Gannett Fleming

Excellence Delivered ***As Promised***

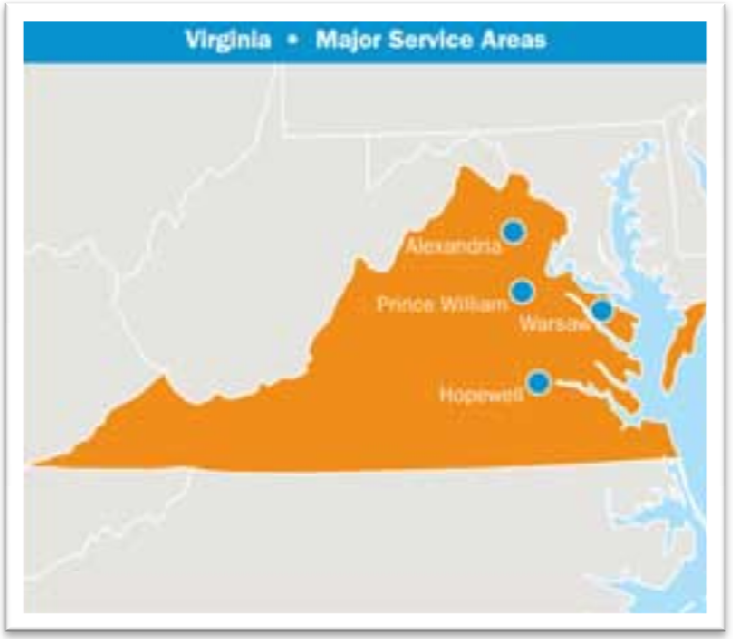
Advanced Oxidation Processes to Reduce Drinking Water Taste and Odor

Jamie R. Shambaugh, P.E.

Lori L. Kappen, P.E.

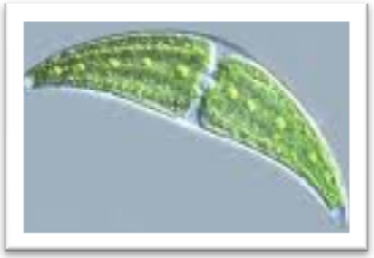
Additional Contributors

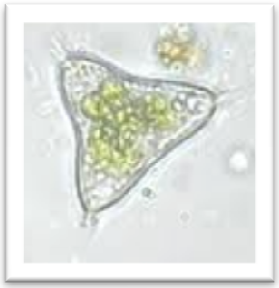
- **Virginia American Water Hopewell District**
  - Michael Youshock, P.E.
  - Christian Volk, Ph.D.



Significant Algae Blooms can Result in Extreme Taste and Odor Event

- **Customer Complaints – earthy/musty taste and smell**
- **Methyl-Iso-Borneol (MIB)**
- **Geosmin**
- **MIB produced by:**
  - Cyanobacteria
  - Green Algae
- **Non-toxic to humans**

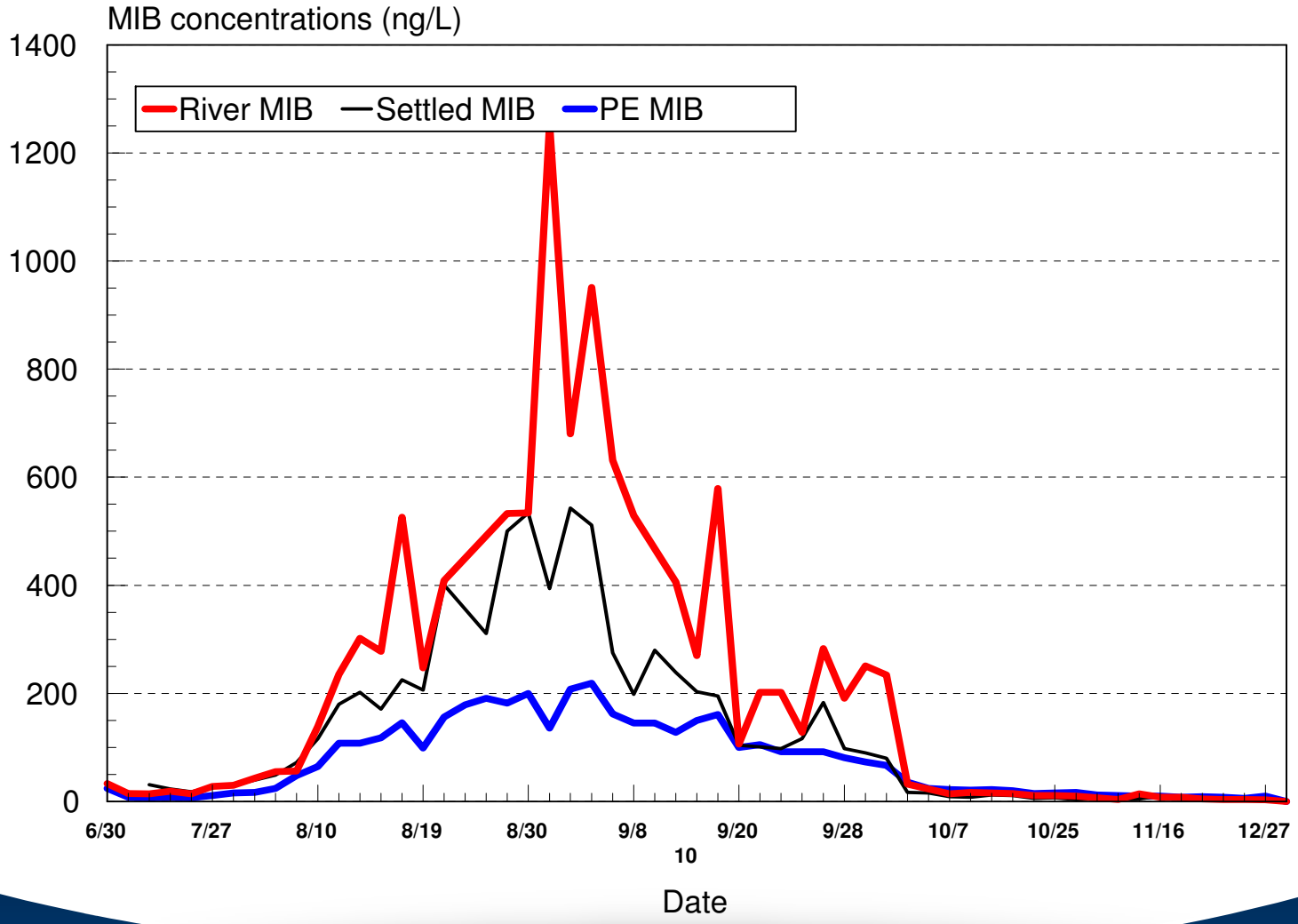


Existing WTP Achieved Good Removal Percentage But High Concentrations Remained

- **Existing Treatment**
  - Sodium Permanganate, PAC, Aeration, Clarification, Filtration, GAC, Chlorine
- **MIB difficult to oxidize with typical oxidants**
- **Existing facilities removed 50 to 75% of T&O**
- **Taste and Odor detectable at <10 ng/L**
- **Plant influent concentrations >1,200 ng/L**
- **Plant effluent concentrations >200 ng/L**

