# Testing Add-On Phosphorus Removal Processes at Upper Blackstone to Balance Low-Level Phosphorus *and* Metals Permit Limits

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NEWEA – 2018 Annual Conference & Exhibit

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# Upper Blackstone Wastewater Treatment Facility

- Serves 250,000 people in central Massachusetts, including the City of Worcester
- Discharges into the Blackstone River which ultimately flows to the Narragansett Bay
- Designed for 45 mgd ADF and 160 mgd peak hour; 30 mgd current ADF
- Regional biosolids facility

# Upper Blackstone's NPDES Permit Limits

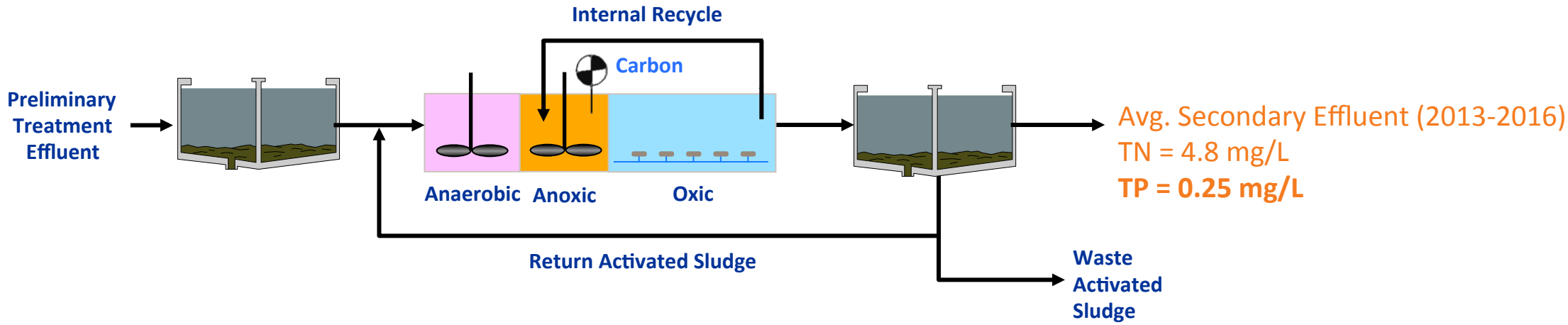
| Constituent | 2012 Permit |
|---|---|
| Total Nitrogen (mg/L) – Monthly average | 5.0 |
| Total Phosphorus (mg/L) –60-day rolling average | |
| April-October | 0.10 |
| November-March | 1.0 |
| Aluminum (µg/L) | 87 |
| Cadmium (µg/L) | |
| Average Monthly | 0.2 |
| Maximum Day | 1.5 |
| Copper (µg/L) | |
| Average Monthly | 7.2 |
| Max Day | 10.2 |
| Zinc (µg/L) | 91.3 |
| Lead and Nickel (µg/L) | Report |

Narragansett Bay

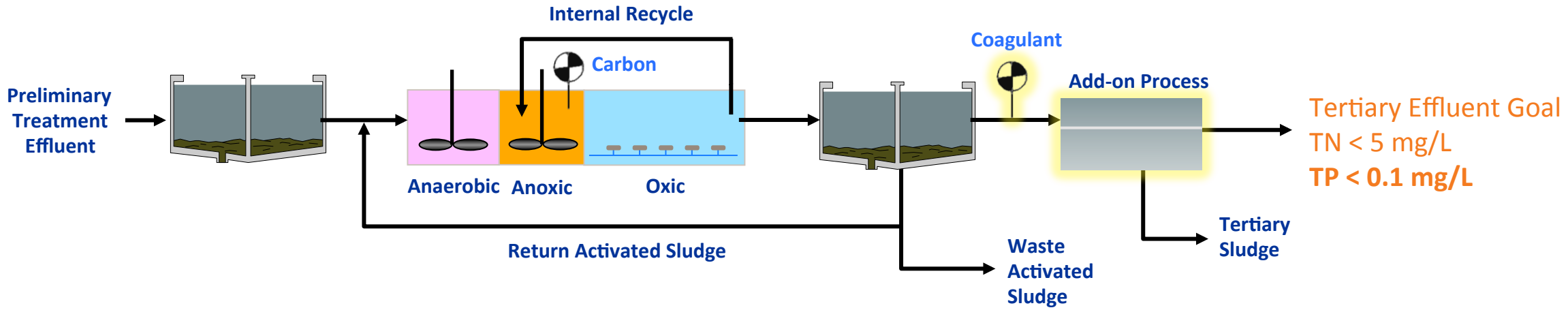
Blackstone River

- Currently operating under interim limits:
  - TN of 6 mg/L
  - TP of 0.45 mg/L
- Typically achieve:
  - TN of ≈ 4.8 mg/L
  - TP of ≈ 0.25 mg/L
- Meet metals limits but not TP limit

# Current Anaerobic/Anoxic/Oxic ($A^2/O$) Process Configuration:



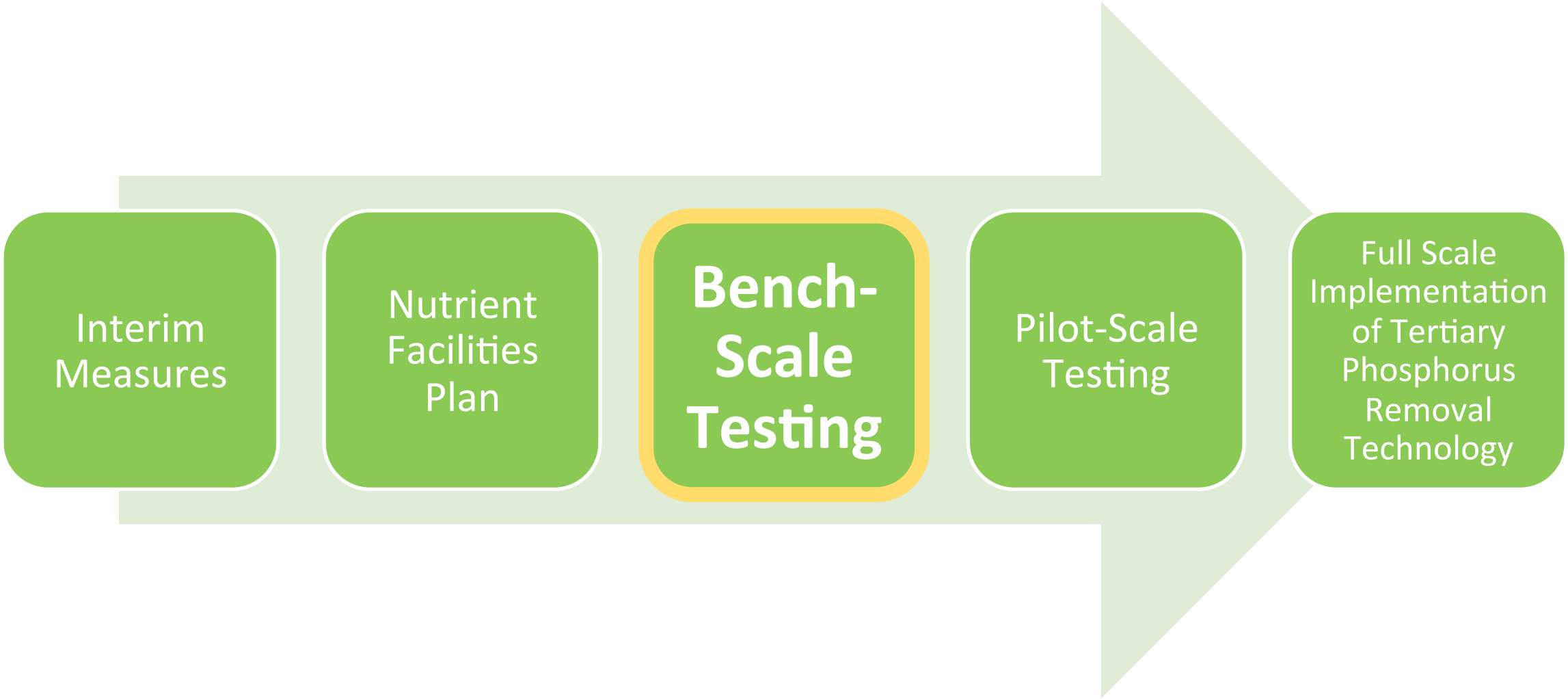
# Proposed Process Configuration to Achieve TP Compliance:




**Which coagulant?**

**Which add-on process?**

# Steps Toward Achieving 2012 TP Permit Limit



## Coagulants Bench-Tested:

**Aluminum-Based**

- **Alum** (Aluminum Sulfate)
  $Al^{3+}$
  ≈4.4% Al
- **PACl** (Polyaluminum Chloride)
  **$Al^{3+}$**
  **≈5.6% Al**
- **ACH** (Aluminum Chloride Hydrate)
  **$Al^{7+}$**
  **≈12.4% Al**

