Message

From: Andrews Dale [dale.andrews@[redacted]
Sent: 1/9/2018 8:56:15 PM
To: Benware, Richard [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=4b2e011a22a44312a04299f118cc4d11-Benware, Richard]
CC: Ryan Novak [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=userb996a810]
Subject: RE: Carmeuse EPA
Attachments: Pozzotec Solution to ELG-EPA.pdf

W/O Water Research....

Dale C. Andrews, PG
Carmeuse Lime & Stone

From: Andrews Dale
Sent: Tuesday, January 09, 2018 2:02 PM
To: 'benware.richard@epa.gov'
Cc: 'ryan.novak@erg.com'
Subject: Carmeuse EPA

Hello,

Presentation attached.

Dale C. Andrews, PG
Technical Marketing Manager

Carmeuse Lime & Stone
11 Stanwix Street, 21st Floor
Pittsburgh, PA 15222
Phone: [redacted] / Mobile: [redacted]
Visit www.carmeusena.com

CARMEUSE
NATURAL SOLUTIONS

CARMEUSE
LIME & STONE
and
STT ENVIRO CORP.

Look forward to
meeting you at

BOOTH N452

WORLD OF CONCRETE

WORLD OF CONCRETE 2018
EXHIBITS: JANUARY 23-26
SEMINARS: 22-26
LAS VEGAS CONVENTION CENTER

Pozzotec Solution to ZLD

Dale Andrews
Craig Addison
Matt Radaker

EPA

CARMEUSE

01/09/2018

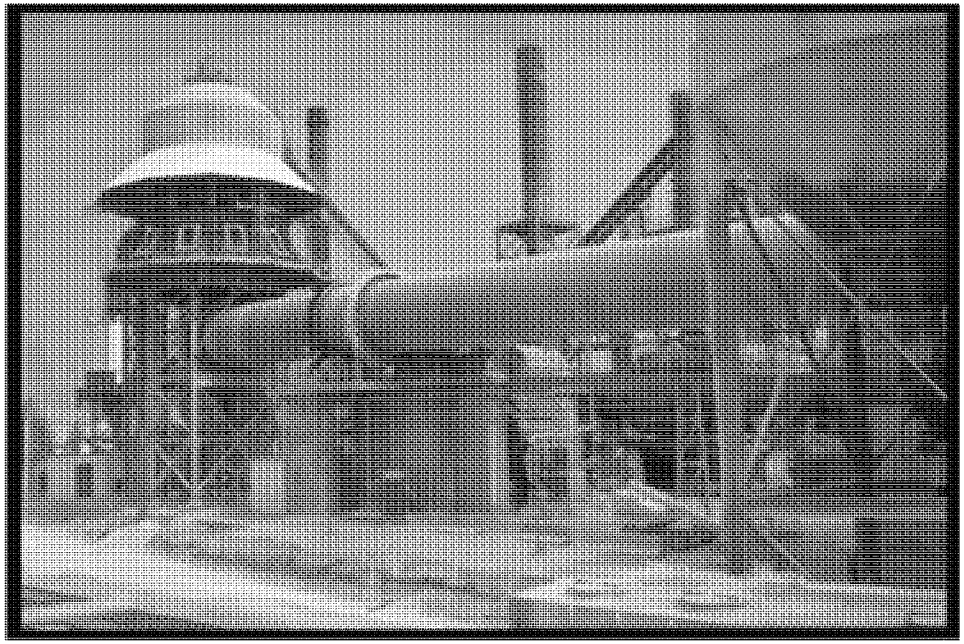
Carmeuse Lime & Stone— PRODUCTION FACILITIES

Headquarters

Quarries and Operations

- Dolomitic Quicklime
- High Calcium Quicklime
- Limestone / Milled Limestone
- Hydrated Lime

Limestone Conversion to Calcium Oxide (Quicklime)



$$\underbrace{CaCO_3 + MgCO_3}_{\text{Limestone}} \longrightarrow \underbrace{CaO + MgO}_{\text{Quicklime}} + CO_2$$

Environmental Market Benefits

Calcium Products provide a world of Applications:

- Power Generation
  - Flue Gas Desulphurization
  - Pozzotec
- Waste Water Treatment
  - pH Adjustment
  - Hazardous Metals Removal
  - Hazardous Nutrient Removal
  - Biosolids Treatment and Recovery
- Coal Mining
  - Acid Mine Drainage
  - pH Adjustment
  - Hazardous Metals Removal
- Agriculture and Farming
  - Wastewater Treatment
- Land Reclamation
  - Superfund Recovery
  - Brownfield Recovery
- And more!

Disaster strikes on 12/22/2008

Catalyst for the introduction of Zero Liquid Discharge

TVA Kingston Fossil Plant coal fly ash slurry spill

- TVA dike ruptured
  - Releasing an 84-acre (0.34 km^2) impoundment of "solid" waste
- 1.1 billion US gallons (4,200,000 m^3) of coal fly ash slurry was released.

The end of Impoundments

Catalyst for the introduction of Zero Liquid Discharge

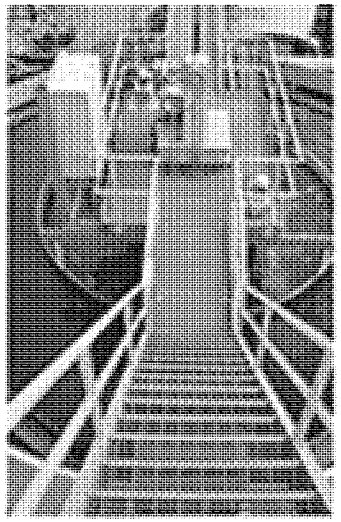
EPA

Establishes safer standards...

40 CFR Part 257 – Disposal of CCR from Electric Power Plants

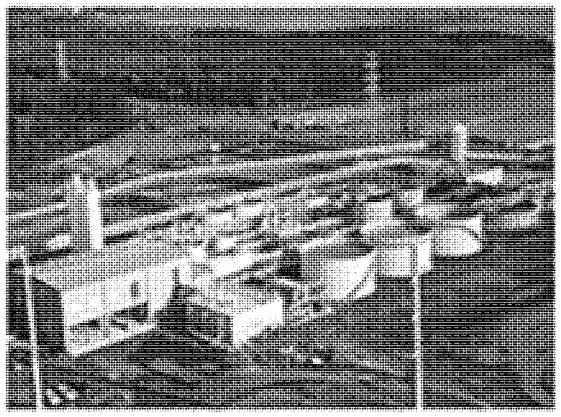
40 CFR Part 423 – Effluent Limitations Guidelines for Steam Generating Electric Utilities

ELG/CCR Timeline



APRIL 17, 2015
Final CCR Rule Issued

SEPTEMBER 30, 2015
Final Rule signed by EPA
Effective Date (TBD) 60 days after publication in Federal Register

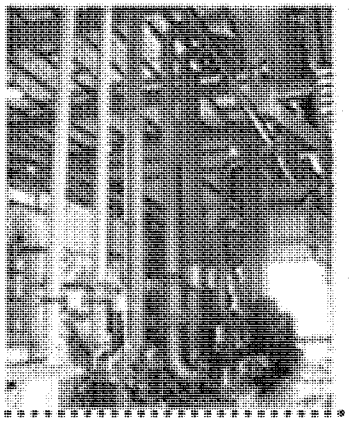


DECEMBER 31, 2023
Deadline for ELG implementation if complying via voluntary incentive program for Flue Gas Desulfurization (FGD) Wastewater

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

SEPTEMBER 2009
Final detailed study report released and EPA announces decision to proceed with amendment

JUNE 7, 2013
Proposed ELG amendment issued



NOVEMBER 2018-DECEMBER 2023
PERMIT IMPLEMENTATION PERIOD
Permitting authorities incorporate final ELGs into NPDES and pre-treatment permits

ELG Related Issues Faced at Coal Fired Utilities

Water Balance (WB)

- As WB is tightened, dissolved chemistry elevates, causing corrosion and process control issues.

Dewatering

- As WB is tightened, systems that once used thickeners for solid/liquid separation, now require mechanical filtration of a material that does not filter well.

Loss of Profitable Byproduct

- With high TDS in water, reduced gypsum quality has made the material no longer usable.

Transportation

- This gypsum waste that was once byproduct is now being shipped very far away to be landfilled.

Utilities Response – Spending Millions in Research

FGD/Process Wastewater Treatment: Focusing on technologies to treat and reuse water from various waste sources throughout the plant – including flue gas desulfurization (FGD) discharges, cooling tower blowdown, floor drains and storm water runoff.

Zero-Liquid Discharge: Exploring technologies that separate pollutant-bearing waters into a solid material that can be used or landfilled and a high-quality distillate that can be reused.

Solid Landfill Water Management: Exploring water issues related to managing on-site landfills with the addition of new solids such as zero-liquid discharge salts and sludge.

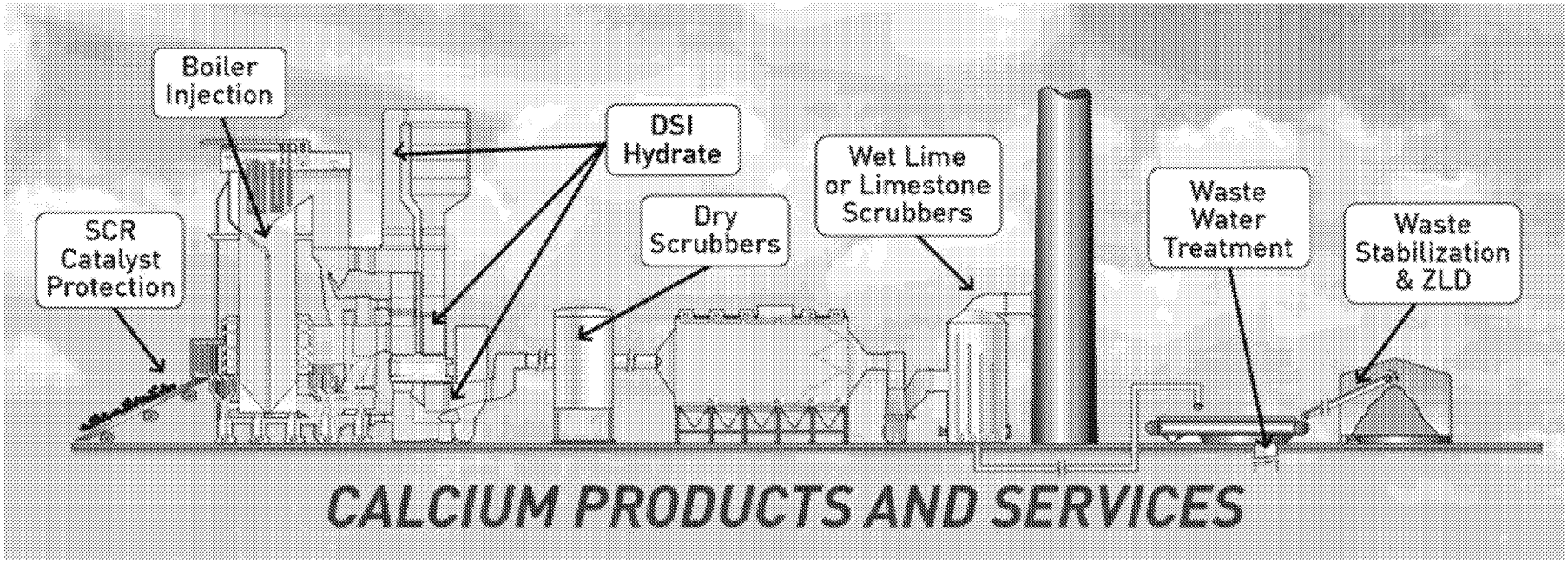
EPRI

SR SOUTHERN RESEARCH

Flue Gas Treatment & Lime Relationship

- Coal Fired Power Plants currently use lime and have the equipment and handling capabilities in place today to receive lime
- Vendor relationships are already in place across the country
- Material safety measures are already implemented.

FGT Inputs for Cleaner Air



Primary Use at Coal Fired Power Plants - FGD

- Calcium products clean the air.

Secondary Use at Coal Fire Power Plants – Water Treatment

- Calcium products can also clean the water that is produced.

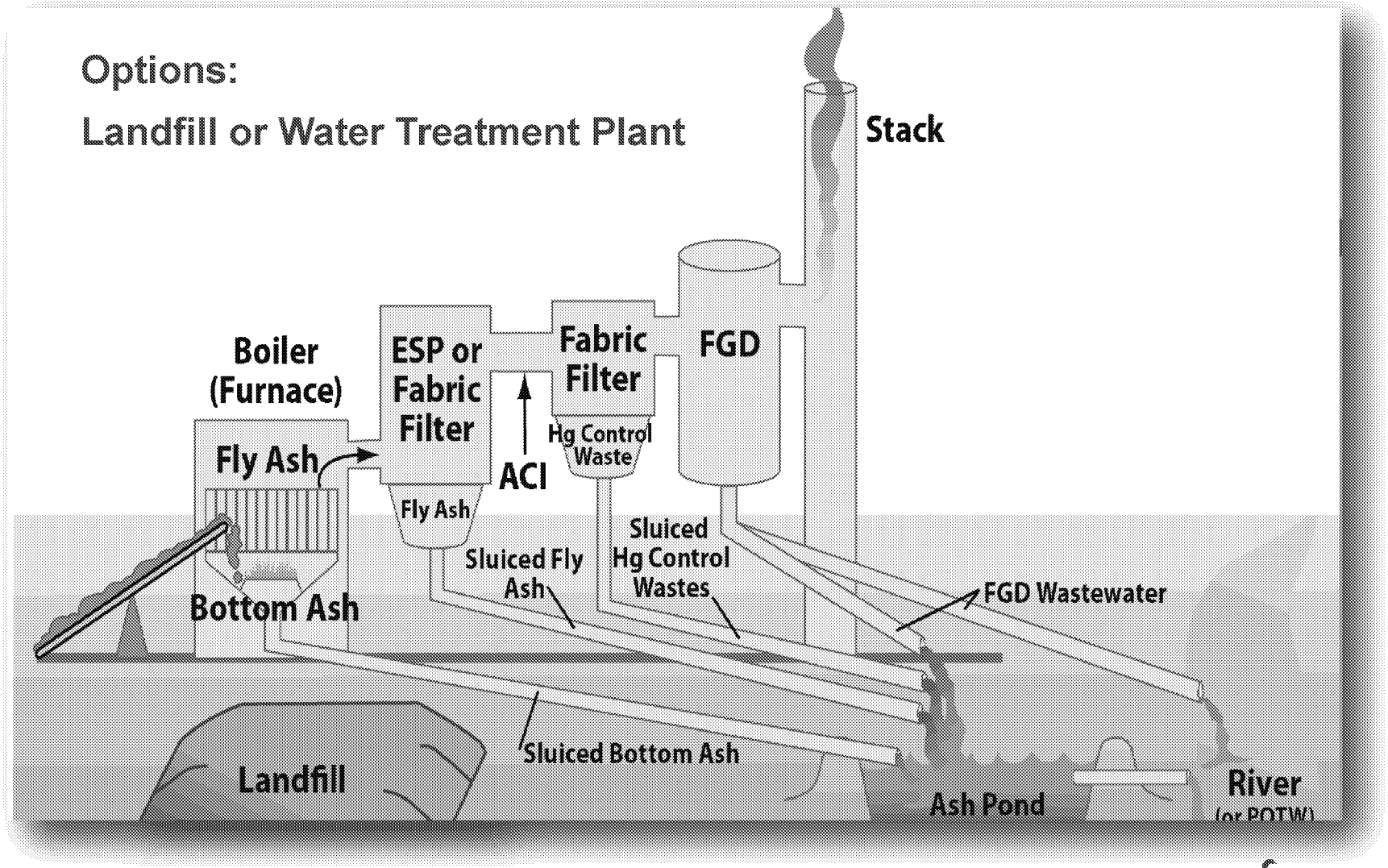
Tertiary Use at Coal Fire Power Plants – Pozzotec Process

- Calcium products can help to fixate scrubber sludge

FGT Output – FGT Wastewater

Options:

Landfill or Water Treatment Plant



Other ZLD options and their shortcomings

- Water Optimization
  - Recycle low chloride water (~20K-30K ppm chlorides)
- Porous Membranes
  - High energy demand (~40K-60K ppm chlorides)
- Thermal
  - High energy demand
  - Additional air quality constraints (>60K ppm chlorides)

The Pozzotec Option for ZLD

Issues with the 3 previous ZLD options:

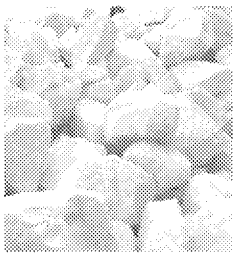
- Capital costs
- Diminishing return – Cost Inc. as Concentration Inc.

The Pozzotec option:

- Lower cost
- Materials on site
- Effective at low and high chloride concentration levels

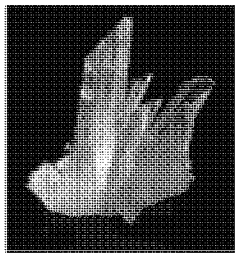
Pozzolanic Reaction

Basic Pozzolanic Reaction:



Lime (Calcium)

+



Fly Ash (Silica + Alumina)

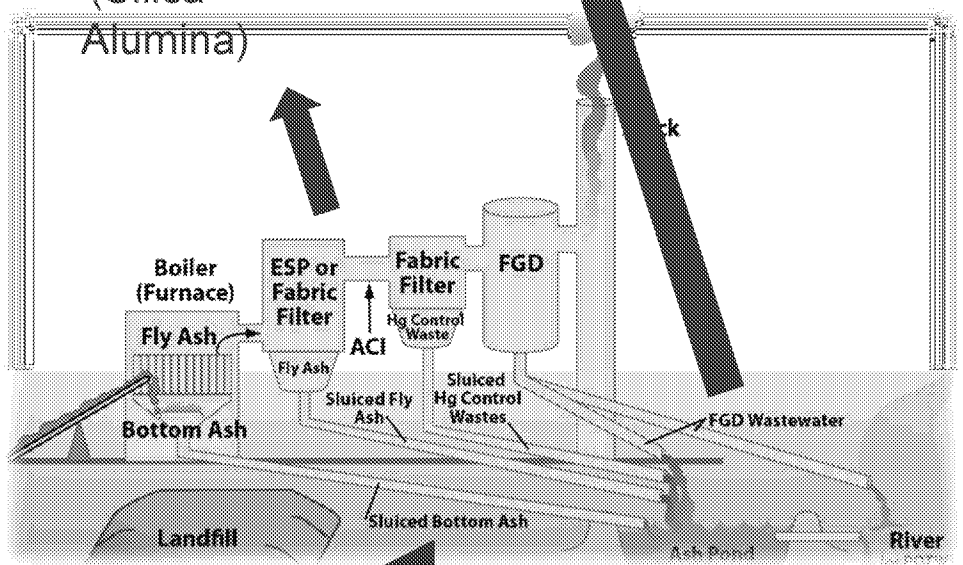
+

H_2O

Pozzotec Process

Calcium Silicate Hydrate (CSH)
Calcium Alumina Hydrate (CAH)

Lime supplier

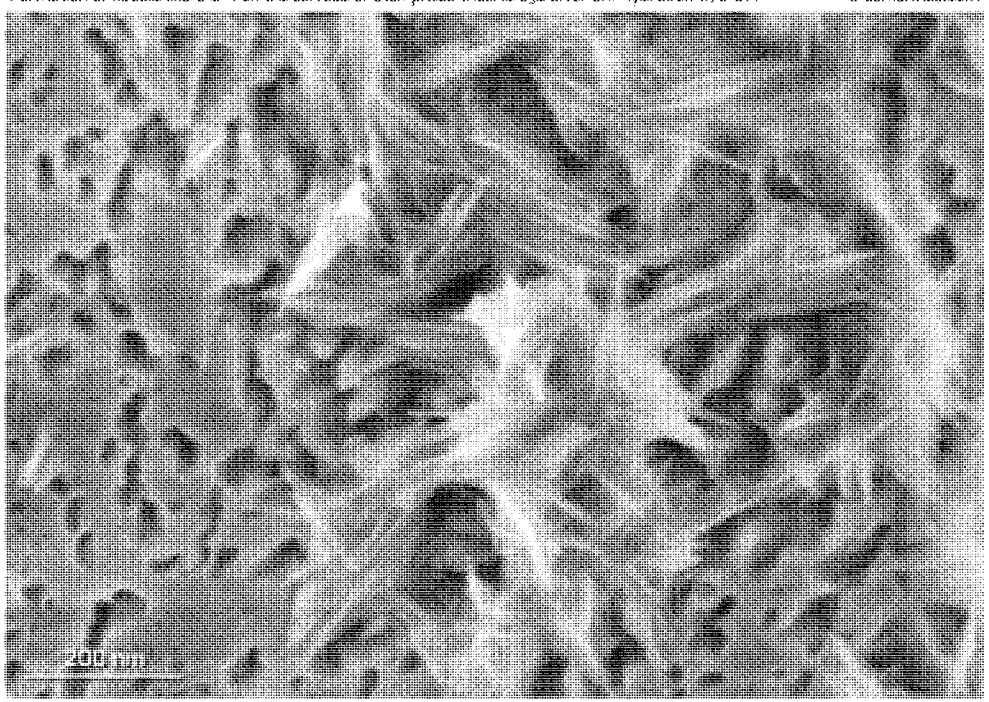


Pozzolanic Reaction

What is the end product of a Pozzolanic Reaction:

- C-S-H
  - Is what makes concrete the irreplaceable material that it is.
  - Binds Particles together creating high strength
  - Creates a matrix that fills voids, lowering permeability

Formation of needle like C-S-H on the surface of etch-pitted triclinic C_3S after 5hr hydration w/c=0.4 © cementlab.com



Pozzotec Process - Pozzolanic Reactions

$SiO_2 + Ca(OH)_2 + H_2O \rightarrow CaO{\cdot}SiO_2 \cdot 2H_2O$

silica dioxide + calcium oxide + water → calcium silicate hydrate

$Al_2O_3 + 4Ca(OH)_2 + 9H_2O \rightarrow 3CaO{\cdot}\ Al_2O_3 \cdot 12H_2O$

alumina + calcium oxide + water → calcium aluminate hydrate

$Fe_2O_3 + Al_2O_3 + 6Ca(OH)_2 + 6H_2O \rightarrow 6CaO{\cdot}\ Al_2O_3 \cdot Fe_2O_3 \cdot 12H_2O$

iron oxide + alumina + calcium oxide → calcium aluminoferrite hydrate

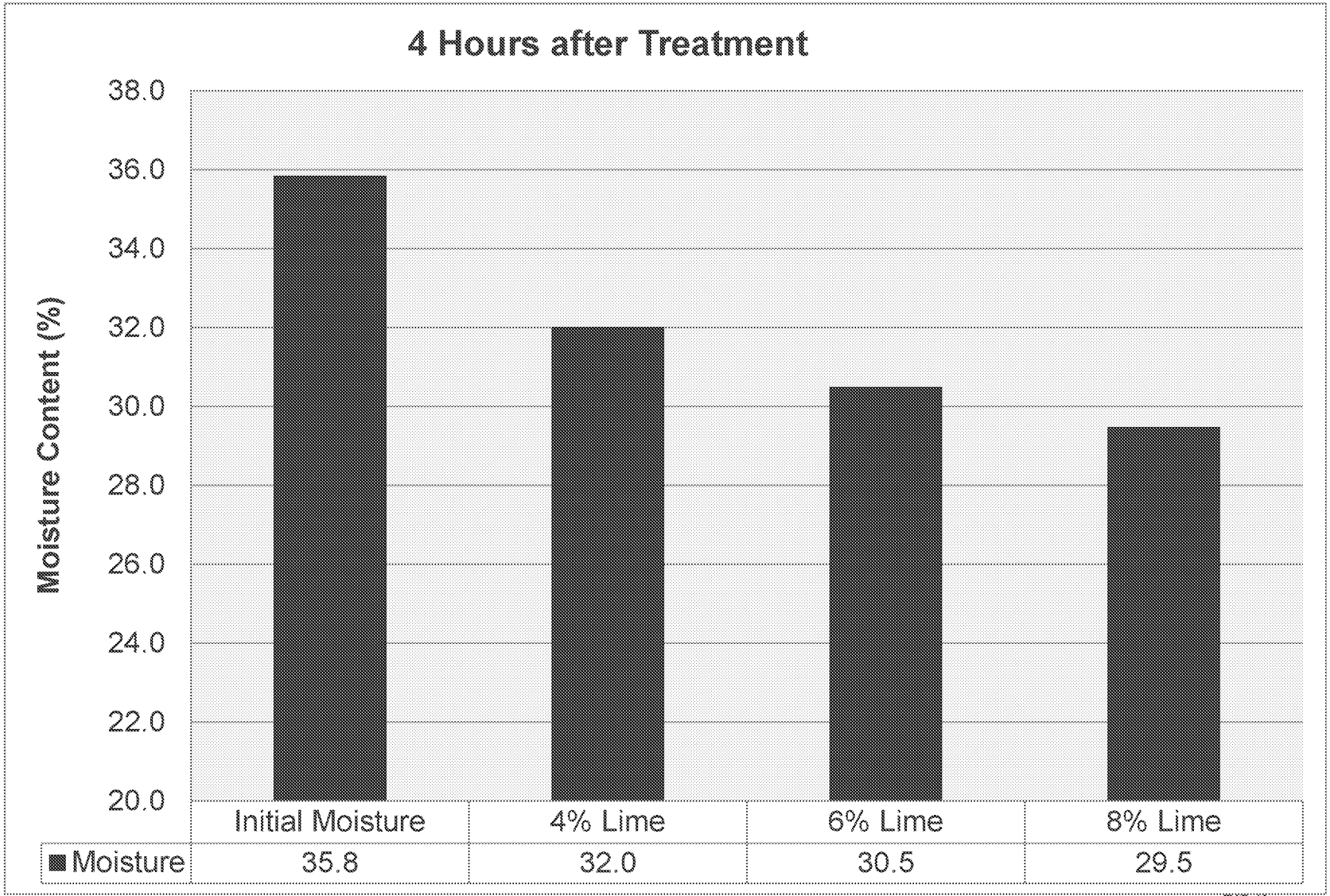
Result: creates a cement and binds free water

Decreased Disposal Tonnage

- Addition of lime allows for less fly ash addition with similar strength gains
- This allows for a reduction in total tonnage disposed
  - Increasing landfill life span
  - Reducing the amount of trucks needed

Trial Date	Trial #	Filter Cake % solids	Fly Ash Added % Dry wt	Lime %	Tested Slurry Solids (%)	1-Day Strength (ambient)	6-Day Strength (MSHA environs)
02/16/17	1	48.9%	20.0	4.0%	55.3%	0	0.25
02/16/17	3	48.9%	0.0	4.0%	51.1%	0	0.25
02/16/17	8	48.9%	20.0	8.0%	58.8%	0.25	1.50
02/16/17	11	48.9%	0.0	8.0%	53.3%	0.25	1.25

Increased Water Disposal



Solving the water problem

How do these reaction help

- Addition of lime dries material by chemically bonding free water
- Then the hydrated lime starts reacting to form CSH matrix, converting ash waste into weight bearing solid material
- This weight baring material is easily managed-
  - High effluent water content sludge materials are manageable hours after treatment
  - Passing a paint filter test almost immediately
  - Once placed in landfills strength gaining pozzolanic reaction start almost immediately

Ash Impoundment Stabilization Project

- Mix Design testing determined a 5% quicklime and 5% fly ash addition was needed
- After <24 hours, no free water & adequate strength for landfill

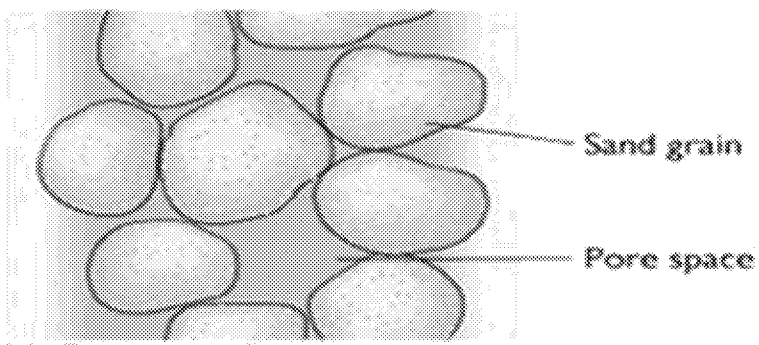
			Confined Compressive Strength				Remixed*			Unconfined Compressive Strength			pH
Impoundment Site	% Solids	Free Water @ 24 hrs.	TSF @1Day	TSF @ 2Days	TSF @ 3Days	TSF @ 7Days	TSF @1Day	TSF @ 2Days	TSF @ 3Days	UCS @3Days PSI	UCS @7Days PSI	UCS @28Days PSI	pH @7 days
Site 1	72.8	No	1.00	2.50	3.75	>4.5	1.50	>4.5	>4.5	50	82	147	12.4
Site 2	66.5	No	0.75	1.50	>4.5	>4.5	1.50	>4.5	>4.5	475	509	655	12.4
Site 3	61.5	No	1.25	3.00	>4.5	>4.5	1.50	>4.5	>4.5	108	178	373	12.4

*Samples were mixed initially and mellowed for 1 day before remixing and compacting to simulate field mixing and movement to landfill (ASTM Method D2166 was followed to determine the Unconfined compressive Strength)

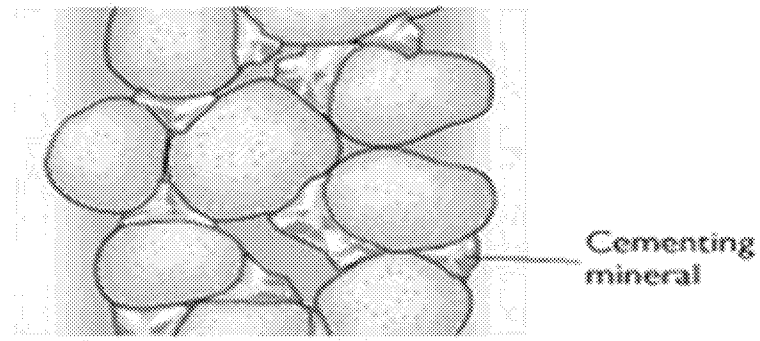
Solidification and Stabilization

Solidification – Change physical properties of waste.

- Increase of Compressive Strengths.
- Decrease of Permeability.
- Encapsulation of Hazardous Constituents.



(a) Porous sandstone



(b) Cemented sandstone

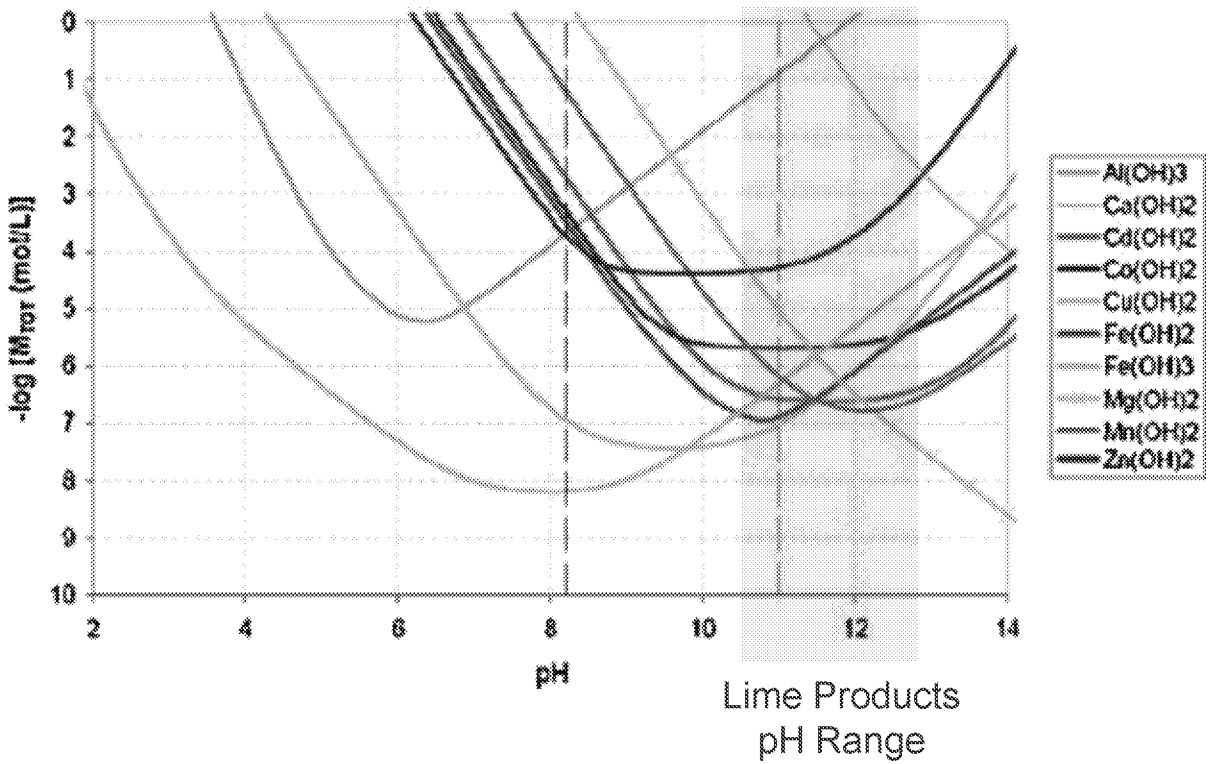
Yan-Jun DU, Song-Yu LIU, et al. "An Overview of Stabilization/Solidifcation Technique for Heavy Metals Contaminated Soils." 2009. pp. 1. Proc. Of Int. Symp. On Geoenvironmental Eng. ISGE2009

Photo credit: Slideplayer.com

Solidification and Stabilization

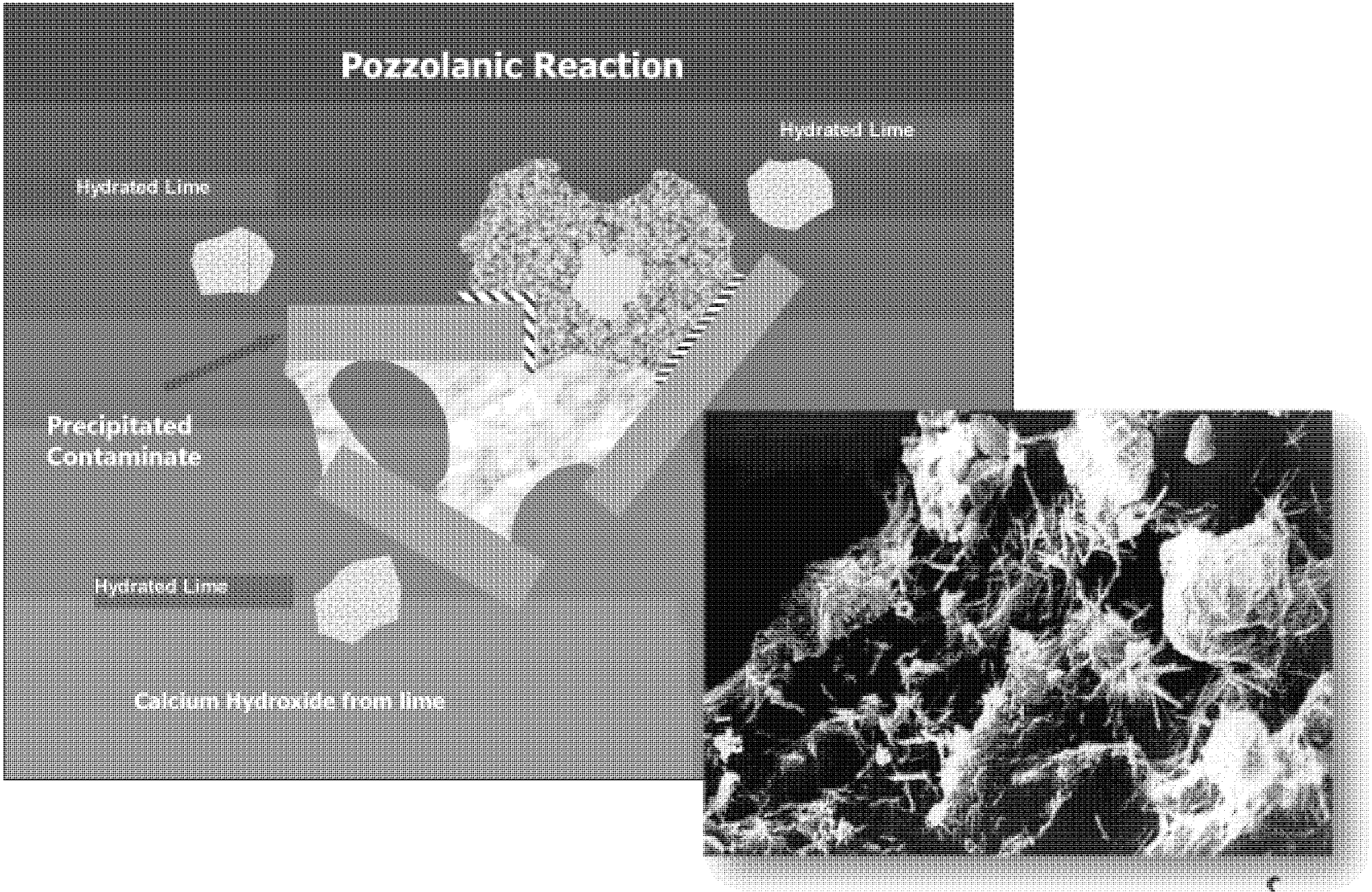
Stabilization – Change chemical properties.

- Convert to less soluble, less mobile, and less toxic forms.



Yan-Jun DU, Song-Yu LIU, et al. "An Overview of Stabilization/Solidifcation Technique for Heavy Metals Contaminated Soils." 2009. pp. 1. Proc. Of Int. Symp. On Geoenvironmental Eng. ISGE2009

Solidification and Stabilization



Added benefits of the Pozzotec Process

Table 1.1: Effectiveness of Stabilization/Solidification on various contaminants (adapted from EPA's "S&S of Organics and Inorganics", 1993)

	Contaminant Group		
	Organics	Inorganics	Reactive Compounds
Demonstrated : Successful tests performed	Halogenated semivolatiles Nonhalogenated semi- and non- volatiles	Volatile metals Nonvolatile metals Asbestos Radioactive materials Inorganic corrosives Inorganic cyanides	Oxidizers Reducers
Potential : Expert opinion that technology will be effective	PCBs Pesticides Dioxins/Furans Organic cyanides Organic corrosives		
Ineffective : Expert opinion that technology will/does not work	Halogenated Volatiles Nonhalogenated Volatiles		

Best Available Technology (BAT) -EPA

Best demonstrated technology for 57 Resource Conservation and Recovery Act (RCRA) listed hazardous waters.

- Used in nearly 24% of Superfund Remediation Action sites in the US.
- Proven effective for many inorganic and radioactive constituents.
- Generally less effective for organic waste constituents.
  - Relies on just solidification rather than both S/S.

Yan-Jun DU, Song-Yu LIU, et al. "An Overview of Stabilization/Solidifcation Technique for Heavy Metals Contaminated Soils." 2009. pp. 1. Proc. Of Int. Symp. On Geoenvironmental Eng. ISGE2009

Bacterial Inhibition

Raising pH to 12.4

- Increasing the pH will inhibit the bacterial growth
- Reducing the impact of these landfills to neighborhoods

			Confined Compressive Strength				Remixed*			Unconfined Compressive Strength			pH
Impoundment Site	% Solids	Free Water @ 24 hrs.	TSF @1Day	TSF @ 2Days	TSF @ 3Days	TSF @ 7Days	TSF @1Day	TSF @ 2Days	TSF @ 3Days	UCS @3Days PSI	UCS @7Days PSI	UCS @28Days PSI	pH @7 days
Site 1	72.8	No	1.00	2.50	3.75	>4.5	1.50	>4.5	>4.5	50	82	147	12.4
Site 2	66.5	No	0.75	1.50	>4.5	>4.5	1.50	>4.5	>4.5	475	509	655	12.4
Site 3	61.5	No	1.25	3.00	>4.5	>4.5	1.50	>4.5	>4.5	108	178	373	12.4

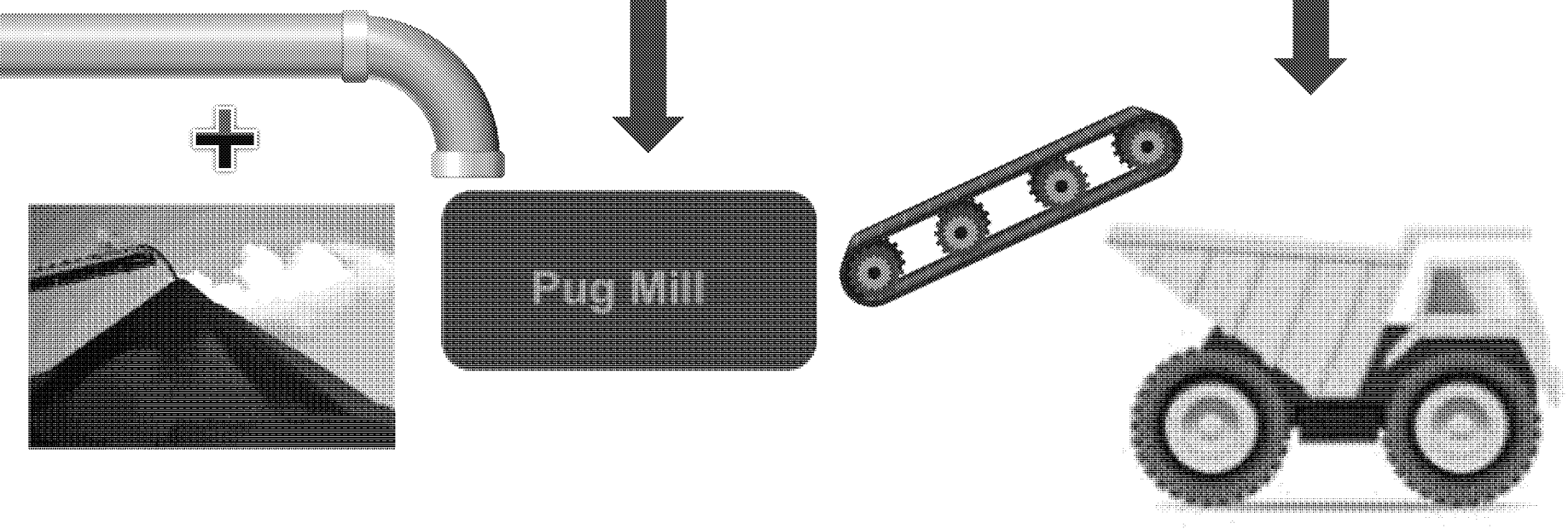
Generating the Pozzotec Process

The key to success is in the simplicity

Waste solid and FGD water (55%-70% solids)

Lime added and mixed 4%-10%

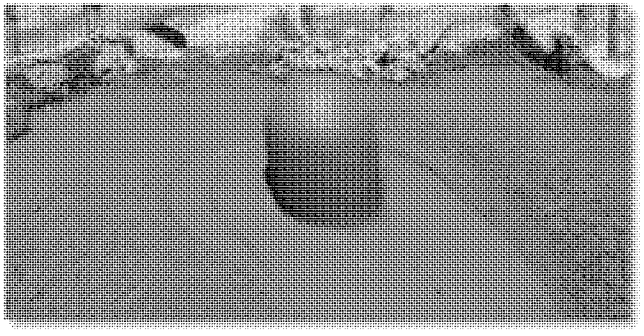
Convey, truck, or barge material to landfill



Pozzotec - Next Generation Research

- Blending proportions to install rheological properties
  - Material is non-segregating
  - Has little to no bleed water
  - Retains the pozzolanic reactivity that will densify and harden

- Benefits of pumping material
  - Pumpable material will remove the need for trucking
  - Flowable filling will maximize landfill use and reduce O&M costs
    - Material will flow into cracks in previous layers



Summary of Pozzotec Benefits

Solidification

- Increase compressive strength of material landfilled
- Reduce permeability of landfill
- Reduce O&M costs at the landfill

Stabilization

- Convert inorganic pollutants to insoluble forms
- Reduce leachate contamination

Inactivation

- Kill bacteria and prevent their regrowth
- Reduce odors

Implementation

- Existing industry practice
- Low capital investment
- Works when other ZLD options fail

Pozzotec Solution to ZLD

Dale Andrews
Craig Addison
Matt Radaker

EPA

CARMEUSE

01/09/2018

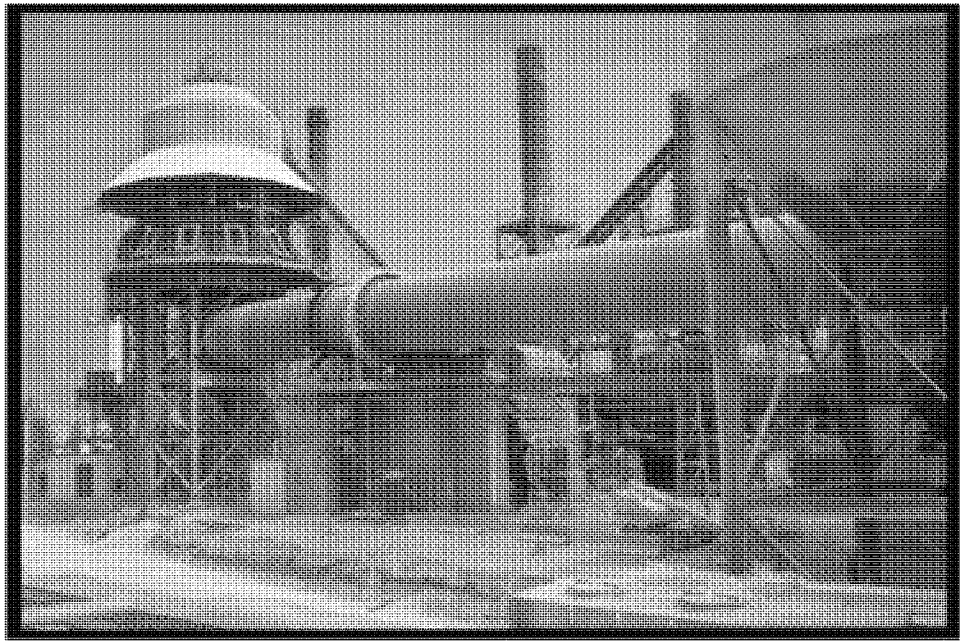
Carmeuse Lime & Stone— PRODUCTION FACILITIES

Headquarters

Quarries and Operations

- Dolomitic Quicklime
- High Calcium Quicklime
- Limestone / Milled Limestone
- Hydrated Lime

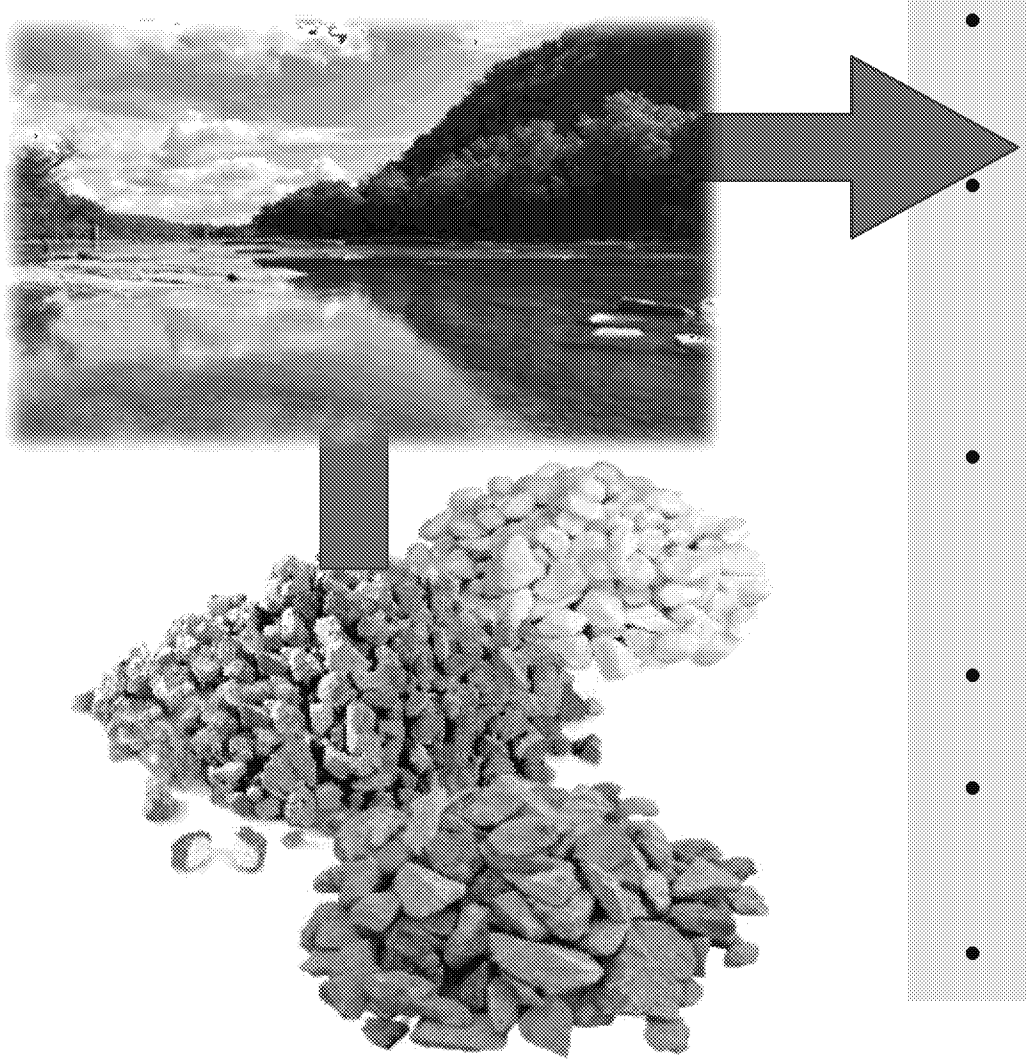
Limestone Conversion to Calcium Oxide (Quicklime)



$$\underbrace{CaCO_3 + MgCO_3}_{\text{Limestone}} \longrightarrow \underbrace{CaO + MgO}_{\text{Quicklime}} + CO_2$$

Environmental Market Benefits

Calcium Products provide a world of Applications:



- Power Generation
  - Flue Gas Desulphurization
  - Pozzotec
- Waste Water Treatment
  - pH Adjustment
  - Hazardous Metals Removal
  - Hazardous Nutrient Removal
  - Biosolids Treatment and Recovery
- Coal Mining
  - Acid Mine Drainage
  - pH Adjustment
  - Hazardous Metals Removal
- Agriculture and Farming
  - Wastewater Treatment
- Land Reclamation
  - Superfund Recovery
  - Brownfield Recovery
- And more!

Disaster strikes on 12/22/2008

Catalyst for the introduction of Zero Liquid Discharge

TVA Kingston Fossil Plant coal fly ash slurry spill

- TVA dike ruptured
  - Releasing an 84-acre (0.34 km^2) impoundment of "solid" waste
- 1.1 billion US gallons (4,200,000 m^3) of coal fly ash slurry was released.

The end of Impoundments

Catalyst for the introduction of Zero Liquid Discharge

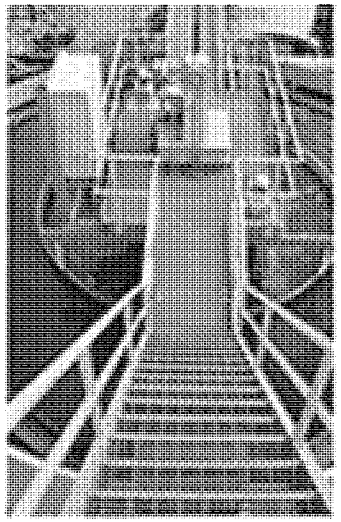
EPA

Establishes safer standards...

40 CFR Part 257 – Disposal of CCR from Electric Power Plants

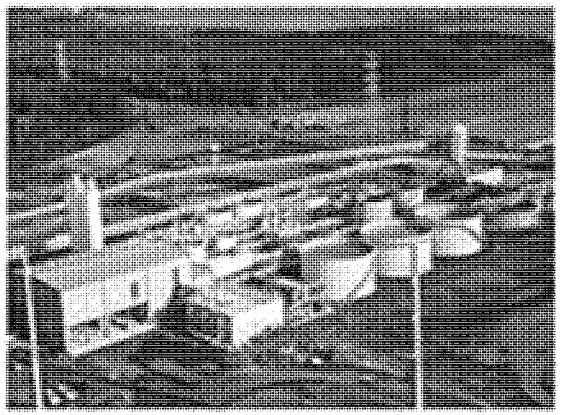
40 CFR Part 423 – Effluent Limitations Guidelines for Steam Generating Electric Utilities

ELG/CCR Timeline



APRIL 17, 2015
Final CCR Rule Issued

SEPTEMBER 30, 2015
Final Rule signed by EPA
Effective Date (TBD) 60 days after publication in Federal Register

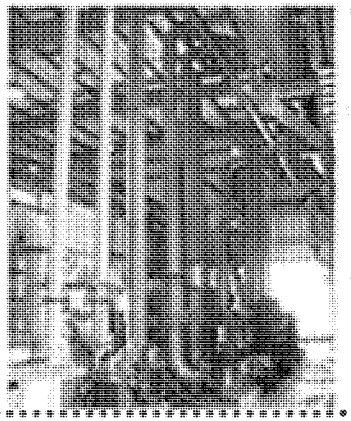


DECEMBER 31, 2023
Deadline for ELG implementation if complying via voluntary incentive program for Flue Gas Desulfurization (FGD) Wastewater

2008 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

SEPTEMBER 2009
Final detailed study report released and EPA announces decision to proceed with amendment

JUNE 7, 2013
Proposed ELG amendment issued



NOVEMBER 2018-DECEMBER 2023 PERMIT IMPLEMENTATION PERIOD
Permitting authorities incorporate final ELGs into NPDES and pre-treatment permits

ELG Related Issues Faced at Coal Fired Utilities

Water Balance (WB)

- As WB is tightened, dissolved chemistry elevates, causing corrosion and process control issues.

Dewatering

- As WB is tightened, systems that once used thickeners for solid/liquid separation, now require mechanical filtration of a material that does not filter well.

Loss of Profitable Byproduct

- With high TDS in water, reduced gypsum quality has made the material no longer usable.

Transportation

- This gypsum waste that was once byproduct is now being shipped very far away to be landfilled.

Utilities Response – Spending Millions in Research

FGD/Process Wastewater Treatment: Focusing on technologies to treat and reuse water from various waste sources throughout the plant – including flue gas desulfurization (FGD) discharges, cooling tower blowdown, floor drains and storm water runoff.

Zero-Liquid Discharge: Exploring technologies that separate pollutant-bearing waters into a solid material that can be used or landfilled and a high-quality distillate that can be reused.

Solid Landfill Water Management: Exploring water issues related to managing on-site landfills with the addition of new solids such as zero-liquid discharge salts and sludge.

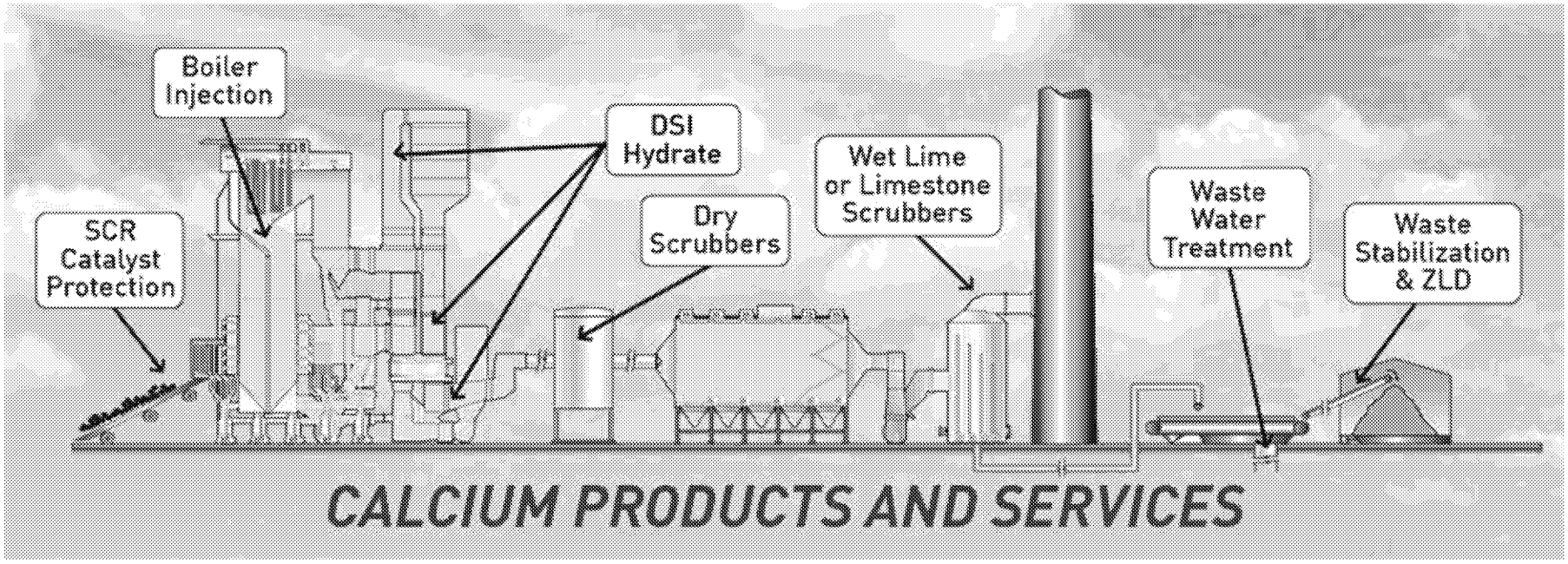
EPRI

SR SOUTHERN RESEARCH

Flue Gas Treatment & Lime Relationship

- Coal Fired Power Plants currently use lime and have the equipment and handling capabilities in place today to receive lime
- Vendor relationships are already in place across the country
- Material safety measures are already implemented.

FGT Inputs for Cleaner Air



Primary Use at Coal Fired Power Plants - FGD

- Calcium products clean the air.

Secondary Use at Coal Fire Power Plants – Water Treatment

- Calcium products can also clean the water that is produced.

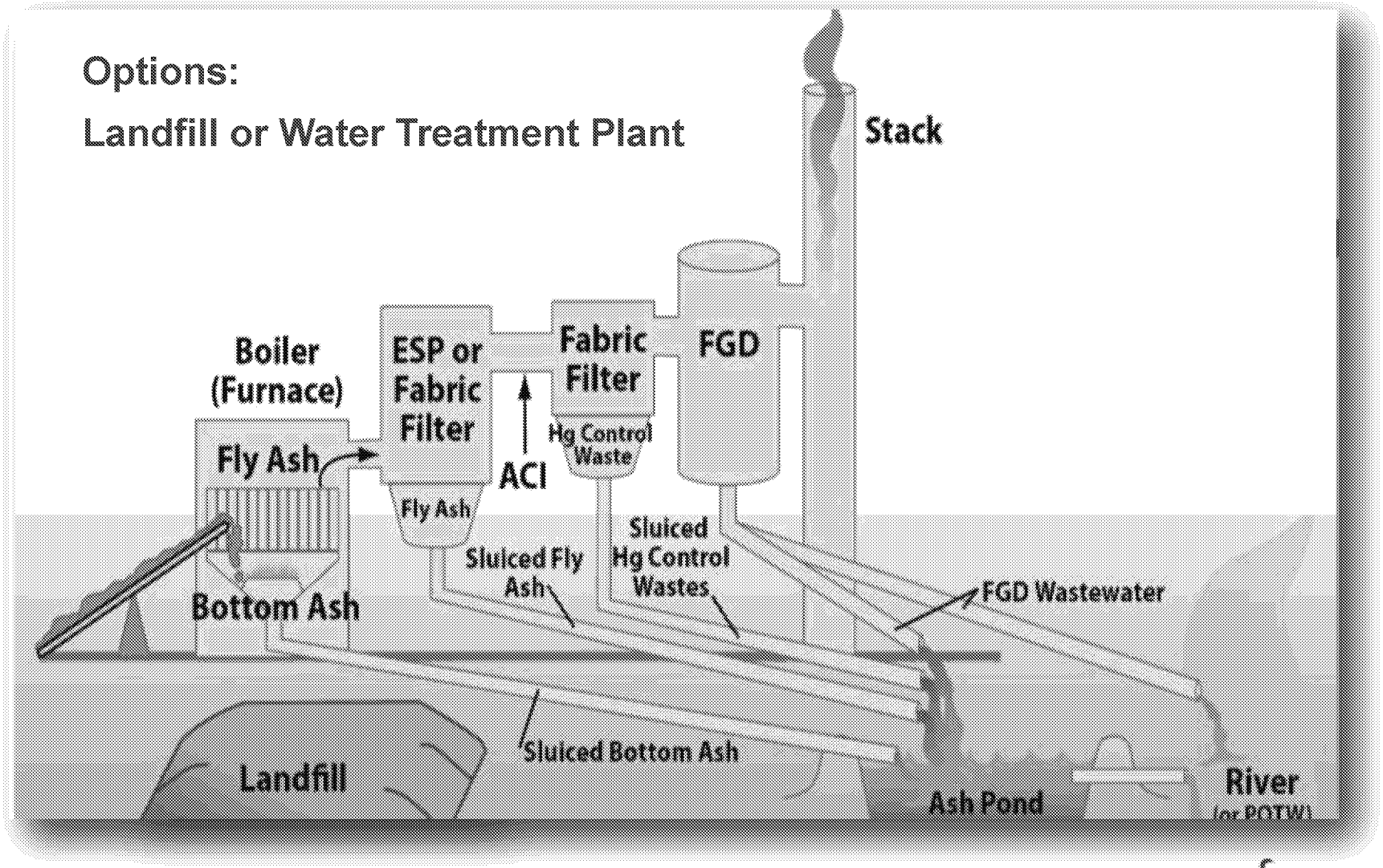
Tertiary Use at Coal Fire Power Plants – Pozzotec Process

- Calcium products can help to fixate scrubber sludge

FGT Output – FGT Wastewater

Options:

Landfill or Water Treatment Plant



Other ZLD options and their shortcomings

- Water Optimization
  - Recycle low chloride water (~20K-30K ppm chlorides)
- Porous Membranes
  - High energy demand (~40K-60K ppm chlorides)
- Thermal
  - High energy demand
  - Additional air quality constraints (>60K ppm chlorides)

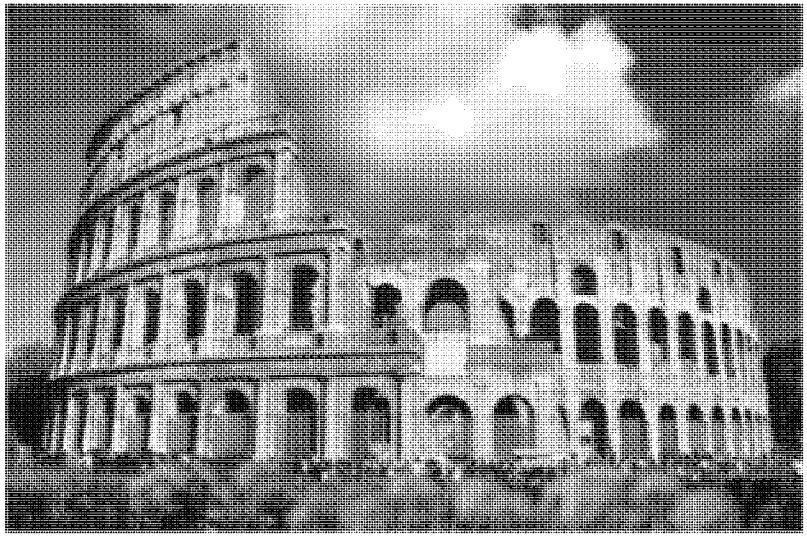
The Pozzotec Option for ZLD

Issues with the 3 previous ZLD options:

- Capital costs
- Diminishing return – Cost Inc. as Concentration Inc.

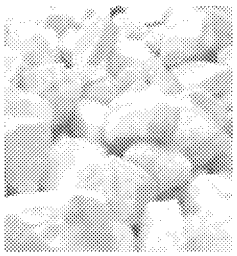
The Pozzotec option:

- Lower cost
- Materials on site
- Effective at low and high chloride concentration levels



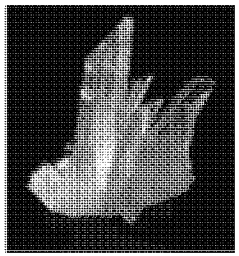
Pozzolanic Reaction

Basic Pozzolanic Reaction:



Lime (Calcium)

+



Fly Ash (Silica + Alumina)

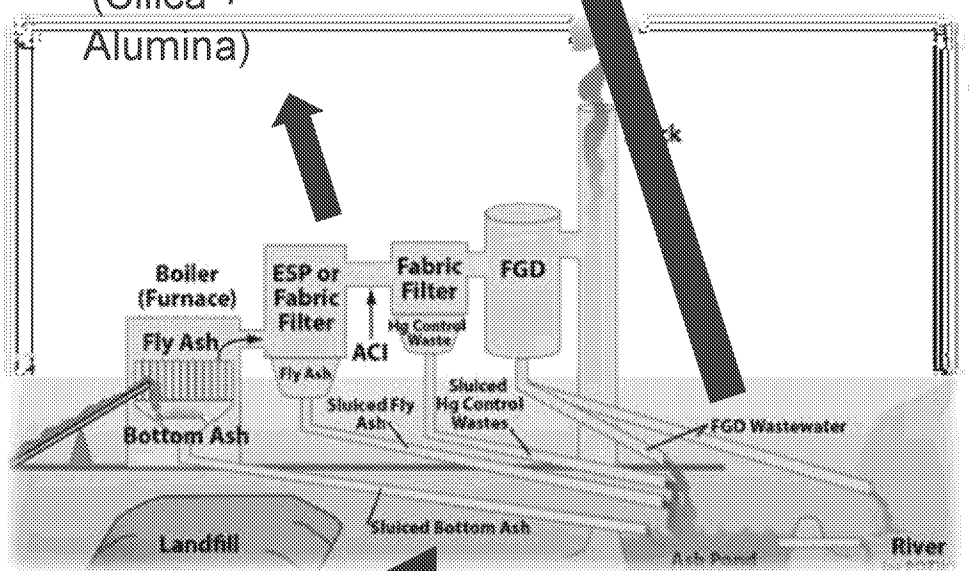
+

H_2O

Pozzotec Process

Calcium Silicate Hydrate (CSH)
Calcium Alumina Hydrate (CAH)

Lime supplier

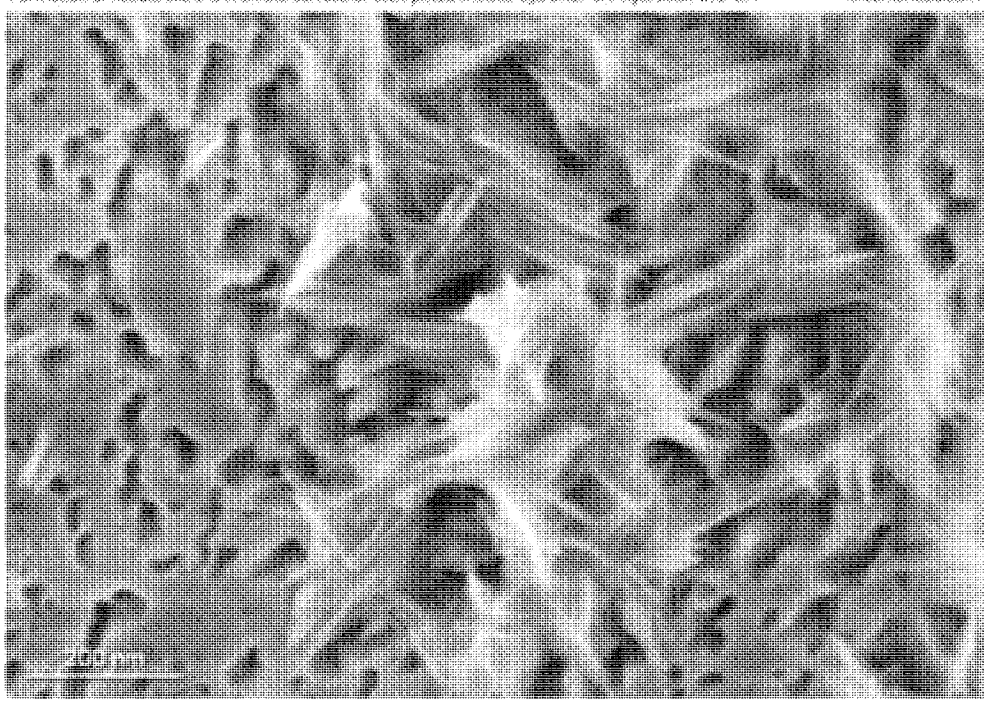


Pozzolanic Reaction

What is the end product of a Pozzolanic Reaction:

- C-S-H
  - Is what makes concrete the irreplaceable material that it is.
  - Binds Particles together creating high strength
  - Creates a matrix that fills voids, lowering permeability

Formation of needle like C-S-H on the surface of etch-pitted triclinic C_3S after 5hr hydration w/c=0.4 © cementlab.com



Pozzotec Process - Pozzolanic Reactions

$SiO_2 + Ca(OH)_2 + H_2O \rightarrow CaO{\cdot}SiO_2 \cdot 2H_2O$

silica dioxide + calcium oxide + water → calcium silicate hydrate

$Al_2O_3 + 4Ca(OH)_2 + 9H_2O \rightarrow 3CaO{\cdot}\ Al_2O_3 \cdot 12H_2O$

alumina + calcium oxide + water → calcium aluminate hydrate

$Fe_2O_3 + Al_2O_3 + 6Ca(OH)_2 + 6H_2O \rightarrow 6CaO{\cdot}\ Al_2O_3 \cdot Fe_2O_3 \cdot 12H_2O$

iron oxide + alumina + calcium oxide → calcium aluminoferrite hydrate

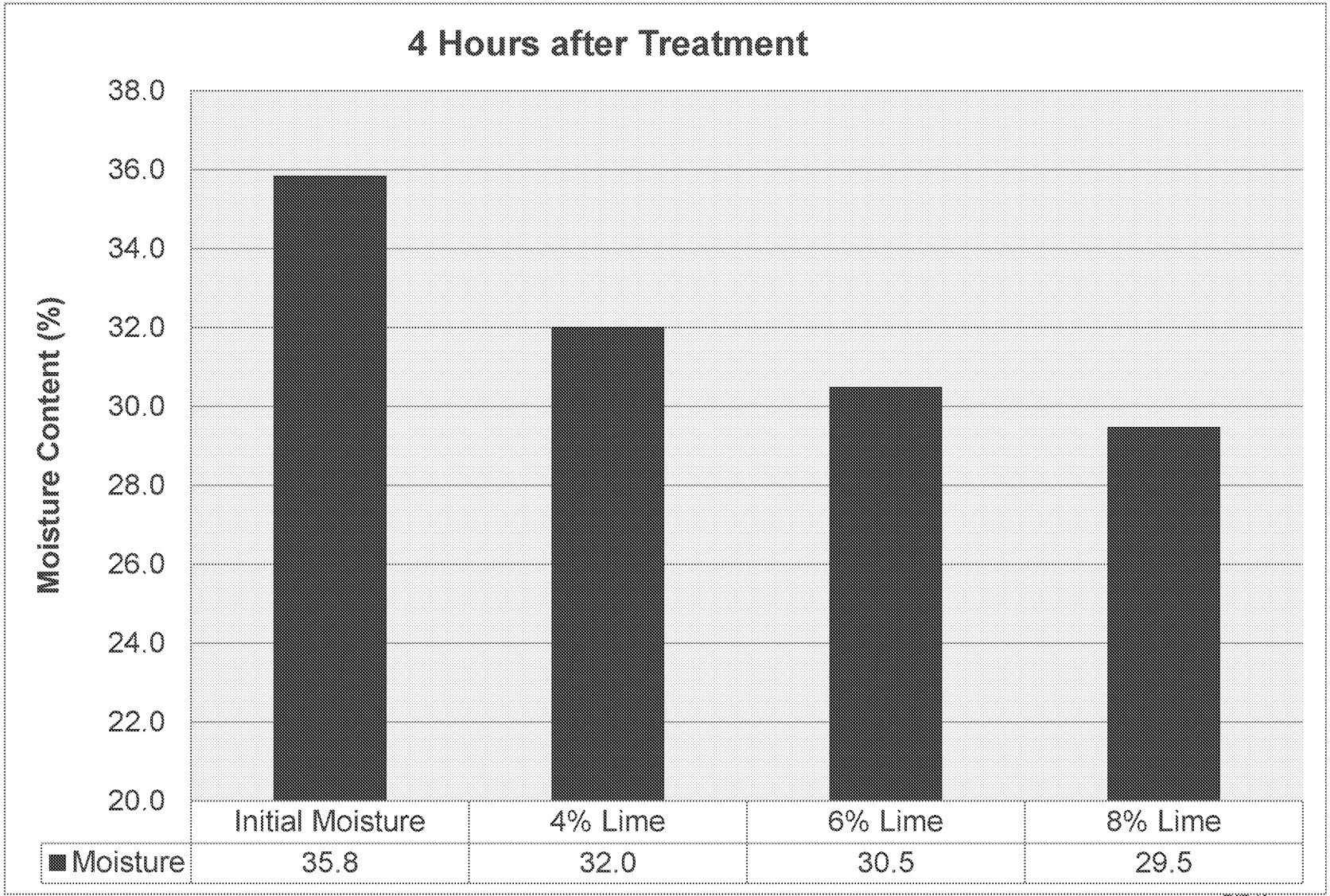
Result: creates a cement and binds free water

Decreased Disposal Tonnage

- Addition of lime allows for less fly ash addition with similar strength gains
- This allows for a reduction in total tonnage disposed
  - Increasing landfill life span
  - Reducing the amount of trucks needed

Trial Date	Trial #	Filter Cake % solids	Fly Ash Added % Dry wt	Lime %	Tested Slurry Solids (%)	1-Day Strength (ambient)	6-Day Strength (75F curing)
02/16/17	1	48.9%	20.0	4.0%	55.3%	0	0.25
02/16/17	3	48.9%	0.0	4.0%	51.1%	0	0.25
02/16/17	8	48.9%	20.0	8.0%	58.8%	0.25	1.50
02/16/17	11	48.9%	0.0	8.0%	53.3%	0.25	1.25

Increased Water Disposal



Solving the water problem

How do these reaction help

- Addition of lime dries material by chemically bonding free water
- Then the hydrated lime starts reacting to form CSH matrix, converting ash waste into weight bearing solid material
- This weight baring material is easily managed-
  - High effluent water content sludge materials are manageable hours after treatment
  - Passing a paint filter test almost immediately
  - Once placed in landfills strength gaining pozzolanic reaction start almost immediately

Ash Impoundment Stabilization Project

- Mix Design testing determined a 5% quicklime and 5% fly ash addition was needed
- After <24 hours, no free water & adequate strength for landfill

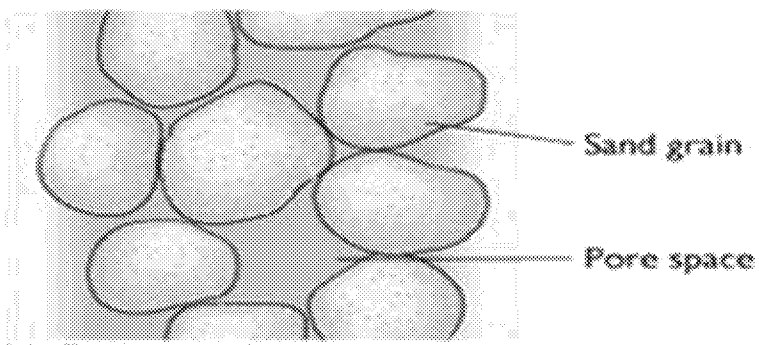
			Confined Compressive Strength				Remixed*			Unconfined Compressive Strength			pH
Impoundment Site	% Solids	Free Water @ 24 hrs.	TSF @1Day	TSF @ 2Days	TSF @ 3Days	TSF @ 7Days	TSF @1Day	TSF @ 2Days	TSF @ 3Days	UCS @3Days PSI	UCS @7Days PSI	UCS @28Days PSI	pH @7 days
Site 1	72.8	No	1.00	2.50	3.75	>4.5	1.50	>4.5	>4.5	50	82	147	12.4
Site 2	66.5	No	0.75	1.50	>4.5	>4.5	1.50	>4.5	>4.5	475	509	655	12.4
Site 3	61.5	No	1.25	3.00	>4.5	>4.5	1.50	>4.5	>4.5	108	178	373	12.4

*Samples were mixed initially and mellowed for 1 day before remixing and compacting to simulate field mixing and movement to landfill (ASTM Method D2166 was followed to determine the Unconfined compressive Strength)

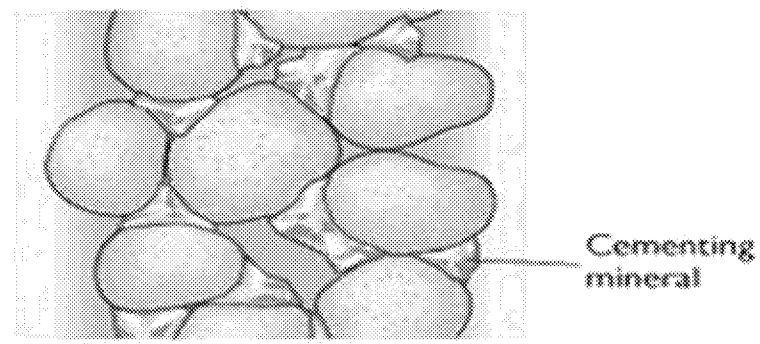
Solidification and Stabilization

Solidification – Change physical properties of waste.

- Increase of Compressive Strengths.
- Decrease of Permeability.
- Encapsulation of Hazardous Constituents.



(a) Porous sandstone



(b) Cemented sandstone

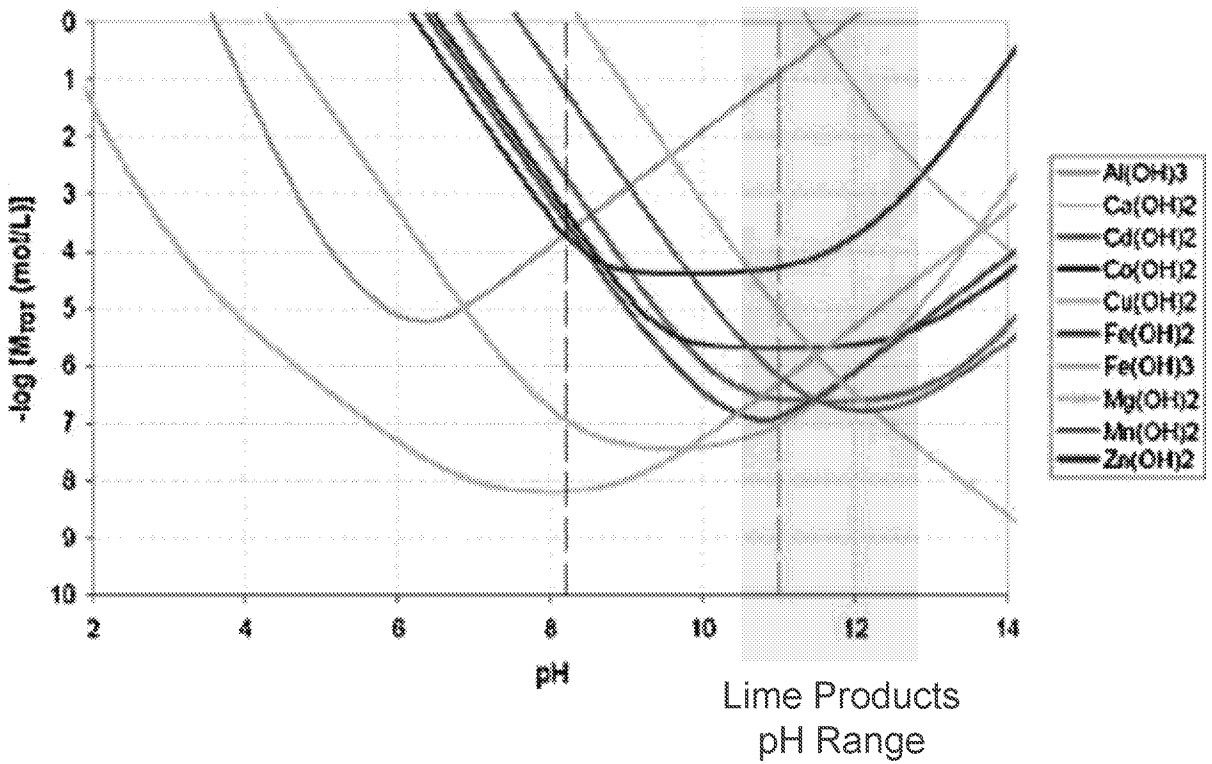
Yan-Jun DU, Song-Yu LIU, et al. "An Overview of Stabilization/Solidifcation Technique for Heavy Metals Contaminated Soils." 2009. pp. 1. Proc. Of Int. Symp. On Geoenvironmental Eng. ISGE2009

Photo credit: Slideplayer.com

Solidification and Stabilization

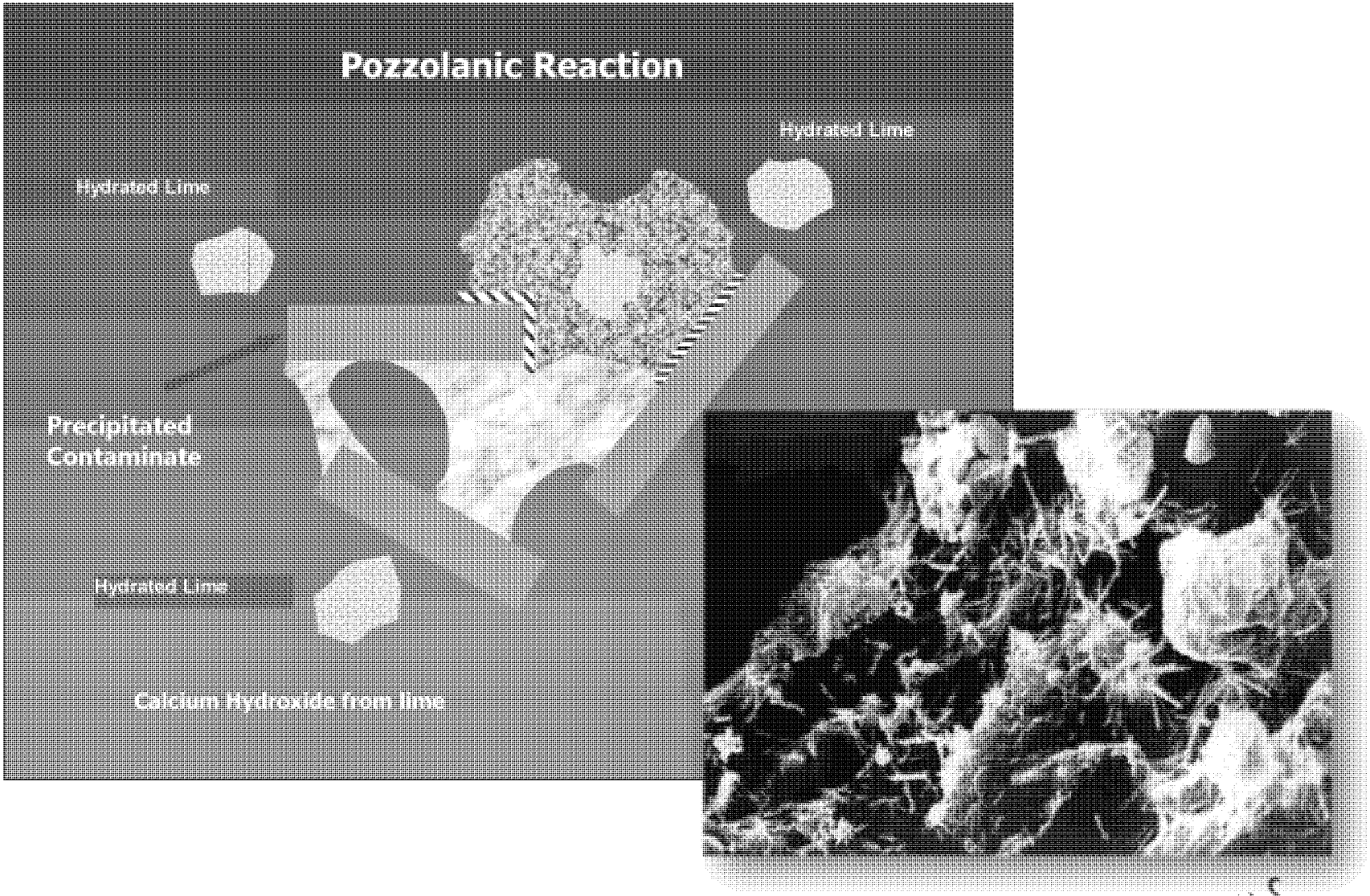
Stabilization – Change chemical properties.

- Convert to less soluble, less mobile, and less toxic forms.



Yan-Jun DU, Song-Yu LIU, et al. "An Overview of Stabilization/Solidifcation Technique for Heavy Metals Contaminated Soils." 2009. pp. 1. Proc. Of Int. Symp. On Geoenvironmental Eng. ISGE2009

Solidification and Stabilization



Added benefits of the Pozzotec Process

Table 1.1: Effectiveness of Stabilization/Solidification on various contaminants (adapted from EPA's "S&S of Organics and Inorganics", 1993)

	Contaminant Group		
	Organics	Inorganics	Reactive Compounds
Demonstrated : Successful tests performed	Halogenated semivolatiles Nonhalogenated semi- and non- volatiles	Volatile metals Nonvolatile metals Asbestos Radioactive materials Inorganic corrosives Inorganic cyanides	Oxidizers Reducers
Potential : Expert opinion that technology will be effective	PCBs Pesticides Dioxins/Furans Organic cyanides Organic corrosives		
Ineffective : Expert opinion that technology will/does not work	Halogenated Volatiles Nonhalogenated Volatiles		

Best Available Technology (BAT) -EPA

Best demonstrated technology for 57 Resource Conservation and Recovery Act (RCRA) listed hazardous waters.

- Used in nearly 24% of Superfund Remediation Action sites in the US.
- Proven effective for many inorganic and radioactive constituents.
- Generally less effective for organic waste constituents.
  - Relies on just solidification rather than both S/S.

Yan-Jun DU, Song-Yu LIU, et al. "An Overview of Stabilization/Solidifcation Technique for Heavy Metals Contaminated Soils." 2009. pp. 1. Proc. Of Int. Symp. On Geoenvironmental Eng. ISGE2009

Bacterial Inhibition

Raising pH to 12.4

- Increasing the pH will inhibit the bacterial growth
- Reducing the impact of these landfills to neighborhoods

			Confined Compressive Strength				Remixed*			Unconfined Compressive Strength			pH
Impoundment Site	% Solids	Free Water @ 24 hrs.	TSF @1Day	TSF @ 2Days	TSF @ 3Days	TSF @ 7Days	TSF @1Day	TSF @ 2Days	TSF @ 3Days	UCS @3Days PSI	UCS @7Days PSI	UCS @28Days PSI	pH @7 days
Site 1	72.8	No	1.00	2.50	3.75	>4.5	1.50	>4.5	>4.5	50	82	147	12.4
Site 2	66.5	No	0.75	1.50	>4.5	>4.5	1.50	>4.5	>4.5	475	509	655	12.4
Site 3	61.5	No	1.25	3.00	>4.5	>4.5	1.50	>4.5	>4.5	108	178	373	12.4

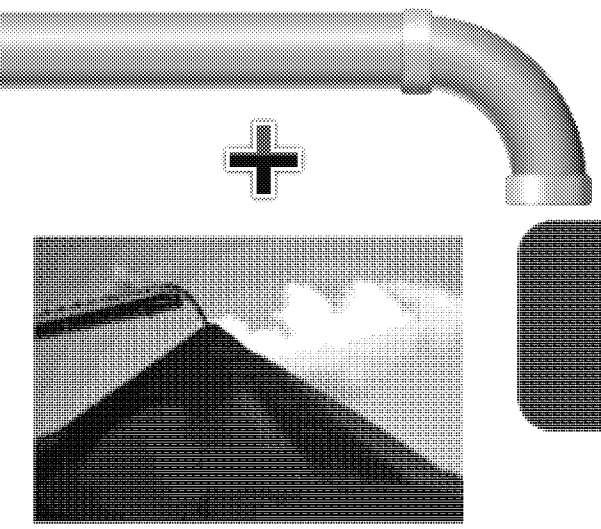
Generating the Pozzotec Process

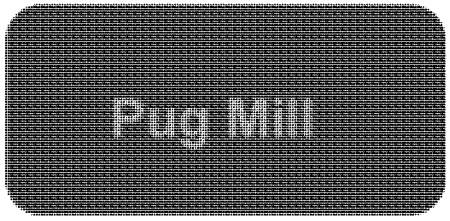
The key to success is in the simplicity

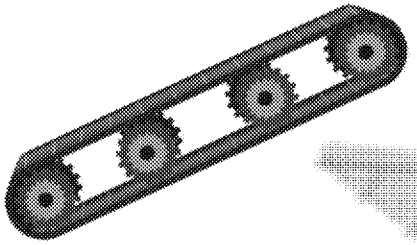
Waste solid and FGD water (55%-70% solids)

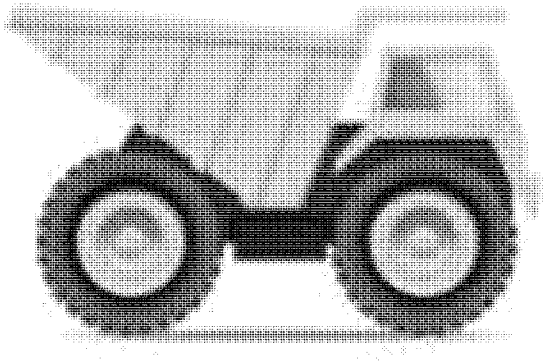
Lime added and mixed 4%-10%

Convey, truck, or barge material to landfill









Pozzotec - Next Generation Research

Can we further reduce the environmental impact of ash disposal?

EPRI

SR SOUTHERN RESEARCH

DUKE ENERGY

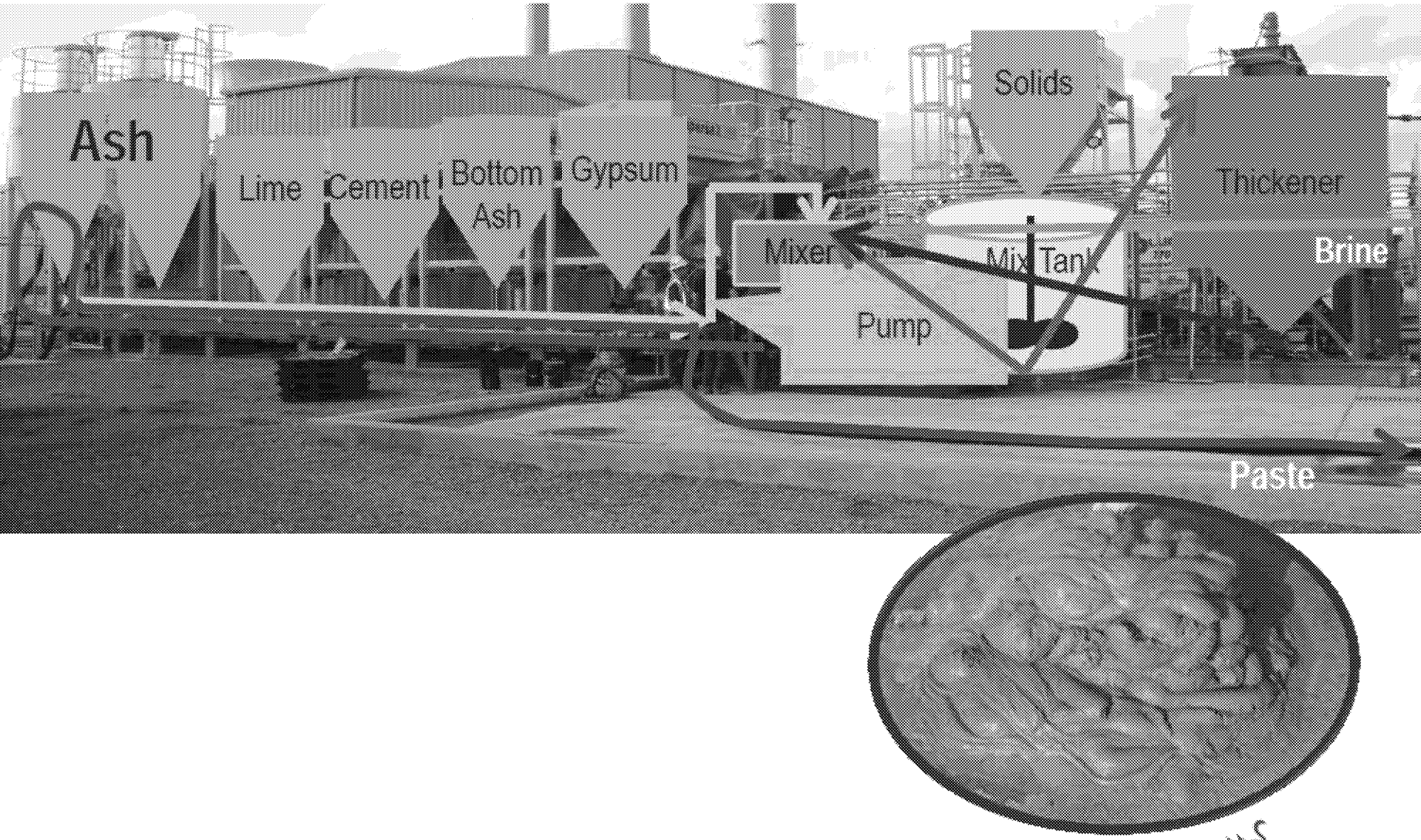
Southern Company

CARMEUSE

Southern Research – Water Research Center

Southern Research – Water Research Center

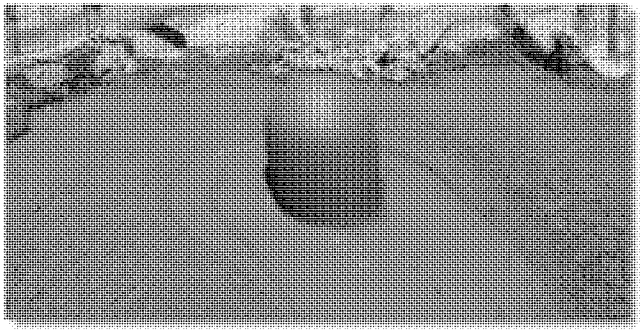
Southern Research – Water Research Center



Pozzotec - Next Generation Research

- Blending proportions to install rheological properties
  - Material is non-segregating
  - Has little to no bleed water
  - Retains the pozzolanic reactivity that will densify and harden

- Benefits of pumping material
  - Pumpable material will remove the need for trucking
  - Flowable filling will maximize landfill use and reduce O&M costs
    - Material will flow into cracks in previous layers



Summary of Pozzotec Benefits

Solidification

- Increase compressive strength of material landfilled
- Reduce permeability of landfill
- Reduce O&M costs at the landfill

Stabilization

- Convert inorganic pollutants to insoluble forms
- Reduce leachate contamination

Inactivation

- Kill bacteria and prevent their regrowth
- Reduce odors

Implementation

- Existing industry practice
- Low capital investment
- Works when other ZLD options fail

BEVERIDGE & DIAMOND PC

Benjamin F. Wilson
1350 I Street, N.W.
Suite 700
Washington, D.C. 20005-7202
Direct: (202) 789-6023
Fax: (202) 789-6190
DukeEnergyCAM@bdlaw.com

December 22, 2016

Via First Class Mail

Mr. Brad Corcoran
City of Eden
308 E Stadium Drive
Eden, NC 27288

Re: Example Support Materials for Duke Energy Bromide Claims Process

Dear Mr. Corcoran:

In April, you received a letter from Duke Energy notifying you of your potential eligibility to file a reimbursement claim for impacts to your water supply from Duke Energy's bromide discharges. Duke Energy also provided you with a copy of the Bromide Restitution and Remediation Process, which will guide the claims process; you can also access an electronic copy at https://www.duke-energy.com/our-company/environment/compliance-and-reporting/environmental-compliance-plans (scroll down to "Bromide Claims Process"). In July, I wrote to you to introduce myself as the Court Appointed Monitor ("CAM") overseeing the bromide claims process. The CAM is responsible for evaluating all submitted claims, and for determining whether a local government has presented a cognizable claim for reimbursement. In my capacity as the CAM, I serve as the Court's representative in this matter.