Extreme Raw Water MIB Concentrations Present Treatment Challenges



Many Factors Determine the Course of Corrective Action

- No similar T&O issues previously
- T&O is an aesthetic problem, not regulated
- Solutions may have high cost
- Unknown potential/frequency of recurrence
- Need to address customer and city officials concerns

Selected Course of Action
Addressed Needs in a Responsible Manner

- **Formed Stakeholder Advisory Group**
  - Regular Public Meetings
- **Identified Source of Problem**
- **Identified Potential Solutions**
  - Regional/Environmental – Long Term
  - Operational and Engineering – Short Term
- **Implement Solutions with Stakeholder Buy-in**

Environmental Factors Impact Frequency and Severity of Algae Blooms / T&O Events

- **Part of Chesapeake Bay Watershed Issues**
- **Increased Frequency and Severity of Blooms:**
  - High Nutrient Levels
  - Reduced Flow Caused by Drought
  - High Temperature

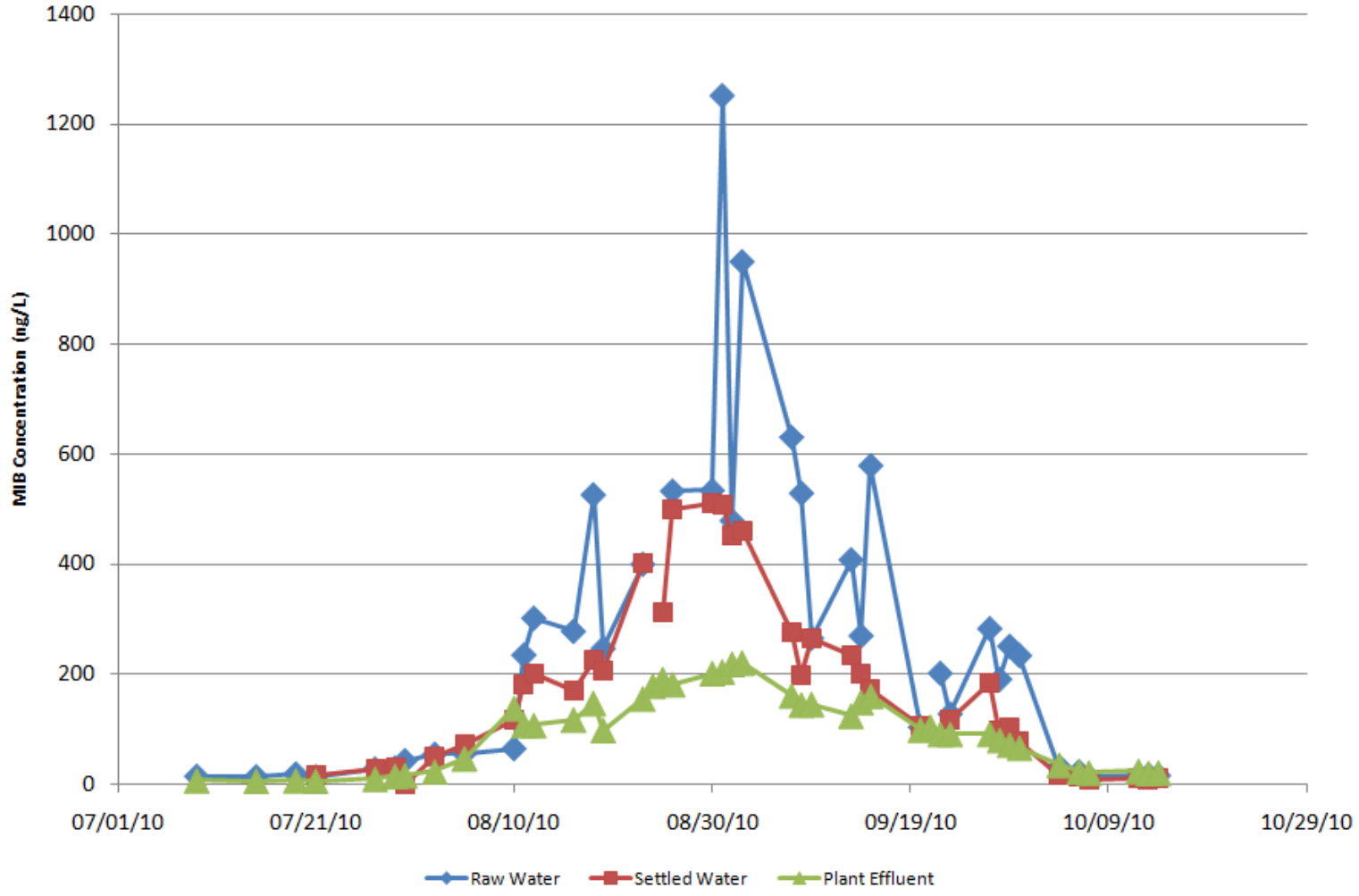
Regional/Environmental Changes Can Provide Long-Term Solution

- **Regulations & Enforcement of Clean Water Act**
- **Watershed Protection Plans:**
  - Focus on non-point sources of pollution
  - Establish local watershed TMDL
- **Community Awareness Programs**
- **State programs - Chesapeake Bay watershed**

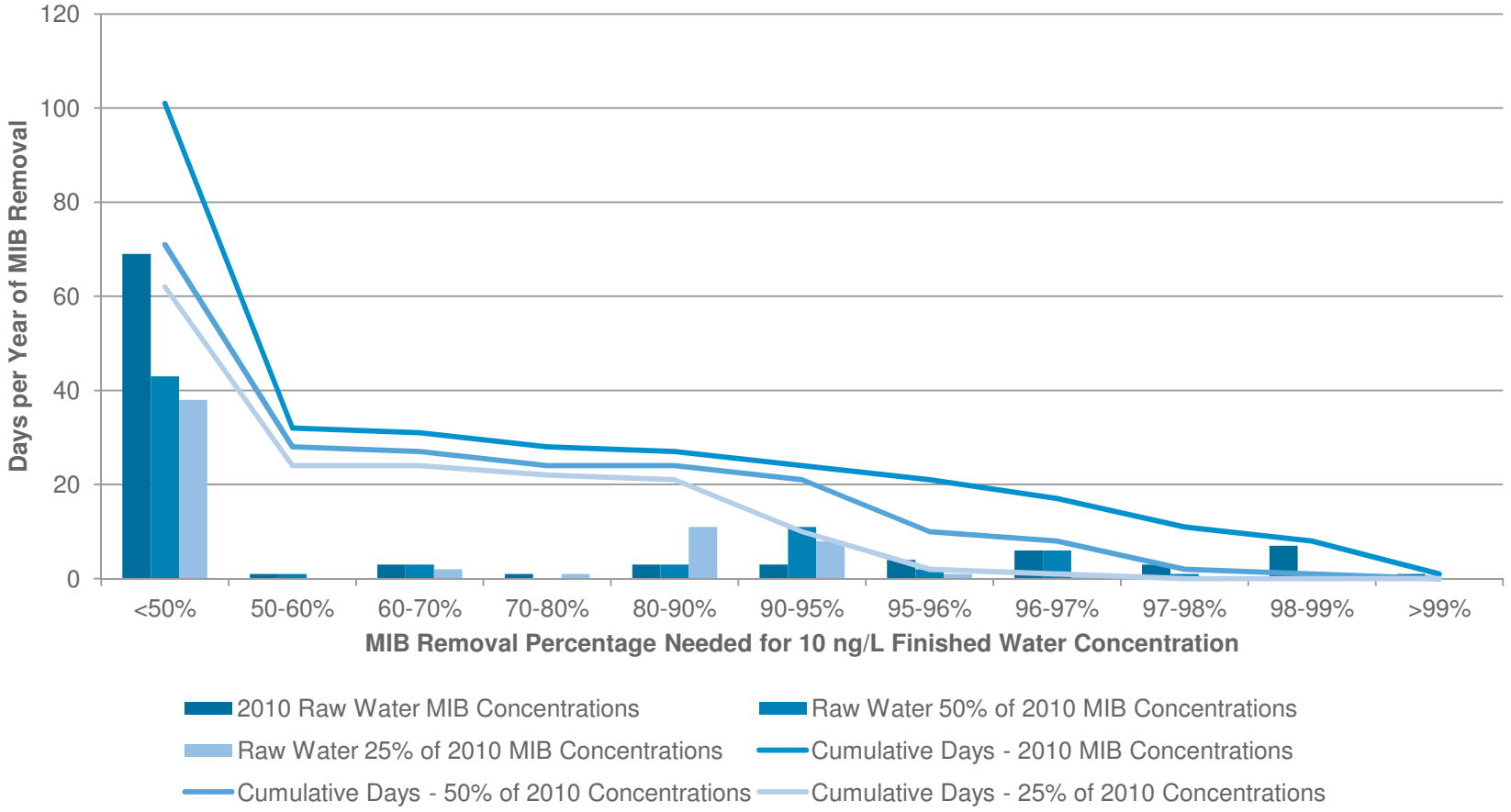
Process Selection Study to Evaluate Operational and Engineering Solutions

