# LACR Method for Alkalinity and TOC Control

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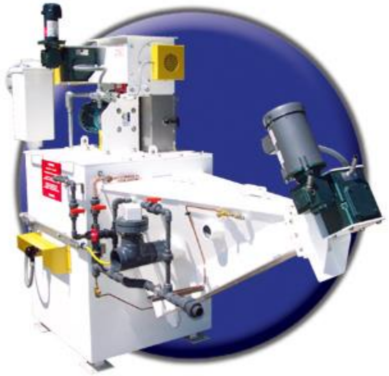
# Agenda

- LACR Defined
- Applicability of LACR in Treatment
- Development of LACR Method
- Coagulant Reactions Review
- Establishing LACR Targets
- Process Applications and Results
- Questions



# LACR Definition

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- LACR (pr: lacker)
  - **L**ime to **A**lkalinity **C**onsumed **R**atio
    - Lime most common alkalinity supplement
  - Replacement of alkalinity reacted during coagulation to foster optimum metal hydroxide formation
    - Metal hydroxides adsorb organic contaminants (TOC)
    - Alkalinity control needed for optimum coagulation, corrosion control, and stability control
- LACR maintains control of alkalinity levels and TOC reduction
  - Alkalinity replacement commonly with lime
  - Alkalinity replacement can be made with other chemicals

# Definition

$$LACR = \frac{alkalinity \quad dosage, mg/L}{k * coagulant \quad dosage, mg/L}$$

$$k = alkalinity \quad consumption \quad coefficien\,t$$

$$LACR * k * coagulant \quad dosage, mg/L = alkalinity \quad dosage, mg/L$$

# Applicability in Treatment

# Applicability in Treatment

- TOC removal believed to be adsorption function primarily onto metal hydroxide (coagulant sludge)
  - Occurs predominantly in flocculation step of treatment
  - Particle collisions important for optimum TOC adsorption
  - Optimizing floc movement maximizes TOC removal
- Magnesium hydroxide also adsorbs TOC
  - Softening treatment with pH ≥10.6 for magnesium precipitation
    - Enhanced softening – 10 mg/L magnesium reduction or greater
  - About 10% to 15% more TOC reduction than coagulant feed alone

# Applicability in Treatment

- Maintaining proper alkalinity appears to improve TOC removals and alkalinity maintenance
  - Designed for source water less than 60 mg/L
  - Operational tool to improve TOC removal with minimal cost
    - Alkalinity recommended above 50 mg/L
  - Alkalinity supplements generally add 1 mg/L alkalinity for each 1 mg/L chemical feed
    - Lime
    - Caustic soda
    - Soda ash
    - Magnesium hydroxide
    - Potassium hydroxide
    - Sodium bicarbonate

# Applicability in Treatment

- Coagulation reactions well known
  - Reactions define alkalinity consumption for form hydroxide floc
  - Reactions define byproducts produced based on coagulant type
    - Byproducts include sludge, generally noncarbonate hardness, carbon dioxide
    - Sludge usually is a metal hydroxide, $Al(OH)_3$, $Fe(OH)_3$, etc.
- Alkalinity must be present in water to drive the chemical reaction
  - Bicarbonate alkalinity most common, but can be carbonate
    - Much of the source TOC is adsorbed during flocculation with hydroxide matter
    - Insufficient alkalinity fosters coagulant species byproducts that are poor TOC removal materials

# Development of LACR Method

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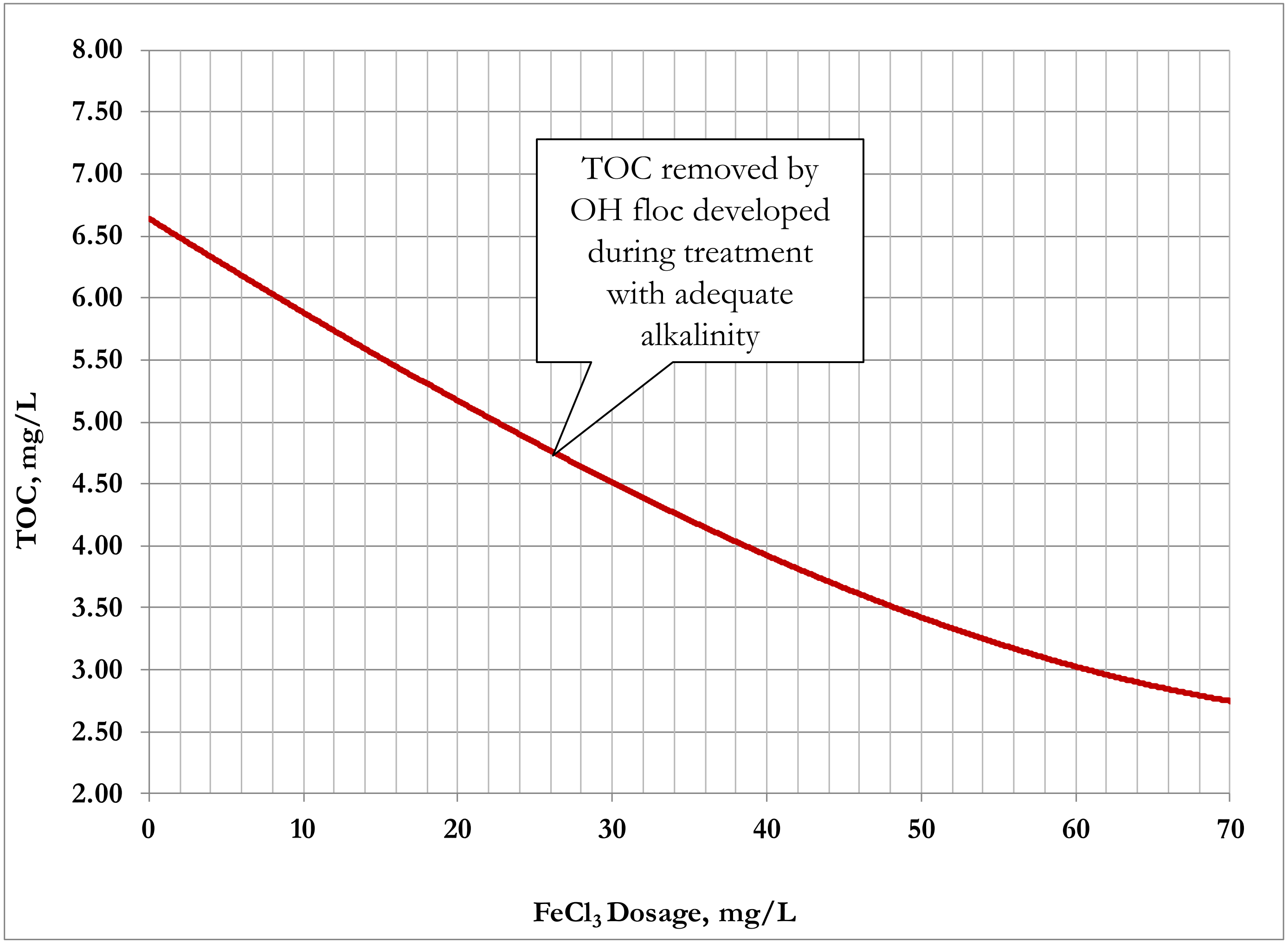
- Jar testing with coagulants where alkalinity is absent generally results
  - poor floc formation
  - poor TOC removal
  - poor turbidity control
- Coagulant investigations with low alkalinity source water
  - Relatively effective treatment until alkalinity consumed below reaction requirements
  - Poor floc development (size and settleability)
  - TOC reductions generally 20%±
  - Turbidity increases once alkalinity falls below 15 mg/L
    - Excess solids loading to filters

