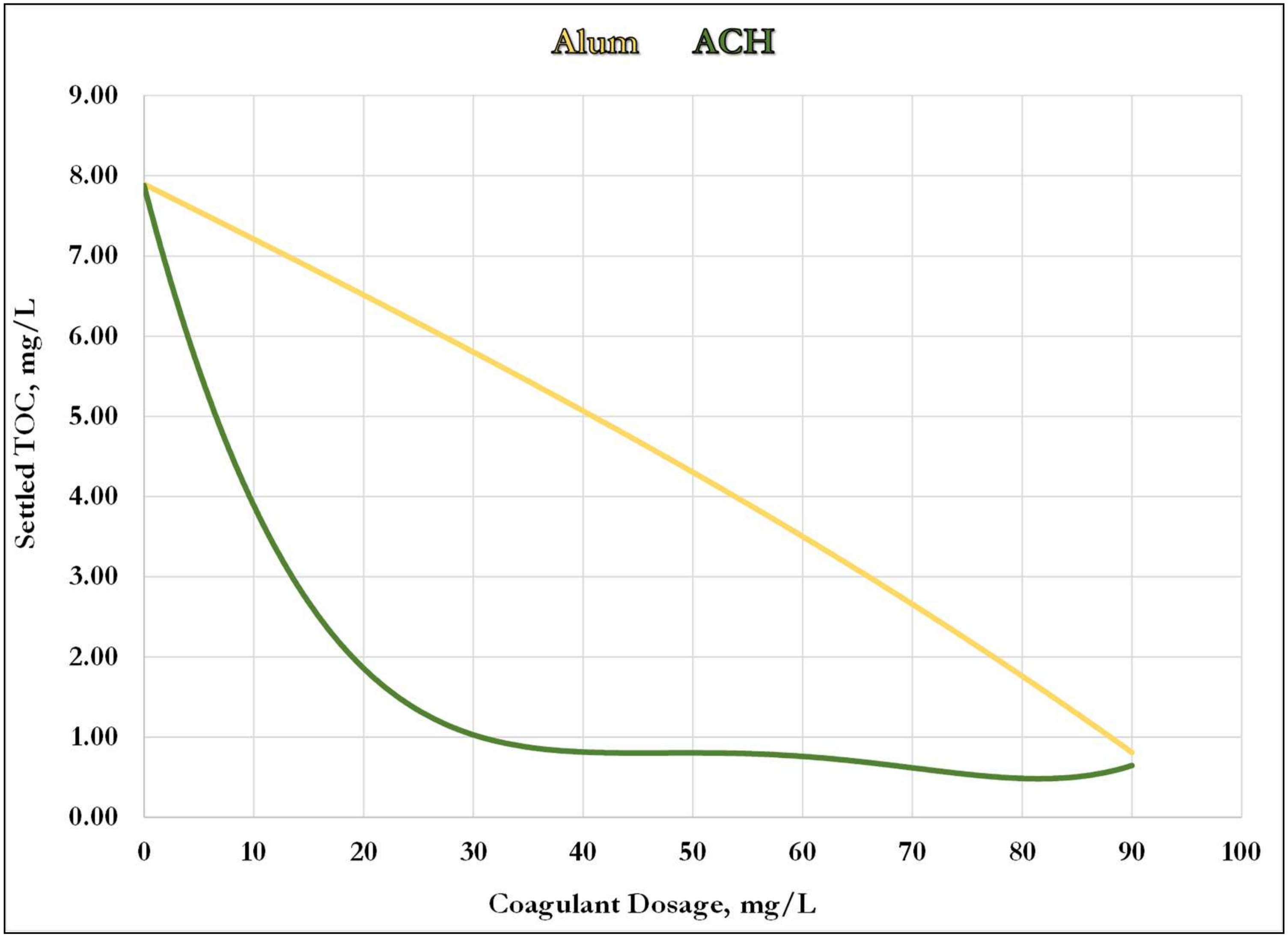
Coagulant Comparisons



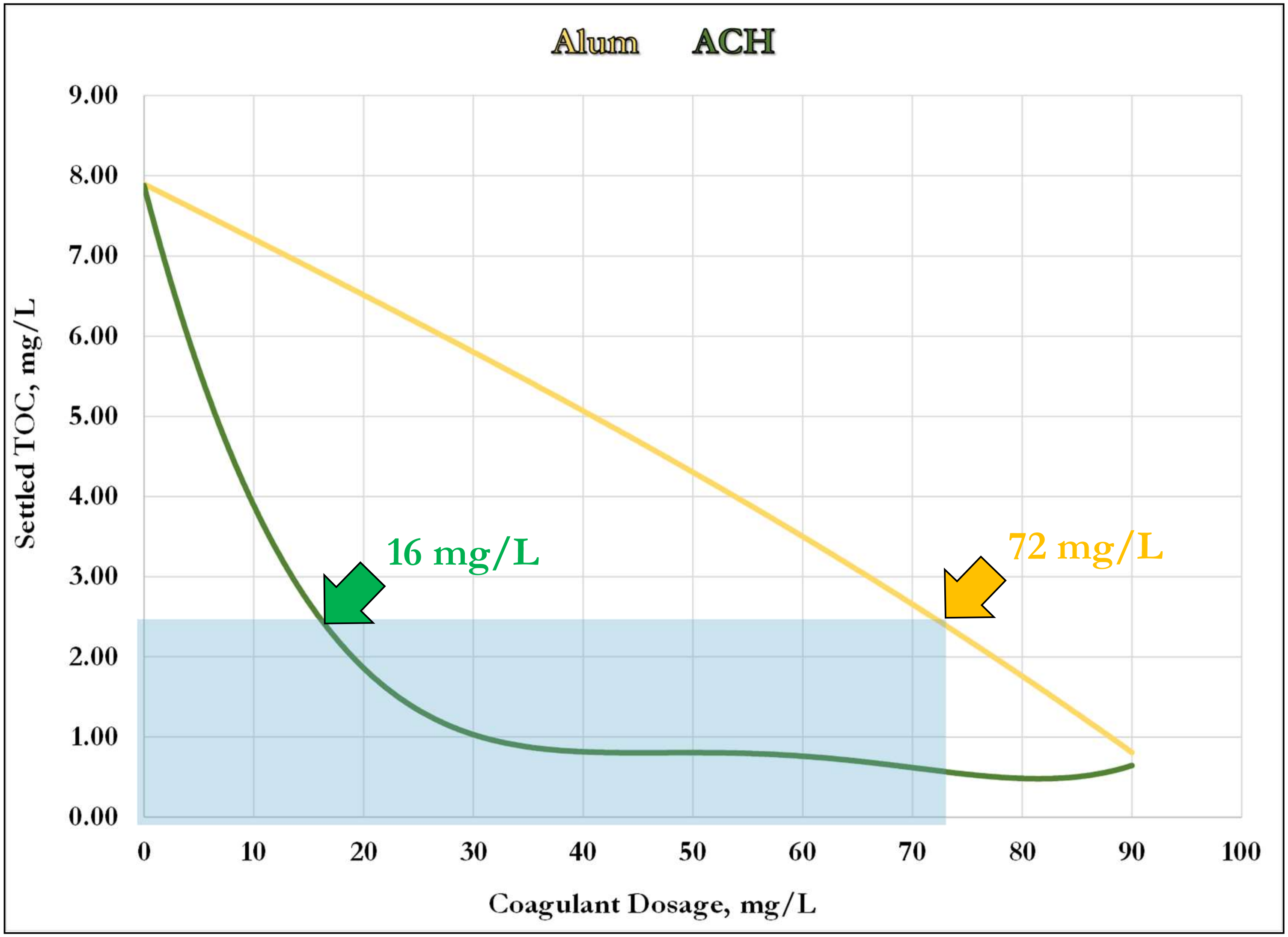
Coagulant Comparisons



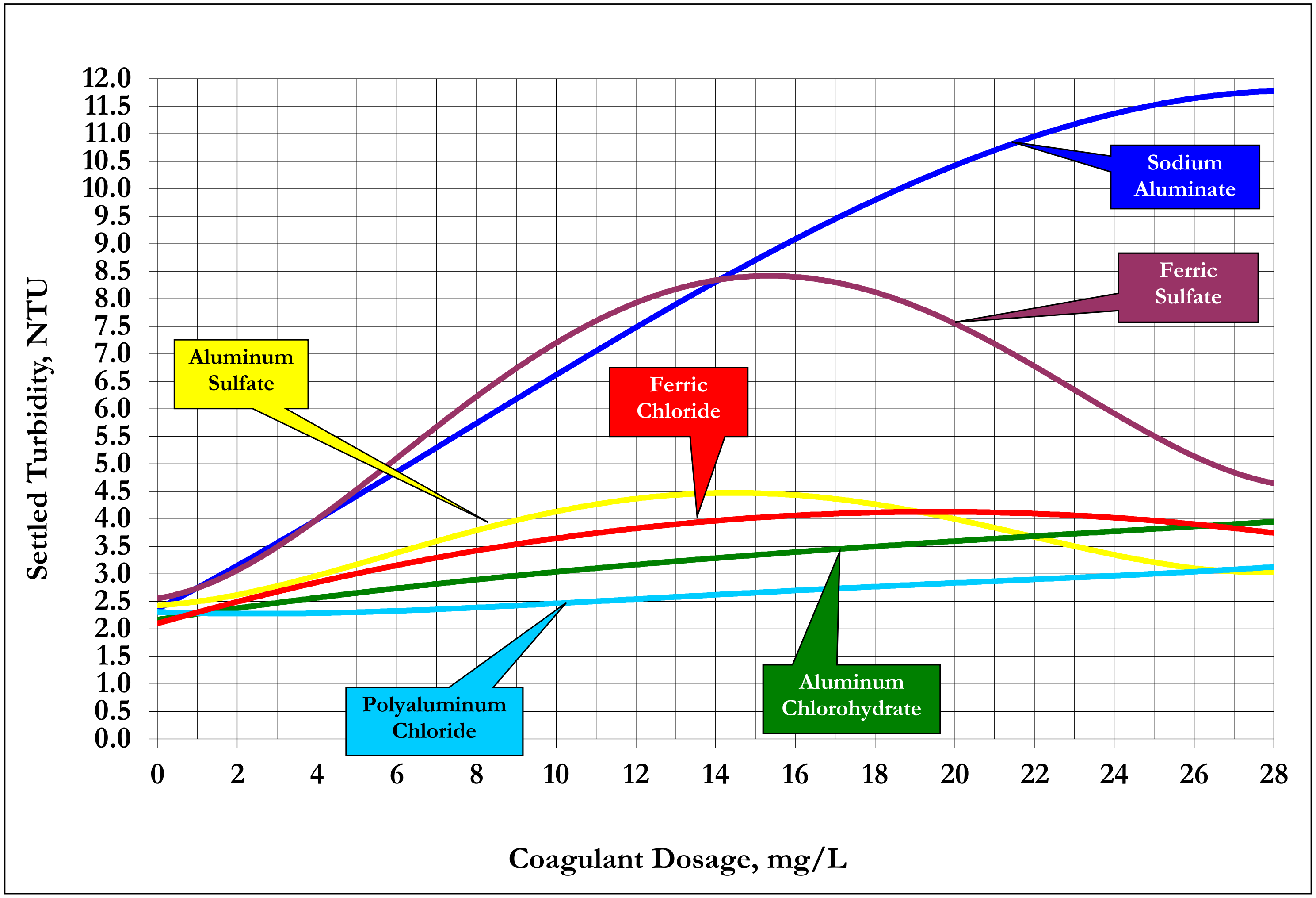
Coagulant Comparisons



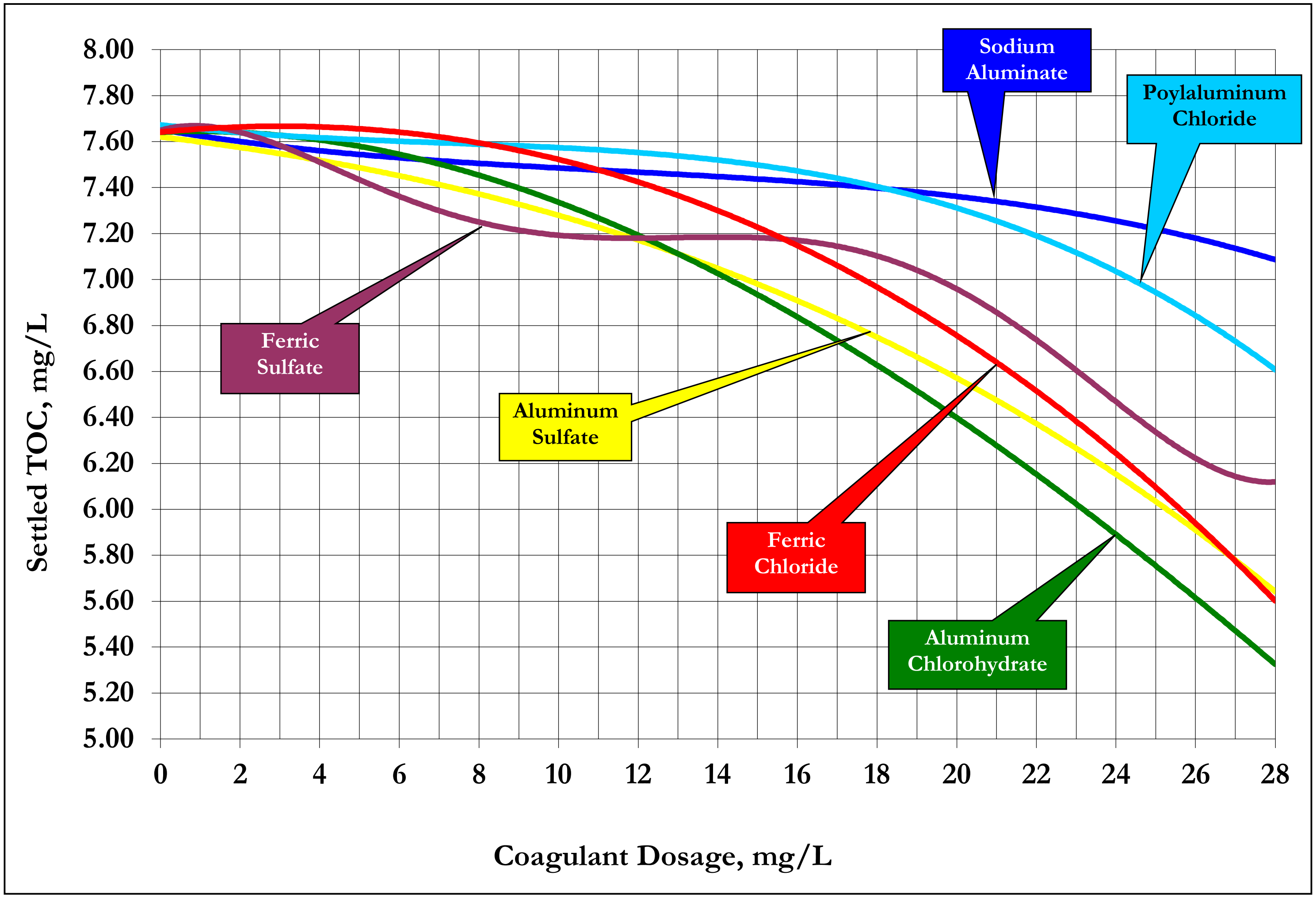
Coagulant Comparisons



Coagulant Comparisons

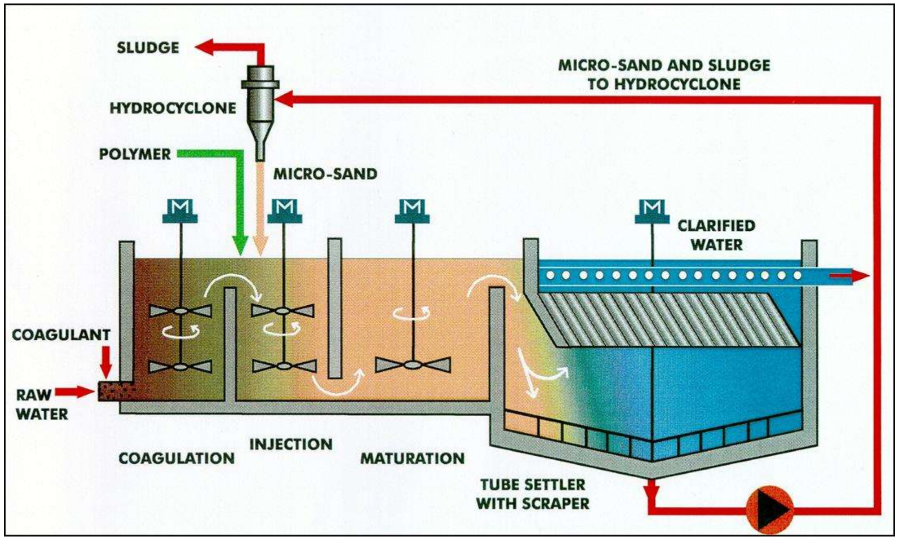


Coagulant Comparisons