- **Operational Solutions:**
  - Optimize Existing Processes
  - Evaluate Effectiveness of Existing Processes:
    - Different Types of PAC
    - GAC media replacement frequency and timing
  - Increase raw water sampling, on-line instruments
- **Engineering Solutions:**
  - Feasibility study of advanced treatment options
  - Pilot study using UV and hydrogen peroxide

Raw Water MIB Concentrations Resulted in High Plant Effluent Concentrations



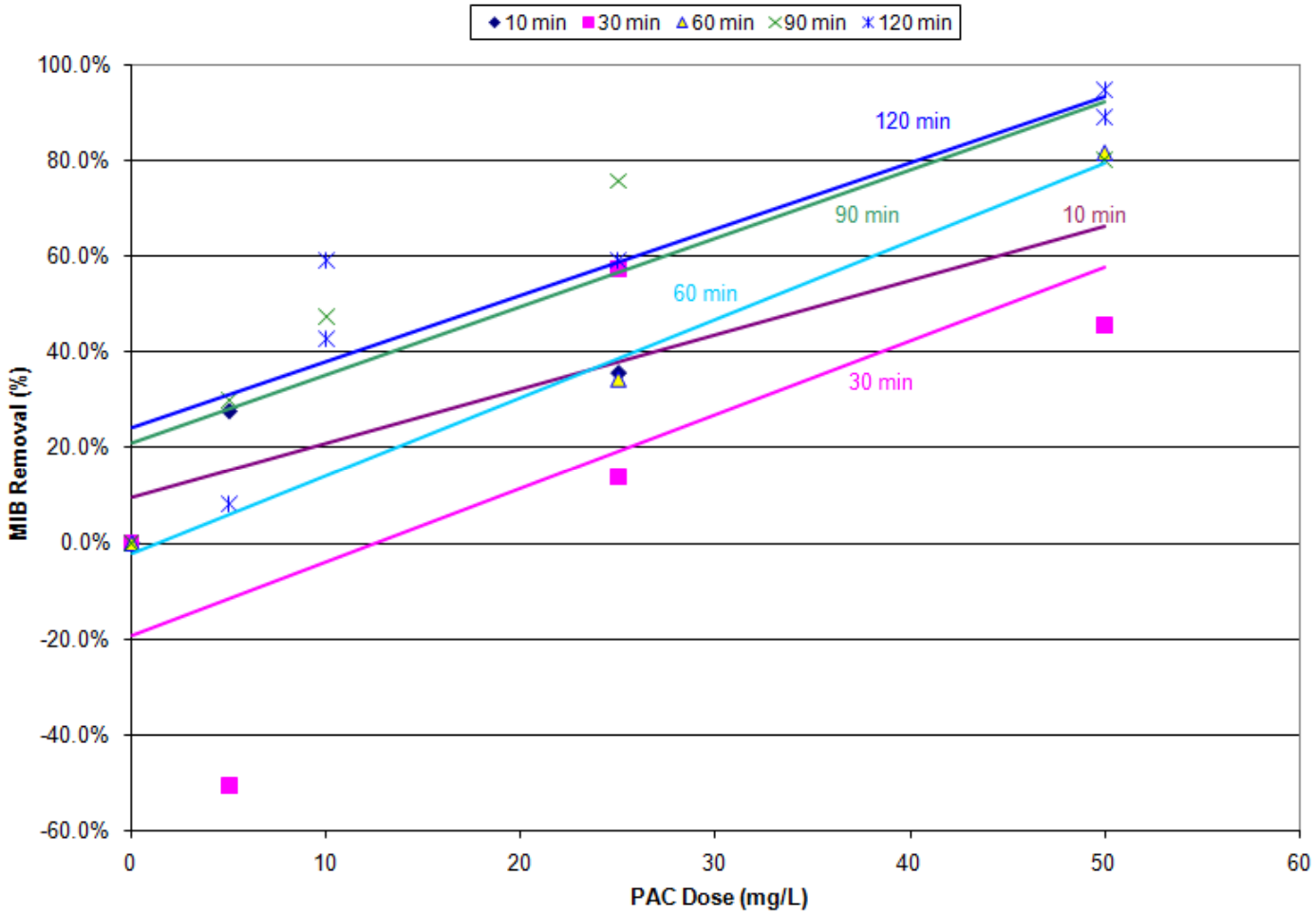
Frequency of Required Percent Removal Drives Process Selection