# Development of LACR Method

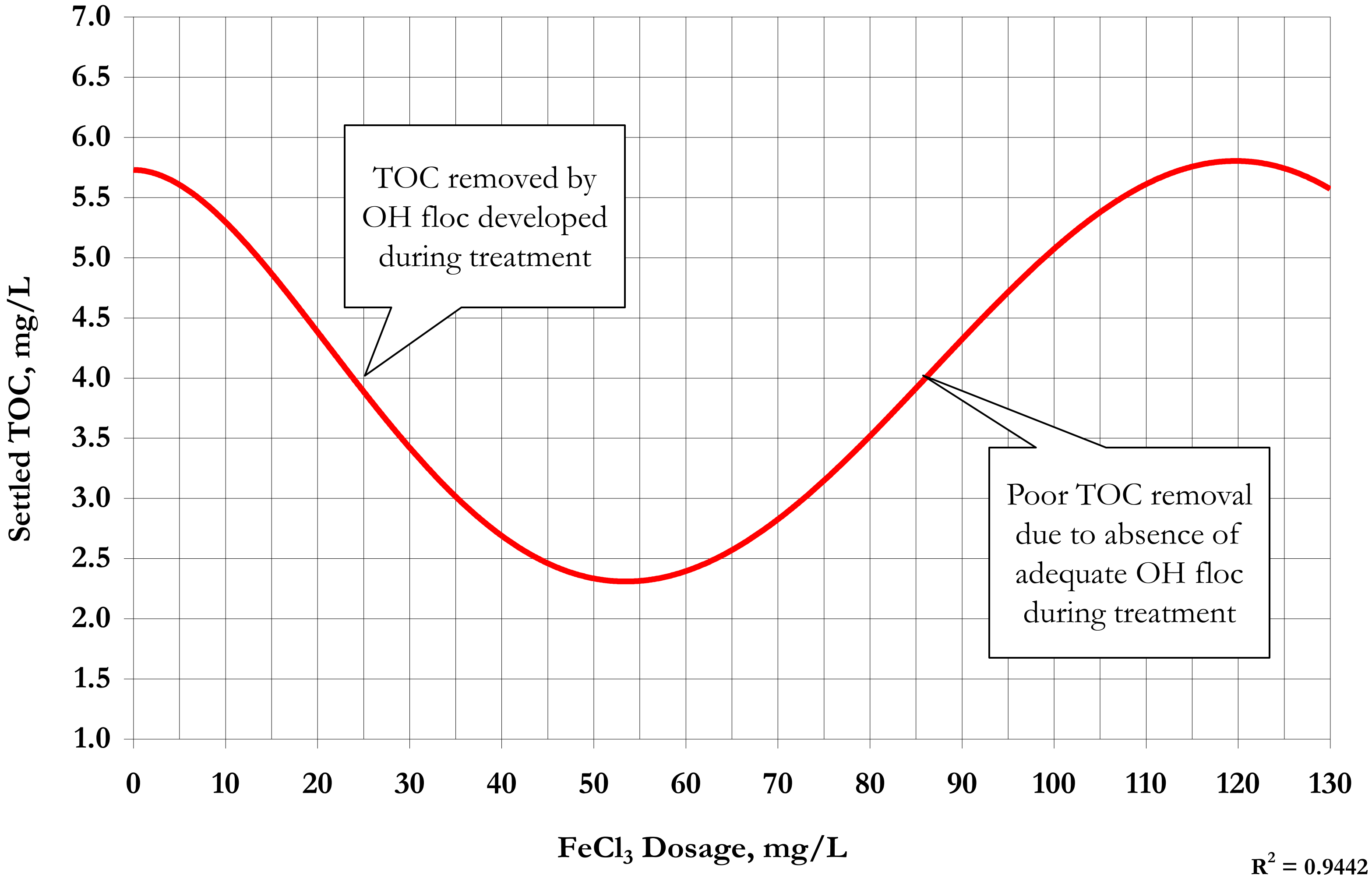
- Coagulant investigations with adequate source water alkalinity
  - Relatively effective treatment until hydrophobic organic matter is removed
  - Good floc development
    - 0.5 mm to 3 mm diameter
    - Settleability usually greater than 0.5 gpm/$ft^2$
  - TOC reductions range 40% to 95%
    - Dependent on source water organic character, water temperature, coagulant
  - Turbidity reduction leading to low settled water solids content
    - Commonly 0.5 NTU to 2 NTU