High-rate Clarification Simulations

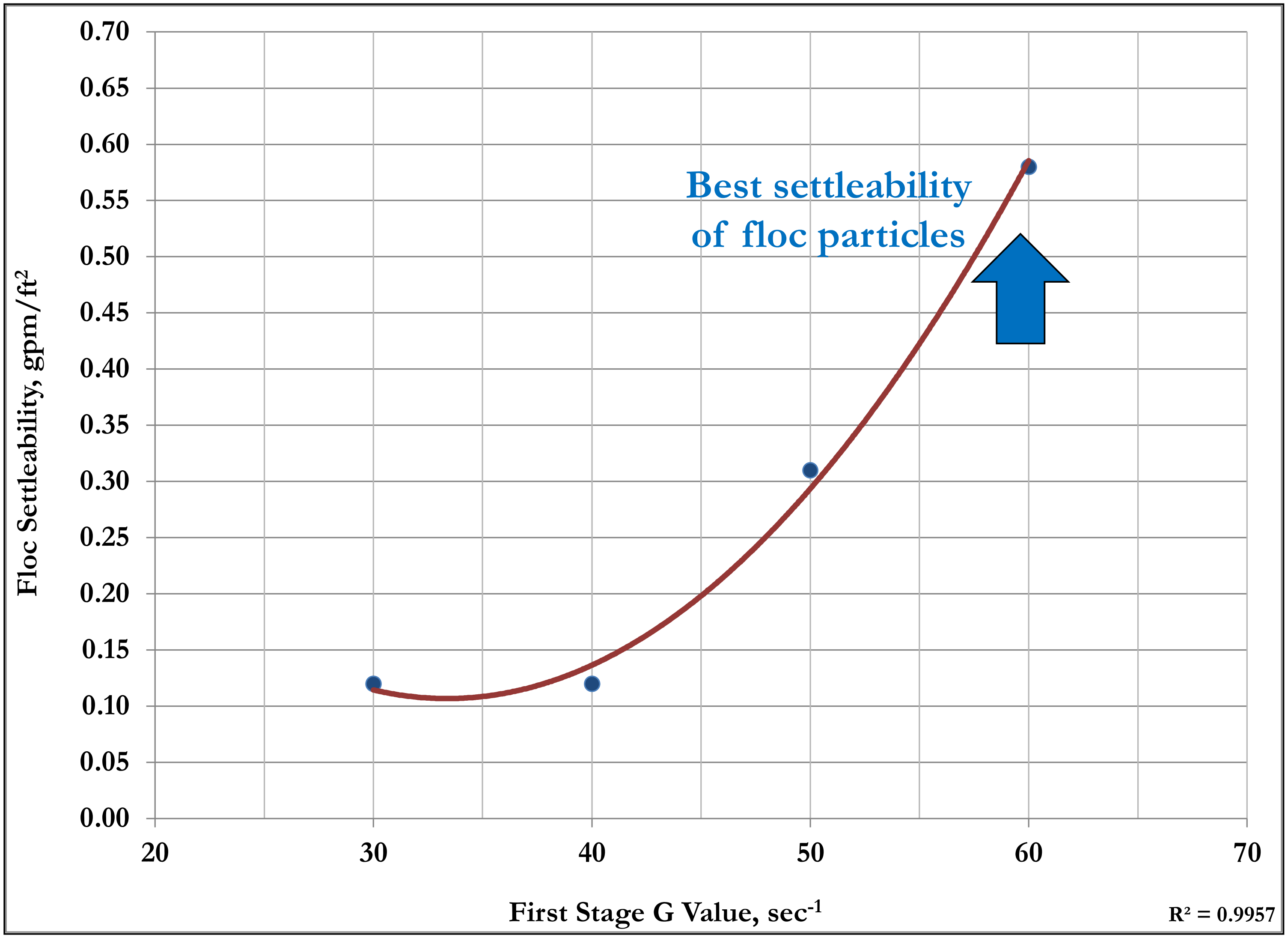
- Actiflo™ process treatment simulations
  - Coagulant, polymer, micro sand
  - Overflow rates up to 20 gpm/ft^2
  - Microsand added to coagulation
    - 4 g/L to 8 g/L dosing typical
    - Significant increase in floc density
    - Very high floc settling rates