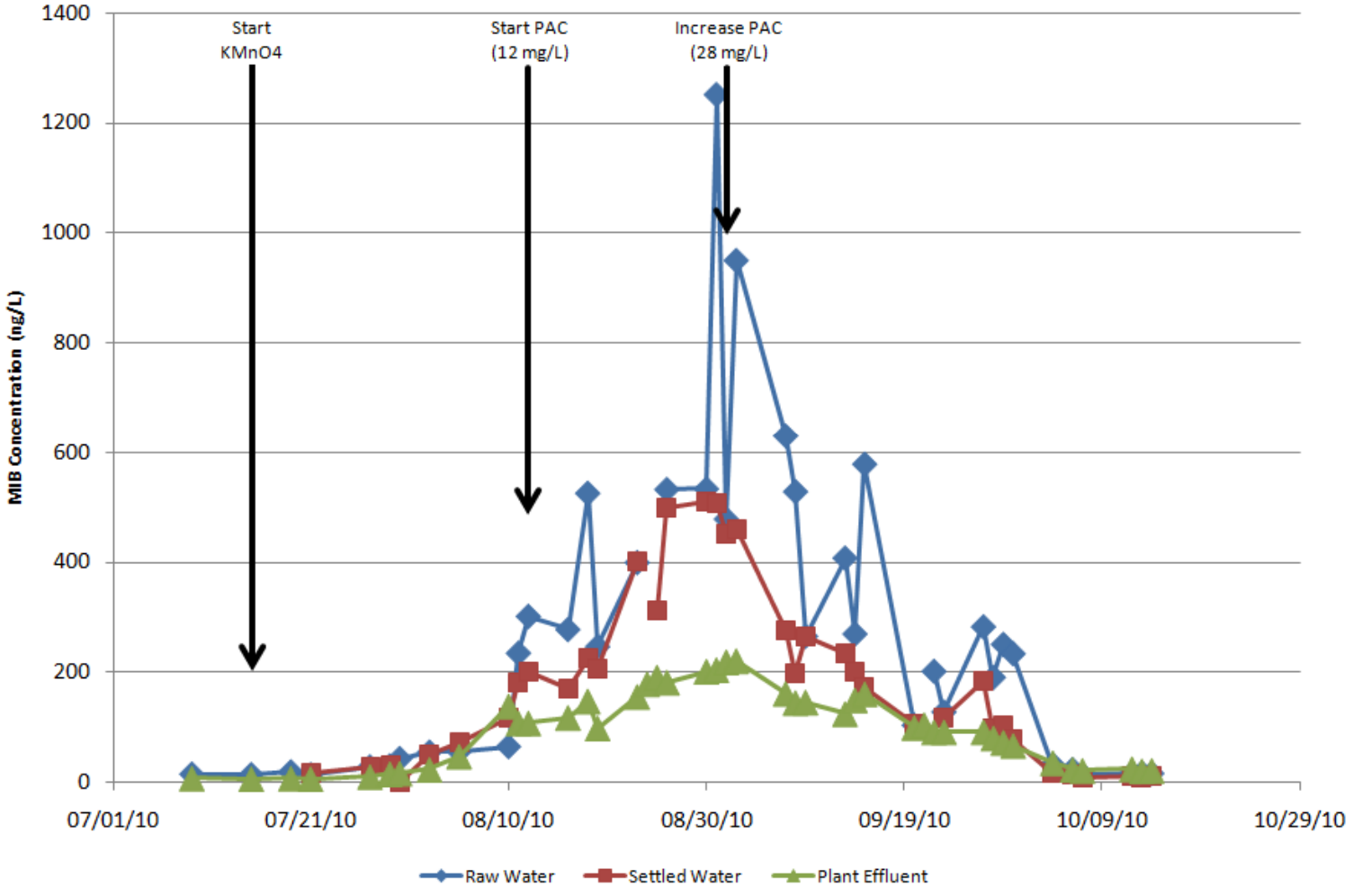
Process Selection Study Evaluated T&O Reduction Alternatives

- **Raw Water Improvements – Not Practical**
- **Chemical Oxidation – Limited Effectiveness, Increased Odors**
  - Chlorine, chlorine dioxide, permanganate, ferrate
- **Adsorption (PAC and/or GAC)**
- **Advanced Oxidation Processes (AOP)**
  - Peroxone
  - UV/Peroxide

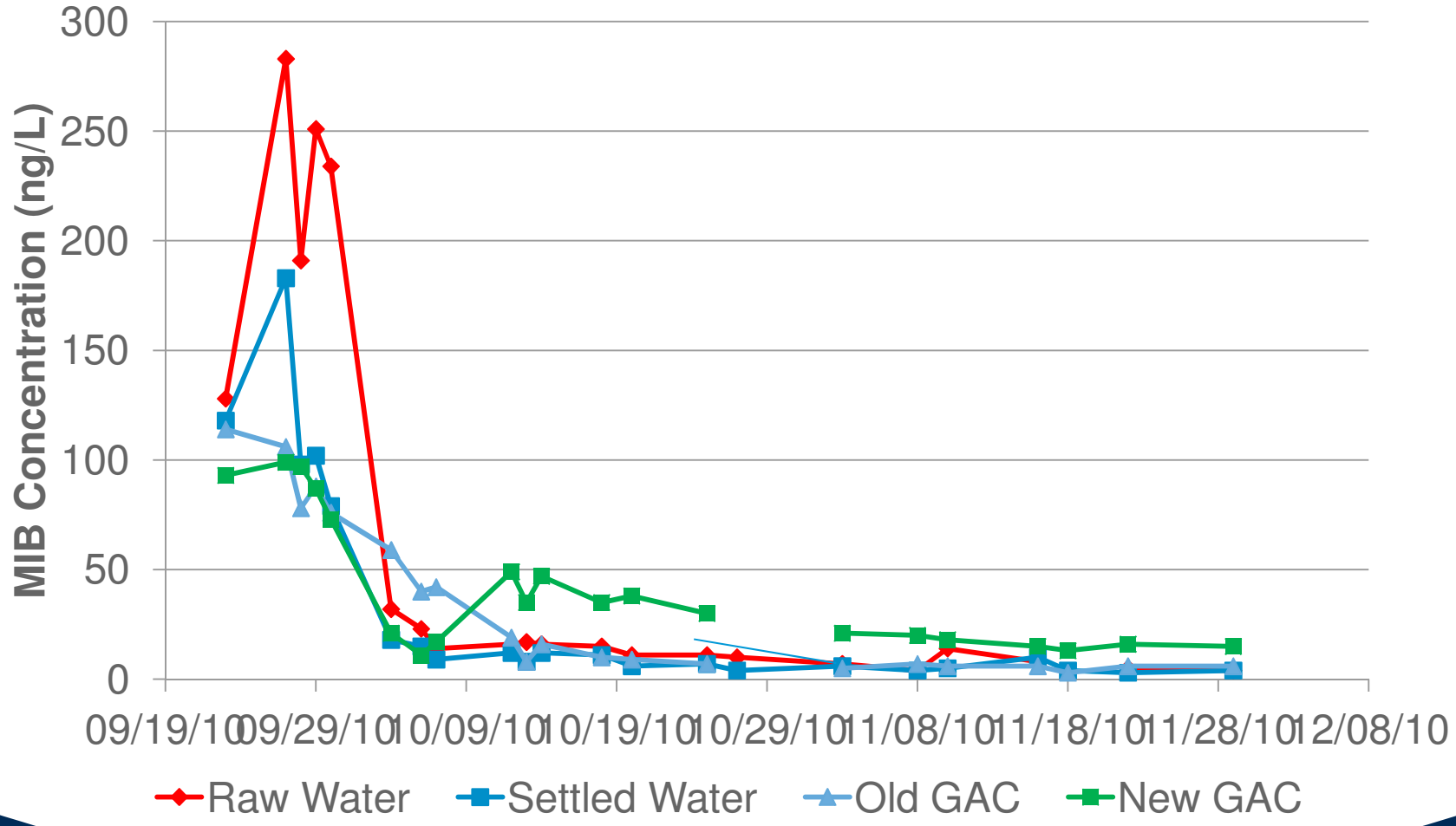
PAC and/or GAC are Effective for Moderate Concentrations