# Development of LACR Method



TOC removed by OH floc developed during treatment with adequate alkalinity

# Development of LACR Method



TOC removed by OH floc developed during treatment

Poor TOC removal due to absence of adequate OH floc during treatment

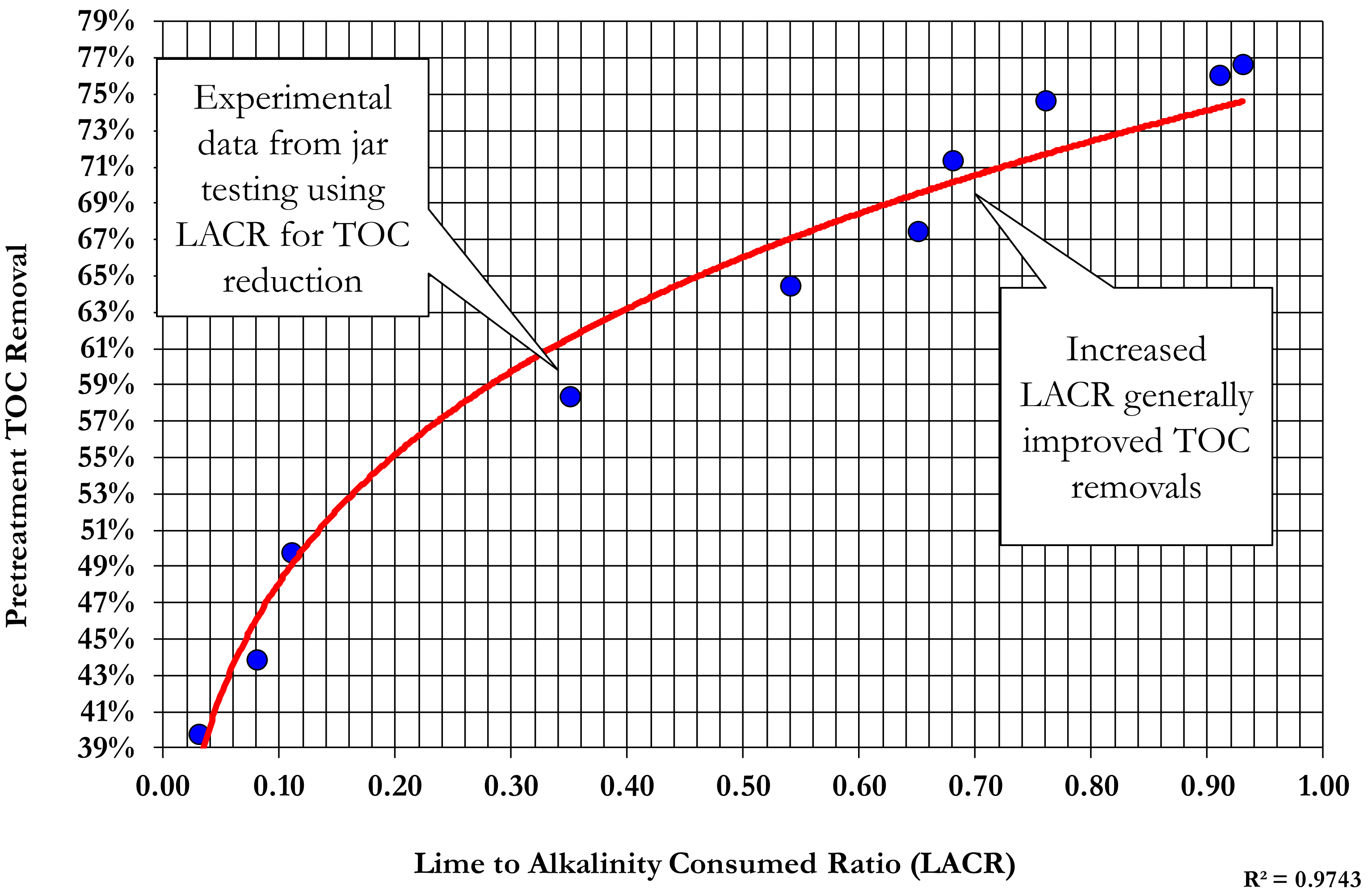
# Development of LACR Method

- Coagulation issues in low alkalinity source water
  - Poor floc development
  - Poor settleability
  - Poor organics reduction
  - Alkalinity less than 60 mg/L generally demonstrates TOC removal problems
- Supplemental alkalinity regains effective treatment
  - Generally believed OH floc fosters better organics removal
  - Good floc development
  - Good settleability
  - Improved TOC reductions

# Development of LACR Method

- Coagulant reactions are well known (literature)
  - Reaction chemistry defines alkalinity consumed to form OH floc and other byproducts
  - Coagulants have separate alkalinity consumption for each mg/L coagulant feed
  - Alkalinity reacted in coagulation easily replaced by chemical addition
    - Generally one to one ratio for the alkaline substances

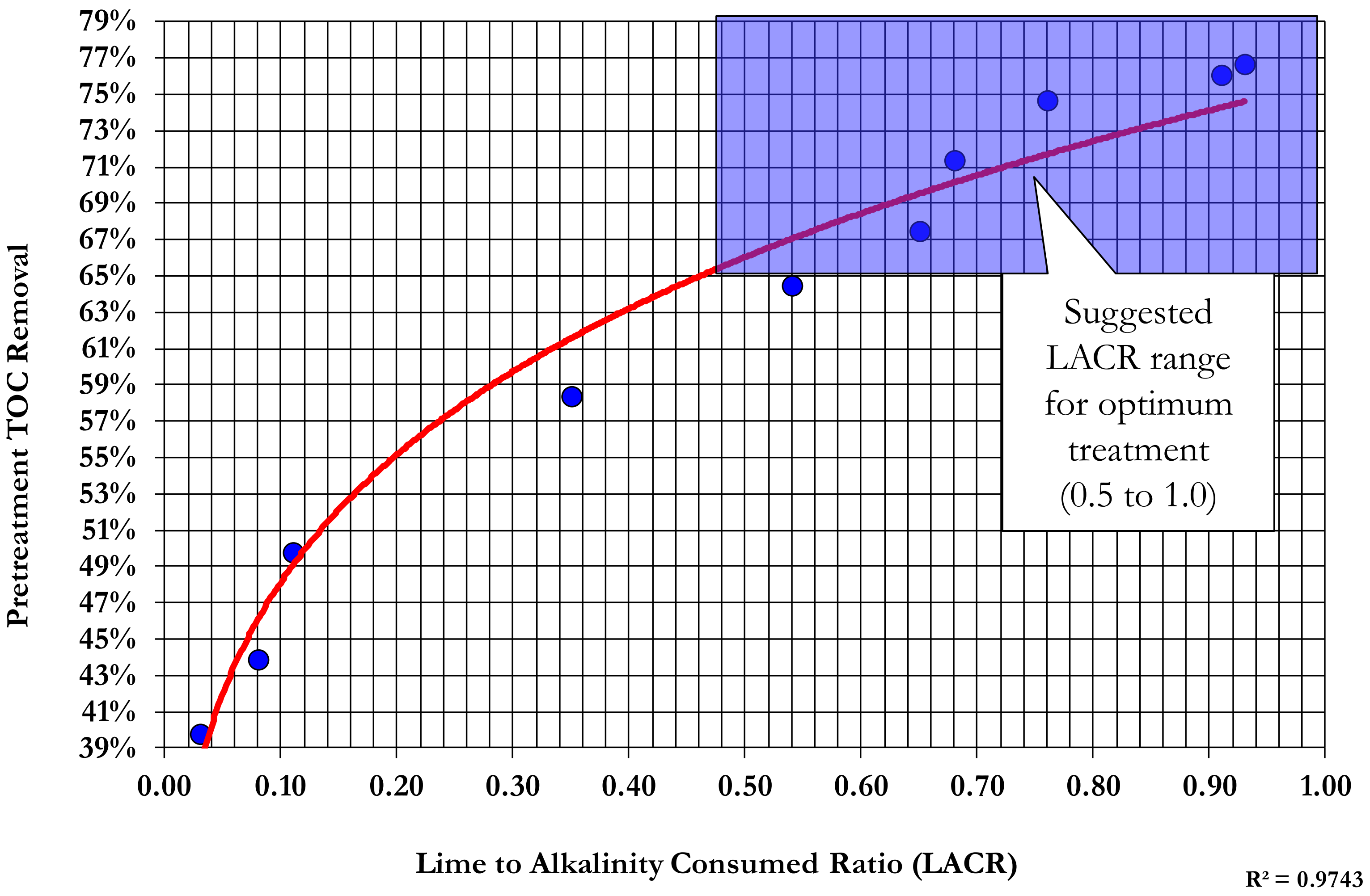
# Development of LACR Method



Experimental data from jar testing using LACR for TOC reduction

Increased LACR generally improved TOC removals

# Development of LACR Method



Suggested LACR range for optimum treatment (0.5 to 1.0)

# Coagulant Reactions Review

# Common Coagulants

- Aluminum sulfate (alum)
- Ferric chloride (FC)
- Ferric sulfate (FS)
- Aluminum chlorohydrate (ACH)
- Polyaluminum chloride (PACl)
- Polyaluminum chlorosulfate (PACS)
- Sodium aluminate (SA)
- Aluminum chloride (AC)

# Coagulant Reactions

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

- Chemical reactions illustrate reactant chemistry and byproduct formation
  - Provides information relative to alkalinity consumption needed for LACR
  - Mole relationships and stoichiometry determine $Ca(HCO_3)_2$ reacted
    - Conversion of $Ca(HCO_3)_2$ to $CaCO_3$ to estimate alkalinity consumption during coagulation treatment
    - Equivalent weight method for conversion

$$Ca(HCO_3)_2 * \frac{EQ_2}{EQ_1} = CaCO_3$$

# Alum Coagulation

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

MW = 594
1 mg/L

MW = 162
0.818 mg/L

$$A*\frac{EQ_2}{EQ_1} = A' \qquad 0.818 \quad mg/L*\frac{50}{82} = 0.50 \quad mg/L \quad consumed$$