I have received several inquiries from prospective local government claimants regarding the types of evidence that may be relevant to supporting possible claims. Rather than provide informal guidance on an individual basis to each local government that contacts me, I am providing the enclosed list to all potential claimants. This list identifies the types of evidence that might support a cognizable claim. It is not intended to provide a set of mandatory requirements, nor is it exclusive. The list simply is intended to provide some preliminary guidance for local governments that are considering preparation of claims. I will evaluate each claim and the information submitted in support individually on a case-by-case basis.

Please note that **going forward I generally intend to provide additional updates about the bromide claims process by submitting them to Duke for posting on its website**, rather than

BEVERIDGE & DIAMOND PC

by mail, as I believe electronic posting to be more efficient. Accordingly, I encourage you to regularly monitor the website address identified above for future notices and general communications (including any revisions to this list of example support materials). Apart from such notices and general communications, I will communicate any claim-specific information to the particular claimant and Duke in accordance with the provisions of the Bromide Restitution and Remediation Process.

Finally, with the goal of further minimizing the need for hard copy mailings of bromide claims updates, please provide me with a designated contact email address that I will use in the event I determine that direct notification to all potential claimants about a particular update is warranted in the future. Please send that contact information to me by email at DukeEnergyCAM@bdlaw.com.

Sincerely,

Benjamin F. Wilson

Enclosure (1)

cc: Jim Wells, Duke Energy
Steve Struble, Duke Energy
Lara Nichols, Duke Energy
Matt Hanchey, Duke Energy
Julie Janson, Duke Energy
Lana Pettus, United States Department of Justice
Banu Rangarajan, United States Department of Justice
JoAnna McFadden, United States Department of Justice
Steve Kaufman, United States Department of Justice
Seth Wood, United States Department of Justice
Dwayne Benfield, United States Probation Office
John Wasco, United States Probation Office
Chris Bell, Greenberg Traurig
Stacey Wiggins, Eastern District of North Carolina
Jake Warner, Eastern District of North Carolina

November 17, 2016

Bromide Restitution and Remediation Process:
Example Support Materials for Claims

The Court Appointed Monitor (CAM) is providing this list of example support materials for inclusion in claims submitted under the Bromide Restitution and Remediation Process (BRRP) as a helpful tool for parties preparing to submit claims. Please note that this list is preliminary guidance only, which the CAM has prepared as a general response to various inquiries from local governments. Each claim will be unique, and the information required to constitute a cognizable claim will depend on each party's specific circumstances. The CAM encourages each claimant to submit as much information as possible. Also, the CAM has not yet made any determinations on admissibility or relevance of evidence; these will be addressed on a case by case basis. The CAM may update this list in the future based on the parties' comments and as our experience with claims increases, and the CAM invites claimants to submit any comments or further inquiries to DukeEnergyCAM@bdlaw.com.

Example Support Materials for Claims:

1. **Location information.** Examples of the types of information include: town, county, state where utility is located; location of water intakes (latitude and longitude and identification on a map); and distance from relevant Duke facility and direction of water flow.

2. **Utility operational information.** Examples of the types of information include: sources of raw water; treatment plant capacity and average daily production (both in MGD) and the population served; age of treatment plant; and how water is treated (processes and chemicals employed, along with chemical application points). A flow sheet would be helpful. Also, consider identifying treatment changes (if any) made over the time period of interest (such as equipment, chemical or dose changes) and their dates.

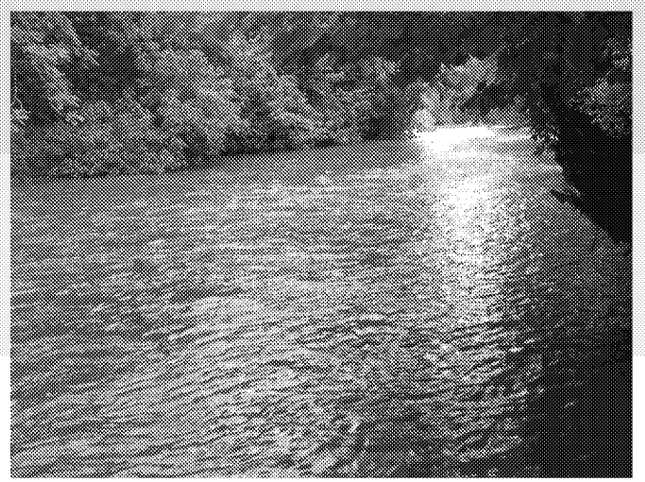
3. **Data.** Data may include the historical record of trihalomethanes (THM) concentrations (total and individual species) and raw water bromide concentrations, with sampling locations. Historical time plots of data would be useful. If available, consider providing at least several years of data predating the FGD scrubber installation along with more recent data. Duke will share the date of FGD scrubber installation on its website, at [*insert exact URL here*], and copies of this information will also be distributed to the local governments by mail. Also, if available, consider providing raw water temperature and raw and settled water total organic carbon concentrations coinciding with THM data. If claimant chooses to rely upon numerical modeling, please be prepared to provide backup data (such as modeling software, input files, data used to support model development and validation, technical memorandum/report describing model setup, assumptions, parameterization and results).

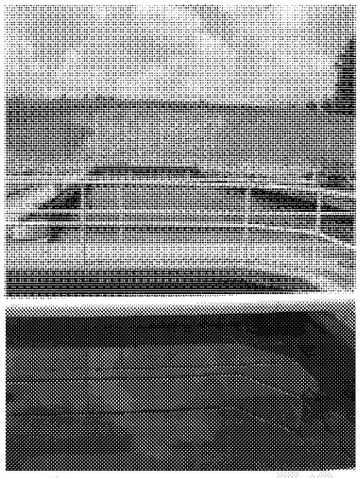
4. **Discussion of data.** Please explain how claimant construes the data and how they relate to the Duke's FGD scrubber use. If there are a variety of contributing bromide sources, consider discussing these and how they may relate to the claim.

5. **Other water users.** Consider providing information on whether claimant's treated water is sold to another utility and, if so, (a) to whom and how much (in MGD) and (b) what changes, if any, that user had to make in response to increases in bromides or other impacts.

6. **A summary of impacts.** This may include a summary of actions taken and planned in response to increases in bromides, associated expenditures, and any other basis for restitution.

FINAL REPORT





STAGE 2 DISINFECTANTS/DISINFECTION BYPRODUCTS RULE COMPLIANCE PLAN

City of Eden, North Carolina

June 2013

HAZEN AND SAWYER
Environmental Engineers & Scientists

FINAL REPORT
STAGE 2 DISINFECTANTS/DISINFECTION BYPRODUCTS RULE COMPLIANCE PLAN

City of Eden, North Carolina

NORTH CAROLINA PROFESSIONAL SEAL 029976 ENGINEER DAVID S. BRILEY 6-7-13

NORTH CAROLINA PROFESSIONAL SEAL 30433 ENGINEER D. CORY HOPKINS 6-7-13

June 2013

HAZEN AND SAWYER
Environmental Engineers & Scientists

4011 WestChase Boulevard, Suite 500
Raleigh, NC 27607

List of Sections

Section **Page**

Executive Summary ES-1

1 Introduction
1.1 Background 1-1
1.2 Scope of Work 1-3

2 Regulatory Overview and Water Quality Goals
2.1 General 2-1
2.2 Finalized Drinking Water Regulations 2-2
2.2.1 Lead and Copper Rule (LCR) 2-3
2.2.2 Stage 2 Disinfection Byproducts Rule (Stage 2 DBPR) 2-5
2.2.3 Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) 2-8
2.3 Future Water Quality Regulations 2-11
2.4 Regulatory Issues Regarding Emerging Contaminants 2-11
2.5 Water Quality Goals 2-13

3 Existing Treatment Facilities and Distribution System
3.1 Robert A. Harris WTP 3-1
3.1.1 Treatment Process 3-1
3.1.2 Chemical Additions 3-2
3.1.3 Typical Water Quality 3-2

4 Optimization of Existing WTP Processes for DBP Reduction
4.1 Bench-Scale Testing Procedures 4-1
4.1.1 Coagulant Testing 4-3
4.1.2 Disinfection By-Products (DBPs) 4-3
4.1.2.1 Sample Preparation and DBP Details 4-4
4.2 Dan River Bench-Scale Testing 4-5
4.2.1 Raw Water Quality 4-5
4.2.2 Coagulant Screening 4-5
4.2.3 Polymer Testing 4-7
4.2.4 Potassium Permanganate Testing 4-9
4.2.5 Powdered Activated Carbon (PAC) Testing 4-10
4.2.6 SDS DBP Testing 4-12

List of Sections (Continued)

Section **Page**

4 Optimization of Existing WTP Processes for DBP Reduction (Continued)
4.3 Chloramine Testing 4-13
4.3.1 CT Evaluation 4-13
4.3.2 Proposed Improvements for Conversion to Chloramines 4-16
4.3.3 SDS DBP Testing 4-17

5 Evaluation of Advanced Treatment Technologies
5.1 MIEX® 5-1
5.1.1 Process Description 5-1
5.1.2 Process Effectiveness 5-5
5.1.3 Impacts on Existing WTP Operations 5-11
5.1.3.1 Site Constraints 5-11
5.1.3.2 Hydraulic Constraints 5-14
5.1.3.3 Regeneration Waste Disposal 5-15
5.1.3.4 Intermittent Process Operations 5-17
5.1.4 Impacts on Distribution System Water Quality 5-17
5.1.5 Ease of Construction 5-20
5.1.6 Regulatory Acceptance 5-20
5.1.7 Regulatory Compliance Constraints 5-20
5.1.8 Capital and O&M Costs 5-21
5.2 Anion Exchange 5-22
5.2.1 Process Description 5-22
5.2.2 Conceptual Design 5-25
5.2.3 Effectiveness for DBP Reduction 5-27
5.2.4 Impacts on Existing Plant Operations 5-27
5.2.4.1 Site Constraints 5-27
5.2.4.2 Hydraulic Constraints 5-27
5.2.4.3 Regeneration Waste Disposal 5-28
5.2.5 Impacts on Distribution System Water Quality 5-29
5.2.6 Ease of Construction 5-29
5.2.7 Regulatory Acceptance/Permitting 5-29
5.2.8 Regulatory Compliance Constraints 5-30
5.2.9 Capital and O&M Costs 5-30

List of Sections (Continued)

Section **Page**

5 Evaluation of Advanced Treatment Technologies (Continued)
5.3 Granular Activated Carbon 5-31
5.3.1 Process Description 5-31
5.3.2 Conceptual GAC Filter Design 5-36
5.3.3 Effectiveness for DBP Reduction 5-37
5.3.4 Impacts on Existing WTP Operations 5-40
5.3.4.1 Site Constraints 5-40
5.3.4.2 Hydraulic Constraints 5-42
5.3.4.3 GAC Waste Backwash Disposal 5-42
5.3.5 Impacts on Distribution System Water Quality 5-42
5.3.6 Ease of Construction 5-43
5.3.7 Regulatory Acceptance/Permitting 5-43
5.3.8 Regulatory Compliance Constraints 5-43
5.3.9 Capital and O&M Costs 5-44
5.3.10 Considerations for the Robert Harris WTP 5-45

6 Alternate Water Supply Source – Smith River
6.1 Description 6-1
6.2 Bench-Scale Testing for Smith River Water 6-3
6.2.1 Bench-Scale Testing Procedures 6-3
6.2.2 Smith River Raw Water Quality 6-5
6.2.3 Coagulant Screening 6-6
6.2.4 Smith River Hydrology 6-10
6.2.5 Alternative Sites for Smith River Water Supply Intake 6-11
6.2.5.1 Upstream of Spray Dam 6-11
6.2.5.2 Historic Fieldcrest Mills Intake 6-12
6.2.5.3 Downstream of Hydroelectric Facility in Barnett Canal Discharge 6-14

List of Sections (Continued)

Section **Page**

7 Findings and Summary
7.1 Summary of Costs 7-1
7.2 Implementation Schedule 7-2
7.3 Feasible DBP Compliance Options 7-2
7.3.1 Chloramination 7-3
7.3.2 GAC Contactors 7-3
7.3.3 Smith River Water Supply 7-4
7.4 Proposed DBP Compliance Strategy 7-4
7.4.1 Corrosion Control Pilot Study 7-5
7.4.2 Public Information Program 7-6
7.4.3 Distribution System Flushing 7-6
7.4.4 Development of Nitrification Control Plan and Distribution System Monitoring 7-6
7.4.5 Startup Assistance 7-6
7.5 Project Implementation Schedule 7-6

Appendices

Appendix A: Impacts of Bromamines on Chloramines Stability

Appendix B: Granular Activated Carbon (GAC) Pilot Study at the Robert A. Harris Water Treatment Plant

List of Tables

Table		Page
ES-1	Capital and O&M Costs for Robert Harris WTP	ES-3
ES-2	Net Present Worth of Evaluated Technologies for 11 MGD and 21 MGD Capacities	ES-4
ES-3	Capital Improvements Plan for Stage 2 DBP Compliance	ES-6
1-1	Comparison of TTHM Speciation at Site 343	1-2
2-1	Stage 2 DBPR Critical Deadlines	2-6
2-2	Cryptosporidium Treatment Categories for Filtered Systems	2-8
2-3	Microbial Toolbox Components	2-10
2-4	Finished Water Quality Goals	2-13
3-1	Typical Chemical Use at the Robert Harris WTP	3-2
4-1	Bench Scale Test Calibration	4-2
4-2	Jar Test Parameters at 10 MGD	4-2
4-3	Dan River Free Chlorine DBP Sample Preparation	4-4
4-4	Dan River Chloramine DBP Sample Preparation	4-4
4-5	Dan River Water Quality	4-5
4-6	Polymer Performance Comparison	4-8
4-7	Raw Water (Potassium) Permanganate Screening	4-10
4-8	Permanganate Performance	4-10
4-9	PAC Specifications	4-11
4-10	Dan River Free Chlorine 10 Day SDS Testing - DBP Speciation	4-13
4-11	Ammonia Feed Point CT Comparison	4-15
4-12	Baffling Classifications	4-16
4-13	Dan River Chloramine 10 Day SDS-DBP Speciation	4-20
5-1	MIEX® Process Advantages and Disadvantages	5-5
5-2	Waste Product Storage Volume Estimates	5-16
5-3	Stage 2 DBPR Compliance Schedule Constraints	5-21
5-4	MIEX® Facility Capital and O&M Costs Summary	5-22
5-5	Anion Exchange Process Advantages and Disadvantages	5-25
5-6	Conceptual Anion Exchange Design	5-26
5-7	Stage 2 DBPR Compliance Schedule Constraints	5-30
5-8	Anion Exchange Facility Capital Costs Summary	5-31
5-9	Physical Characteristics of Bituminous GAC	5-32
5-10	Summary of Filtered Water TOC for the Robert Harris WTP	5-37
5-11	Preliminary Design of the GAC Filters at the Robert Harris WTP	5-37

List of Tables (Continued)

Table **Page**

5-12 GAC Advantages and Disadvantages 5-40
5-13 Stage 2 D/DBP Rule Compliance Schedule for the GAC Process 5-44
5-14 GAC Facility Capital Costs for the Robert Harris WTP 5-45
6-1 Water Quality Monitoring Plan – Phase 1 6-2
6-2 Comparison of Dan River and Smith River Water Quality 6-3
6-3 Bench Scale Test Calibration 6-4
6-4 Jar Test Parameters at 10 MGD 6-5
6-5 Smith River Water Quality 6-5
6-6 Smith River Free Chlorine DBP Sample Preparation 6-8
6-7 Smith River Free Chlorine 10 Day SDS-DBP Results by Species 6-10
6-8 Smith River Summary Flow and Stage Statistics at USGS Gauge 02074000 6-10
6-9 Cost Opinion for Smith River Intake Project (21 MGD Design Capacity) 6-18
7-1 Capital and O&M Costs for Robert Harris WTP 7-1
7-2 Net Present Worth of Evaluated Technologies for 11 MGD and 21 MGD Capacities 7-1
7-3 Capital Improvements Plan for Stage 2 DBP Compliance 7-7

List of Figures

Figure		Page
1-1	Quarterly Average TTHM Results from Stage 1 Sites	1-1
1-2	TTHM Concentrations at Stage 2 Sites	1-3
3-1	Filtered Flow (2009-2012)	3-4
3-2	Raw Water Total Organic Carbon (2007-2012)	3-4
3-3	Total Organic Carbon (2007-2011)	3-5
3-4	Raw Water Turbidity (2007-2012)	3-5
3-5	Settled Water Turbidity (2007-2012)	3-6
3-6	Alkalinity and Temperature (2007-2012)	3-6
3-7	Raw, Settled, and Finished Water pH (2006-2012)	3-7
3-8	Raw and Finished Water Hardness (2007-2012)	3-7
3-9	Coagulant Dose and Raw and Finished Water TOC (2009-2012)	3-8
3-10	Chlorine Residuals throughout WTP (2007-2012)	3-8
3-11	Reservoir Bromide Concentrations (2011-2012)	3-9
3-12	THM Speciation and Concentration with Reservoir Bromide Levels (2010-2012)	3-9
3-13	Historical DBP Concentrations (2004-2012)	3-10
3-14	DBP Speciation (2006-2012)	3-11
4-1	Coagulant Screening – Settled Water Turbidity	4-6
4-2	Coagulant Screening – UV_{254} Absorbance	4-7
4-3	Stockhausen 321 TR Performance	4-8
4-4	Stockhausen 2500 Performance	4-9
4-5	Powdered Activated Carbon Comparison (with Alum and Polymer)	4-11
4-6	Simulated Distribution System Testing Dan River with Free Chlorine	4-12
4-7	Dan River Chloramine 10-Day SDS-DBP Results	4-18
4-8	Contact Time With One and Both Clearwells	4-19
5-1	MIEX® Absorption and Regeneration Processes	5-2
5-2	High-Rate MIEX® Process Schematic	5-3
5-3	Impact of MIEX® on TTHM LRAA – Stage 1 DBPR Monitoring Sites	5-7
5-4	Impact of MIEX® on TTHM Levels – Stage 2 DBPR Monitoring Sites	5-8
5-5	Impact of Partial MIEX® Treatment on TTHM LRAA – Stage 1 DBPR Monitoring Sites	5-9
5-6	Impact of Partial MIEX® Treatment on TTHM Levels – Stage 2 DBPR Monitoring Sites	5-10
5-7	Typical WTP Process Schematic with MIEX®	5-11

List of Figures (Continued)

Figure		Page
5-8	Conceptual MIEX® Facility Layout	5-12
5-9	Packaged MIEX® System	5-12
5-10	Custom Designed MIEX® System	5-13
5-11	Typical Corrosion Study Pilot Plant	5-19
5-12	Typical Corrosion Study Pilot Plant	5-19
5-13	Schematic of Anionic Resin	5-23
5-14	Ion Exchange Operational Stages	5-24
5-15	Conceptual Anion Exchange Facility Layout	5-26
5-16	Typical WTP Process Schematic with Anion Exchange	5-27
5-17	GAC Micro Pore Structure	5-32
5-18	Example Freundlich Adsorption Isotherm	5-34
5-19	Photograph of the GAC Pilot Plant (Filters 5 through 8)	5-35
5-20	GAC Pilot Plant Flow Schematic	5-35
5-21	RSSCT Columns at Clermont County, Ohio's Bob McEwen WTP	5-36
5-22	GAC Pilot Plant Results – Total Organic Carbon	5-38
5-23	GAC Pilot Plant Results: 10-day SDS TTHMs	5-39
5-24	Typical Location of GAC Filtration Facility	5-40
5-25	Conceptual GAC Filtration Facility Layout	5-41
6-1	Smith River in the Vicinity of Eden, NC	6-1
6-2	Smith River - Primary Coagulant Settled Water Turbidity	6-6
6-3	Smith River - Primary Coagulant UV Absorbance	6-7
6-4	Smith River – Alum and Calgon WPH	6-8
6-5	Smith River Free Chlorine 10-Day SDS-DBP Testing	6-9
6-6	Smith River Rating Curve Approximation at Church Street Bridge	6-13
6-7	Smith River Stage-Frequency Approximation at Church Street Bridge	6-13
6-8	Smith River Velocity-Frequency Approximation at Church Street Bridge	6-14
6-9	Conceptual Layout of Facilities Surrounding the Spray Cotton Mill	6-15
6-10	Smith River Intake and Pump Station	6-16
6-11	Smith River Intake Alternate Raw Water Transmission Routings	6-17
7-1	Implementation Schedule for Chloramines, Smith River Intake, and GAC Contactors	7-2

EXECUTIVE SUMMARY

The City of Eden operates a 20.6 million gallon per day (mgd) conventional water treatment facility which obtains its supply from the Dan River. The City has experienced elevated Total Trihalomethanes (TTHM) since spring/summer 2008, which coincides with a new industrial discharge containing bromide. The City retained Hazen and Sawyer to evaluate alternatives to reduce Disinfection Byproducts (DBP) formation to ensure compliance with the US Environmental Protection Agency's Stage 2 Disinfectants/Disinfection Byproducts Rule (Stage 2 DBPR).

The Stage 2 DBP Rule requires that the maximum contaminant levels (MCL) for total trihalomethanes (TTHMs) of 80 parts per billion (ppb) and five haloacetic acids (HAA5s) of 60 ppb be met on a locational running average basis. Locational running annual average (LRAA) means that the 4-quarter average for each specific sampling site location must comply with the MCLs rather than being able to average all sampling sites over 4 quarters as required under the current Stage 1 DBP Rule.

Compliance dates for the Stage 2 DBP Rule is based on the population served. For the City of Eden, monitoring at the Stage 2 sites will begin in October 2013 with the first LRAA calculation for compliance in 3rd quarter 2014. However, NC Department of Environment and Natural Resources (NC DENR) may grant up to a 2-year extension if major capital improvements are necessary for Stage 2 DBP Rule compliance.

DBP levels can vary due to seasonal changes in source water organic and bromide levels, water treatment plant (WTP) and distribution system operations, seasonal temperature changes and many other factors. Due to this variability, DBP goals have been set at 80 percent of the MCL as an operational target for RWSA to provide assurance of one hundred percent regulatory compliance. Therefore, the DBP goals are 64 ppb for TTHMs and 48 ppb for HAA5s.

Hazen and Sawyer evaluated alternatives to reduce DBP formation through changes in treatment processes at the Robert Harris WTP. Hazen and Sawyer further evaluated opportunities to optimize existing WTP processes and considered installation of advanced treatment technologies to reduce DBP levels.

Optimization of Existing Treatment Processes

Optimization of existing treatment processes for natural organic matter removal was evaluated in this study for effectiveness in meeting the DBP reduction goals. A bench-scale testing program was developed to confirm the effectiveness of each optimization strategy for DBP control.

Enhanced Coagulation

Bench-scale tests were conducted at the Robert Harris WTP to evaluate enhanced coagulation using the current coagulants (polyaluminum chloride and alum) as well as

an alternate coagulant (ferric sulfate). Ferric sulfate demonstrated improved organics removal as compared to alum and polyaluminum chloride. However, simulated distribution tests showed that enhanced coagulation with any of the coagulants tested did not meet the DBP goals using free chlorine. Bench-scale testing was also conducted to evaluate the effectiveness of powdered activated carbon (PAC) for DBP control. Tests were conducted at various PAC doses and contact times, however, simulated distribution test results exceeded the DBP goals. Pre-oxidation with potassium permanganate was also assessed and it had little impact on controlling DBP formation.

Chloramination

For the bench-scale tests described above, the potential effectiveness of chloramination for DBP control was also assessed. Ammonia was added to form chloramines and samples were held for 10 days to simulate the maximum residence time in the Eden distribution system. With chloramines, all samples were below 50 ppb; well below the goal of 64 ppb TTHMs. The use of PAC or an alternate coagulant such as ferric sulfate resulted in even lower TTHM levels compared to the existing treatment scheme.

Advanced Treatment Technology Evaluation

The addition of new treatment technologies were evaluated for this study to assess expected effectiveness for removing total organic carbon (TOC) or bromide. The processes evaluated were:

- Magnetic Ion Exchange Resin (MIEX®)
- Granular Activated Carbon Contactors (GAC)
- Post-filter Anion Exchange

These advanced treatment processes would allow for the continued use of free chlorine as a residual disinfectant. The advanced treatment strategies were evaluated based on the following criteria:

- **Effectiveness for DBP Control**: The expected ability of the strategy to achieve compliance with the Stage 2 DBPR and the City's goal of 80% of the MCL (64 ppb for TTHMs) for compliance reliability.
- **Impact to WTP Operations and Maintenance**: Reflects the relative impacts to plant and/or distribution system operations and maintenance.
- **Residuals Management Issues**: Consideration of changes to residuals management, such as increase in backwash water production, or disposal of a brine waste, should the strategy be implemented.

- **Ease of Construction**: Considers the complexity of the upgrades and impacts during construction to the facility.
- **Impact to Distribution System Water Quality**: The potential regulatory compliance impacts to distribution system water quality such as lead and copper, and the potential for nitrification was evaluated.
- **Regulatory Acceptance and Permitting**: The perception of a treatment strategy to be permitted by NC DENR (i.e. precedence) and the need for piloting prior to approval was considered.
- **Time to Implement**: The time needed to implement the strategy with regard to pilot testing, if required, as well as design and construction periods was evaluated.
- **Life Cycle Costs**: Capital costs and operation and maintenance costs were estimated for each technology to determine net present worth.

Alternate Water Source

Hazen and Sawyer also evaluated the feasibility of utilizing an alternate water supply source, the Smith River. Water quality monitoring results showed that the Smith River has similar water quality to the Dan River, expect bromide levels are significantly lower. Bench-scale testing of Smith River water indicated that the Stage 2 DBP Rule requirements could be met using this water source and the existing treatment at the Robert Harris WTP.

Summary of Costs

The capital and O&M costs for each of the alternatives evaluated for the Robert Harris WTP are shown in **Table ES-1.** Costs were developed for both the full WTP capacity of 21 mgd as well as 11 mgd in the event that the City elects to pursue a phased approach. Annual O&M costs were based on average plant production rates.

Table ES-1: Capital and O&M Costs for Robert Harris WTP

Advanced Technology	Advanced Treatment Capacity (MGD)	Capital Costs	Annual O&M Costs	Unit O&M Costs ($/1,000 gal)
MIEX®	11	$12,742,000	$332,000	$0.15
	21	$24,126,000	$607,000	$0.12
Anion Exchange	11	$12,257,000	$738,000	$0.34
	21	$23,525,000	$1,402,000	$0.27
GAC	11	$7,580,000	$1,622,000	$0.74
	21	$14,470,000	$3,062,000	$0.60
Chloramines	11	$1,300,000	$20,200	$0.01
	21	$1,310,000	$33,100	$0.01
Smith River Intake*	21	$16,280,000	$200,000	$0.04

* Capital costs for an 11-mgd option were not developed. Insignificant cost savings are anticipated through a phased approach for this alternative.

The net present worth for each of the alternatives evaluated for the Robert Harris WTP are shown in **Table ES-2**. Net present worth was developed on a 20-year basis at a discount rate of 5 percent.

Table ES-2: Net Present Worth of Evaluated Technologies for 11 MGD and 21 MGD Capacities

Capacity	11 MGD	21 MGD
MIEX®	$16,879,000	$31,691,000
Anion Exchange	$21,454,000	$40,997,000
GAC	$44,340,000	$52,630,000
Chloramines	$1,552,000	$1,722,000
Smith River Intake	N/A	$18,772,000

Feasible DBP Compliance Options

Chloramination, post-filter GAC contactors, and a new raw water intake on the Smith River have been identified as the three favorable alternatives for Stage 2 DBP Rule compliance for the Robert Harris WTP. The City has selected chloramination at its compliance strategy for the Stage 2 DBP Rule due to its low cost relative to capital and operating costs, effectiveness for controlling DBP formation, and long history and widespread use throughout the U.S., and particularly in North Carolina.

The use of chloramines at the Robert Harris WTP would require the addition of an aqueous ammonia storage and feed system. The concept is that primary disinfection would be achieved via free chlorine through the first clearwell, and then ammonia would be added to form chloramines prior to the second clearwell. By using only one clearwell for primary disinfection CT, free chlorine contact time would be reduced and thus, TTHM levels should be lower at the point of entry.

It is expected that the proposed facilities can be constructed and online in Spring 2015. The City's compliance deadline is October 2013, so the City will need to request an extension from the NC DENR as allowed by the Stage 2 DBPR.

In addition to design and construction of the proposed capital improvements, several activities are recommended as part of the conversion to chloramination:

- Corrosion coupon/loop study – a corrosion coupon/loop study is recommended to assess lead and copper corrosion control with chloramines. NC DENR usually requires a corrosion study to accompany any major change in treatment.

- Public Information Program - to disseminate information to City water customers regarding the change in disinfectant and potential impacts to special water use groups such as the medical community, fish and aquarium stores, and certain industries.

- Distribution System Flushing - a flushing program should be developed to prepare the distribution system for the conversion to chloramines.

- Development of Nitrification Control Plan and Distribution System Monitoring – additional monitoring of distribution system quality is recommended as part of a nitrification control plan.

- Startup Assistance – engineering support during the chloramines system startup to ensure persistent disinfectant residual formation and to limit blending of chlorinated and chloraminated water during the conversion.

Project Implementation Schedule

A preliminary Project Implementation Schedule is shown in **Table ES-3** for the Stage 2 DBPR Upgrades for the Robert Harris WTP. This schedule was developed to provide a basis for budgeting needs through fiscal year 2015. It is recommended that the projects be implemented along with the discussion with NCDENR of an extension for compliance with Stage 2 DBPR. Extensions of time are allowed by regulation for treatment facilities that require major capital upgrades such as new facilities to be added to an existing WTP. A formal request to NC DENR for the 2-year extension should be pursues as soon as possible to secure the waiver for regulatory compliance prior to the current compliance deadline of October 2013.

Table ES-3 Capital Improvements Plan for Stage 2 DBP Compliance

Start Date	Major Activity Description	Cost in 2013 Dollars ($)	Notes
FY 2014			
Jul. 2013	Final Decision on Stage 2 DBP Strategy / Authorize Engineer for WTP Upgrades	--	
Aug. 2013	Corrosion Study	$70,000	Confirm corrosion control with conversion to chloramines
Oct. 2013	Develop PER WTP Upgrades	$28,500	Prepare Preliminary Engineering Report and submit to NC PWS
Dec. 2013	Standard Lead and Copper Monitoring Site Selection	--	City to confirm if sampling sites still available. Increased sampling and analytical costs to return to standard monitoring for at least 3 years.
Mar. 2014	Final Design Complete	$66,500	Final design of proposed WTP improvements
Apr. 2014	Advertise for Bids	in design fee	
Jun. 2014	Award Contract	$1,055,000	
FY 2015			
Jul. 2014	Construction Starts (Notice to Proceed)	--	
Jul. 2014	Construction Administration and Observation	$63,100	
Jul. 2014	Develop Public Information Program	$35,000	Prepare public information materials. Plan to roll out by Dec. 2014.
Jul. 2014	Develop Flushing Program and Nitrification Control Plan	$40,000	Distribution system flushing program for conversion to chloramines.
May 2015	Construction complete – startup and conversion to chloramines	---	

1 INTRODUCTION

1.1 Background

The City of Eden operates a 20.6 million gallon per day (mgd) conventional water treatment facility which obtains its supply from the Dan River. The City has experienced elevated Total Trihalomethanes (TTHM) since spring/summer 2008, which coincides with a new industrial discharge containing bromide. The City has monitored bromide levels in the Dan River at their intake and found bromide concentrations ranging from 22 to 433 parts per billion (ppb). In the presedimentation basin, bromide levels have been recorded up to 492 ppb. **Figure 1-1** shows quarterly average TTHMs for all Stage 1 monitoring sites. Prior to summer 2008, the average of all quarterly TTHM samples ranged from 9 to 62 ppb (1 ppb = 1µg/L). After summer 2008, the average of quarterly TTHM samples ranged from 19 to 120 ppb. Also, TTHM speciation clearly shifted from being dominated by chloroform (with only 25 percent of TTHM being brominated). After the new discharge, approximately 80 percent of TTHMs are the brominated species. This strongly suggests that the increase in TTHM concentration is a result of bromide incorporation into TTHMs.

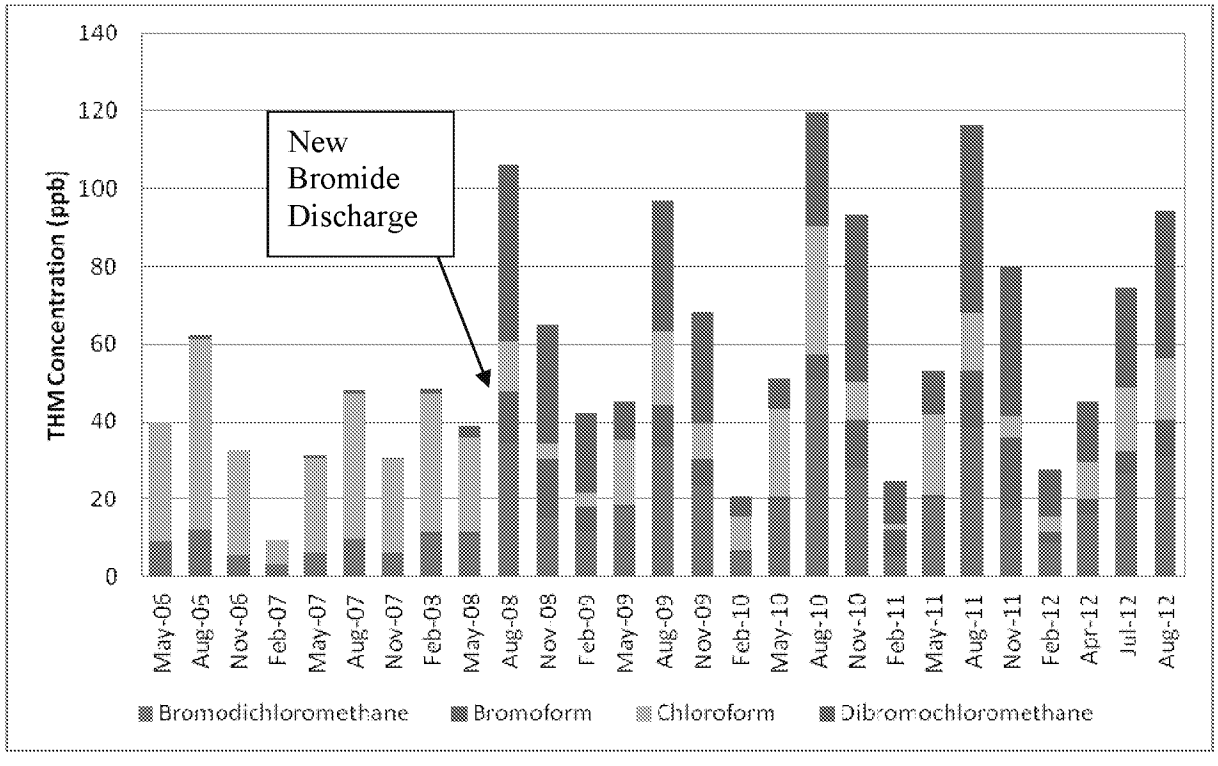


Figure 1-1: Quarterly Average TTHM Results from Stage 1 Sites.

Bromide gets incorporated into TTHMs first by being chlorine oxidizing bromide to hypobromous acid. Hypobromous acid is a stronger halogen substitution agent than hypochlorous acid. Hypobromous acid then reacts with natural organic matter to form disinfection byproducts. When significant levels of bromide are present in the raw water, TTHM speciation shifts more towards the brominated species. Brominated species have higher molecular weight, so the mass concentration of TTHMs can increase even if molar concentrations are similar. Also, TTHM formation occurs at a more rapid rate in the presence of hypobromous acid.

Table 1-1 compares TTHM concentrations for Site 343, one of the Stage 1 monitoring sites in the distribution system, on two dates (August 2007 and November 2011) in which the TTHMs concentrations on a molar basis were similar; approximately 0.418 x 10^6 mol. In August 2007, bromide levels in the source water were low. TTHM concentrations were 53 ppb, and brominated species represented only 21 percent of the total TTHMs. In November 2011, TTHM concentrations were 81 ppb, and brominated species represented 93 percent of the total TTHMs. Therefore, on a mass basis, TTHMs were almost 53 percent higher although the molar concentration was the same.

Table 1-1: Comparison of TTHM Speciation at Site 343

THM Species	Aug. 2007			Nov. 2011		
	THM Conc. (ppb)	Percent of Total	Molar Conc (x10^6 mol)	THM Conc. (ppb)	Percent of Total	Molar Conc (x10^6 mol)
Bromodichloromethane	10	19%	0.0610	18	22%	0.1099
Bromoform	0	0%	0.0	18	22%	0.0712
Chloroform	42	79%	0.3518	6	7%	0.0503
Dibromochloromethane	1	2%	0.0048	39	48%	0.1872
Total THM	**53**	**100%**	**0.418**	**81**	**100%**	**0.419**

The City has monitored TTHM concentrations at their Stage 2 DBP sampling sites (**Figure 1-2**). During the summer months, TTHM concentrations have exceeded 150 ppb in the system, and exceeded 100 ppb at the point of entry.

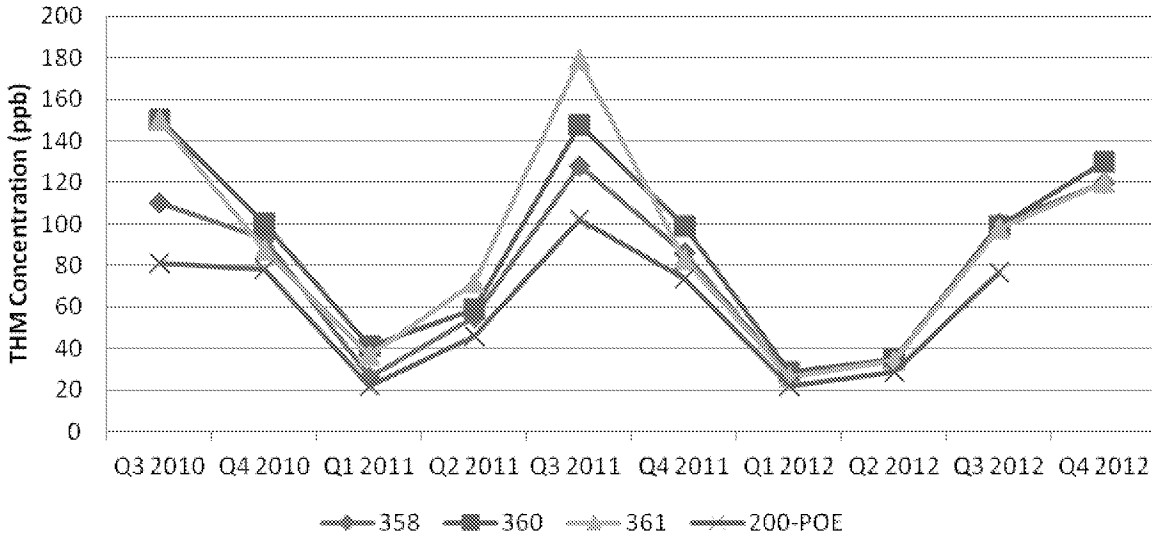


Figure 1-2: TTHM Concentrations at Stage 2 Sites

The Locational Running Annual Average (LRAA) for the Stage 2 sites currently ranges from 61 to 90 ppb. The Stage 2 Disinfectants/Disinfection ByProducts Rule (Stage 2 DBPR) requires that the four-quarter average at each monitoring site be below the MCL of 80 ppb for TTHMs and 60 ppb for five halocaetic acids (HAA5). This also referred to as the locational running annual average, or LRAA. Recent monitoring data suggest that City of Eden will have significant challenges in complying with the Stage 2 D/DBP Rule. The City of Eden must be in compliance with the Stage 2 D/DBP Rule by October 2013. Therefore, the City of Eden retained Hazen and Sawyer to evaluate alternatives to reduce DBP formation and comply with the Stage 2 D/DBP Rule. The scope of work for this evaluation is outlined in the following section.

1.2 Scope of Work

The overall objective for this project is to develop the most feasible and cost-effective solution to meet the requirements of the Stage 2 D/DBP Rule. The general scope of work for this evaluation is as follows:

Task 1: Data and Studies Review and Analysis. Site visits were made to each WTP, and reviews were completed of previous studies and reports regarding DBP reduction efforts, engineering plans, monthly operating reports and water quality data to assess treatment plant performance.

Task 2: Alternate Water Supply Source Assessment. The feasibility of utilizing the Smith River as an alternate water supply source was investigated. Available flow and stage records were reviewed for the Smith River to understand hydrology and potential yield. A raw water quality monitoring program was developed and the City began to collect samples to assess water quality trends for the Smith River. Bench-scale testing was conducted to assess treatability and DBP formation of the Smith River. Alternate sites for a water supply intake and pump station were evaluated and a conceptual design and cost opinion was prepared.

Task 3: Existing Plant Process Optimization. Opportunities to optimize existing treatment processes that are deemed cost-effective and feasible for additional DBP control were evaluated via bench-scale testing. Use of potassium permanganate as a pre-oxidant, alternative coagulants such as ferric sulfate and polyaluminum chloride, were evaluated. Powdered Activated Carbon (PAC) was also evaluated using bench scale tests.

Task 4: Evaluation of Chloramination. Using water from bench-scale tests, the effectiveness of chloramination was assessed through simulated distribution system (SDS) tests. CT requirements for the Robert Harris WTP was evaluated and alternative strategies developed to meet CT using free chlorine and then add ammonia for formation of monochloramines.

Task 5: New Treatment Technology Evaluation. New treatment technologies were considered and evaluated should they be needed for compliance. The new technology candidates included granular activated carbon contactors, MIEX ion exchange, and fixed bed anion exchange. The technologies were compared with regard to cost and non-economic criteria.

Task 5: Selection of the Best Strategy for Regulatory Compliance. In this task, the advantages and disadvantages of feasible options was evaluated. An implementation schedule was developed for each feasible Stage 2 D/DBP Rule compliance option to ensure compliance with their respective regulatory schedule. The final report will include recommended improvements for the selected Stage 2 D/DBP Rule compliance strategy.

2 REGULATORY OVERVIEW AND WATER QUALITY GOALS

2.1 General

The Safe Drinking Water Act (SDWA) was passed by the United States (U.S.) Congress in 1974 to protect public health by regulating the nation's public drinking water supplies, and applies to all public water systems in the U.S. The SDWA was subsequently amended in 1986 and 1996, to protect drinking water and its sources (i.e. rivers, lakes, reservoirs, springs, and ground water wells; the SDWA does not regulate private wells that serve fewer than 25 individuals). To ensure that the drinking water is safe, the SDWA has set up multiple barriers against pollution. These barriers include source water protection, treatment, distribution system integrity, and public information.

The SDWA authorized the U.S. Environmental Protection Agency (EPA) to set national health-based standards for drinking water to protect against both naturally-occurring and man-made contaminants that may be found in drinking water. The EPA has set these national standards based on sound science to protect against health risks, considering available technology and costs. These National Primary Drinking Water Regulations (NPDWR) set enforceable maximum contaminant levels (MCLs) for particular contaminants in drinking water and/or required ways to treat water to remove contaminants. Each standard also includes requirements for water systems to test for contaminants in the water to ensure that these standards are being achieved. In addition to setting these standards, the EPA provides guidance, assistance, and public information about drinking water, collects drinking water data, and oversees state drinking water programs. Additional information on the SDWA can be found at the following website: www.epa.gov/safewater/sdwa.

State drinking water programs are often entrusted with oversight of water systems. States are granted "primacy" (the authority to implement the SDWA within their jurisdiction) by the EPA, if states can show that they will adopt standards at least as stringent as the EPA and make sure that water systems meet these standards. The EPA, state drinking water programs, and public water systems work together to make sure that these standards are met.

The EPA is continuously expanding and modifying drinking water regulations under the SDWA and its subsequent reauthorizations. The North Carolina Department of the Environment and Natural Resources (NCDENR) serves as the agency responsible for implementing and enforcing drinking water regulations for the State of North Carolina, including the jurisdiction of the city of Eden. Development of these regulations is a time-consuming process, considering the influence of scientific and political agendas. While a number of these regulations are enforceable, there is still ongoing discussion and development of regulations that will be promulgated in the near future.

EPA drinking water regulations can be classified by their development as either finalized, proposed, or under development. Finalized regulations include those that are fully developed and published by the Federal Register. Finalized rules provide two levels of regulatory standards – primary and secondary. Primary standards are health-related criteria that must be enforced by the State of North Carolina. The NPDWRs, or primary standards, are legally enforceable standards that apply to all public water systems. The regulated contaminants are classified as microorganisms, disinfectants, disinfection byproducts, inorganic chemicals, organic chemicals, or radionuclides.

The EPA has also established the National Secondary Drinking Water Regulations (NSDWRs), or secondary standards. Secondary standards relate to the aesthetics of the water. Even though the EPA does not require a state to enforce secondary standards, a state may choose to adopt them as enforceable standards. Violation of a secondary standard prompts action to determine if the substance can be removed through treatment or if a more suitable, available supply exists. If one of these actions is found to exist, the public water system shall promptly conform to such action. Aesthetic factors significantly affect the public's perception and eventual acceptance of the finished water. Therefore, parameters such as taste, odor and color as well as iron and manganese levels are often regulated. A comprehensive list of the primary and secondary standards enforced by the State of North Carolina is available at the following website: http://www.epa.gov/safewater/mcl.html.

Proposed rules are in an intermediate stage of development open for comments from outside, interested parties. It is during this stage of development that a rule can be altered to address comments or additional information now available for review.

Regulations under development identify rules that have not yet been formally proposed. At this stage of development, these informal regulations can be drafted without concern for addressing outside party interests.

2.2 Finalized Drinking Water Regulations

Below is a list of drinking water regulations, which apply to the City of Eden, with their respective promulgation dates:

- Safe Drinking Water Act (SDWA); National Interim Primary Drinking Water Regulations (NIPDWR) – 1974
- SDWA Amendments of 1986; National Primary Drinking Water Regulations (NPDWR) – 1986
- Surface Water Treatment Rule (SWTR) – 1989
- Total Coliform Rule (TCR) – 1989 (revisions finalized in 2012)
- **Lead and Copper Rule (LCR) – 1991 (revisions finalized in 2007)**

- Interim Enhanced Surface Water Treatment Rule (IESWTR) – 1998
- Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR) – 1998
- Radionuclides Rule – 2000
- Arsenic Rule – 2001
- Long Term 1 Enhanced Surface Water Treatment Rule – 2002
- **Stage 2 Disinfectants and Disinfection Byproducts Rule (DBPR) – 2006**
- **Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) – 2006**
- Unregulated Contaminant Monitoring Rule 2 (UCMR2) – 2006
- Unregulated Contaminant Monitoring Rule 3 (UCMR3) – 2012

The following subsections outline in greater detail the requirements of the rules identified in bold font from the list above. These rules are presented in the chronological order in which they were adopted and are considered the most pertinent rules to the objectives of the study identified in **Section 1**.

2.2.1 Lead and Copper Rule (LCR)

The LCR was promulgated by the EPA in June 1991. The rule has four major components:

1. MCLGs for lead and copper were set at 15 ppb and 1.3 ppm, respectively.
2. Increased monitoring programs were required for lead and copper in the distribution system and at consumers' taps, based on the population served by the system. Targeted samples are collected from locations where consumers are most likely to be exposed to increased copper or lead levels.
3. Large systems (population greater than 50,000) were mandated to conduct corrosion control studies and implement optimal treatment programs by January 1997.
4. Treatment technique requirements are triggered if greater than 10% of measurements exceed the action levels of 15 ppb for lead or 1.3 mg/L for copper.

In the event the lead action level is exceeded, the water system must undertake a number of additional actions to control corrosion, inform the public of protective steps that will safeguard their health, and potentially be required to replace existing lead service line(s).

Revisions to the LCR were finalized in October 2007 and include the following:

- Changes to the monitoring requirements:
  - Clarify language that describes the number of samples and collection sites.
  - Sample averaging will no longer be permitted.
  - The maximum time allotted between lead monitoring will be no greater than three years.
  - Water quality will no longer be used to verify corrosion control. Reduced monitoring eligibility is limited to Public Water Supplies (PWSs) that meet the lead action limit.
- Intended changes to a source water or treatment processes that may increase lead corrosion must receive prior approval from the primacy agency before implementation.
- Public notification changes:
  - Notification of tap water monitoring results for lead will be provided to owners and/or occupants of homes as well as buildings that are part of a utility's sampling program.
  - Changes to public notification content, delivery, and timeframe are also considered.
  - Changes to the educational statements of lead in drinking water addressed in Consumer Confidence Reports are included.
- Re-evaluation of "tested out" lead service lines for utilities participating in a lead service line replacement program.
- Improved compliance with public education requirements of the rule including guidance for lead in schools.

2.2.2 Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR)

The Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR) and the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) are part of the Microbial/Disinfection Byproducts (M/DBP) Cluster. The M/DBP Cluster is a set of interrelated regulations that address risks from microbial pathogens and disinfectants/disinfection byproducts. Both the Stage 2 DBPR and the LT2ESWTR were promulgated simultaneously in January 2006 to address concerns about risk tradeoffs between pathogens and DBPs. The goal of the Stage 2 DBPR is to target the highest risk systems for changes beyond those required by Stage 1 DBPR. Proposed in August 2003, the Stage 2 DBPR builds on the 1979 Total Trihalomethane Rule and the 1998 Stage 1 DBPR by requiring better control of DBPs in water distribution systems. The Stage 2 DBPR applies to all community water systems and non-transient, non-community water systems that add a primary or residual disinfectant other than ultraviolet light and those that deliver such water.

The key requirements of the Stage 2 DBPR are summarized below:

- Conduct an Initial Distribution System Evaluation (IDSE) to choose Stage 2 DBPR monitoring sites. There are four IDSE Compliance Options:
  - 40/30 Certification (40/30) – If individual Stage 1 DBPR compliance samples have been consistently less than or equal to 40 ppb for TTHMs and 30 ppb for HAA5s and there have been no monitoring violations during the same time period, NCDENR can grant a 40/30 certification. In this case, the system has no IDSE monitoring requirements, but must still conduct Stage 2 DBPR compliance monitoring.
  - Very Small System Waiver (VSS) – This applies to systems that serve fewer than 500 people; no IDSE is required.
  - Standard Monitoring (SM) – One year of increased monitoring for TTHMs and HAAs in addition to the Stage 1 DBPR compliance monitoring sites. Data collected from IDSE monitoring sites and Stage 1 sites will be used to select the new Stage 2 compliance monitoring sites. Monitoring frequency and number of distribution system monitoring locations for the IDSE are dependent upon the population served by the distribution system. The City of Eden performed a SM to determine appropriate DBP monitoring sites.
  - System Specific Study (SSS) – Systems that have extensive TTHM and HAA5 data (including Stage 1 DBPR compliance data) or technical expertise to prepare a hydraulic model may choose to conduct a SSS to select Stage 2 DBPR compliance monitoring locations.

- Begin complying with monitoring requirements of the Stage 2 DBPR as indicated by the appropriate compliance schedule based on the size of the population served by the water system. A two-year extension may be granted to systems requiring significant capital improvements to ensure rule compliance.

Table 2-1 summarizes critical deadlines regarding the IDSE as well as monitoring and operational evaluation level compliance for the Robert A. Harris WTP.

Table 2-1: Stage 2 DBPR Critical Deadlines

Compliance Schedule	Submit IDSE SM Plan, SSS Plan, or 40/30 Certification	Begin IDSE SM or SSS	Complete IDSE SM or SSS	Submit IDSE Report	Monitoring Compliance	Operational Evaluation Level Compliance
3	October 2007 (completed)	October 2008 (completed)	September 2009 (completed)	January 2010 (completed)	October 2013 (October 2015)[1]	July 2014 (July 2016)[1]

1. NCDENR may grant up to 2 years for the completion of any significant capital improvements designed to achieve Stage 2 DBPR compliance.

Compliance with the TTHM/HAA5 MCLs of 80/60 ppb, will be determined through the use of Locational Running Annual Average (LRAA) measurements at critical monitoring sites identified during the IDSE. The LRAA approach uses the annual average at each sampling location to determine compliance, addressing concerns of spatial variation in DBP exposure throughout the distribution system. The number of system monitoring locations again depends on the size of the population served by the given water system. Monitoring locations include a combination of highest TTHM locations, highest HAA5 locations, near entry point locations, average residence time locations, and existing Stage 1 DBPR locations. Accordingly, the City of Eden must monitor DBP concentrations at four (4) locations in the distribution system.

The IDSE and LRAAs calculation will lead to lower DBP concentration requirements overall. However, this approach may still allow individual DBP samples above the MCL even when the system is in compliance. The rule requires systems that exceed "operational evaluation levels" to evaluate system operational practices and identify opportunities to reduce DBP concentrations in the distribution system. The operational evaluation levels for each monitoring location are determined by the following equation:

Operational Evaluation Level = $(Q_1 + Q_2 + 2Q_3) / 4$, where:

Q_1 = quarter before previous quarter measurement
Q_2 = previous quarter measurement
Q_3 = current quarter measurement

If the operation evaluation level is greater than the MCL, then the system must conduct an operational evaluation.

The operational evaluation involves an examination of system treatment and distribution operational practices, including changes in sources or source water quality, storage tank operations, and excess storage capacity, which may contribute to high TTHM and HAA5 formation. Systems must also identify what steps could be considered to minimize exceeding operational evaluation levels in the future. In cases where the system can identify the cause of DBP levels that resulted in the operational evaluation (based on factors such as water quality data, plant performance data, and distribution system configuration) the system may request, and the state may allow, limiting the evaluation to the identified cause. The State must issue a written determination approving limiting the scope of the operational evaluation. The system must submit their operational evaluation report to the State for review within 90 days after being notified of the analytical result that initiates the operational evaluation. Public water systems must begin Stage 2 DBPR operational evaluation level compliance approximately nine months after beginning Stage 2 DBPR monitoring compliance to determine if operational evaluation levels for TTHMs and HAA5s are exceeded.

Under the Stage 2 DBPR, the EPA has identified the best available technology (BAT) for complying with TTHM and HAA5 MCLs. The EPA has specified a different BAT for systems that treat their own source water than that of consecutive systems. For systems that treat their own source water, EPA identified the following three technologies:

- GAC10 (granular activated carbon filter beds with an empty-bed contact time of 10 minutes based on average daily flow and a carbon reactivation frequency of every 120 days)

- GAC20 (granular activated carbon filter beds with an empty-bed contact time of 20 minutes based on average daily flow and a carbon reactivation frequency of every 240 days)

- Nanofiltration (NF) using a membrane with a molecular weight cutoff of 1000 Daltons or less

The BATs for consecutive systems are:

- Chloramination with management of hydraulic flow and storage to minimize residence time in the distribution system for systems serving at least 10,000 people

- Management of hydraulic flow and storage to minimize residence time in the distribution system for systems serving fewer than 10,000 people

2.2.3 Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)

The LT2ESWTR was promulgated on January 5, 2006, concurrently with the Stage 2 DBPR. The LT2ESWTR applies to all public water systems which use surface water or have ground water under the direct influence (GWUDI) of surface water. Protection of public health from illness due to *Cryptosporidium* and other microbial pathogens in drinking water while addressing risk trade-offs with the control of DBPs is the primary objective of the LT2ESWTR. Data from human health studies have indicated that the potential for *Cryptosporidium* to cause infection is likely greater than previously recognized. These findings led the EPA to conclude that existing requirements do not provide adequate public health protection in filtered water systems with the highest source water *Cryptosporidium* levels. Consequently, EPA decided to establish additional, risk-targeted treatment requirements for such filtered water systems.

Under the LT2ESWTR, specific criteria are set for sampling frequency and schedule, sampling location, using previously collected data (i.e. "grandfathering' data), and for providing treatment instead of monitoring. Much like the Stage 2 DBPR, a water system's compliance schedule is dictated by the populated size served by the system. Twenty-four (24) months of source water monitoring for *Cryptosporidium* is required while recording source water *E. coli* and turbidity levels; only *E. coli* (or an alternative State-approved indicator) and turbidity measurements are required for water systems serving fewer than 10,000 people. A PWS will be classified into one of four "Bins" (see **Table 2-2**) based on source water monitoring results. Additional treatment for *Cryptosporidium* will be required for systems placed in Bin 2 or greater.

Table 2-2: *Cryptosporidium* Treatment Categories for Filtered Systems

Bin Number	Source Water Pathogen Concentration – MRAA[1]	LT2ESWTR Treatment Requirements for Filtered Systems
1	< 0.075 oocysts/L	No action required
2	0.075 to < 1.0 oocysts/L	Additional 1.0-log action required
3	1.0 to < 3.0 oocysts/L	Additional 2.0-log action required[2]
4	3.0 oocysts/L or greater	Additional 2.5-log action required[2]

1. MRAA = Maximum Running Annual Average
2. Minimum of 1.0-log must be obtained from either inactivation using ozone, chlorine dioxide, UV, membranes, bag filtration, cartridge filtration, or bank filtration.

Additional *Cryptosporidium* treatment credit may be achieved through additional treatment steps like ozone, chlorine dioxide, UV, and membranes. Further, PWSs can receive a higher level of credit for existing treatment processes through achieving very low filter effluent turbidity or through a demonstration of performance. Section IV.D of the LT2ESWTR in the Federal Register presents criteria for awarding *Cryptosporidium* treatment credit to these and other treatment and control options, which collectively comprise the "Microbial Toolbox", presented in **Table 2-3**.

The Stage 2 M/DBP Advisory Committee recommended the Microbial Toolbox to provide PWSs with broad flexibility in selecting cost-effective LT2ESWTR compliance strategies. Most options in the Microbial Toolbox carry prescribed credits toward *Cryptosporidium* treatment requirements. PWSs receive these credits by demonstrating compliance with required design and operational criteria. In addition, States may award treatment credits other than the prescribed credit through a "demonstration of performance," which involves site-specific testing by the PWS with State-approved protocol.

Further, the LT2ESWTR addressed risks from uncovered finished water storage facilities. Under the LT2ESWTR, public water systems must limit potential risks by covering or treating the discharge from uncovered finished water storage facilities.

Table 2-3: Microbial Toolbox Components

Approach	Potential Log Credit			
	0.5	1.0	2.0	≥2.5
Watershed Control Program[1]	x			
Alternative Source/Intake Management[2]	No prescribed credit			
Pre-Sedimentation Basin with Coagulants[3]	x			
Two-Stage Lime Softening[4]	x			
Bank-Filtration[5]	x	x		
Combined Filter Performance (≤0.15 NTU in 95% of samples each month)	x			
Individual Filter Performance (≤ 0.15 NTU in 95% of samples each month and never > 0.3 NTU in two consecutive measurements in any filter)[6]	x			
Demonstration of Performance [7]	Based on demonstration			
Slow Sand Filters[8]				x
Second Stage Filtration[9]	x			
Membranes – MF, UF, NF, RO[10]	Based on demonstration			
Bag Filters and Cartridge Filters[11]	x	x	x	x
Chlorine Dioxide[12]	x	x	x	x
Ozone[12]	x	x	x	x
UV[13]	x	x	x	x

1. State-approved program consisting of required elements, annual program status report to State, and regular watershed survey.
2. PWSs may simultaneously monitor for *Cryptosporidium* at alternative locations to determine Bin classification or under alternative intake management strategies.
3. Based on monthly mean reduction of 0.5-log or greater in turbidity or alternative State-approved performance criteria. Basins must be continuously operated with coagulant addition with all plant flow routed through the basins.
4. Chemical addition and hardness precipitation in both stages with all plant flow passing through both stages.
5. 0.5-log credit for 25-foot setback. 1.0-log credit for 50-foot setback.
6. In addition to 0.5-log combined filter performance credit.
7. Credit awarded based on demonstration to the State with State-approved protocol.
8. No prior chlorination.
9. Requires coagulation prior to first filter.
10. Credit equivalent to removal efficiency demonstrated in challenge test for device if supported by direct integrity testing.
11. Credit awarded based on demonstration of log removal in a challenge test when used either singularly or in series.
12. Based on measured CT.
13. Based on validated UV dose. Reactor validation testing is required to establish UV dose and operating conditions.

2.3 Future Water Quality Regulations

As part of the 1996 amendments to the SDWA, review and revisions to a NPDWR are required no less than every six years. Revisions to the rule are intended to improve monitoring requirement effectiveness by balancing both public health gains, via proactive problem identification, and resolution while attempting to reduce sampling requirements. The EPA is in the process of developing a new NPDWR regulating perchlorate, a naturally occurring and man-made chemical that is commonly used in the production of sodium hypochlorite, fertilizers, rocket fuel, and explosives. The proposed rule for perchlorate is anticipated sometime in 2013.

2.4 Regulatory Issues Regarding Emerging Contaminants

The EPA has been under political pressure to streamline their process for identifying, evaluating, and regulating new compounds of concern. The year 2010 brought about several major developments worth noting in considering a master plan for water treatment plants: (1) The Six-Year Review, (2) The Third Contaminant Candidate List (CCL3), and (3) EPA's Drinking Water Strategy for grouping contaminants. Each of these issues is discussed briefly in the following paragraphs.

The results of the US EPA's Six-Year Review were published on March 29, 2010 in the Federal Register (EPA–HQ–OW–2008–0747; FRL–9130–3). While most drinking water contaminants were not selected for re-evaluation, four contaminants were chosen for potential reduction/lowering of the maximum contaminant level (MCL): tetrachloroethylene (PCE), trichloroethylene (TCE), acrylamide, and epichlorohydrin. Both PCE and TCE are industrial solvents that have MCLs based on older analytical method limitations. It was indicated in the review process that newer methods could lower the detection limits and may provide a tangible public health benefit if the MCL is reduced from 5 µg/L to 1 µg/L. Acrylamide and epichlorhydrin are both regulated based on a treatment technique (TT) approach as they are associated with the application of specific polymers used in some drinking water treatment plants. The current MCL for these two compounds is 0.5 µg/L, and could be lowered to 0.1 ug/L, essentially forcing a modification of the amount of polymer used during treatment.

The final CCL3 was published October 8, 2009 (EPA–HQ–OW–2007–1189; FRL–8963–6) with a total of 104 chemicals or chemical groups and 12 microbial contaminants, although discussions regarding the third round of unregulated contaminant monitoring rules (UCMR3) did not begin until 2010. In April 2010, the EPA had a stakeholder session announcing an initial list of contaminants which could be included in UCMR3. Many of the compounds on the EPA's proposed list were *not* included in the CCL3. Several "groups" of compounds were proposed, arranged by analytical methods to cover a broader range of compounds than those included on the CCL3. The groups include seven steroid hormones, four heavy metals, nine volatile organic compounds (VOCs), six perfluorinated compounds (PFCs), two viruses, 1,4-dioxane, and chlorate. The UCMR3, finalized on April 16, 2012, included a list of 30 contaminants to be monitored; however, their inclusion is not indicative of definitive future regulatory action. These contaminants are split into three types of monitoring efforts:

- **Assessment Monitoring** uses common analytical method technologies used by drinking water laboratories. All PWSs serving more than 10,000 people and 800 representative PWSs serving 10,000 or fewer people will monitor for 21 List 1 contaminants during a 12-month period from January 2013 through December 2015.

- **Screening Survey** monitoring uses specialized analytical method technologies not as commonly used by drinking water laboratories. All PWSs serving more than 100,000 people, 320 representative PWSs serving 10,001 to 100,000 people, and 480 representative PWSs serving 10,000 or fewer people are required to monitor for seven List 2 contaminants during a 12-month period from January 2013 through December 2015.

- **Pre-Screen Testing** uses newer analytical method technologies not as commonly used by drinking water laboratories. 800 representative PWSs serving 1,000 or fewer people that do not disinfect with wells located in areas of karst or fractured bedrock, will participate in monitoring for two List 3 viruses during a 12-month period from January 2013 through December 2015.

Perchlorate was also not included in the list (despite being on each of the CCL1, CCL2, and CCL3) as the EPA is expected to make a final regulatory determination sometime this year.

On March 22, 2010, the EPA Administrator Lisa Jackson unveiled the agency's new drinking water strategy (815-F-10-001) whereby contaminants will be assessed (and possibly regulated) by groups. The strategy is similar to the existing paradigm of regulating disinfection byproducts by summing the concentration of individual chemical species. However, there appear to be few, if any, groups where such an approach could adequately protect human health due to the wide range of toxicity associated with specific compounds within a "group". Thus, while the approach is well-intentioned, current dialogue within the scientific community indicates limited applicability of the approach, and it is unclear at this time where the approach will lead in terms of new regulations or regulatory processes.

Beyond these tangible statements and programs published by the EPA, any further information regarding potential regulation of emerging contaminants is purely speculative. Research reports and articles are available addressing concerns regarding the toxicological relevance of emerging contaminants in water. These publications indicate that most pharmaceuticals and personal care products (PPCPs) found in water are far below thresholds of concern and therefore pose little risk to human health from consumption in drinking water. Despite this information, it is unclear what impact these publications will have on the political pressures surrounding the regulatory process.

2.5 Water Quality Goals

Water quality goals were developed as a basis for recommended improvements to the Robert A. Harris WTP. These goals were selected primarily to meet or exceed all primary water quality standards enforced by the NCDENR. Additionally, water quality goals associated with secondary standards have been established to ensure the aesthetic quality (i.e. color, taste, and odor) of the finished water. A brief summary of these individual water quality goals are provided below in **Table 2-4.**

Table 2-4: Finished Water Quality Goals

Parameter	Goal	Comment
Filtered water turbidity	≤ 0.10 NTU	Terminate filter runs at 0.20 NTU
Particle counts	Minimize particles and avoid peaks	Surrogate parameter for microbes
UV-254 absorbance	None	Used to monitor organic content only
pH and corrosion control	None	Post-treatment to be provided in full-scale plant for final pH correction and corrosion control ("optimal treatment") to minimize corrosivity; phosphate inhibitor addition to be provided
Aluminum	≤ 0.20 mg/L	Secondary MCL of < 0.20 mg/L
TOC	≤ 0.5 mg/L	Minimize DBP formation
Giardia	3.0-log inactivation	SWTR requirement
Cryptosporidium	2.5-log inactivation	2.5-log removal was assumed from filtration by achieving ≤ 0.10 NTU in 95% of filtered water samples; Bin placement (under the LT2ESWTR) could increase the goal thus requiring additional treatment
Viruses	4.0-log inactivation	SWTR requirement
TTHM	≤ 64 ppb	Typical goal of 80% of LRAA MCL of 80 ppb.
HAA5	≤ 48 ppb	Typical goal of 80% of LRAA MCL of 60 ppb.
Color	< 15 CU	Secondary standard
Manganese	< 0.01 mg/L	Secondary Standard < 0.05 mg/L; lower goal minimizes color consumer complaints
Iron	< 0.1 mg/L	Secondary Standard < 0.30 mg/L; lower goal minimizes color consumer complaints
Free chlorine residual	< 4.0 mg/L (as Cl_2)	MRDL < 4.0 mg/L.
Fluoride	< 0.7 mg/L	Finished water level for optimal dental benefits

3 EXISTING TREATMENT FACILITIES AND DISTRIBUTION SYSTEM

3.1 Robert A. Harris WTP

The Robert A. Harris Water Treatment Plant was constructed in 1978 and expanded to its current capacity in 1994. It has a rated finished water production capacity of 20.6 million gallons per day (MGD). The plant operates 24 hours per day and produces an average of 7.4 MGD (based on data from January 2008 until May 2012). The raw water source is the Dan River, upstream of the confluence with the Smith River. The Harris WTP serves the City of Eden, the MillerCoors brewery and several consecutive systems, including the Henry County Public Service Authority, and the Dan River Water Inc.

3.1.1 Treatment Process

The plant is a conventional surface water treatment plant that uses the Dan River for its raw water source. Raw water is pumped from the Dan River via an intake on the north bank of the river near Fieldcrest Cannon's Karastan Rug Mill. The raw water pump station is equipped with one 10 MGD and two 13 MGD vertical turbine pumps. Raw water is conveyed approximately 7,000 feet to the 87-million gallon pre-sedimentation basin located on the north side of the plant site via a 30-inch pipeline. The pre-settling basin allows for flexibility in raw water pumping and reduced turbidities due to settling in the basin. Raw water flows by gravity to the treatment plant.

Coagulant and pH adjustment chemicals are added in the 30-inch pipe just upstream of rapid mix. A dual stage rapid mix basins distribute the raw water chemicals. Aluminum sulfate is the primary coagulant, and polyaluminum chloride is used seasonally. Polymer is used in conjunction with alum. Sodium hydroxide (caustic) is used to adjust pH and alkalinity, however the raw water feed point for caustic is not currently used. Coagulated water flows to six consecutive flocculation basins and seven sedimentation basins. The plant has seven dual media filters. These filters operate at a loading rate of 4 gallons per minute per square foot (gpm/sf). Chlorine gas is dosed at the filters for iron and manganese oxidation. Finished water chemicals (chlorine, corrosion inhibitor, caustic and fluoride) are dosed in the filtered water flume located below the filter gallery. Finished water is stored on site in the two 4-million gallon above ground clearwells. The high service pump station has one 9 MGD and two 12 MGD pumps. There are five city-owned elevated storage tanks in the distribution system. One additional tank is owned by Fieldcrest Cannon.

Solids from the sedimentation basin are collected by mechanical rakes into a sludge hopper. Sludge is discharged to the Mebane Bridge Wastewater Treatment Plant. Backwash waste is conveyed to one of two equalization waste basins and then to the WWTP.

3.1.2 Chemical Additions

Copper sulfate is periodically added to the pre-sedimentation basin to control algae growth. Historically, chlorine gas was fed at rapid mix, however the initial feed point has been moved to the filters to limit chlorine contact time and DBP formation. The plant has the ability to feed powdered activated carbon and potassium permanganate in the raw water, but neither of these facilities is currently used. Typical chemical feed concentrations are shown in **Table 3-1**.

Table 3-1: Typical Chemical Use at the Robert Harris WTP

Chemical	Average Dose (mg/L)*	90th Percentile Dose (mg/L)*
Copper Sulfate	2.8	4.2
Alum	21.6	26.0
Coagulant Aid Polymer	0.04	0.1
Polyaluminum Chloride	24.7	33.0
Pre Chlorine	3.2	4.6
Post Chlorine	1.0	2.0
Pre Caustic	N/A	N/A
Post Caustic	9.5	14.0
Corrosion Inhibitor	5.0	8.3
Fluoride	0.8	1.1

*Dose statistics are based upon data from 1/1/2007 to 5/31/2012.

3.1.3 Typical Water Quality

Raw water at the Harris WTP is typically characterized by low total organic carbon (TOC) concentrations ranging between 1.0 and 5.9 mg/L. TOC concentrations do not vary widely with the majority of values falling between 1.0 and 3.0 mg/L in all seasons as shown in **Figure 3-2**. Finished water TOC concentrations also do not widely vary with the majority of the values falling between 1.0 and 1.3 mg/L in all season. **Figure 3-3** illustrates the raw and finished water TOC over the past five years. The average turbidity of the raw water is about 18 NTU with peaks around 40 NTU and a maximum value since 2007 of 62 NTU. Turbidity does not seem to trend seasonally as shown in **Figure 3-4** and **Figure 3-5**. The raw water source for the WTP also has a relatively low alkalinity, ranging between 16.0 and 33.0 mg/L as $CaCO_3$. The raw water temperature ranges from lows near 4 degrees C in the winter to around 30 degrees C in the summer. The raw water temperature and alkalinity and the finished water alkalinity are shown in **Figure 3-6**.

Figure 3-7 shows the raw water, settled water and finished water pH. Filtered water pH data is only available from 2006 to 2008 but this graph shows that the filtration pH is typically lower (6.2 to 6.6) in the summer months for TOC removal and increased (7.0 to 7.4) during the winter months to increase settleability. Addition of coagulant aids or adjustment of coagulant doses could be investigated to improve filterability when the temperatures are low. Finished water pH typically is within the range of 7.2 to 7.5.

The raw water source for the WTP has experienced increases in hardness over the past five years as shown in **Figure 3-8**. The average raw water hardness is 33.2 mg/L but has a maximum of 66.0 mg/L. The increased raw water hardness could be a result of increased mineral content in discharges to the Dan River. As a result of increased raw water hardness, finished water hardness has also increased in the past five years as shown in **Figure 3-8**.

The Robert A. Harris WTP uses different coagulants seasonally in order to meet the TOC removal objectives. Aluminum sulfate (alum) is used during the summer months and polyaluminum chloride (PACl) is used in the winter months to improve settleability. The dosing of either alum or PACl is directly related to the raw water TOC as shown in **Figure 3-9**.

The point of entry (POE), pre-filter, and combined filter effluent (CFE) chlorine residuals were evaluated from 2007 through 2012. The combined filter effluent data, however, is only available from 2009 to 2012. **Figure 3-10** illustrates that the residual disinfectant at the POE ranges from 0.5 to 2.7 mg/L whereas the CFE residual disinfectant ranges from 0.9 to 2.2 mg/L. Recently, the chloride residual in the filter effluent has been reduced to about 0.5 mg/L to reduce DBP formation.

Additionally, the filtered flow through the WTP has remained relatively constant over the past three years as shown in **Figure 3-1**. The average annual flow is 5.70 MGD with a maximum flow of 11.40 MGD and a minimum flow of 2.36 MGD.

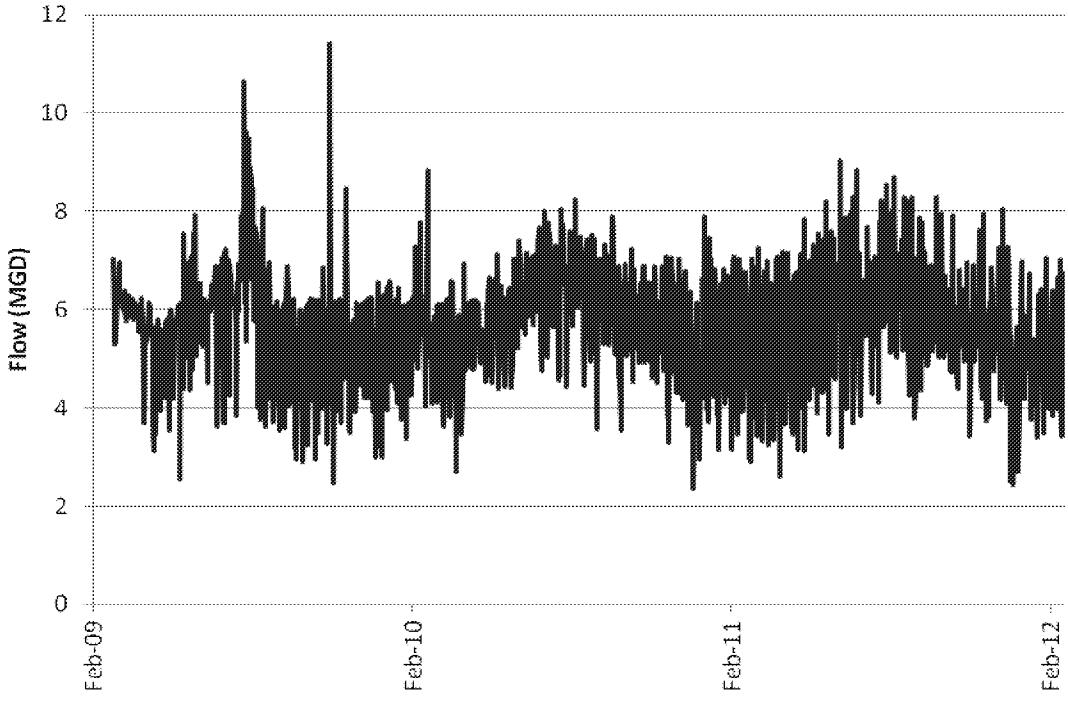


Figure 3-1: Filtered Flow (2009-2012)

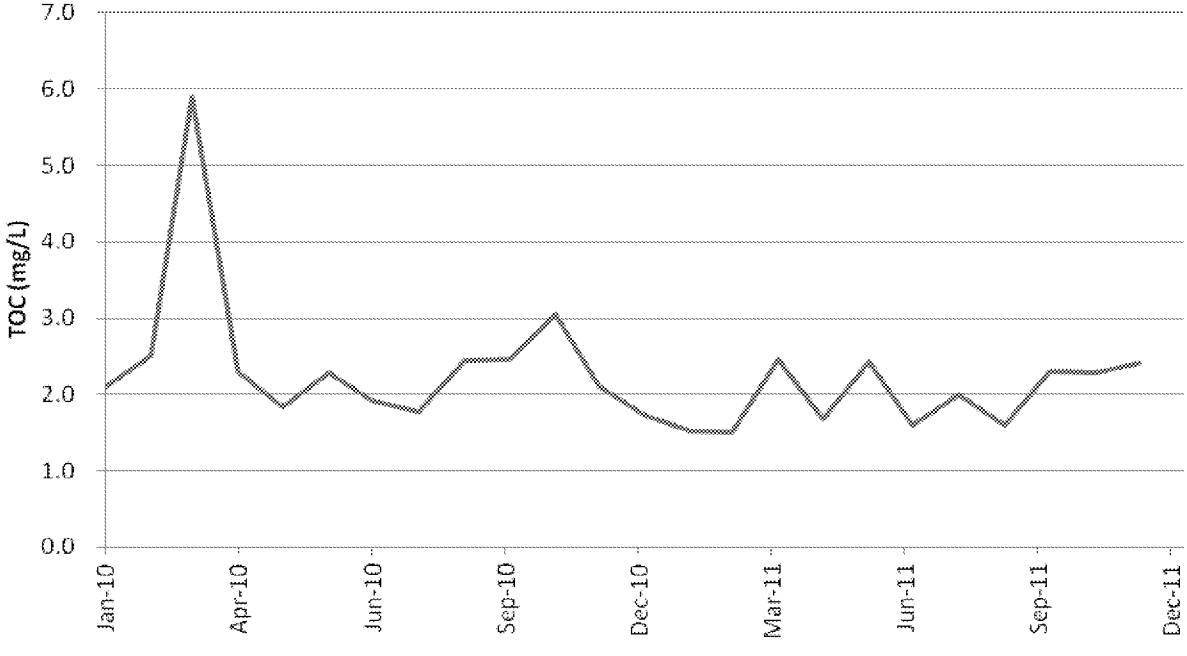


Figure 3-2: Raw Water Total Organic Carbon (2007-2012)

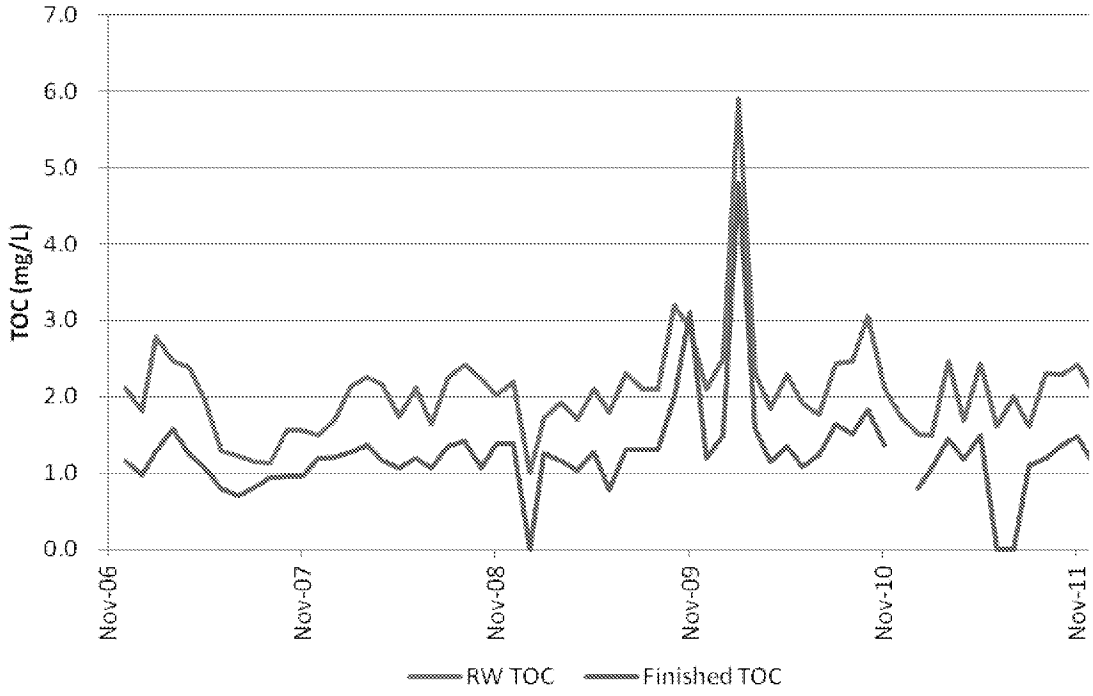


Figure 3-3: Total Organic Carbon (2007-2011)

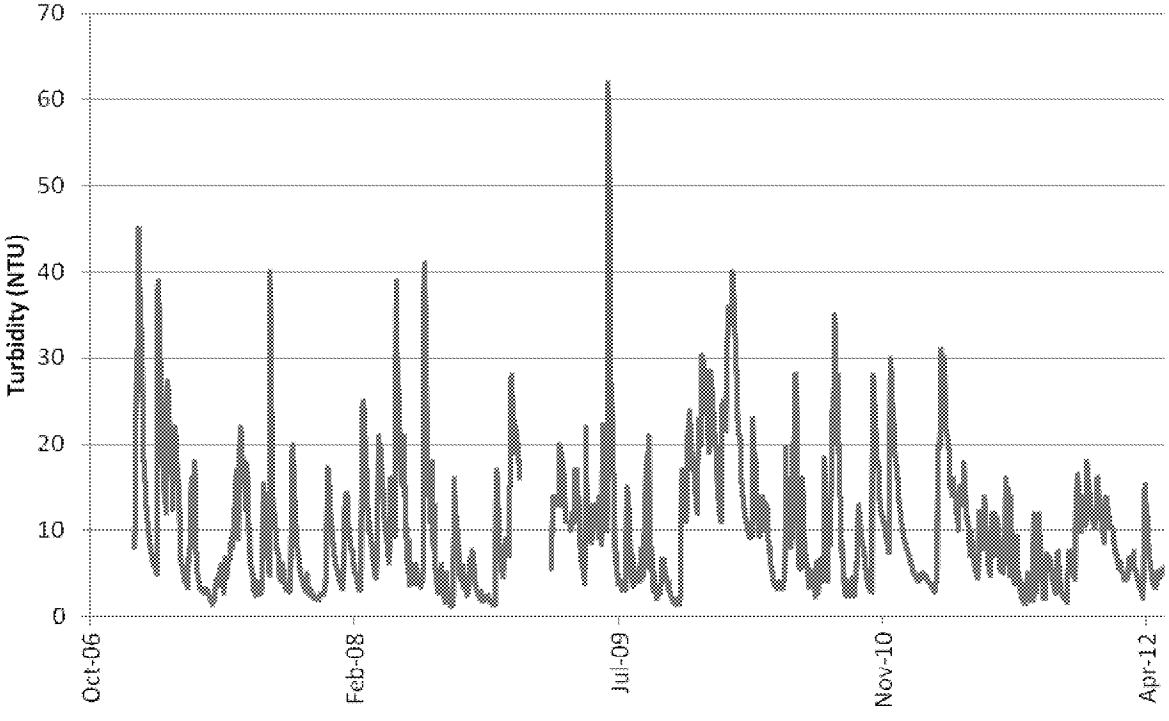


Figure 3-4: Raw Water Turbidity (2007-2012)

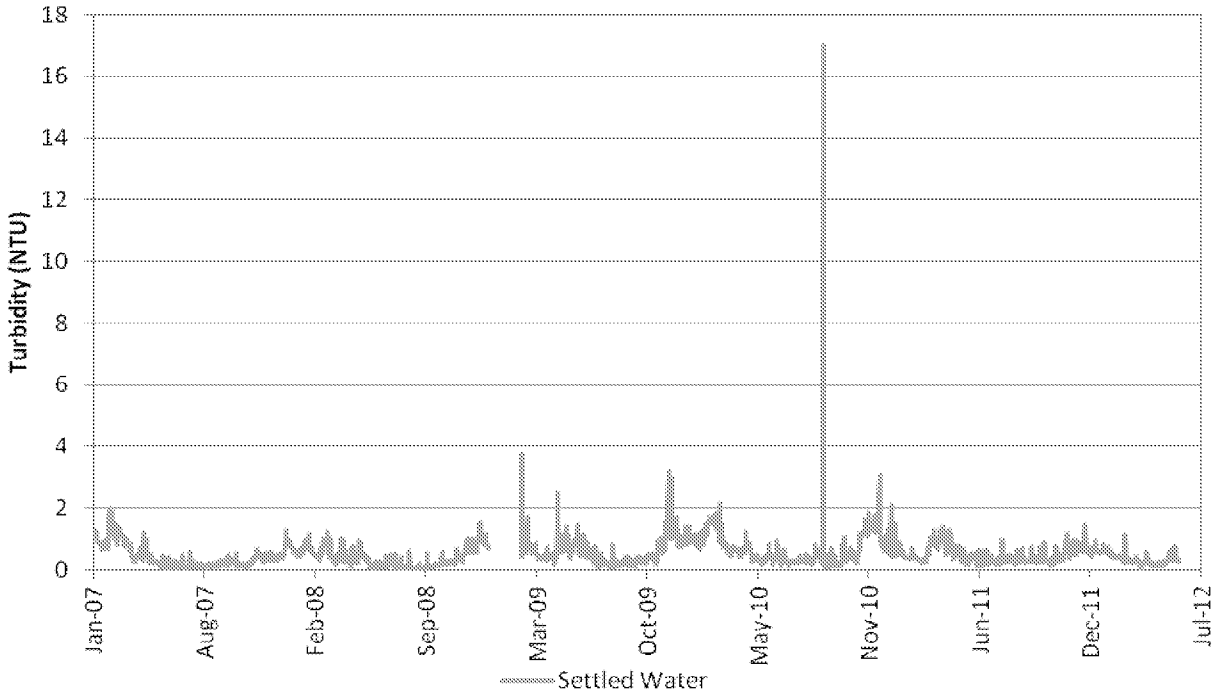


Figure 3-5: Settled Water Turbidity (2007-2012)

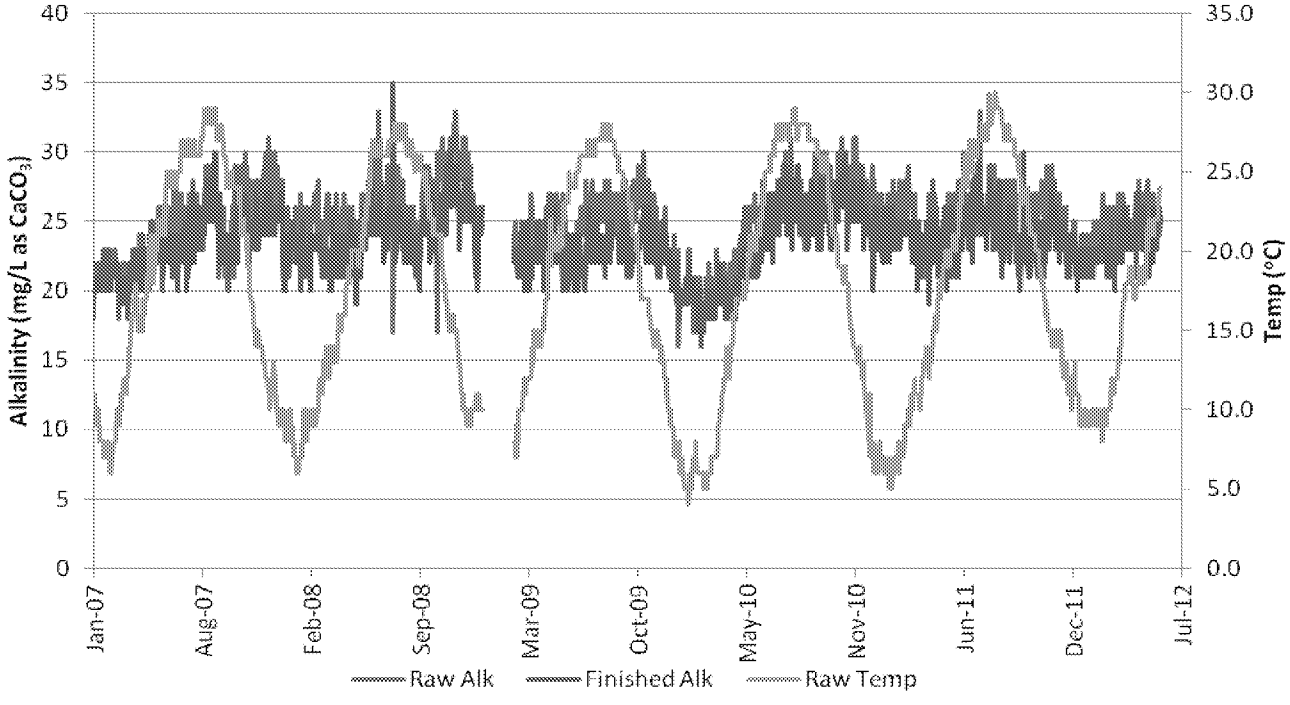


Figure 3-6: Alkalinity and Temperature (2007-2012)

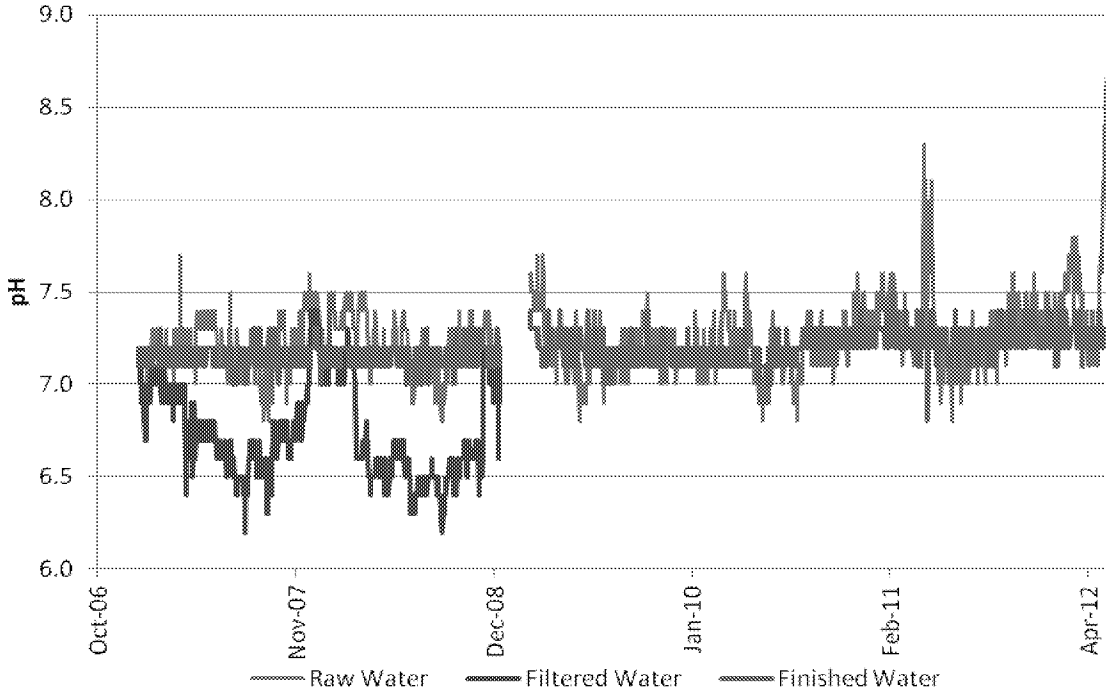


Figure 3-7: Raw, Settled, and Finished Water pH (2006-2012)