PAC/GAC was Moderately Effective During 2010 Event



Desorption From New GAC
Prolonged Taste and Odor Event



Advanced Oxidation Processes can Provide More Effective Treatment

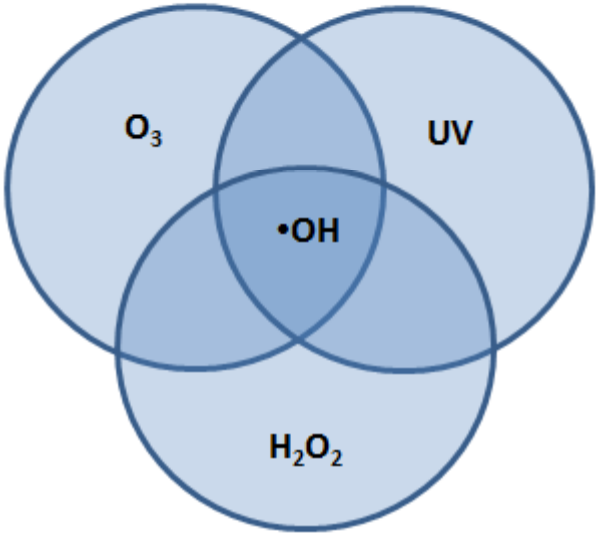
- **Based on oxidation by highly reactive radicals**
- **Hydroxyl radical (•OH) primary oxidant**

Oxidative Species	Redox Potential (V)
Hydroxyl radical	2.80
Ozone	2.07
Hydrogen peroxide	1.78
Permanganate	1.69
Chlorine Dioxide	1.56
Chlorine	1.36
Oxygen	1.23

J. Environ. Eng. Sci. Vol. 1, 2002

Advanced Oxidation Processes Require Production of Hydroxyl Radicals

- **The generation of OH radicals is accelerated by combining:**
  - Ozone
  - Hydrogen Peroxide
  - UV Radiation
- **In combinations such as:**
  - O_3-H_2O_2
  - O_3-UV
  - H_2O_2-UV



AOPs Require Formation of Hydroxyl Radicals

- **Ozone – Hydrogen Peroxide (Peroxone)**

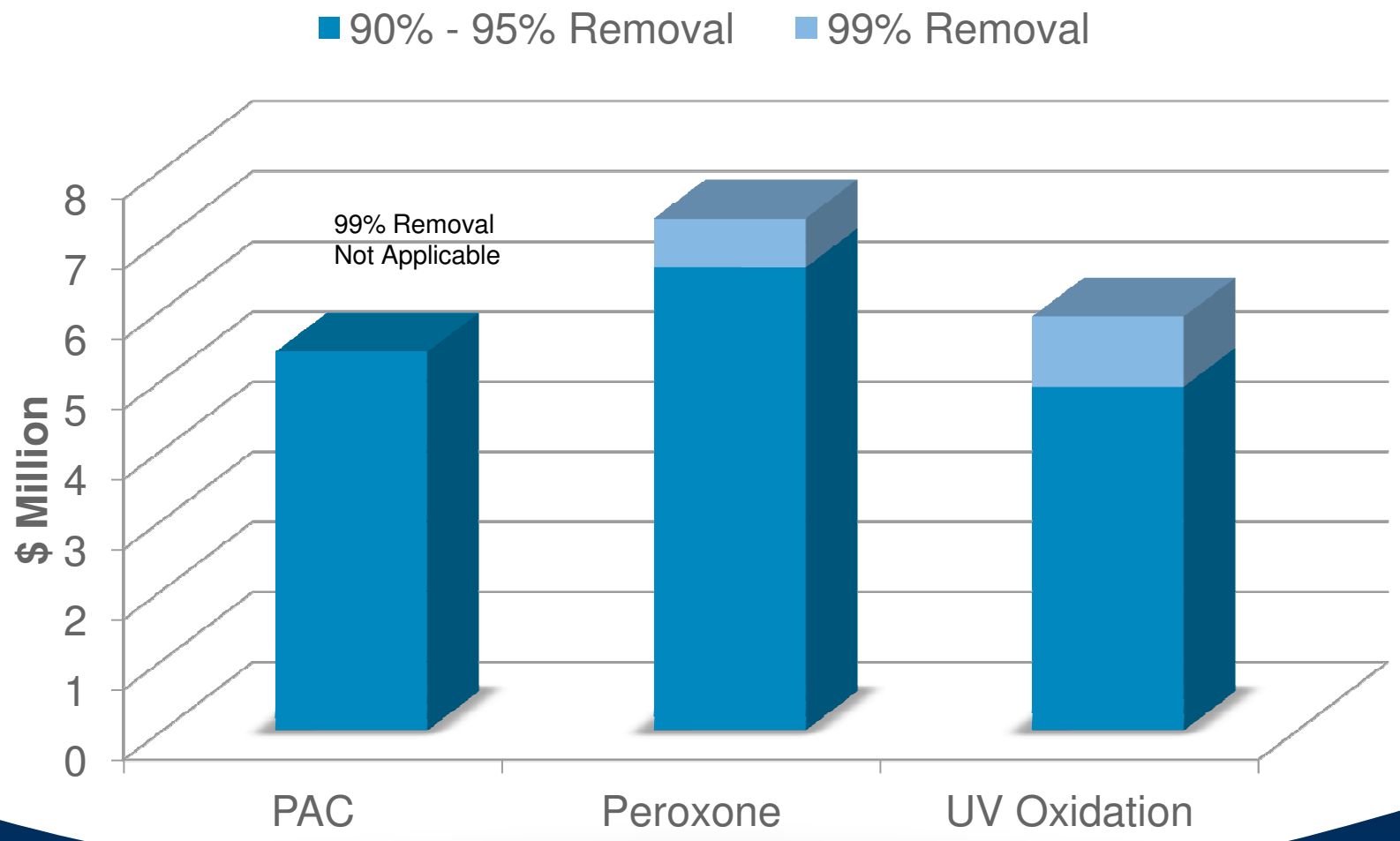
  $H_2O_2 + H_2O \rightarrow HO_2^- + H_3O^+$