**1 mg/L alum consumes 0.50 mg/L alkalinity during coagulant reactions**

***k*** **= 0.50 for alum**

# Ferric Chloride Coagulation

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

| | |
|---|---|
| MW = 326 | MW = 162 |
| 1 mg/L | 0.746 mg/L |

$$A * \frac{EQ_2}{EQ_1} = A' \qquad 0.746 \quad mg/L * \frac{50}{82} = 0.46 \quad mg/L \quad consumed$$

**1 mg/L FeCl$_3$ consumes 0.46 mg/L alkalinity during coagulant reactions**

***k* = 0.46 for ferric chloride**

# Ferric Sulfate Coagulation

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

MW = 562
1 mg/L

MW = 162
0.865 mg/L

$$A * \frac{EQ_2}{EQ_1} = A' \qquad 0.865 \quad mg/L * \frac{50}{82} = 0.53 \quad mg/L \quad consumed$$

**1 mg/L $Fe_2(SO_4)_3$ consumes 0.53 mg/L alkalinity during coagulant reactions**

***k* = 0.53 for ferric sulfate**

# Aluminum Chlorohydrate Coagulation

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

MW = 175
1 mg/L

MW = 162
0.465 mg/L

$$A * \frac{EQ_2}{EQ_1} = A' \qquad 0.465 \quad mg/L * \frac{50}{82} = 0.29 \quad mg/L \quad consumed$$

**1 mg/L ACH consumes 0.29 mg/L alkalinity during coagulant reactions**

**$k$ = 0.29 for ACH**

# Polyaluminum Chloride Coagulation

$$\underline{2Al_2Cl_3(OH)_3} + \underline{3Ca(HCO_3)_2} \Rightarrow 4Al(OH)_3 + 3CaCl_2 + 6CO_2$$

| | |
|---|---|
| MW = 211 | MW = 162 |
| 1 mg/L | 1.15 mg/L |

$$A * \frac{EQ_2}{EQ_1} = A' \qquad 1.15 \ \ mg/L * \frac{50}{82} = 0.71 \ \ mg/L \ \ consumed$$

**1 mg/L PACl consumes 0.71 mg/L alkalinity during coagulant reactions**

***k* = 0.71 for PACl**

# Polyaluminum Chlorosulfate Coagulation

$$\underline{2Al_3Cl_3(OH)_5(SO_4)} + \underline{3Ca(HCO_3)_2} \Rightarrow 6Al(OH)_3 + 3CaCl_2 + 2H_2SO_4 + 6CO_2$$

| | |
|---|---|
| MW = 422 | MW = 162 |
| 1 mg/L | 0.576 mg/L |

$$A*\frac{EQ_2}{EQ_1} = A' \qquad 0.576 \quad mg/L*\frac{50}{82} = 0.36 \quad mg/L \quad consumed$$

**1 mg/L PACS consumes 0.36 mg/L alkalinity during coagulant reactions**

***k* = 0.36 for PACS**

# Sodium Aluminate Coagulation

$$\underline{Na_2Al_2O_4} + \underline{3Ca(HCO_3)_2} \Rightarrow 4Al(OH)_3 + 3CaCl_2 + 6CO_2$$

| | |
|---|---|
| MW = 184 | MW = 162 |
| 1 mg/L | 0.881 mg/L |

$$A * \frac{EQ_2}{EQ_1} = A' \qquad 0.881 \quad mg/L * \frac{50}{82} = 0.54 \quad mg/L \quad consumed$$

**1 mg/L SA consumes 0.54 mg/L alkalinity during coagulant reactions**

***k*** **= 0.54 for SA**

# Alkalinity Consumption Summary

| Coagulant Type | Alkalinity Consumed (k) |
|---|---|
| Alum | 0.50 |
| Ferric chloride | 0.46 |
| Ferric sulfate | 0.53 |
| Aluminum chlorohydrate | 0.29 |
| Polyaluminum chloride | 0.71 |
| Polyaluminum chlorosulfate | 0.36 |
| Sodium aluminate | 0.54 |

# Establishing LACR Targets

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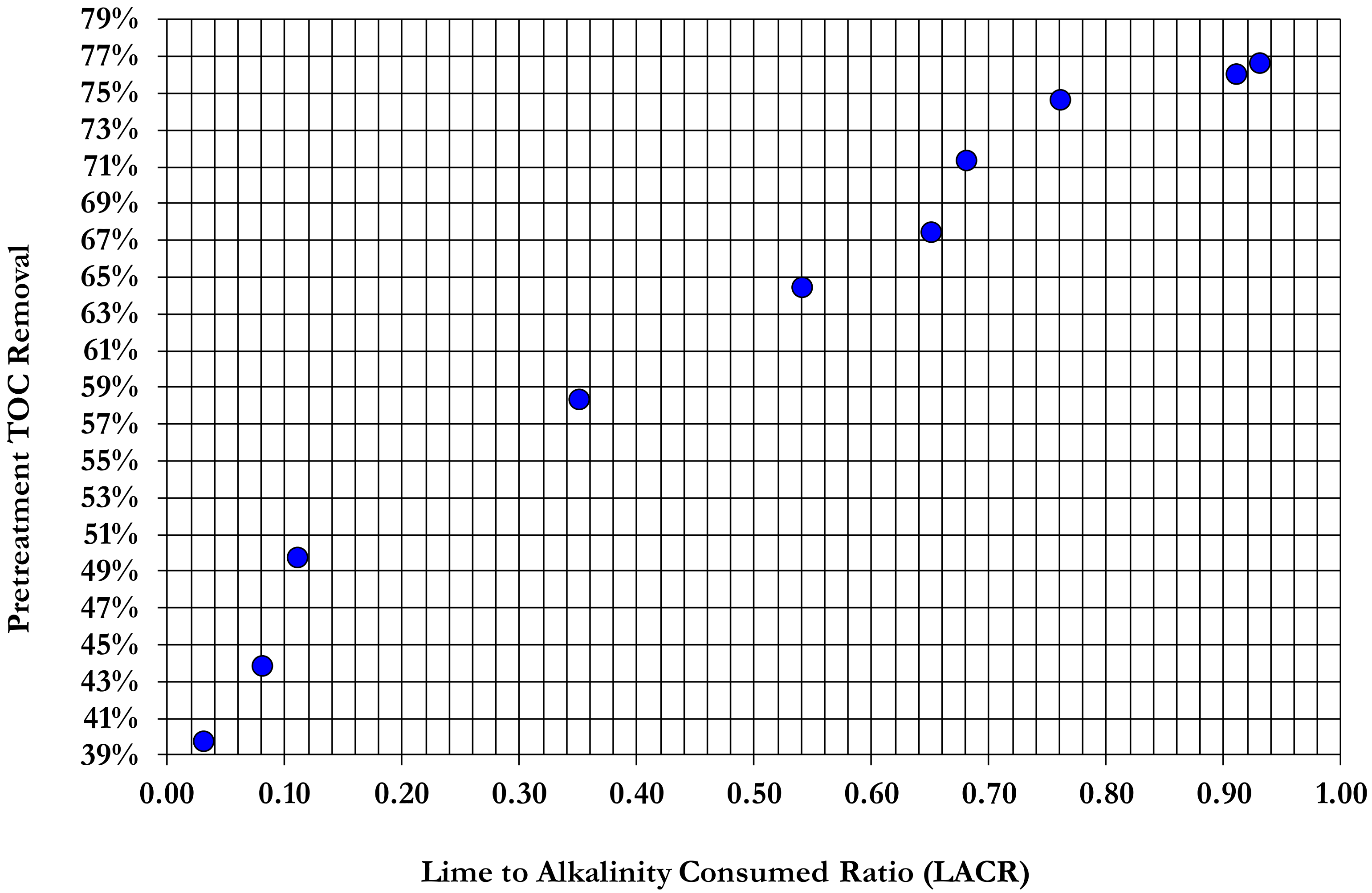
- Bench-scale applications define target values for optimum TOC removal
- Jar testing confirms treatment capabilities
  - Supplemental alkalinity needs for optimum turbidity and TOC reductions
  - Lime dosing varied up to 100% of alkalinity consumed by coagulant treatment
  - Graphical representation of chemical dosing and TOC removal
  - Other water quality data used to establish target treatment values