**Iron-Based**

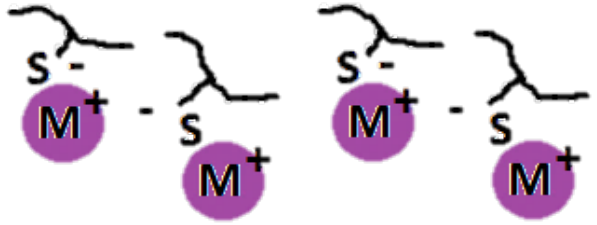
- **Ferric Chloride**
  $Fe^{3+}$
  ≈13.5% Fe
- **Ferric Sulfate**
  $Fe^{3+}$
  ≈13.1% Fe

**Rare Earth**

- **RE-100** (Cerium Chloride)
  $Ce^{3+}$
  ≈17.9% Ce

## Polymer Bench-Tested:

MetClear™ 2405
**(Sulfide-Based Polymer)**
*Anionic Polymer*




## Chemicals Tested on the Pilot-Scale:

- **Alum** (Aluminum Sulfate)
  $Al^{3+}$
  ≈4.4% Al
- **Ferric Chloride**
  $Fe^{3+}$
  ≈13.5% Fe
- **RE-100** (Cerium Chloride)
  $Ce^{3+}$
  ≈17.9% Ce

MetClear 2405
**(Sulfide-Based Polymer)**
*Anionic Polymer*

# Key Bench-Scale Conclusions

- No pH adjustment required with alum, ferric chloride, and RE-100
- MetClear™ 2405 was able to reduce heavy metal concentrations
  - Copper by >50%
  - Cadmium by 30%

## Alum

- Most effective at pH <7
- Molar Ratio- 5:1 (9 mg/L)
- $34,000/year
  - Least expensive coagulant
- Increases Al concentrations

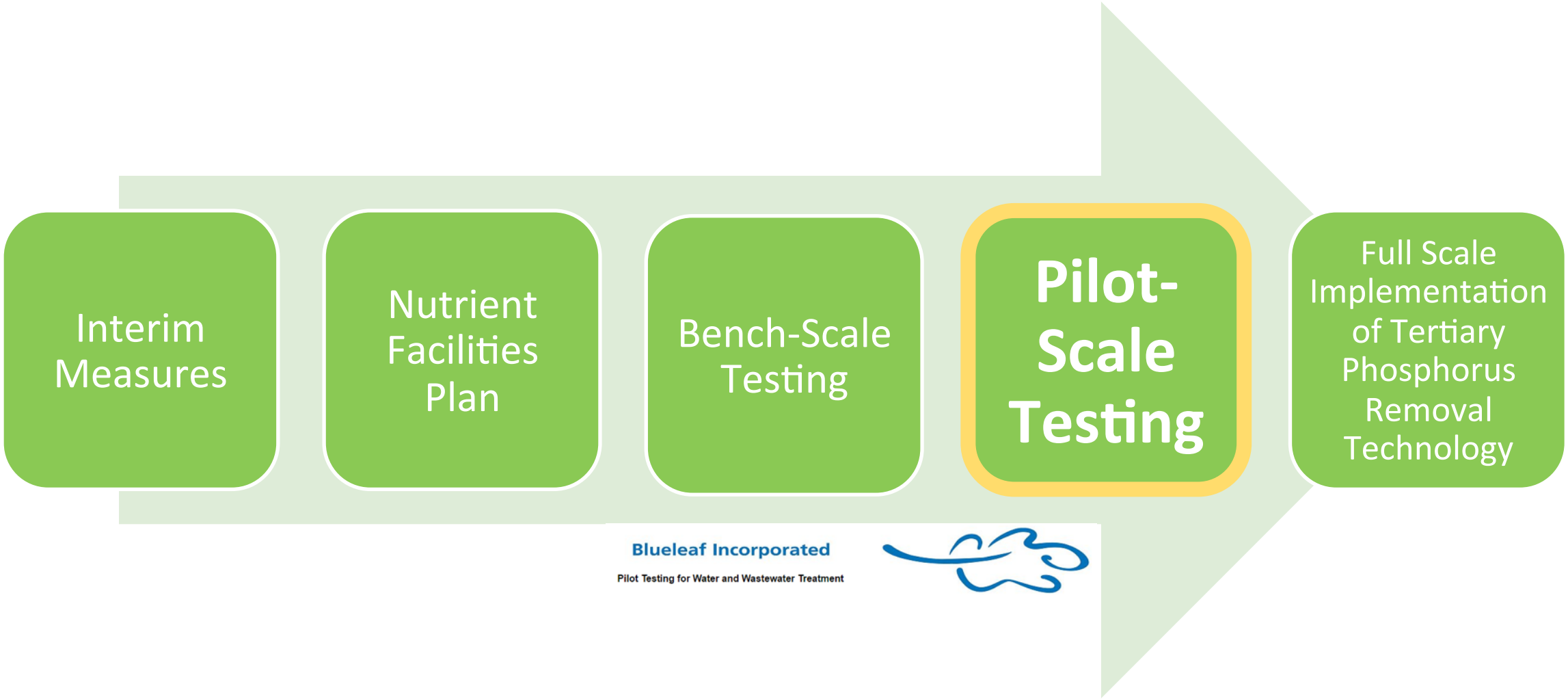
## Ferric Chloride

- Little impact of pH
- Molar Ratio- 5:1 (5 mg/L)
- $49,000/year
  - Second least expensive coagulant
- Increases Cu concentrations

## RE-100

- Molar Ratio- 2:1 (3 mg/L)
- $286,000/year
  - Higher cost could be offset by savings attributed to low residuals/solids handling
- No impact on metals

# Steps Toward Achieving 2012 TP Permit Limit



# Phosphorus Removal Technologies Piloted

**ACTIFLO®**- *Ballasted Flocculation with Microsand, by Kruger Inc.*

**CoMag®-** *Ballasted Flocculation with Magnetite, by Evoqua Water Technologies*

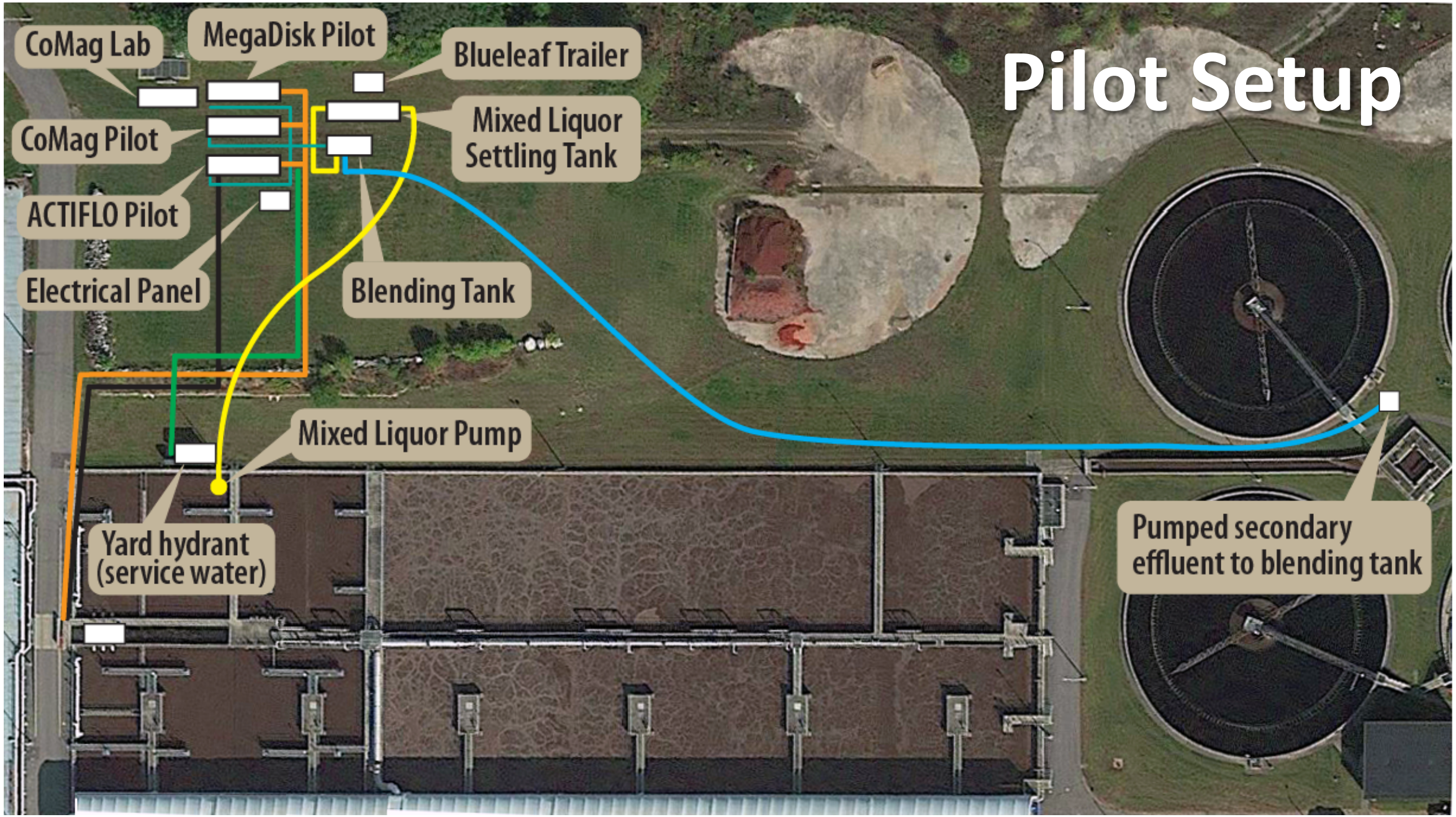
**Aqua MegaDisk®-** *Rotating Cloth Filters, by Aqua-Aerobic Systems, Inc.*