  $HO_2^- + O_3 \rightarrow \bullet OH + O_2^- + O_2$

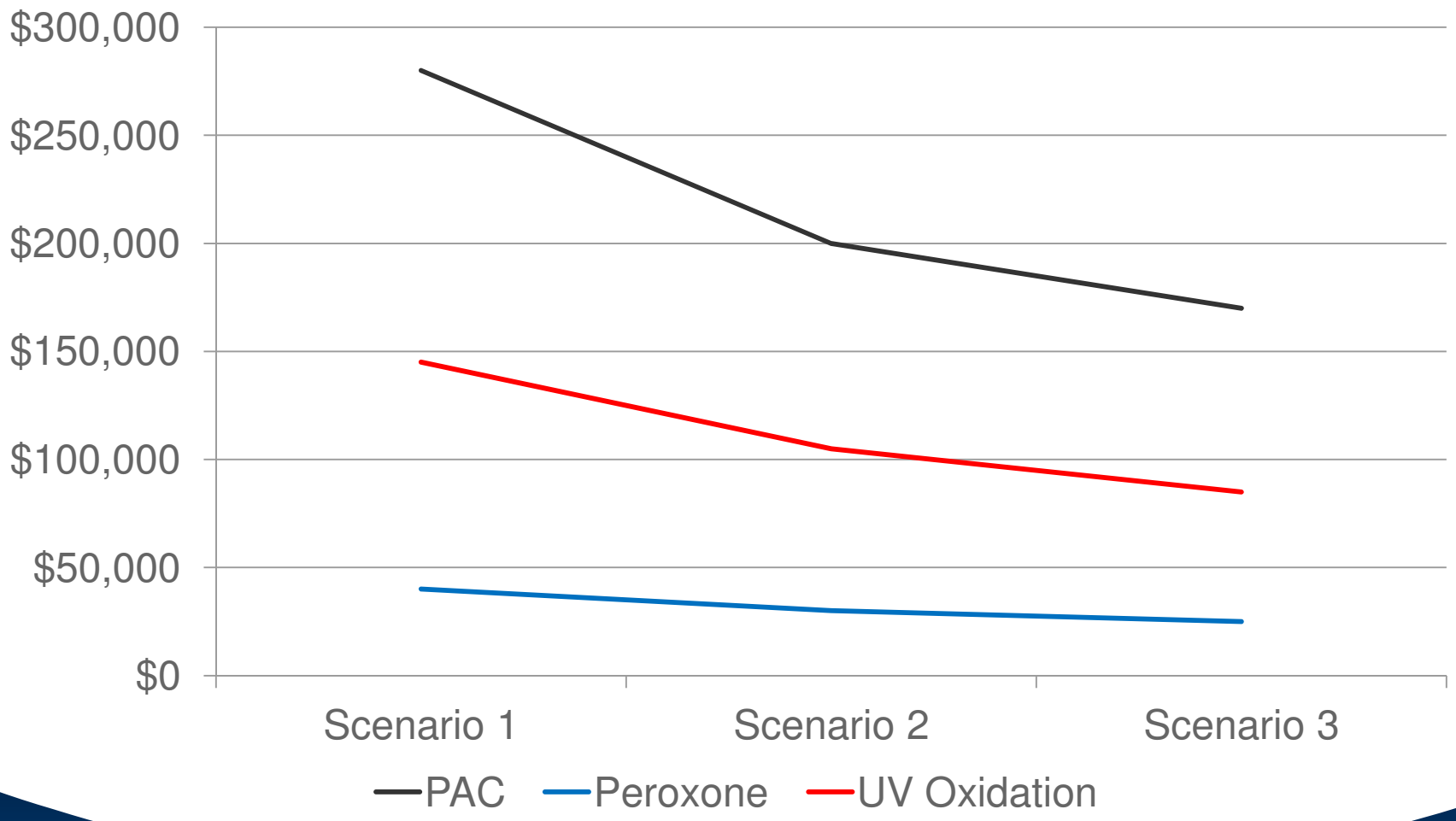
- **Ultraviolet – Hydrogen Peroxide**

  $H_2O_2 + \upsilon \rightarrow 2 \bullet OH$

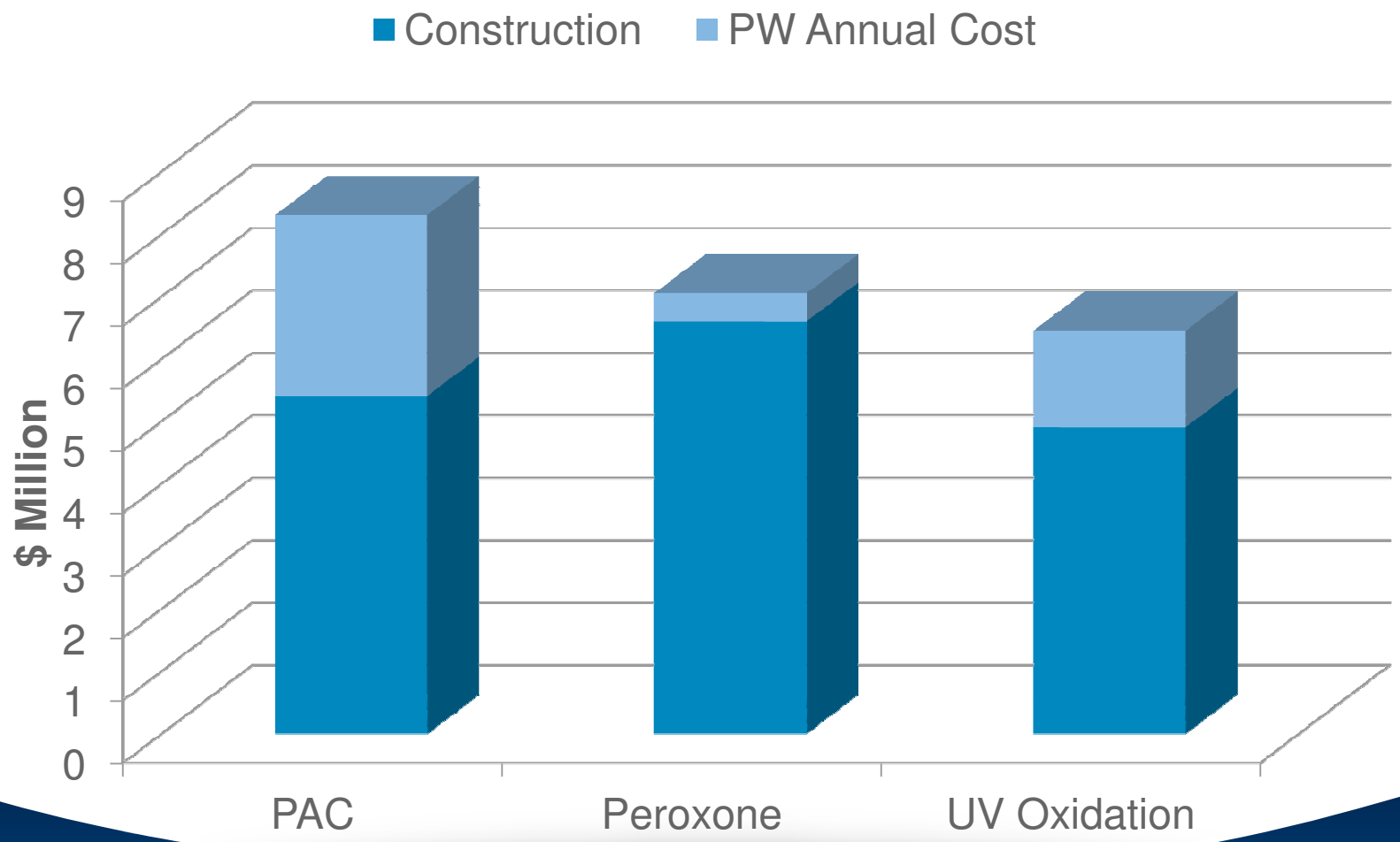
WTP Characteristics Resulted in Favorable Probable Construction Costs for UV Oxidation