# Establishing LACR Targets



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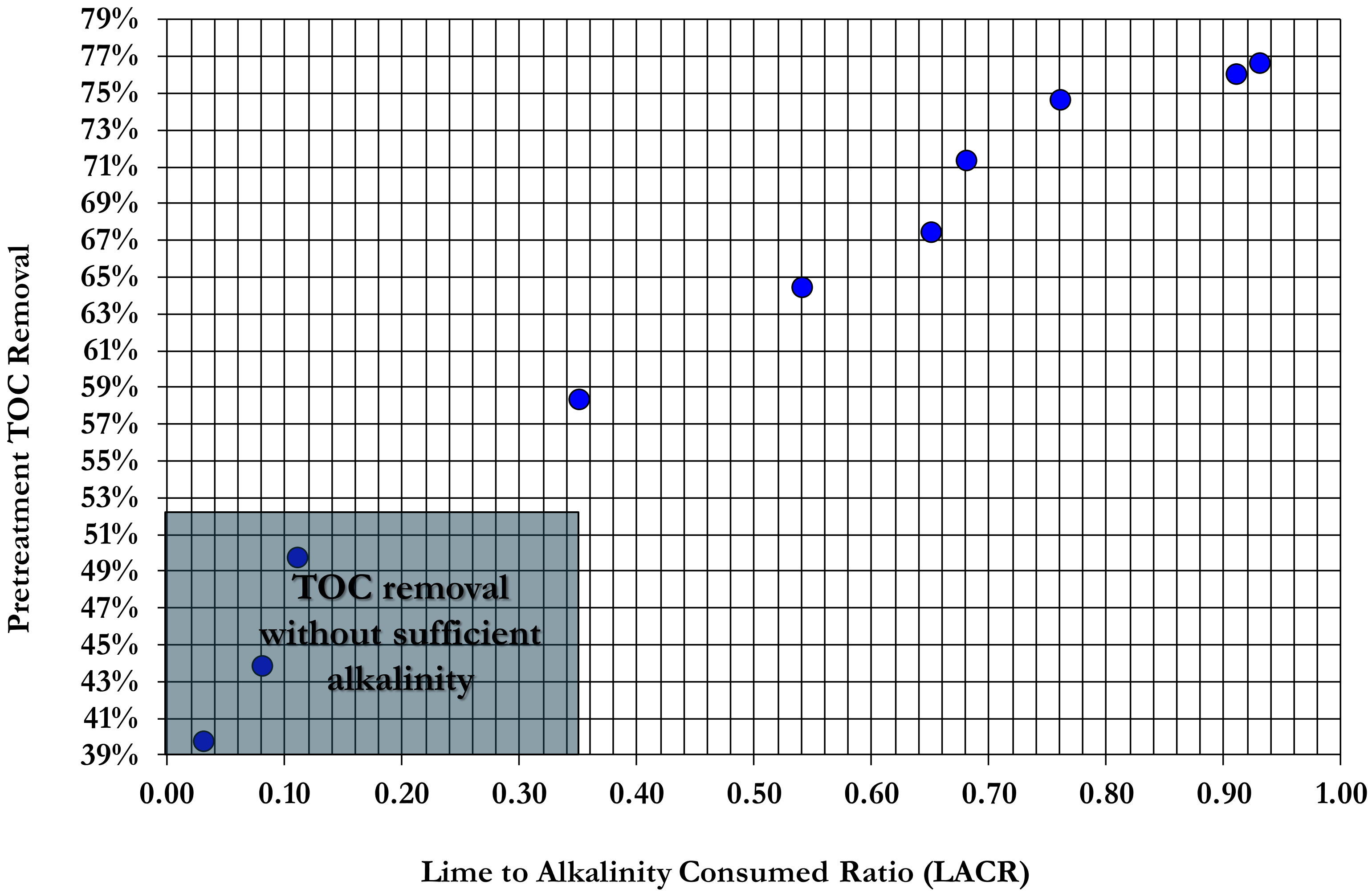

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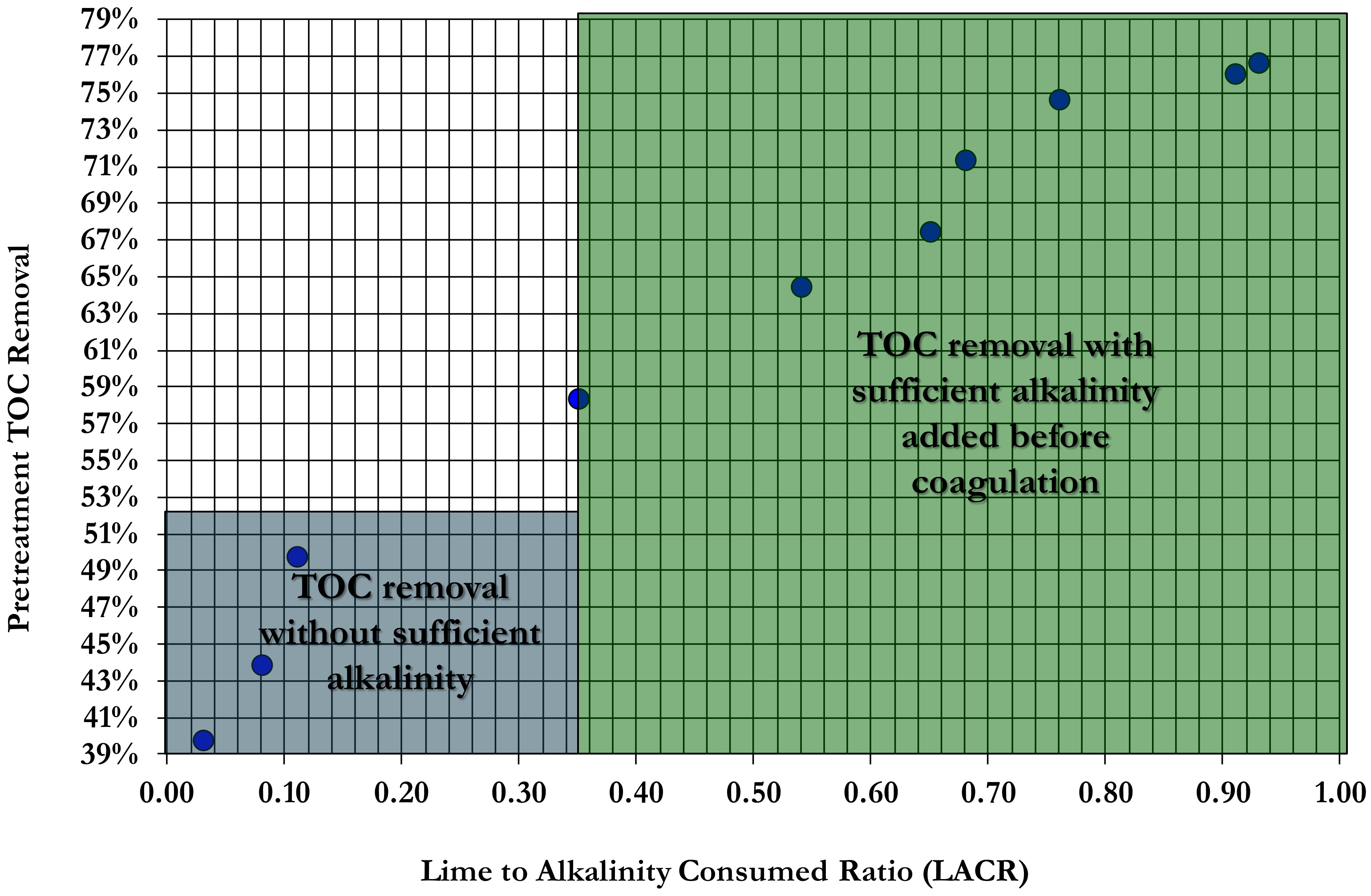