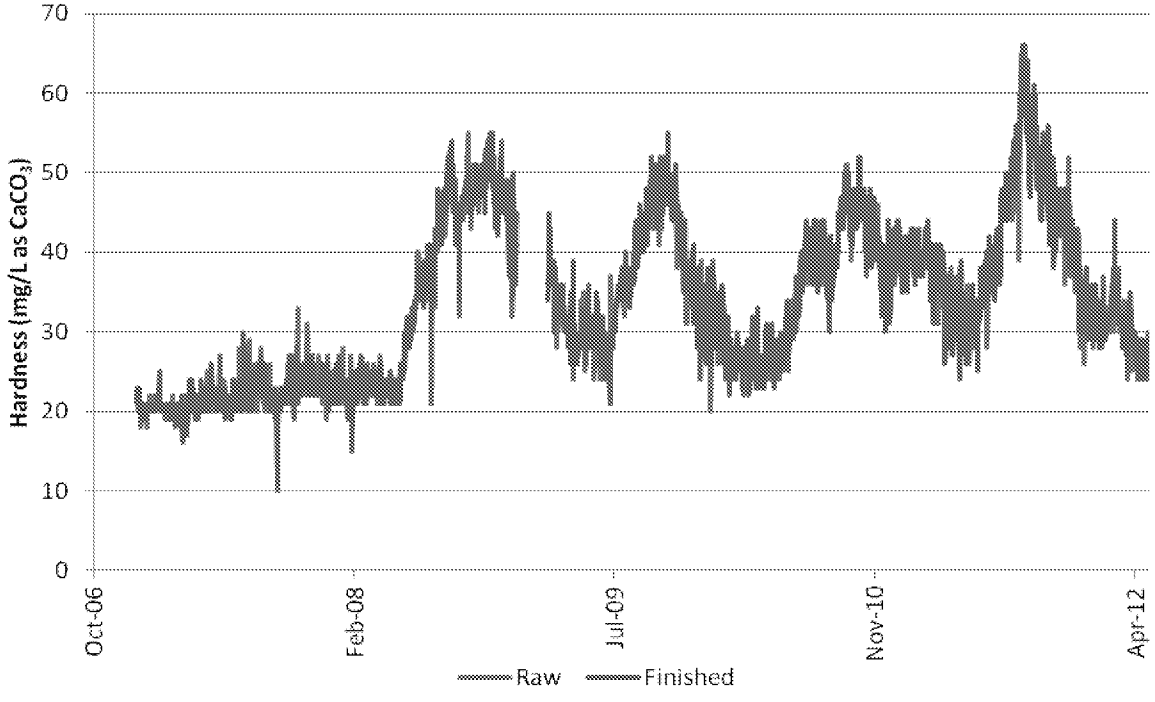


Figure 3-8: Raw and Finished Water Hardness (2007-2012)

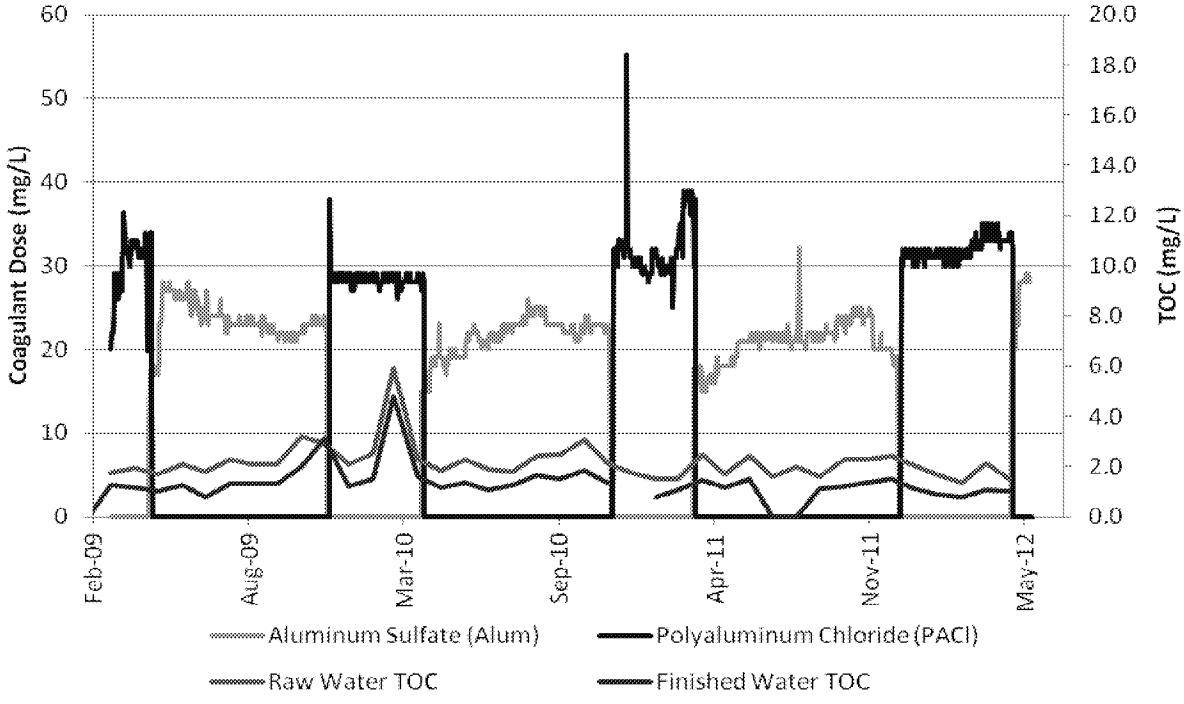


Figure 3-9: Coagulant Dose and Raw and Finished Water TOC (2009-2012)

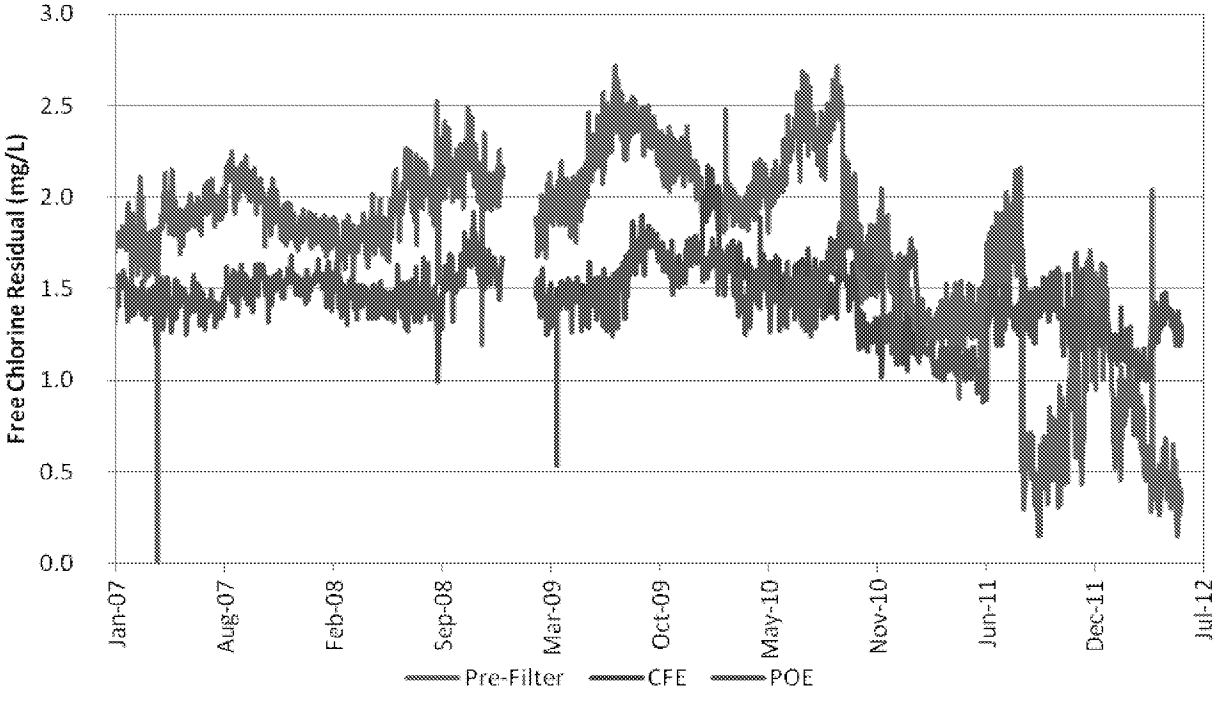


Figure 3-10: Chlorine Residuals throughout WTP (2007-2012)

Despite the relatively constant raw water characteristics for the past five years, one significant water quality issue is increased bromide levels. **Figure 3-11** illustrates the historical terminal reservoir bromide concentrations from November 2011 through September 2012. Reservoir bromide concentrations have a direct correlation to the concentration of THMs and the speciation of THMS. When reservoir bromide levels are high, THM speciation is primarily composed of brominated THMs and the total concentration of THMs is higher (**Figure 3-12).**

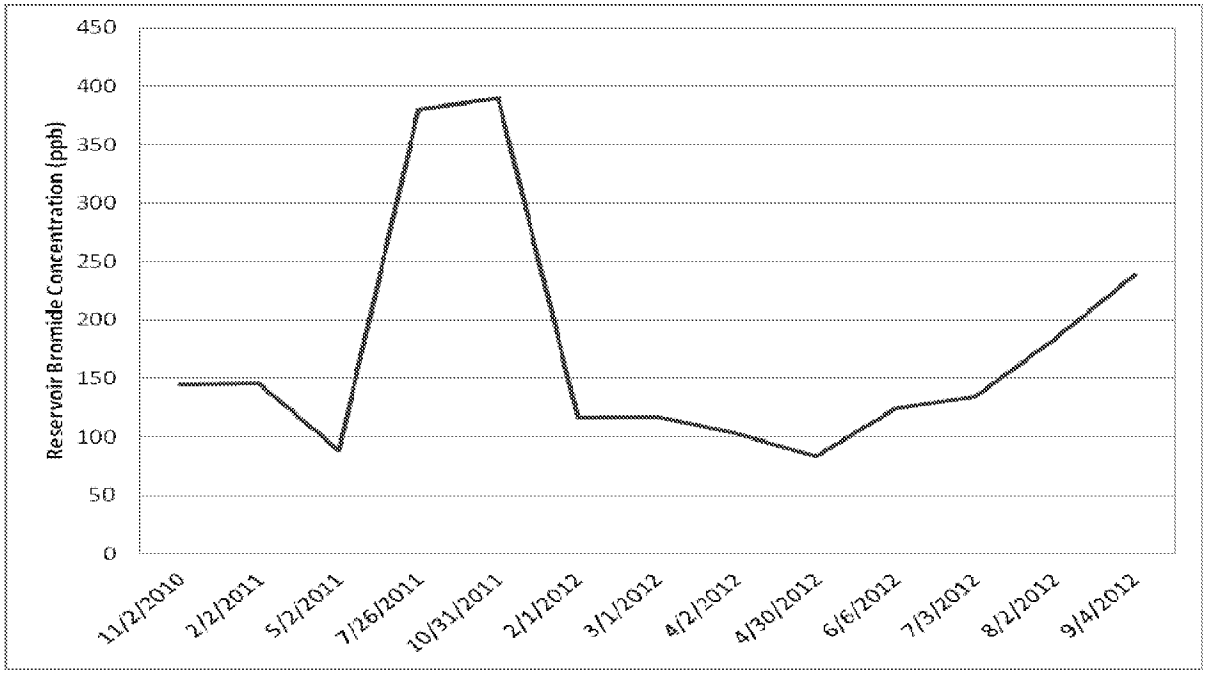


Figure 3-11: Reservoir Bromide Concentrations (2011-2012)

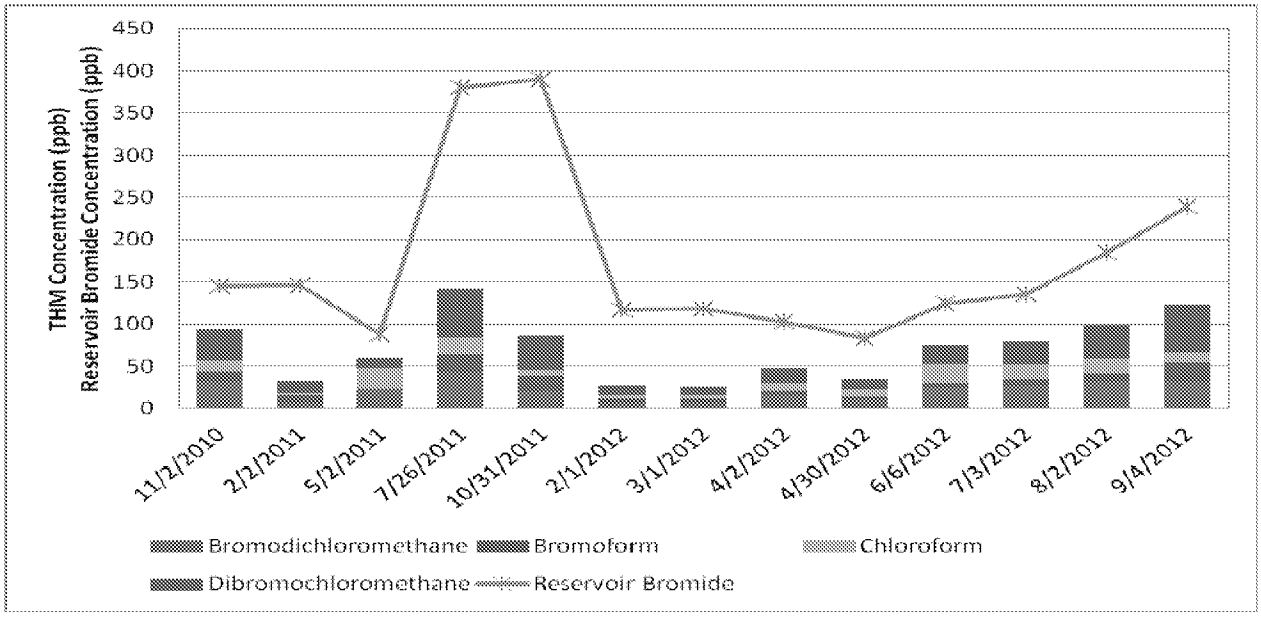


Figure 3-12: THM Speciation and Concentration with Reservoir Bromide Levels (2010-2012)

Since Spring/Summer 2008, the plant has seen increased DBP levels, particularly TTHMs and the species of TTHMs has shifted from chlorinated species to brominated species as shown in **Figure 3-13**. Over the last 8 years Reservoir TOC has remained consistent between 1 mg/L and 3 mg/L. As such, the increased TTHM levels experienced by the Robert Harris WTP are unlikely to be caused solely by natural organic matter interactions with chlorine. The increased reservoir bromide concentrations have illustrated a direct correlation to increased TTHM concentrations. These correlations indicate that bromide, in addition to natural organic matter, in the raw water are major contributors to the elevated TTHM concentrations experienced over the past several years. In the spring of 2008, bromide concentrations in an upstream industrial discharge increased significantly. The City has monitored bromide levels in the Dan River at their intake and has found bromide concentrations ranging from 22 to 433 ppb. These elevated bromide levels have contributed to the increased DBP concentrations occurring at the plant and in the distribution system due to the reactivity of bromide with chlorine and organics in the water. Elevated levels of brominated DBPs consisting of bromoform and dibromochloromethane are shown in **Figure 3-14**. Brominated DBPs have higher molecular weights than their chlorinated counterparts and therefore increased the weight-based concentration of DBPs while the molecular concentration remains the same. Therefore, controlling the creation of brominated DBPs in the WTP is one of the highest priorities at the Harris WTP.

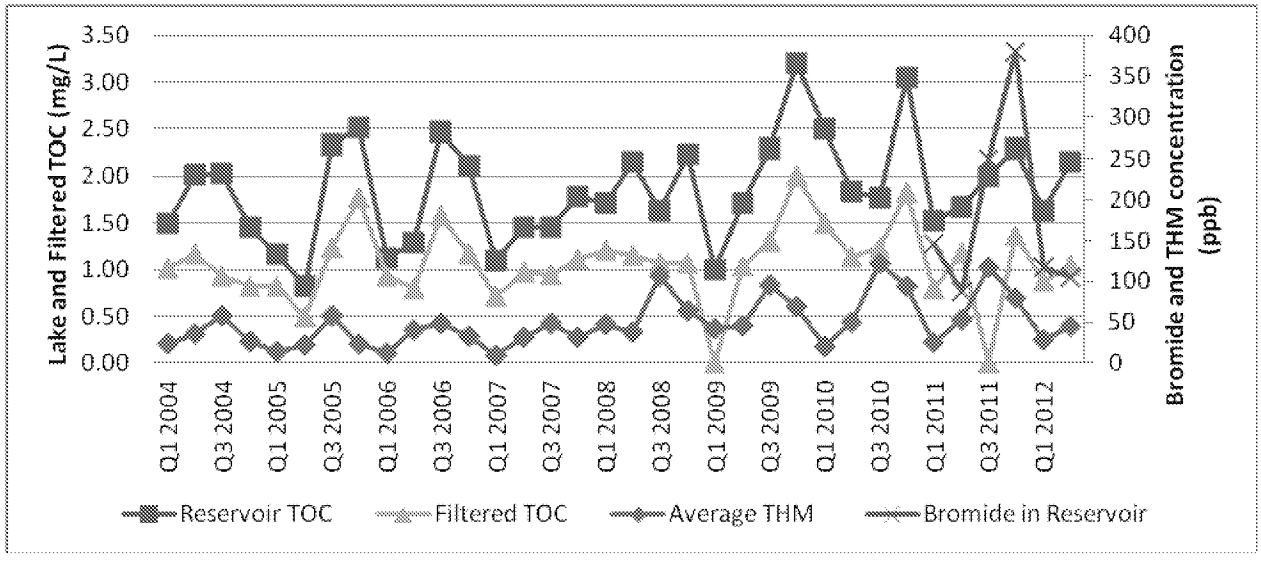


Figure 3-13: Historical DBP Concentrations (2004-2012)

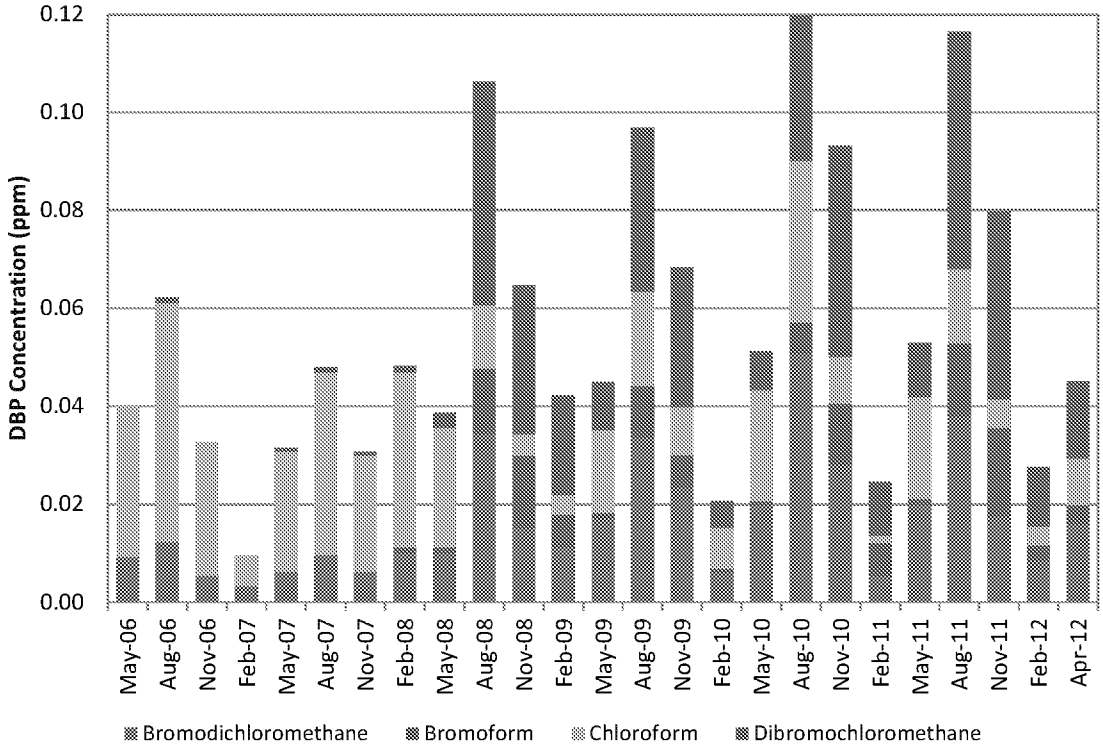


Figure 3-14: DBP Speciation (2006-2012)

4 OPTIMIZATION OF EXISTING WTP PROCESSES FOR DBP REDUCTION

4.1 Bench-Scale Testing Procedures

Bench-scale testing was conducted on site at the Robert Harris Water Treatment Plant using the Hazen and Sawyer mobile laboratory trailer. A Phipps and Bird 6-gang mixer, with 2-liter square jars was used to evaluate alternative coagulant treatment strategies. TTHMs, HAAs, and TOC samples were collected and forwarded to James R. Reed Laboratories, Newport News, VA., for analysis. All other testing was performed on-site by Hazen and Sawyer staff.

The first step in the bench-scale test procedures was to establish a calibration between the full-scale plant and the bench scale testing procedures. Plant staff currently conduct bench-scale jar testing on a routine basis and bench-scale testing procedures are modified when changes in plant flow rate and/or flocculation speeds occur. Data collected from the full-scale plant to establish this calibration included:

- Chemical dosages and application points
- Plant flow rates
- Basin surface areas and volumes

Typically, rapid mix and flocculation times used in jar testing are equal to full-scale counter-parts. Jar test rapid mix and flocculation energies can be found by trial and error and should match the energy inputs in the full-scale plant. Bench-scale settling time is based on the full-scale surface area loading rate. To establish similitude between the 2-liter jar and the full-scale basin loading rates, the following equation is used:

$$(\text{Settling rate in cm/min})(1\ \text{ft}/30.48\ \text{cm})(1440\ \text{min/day})(7.48\ \text{gal/cf}) = \text{gpd/sf}$$

The sampling tap in each jar is fixed 10 cm below the surface of the water. The calculated settling rate is found by setting the equation equal to the basin loading rate and solving for minutes. Based on the plant flow of 10 MGD during the bench-scale testing, the sedimentation basin loading rate is 316 gpd/sf and the calculated settling rate is 11 minutes.

By using the same chemicals and doses as the full-scale plant, jar tests 1-1 through 1-4 produced results that approximated full-scale settled water parameters (**Table 4-1**).

Mixing times and energies selected to simulate the full-scale plant at a flow rate of 10 MGD are presented in **Table 4-2**.

Table 4-1: Bench Scale Test Calibration

Chemical Dose (mg/L)	Full-Scale Plant 9/10/12	Jar 1-1	Jar 1-2	Jar 1-3	Jar 1-4
Alum	20	20	20	20	20
Poly 321 TR	0.05	0.05	-	0.05	0.05
pH (Units)	5.94	6.04	6.05	5.96	5.95
Filtered UV-254 (1/cm)	0.020	0.022	0.020	0.018	0.019
Temperature (^{0}C)	24.4	-	-	-	-
Alkalinity (mg/L)	10	11	11	10	10
Turbidity (NTU)	0.53	1.86	1.29	1.09	0.76

Table 4-2: Jar Test Parameters at 10 MGD

Treatment Stage	Mixing	Jar 1-1	Jar 1-2	Jar 1-3	Jar 1-4
Rapid Mix	**RPM**	100	100	100	100
	Duration (sec)	120	120	120	120
1st Stage Flocculation	**RPM**	20	15	15	20
	Duration (min)	16	16	16	16
2nd Stage Flocculation	**RPM**	18	15	15	12
	Duration (min)	16	16	16	32
3rd Stage Flocculation	**RPM**	15	12	12	-
	Duration (min)	16	16	16	-
Settling Time (min)		11	11	11	11

As shown in **Table 4-2**, one, two, and three-stage flocculation at various mixing energies were evaluated. Based on a comparison of the jar test results presented in **Table 4-1**, Jar 1-4 achieved the lowest turbidity which was closest to the plant results. The mixing energy strategy used for Jar 1-4 was selected, using two-stage flocculation, based on a performance comparison of the different mixing strategies. These jar test procedures were used for all bench-scale testing.

4.1.1 Coagulant Testing

During bench-scale testing, samples are collected from all test jars and analyzed for pH, turbidity, alkalinity, and (UV_{254}). Direct measurements of TOC can be costly and time consuming. TOC levels are well indicated by UV-Absorbance at 254 nm (UV_{254}). As such, UV_{254}, a less expensive and faster surrogate indicator of NOM, is an appealing and reliable alternative. Comparison of UV_{254} readings can also be used to determine the relative efficiency of a process strategy in removing DBP precursors. Therefore, testing coagulation strategies that optimize TOC removal (UV_{254} removal) could lead to the development of treatment strategies that decrease overall DBP concentrations.

Naturally occurring organics remain dissolved at or near neutral pH (7.0) values. As the pH is lowered during coagulation, the organics become insoluble (come out of solution). TOC is a surrogate for NOM concentration and TOC solubility is pH dependent. As the pH decreases during coagulation, more NOM can typically be removed. Ferric coagulants, as opposed to aluminum- based coagulants, form hydroxide flocs at much lower pH values (i.e. 5.0 to 6.0) and therefore may have the ability to remove more NOM. When using aluminum based coagulants, the pH is typically limited to 6.0 - 6.2 pH units to optimize coagulation performance. At pH values less than 6.0, aluminum becomes more soluble and does not form aluminum hydroxide floc, resultantly passing through the filter and post-filter. However, subsequent pH adjustment for corrosion control provides sufficient alkalinity for aluminum hydroxide floc to form in the clearwell and the distribution system. Therefore, by designing for coagulation at lower pH values, ferric based coagulants can sometimes provide greater TOC removals and subsequent lower DBP concentrations in the distribution system.

4.1.2 Disinfection By-Products (DBPs)

The potential alternatives to reduce distribution system DBPs, were developed using bench scale testing techniques. The alternatives included using potassium permanganate, powdered activated carbon, ammonia addition to form chloramines, and alternative coagulants: ferric sulfate and polyaluminum chloride. Simulated Distribution System Disinfection By-Product testing was conducted for each of the alternative strategies to determine their feasibility. Details of the sample preparation and DBP results, in graphical and table format with DBP species details, are presented below:

4.1.2.1 Sample Preparation and DBP Details

To prepare bench-scale test samples, settled water from the test jars was filtered using a 1-micron glass fiber filter to simulate filtration.

Free chlorine samples were dosed with free chlorine and held for 10 days to simulate the detention time in the distribution system and then quenched and sent to the laboratory for analysis. For chloramine evaluations, samples were contacted with free chlorine for 15 hours, which is a conservative estimate of free chlorine contact time through the filters, filter effluent flume, and one clearwell at current WTP production rates. Then, liquid ammonium sulfate (LAS) was added and pH adjusted to 7.8. Chloramine samples were held for 10 days to simulate the detention time in the distribution system and then quenched and sent to the laboratory for analysis. The sample preparation details are presented in **Table 4-3**.

Table 4-3: Dan River Free Chlorine DBP Sample Preparation

ID	Time Set	Treatment Strategy	Chlorine Dose mg/L	Caustic Dose mg/L	pH	Free Cl Residual @15 hrs
15-1-C	4:15 PM	40 Alum	3.5	3	7.28	1.32
15-2-C	4:25 PM	40 Ferric	3.5	2	7.31	2.68
15-3-C	4:30 PM	40 PACl	3.5	2	7.37	1.41
15-4-C	4:40 PM	20 PAC + 40 Alum	3.5	3	7.38	1.97
15-5-C	4:45 PM	0.2 KMnO4 + 40 Alum	3.5	2	7.26	2.5
15-6-C	4:50 PM	0.2 KMnO4 + 40 Ferric	3.5	3	7.33	2.42

After 15 hours, the samples were analyzed for free chlorine residual and then the samples were split (**Table 4-3**). One set was dosed with free chlorine and held for 10 days, and the other set was used for chloramines. The chloramine samples received additional doses of chlorine, ammonia, and caustic. The Dan River chloramine sample preparation is presented in **Table 4-4**.

Table 4-4: Dan River Chloramine DBP Sample Preparation

ID	Time	Chlorine Dose mg/L	LAS Dose mg/L	Caustic Dose mg/L	pH
15-1-MC	7:30 AM	2.6	1	2	7.78
15-2-MC	7:50 AM	1.3	1	2	7.84
15-3-MC	8:00 AM	2.6	1	2	7.88
15-4-MC	8:15 AM	2	1	2	7.93
15-5-MC	8:35 AM	1.5	1	2	7.87
15-6-MC	8:50 AM	1.5	1	2	7.74
15-1-MC-9	7:40 AM	2.6	1	4	8.53

As shown in **Table 4-4**, chloramine sample 15-1-MC-9 was held at a higher pH to see if there were any pH effects with chloramination. Comparisons were made between 15-1-MC and 15-1-MC-9 to ascertain pH influence

4.2 Dan River Bench-Scale Testing

4.2.1 Raw Water Quality

Raw water from the Dan River (from the Presedimentation Basin) was analyzed to determine basic water quality parameters. The results are shown in **Table 4-5**.

Table 4-5: Dan River Water Quality

Analysis	9/10/12 Reservoir 10 am	9/11/12 Reservoir 2 pm	9/12/12 Reservoir 7 am	9/12/12 Reservoir 9 am	9/13/12 Reservoir 9 am	9/17/12 Reservoir 10 am
pH (units)	6.12	6.68	6.59	6.71	6.49	7.20
UV-254 (1/cm)	0.079	0.067	0.041	0.051	0.076	0.072
Turbidity (NTU)	54.9	25.9	106	36.3	16.7	18.1
Alkalinity (mg/L)	21	21	22	21	22	20
Temperature (^{0}C)	24.4	23.5	24.0	23.7	23.6	22.7

Water quality samples were collected from the plant raw water sample tap and analyzed during the bench-scale testing from September 10 through September 17, 2012. Turbidity, pH, and UV254 measurements from the Dan River varied over the testing dates. UV254 readings varied from a low of 0.041/cm to a high of 0.079/cm, a difference of 48%. Since organic levels directly affect coagulant demand, the changing of UV_{254} measurements can have a significant effect on WTP performance and coagulant dose strategy. Temperature and alkalinity measurements, on the other hand, were relatively stable throughout testing.

4.2.2 Coagulant Screening

As part of bench-scale testing procedures, three primary coagulants were evaluated: aluminum sulfate (Alum), ferric sulfate (Ferric), and polyaluminum chloride (DelPac 1525). Coagulant testing was completed from September 10th, 2012 through September 17th, 2012. Settled water turbidity results from the three primary coagulant tests are presented for comparison in **Figure 4-1**. Turbidity data indicated that the optimal coagulant dose for ferric and polyaluminum chloride was approximately 30mg/L; for alum, an optimal dose of 20mg/L was determined.

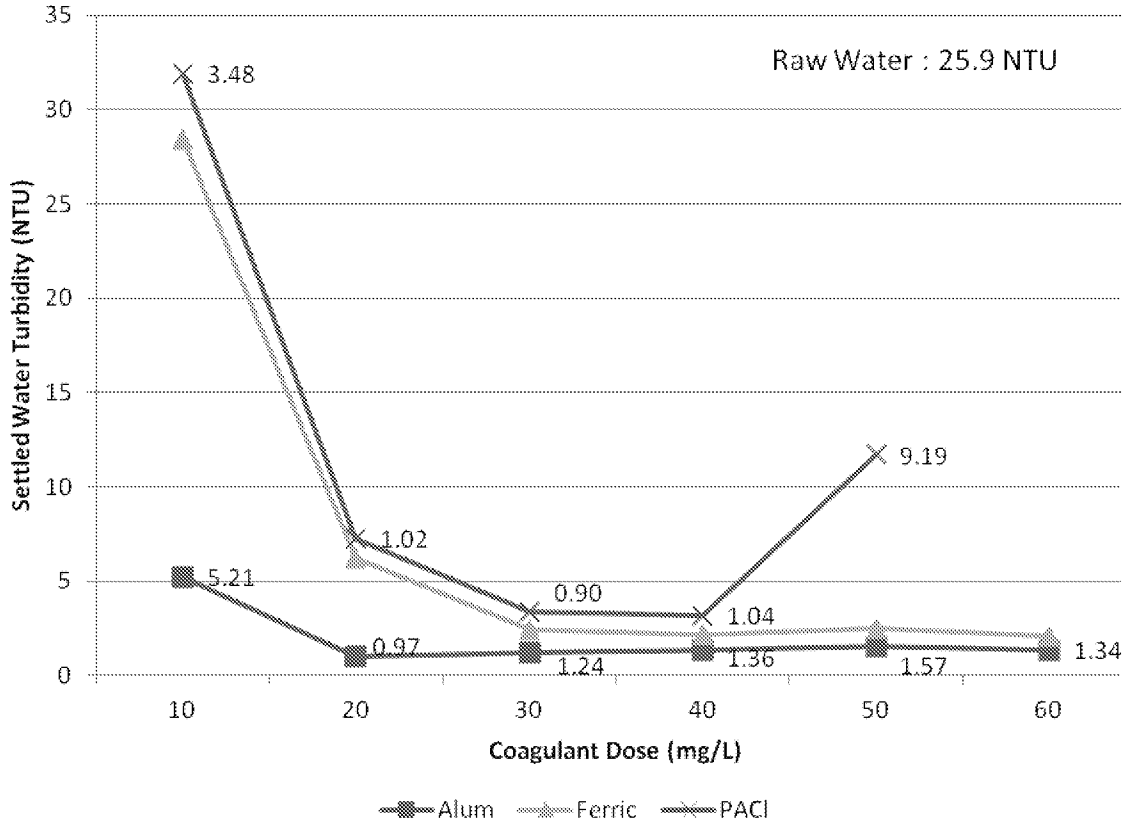


Figure 4-1: Coagulant Screening – Settled Water Turbidity

Each coagulant was tested at doses of 10 to 60 mg/L without polymer. The results for each coagulant followed the same trend, regardless of dose. UV_{254} data was also collected during the primary coagulant tests. Raw water UV_{254} was 0.0.67/cm and post-coagulation UV_{254} values were used as surrogate indicators for organics removals. The results are presented in **Figure 4-2**.

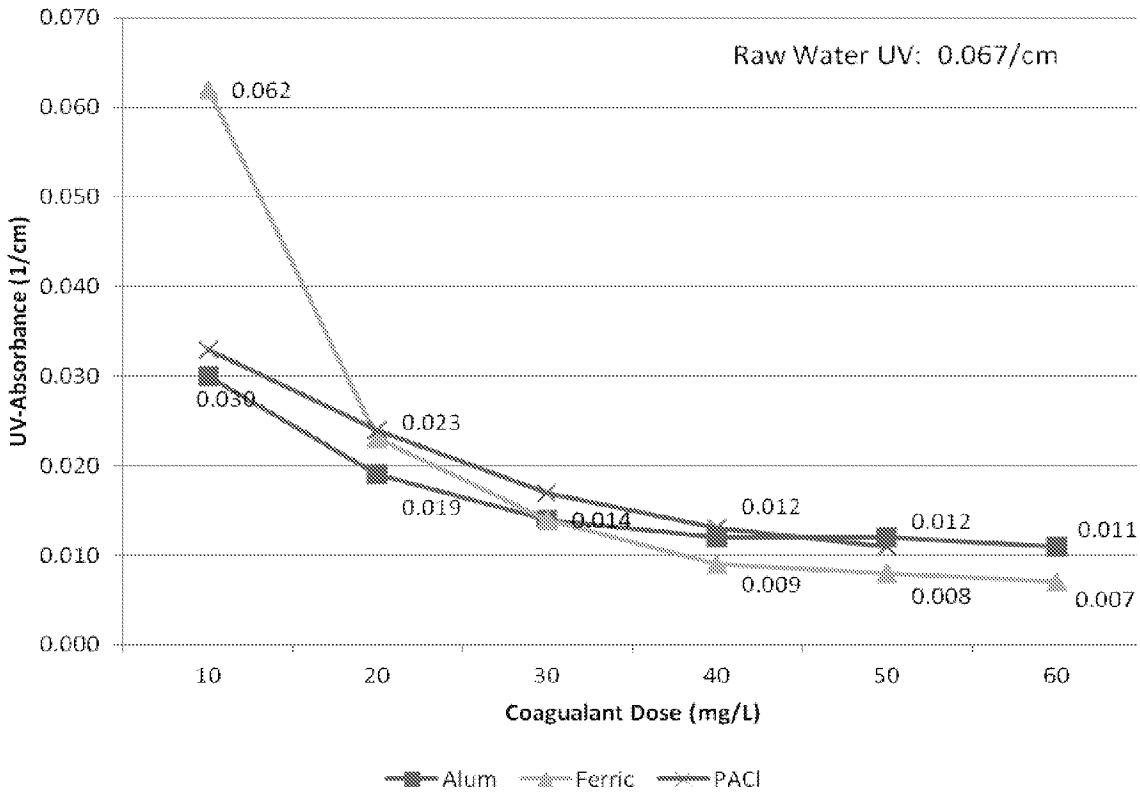


Figure 4-2: Coagulant Screening - UV_{254} Absorbance

All four coagulants generally performed well with respect to UV-Absorbance reductions, providing similar performances at similar doses. Ferric sulfate provided the lowest UV values over the range of doses tested. Based on these results, the slight differences in the UV values for the different coagulants are not significant, although it appears that ferric sulfate may provide a slight advantage. However, all coagulants essentially appear to provide similar organic precursor removals.

4.2.3 Polymer Testing

Previous testing conducted on Dan River water for the City of Danville by Hazen and Sawyer included polymer screening from several different manufacturers. The results of that testing, indicated that Stockhausen 2500 provided the best settled water turbidity values. While polymer screening/testing was not included in the original scope of work, Stockhausen 2500 was compared to the current plant polymer, Stockhausen 321 TR, to determine if settled water turbidity could be improved. Stockhausen 2500 is a nonionic polymer while Stockhausen 321 TR is cationic. Both are available in dry powder form. Simulated polymer additions at the rapid mix and at the influent of the 3rd flocculator were conducted using doses of 0.05 to 0.15 mg/L. The polymer results are presented in **Table 4-6**.

Table 4-6: Polymer Performance Comparison

Alum Dosed at 30 mg/L						
	Polymer Dosed at Rapid Mix			Polymer Dosed at 3rd Flocculator		
Polymer Dose (mg/L)	0.05	0.10	0.15	0.05	0.10	0.15
321 TR Settled Turbidity (NTU)	1.36	1.52	1.40	1.41	1.49	1.36
2500 Settled Water Turbidity (NTU)	1.49	0.66	0.66	0.53	0.61	0.53

The results indicate that 2500 polymer can provide significant reductions in settled water turbidity when added to the influent of the 3rd flocculator. Full-scale plant testing by plant staff is recommended to further quantify the expected turbidity reductions. Polymer performance results, including coagulation pH and UV values, for the 321 TR and the 2500 are presented in **Figures 4-3 and 4-4**.

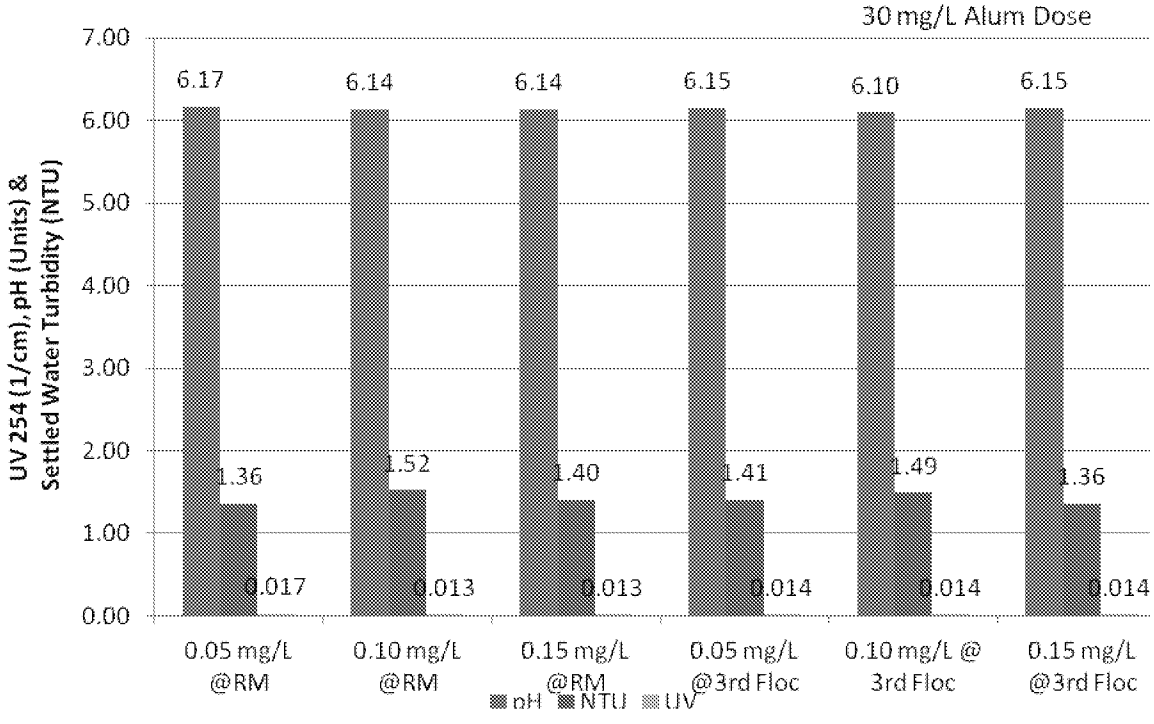


Figure 4-3: Stockhausen 321 TR Performance

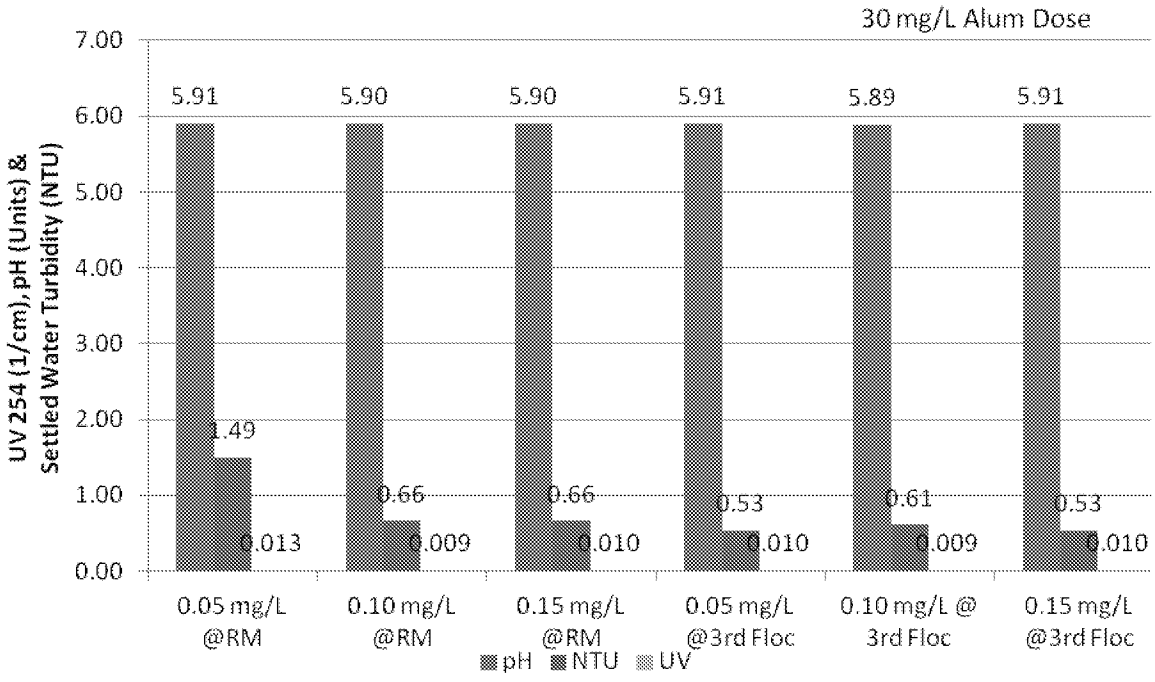


Figure 4-4: Stockhausen 2500 Performance

Slightly lower coagulation pH values for 2500, as compared to the pH for 321 TR, may have enhanced TOC removal and resulted in lower UV absorbance readings for the 2500. Stockhausen 2500 performance should also be confirmed by full-scale testing.

4.2.4 Potassium Permanganate Testing

Potassium Permanganate ($KMnO_4$) is a common oxidant used in drinking water treatment to precipitate soluble iron and manganese, to control taste and odor, and to remove color. Potassium permanganate may also help improve TOC removal in coagulation when used as a pre-oxidant. When permanganate is added to the raw water for manganese control, the oxidant is typically more effective at pH values greater than standard coagulation pH levels. As such, manganese may be more difficult to remove following coagulant addition. Potassium permanganate is the powder form ($KMnO_4$), and sodium permanganate is the liquid form ($NaMnO_4$) of the "permanganate oxidant". They both disassociate in water through the following reactions:

Potassium permanganate: $KMnO_4 \longrightarrow K^+ + MnO_4^-$
Sodium permanganate: $NaMnO_4 \longrightarrow Na^+ + MnO_4^-$

The active form of permanganate ions (MnO_4^-) can be provided from either liquid or solid. To determine the appropriate dose for potassium permanganate, a "30 minute" demand test was conducted. Potassium permanganate doses ranging from 0.1 to 1.0 mg/L were added to the raw water and gently mixed for 30 minutes. A dose of 0.5 mg/L achieved no color at the end of the 30 minutes. Doses higher than 0.5 mg/L began to show a characteristic pink color, typical of unreacted potassium permanganate. The detailed results of the permanganate testing are presented in **Table 4-7**.

Table 4-7: Raw Water (Potassium) Permanganate Screening

Dose (mg/L)	0.1	0.2	0.5	0.7	1.0
Color	No Color	No Color	Faint	Darker	Very Dark

Permanganate demand varies with raw water quality conditions; therefore, the data represent a "snap shot" of the demand on the day of the testing. As shown, a dose of 0.2 mg/L appears to be sufficient to satisfy the oxidant demand. Accordingly, permanganate was tested with alum to evaluate performance. The results are presented in **Table 4-8**.

Table 4-8: Permanganate Performance

Results	**40 mg/L Alum**	**0.2mg/L $KMnO_4$ + 40 mg/L Alum**
pH (Units)	6.23	6.24
UV-254 (1/cm)	0.013	0.008
Settled Water Turbidity (NTU)	0.45	0.48

Potassium permanganate addition provides a reduction in UV_{254}, but did not affect settled water turbidity. There is some benefit in using potassium permanganate to help reduce dissolved organics when using alum as the primary coagulant considering the improvement in UV_{254}. Potassium permanganate was not tested with ferric coagulants because the pH values for ferric coagulation are generally well below pH 6.0. At these low pH values, permanganate would be reduced to dissolved manganese and would not provide any benefit as an oxidant, but would require removal at the filters with pH adjustment and chlorine addition.

4.2.5 Powdered Activated Carbon (PAC) Testing

Powdered Activated Carbon (PAC) is typically used to help control periodic taste and odor events and serve an emergency treatment for petroleum compounds and pesticides. Because PAC can also absorb Dissolved Organic Carbon (DOC), UV_{254} testing was conducted to compare DOC removal performances of several carbons.

Many different PAC products are available for use in water treatment and to determine the appropriate PAC and dose, previous experience with other waters was used. Two commercially available PACs were tested, Norit Hydrodarco B and Calgon WPM-M. Their general specifications are presented in **Table 4-9**.

Table 4-9: PAC Specifications

Product Designation	Carbon Source	Iodine Number (mg/g)
Hydrodarco B	Lignite	500
Calgon WPH-M	Coal	500

PACs were tested at 5 to 60 mg/L doses and UV_{254} was used as a surrogate indicator of relative DOC removal. The results are presented in **Figure 4-5**, comparing carbon type/dose (x-axis) to the settled water quality parameters of turbidity and UV-254 (y-axis).

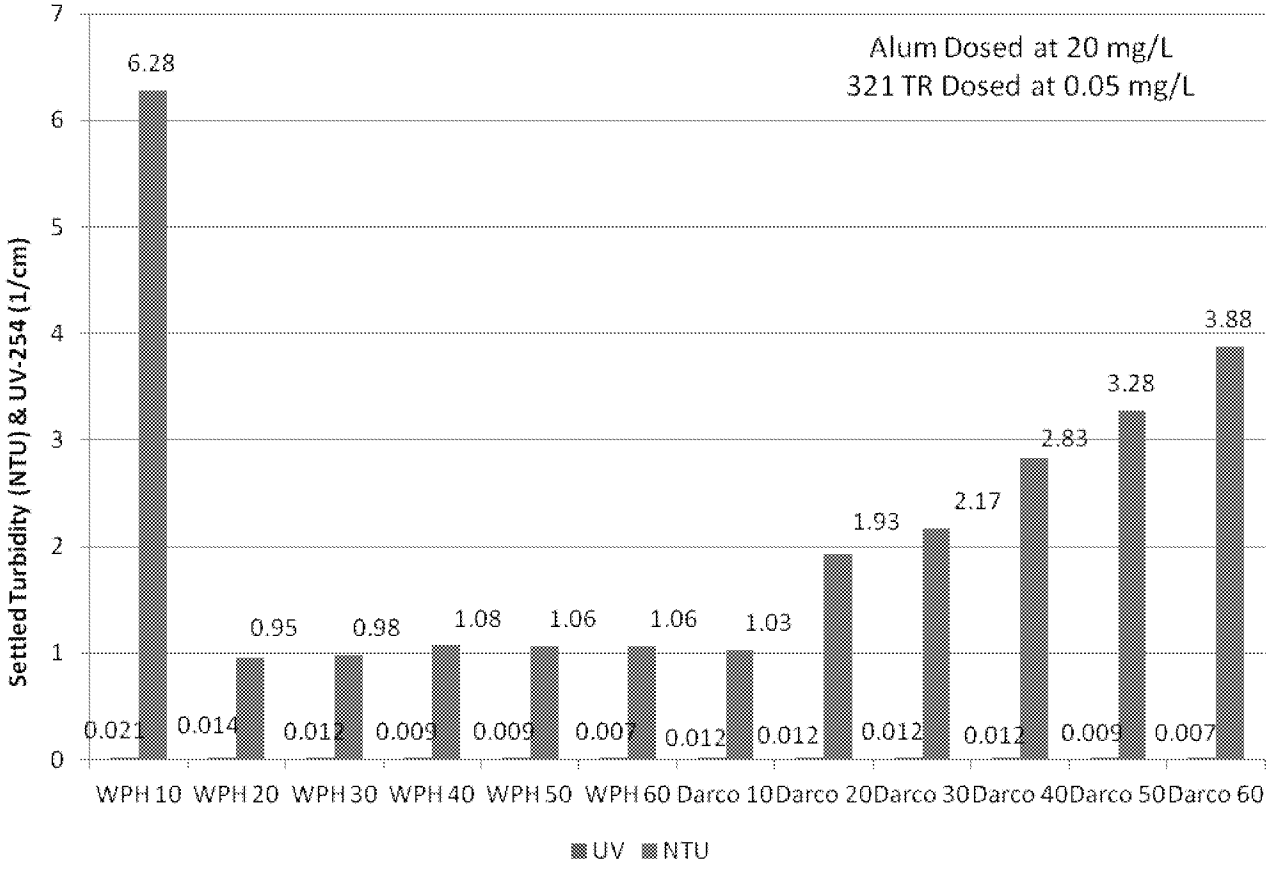


Figure 4-5: Powdered Activated Carbon Comparison (with Alum and Polymer)

Calgon WPH showed the best performance, considering both UV and settled water turbidity results. Norit Hydrodarco provided better UV, but unacceptable settled water turbidity results at higher doses.

4.2.6 SDS DBP Testing

Simulated distribution system (SDS) testing was used to predict DBP formation in the distribution system. During SDS testing, samples were held for 10 days, quenched, and then analyzed for TOC, TTHM and HAA5 concentrations. A holding time of 10 days was selected to mimic the water age at the furthest points of the City of Eden distribution system.

Figure 4-6 shows the results of SDS testing with various coagulant scenarios. Each of these scenarios uses free chlorine at the primary and secondary disinfectant.

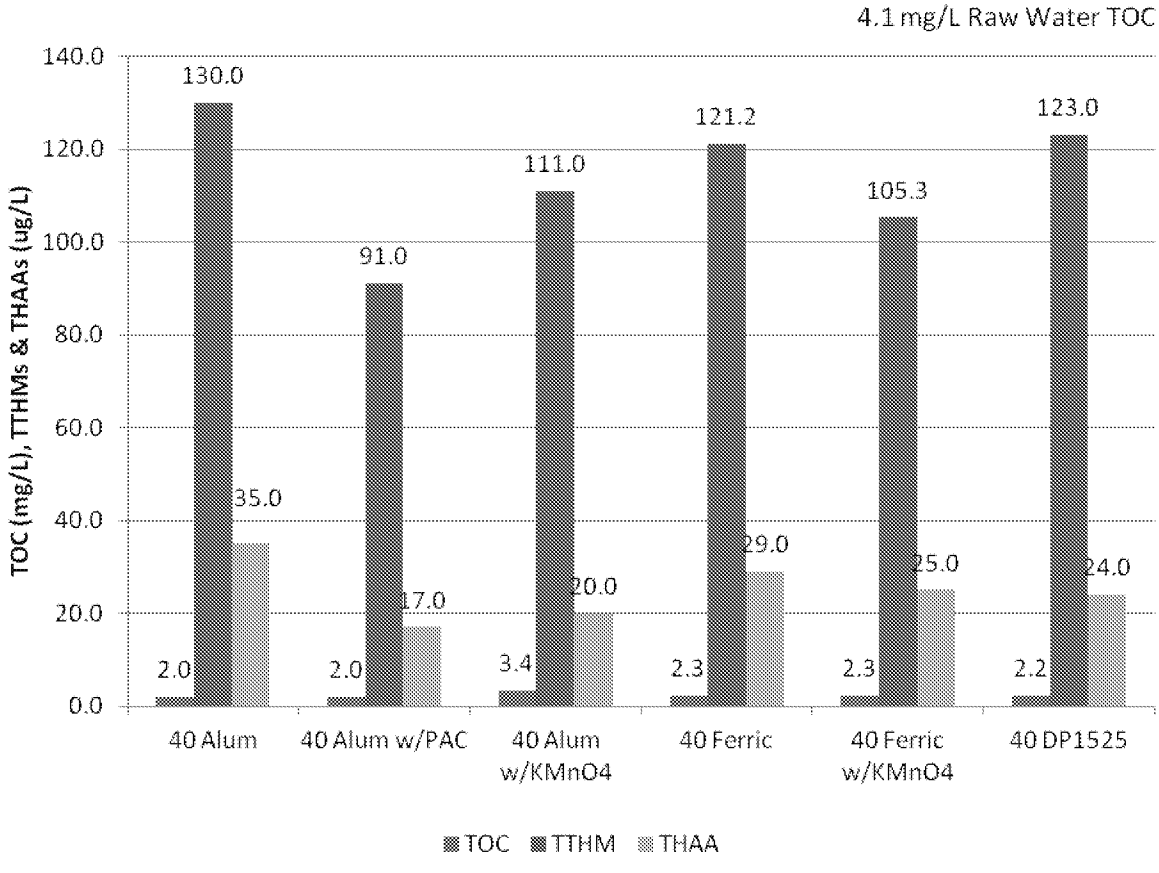


Figure 4-6: Simulated Distribution System Testing Dan River with Free Chlorine

The treatment strategies for the Dan River using free chlorine exceeded the 80 ppb MCL for TTHMs. As such, none of the free chlorine strategies tested are feasible as standalone strategies for DBP control based on the SDS-DBP testing.

For clarity, the individual DBP species for each of the tests conducted are presented in **Table 4-10**. The comparisons are presented side by side to show how each treatment strategies affected the different forms of DBPs.

Table 4-10: Dan River Free Chlorine 10 Day SDS Testing - DBP Speciation

Species	40 mg/L Alum	40 mg/L Alum w/PAC	40 mg/L Alum w/$KMnO_4$	40 mg/L Ferric Sulfate	40 mg/L Ferric Sulfate w/$KMnO_4$	40 mg/L DelPac 1525
Chloroform	21.9	13.2	17.0	19.4	16.4	21.0
Bromodichloromethane	43.2	29.9	36.4	41.2	35.4	43.2
Dibromochloromethane	48.1	33.7	43.1	44.5	39.4	43.2
Bromoform	16.5	13.8	14.4	16.1	14.0	15.6
Total Trihalomethanes	**129.7**	**90.6**	**110.9**	**121.2**	**105.3**	**123.0**
Monochloroacetic Acid	<1	<1	<1	<1	<1	<1
Monobromoacetic Acid	2	<1	<1	1	<1	<1
Dichloroacetic Acid	16	8	10	14	12	12
Trichloroacetic Acid	3	<1	1	2	2	2
Dibromoacetic Acid	14	9	9	12	11	10
Total Haloacetic Acids	**35**	**17**	**20**	**29**	**25**	**24**

4.3 Chloramine Testing

4.3.1 CT Evaluation

Chloramines were evaluated for its effectiveness to reduce DBP formation. DBP formation with chloramines is very low, so once monochloramines are formed, the DBP formation reaction is nearly halted. First, an evaluation was conducted to determine the CT requirements for the Robert Harris WTP, and then determine the appropriate feed point for ammonia.

According to the "North Carolina Guideline – Treatment Facility Capabilities for CT Credit" worksheet completed in April 1991 the plant is approved for 2.45–log *Giardia* inactivation credit and 1.96-log viral inactivation credit. The plant must therefore achieve 0.55-log *Giardia* inactivation credit through free chlorine disinfection in order to meet the required 3.00-log inactivation. Likewise for viruses, the plant must achieve 2.04-log inactivation credit through free chlorine disinfection practices to ensure compliance with the Surface Water Treatment Rule (SWTR).

In order to determine the *Giardia* and virus inactivation achieved by free chlorine contact, the hydraulic detention time (T_d) and contact time (T_{10}) were calculated for segments in which the water is in contact with free chlorine. T_{10} is a function of T_d and baffling. CT is a function of

T_{10}, chlorine residual, pH, and temperature. Worst case conditions were evaluated to ensure that the plant always achieves the disinfection requirements of the SWTR.

The following assumptions were made when calculating a worse-case CT:

- Maximum rated flow at the WTP is 20.6 million gallons per day (mgd)
- Minimum free chlorine residual is 1.4 ppm
- Maximum finished water pH is 7.5
- Minimum raw water temperature is 5° F
- The two 4-million gallon clearwells were assumed to be half full.

Under the worst case condition, several potential ammonia feed points were evaluated:

- Downstream of the two clearwells
- Between the two clearwells
- Downstream of the filters.

Table 4-12 was taken from the *Disinfection Profiling and Benchmarking Guidance Manual* and displays typical baffling conditions and associated baffle factors (T_{10}/T_d). Hydraulic detention times were determined using the calculated volumes and maximum plant flow. T_{10} is calculated by multiplying the hydraulic detention time by the baffle factor. CT was calculated using the T_{10} and free chlorine residual for each section. CT calculations for each disinfection segment are shown in **Table 4-11**.

When ammonia is added downstream of the clearwells, the plant achieves 2.06-log inactivation of *Giardia* and 64.24-log inactivation of viruses. Both inactivation levels exceed the requirement as determined by the CT Credit granted to the treatment processes.

Using the same detention times and baffle factors, the study was repeated as if ammonia is added between the two clearwells. In this scenario, 1.20-log inactivation of *Giardia* is achieved and 34.95-log inactivation of viruses is achieved. Therefore, the Robert Harris WTP can achieve the required *Giardia* and virus inactivation using free chlorine through the filters and the first clearwell if chloramines are formed between the two existing clearwells.

Table 4-11: Ammonia Feed Point CT Comparison

				Ammonia Feed Point Downstream of Two Clearwells				Ammonia Feed Point Downstream of First Clearwell				Ammonia Feed Point downstream of filters			
Seg.	**Description**	**Disinfection Detention Time T_{10} (min.)**	**Baffle Factor**	**Free Chlorine Residual (mg/L)**	**CT (mg-min/L)**	**Giardia Log Inactivation Credit**	**Virus Log Inactivation Credit**	**Free Chlorine Residual (mg/L)**	**CT (mg-min/L)**	**Giardia Log Inactivation Credit**	**Virus Log Inactivation Credit**	**Free Chlorine Residual (mg/L)**	**CT (mg-min/L)**	**Giardia Log Inactivation Credit**	**Virus Log Inactivation Credit**
1	Filter Gullet														
2	Filter Bed (above media)	3.9	0.6		5.54	0.09	2.77		5.54	0.09	2.77		5.54	0.10	2.77
3	Filter Effluent Flume - Filter 1 to FW POA	0.3	0.6		0.49	0.01	0.21		0.49	0.01	0.21	1.4	0.49	0.01	0.21
4	Filter Effluent Flume - FW POA to 36" FW Pipe	1.1	0.6		1.76	0.02	0.76	1.4	1.76	0.02	0.76	Chloramines	1.76	0.00	0.00
5	36" FW Pipe	0.5	1.0	1.4	0.70	0.01	0.35		0.70	0.01	0.35	Chloramines	0.70	0.00	0.00
6	30" FW Pipe	2.1	1.0		2.94	0.05	1.47		2.94	0.05	1.47	Chloramines	2.94	0.00	0.01
7	Clearwell No. 2	41.8	0.3		97.58	0.94	29.27		97.58	0.94	29.27	Chloramines	97.58	0.08	0.12
8	Clearwell No. 1	41.8	0.3		97.58	0.94	29.27	Chloramines	97.58	0.08	0.12	Chloramines	97.58	0.08	0.12
9	30" PW Pipe to High Service Pump Station	0.2	1.0		0.28	0.00	0.14	Chloramines	0.28	0.00	0.00	Chloramines	0.28	0.00	0.00
	Total	**1.5 hours**	n/a	n/a	**207**	**2.06**	**103**			**1.20**	**34.95**			**0.27**	**3.23**
					Required	**0.55**	**2.04**		**Required**	**0.55**	**2.04**		**Required**	**0.55**	**2.04**

Table 4-12: Baffling Classifications

Baffling Condition	T_{10}/T	Baffling Description
Unbaffled (mixed flow)	0.1	None, agitated basin, very low length to width ratio, high inlet and outlet velocities. Can be approximately achieved in flash mix tank.
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles
Average	0.5	Baffled inlet or outlet with some intra-basin baffles
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders
Perfect (plug flow)	1.0	Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intra-basin baffles

A third scenario was evaluated in which ammonia is dosed just downstream of the filters, limiting free chlorine contact to the filters, so CT credit would have to be achieved using chloramines. In this scenario, 0.27-log inactivation of *Giardia* and 3.23-log inactivation of viruses is achieved through contact with free chlorine and chloramines. The virus inactivation is sufficient, but the *Giardia* inactivation is less than required. Therefore, achieving CT credit with chloramines at the WTP is not feasible under the worst-case conditions.

Under worst-case conditions, the plant can achieve the required *Giardia* and virus inactivation by maintaining free chlorine through one or both clearwells.

4.3.2 Proposed Improvements for Conversion to Chloramines

Converting the Robert Harris WTP to chloramination will involve the construction of main structures: a chemical storage and feed facility and a chemical feed vault.

The chemical feed facility will include a 16'x12' pre-cast concrete building to house two aqueous ammonia metering pumps in a duty/standby configuration. The building will be equipped with an electric unit heater and exhaust system. A 7,000-gallon aqueous ammonia storage tank will be located adjacent to the feed facility in a concrete secondary containment. A fill station will be provided for filling the bulk tank. The tank will be insulated to protect from freezing. The containment areas in the fill station and feed facility will be connected, allowing for one sump pump to empty those areas in the event of a spill.

Ammonia, chlorine and caustic will be fed in a chemical vault that will be located between the two finished water storage tanks. Ammonia will be fed from the new chemical feed facility.

Feed lines for chlorine and caustic soda will be rerouted from the existing finished water feed point to the new chemical feed vault. The first storage tank (Clearwell #2) will provide the necessary volume for disinfection (CT) using free chlorine.

The second tank (Clearwell #1) will provide storage for equalization and operational flexibility. Within the chemical vault, a magnetic flow meter will provide accurate flow measurements to ensure proper dose pacing of the chemicals. A static mixer will be provided to ensure adequate mixing and formation of monochloramines prior to the second clearwell. A sample pump will provide a continuous sample to online analyzers and to the lab in the existing building. Online analyzers will be provided in the chemical feed vault to monitor for free chlorine and pH from the outlet of the first clearwell. Following the static mixer, a sample tap will be provided and samples routed to online analyzers for monochloramines, free ammonia, and total chlorine.

The 30-inch line between the two clearwells is approximately 28 feet below ground. This poses some challenges in installing the proposed chemical feed vault. Two options were evaluated for construction of a chemical feed vault. Option 1 involves construction of a 28-foot deep feed chemical feed vault at the current depth of the 20-inch finished water line. Significant construction costs are incurred in this option by the excavation requirements, concrete quantities, and stairway access. In order to house the meter and static mixer, as well as access stairs, the vault will need to be about 24-feet long by 14 feet wide.

Option 2 involves installing a new 30-inch outlet into Clearwell #2 at a higher elevation (approximately 547 feet). In this option, the chemical feed vault would be approximately 10 feet deep. This significantly reduces the excavation and concrete quantities. Crom Corporation evaluated this option and has concluded that it is feasible to install a new 30-inch line into the existing pre-stressed concrete tank. Based on Crom's quotation. it will cost approximately $35,000 to install an 30-inch outlet to the side of the clearwell. Additional yard piping will also be required from the clearwell to the feed vault.

Costs for both options were evaluated and found to be nearly equivalent. The cost basis presented in Section 7 of this report is Option 1 to install the larger chemical feed vault.

4.3.3 SDS DBP Testing

Bench-scale testing was conducted to determine if reducing free chlorine contact time by converting to chloramines would reduce disinfection by product (DBP) formation. This testing considered a scenario in which the water was in contact with free chlorine for 15 hours. Once chloramines were formed, the sample was held for ten days to simulate time in the distribution system. In the scenarios described in Section 4.4.1, the total T10 time modeled is 2.5 hours. **Figure 4-8** illustrates that the 15 hours used with the various scenarios described in Section 4.4.1, adequately captures the historical detention time in the plant. When one clearwell is used for disinfection requirements, the chlorine contact time is reduced but the WTP is more than able to meet the required CT with current chlorine doses. **Figure 4-7** illustrates TOC, TTHM and HAA5 concentrations for multiple treatment strategies in conjunction with chloramines. **Table 4-13** shows the speciation of DBPs formed in this bench-scale test.

As shown in **Figure 4-8** and **Table 4-13**, DBP results with 15 hours of free chlorine contact time followed by formation of chloramines were significantly lower than the water quality goal of 64 ppb TTHMs. Therefore, chloramines appear to be a viable strategy for Stage 2 DBP Rule compliance.

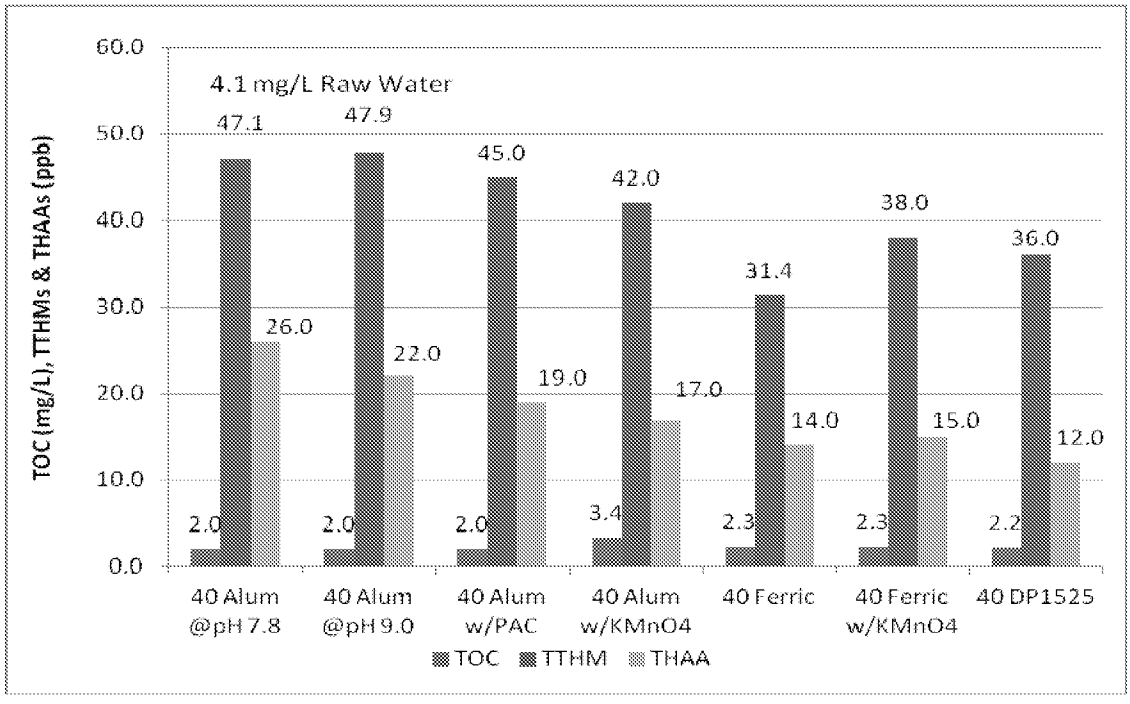


Figure 4-7: Dan River Chloramine 10-Day SDS-DBP Results

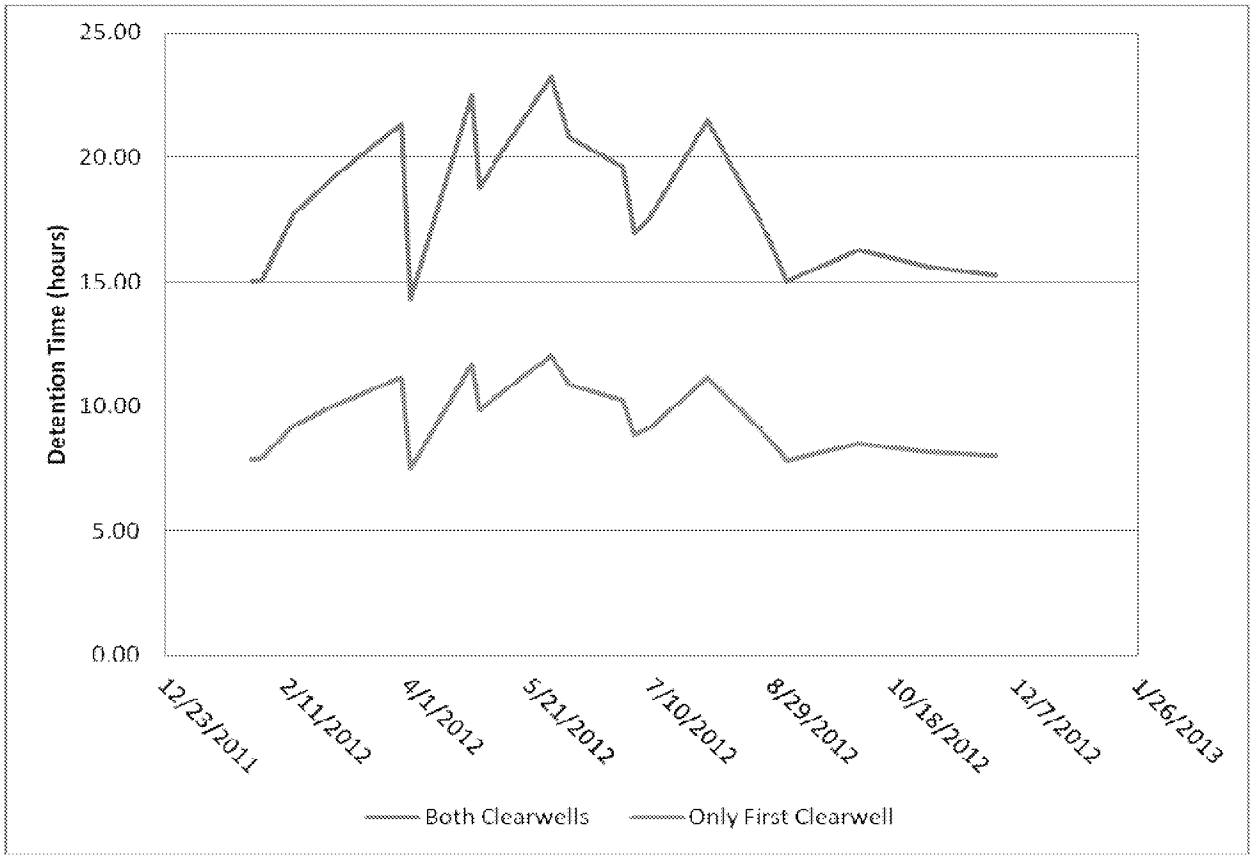


Figure 4-8: Contact Time with One and Both Clearwells

Table 4-13: Dan River Chloramine 10 Day SDS-DBP Speciation

=Species	40 mg/L Alum @pH 7.8	40 mg/L Alum @pH 9.0	40 mg/L Alum w/PAC	40 mg/L Alum w/$KMnO_4$	40 mg/L Ferric Sulfate	40 mg/L Ferric Sulfate w/$KMnO_4$	40 mg/L DelPac 1525
Chloroform	14.0	14.8	8.2	8.2	9.0	8.3	10.7
Bromodichloromethane	13.1	13.7	8.5	10.6	12.7	10.2	12.0
Dibromochloromethane	14.3	13.9	9.9	12.9	15.5	12.0	13.5
Bromoform	5.7	5.5	4.8	6.1	7.8	5.4	5.4
Total Trihalomethanes	**47.1**	**47.9**	**31.4**	**37.8**	**45**	**35.9**	**41.6**
Monochloroacetic Acid	<1	<1	<1	<1	<1	<1	<1
Monobromoacetic Acid	<1	<1	<1	<1	<1	<1	<1
Dichloroacetic Acid	13	11	8	7	9	6	9
Trichloroacetic Acid	6	4	1	2	2	1	2
Dibromoacetic Acid	7	7	5	6	8	5	6
Total Haloacetic Acids	**26**	**22**	**14**	**15**	**19**	**12**	**17**

5 EVALUATION OF ADVANCED TREATMENT TECHNOLOGIES

The addition of new treatment technologies were evaluated for this study to assess expected effectiveness for removing total organic carbon (TOC) and/or preformed disinfection byproducts (DBPs) to mitigate levels observed in the distribution system. The processes evaluated were: 1) MIEX® (ion exchange) for enhanced organics removal, 2) anion exchange for bromide removal, and 3) granular activated carbon (GAC) for organics and preformed DBP removal.

The use of chlorine dioxide was not included in the comparison. Chlorine dioxide as a primary disinfectant was not considered since it is limited to a 1.0 mg/l feed rate and maintenance of a residual for secondary disinfection purposes in the distribution system could be problematic, especially with part-time operation. Taste and odors are also a periodic issue with chlorine dioxide, as well as the formation of chlorite, which is regulated to a MCL of 1.0 mg/l.

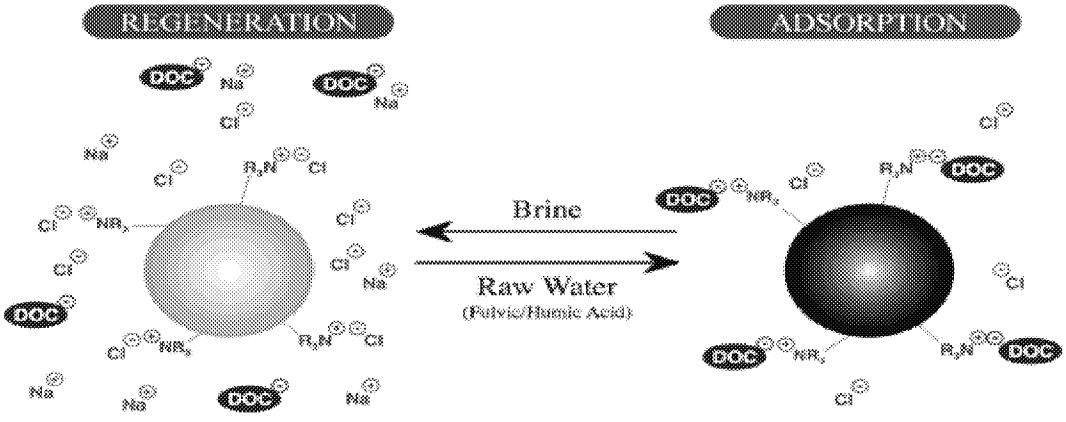
The following is a discussion of the candidate technologies and the considerations for installing them at the WTP including cost considerations. All three TOC removal processes (GAC and MIEX®) may allow the continued use of free chlorine as a residual disinfectant in the distribution system.

5.1 MIEX®

5.1.1 Process Description

MIEX® is a dissolved organic carbon (DOC) removal technology marketed by the Australian company Orica Watercare, Inc. The MIEX® technology, utilizing the MIEX® resin, was developed beginning in the mid-1980s. In July 2001, the first MIEX® facility was started up by South Australia Water in Adelaide, Australia for the removal of DOC.

MIEX® is an anion exchange process in which the resin is mixed with the raw water containing the negatively-charged target anions (i.e. DOC), which exchange for other negatively-charged ions attached to the resin's active sites via adsorption. When the resin is regenerated, it is mixed with a strong salt solution (typically sodium chloride or sodium bicarbonate) to exchange anions from the strong salt solution with the target anions attached to the resin. The adsorption and regeneration processes are represented schematically in **Figure 5-1.**



[1] Figure is provided courtesy of Orica Watercare Inc.

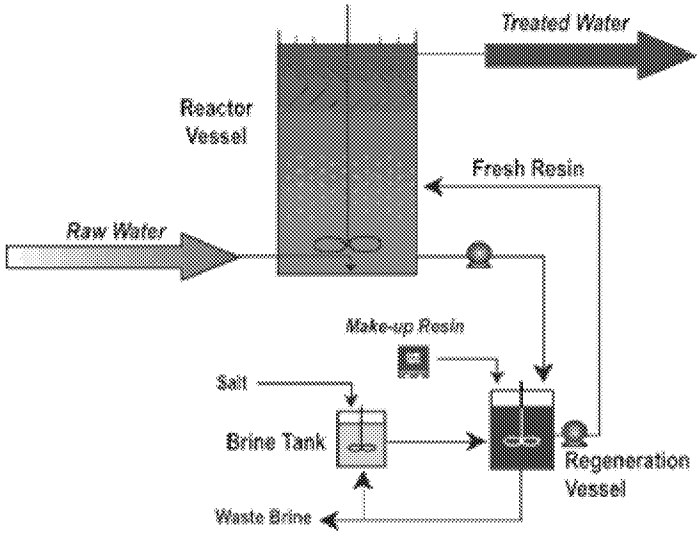
Figure 5-1: MIEX® Absorption and Regeneration Processes

The MIEX® resin is designed specifically to be used in a continuous ion exchange process that utilizes the high surface area of the resin beads to provide ion exchange in mixed and/or fluidized bed contactors at very low resin concentrations (i.e. 20 to 30% of contactor volume) and short detention times. The magnetic property of the resin results in the formation of agglomerates settling rapidly or fluidizing at high hydraulic loading rates, thus allowing small unit process footprints.

The core of the MIEX® process occurs within high-rate contactors fitted with either tube or plate settlers. Raw water is fed to the base of the contactor where the water is mixed with the MIEX® resin and the DOC is removed from the water. In the fluidized bed the magnetic resin beads are attracted to each other to form large agglomerates that form a stable resin suspension at hydraulic loading rates up to 12 gpm/sf. An agitator operating at slow speeds keeps the resin/water suspension uniformly mixed, particularly at lower raw water flows to the MIEX® contactors. A series of tube or plate settlers at the top of the contactor prevent resin carry-over. MIEX®-treated water then overflows into collection launders to downstream treatment processes.

A small stream of resin is withdrawn from the contactor, regenerated with a concentrated salt solution (typical strength of 10 to 12%), and returned to the reactor vessel to maintain the ion exchange capacity of the resin in the contactor. A waste stream is generated as a result of the regeneration process, consisting primarily of organics and leftover salt. A portion of this waste stream is re-circulated for use in future regeneration steps. The remaining portion of the waste stream must be disposed of properly. Salt solutions typically consist of sodium chloride but other salts such as potassium chloride, magnesium chloride, sodium sulfate, or sodium bicarbonate can also be used if sodium or chloride is not desired in the waste discharge. **Figure 5-2** portrays the high-rate MIEX® process flow schematic.

Several advantages exist for the implementation of the MIEX® process into drinking water treatment applications. Apart from humic and fulvic acids, which contribute to taste and odor issues and comprise the majority of DOC compounds, other compounds including sulfides, nitrates, bromide, and arsenic may also be removed. To augment taste and odor control and limited DBP formation benefits, other WTP process performance enhancements may be garnered as a result of the MIEX® process.



[1] Figure is provided courtesy of Orica Watercare Inc.

Figure 5-2: High-Rate MIEX® Process Schematic[1]

Coagulation processes can be improved as there is less DOC to compete with the coagulant in binding to non-DOC material. MIEX® targets low to medium molecular weight natural organic matter (NOM), thus freeing the coagulant to target high molecular weight NOM that typically comprises the majority of TOC. This not only results in improved settling associated with larger floc particles, but also results in lower volumetric solids residuals production, thus reducing residuals handling and treatment costs.

DOC reduction also improves UV transmittance. The quantity of compounds that typically would absorb UV light is reduced. In addition, the removal of humic and fulvic acids that typically compete with activated carbon to bind with taste and odor (T&O) compounds results in improved PAC performance.

Compared to post-filtration granular activated carbon (GAC) contactors, operating costs are typically less for the MIEX® process. The difference in cost may be attributed to the material cost of GAC media replacement as well as the electrical cost of intermediate pumping operations. GAC contactors are commonly located after an initial filtration step to avoid rapid fouling and media wear. Often, additional pumping is needed for hydraulic purposes when retrofitting post-filter GAC contactors into an existing WTP profile to address inadequate driving head conditions. Moreover, MIEX® is typically placed at the head of the WTP

yielding performance improvements in most downstream unit processes, especially clarification. Reduced chemical usage (as much as 50%) in coagulant, pH adjustment, and oxidation chemicals (i.e. chlorine) may be realized as a result of the significant DOC reductions through MIEX®.

Since DBP formation potential is significantly reduced, free chlorine disinfection practices may continue in the distribution system. Using chloramines disinfection in the distribution system would further limit DBP formation potential but may not be needed to meet Stage 2 D/DBPR compliance. Maintaining free chlorine disinfection in the distribution system may also prevent the following operational challenges with chloramines disinfection practices:

- Nitrification due to disinfectant residual decay in a high water age system
- Nitrosodimethylamine (NDMA) formation – disinfection byproduct of chloramines disinfection
- Corrosion and lead issues

As noted above, the regeneration step of the MIEX® process generates a waste product highly concentrated with salt and organic matter. Typical disposal methods consist of hauling the solution off-site or discharging to a sanitary sewer along with other WTP waste flows. On-site treatment of the waste product is also available through the use of Orica's proprietary EcoRegen™ system, an advanced membrane filtration process, designed to separate the organic matter and the salt solution. The filtered salt solution may be recycled for future regeneration activities reducing waste volumes and salt consumption.

Implementation of the MIEX® process has grown over the past several years in the United States. Although most early installations were for small systems (i.e. less than 1-MGD), many larger, proactive utilities have recently implemented the process for DBP formation management. As Stage 2 DBPR compliance dates draw nearer, the number of MIEX® installations is anticipated to grow even further.

However, one challenge that concerns many utilities about implementing the MIEX® process at their facilities is the sole-source supply of the magnetic resin. Currently, the resin is only manufactured overseas and therefore must be shipped from Orica's plant in Melbourne, Australia. Although plans are underway to develop a manufacturing plant in the United States, presently only one source of supply exists. Three warehouses are strategically located domestically for replacement resin supply. Orica Watercare, Inc. reserves a quantity of resin for each of its customers at one of these warehouses. The manufacturer will also provide recommendations for the quantity of resin to store on-site; the utility will then be responsible for tracking resin consumption and ordering replacement resin in a timely fashion.

Coagulation and other treatment chemical savings may help off-set costs of MIEX® resin and salt, but this difference is not expected to completely recoup these annual MIEX® chemical expenditures. Nonetheless, source water quality will ultimately dictate the overall difference in chemical usage at the WTP. Piloting of the technology is strongly recommended prior to its

selection and implementation at the WTP to quantify the effectiveness of the process for DBP control and to grasp the anticipated O&M costs associated with process implementation.

Further, it should be noted that MIEX® is not alone a substitute for traditional clarification and filtration technologies; it only assists in improving the performance of these processes. The technology is most useful for source waters with high TOC/DOC or groundwaters with significant concentrations of sulfide, arsenic, and nitrates. Moreover, the technology is not effective for all high DOC waters; only those with high levels of low-molecular weight NOM.

A summary of the advantages and disadvantages of the MIEX® process are listed in **Table 5-1**.

Table 5-1: MIEX® Process Advantages and Disadvantages

Advantages	Disadvantages
• Excellent DOC removal – superior DBP pre-cursor removal (some bromide removal) • Very good taste and odor compounds, color, sulfides, nitrates, and arsenic removal • Less clarifier residuals • Less coagulant demand • Significant reduction in chlorine demand. • Reduced membrane fouling. • Improved UV transmittance and lamp performance • High loading rates (up to 12 gpm/sf) • Continue free chlorine disinfection practices in distribution system • Potential lifecycle cost advantages over GAC contactors	• Higher capital costs compared to GAC contactors • Relatively new technology in the U.S. • Additional facility space for reactors and ancillary equipment required • Most beneficial to utilities with high DOC raw waters • Waste solution disposal must be considered • Sole-source resin supplier • Resin not manufacturing domestically • No turbidity removal – clarification and filtration still required • Piloting is required to establish design parameters

5.1.2 Process Effectiveness

The effectiveness of the MIEX® process to limit the formation potential of DBPs varies as a result of the characterization of a utility's source water. Pilot testing is the preferred means to quantify the overall impact of the MIEX® process on DBP formation potential as well as other water treatment facility operations. Piloting efforts evaluate the beneficial enhancements of

implementing MIEX® including, but not limited to, DBP formation potential reduction, impacts to downstream treatment performance, and chemical usage. Likewise, any unforeseen detrimental impacts may also be observed. Commonly, parameters such as DOC concentrations, UV_{254} measurements, and simulated distribution system (SDS) DBP levels are analyzed to quantify DBP formation potential. It is not uncommon for the parameters listed above to see an approximate 50 percent reduction (or greater) when implementing the MIEX® process upstream of conventional treatment practices.

A DBP treatment goal has been identified for the Robert Harris WTP that includes LRAA DBP levels less than or equal to 80 percent of the Stage 2 DBPR MCLs. To determine if this goal is potentially viable, both Stage 1 and Stage 2 DBPR monitoring site data was evaluated assuming a 50 percent reduction in DBP levels with the implementation of MIEX®. For this exercise, data was limited to TTHMs; historic DBP sampling does not indicate that the City of Eden will face issues with HAA5 MCL compliance. Further, note that the Stage 2 DBPR monitoring site data is non-compliance data, collected by the City of Eden to assist in forecasting the utility's potential for future Stage 2 DBPR compliance. For this analysis, LRAA values were determined for the Stage 1 DBPR monitoring site data and compared to the MCL and treatment goal (see **Figure 5-3**). A LRAA was not calculated for the Stage 2 DBPR monitoring site data given it was not collected on a quarterly basis (sometimes more frequently, other times less frequently); as such, data from these individual monitoring events data is compared to the MCL and treatment goal (see **Figure 5-4**). Based on these analyses, MIEX® may offer the Robert Harris WTP the level of DBP formation potential reduction needed to achieve Stage 2 DBPR compliance; however, additional piloting is recommended to more accurately quantify the effectiveness of MIEX® for the City of Eden.

Certainly a significant economic benefit exists if a facility can implement partial treatment practices and achieve Stage 2 DBPR compliance with the LRAA MCLs for TTHMs and HAA5s. Generally, a WTP would direct to a MIEX® facility only what portion of the raw water flow is needed to reduce DBP levels to an acceptable level in the blended water product delivered to the distribution system. Smaller capacity MIEX® facilities are expected to significantly reduce initial capital investments as well as operation and maintenance costs when compared to the costs associated with full capacity MIEX® facilities. As described above, a similar analysis was performed on the Stage 1 and Stage 2 DBPR monitoring site data looking at 50 and 75 percent capacity MIEX® facilities (see **Figure 5-5** and **5-6**, respectively). Again, the portion of the raw water treated with MIEX® assumes a 50 percent reduction in TTHM levels. Based on these analyses, partial treatment does not initially look like a viable alternative for Stage 2 DBPR compliance. Although the Stage 1 DBPR monitoring site data evaluation looks promising, the Stage 2 data set (indicative of the worse-case problematic compliance sites in the distribution system) indicates mixed results. Given TTHM measurements above the MCL with the evaluated blending options, extensive piloting is recommended to determine the anticipated effectiveness of a partial treatment strategy to ensure regulatory compliance.