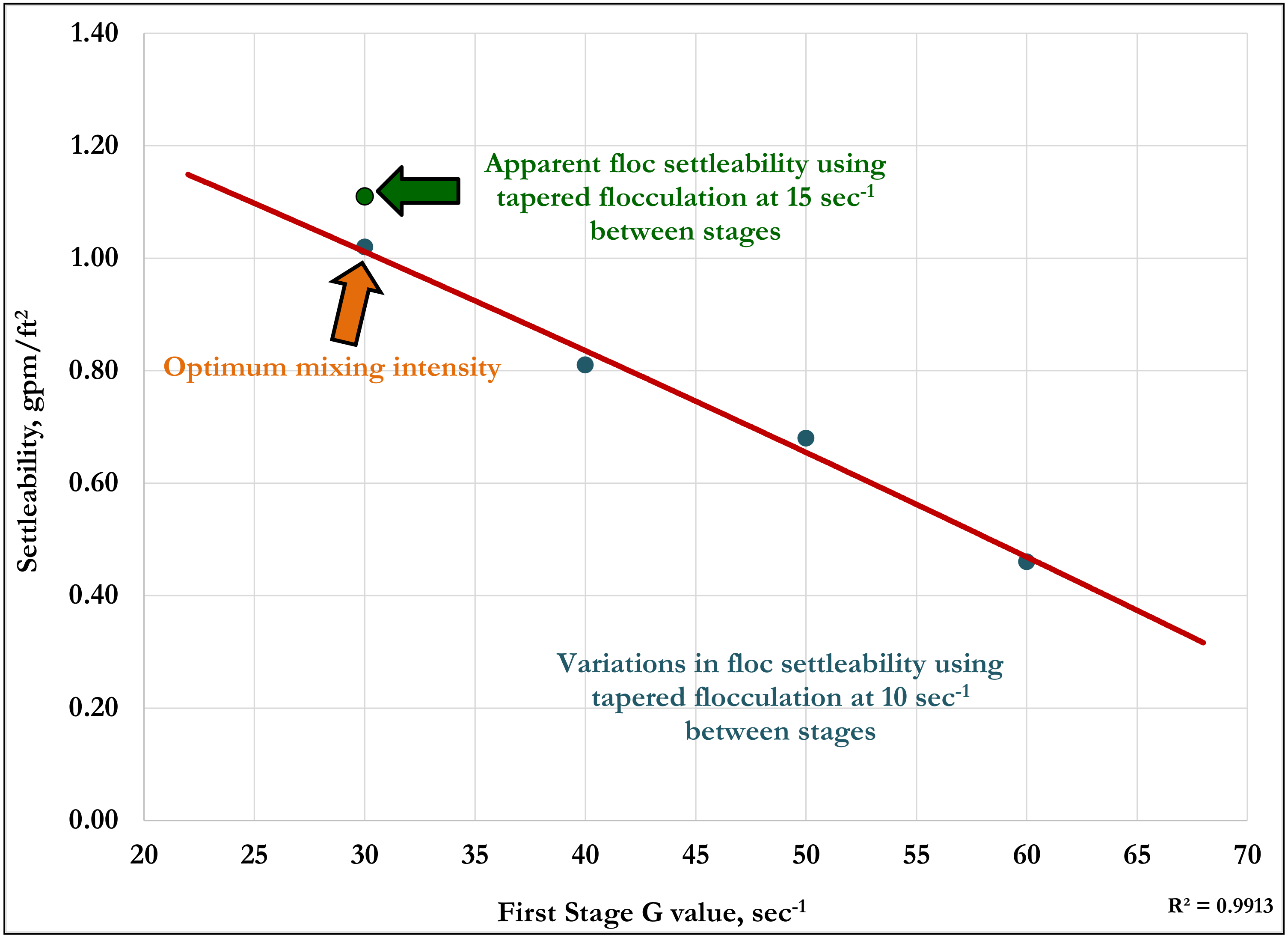
Flocculator Optimization

- Jar testing used to define optimum mixing conditions and G values
  - Existing coagulant dosage
  - Vary mixing speeds (G values)
  - Measure floc settling rate
  - Compare results