# Experimental Approach

*August 16 to October 29, 2016*

| Pilot Influent Condition | Description | Effluent TP Target | |
|---|---|---|---|
| | | 0.10 mg/L | 0.05 mg/L |
| 1.00 mg/L TP | Design max month and day | Trials 1 & 3 | Trial 2 |
| 0.30 mg/L TP | Average secondary effluent 2013-2015[1] | Trial 4 | Trial 5 |
| 30 mg/L TSS | Potential clarifier upset condition/BNR upset condition | Trial 6 | Trial 7 |
| 1.00 mg/L TP | Metclear™ polymer addition for metals removal | Trial 8 | |
| 0.1-0.2 mg/L TP | Hydraulic loading (20 MGD to 120 MGD) | Trial 9 | |
| 0.1-0.2 mg/L TP | Existing secondary effluent | Trial 10 | |
| 0.3 mg/L TP | Additional tests for individual manufacturers | Trial 11 | |

1. The 95% confidence interval on the mean was selected to represent the average TP into the tertiary system. The actual average of secondary effluent from 2013-2015 was 0.22 mg/L.

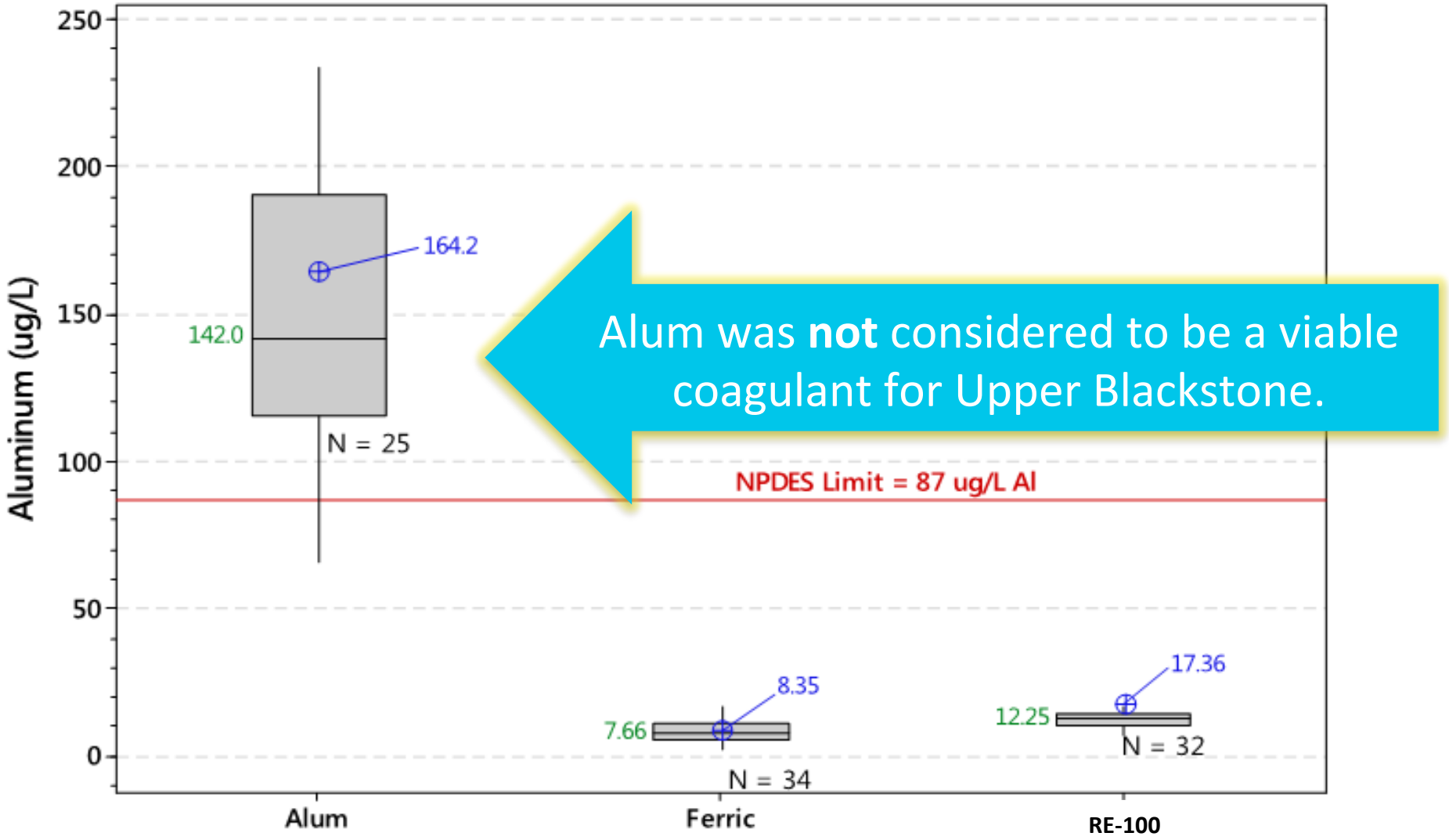

Pilot Setup
CoMag Lab
MegaDisk Pilot
Blueleaf Trailer
CoMag Pilot
Mixed Liquor Settling Tank
ACTIFLO Pilot
Electrical Panel
Blending Tank
Mixed Liquor Pump
Yard hydrant (service water)
Pumped secondary effluent to blending tank

# Pilot-Scale Metals Removal Performance:

- No statistically significant difference of metals removal between technologies
- **Coagulant** used did have an impact

| Metal (µg/L) | NPDES Limit | Mean ± standard deviation (min – max) | | |
|---|---|---|---|---|
| | | Alum [n=25] | Ferric Chloride [n=34] | RE-100 [n=32] |
| **Aluminum** | 87 µg/L | **164** ± 1 (66 – **381**) | 8 ± 5 (ND {1.69} – 26) | 17 ± 26 (7 – 155) |
| **Cadmium** | 0.2 µg/L | 0.24 ± 0.10 (0.07 – 0.43) | 0.27 ± 0.09 (0.10 – 0.45) | 0.27 ± 0.07 (0.16 – 0.46) |
| **Copper** | 7.2 µg/L | 2.5 ± 0.5 (1.6 – 3.7) | 5.7 ± 1.3 (2.6 – **8.1**) | 2.9 ± 1.0 (1.6 – 7.3) |
| **Lead** | None (report) | 0.31 ± 0.05 (0.22 – 0.35) | 0.34 ± 0.05 (0.24 – 0.45) | 0.34 ± 0.08 (0.13 – 0.55) |
| **Nickel** | None (report) | 3.6 ± 0.77 (2.3 – 5.2) | 6.2 ± 2.2 (3.4 – 12) | 3.5 ± 0.87 (1.9 – 5.8) |
| **Zinc** | 91.3 µg/L | 35 ± 9 (18 – 54) | 38 ± 9 (25 – 55) | 37 ± 8 (28 – 64) |

# Coagulant vs. Coagulant:
# Pilot Scale Resultant **Aluminum** Concentrations




Alum was **not** considered to be a viable coagulant for Upper Blackstone.