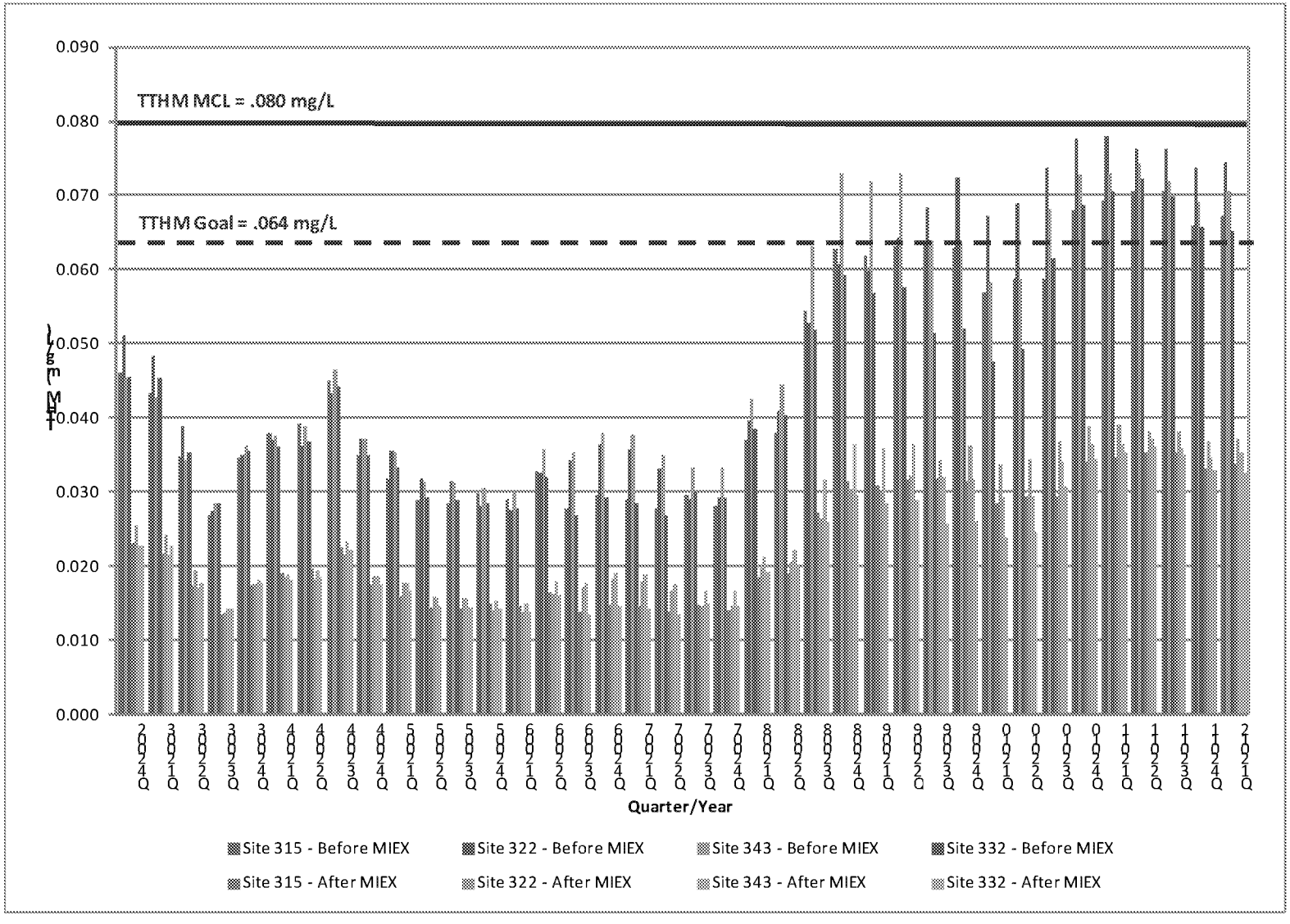


Figure 5-3: Impact of MIEX on TTHM LRAA – Stage 1 DBPR Monitoring Sites

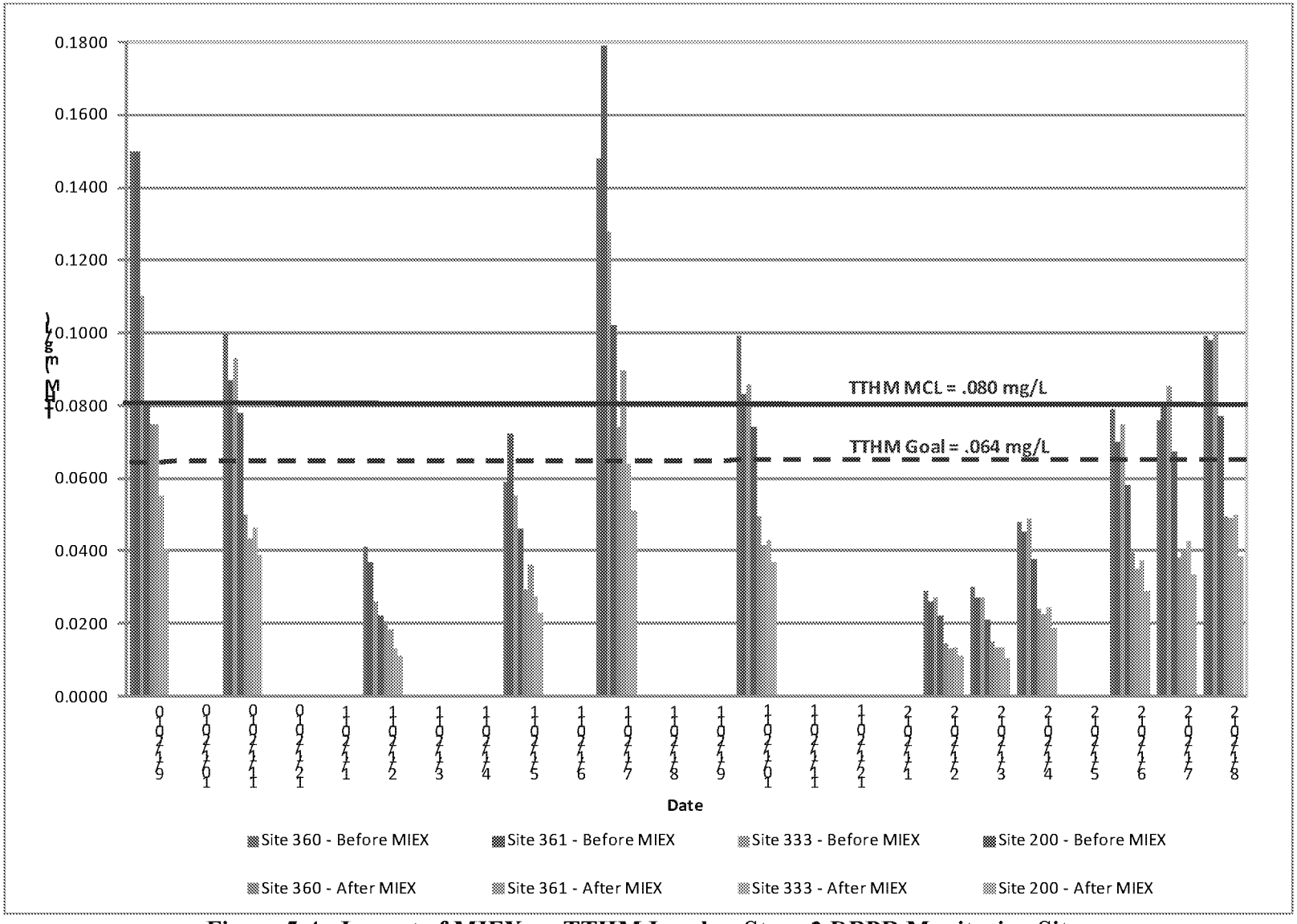


Figure 5-4: Impact of MIEX on TTHM Levels – Stage 2 DBPR Monitoring Sites

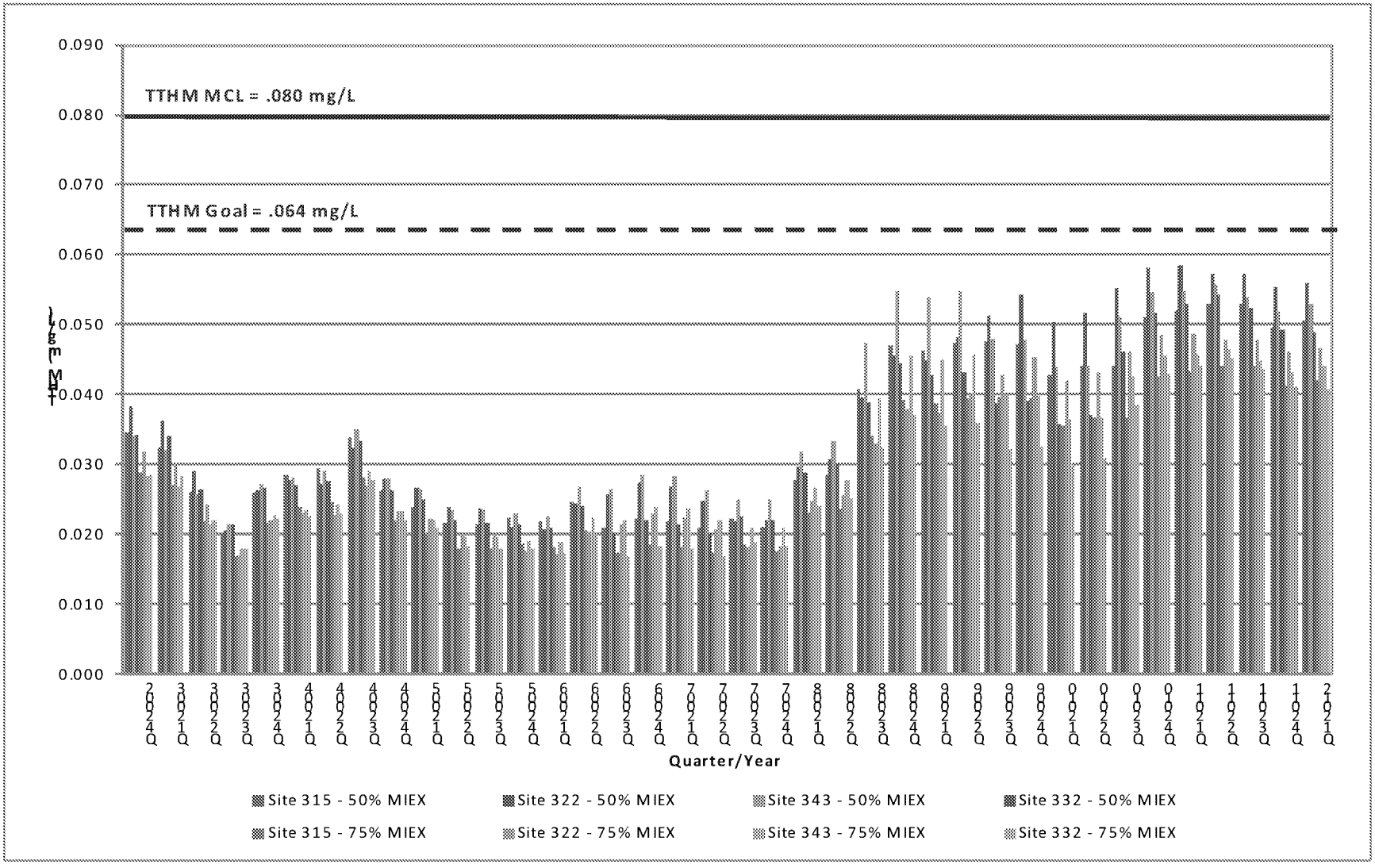


Figure 5-5: Impact of Partial MIEX Treatment on TTHM LRAA – Stage 1 DBPR Monitoring Sites

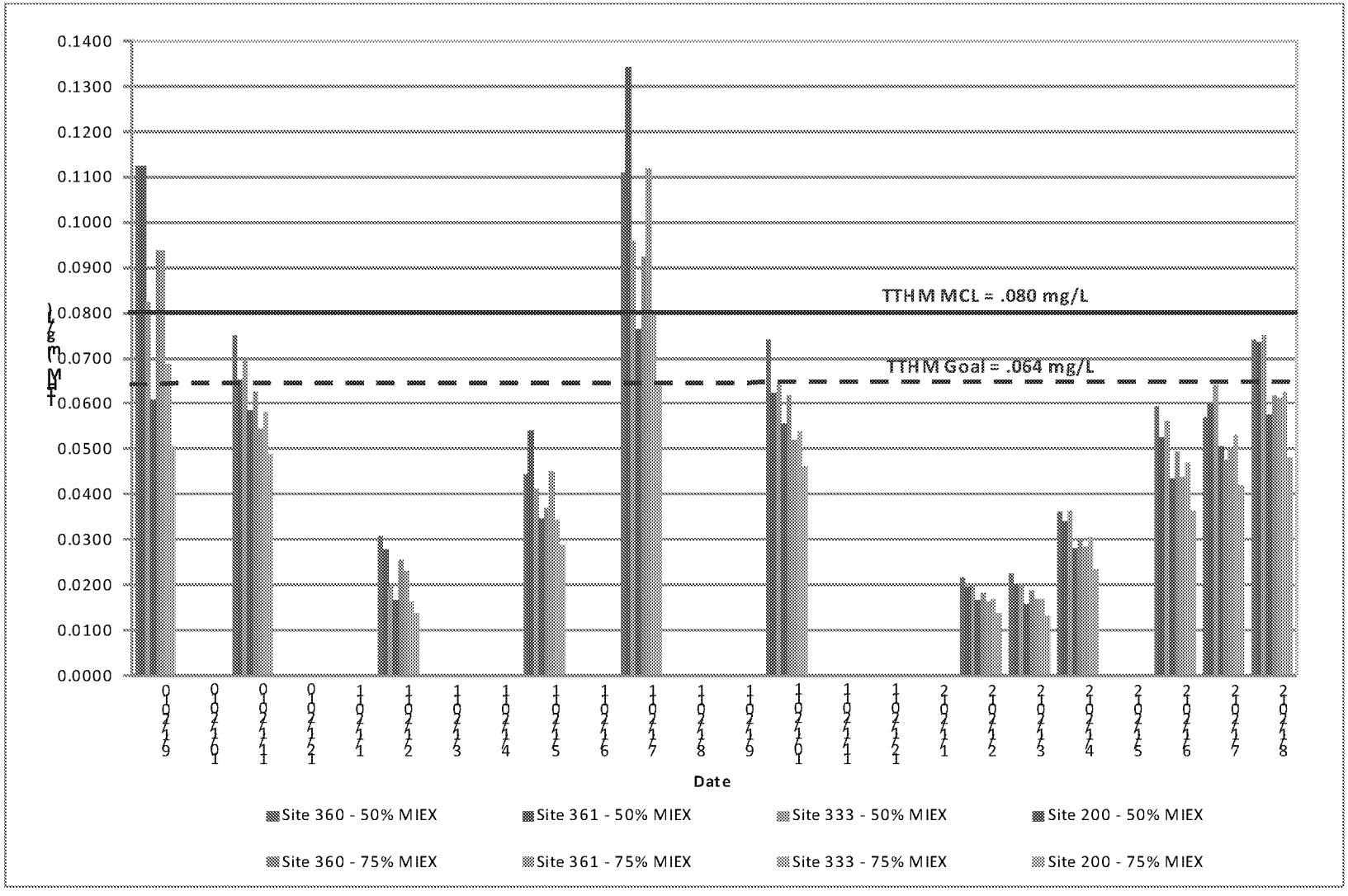


Figure 5-6: Impact of Partial MIEX Treatment on TTHM Levels – Stage 2 DBPR Monitoring Sites

5.1.3 Impacts on Existing WTP Operations

5.1.3.1 Site Constraints

As previously noted, the MIEX® process is typically implemented into the front end of a WTP's process train as observed in **Figure 5-7** allowing the utility to reap the operational benefits to downstream treatment processes including reduced chemical doses and residuals production. Ideally, a MIEX® installation is located on the WTP site for staff accessibility and to utilize to the greatest extent any existing raw water pumping and piping infrastructure where applicable. The existing raw water transmission must be intercepted directing the incoming WTP flow (or a portion thereof) to the MIEX® facility. MIEX®-treated water will then proceed to the original head of the WTP process train.

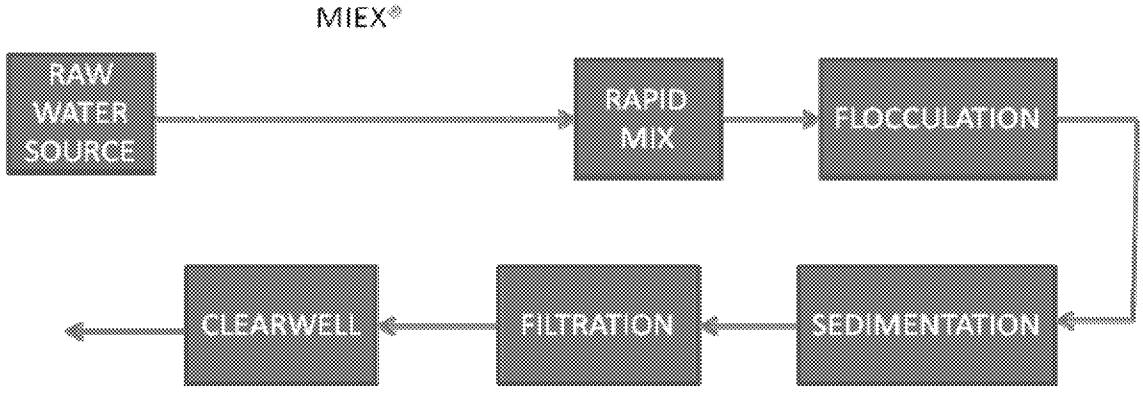


Figure 5-7: Typical WTP Process Schematic with MIEX®

Figure 5-8 presents a conceptual MIEX® installation layout for the Robert Harris WTP. The layout consists of the following major components required for a complete installation:

- MIEX® facility – consists of contactors, regeneration equipment, air compressor system (for pneumatically operated valves and pumps), various process tanks, bulk resin storage, and electrical/control rooms.
- Bulk salt storage – consists of a salt saturator vessel with truck access for deliveries.
- Waste solution storage – consists of tanks for waste solution storage/equalization.
- Process piping – raw water and MIEX®-treated water piping.

Salt saturator vessel and waste solution tanks are often located in near proximity to the MIEX® facility. The MIEX® process may be provided as a packaged system or as a custom designed system, directly impacting the overall footprint of the MIEX® installation at a WTP site. MagnaPak® packaged systems are available for throughputs up to 700 gallons per minute (i.e. approximately 1-MGD), are delivered as preassembled, skid-mounted systems, and are most often the most economical selection for smaller facility installations.

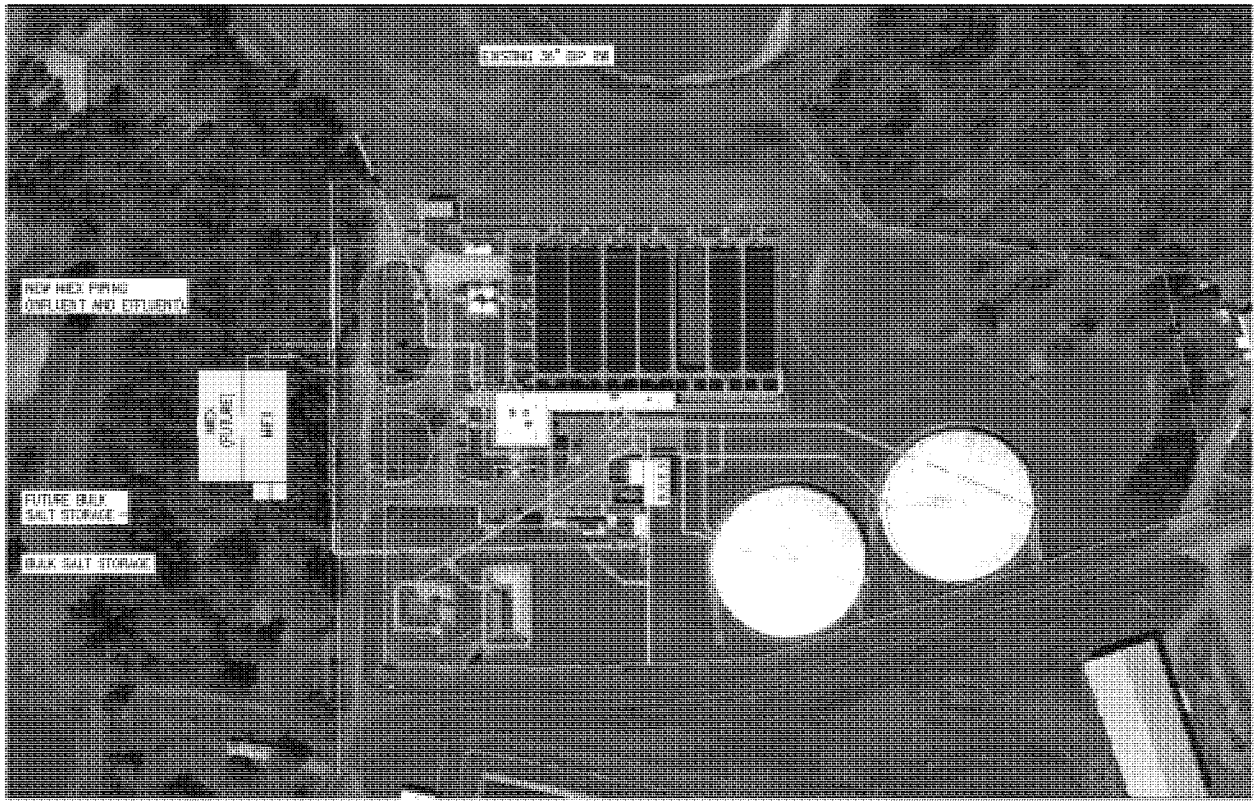
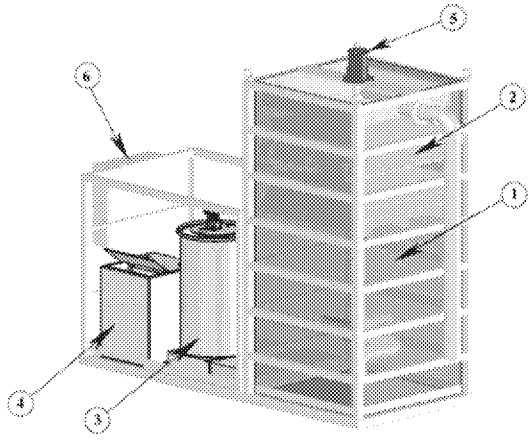


Figure 5-8: Conceptual MIEX® Facility Layout

Figure 5-9 identifies the individual components of the packaged system which are typically either covered or located within an enclosed building depending on the climate of the installation location.



MAGNAPAK®
System Components
1. High Rate Reactor Vessel
2. Lamella Plates / Tube Settlers
3. Resin Regeneration Vessel
4. Brine Storage Vessel
5. High Rate Reactor Agitator
6. Electrical Control Box

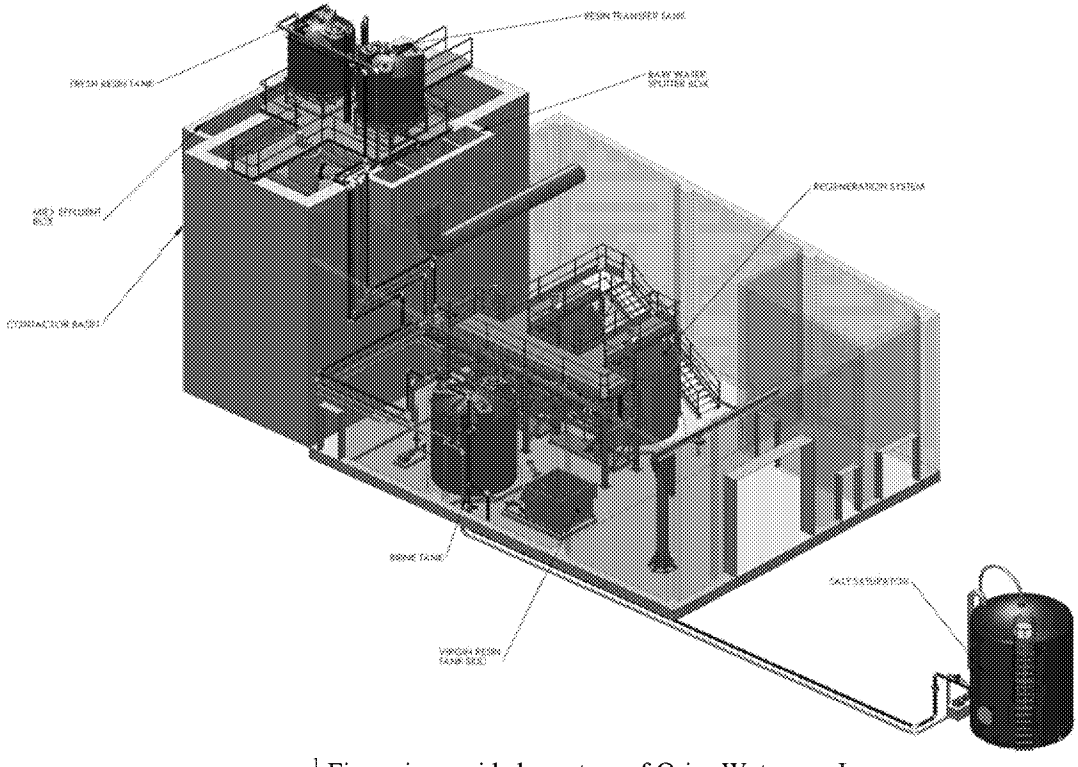
[1] Figure is provided courtesy of Orica Watercare Inc.

Figure 5-9: Packaged MIEX® System[1]

On the other hand, custom designed systems are commonly utilized for larger facility installations (i.e. greater than 700 gallons per minute) consisting of cast-in-place concrete contactors. MIEX equipment provided for a custom design includes, but is not limited to, the following:

- Contactor agitators/mixers
- Contactor tube or plate settlers
- Regeneration skid – consisting of regeneration tanks and pertinent pumps, valves, and process piping
- Virgin resin skid – consists of eductor system to introduce virgin resin into the process
- Fresh resin tank – houses regenerated resin to be conveyed back to the contactors
- Resin transfer tank – houses exhausted resin removed from the contactors
- Salt tank – houses diluted salt solution used for regeneration
- Air compressor system – air supply for pneumatically-operated equipment
- Control system

This equipment is typically housed in an engineered building comprising the MIEX® facility as seen in **Figure 5-10**. A custom designed MIEX® facility is most economical for implementation at the Robert Harris WTP.



[1] Figure is provided courtesy of Orica Watercare Inc.

Figure 5-10: Custom Designed MIEX® System[1]

5.1.3.2 Hydraulic Constraints

Raw water is conveyed to a high-rate MIEX® contactor outfitted with tube or plate settlers. MIEX®-treated water is collected at the top of the contactor and directed to downstream treatment processes. Headloss across the MIEX® facility is directly related to the flow and the design of the facility's hydraulic components – including influent and effluent piping, contactor plates/tubes, weirs, etc. Typical MIEX® facility headloss is approximated at 3 to 4 feet.

As previously mentioned, MIEX® installations are typically located upstream of conventional water treatment processes and require the interception and redirection of raw water transmission to the high rate MIEX® contactors. Good engineering practice will ensure the contactor location is coordinated with the existing hydraulic profile to accommodate existing process infrastructure. Ideally, MIEX® treated water would flow by gravity to the head of the WTP eliminating the need to re-pump the raw water flow. To ensure re-pumping is not required, the operating water surface elevation of the MIEX® contactors must be designed to a higher elevation than that observed in the subsequent downstream treatment process (most often, either the rapid mix or flocculation basins). The selected operating water surface elevation in the MIEX® contactors must take into account the accumulated headloss between the contactors and the downstream process. Any existing raw water pumping equipment should be reused to the extent possible to direct raw water to the MIEX® contactors. Pump hydraulics should be thoroughly investigated to determine any flow limitations and thus pumping improvements needed to accommodate the additional total dynamic head associated with the operating water surface elevation desired in the MIEX® contactors.

Additional hydraulic concerns exist in the event that partial treatment practices are implemented at a given WTP. One such constraint involves the means by which raw water flow is split and controlled between the MIEX® and bypass treatment trains. Often, a flow control valve and meter combination is installed for this purpose. Raw water pumping and transmission infrastructure may also be dedicated to the MIEX® treatment train to address flow split and control challenges. Either a variable frequency drive or a flow control valve and meter combination may be used in conjunction with a dedicated pump to precisely control raw water flow to the MIEX® contactors. A relatively constant MIEX® flow is desired to prevent the need for abrupt changes to the process, potentially limiting the effectiveness of the contactor for DOC removal.

Hydraulic challenges also exist when blending MIEX® and bypass treatment train flows together following partial flow treatment through a MIEX® facility. Unfavorable hydraulic conditions (i.e. flow recirculation) may develop as a result of splitting and controlling the flow as desired between these two trains. A hydraulic break/disconnect (i.e. a weir box structure) or control device (i.e. orifice, valve, etc.) may be required to prevent such issues. These preventive measures must be considered when selecting the operating water surface elevation of the MIEX® contactors and the piping and appurtenances between the contactors and the subsequent downstream process.

5.1.3.3 Regeneration Waste Disposal

A strong salt and organics waste product is generated as a result of regeneration of the MIEX® resin. Typical waste stream composition consists of 90 to 120 g/L of salt and 5 to 15 g/L of dissolved organic material. The quantity of this waste product is directly related to the raw water DOC concentrations controlling the frequency of resin regeneration. Therefore, waste quantities may vary seasonally as the DOC concentration in the raw water changes throughout the year.

Combining this waste product with other residuals streams generated at the WTPs is not typically a recommended practice, particularly if the waste stream comprises a significant percentage of the overall waste volumes produced at the site. However, the waste product generated from a more inert salt, such as sodium bicarbonate, may potentially be combined with other WTP residuals streams if the waste product volume is relatively insignificant. Any 'zero discharge' facilities recycling a treated residuals stream would only recycle the problematic organics removed by MIEX® back to the head of the WTP. WTPs utilizing a National Pollutant Discharge Elimination System (NPDES) discharge may have difficulty meeting specific constituent limits (i.e. flow, total dissolved solids (TDS), etc.) in the discharge stream if the waste product volume represents a significant portion of the discharge flows.

Two methods of waste product disposal are commonly implemented with MIEX® installations; either the solution is discharged to the sanitary sewer or the solution is hauled off-site for further treatment and/or ultimate disposal. Discharge of the waste product to the sewer is certainly the most economical means of disposal with the appropriate sewer infrastructure and capacity in place. Typically, WWTPs can handle salt levels of 2,000 mg/L without detrimentally impacting biological processes. As an example, salt quantities conveyed to the WWTP from the regeneration waste stream leaving the Robert Harris WTP could reach over 70,000 lb/d if the plant is treating a maximum flow of 21-MGD considering a regeneration waste production rate equal to 350 gal waste/MG treated water. Combination of this waste product stream with a typical 3-MGD influent WWTP flow containing 223 mg/L of total dissolved solids would result in nearly a 300 mg/L increase in influent salt concentrations. However, the net increase this waste product stream contributes to the WWTP's influent salt levels is not anticipated to disturb biological WWTP operations.

Many wastewater facilities have TDS limits in their NPDES permits regulating point source pollutant discharge to receiving streams. Further, more stringent effluent TDS limits may be in place for WWTP outfalls within a predetermined nautical mile distance upstream of a classified water supply source and intake. Compliance with the more stringent TDS limit becomes more challenging if the waste product volume comprises a significant contribution to the influent stream of the WWTP. Currently, there is no TDS limit in the City of Eden's WWTP's NPDES permit that must be met.

To counteract these potential operational concerns at WWTPs, dilution and control of the waste solution sewer discharge is often recommended for this commonly practiced means of disposal. Equalization tanks are generally provided on-site at the WTP with adequate volume for two to three days of storage at maximum waste solution generation rates. Also, connection to a non-potable water supply can be provided in near proximity to these tanks to provide for waste stream dilution, reducing salt and DOC concentrations to acceptable, manageable levels. Additional equalization volume will be needed to accommodate the non-potable water addition to the waste volume if dilution practices are implemented at the WTP.

Off-site disposal of the waste product typically requires significantly greater on-site storage to offset the operation costs associated with the transportation and further treatment of the waste product. 5,000 gallons of storage per million gallon of water treated is recommended with this disposal practice resulting in approximately 2 weeks of on-site storage.

In all likelihood, the regeneration waste solution would be discharged to the WWTP located directly across the street from the Robert Harris WTP. Additionally, equalization storage is already available on the plant site in the form of two equalization basins to accommodate sedimentation residuals and used filter backwash streams. As noted above, equalization storage must consider not only the maximum waste product quantities but any dilution water volume needed also to reduce salt to acceptable discharge concentrations. For comparative purposes, providing a 100 percent dilution of the waste solution would approximately double the waste storage volume needed. Further, it may be necessary to isolate the waste stream from the sedimentation residuals and used filter backwash streams. **Table 5-2** summarizes the maximum estimated daily waste product volume generated and recommended waste storage volumes for both waste disposal options at the Robert Harris WTP. Waste storage volumes presented do not include dilution water volumes at this time.

Table 5-2: Waste Product Storage Volume Estimates

MIEX Plant Capacity (MGD)	Estimated Max Day Waste Volume Production (gal/d)	Waste Storage Volume Required (gal)[1]
		Disposal to Sewer[2]
11	3,850	11,550
21	7,350	22,050

1. Waste storage volume required does not account for dilution water volumes if required.
2. Provides 3 days of storage at maximum daily waste volume production estimates.

Orica Watercare, Inc. has recently developed a new EcoRegen™ system, designed to significantly reduce waste product volume, salt consumption, and the carbon footprint of the MIEX® process. The waste product of MIEX® is conveyed to an automated, skid-mounted, advanced membrane treatment system where the accumulated DOC and salt fractions of the waste product are separated. DOC concentrate must be properly disposed of while the salt permeate is recycled for use in future regeneration cycles. Published documentation claims that system implementation may allow the recycle of 70 percent of the original waste product volume, significantly reducing the volume of the final waste product. Recycling activities also reduces the salt make-up rate at the salt saturator, reducing the overall salt consumption of the MIEX® process. The EcoRegen™ system may prove to be a viable, economical

alternative for regenerant waste disposal, particularly concerning MIEX® installations with high regeneration rates (i.e. high salt consumption and waste product production). A lifecycle cost evaluation is needed on a utility-by utility basis to determine the economic feasibility of implementing the EcoRegen™ system. Consideration of this system for the Robert Harris WTP would be evaluated during a final design effort.

5.1.3.4 Intermittent Process Operations

The Robert Harris WTP operates discontinuously, most commonly shutting down treatment operations over the weekend. During facility shutdown, it is important to maintain the MIEX® contactor resin in a fluidized state to prevent excessive settling along the contactor bottom. Either a vertical mixer or recirculation pump is used to mix the contents of the contactor while the facility is off-line. Mixer or pump speed is decreased slowly as the facility is brought on-line, utilizing the turbulence of the incoming flow to assist in the fluidization of the resin.

Concern exists that intermittent operation of the MIEX® process may compromise the performance of the process regarding DOC removal, particularly at facility start-up. Unacceptable water quality conditions exiting the MIEX® facility may require recycling or potentially wasting the raw water stream until acceptable conditions are met. The impact of intermittent operations on MIEX® treatment has been previously investigated to quantify any reduction in DOC removal performance and the length of time between facility start-up and production of acceptable water quality (see Water Research Foundation (WRF) report titled *Impact of Anion Exchange Pre-Treatment on Downstream Processes*, 2010). Results from this investigation indicated acceptable MIEX®-treated water quality production from start-up onward, allowing immediate conveyance of the treated water to subsequent downstream treatment processes. Further, recent installation information provided by Orica Watercare, Inc. identified several recent MIEX® installations (within 5 years) with successful, intermittent treatment operations. As such, the intermittent operations of the Robert Harris WTP are not anticipated to impact the performance of a MIEX® process installation.

5.1.4 Impacts on Distribution System Water Quality

Impacts of the MIEX® process do not reside at the WTP site alone, but extend outward into a utility's distribution system. The chemical conditions of the distribution system are inevitably altered as a result of MIEX® implementation. Process changes (or additions such as MIEX®) that alter the chemical dosing practices and composition of the treated water at a WTP present the potential for impacting (positively or negatively) the corrosion of existing distribution system infrastructure. The impact of such changes requires thorough investigation to determine the appropriate corrosion control strategy to implement for protection of the distribution system going forward.

Very limited data is available regarding the real-world impact of MIEX® implementation on distribution system corrosion. To date, research exists that simply predicts the potential for favorable corrosion conditions in a distribution system as a result of the use of the MIEX® process at a WTP. The 2010 WRF Study (referenced above) evaluated this potential impact based on the results of previous research efforts regarding distribution system corrosion conditions; the findings of which are summarized below:

- Chloride-to-sulfate ratios are greater in MIEX®-treated waters as a result of three factors:
  - Reduced coagulant dose reducing the sulfate concentrations found in MIEX®-treated waters utilizing a sulfate-based coagulant
  - Removal of sulfate present in the raw water through adsorption onto the MIEX® resin
  - Chloride release from the reactive sites of the MIEX® resin with the use of a sodium chloride regeneration salt
- Chloride-to-sulfate ratios greater than the 0.5 mg/mg threshold in MIEX®-treated waters are indicative of favorable corrosion conditions prevalent in the distribution system.
- Greater chloride-to-sulfate ratios exist in MIEX®-treated waters utilizing a sodium chloride regeneration salt compared to a sodium bicarbonate salt. Ratios were still greater than the threshold utilizing the sodium bicarbonate salt for regeneration of the MIEX® resin.
- Predicted Langelier, Ryznar, and Aggressiveness indices were indicative of greater corrosion potential conditions in the distribution system.

The preceding findings do not consider the use of corrosion inhibiting chemicals. However, the Robert Harris WTP utilizes a corrosion inhibitor for protection of its distribution system. Predicted lead solubility, total dissolved solids concentrations, and conductivity measurements are all less in MIEX®-treated waters utilizing a corrosion inhibitor, indicative of water chemistry conditions that are less favorable to experiencing corrosion issues in the distribution system.

A corrosion control study should be considered for any WTP utilizing the MIEX® process to determine the appropriate corrosion inhibitor chemical and dose to offset any potential detrimental impacts regarding escalated corrosion activities. The study can be conducted after the MIEX® process is installed to determine the best strategy for protection against corrosion.

Corrosion control studies may be performed using a custom-built corrosion study pilot plant as seen in **Figure 5-11** and **Figure 5-12**. The corrosion control study is typically conducted over several months to capture the onset and extent of corrosion in finished water piping as a result of changes in the treatment practices at the WTP. Pilot plants consist of multiple corrosion trains with the ability to add a different corrosion inhibitor chemical and dose to each train. Testing often includes lead, copper, and steel coupons inserted into the PVC piping of each train. The coupons are analyzed over various time periods; often at 3, 6, and 9 month intervals, for corrosion rates. Within each train, isolation valves and a bypass valve are furnished in the copper pipe loop portion of the train allowing water to be isolated in the copper pipe loop for eight hours, simulating 8-hour standing samples. An aqueous lead and copper analysis is performed on the collected samples from the copper pipe loops at various times over the course of a study.

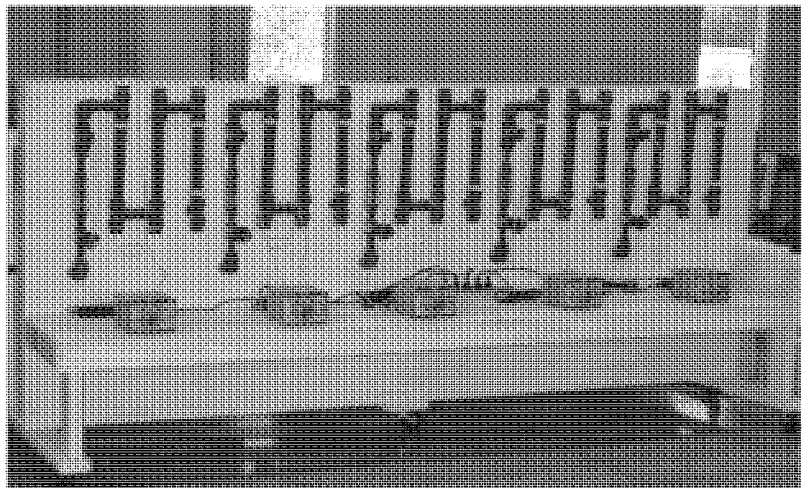


Figure 5-11: Typical Corrosion Study Pilot Plant

Figure 5-12: Typical Corrosion Study Pilot Plant

5.1.5 Ease of Construction

The challenges experienced throughout the construction of a MIEX® facility at a WTP site will vary depending on individual site constraints as well as the type of MIEX® system implemented at the WTP – a custom or packaged design. Individual site constraints that may complicate construction activities include, but are not limited to, congested site space, challenging topography, extensive buried infrastructure, rock excavation, and limited site access. The Robert Harris WTP site appears to have sufficient space available for the addition of a new process facility near existing raw water lines (see **Figure 5-8**).

As discussed earlier, the packaged MIEX® design is delivered as a preassembled, skid-mounted system including system controls. The compact layout of the packaged system design lends itself better to the construction of a MIEX® facility utilizing a pre-engineered building. Such buildings come in pre-fabricated sections, significantly reducing the complexity of building assembly. Noted earlier, custom designs house several ancillary components of the core MIEX® process and must be designed as such to accommodate these components. Complete and thorough structural, architectural, electrical, HVAC, and plumbing designs must be performed for a customized building, notably increasing the complexity of the building effort. As noted earlier, considering the capacities under evaluation, a custom designed facility is anticipated for the Robert Harris WTP.

The existing raw water piping must be intercepted, directing flow to the new MIEX® facility; modifications that may be performed during a typical WTP shutdown preventing interference with daily WTP operations.

5.1.6 Regulatory Acceptance

MIEX® is a proven advanced treatment technology implemented for the control of DBP formation. With Stage 2 DBPR compliance dates quickly approaching, several additional MIEX® installations are expected at WTPs across the country, particularly with utilities serving 50,000 people or less. Many surface and ground water systems throughout the southeastern United States have recently implemented MIEX® treatment. Regulatory acceptance of the MIEX® process by the North Carolina Department of Environment and Natural Resources (NCDENR) is vital to any near term MIEX® design and construction to ensure the facility is in place in a timely manner to ensure LRAA MCL compliance out in the distribution system. Recently, NCDENR has permitted the construction of a 6.75-MGD MIEX® facility design for the Johnston County WTP located in Wilson Mills, NC.

5.1.7 Regulatory Compliance Constraints

The effectiveness of the MIEX® process for DBP formation control should be confirmed to determine if this advanced treatment process is the best selection going forward for the Robert Harris WTP. Therefore, piloting efforts are recommended for any future considerations of implementing MIEX® into the existing plant treatment train. Such efforts would occur prior to design and construction of a new MIEX® facility with adequate time allotted to conduct these tests.

Table 5-3 summarizes a preliminary schedule for MIEX® piloting, design, and construction tasks for the WTP compared to the established Stage 2 DBPR compliance schedules. The construction completion dates exceed the initial compliance date indicated in the table. Yet, NCDENR may grant a system up to an additional 2 years if significant capital improvements are needed to achieve Stage 2 DBPR compliance; dates noted in parentheses indicate the revised compliance dates. If selected for implementation, discussions with NCDENR should be initiated immediately to ensure the 2-year extension is granted to prevent the potential for Stage 2 DBPR violation in the interim. Despite the extension, implementation of the MIEX® process at the Robert Harris WTP may still be difficult to place into operation before the October 2015 compliance date. As a result, additional interim strategies may be needed to assist with limiting DBP formation until the MIEX® facility can be initiated at the plant.

Table 5-3: Stage 2 DBPR Compliance Schedule Constraints

Compliance Date[1]	Pilot Testing Completion Date	Design/Bid Completion Date	Construction Completion Date
October 2013 (October 2015)	August 2013	November 2014	May 2016

1. An additional 2 years may be granted to systems requiring significant capital improvements to ensure compliance with the LRAA MCLs.

5.1.8 Capital and O&M Costs

Both capital and annual operation and maintenance (O&M) cost estimates have been prepared for the implementation of the MIEX® process at the Robert Harris WTP. Although the WTP has a rated capacity of 21-MGD, given recent historical demands, an 11-MGD MIEX® facility appears sufficient to treat the anticipated WTP flows. As such, capital and O&M costs have been prepared for this smaller capacity. Additionally, costs have been prepared for a facility capable of treating the plant's rated capacity, 21-MGD.

Construction costs are prepared in 2013 dollars and include all civil (i.e. site), mechanical (i.e. equipment), structural, architectural, HVAC, plumbing, electrical, and instrumentation and control components associated with construction of a MIEX® facility. Additionally, the following supplemental costs are accounted for in the preparation of each construction cost estimate:

- 30% Contingency – to account for variability in equipment and material costs as well as other construction costs that remain unidentifiable at this time;
- 15% Contractor overhead and profit; and
- Engineering fee – to account for design and construction administration services.

Operation and maintenance costs associated with the MIEX® process include the following components:

- Chemicals – a net increase in cost is anticipated as a result of MIEX® resin and salt usage, despite savings in downstream process chemical usage (i.e. coagulant, oxidants, pH adjustment, etc.);
- Labor – a net increase in cost associated with daily, monthly, and yearly tasks associated with the monitoring, operation, and maintenance of the MIEX® facility; and
- Electrical – a net increase in cost is anticipated due to additional power consumption of the MIEX® process.

The additional costs associated with waste regenerant solution handling are considered negligible; this solution will be directed to the WWTP located adjacent to the Robert Harris WTP. Likewise, the potential cost savings associated with the handling of a smaller residuals quantity from the plant's sedimentation basins are considered negligible; minor modifications to current handling and treatment practices are anticipated.

Table 5-4 summarizes the capital and annual O&M costs prepared for the different MIEX® facility sizes. These costs are prepared to provide the City of Eden with a conservative estimate of the construction costs and would be refined during preliminary and later final design efforts to reflect site specific design and construction constraints. Unit capital and O&M costs have also been prepared for each of the different capacity facilities. As expected, unit costs are greater with the smaller capacity MIEX® facility.

Table 5-4: MIEX® Facility Capital and O&M Costs Summary

WTP Capacity (MGD)	MIEX® Capacity (MGD)	Capital Cost ($)	Unit Capital Cost ($/gpd)	Annual O&M Cost ($)	Unit O&M Cost ($/1,000 gal)
21	11	$12,742,000	1.16	$332,000	0.15
	21	$24,126,000	1.15	$607,000	0.12

5.2 Anion Exchange

5.2.1 Process Description

Ion exchange processes remove undesirable ions through a chemical reaction using an ion exchange resin. The resins can be designed to remove a wide variety as well as specific ions. At the Robert Harris WTP, a bromide-selective resin would be utilized. Undesirable ions are captured on reactive sites of the resins. The ions that were initially attached to the reactive sites are released into the water during exchange. The adsorption process is very similar to what occurs in a MIEX® reactor. A reversible reaction is most useful as it allows for recharge of the resin.

Ion exchange systems generally consist of pressure vessels. The typical arrangement of an ion exchange unit consists of a baffled inlet that allows for even flow distribution onto the media followed by freeboard/air space that allows for headloss accumulation and bed expansion. Following the air space, the ion exchange pressure vessel contains a fixed bed of four to five feet of resin followed by graded gravel to further allow for even distribution during backwashing. Lastly, an underdrain support structure is provided for the media within the pressure vessel to again aid in flow distribution during both service and backwashing stages of operation.

The resin has two major components: the polymer matrix and the functional group. The polymer matrix consisting of cross-linked bases provides the structural support of the resin. The functional group serves as the active sites on the resin. Co-ions are fixed to the functional group, and the mobile counter ions attached also to these reactive sites, can release and exchange with the undesirable ions in the water. The functional group determines the resin charge and strength. A strong resin has little selectivity and removes most ions present in the water with a tight bond over a wide pH range. Strong resins are costly to operate. Weak resins are less expensive to operate and hold exchange ions less tightly over a narrower pH range. Weak cationic resins must have a pH greater than 6, and weak anionic resins must operate at a pH less than 8. A schematic of an anionic resin is shown below in **Figure 5-13.**

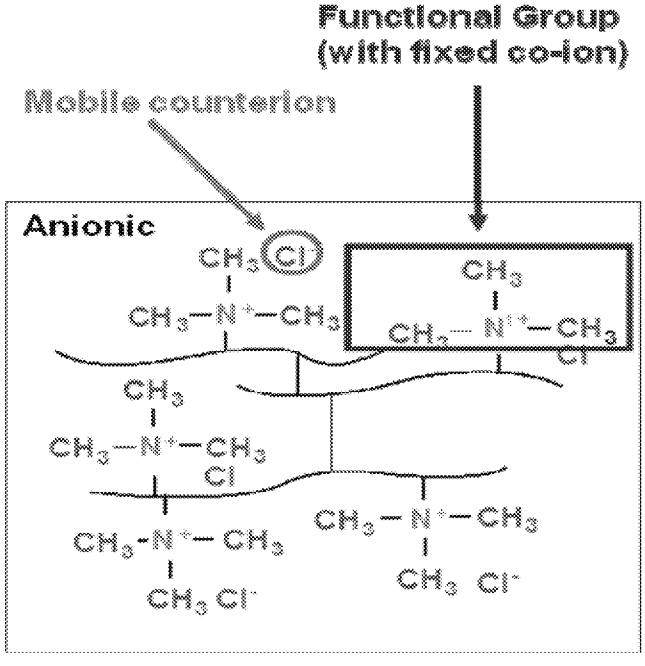


Figure 5-13: Schematic of Anionic Resin

Ion exchange pressure vessels can either be designed for individual unit configurations or multiple unit configurations. When multiple ion exchange pressure vessels are used, they can be in lead/lag, series, or parallel configurations. A lead/lag configuration provides a unit to be available continually for treatment. Series configurations are often implemented when high priority is desired or if multiple ions are desired to be removed through different selective resins. Parallel configurations offer the advantage of higher throughput capacity.

There are four stages of operation for an ion exchange system: service, backwash, regeneration and rinse. **Figure 5-14** shows a schematic of the inlets and outlets of an ion exchange vessel necessary for these four stages. During the service (or normal operation) stage, undesirable, charged ions exchange with the mobile counter-ions. As this exchange occurs, the available reactive sites diminish slowly reducing the exchange capacity of the resin. The service stage duration depends on the influent water quality, the presence of competing ions, the size of the ion exchange vessel and the number of fixed charged sites per unit volume of the resin. The end of the service stage is marked by "breakthrough". Breakthrough occurs when the reactive sites of a resin have been used and the resin must be recharged. Breakthrough can be determined in several different ways: measure effluent pH, measure conductivity of effluent water, based on time or volume per service stage, on-line monitoring of ion levels in the resin or off-line grab sampling of effluent quality.

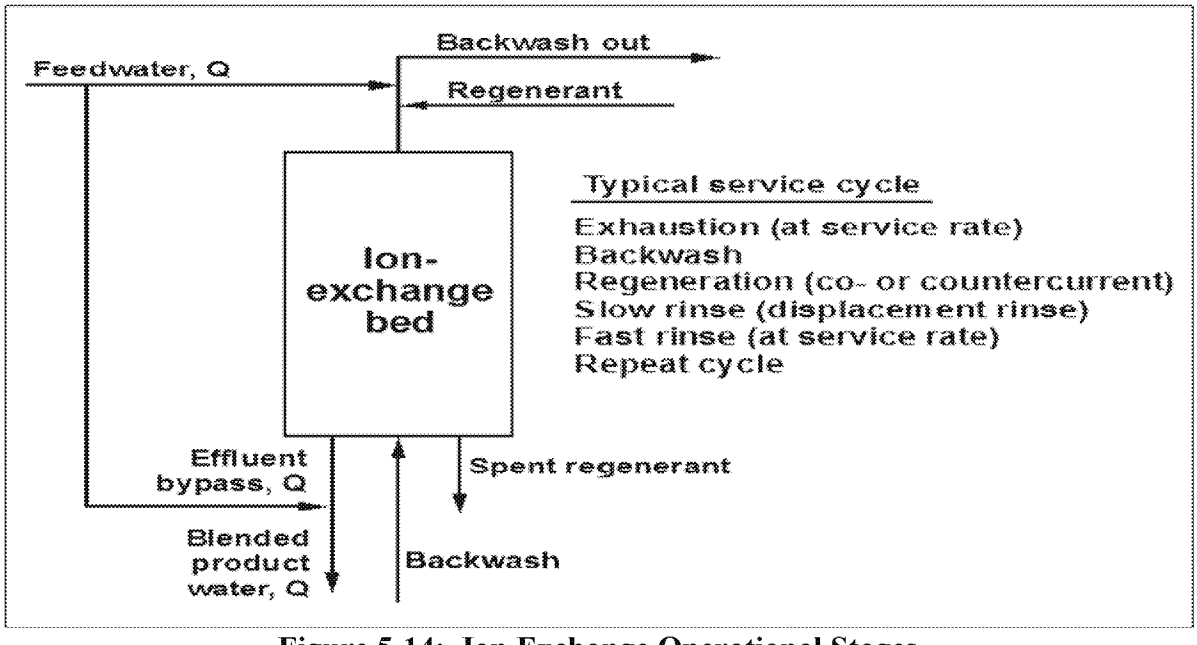


Figure 5-14: Ion Exchange Operational Stages

Like conventional filters, ion exchange beds must be backwashed. Backwashing expands and cleans the resin beads and removes any particulates caught within the resin. Backwash water is applied at a slow steady rate to provide as much as 75% to 100% bed expansion. Resin strength and water temperature influence backwash cycle duration and flow rate; stronger resins and warmer waters require an extended backwash time, larger flow, or a combination of both.

When the reactive sites on a resin have been spent, the resin must be recharged or regenerated. During regeneration, a strong regenerant solution is introduced to the vessel, causing the reverse of the substitution reaction that occurs during normal operation. The reactive sites that contain undesirable ions from the treated water release these ions in exchange for the innocuous ions that originally occupied those sites. There are two steps to regeneration: recharge which occurs at a typical loading rate of 1 to 2 gpm/ft^2 and fast drain which occurs at a typical rate of 3 to 5 gpm/ft^2. For an anionic resin, the regenerant solution can either be a strong mineral salt with abundant chloride ions or a strong base commonly with plentiful hydroxide ions such as a caustic solution. Regenerant is often delivered to the resin in two different ways. The batch in-column approach requires filling the column with the regenerant solution and allowing it to soak for a specified time. The second approach, known as the continuous in-column delivery method, allows a specified amount of regenerant to continuously pass through the resin. Continuous delivery of regenerant usually requires less solution but does require more stringent monitoring and control. The optimal delivery strategy is chosen to minimize frequency of regeneration (recharges thoroughly) and to minimize volume of wasted regenerant.

The fourth and final stage in ion exchange operation is the rinse stage. This stage removes waste products and excess regenerant solution. The duration of this cycle depends on the vessel size, but is typically between 20 and 40 minutes long. The correct time can be determined by measuring conductivity and specific gravity of the rinse water as it leaves the vessel.

A complete summary of the advantages and disadvantages to anion exchange is illustrated in **Table 5-5**.

Table 5-5: Anion Exchange Process Advantages and Disadvantages

Advantages	Disadvantages
• Selectively remove specific constituents (bromide) • Simple operation • Independent from other treatment processes • Could be used in conjunction with a DOC-selective resin	• Bromide-selective resin is expensive • Could require frequent regeneration depending on bromide concentrations • Using only a bromide-selective resin will not prevent the formation of chlorinated DBPs • Reduced exchange capacity if other competing anions are present in the water • Could require dechlorination before ion exchange processes

5.2.2 Conceptual Design

Implementation of anion exchange at the Robert Harris WTP would require the addition of an intermediate pumping station (to accomodate the additional headloss across the process) and

electrical/control room. Depending on the capacity chosen for design, thirteen to twenty-five pressure vessels would be necessary for treatment capacities of 11-mgd and 21-mgd, respectively. Each vessel would be 12-foot in diameter, providing a surface area of 113 square feet. 565 cubic feet of bromide-selective resin would be held within each filter. A summary of the conceptual anion exchange design is shown in **Table 5-6**.

Table 5-6: Conceptual Anion Exchange Design

Capacity (MGD)	Loading Rate (gpm/sf)	Number of Vessels	Flow/Vessel (gpm)
21	5.25	25	583
11	5.25	13	588

A new ion exchange facility would be located downstream of the plant's existing conventional filter complex; this prevents excessive plugging of the resin by particulates that may increase headloss and compromise the exchange capacity of the resin. The addition of anion exchange to the Robert Harris WTP would also require the relocation of post-filter chemical application points downstream of the process. A dechlorinating agent may also be needed to prevent breakdown of the resin considering the plant utilizes chlorine on top of the conventional filters for manganese oxidation. Additionally, new ion exchange piping for influent and effluent streams would be necessary. **Figure 5-15** illustrates the conceptual anion exchange facility layout based on 12-foot diameter pressure vessels.

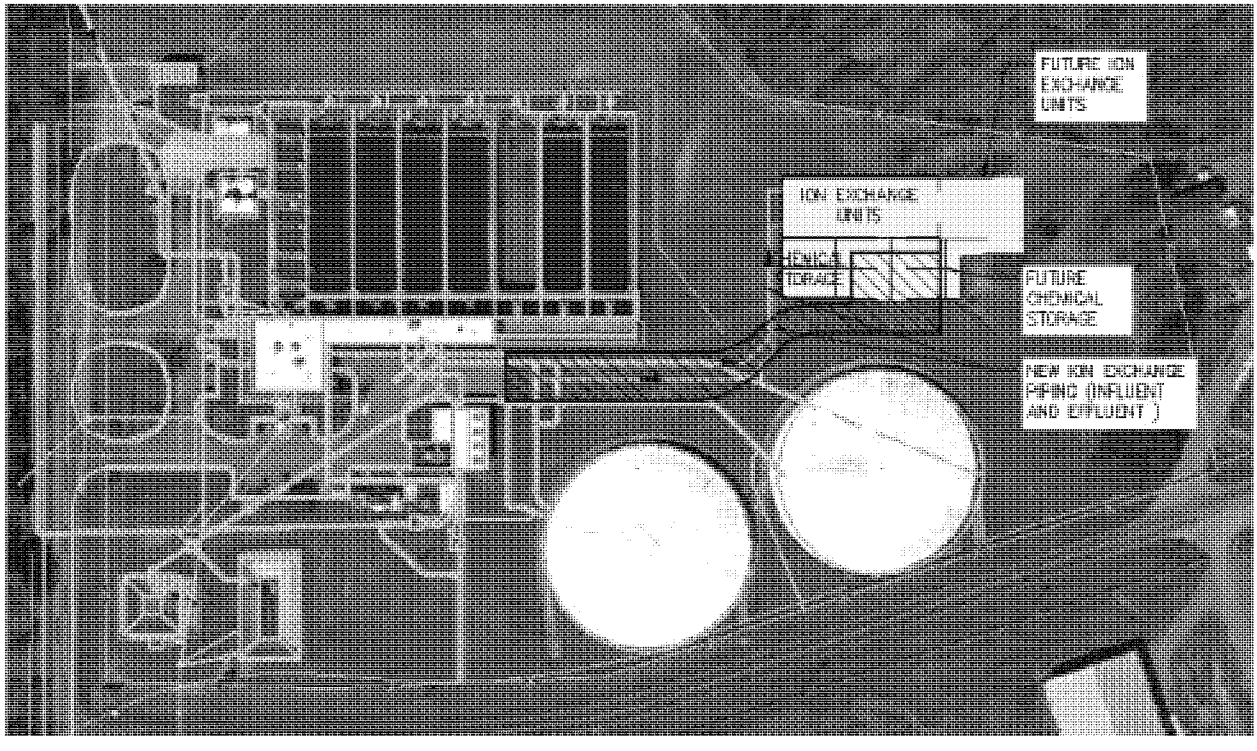


Figure 5-15: Conceptual Anion Exchange Facility Layout

5.2.3 Effectiveness for DBP Reduction

The effectiveness of the anion exchange process to reduce DBPs varies as a result of the characterization of a utility's source water. Bench scale testing can provide a glimpse into the effectiveness of a particular resin for a specific ion of concern. However, pilot testing is the preferred means to quantify the overall impact of the anion exchange process on DBP formation potential as well as other water treatment facility operations.

5.2.4 Impacts on Existing Plant Operations

5.2.4.1 Site Constraints

Anion exchange is typically implemented after filtration and prior to the water entering the clearwells as shown in **Figure 5-16**. Ideally, an anion exchange installation is located on the WTP site for staff accessibility and to utilize to the greatest extent any existing infrastructure where applicable. The preliminary site selected for the facility provides adequate space for the conceptual facility footprint while accommodating the new piping to and from the facility. However, a geotechnical subsurface investigation is warranted to determine if the subsurface is suitable to support a new process facility.

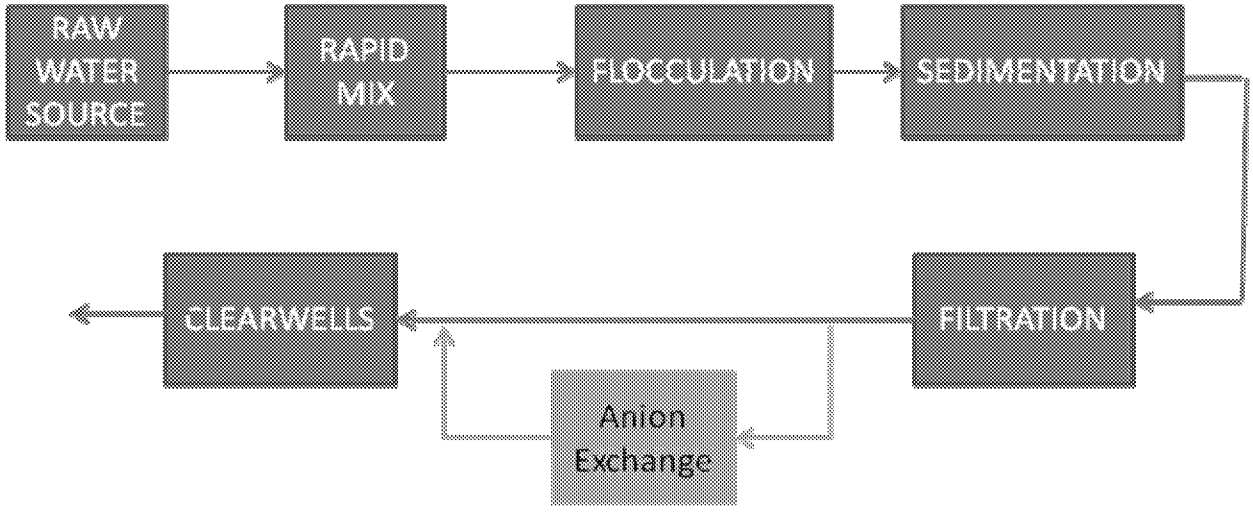


Figure 5-16: Typical WTP Process Schematic with Anion Exchange

5.2.4.2 Hydraulic Constraints

The hydraulics of anion exchange is conceptually simple – filtered water is conveyed to the anion exchange pressure vessel which is outfitted with the selective resin necessary for treatment. Anion exchange-treated water is collected at the bottom of the pressure vessel and directed to the clearwells.

As previously mentioned, anion exchange installations are typically located in between the filters and the clearwells. Good engineering practice will ensure the contactor location is coordinated with the existing hydraulic profile to accommodate existing process infrastructure. Ideally, anion exchange treated water would flow by gravity to the clearwells eliminating the need to re-pump the anion exchange effluent. The hydraulic design of the new process must take into account the accumulated headloss across the facility, and piping to and from the facility. Downstream pump hydraulics should also be thoroughly investigated to determine any pumping improvements needed to accommodate the additional headloss imparted by the anion exchange process. Often times, prevailing hydraulic conditions at a facility do not allow for the additional headloss anticipated across a new treatment process. As such, intermediate low lift pumps are commonly required upstream of the new process to provide the additional head needed across the plant.

Additional hydraulic concerns exist in the event that partial treatment practices are implemented at a given WTP. One such constraint involves the means by which filtered water flow is split and controlled between the anion exchange and bypass treatment trains. Flow control valve and meter combinations may be installed for this purpose as well as dedicated pumps and piping to the anion exchange process. Consideration must be given to the splitting and recombination of flows (treated and bypassed) for partial treatment practices.

As noted above, hydraulic challenges also exist when blending anion exchange and bypass treatment train flows together following partial flow treatment through the anion exchange pressure vessels. Unfavorable hydraulic conditions (i.e. flow recirculation) may develop as a result of splitting and controlling the flow as desired between these two trains. A hydraulic break/disconnect (i.e. a weir box structure) or control device (i.e. orifice, valve, etc.) may be required to prevent such issues.

5.2.4.3 Regeneration Waste Disposal

A corrosive waste product is generated as a result of regeneration of anion exchange resin. The quantity of this waste product is directly related to the raw water bromide and DOC concentrations controlling the frequency of resin regeneration. Therefore, waste quantities may vary seasonally as the bromide and DOC concentrations in the raw water changes throughout the year.

As with the MIEX® process, combining this waste product with other residuals streams generated at the WTPs is not typically a recommended practice. Use of more inert salts may potentially be combined with other WTP residuals streams. However, the waste product volume should comprise an insignificant amount of the total residuals volume produced at the WTP. 'Zero discharge' facilities would only recycle the problematic organics or bromide removed by anion exchange back to the head of the WTP. WTPs utilizing a National Pollutant Discharge Elimination System (NPDES) discharge may have difficulty meeting specific constituent limits (i.e. flow, total dissolved solids (TDS), etc.) in the permit.

The same methods and limitations of waste product disposal outlined for the MIEX® process in Section 5.1.3.3 would be applicable to anion exchange.

5.2.5 Impacts on Distribution System Water Quality

Impacts of anion exchange may also extend outward into a utility's distribution system. The chemical conditions of the distribution system are altered as a result of the anion exchange process. Alterations to post-filter chemical dosing practices and composition of the treated water at a WTP present the potential for impacting (positively or negatively) the corrosion of existing distribution system piping infrastructure. The impact of such changes requires thorough investigation to determine the appropriate corrosion control strategy to implement for protection of the distribution system going forward.

Similarly to MIEX®, corrosion control studies should be considered to determine the appropriate corrosion inhibitor chemical and dose to offset any potential detrimental impacts from implementing the anion exchange process. The study can be conducted after the anion exchange is installed to determine the best strategy for protection against corrosion. Again, similarly to MIEX, corrosion control studies may be performed with the same protocol as described in Section 5.1.4 and using a custom-built corrosion study pilot plant as seen in **Figure 5-11** and **Figure 5-12**.

5.2.6 Ease of Construction

The challenges experienced throughout the construction of an anion exchange facility at a WTP site will vary depending on individual site constraints as well as the configuration of the anion exchange units implemented at the WTP. Individual site constraints that may complicate construction activities include, but are not limited to, congested site space, challenging topography, extensive buried infrastructure, rock excavation, and limited site access. The Robert Harris WTP site appears to have sufficient space available for the addition of new process facility in between the filters and the clearwells (see **Figure 5-13**). As noted previously, the existing post-filter chemical application points would have to be relocated with the conceptual layout.

5.2.7 Regulatory Acceptance/Permitting

Anion exchange is a proven advanced treatment technology that may be implemented for the control of DBP formation via organics and/or bromide removal. With Stage 2 DBPR compliance dates quickly approaching, additional anion exchange installations are anticipated at WTPs across the nation. Regulatory acceptance of the anion exchange process by the North Carolina Department of Environment and Natural Resources (NCDENR) is vital to any near term anion exchange designs and construction to ensure the facility is in place in a timely manner to ensure LRAA MCL compliance out in the distribution system.

5.2.8 Regulatory Compliance Constraints

The City of Eden falls under the Schedule 3 compliance schedule for the Stage 2 DBPR. The effectiveness of the anion exchange process should be confirmed through piloting efforts. At this time various resins (and combinations and configurations) may be examined for their removal capabilities of organics and/or bromide. Other competing ions in the filtered water may also be discovered at this time which may reduce the exchange capacity for the targeted anions. This data will prove helpful in determining O&M costs (i.e. regeneration frequency) and selecting the appropriate anionic resins. Such efforts would occur prior to design and construction of a new anion exchange facility with adequate time allotted to conduct these tests.

Table 5-7 summarizes a preliminary schedule for anion exchange piloting, design, and construction tasks for the WTP to ensure compliance in accordance with the established Stage 2 DBPR schedules. The construction completion dates exceed the compliance dates indicated in the table. Yet, NCDENR may grant a system up to an additional 2 years if significant capital improvements are needed to achieve Stage 2 DBPR compliance; dates noted in parentheses indicate the revised compliance dates.

Table 5-7: Stage 2 DBPR Compliance Schedule Constraints

Compliance Date[1]	Pilot Testing Completion Date	Design/Bid Completion Date	Construction Completion Date
October 2013 (October 2015)	August 2013	November 2014	May 2016

1. An additional 2 years may be granted to systems requiring significant capital improvements to ensure compliance with the LRAA MCLs.

5.2.9 Capital and O&M Costs

Both capital and annual O&M cost estimates have been prepared for the implementation of anion exchange at the Robert Harris WTP. Although the WTP has a rated capacity of 21-MGD, given the average daily flows at the WTP, an 11-MGD anion exchange option may be sufficient to address near term plant flows. As such, costs have been prepared for both 11- and 21-MGD capacities.

Construction costs are prepared in 2013 dollars and include pertinent components of construction (civil, mechanical, structural, architectural, electrical, and instrumentation and control). Additionally, the following supplemental costs are accounted for in the preparation of each construction cost estimate:

- 30% Contingency
- 15% Contractor overhead and profit

- 15% Engineering fee

Operation and maintenance costs associated with the anion exchange process include the following components:

- Chemicals – a net increase in cost is anticipated as a result of anion exchange resin and salt usage
- Labor – a net increase in cost associated with daily, monthly, and yearly tasks associated with the monitoring, operation, and maintenance of the anion exchange pressure vessels
- Electrical – a net increase in cost is anticipated due to additional power consumption with anion exchange processes and the potential need for intermediate low lift pumping

Table 5-8 summarizes the capital and annual O&M costs prepared for the different anion exchange facility sizes. These costs are prepared to provide the City of Eden with a conservative estimate of the construction costs and would be refined during preliminary and later final design efforts to reflect site specific design and construction constraints if anion exchange is the selected treatment strategy moving forward. Unit capital and O&M costs have also been prepared for each of the different capacity facilities.

Table 5-8: Anion Exchange Facility Capital Costs Summary

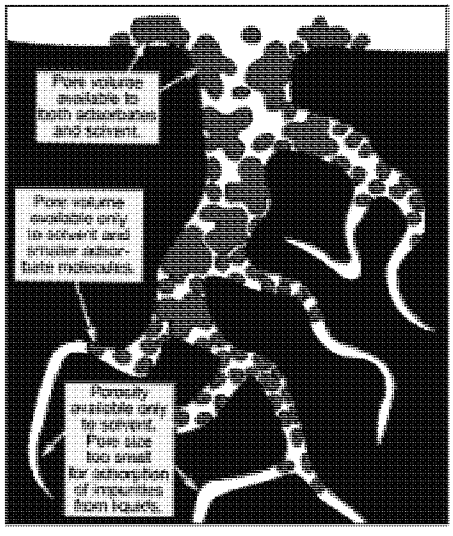
WTP Capacity (MGD)	Anion Exchange Capacity (MGD)	Capital Cost ($)	Annual O&M Cost ($)	Unit O&M Cost ($/1,000 gal)
21	11	$12,257,000	$738,000	$0.34
	21	$23,525,000	$1,402,000	$0.27

5.3 Granular Activated Carbon

5.3.1 Process Description

Granular activated carbon (GAC) is a highly porous material that can remove organic compounds from water via the adsorption process. In adsorption, the organic compounds present in water are attracted and bound to the surface of the pores in GAC particles as the water flows through the GAC media. GAC for drinking water is usually manufactured from bituminous coal by crushing and sizing, followed by processing at low and high temperature furnaces. This heating process is known as "activation" which results in the highly porous structure of the GAC particles. GAC can also be produced from lignite coal, peat, wood and from coconut shells.

The micro pore structure of GAC is shown in **Figure 5-17**. The micro pore structure allows for a very high unit surface area (surface area per unit weight).



[1] Figure is provided courtesy of Norit-Americas

Figure 5-17: GAC Micro Pore Structure[1]

Typical physical properties for bituminous GAC are presented in **Table 5-9**. The pore volume is defined as the pore volume (in mL) in one gram of GAC. The unit surface area is the amount of surface area (in m^2) in one gram of GAC. The bulk density is expressed in units of g/cc and is used to estimate the weight of a certain volume of GAC. Other physical properties include total ash content (which is a measure of mineral content such as calcium, magnesium, silicon, and iron), abrasion or hardness number (which is a measure of the GAC to resist attrition during handling and use), and particle size (expressed in terms of effective size, uniformity coefficient and mesh number range). Adsorption effectiveness is sometimes characterized using Iodine Number, Tannin Value and Molasses Number. These parameters may not always be accurate in predicting the GAC effectiveness for the removal of a particular organic compound.

Table 5-9: Physical Characteristics of Bituminous GAC

Physical Property	Range
Pore Volume	0.7 to 0.8 mL/g
Unit Surface Area	900 to 1,050 m^2/g
Bulk Density	0.45 to 0.50 g/cc

GAC or powdered activated carbon (PAC) is widely used in drinking water treatment. PAC is usually used for the removal of taste and odor (T&O) causing compounds. In some recent cases, PAC has also been used for TOC removal when used in higher doses. In 1986, it was estimated that about 29 percent of the 600 largest public water utilities were using PAC. In recent years, GAC has gained more prominence and use in drinking water treatment for the removal of TOC, T&O compounds and other trace organic compounds.

GAC is commonly used as a post-filter GAC absorber for additional TOC removal. GAC is also used as a filter media (replacing anthracite) in dual-media or mono-medium filters. In other cases, anthracite-sand filters are capped with GAC on the top for the removal of T&O compounds. When GAC is used as filter media along with raw water or intermediate ozonation (usually at ozone doses greater than 1.0 mg/L ozone per mg/L TOC), the GAC filters are converted to biological filters where a biofilm develops on the GAC particles and can remove additional TOC by using the TOC as an energy source. These biological filters can typically remove an additional 10 to 20 percent TOC.

GAC filter media and GAC filter caps are not applicable to the Robert Harris WTP since the raw water has manganese and the WTP currently uses pre-filter chlorine to remove manganese on the anthracite-sand filters. If GAC was used in the filters, it would quench the chlorine residual and the mechanism to remove manganese during filtration would be lost. Biological filtration is not applicable since the WTP does not use raw water or intermediate ozonation. The post-filter GAC filters are the most applicable GAC treatment process for the Robert Harris WTP.

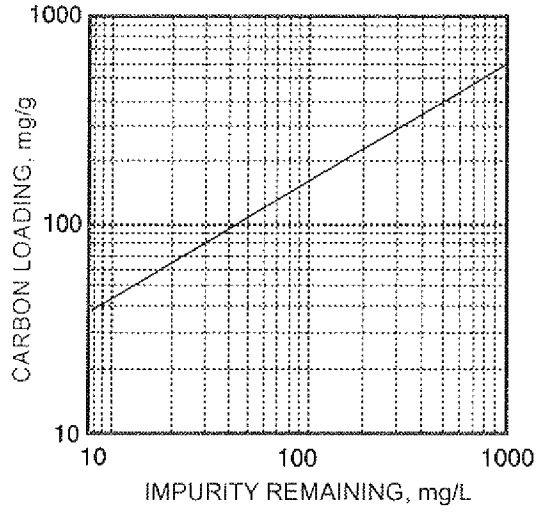
An important aspect of the adsorption process is the quantity of adsorbate (in this case, TOC) that can be adsorbed on the adsorbent (GAC). The equilibrium relationship between the amount of adsorbate per unit adsorbent (q_e) and liquid-phase adsorbate concentration (C_e) is called an adsorption isotherm. The two common adsorption equations are the Freundlich and Langmuir equations. The Freundlich equation is an empirical equation and often accurately describes adsorption data, and is defined as:

$$\mathbf{q_e = KC_e^{1/n}}$$

This equation can be linearized as:

$$\mathbf{Log(q_e) = log(K) + 1/n\ log(C_e)}$$

Figure 5-18 is an example of a Freundlich adsorption isotherm. Factors that affect adsorption include pore surface area, pore size distribution, and surface chemistry.



[1] Figure is provided courtesy of Norit-Americas

Figure 5-18: Example Freundlich Adsorption Isotherm[1]

Typical design parameters for post-filter GAC filters include the empty bed contact time (EBCT), filter surface loading rate, and carbon exhaustion time. The EBCT is defined as the tank volume occupied by the GAC divided by the water flow rate. Typical EBCT values for post-filter GAC filters for TOC removal range from 10 to 20 minutes. The GAC filter surface loading rate is similar to a filter loading rate. Typical GAC filter surface loading rates can vary from 4 to 8 gpm/sf with typical values of 5 to 6 gpm/sf. The carbon exhaustion time is defined as the time when the GAC filter effluent TOC exceeds an operational value (also called breakthrough).

GAC breakthrough curves can be developed for a particular water by running pilot GAC filter columns using full-size GAC media columns. The common practice is to use 12 x 40 U.S. standard mesh (1.68 mm x 0.42 mm) or 8 x 30 mesh (2.38 mm x 0.60 mm) GAC in the filters. The larger size 8 x 30 mesh can be used in deeper beds to remove turbidity and also have longer filter runs. A typical pilot GAC filter column may take 3 months to one year to reach breakthrough for TOC removal purposes. A plot of the column effluent TOC versus time is called a breakthrough curve.

Pilot column testing of GAC for organics and DBP precursor removal was tested at the Robert Harris WTP for a period of five months (from September 2012 to February 2013). The pilot was located in the WTP filter gallery. Six-inch diameter columns were used for this study. The GAC pilot plant was fed using filtered water from the Robert Harris WTP. **Figure 5-19** is a photograph of one of the two column racks in GAC pilot plant used at the Robert Harris WTP. A schematic of the GAC pilot is shown in **Figure 5-20**. The report for the *Granular Activated Carbon (GAC) Pilot Study at the Robert A. Harris Water Treatment Plant* is included in **Appendix B**.

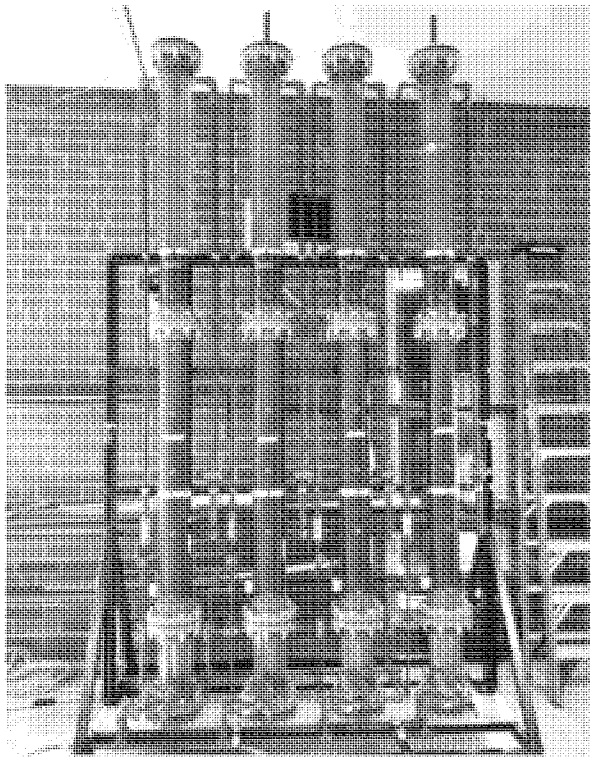


Figure 5-19: Photograph of the GAC Pilot Plant (Filters 5 through 8)

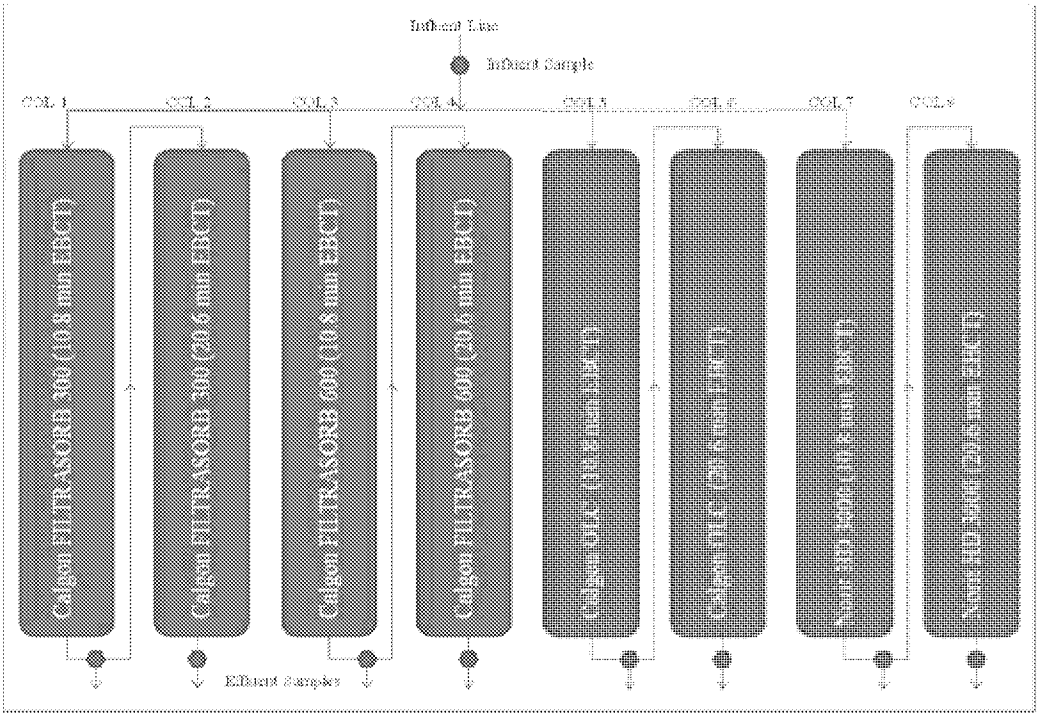


Figure 5-20: GAC Pilot Plant Flow Schematic

When there is not sufficient time to run the GAC pilot filter columns to breakthrough, a rapid small scale column test (RSSCT) can be run (usually, in less than a month) to determine the breakthrough curve. The full-size GAC is ground to a smaller size and packed in smaller diameter columns to run the RSSCTs. **Figure 5-21** represents a bench-top RSSCT column apparatus.

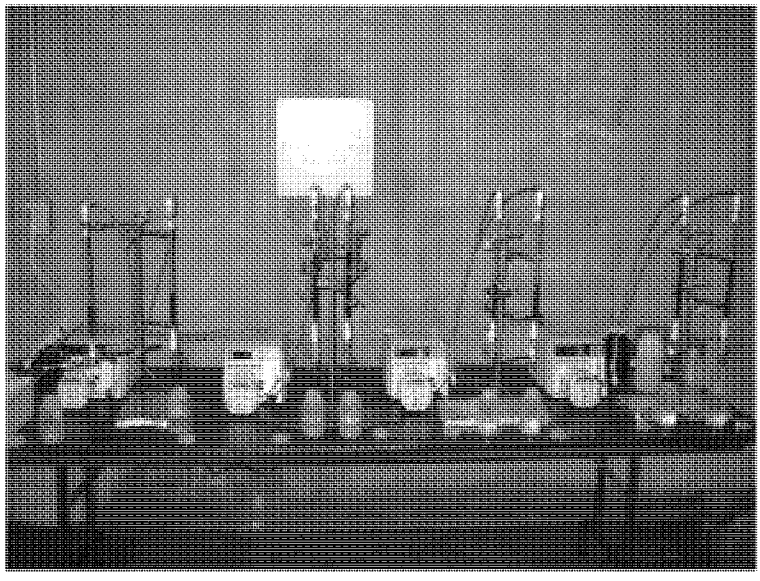


Figure 5-21: RSSCT Columns at Clermont County, Ohio's Bob McEwen WTP

Post-filter GAC filters can be designed either as steel tanks operated in pressure mode, or as concrete filter boxes operated in gravity mode (similar to dual-media filters). The steel tanks are usually used for smaller treatment capacities (less than 10- to 15-MGD capacity), and the concrete filter boxes are more cost effective at higher flow rates (greater than 15-MGD capacity). Concrete filter boxes were laid out for the Robert Harris WTP.

5.3.2 Conceptual GAC Filter Design

A DBP treatment goal has been identified to evaluate the implementation of GAC at the Robert Harris WTP. This goal requires that LRAA DBP measurements at all Stage 2 DBPR monitoring sites be less than 80 percent of their respective MCLs (64 ppb for TTHMs and 48 ppb for HAA5s). Limiting DBP formation to this conservative level is considered sufficient to achieve safe compliance with the Stage 2 DBPR.

Since the GAC filters will be located downstream of the WTP's conventional, dual media filters, the filtered water TOC data for the Robert Harris WTP was analyzed in order to develop design criteria for the GAC filters. The filtered water TOC data is summarized in **Table 5-10**.

Table 5-10: Summary of Filtered Water TOC for the Robert Harris WTP

Date Range	Filtered Water TOC (mg/L)				
	Min	Avg	Max	95-%ile	99-%ile
01/07 – 5/12	0.70	1.30	4.80	1.83	3.78

A preliminary GAC filter facility design was developed for the Robert Harris WTP with concrete basin filter beds. The design is expandable from 11-MGD to 21-MGD. Given the selected filter bed dimensions and media depth, at 11-MGD, and 21-MGD an EBCT of 16.4 minutes and 14.4 minutes is achieved respectively. These EBCTs were chosen as an approximate average between the EBCTs are being tested in the pilot plant. **Table 5-11** summarizes the number of filters required for the WTP, design EBCT, and GAC exhaustion times. The GAC pilot study determined the GAC exhaustion times and the corresponding exchange frequencies.

Table 5-11: Preliminary Design of the GAC Filters at the Robert Harris WTP

Facility Capacity (MGD)	Annual Average Flow (MGD)	Empty Bed Contact Time (min)	Number of Filters	GAC Exhaustion Time (mos)
11	6	16.4	6	5.0
21	14	14.4	10	5.0

5.3.3 Effectiveness for DBP Reduction

The effectiveness of a post-filter GAC adsorption process is a function of many factors and as a result is site-specific. GAC is typically effective not only in removing TOC, but also T&O causing compounds, trace and synthetic organic compounds, pesticides and herbicides, and emerging contaminants such as endocrine disrupting compounds (EDCs) and pharmaceutical and personal care products (PPCPs). The ability of GAC to remove a wide variety of organic compounds makes it an attractive option as an additional treatment step. However, despite this benefit, there is the potential trade-off in the exhaustion rate of the media particularly if the filtered water contains notable quantities of these other compounds that will compete for the adsorptive sites on the media.

The effectiveness of GAC adsorption for Stage 2 DBPR compliance has been evaluated thoroughly in the GAC pilot column study conducted at the Robert Harris WTP (**see Appendix B**) for complete results and discussion. The GAC pilot study was conducted from September 2012 to February 2013 consisting of eight 6-inch columns. Four types of GAC are being tested at two different empty bed contact times (EBCTs): 10 and 20 minutes. Columns 1 and 2 contain Calgon Fitrasorb 300-M. Columns 3 and 4 contain Calgon Fitrasorb 600. Columns 5 and 6 contain Calgon OLC 12x30. Columns 7 and 8 contain Norit Hydrodarco 3000. The Calgon Filtrasorb 300-M and 600 are bituminous coal carbons. The Calgon OLC

12x30 is a coconut shell based carbon. The Norit Hydrodarco 3000 is a lignite coal carbon. Each column provides 10 minutes of EBCT. Effluent from the first column of each carbon passes through the second column to achieve the 20 minute EBCT.

The pilot plant has proven the effectiveness of GAC at the Harris WTP. The Calgon Filtrasorb 300-M and Norit Hydrodarco 3000 have outperformed the other carbons based on TOC breakthrough and 10-day simulated distribution system TTHM testing. **Figure 5-22** shows the normalized TOC concentrations for each column over time. A value of 1.0 on the y-axis indicates no TOC removal. This figure shows the steady increase in TOC breakthrough over time. As expected, columns with 20 minute EBCTs outperform their 10 minute EBCT counterparts. **Figure 5-23** shows TTHM concentrations after the effluents have been held for 10 days. This test simulates DBP formation in the distribution system. The 300-M and 3000 columns (1, 2, 7 and 8) a performed best in this respect as well, significantly limiting TTHM formation below the 80ppb MCL at 10-day simulated water age in the distribution system.

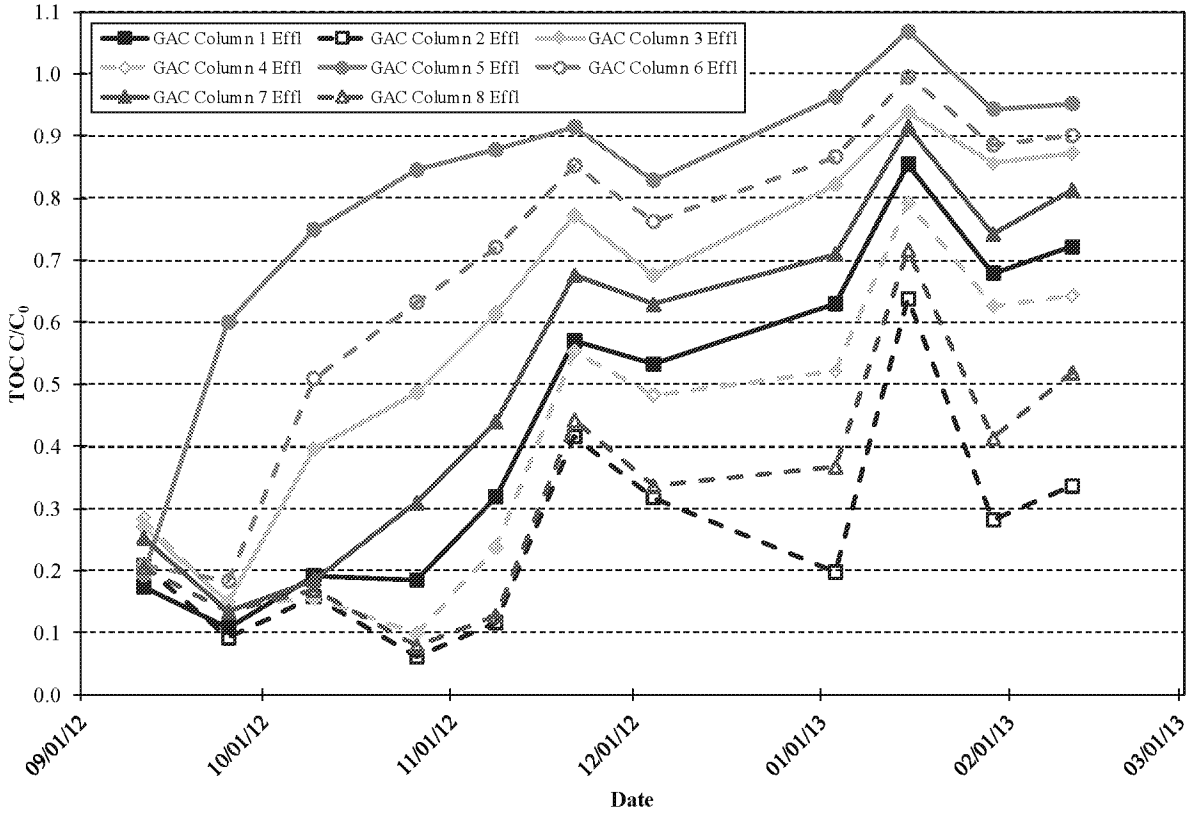


Figure 5-22: GAC Pilot Plant Results – Total Organic Carbon

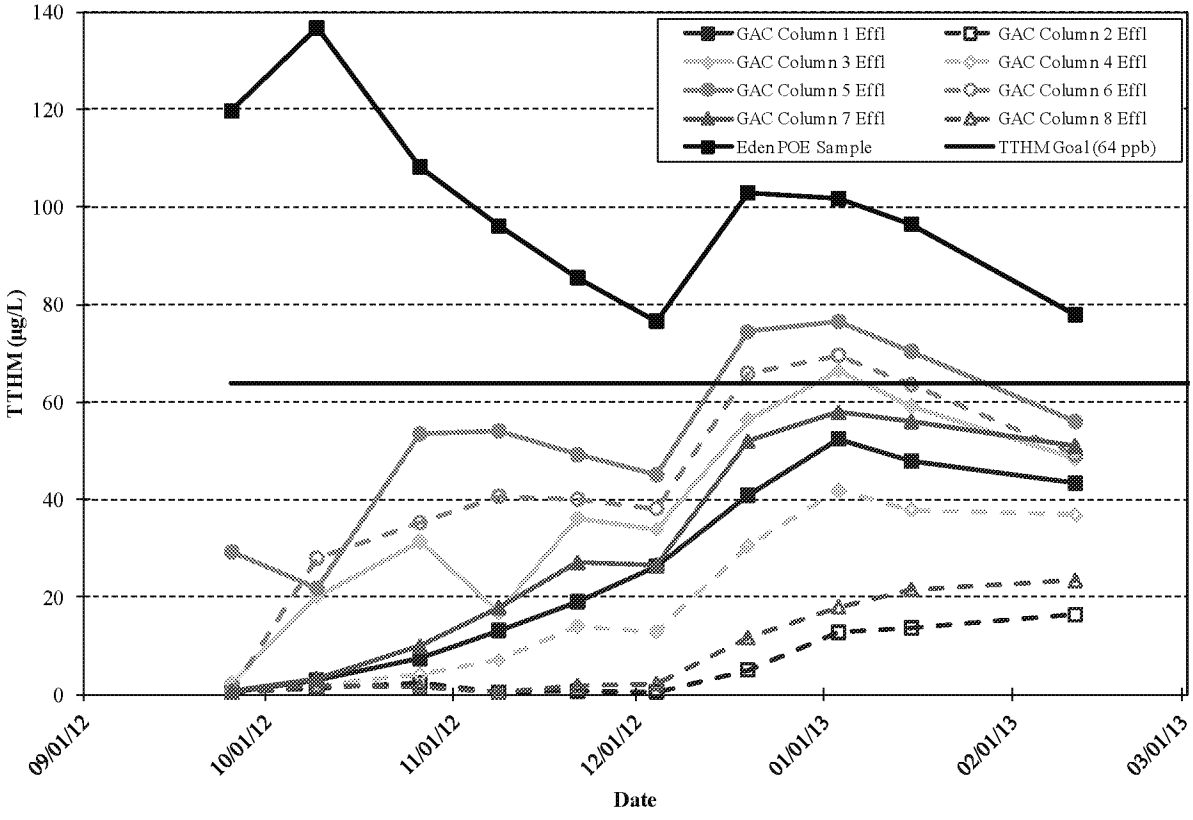


Figure 5-23: GAC Pilot Plant Results: 10-day SDS TTHMs

Capital cost and annual O&M cost for GAC filters can be high; depending on the filtered water TOC (GAC filter influent TOC) and desired GAC filter effluent TOC, the GAC media can be exhausted quickly (three months to a year). When exhausted, the GAC must be replaced with either new, virgin GAC or with custom-regenerated GAC (by only using spent GAC from municipal facilities only). This may increase the GAC regeneration cost slightly. Although a possibility, most GAC is not regenerated on-site, but is usually shipped to a central regeneration facility. As such, transportation costs should be considered in the overall GAC regeneration expense. **Table 5-12** lists the advantages and disadvantages of GAC adsorption, compared to other advanced technologies.

Table 5-12: GAC Advantages and Disadvantages

Advantages	Disadvantages
• Excellent DOC removal; provides the ability to comply with the Stage 2 DBPR • Also removes T&O compounds, synthetic and trace organics, and emerging contaminants such as EDCs and PPCPs • Ease to operate • Provides the option to stay with free chlorine residual in the distribution system • Low backwash usage; Since the GAC filters are downstream of the filters, they need to be backwashed once every 15 to 30 days • Reduced filter footprint; can be operated at higher loading rates of 6 to 8 gpm/sqft	• Higher capital costs • High annual O&M costs due to carbon regeneration and transport to centralized regeneration facilities • Potentially requires an intermediate, low lift pump station ahead of the GAC process to accommodate hydraulic restrictions • Carbon regeneration requires removal of spent carbon and filling of regenerated GAC. This can be contracted to the GAC supplier, but usually at an additional cost.

5.3.4 Impacts on Existing WTP Operations

5.3.4.1 Site Constraints

The GAC adsorption process (for TOC removal) is typically implemented after the filtration process to maximize the GAC exhaustion times and prevent media plugging by particulates that may reduce access to adsorption sites (see **Figure 5-24**). GAC effluent would then proceed to the plant's clearwells from where finished water is pumped to the City of Eden distribution system using vertical turbine pumps.

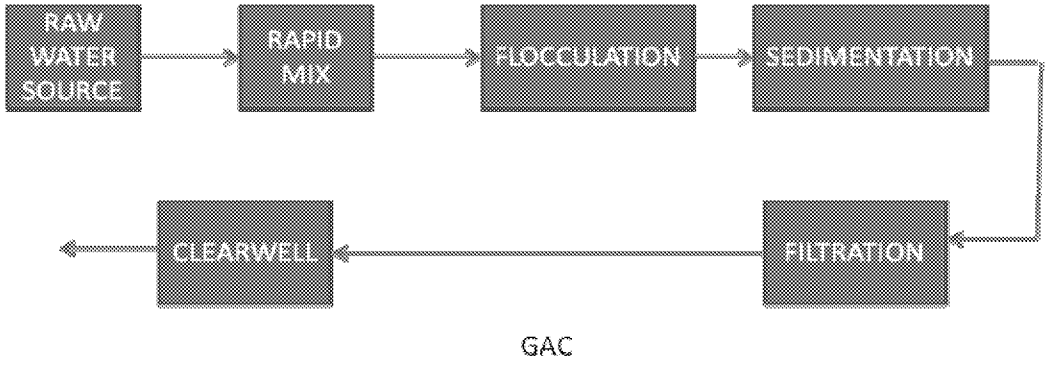


Figure 5-24: Typical Location of GAC Filtration Facility

The conceptual design of the GAC facilities includes an intermediate, low lift pump station ahead of the GAC filters. GAC filtration may require as much as 20 feet of hydraulic head which is not available in the existing hydraulic profile of the Robert Harris WTP. The common filtered water pipe will be routed to the new pump station and then onto the GAC filters using vertical turbine pumps hanging in a concrete wetwell. The effluent from the GAC filters will be routed to the existing clearwells so that the existing finished water pumps can be used to pump to the distribution systems. The GAC influent pump station and the GAC filters will be located inside the same complex.

A conceptual 21-MGD GAC filter facility layout for the Robert Harris WTP is shown in **Figure 5-25**.