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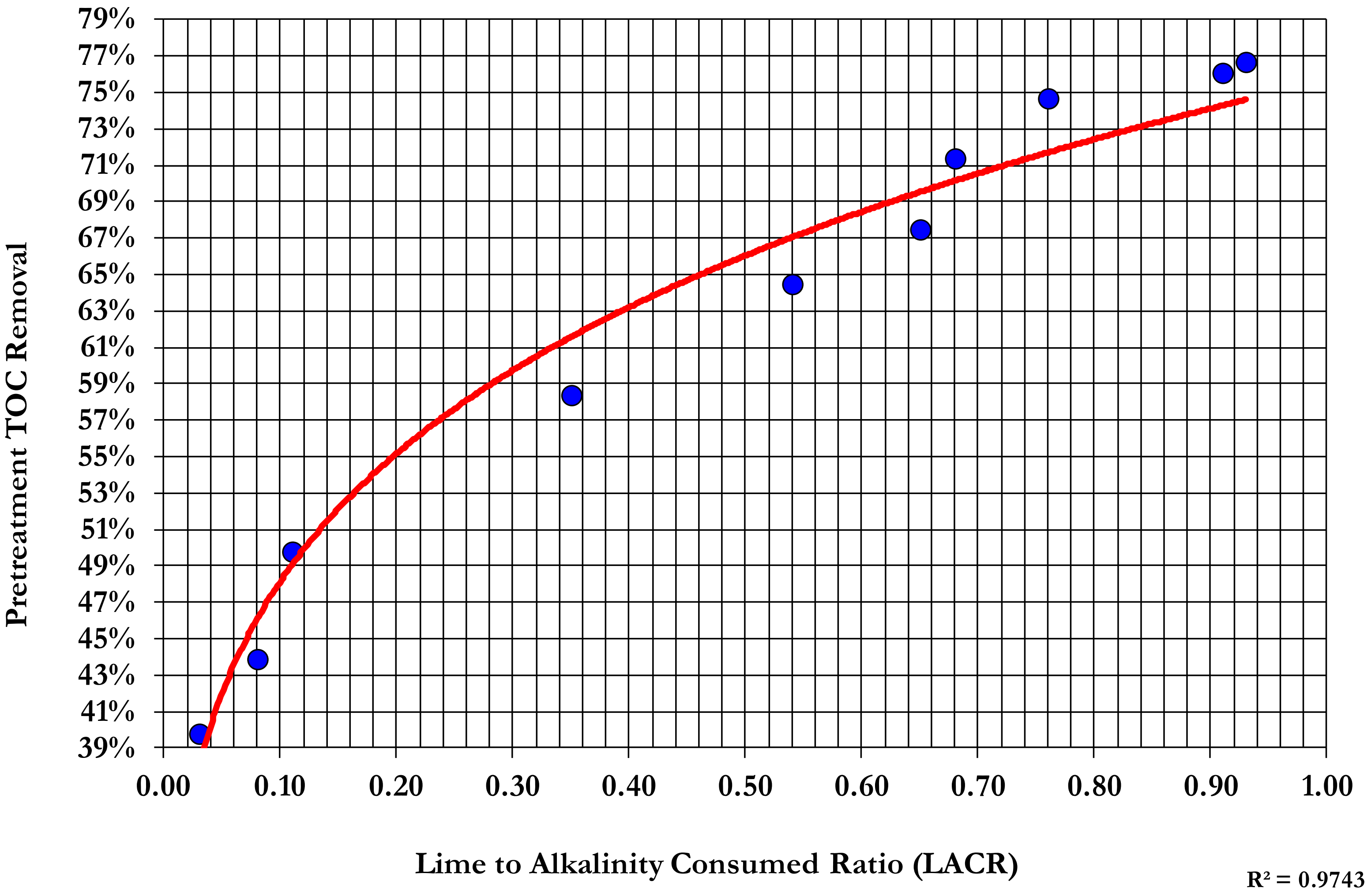

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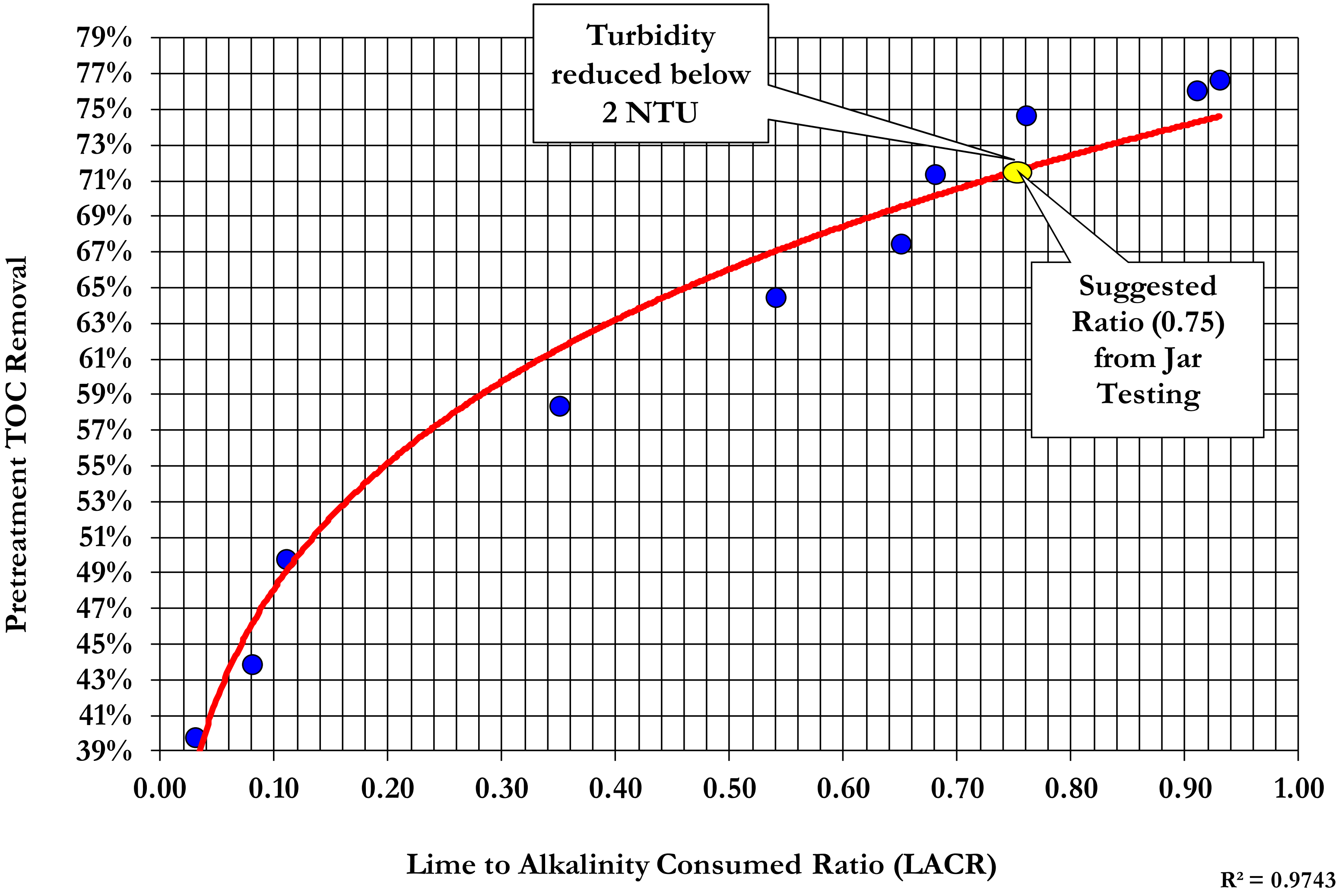