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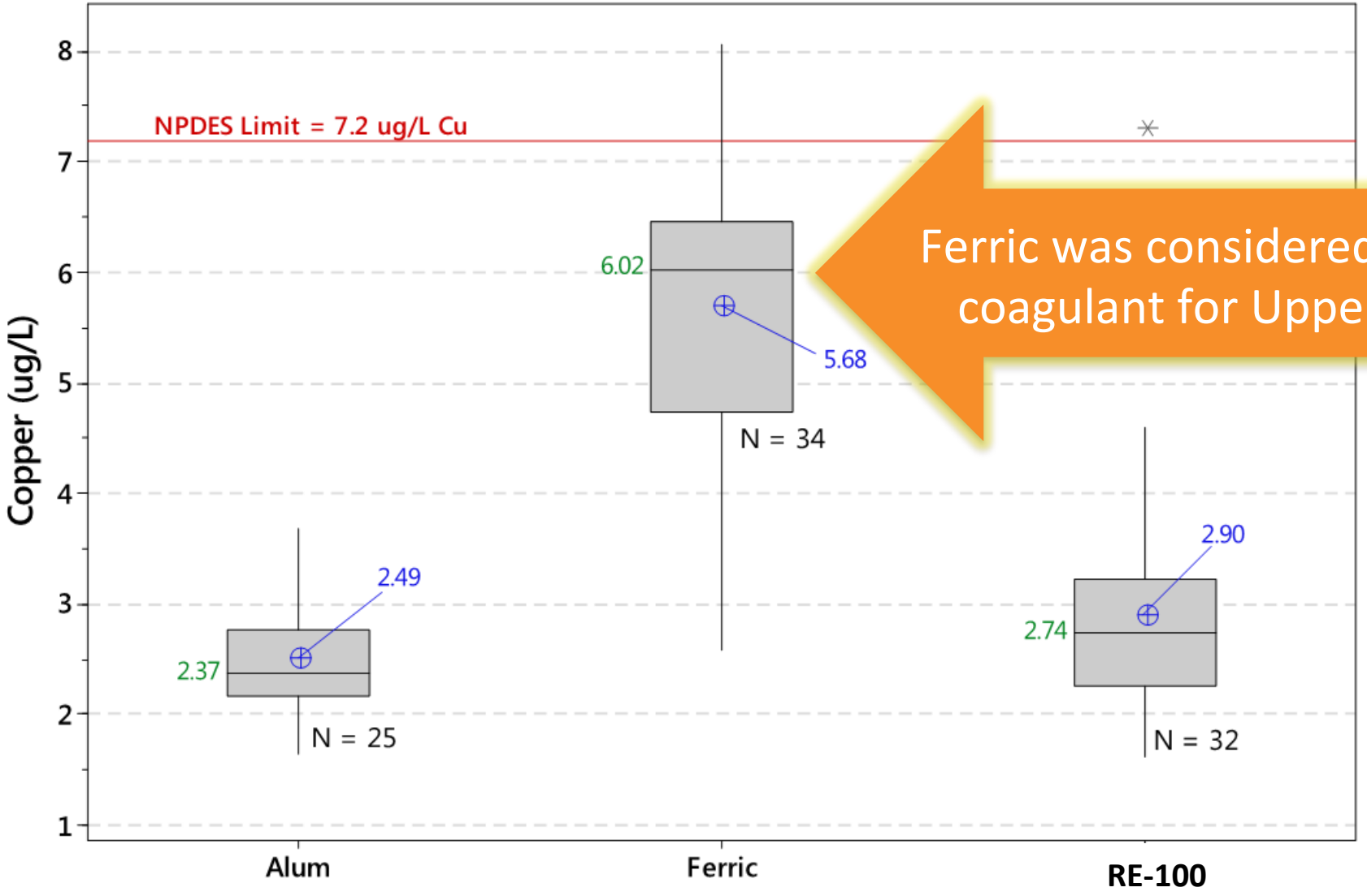
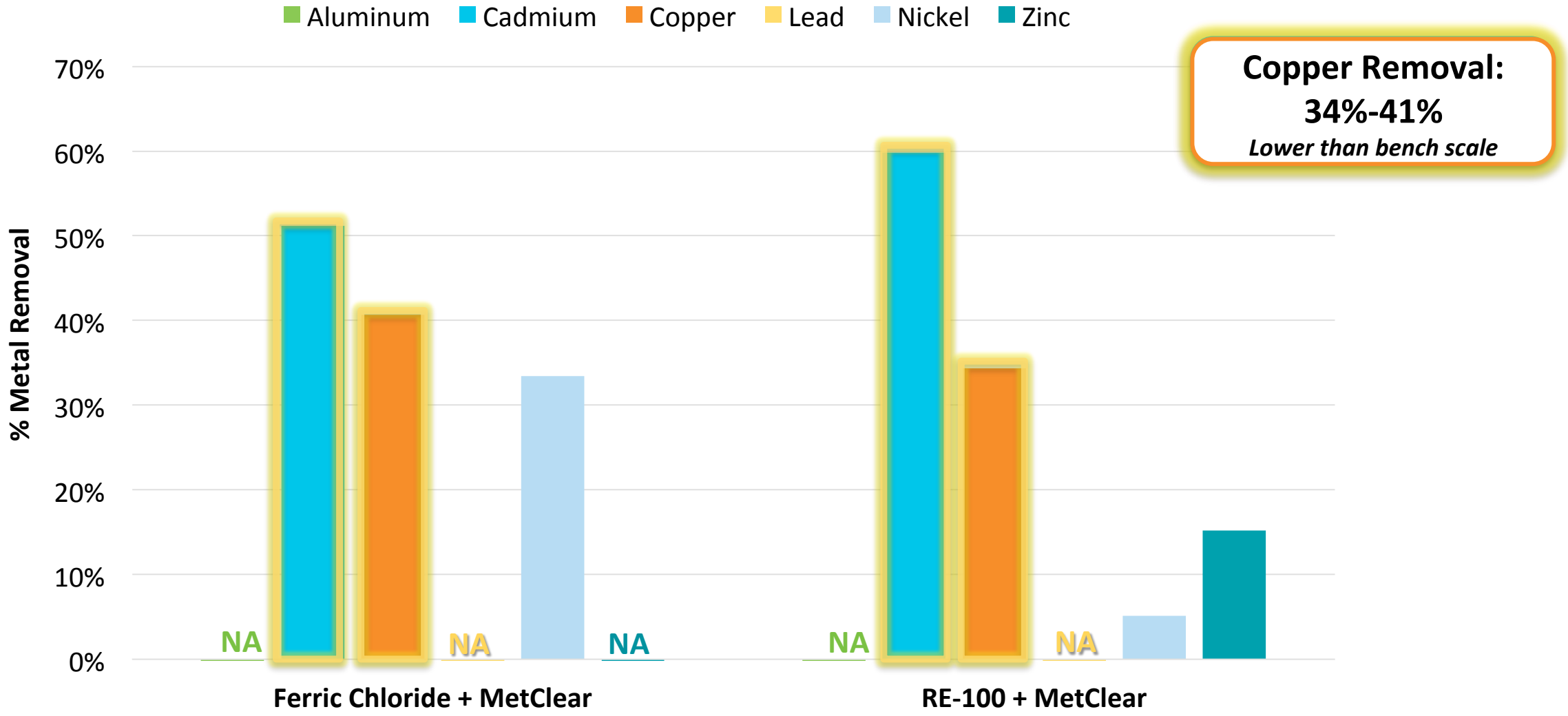
# Coagulant vs. Coagulant:
# Resultant **Copper** Concentrations




Ferric was considered to be a viable coagulant for Upper Blackstone.