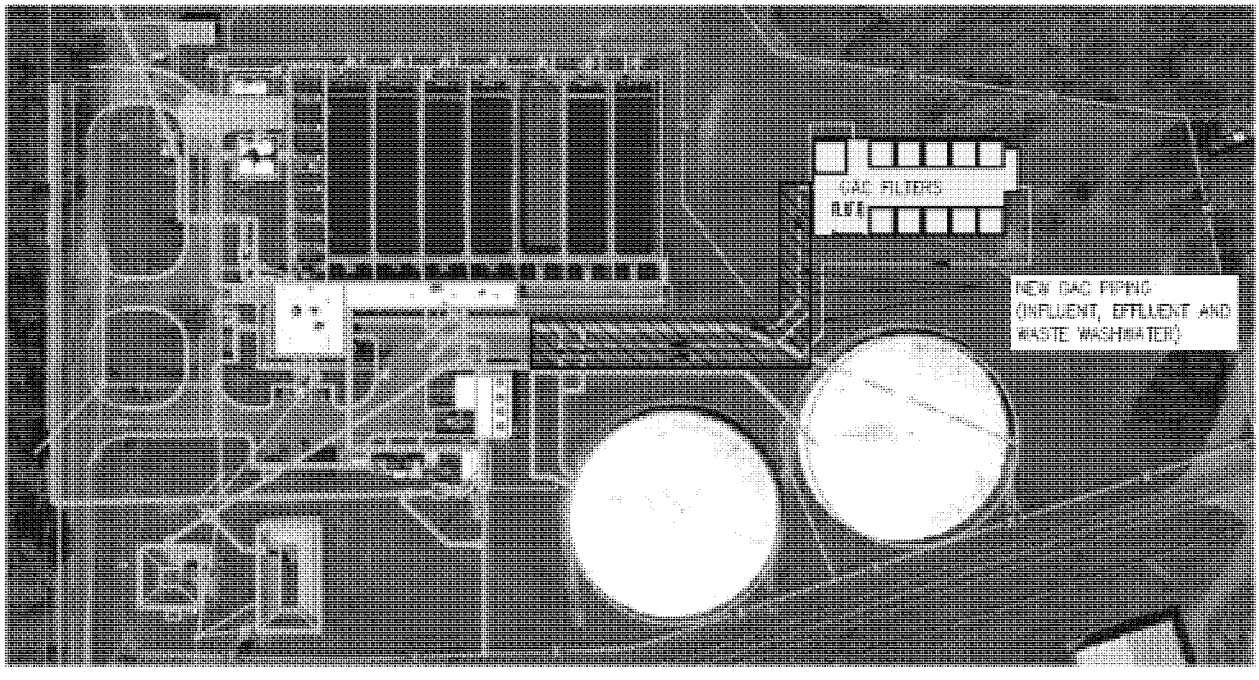


Figure 5-25: Conceptual GAC Filtration Facility Layout

For conservative WTP site space allotment, the installation layout was prepared for the larger capacity – requiring the greater number of filters and, consequently, the larger footprint. Facility design at the smaller capacity (11-MGD) would result in a smaller facility footprint. Accommodations to expand the facility to a capacity of 21-MGD would be implemented in the smaller capacity facility design. The GAC filter facility consists of the following major components:

- GAC Filters and Pipe Gallery – consists of ten 20-foot by 17.5-foot concrete filter basins, influent piping from the pump station, effluent piping to the finished water clearwell, and backwash supply and drain piping. Additional space has been allotted for storage.

- GAC Intermediate Pump Station – The pump station is incorporated in the filter building design consisting of a wetwell and vertical turbine pumps to provide the additional hydraulic head required by the GAC filters.

5.3.4.2 Hydraulic Constraints

Filtered water from the existing conventional, dual-media filters will flow by gravity to the GAC influent pump station. GAC influent pumps will be used to pump water to the top of the GAC filters. Headloss is experienced through the GAC filters as with conventional dual-media filters (i.e. media and under drain losses). The GAC filters will be backwashed as the media compresses and headloss accumulates across the media. Backwashing will remove fines and "fluff" GAC media that has been compressed by the forward, downward acting flow over the filter bed. The existing finished water pumps will then pump from the finished clearwell(s) to the distribution system. As previously noted, many plants do not have the available head across the plant's existing hydraulic profile to accommodate the headloss experienced across the GAC filters. The Robert Harris WTP is no exception requiring intermediate, low lift pumps to address this concern.

5.3.4.3 GAC Waste Backwash Disposal

The GAC filters are expected to require backwashing once every 15 to 30 days. The backwash waste remaining is expected to have some TOC as well as turbidity since the GAC filters may remove some of the remaining filtered water turbidity. In general, the GAC backwash waste is expected to be similar to or better than the conventional dual media filter backwash quality and can be blended with the rest of the WTP residual streams in the on-site equalization basins. New drain piping is needed to accommodate this new waste flow at the WTP.

5.3.5 Impacts on Distribution System Water Quality

The addition of post-filter GAC filters at the Robert Harris WTP is expected to have some impacts on the distribution system water quality in the Eden system. The additional removal of TOC can make the water more corrosive. The corrosion inhibitor dose may need to be increased after the GAC filters are put into service in order to re-passivate the system and minimize any elevated lead and copper levels in the distribution system. Alternatively, the City of Eden may choose to conduct a corrosion control study to determine the optimal corrosion inhibitor type and dose. Hazen and Sawyer has completed several corrosion control studies over the past several years using custom-built corrosion pilot plants where up to five corrosion inhibitor chemicals can be tested (see discussion from Section 5.1.4 above).

5.3.6 Ease of Construction

Site constraints that may complicate construction activities include, but are not limited to, congested site space, difficult topography, extensive buried infrastructure, and limited site access. Sufficient open field space appears available for the location of a new GAC filter facility east of the existing treatment plant and north of the existing clearwells (see **Figure 5-24**). A paved extension of the existing access road would allow WTP staff vehicular access to the new filter complex. Post-filter chemical feed points will be relocated downstream of the GAC filter facility to prevent any interference between the intended use of the chemicals and the adsorption process. As an example, chlorine is commonly added to the filtered water for disinfection purposes. Yet, leaving the current application point in place will result in the adsorption of this chemical on the GAC media. To prevent excessive feed of chlorine, it is best to relocate the chlorine feed point downstream of the GAC adsorption process.

5.3.7 Regulatory Acceptance/Permitting

GAC is a proven advanced treatment technology that is effective for the removal of TOC, and also provides a treatment barrier for T&O compounds, synthetic and trace organics, and emerging contaminants. Several Midwestern utilities have installed GAC facilities to protect against synthetic and trace organics and for TOC removal. The Greater Cincinnati Water Works (GCWW) in Cincinnati, Ohio has been using GAC contactors and on-site GAC regeneration since 1992. Additionally, a post-filtration GAC facility has been implemented for Clermont County, Ohio's Bob McEwen WTP for TOC removal purposes.

As noted earlier in Section 2, the EPA identifies GAC adsorption as one of the best available technologies (BATs) to implement at a WTP to ensure Stage 2 DBPR compliance. Therefore, it is expected that NCDENR will approve the use of GAC adsorption for compliance purposes at the Robert Harris WTP.

5.3.8 Regulatory Compliance Constraints

The distribution system of the City of Eden falls under the Stage 2 DBPR compliance schedule 3, based on the population served by the system. Prior to detailed design of the GAC facilities, design parameters for the GAC adsorption process such as GAC size, EBCT and GAC exhaustion times should be confirmed from the study performed at the Robert Harris WTP.

Table 5-13 is a summary of the preliminary schedule for piloting, design and construction of a new GAC filter facility at the Robert Harris WTP. As it stands now, this schedule is just shy of meeting the extended compliance deadlines established by the Stage 2 DBPR. At its discretion, NCDENR may grant a system up to an additional 2 years if significant capital improvements are needed to achieve regulatory compliance.

If the City of Eden chooses to move forward with GAC adsorption, it is strongly recommended that a meeting with NCDENR is scheduled to ensure that the 2-year extension will be granted. The date noted in parentheses in **Table 5-13** indicates the revised compliance date based on a granted 2-year extension.

Table 5-13: Stage 2 D/DBP Rule Compliance Schedule for the GAC Process

Monitoring Compliance Date[1]	Pilot Testing Completion Date	Design/Bid Completion Date	Construction Completion Date
October 2013 (October 2015)	February 2013	June 2014	November 2015

1. An additional 2 years may be granted to systems requiring significant capital improvements to ensure compliance with the LRAA MCLs.

5.3.9 Capital and O&M Costs

Both capital and annual O&M costs have been prepared for the implementation of the post-filtration GAC filter facility at the Robert Harris WTP. The plant is currently rated at 21-MGD; however, most recently daily flows have rarely exceed 11-MGD and average closer to 6-MGD. Therefore, GAC capital and O&M costs have been prepared for both 11-MGD and 21-MGD capacity GAC filtration facilities.

Construction costs were prepared in 2013 dollars and included all civil (i.e. site), mechanical (i.e. equipment), building, electrical and instrumentation and control components associated with the construction of GAC facilities at the Robert Harris WTP. Additionally, the following supplemental costs were included in the preparation of each construction cost estimate:

- 30% Contingency
- 15% Contractor overhead and profit
- 15% Engineering fee

Table 5-14 summarizes the GAC capital and O&M costs prepared for the Robert Harris WTP. These costs were prepared to provide a conservative estimate of the construction costs and should be refined during preliminary and final design efforts.

Annual O&M costs associated with the GAC process included the following components:

- GAC regeneration or replacement cost – The GAC replacement costs were based on annual GAC usage rates and a unit GAC replacement cost of $1.40/lb (provided by Calgon Carbon, Inc. including all transportation and handling costs during removal of spent GAC and delivery of fresh GAC). This unit GAC replacement cost may be slightly conservative. It was assumed, based on the GAC pilot that the carbon will be changed out every 5 months.

- Energy cost – Much of the energy cost is attributed to intermediate pump operations providing 20 feet of head at average flow conditions (6-MGD and 14-MGD for plant capacities of 11 and 21-MGD, respectively).
- Labor cost – The labor cost was estimated based on labor hours per day and a unit labor rate of $37.50 per hour (accounting for wages and benefits).

Table 5-14: GAC Facility Capital Costs for the Robert Harris WTP

GAC Treatment Capacity (mgd)	GAC Capital Cost ($)	Unit GAC Capital Cost ($/gpd)	GAC Annual O&M Cost ($)	Unit GAC Annual O&M Cost ($/1,000 gal)
11	7,580,000	0.69	1,622,000	0.74
21	14,470,000	0.69	3,062,000	0.60

5.3.10 Considerations for the Robert Harris WTP

The GAC adsorption process is well-suited for the Robert Harris WTP and thus a viable advanced technology candidate. GAC can be effective in reducing finished water TOC so that the DBP levels in the distribution systems are low, ensuring safe compliance with the Stage 2 DBPR. Specific GAC medias can also very effectively remove DBPs that may form upstream of the adsorption process.

Some of the considerations in evaluating GAC against other advanced treatment technologies include that GAC adsorption:

- Can reduce TOC in the finished water to safe Stage 2 D/DBP Rule compliance levels
- Can also remove T&O causing compounds such as MIB and geosmin
- Can remove trace and synthetic organic compounds, and some of the emerging contaminants such as EDCs and PPCPs
- Operation is similar to filter operation so additional operator training is minimal
- Has higher capital costs and high annual O&M costs that must be budgeted for appropriately.

6 ALTERNATE WATER SUPPLY SOURCE – SMITH RIVER

6.1 Description

The Smith River flows from the Phillpott Reservoir in southwest Virginia to the City of Eden. The Smith River bisects the City, flowing from north to south to its confluence with the Dan River. Key features of the Smith River in the vicinity of Eden include the Spray Dam and Barnett Canal, which are associated with the historic Spray Cotton Mills textile manufacturing facility. Also, there is the historic Fieldcrest Mills water supply intake at the Church Street / Highway 770 bridge crossing, which has been abandoned. The Spray Dam is a low-head run-of-river dam that is used to divert flow to the Barnett Canal in order to supply a hydroelectric power installation located at the historic Spray Cotton Mills. Historically, the hydroelectric plant was used to provide power for operations at Spray Cotton Mills, however it is understood that the hydroelectric facilities are currently operated independently. The Smith River is classified as WS-IV from the state line to the Fieldcrest Mills intake indicating that this water supply may be used as a raw water source for drinking water treatment. **Figure 6-1** is a vicinity map of the Smith River in Eden, NC.

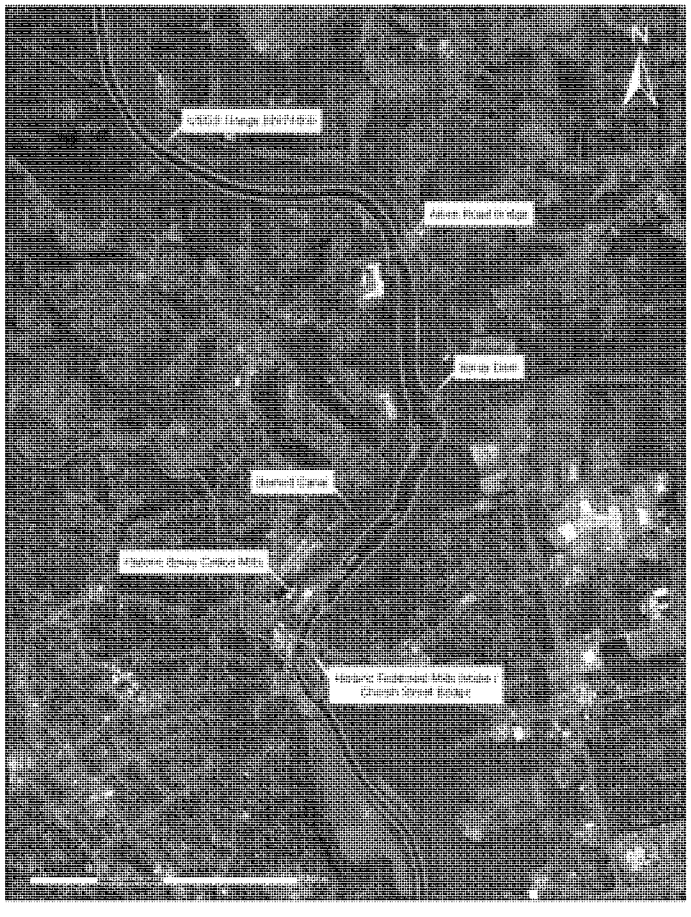


Figure 6-1: Smith River in the Vicinity of Eden, NC

A raw water quality monitoring plan was developed in two phases and the City began collecting samples from the Smith River in 2012. Phase 1 of the water quality monitoring plan consisted of biweekly and monthly sampling events, beginning in July 2012. The parameters included in Phase 1 are shown in **Table 6-1.**

Table 6-1: Water Quality Monitoring Plan – Phase 1

Parameter	Biweekly	Monthly
Alkalinity	X	
Bromide	X	
Chloride	X	
Color	X	
Conductivity	X	
Dissolved Organic Carbon	X	
Dissolved Oxygen	X	
Fluoride		X
Hardness	X	
pH	X	
Temperature	X	
Total Dissolved Solids	X	
Total Suspended Solids	X	
Turbidity	X	
Fecal Coliform and E. coli		X
Total Coliforms		X
Manganese		X
Iron		X

Phase 2 of the water quality monitoring plan is on-going monitored the same parameters as Phase 1 but also including radionuclides, inorganics (metals and nutrients), and organics consisting of volatile organic compounds (VOCs), synthetic organic compounds (SOCs) and pesticides. Radionuclides are sampled on an annual basis, while the majority of metals and nutrients are sampled monthly. VOCs are sampled quarterly, and SOCs and pesticides will be sampled in the spring. Preliminary indications of raw water quality in the Smith River, provided below in **Table 6-2**, are favorable as an alternative raw water supply. The Smith River exhibits similar water quality characteristics to the Dan River in terms of turbidity, TOC, alkalinity, and color. However, concentrations of bromide and chloride are much lower in the Smith River. The Smith River does have higher concentrations of total coliforms and higher pH than the Dan River.

Table 6-2: Comparison of Dan River and Smith River Water Quality

Constituent	Dan River[1]	Smith River[2]
Bromide (mg/L)	139 - 433	9.4 - 16.2
Chloride (mg/L)	27 - 43	ND - 8.8
TOC (mg/L)	1.6 - 2.0	1.6 - 2.6
Alkalinity (mg/L as $CaCO_3$)	25 - 30	24 - 31.9
Color	13 - 71	15 - 46
Total Coliforms (# per 100 mL)	20 - 1,400	241.4 - >2419.6
pH	6.9 - 7.3	7.1 - 8.9

1. Data collected from plant monthly operating reports.
2. Data collected at the raw water source beginning in July 2012.

Elevated total coliform counts observed for the Smith River may be attributed to the primarily agricultural land use and stormwater runoff in the watershed. It is understood that upstream water systems are classified as Bin 1 for source water Cryptosporidium levels according to the Long-Term 2 Enhanced Surface Water Treatment Rule, which is also a promising indication for developing the Smith River as an alternative water supply.

The City of Eden is an active participant in the Piedmont Triad Regional Council - Eden Area Watershed Restoration Plan, which is a multi-stakeholder group charged with developing a local watershed plan for the Smith and Dan Rivers in the vicinity of Eden in order to identify sources of pollution and ways to restore these waters to ecological supporting status. Currently, the Smith River is listed as impaired for aquatic life from the North Carolina-Virginia State Line downstream to the Fieldcrest Mills water supply intake due to copper and biological habitat degradation. Meeting notes from the watershed restoration effort tend to indicate that the presence of heavy metals, specifically copper, in the Smith River may be a concern in terms of ecological/biological integrity, which is consistent with historic industrial / mining operations in the watershed. Hence, the presence of copper and other heavy metals is suspected in the sediments collected behind Spray Dam. However, this stretch of river is classified as WS-IV which is favorable for water supply development.

6.2 Bench-Scale Testing for Smith River Water

6.2.1 Bench-Scale Testing Procedures

Bench-scale testing was conducted on site at the Robert Harris Water Treatment Plant using the Hazen and Sawyer mobile laboratory trailer. A Phipps and Bird 6-gang mixer, with 2-liter square jars was used to evaluate alternative coagulant treatment strategies. TTHMs, HAAs, and TOC samples were collected and forwarded to James R. Reed Laboratories, Newport News, VA., for analysis. All other testing was performed on-site by Hazen and Sawyer staff.

The first step in the bench-scale test procedures was to establish a calibration between the full-scale plant and the bench scale testing procedures. Plant staff currently conduct bench-scale jar testing on a routine basis and bench-scale testing procedures are modified when changes in plant flow rate and/or flocculation speeds occur. Data collected from the full-scale plant to establish this calibration included:

- Chemical dosages and application points
- Plant flow rates
- Basin surface areas and volumes

Typically, rapid mix and flocculation times used in jar testing are equal to full-scale counter-parts. Jar test rapid mix and flocculation energies can be found by trial and error and should match the energy inputs in the full-scale plant. Bench-scale settling time is based on the full-scale surface area loading rate. To establish similitude between the 2-liter jar and the full-scale basin loading rates, the following equation is used:

(Settling rate in cm/min)(1 ft/30.48 cm)(1440 min/day)(7.48 gal/cf) = gpd/sf

The sampling tap in each jar is fixed 10 cm below the surface of the water. The calculated settling rate is found by setting the equation equal to the basin loading rate and solving for minutes. Based on the plant flow of 10 MGD during the bench-scale testing, the sedimentation basin loading rate is 316 gpd/sf and the calculated settling rate is 11 minutes.

By using the same chemicals and doses as the full-scale plant, jar tests 1-1 through 1-4 produced results that approximated full-scale settled water parameters (**Table 6-3**).

Mixing times and energies selected to simulate the full-scale plant at a flow rate of 10 MGD are presented in **Table 6-4**.

Table 6-3: Bench Scale Test Calibration

Chemical Dose (mg/L)	Full-Scale Plant 9/10/12	Jar 1-1	Jar 1-2	Jar 1-3	Jar 1-4
Alum	20	20	20	20	20
Poly 321 TR	0.05	0.05	-	0.05	0.05
pH (Units)	5.94	6.04	6.05	5.96	5.95
Filtered UV-254 (1/cm)	0.020	0.022	0.020	0.018	0.019
Temperature (^{0}C)	24.4	-	-	-	-
Alkalinity (mg/L)	10	11	11	10	10
Turbidity (NTU)	0.53	1.86	1.29	1.09	0.76

Table 6-4: Jar Test Parameters at 10 MGD

Treatment Stage	Mixing	Jar 1-1	Jar 1-2	Jar 1-3	Jar 1-4
Rapid Mix	RPM	100	100	100	100
	Duration (sec)	120	120	120	120
1st Stage Flocculation	RPM	20	15	15	20
	Duration (min)	16	16	16	16
2nd Stage Flocculation	RPM	18	15	15	12
	Duration (min)	16	16	16	32
3rd Stage Flocculation	RPM	15	12	12	-
	Duration (min)	16	16	16	-
Settling Time (min)		11	11	11	11

As shown in **Table 6-4**, one, two, and three-stage flocculation at various mixing energies were evaluated. Based on a comparison of the jar test results presented in **Table 6-3**, Jar 1-4 achieved the lowest turbidity which was closest to the plant results. The mixing energy strategy used for Jar 1-4 was selected, using two-stage flocculation, based on a performance comparison of the different mixing strategies. These jar test procedures were used for all bench-scale testing.

6.2.2 Smith River Raw Water Quality

Raw water from the Smith River was analyzed to determine basic water quality parameters at the time of bench-scale testing (**Table 6-5**).

Table 6-5: Smith River Water Quality

Analysis	9/13/12	9/14/12
pH (units)	7.09	6.94
UV-254 (1/cm)	0.051	0.036
Turbidity (NTU)	11.8	10.6
Alkalinity (mg/L)	28	28
Temperature (°C)	20.3	20.7

UV_{254} and turbidity values are significantly lower in the Smith River as compared to the water quality results from the Dan River (see **Table 4-6**).

6.2.3 Coagulant Screening

To determine Smith River treatability, three primary coagulants were evaluated: aluminum sulfate, ferric sulfate, and polyaluminum chloride (DelPac 1525). Settled water turbidity results from these four primary coagulants are presented for comparison in **Figure 6-2**.

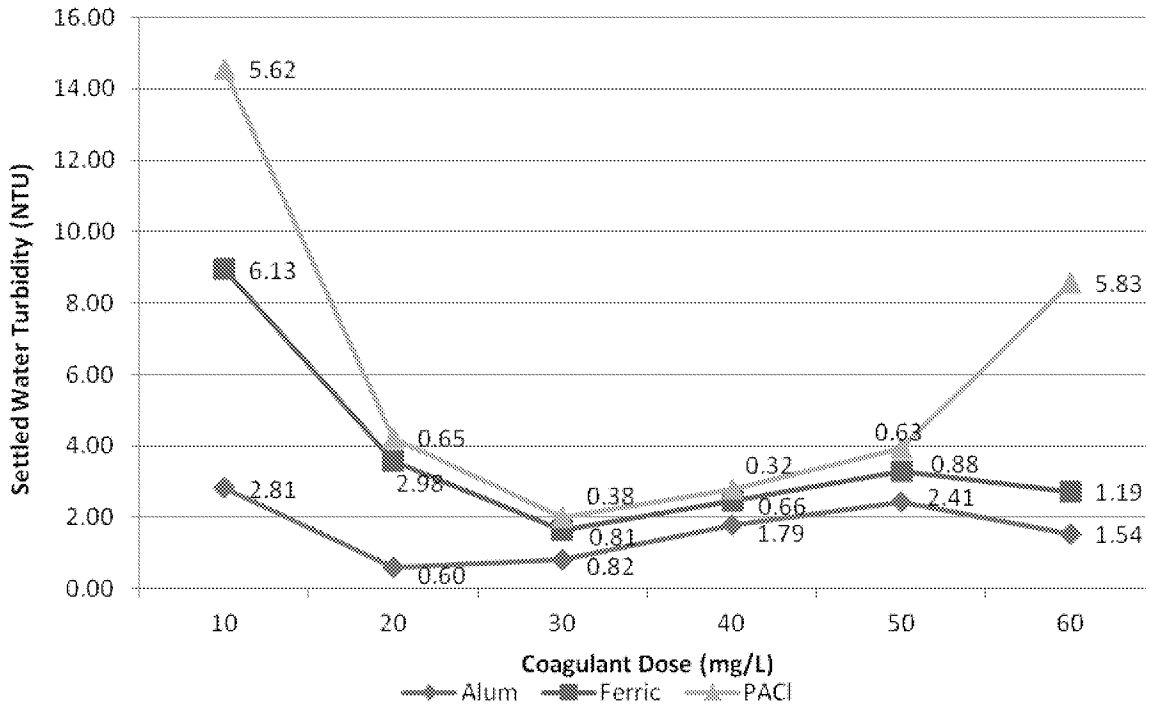


Figure 6-2: Smith River - Primary Coagulant Settled Water Turbidity

The settled water turbidity values presented in **Figure 6-2** were obtained without any polymer addition. Polymer addition may further improve settled water turbidity performance. All the coagulants provided similar settled water turbidity values at 20 to 40 mg/L doses.

Samples were also collected and analyzed to determine UV_{254} and are presented in **Figure 6-3**.

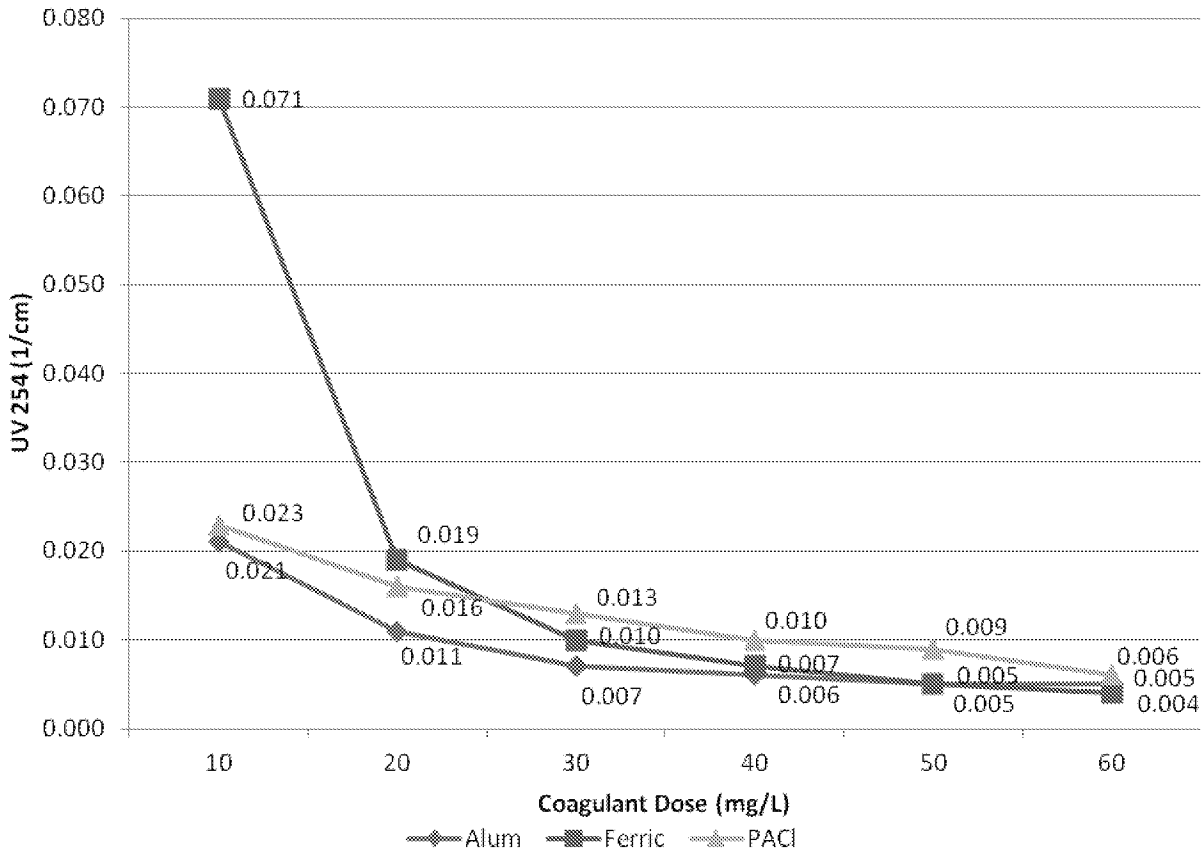


Figure 6-3: Smith River - Primary Coagulant UV Absorbance

All coagulants provided similar UV_{254} reductions. Therefore, any of the coagulants tested could be effective for coagulation and DOC removal with Smith River water based on this test data.

Smith River water was also tested with various PAC doses followed by alum coagulation at a dose of 20 mg/L. Calgon WPH was the PAC tested and a contact time of 30 minutes was used prior to coagulation. The settled water turbidity and UV_{254} results are presented in **Figure 6-4**. PAC doses greater than 20 mg/L were necessary to observe DOC removal higher than with alum and no PAC added. A PAC dose of 50 mg/L followed by alum coagulation at 20 mg/L resulted in low settled water UV_{254}, similar to that with alum coagulation at a dose of 50 mg/L.

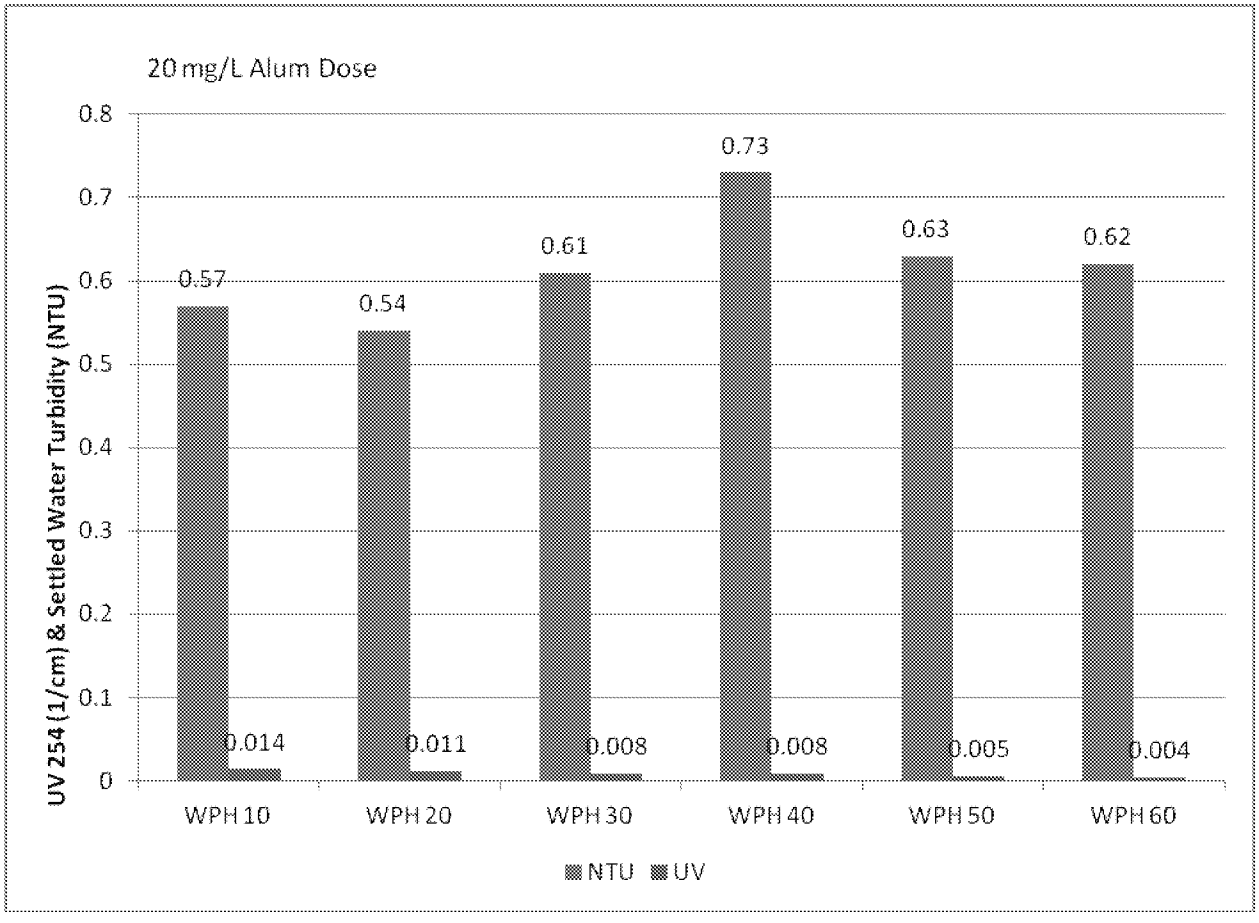


Figure 6-4: Smith River – Alum and Calgon WPH

Water from the Smith River jar tests were used to conduct SDS testing using free chlorine. SDS test conditions are summarized in **Table 6-6**.

Table 6-6: Smith River Free Chlorine DBP Sample Preparation

ID	Time	Treatment Strategy	Chlorine Dose mg/L	Caustic Dose mg/L	pH	Free Cl Residual @15 hrs
13-1	5:15 PM	30 Alum	3.5	3	7.28	3.42
13-2	5:30 PM	40 Ferric	3.5	4	7.38	3.12
13-3	5:45 PM	40 PACl	3.5	3	7.4	2.96

The SDS-DBP results for the Smith River using free chlorine are presented in **Figure 6-5**. Ferric sulfate resulted in the lowest TOC, TTHM and THAA concentrations. Coagulation with either alum or PACl resulted in DBPs below the MCL, but had TTHMs above the water quality goal of 64 ppb (80 percent of the MCL). Based on these preliminary results and low levels of TOC and turbidity, it appears that the Smith River may be feasible as an alternate water supply for the City of Eden, and the low levels of bromide may allow the City to meet the Stage 2 DBPR requirements. Additional water quality monitoring and testing on the Smith River is needed to determine the impact of seasonal water quality values and changes.

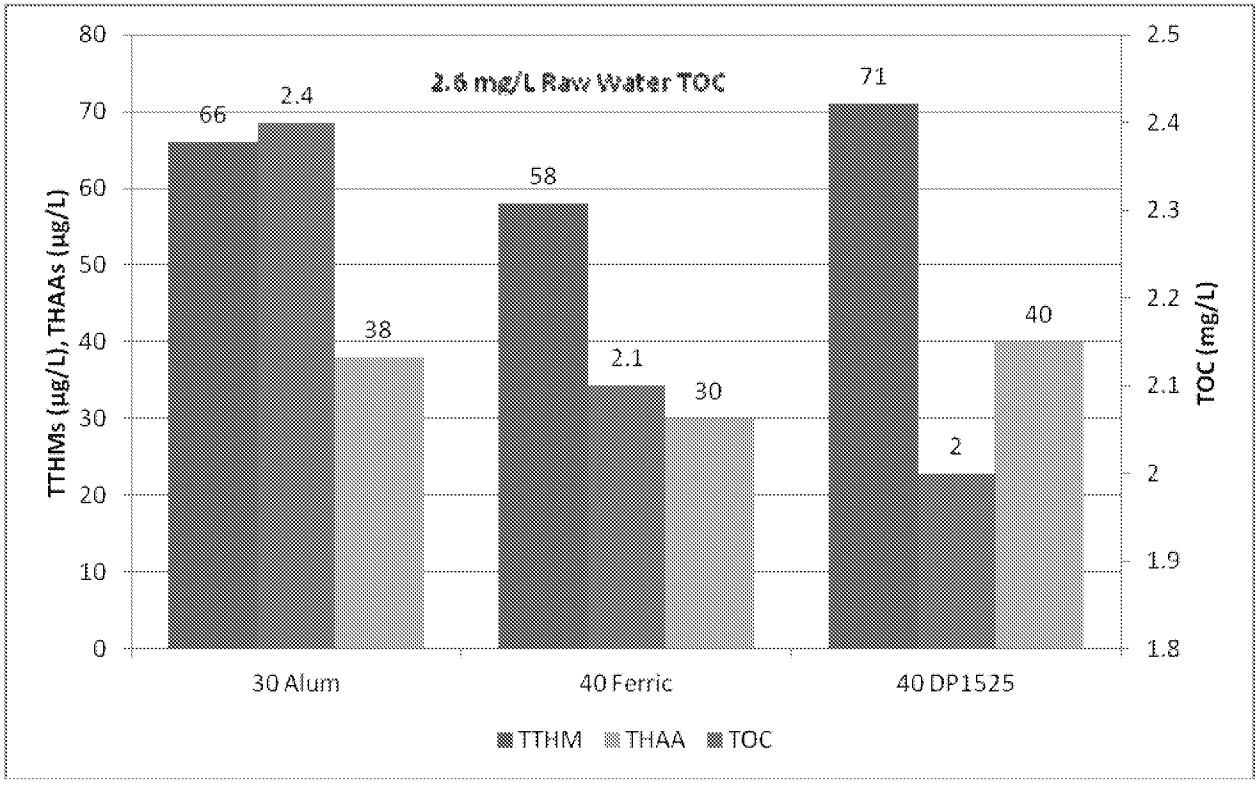


Figure 6-5: Smith River Free Chlorine 10-Day SDS-DBP Testing

DBP results for free chlorine using the Smith River are listed according to species in **Table 6-7**. Unlike DBPs formed with Dan River water, the dominant species of TTHM formed with Smith River water is chloroform.

Table 6-7: Smith River Free Chlorine 10 Day SDS-DBP Results by Species

Species	30 mg/L Alum	40 mg/L Ferric Sulfate	40 mg/L DelPac 1525
Chloroform	57.8	49.6	62.2
Bromodichloromethane	7.6	7.1	7.4
Dibromochloromethane	0.9	1.0	0.9
Bromoform	<0.5	<0.5	<0.5
Total Trihalomethanes	**66.3**	**57.7**	**70.5**
Monochloroacetic Acid	<1	<1	<1
Monobromoacetic Acid	<1	<1	<1
Dichloroacetic Acid	24	19	22
Trichloroacetic Acid	14	11	18
Dibromoacetic Acid	<1	<1	<1
Total Haloacetic Acids	**38**	**30**	**40**

6.2.4 Smith River Hydrology

The hydrology of the Smith River in the vicinity of Eden, NC was evaluated for the conceptual design of a water supply intake. Data from the USGS Gauge 02074000 Smith River at Eden, NC located just over a river mile upstream of the Spray Dam were used to establish flow and depth frequency relationships. **Table 6-8** provides a summary of flow and stage statistics at the gauge. Results indicate that overall flows in the Smith River supports water supply development as 20 percent of the 7-day, 10-year annual low flow (7Q10) is 35 cfs or 22.6 mgd of raw water, which relates to approximately 21.0 mgd of finished water. NC DENR guidelines are that withdrawals less than 20 percent of the 7Q10 flow are considered to have minimal impact, and this an in-stream flow study is not required. Instream flow studies can be intensive in nature, and usually require 2 to 3 years to complete.

However, depths observed at the gauge indicate that water supply development would be a challenge as stage is less than two feet over 5 percent of the time.

Table 6-8: Smith River Summary Flow and Stage Statistics at USGS Gauge 02074000

	Average	5th Percentile	95th Percentile	7Q10
Flow (cfs)	643	176	1,540	175
Stage (ft)	2.55	1.88	3.59	N/A

6.2.5 Alternative Sites for Smith River Water Supply Intake

Three alternative sites were assessed for a water supply intake on the Smith River:

1. Area immediately upstream of the Spray Dam.
2. Adjacent to the historic Fieldcrest Mills water supply intake at the Church Street bridge crossing.
3. Barnett canal discharge immediately downstream of the hydroelectric power installation located at the historic Spray Cotton Mills.

The feasibility of each alternative is assessed below.

6.2.5.1 Upstream of Spray Dam

For this alternative, the concept is to construct a water supply intake in the area immediately upstream of the Spray Dam to utilize the backwater and depth provided by the dam. Development of this alternative involved the preferential location of an intake on the west bank of the river, which would eliminate the need for boring under the river to install a raw water transmission main to the WTP. Land acquisition for this option would likely involve Spray Cotton Mills, the owner of most of the property on the east side of the river between Aiken Road and the Spray Dam. However, a bathymetric survey was conducted for this area and shallow depths were observed. Depths generally ranged from approximately 1 to 4 ft on the east side of the river while slightly deeper (3 to 6 ft) on the west side of the river, which is likely due to scour associated with flow through the gate into the Barnett Canal. Due to possible accumulation of heavy metals in the sediment stored behind the dam as a result of the historic industrial nature of the watershed, dredging of this area to restore original depth may not be feasible from an environmental permitting perspective.

Some additional limitations of locating a water supply intake upstream of the Spray Dam include reliance on the Spray Dam and Barnett Canal infrastructure. The Spray Dam is a run-of-river impoundment which is not currently regulated by the State of North Carolina Dam Safety due to its size. Hence, the condition and structural integrity of the Spray Dam and Barnett Canal are unknown. Long-term maintenance of the structures would be a consideration for the City, and those costs are difficult to estimate without an understanding of the current condition.

However, despite these considerations, the critical concern in the evaluation of this intake location alternative becomes the diversion of flow from the Smith River upstream of an established hydroelectric power-generating facility. Due to the legal implications associated with the location of an intake upstream of the Spray Dam, this alternative was eliminated from further consideration.

6.2.5.2 Historic Fieldcrest Mills Intake

The area in the vicinity of the historic Fieldcrest Mills intake was next evaluated as a possible site for a water supply intake. This location is significant because it is the only site on the Smith River with the appropriate water supply classification not located upstream of the Spray Dam and hydroelectric facility that benefits from the full flow of the river. The abandoned Fieldcrest Mills intake structure is located to the southeast of the Church Street Bridge, but has deteriorated over time, and it is doubtful that the facility can be operated in its present condition. Also, the City has observed that the intake was exposed during the drought of 2007/2008. Therefore, development of this alternative involved the preferential location of an intake to the northeast of Church Street Bridge so as to take advantage of the west side of the river and not interfere with the historic intake structure. Land acquisition for this option would involve approaching a private owner for the approximately 15 acre parcel located in this area.

Though a detailed account of river flow and stage frequency were not available for this location, flow data from the upstream USGS gauge were employed through an assumption of conservation of flow and coupled with an approximate river cross section at the Church Street Bridge obtained from the North Carolina Department of Transportation to develop an approximate rating curve for this site, shown in **Figure 6-6**. The resulting approximate stage-frequency relationship is provided in **Figure 6-7**. It is important to note that these frequency data are based on crude estimates, and meant only to provide an indication of water depth at this location. Further, due to the river storage provided by the impounding Spray Dam upstream, flows and thus, stages predicted at the Church Street Bridge below may be somewhat overrepresented. The depths estimated below do not tend to support water supply development as stage is less than 2 feet over 5 percent of the time. Moreover, the additional analysis of channel velocities was performed to determine if a shallow, recessed, sluice-type intake design could be incorporated at this site which would rely on relatively high water velocities (greater than about 2 ft/s). Results contained below in **Figure 6-8** indicate that channel velocities, perhaps due to backwater considerations, would not tend to support development of this type of intake. Therefore, a water supply intake at this location could be challenged by low stages, and insufficient velocities to prevent siltation.

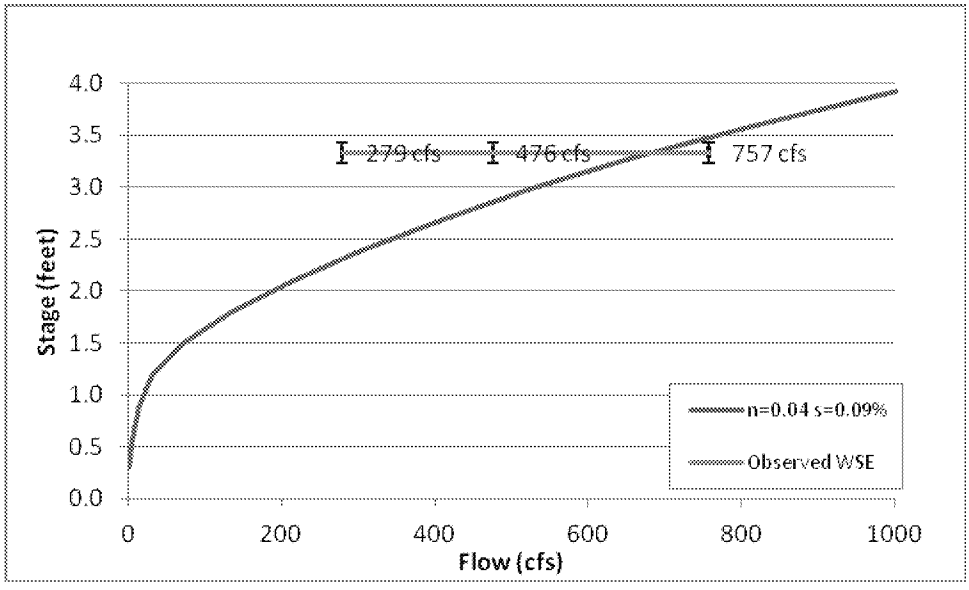


Figure 6-6
Smith River Rating Curve Approximation at Church Street Bridge

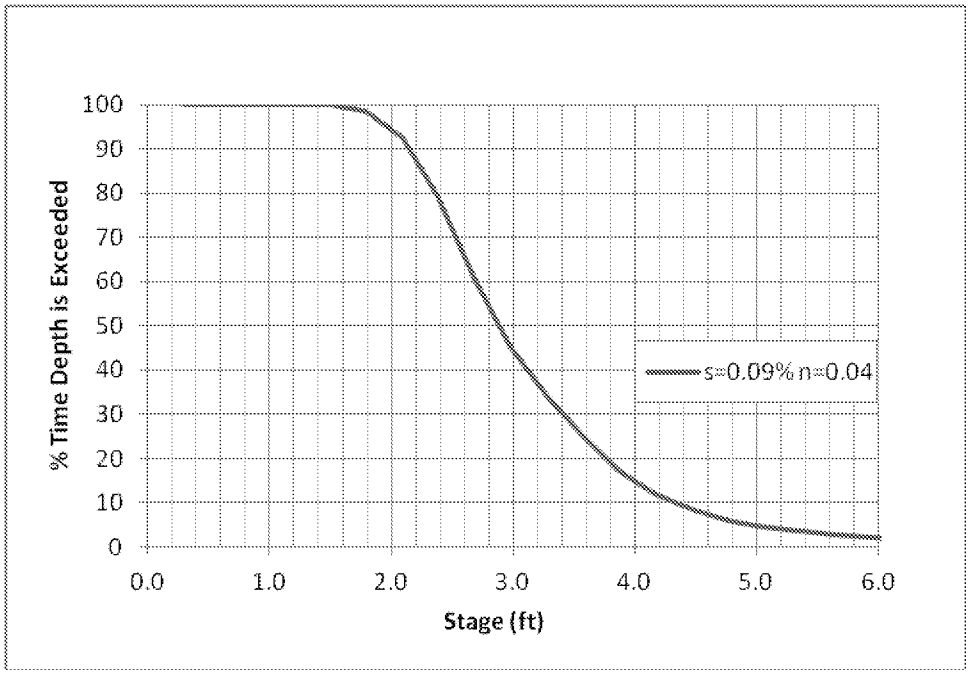


Figure 6-7
Smith River Stage-Frequency Approximation at Church Street Bridge

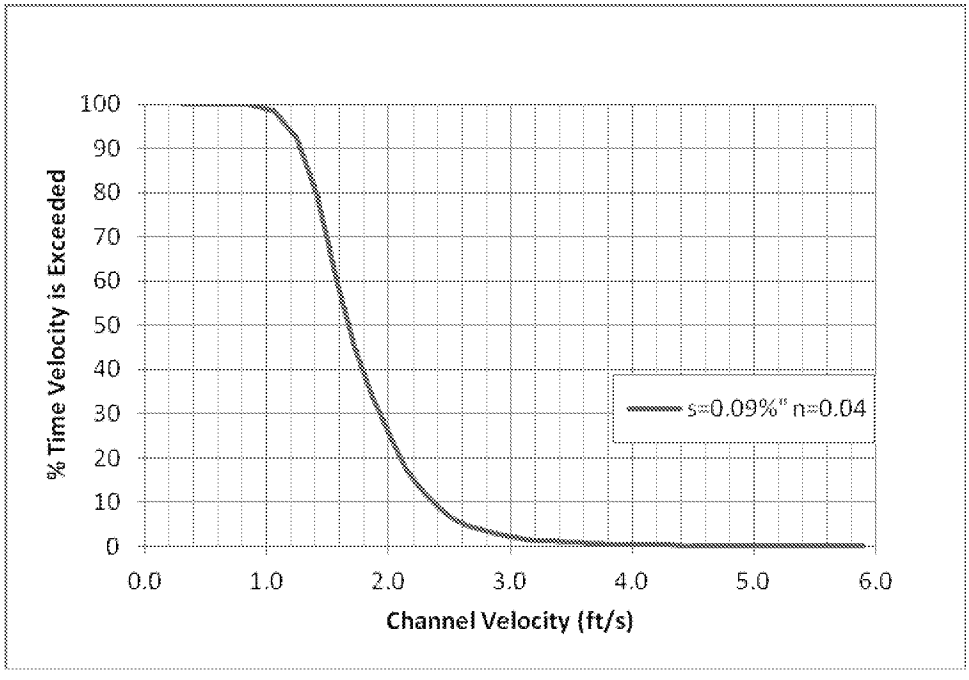


Figure 6-8
Smith River Velocity-Frequency Approximation at Church Street Bridge

6.2.5.3 Downstream of Hydroelectric Facility in Barnett Canal Discharge

The third water supply intake site alternative is the canal discharge area immediately downstream of the hydroelectric power installation located at Spray Cotton Mills. Channel flow and stage frequency relationships could not be developed or assessed for this location due to insufficient information. However, based on visual observations, the canal conveys a large portion of the Smith River flow and velocities seemed high enough to support water supply development. Consequently, additional information regarding flow and stage in the channel outlet from Spray Cotton Mills, the owner of the hydroelectric facility, would be required to advance beyond the conceptual stage of development for this alternative.

The conceptual design for this alternative includes a water supply intake and raw water pump station on the south side of the canal, and a raw water transmission pipeline to the Robert A. Harris WTP Presedimentation Basin. The conceptual layout of facilities in relation to Spray Cotton Mills parcels and surrounding features is provided below in **Figure 6-9** while a schematic section of the intake and pump station is shown in **Figure 6-10**. Alternative routing options for the 30-inch raw water transmission main are presented in **Figure 6-11**.

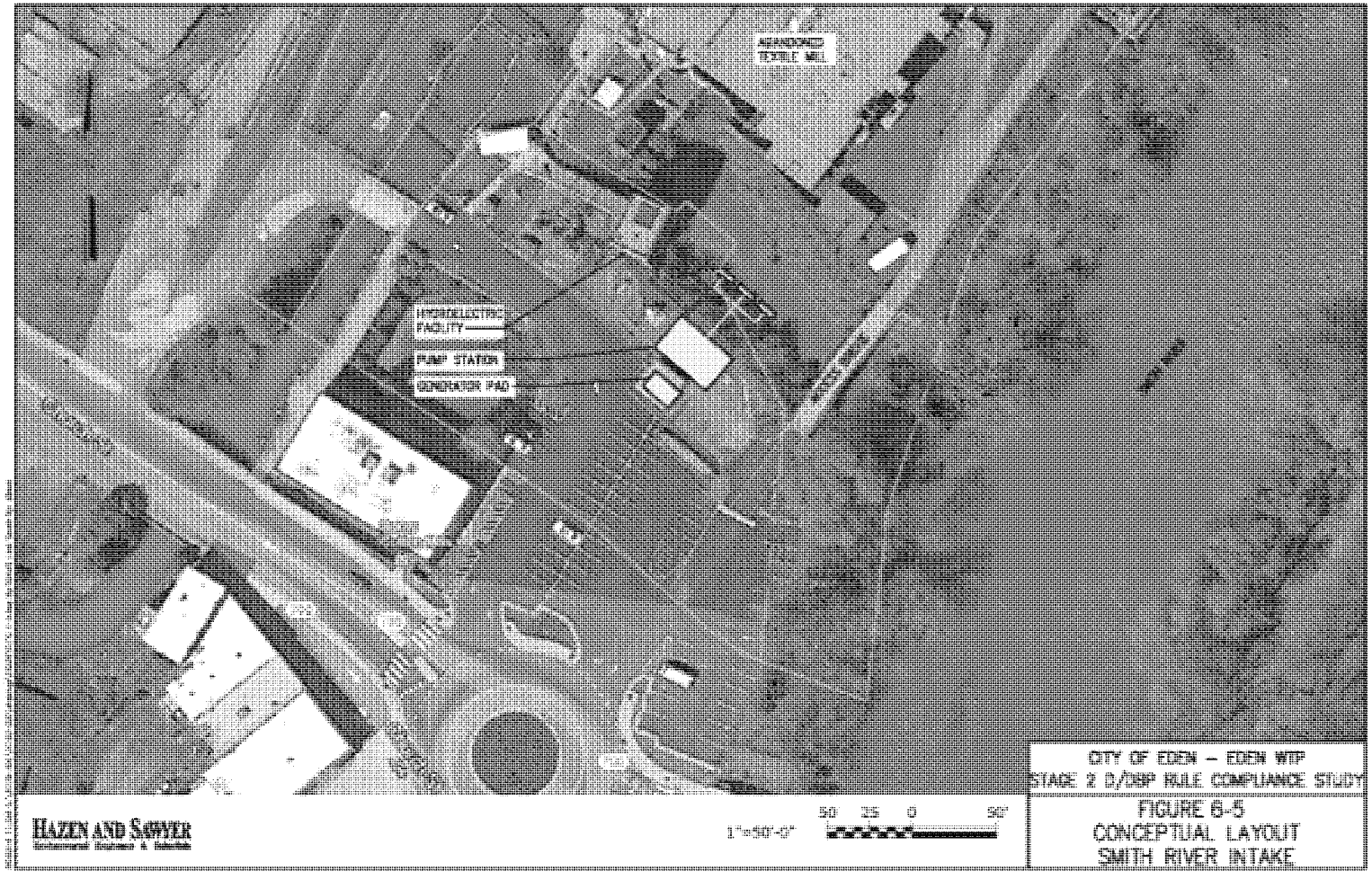


Figure 6-9: Conceptual Layout of Facilities Surrounding the Spray Cotton Mill

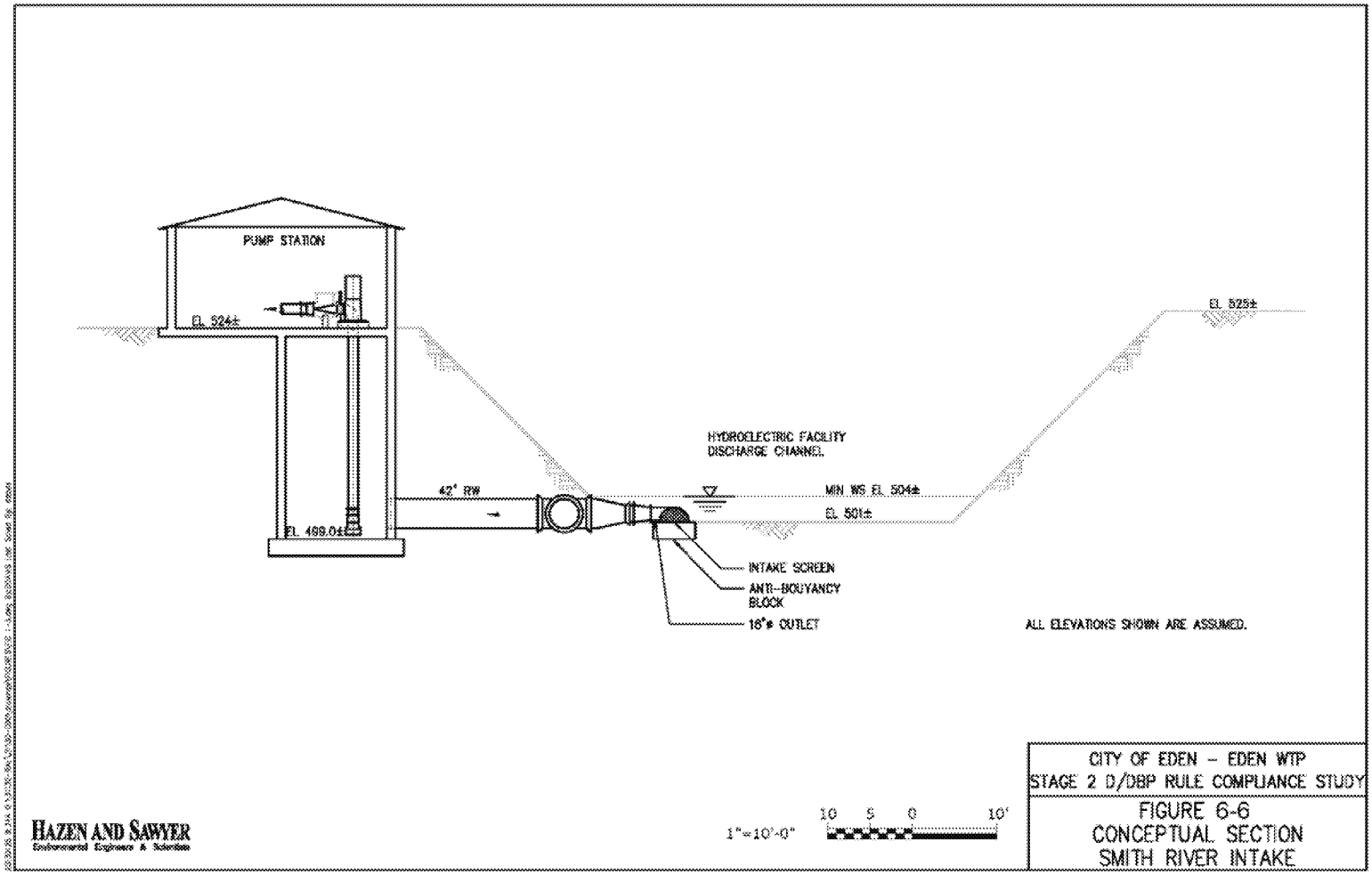


Figure 6-10: Smith River Intake and Pump Station

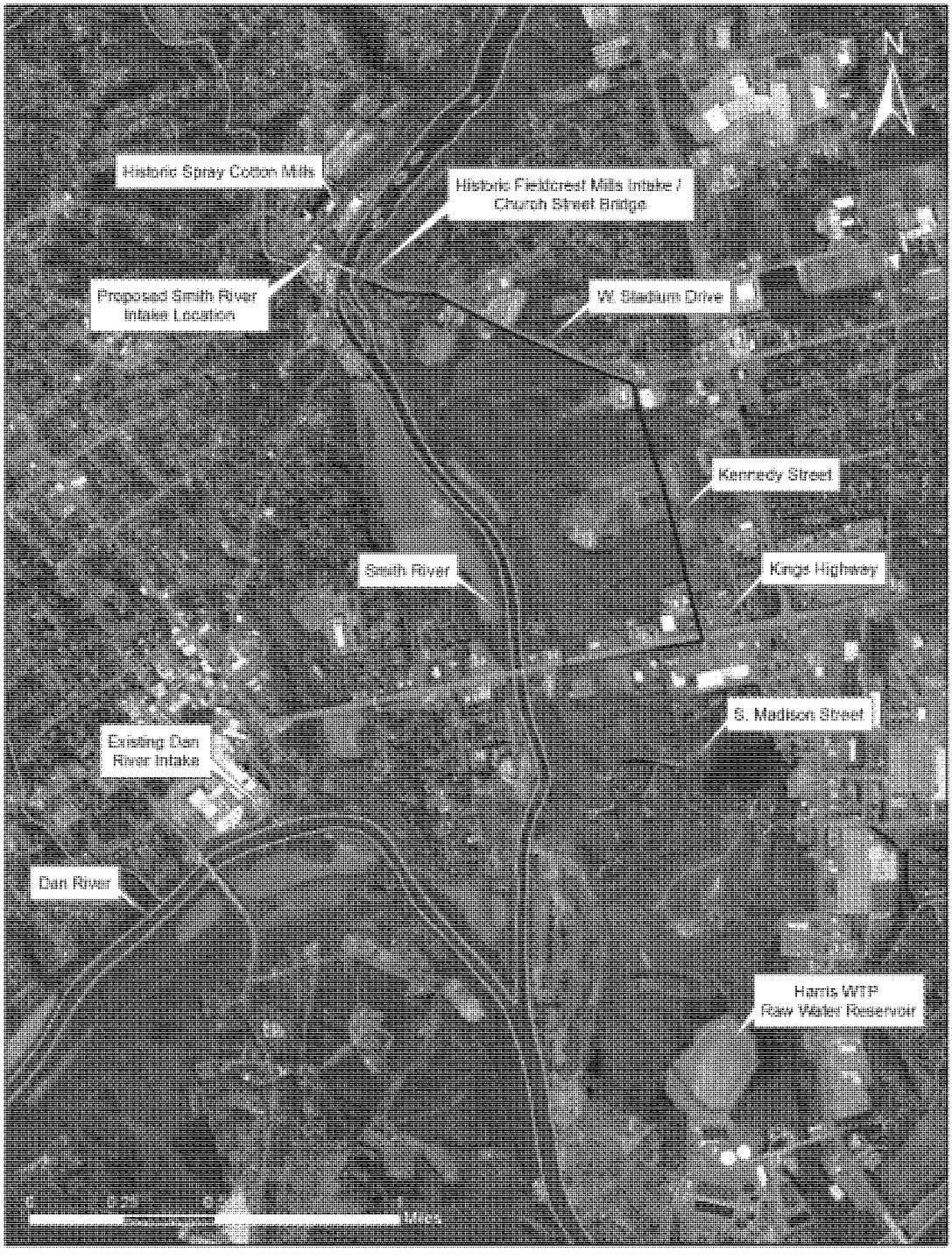


Figure 6-11: Smith River Intake Alternate Raw Water Transmission Routings

Disadvantages to the development of the proposed intake at this location include reliance on the owner/operator of the upstream Spray Dam and Barnett Canal infrastructure for control of flow through the canal as well as long-term maintenance of the Spray Dam and Barnett Canal. Land acquisition would involve Spray Cotton Mills with potential constraints associated with the surrounding businesses, and crossing over the Smith River with the raw water transmission main will result in higher project capital costs. Although there are significant considerations and potential obstacles for this project, the channel immediately downstream of the hydroelectric installation represents the most favorable location for a water supply intake on the Smith River.

The cost opinion provided in **Table 6-9** was prepared based on conceptual-level information and would constitute an order of magnitude estimate for the purpose of evaluating alternative projects to achieve Stage 2 DBPR Compliance. Construction costs are prepared in 2013 dollars and include all civil (i.e. site), mechanical (i.e. equipment), structural, architectural, HVAC, plumbing, electrical, and instrumentation and control components associated with construction of the intake, pump station, and raw water transmission main. Additionally, the following supplemental costs are accounted for in the preparation of each construction cost estimate:

- 30% Contingency – to account for variability in equipment and material costs as well as other construction costs that remain unidentifiable at this time;
- 15% Contractor overhead and profit; and
- Engineering fee – to account for design and construction administration services.

Operation and maintenance costs associated with the intake and pump station include the following components:

- Electrical – estimated electrical costs related with raw water pumping.

Table 6-9: Cost Opinion for Smith River Intake Project (21 MGD Design Capacity)

Description	Conceptual Capital Cost
Intake Piping / Screens	$702,000
Raw Water Pump Station	$4,250,000
Raw Water Transmission (30-inch to Raw Water Reservoir)	$4,230,000
Project Subtotal	$9,182,000
Contractor Mobilization, Overhead and Profit (15%)	$1,377,300
Contingencies (30%)	$3,167,800
Engineering Design / Construction Services (15%)	$2,059,100
Environmental Assessment / Permitting	$250,000
Raw Water Transmission Easements	$235,000
Estimated Project Cost	**$16,271,200**
Estimated Project Cost (Rounded)	**$16,280,000**
	Conceptual O&M Cost
Annual Operation Cost	**$200,000**
Present Worth of Annual Operation Cost	**$2,500,000**

7 FINDINGS AND SUMMARY

Bench-scale testing results of optimization strategies such as optimizing existing coagulation, using an alternate coagulant, and addition of PAC did not result in DBP levels that could ensure compliance with the Stage 2 D/DBP Rule. Chloramination, alternate water supply source from the Smith River, and advanced treatment technologies such as MIEX®, anion exchange, and post-filter GAC contactors, were all evaluated as technologies for reducing TTHM levels at the Robert Harris Water Treatment Plant (WTP) in Eden, NC. Costs for these options are summarized in the following section.

7.1 Summary of Costs

The capital and O&M costs for each of the alternatives evaluated for the Robert Harris WTP are shown in **Table 7.1.** Costs were developed for both the full WTP capacity of 21 mgd as well as 11 mgd in the event that the City elects to pursue a phased approach. Current average day demands are approximately 6 mgd and peak demands are approximately 9 mgd. Phased costs were not developed for the Smith River intake option since much of the capital costs are associated with infrastructure that is more difficult or costly to construct in phases such as the intake structure and the raw water transmission main. Annual O&M costs are based on anticipated average production rates at the rated capacities of 11 and 21 mgd.

Table 7.1: Capital and O&M Costs for Robert Harris WTP

Advanced Technology	Advanced Treatment Capacity (MGD)	Capital Costs	Annual O&M Costs	Unit O&M Costs ($/1,000 gal)
MIEX®	11	$12,742,000	$332,000	$0.15
	21	$24,126,000	$607,000	$0.12
Anion Exchange	11	$12,257,000	$738,000	$0.34
	21	$23,525,000	$1,402,000	$0.27
GAC	11	$7,580,000	$1,622,000	$0.74
	21	$14,470,000	$3,062,000	$0.60
Chloramines	11	$1,300,000	$20,200	$0.01
	21	$1,310,000	$33,100	$0.01
Smith River Intake	21	$16,280,000	$200,000	$0.04

The net present worth for each of the alternatives evaluated for the Robert Harris WTP are shown in **Table 7.2**. Net present worth was developed on a 20-year basis at a discount rate of 5 percent.

Table 7.2: Net Present Worth of Evaluated Technologies for 11 MGD and 21 MGD Capacities

Capacity	11 MGD	21 MGD
MIEX®	$16,879,000	$31,691,000
Anion Exchange	$21,454,000	$40,997,000
GAC	$44,340,000	$52,630,000
Chloramines	$1,552,000	$1,722,000
Smith River Intake	N/A	$18,772,000

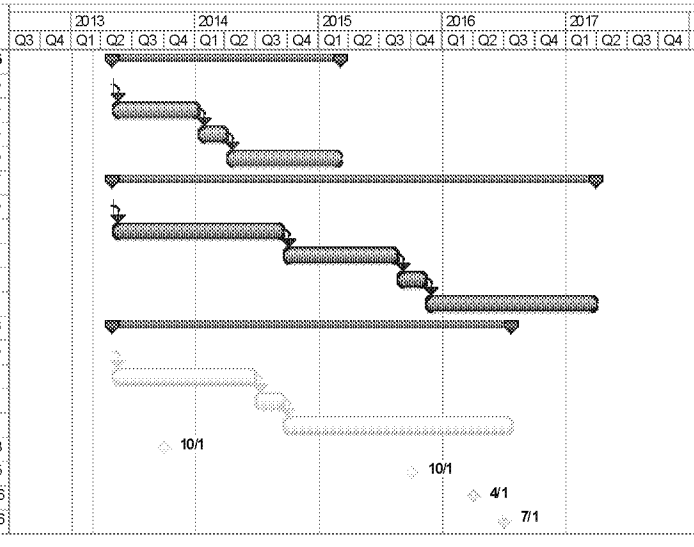
7.2 Implementation Schedule

To comply with the Stage 2 DBP Rule, the City of Eden must begin collecting DBP samples at Stage 2 sites in October 2013. The City can request a two-year extension to push the Stage 2 monitoring to October 2015. This would extend the date of the first LRAA calculations for Stage 2 DBP compliance to 3rd quarter 2016.

The implementation schedules for the three feasible alternatives for Stage 2 DBP Rule compliance are shown in **Figure 7-1**. Chloramination is the only alternative that could be implemented to comply with the Stage 2 DBP Rule compliance dates. It is estimated that implementation of chloramines can be completed by early 2015. The addition of GAC contactors could be completed by mid 2016. Therefore, the City would be collecting Stage 2 DBP compliance samples for at least 3 quarters before GAC was online. The Smith River intake has the longest projected implementation schedule due permitting constraints. It is estimated that the new intake option could take until mid 2017 to be completed, which could leave the City at risk for non-compliance for at least one year.

Figure 7-1: Implementation Schedule for Chloramines, Smith River Intake, and GAC Contactors

ID		Task Name	Duration	Start	Finish
1		**Chloramines**	**481 days**	**Wed 5/1/13**	**Wed 3/4/15**
2		NTP	1 day	Wed 5/1/13	Wed 5/1/13
3		Design	9 mons	Thu 5/2/13	Wed 1/8/14
4		Bidding	3 mons	Thu 1/9/14	Wed 4/2/14
5		Construction	12 mons	Thu 4/3/14	Wed 3/4/15
6		**Smith River Intake**	**1021 days**	**Wed 5/1/13**	**Wed 3/29/17**
7		NTP	1 day	Wed 5/1/13	Wed 5/1/13
8		Permitting/EA-EIS	18 mons	Thu 5/2/13	Wed 9/17/14
9		Design	12 mons	Thu 9/18/14	Wed 8/19/15
10		Bidding	3 mons	Thu 8/20/15	Wed 11/11/15
11		Construction	18 mons	Thu 11/12/15	Wed 3/29/17
12		**GAC**	**841 days**	**Wed 5/1/13**	**Wed 7/20/16**
13		NTP	1 day	Wed 5/1/13	Wed 5/1/13
14		Design	15 mons	Thu 5/2/13	Wed 6/25/14
15		Bidding	3 mons	Thu 6/26/14	Wed 9/17/14
16		Construction	24 mons	Thu 9/18/14	Wed 7/20/16
17		Begin Monitoring	1 day	Tue 10/1/13	Tue 10/1/13
18		2-year Extension	1 day	Thu 10/1/15	Thu 10/1/15
19		OEL Compliance	1 day	Fri 4/1/16	Fri 4/1/16
20		LRAA Compliance	1 day	Fri 7/1/16	Fri 7/1/16



7.3 Feasible DBP Compliance Options

Chloramination, post-filter GAC contactors, and a new raw water intake on the Smith River have been identified as the three favorable alternatives for Stage 2 DBPR compliance for the Robert Harris WTP.

7.3.1 Chloramination

Chloramination has a long history of use throughout the U.S., and particularly in North Carolina. Many of the larger water systems in North Carolina such as Raleigh, Greensboro, Fayetteville, Durham, and Greenville practice chloramination. Chloramines are a persistent and stable residual without the "chlorine" taste and odor. Chloramines controls microbial regrowth within the distribution system. However, there is a potential for nitrification if excessive free ammonia is introduced into the distribution system. Chloramination is used successfully as long as the chlorine to ammonia ratio is carefully controlled and water quality in the distribution system is closely monitored.

The use of chloramines at the Robert Harris WTP would require the addition of an aqueous ammonia storage and feed system. The concept is that primary disinfection would be achieved via free chlorine by using the contact time (CT) in the filters, filter effluent flume, and the first clearwell. Ammonia would be added to form chloramines prior to the second clearwell. By using only one clearwell for CT, the free chlorine contact time would be reduced such that DBP formation at the point of entry would also reduced. In addition to an aqueous ammonia system, a flowmeter and mixing system would be added prior to the second clearwell. Chlorine and caustic soda feed points would also be added at this point. Also, a significant public information program must be conducted to inform end users of the switch in secondary disinfections used in the distribution system.

Chloramination represents the lowest net present worth option with a net present worth of $1,552,000 and $1,722,000 for 11 and 21 MGD, respectively. Also, we expect that chloramination could be implemented prior to Stage 2 DBPR compliance deadlines.

7.3.2 GAC Contactors

If a phased approach is Post-filter GAC contactors have been identified as a highly effective treatment option to significantly reduce dissolved organic carbon and DBPs. In addition, GAC has other water quality benefits such as removal of taste and odor compounds, pesticides, herbicides, and emerging contaminants that are not yet regulated. GAC can also reduce chlorine demands and downstream chemical doses. GAC adsorption processes are widely used across the US and, as such, there are multiple carbon suppliers available. GAC can achieve very low DOC and DBP precursor levels, but has higher capital and O&M costs as compared to other technologies.

The use of GAC contactors at the Robert Harris WTP would require the addition of 6 deep-bed, gravity GAC contactors for a design capacity of 11 MGD or 10 GAC contactors for a design capacity of 21 MGD. The contactors would be placed after filtration and prior to the clearwells. A 15-minute empty bed contact time would be the design criteria for the GAC contactors. Additionally, an intermediate pumping station and electrical/control would be required additions to the plant.

On a capital cost basis, GAC Contactors was the second least costly option behind chloramination. However, on a net present worth basis, GAC contactors are the most expensive compliance option with a net present worth of $44,340,000 and $52,630,000 for 11 and 21 MGD, respectively. This is mainly due to the O&M costs associated with carbon regeneration. Regeneration costs were based on a GAC bed life of 5 months. However, the pilot testing has recently been completed and Hazen and Sawyer and NC State University are still analyzing all the results. It is possible that GAC bed life estimates may be lowered after the final data are analyzed. However, the estimated regeneration rate of GAC also needs to consider seasonal fluctuations of water quality and not just the results obtained during the pilot testing.

The estimated schedule for GAC implementation at the Robert Harris WTP indicates that GAC could be online in 3rd quarter 2016. There could be up to 3 quarterly Stage 2 sampling events before GAC is online. This leaves the possibility of NOVs once LRAA values are calculated in 3rd quarter 2016.

7.3.3 Smith River Water Supply

The addition of a new raw water intake on the Smith River would provide an additional water supply source, and therefore, add a measure of reliability for the Robert Harris WTP. The Smith River has sufficient flow to meet the needs of the Robert Harris WTP at its rated capacity, and preliminary water quality collected to date indicate that the Smith River is a viable source. However, there are several challenges with developing the Smith River as a water supply in Eden such as the existing hydroelectric facility, and low stages in the Smith River. Additional data will need to be collected to confirm flows and river stages at the selected intake location to further develop a conceptual design for a water supply intake.

The Smith River intake option represented the second lowest cost option on a NPW basis at $18,772,000. The new raw water intake would require the construction of a water supply intake, raw water pump station and a raw water transmission main to the WTP.

The implementation schedule for the Smith River intake has the most unknowns due to the environmental assessment and other permitting required. It is not likely that the Smith River option could be implemented prior to the 3rd quarter 2015, thereby, adding a risk of NOVs before the new water supply is available. Additional water quality testing with this source water and free chlorine residual in the distribution system should also be evaluated as TOC variability is unknown at this point in time.

7.4 Proposed DBP Compliance Strategy

Due to the costs of implementation, the City has selected chloramination as its DBP compliance strategy. The Robert Harris WTP will continue to rely on free chlorine for primary disinfectant, but will convert to chloramines for secondary (or residual) disinfection. The capital costs for chloramine addition are based on the use of aqueous ammonia and continued use of gaseous chlorine.

The construction of the new facilities at the Robert Harris WTP will require a sequence of activities for design, permitting, construction and startup before the Stage 2 DBP compliance dates begin at the LRAA points. It is expected that the new facilities will be constructed and online in Spring 2015. The City's compliance deadline is October 2013, so the City will need to request an extension from the NC DENR as allowed by the Stage 2 DBPR. We recommend that the extension request be filed once a Preliminary Engineering Report has been prepared that outlines the preliminary design and scope of the capital improvements.

The Project Implementation Schedule shown in **Figure 7-1** allocates time for the major design and construction activities as well as related tasks or activities. The schedule includes an approximate "float time" of five months between construction completion and startup, and the first quarter of compliance monitoring.

In addition to design of the proposed capital improvements, several related activities are recommended as part of the conversion to chloramination:

- Corrosion coupon/loop study
- Public Information Program
- Distribution System Flushing
- Development of Nitrification Control Plan and Distribution System Monitoring

7.4.1 Corrosion Control Pilot Study

A corrosion coupon/loop study is recommended to assess lead and copper corrosion control with chloramines. NC DENR usually requires a corrosion study to accompany in major change in treatment such as a change in coagulant or disinfectant. A corrosion loop study would include the use of a pilot loop system with copper piping and lead solder joints installed at the Robert Harris WTP for a period of approximately 6 months. The pilot would use filtered water from the Robert Harris WTP and then chlorine and ammonia added to produce chloraminated water for the pilot. Different corrosion treatments can be evaluated for lead and copper control with the City's existing corrosion treatment strategy used as a control.

Besides corrosion testing, VDH will also require under the Lead and Copper Rule, a return to standard monitoring for Pb and Cu in the Urban System. Standard monitoring requires that sample sites be monitored *every six months* versus every three years, and the number of sites will approximately double from the current sample locations. Return to reduced monitoring is typically allowed with two rounds of lead compliance. Standard monitoring would be triggered by the actual conversion date to chloramines in the system, and should be discussed further with VDH. Selection and approval by VDH of new lead monitoring sites should be done early during the construction phase and require the selection of additional sample sites. Previous standard monitoring locations may be able to be used.

7.4.2 Public Information Program

Along with the conversion to chloramination, it is recommended that the City develop a Public Information Program to disseminate information to its water customers regarding the change in disinfectant and potential impacts to special water use groups such as the medical community, fish and aquarium stores, and certain industries will need to be advised of the change in disinfectant.

7.4.3 Distribution System Flushing

The City of Eden should develop a flushing program to prepare for the conversion to chloramines. Distribution system flushing should be conducted in advance of the conversion to chloramines to scour piping and reduce the existing biofilm to reduce the potential for nitrification. Also, a flushing program should be developed to assist with a rapid turnover of water in the distribution system during the initial conversion to chloramines to reduce the potential for taste and odor events

7.4.4 Development of Nitrification Control Plan and Distribution System Monitoring

We also recommend that the City develop a Nitrification Control Plan to consist of routine monitoring of distribution system quality, including nitrite, nitrate, pH, and residual disinfectant, to detect nitrification events. Also, a response plan should be developed to outline steps to control nitrification if it occurs in portions of the distribution system.

7.4.5 Startup Assistance

We recommend that the City have engineering support during the chloramines system startup. This should also include training for WTP staff on chloramines chemistry, operation of the aqua ammonia system, and other chemical feed system controls to ensure monochloramine formation. Startup support would ensure persistent disinfectant residual formation and limit blending of chlorinated and chloraminated water during the conversion to chloramines.

7.5 Project Implementation Schedule

A preliminary Project Implementation Schedule is shown in **Table 7-3** for the Stage 2 DBP Upgrades for the Robert Harris WTP. This schedule was developed to provide a basis for budgeting needs through fiscal year 2015. It is recommended that the projects be implemented along with the discussion with NCDENR of an extension for compliance with Stage 2 DBPR. Extensions of time are allowed by regulation for treatment facilities that require major capital upgrades such as new facilities to be added to an existing WTP. A formal request to NC DENR for the 2-year extension should be pursues as soon as possible to secure the waiver for regulatory compliance prior to the current compliance deadline of October 2013.

Table 7-3 Capital Improvements Plan for Stage 2 DBP Compliance

Start Date	Major Activity Description	Cost in 2013 Dollars ($)	Notes
FY 2014			
Jul. 2013	Final Decision on Stage 2 DBP Strategy / Authorize Engineer for WTP upgrades		
Aug. 2013	Corrosion Study	$70,000	Confirm corrosion control with conversion to chloramines
Oct. 2013	Develop PER WTP Upgrades	$28,500	Prepare Preliminary Engineering Report and submit to NC PWS
Dec. 2013	Standard Lead and Copper Monitoring Site Selection	--	City to confirm if sampling sites still available. Increased sampling and analytical costs to return to standard monitoring for at least 3 years.
Mar. 2014	Final Design Complete	$66,500	Final design of proposed WTP improvements
Apr. 2014	Advertise for Bids	in design fee	
Jun. 2014	Award Contract	$1,055,000	
FY 2015			
Jul. 2014	Construction Starts (Notice to Proceed)	--	
Jul. 2014	Construction Administration and Observation	$63,100	
Jul. 2014	Develop Public Information Program	$35,000	Prepare public information materials. Plan to roll out by Dec. 2014.
Jul. 2014	Develop Flushing Program and Nitrification Control Plan	$40,000	Distribution system flushing program for conversion to chloramines.
May 2015	Construction complete – startup and conversion to chloramines	---	

Appendix A

Impacts of Bromamines on Chloramines Stability

HAZEN AND SAWYER
Environmental Engineers & Scientists

To:
City of Eden
Terry Shelton
Dena Spencer Reid
Melanie Clark

Copies:
David S. Briley, PE
Cory Hopkins, PE

Hazen and Sawyer, P.C.
4011 WestChase Blvd.
Raleigh, NC 27607
919-833-7152
Fax: 919-833-1828

Firm License No. C-0381

From:
Ben Stanford, PhD
Allison Reinert

Date:
May 13, 2013

Subject:
Impacts of Bromamines on Chloramines Stability
Stage 2 DBP Compliance Plan

---

1. What are Bromamines?

The term "bromamines" covers three distinct molecules: monobromamine, dibromamine, and tribromamine, and are analogous to chloramines used in drinking water treatment. Monobromamine is the least reactive of the bromamine species, followed by dibromamine and then tribromamine. Tribromamines are typically not formed during typical water treatment plant conditions and resultantly will not be discussed in this memo. When hypochlorous acid (HOCl) and/or hypochlorite (OCl^-) is added to water for disinfection, any bromide (Br^-) that is present in the source water can be oxidized to hyprobromous acid ($HOBr^-$) or hypobromite (OBr^-), depending on pH, as shown in **Equations 1 and 2**.

$$HOCl + Br^- \leftrightarrow HOBr + Cl^- \quad (1)$$
$$OCl^- + Br^- \leftrightarrow OBr^- + Cl^- \quad (2)$$

The reaction rates of hyprobromous acid and hypobromite are on the order of seconds to a few minutes. Therefore, in most water treatment operations, all of the bromide will be oxidized to HOBr with the current chlorine contact times.

When chloramination is used at a drinking water treatment plant, ammonia (NH_3) is added so that the Cl_2:N ratio is below the chloramine breakpoint in order to form chloramines, and ideally at a ratio of 4:1 to preferentially form monochloramine. With the addition of ammonia, both HOCl and HOBr react quickly to form monochloramine (NH_2Cl) and monobromamine (NH_2Br), respectively, with completion occurring in less than one second (**Equations 3** and **4**).

$$HOCl + NH_3 \leftrightarrow NH_2Cl + H_2O \quad (3)$$
$$HOBr + NH_3 \leftrightarrow NH_2Br + H_2O \quad (4)$$

Once monobromamine (NH_2Br) is formed it can undergo further oxidation by hypobromous acid or dissociate into dibromamine ($NHBr_2$) as shown in **Equation 5** and **6**, respectively.

$$HOBr + NH_2Br \leftrightarrow NHBr_2 + H_2O \qquad (5)$$
$$2NH_2Br \leftrightarrow NHBr_2 + NH_3 \qquad (6)$$

Bromamines are more reactive than their chloraminated counterparts and can auto-decompose or react with natural organic matter (NOM) to form brominated disinfection byproducts (DBPs).

2. Why are Bromamines a Concern?

The formation of bromamines during chloramination processes are of concern due to the increased potential to exceed DBP maximum contaminant levels (MCLs) and the potential loss of disinfectant residual in the distribution system. Brominated DBPs weigh more than their chlorinated analogs and as such, fewer brominated DBP molecules are needed to reach the MCL. Additionally, the presence of bromamines can cause decay in chloramine concentration due to the process described here: When bromamine decomposes or incompletely reacts with NOM, free bromide may be released back into solution. The bromide can then replace a chlorine atom on the chloramine molecule, thereby acting as a catalyst to decay NH_2Cl through the following reaction:

$$NH_2Cl + Br^- \rightarrow NH_2Br^- + Cl^- \qquad (6)$$

The stability of chloramines, and therefore disinfectant residual, is highly dependent upon oxidant dose, dissolved organic carbon (DOC) concentration, and Br^- ion concentration.

Overall, in waters with elevated bromide concentration, monobromamine can either dissociate or become oxidized to dibromamine. Dibromamine is far less stable than monobromamine and as such it will subsequently auto-decomposes (or interact with NOM to form brominated DBPs) to release more bromide ions. The released Br^- ions can then be reoxidized to bromamine by chloramines and the auto-decomposition will continue in this cycle to reduce the chloramine residual over time.

3. Conditions Likely to Lead to Bromamine/Chloramine Instability?

The most important factor in bromamine chemistry is the bromide concentration. When the bromide concentration is less than 300 mg/L, at a pH of 8.5, and with an average concentration of NOM or DOC, chloramine decay seems to be minimized even with the conventional order of chemical addition for chloramination (Zhang, Tseng et al. 2012). When bromide concentrations occur between 300 and 500 mg/L with the conventional chemical addition, there can be moderate chloramines decay even at the optimum pH. At higher bromide concentrations (>500 mg/L), there can be significant decay of the chloramines residual.

HAZEN AND SAWYER
Environmental Engineers & Scientists

Previous research has indicated that there may be a relationship between DOC concentration and the stability of chloramines in brominated water, though this relationship is not clear-cut. It is thought that bromamines may preferentially react with the organic matter and reduce the overall concentration of bromamines available to auto-decompose and scavenge the chloramine residual. However, the unintended consequence in this case would be higher formation of brominated DBPs.

Waters with pH < 7.0 have been shown to increase auto-decomposition of bromamines, leading to decreased chloramines stability. The optimum chlormaine stability in the presence of bromamines occurs at a pH of 8.5. If a utility needs to change or stabilize pH to 8.5, the addition of alkalinity (particularly bicarbonate) should be considered in poorly buffered waters, or simply adding caustic to waters with greater buffer capacity (i.e., alkalinity > 20-30 mg/L).

Tables 1 and **2** illustrate previously published data from waters that have been evaluated for disinfectant residual in the presence of bromide/bromamines.

Table 1: Chloramine Stability for Blended Waters

Plant	Water Type or Ratio	pH	Total Alkalinity	[Br⁻] (µg/L)	DOC (mg/L)	Chloramines Stable in Jar Test?
Floridian Aquifer	Brackish Groundwater	~8	170	8420	1	No
FKAA + Floridian	4% Floridian + SWRO	7-8	44	615	1.5	Yes
Tampa Bay Water	Surface Water	~8	58	134	1.9	Yes
TBW +Surface Water	12% SWRO	--	51	273	1.8	Yes
TBW RO + Surface Water	50:50	--	51	712	1.5	Moderate

Where FKAA = Florida Keys Aqueduct Authority, TBW = Tampa Bay Water, SWRO = Seawater Reverse Osmosis Permeate

*Table 2: Chloramine Stability for Recycled Water***

Plant	Water Type or Ratio	Total Alkalinity	[Br⁻] (µg/L)	DOC 5.7(mg/L)	Chloramines Stable in Jar Test?
CCWRD	Reuse	130	222	8.2	Not very
Pinellas Co	Reuse	230	661	0.2	Not Very
OCWD	Reuse	44	<20	0.2	Yes
West Basin*	Reuse	27	<20	<0.2	Not Very
Bundamaba	Reuse	83	<20	<0.2	Yes

**pH values unknown for these plants
*Outlier: chloramines instability thought to be influenced by non bromide interactions
Where CCWRD = Clark County Water Reclamation District, OCWD = Orange County Water District (California)

4. Possible Mitigation Strategies for Bromamines

Some possible mitigation strategies for controlling the formation and auto-decomposition of bromamines consist of controlling the pH of the water, or changing the order of chemical addition (ammonia followed by chlorine as compared to conventional method of chlorine followed by ammonia) can also aid in the control of bromamine formation and bromamines auto-decomposition, though this tends to be very site specific and depends on the water chemistry. Likewise, minimizing the bromide concentration in water is the best method to reduce the possibility of bromamines occurrence.

Previous studies have found that controlling the pH between 7 and 8.5 can limit the speciation to monobromamine which is less reactive than the other bromamines (Inman and Johnson 1984)(Sugam and Helz 1978). Elevated pH (typically around pH 8.5) stabilizes bromamines and prevents auto-decomposition. By adding alkalinity to the water (particularly bicarbonate) the pH can be more easily controlled to prevent auto-decomposition and therefore reduced chloramine residual.

In some cases, the order of chemical addition (e.g., ammonia then chlorine) can mitigate the oxidation of bromide ions to hypobromous acid and the subsequent formation of bromamines, though this is not always the case. Bromamines may still be formed if ammonia is added first, but the oxidation of bromide to bromamines by chloramines is slower as compared to their formation via hypobromous acid/hypobrome (**Equation 3** and/or **Equation 4**). The importance of the order of chemical addition is illustrated in **Figure 1** (Water RF 4159 Study) for a California water with a high bromide ion concentration.

HAZEN AND SAWYER
Environmental Engineers & Scientists

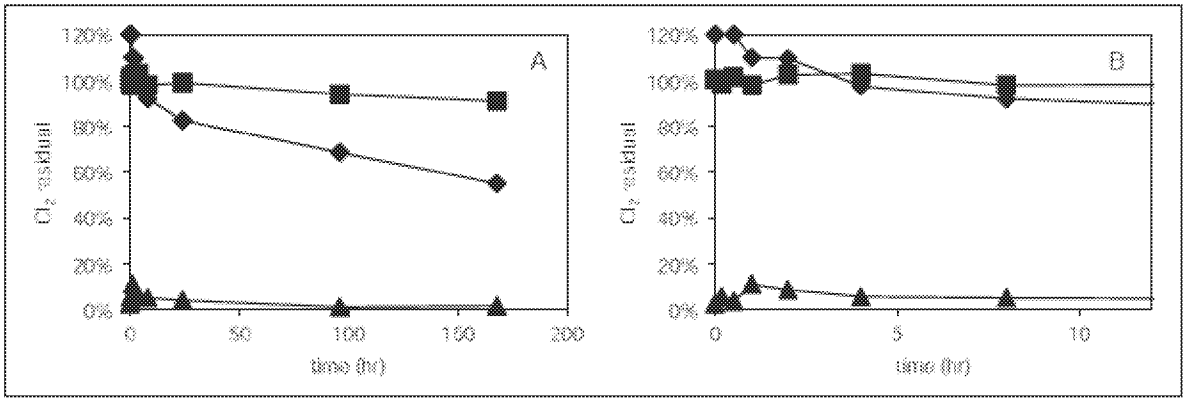


Figure 1: Illustrates chroramines formed in two different ways (free chlorine first in the diamonds, and ammonia first in the squares) as well as the stability of the free chlorine in the triangles for the West Basin reuse water. Graph A focuses on a longer time pereiod whereas Graph B only covers the first 10 hours.

5. Results of Monochloramine Stability Test

In order to determine the likely impact of bromamines on the City of Eden water system, a series of chlorine/chloramine stability tests were conducted. Combined filter effluent (CFE) was collected from the Robert Harris Water Treatment Plant on April 29, 2013. The bromide concentration of the collected CFE water was less than 100 µg/L and had a pH value of 6.05. The City reported that treated water TOC was 1.2 mg/L in the April sample. Treated water TOC at the Robert Harris WTP is usually in the range of 0.9 to 1.3 mg/L. The collected water was used to create the following test matrix as shown in **Table 3**.

The collected filtered water was pH-adjusted to 7.5, 8, and 8.5 and then tested for the free chlorine residual. The free chlorine residual results after pH adjustment are shown in **Table 4**.

Following pH adjustment, a sodium bromide solution was added to each sample bottle to spike bromide concentrations by 200, 400, and 600 µg/L. The bromide concentrations reported do not take into account the background bromide concentrations in the water. Chlorine was added to each sample bottle and then held for 12 hours to simulate free chlorine contact time in the WTP. Then, liquid ammonia was added to achieve a chlorine:nitrogen ratio of 4:1.

Monochloramine concentrations were measured after the ammonia addition and then on a daily basis for the following 9 days. The results for the average chloramines concentration for each pH and bromide concentration are shown in **Table 5**.

HAZEN AND SAWYER
Environmental Engineers & Scientists

Table3: Monochloramine Stability Test Plan

pH	Amount of Bromide Added (µg/L)	Sample Size	Sample Number
7.5	0 (Blank)	500 mL	2
	200	500 mL	2
	400	500 mL	2
	600	500 mL	2
8.0	0 (Blank)	500 mL	2
	200	500 mL	2
	400	500 mL	2
	600	500 mL	2
8.5	0 (Blank)	500 mL	2
	200	500 mL	2
	400	500 mL	2
	600	500 mL	2

Table 4: Free Chlorine Residual Results After pH Adjustment

Sample pH	Free Chlorine Residual
7.5	0.24 mg/L
8.0	0.18 mg/L
8.5	0.11 mg/L

HAZEN AND SAWYER
Environmental Engineers & Scientists

Table 5: 10-Day Monochloramine Concentrations

pH	Amount of Bromide Added (µg/L)	Monochloramine Concentration (mg/L)							
		5/1/13	5/2/13	5/3/13*	5/6/13	5/7/13	5/8/13	5/9/13	5/10/13
7.5	0 (Blank)	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00
	200	4.98	4.90	4.89	4.80	4.78	4.68	4.75	4.74
	400	4.31	4.22	4.15	4.13	4.10	4.06	4.08	4.15
	600	3.68	3.48	3.51	3.46	3.40	3.44	3.41	3.25
8.0	0 (Blank)	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00
	200	4.83	4.77	4.66	4.77	4.63	4.68	4.72	4.53
	400	4.12	4.06	4.12	4.07	4.06	4.01	4.08	3.95
	600	3.61	3.56	3.57	3.54	3.48	3.47	3.47	3.47
8.5	0 (Blank)	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00	≥5.00
	200	4.74	4.79	4.78	4.73	4.66	4.65	4.71	4.64
	400	4.13	4.25	4.11	4.05	4.03	4.04	3.99	3.88
	600	3.52	3.51	3.47	3.42	3.43	3.39	3.41	3.24

*Samples on Saturday 5/4/13 and Sunday 5/5/13 were not analyzed

HAZEN AND SAWYER
Environmental Engineers & Scientists

The stability of the monochloramines concentrations was determined by taking the difference of each sample day concentration from the initial concentration on May 1, 2013. The stability results after the tenth day of sampling are shown in **Table 6**.