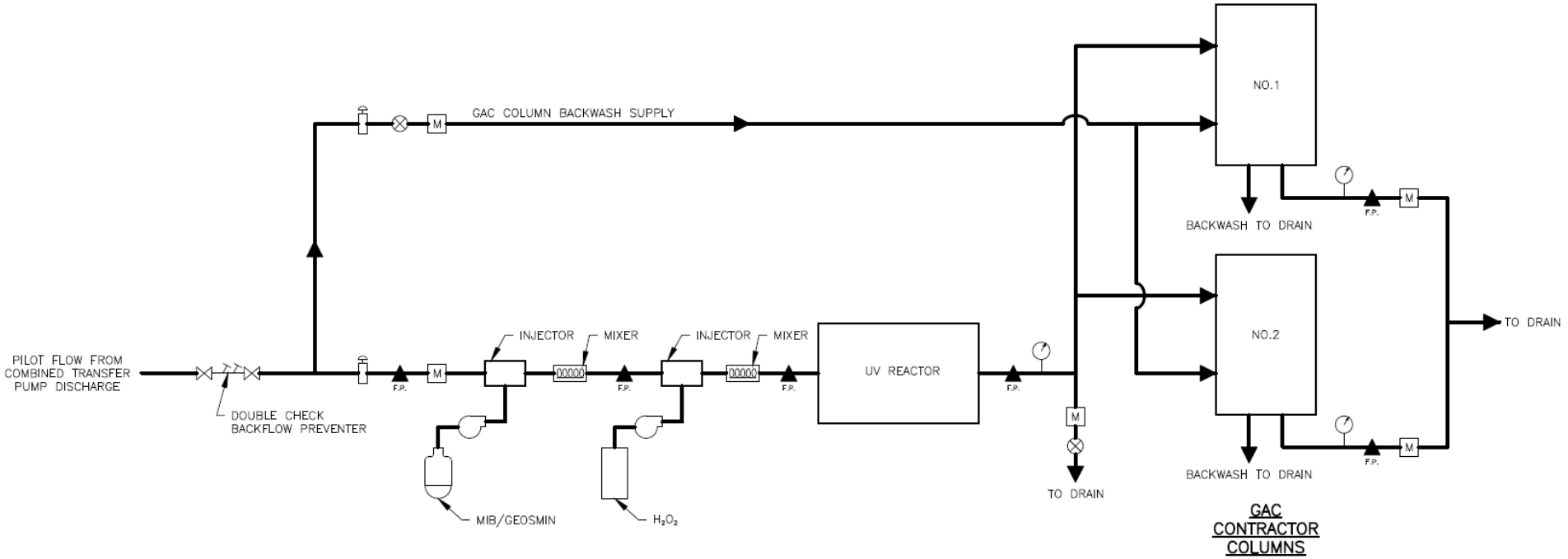
Peroxone Alternative Has Lowest Probable Annual Operating Cost



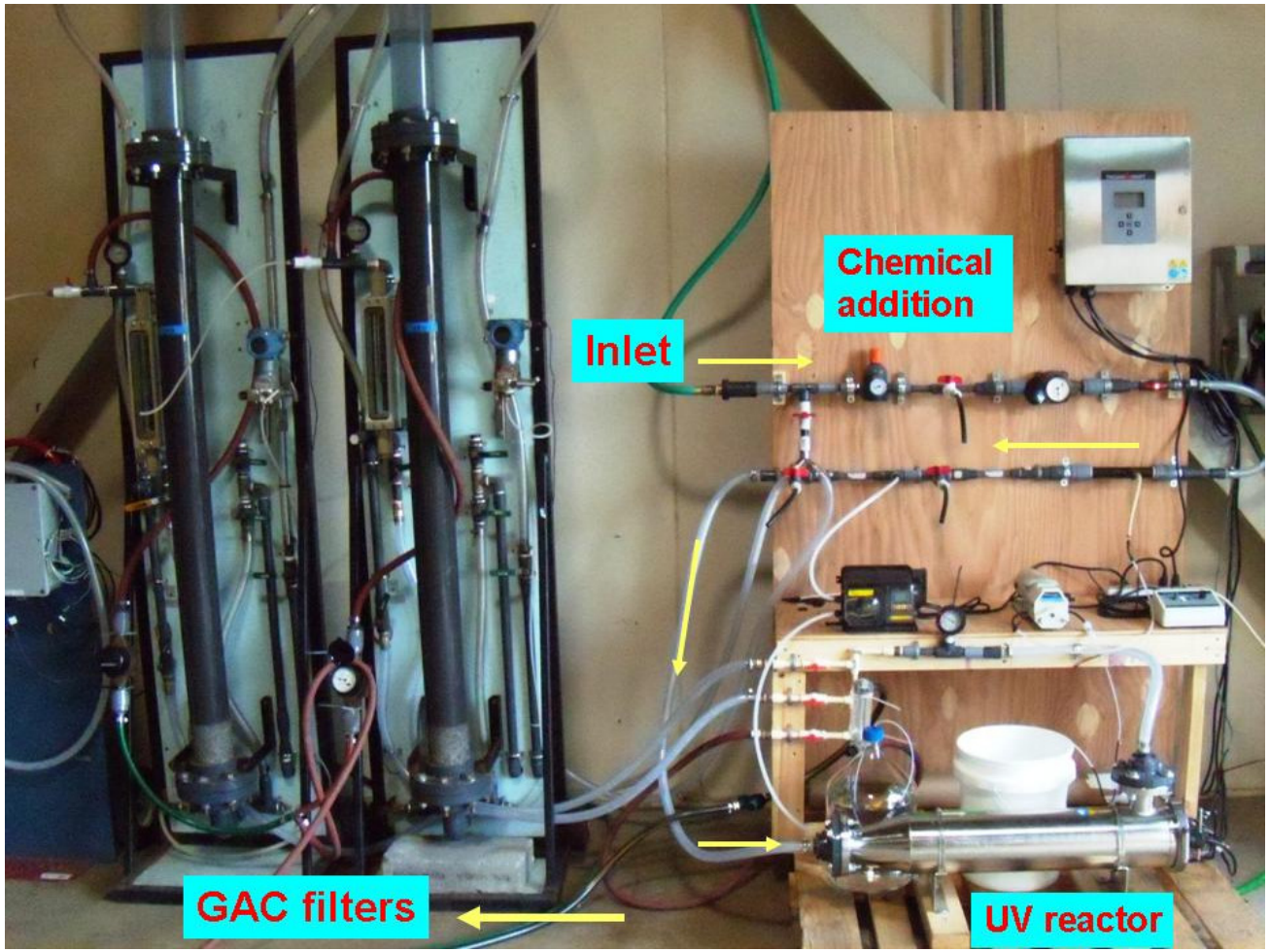
Comparison of 20-Year Present Worth Cost Comparison Results in Appropriate Selection