Flocculator Optimization



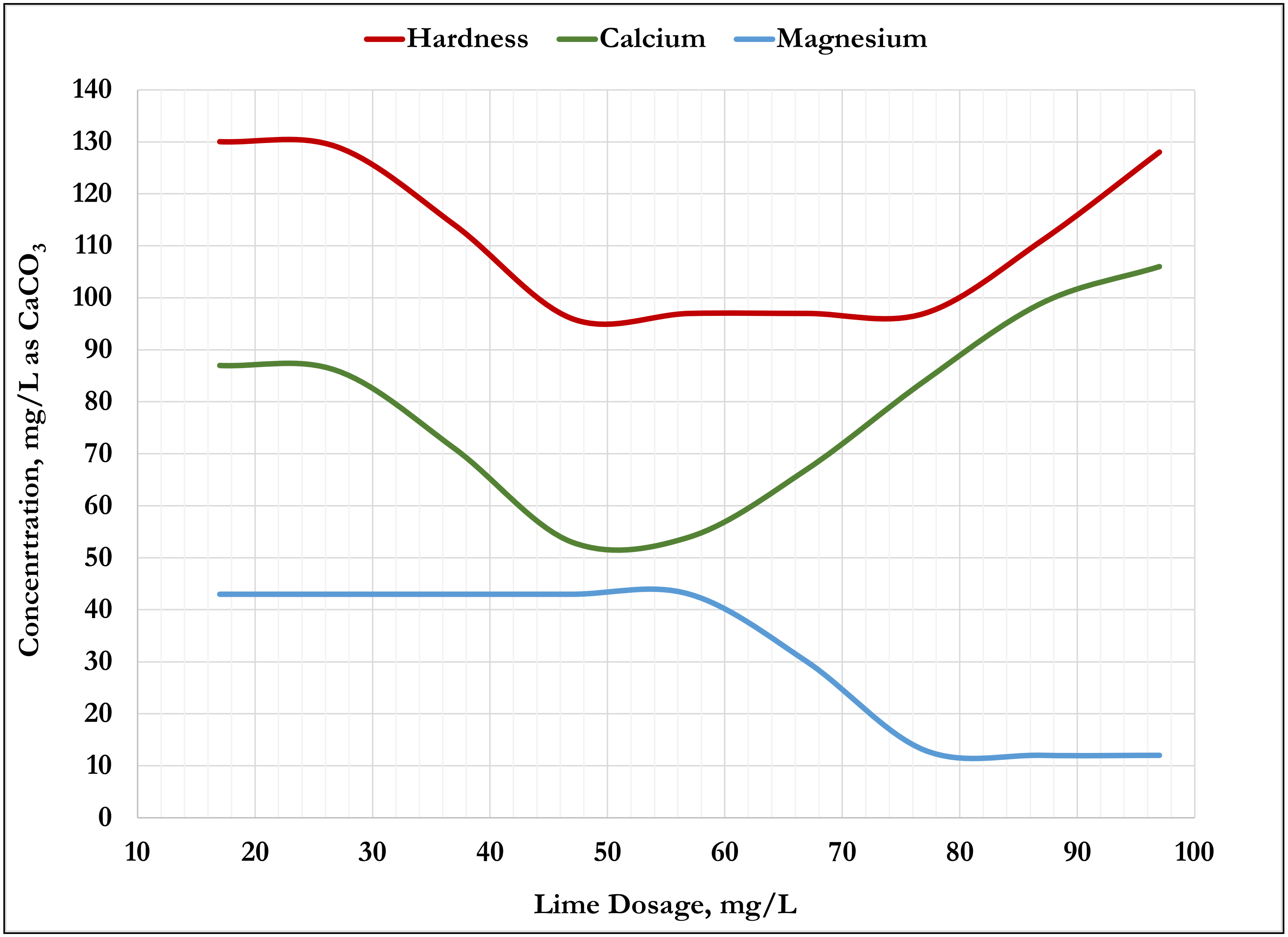
Flocculator Optimization



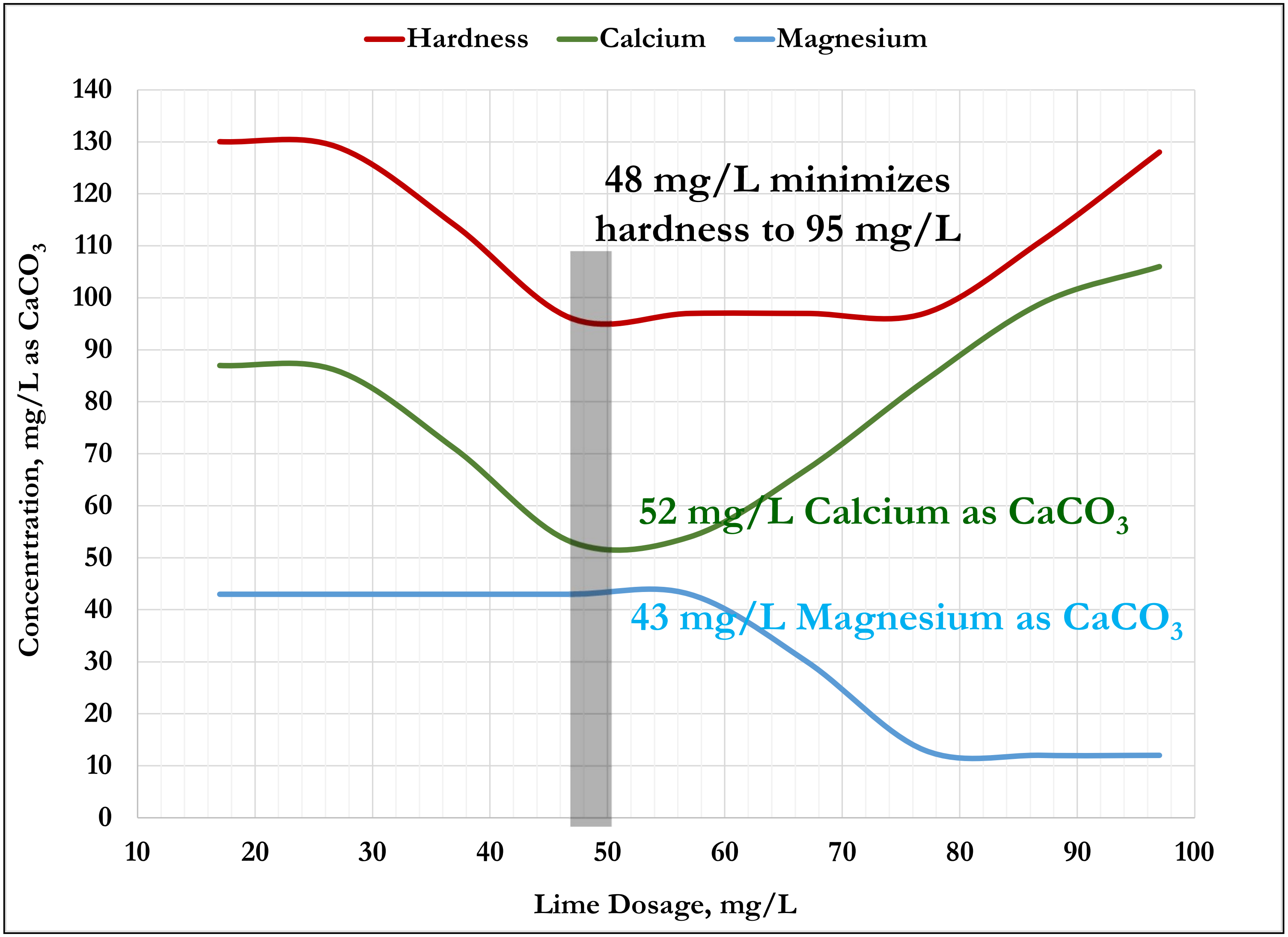
Softening Optimization

- General hardness goal
  - 140 mg/L to 150 mg/L
- Alkalinity needed for corrosion control
  - 50 mg/L to 80 mg/L
- Adjust lime dosage to achieve hardness goals
  - Verify with jar testing without compromising water quality

Softening Optimization



Softening Optimization



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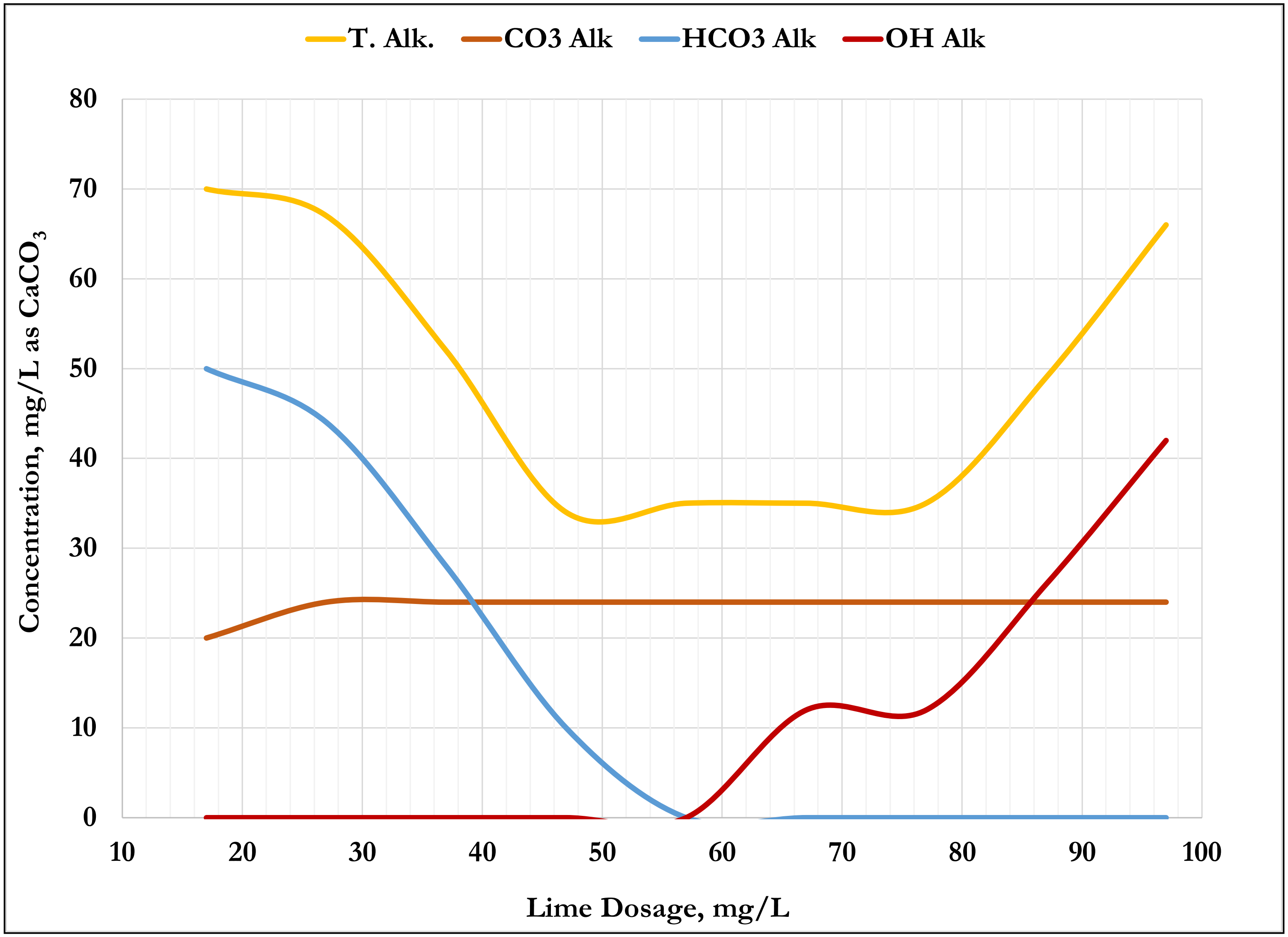