Table 6: Monochloramine Stability Over 10 days

pH	Amount of Bromide Added (µg/L)	Monochloramine Reduction Over 10 Days (%)
7.5	0 (Blank)	0
	200	4.7
	400	3.7
	600	12
8.0	0 (Blank)	0
	200	6.1
	400	4.1
	600	3.9
8.5	0 (Blank)	0.0
	200	2.2
	400	6.2
	600	8.0

The trend of the monochloramines stability over the 10 day study is also illustrated in **Figure 2**.

HAZEN AND SAWYER
Environmental Engineers & Scientists

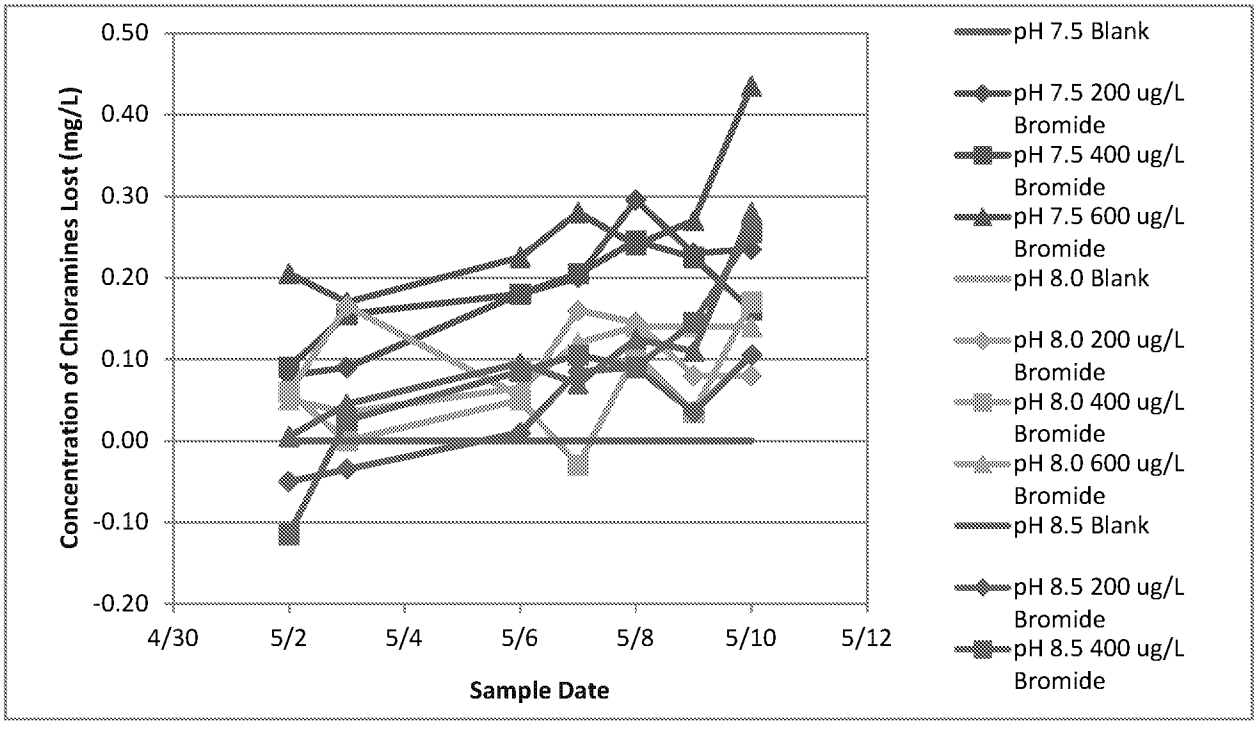


Figure 2: Monochloramine Reduction Over 10 days

6. Summary and Conclusions

Based on the results of this monochloramines stability test, it is evident that bromamines formation did not drastically increase monochloramine residual scavenging under the conditions tested. Therefore, bromamines does not appear to be a significant issue for the City of Eden. The highest monochloramine residual scavenging was approximately 12 percent and was observed at pH 7.5 with a bromide concentration of 600 µg/L. Monochloramine scavenging appeared to be suppressed at higher pH values and lower bromide concentrations.

However, there are some competing water quality considerations with respect to pH. Monochloramine formation is more rapid at a pH range of pH 7.5 to 8.5 (when the reaction is complete within 0.1 to 0.2 seconds) with the optimal pH at 8.3. Also, studies have shown that phosphate-based corrosion inhibitors are less effective at pH values greater than 7.8. Therefore, the City of Eden should target a finished water pH in the range of 7.8 to 8.0 to balance between effectiveness of the phosphate-based corrosion inhibitor, and monochloramines residual scavenging. NC Department of Environment and Natural Resources typically requires a corrosion study to evaluate corrosion treatment when a switch to chloramines disinfection is being considered. During this study, alternate finished water pH values could be evaluated to assess the impact on lead and copper corrosion, and monochloramine stability.

During design of the chloramines upgrades, we also recommend that the need for chlorine/chloramine boosting be evaluated for the points of sales to wholesale customers. In these locations, water age may be significantly higher than the 10 days simulated in this test.

HAZEN AND SAWYER
Environmental Engineers & Scientists

7. References

Benotti, M. J.; Wert, E. C.; Snyder, S. A.; Owen, C.; Cheng, R. (2011). “Role of Bromamines on DBP Formation and Impact on Chloramination and Ozonation”. Water Research Foundation Report 4159.

Inman, G. W. and J. D. Johnson (1984). "Kinetics of Monobromamine Disproportionation-Dibromamine Formation in Aqueous Ammonia Solutions." Environmental Science & Technology **18**(4): 219-224.

Sugam, R. and G. R. Helz (1978). "Seawater Chlorination: A Descirption of Chemical Speciation." 427-433.

Zhang, Y., T. J. Tseng, et al. (2012). "Pilot-Scale Evaluation of Blending Desalinated seawater into a Distribution System." JAWWA **104**(0109): 416-430.

Appendix B

Granular Activated Carbon (GAC) Pilot Study at the Robert A. Harris Water Treatment Plant

CITY OF EDEN, NORTH CAROLINA

Granular Activated Carbon (GAC) Pilot Study at the Robert A. Harris Water Treatment Plant

May 2013

HAZEN AND SAWYER
Environmental Engineers & Scientists
4011 WestChase Boulevard, Suite 500
Raleigh, NC 27607

TABLE OF CONTENTS

LIST OF FIGURES ii

LIST OF TABLES iii

1 INTRODUCTION 1-1

1.1 Background 1-1

1.2 Objectives and Scope 1-2

1.3 Report Organization 1-2

2 EXPERIMENTAL SET-UP AND METHODS 2-1

2.1 General 2-1

2.2 GAC Pilot Experimental Set-Up 2-2

2.3 Pilot Testing Methods 2-4

3 RESULTS 3-1

3.1 GAC Pilot Results - General Water Quality 3-1

3.2 GAC Pilot Results – Bromide Data 3-5

3.3 GAC Pilot Results – TOC Data 3-6

3.4 GAC Pilot Results - TTHM Data 3-9

4 CONCLUSIONS AND RECOMMENDATIONS 4-1

LIST OF FIGURES

Figure 1: Photograph of the GAC Pilot Plant (Filters 5 through 8) 2-1
Figure 2: GAC Pilot Plant Flow Schematic 2-4
Figure 3: Turbidity Data 3-2
Figure 4: UV_{254} Data 3-4
Figure 5: Bromide Concentration Data 3-6
Figure 6: TOC C/C0 for Each Column 3-7
Figure 7: GAC Column Influent and Effluent TOCs 3-8
Figure 8: SDS-TTHM Data 3-11

LIST OF TABLES

Table 1: GAC Type and EBCTs for the Eight Pilot Columns 2-2
Table 2: Typical Properties of the GACs Tested 2-3
Table 3: Turbidity Data 3-1
Table 4: UV_{254} Data 3-3
Table 5: pH Data 3-4
Table 6: Bromide Concentration Data 3-5
Table 7: TOC Data 3-9
Table 8: SDS-TTHM Data 3-10

1 INTRODUCTION

1.1 BACKGROUND

The Robert A. Harris Water Treatment Plant (Robert Harris WTP) provides drinking water to the City of Eden, North Carolina and some surrounding communities that purchase water from the City of Eden. The Robert Harris WTP is a conventional water treatment plant and has been in service since 1978. The WTP has a current capacity of 21 million gallons per day (mgd) and is located at 191 Mebane Bridge Road in Eden.

The WTP gets its raw water from the Dan River with an intake and a raw water pumping station located at the south end of Bridge Street. A 30-inch diameter pipe delivers water to the WTP site into the 87 million gallon capacity pre-settling impoundment (pre-sedimentation basin). The treatment process consists of the pre-settling impoundment (provides approximately 4 to 5 days of detention time and turbidity equalization), rapid mix tank with mixer (where alum and caustic are added), six-stage flocculation tank with mechanical flocculators and tapered mixing (hydraulic detention time of 45 minutes at 21 mgd flow), seven settling basins, and seven dual-media filters with 18 inches of anthracite over 12 inches of silica sand. Chlorine is added upstream of the filters to maintain a chlorine residual of 0.3 to 0.7 mg/L in the filter effluent. Filtered water enters a series of flumes below the filters. The following post-filtration chemicals are added in these flumes: caustic for pH/alkalinity adjustment, chlorine for disinfection, and fluoride and a corrosion inhibitor chemical. The Eden water system uses free chlorine for both primary and secondary disinfection.

In 2008, the City of Eden began observing elevated levels of total trihalomethanes (TTHMs) at its Stage 1 D/DBP Rule monitoring sites. Even though there was no significant increase in raw water and finished water TOCs, the WTP also noticed an increase in raw water hardness and chloride at the same time. In 2011, another consulting firm prepared a D/DBP Compliance Study Report for the City of Eden and identified bromide as a significant component of the TTHMs and attributed the TTHM increase to changes in raw water quality.

In January 2011, WTP staff collected water samples from the Dan River upstream of the Robert Harris WTP at various bridge locations to identify the bromide source. During 2011, the raw water (pre-sedimentation basin) bromide concentration varied from a low of 88 parts per billion (ppb) to a high of 492 ppb. A review of the TTHM speciation showed an increase in the percentage of brominated THMs (bromodichloromethane, dibromochloromethane and bromoform) and a corresponding decrease in the chlorinated THM species percentage.

Due to the increase in bromide levels and higher TTHMs in the distribution system, the City of Eden was concerned over Stage 2 D/DBP Rule compliance since the new rule uses the locational running annual average (LRAA) approach. The Stage 2 D/DBP Rule becomes effective for Eden in October 2013.

This GAC pilot study was authorized to study the impact of granular activated carbon (GAC) on the removal of TOC, bromide and pre-formed TTHMs (TTHMs formed due to chlorine addition during the filtration process). The GAC pilot study also evaluated TTHM formation potential of the GAC treated water. Pilot-scale post-filtration GAC contactors were used in this study. The rate and extent of TTHM formation is a function of many factors. These factors include amount of TOC (or natural organic matter) present, pH, temperature, chlorine dose and chlorine contact time, and bromide concentration (when bromide is present).

1.2 Objectives and Scope

The purpose of this GAC pilot study was to evaluate granular activated carbon (GAC) as a post-filtration treatment method to reduce the amount of total organic carbon (TOC), bromide, and pre-formed total trihalomethanes (TTHMs) in the finished water prior to final chlorination in order to comply with the Stage 2 D/DBP Rule. The main objectives of this study were to:
(1) Monitor raw water, filtered water and GAC effluent TOC and bromide concentrations to evaluate the removal potential over time
(2) Study the removal of pre-formed THMs in the GAC columns and estimate TTHM formation at the high water age sites in the Eden distribution system using simulated distribution system (SDS) THM tests
(3) Monitor filtered water quality and GAC effluent water quality
(4) Evaluate Stage 2 Disinfectants/Disinfection Byproducts (D/DBP) Rule using SDS-THM data
(5) Evaluate GAC life based on TOC breakthrough and SDS-THM data.

This study was conducted for 5 months (September 2012 through February 2013) to assess performance with variable TOC and bromide concentrations.

Four different GACs were obtained from two different manufacturers and tested to determine performance for two different empty bed contact times (EBCTs). The Robert Harris WTP filtered water was used as influent to the GAC pilot columns. Two EBCTs (approximately 10 minutes and 20 minutes) were used to test each type of GAC.

1.3 Report Organization

This report has been divided into four sections:

- Section 1 – Introduction
- Section 2 – Experimental Set-Up and Methods
- Section 3 – Results
- Section 4 – Conclusions and Recommendations

2 EXPERIMENTAL SET-UP AND METHODS

2.1 GENERAL

Pilot column testing of GAC for organics and DBP precursor removal was tested at the Robert Harris WTP for a period of five months (from September 2012 to February 2013). The pilot was located in the WTP filter gallery. Six-inch diameter columns were used for this study. The GAC pilot plant was fed using filtered water from the Robert Harris WTP. Figure 1 is a photograph of one of the two column racks in GAC pilot plant used at the Robert Harris WTP.

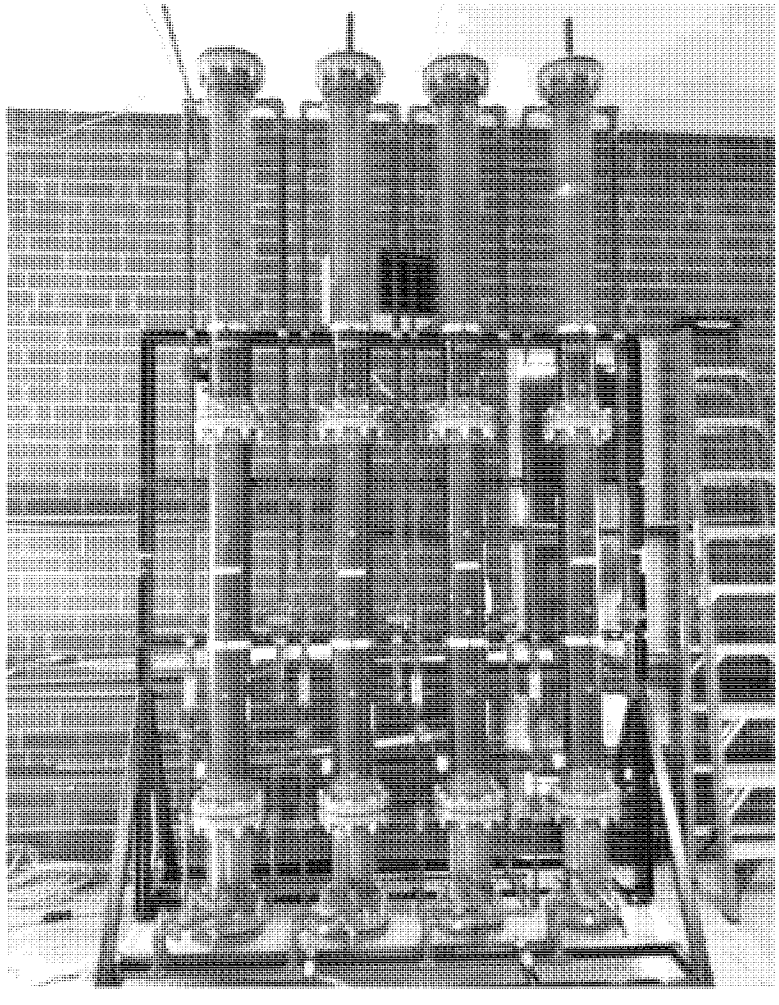


Figure 1: Photograph of the GAC Pilot Plant (Filters 5 through 8)

2.2 GAC Pilot Experimental Set-Up

Six-inch diameter columns were used for the pilot study. Each column was filled with 65 inches of GAC on top of 8 inches of torpedo sand. The empty bed contact time (EBCT) in each pilot column was 10.8 minutes. The GAC filters were operated at a flow rate of 0.8 gpm. This corresponded to a filter loading rate of 4.1 gallons per minute per square feet (gpm/sqft). Due to height restrictions in the filter gallery, the tops of filters 1, 3, 5 and 7 were capped and operated under pressure to provide adequate head in filters 2, 4, 6 and 8 to maintain the 0.8 gpm flow rate. The effluent valves for filters 1, 3, 5 and 7 were fully open while the effluent valves for filters 2, 4, 6 and 8 were partially closed to maintain the desired flow rate while maintaining adequate water head in these filters (approximately 3 to 4 ft of water above the GAC media)

Four different GACs were tested in this study. Two of the GACS were bituminous coal based, one was coconut shell based, and another was lignite coal based. Columns 1 and 2 were filled with Calgon Carbon Corporation's FILTRASORB 300 (8 x 30 mesh). Columns 3 and 4 were filled with Calgon Carbon Corporation's FILTRASORB 600 (12 x 40 mesh). Columns 5 and 6 were filled with Calgon Carbon Corporation's OLC (12 x 30 mesh). Columns 7 and 8 were filled with Norit Americas Inc.'s HD 3000 (8 x 30 mesh).

Columns 1 and 2 were operated in series, with effluent from Column 1 providing 10.8 minutes of EBCT and effluent from Column 2 providing 21.6 minutes of EBCT (FILTRASORB 200). Similarly, Columns 3 and 4 were operated in series, and columns 5 and 6 were operated in series. Table 1 summarizes the type of GAC used and the EBCT for the eight columns.

Table 1: GAC Type and EBCTs for the Eight Pilot Columns

Column No.	GAC Media	EBCT (min)
1	FILTRASORB 300	10.8
2	FILTRASORB 300	21.6
3	FILTRASORB 600	10.8
4	FILTRASORB 600	21.6
5	OLC	10.8
6	OLC	21.6
7	HD 3000	10.8
8	HD 3000	21.6

Table 2 summarizes the typical properties and product specifications for FILTRASORB 300, FILTRASORB 600, OLC, and HD 3000 (obtained from the manufacturer's data sheets). All of the GACs tested meet NSF/ANSI Standard 61 requirements.

Table 2: Typical Properties of the GACs Tested

Parameter	F300-M	F600	OLC 12x30	HD3000
Manufacturer	Calgon	Calgon	Calgon	Norit
GAC type	Bituminous coal	Bituminous coal	Coconut shell based	Lignite coal
Mesh size	8 x 30 (15% max on 8 mesh, 4% max thru 30 mesh)	12 x 40 (5% max on 12 mesh, 4% max thru 40 mesh)	12 x 30	8 x 30 (5% max on 8 mesh, 5% max thru 30 mesh)
Effective Size and Uniformity Coeff	ES = 0.8-1.0 mm UC = 2.1 (max)	Not available	Not available	ES = 0.7-0.9 mm UC = 2.1 (max)
Iodine Number	900 mg/g (min)	850 mg/g (min)	Not available	500 mg/g (min)
Tannin Value	Not available	Not available	Not available	150 mg/L
Abrasion Number	78 (min)	80 (min)	Not available	70 (min)
Apparent Density	0.58 g/cc	0.62 g/cc	Not available	0.38 g/cc
Trace Capacity Number	10 mg/cc (min)	16 mg/cc (min)	Not available	Not available

Figure 2 is a schematic of the GAC pilot plant. Robert Harris WTP filtered water was split as feed water to Columns 1, 3, 5, and 7. The Harris WTP has a filtered water sample pump located in the filter gallery to pump filtered water from the filter flume to the laboratory. A tee was installed on the sample pump discharge and was used as feed water to the GAC pilot plant. Two separate garden hoses were used to feed the two sets of pilot filters. The flow to GAC columns 1, 3, 5 and 7 were adjusted to 0.8 gpm using the corresponding ball valves. The gate valves to filters 2, 4, 6 and 8 were left fully open since these columns were being fed by filters 1, 3, 5 and 7 respectively. A sample tap on the feed line was used to collect the influent sample. Effluent from Column 1 flowed to Column 2, effluent from Column 3 flowed to Column 4, effluent from Column 5 flowed to column 6, and effluent from Column 7 flowed to Column 8. Sample taps were provided at the bottom of the eight columns to collect effluent samples from those columns.

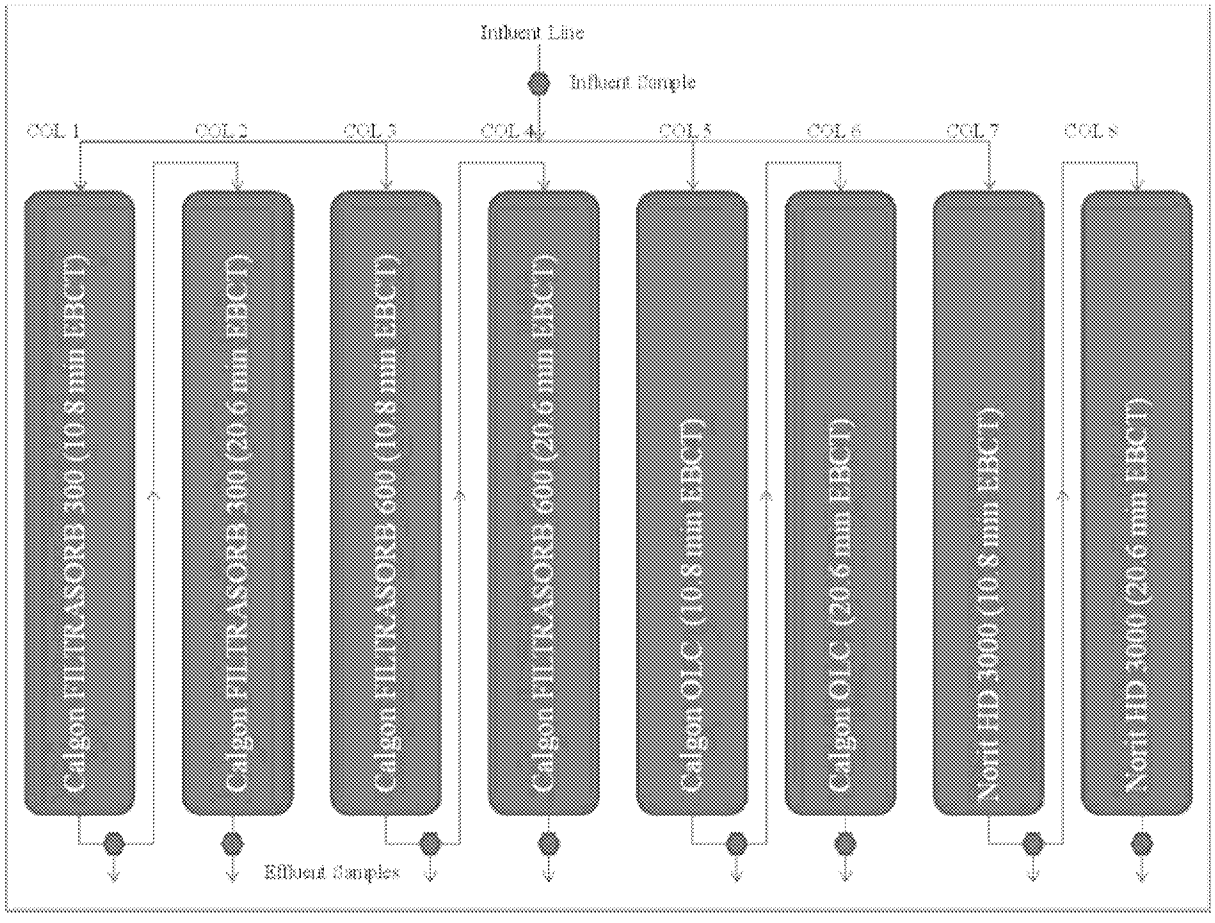


Figure 2: GAC Pilot Plant Flow Schematic

The eight filter columns were mounted on two separate unistrut frames (four filters per unistrut frame). Figure 1 (in Section 1) is a photograph of one of the unsitrut frames with four filters. The two unistrut frames, along with the eight filters, were located in the Harris WTP filter gallery during the study.

The first unsitrut frame was labeled 1-2 and included filter columns 1 through 4. The second unistrut frame was labeled 3-4 and included filter columns 5 through 8. The influent pipe to each filter was equipped with a gate valve and flow meter.

2.3 Pilot Testing Methods

Hazen and Sawyer staff visited the GAC pilot plant once every two weeks. During each visit, the rotameters for the eight columns were checked and the flows were adjusted accordingly. Between visits, Robert Harris WTP staff monitored the GAC pilot plant on a daily basis.

TOC samples were collected from the following locations: raw water intake, GAC influent, Column 1 effluent, Column 2 effluent, Column 3 effluent, Column 4 effluent, Column 5 effluent, Column 6 effluent, Column 7 effluent, Column 8 effluent. The TOC samples were shipped to a certified environmental laboratory (James R. Reed and Associates, Newport News, VA) for analysis.

Simulated distribution system (SDS) tests for TTHMs were conducted by both a certified environmental laboratory and NC State University five times during the GAC pilot study. The SDS tests were conducted by dosing with chlorine and storing the samples in a headspace-free amber glass bottles (away from direct sunlight) at room temperature (approximately 75°F) for 14 days. At the end of the 14 days, one 20 mL vial of the same was used to measure the total residual chlorine concentration. The remaining samples were quenched using sodium thiosulfate. The samples were then stored in a refrigerator (40°F) until they were shipped to the certified laboratory for analysis.

The SDS-TTHM tests were conducted on the eight GAC column effluent samples. A SDS-TTHM test on the GAC column influent water was conducted each time to compare changes in THM formation.

3 RESULTS

3.1 GAC Pilot Results - General Water Quality

Pilot influent and effluent water quality data was collected during the study. Samples of the pre-sedimentation basin raw water, GAC influent, and the eight column effluents were collected and analyzed for turbidity, and UV_{254}. Samples of the GAC influent, the point of entry (POE), and only Columns 1, 3, 5, and 7 were analyzed for pH.

Turbidity data is summarized in Table 3 and Figure 3. UV_{254} data is summarized in Table 4 and Figure 4 and pH data is summarized in Table 5.

Table 3: Turbidity Data

Date	Turbidity (NTU)								
	GAC Influent	GAC Col 1 Calgon F300 (EBCT= 10.8 min)	GAC Col 2 Calgon F300 (EBCT= 21.6 min)	GAC Col 3 Calgon F600 (EBCT= 10.8 min)	GAC Col 4 Calgon F600 (EBCT= 21.6 min)	GAC Col 5 Calgon OLC (EBCT= 10.8 min)	GAC Col 6 Calgon OLC (EBCT= 21.6 min)	GAC Col 7 Norit HD 3000 (EBCT= 10.8 min)	GAC Col 8 Norit HD 3000 (EBCT= 21.6 min)
9/25/12	0.05	0.05	0.05	0.06	0.05	0.05	0.06	0.05	0.05
10/09/12	0.06	0.06	0.07	0.06	0.06	0.09	0.09	0.07	0.07
10/26/12	0.07	0.08	0.08	0.12	0.07	0.06	0.06	0.08	0.07
11/18/12	0.06	0.07	0.05	0.06	0.07	0.06	0.06	0.05	0.06
11/21/12	0.07	0.06	0.06	0.07	0.08	0.07	0.08	0.06	0.07
12/04/12	0.07	0.04	0.05	0.06	0.05	0.06	0.06	0.05	0.05
12/19/12	0.05	0.06	0.06	0.06	0.06	0.10	0.23	0.07	0.07
1/03/13	0.05	0.06	0.09	0.06	0.06	0.09	0.10	0.07	0.09
1/15/13	0.05	0.06	0.07	0.06	0.07	0.10	0.11	0.07	0.06
1/29/13	0.06	0.05	0.06	0.20	0.08	0.18	0.09	0.12	0.06
2/11/13	0.07	0.07	0.06	0.13	0.06	0.09	0.09	0.08	0.08

The Robert Harris WTP measures turbidity in the raw water and settled water on a daily basis. Little difference was observed from the GAC influent turbidities and the GAC column effluents.

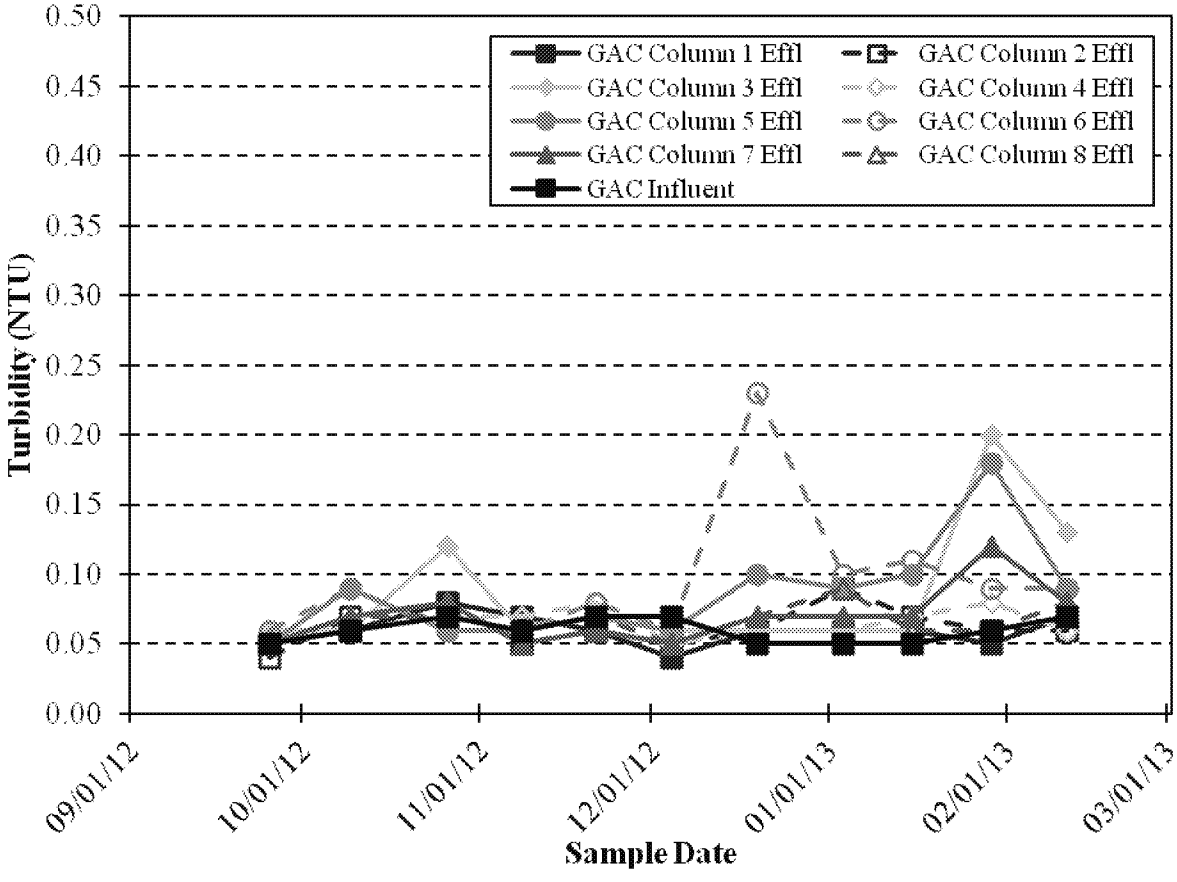


Figure 3: Turbidity Data

Table 4: UV_{254} Data

Date	UV_{254} (cm^{-1})									
	Pre-Sed Basin Raw	GAC Influent	GAC Col 1 Calgon F300 (EBCT = 10.8 min)	GAC Col 2 Calgon F300 (EBCT = 21.6 min)	GAC Col 3 Calgon F600 (EBCT = 10.8 min)	GAC Col 4 Calgon F600 (EBCT = 21.6 min)	GAC Col 5 Calgon OLC (EBCT = 10.8 min)	GAC Col 6 Calgon OLC (EBCT = 21.6 min)	GAC Col 7 Norit HD 3000 (EBCT = 10.8 min)	GAC Col 8 Norit HD 3000 (EBCT = 21.6 min)
9/11/12	--	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9/25/12	0.083	0.018	0.000	0.000	0.000	0.000	0.008	0.002	0.000	0.000
10/09/12	0.080	0.015	0.000	0.000	0.003	0.000	0.009	0.004	0.000	0.002
10/26/12	0.066	0.017	0.001	0.000	0.005	0.000	0.010	0.008	0.001	0.000
11/08/12	0.067	0.014	0.001	0.000	0.007	0.001	0.013	0.008	0.002	0.000
11/21/12	0.066	0.011	0.002	0.000	0.006	0.001	0.010	0.008	0.002	0.000
12/04/12	0.054	0.011	0.003	0.001	0.008	0.002	0.009	0.008	0.004	0.000
12/19/12	0.040	0.011	0.003	0.000	0.006	0.003	0.008	0.007	0.005	0.001
1/03/13	0.067	0.015	0.007	0.000	0.009	0.005	0.013	0.013	0.007	0.001
1/15/13	0.062	0.017	0.007	0.001	0.010	0.007	0.013	0.013	0.010	0.005
1/29/13	0.095	0.016	0.008	0.002	0.011	0.008	0.014	0.013	0.009	0.003
2/11/13	0.066	0.014	0.007	0.001	0.009	0.005	0.011	0.010	0.008	0.003

For UV_{254}, the column effluent UV_{254} values increased with time. The column effluent UV_{254} values were much lower than the pre-sedimentation basin raw water and the GAC influent UV_{254} values indicating that the GAC removed aromatic organic content, which can lead to decreased DBP formation. Comparing the four different types of GACs, Calgon bituminous coal based carbons and the Norit lignite coal based carbon were comparable, while the Calgon coconut shell based carbon performed the worst. The Norit HD 3000 performed the best at the 21.6 min EBCT.

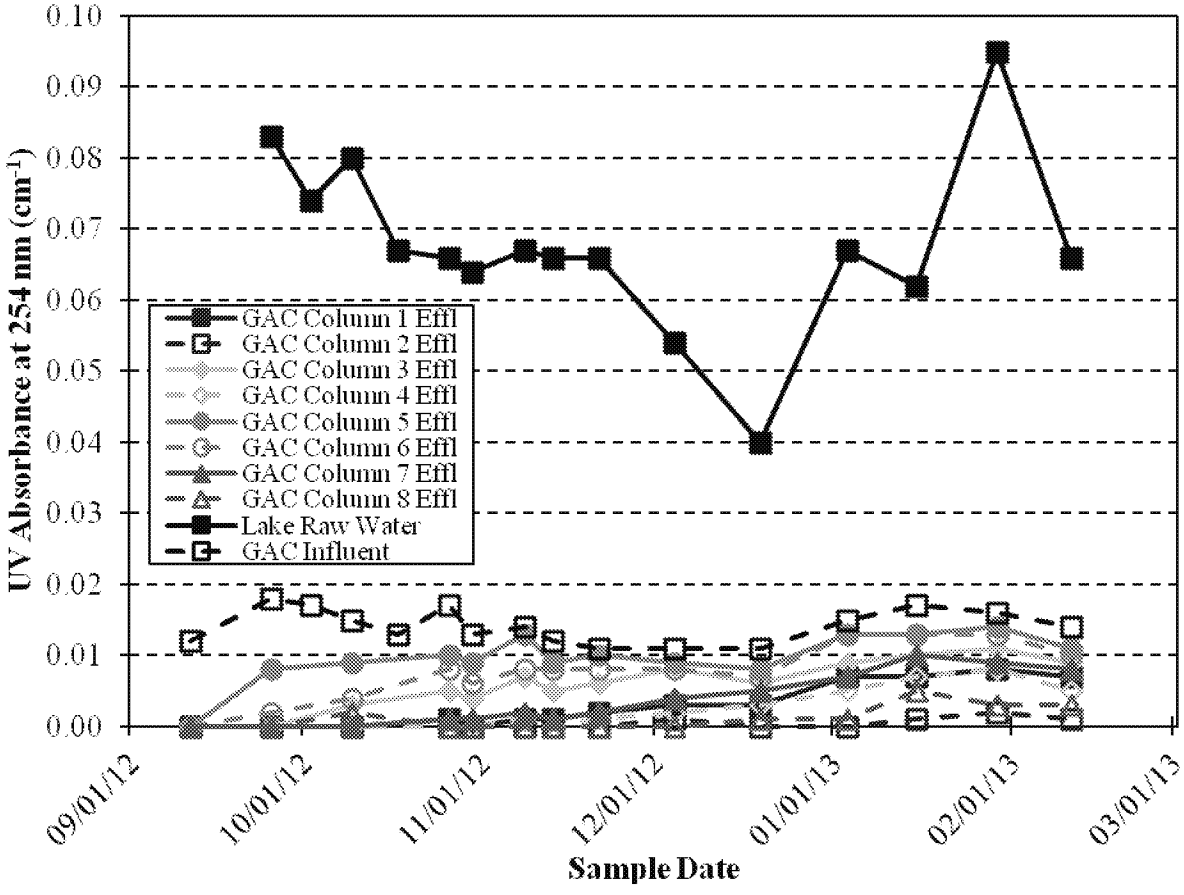


Figure 4: UV_{254} Data

Table 5: pH Data

Date	pH					
	POE	GAC Influent	GAC Col 1 Calgon F300 (EBCT= 10.8 min)	GAC Col 3 Calgon F600 (EBCT= 10.8 min)	GAC Col 5 Calgon OLC (EBCT= 10.8 min)	GAC Col 7 Norit HD 3000 (EBCT= 10.8 min)
9/25/12	7.2	6.4	6.2	6.1	6.1	6.1
10/09/12	7.2	6.4	6.3	6.2	6.2	6.2
10/26/12	7.2	6.4	6.3	6.3	6.3	6.4
11/08/12	7.1	6.4	6.5	6.4	6.4	6.4
11/21/12	7.2	6.5	6.5	6.5	6.5	6.4
12/04/12	7.2	6.6	6.7	6.6	6.6	6.6
12/19/12	7.2	7.1	7.1	7.1	7.1	7.1
1/13/12	7.1	7.1	7.1	7.0	7.0	7.0
1/15/12	7.1	6.8	6.8	6.8	6.8	6.8
1/29/12	7.1	6.7	6.6	6.6	6.6	6.6
2/11/12	7.2	6.8	6.8	6.8	6.8	6.8

The pH values remained relatively steady throughout the study. Little difference was observed between the influent and the effluent from the GAC columns.

Temperature of the GAC influent was also collected throughout the study. Temperature varied between a high of 23°C (73°F) in September 2012 to a low of 8°C (46°F) in January 2013.

3.2 GAC Pilot Results – Bromide Data

Bromide samples were collected during the course of the study at WTP influent (following pre-sedimentation basin), GAC influent (with the quenching agent, sodium thiosulfate, added), and the eight column effluents were collected for bromide concentration analysis.

The bromide test data for the pre-sedimentation basin raw water and the eight GAC column effluents is summarized in Table 6. Bromide concentration data are also illustrated in Figure 5 for the twelve data sets.

Table 6: Bromide Concentration Data

Date	Bromide (ppb)								
	Raw (Pre-Sed)	GAC Col 1 Calgon F300 (EBCT= 10.8 min)	GAC Col 2 Calgon F300 (EBCT= 21.6 min)	GAC Col 3 Calgon F600 (EBCT= 10.8 min)	GAC Col 4 Calgon F600 (EBCT= 21.6 min)	GAC Col 5 Calgon OLC (EBCT= 10.8 min)	GAC Col 6 Calgon OLC (EBCT= 21.6 min)	GAC Col 7 Norit HD 3000 (EBCT= 10.8 min)	GAC Col 8 Norit HD 3000 (EBCT= 21.6 min)
9/11/12	221	35	30	11	10	43	52	10	10
9/25/12	205	125	147	122	146	136	111	120	141
10/09/12	168	99	112	106	119	98	107	99	100
10/26/12	156	98	97	99	97	101	100	101	97
11/18/12	174	101	99	102	99	101	103	95	101
11/21/12	148	95	95	93	94	92	93	97	95
12/04/12	155	97	93	96	93	95	97	96	99
12/19/12	195	137	132	133	129	134	133	158	139
1/03/13	155	99	99	100	102	97	96	101	104
1/15/13	170	115	114	112	113	112	110	119	125
1/29/13	117	80	81	78	80	74	76	85	85
2/11/13	95	68	72	66	72	62	66	71	72

For bromide, the column effluent bromide concentrations were much lower than the raw water (pre-sedimentation basin) bromide concentrations indicating that during the treatment process, some bromide is removed or transformed. The column effluent bromide concentrations were not significantly different from the GAC influent concentrations, indicating that the GAC columns do not provide substantial bromide reductions. Additionally, there was no significant difference between the 10.8 min and 21.6 min EBCT columns.

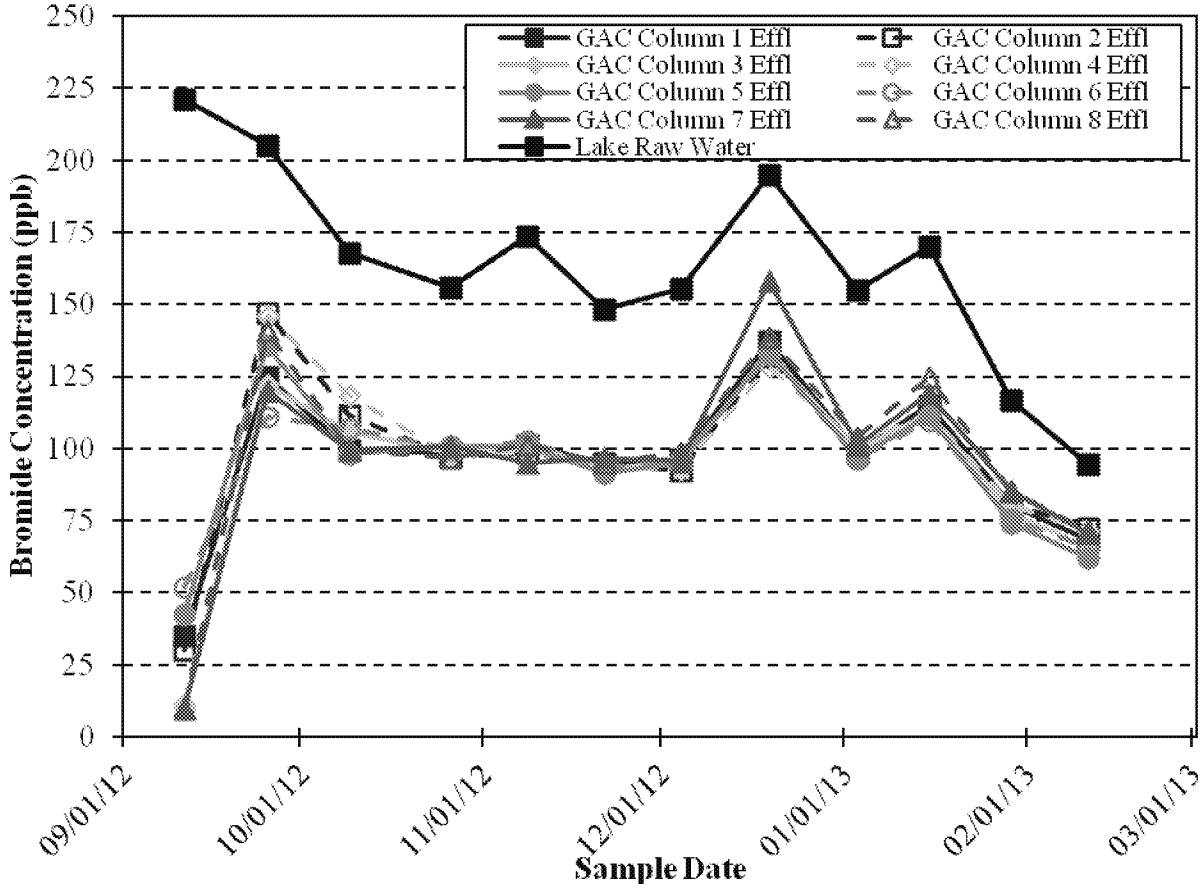


Figure 5: Bromide Concentration Data

3.3 GAC Pilot Results – TOC Data

Typically, TOC is removed by the GAC and resultant effluent TOCs are usually very low (<0.5 mg/L). Over time, GAC adsorption capacity is utilized and TOC removal column effluent TOC concentrations begin to increase until a "breakthrough" value is reached. At that time, the GAC is considered to be exhausted and should be replaced with new virgin GAC or regenerated GAC. The amount of time it takes for the GAC to reach the breakthrough TOC value is termed as "GAC exhaustion time".

A plot of GAC column effluent TOC versus time is referred to as a TOC breakthrough curve. During this study, TOC curves were developed for all eight GAC pilot columns. Figure 6 is breakthrough plot of the raw TOC, influent TOC, and effluent TOC for the eight GAC columns. Figure 7 illustrates the trends of the influent and effluent TOCs for each of the eight columns.

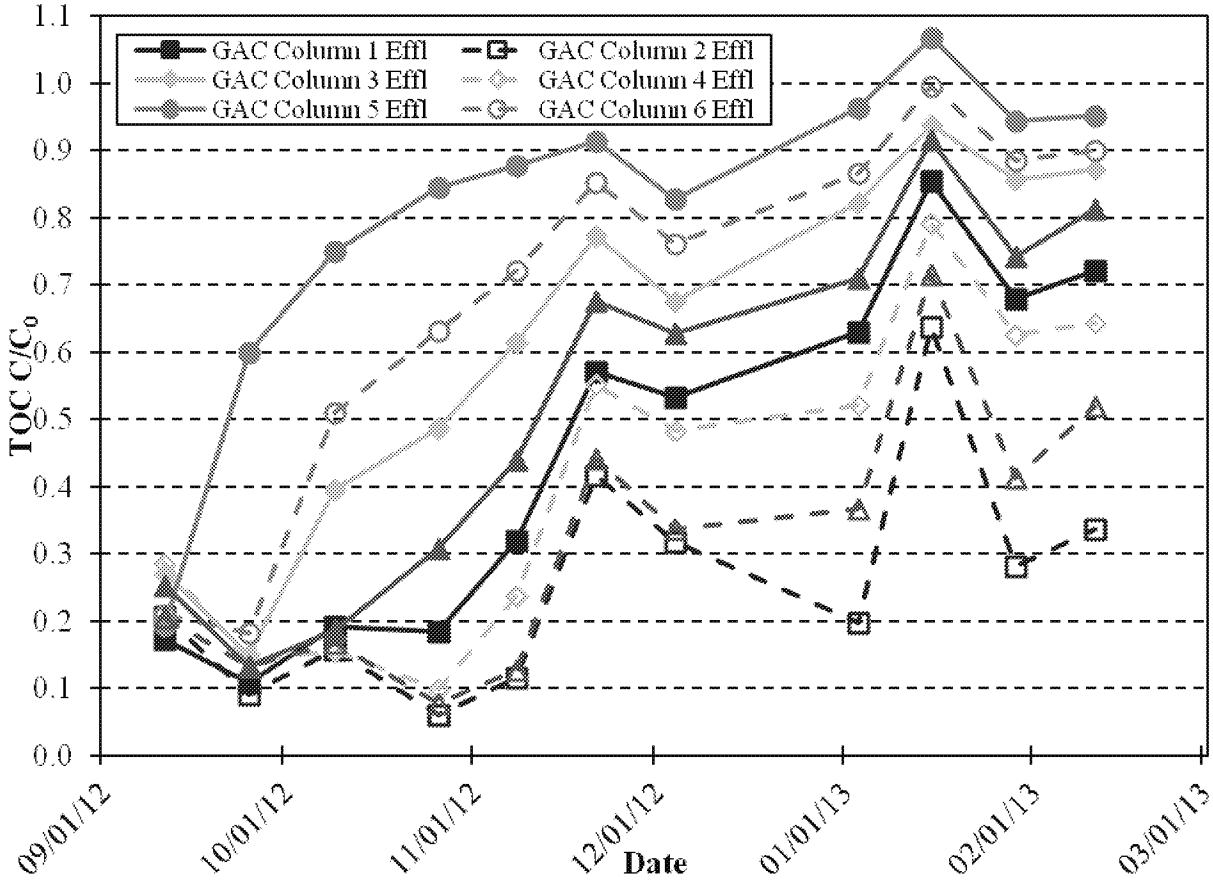


Figure 6: TOC C/C0 for Each Column

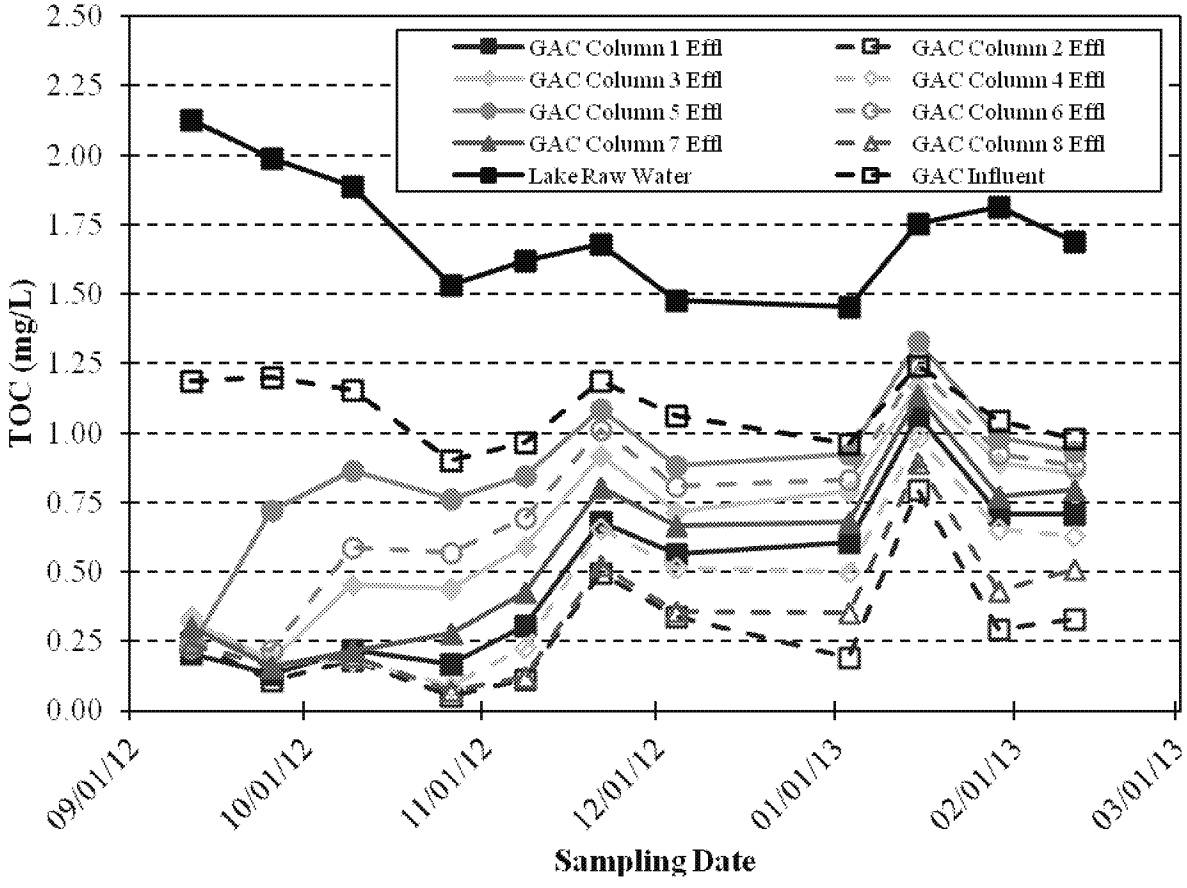


Figure 7: GAC Column Influent and Effluent TOCs

During the pilot Study (September 2012 to February 2013), the raw water TOC varied from 1.45 mg/L to 2.13 mg/L. Filtered water TOC (GAC column influent) varied from 0.90 mg/L to 1.24 mg/L. TOC concentrations in the GAC effluent are a function of the influent TOC as shown in Figure 6, particularly once the carbon begins to reach exhaustion. Table 7 is a summary of TOC data.

Table 7: TOC Data

Date	TOC (mg/L)									
	Pre-Sed Basin Raw	GAC Influent	GAC Col 1 Calgon F300 (EBCT = 10.8 min)	GAC Col 2 Calgon F300 (EBCT= 21.6 min)	GAC Col 3 Calgon F600 (EBCT = 10.8 min)	GAC Col 4 Calgon F600 (EBCT = 21.6 min)	GAC Col 5 Calgon OLC (EBCT = 10.8 min)	GAC Col 6 Calgon OLC (EBCT = 21.6 min)	GAC Col 7 Norit HD 3000 (EBCT = 10.8 min)	GAC Col 8 Norit HD 3000 (EBCT = 21.6 min)
09/11/12	2.13	1.19	0.21	0.25	0.32	0.34	0.23	0.25	0.30	0.24
09/25/12	1.99	1.20	0.13	0.11	0.18	0.17	0.72	0.22	0.16	0.16
10/09/12	1.89	1.15	0.22	0.18	0.46	0.18	0.86	0.59	0.21	0.19
10/26/12	1.54	0.90	0.17	0.06	0.44	0.09	0.76	0.57	0.28	0.07
11/08/12	1.62	0.97	0.31	0.11	0.59	0.23	0.85	0.70	0.42	0.12
11/21/12	1.68	1.19	0.68	0.49	0.92	0.66	1.09	1.01	0.80	0.53
12/04/12	1.48	1.06	0.57	0.34	0.72	0.51	0.88	0.81	0.67	0.36
01/03/13	1.45	0.96	0.61	0.19	0.79	0.50	0.93	0.83	0.68	0.35
01/15/13	1.75	1.24	1.06	0.79	1.17	0.99	1.33	1.24	1.14	0.89
01/29/13	1.81	1.04	0.71	0.29	0.89	0.65	0.98	0.92	0.77	0.43
02/11/13	1.69	0.98	0.71	0.33	0.85	0.63	0.93	0.88	0.80	0.51

3.4 GAC Pilot Results - TTHM Data

Total trihalomethanes (TTHMs) data was collected biweekly during this study. Samples of the GAC column influent, point of entry (POE), and the eight GAC pilot column effluents were collected for TTHM analyses. A 10-day simulated distribution system (SDS) test was used to predict TTHM concentrations at the high water age Stage 2 D/DBP Rule monitoring sites. Samples of the POE and the eight pilot column effluents were used for the 10-day SDS-TTHM tests.

The SDS-TTHM test data is summarized in Table 8. TTHM data are also illustrated in Figure 7.

Table 8: SDS-TTHM Data

Date	SDS-TTHM (ppb)								
	POE	GAC Col 1 Calgon F300 (EBCT= 10.8 min)	GAC Col 2 Calgon F300 (EBCT= 21.6 min)	GAC Col 3 Calgon F600 (EBCT= 10.8 min)	GAC Col 4 Calgon F600 (EBCT= 21.6 min)	GAC Col 5 Calgon OLC (EBCT= 10.8 min)	GAC Col 6 Calgon OLC (EBCT= 21.6 min)	GAC Col 7 Norit HD 3000 (EBCT= 10.8 min)	GAC Col 8 Norit HD 3000 (EBCT= 21.6 min)
9/25/12	119.7	0.5	0.5	2.3	0.5	29.3	0.6	0.7	0.6
10/09/12	136.7	3.0	1.4	20.0	2.0	21.8	28.0	3.3	1.9
10/26/12	108.2	7.4	2.5	31.4	4.1	53.5	35.3	10.0	1.7
11/08/12	96.1	13.2	0.5	16.9	7.1	54.1	40.7	17.9	0.5
11/21/12	85.5	19.1	0.7	36.1	14.0	49.2	40.1	27.1	1.9
12/04/12	76.6	26.4	0.6	33.9	12.9	45.1	38.2	26.6	2.3
12/19/12	102.9	40.9	5.1	56.4	30.5	74.4	65.9	52.0	11.7
1/03/13	101.7	52.5	12.8	66.4	41.9	76.5	69.6	57.9	18.0
1/15/13	96.5	47.9	13.7	59.2	37.9	70.4	63.6	56.0	21.6
2/11/13	77.9	43.4	16.4	48.4	36.9	56.0	49.2	51.0	23.4

All measures TTHM values were lower than the TTHM maximum concentration level (MCL) of 80 ppb but many of the TTHM values exceeded the water quality goal of 80 percent of the MCL (64 ppb).

For TTHMs, the column effluent SDS-TTHM increased with time and the 10.8 min EBCT TTHM values were higher than those for the 21.6 min EBCT columns. The column effluent TTHMs were much lower than the POE TTHMs indicating that the GAC removed TTHM precursors. Comparing the four different types of GACs, Calgon has slightly lower values than Norit for the 10.8 min EBCT columns. When comparing the 21.6 min EBCT columns, the bituminous coal and lignite coal based GACs performed much better than the coconut shell based GAC. The Calgon F300 performed the best at the 21.6 min EBCT. Figure 8 illustrates the SDS-THM data from the eight different pilot columns.

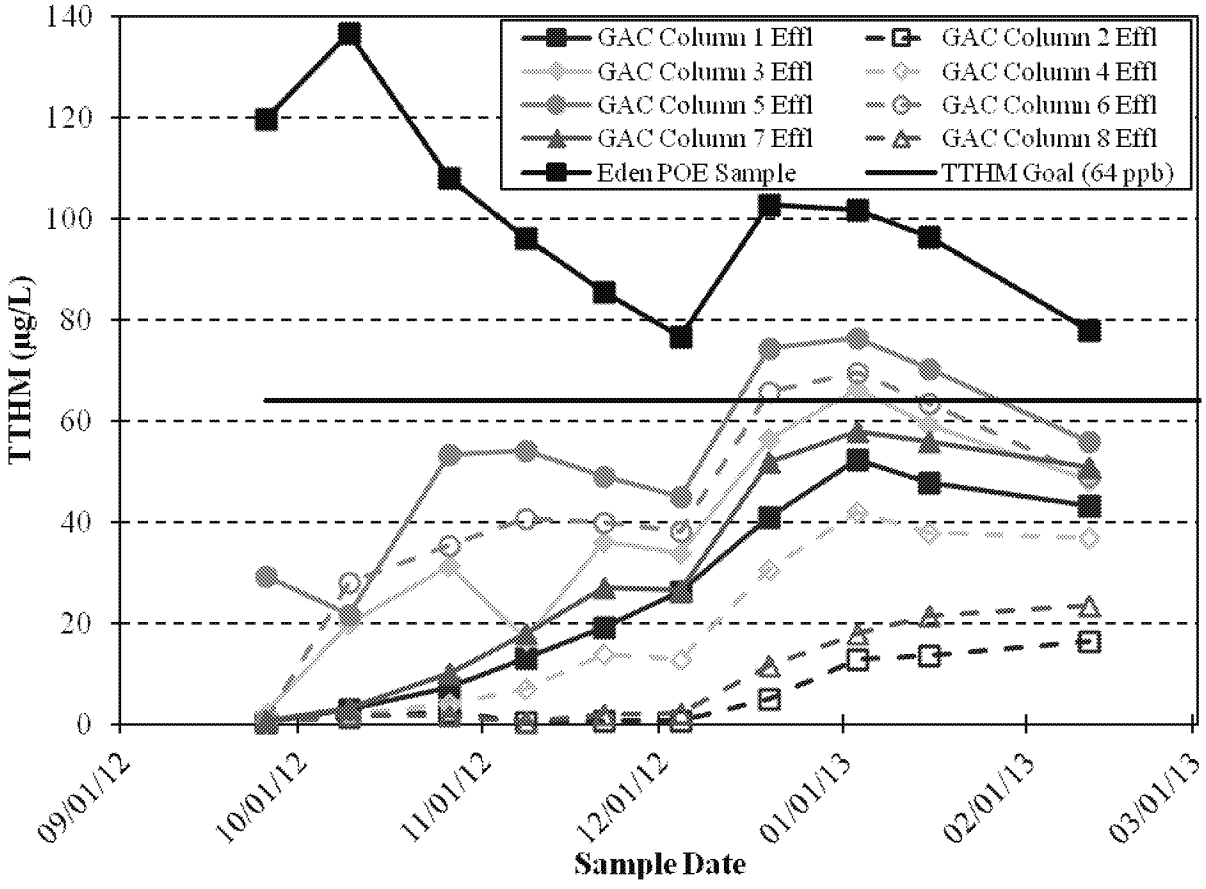


Figure 8: SDS-TTHM Data

4 CONCLUSIONS AND RECOMMENDATIONS

A five-month GAC pilot study was conducted at the Robert Harris WTP from September 2012 to February 2013. The Robert Harris WTP filtered water was used as influent to the GAC pilot plant. The GAC pilot plant included eight columns to evaluate four different carbons, Calgon FILTRASORB 300, Calgon FILTRASORB 600, Calgon OLC, and Norit HD 3000, at two EBCTs; 10.8 minutes and 21.6 minutes.

As expected, during the pilot study, UV_{254} measurements indicated that GAC was effective at removing aromatic organic compounds. Reduced aromatic content can be directly correlated to a reduction in final DBP concentrations. Additionally, pH and turbidity were not significantly altered through the use of GAC contactors throughout the pilot study.

During the pilot study, the column effluent TOCs varied widely depending on carbon type and EBCT. For many of the carbons, exhaustion was achieved during the five month study with over 80% breakthrough of TOC.

Bromide testing during the pilot study revealed that there was significant bromide removal from the pre-sedimentation basin raw water during the treatment process when GAC was included. However, bromide removal was not seen to be significantly enhanced by GAC contact.

SDS testing of TTHMs revealed that GAC was effective for removing THM precursors. The effluent SDS testing resulting in TTHM concentrations less than the 80µg/L MCL throughout the study. The Calgon OLC carbon made out of coconut shell came close to reaching the MCL with an EBCT of 10.8 min, but the remaining carbon based GACs were much better suited to reducing THM precursors. The 21.6 minute EBCT column effluents had much lower SDS-TTHM values. Hence the addition of 20 minute EBCT post-filter bituminous or lignite coal based GAC columns at the Robert Harris WTP is expected to allow the City of Eden to comply with the Stage 2 D/DBP Rule, and produce high quality potable water.

Draft Notes from Site Visit to Harris Treatment Plant on December 12, 2017

EPA conducted a site visit at the Robert A. Harris Water Filtration Plant (Harris Treatment Plant), a drinking water treatment (DWT) plant located in Eden, NC on Tuesday, December 12, 2017. The purpose of the site visit was to learn about DWT industry concerns regarding elevated bromide levels in source (intake) water to DWT plants, specifically the sources and impact of bromide on drinking water treatment and efforts to mitigate increased formation of disinfection byproducts (DBPs). Representatives from the Harris Treatment Plant, Town of Madison water treatment plant (Madison Water Treatment Plant), and North Carolina's Department of Environmental Quality (NC DEQ) participated in the discussion with EPA. ~~Error! Reference source not found. Error! Reference source not found. Table 1~~, below, lists the site visit participants. Attachment 1 is a presentation Harris Treatment Plant and Madison Water Treatment Plant personnel gave during the site visit. Attachment 2 is the National Pollutant Discharge Elimination System (NPDES) permit for Belews Creek Steam Station (Belews Creek Plant), a steam electric power generating facility located upstream from the water treatment plants. Attachment 3 is a written response from NC DEQ to the pre-site-visit questions drafted by EPA staff on the state's perspective on elevated bromide levels and drinking water treatment. Additional materials provided by the Harris Treatment Plant and the Madison Water Treatment Plant (i.e., multiple data spreadsheet files during and after the meeting) are included in the steam electric rulemaking record (DCN SE06477).

Table 1. Site Visit Attendees

Name	Organization	Contact Information
Dena Reid	Harris Treatment Plant	Phone: 336-627-1009 (ext. 131) Email: dreid@edennc.us
Melanie Clark	Harris Treatment Plant	Phone: 336-627-1009 Email: mclark@edennc.us
Terry Shelton	Harris Treatment Plant	Phone: 336-627-1009 Email: tshelton@edennc.us
Kevin Yates	Madison Water Treatment Plant	Phone: 336-427-3971 Email: madisonwtp@townofmadison.org
Eric Hudson	NC Department of Environmental Quality	Phone: 336-776-9665 Email: eric.hudson@ncdenr.gov
Rodney Darr	NC Department of Environmental Quality	Phone: 336-776-9662 Email: rodney.darr@ncdenr.gov
Gary Norris	EPA Office of Research and Development	Phone: 919-541-1519 Email: norris.gary@epa.gov
Michael Elovitz	EPA Office of Research and Development	Phone: 513-569-7642 Email: elovitz.michael@epa.gov
Richard Benware	EPA Office of Water	Phone: 703-308-0436 Email: benware.richard@epa.gov
Jimmy Chen	EPA Office of Water	Phone: 202-564-5258 Email: chen.jimmy@epa.gov
Ryan Novak	Eastern Research Group, Inc.	Phone: 703-633-1668 Email: ryan.novak@erg.com

Background

- The primary objective of Harris Treatment Plant and Madison Water Treatment Plant is production of potable water prior to distribution to the ~~Henry~~ Rockingham County public water system. Both facilities withdraw water through intakes on the

Dan River; the intake water is pumped to the treatment plant and treated to meet federal and state drinking water regulatory requirements, including DBP standards. The Harris Treatment Plant and Madison Water Treatment Plant have been operating since 1978 and 1972, respectively.

- **Harris Treatment Plant**, the larger of the two facilities, is located in Eden, NC and has a ~~service~~ population of 15,527 and serves approximately ~~69,000~~ 6,800 service connections~~households~~. The City of Eden also sells water to Dan River Water, Inc. that has approximately 4,700 service connections. Harris Treatment Plant has the capacity to produce 21 million gallons per day (MGD) of potable water, although current, routine operations are only 3 to 4 MGD. Water pumped from the Dan River ~~is~~ can be retained in a pre-settling impoundment for a period of five days. The impoundment allows the plant to operate for several days without drawing from the Dan River, as well as achieving reduction of turbidity and solids settling prior to active treatment. Active treatment consists of coagulation, disinfection, flocculation, sedimentation (solids settling), and filtration. More information on this facility can be found at https://www.edennc.us/220/Water-Treatment-Filtration-Division ~~https://www.edennc.us/199/Wastewater-Treatment-Division~~. [Note to Harris Facility: where was the disinfectant (i.e., chlorine before August 2017) typically applied before and after 2011 (e.g., at sedimentation basin, filter, and/or clearwell)? Please provide the total volume for each of the water storage facilities, including clearwell and water storage tanks in distribution system.] The first point of chlorination since 2002 has been at the filters. The finished water is stored in two 4 Million Gallon Clearwells before going into the distribution system. The system consists of 5 elevated storage tanks that can hold 2.25 million gallons of water total.

- **Madison Water Treatment Plant** is located in Madison, NC and has a service population of approximately 3,000 households. Madison Water Treatment Plant is designed to produce 1.5 MGD of potable water, but typical operations are approximately 0.5 MGD. Unlike Harris Treatment Plant, the water pumped from the Dan river is directly fed into the treatment process train in this plant. The plant treats the intake water in five steps: chemical coagulation, flocculation, sedimentation, filtration, and disinfection. http://madisonnc.govoffice3.com/index.asp?SEC=A281EA12-AD12-42AD-B59D-9654D76F1ACF&Type=B_BASIC&pri=0&tri=275 [Note to Madison Facility: where was the disinfectant (i.e., chlorine) typically applied before and after 2011 (e.g., at sedimentation basin, filter, and/or clearwell)? Please provide the total volume for each of the water storage facilities, including clearwell and water storage tanks in distribution system.]

- As part of the drinking water treatment process, Harris Treatment Plant and Madison Water Treatment Plant use a disinfectant (i.e., chlorine) to control harmful pathogens (e.g., *Giardia, Cryptosporidium,* viruses) in the source water. Disinfectants, such as chlorine, will inactivate or kill these microbial pathogens;

> however, these disinfectants may react with organic and inorganic constituents (including bromide) in source water to form DBPs, including trihalomethanes (THMs) and haloacetic acids (HAAs) when chlorine is used. These DBPs, if consumed in excess of EPA's standard over many years, may increase health risks.[1]

All public water systems that add a disinfectant, other than ultraviolet light, to the drinking water during the treatment process are required to comply with EPA's Stage 1 and Stage 2 Disinfectants and Disinfection Byproducts Rules (DBPRs). The DBPRs strengthen public health protection through standards, treatment techniques, and compliance monitoring requirements to reduce DBPs exposure. See the EPA's webpages for more related information: https://www.epa.gov/dwreginfo/stage-1-and-stage-2-disinfectants-and-disinfection-byproducts-rules

Emergence of DBPs Issues

- In accordance with EPA's DBPRs, Harris Treatment Plant and Madison Water Treatment Plant conduct quarterly monitoring of treated water for the regulated total THMs (TTHM or THM4) and HAA5.[2] In 2008, both facilities began observing significantly increased concentrations of DBPs in treated water. Specifically, the concentrations of TTHM in the treated water increased by a factor of nearly two, resulting in exceedances of the 80 parts-per-billion (ppb) maximum contamination level (MCL) for TTHM.[3] Attachment 1 includes graphic summaries of TTHM monitoring data collected at the compliance monitoring locations at Harris Treatment Plant from 2002 to 2012 and Madison Water Treatment Plant from 2004 to 2011.

- The facilities observe the highest concentrations of TTHM in treated waters during periods of hot, dry weather. Given a dose of chlorine, chlorine residual levels decrease with high temperatures and exposure to direct ultraviolet light; to maintain the targeted chlorine residual levels, therefore, the facilities add higher dosages of chlorine during hot, sunny days. Additional chlorine may drive reactions with organic and inorganic constituents and result in the formation of DBPs. The highest concentrations of TTHM in treated water were recorded in 2011, which was an exceptionally dry year with below average Dan River flow.

- Uncertain what was driving the increased formation of DBPs, the facilities continued to struggle with elevated concentrations of TTHM in treated water from 2008 to 2011. During this period, the Harris Treatment Plant selectively pumped

---

[1] THMs are classified as Group B carcinogens (shown to cause cancer in laboratory animals). Chronic HAA exposure may cause adverse effects to the nervous system and/or liver.

[2] The TTHM or THM4 concentration is a sum of concentrations of trichloromethane (chloroform), bromodichloromethane, dibromochloromethane, and tribromomethane (bromoform). Regulated the HAA5 concentration is a sum of concentrations of monobromoacetic acid (bromoacetic acid), dibromoacetic acid, monochloroacetic acid, dichloroacetic acid, and trichloroacetic acid.

[3] In general, neither water treatment plant has experienced any issues with consistently achieving HAA requirements.

water from the Dan River to the large pre-settling impoundment following storm events (when source water was diluted).

- Because of the elevated TTHM levels in the treated water, the Harris Treatment Plant lost a contract of selling the treated water to its neighboring community in VA.

Investigation of DBPs Issue

- Harris Treatment Plant and Madison Water Treatment Plant began collaborating in 2011~~0~~ to investigate the cause of increased formation of THMs in treated waters. Review of quarterly detailed compliance monitoring data from both facilities revealed that the concentrations of brominated THMs (i.e., dibromochloromethane, bromodichloromethane, and bromoform) sharply increased from a minority proportion of the TTHM in the first half of 2008 to more than 75 percent in the latter half of 2008 at the Harris Treatment Plant. A similar change occurred at the Madison Water Treatment Plant when comparing 2008 and 2009 monitoring data. Consequently, during the same period, the concentrations of non-brominated THMs (i.e., chloroform) sharply declined. Attachment 1 includes quarterly sampling results for the four THM species at both facilities.

- ~~In 2011, T~~the facilities ~~began~~ routinely monitor~~ing~~ ~~additional~~ parameters in the influent to the treatment plants, including (but not limited to) alkalinity, conductivity, pH, chloride, ~~sulfate~~hardness~~,~~, ~~bromide, bromate, sulfate~~, total organic carbon (TOC), and dissolved organic carbon(DOC). They began monitoring for bromide and bromate in 2011 ~~oxygen~~. Previously, only a handful of pollutants were monitored in the influent for process control (e.g., adjust treatment chemical dosages based on influent characteristics). A summary of the 2011 water quality of the influent from the Dan River and pre-settling impoundment (referred to as the lake) to Harris Treatment Plant and the influent from the Dan Rive to Madison Water Treatment Plant is provided in Attachment 1. [Note to facilities: are you aware of any bromide monitoring data in Dan river before 2011?]We are not aware of any bromide monitoring on the Dan River prior to 2011.

- To complement and augment influent and in-process monitoring data, Harris Treatment Plant also began ~~monthly~~ sampling of the Dan River at locations between and upstream of the facilities. Initially, samples were collected at each bridge over the Dan River up to 35 miles upstream of the Harris Treatment Plant. Additional sampling was conducted via canoe for each Dan River tributary between the bridge at 311 over the Dan River and at Pine Hall Road. This area had been identified during the previous sampling to have the source of the contamination. The objective of this sampling program was to identify the DBPs precursors and potential sources. Certified analysis of most samples was performed by Pace Analytical laboratories.

- DCN SE06477, provided by the facilities during the site visit, includes detailed Dan River influent, in-process, and treated water monitoring data collected between 2011 and 2017.

- Harris Treatment Plant asserts that bromide and TOC are the primary constituents of treatment plant's influent that result in the formation of brominated THMs. This assertion is predicated on the field observation that THM concentrations in treated water have a strong correlation with TOC and bromide concentrations in the Dan River and influent to the treatment plant. Particularly, the multiple-year monitoring records indicate that elevated bromide levels in the water intakes were strongly associated with the increased formation of TTHMs and brominated THMs.

- EPA indicated that brominated THMs have greater molecular weights compared to chlorinated DBPs. The MCL for TTHM is mass-based, therefore the same amount of organic precursors will result in higher concentrations of TTHM when reacting with bromine compared to chlorine. In general, an application of chlorine at the presence of bromide can lead to formation bromine, which is more reactive than chlorine for DBPs. Also, brominated THMs are suspected to form faster than chlorinated THMs. Thus, the above observation presented by facility is consistent with the water chemistry of TTHM/brominated THMs.

- The facilities also observed that bromide concentrations in the Dan River increased by two to three magnitudes between samples collected upstream and downstream of the discharge outfall (i.e., Outfall 003) for Duke Energy's Belews Creek Plant. Certified analysis of August 2011 monitoring data indicates that samples collected at the point of discharge had bromide concentrations greater than 8,800 ppb (more than 500 times higher than the next upstream sampling point). Belews Creek Plant operates two coal-fired generating units with a baseload generating capacity of 2,240 megawatts (MW). [Note to Harris Facility: Additional infomation provided after the meeting show that, due to the elevated Br levels in the lake, there were $9k of additional monitoring costs related to monitoring THMs and bromide. Any other noticeable additional monitoring costs?](These additional costs have been incurred **each** year since 2011.)

- The facilities contend that issues with brominated THMs began emerging shortly after Duke Energy's Belews Creek Plant began operation of wet flue gas desulfurization (FGD) scrubber systems. Belews Creek Plant began operating a wet limestone forced oxidation FGD scrubber on the first generating unit in February 2008. A second wet limestone forced oxidation FGD scrubber system on the second generating unit began operating in May 2008 (DCN SE05903). Wastewater generated by the wet FGD scrubber systems is treated and discharged to the Dan River via Outfall 003 in accordance with the facility's NPDES permit (NC0024406). Belews Creek Plant's Outfall 003 is approximately 8 miles upstream of the Madison Water Treatment Plant intake and 25 miles upstream of the Harris Treatment Plant intake. [Note to facilities: Do these measurements represent river miles or linear miles?](Approximate River miles)

- Attachment 2 is a copy of the Belews Creek Plant NPDES permit, effective November 2012 through February 2017, which was provided by NC DEQ during the site visit. The permit requires monthly monitoring of bromide at Outfall 003; however, no bromide limitations are established. The permit also requires Duke Energy to "investigate technical solutions to reduce bromide in the discharge from Outfall 003," "submit semi-annual reports on the efforts it undertakes to reduce bromide at the source as well as efforts at downstream water treatment plants to reduce formation of THMs," and "find a solution to the issue of the total THM formation in the distribution system of the downstream water systems." [Note to facilities: If you have received copies of the Belews Creek Plant semi-annual status reports submitted to the NC Division of Water Quality, please provide.]I have requested some of this information and it is in a separate emailing. The subject is titled "Semi-annual Reports".

- According to NC DEQ, Belews Creek Plant is not using halogen additives, such as bromide salts, for the purposes of mercury emission control. The bromide in the plant's discharges are suspected to originate from the plants use of high-halogen content coal (e.g., Pittsburgh 8 bituminous coal). EPA (ORD) indicated this specific coal is known to have high bromine concentrations. The coal for Belews Creek Plant was sourced from the same mines as the Homer City Generating City (another documented bromide discharger impacting downstream WTPs).

Efforts to Mitigate DBPs Formation

- In 2012, the Harris Treatment Plant hired Hazen and Sawyer, an engineering firm, to evaluate alternative treatment technologies and management practices that may improve compliance with the DBPRs. The evaluation focused on approaches that would reduce THM precursors (e.g., TOC, bromide) and/or slow formation of THMs downstream of the treatment units. Capital and operating costs were considered for each potential compliance option. Figure 1, extracted from the DWT plants' presentation (i.e., Attachment 1), identifies the treatment technologies and optimization techniques reviewed as part of this evaluation. [Note to Harris facility: Please provide the full study report by the engineering firm, if available.] Included is the original report from Arcadis Engineering title "Report – eden wtp dbp study – Final012711" and the Hazen and Sawyers Report titled "Final Report_8.13.13." attached.

Figure 1. Technologies and Techniques Considered

Table 1 - Technologies and Techniques Considered					
	DBP Precursor Removal				
Improvement Option	TOC	Bromide	DBP Formation Control	DBP Removal	Meets Compliance Goals
Ion Exchange (e.g. MIEX)	√	Up to 100 %[2]			Possibly[1]
Iron-based Coagulant (e.g. Ferrous Sulfate, Ferric Sulfate, Ferric Chloride)[3]; Replaces Alum	√	20 %[4]			Possibly[1]
Powdered Activated Carbon	√	20-50 %[5]			Possibly[1]
Improved Coagulation/Mixing	√				Optimization Technique
Chlorine Dioxide (Replaces Pre-Filter Chlorine)			√		Optimization Technique[1]
Alternate Chemical Feed Locations (esp. Chlorine)	√		√		Optimization Technique
Improved Clearwell/CT Management			√		Optimization Technique
Chloramination (Replaces Free Chlorine)			√		Possibly[1]
Granular Activated Carbon	√	Up to 100 %[5]		√	Possibly[1]
Distribution System			√		Optimization
Uni-Directional Flushing					Technique
Improved Distribution System Tank Management			√		Optimization Technique
Nanofiltration Membranes	√	>40 %		√	Possibly[1]

[1] Would require pilot or bench-scale testing to determine effectiveness
[2] Resin specific
[3] Carbon specific, pH specific, source water anion specific
[4] At low pH
[5] Poly-aluminum chloride (PACL) blend varieties may also prove beneficial

- Initially, the facilities investigated proven methods for controlling THMs downstream of treatment units, namely improving hydraulic conditions in distribution system to reduce water age. THMs form when organic matter and chlorine residual react as water travels through the distribution system, thus reducing water age reduces formation of THMs.

- In 2012, Harris Treatment Plant installed mixers, manufactured by PAX Water Technologies (PAX), in four ~~each of the five~~ elevated water storage tanks, passive mixing was already in the newest and largest tank. ~~and~~ They also began an "aggressive" flushing program to reduce thermal stratification and water ages in storage tanks, as well as to improve hydraulic conditions in the pipes. This combined approach had positive short-term results, but the Harris Treatment Plant found that frequent flushing was too expensive and TTHM would build up between flushes. [Note to Harris facility: What was the frequency of distribution system flushes and volume of treated water lost, typically? What is the

approximate cost associated with each flush?] There are 28 flushing units throughout the distribution system that only run from May 1 – November 1. The estimated gallons for all of the flushing units is 5,000 gallons per day times 184 days. The charge for each 1000 gallons is $5.09 for a total cost of ((5000 x 184 =920,000 gallons flushed)/1000)=920 x 5.09 per 1000 gallons = $4,682.80

- In 2013, Harris Treatment Plant ~~replaced the PAX mixers in each elevated storage tank with~~ added a PAX Trihalomethane Removal System (TRS), a specialized aeration system for management of THMs to one of the elevated tanks. The PAX TRS integrates various aeration technologies (i.e., sprayers, mixers, ventilation) and real-time operational data to maximize the THM removal from ~~each~~ the tank. For each tank, PAX develops a model to determine the maximum achievable THM removal, designs a custom TRS system, and guarantees that the TRS will achieve the target removal rate. The total capital cost of the ~~five~~ PAX TRS was approximately $~~818,000~~148,827.00.

- Although the PAX TRS system reduced THM formation in the elevated storage tank~~s~~, the issue persisted in other parts of the distribution system such as the 4,000,000 gallon clearwell (volume was too large to effectively aerate with TRS). Harris Treatment Plant decided to move forward with installation construction of a chloramination system in January 2015.

- Chloramines are a secondary disinfection agent that provides longer-lasting disinfection as drinking water moves through pipes to consumers, as compared to chlorine. Harris Treatment Plant selected chloramination as a solution because it was more affordable than other technologies evaluated (see Attachment 1), chloramines are less reactive than free chlorine, and an addition of ammonia to form chloramines can be turned off if bromide discharges upstream became controlled. The Harris Treatment Plant began operating the chloramination system in August 2017.

- As part of the technology evaluation, Hazen and Sawyer estimated that the capital and annual operation and maintenance (O&M) costs for a chloramination system at Harris Treatment Plant would be approximately $835,000 and $105,000, respectively. The facility has not operated the system for enough time to comment on the accuracy of the O&M cost estimate. As compared to the former chlorination system, Harris Treatment Plant expects to use higher chemical feed rates for chorine, ammonia, and pH adjustment (chloramine is a more effective disinfectant at higher pH than chlorine). [Note to Harris Facility: What was the total capital cost of the chloramination system? Please provide engineering and cost bids provided to Harris Treatment Plant from vendors for installation of the PAX TRS (Included as "Proposal from Utility Services for PAX TRS.)and chloramination systems, respectively.(The construction cost estimate can be found on page 27 of the report "PER_Chloramines Conversion_Final" attached. The spreadsheet "Engineering and Construction Prices for chloramines" is also attached. Also, please provide any additional bids received for other treatment technologies not selected. In addition, please provide the additional O&M costs for operating the chloramination system, relative to the chlorination system.]In the

attachment "Additional Cost of Chemicals for Chloramines" is a breakdown of the additional cost associated with the chloramines over the last 6 months.

- Duke Energy was ordered by the courts to reimburse the Harris Treatment Plant approximately $2,200,000 for the full capital cost of the ~~PAX TRS and~~ [The PAX TRS system was purchased by the City of Eden in 2013]-chloramination system installed. The agreement with Duke Energy does not include reimbursement for O&M costs of these treatment systems. ~~Harris Treatment Plant received financial assistance from the state to alleviate the burden on ratepayers.~~[The Harris Water Plant received no financial assistance from the state for the chloramines. I think the financial assistance you are speaking of was mentioned for the administrative order for the collections system]-[Note to facilities: Did Duke Energy fund any of the research performed by the facilities? Duke Energy did fund the research that was performed by Hazen and Sawyers. They did not fund any of the Research performed by Arcadis. Please elaborate on the court's findings and order to Duke Energy. We were not involved in the court case with Duke Energy which happened after the coal ash spill but did include the bromide once it got started. I am including documents that were sent to us after the court's decision and Duke Energy guilty plea. These documents are titled "Restitution and Remediation Process from Duke Energy" and "Bromide Claims Process" Please provide O&M costs for the one ~~five~~ PAX TRS. Do you operate the PAX TRS continuously or seasonally (e.g., shutting down during cold months)? Now stopped during cold months. Please identify any additional costs besides the additional costs associated with the installation and operation of chloramination and PAX TRS systems (e.g., additional costs associated with the improved TOC removal).]The TOCs for the Harris Water Plant are historically low, less than 1.5 mg/l on the combined filter effluent. Hazen and Sawyer investigated other coagulants for the purpose of lowering the TOCs but with the TOCs already low it was hard to determine the effectiveness and there was no recommendation to change coagulant.

- Madison Water Treatment Plant, the smaller of the two facilities, did not hire any consultants to evaluate the DBPs issues. Following the installation of the PAX TRS at the Harris Treatment Plant, Madison Water Treatment Plant installed a PAX TRS in the facility's clearwell for a capital cost of $216,000. The clearwell TRS removed more than half of the TTHM in the treated water (target removal rate was 25 percent). Subsequently, Madison Water Treatment Plant installed three more TRS, one in each of three elevated storage tanks. Each elevated tank TRS has a target THM removal of at least 60 percent and a capital cost of approximately $160,000. O&M costs and energy requirements for the PAX TRS system are small (mainly power for 10 horsepower motor). Duke Energy reimbursed the complete capital costs associated with the four PAX TRS ($704,000). [Note to Madison Facility: Please provide engineering and cost bids provided to Madison Water Treatment Plant from PAX for installation of the TRS. Also provide any additional bids provided to Madison for other treatment technologies not selected. Is that correct that there are negligible additional O&M costs associated with the four PAX TRS?]

- Madison Water Treatment Plant's strategy for DBPs management involves facilitating a high rate of bromination and formation of THMs to occur within the system followed by volatilization of all THMs using the PAX TRS. To promote creation of THMs prior to the clearwell, chlorine injection and pH adjustment have been incorporated earlier in the drinking water treatment process (i.e., applying chlorine prior to the sedimentation basin).

- The Q4 2017 compliance monitoring samples at both facilities indicate that the concentrations of TTHM in treated water have decreased since operation of the PAX TRS and chloramination system at the Harris Treatment Plant and the PAX TRS at the Madison Water Treatment Plant. Both facilities are satisfying DBPR requirements.

Perspective of NC DEQ

- Prior to the site visit, EPA requested NC DEQ to present the state's perspective of elevated bromide levels in drinking water treatment plant influent and comment on efforts to identify (and resolve) these issues. Attachment 3 includes written responses from NC DEQ regarding these topics.

Further Study of Bromide and DBPs

- EPA Office of Research and Development (ORD) is conducting an ongoing investigation of scientific information relating to pollutant releases to air, land and water (and their potential consequences and fates) associated with the emerging use of halogen addition (i.e., bromine, iodine) for mercury emissions control at coal-fired power plants. As part of this effort, EPA ORD developed a portable ion chromatograph for automated monitoring of conductivity and anions. The sensor can be deployed in a remote location, such as a public water system intake, and sampling data can be uploaded without accessing the device.

- During the meeting, EPA ORD brought and demonstrated a potable conductivity real-time field sensor. EPA ORD put forth for consideration pilot-testing the portable anion chromatograph at the Harris and/or Madison drinking water treatment plants.

- EPA ORD is working to compile a listing of steam electric power plants that are currently using, or have historically used, bromine additives. EPA ORD is also investigating other anthropologic sources of bromide to surface waters, such as discharges from chemical manufacturing facilities, cooling towers using biocides for disinfection, unconventional oil and gas wastewater, and textile plants that produce brominated flame retardant clothing.

- EPA inquired whether NC DEQ or the facilities were aware of other water treatment plants experiencing issues with DBPs as a result of bromide discharges from steam electric power plants. The facility representatives stated that Duke Energy facilities on Lake Norman and Lake Wylie (Marshall and Allen plants, respectively) stopped adding calcium bromide after downstream water treatment

plants started observing issues with DBPs. NC DEQ believes that Duke Energy has stopped using halogen additives, including bromine salts, for the purposes of mercury emission control at all their North Carolina plants. The facilities also stated water treatment plants located near Fayettesville and Wilmington (NC), which draw water from the Cape Fear River, were experiencing issues with DBPs; however, it is believed that a chemical manufacturing plant is the primary source of DBPs precursors.

PRELIMINARY ENGINEERING REPORT

Chloramines Conversion
Robert A. Harris Water Treatment Plant

NORTH CAROLINA PROFESSIONAL SEAL 029976 ENGINEER DAVID S. BRILEY

NORTH CAROLINA PROFESSIONAL SEAL 31433 ENGINEER D. CORY HOPKINS

July 2014

HAZEN AND SAWYER
Environmental Engineers & Scientists

4011 WestChase Boulevard, Suite 500
Raleigh, NC 27607

TABLE OF CONTENTS

CONTENTS

1 INTRODUCTION 1-1
1.1 Background 1-1
1.2 Proposed Improvements 1-1
1.3 Chloramination Principles 1-2
2 EXISTING ROBERT A. HARRIS WATER TREATMENT FACILITIES 2-1
2.1 Treatment Process 2-1
2.2 Chemical Additions 2-1
3 Liquid Ammonium Hydroxide versus Liquid Ammonium Sulfate 3-1
3.1 Liquid Ammonium Hydroxide 3-1
3.1.1 Chemical Properties and Safety 3-1
3.1.2 Storage and Dosing 3-1
3.1.3 Cost and Availability 3-2
3.1.4 Local User Experience 3-2
3.2 Liquid Ammonium Sulfate 3-2
3.2.1 Chemical Properties and Safety 3-2
3.2.2 Storage and Dosing 3-2
3.2.3 Cost and Availability 3-3
3.2.4 Local User Experience 3-3
3.3 Conclusions 3-3
4 PROPOSED IMPROVEMENTS AND BASIS OF DESIGN 4-1
4.1 Hydraulic Profile 4-2
4.2 CT Analysis and Calculations 4-3
4.3 Proposed Site Plan 4-5
4.4 Ammonia Storage and Feed 4-5
4.5 Chemical Injection/Meter Vault 4-6
4.6 Existing Chemical System Modifications 4-7
4.6.1 Chlorine Storage and Feed System 4-8
4.6.2 Caustic Storage and Feed System 4-14
5 Preliminary Opinion Of Construction Cost 5-1

APPENDICES

Appendix A: Preliminary Drawings

Appendix B: Preliminary Opinion of Probable Construction Cost

1 INTRODUCTION

1.1 Background

The City of Eden (City) operates a 20.6 million gallon per day (mgd) conventional water treatment plant (WTP) which obtains its supply from the Dan River. The City has experienced elevated Total Trihalomethanes (TTHM) since spring/summer 2008, which coincides with a new industrial discharge containing bromide. The City has monitored bromide levels in the Dan River at their intake and found bromide concentrations ranging from 22 to 433 parts per billion (ppb) (2008-2012). In the pre-sedimentation basin, bromide levels have been recorded up to 492 ppb (2008-2012).

The US Environmental Protection Agency (EPA) promulgated two new rules simultaneously in January 2006; the Stage 2 Disinfectants and Disinfection Byproducts (DBP) Rule and the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). These two rules are part of the Microbial-DBP Cluster, which is a set of interrelated regulations that address the risk trade-offs between microbial pathogens and DBPs mitigation. Compliance with both of these rules can be challenging for some systems.

The City is currently in compliance with the Stage 1 DBP Rule. However, the requirements in the Stage 2 DBP Rule are more stringent. The Stage 2 DBP Rule requires that the City meet the maximum contaminant level (MCL) for TTHMs and five haloacetic acids (HAA5) on a locational running annual average (LRAA) basis rather than on an average of all sample sites throughout the distribution system. The Stage 2 DBP Rule requires that the four-quarter average at each monitoring site be below the MCL of 80 ppb for TTHMs and 60 ppb for HAA5s. Special samples (i.e. non-compliance) collected by the City at the Stage 2 sites had LRAA TTHMs concentrations ranging from 61 to 90 ppb from 2010 to 2012. Recent monitoring data suggest that the City will have significant challenges in complying with the Stage 2 DBP Rule. Furthermore, the City provides potable water to consecutive systems such as Dan River Water and Henry County Public Service Authority. The additional residence time may further exacerbate the DBP levels observed in these systems that are also required to comply with the Stage 2 Rule. Initially, the City was required to be in compliance with the Stage 2 DBP Rule by October 2013. An extension was granted by NC DENR and the new compliance deadline is summer 2015.

1.2 Proposed Improvements

The City retained Hazen and Sawyer to evaluate alternatives to reduce DBP formation to ensure compliance with the US EPA's Stage 2 DBP Rule. Hazen and Sawyer evaluated alternatives to reduce DBP formation through changes in treatment processes and source water at the Robert A. Harris WTP. Hazen and Sawyer issued the *Stage 2 Disinfectants/Disinfection Byproducts Rule Compliance Plan Final Report* in June 2013.

As a first step, Hazen and Sawyer screened alternatives to optimize existing WTP processes for DBP control. For strategies that could help the City meet their DBP reduction goals, bench-scale testing was conducted to confirm the effectiveness for DBP control. Enhanced coagulation using the current coagulant and alternate coagulants was evaluated as well as the use of powdered activated carbon and potassium permanganate. The potential effectiveness of chloramination for DBP control was also assessed for the described bench-scale tests.

Where optimization strategies alone could not guarantee Stage 2 DBP Rule compliance, new treatment technologies were also considered, including, magnetic ion exchange (MIEX®), granular activated carbon contactors, and post-filter anion exchange. A multi-variate analysis was used to evaluate technologies based on life cycle costs and non-economic factors. Hazen and Sawyer also evaluated the feasibility of utilizing an alternate water supply source, the Smith River.

For the Robert A. Harris WTP, conversion to chloramines is planned due to its lower cost (capital and operating) relative to the other strategies, effectiveness for controlling DBP formation, and long history and widespread use through the U.S., particularly in North Carolina.

1.3 Chloramination Principles

To limit the formation of DBPs that result from the reaction of free chlorine, bromide, and organics in the water, the City plans to use chloramines for secondary disinfection. The City will continue to use free chlorine at the WTP for primary disinfection as well as oxidation of iron and manganese.

Chloramines are a much weaker disinfectant than free chlorine, but are more persistent and, therefore, are often used as a secondary disinfectant in the distribution system. Chloramines are formed when free chlorine reacts with ammonia. There are three species of chloramines: monochloramines, dichloramines and trichloramines. Monochloramines are most desired for secondary disinfection. Di- and tri-chloramines may lead to taste and odor issues and are considered weak residual disinfectants. Maintaining a pH between 7.5 to 8.5 and a chlorine to ammonia ratio of 3:1 to 5:1 will help promote the formation of monochloramines over other chloramine species.

Table 1-1 below details pros and cons for chloramines conversion.

Table 1-1: Chloramination Pros and Cons

Pros	Cons
Reduction of THM and HAA5 formation	Potential nitrification issues in the distribution system
Monochloramine residual is more stable than free chlorine residual	Potential higher dose or change in corrosion inhibitor
Effective in controlling biofilm	Requires public education and awareness program
Less taste and odor complaints	Quenching necessary if flushing to streams (similar to free chlorine)
Lower capital and annual O&M costs compared to other advanced treatment DBP mitigation technologies	Reports of customer complaints of rashes / asthma-type conditions
	Staff training

The City is proactively exploring and addressing the potential concerns with chloramines conversion with the assistance of Hazen and Sawyer, including:

- Developing a flushing and nitrification control plan for the distribution system,
- Implementing a nine month corrosion study to determine the optimum corrosion inhibitor chemical strategy for the Robert A. Harris WTP, and
- Developing a Public Information program regarding conversion to chloramines.