# LACR Targets - Multipliers

| LACR Target | Multiplier |
|---|---|
| 0.45 | 0.225 |
| 0.50 | 0.250 |
| 0.55 | 0.275 |
| **0.60** | **0.300** |
| 0.65 | 0.325 |
| 0.70 | 0.350 |

$$0.60 \quad LACR * 0.5 \quad mg/L = 0.300$$

- Example alkalinity dosing calculation
  - Alum dose 70 mg/L
  - LACR target value **0.60**
  - Lime dosage
    - 70 mg/L ***0.300** = 21 mg/L alkalinity needed
    - 21 mg/L Lime to replace 21 mg/L alkalinity
  - Different multipliers according to coagulant fed

# LACR Targets - Multipliers

## Aluminum Sulfate k=0.50

| LACR Target | Multiplier |
|---|---|
| 0.50 | 0.250 |
| 0.55 | 0.275 |
| 0.60 | 0.300 |
| 0.65 | 0.325 |
| 0.70 | 0.350 |
| 0.75 | 0.375 |

## Ferric Chloride k=0.46

| LACR Target | Multiplier |
|---|---|
| 0.50 | 0.230 |
| 0.55 | 0.253 |
| 0.60 | 0.276 |
| 0.65 | 0.299 |
| 0.70 | 0.322 |
| 0.75 | 0.345 |

# LACR Targets - Multipliers

**Ferric Sulfate k=0.53**

| LACR Target | Multiplier |
|---|---|
| 0.50 | 0.265 |
| 0.55 | 0.292 |
| 0.60 | 0.318 |
| 0.65 | 0.345 |
| 0.70 | 0.371 |
| 0.75 | 0.398 |

**Aluminum Chlorohydrate k=0.29**

| LACR Target | Multiplier |
|---|---|
| 0.50 | 0.145 |
| 0.55 | 0.160 |
| 0.60 | 0.174 |
| 0.65 | 0.189 |
| 0.70 | 0.203 |
| 0.75 | 0.218 |

# LACR Targets - Multipliers

**Polyaluminum chloride k=0.71**

| LACR Target | Multiplier |
|---|---|
| 0.50 | 0.355 |
| 0.55 | 0.391 |
| 0.60 | 0.426 |
| 0.65 | 0.462 |
| 0.70 | 0.497 |
| 0.75 | 0.533 |

**Polyaluminum chlorosulfate k=0.36**

| LACR Target | Multiplier |
|---|---|
| 0.50 | 0.180 |
| 0.55 | 0.198 |
| 0.60 | 0.216 |
| 0.65 | 0.234 |
| 0.70 | 0.252 |
| 0.75 | 0.270 |

# LACR Targets - Multipliers

**Sodium aluminate k=0.54**

| LACR Target | Multiplier |
|---|---|
| 0.50 | 0.270 |
| 0.55 | 0.297 |
| 0.60 | 0.324 |
| 0.65 | 0.351 |
| 0.70 | 0.378 |
| 0.75 | 0.405 |

# Process Applications and Results

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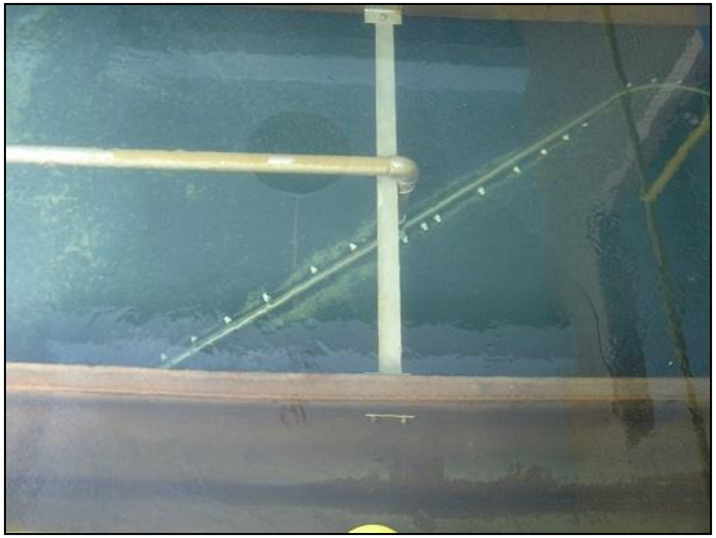
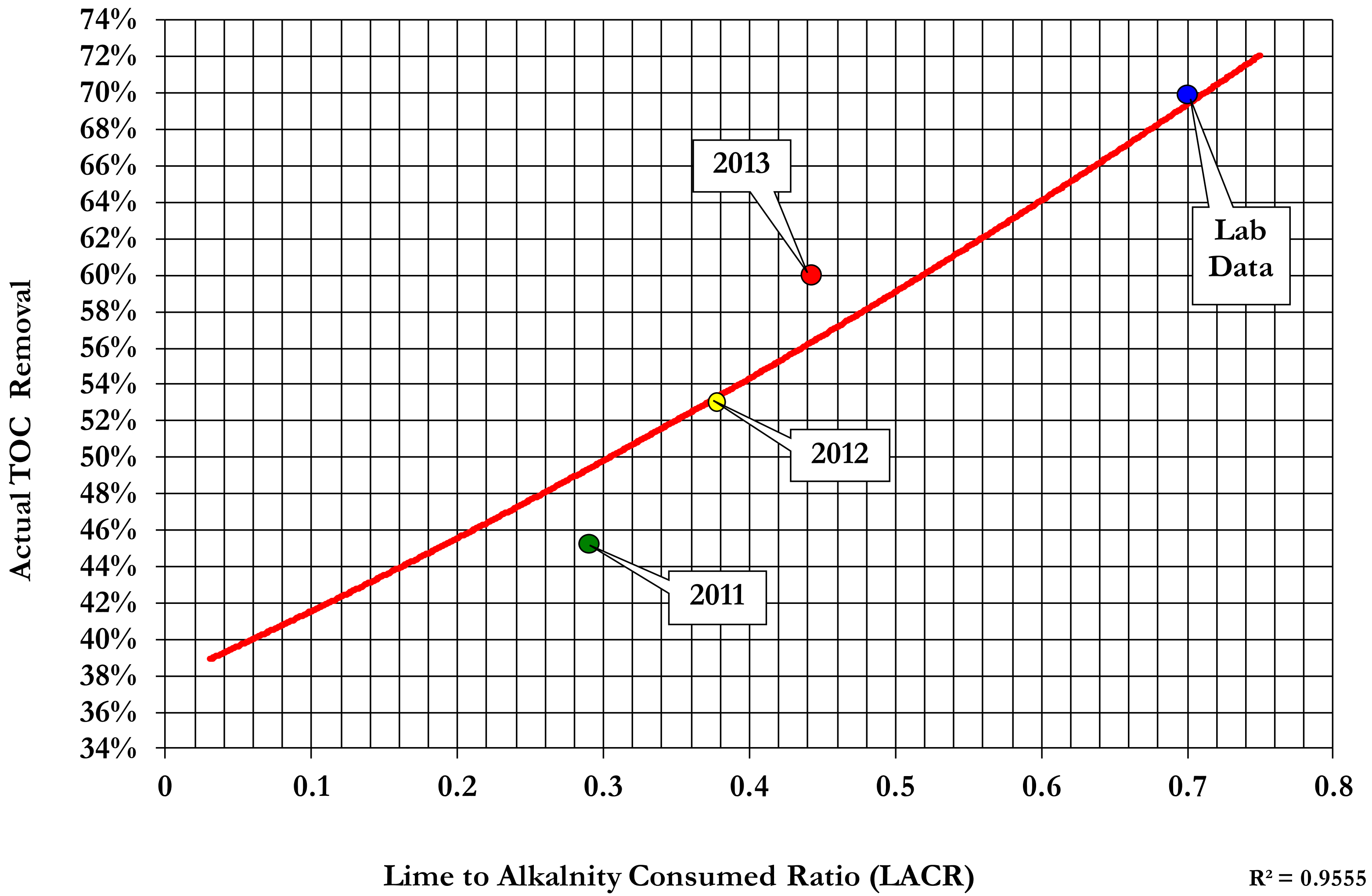
- Two cases studies on surface water plants
  - Low alkalinity source water (<65 mg/L)
  - Coagulation / pH adjustment
  - LACR trial periods and observations
  - Plant A 3 mg/L to 22 mg/L TOC
    - Alum and lime pretreatment
  - Plant B 1.5 mg/L to 5 mg/L TOC
    - Ferric chloride and lime pretreatment