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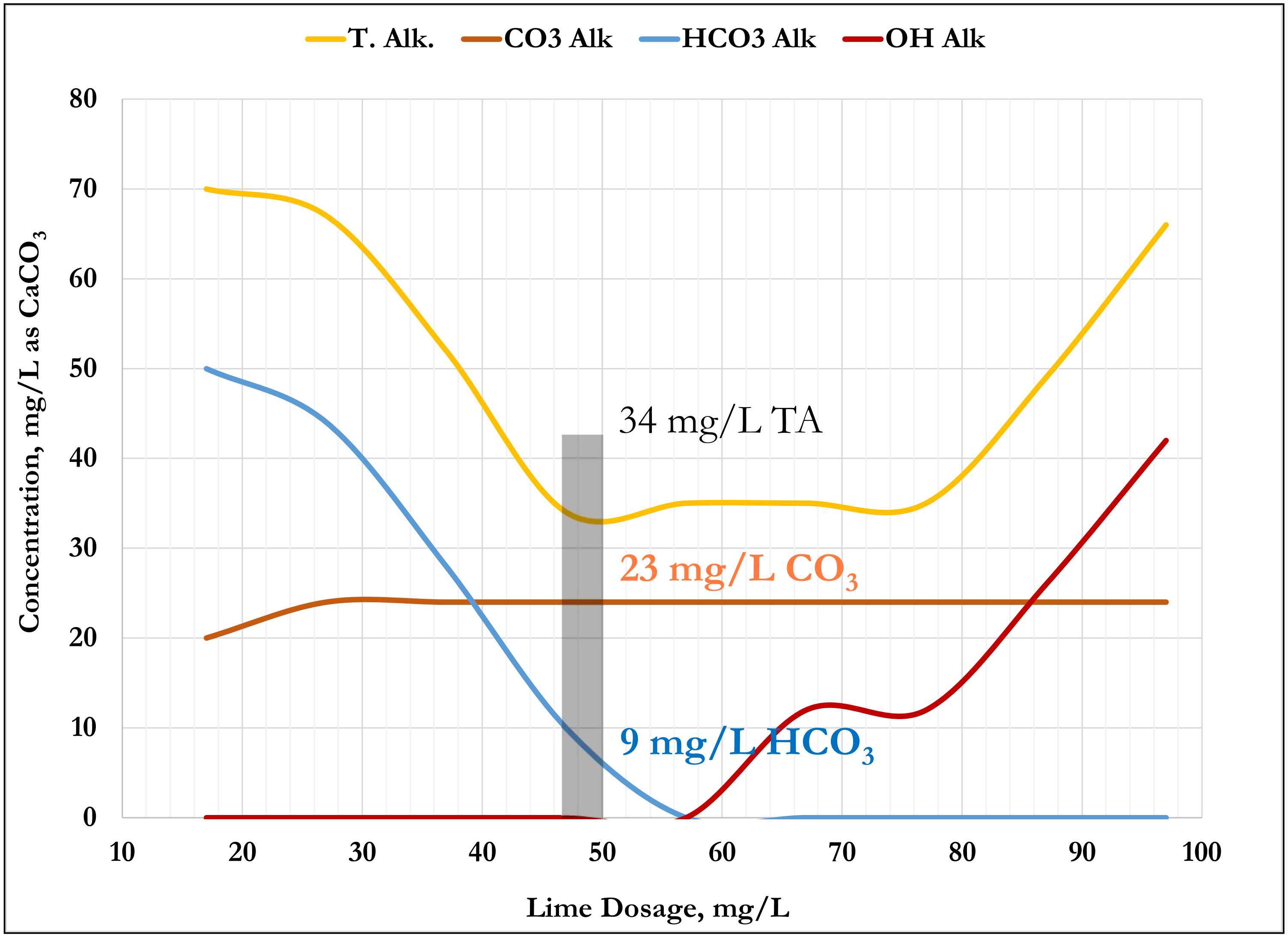

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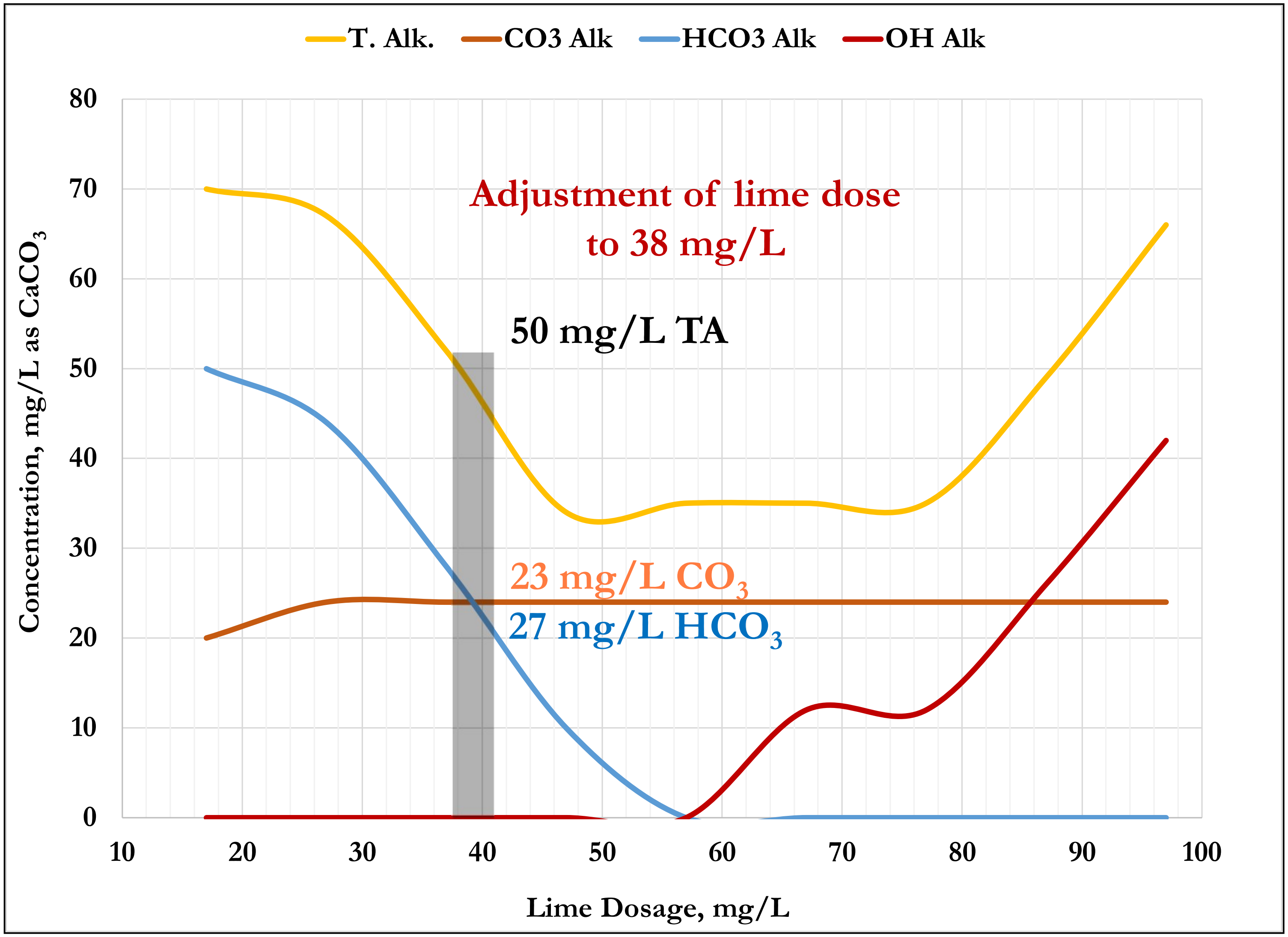