2 EXISTING ROBERT A. HARRIS WATER TREATMENT FACILITIES

The Robert A. Harris WTP was constructed in 1978 and expanded to its current capacity in 1994 of 20.6 mgd. The plant produces an average of 7.3 mgd (based on data from January 2007 until September 2013). The raw water source is the Dan River, with the plant's intake located upstream of the confluence with the Smith River. The Robert A. Harris WTP serves the City of Eden, the MillerCoors brewery and consecutive systems, including the Henry County Public Service Authority, and Dan River Water Inc.

2.1 Treatment Process

Raw water is pumped from the Dan River via an intake on the north bank of the river near Fieldcrest Cannon's Karastan Rug Mill. The raw water pump station is equipped with one 10 mgd and two 13 mgd vertical turbine pumps. Raw water is conveyed approximately 7,000 feet to the 87-million gallon pre-sedimentation basin located on the north side of the plant site via a 30-inch pipeline. The pre-sedimentation basin allows for flexibility in raw water pumping and reduced turbidities due to settling in the basin. Raw water flows by gravity to the treatment plant.

Coagulant and pH adjustment (if necessary) chemicals are added in the 30-inch pipe just upstream of rapid mix. A dual-stage rapid mix facility disperses these chemicals into the raw water. Aluminum sulfate is the primary coagulant, and polyaluminum chloride is used seasonally to address challenges in treating colder waters. A coagulant-aid polymer is used in conjunction with alum to promote floc development. Sodium hydroxide (caustic) is used to adjust pH and alkalinity; however, the raw water feed point for caustic is not currently used. Coagulated water flows to six consecutive flocculation basins and then disperses to seven parallel sedimentation basins. The plant has seven dual media filters. These filters operate at a maximum loading rate of 4 gallons per minute per square foot (gpm/sf). Chlorine gas is dosed at the filters for iron and manganese oxidation. Post-filter chemicals (chlorine, corrosion inhibitor, caustic and fluoride) are dosed in the filtered water flume located below the filter gallery. Finished water is stored on site in the two 4-million gallon, above-ground clearwells. The high service pump station has one 9 mgd and two 12 mgd pumps that convey finished water to the distribution system.

Solids from the sedimentation basin are collected by mechanical rakes into a sludge hopper. Sludge is discharged to the Mebane Bridge Wastewater Treatment Plant (WWTP). Backwash wastewater is conveyed to one of two equalization waste basins and then proceeds to the WWTP.

2.2 Chemical Additions

Copper sulfate is periodically added to the pre-sedimentation basin to control algae growth. Historically, chlorine gas was fed at rapid mix; however, the initial feed point has been moved to the filters to limit chlorine contact time and, in turn, DBP formation. The plant is also equipped to feed chlorine gas downstream of Clearwell No. 2, but this feed point is not currently in use. The plant has the ability to feed powdered activated carbon and potassium permanganate in the raw water, but neither of these facilities is currently used. The existing chemical feed points and analyzer locations downstream of the sedimentation basins are illustrated in **Drawing G4** in **Appendix A**. Average and 90th percentile chemical doses were calculated based on over two

years of data and are shown in **Table 2-1**. This date range captures the chemical adjustments made by the City to address the increase in raw water bromide concentration.

Table 2-1: Typical Chemical Use at Robert A. Harris WTP

Chemical	Average Dose (mg/L)*	90th Percentile Dose (mg/L)*
Copper Sulfate	2.9	4.0
Alum	22.0	26.0
Coagulant Aid Polymer	0.05	0.07
Polyaluminum Chloride	31.6	36.0
Pre Chlorine	1.9	2.3
Post Chlorine	1.6	2.4
Pre Caustic	N/A	N/A
Post Caustic	8.9	13.0
Corrosion Inhibitor	5.3	7.2
Fluoride	0.4	0.8

*Dose statistics are based upon data from 8/1/2011 to 9/30/2013.

3 LIQUID AMMONIUM HYDROXIDE VERSUS LIQUID AMMONIUM SULFATE

Hazen and Sawyer conducted an evaluation of liquid ammonium hydroxide and liquid ammonium sulfate (LAS) as alternatives for the ammonia system that the City of Eden will implement. This section explores the chemical properties, safety, storage/feed requirements, cost, and local user experience for the two chemicals.

3.1 Liquid Ammonium Hydroxide

3.1.1 Chemical Properties and Safety

The chemical properties of liquid ammonium hydroxide, commonly known as aqua ammonia, are detailed in **Table 3-1** below. The high pH indicates a basic solution which can minimize the amount of caustic needed for pH adjustment at the post-filtration feed point to optimize monochloramine formation. The low boiling point indicates that aqua ammonia is a highly volatile solution and is considered to be instable. Aqua ammonia can experience vapor loss, impacting the solution prior to chlorine contact. As a result, aqua ammonia must be properly stored in a pressurized vessel in order to provide a consistent solution strength and consistent ammonia dose.

Table 3-1: Liquid Ammonium Hydroxide Chemical Properties

Property	Value
Chemical Formula	$NH_4OH + H_2O$
% Availability	18.5 - 30
Color	Clear
Odor	Strong, pungent ammonia odor
Specific Gravity	0.90 – 0.93
pH	10.6 – 11.7
Boiling Point	82.8°F

Aqua ammonia is considered hazardous and requires special handling and safety procedures. It can cause severe irritation to the lungs if inhaled. Appropriate venting must be implemented to ensure proper safety precautions in the event the chemical is stored indoors. Additionally, skin and eye contact with aqua ammonia may cause severe irritation and burns.

Due to safety concerns, aqua ammonia is subject to strict Occupational Safety and Health Administration (OSHA) regulation and, depending on the quantity stored on site, may require an emergency plan to be filed with the State. If storage quantities are less than 20,000 pounds and are at concentrations of less than 20%, most of the regulatory issues may not apply. As a result, the majority of WTPs that utilize aqua ammonia use a 19% solution.

3.1.2 Storage and Dosing

The volatility of aqua ammonia requires it to be contained in pressurized storage tanks with conservation vents. Common tank materials of construction include carbon or stainless steel. Piping is typically steel or PVC as moist ammonia is corrosive to copper, silver, zinc, and alloys.

Teflon, EPDM, neoprene, or stainless steel may be installed for gaskets, seals, and pumping components.

Dosing consideration should include determining the actual concentration of nitrogen for an ammonia solution as only the nitrogen component is involved in the formation of chloramines. For example, a 19% aqua ammonia solution has 14.7% available nitrogen.

3.1.3 Cost and Availability

Aqua ammonia is readily available and is supplied locally by Airgas, Amerochem, Brenntag Mid-South, CFS Enterprises, Colonial Chemical Solutions, JCI Chemicals, Tanner Industries, and Univar. A local utility is currently paying $179 per wet ton for 19% aqua ammonia. In the past 5 years, their 19% aqua ammonia cost has ranged from $169 to $213 per wet ton.

3.1.4 Local User Experience

Several local municipalities employ aqua ammonia within their drinking water treatment plants. This includes the City of Burlington, the City of Durham, and the Fayetteville Public Works Commission.

3.2 Liquid Ammonium Sulfate

3.2.1 Chemical Properties and Safety

Table 3-2 below details chemical properties of LAS. The low pH indicates an acidic solution which may require additional caustic dose to achieve the desired finished water pH. The high boiling point indicates that LAS is a non-volatile solution. Unlike alternatives which experience vapor loss, all of the ammonia in LAS remains bound in solution until it contacts chlorine. As a result, the ammonia dose can be more consistent, which provides better control over the chlorine to ammonia ratio and the monochloramine residual.

Table 3-2: Liquid Ammonium Sulfate Chemical Properties

Property	Value
Chemical Formula	$(NH_4)_2SO_4 + H_2O$
% Availability	15 - 40
Color	Clear
Odor	Odorless
Specific Gravity	1.11 – 1.28
pH	3.0 – 5.0
Boiling Point	214.6°F

LAS may cause eye and skin irritation. Inhalation of LAS mists may also cause irritation to the respiratory tract.

3.2.2 Storage and Dosing

The non-volatility of LAS does not require it to be contained in pressurized storage tanks. LAS is corrosive to stainless steel, copper, cast iron, Tygon, Viton, nylon, brass and alloys. Piping for an LAS system is typically polyethylene, polypropylene, or schedule 80 PVC. Neoprene, rubber, and EPDM may be installed for gaskets, seals, and pumping components.

Like aqua ammonia, dosing consideration should include determining the actual concentration of nitrogen for an ammonia solution as only the nitrogen component is involved in the formation of chloramines. For example, a 40% LAS solution has 8.46% available nitrogen.

3.2.3 Cost and Availability

LAS is supplied locally by Brenntag Mid-South and General Chemical. Current LAS costs are $260 to $310 per wet ton for 40% LAS.

3.2.4 Local User Experience

Currently, the only known local utility with LAS experience is the City of Greensboro. However, several additional local utilities are considering conversion to LAS from aqua ammonia including the City of High Point, the Piedmont Triad Regional Water Authority, and the City of Reidsville.

3.3 Conclusions

The following **Table 3-3** summarizes and compares the findings for the ammonia alternatives.

Table 3-3: Aqua Ammonia and LAS Comparison

	Aqua Ammonia	LAS
Chemical Properties	18.5 – 30% solution	15 – 40% solution
	High pH	Low pH
	Low boiling point	High boiling point
	Loss of solution strength can lead to inconsistent and inaccurate dosing	Less volatile, better control over ammonia dose
Safety	Hazardous	Irritant
	Potential OSHA regulations	
Storage and Dosing	Pressurized vessels	Non-pressurized vessels
	20% sol. has 14.7% available nitrogen	40% sol. has 8.46% available nitrogen
Cost and Availability	8 identified vendors	2 identified vendors
	$179 per wet ton for 19% solution	$260 - $310 per wet ton for 40% solution
Select Local User Experience	City of Burlington	City of Greensboro
	City of Durham	
	Fayetteville Public Works Commission	

In general, aqua ammonia is more hazardous than LAS. Storage and feed system costs for aqua ammonia are higher to provide pressurized storage tanks and the appropriate materials of construction. LAS can utilize standard high density polyethylene (HDPE) bulk chemical storage tanks and cheaper materials of construction. Theoretically, based on stoichiometric calculations, aqua ammonia chemical costs are approximately 70 percent of the cost of LAS per pound of available ammonia in solution. As an example, considering an average day demand of 7-mgd and

a 1-mg/L ammonia dose (as nitrogen), the annual chemical costs would be approximately $25,000 and $35,500 for aqua ammonia and LAS, respectively.

However, in reality, this cost difference may be less considering the potential for the aqua ammonia product to off-gas during transport, loading/unloading, and storage activities. Due to the volatility of aqua ammonia, the City may purchase larger quantities than what would be expected based on typical ammonia dose and treatment rates. This may be particularly evident in warmer months when aqua ammonia off-gassing rates would be higher. Recent experience in the City of Greensboro, NC suggests this to be the case with aqua ammonia costs closer to 80% of the cost of LAS.

Despite the cost differences, through proper handling, storage, and feed, both chemicals may be used to produce an acceptable finished water monochloramine residual that will meet the needs of the City of Eden. Based on the information detailed above and discussions with staff, it is recommended that the Robert Harris WTP implement LAS for the conversion to chloramination.

4 PROPOSED IMPROVEMENTS AND BASIS OF DESIGN

Drawing G4 illustrates the proposed additional chemical feed points that are associated with the chloramine conversion at the Robert A. Harris WTP (see **Appendix A**). Converting the City of Eden water system to chloramination will involve the construction of two main structures at the WTP: a chemical storage facility and a chemical injection/meter vault.

The two main structures will be located north of Clearwell No. 2 on the south side of the dirt roadway. The Robert A. Harris WTP has an existing dirt roadway that extends from the east side of the parking lot around the two clearwells and exits through a gated entrance on Mebane Bridge Road. The roadway will require upgrades to either gravel or paved road in order to provide acceptable access for chemical delivery trucks.

The chemical storage facility will include a minimum 6,150-gallon LAS storage tank located in a concrete secondary containment designed to accommodate the displaced volume of the tank. The tank will be insulated to protect from freezing of the LAS product and protect the tank from UV rays. A fill station will be provided along the road-side of the facility for filling the bulk tank. There will be a containment area equipped with a sump pump within the bulk storage area.

Conversion to chloramines is proposed between the plant's two clearwells with the addition of ammonia, chlorine, and caustic feeds in a new chemical injection/meter vault. Ammonia will be fed from the new LAS storage facility. Feed lines for chlorine and caustic will be routed from the existing chemical feed areas to the new chemical injection/meter vault.

The first storage tank (Clearwell No. 1) will provide the necessary volume for disinfection (CT) using free chlorine. CT analysis and calculations can be found below in Section 4.2. Ammonia will be added after Clearwell No. 1 to form monochloramines. The second tank (Clearwell No. 2) will provide storage of chloraminated water for equalization and operational flexibility.

Within the chemical injection/meter vault, a magnetic flow meter will provide accurate flow measurements to ensure proper dose pacing of the chemicals. An in-line mechanical mixer will be provided to ensure adequate mixing and formation of monochloramines prior to the second clearwell. Sample pumps will provide a continuous sample to online analyzers and to the lab in the existing Administration Building. Online analyzers will be provided in the upper access to the chemical injection/meter vault to monitor for free chlorine and pH from the outlet of the first clearwell, and monochloramines and pH after the chemical additions. The LAS chemical feed pumps will also be located in the upper access to the chemical injection/meter vault.

The 30-inch finished water line between the two clearwells is approximately 28 feet below ground. This depth poses a challenge in installing the proposed chemical injection/meter vault. The two clearwells on site are prestressed concrete tanks. Clearwell No. 1 was constructed by Precon Corporation in 1992. Because these tanks are constructed with prestress wires throughout the walls of the tank, there is a very narrow window for side wall penetrations. Any penetration would need to be installed in a two-foot wide area that is approximately 4.5 feet above the tank floor. Therefore, it is not feasible to add a new outlet through the wall of the tank. The existing 30-inch outlet will be modified to maintain a minimum depth of 12 feet in the tank while allowing the tank to be completely drained in the event of require maintenance. A 30-inch riser pipe will be installed above the existing outlet, which is imbedded in the foundation of the tank. This riser will extend

to an elevation of 550 feet and will ensure the depth required to meet CT. To allow the tank to be drained, a tee with a valve will be installed at the base of the riser pipe such that the invert of the tee branch will be at or very near the invert of the tank. The valve operator stem will extend through the roof of the tank to a valve operator box. A 30-inch tee will be installed on the existing 30-inch tank outlet piping in the yard to divert the flow to the proposed chemical injection vault. Diverting the flow through new piping while maintaining the existing piping between the two clearwells will allow the proposed chemical vault to be completely bypassed. The piping will increase in size to 36-inch piping immediately after the tee. The piping from this tee to the vault will be installed on a slope such that the depth of the vault will be minimized. Downstream of the chemical vault, the piping will tie back into the existing piping between Clearwell No. 1 and Clearwell No. 2. The 36-inch piping will step down to 30-inch piping just before tying back into the existing system.

4.1 Hydraulic Profile

A hydraulic profile was prepared for the Robert A. Harris WTP from the filter influent channel through the high service pump station wet well to evaluate hydraulic impacts of the proposed improvements. A partial hydraulic profile through the Robert A. Harris WTP is shown on **Drawing G3** (see **Appendix A**). Several scenarios are shown on the profile. The first scenario models the hydraulic losses experienced at the plant in its current configuration at the maximum plant rated flow of 21 mgd. The remaining three scenarios show the hydraulic losses through this portion of the plant with the proposed improvements at 3 mgd (minimum), 7 mgd (average) and 21 mgd (rated) plant flow rates. Each scenario is modeled from the weir in the filtered water flume to the high service pump station. Because the weir is not submerged in any scenario, it serves as a hydraulic break and should ensure that the proposed improvements will not affect upstream filter performance.

The hydraulic profile was developed with the water level in Clearwell No. 1 near full. The water levels in Clearwell No. 2, and the high service pump station vary in each scenario. **Table 4-1** below shows the available storage in each clearwell for each hydraulic scenario. As flows increase, the available storage in Clearwell No. 2 decreases. This is due to headloss induced at high flowrates through the 30-inch piping between the two clearwells and the high service pump station. At the WTP capacity of 21 mgd, pipe velocities would exceed 6.5 ft/s in the 30-inch piping. Therefore, this piping is under-sized to handle the full WTP flow. At the highest flow rate of 21 mgd, the proposed improvements induce approximately 3.3 feet of additional headloss when compared to the existing plant configuration.

Table 4-1: Available Storage in Clearwell No. 1 and Clearwell No. 2

	Clearwell No. 1		Clearwell No. 2	
Scenario	**Volume (MG)**	**Depth (ft)**	**Volume (MG)**	**Depth (ft)**
Existing Maximum Flow - 21 mgd	3.99	23.5	2.84	16.7
Proposed Minimum Flow - 3 mgd	3.94	23.2	3.90	23.0
Proposed Average Flow - 7 mgd	3.99	23.5	3.84	22.62
Proposed Maximum Flow - 21 mgd	3.99	23.5	2.27	13.41

4.2 CT Analysis and Calculations

According to the "North Carolina Guideline – Treatment Facility Capabilities for CT Credit" worksheet completed in April 1991 the plant is approved for 2.45–log *Giardia* inactivation credit and 1.96-log viral inactivation credit. The plant must therefore achieve 0.55-log *Giardia* inactivation credit through free chlorine disinfection in order to meet the 3.0-log *Giardia* inactivation required by the Surface Water Treatment Rule (SWTR). For viruses, the plant must achieve an additional 2.04-log inactivation credit through free chlorine disinfection practices to ensure SWTR compliance (4.0-log required).

In order to determine the *Giardia* and virus inactivation achieved by free chlorine contact, the hydraulic detention time (Td) and contact time (T10) were calculated for segments in which the water will be in contact with free chlorine. T10 is a function of Td and baffling. CT is a function of T10, chlorine residual, pH, and temperature. Worse case conditions were evaluated to ensure that the plant always achieves the disinfection requirements of the SWTR.

The following assumptions were made when calculating a worse-case CT:

- Maximum rated flow at the WTP is 20.6 million gallons per day (mgd)
- Minimum free chlorine residual is 0.5 ppm in the filter effluent and 1.0 ppm downstream of the filters
- Maximum finished water pH is 7.5
- Minimum raw water temperature is 5° C
- The two 4-million gallon clearwells were assumed to be half full.

Table 4-2 was taken from the Disinfection Profiling and Benchmarking Guidance Manual and displays typical baffling conditions and associated baffle factors (T10/Td). Hydraulic detention times were determined using the calculated volumes and maximum plant flow (20.6 mgd). T10 is calculated by multiplying the hydraulic detention time by the baffle factor. CT was calculated using the T10 and free chlorine residual for each section.

Table 4-2: Baffling Classifications

Baffling Condition	T_{10}/T	Baffling Description
Unbaffled (mixed flow)	0.1	None, agitated basin, very low length to width ratio, high inlet and outlet velocities. Can be approximately achieved in flash mix tank.
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles
Average	0.5	Baffled inlet or outlet with some intra-basin baffles
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders
Perfect (plug flow)	1.0	Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intra-basin baffles

CT calculations for each disinfection segment are shown in **Table 4-3** with free chlorine contact occurring from the filters through Clearwell No. 1. In this scenario, 0.80-log inactivation of *Giardia* is achieved and 23.82-log inactivation of viruses is achieved. Therefore, the Robert A. Harris WTP can achieve the required *Giardia* and virus inactivation using free chlorine through the filters and the first clearwell if chloramines are formed between the two existing clearwells.

Table 4-3: Achieved CT in Each Disinfection Segment

Description	Disinfection Detention Time T_{10} (min.)	Baffle Factor	Free Chlorine Residual (mg/L)	CT (mg-min/L)	Giardia Log Inactivation Credit	Virus Log Inactivation Credit
Filter Bed (above media)	3.96	0.6	0.5	1.98	0.03	0.99
Filter Effluent Flume - Filter 1 to FW Cl dose point	0.3	0.6	0.5	0.15	0.00	0.08
Filter Effluent Flume - FW Cl dose point to 36" FW Pipe	1.08	0.6	1.0	1.08	0.02	0.54
36" FW Pipe	0.5	1.0	1.0	0.50	0.01	0.25
30" FW Pipe	2.1	1.0	1.0	2.10	0.04	1.05

Description	Disinfection Detention Time T_{10} (min.)	Baffle Factor	Free Chlorine Residual (mg/L)	CT (mg-min/L)	Giardia Log Inactivation Credit	Virus Log Inactivation Credit
Clearwell No. 1	41.8	0.3	1.0	41.82	0.70	20.91
Clearwell No. 2	41.8	0.3	Chloramines	0[1]	0[1]	0[1]
30" PW Pipe to High Service Pump Station	0.2	1.0	Chloramines	0[1]	0[1]	0[1]
				Total	**0.80**	**23.82**
				Required	**0.55**	**2.04**

[1]Any disinfection achieved by chloramines was not considered in this study.

4.3 Proposed Site Plan

A preliminary site plan for the Robert A. Harris WTP is shown on **Drawing M1** in **Appendix A**. The new ammonia storage facility and the new chemical injection/meter vault will be located north of Clearwell No. 2 between the existing influent and effluent lines of Clearwell No. 1. The two structures will be located along the existing access road.

4.4 Ammonia Storage and Feed

The LAS storage facility will include a minimum 6,150-gallon bulk storage tank. At an average dose of 1.0 mg/L, the tank will provide up to 59 days of storage at 11 mgd and up to 31 days of storage at 21 mgd. LAS will typically be delivered to the site in 4,000-gallon loads. Therefore, the storage tank is capable of receiving a full delivery volume when the tank is approximately 30 percent full.

The LAS bulk storage tank will be a cross-linked polyethylene tank located outdoors in a concrete secondary containment. The tank will be equipped with an ultrasonic level sensor, drain line, overflow and access manway. **Table 4-4** below details the basis of design for the LAS storage tank.

Table 4-4: LAS Storage Tank Basis of Design

Parameter	Value
30 day Storage Requirement	5,946 gallons
Number of Tanks	1
Material	Cross-Linked Polyethylene
Volume	6,150 gallons
Diameter	10 feet 2 inches
Height	12 feet 5 inches

Chemical feed pumps will be located in the upper access to the chemical injection meter vault adjacent to the storage tank containment. Two mechanical diaphragm metering pumps (one duty and one standby) will be provided to convey LAS to the feed point in the new chemical injection/meter vault. These feed pumps will provide a maximum feed rate of about 12.4 gallons per hour (gph) and will have a turndown ratio of 25 to accommodate the anticipated range of plant flows. **Table 4-5** below summarizes the basis of design for the LAS metering pumps.

Table 4-5: LAS Metering Pump Basis of Design

Parameter	Value
Number of Pumps	2 (duty / standby)
Type	Mechanical Diaphragm
Maximum Feed Rate	12.4 gph
Minimum Feed Rate	0.5 gph
TDH	Negligible due to elevation of chemical injection/meter vault

A preliminary layout for the new ammonia storage facility is shown in **Drawing M801** in **Appendix A**.

4.5 Chemical Injection/Meter Vault

The new chemical injection/meter vault will provide access to the new injection points, the magnetic flow meter, and the in-line mechanical mixer. Layout and section views of the vault can be found on **Drawing M850** (see **Appendix A**). This vault will be approximately 16 feet deep with access stairs and an at-grade door with superstructure for easy access. There will be two sample points in the chemical vault, one upstream of the chemical injectors and one downstream of the in-line mechanical mixer. The sample upstream of the chemical injectors will be sent to a free chlorine residual analyzer and to a pH analyzer. The sample taken downstream of the in-line mechanical mixer will be sent to a ChemScan unit (which measures free ammonia, total chlorine and monochloramines concentration) and a pH analyzer. A sample from both sample points will also be sent to the lab in the existing water treatment plant building. These analyzers are

preferentially located in close proximity to the sample points to provide real-time feedback of residual and pH measurements. As such, the proposed location of these analytical instruments is within the superstructure at the top of the stairs to the vault.

To accommodate fumes and odors associated with chemical feed activities in this vault, active ventilation of this area is necessary. An emergency shower and eyewash station with tempered water will also be located within the vault for the protection of plant personnel. The tempered water system will be located in the upper access of the vault and will also service the LAS containment emergency shower and eyewash. A sump pump is proposed to handle drainage within the vault. Due to the possibility of a chemical leak in the vault, the sump pump will not have automatic float switches. The sump pump will be manually controlled by the operator to pump clean water or storm water entering the vault to a nearby drain or waste manhole. In the event of a chemical spill, provisions will be made in the sump pump discharge piping to convey the chemical to containment for controlled disposal. Float activated alarms will alert staff to elevated liquid levels in the vault.

The current design for the chemical injection meter vault utilizes a 10 horsepower in-line mechanical mixer. A mechanical mixer would be able to adequately mix over a large range of flows and induces very low headloss. The mechanical mixer may be equipped with a variable-frequency drive (VFD) to adjust mixing energy imparted by the mixer across the range of flows. Although a constant-speed mixer may provide excess mixing energy for the purpose of blending chemicals at the higher plant flows, the potential operational cost savings utilizing the VFD to reduce mixing energy and any realized blending performance benefits are not anticipated to justify the additional capital cost of the VFDs. A static mixer was also considered due to minimal maintenance requirements. The mechanical in-line mixer will have greater maintenance requirements than a static mixer, higher electrical costs, and require minor additional capital costs to provide power to the equipment. However, static mixers cannot work effectively over the large range of flows that will be treated at the Robert A. Harris WTP. Currently, the 21 mgd WTP treats flows as low as 7 mgd. A static mixer designed to provide adequate mixing at the lowest WTP flows would induce excessive headloss at flows approaching the plant's rated capacity. As a result, the in-line mechanical mixer was selected.

4.6 Existing Chemical System Modifications

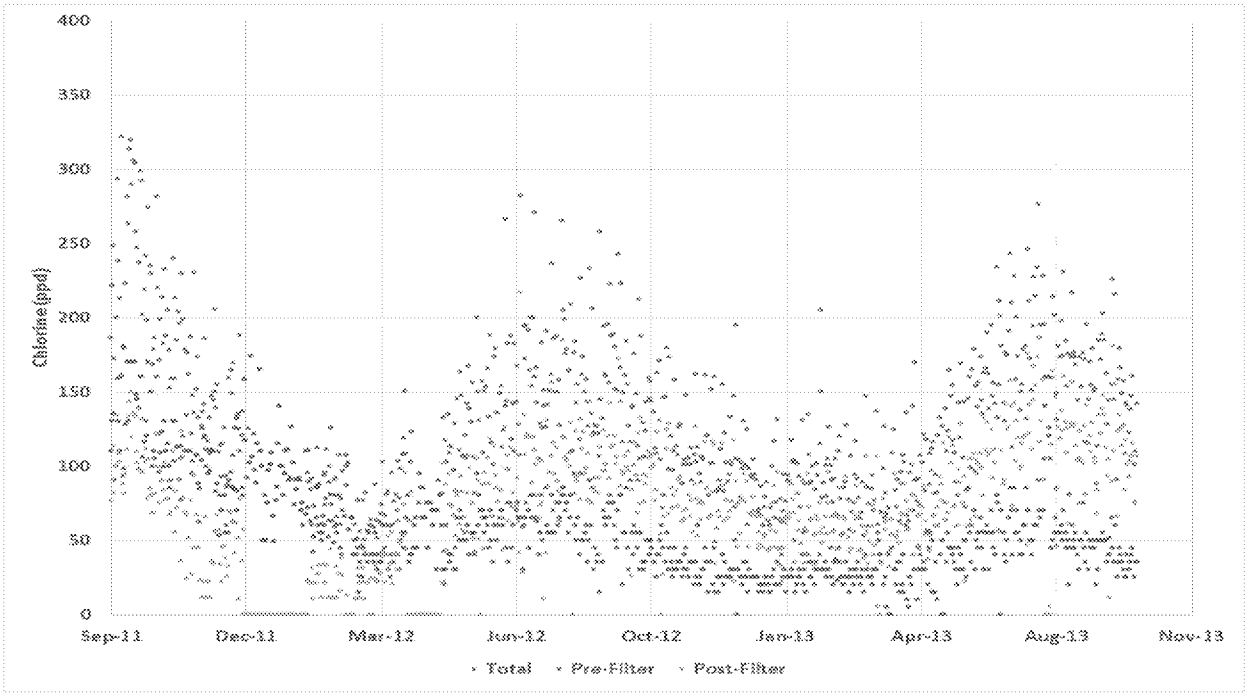
A new chemical ductbank will be provided to convey the chemicals and potable water from the existing WTP building to the proposed chemical injection/meter vault for chloramines formation purposes. The ductbank will be designed to provide containment with chemical feed lines routed through a secondary, casing line. Compared to direct bury of these lines, the ductbank design allows for better detection and location of leaks. Also, the ductbank arrangement would facilitate the replacement of chemical feed lines more quickly than the direct bury option.

Additional improvements are required to provide chlorine and caustic feed points in the chemical injection/meter vault. The subsequent subsections below discuss the improvements to the chlorine and caustic storage and feed systems to accommodate the new feed points.

4.6.1 Chlorine Storage and Feed System

The Robert A. Harris WTP's existing chlorine gas storage feed system utilizes chlorinators to inject chlorine gas into solution for dosing at pre-filter and post-filter feed points. Plant flows and chlorine dosages from September 2011 to September 2013 were compiled to assess historical challenges within the existing chlorine gas storage and feed system. **Figure 4-1** illustrates the historical daily chlorine usage (ppd) at the Robert A. Harris WTP.

Figure 4-1: Historical Chlorine Usage



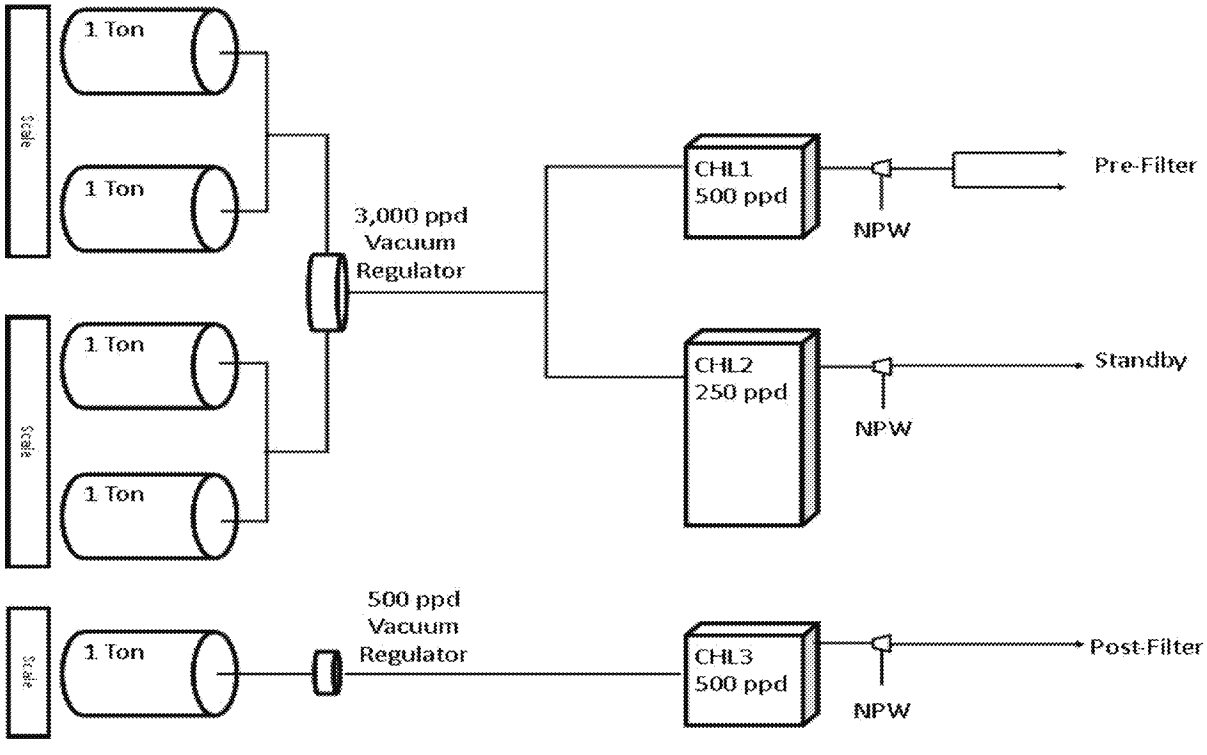
Historical chlorine doses for these two feed points are summarized in **Table 4-6**. Upon further investigation of the historical doses, the maximum values identified in the table are outliers to more typical maximum dose values. As a result, 95th percentile values are used going forward to represent maximum dose events.

Table 4-6: Historical Doses

Feed Point	Dose (mg/L)			
	Minimum	Average	95th Percentile	Maximum
Pre-Filter	0.0	1.3	2.6	5.3
Post-Filter	0.0	1.6	2.5	3.9

Figure 4-2 illustrates the existing chlorine gas storage and feed system. The WTP has five (5), 1-ton chlorine gas cylinders to feed the three (3) chlorinators. Practically, a one-ton chlorine gas cylinder at room temperature has a maximum withdrawal rate of 400 ppd (*Handbook of Chlorination*, White). One (1) cylinder is equipped with a 500 pound per day (ppd) vacuum regulator. The remaining four (4) cylinders are equipped with a 3,000 ppd vacuum regulator switchover unit with two cylinders on each side. The practical withdrawal limits on the one-cylinder and four-cylinder systems is 400 ppd and 800 ppd, respectively. Chlorinator 1 (CHL1) is manually flow-paced and has a capacity of 500 ppd. Chlorinator 2 (CHL2) is also manually flow-paced and has a capacity of 250 ppd. Both CHL1 and CHL2 are fed from the four-cylinder switchover system. Chlorinator 3 (CHL3) is manually flow-paced and has a capacity of 500 ppd. It is fed from the single cylinder system with the 500 ppd vacuum regulator.

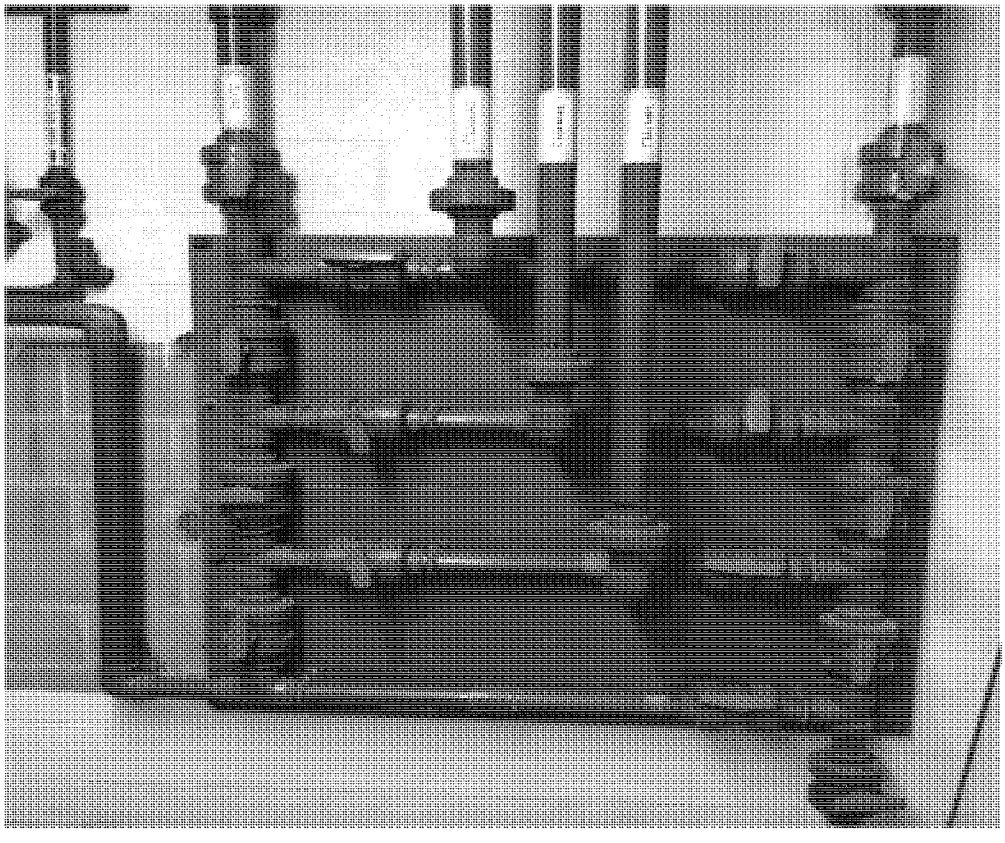
Figure 4-2: Existing Chlorine Storage and Feed System



For standard operation, CHL1 feeds chlorine solution via two lines to the pre-filter point while CHL3 feeds to the post-filter point. For standby operation (not shown in **Figure 4-2**), CHL2 typically feeds at the post-filter point when CHL3 runs out of chlorine gas supply from its dedicated 1-ton cylinder.

A pipe manifold downstream of the injectors allows for the chlorinators to feed at either application point (see **Figure 4-3**). The manifold has piping to an additional feed point downstream of Clearwell No. 2 called "Distribution System". However, this feed point is not in use. As a result, the unused Distribution System line was modified with a tee and piping was routed to dose chlorine gas solution at the pre-filter point. This piping represents the second of two lines conveying solution to pre-filter feed point. Additionally, the pipe manifold has a chlorine solution line to rapid mix that is not typically used in the treatment process.

Figure 4-3: Existing Chlorine Solution Manifold



The current system is limited by maximum gas withdrawal rate of the single-cylinder system during standard operation and the use of the 250 ppd CHL2 during standby operation thus preventing the plant from providing the 95th percentile chlorine doses at the plant's rated capacity (21 mgd). However, these identified limitations have not been an issue for plant staff to date as historical maximum flows and maximum doses have not occurred simultaneously. From **Figure 4-1**, the combined pre-filter and post-filter chlorine usage has not exceeded a 350 ppd withdrawal rate.

During standard operation, the historical 95th percentile dose for the pre-filter feed point is 2.6 mg/L. At this dose, CHL1 may accommodate the plant's rated capacity. However, the historical 95th percentile dose for the post-filter feed point is 2.5 mg/L, and at this dose CHL3 may only feed chlorine up to a maximum WTP flow of 19.2 mgd.

During standby operation, the post-filter feed point is dosed from the 250 ppd chlorinator (CHL2). At the 95th percentile doses, CHL2 may only feed this chlorine dose up to 12.0 mgd. Due to the dosing limitations of CHL2, the City of Eden plans to replace it with an automatically flow-paced 500 ppd chlorinator. Both CHL1 and CHL2 pull from the four-cylinder switchover system which has a maximum withdrawal rate of 800 ppd. If CHL2 is upgraded to a 500 ppd chlorinator, CHL1 and CHL2 can accommodate the maximum withdrawal rate from the four cylinder switchover system. Therefore, the two chlorinators could feed chlorine up to a maximum WTP flow of 18.8 mgd taking into consideration the historical 95th percentile doses at these two feed points. **Table 4-7** summarizes the flow limitations for the various scenarios at the 95th percentile doses.

Table 4-7: Flow Limitations

Scenario	Limitation	Treated Plant Flow (mgd) @ 95th Percentile Dose
Standard Operation	Cylinder Withdrawal Rate	19.2
Standby Operation (Existing 250 ppd CHL2)	250 ppd Chlorinator	12.0
Standby Operation (Upgraded 500 ppd CHL2)	Cylinder Withdrawal Rate	18.8

Chloramines conversion at the Robert A. Harris WTP will be automated using compound loop control to accurately dose the chloramines chemicals, including the chlorine gas solution. The chloramines conversion project includes the addition of a third chlorine feed point at the plant, the post-Clearwell No. 1 feed point, located in the new Chemical Injection / Meter Vault (see **Drawing G4**). This will require a new automatically flow-paced 500 ppd chlorinator (CHL4). The historical chlorine usage data was combined with a theoretical maximum dose of 3.0 mg/L for the post-Clearwell No. 1 feed point at the Chemical Injection / Meter Vault. This dose considers the historical minimum point-of-entry chlorine residual and the additional chlorine dose necessary to provide up to 4.0 mg/L of chlorine for chloramines conversion. **Table 4-8** below details the basis of design for the chlorinator.

Table 4-8: Post-Clearwell No. 1 Chlorinator Basis of Design

Parameter	Value
Capacity	500 ppd
Dose Range	1 - 3 mg/L
Maximum Feed Rate	525 ppd
Minimum Feed Rate[1]	58 ppd

1. Based on a minimum plant flow rate of 7 mgd.

The maximum feed rate determined at rated plant capacity is slightly greater that the capacity of the chlorinator. However, **Figure 4-4,** illustrating historical chlorine usage with the addition of the new chlorine feed point, notes that this additional feed point at the maximum dose would not have caused the chlorine demand to exceed 800 ppd (maximum withdrawal of the four-cylinder switchover system) given the range of plant flows observed the past several years. This indicates that the current chlorine cylinder configuration is sufficient at current dosages and flows for the additional chlorinator, even when serving the post-filter feed point. However, if plant flows were to increase significantly in the future, the Robert A. Harris WTP would need to consider additional upgrades to the chlorine gas storage system that would maximize withdrawal from the chlorine cylinders.

Figure 4-4: Historical Doses with 3 mg/L at New Feed Point

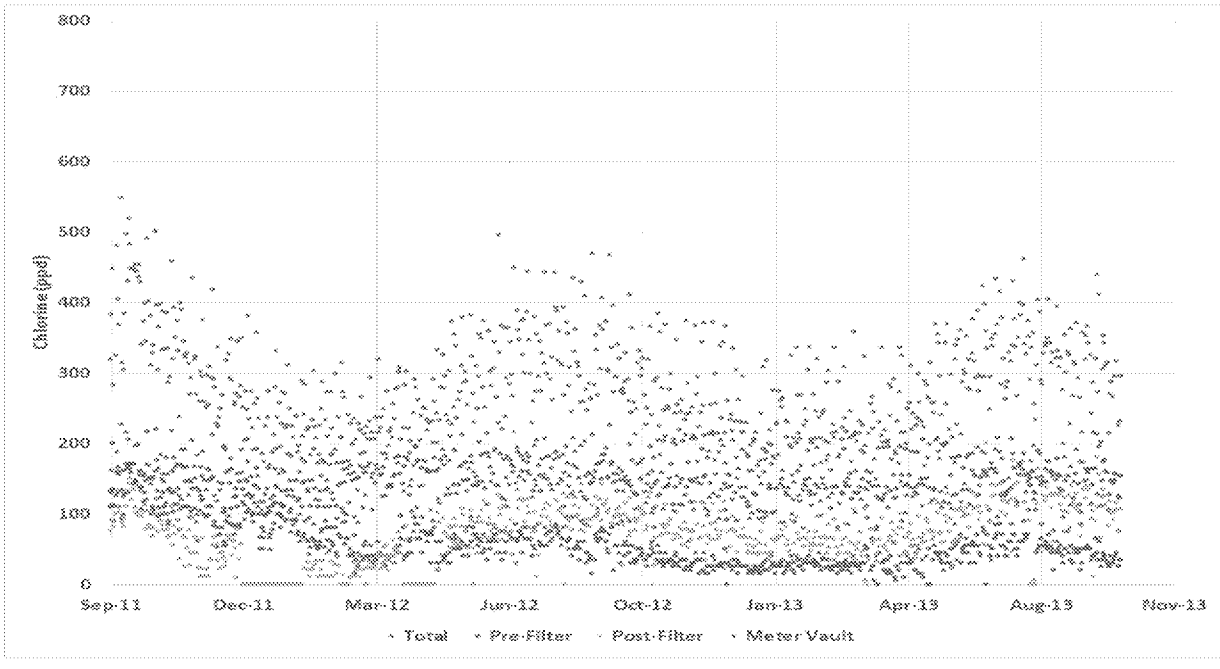
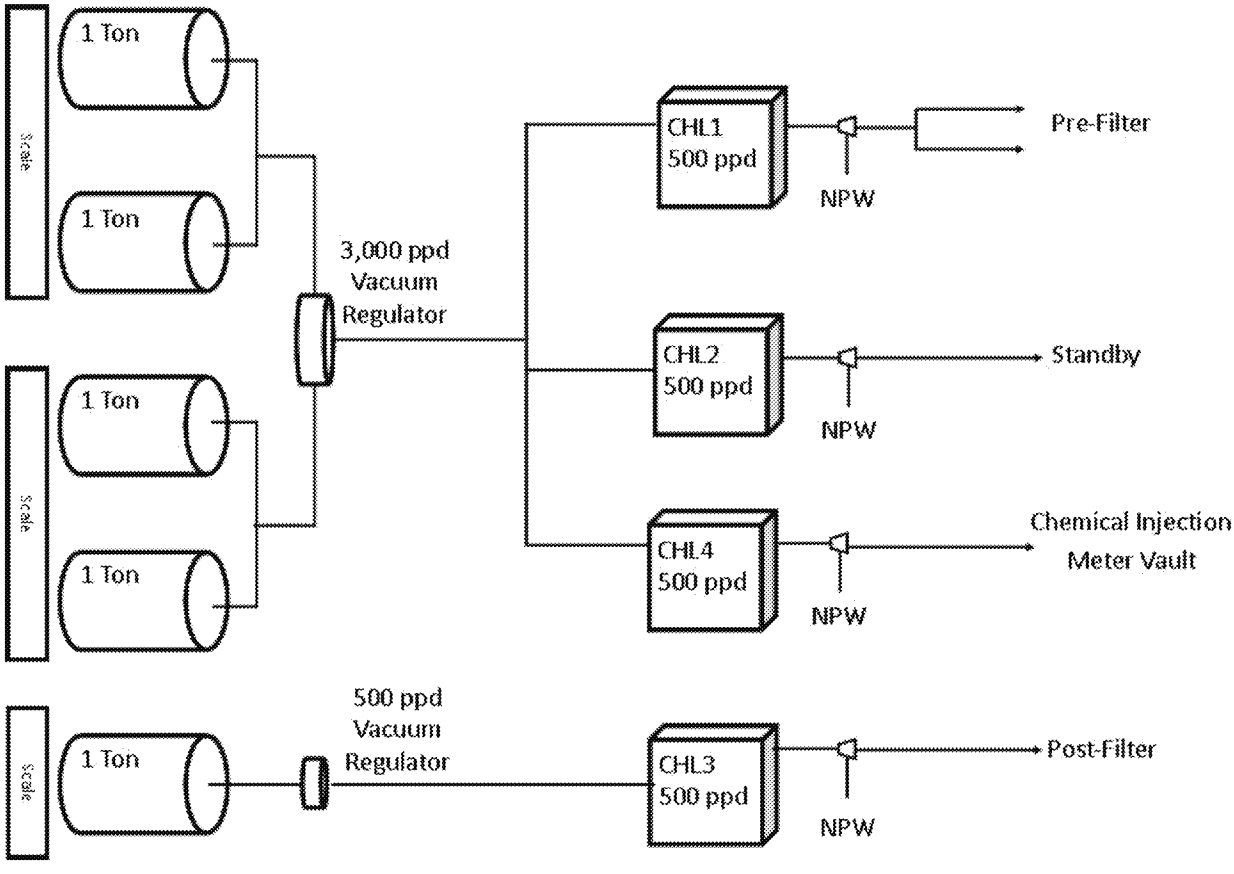


Figure 4-5 illustrates the updated chlorine feed schematic with the existing cylinder configuration to accommodate the addition of CHL4. CHL3 will continue to be fed by the single chlorine cylinder system. CHL4 will be fed by the four-cylinder system along with CHL1 and CHL2.

Figure 4-5: Updated Chlorine Storage and Feed System



Existing 1-½" piping from the vacuum regulator to the chlorinators is sized to accommodate the additional chlorine gas demand from the new feed point. There is minimal wall space available in the existing chlorinator room for a new chlorinator. However, space is available to allow the stanchion-mounting of a new chlorinator in the center of the chlorine feed room adjacent to the larger, existing chlorinators. The chlorine gas solution pipe manifold will be demolished and reconfigured in order for CHL2 to act as the standby for the other three chlorinators and their dedicated feed points (not shown in **Figure 4-5**). The other chlorinators (CHL1 and CHL3) will not have the ability to dose at the post-Clearwell No. 1 feed point due to the inability to automatically flow-pace these units.

During standard operation, a maximum treated flow of 19.2 mgd remains as a result of the maximum gas withdrawal rate for the single cylinder serving CHL3 at the 95th percentile post-filter dose condition. However, the four-cylinder switchover system is more greatly limited than the single-cylinder system as a result of the additional demand from the new post-Clearwell No. 1

feed point, served by CHL4. In standard operation, considering the post-Clearwell No. 1 maximum dose in combination with the 95th percentile pre-filter dose, the four-cylinder switchover system could feed chlorine up to a maximum WTP flow of 17.1 mgd. As a result, the maximum flow treated at the plant is limited to 17.1 mgd.

For standby operation, CHL1, CHL2, and CHL4 will pull from the four-cylinder switchover system which remains at a maximum withdrawal rate of 800 ppd. In standby operation, CHL2 would serve the post-filter feed point while the 1-ton cylinder is being replaced for the single-cylinder system. During this event, the four-cylinder switchover system would be responsible for all typical chlorine feed points in the plant, limiting the treated plant flow to 11.8 mgd. **Table 4-9** summarizes the flow limitations for standard and standby operating scenarios at 95th percentile pre- and post-filter doses and the maximum post-Clearwell No. 1 dose.

Table 4-9: Chloramines Conversion System Limitations

Scenario	Limitation	Treated Plant Flow (mgd) @ 95th Percentile Dose
Standard Operation	Cylinder Withdrawal Rate	17.1
Standby Operation	500 ppd Chlorinators	11.8

4.6.2 Caustic Storage and Feed System

The Robert A. Harris WTP currently has three mechanical diaphragm pumps with the ability to feed caustic at rapid mix and post-filter feed points. The rapid mix feed point is rarely used for caustic feed but is maintained for occasional raw water quality excursions. It is recommended that the existing three mechanical diaphragm pumps be dedicated to the post-filter feed point and the new post-Clearwell No. 1 feed point. This will provide a standby pump during standard operations. In the event that caustic must be fed at rapid mix, the standby pump will dose to the rapid mix feed point.

5 PRELIMINARY OPINION OF CONSTRUCTION COST

A preliminary opinion of probable construction cost for the Chloramines Conversion at the Robert A. Harris WTP is summarized in **Table 5-1**. The cost opinion does not include any engineering or construction administration and observation services. Costs include a 10 percent contingency and 20 percent markup for contractor overhead and profit.

A preliminary opinion of probable construction cost for the Chloramines Conversion at the Robert A. Harris WTP is $1,283,900 in 2014 dollars. A detailed breakdown of the preliminary cost opinion is provided in **Appendix B**.

Table 5-1: Capital Costs for Proposed WTP Improvements

Process	Total Project Cost
Sitework / Civil[1]	$109,100
Structural[2]	$157,400
Mechanical[3]	$459,100
Architectural / HVAC	$5,100
Electrical	$93,200
Instrumentation[4]	$148,700
Subtotal Construction Costs	**$972,600**
Contingency (10%)	$97,300
Overhead and Profit (20%)	$214,000
TOTAL CONSTRUCTION COST	**$1,283,900**

[1]Include pavement of access roadway and general sitework.
[2]Includes excavation/fill, concrete for LAS storage and chemical injection meter vault.
[3]Includes associated equipment and piping for LAS storage and chemical injection meter vault.
[4]Includes magnetic flow meter, analyzers, and SCADA programming.

APPENDIX A:

PRELIMINARY DRAWINGS
FOR THE ROBERT A. HARRIS WATER TREATMENT PLANT CHLORAMINATION UPGRADES

APPENDIX B:

PRELIMINARY OPINION OF PROBABLE CONSTRUCTION COSTS FOR THE ROBERT A. HARRIS WATER TREATMENT PLANT CHLORAMINES CONVERSION

Proposal From:

WaterMix

Utility Service Co.
INCORPORATED

535 Courtney Hodges Blvd.
P.O. Box 1350, Perry, Georgia 31069
Phone: 800-223-3695

www.utilityservice.com

FAX SIGNED COPY TO:
478-987-2991

Date March 18, 2013 SFID: CN: SO: Page No. 3 of 3

Proposal Submitted to: City of Eden, NC		Attn: Dena Reid	Phone (336) 627-1009 Fax
Address: PO Box 70		Job Name: Trihalomethane Removal System (TRS)	
City: Eden	State: NC / Zip Code: 27289	Job Location: Dunn St. Tank	County / Parish: Rockingham
Tank Name: Dunn St. Tank	Tank Size & Style: 500,000 Elevated	Est. Start Date: Upon Approval	Submitted by: Scotty Wilkins

10. Upon completion of the TRS installation the tank will be disinfected in accordance with AWWA C652 Spray Method #2. The tank will be sealed and made ready for service.

11. USCI/PAX will power up each TRS and complete an electrical and control panel operational check to verify power operation. USCI/PAX will also take samples entering the tank upon startup and after 21 days to validate the model accuracy of the results.

12. The design basis configured into the Neptune model:

Name	Dunn St. Tank
Type	Elevated
Tank Volume [gal]	500,000
Tank Diameter [ft]	56.0
Tank Height (TH) [ft]	30.0
Riser Height (RH) [ft]	35.0

*The total cost of this project shall be spread over several payments. The first payment of $49,609.00, plus all applicable taxes, shall be due and payable upon completion of the TRS installation or June 30, 2013, whichever comes first. The second payment of $49,609.00, plus all applicable taxes, shall be due on July 1, 2013. The third and final payment of $49,609.00, plus all applicable taxes, shall be due on July 1, 2014.

Please sign and date this proposal and return one copy to our office.

Proposal From:

WaterMix

Utility Service Co.

INCORPORATED

535 Courtney Hodges Blvd.
P.O. Box 1350, Perry, Georgia 31069
Phone: 800-223-3695

www.utilityservice.com

FAX SIGNED COPY TO:
478-987-2991

Date March 18, 2013 SFID: CN: SO: Page No. 2 of 3

Proposal Submitted to: City of Eden, NC			Attn: Dena Reid	Phone (336) 627-1009 Fax
Address: PO Box 70			Job Name: Trihalomethane Removal System (TRS)	
City: Eden	State: NC	Zip Code: 27289	Job Location: Dunn St. Tank	County / Parish: Rockingham
Tank Name: Dunn St. Tank	Tank Size & Style: 500,000 Elevated		Est. Start Date: Upon Approval	Submitted by: Scotty Wilkins

6. The proprietary USCI/PAX Trihalomethane Removal System (TRS) will be installed in the tank to remove Trihalomethanes (THM). The TRS has been custom designed using the PAX Neptune Toolbox, a state of the art computer model which contains proprietary detailed physicochemical models of THM transport processes inside specific potable water storage tanks. The Neptune model allows prediction of process dynamics and system performance for various configurations of aeration systems and their effect on THM concentration in the tank. Using the specific details of each tank listed above along with the hydraulic operations and water chemistries furnished by the owner, the Neptune Toolbox predicts a THM reduction:

	Dunn St. Tank
Capacity [MG]	0.500
Turnover [MGPD]	0.197
Target Removal	40% @ 197,000 GPD

7. The TRS will consist of one (1) efficient recirculation pump along with 8 spray nozzles positioned in the roof of the water tank as dictated by the Neptune model. The existing vents will be removed and replaced with a custom designed proprietary power vent along with (2) additional makeup air vents all in accordance with the AWWA D100.

8. The owner shall furnish (1) 230 VAC, 40 AMP GFCI and (1) 120 VAC, 20 AMP GFCI-protected grid power to the base of the tank approximately 42-60 inches above grade and will be responsible for all trenching, conduit and electrical connections outside the tank. USCI will furnish all electrical control boxes, conduit, tank sidewall penetrations and electrical connections within and on the tanks. USCI will furnish a certified electrician as required for electrical work up to the tank.

9. The TRS includes an optional wireless monitoring and alert system that continuously monitors the functioning of the TRS and its major subsystems. If any subsystem loses power, or if the hydraulic performance of the system falls out of specification, this system immediately alerts PAX Water (and the utility, if desired). PAX Water can either alert the utility as to the nature of the problem, or, if the utility has purchased a TRS maintenance plan, alert Utility Service to inspect and repair the system. The price for the monitoring system includes a free data plan for the first year.

Proposal From:

WaterMix

Utility Service Co. INCORPORATED

535 Courtney Hodges Blvd.
P.O. Box 1350, Perry, Georgia 31069
Phone: 800-223-3695

www.utilityservice.com

FAX SIGNED COPY TO:
478-987-2991

Page No. 1 of 3

Date March 18, 2013 SFID: CN: SO:

Proposal Submitted to: City of Eden, NC		Attn: Dena Reid	Phone (336) 627-1009 Fax
Address: PO Box 70		Job Name: Trihalomethane Removal System (TRS)	
City: Eden	State: NC / Zip Code: 27289	Job Location: Dunn St. Tank	County / Parish: Rockingham
Tank Name: Dunn St. Tank	Tank Size & Style: 500,000 Elevated	Est. Start Date: Upon Approval	Submitted by: Scotty Wilkins

Utility Service Co., Inc. agrees to provide all labor, equipment, and materials needed to complete the following:

1. The price listed below is for the complete installation of one (1) TRS installation as defined in this proposal.
2. USCI shall provide all services to request the necessary permitting from the appropriate agency, including design basis, drawing completion, and any follow up documentation necessary. USCI shall also submit the completion certification to said agency upon satisfactory installation of the TRS.
3. A date shall be coordinated by both parties for draining of each tank and installation of each TRS.
4. The interior floor and lower walls of the tank will be cleaned using a pressure washer to remove all mud, silt, and foreign sediment. The tank is not to be rigged to pressure wash the upper walls above the high water line, and roof unless specified by this agreement.
5. An NSF 60 approved patented chemical cleaning agent will be applied to the interior walls up to the high water line and floor to clean and remove any bio-film. This will be followed with a fresh water rinse to all surfaces to remove cleaning agent which will be diluted and neutralized. Pricing assumes that neutralized wash water and sediment will be disposed of by the owner or disposed of on-site.

One Hundred Forty-Eight Thousand Eight Hundred Twenty-Seven and 0/100 dollars ($ 148,827.00 + tax*)

Payment to be made as follows: *Payment Spread over Three Payments – plus all applicable taxes*

Remittance Address: Utility Service Company, Inc., P. O. Box 116554, Atlanta, GA 30368-6554

All material is guaranteed to be as specified. All work to be completed in a substantial workmanlike manner according to specifications submitted, per standard practices. Any alteration or deviation from above specifications involving extra costs will be executed only upon written orders, and will become an extra charge over and above the estimate. All agreements contingent upon strikes, accidents or delays beyond our control. Owner to carry fire, tornado and other necessary insurance. Our workers are fully covered by Workmen's Compensation Insurance.

Authorized USCI Signature

Note: This proposal may be withdrawn by us if not accepted within Sixty (60) days

Acceptance of Proposal — The above prices, specifications and conditions are satisfactory and are hereby accepted. You are authorized to do the work as specified. Payment will be made as outlined above.

Signature

Date of Acceptance 3-20-13 Printed Name Brad Lorenzen

MALCOLM PIRNIE | ARCADIS

The Water Division of ARCADIS

Imagine the result

City of Eden, North Carolina

WTP Stage 2 D/DBP Rule Compliance Study Report

January 2011

ARCADIS

WTP Stage 2 D/DBP Rule Compliance Study Report

1/28/11
David A. Hamilton, PE
Project Manager

1-28-11
David M. Baird, PE
Chief Process Engineer

1/28/2011
Rebecca L. Cramer, PE
Process Engineer

Prepared for:
Eden, North Carolina

Prepared by:
ARCADIS G&M of North Carolina, Inc.
1 Centerview Drive
Suite 208
Greensboro
North Carolina 27407
Tel 336.292.2271
Fax 336.855.5648

Our Ref.:
GREDN013.R001

Date:
January 2011

This document is intended only for the use of the individual or entity for which it was prepared and may contain information that is privileged, confidential and exempt from disclosure under applicable law. Any dissemination, distribution or copying of this document is strictly prohibited.

ARCADIS

Table of Contents

Introduction **1**

Data Collection and Review **1**

Water Treatment Plant 1

Distribution System 3

Total Trihalomethanes 5

HAA5s 6

Contributing Factors 6

Total Organic Carbon 10

Hardness 11

Conclusions 14

Recommended Improvements **14**

Improvement Options 14

Recommendations 19

Source Water and Distribution System Monitoring 19

Perform Treatability Study 21

Implement Treatment and Distribution System Optimization Techniques 21

Tables

Table 1 – Technologies and Techniques Considered 15

Table 2 – Improvement Cost Comparison 18

Figures

Figure 1 – WTP Process Schematic - Existing 2

Figure 2 – Water Distribution System Schematic 4

Figure 3 – Total TrihaloMethanes 5

Figure 4 – Haloacetic Acids 6

Figure 5 – Temperature vs. TTHMs 7

Figure 6 – Water Age vs. TTHMs – All Data 9

Figure 7 – Water Age vs TTHMs – Outlying Data Removed 9

Figure 8 – Total Organic Carbon 11

Figure 9 – Alkalinity vs. Hardness 12

Figure 10 – TTHM Species (Monitoring Site 343) 13

Figure 11 – Source Water Bromide Sampling 20

Introduction

In November 2009 the City completed an Initial Distribution System Evaluation (IDSE) as one of several steps to comply with the 2006 SDWA Stage 2 Disinfectants and Disinfection Byproducts Rule. The IDSE identified proposed monitoring sites in the distribution system where regulated contaminants, total trihalomethames (TTHM) and five haloacetic acids (HAA5), should be tested to indicate the distribution system water quality.

Preliminary test results suggest that the regulatory limits of 0.060 mg/l for HAA5 may be met while the regulatory limit of 0.080 mg/l for TTHM may not be met when Eden is required to comply with the Stage 2 Rule in October 2013 (based on the locational running annual averages for individual sites).

Since source water organics and inorganics combined with disinfectant chemicals form the contaminants, an evaluation of the City's Harris Water Treatment Plant was commissioned. For this study the City has asked ARCADIS to review the plant processes and operations to evaluate the potential for improved Total Organic Carbon (TOC) removal at the plant and TTHM and HAA5 formation control at the plant and in the distribution system. Both treatment process and operational strategies will be discussed and recommended by this Report.

Data collection/review, improvement options, and recommendations will be discussed in the following Report sections.

Data Collection and Review

Water Treatment Plant

WTP operating data from 2002 through 2010 was gathered and reviewed. The initial step to understanding and assessing this data was to create a plant process schematic identifying treatment processes including chemical addition and sample locations.

The resultant schematic is included on the following page as **Figure No. 1 – WTP Process Schematic - Existing**.

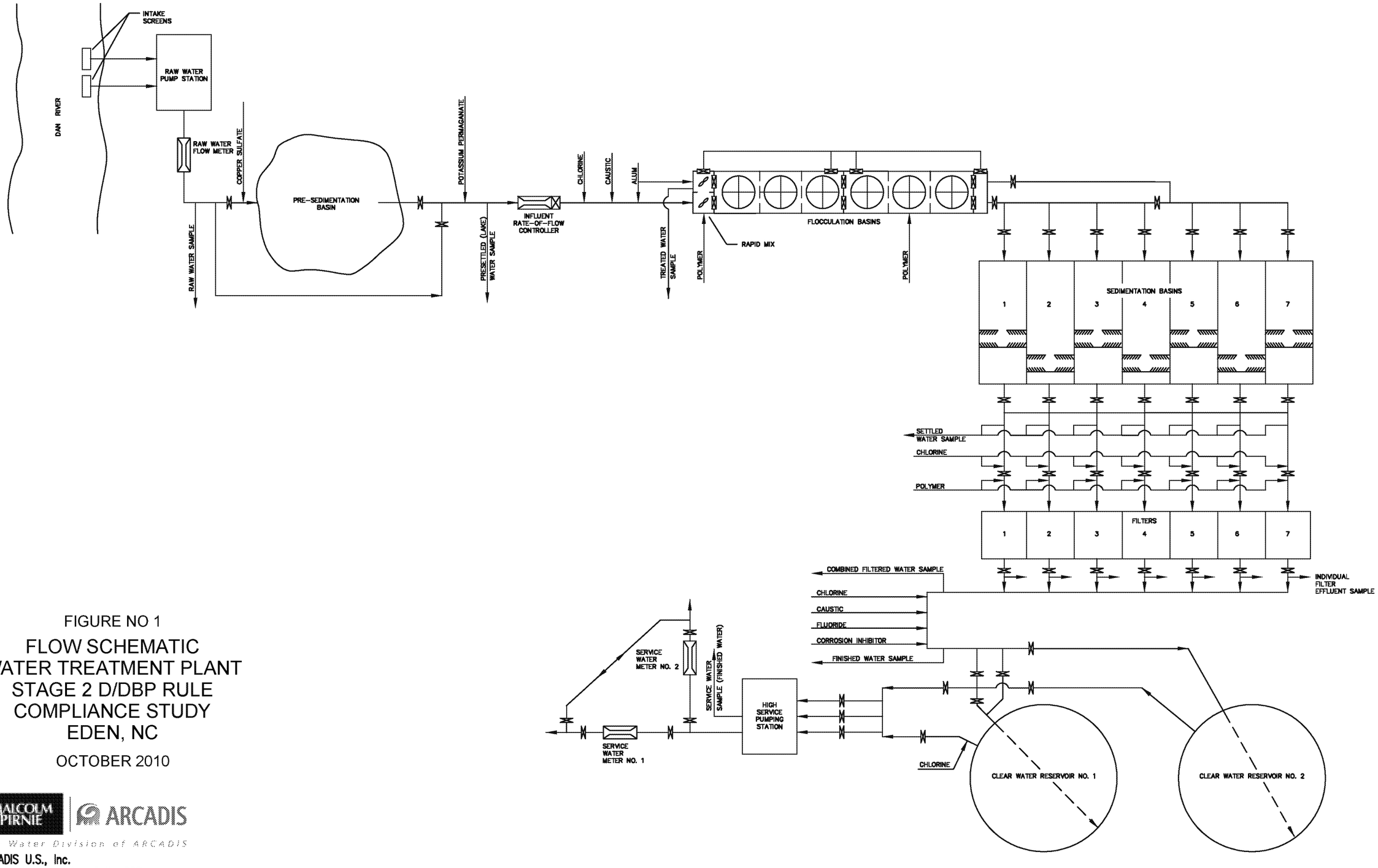


FIGURE NO 1

FLOW SCHEMATIC WATER TREATMENT PLANT STAGE 2 D/DBP RULE COMPLIANCE STUDY EDEN, NC

OCTOBER 2010

MALCOLM PIRNIE | ARCADIS

The Water Division of ARCADIS

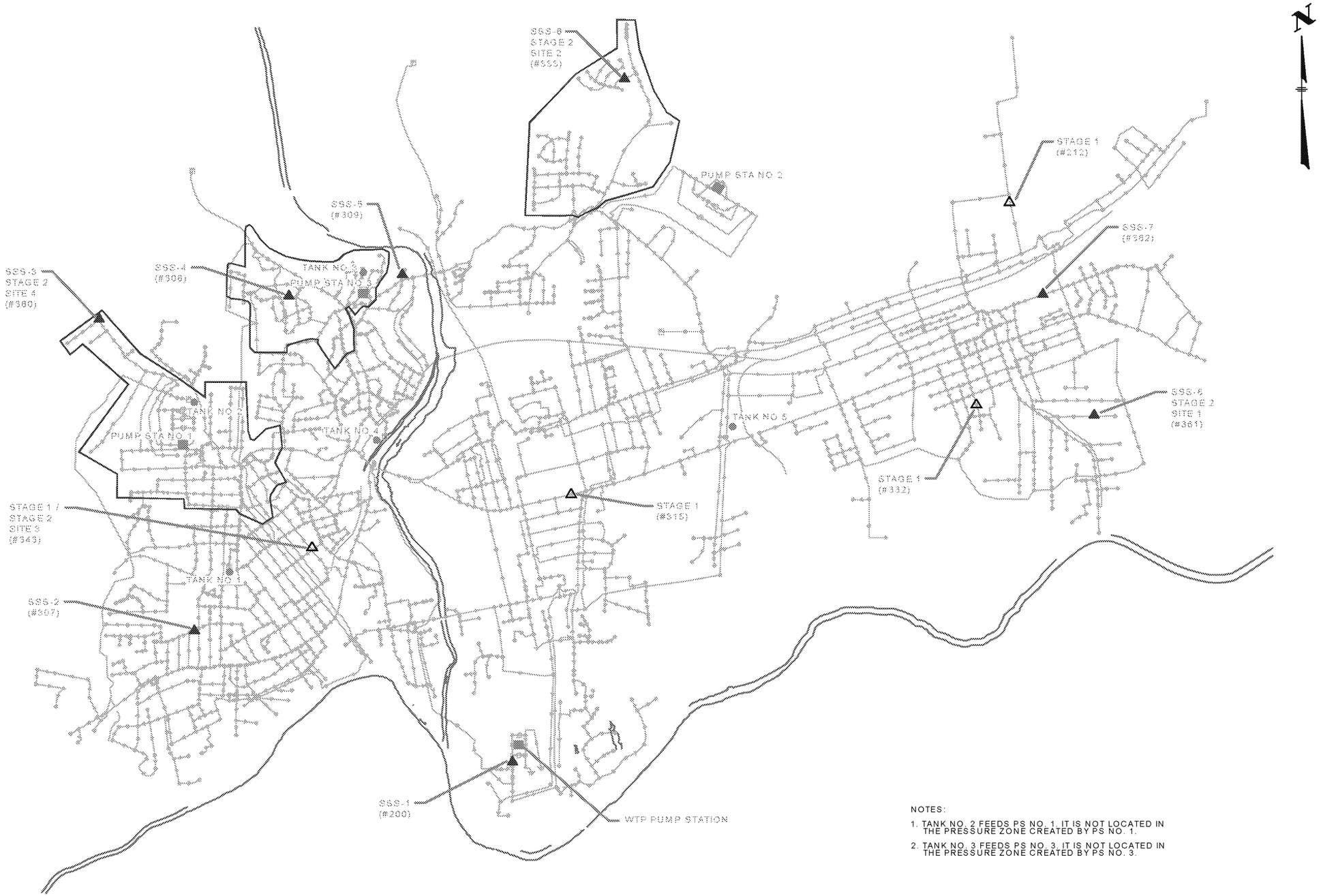
ARCADIS U.S., Inc.
One Centerview Drive, Suite 208
Greensboro, North Carolina 27407
Tel: 336-292-2271 Fax: 336-855-5648
www.arcadis-us.com
License Number C-1869

Acad Version : R17.0s (LMS Tech) User Name : sorquata
Date\Time : Mon, 10 Jan 2011 - 2:02pm Path\Name : G:\PROJECT\Eden NC\GRIDNO13.RD01 (WTP TOC Study)\Dwg\1x17_border.dwg
Current Pitstyle : ByColor Layout Tab: Layout1

Raw water is drawn from the Dan River upstream of the confluence of the Dan and Smith Rivers and pumped into a pre-sedimentation basin (lake) where it then flows by gravity to the treatment plant. Copper sulfate can be fed at times at the lake influent. After the water leaves the lake the plant treatment processes include optional chemical addition (potassium permanganate, caustic, alum or poly-aluminum chloride, polymer), rapid mix, flocculation with polymer addition, sedimentation, chemical addition (chlorine and optional polymer), filtration, post-filter chemical addition (chlorine, caustic, fluoride, corrosion inhibitor), and finished water storage and supplemental chlorine addition before pumping to the distribution system.

Distribution System

The four monitoring sites required by the Stage 1 D/DBP Rule have been tested quarterly for TTHMs and HAA5s since 2002. Additionally, TTHMs and HAA5s were tested in samples taken from the Stage 2 monitoring locations in Q3 2009 and Q3 and Q4 2010. These monitoring locations are shown on the water distribution schematic published with the November 2009 IDSE Report (included on the following page as **Figure 2 – Water Distribution System Schematic**).



NOTES:

1. TANK NO. 2 FEEDS PS NO. 1. IT IS NOT LOCATED IN THE PRESSURE ZONE CREATED BY PS NO. 1.
2. TANK NO. 3 FEEDS PS NO. 3. IT IS NOT LOCATED IN THE PRESSURE ZONE CREATED BY PS NO. 3.

0 1500 3000 4500

SCALE 1"= 1500'

LEGEND

- DISTRIBUTION SYSTEM TANK
- PUMP STATION
- STAGE 1DBPR LOCATION
- PROPOSED IDSE SAMPLE LOCATION
- PRESSURE ZONE BOUNDARY

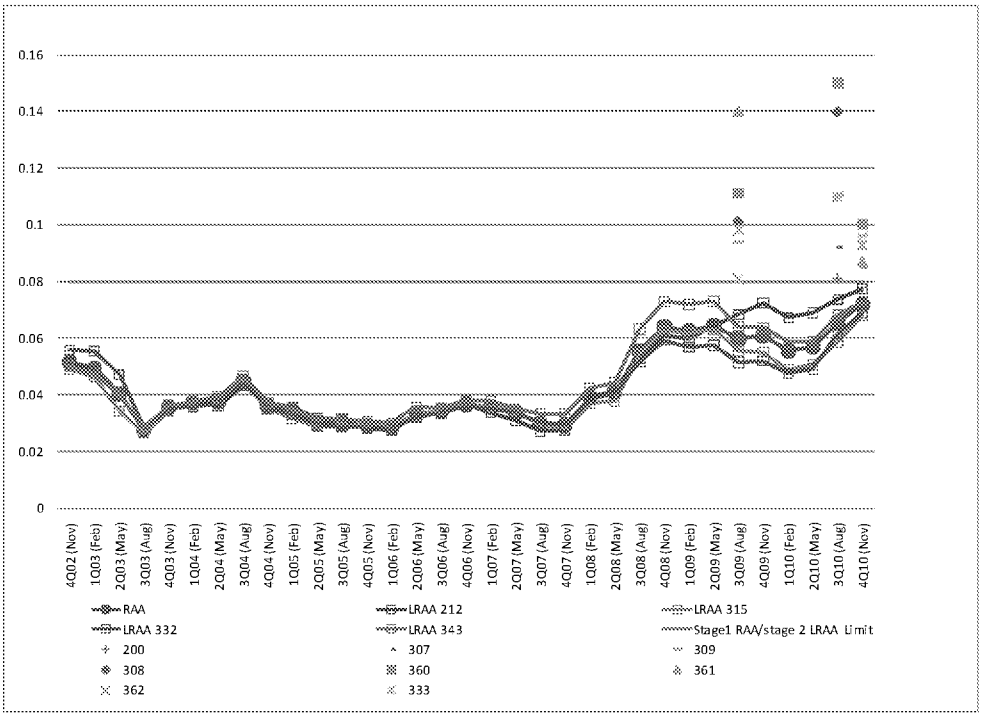
WATER DISTRIBUTION SYSTEM SCHEMATIC

NOVEMBER 2009

Total Trihalomethanes

The Stage 1 site locational running annual averages (LRAA) and the system running annual average (RAA) TTHM test results are graphed from 2002 to 2010 in **Figure 3** and indicate a dramatic upward trend in values beginning around Q4 2007. These RAA values increase from around 0.040 mg/l to just under the 0.080 mg/l threshold and then level off at that value for a time (from Q4 2008 to Q2 2010), then continue to rise to the present. The Stage 2 site test values taken in Q3 2009, Q3 2010 (Q3 considered the most likely time of the year to have high TTHM values due to elevated water temperatures), and Q4 2010 all indicate values exceeding the 0.080 mg/l locational running annual average (LRAA) threshold. Although, it is important to note that these values would be averaged (by location) with lower results that are expected to be achieved throughout the remaining three quarters. Even so, these data suggest that LRAA TTHM violations are likely to occur at some of the Stage 2 monitoring sites.

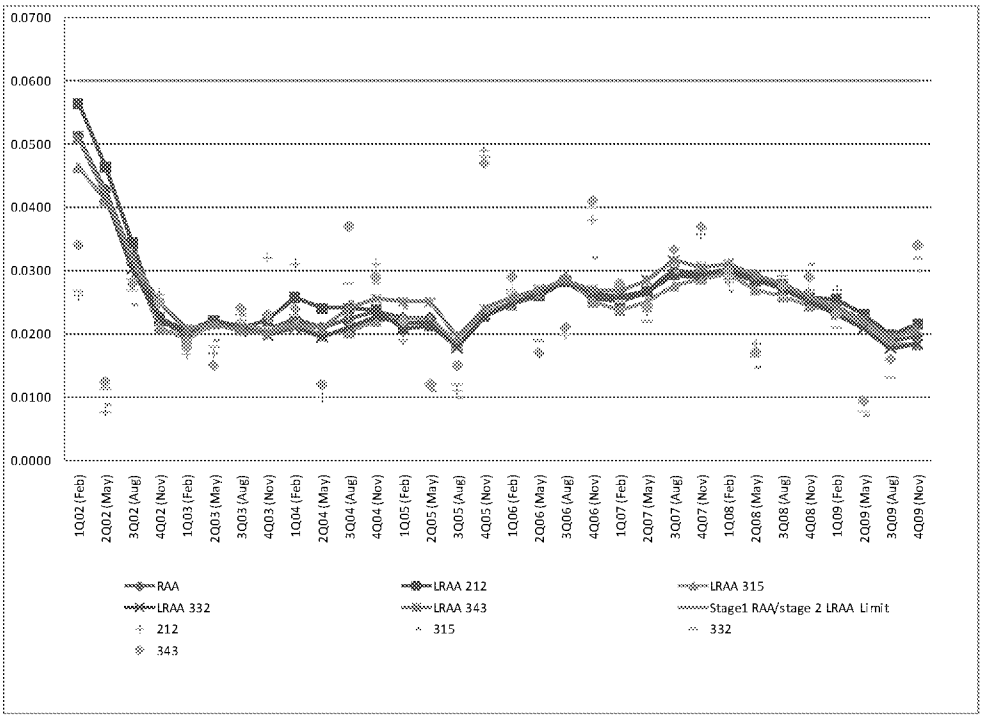
Figure 3 – Total TrihaloMethanes



HAA5s

The Stage 1 sites and one Stage 2 site haloacetic acids (HAA5) test results are graphed from 2002 to 2010 in **Figure 4** and indicate the values (except during 2002 and earlier) are comfortably below the 0.060 mg/l limit. When locational running annual averages are used at Stage 2 sites in the future, it appears the City will continue to be in compliance.

Figure 4 – Haloacetic Acids

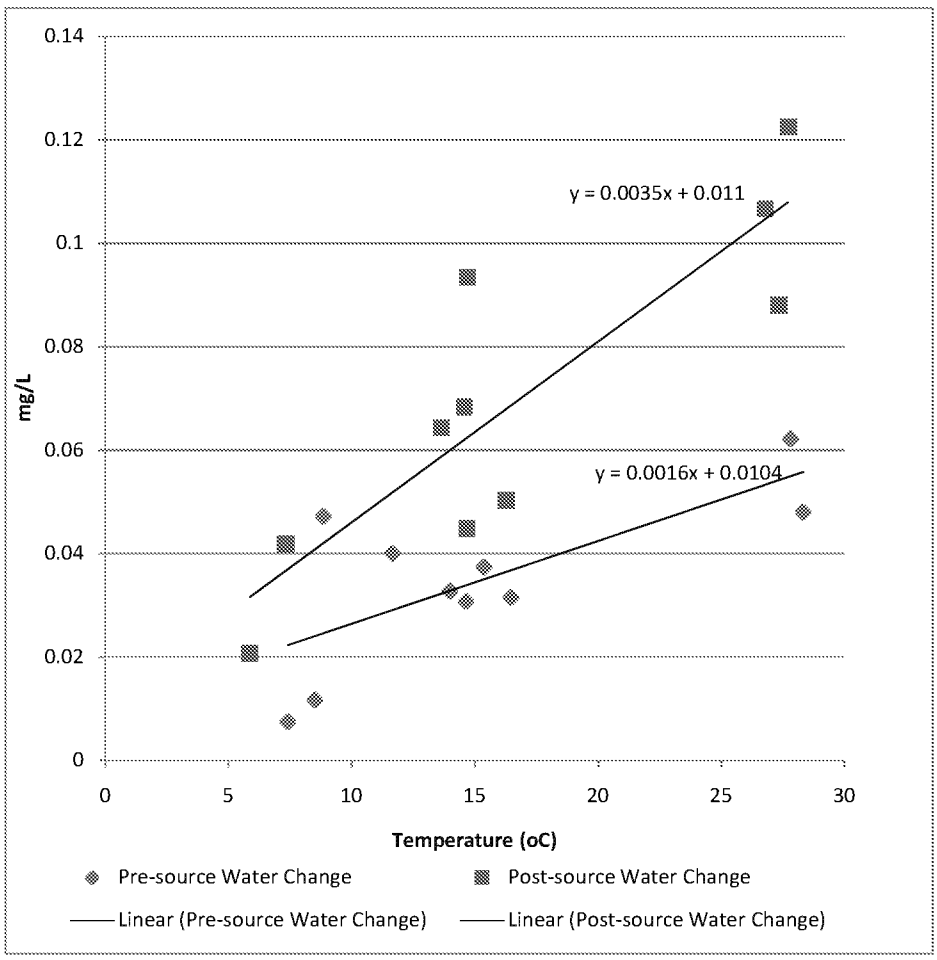


Contributing Factors

A number of factors and events may have a bearing on TOC removal and TTHM/HAA5 control. They include environmental (weather) conditions, raw water quality, treatment processes, the distribution system, and other factors. Environmental factors such as air (and subsequently water) temperature and rainfall (or drought) can effect concentration and settleability of solids at the water treatment plant and pre-sedimentation basin. It should be noted that severe drought was experienced in the

area in 2002 and a moderate drought occurred in 2007. Certainly, temperature affects the formation rate of DBPs in the distribution system and particularly the potential for temperature stratification in storage tanks which can affect the natural or forced mixing ability in the tank. Therefore, annual high summertime (August) temperatures coincide with routinely high TTHM values (see **Figure 5**, below). The two trend lines represent the time period prior to and after the rise in TTHM observed in 2008. The shift in the trend line indicates a potential change in raw water quality.

Figure 5 – Temperature vs. TTHMs



WTP process selection and effectiveness have a significant affect on TOC removal. Treatment chemical type, dose, and feed points all require maintaining a critical balance to optimize DBP precursor removal and reduce DMP formation potential. One example of the efforts to minimize TOC's is that the City commonly changes coagulants at the WTP to match temperature conditions; using aluminum sulfate (Alum) coupled with polymer when temperatures rise above 15°C and poly-aluminum chloride (PACL) when temperatures drop below 10°C. The WTP staff has noticed a reduction in the strength (and effectiveness) of Alum beginning at a distinct point in time; this is attributed to the quality of available Alum in today's market. The only other chemical change to note is the chlorine feed to the influent was stopped and moved to on top of the filters in 2002. This move of the chlorine feed point is likely a contributing factor in the reduced byproduct formation from the 2002 levels. The only other treatment process change made in the last decade is the addition of a polymer feed to the 5th flocculation basin when Alum is fed. This polymer feed is necessary to maintain the removal rate of TOC.

In the finished water distribution system several changes have occurred in the last 8-10 years that could affect DBP formation potential. These changes include infrastructure modifications as well as customer demand changes. A number of infrastructure improvements have been implemented including the removal of check valves in 2005 that originally separated parts of the distribution system. Also, a series of pressure enhancement projects occurred between the summer of 2007 and autumn of 2008, such as high service pump variable frequency drive additions, remote booster pumping station upgrades and additions, various water main improvements, the addition of Freedom Park Tank, the abandonment of Byrd Street Tank, and the elimination of the Karastan Tank. A review of tank operation for the system reveals that each tank appears to achieve good daily turnover (15% - 25% of volume) accomplished by shutting high service pumps off for periods of time. Perhaps of more significance is the overall system demand reduction due to industrial customer closings: Pluma in 2002, Spray Cotton Mill in 2002, Fieldcrest in 2003, Parkdale in 2006, Liberty Screen Print in 2007, and Hanes Brand (National Textiles) at the end of 2009. These large customer demand reductions have a significant impact on distribution system water age.

Figure 6, below, represents all data points for TTHM and water age at the twelve distribution system monitoring sites (two data points for each site; one take in Q3 2009 and the other in Q3 2010).

Figure 6 – Water Age vs. TTHMs – All Data

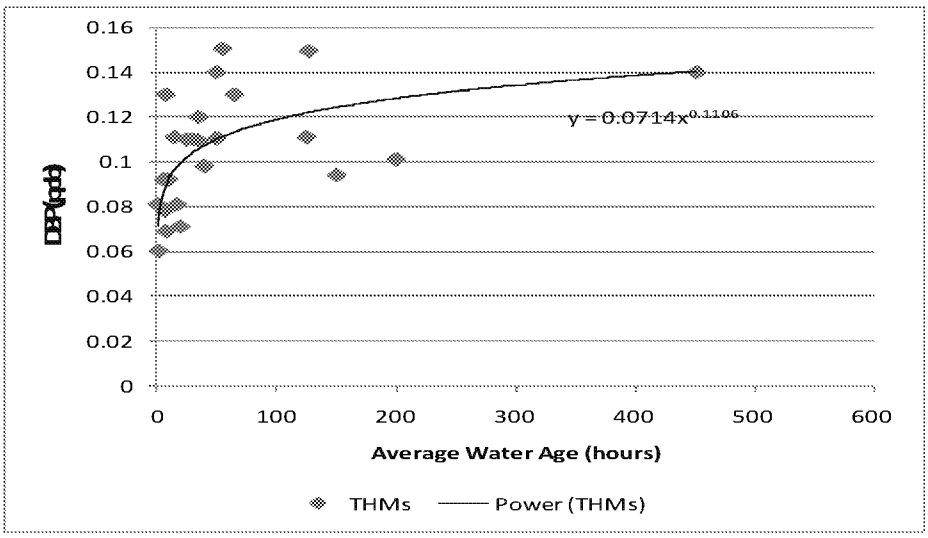
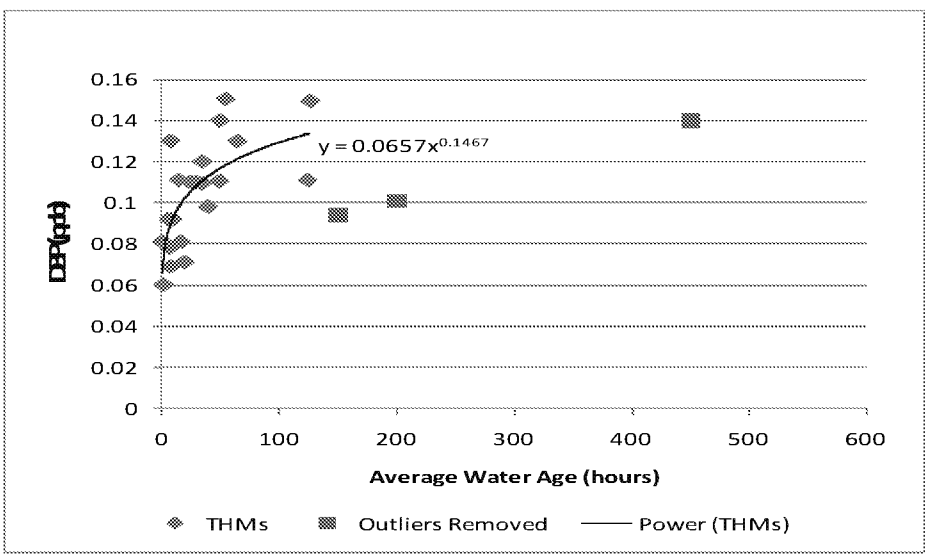


Figure 7, below, represents the same data with the three obvious outliers omitted to generate the trend curve. **Figure 7** indicates a distinct trend of increased TTHMs with increased water age.

Figure 7 – Water Age vs TTHMs – Outlying Data Removed



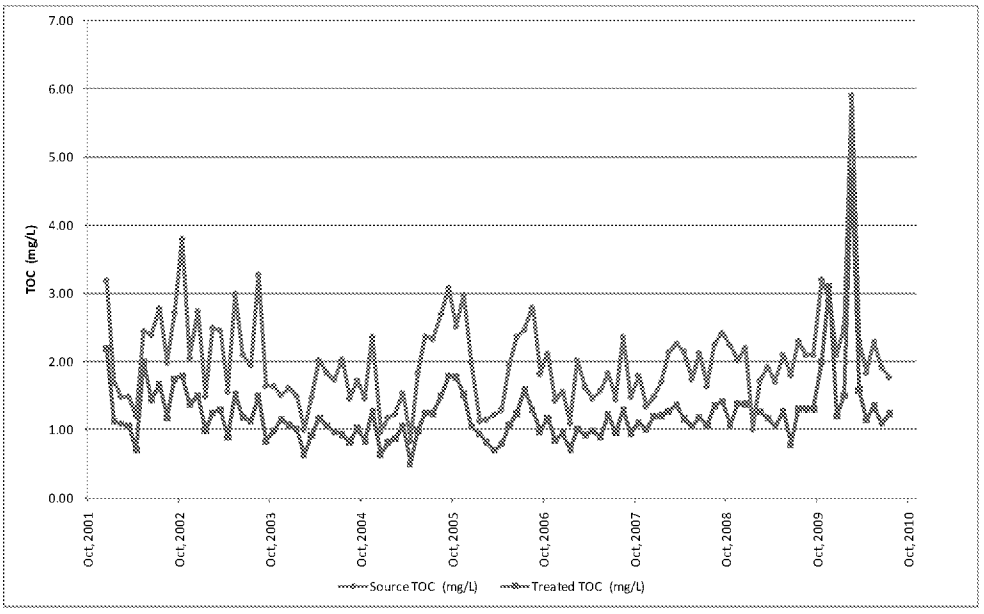
These two figures also show a tendency for high TTHM at a low water age. Although data is not available for the time period prior to the observed TTHM increase (in 2008), we believe that this rapid formation of TTHMs is a result of a change in raw water quality.

Other factors such as sampling techniques and laboratory analysis techniques also can have an affect on the TTHM and HAA5 test results. It was noted that a change in labs that performed the TTHM testing was made in 2007; after which the TTHM results began to rise until reaching a plateau in 2008.

Total Organic Carbon

Monthly Operating Reports (MORs) dating back to January 2002 provided the data for the source water and treated water TOC. The source water sample is taken at the pre-sedimentation basin (lake) effluent and the treated water sample is taken from the combined filter effluent. TOC values are shown graphically on **Figure 8**. Eden consistently meets the State regulated removal percentages at this time by coagulated particle removal in the sedimentation and filtration processes. It is also valuable to recognize that the upward TTHM trend does not follow the relatively level TOC trend over the past decade. Therefore, no direct correlation between TOC at the WTP and the increase in TTHM can be identified.

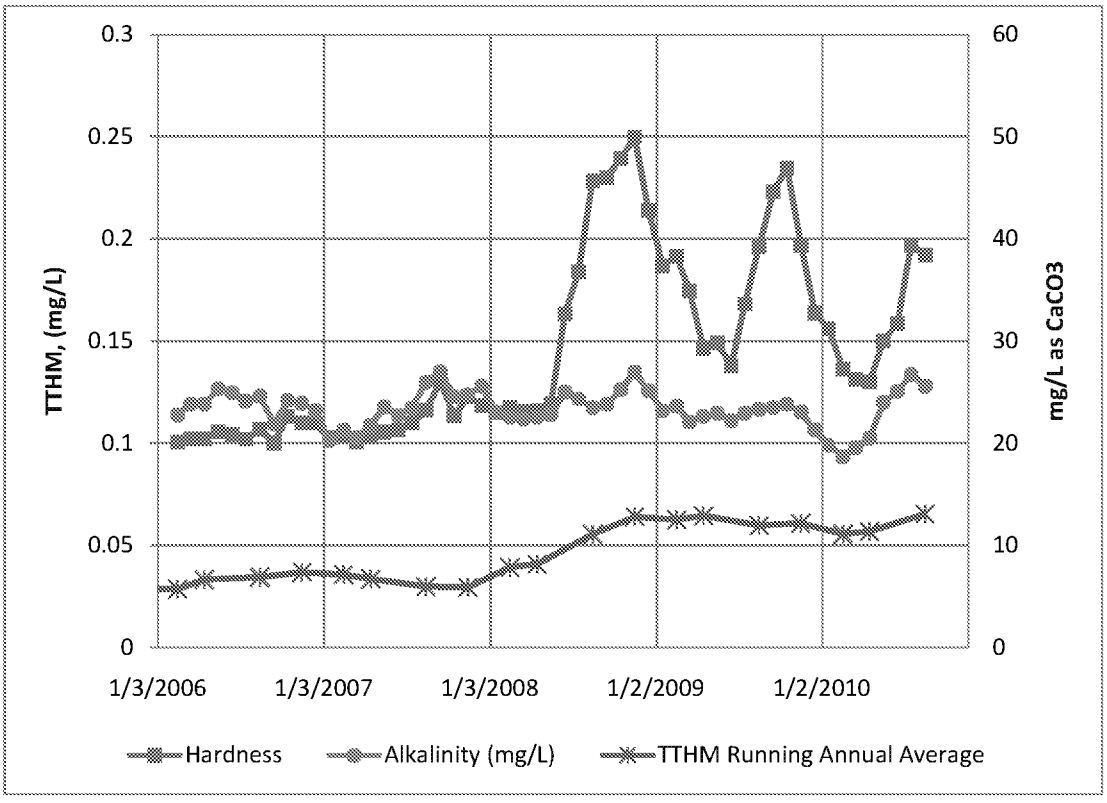
Figure 8 – Total Organic Carbon



Hardness

Source water characteristics such as alkalinity and total hardness were also reviewed. Historically, for Eden's raw water hardness and alkalinity have been around 25 mg/l for each indicating that the hardness has been primarily carbonate hardness. However, as seen on the following **Figure 9**, the source water hardness values increase and diverge from the alkalinity values beginning around year 2008 and have exceeded 50 mg/l at times. This indicates that non-carbonate hardness is present. This non-carbonate hardness could come from the presence of other di- and tri-valent compounds not typically seen in drinking water, among other sources. The change in hardness, both in magnitude and relative to alkalinity, is further evidence that a change in the source water quality has occurred. It is worth noting that the City of Danville's WTP (downstream of Eden on the Dan River) has similarly experienced high raw water hardness.