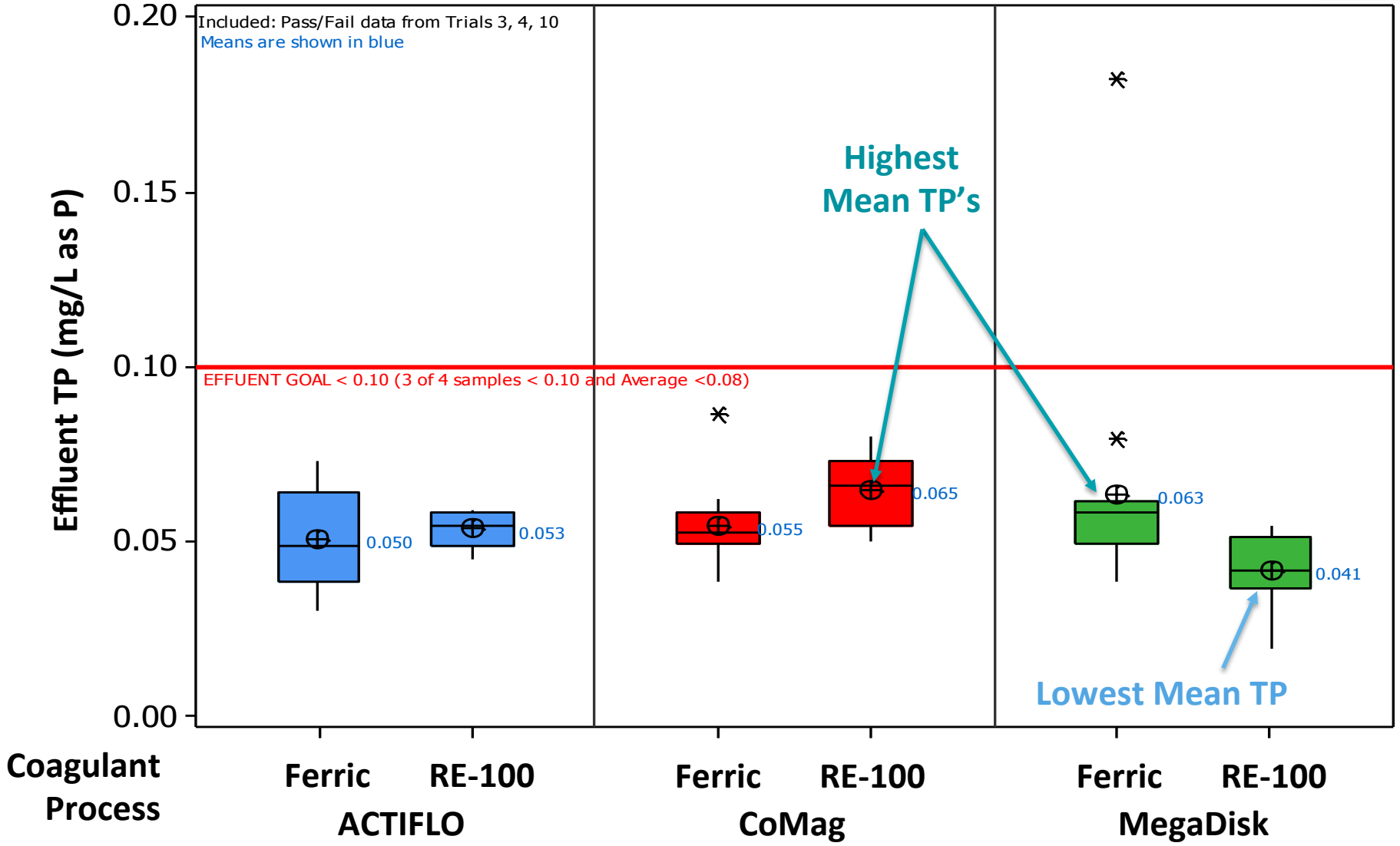
# Effectiveness of Sulfide-Based Polymer (MetClear™ 2405 )

*Results from all 3 Pilot Technologies*



# Phosphorus Removal Performance:
# **Effluent Goal=0.10 mg/L TP**

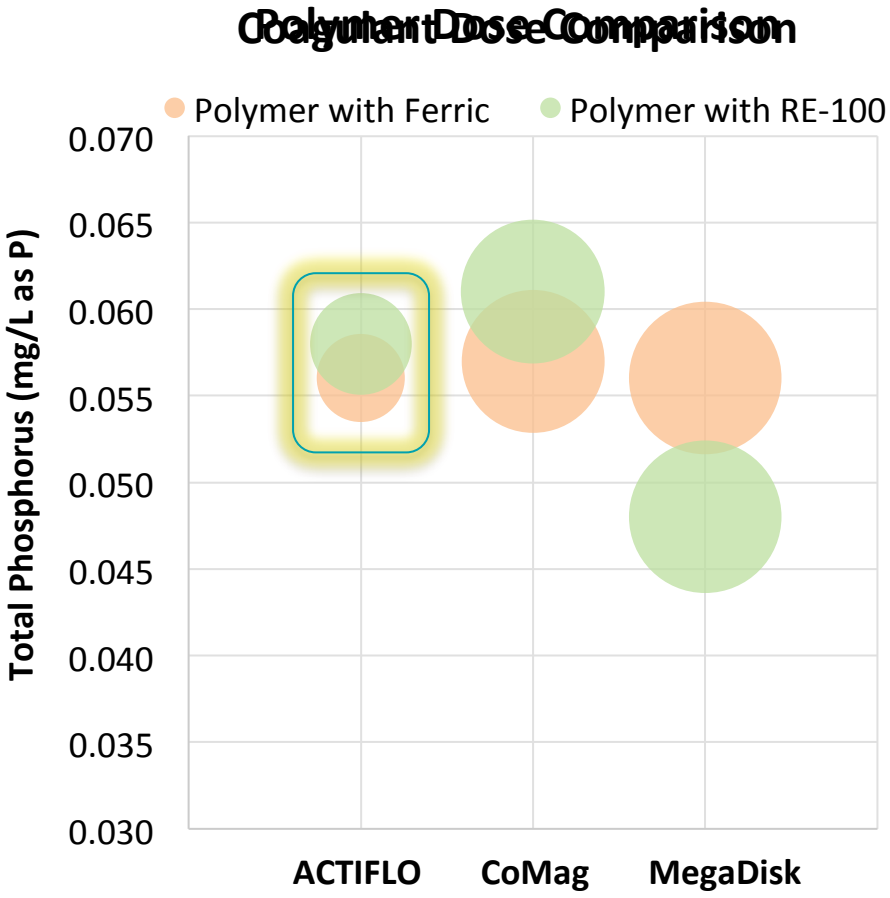
**Influent TP Concentrations:**
**Trial 3**: 1.0 mg/L TP
**Trial 4**: 0.3 mg/L TP
**Trial 10**: 0.1-0.2 mg/L TP



# Chemical Dosage Summary:
# Effluent Goal=0.10 mg/L TP

**Bolded=** Influent 0.30 mg/L TP
*(Italics Range)=Min-Max*

| System | Coagulant Dose *(mg/L)* | Polymer Dose *(mg/L)* | Effluent TP Achieved *(mg/L)* |
|---|---|---|---|
| **Ferric Chloride** | | | |
| ACTIFLO | **10.4** *(7.71-24.0)* | **0.30** *(0.25-0.45)* | **0.056** *(0.037-0.058)* |
| CoMag | **10.9** *(4.92-20.3)* | **0.79** *(0.80-0.99)* | **0.057** *(0.048-0.058)* |
| MegaDisk | **6.87** *(1.91-20.3)* | **0.90** *(0.79-0.90)* | **0.056** *(0.044-0.058)* |
| **RE-100** | | | |
| ACTIFLO | **11.0** *(8.89-19.9)* | **0.40** *(0.40-0.51)* | **0.058** *(0.048-0.058)* |
| CoMag | **5.66** *(4.98-12.0)* | **0.80** *(0.81-1.39)* | **0.061** *(0.064-0.70)* |
| MegaDisk | **3.59** *(1.01-10.9)* | **0.90** *(0.75-1.0)* | **0.048** *(0.030-0.050)* |





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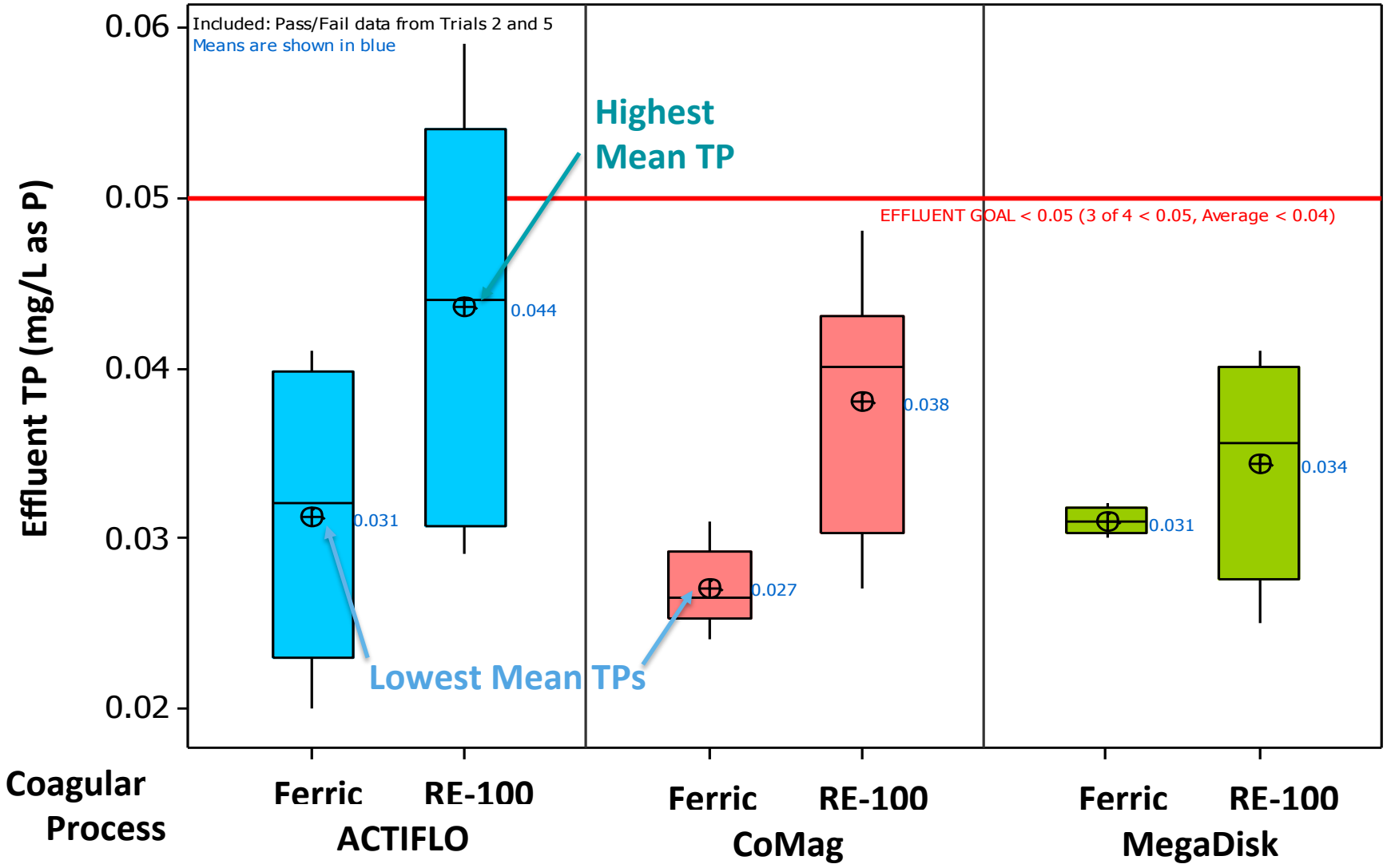
# Phosphorus Removal Performance:
# Effluent Goal=0.05 mg/L TP