# Plant A LACR Implementation

- Difficulty meeting HAA5 limits in 2011
  - Chloramination used following CT compliance
  - Relatively poor turbidity and TOC removal
    - Seasonal TOC up to 22 mg/L
    - Insufficient alkalinity at alum dosages greater than 55 mg/L
  - LACR implemented in late 2011
    - Initial LACR averaged 0.29 - 46% TOC reduction common
    - 2012 LACR average 0.38 - 53% TOC reduction
    - 2013 LACR average 0.45 - 60% TOC reduction

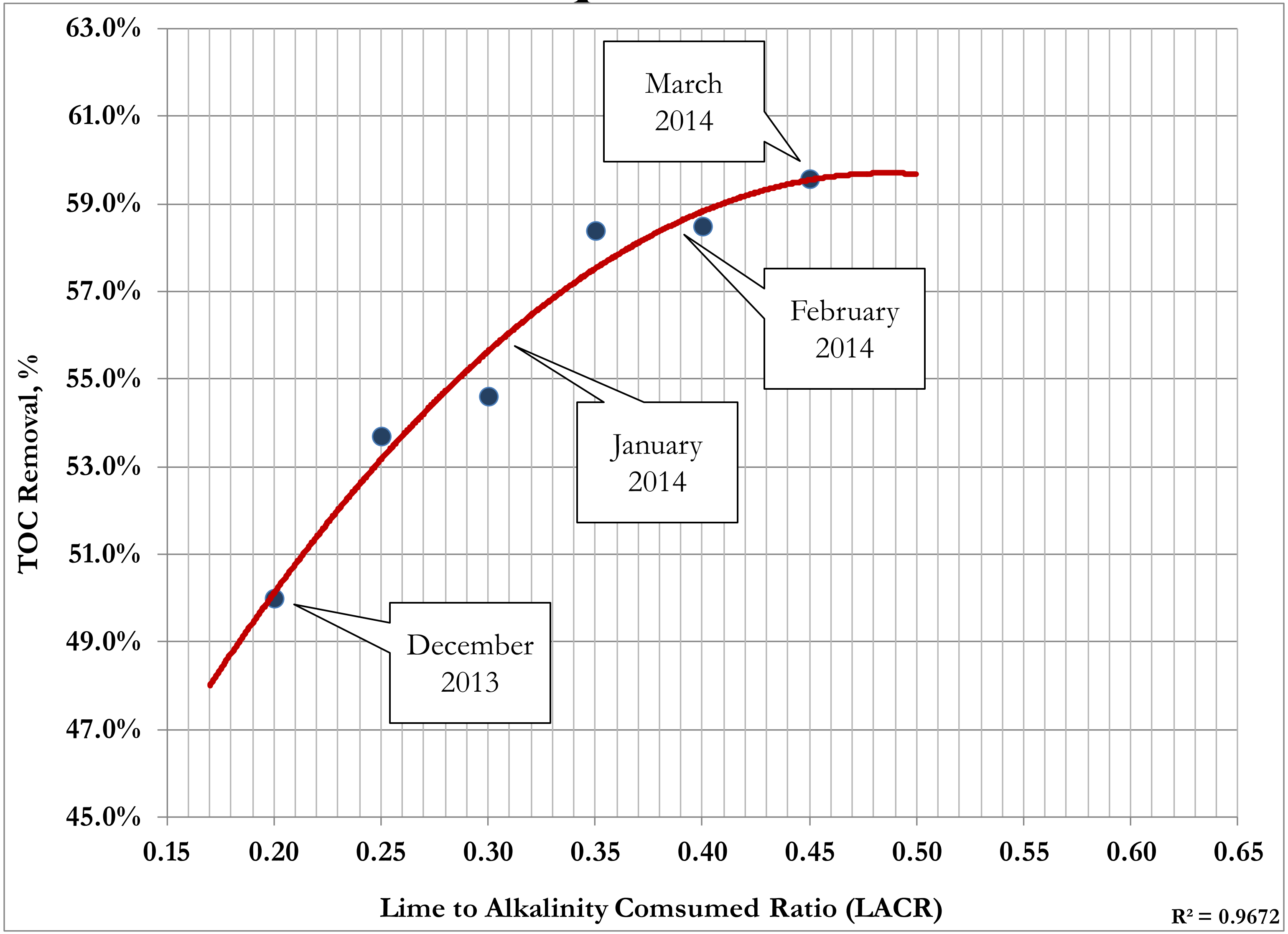
# Plant A LACR Implementation



# Plant B LACR Implementation

- Difficulty meeting THM limits in summer months
  - Chlorination used following CT compliance
  - Relatively good turbidity control, but lower TOC removal
    - 0.5 NTU applied turbidity annual average
    - Raw TOC doubles each quarter
    - Annual TOC reduction - 48%
    - Insufficient alkalinity at ferric chloride dosages greater than 30 mg/L
  - LACR implemented in December 2013
    - Initial LACR averaged 0.20 - 50% TOC reduction
    - Adjusted every 3 weeks since implementation
    - Current LACR 0.45

# Plant B LACR Implementation



# Questions

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