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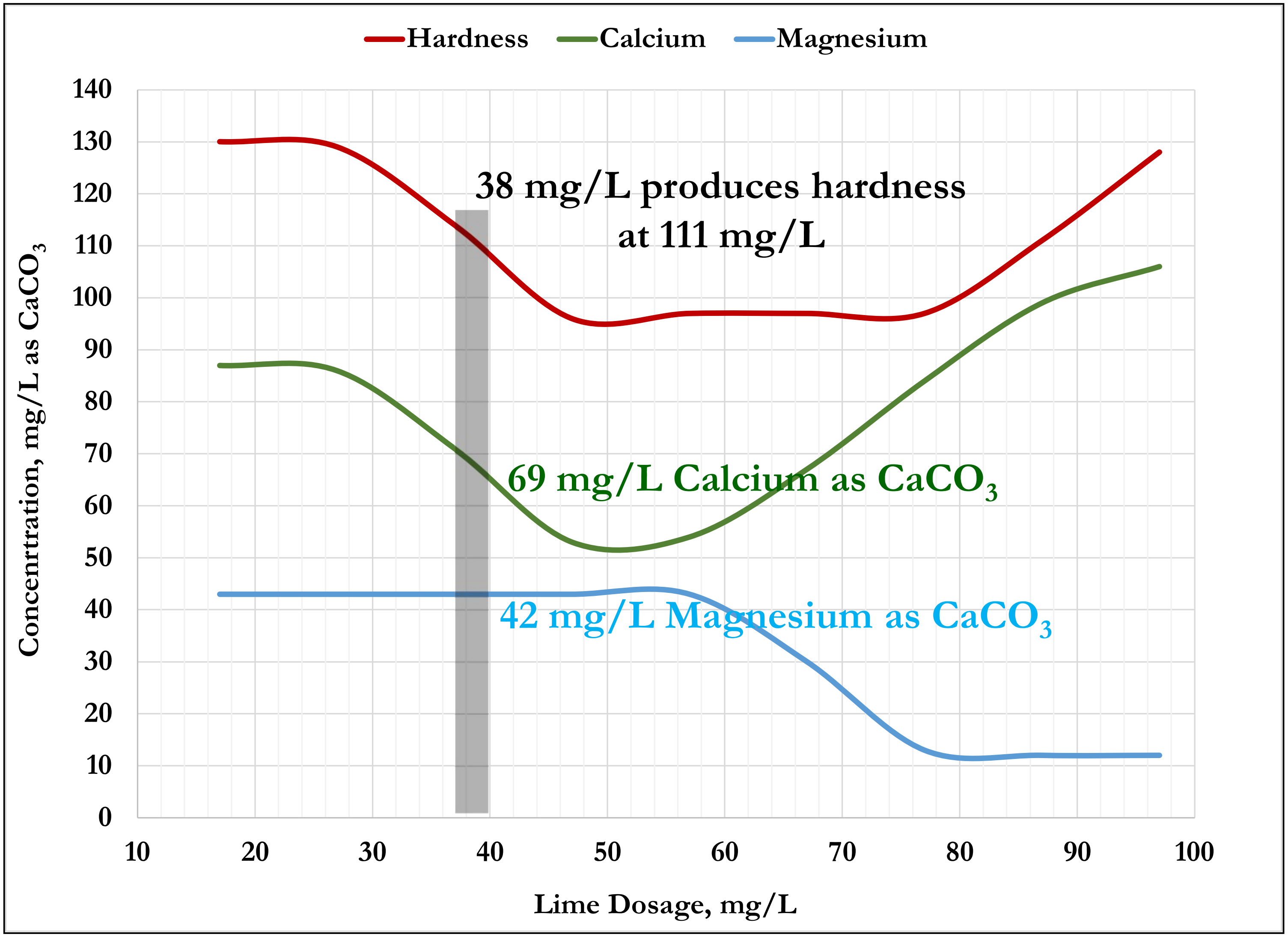
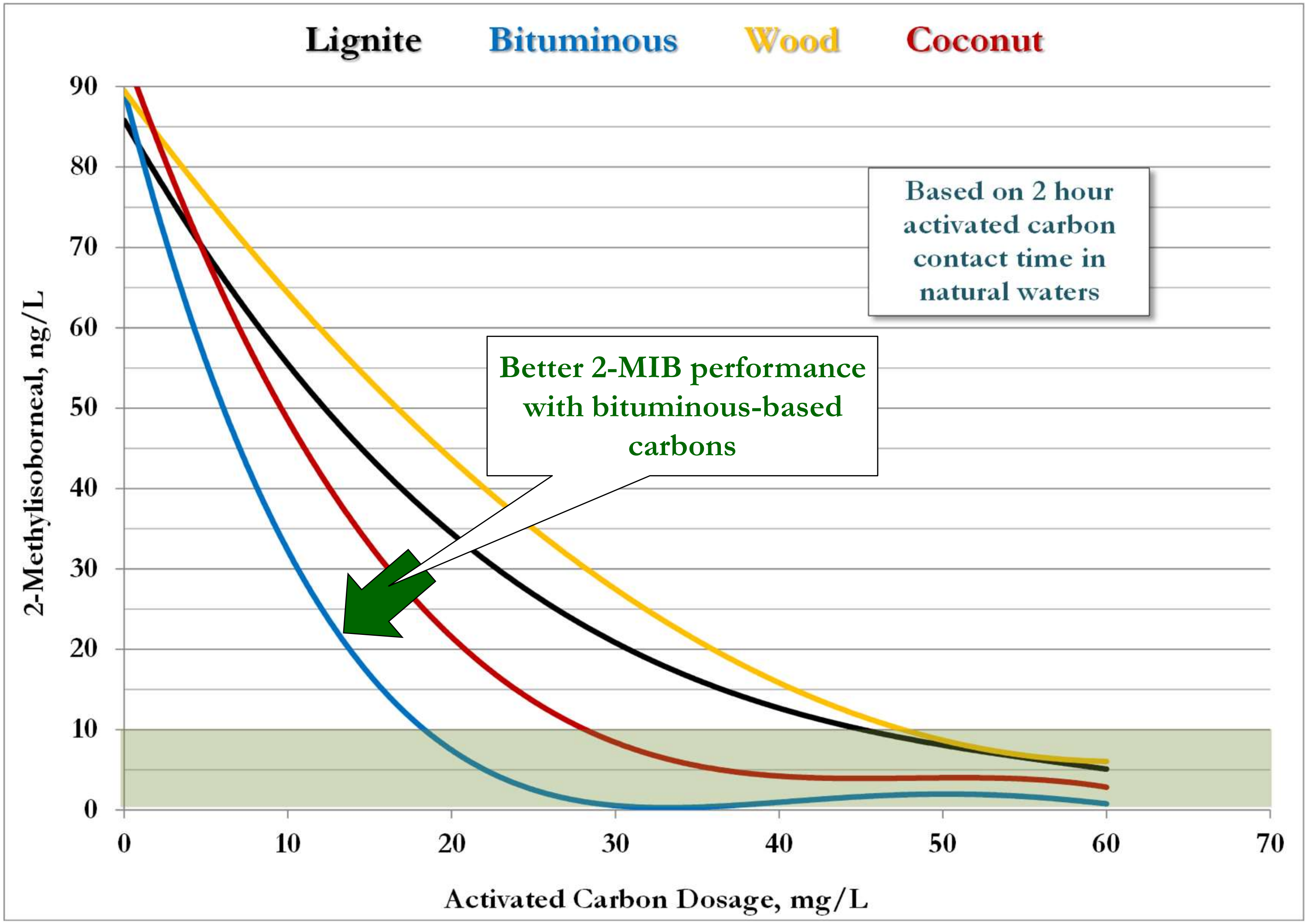


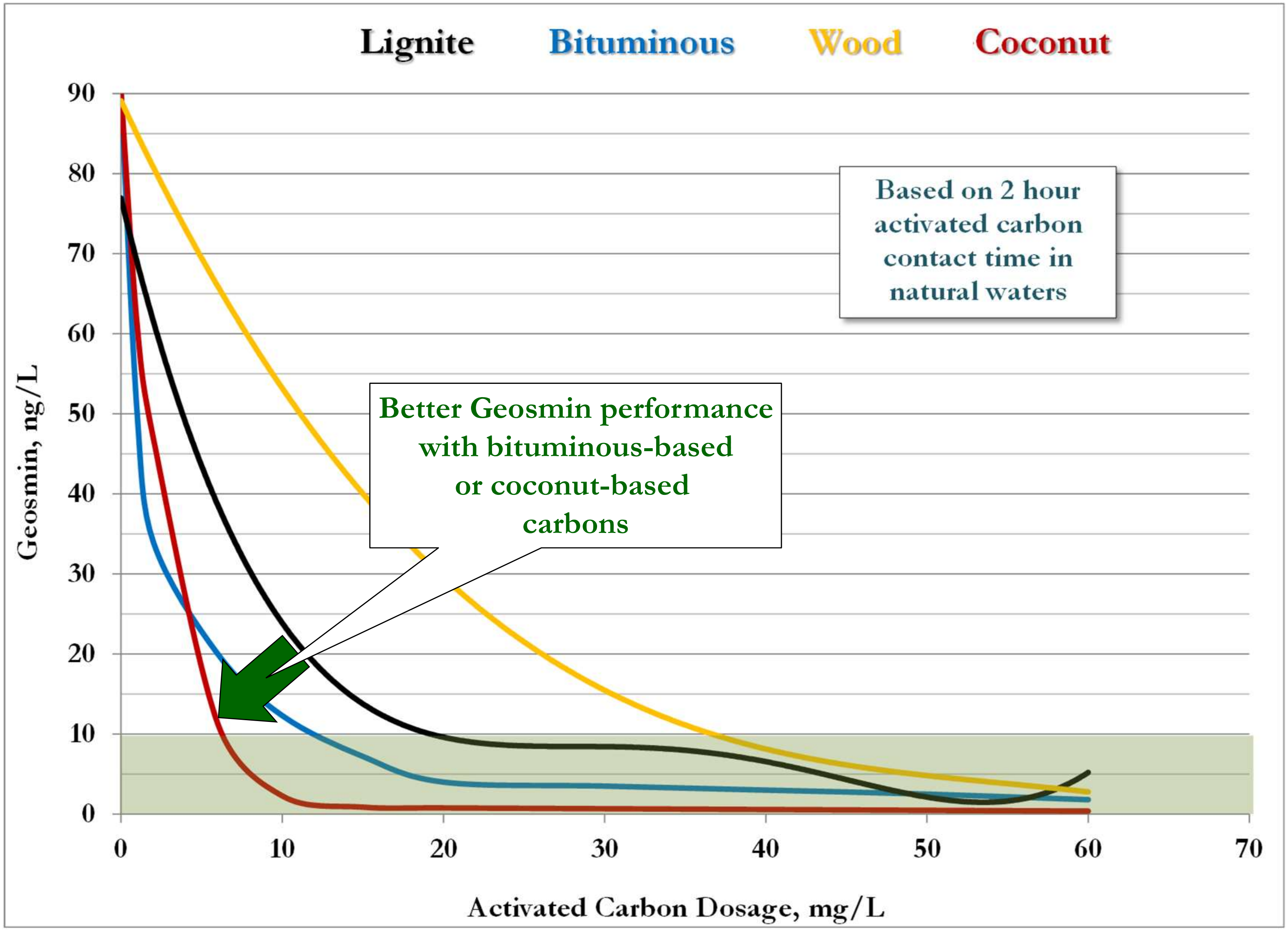
Carbon Adsorption Studies

- Generally, tastes and odor control or TOC reduction
  - Powdered carbon can be used in jar testing easily
  - Carbon slurry mixed for 60 minutes to displace air from carbon pores
  - Vary dosages accordingly
    - 3 mg/L to 50 mg/L for T/O issues common
    - May need longer detention time for some T/O
  - Compare results