**Influent TP Concentrations:**
**Trial 2**: 1.0 mg/L TP
**Trial 5**: 0.3 mg/L TP





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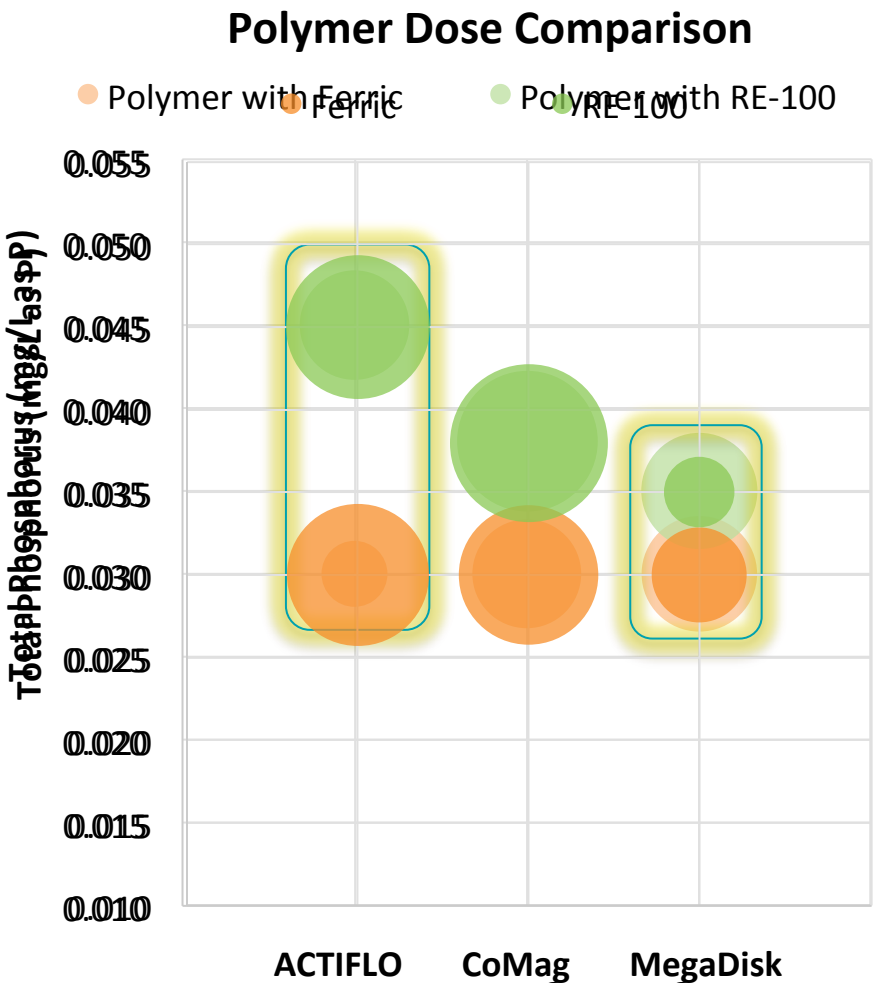
# Chemical Dosage Summary:
# Effluent Goal=0.05 mg/L TP

**Bolded=** Influent 0.30 mg/L TP

| System | Coagulant Dose *(mg/L)* | Polymer dose *(mg/L)* | Effluent TP Achieved *(mg/L)* |
|---|---|---|---|
| **Ferric Chloride** | | | |
| **ACTIFLO** | **19.9** (up to 53.0) | **0.29** (up to 0.33) | **0.04** (0.02) |
| **CoMag** | **19.2** (up to 48.5) | **0.79** (up to 0.80) | **0.03** (0.03) |
| **MegaDisk** | **8.9** | **0.89** | **0.03** |
| **RE-100** | | | |
| **ACTIFLO** | **20.4** (up to 53.7) | **0.80** (up to 0.91) | **0.045** (0.031-0.056) |
| **CoMag** | **24.6** (up to 33.7) | **1.32** (up to 0.79) | **0.033** (0.043) |
| **MegaDisk** | **4.9** (up to 15.4) | **0.90** (up to 1.60) | **0.031** (0.039) |





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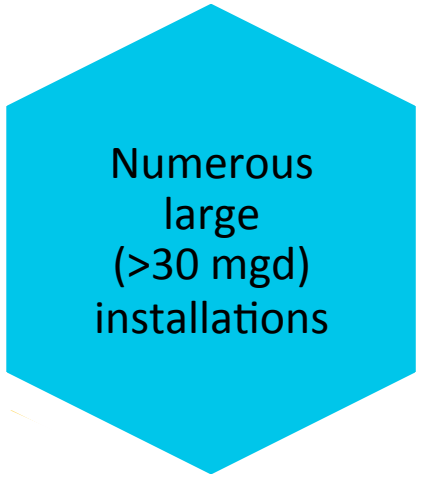
# Phosphorus Removal Evaluation: Preferred Coagulant

- Each system performs better with one coagulant over the other
  - Lower chemical doses
  - Decreased maintenance
  - Less sludge production
- Preferred coagulant based on pilot performance is:
  - ACTIFLO: ferric chloride;
  - CoMag: ferric chloride;
  - MegaDisk: RE-100

# Phosphorus Removal Full-Scale Evaluation: Economic Evaluation

| | Add-On Systems for Tertiary Phosphorus Removal | | |
|---|---|---|---|
| | **ACTIFLO** + Ferric Chloride | **CoMag** + Ferric Chloride | **MegaDisk** + RE-100 |
| **Estimated Relative Capital Costs** | $47,000,000 | $45,000,000 | $33,000,000 |
| **Estimated Annual O&M Costs** | $800,000 | $800,000 | $1,000,000 |
| **Present Worth of 20-Year Life Cycle Costs** | **$57,000,000** ≈ | **$52,000,000** ≈ | **$50,000,000** |

# Non-Economic Criteria ACTIFLO




**Success at Other installations**

# Key Pilot Conclusions

- All systems were capable of achieving the 0.10 and 0.05 mg/L effluent TP objective
- Dosing alum resulted in effluent aluminum exceedances
- Sulfide-based polymer effective in removing Cu, Cd, & Ni (not Al)
- Each technologies achieved the TP goals & with metals limits while dosing $FeCl_3$ and RE-100
  - $FeCl_3$ dose must be controlled to avoid elevated Cu
- Ballasted flocculation processes required higher RE-100 doses than cloth filters (absence of hydroxide floc!)
- Non-economic factors were the primary differentiator between systems
  - ACTIFLO with ferric chloride received the highest non-economic score, mainly due to its success at other similarly sized installations

# Acknowledgements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*Engineering:* **Mark Johnson, P.E.** & **Randy Komssi**