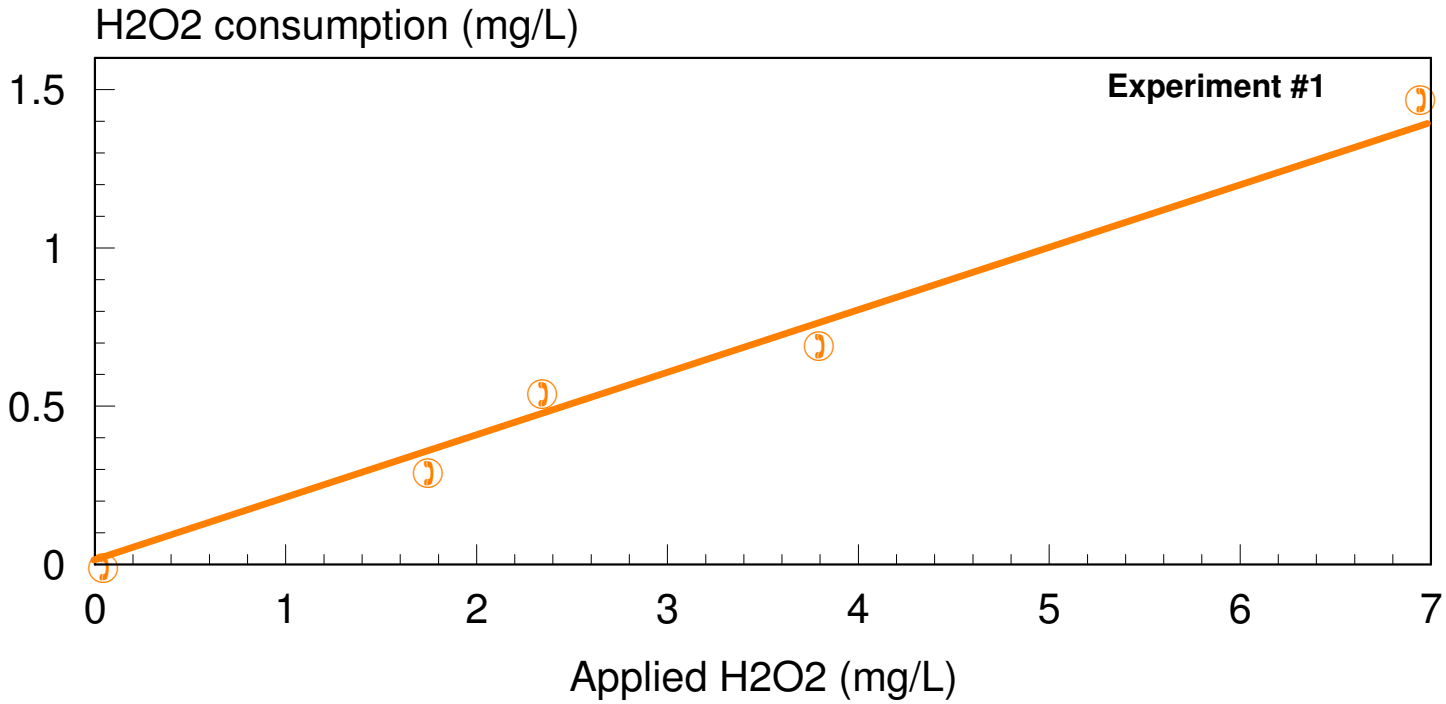
Pilot Test Designed to Prove Concept



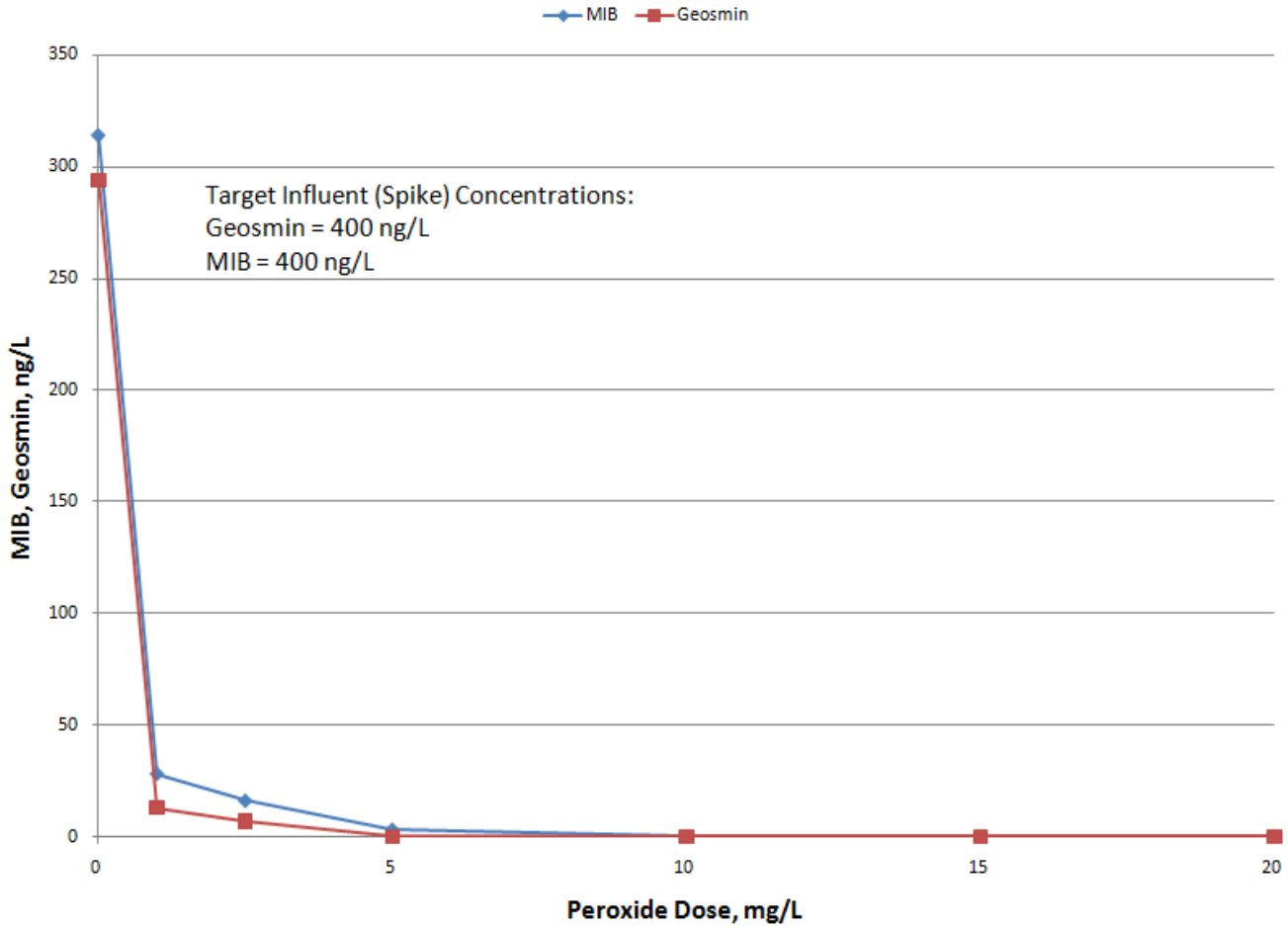
Pilot Test Arrangement for Proof of Concept Testing



Pilot Test Verification of Hydroxyl Radical Production as a Function of Peroxide Dose



Pilot Test Demonstrates Complete Removal of MIB and Geosmin



Disadvantages of AOPs Must be Considered

- **Power consumption (can be 4 times that for disinfection)**
- **Significant Capital Cost**
- **Quenching of Peroxide Residual**
  - Chlorine at 2:1 ratio or GAC/BAC

Advantages of AOPs Outweigh Disadvantages and Provide the Required Treatment

- Minimal operator attention required
- Effective for T&O control, disinfection, PPCPs & EDC
- No residuals or byproducts (AOC)
- On/Off seasonally or turndown for disinfection only
- Removal percentages not available from other technologies
- Cost advantages for T&O at extreme concentrations
- Smaller footprint compared to contact tanks
- Nearly instantaneous treatment
- Smaller carbon footprint reported by others

Summary and Conclusions

- **Taste and Odor issues are becoming more common**
  - VAW's Hopewell System faced a very severe episode
- **AOP's can be a cost effective approach**
  - Not a "one size fits all" solution
- **Educate and involve Stakeholders and consider:**
  - Severity of the T&O constituents
  - Source water characteristics
  - Attributes of the existing process
- **Narrow alternatives based on technical requirements**
- **Evaluate capital and operating costs**
- **Consider operational impacts**
- **Select the optimum treatment approach for your system**