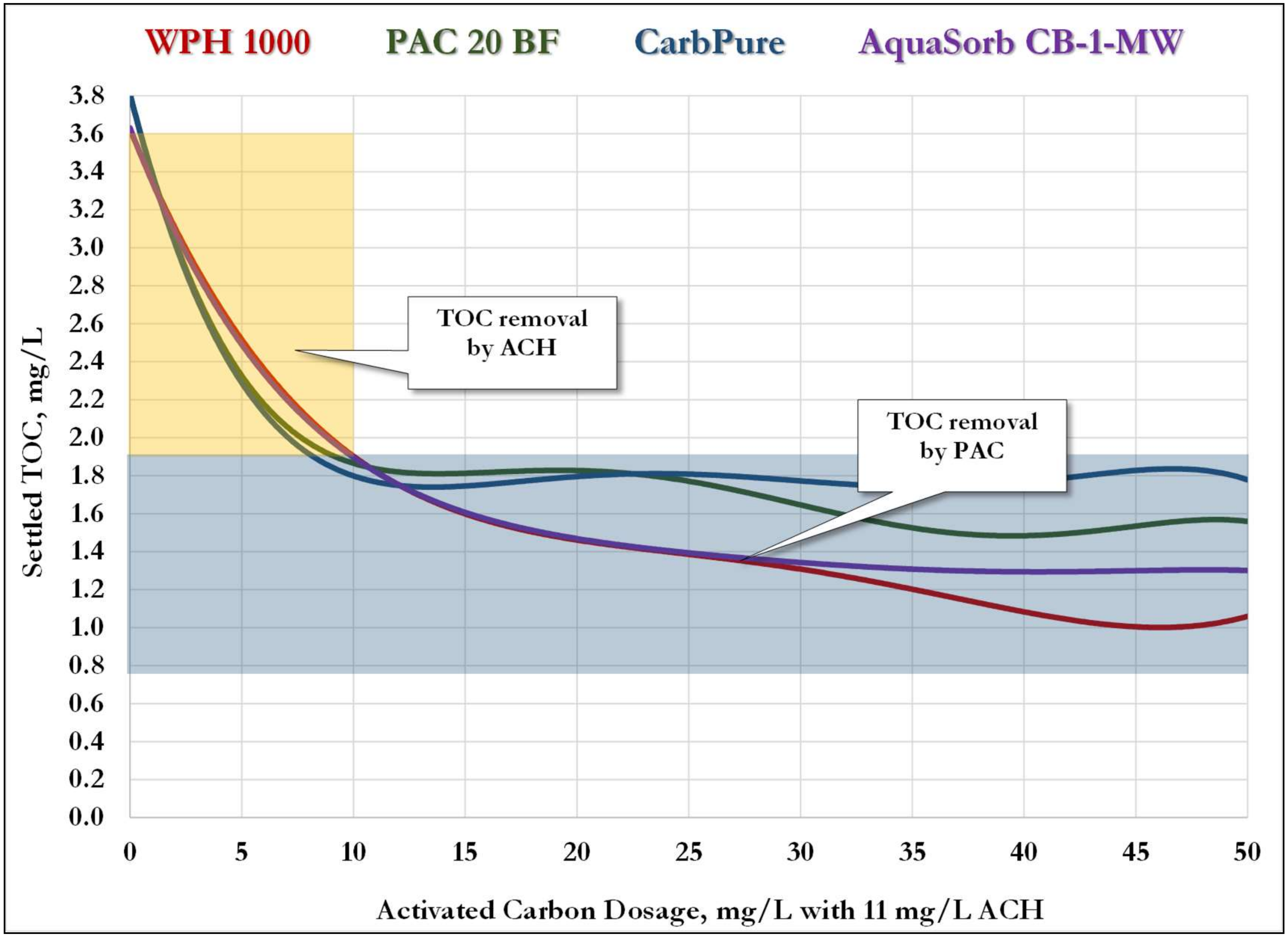
Carbon Adsorption Studies



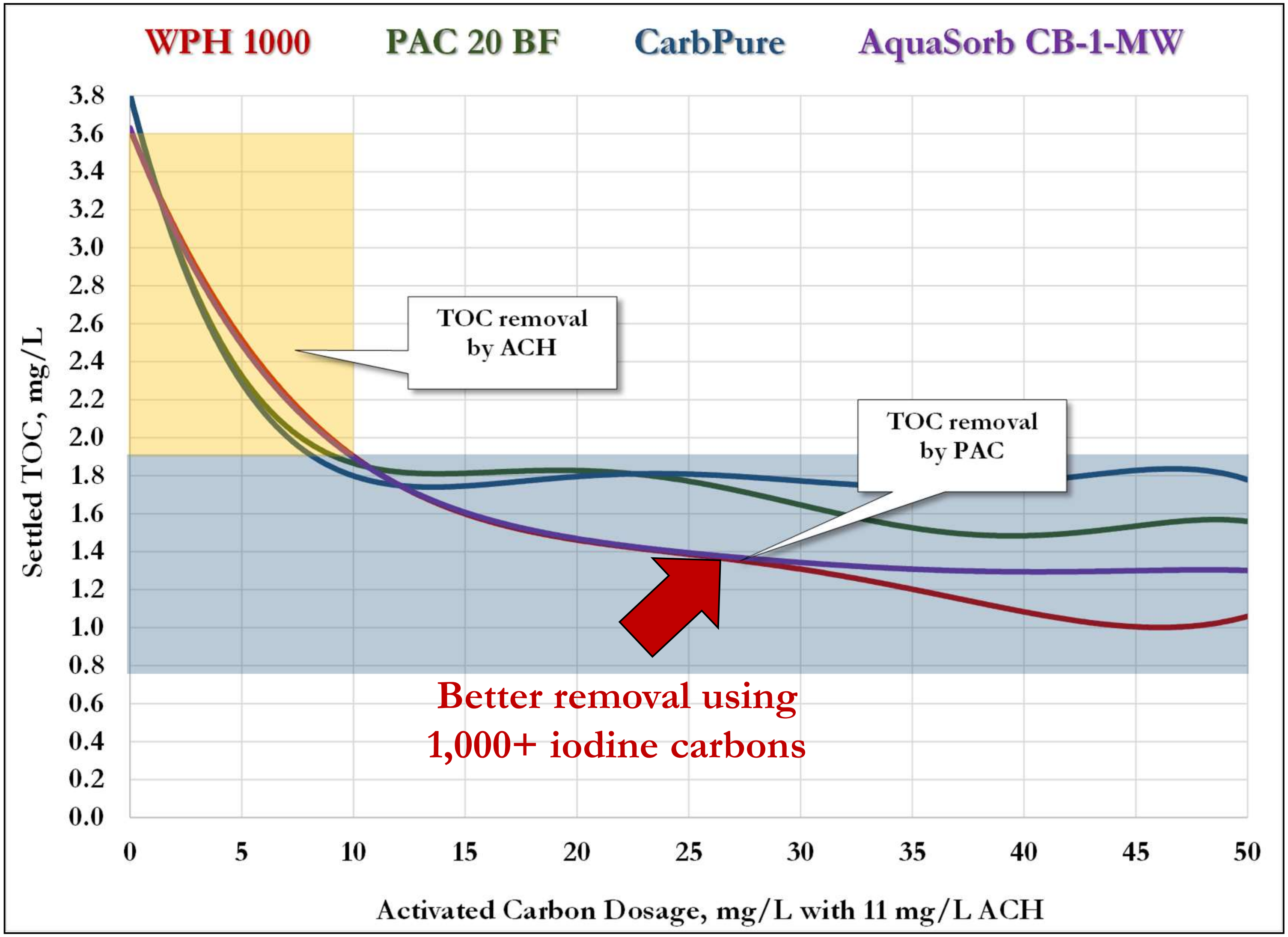
Carbon Adsorption Studies



Carbon Adsorption Studies

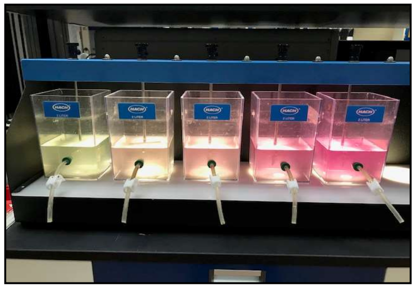


Carbon Adsorption Studies



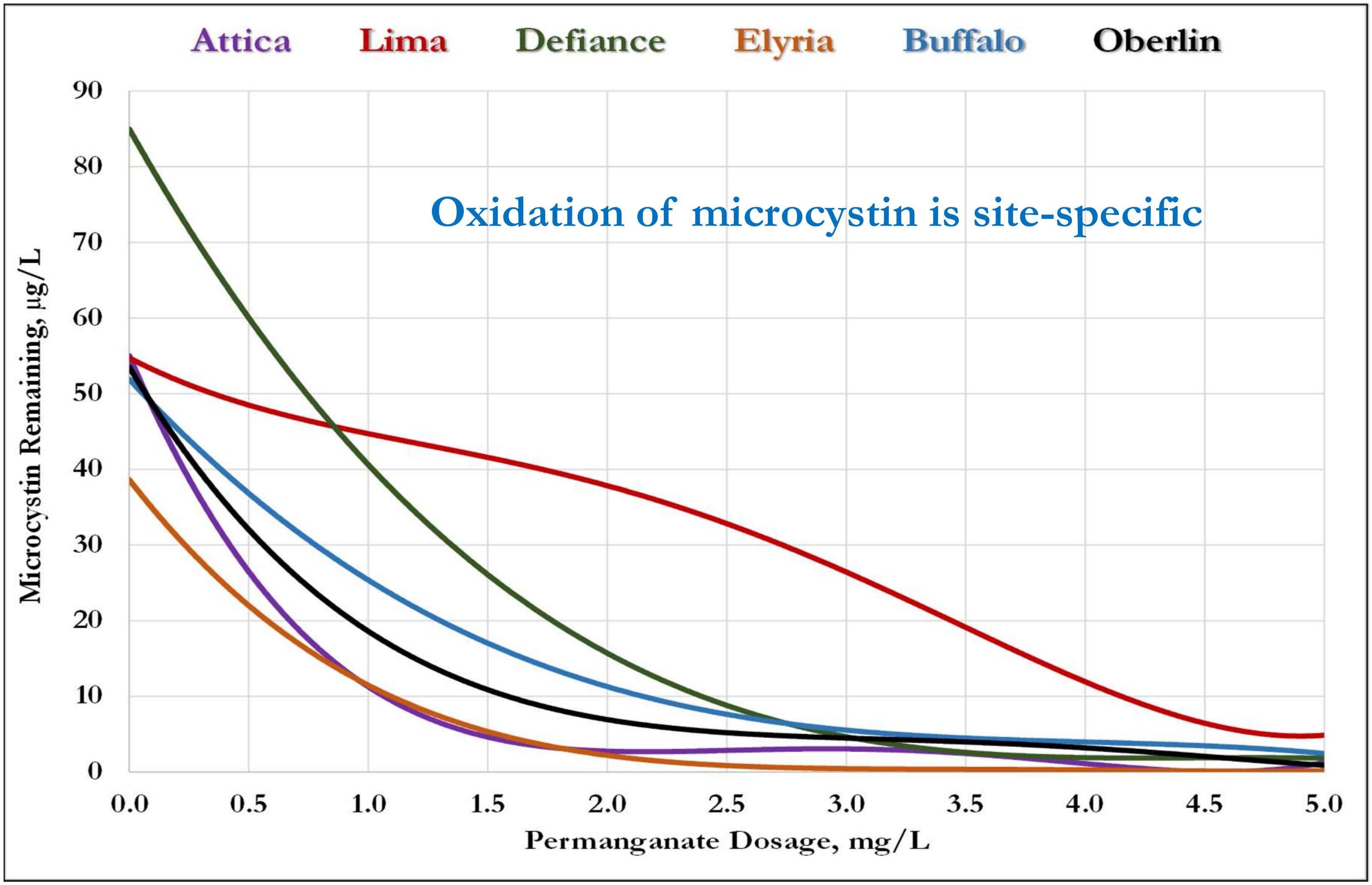
Cyanotoxin Treatment Strategies

- Can define oxidation strategies and adsorption strategies
  - Jar testing with microcystin spiked water samples
- Permanganates oxidize microcystins easily
  - Site-specific dosages