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**George Swedberg**

& **Fred Lusky**

Blueleaf Incorporated

Pilot Testing for Water and Wastewater Treatment

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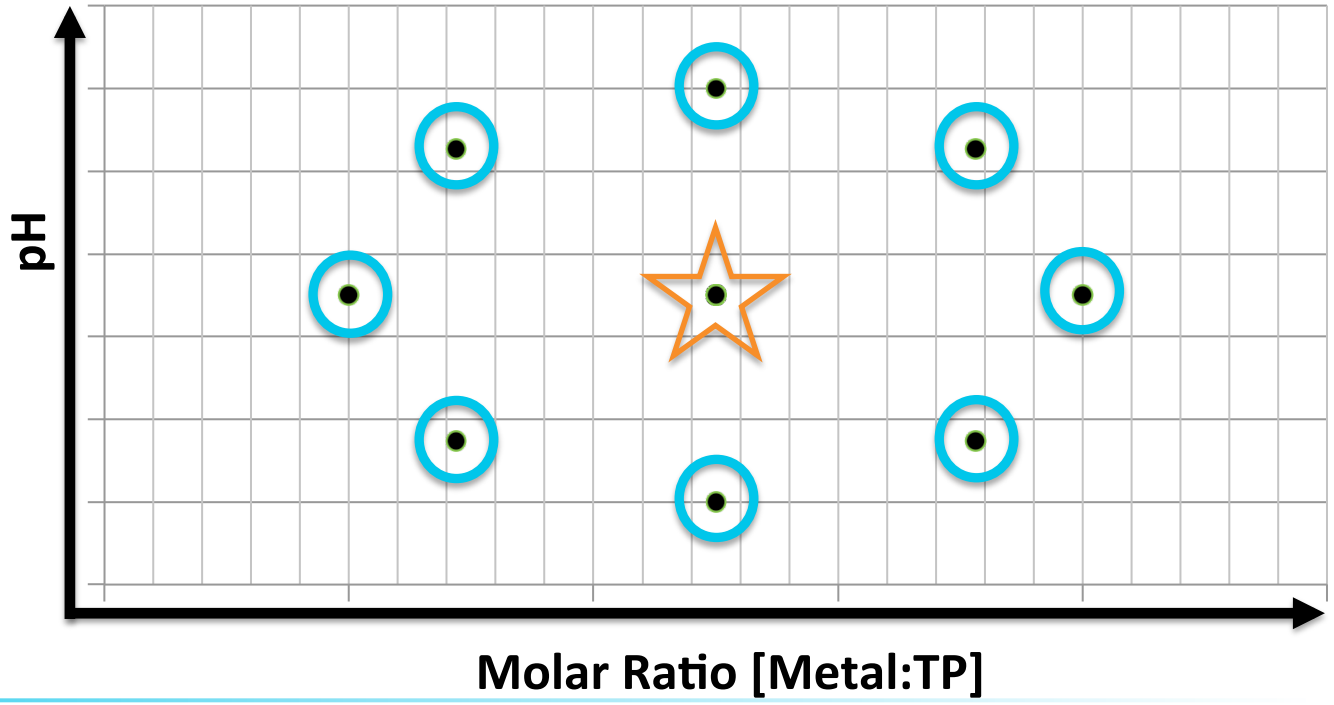
# Response Surface Testing Approach:

*Evaluates the effect of two independent variables on a dependent variable, when two independent variables interact*

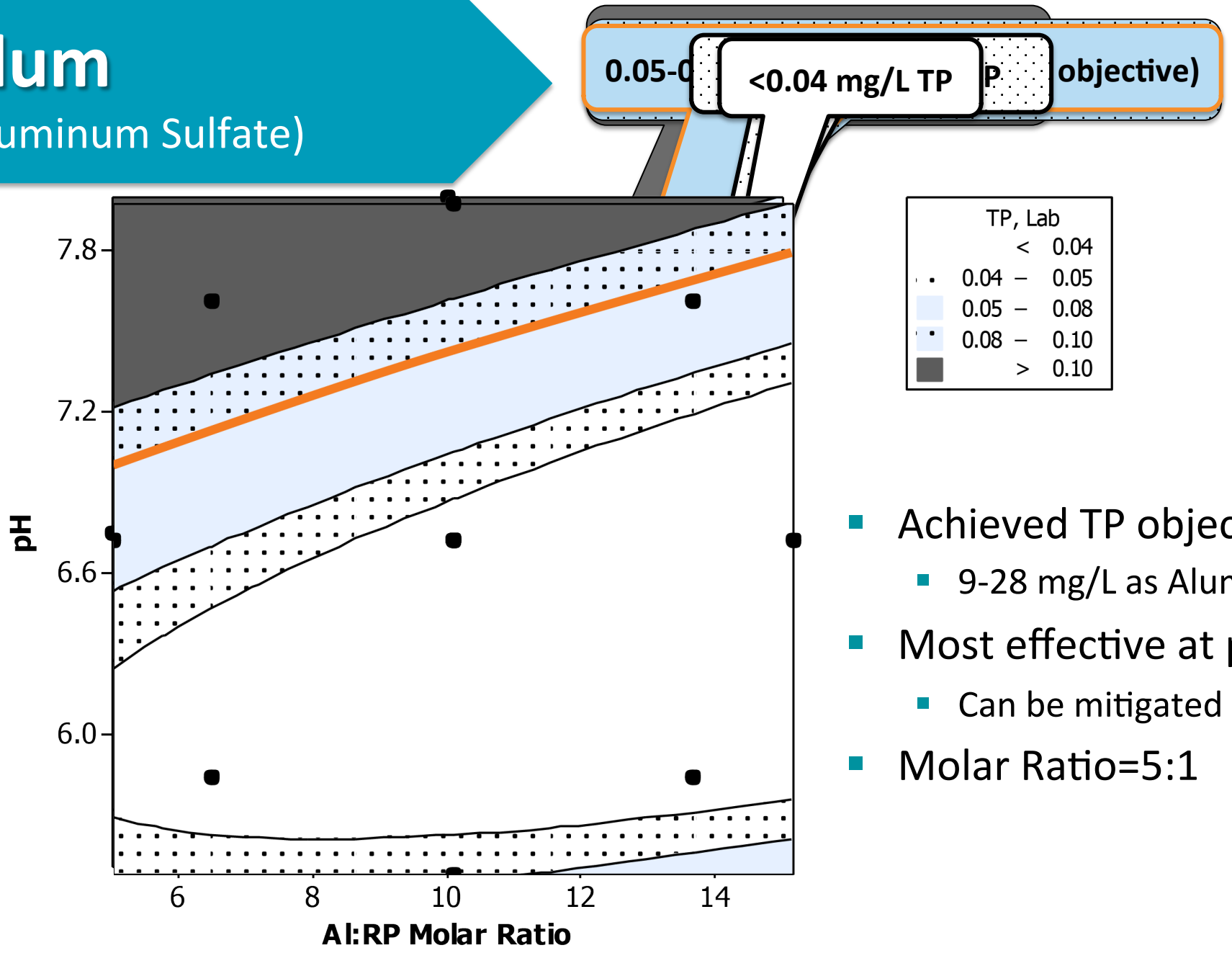
## pH x Coagulant Dose

Center point tested with 5 replicate jars to evaluate variability




Each of the 8 perimeter points represent one jar test (a particular coagulant dose and pH level)

# Alum
(Aluminum Sulfate)

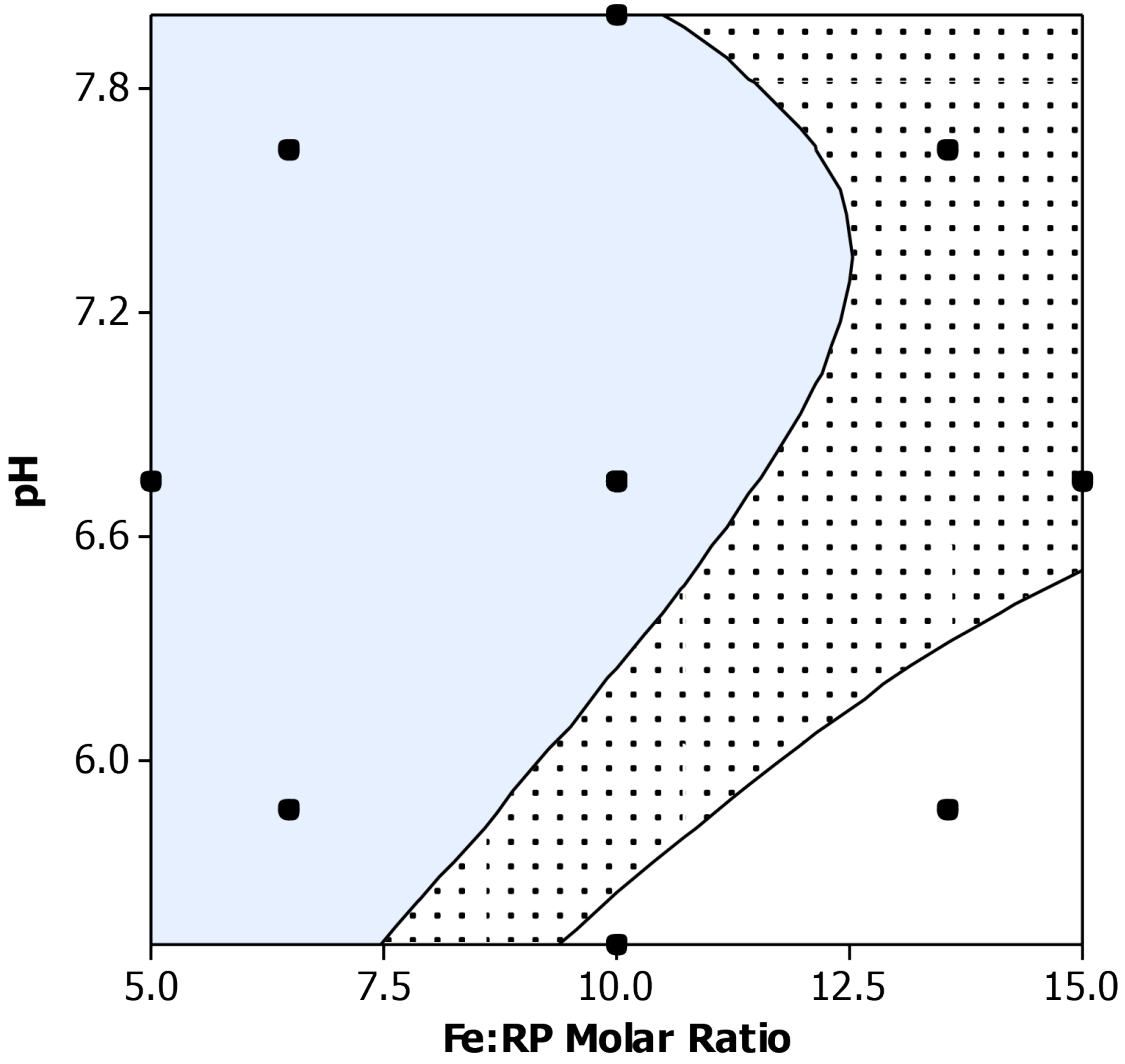


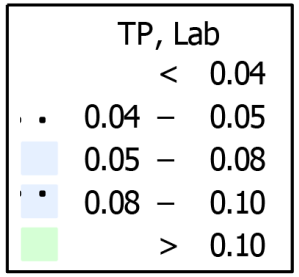

13
Al
26.98

- Achieved TP objective at all molar ratios
  - 9-28 mg/L as Alum
- Most effective at pH <7.0
  - Can be mitigated by higher alum doses
- Molar Ratio=5:1

# Ferric Chloride

26
Fe
55.85

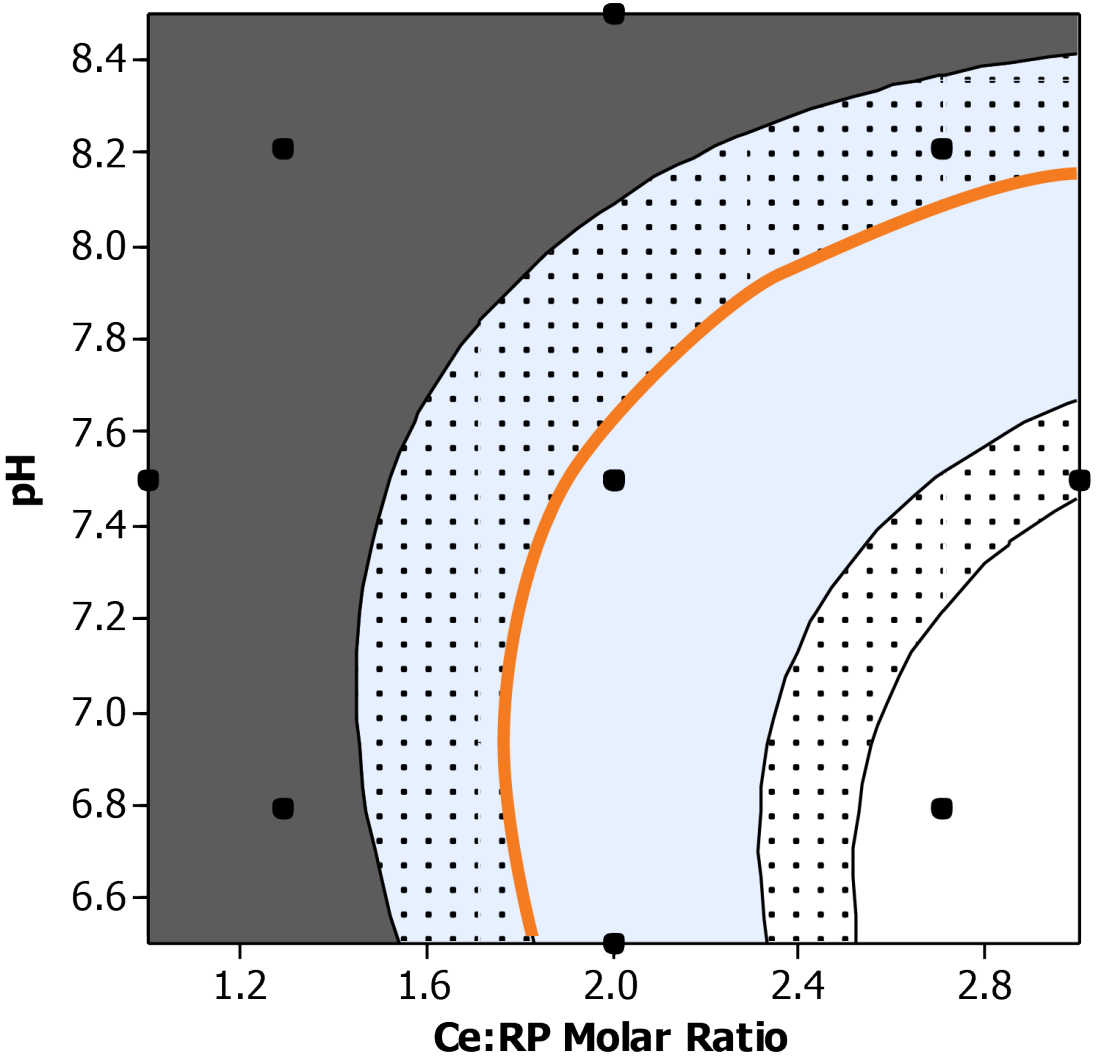


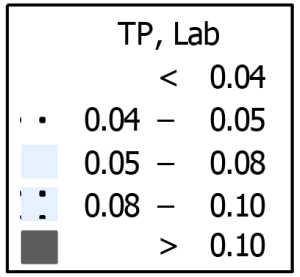




- Achieved TP objective at all molar ratios tested
  - 5-15 mg/L as Ferric Chloride
- Little effect from pH
- Molar Ratio=5:1
  - Similar to Alum

# RE-100
## (Cerium Chloride)

58
Ce
140.1




- Achieved TP objective at molar ratios >2:1
  - 3 mg/L RE-100
- Molar Ratio=2:1
  - The lowest molar ratio of all coagulants

# Summary of Tertiary "Solids" Analyses

- Evaluate impact on existing solids handling facilities of chemical "sludge" produced from the tertiary systems
  - Quantity and quality of residuals
- Komline-Sanderson Engineering Corporation
  - Thickened sludge for thickening evaluation
    - Kompress® Belt Filter Press
    - Simulate full-scale Kompress® G-GRSLX Series III
    - Gravity belt drainage and pressure belt drainage
- Alfa Laval Incorporated
  - Unthickened sludge for dewatering evaluation
  - Thickened sludge for thickening evaluation
    - Centrifuge
    - 3 Belt Klampress
    - Extended Klampress

# Summary of Tertiary "Solids" Analyses

Influent TP=0.3 mg/L TP (~secondary effluent)

| System | Waste Rate (% of Forward Flow) | TSS of Unthickened Samples (mg/L)[1] | TS of Pre-Thickened Samples | | Cake Solids Range (%) | |
|---|---|---|---|---|---|---|
| | | | Alfa Laval | Komline | Alfa Laval | Komline |
| **Ferric Chloride** | | | | | | |
| ACTIFLO | 3.8% | NA[2] | 0.83 | 0.77 | 17-20 | 15-16 |
| CoMag | 1.0% | 770 | 1.4 | 0.81 | 20-23 | 21-22 |
| MegaDisk | 8.8% | 58 | 0.43 | 0.63 | 18-22 | 11-14 |
| **RE-100** | | | | | | |
| ACTIFLO | 4.4% | 338 | 1.76 | 2.88 | 36-39 | 26-33 |
| CoMag | 0.8% | 860 | 1.49 | 1.22 | 24-27 | 21-23 |
| MegaDisk | 9.3% | 60 | NA[3] | NA[3] | NA[3] | NA[3] |

Notes:

1. Minimum solids concentration for testing for thickening and dewatering was 0.3% (3,000 mg/L).
2. Sample did not survive transport, no TSS analysis was completed.
3. Not enough solids generated to collect the required sample volume (4 L).