  - Potassium usually better than sodium

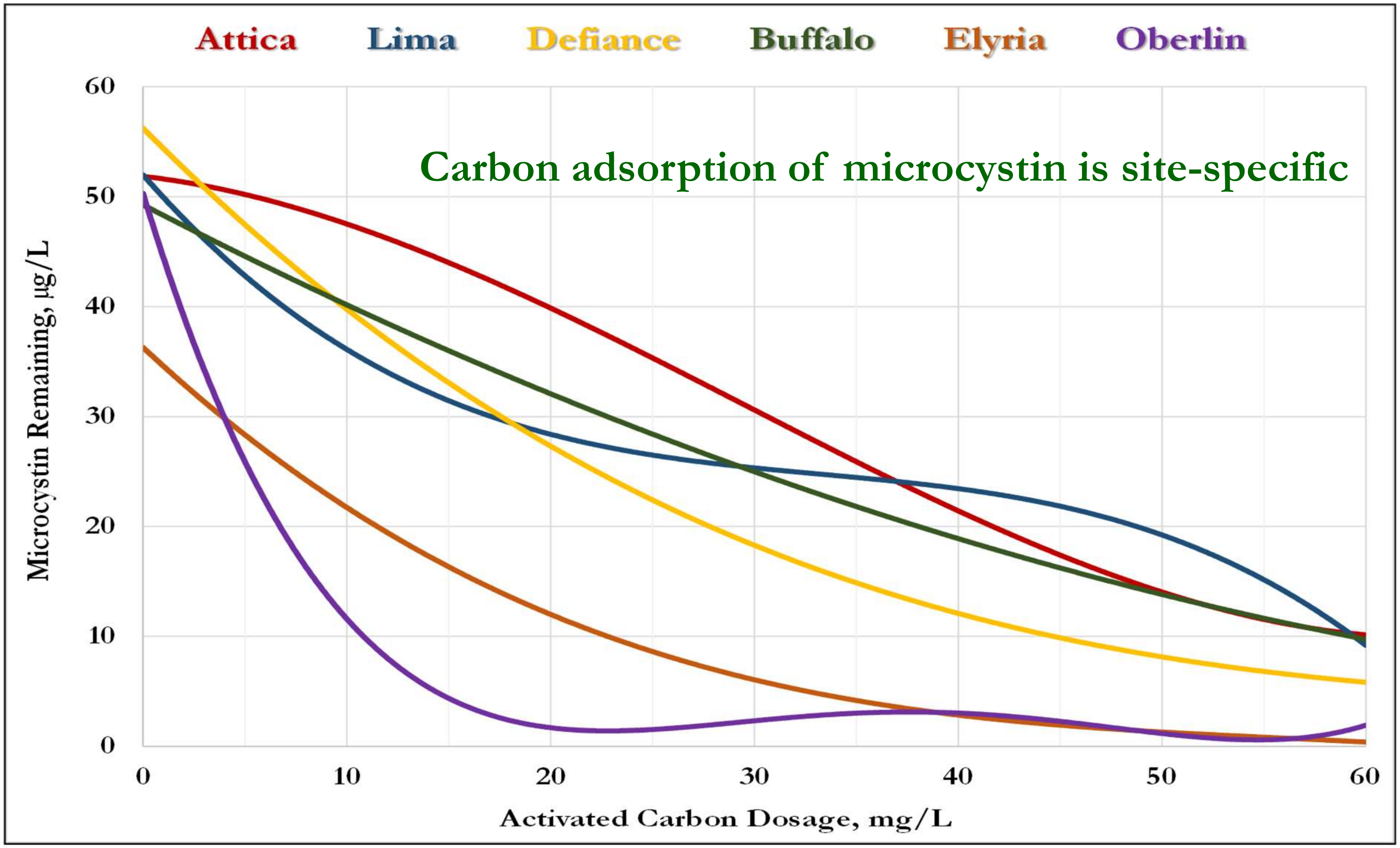


- Carbon products adsorb microcystin
  - Bituminous or blended carbons appear to be most effective
  - Iodine number 1,000+
- Chlorine oxidation effective for some cyanotoxins
  - Site-specific dosages and residuals
  - pH dependence as well

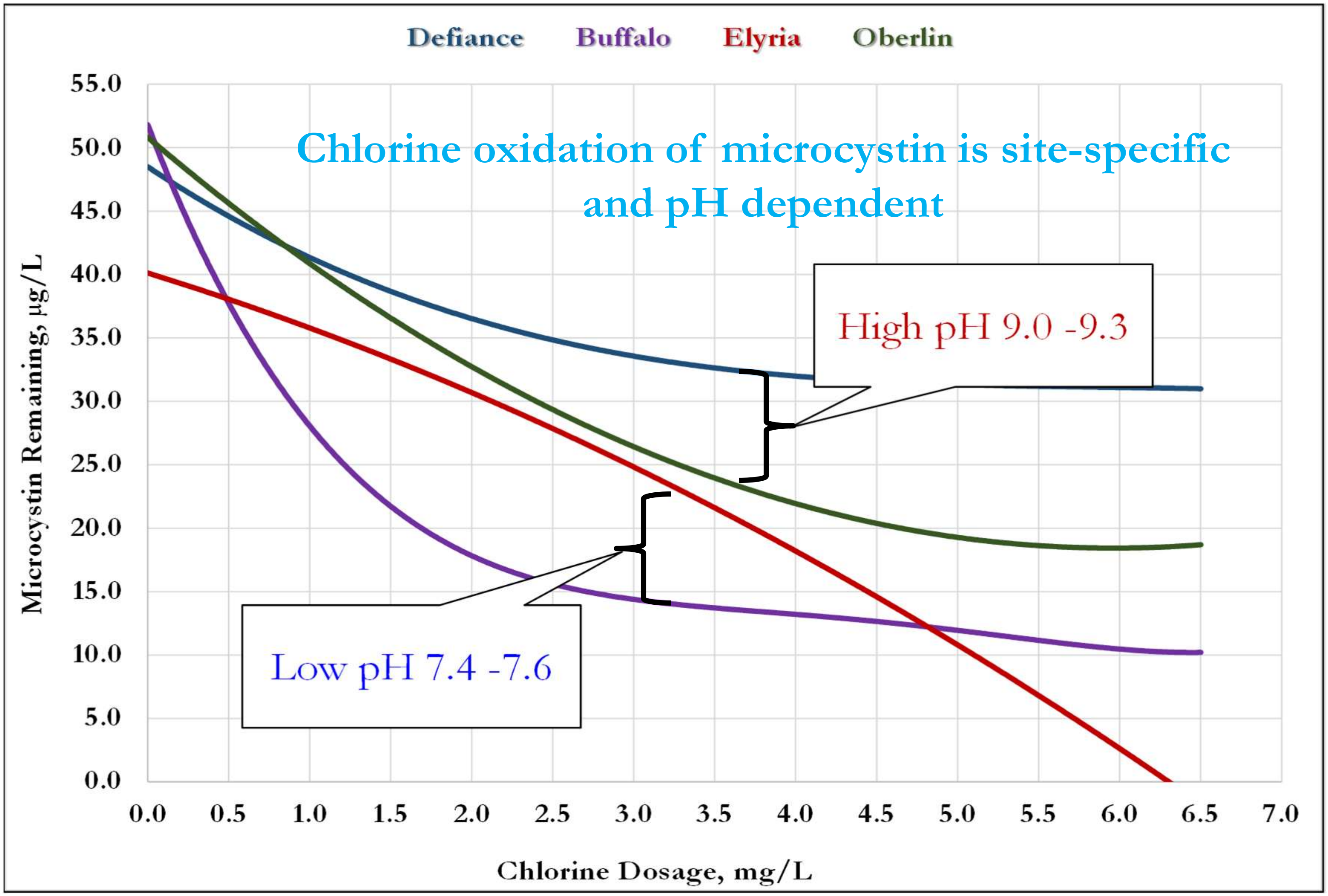
Cyanotoxin Treatment Strategies



Cyanotoxin Treatment Strategies



Cyanotoxin Treatment Strategies



Questions

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