Figure 9 – Alkalinity vs. Hardness

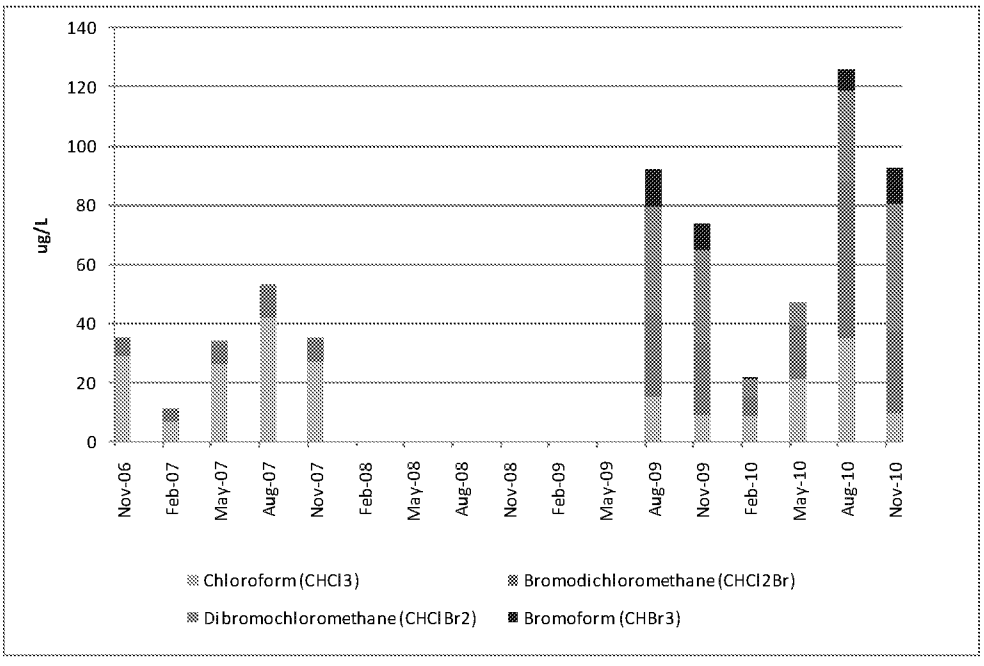


In researching the possible cause of elevated hardness, bromide has been identified as a significant component of the TTHM speciation (the individual components of TTHM: chloroform, bromoform, dibromochloromethane, and bromodichloromethane) starting in 2008. Bromide can be found in salts in surface or ground water and are either naturally-occurring, or are a result of industrial wastes, agricultural runoff, etc. Because bromide is an inorganic DBP precursor bromide is oxidized by hypochlorous acid to form hypobromous acid and then reacts with natural organic material (NOM) to form brominated TTHMs. Waters with bromide, therefore, typically form more TTHM and HAA than waters without bromide. Since hypobromous acid is a stronger substituting agent than hypochlorous acid, bromide in the raw water can change the species balance of TTHMs and HAAs resulting in lower levels of chloroacetic acid compounds and higher levels of bromoacetic acid compounds in the resultant treated water. *(Ref: EPA Stage 2 DDBP Rule Operational Evaluation Guidance Manual,*

2008). In fact TTHM values are relatively high even as treated water leaves the Eden WTP.

As mentioned above, a correlation does exist between source water bromide and distribution system TTHMs. To further illustrate the point the following **Figure 10** indicates the increase in distribution system TTHM levels and change in speciation that began occurring around 2008 as bromide compounds begin to dominate the TTHM speciation. Speciation results between November 2007 and August 2009 are not available at this time.

Figure 10 – TTHM Species (Monitoring Site 343)



It should be noted, though, that the presence of bromide in the water may lead to a reduction of HAA5s due to the shift of bromated species that are not a part of HAA5. These situations are case-specific and would need to be investigated further to be conclusive. *(Ref: EPA Stage 2 DDBP Rule Operational Evaluation Guidance Manual, 2008).*

Conclusions

From the data review it appears that the source water has changed, as indicated by the changes in hardness and the TTHM speciation with an increase in brominated byproducts. The increase in brominated byproducts strongly points to an increase of bromide in the raw water.

The rise in TTHM levels, in spite of the continued high level of TOC removal, indicates that the focus of any proposed improvement should be on removing inorganic compounds such as bromide and controlling DBP formation, rather than strictly TOC removal.

HAA5s are sufficiently low and would not be the driver for any proposed improvement.

Among the main contributing factors to the high TTHM values are high summertime water temperatures and high water age due to recently lowered demands. (Notably, however, it does not appear that a direct correlation exists between TTHMs and distribution system improvements made over the last few years). Also, since TTHMs are relatively high leaving the WTP and TTHM speciation supports it, there is a strong potential that DBP formation is being influenced by the bromide existing in the source water.

Recommended Improvements

Improvement Options

Numerous treatment process technologies and operational techniques could be considered to improve either DBP precursor (both TOC and bromide) removal, DBP formation control, and DBP removal. However, only a few alone can meet the compliance goals, while others simply optimize DBP precursor removal or formation control. Additionally, only a select few are capable of removing bromide. **Table 1** below, indicates the technologies and techniques considered for the City of Eden and whether or not they can effectively meet the compliance goals.

Table 1 – Technologies and Techniques Considered					
	DBP Precursor Removal				
Improvement Option	TOC	Bromide	DBP Formation Control	DBP Removal	Meets Compliance Goals
Ion Exchange (e.g. MIEX)	√	Up to 100%[2]			Possibly[1]
Iron-based Coagulant (e.g. Ferrous Sulfate, Ferric Sulfate, Ferric Chloride)[5]; Replaces Alum	√	20%[4]			Possibly[1]
Powdered Activated Carbon	√	20-50%[3]			Possibly[1]
Improved Coagulation/Mixing	√				Optimization Technique
Chlorine Dioxide (Replaces Pre-Filter Chlorine)			√		Optimization Technique[1]
Alternate Chemical Feed Locations (esp. Chlorine)	√		√		Optimization Technique
Improved Clearwell/CT Management			√		Optimization Technique
Chloramination (Replaces Free Chlorine)			√		Possibly[1]
Granular Activated Carbon	√	Up to 100%[3]		√	Possibly[1]
Distribution System			√		Optimization

Table 1 – Technologies and Techniques Considered					
	DBP Precursor Removal				
Improvement Option	TOC	Bromide	DBP Formation Control	DBP Removal	Meets Compliance Goals
Uni-Directional Flushing					Technique
Improved Distribution System Tank Management			√		Optimization Technique
Nanofiltration Membranes	√	>40%		√	Possibly(1)

(1) Would require pilot or bench-scale testing to determine effectiveness
(2) Resin specific
(3) Carbon specific, pH specific, source water anion specific
(4) At low pH
(5) Poly-aluminum chloride (PACL) blend varieties may also prove beneficial

Considering first, only those improvements that by themselves may be able to achieve compliance, we are left with ion exchange, iron-based coagulants (such as ferrous sulfate, ferric sulfate and ferrous chloride) as a substitute coagulant, powdered activated carbon, chloramines as a substitute disinfectant, granular activated carbon, and nanofiltration membranes as the only viable alternatives.

Ion exchange, such as Magnetic Ion Exchange (MIEX), is a DBP precursor removal technology that employs a positively charged resin to adsorb negatively charged humic and fulvic acids to reduce dissolved organic carbon (DOC) in raw water. This process can also be effective for bromide removal when used with a bromide-selective resin. The resin is regenerated in a brine solution where chloride ions exchange places with the organic and inorganic ions and adsorb to the resin once again. A reactor tank, regeneration tank, a brine tank, make-up resin, salt, and various small capacity pumps are required for this system.

Ferrous Sulfate, Ferric Sulfate, and Ferric Chloride are coagulants handled and fed like Alum with similar treatment attributes. However, these iron-based coagulants have the added benefit of being capable of bromide compound removal. Doses larger than that of Alum would be needed, so additional day tank storage and additional metering

pump capacity would be needed, as well as replacement supply and solution piping may be needed to provide the compatible materials. These iron-based coagulants can be corrosive to concrete treatment basins and equipment as well, so basin linings and some equipment/material replacements may be needed. Likewise, PACL blend varieties should be considered for bromide removal potential as well.

Powdered activated carbon (PAC) adsorbs TOC and inorganic compounds such as bromide and allows it to be settled or filtered. The PAC is "consumed" by the treatment process. Dry carbon feed equipment and a dust collection system would comprise the system. A storage/feed building with features to protect the structure against explosion damage would be required.

Chloramination is a DBP formation control technology that disinfects treated water by forming chloramines using chlorine followed by ammonia addition. (The typical chlorine to ammonia dose ratio is from 3:1 to 5:1). Chloramines provide a longer-lasting disinfectant residual and chloramines have a much lower tendency to react with organic matter to form TTHMs than free chlorine does. However, bromide presence significantly complicates chloramination chemistry. Bromide reacts with chlorine and chloramines to form bromamines and bromochloramines. These compounds can form DBPs. Ammonia feed would typically follow a free chlorine contact zone to achieve CT compliance. A liquid ammonia tank and small capacity metering pumps and an additional caustic feed point are required for this system.

Granular activated carbon (GAC) is used to remove suspended solids and organic and inorganic compounds by filtration through a carbon bed. The GAC can be "consumed" or regenerated and reused depending on the carbon exhaust rate of a facility. Regeneration can be offsite or onsite and is done by drying and heating to destroy organics. Waste products can be classified as hazardous and must be treated and disposed of properly. GAC systems consist of GAC in contact beds, transfer pumps and transfer piping, and if regenerating carbon on site, regeneration facilities and waste handling and treatment systems are needed.

Nanofiltration (NF) membrane treatment would remove very small organic and inorganic matter via use of a porous synthetic membrane. NF membrane can be formed by wrapping a flat membrane sheet around a perforated permeate collection tube. The feed water flows on one side of the membrane and permeate is collected on the other side of the membrane and spirals in toward the center collection tube. These units are combined into modules to suit the desired capacity. Hollow fine-fiber configurations can be used as well, instead of the sheet/tube style. The membrane

process would be added to the treatment plant post-filter to minimize NF membrane fouling. The process would likely need to be a pressurized system. The cost to construct a recently completed 6 MGD nanofiltration membrane plant treating groundwater was $24.2M. Due to the exorbitant cost of NF membrane technology for this size (21 MGD) treatment facility, it will be excluded from further consideration.

See **Table 2** for the relative costs of these technologies. The costs are based on a 21 MGD peak treatment capacity. Project Costs include the initial construction cost, contingencies, and technical services. Present Worth Values (PWV) are based on a 20-year useful life and 4% interest. Please note that, until bench or pilot testing is performed to define the bromide removal capability of the option, each cost component (initial, annual, and present worth value) is an approximation.

Table 2 – Improvement Cost Comparison

Improvement Option	Initial Project Cost ($)	Annual O&M Cost ($)	Present Worth Value ($)
Ion Exchange (MIEX)[1]	5,730,000	510,000	12.6M
Iron-based Coagulant[2][7] to replace Alum	200,000	5,000	0.3M
Powdered Activated Carbon[3]	730,000	TBD[6]	TBD[6]
Chloramination[4]	835,000	105,000	2.2M
Granular Activated Carbon[5]	9,620,000	700,000	19.1M

(1) Heyward, Inc. for Orica Watercare
(2) Based on Greensboro, NC WTP Improvements
(3) Based on Salem, VA WTP Improvements
(4) Based on Reidsville, NC WTP Improvements
(5) EPA 625/4-89/023
(6) Need testing to determine cost
(7) Or a PACL blend variety

Recommendations

Source Water and Distribution System Monitoring

To identify the potential source and magnitude of bromide in the raw water and its effect on distribution system TTHMs it is recommended that the following monitoring occur:

- Sample the source water to include alkalinity, hardness, pH, TOC, UV254A, and bromide at locations upstream of the WTP intake on the Dan River as shown on **Figure 11**, below.

- Sample the distribution system water to include TTHM speciation data at the entry point into the distribution system and at the shared Stage1/Stage 2 monitoring site in the distribution system.

- Begin planning bench and pilot testing of chemicals (such as iron-based coagulants and PACL blends) and processes (such as ion exchange, and carbon adsorption) that appear to have merit for bromide removal. These tests need to follow the gathering and assimilation of the additional data recommended above and testing could likely begin in Q3 2011.

MALCOLM PIRNIE | ARCADIS

The Water Division of ARCADIS

EDEN- TOC and Stage 2 Disinfectants and By-Products Study

Project No.

Perform Treatability Study

Due to the complexity added by the presence of bromide in the source water, and assuming its presence may persist even after the cause is determined, a treatability study is recommended before a final DBP prevention technique is selected. The study should strive to identify which single, or combination of, treatment technique(s) would effectively keep Eden in compliance with the Stage 2 DBP Rule. Depending on which possibilities are initially deemed most feasible for Eden, a treatability study program can be outlined and budgeted.

Implement Treatment and Distribution System Optimization Techniques

Although these techniques alone are not expected to meet the compliance goals, it is recommended that the following optimization techniques be implemented or evaluated further as needed to enhance DBP precursor removal and DBP formation control:

- Pre-Filter Chlorination Modifications – Placing free chlorine in contact with organic matter should be avoided. Therefore, the following options are preferred over pre-filter chlorination:
  - Eliminate chlorine feed at pre-filter entirely and relocate it to post-filter (allowing a biologically active filter).
  - Maintain some chlorine feed at pre-filter, but only a small dose on the filter; then add chlorine post-filter sufficient to maintain a residual for chlorine contact in the clearwells.
  - Feed chlorine dioxide at pre-filter, instead of free chlorine; then add chlorine post-filter.

- Further evaluate WTP process enhancements such as:
  - Verify coagulation/mixing is optimized by appropriate detention times and mixing velocity gradients.
  - Review clearwell chlorine contact time and, if possible, reduce the volume of water in contact with free chlorine by either reducing water levels in the clearwells or by taking a clearwell out of service.

- Further evaluate distribution system enhancements such as:
  - Review storage tank volume management to improve tank mixing if possible. More complete mixing could be achieved by piping modifications or mechanical mixing as needed.
  - Consider a uni-directional flushing program to reduce water age, especially for large, low flow pipes.

DUKE ENERGY.

James Wells
Vice President
Environmental, Health & Safety-
Coal Combustion Products
526 South Church Street
Mail Code EC12H
Charlotte, NC 28202
(980) 373-9646

April 12, 2016

Via UPS – Signature Required

Mr. Brad Corcoran
City Manager
City of Eden
308 East Stadium Drive
Eden, North Carolina 27288

Subject: Notice Regarding Bromide Restitution and Remediation Process ("BRRP")

Dear Mr. Corcoran:

On May 14, 2015, Duke Energy Carolinas and Duke Energy Progress each entered a guilty plea in the United States District Court for the Eastern District of North Carolina for misdemeanor violations of the Clean Water Act, pursuant to plea agreements with the United States Department of Justice. As part of those plea agreements, Duke Energy agreed to participate in a restitution and remediation process for local governments whose water supplies may be affected by discharges of bromide from certain Duke Energy facilities. The court assigned a Court Appointed Monitor (CAM) to oversee Duke's compliance with the plea agreements and to create and implement that restitution and remediation process. Enclosed is a copy of that process, which the court has approved, and a notice indicating that the city of Eden is potentially eligible to file a claim for restitution and remediation costs.

The Court Appointed Monitor responsible for overseeing this process is available to answer any questions you may have related to it. He may be reached via email at DukeEnergyCAM@bdlaw.com, or by regular mail at 1350 I St. NW, Suite 700, Washington, DC 20005.

Sincerely,

James Wells
Vice President, Environment, Health & Safety-
Coal Combustion Products
Duke Energy

Compliance Officer
Duke Energy Business Services

Enclosure

Cc: Ms. Dena Reid, Water Plant Superintendent

Duke Energy CAM Bromide Restitution and Remediation Claims Process (BRRP)

On May 14, 2015, Duke Energy Progress, Inc., Duke Energy Carolinas, LLC, and Duke Energy Business Services, LLC pleaded guilty in the United States Court for the Eastern District of North Carolina to nine misdemeanor violations of the Clean Water Act. As part of the Plea Agreements associated with those guilty pleas, Duke Energy agreed to the creation of a bromide restitution and remediation process (BRRP). In addition to describing the claims process, the BRRP sets forth the deadline for filing a claim with the CAM. However, the CAM strongly encourages any local government to file its claim, or advise the CAM of its intent to do so, as soon as practicable after it receives the attached notice so that the CAM can facilitate a timely and complete review of the claim.

I. Definitions/Acronyms

a. "BRRP" refers to the Bromide Restitution and Remediation Process set forth herein and required under the Plea Agreements.

b. "CAM" refers to the Court Appointed Monitor or his designee.

c. "CAM Appointment Order" refers to the Order issued on August 6, 2015 appointing Benjamin F. Wilson, Esq. as the CAM.

d. "Court" refers to the United States District Court for the Eastern District of North Carolina.

e. "DEC" refers to Duke Energy Carolinas, LLC.

f. "DEP" refers to Duke Energy Progress, Inc.

g. "Duke Energy" refers to the Duke Energy corporate family, including DEC and DEP.

h. "Duke Energy facility" refers to any one or more of the several Duke Energy facilities covered by the Plea Agreements.

i. "FGD" refers to Flue Gas Desulfurization.

j. "Local Government" refers to a government or public entity, or entity controlled or funded by a governmental body or municipal authority, in North Carolina, South Carolina, Tennessee or Virginia, that draws water into a water treatment facility and is downstream from a Duke Energy facility with an FGD scrubber system.

k. "Plea Agreements" refers to the Plea Agreements entered into on May 14, 2015 by Duke Energy in the United States Court for the Eastern District of North Carolina with the United States Attorneys' Offices for the Eastern, Middle, and Western Districts of North Carolina, the Environmental Crimes Section of the United States Department of Justice, and the Environmental Protection Agency Criminal Investigation Division.

l. "Probationary Period" refers to the period of May 14, 2015 to May 14, 2020, which is the duration of Duke Energy's term of probation under the Plea Agreements.

m. "THMs" refers to trihalomethanes.

n. "United States" refers to the United States Attorneys' Offices for the Eastern, Middle, and Western Districts of North Carolina, the Environmental Crimes Section of the United States Department of Justice, the Environmental Protection Agency Criminal Investigation Division, and the United States Probation Office.

II. Implementation and Effect of the Bromide Restitution and Remediation Process

a. These procedures implement the BRRP.

b. Local Governments are not obligated to submit a claim through this process and this process is not exclusive. Local Governments are not bound by any recommendation of the CAM, and may pursue any civil and/or administrative remedies otherwise available to them.

c. At any time during the CAM's oversight of the BRRP, the CAM may consult with an independent technical expert that has been approved by the Court to provide the CAM with expert advice on bromide-related issues. The reasonable costs for the independent expert shall be paid by Duke Energy consistent with the terms of the Plea Agreements and CAM Appointment Order and subject to the Court's review and approval.

III. Notice of Eligibility to File a Claim

a. No later than May 14, 2016, or within ninety (90) days of the installation of a new FGD scrubber system thereafter, Duke Energy shall identify all facilities operated by it in North Carolina that utilize or will utilize FGD scrubbers during the probationary period that will result in an increase in bromide discharge into surface waters.

b. No later than May 14, 2016, or within ninety (90) days of the installation of a new FGD scrubber system thereafter, Duke Energy shall identify all Local Governments, as that term is defined above.

c. No later than May 14, 2016, or within ninety (90) days of the installation of a new FGD scrubber system thereafter, Duke Energy shall provide written notice regarding the availability of the BRRP, in the form attached hereto as Exhibit A, to all Local Governments identified pursuant to Section III.b. Duke Energy shall include a copy of the BRRP with the notice. Duke Energy shall obtain written confirmation of delivery of the notice of the BRRP via certified mail or other equally similar mailing service. Duke Energy shall also post a copy of the BRRP and notice on a publicly accessible webpage within ten (10) days of providing the written notice to the Local Governments.

d. The recipients of the notice will include, at a minimum, the Local Governments identified in accordance with Section III.b. of the BRRP. The omission of a Local Government from the list of entities identified by Duke shall not, however, preclude that Local Government from submitting a claim for restitution of its own accord under the BRRP, provided that the entity (1) submits a claim within the time period provided for in Section XI, and (2) its claim conforms to the substantive and procedural requirements for pursuing a good faith claim set forth in the BRRP.

e. Duke shall provide copies of the delivery confirmations obtained pursuant to

Section III.c. to the CAM and the United States.

f. The CAM will be available to respond to any questions from Local Governments regarding the BRRP purpose and procedures until such time as a Local Government files a claim. The CAM can be contacted with questions at the email address provided in Section XIII.

IV. Developing and Sharing Relevant Data

a. Over the course of the probationary period, Duke Energy may gather or develop data related to bromide discharges from its facilities and their potential impacts on Local Government water treatment facilities.

b. Duke Energy shall provide any such data relevant to a particular Local Government's water treatment system to that Local Government, and shall copy the CAM on the transmission of data. Duke Energy shall provide any such data as it becomes available and after Duke Energy has a reasonable opportunity to review the data for quality assurance purposes.

c. When providing data to a Local Government, Duke Energy shall notify the Local Government that it is required to publicly post the data within ten (10) business days, pursuant to Section IV.d., and that the Local Government has the right to object to the CAM regarding the public posting of the data.

d. Within ten (10) days of providing any data to a Local Government and the CAM, Duke Energy shall publish that data on a publicly available website. Duke Energy shall update that website within ten (10) days of providing the Local Government with any new relevant data. Duke Energy shall notify the CAM in writing when it has published its original data to the website, and upon publishing any supplemental data to the website.

e. To the extent that Duke Energy does not make any relevant data available to a Local Government or does not publish it on the website, the CAM may consider whether Duke Energy shall be precluded from relying on that data to resolve any claim under the BRRP. In making its determination, the CAM shall consider whether there was a reasonable basis for withholding the evidence, any prejudice to the Local Government that was occasioned thereby, and whether Duke Energy would be unduly prejudiced if it was foreclosed from relying upon the withheld evidence.

f. If a Local Government objects to the public posting of any data, Duke Energy shall refrain from posting it until such time as the CAM renders a decision regarding the Local Government's objection. The CAM will give due consideration to any reasonable request by a Local Government to exclude data from public posting.

V. Submission of a Claim

a. Any Local Government may file a good faith claim for remediation or restitution according to the deadlines set out in Section XI of the BRRP.

b. Purchasers of water from Local Governments may not file a claim under this BRRP. However, in order to ensure that a Local Government water treatment

facility provides drinking water that is protective of public health, a Local Government that submits a claim should consult with its wholesale purchasers in preparing its claim. Local Governments should also gather information regarding potential impacts of THM increases on any such purchasers and the consumers they serve. The Local Government's claim should incorporate any such information, as appropriate, including information related to any remediation or restitution necessary to protect public health and the water quality of the Local Government's wholesale customers and the consumers they serve.

c. Local Governments shall submit their BRRP claims in writing via First Class mail and email to both Duke Energy and the CAM, simultaneously, to the addresses provided in Section XIII. The claim shall clearly identify the contact information for a designated representative of the Local Government for purposes of notifications under the BRRP. In filing its claim for restitution or remediation, the Local Government must set forth the basis for its belief that:

    i. It is downstream from a Duke Energy facility that uses FGD scrubbers;

    ii. The discharge of bromide from an upstream Duke Energy facility utilizing an FGD scrubber substantially contributed to an increase in THMs in the water drawn into the Local Government's water treatment facility; and

    iii. It has or will incur expenses as part of a reasonable response to the increase in THMs or as part of the investigation into the increase in THMs.

d. Once the claim is received by Duke Energy, Duke Energy will assign the claim a tracking number and will track the claim and all documentation supporting the claim. Duke Energy shall share the tracking number with the CAM.

e. Once a claim is filed, Duke Energy and the Local Government shall be considered "parties" for purposes of the individual claim. Thereafter the CAM and the parties to a claim shall copy each other on all correspondence and submissions regarding that particular claim.

f. In filing a claim, the Local Government may seek restitution for:

    i. All costs, whenever incurred, associated with water treatment system upgrades undertaken to respond to an increase of THMs including, but not limited to, maintenance, operations, and capital costs.

    ii. All costs associated with investigating and responding to increased discharges of bromide and/or the increase of THMs.

    iii. All costs associated with investigating and preparing the Local Government's submissions to the CAM, including reasonable attorney's fees.

VI. Review of a Claim by the CAM

a. Within ten (10) days of the receipt of the claim, the CAM will acknowledge receipt of the claim and shall transmit a copy of the claim to the United States.

b. Within twenty (20) days of the receipt of the claim, the CAM shall review the claim and any supporting evidence to determine whether the Local Government has made a threshold showing that:

i. It is downstream from a Duke Energy facility that uses FGD scrubbers;

ii. The discharge of bromide from an upstream Duke Energy facility utilizing an FGD scrubber substantially contributed to an increase in THMs in the water drawn into the Local Government's water treatment facility; and

iii. It has or will incur expenses as part of a reasonable response to the increase in THMs or as part of the investigation into the increase in THMs.

iv. The threshold showing with regard to expenses requires only a description of incurred and future anticipated expenses and an estimate of the projected monetary costs. The initial monetary estimate does not prevent the Local Government from providing updated estimates, calculations, or proof of costs in later stages of the claim. The initial monetary estimate also does not bind the final decision of the CAM.

c. The CAM shall advise the Local Government claimant whether its submission provides a sufficient basis to proceed with the next steps in the BRRP process and warrant a response from Duke. If the CAM believes the content of the submission is not sufficient to inform the BRRP process and elicit a meaningful response from Duke, it will (1) advise the Local Government and Duke of the same; (2) identify the nature and type of evidence that it believes would be necessary to state a valid claim; and (3) allow the Local Government thirty (30) days, or such other time as the CAM determines to be reasonable, to cure any deficiency and resubmit its claim.

d. If, on the other hand, the CAM believes the submission is sufficient to inform the claims process, it will advise the parties accordingly. The CAM will provide a copy of this notice and the schedule for responding to Duke Energy, the Local Government claimant, and the United States.

e. Duke Energy shall respond to the CAM's notification within ninety (90) days, unless an alternative schedule is developed after consultation with the parties as described herein.

f. At Duke Energy's request, the CAM may grant one extension of thirty (30) days to Duke Energy's response deadline, subject to reasonable modification beyond that time to reflect changed circumstances or scheduling burdens that may be occasioned by the need to respond to multiple claims concurrently. A request for such an extension shall be served upon the Local Government claimant, which shall have seven (7) business days to comment on the proposed extension.

g. After Duke Energy has submitted its response to the Local Government's claim, the Local Government may, within forty-five (45) days of Duke Energy's submission, submit a reply. The reply may include any additional information the Local Government believes the CAM should consider in evaluating the Local Government's claim. The CAM may grant one extension of thirty (30) days for the Local Government to file the reply. A request for such an extension shall be served upon Duke Energy, which shall have seven (7) business days to comment on the proposed extension.

h. The CAM may exercise his discretion to extend any of the above deadlines as

necessary and appropriate to facilitate the negotiation and consummation of a resolution of a claim by the parties, including a reasonable extension to accommodate any necessary technical work by the Local Governments or Duke. The CAM's approval of extension requests will not unreasonably be withheld as long as the request for an extension does not jeopardize resolution of the claim within the probationary period.

i. A Local Government may amend its claim once before Duke responds without requiring the permission of the CAM. If a Local Government seeks to amend its claim more than one time, or after Duke responds, it must obtain permission from the CAM. In either case, the Local Government shall notify Duke and the CAM simultaneously in writing.

j. If the Local Government's claim is amended, whether permission was required or not, the CAM shall determine whether the briefing process should be amended or revised based on the status of the claim at the time of the amendment and the substance of the amendment. The CAM shall provide Duke Energy with a reasonable opportunity to respond and offer evidence.

k. In evaluating a claim under these rules, the CAM may, as a supplement to the briefings described herein, consult with its own experts and request any additional documentary or testimonial evidence or argument it deems necessary from the parties. This may include asking the parties to present evidence and argument in person or by deposition at reasonable times and places. The CAM may request information as many times as the CAM deems necessary. The CAM may also take administrative notice of any information not set forth in the parties' submissions, including but not limited to relevant data, analyses, scientific and technical literature, and studies in the public domain. To the extent the CAM considers information which was not included in the parties' briefings in reaching a decision, the CAM will afford the parties the opportunity to comment on the reliance on that information.

l. The parties' submissions pursuant to the BRRP, including claims, responses, replies, and any associated exhibits, shall be posted by Duke on a publicly available webpage within ten (10) business days of submission.

m. The CAM, in its discretion, and after hearing from the parties on the issue, may bifurcate the causation and investigative/response aspects of its review and require the parties to brief those issues separately. The CAM may bifurcate the claims review process for any reason, including easing the financial or resource burden on the parties.

n. The CAM shall be guided by, as appropriate, the Federal Rules of Evidence, including the rules pertaining to opinion, expert testimony, and the admission of hearsay evidence.

o. Subject to the terms of the Plea Agreements, he CAM shall be guided by, as appropriate, the Safe Drinking Water Act and all other relevant environmental regulations in evaluating information under the BRRP.

p. The precedents of the Supreme Court of the United States, United States Court of Appeals for the Fourth Circuit, and United States Court for the Eastern District of

North Carolina, and/or the precedents of the U.S. Court of Appeals and U.S. District Court for the jurisdiction in which the Local Government is located, shall apply to claims under this process. Decisions of the CAM under the BRRP shall have no precedential effect.

q. To the extent an interpretation of a question of state law is necessary to resolve a claim, a claim shall be treated as though it was filed in the state of the filing Local Government.

VII. Evaluating and Resolving a Claim

a. After evaluating the information offered by the parties, the CAM shall make an independent evaluation of the Local Government's claim and issue a written decision resolving the claim. In its written decision, the CAM may grant the Local Government's claim, grant the claim in part, deny the claim, or propose a modification.

b. The CAM shall issue the written decision based on the parties' written submissions. However, either party may request that the CAM entertain oral presentations related to the merits of a particular claim. Parties requesting oral presentations must state their request in writing at the time they submit their claim. The CAM may exercise sole discretion over the determination as to whether to entertain such a presentation/oral argument. If the CAM determines that oral presentations will materially assist in evaluation of the claim and proposed resolution, the CAM will coordinate with the parties to schedule a reasonable period of time and to select a location for such presentations.

c. In evaluating a claim, the CAM shall consider whether the Local Government has shown, by a preponderance of the evidence, that:

   i. THMs have increased at the Local Government's water treatment facility; and

   ii. The discharge of bromide from a Duke Energy facility with FGD scrubbers substantially contributed to the increase in THMs.

d. In determining the amount of restitution, the CAM shall review for reasonableness the proposed remediation actions and costs or anticipated costs associated with investigating, responding to, and remediating increased bromides and THMs. The CAM may order restitution for properly demonstrated expenses, including but not limited to those expenses enumerated in Section V.f.

e. The CAM shall file on the docket of each of the underlying criminal cases, via the Court's CM/ECF system, a copy of the decision in each claim, thereby giving notice to Duke Energy and the United States. Additionally, the CAM shall serve a copy on the Local Government who made the claim. The written decision shall include a notice with instructions for filing an appeal of the decision, and a clear statement regarding the time period for doing so, as stated in Section VIII.a. below. The CAM shall serve a copy of the written decision on the Court, the parties and the United States on the day that it is issued. Within ten (10) business days of receiving the written decision, Duke Energy shall publish it on a publicly available webpage.

VIII. Appeal

a. Once the written decision is issued, Duke Energy or the Local Government may appeal an adverse decision to the United States District Court. Such an appeal must be filed with the District Court within thirty (30) days of service of the decision on the appealing party, according to the instructions provided in the CAM's written decision, pursuant to Section VII.e. above.

b. In such an appeal, the decision of the CAM shall be subject to a rebuttable presumption of correctness.

c. If Duke Energy unsuccessfully appeals, Duke Energy shall bear all of the costs of the appeal, including the costs of the CAM and the reasonable attorneys' fees of the Local Government. The Court shall make the final determination of the reasonableness of such fees.

d. If Duke Energy successfully appeals, Duke Energy shall bear the costs of the CAM, and the Local Government shall bear the costs of its attorneys' fees.

e. If the Local Government successfully appeals, Duke Energy shall bear all of the costs of the appeal, including the costs of the CAM and the reasonable attorneys' fees of the Local Government. The Court shall make the final determination of the reasonableness of such fees.

f. If the Local Government unsuccessfully appeals, Duke Energy shall bear the costs of the CAM, and the Local Government shall bear the costs of its attorneys' fees.

IX. Payment of Claims

a. Duke Energy shall pay any approved restitution costs to the claimant within thirty (30) days of the issuance of the CAM's written opinion and recommendation to the Court, unless Duke Energy or a Local Government files an appeal to the District Court as provided above.

b. If, after appeal, the District Court upholds, in whole or in part, the CAM's opinion approving such costs, Duke Energy shall pay the approved costs to the claimant and submit proof of payment to the District Court within thirty (30) days of the Court's opinion.

c. Simultaneously with making payment, Duke shall submit proof of payment to the CAM.

d. Nothing in this subsection will bar the CAM or the District Court from ordering a different payment schedule as appropriate.

X. Alternative Dispute Resolution

a. The CAM encourages the parties to seek mutually agreeable resolutions to pending or potential claims. The parties may reach such a resolution any time before the CAM issues a written decision on a pending claim.

b. If a Local Government and Duke Energy jointly agree on a resolution to a pending or potential claim under these rules, they must request in writing that the CAM approve the resolution.

c. In reviewing a proposed resolution, the CAM shall consider whether the proposal

is in the interests of Duke Energy, the Local Government, and the public, and the CAM will apply a standard of review that gives liberal deference to the parties' proposed resolutions.

d. The CAM shall issue a written statement to both parties either providing approval of the proposed resolution, or withholding approval and providing recommendations for a revised resolution. This written statement will not be publicly shared, except as otherwise agreed to by the Parties or as required by law.

XI. Deadline for Filing Claims

a. Any Local Government that received notice of the BRRP pursuant to Section III.c. must notify the CAM of its intent to submit a claim by no later than November 14, 2017, unless it has already submitted a claim. All Local Governments that received notice under Section III.c. must submit their claims and all supporting materials by February 14, 2018, although the CAM may extend the deadline in his discretion.

b. Notwithstanding Section XI.a., Local Governments that did not receive a notice pursuant to Section III.c. are permitted to file claims with the CAM until March 14, 2020. However, any such claims submitted after February 14, 2018 will be subject to an abbreviated review process, to be determined at the time of filing.

XII. Confidential Business or Other Information

a. Subject to the approval of the CAM, the parties may redact confidential business or other information, or any information they reasonably believe could impair the security of their operations, from any documents required to be posted for public access.

b. The CAM shall inspect such proposed redactions to determine the propriety of the redactions. If the CAM approves a redaction, Duke Energy will make the redacted document publicly available and contemporaneously provide a copy of the unredacted document to the Court and the United States.

c. If any publicly posted documents contain redactions, the United States and the parties may challenge the propriety of a redaction by notifying the CAM in writing. The Court shall be the final arbiter of any challenge.

XIII. Notification Information

a. The CAM may be reached at the following addresses:

i. Email: DukeEnergyCAM@bdlaw.com

ii. First Class Mail: Benjamin F. Wilson, Beveridge & Diamond, P.C., 1350 I Street NW, Suite 700, Washington, DC 20005.

b. Duke Energy may be reached at the following addresses:

i. Email: bromide.claims@duke-energy.com

ii. First Class Mail: Duke Energy Manager – Claims Management; Fairfax Operations Center; 2500 Fairfax Road; Greensboro, NC 27407.

Exhibit A

Notice Regarding Bromide Restitution and Remediation Process ("BRRP")

On May 14, 2015, Duke Energy pleaded guilty in the United States Court for the Eastern District of North Carolina to nine misdemeanor violations of the Clean Water Act. As part of the plea agreements associated with those guilty pleas, Duke Energy agreed to the creation of a restitution and remediation process for local governments whose water supplies may be affected by discharges of bromide from Duke Energy facilities.

You have received this notice to inform you that you may qualify to submit a claim for restitution for costs associated with responding to increased levels of trihalomethanes ("THMs") in your water treatment system. You have received this notice because preliminarily available information indicates that [NOTIFIED PARTY] may withdraw water into a water treatment facility from the [WATER BODY] and may be located downstream from [DUKE ENERGY FACILITY].

[DUKE ENERGY FACILITY] uses a Flue Gas Desulfurization ("FGD") scrubber system to remove certain pollutants from the air. The FGD scrubber system, however, also discharges bromides into the [WATER BODY]. Bromides are not currently regulated by Federal or state agencies. When bromides come into contact with certain water treatment disinfectants, however, bromides may contribute to the formation of THMs, a regulated byproduct of drinking water treatment processes.

What is the BRRP?

Under the Bromide Restitution and Remediation Process ("BRRP"), eligible local governments may submit evidence of bromide impacts on their water treatment systems and claims for restitution stemming from these impacts. A copy of the rules governing the BRRP is included with this notice.

Who is eligible for the BRRP?

Local governments are eligible if they are: 1) downstream of a Duke Energy facility with an FGD scrubber; and 2) they experience substantial increases in THMs at their water treatment facilities related to bromide discharges from the upstream Duke Energy facility.

Purchasers of your water may not file a claim under this process. However, you should contact your wholesale purchasers and gather relevant information to consider the potential impacts of THM increases on them. If you file a claim, it should incorporate any such information.

What is the deadline to file a claim under the BRRP?

You must notify the CAM of your intent to submit a claim by no later than November 14, 2017. You must submit your claim and all supporting materials by February 14, 2018, although the CAM may extend the deadline in his discretion.

While this is the deadline for filing a claim, the CAM encourages any local government to file its claim or advise the CAM of its intent to do so as soon as possible.

Local governments that did not receive this notice but can demonstrate that they are eligible to file a claim under the BRRP are permitted to file a claim until March 14, 2020. However, any such claim submitted after February 14, 2018 will be subject to an abbreviated review process, to be determined at the time of filing.

Is the BRRP the only way for a local government to obtain restitution for costs associated with an increase in bromide?

No. A local government is not obligated to submit a claim through the process, is not bound by any recommendation of the CAM, and may pursue any civil and/or administrative remedies available to it.

What if the local government believes it has an eligible claim but is concerned about the costs of developing that claim?

Preparing a claim that demonstrates eligibility for restitution under the BRRP may require local governments to incur costs associated with developing the evidence described above. As part of its claim, the local government may request restitution for those costs and fees as summarized above. The CAM will award restitution of reasonable, appropriately demonstrated costs for all claims with merit. The CAM may not award restitution of any costs or fees incurred by a local government in preparing and pursuing an unsuccessful claim.

May a local government or Duke Energy appeal the CAM's decision?

Yes. The BRRP allows either party to appeal the CAM's decision within 30 days to the U.S. District Court for the Eastern District of North Carolina. The written decision will provide instructions on filing an appeal. On appeal, the CAM's decision will be reviewed with a rebuttable presumption of correctness.

Notice Regarding Bromide Restitution and Remediation Process ("BRRP")

On May 14, 2015, Duke Energy pleaded guilty in the United States Court for the Eastern District of North Carolina to nine misdemeanor violations of the Clean Water Act. As part of the plea agreements associated with those guilty pleas, Duke Energy agreed to the creation of a restitution and remediation process for local governments whose water supplies may be affected by discharges of bromide from Duke Energy facilities.

You have received this notice to inform you that you may qualify to submit a claim for restitution for costs associated with responding to increased levels of trihalomethanes ("THMs") in your water treatment system. You have received this notice because preliminarily available information indicates that the city of Eden may withdraw water into a water treatment facility from Dan River and may be located downstream from Belews Creek Steam Station.

Belews Creek Steam Station uses a Flue Gas Desulfurization ("FGD") scrubber system to remove certain pollutants from the air. The FGD scrubber system, however, also discharges bromides into Dan River. Bromides are not currently regulated by Federal or state agencies. When bromides come into contact with certain water treatment disinfectants, however, bromides may contribute to the formation of THMs, a regulated byproduct of drinking water treatment processes.

What is the BRRP?

Under the Bromide Restitution and Remediation Process ("BRRP"), eligible local governments may submit evidence of bromide impacts on their water treatment systems and claims for restitution stemming from these impacts. A copy of the rules governing the BRRP is included with this notice.

Who is eligible for the BRRP?

Local governments are eligible if they are: 1) downstream of a Duke Energy facility with an FGD scrubber; and 2) they experience substantial increases in THMs at their water treatment facilities related to bromide discharges from the upstream Duke Energy facility.

Purchasers of your water may not file a claim under this process. However, you should contact your wholesale purchasers and gather relevant information to consider the potential impacts of THM increases on them. If you file a claim, it should incorporate any such information.

How may a local government submit a claim under the BRRP?

The District Court appointed Benjamin F. Wilson, Esq. ("Court-Appointed Monitor" or "CAM") to monitor Duke Energy's compliance with various aspects of the plea agreements, including implementation of the BRRP and resolution of claims submitted under it. Local governments must submit their claims (along with any evidence in support of their claims) simultaneously to Duke Energy and to the CAM. The appropriate addresses are listed in Section XIII of the BRRP.

What does a local government have to show to qualify for restitution under the BRRP?

A local government must show, by a preponderance of the evidence, that: (1) THMs have increased at its facility; and (2) the discharge of bromides from a Duke Energy facility substantially contributed to the increase in THMs.

What types of evidence should a local government provide under the BRRP?

A local government's claim could include evidence such as technical models, maps, water sampling data, and invoices for remediation work. Please contact the CAM if you would like further guidance regarding the type of evidence you should submit.

What expenses may be covered by the BRRP?

Pursuant to its plea agreements, Duke Energy has agreed to pay restitution for all costs, whenever incurred, associated with water treatment system upgrades resulting from the increase of THM including, but not limited to: (1) maintenance, operations and capital costs; and (2) all costs associated with investigating, responding to and remediating increased discharges of bromide and/or the increase of THMs. If the CAM determines that restitution in any amount is appropriate, Duke Energy also has agreed to reimburse the local government for costs associated with investigating and preparing its claim, including reasonable attorney's fees.

What happens after a claim is submitted?

If a claim is submitted to the CAM that satisfies the general requirements stated above, the local government will be deemed to have made a "good faith" claim. The claim then will be addressed by the CAM under the BRRP, which is described in the attached document.

Duke Energy and the local government may also work together to evaluate and discuss resolution of bromide issues without filing a formal claim under the BRRP process.

What is the deadline to file a claim under the BRRP?

You must notify the CAM of your intent to submit a claim by no later than November 14, 2017. You must submit your claim and all supporting materials by February 14, 2018, although the CAM may extend the deadline in his discretion.

While this is the deadline for filing a claim, the CAM encourages any local government to file its claim or advise the CAM of its intent to do so as soon as possible.

Local governments that did not receive this notice but can demonstrate that they are eligible to file a claim under the BRRP are permitted to file a claim until March 14, 2020. However, any such claim submitted after February 14, 2018 will be subject to an abbreviated review process, to be determined at the time of filing.

Is the BRRP the only way for a local government to obtain restitution for costs associated with an increase in bromide?

No. A local government is not obligated to submit a claim through the process, is not bound by any recommendation of the CAM, and may pursue any civil and/or administrative remedies available to it.

What if the local government believes it has an eligible claim but is concerned about the costs of developing that claim?

Preparing a claim that demonstrates eligibility for restitution under the BRRP may require local governments to incur costs associated with developing the evidence described above. As part of its claim, the local government may request restitution for those costs and fees as summarized above. The CAM will award restitution of reasonable, appropriately demonstrated costs for all claims with merit. The CAM may not award restitution of any costs or fees incurred by a local government in preparing and pursuing an unsuccessful claim.

May a local government or Duke Energy appeal the CAM's decision?

Yes. The BRRP allows either party to appeal the CAM's decision within 30 days to the U.S. District Court for the Eastern District of North Carolina. The written decision will provide instructions on filing an appeal. On appeal, the CAM's decision will be reviewed with a rebuttable presumption of correctness.

Southern Company

Southern Company / EPA ELG Meeting
AGENDA
June 6, 2018

1. Introductions
2. APC and GPC Overview
3. ELG Compliance Status
4. Bottom Ash Transport Water
5. Scrubber Wastewater
6. Retirement Considerations
7. Schedule and Implementation

HOOSIER ENERGY
A Touchstone Energy® Cooperative

AGENDA

DATE: May 9, 2018

SUBJECT: Effluent Limitation Guidelines

ATTENDEES: Caleb Steiner, Angie Lee, Matt Mabrey

I Introductions

II Hoosier Energy Background

III EPA Objective/Perspective

IV ELG Compliance Timeline

V Bottom Ash Transport Water – Hoosier Preference

VI FGD Wastewater – Hoosier Preference

VII Closing Comments

VIII Adjourn

NIPSCO / NiSource
ELG Data Request Follow-Up Meeting
Agenda
5/31/2018

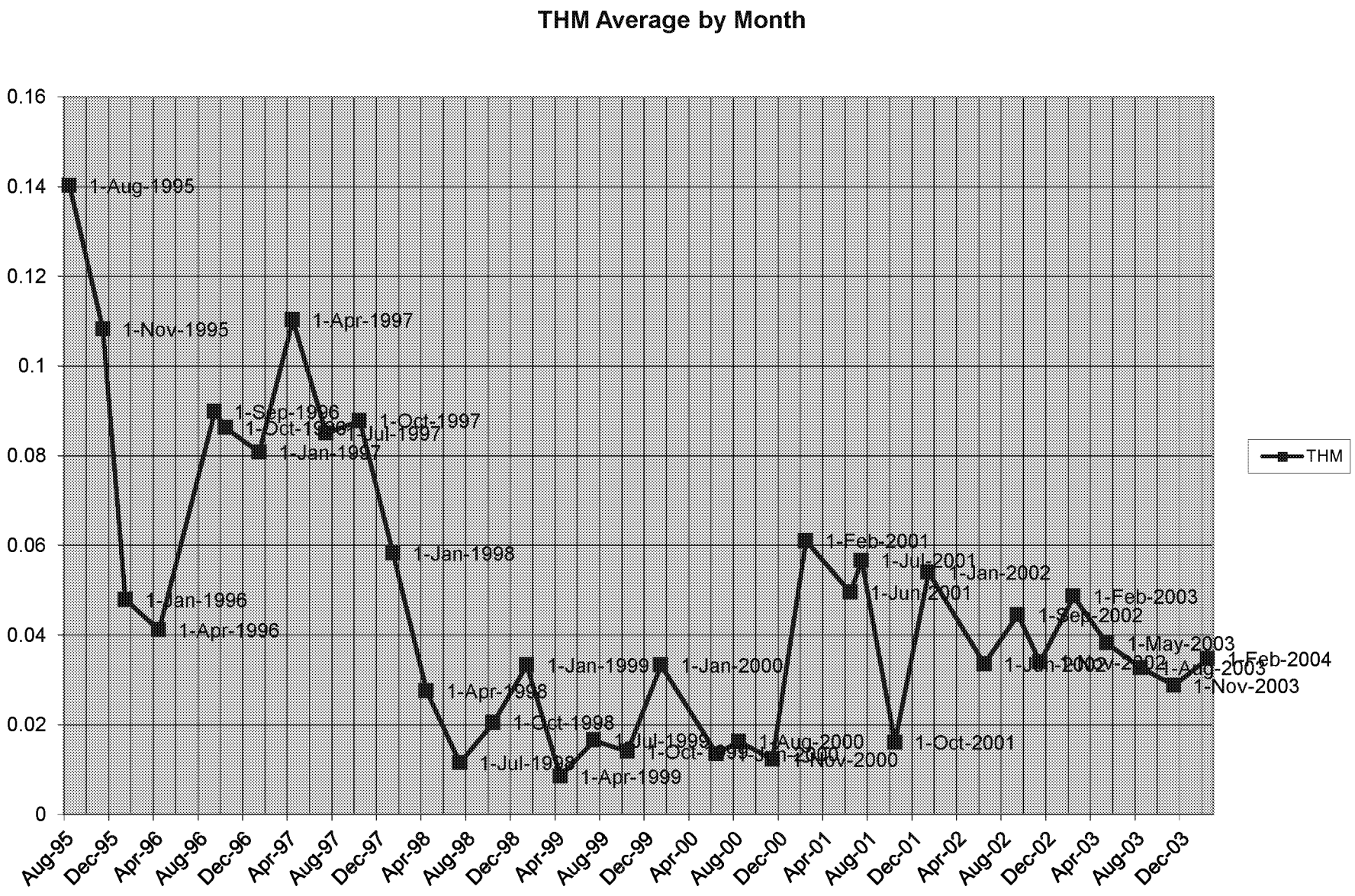
1:30 PM Eastern

1) Introductions (15 min)

2) NIPSCO Submission (30 min)
   a) Conditions
   b) Results
   c) NIPSCO's Interpretation
   d) Questions

3) Concerns with Best Available Technology from the 2015 ELG Rule (45 min)
   a) FGD Wastewater: Concerns with Bio-treatment
      i) Intermittent or variable waste streams
      ii) Long recovery from failure of system
      iii) Cold weather climates
      iv) Site specific cost analysis
      v) Questions
   b) Bottom Ash Transport Water: Concerns with prohibition of discharge
      i) Only blowdown through FGD system
      ii) Concerns during outage cleaning
      iii) Concerns about system chemistry cycle up
      iv) Reasonable, intermittent, controlled discharge could be managed
      v) Questions

4) Compliance Timing (15 min)
   a) Reasonable initial compliance date based on new requirements
   b) Alternative Compliance Schedule
   c) Questions


THM Average by Month
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1-Aug-1995
1-Nov-1995
1-Jan-1996
1-Apr-1996
1-Sep-1996
1-Oct-1996
1-Jan-1997
1-Apr-1997
1-Jul-1997
1-Oct-1997
1-Jan-1998
1-Apr-1998
1-Jul-1998
1-Oct-1998
1-Jan-1999
1-Apr-1999
1-Jul-1999
1-Oct-1999
1-Jan-2000
1-Aug-2000
1-Nov-2000
1-Feb-2001
1-Jun-2001
1-Jul-2001
1-Oct-2001
1-Jan-2002
1-Jun-2002
1-Sep-2002
1-Nov-2002
1-Feb-2003
1-May-2003
1-Aug-2003
1-Nov-2003
1-Feb-2004
Aug-95
Dec-95
Apr-96
Aug-96
Dec-96
Apr-97
Aug-97
Dec-97
Apr-98
Aug-98
Dec-98
Apr-99
Aug-99
Dec-99
Apr-00
Aug-00
Dec-00
Apr-01
Aug-01
Dec-01
Apr-02
Aug-02
Dec-02
Apr-03
Aug-03
Dec-03
THM

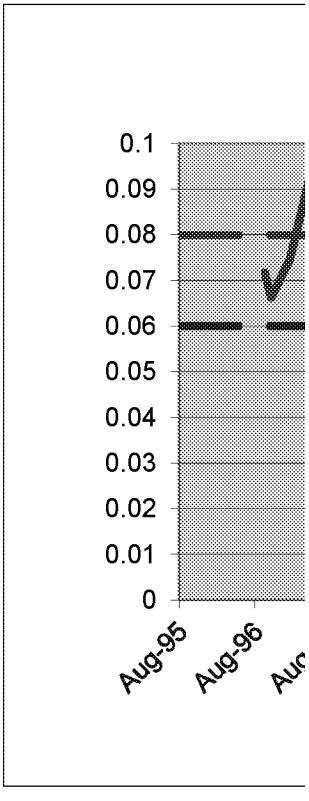
	GC Tank - #4		MC CPW - #3		Oasis - #2	
Date	THM	HAA	THM	HAA	THM	HAA
1-Aug-1995						
1-Nov-1995						
1-Jan-1996						
1-Apr-1996						
1-Sep-1996						
1-Oct-1996						
7-Jan-1997	0.082		0.083		0.085	
1-Apr-1997	0.108		0.101		0.109	
1-Jul-1997	0.092		0.078		0.089	
1-Oct-1997	0.101		0.085		0.081	
1-Jan-1998	0.064		0.061		0.048	
1-Apr-1998	0.027		0.026		0.03	
1-Jul-1998	0.014		0.009		0.011	
1-Oct-1998	0.024		0.016		0.019	
1-Jan-1999	0.039		0.029		0.036	
1-Apr-1999	0.011	0.02337	0.007	0.01241	0.008	0.01656
1-Jul-1999	0.018	0.0111	0.015	0.0101	0.017	0.012
1-Oct-1999	0.015	0.0197	0.014	0.0162	0.015	0.0168
1-Jan-2000	0.035	0.0175	0.033	0.0167	0.033	0.0183
1-Jun-2000	0.016		0.013		0.013	
1-Aug-2000	0.018		0.017		0.017	
1-Nov-2000	0.016		0.011		0.011	
1-Feb-2001	0.065		0.057		0.063	
1-Jun-2001	0.053		0.044		0.05	
1-Jul-2001	0.0635		0.0511		0.0563	
1-Oct-2001	0.0187		0.0168		0.0135	
1-Jan-2002	0.0542	0.0214	0.05	0.023	0.0515	0.0215
1-Jun-2002	0.0397	0.0171	0.0425	0.0177	0.0479	0.0183
1-Sep-2002	0.0462	0.0191	0.0411	0.0146	0.0458	0.019
1-Nov-2002	0.0362	0.0121	0.0306	0.0119	0.0344	0.0106
3-Feb-2003	0.04026	0.03745	0.04993	0.03642	0.05334	0.03601
3-May-2003	0.04109	0.04098	0.03195	0.04269	0.0356	0.0358
13-Aug-2003	0.0334	0.0403	0.03179	0.05109	0.03042	0.0351
12-Nov-2003	0.02875	0.02534	0.02657	0.01732	0.02657	0.01988
10-Feb-2004	0.03939	0.02273	0.03215	0.01848	0.03447	0.02267
11-May-2004	0.03084	0.02082	0.03228	0.01734	0.03033	0.01987
9-Aug-2004	0.03107	0.01885	0.01741	0.00959	0.01882	0.01555
15-Nov-2004	0.0461	0.02581	0.0234	0.02223	0.0179	0.03537
9-Feb-2005	0.02538	0.02476	0.01469	0.02767	0.02736	0.02082
11-May-2005	0.02656	0.01235	0.02544	0.01275	0.03365	0.01329
11-Aug-2005	0.03781	0.01332	0.03751	0	0.03492	0.01192
15-Nov-2005	0.02372	0.01265	0.01822	0.00848	0.02059	0.01243
15-Feb-2006	0.03159	0.02214	0.03354	0.01766	0.03105	0.01773
9-May-2006	0.02325	0.00707	0.02453	0.00662	0.02712	0.00644
10-Aug-2006	0.02626	0.01094	0.02487	0	0.02506	0.00985
8-Nov-2006	0.03427	0.02088	0.03235	0.00353	0.03694	0.02442
20-Jun-2007	0.06059	0.04254	0.06985	0.04126	0.05326	0.04446
1-Aug-2007	0.03384	0.02455	0.03311	0.03045	0.03907	0.03334
1-Nov-2007	0.02091	0.02415	0.0196	0.02228	0.01684	0.01982
4-Feb-2008	0.0336	0.01554	0.03767	0.01627	0.03328	0.01251

8-May-2008	0.05929	0.03402	0.04209	0.03795	0.04563	0.03752
4-Aug-2008	0.02692	0.01961	0.02862	0.01524	0.0281	0.01904
4-Nov-2008	0.04376	0.02332	0.04721	0.02392	0.06577	0.03927
27-Mar-2009	0.0462	0	0.06187	0.04421	0.05407	0.05471
18-May-2009	0.05812	0.04962	0.04235	0.03941	0.05423	0.0512
17-Aug-2009	0.03124	0.02083	0.0334	0.02109	0.03725	0.02002
19-Nov-2009	0.04216	0.0284	0.04749	0.028	0.05114	0.02838
3-Mar-2010	0.03548	0.03063	0.04252	0.02511	0.03442	0.02662
19-May-2010	0.05671	0.04476	0.05712	0.04612	0.06822	0.03947
18-Aug-2010	0.04761	0.01455	0.06024	0.01447	0.06144	0.01344
17-Nov-2010	0.0701	0.01393	0.06307	0.0125	0.06155	0.01219
15-Feb-2011	0.06688	0.00462	0.06315	0.00346	0.05668	0.00385
19-May-2011	0.04176	0.02401	0.04168	0.02534	0.04176	0.02149
16-Aug-2011	0.05826	0.02348	0.04999	0.03103	0.04802	0.02574
17-Nov-2011	0.05411	0.02651	0.05104	0.02395	0.0495	0.02365
20-Mar-2012	0.06757	0.02359	0.06128	0.02169	0.06337	0.02088
6-Jun-2012	0.06902	0.03704	0.06235	0.03423	0.06418	0.03464
6-Sep-2012	0.0517	0.01475	0.04815	0.01567	0.0468	0.01709

Avg. since 1/02	0.039707	0.023012857	0.038060833	0.022207619	0.039574722	0.023949524
Difference from System Avg.	-0.00068	-0.023012857	0.000968649	-0.022207619	-0.00054524	-0.023949524

Kings Grant - #1		Average		Rolling Average		Maximum Level	
THM	HAA	THM	HAA	THM	HAA	MAX THM	MAX HAA
		0.1402				0.08	0.06
		0.1082				0.08	0.06
		0.0479				0.08	0.06
		0.0411				0.08	0.06
		0.0898		0.07175		0.08	0.06
		0.0862		0.06625		0.08	0.06
0.073		0.08075		0.07446		0.08	0.06
0.123		0.11025		0.09175		0.08	0.06
0.081		0.085		0.09055		0.08	0.06
0.084		0.08775		0.09094		0.08	0.06
0.06		0.05825		0.08531		0.08	0.06
0.027		0.0275		0.06463		0.08	0.06
0.012		0.0115		0.04625		0.08	0.06
0.023		0.0205		0.02944		0.08	0.06
0.029		0.03325		0.02319		0.08	0.06
0.008	0.0198	0.0085	0.01804	0.01844		0.08	0.06
0.016	0.0124	0.0165	0.01140	0.01969		0.08	0.06
0.012	0.013	0.014	0.01643	0.01806		0.08	0.06
0.032	0.0201	0.03325	0.01815	0.01806	0.01600	0.08	0.06
0.012		0.0135		0.01931		0.08	0.06
0.013		0.01625		0.01925		0.08	0.06
0.011		0.01225		0.01881		0.08	0.06
0.059		0.061		0.02575		0.08	0.06
0.051		0.0495		0.03475		0.08	0.06
0.0556		0.056625		0.04484		0.08	0.06
0.0151		0.016025		0.04579		0.08	0.06
0.0601	0.0231	0.05395	0.02225	0.04403	0.02225	0.08	0.06
0.004	ND	0.033525	0.01770	0.04003	0.01998	0.08	0.06
0.045	0.0186	0.044525	0.01783	0.03701	0.01926	0.08	0.06
0.0346	0.0092	0.03395	0.01095	0.04149	0.01718	0.08	0.06
0.0509	0.02465	0.0486075	0.03363	0.04015	0.02003	0.08	0.06
0.04413	0.04585	0.0381925	0.04133	0.04132	0.02593	0.08	0.06
0.03518	0.04487	0.0326975	0.04284	0.03836	0.03219	0.08	0.06
0.03304	0.02474	0.0287325	0.02182	0.03706	0.03491	0.08	0.06
0.03269	0.02092	0.034675	0.02120	0.03357	0.03180	0.08	0.06
0.02933	0.02098	0.030695	0.01975	0.03170	0.02640	0.08	0.06
0.02261	0.01749	0.0224775	0.01537	0.02915	0.01954	0.08	0.06
0.0285	0.02582	0.028975	0.02731	0.02921	0.02091	0.08	0.06
0.03176	0.03743	0.0247975	0.02767	0.02674	0.02253	0.08	0.06
0.03095	0.01202	0.02915	0.01260	0.02635	0.02074	0.08	0.06
0.04909	0.01224	0.0398325	0.00937	0.03069	0.01924	0.08	0.06
0.02208	0.01081	0.0211525	0.01109	0.02873	0.01518	0.08	0.06
0.03614	0.01997	0.03308	0.01938	0.03080	0.01311	0.08	0.06
0.0237	0	0.02465	0.00503	0.02968	0.01122	0.08	0.06
0.025	0.01123	0.0252975	0.00801	0.02605	0.01088	0.08	0.06
0.03457	0.00834	0.0345325	0.01429	0.02939	0.01168	0.08	0.06
0.05783	0.03748	0.0603825	0.04144	0.03622	0.01719	0.08	0.06
0.03434	0.03025	0.03509	0.02965	0.03883	0.02335	0.08	0.06
0.02922	0.02097	0.0216425	0.02181	0.03791	0.02680	0.08	0.06
0.03341	0.01466	0.03449	0.01475	0.03790	0.02691	0.08	0.06

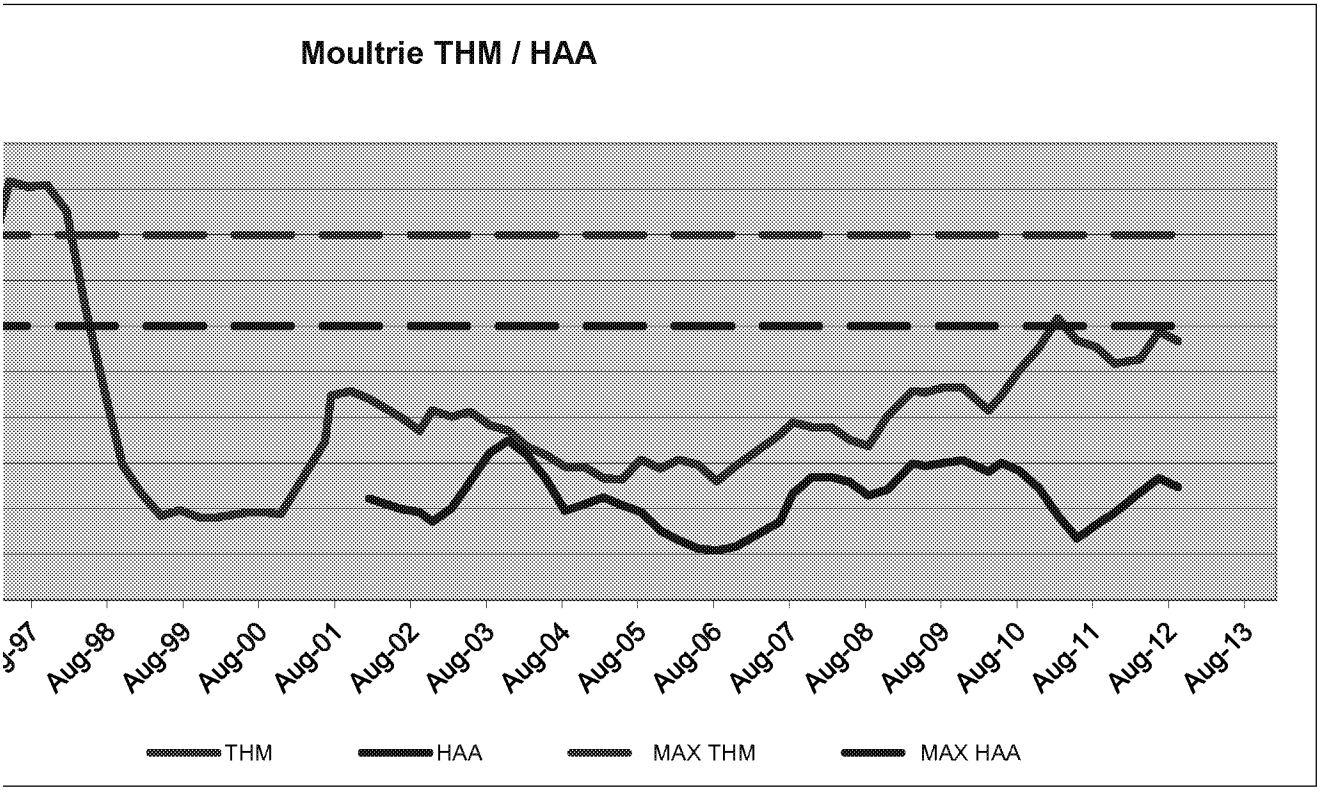
0.0506	0.03914	0.0494025	0.03716	0.03516	0.02584	0.08	0.06
0.03291	0.0186	0.0291375	0.01812	0.03367	0.02296	0.08	0.06
0.03619	0.0207	0.0482325	0.02680	0.04032	0.02421	0.08	0.06
0.06373	0.05161	0.0564675	0.03763	0.04581	0.02993	0.08	0.06
0.03762	0	0.04808	0.03506	0.04548	0.02940	0.08	0.06
0.03231	0.02141	0.03355	0.02084	0.04658	0.03008	0.08	0.06
0.04954	0.03114	0.0475825	0.02898	0.04642	0.03063	0.08	0.06
0.03491	0.0282	0.0368325	0.02764	0.04151	0.02813	0.08	0.06
0.06325	0.04134	0.061325	0.04292	0.04482	0.03010	0.08	0.06
0.05606	0.01159	0.0563375	0.01351	0.05052	0.02826	0.08	0.06
0.07185	0.01506	0.0666425	0.01342	0.05528	0.02437	0.08	0.06
0.06451	0.0053	0.062805	0.00431	0.06178	0.01854	0.08	0.06
0.04203	0.02103	0.0418075	0.02297	0.05690	0.01355	0.08	0.06
0.04503	0.01923	0.050325	0.02487	0.05540	0.01639	0.08	0.06
0.05464	0.02331	0.0523225	0.02436	0.05182	0.01913	0.08	0.06
0.07435	0.02337	0.0666425	0.02238	0.05277	0.02364	0.08	0.06
0.06765	0.03534	0.0658	0.03531	0.05877	0.02673	0.08	0.06
0.04701	0.01841	0.048415	0.01648	0.05670	0.02468	0.08	0.06
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
0.038775429	0.02235122	0.039029482	0.02288	#DIV/0!	#DIV/0!		
0.000254054	-0.02235122			#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		

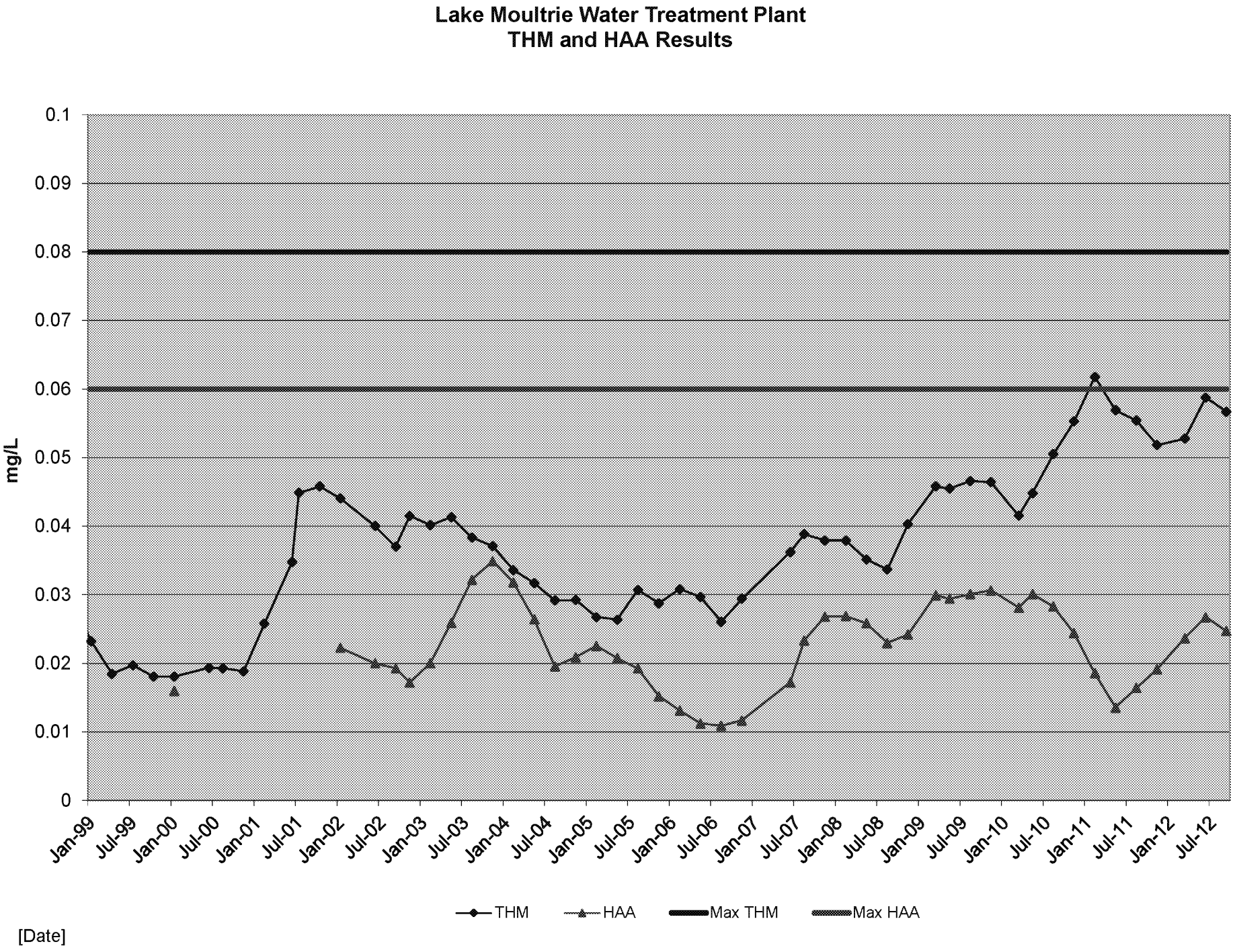


#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

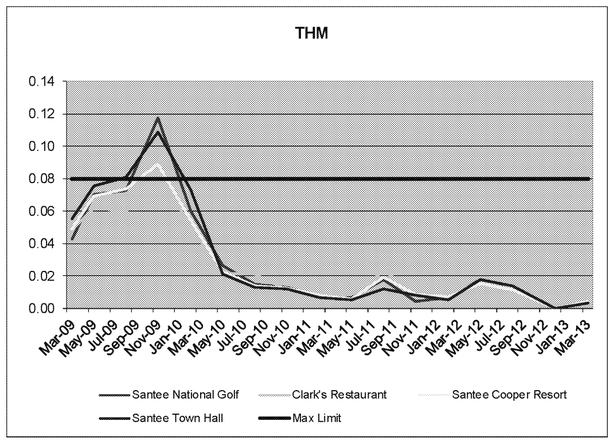
Sampling more than 4 sites until Jun 2000.

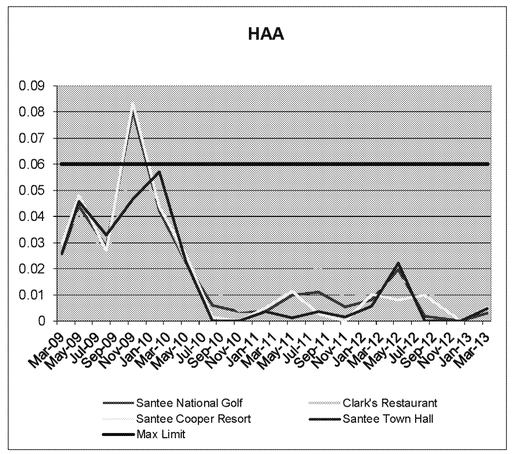
Sampling Reduced to these 4 sites.

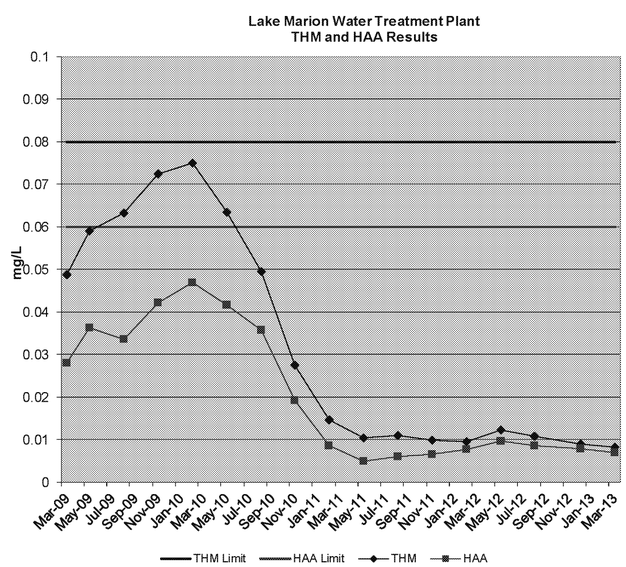

Moultrie THM / HAA
g-97
Aug-98
Aug-99
Aug-00
Aug-01
Aug-02
Aug-03
Aug-04
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Aug-11
Aug-12
Aug-13
THM
HAA
MAX THM
MAX HAA


Lake Moultrie Water Treatment Plant
THM and HAA Results
mg/L
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
THM
HAA
Max THM
Max HAA
[Date]

	DBP-1		DBP-2		DBP-3		DBP-4							
Sample	Santee National Golf		Clark's Restaurant		antee Cooper Reso		Santee Town Hall		Average		g Annual Ave		THM Limit	HAA Limit
Date	THM	HAA	THM	HAA	THM	HAA	THM	HAA	THM	HAA	THM	HAA	0.08	0.06
3/23/2009	0.04262	0.02571	0.04838	0.03071	0.04905	0.02967	0.05522	0.02576	0.04882	0.02796	0.049	0.028	0.08	0.06
5/13/2009	0.07036	0.04392	0.06216	0.04139	0.06934	0.04813	0.07563	0.04579	0.06937	0.04481	0.059	0.036	0.08	0.06
8/5/2009	0.07284	0.02825	0.05943	0.02412	0.07377	0.02702	0.08096	0.03295	0.07175	0.02809	0.063	0.034	0.08	0.06
11/5/2009	0.11743	0.08048	0.08375	0.06019	0.08884	0.08352	0.10882	0.04666	0.09971	0.06771	0.072	0.042	0.08	0.06
2/2/2010	0.06009	0.04209	0.05043	0.04528	0.05433	0.04375	0.07292	0.0571	0.05944	0.04706	0.075	0.047	0.08	0.06
5/4/2010	0.02631	0.02249	0.02148	0.02278	0.02278	0.02527	0.02095	0.02281	0.02288	0.02334	0.063	0.042	0.08	0.06
8/5/2010	0.01479	0.00605	0.02137	0.01243	0.01388	0.00139	0.01308	0	0.01578	0.00497	0.049	0.036	0.08	0.06
11/3/2010	0.0131	0.00364	0.0114	0.00396	0.01243	0	0.01206	0	0.01225	0.00190	0.028	0.019	0.08	0.06
2/2/2011	0.00731	0.00365	0.00949	0.00519	0.00829	0.0052	0.00678	0.00351	0.00797	0.00439	0.015	0.009	0.08	0.06
5/4/2011	0.00688	0.00972	0.00568	0.01215	0.00583	0.01134	0.0052	0.00105	0.00590	0.00857	0.010	0.005	0.08	0.06
8/11/2011	0.018	0.01116	0.02333	0.02106	0.01915	0.00279	0.01219	0.00365	0.01817	0.00967	0.011	0.006	0.08	0.06
11/3/2011	0.00414	0.00528	0.00906	0.00839	0.0088	0	0.00826	0.00146	0.00757	0.00378	0.010	0.007	0.08	0.06
2/2/2012	0.00655	0.00821	0.00732	0.01111	0.00719	0.01011	0.00545	0.00558	0.00663	0.00875	0.010	0.008	0.08	0.06
5/30/2012	0.01784	0.01968	0.01723	0.01599	0.01523	0.00794	0.01773	0.02205	0.01701	0.01642	0.012	0.010	0.08	0.06
8/29/2012	0.01108	0.00174	0.01095	0.01158	0.01151	0.00984	0.01414	0	0.01192	0.00579	0.011	0.009	0.08	0.06
12/5/2012	0	0	0	0.00306	0	0	0	0	0.00000	0.00077	0.009	0.008	0.08	0.06
3/20/2013	0.0041	0.0029	0.0048	0.006	0.0045	0.0052	0.0033	0.0049	0.00418	0.00475	0.008	0.007	0.08	0.06
													0.08	0.06
													0.08	0.06
													0.08	0.06







Moultrie Data

	MO - 1					
	Chloroform	Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs	Chloroform
2/4/2008	0.00706	0.01254	0.01229	0.00171	0.0336	0.00772
5/8/2008	0.02146	0.0198	0.01579	0.00224	0.05929	0.01383
8/4/2008	0.00883	0.01057	0.00752	0	0.02692	0.00984
11/4/2008	0.01198	0.01561	0.01349	0.00268	0.04376	0.01288
2/17/2009	0.0163	0.01628	0.01198	0.00164	0.0462	0.02452
5/18/2009	0.023	0.01037	0.00425	0	0.03762	0.02961
8/17/2009	0.01613	0.01118	0.00393	0	0.03124	0.01692
11/19/2009	0.01798	0.01569	0.00849	0	0.04216	0.02065
3/3/2010	0.02173	0.01134	0.00241	0	0.03548	0.02664
5/19/2010	0.02752	0.02239	0.01334	0	0.06325	0.0301
8/18/2010	0.00653	0.01672	0.0221	0.01071	0.05606	0.00663
11/17/2010	0	0.01043	0.03089	0.03053	0.07185	0
2/15/2011	0.0057	0.01769	0.02606	0.01506	0.06451	0.00438
5/19/2011	0.01357	0.01581	0.0113	0.00135	0.04203	0.01249
8/16/2011	0.01424	0.0177	0.01309	0	0.04503	0.01377
11/17/2011	0.00179	0.0106	0.02307	0.01918	0.05464	0.00173

Marion Data

	MA - 1					
	Chloroform	Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs	Chloroform
8/5/2009	0.02754	0.02389	0.01798	0.00343	0.07284	0.01971
11/5/2009	0.07956	0.02683	0.01104	0	0.11743	0.05015
2/2/2010	0.03971	0.01559	0.00479	0	0.06009	0.0334
5/4/2010	0.01623	0.00769	0.00239	0	0.02631	0.0137
8/5/2010	0.01274	0.00205	0	0	0.01479	0.01282
11/3/2010	0.00529	0.00431	0.0035	0	0.0131	0.00479
2/2/2011	0.00446	0.00285	0	0	0.00731	0.00476
5/4/2011	0.00498	0.0019	0	0	0.00688	0.00412
8/11/2011	0.00812	0.00712	0.00276	0	0.018	0.01143
11/3/2011	0.0023	0.00184	0	0	0.00414	0.00397
2/1/2012	0.02294	0.00186	0.00175	0	0.00655	0.0025

MO - 2					
Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs	Chloroform	Bromodichloromethane
0.01388	0.01393	0.00214	0.03767	0.00802	0.01238
0.01558	0.01151	0.00117	0.04209	0.01513	0.01652
0.01113	0.00765	0	0.02862	0.00942	0.0112
0.01689	0.01468	0.00276	0.04721	0.01702	0.02617
0.02253	0.01378	0.00104	0.06187	0.01895	0.02109
0.01806	0.00656	0	0.05423	0.02318	0.01396
0.01219	0.00429	0	0.0334	0.01887	0.0136
0.0176	0.00924	0	0.04749	0.02207	0.0191
0.013	0.00288	0	0.04252	0.01997	0.01188
0.02339	0.01473	0	0.06822	0.02318	0.02169
0.01797	0.02458	0.01226	0.06144	0.00644	0.01739
0.00815	0.02608	0.02732	0.06155	0	0.01001
0.01599	0.02375	0.01256	0.05668	0.00539	0.01849
0.01611	0.0116	0.00156	0.04176	0.01298	0.01587
0.01958	0.01467	0	0.04802	0.01478	0.01995
0.01046	0.02099	0.01632	0.0495	0.00187	0.01078

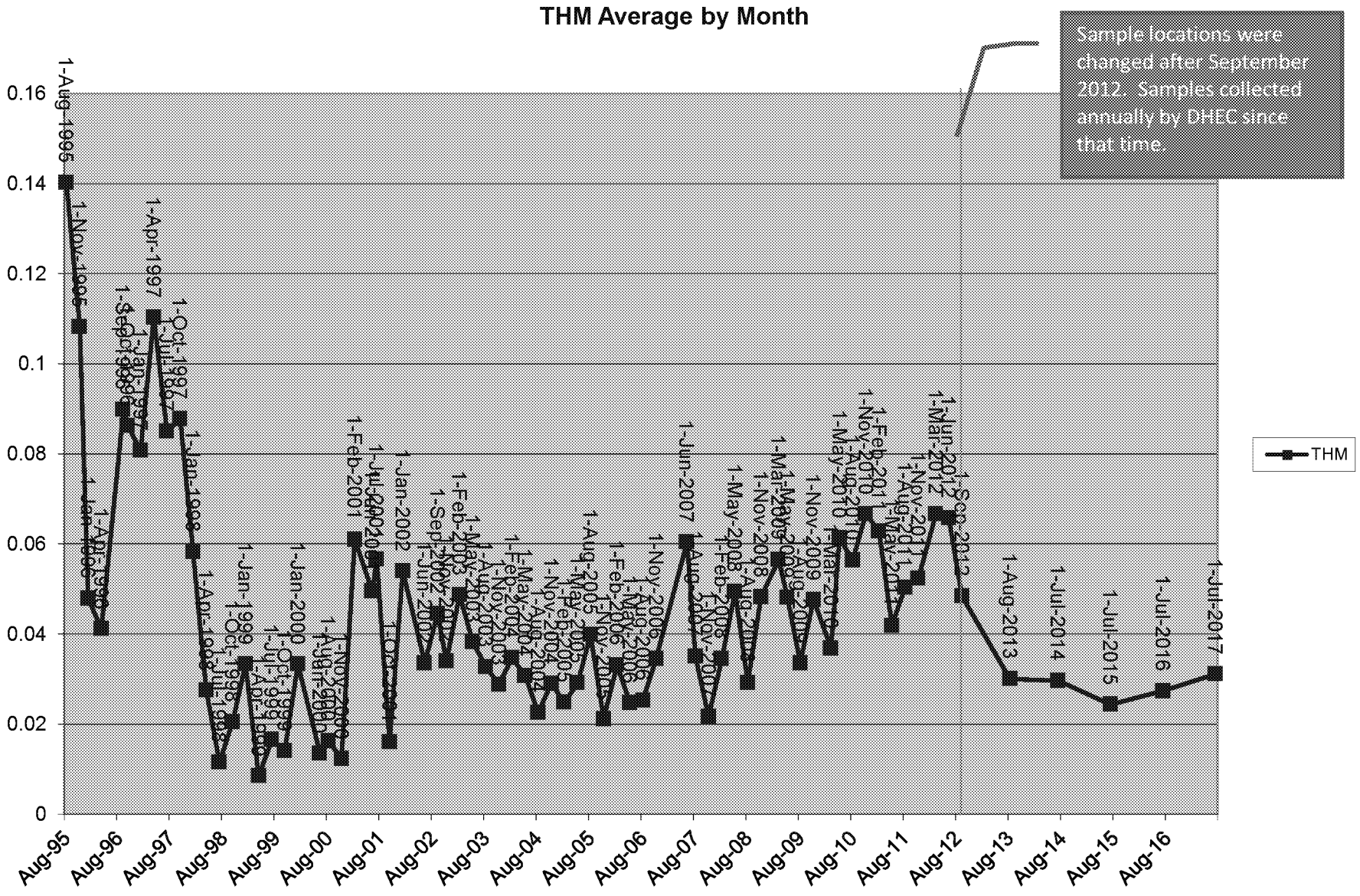
MA - 2					
Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs	Chloroform	Bromodichloromethane
0.02014	0.01636	0.00322	0.05943	0.02918	0.02353
0.02275	0.01085	0	0.08375	0.05639	0.02198
0.01325	0.00378	0	0.05043	0.03616	0.01421
0.00585	0.00193	0	0.02148	0.01408	0.0062
0.00579	0.00276	0	0.02137	0.01149	0.00239
0.00394	0.00267	0	0.0114	0.00549	0.00406
0.00361	0.00112	0	0.00949	0.00436	0.0029
0.00156	0	0	0.00568	0.0043	0.00153
0.00823	0.00367	0	0.02333	0.00917	0.00736
0.00309	0.002	0	0.00906	0.004	0.00306
0.00249	0.00233	0	0.00732	0.00286	0.00219

MO - 3			MO- 4		
Dibromochloromethane	Bromoform	Total THMs	Chloroform	Bromodichloromethane	Dibromochloromethane
0.01179	0.00109	0.03328	0.00742	0.01255	0.01194
0.01252	0.00146	0.04563	0.01798	0.01728	0.01369
0.00748	0	0.0281	0.01203	0.01229	0.00859
0.01897	0.00361	0.06577	0.00929	0.013	0.01166
0.0129	0.00113	0.05407	0.02369	0.02413	0.01468
0.00521	0	0.04235	0.03162	0.01915	0.00735
0.00478	0	0.03725	0.01646	0.0117	0.00415
0.00997	0	0.05114	0.02144	0.01849	0.00961
0.00257	0	0.03442	0.02199	0.01076	0.00216
0.01225	0	0.05712	0.02479	0.02012	0.0118
0.02444	0.01197	0.06024	0.00535	0.0139	0.01922
0.02614	0.02692	0.06307	0	0.01139	0.02878
0.02623	0.01304	0.06315	0.00616	0.01943	0.02682
0.01144	0.00139	0.04168	0.01353	0.01589	0.01118
0.01526	0	0.04999	0.01862	0.02295	0.01669
0.02163	0.01676	0.05104	0.00243	0.01048	0.02248

MA - 3			MA- 4		
Dibromochloromethane	Bromoform	Total THMs	Chloroform	Bromodichloromethane	Dibromochloromethane
0.01773	0.00333	0.07377	0.03435	0.02546	0.01782
0.01047	0	0.08884	0.05799	0.03209	0.01757
0.00396	0	0.05433	0.05281	0.01636	0.00375
0.00219	0	0.02278	0.0136	0.00555	0.0018
0	0	0.01388	0.01071	0.00237	0
0.00288	0	0.01243	0.00506	0.00404	0.00296
0.00103	0	0.00829	0.00396	0.00282	0
0	0	0.00583	0.00379	0.00141	0
0.00262	0	0.01915	0.00619	0.00483	0.00117
0.00174	0	0.0088	0.00334	0.00299	0.00193
0.00214	0	0.00719	0.00425	0.0021	0

Bromoform	Total THMs
0.0015	0.03341
0.00165	0.0506
0	0.03291
0.00224	0.03619
0.00123	0.06373
0	0.05812
0	0.03231
0	0.04954
0	0.03491
0	0.05671
0.00914	0.04761
0.02999	0.07016
0.01447	0.06688
0.00116	0.04176
0	0.05826
0.01872	0.05411

Bromoform	Total THMs
0.00333	0.08096
0.00117	0.10882
0	0.07292
0	0.02095
0	0.01308
0	0.01206
0	0.00678
0	0.0052
0	0.01219
0	0.00826
0	0.00545


THM Average by Month
Sample locations were changed after September 2012. Samples collected annually by DHEC since that time.
THM
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Aug-95
Aug-96
Aug-97
Aug-98
Aug-99
Aug-00
Aug-01
Aug-02
Aug-03
Aug-04
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Aug-11
Aug-12
Aug-13
Aug-14
Aug-15
Aug-16

		GC Tank - #4		MC CPW - #3		Oasi
	Date	THM	HAA	THM	HAA	THM
Previously Entered	1-Aug-1995					
	1-Nov-1995					
	1-Jan-1996					
	1-Apr-1996					
	1-Sep-1996					
	1-Oct-1996					
	7-Jan-1997	0.082		0.083		0.085
	1-Apr-1997	0.108		0.101		0.109
	1-Jul-1997	0.092		0.078		0.089
	1-Oct-1997	0.101		0.085		0.081
	1-Jan-1998	0.064		0.061		0.048
	1-Apr-1998	0.027		0.026		0.03
	1-Jul-1998	0.014		0.009		0.011
	1-Oct-1998	0.024		0.016		0.019
	1-Jan-1999	0.039		0.029		0.036
	1-Apr-1999	0.011	0.02337	0.007	0.01241	0.008
	1-Jul-1999	0.018	0.0111	0.015	0.0101	0.017
	1-Oct-1999	0.015	0.0197	0.014	0.0162	0.015
	1-Jan-2000	0.035	0.0175	0.033	0.0167	0.033
	1-Jun-2000	0.016		0.013		0.013
	1-Aug-2000	0.018		0.017		0.017
	1-Nov-2000	0.016		0.011		0.011
	1-Feb-2001	0.065		0.057		0.063
	1-Jun-2001	0.053		0.044		0.05
	1-Jul-2001	0.0635		0.0511		0.0563
	1-Oct-2001	0.0187		0.0168		0.0135
	1-Jan-2002	0.0542	0.0214	0.05	0.023	0.0515
	1-Jun-2002	0.0397	0.0171	0.0425	0.0177	0.0479
	1-Sep-2002	0.0462	0.0191	0.0411	0.0146	0.0458
	1-Nov-2002	0.0362	0.0121	0.0306	0.0119	0.0344
	3-Feb-2003	0.04026	0.03745	0.04993	0.03642	0.05334
	3-May-2003	0.04109	0.04098	0.03195	0.04269	0.0356
	13-Aug-2003	0.0334	0.0403	0.03179	0.05109	0.03042
	12-Nov-2003	0.02875	0.02534	0.02657	0.01732	0.02657
	10-Feb-2004	0.03939	0.02273	0.03215	0.01848	0.03447
	11-May-2004	0.03084	0.02082	0.03228	0.01734	0.03033
	9-Aug-2004	0.03107	0.01885	0.01741	0.00959	0.01882
	15-Nov-2004	0.0461	0.02581	0.0234	0.02223	0.0179
	9-Feb-2005	0.02538	0.02476	0.01469	0.02767	0.02736
	11-May-2005	0.02656	0.01235	0.02544	0.01275	0.03365
	11-Aug-2005	0.03781	0.01332	0.03751	0	0.03492
	15-Nov-2005	0.02372	0.01265	0.01822	0.00848	0.02059
	15-Feb-2006	0.03159	0.02214	0.03354	0.01766	0.03105
	9-May-2006	0.02325	0.00707	0.02453	0.00662	0.02712
	10-Aug-2006	0.02626	0.01094	0.02487	0	0.02506
	8-Nov-2006	0.03427	0.02088	0.03235	0.00353	0.03694
	20-Jun-2007	0.06059	0.04254	0.06985	0.04126	0.05326
	1-Aug-2007	0.03384	0.02455	0.03311	0.03045	0.03907
	1-Nov-2007	0.02091	0.02415	0.0196	0.02228	0.01684
	4-Feb-2008	0.0336	0.01554	0.03767	0.01627	0.03328

	8-May-2008	0.05929	0.03402	0.04209	0.03795	0.04563
	4-Aug-2008	0.02692	0.01961	0.02862	0.01524	0.0281
	4-Nov-2008	0.04376	0.02332	0.04721	0.02392	0.06577
	27-Mar-2009	0.0462	0	0.06187	0.04421	0.05407
	18-May-2009	0.05812	0.04962	0.04235	0.03941	0.05423
	17-Aug-2009	0.03124	0.02083	0.0334	0.02109	0.03725
	19-Nov-2009	0.04216	0.0284	0.04749	0.028	0.05114
	3-Mar-2010	0.03548	0.03063	0.04252	0.02511	0.03442
	19-May-2010	0.05671	0.04476	0.05712	0.04612	0.06822
	18-Aug-2010	0.04761	0.01455	0.06024	0.01447	0.06144
	17-Nov-2010	0.0701	0.01393	0.06307	0.0125	0.06155
	15-Feb-2011	0.06688	0.00462	0.06315	0.00346	0.05668
	19-May-2011	0.04176	0.02401	0.04168	0.02534	0.04176
	16-Aug-2011	0.05826	0.02348	0.04999	0.03103	0.04802
	17-Nov-2011	0.05411	0.02651	0.05104	0.02395	0.0495
	20-Mar-2012	0.06757	0.02359	0.06128	0.02169	0.06337
	6-Jun-2012	0.06902	0.03704	0.06235	0.03423	0.06418
	6-Sep-2012	0.0517	0.01475	0.04815	0.01567	0.0468
Newly	**5-Aug-2013**					
Entered From	**16-Jul-2014**					
DHEC Website	**20-Jul-2015**					
	20-Jul-2016					
	17-Jul-2017					

Previously-Entered, Not Updated						
	Avg. since 1/02	0.039707	0.023012857	0.038060833	0.022207619	0.039574722
	Difference from System Avg.	-0.00068	-0.023012857	0.000968649	-0.022207619	-0.00054524

s - #2	Kings Grant - #1		Average		Rolling Average		On Site Lab Sink	
HAA	THM	HAA	THM	HAA	THM	HAA	THM	HAA
			0.1402					
			0.1082					
			0.0479					
			0.0411					
			0.0898		0.07175			
			0.0862		0.06625			
	0.073		0.08075		0.07446			
	0.123		0.11025		0.09175			
	0.081		0.085		0.09055			
	0.084		0.08775		0.09094			
	0.06		0.05825		0.08531			
	0.027		0.0275		0.06463			
	0.012		0.0115		0.04625			
	0.023		0.0205		0.02944			
	0.029		0.03325		0.02319			
0.01656	0.008	0.0198	0.0085	0.01804	0.01844			
0.012	0.016	0.0124	0.0165	0.01140	0.01969			
0.0168	0.012	0.013	0.014	0.01643	0.01806			
0.0183	0.032	0.0201	0.03325	0.01815	0.01806	0.01600		
	0.012		0.0135		0.01931			
	0.013		0.01625		0.01925			
	0.011		0.01225		0.01881			
	0.059		0.061		0.02575			
	0.051		0.0495		0.03475			
	0.0556		0.056625		0.04484			
	0.0151		0.016025		0.04579			
0.0215	0.0601	0.0231	0.05395	0.02225	0.04403	0.02225		
0.0183	0.004	ND	0.033525	0.01770	0.04003	0.01998		
0.019	0.045	0.0186	0.044525	0.01783	0.03701	0.01926		
0.0106	0.0346	0.0092	0.03395	0.01095	0.04149	0.01718		
0.03601	0.0509	0.02465	0.0486075	0.03363	0.04015	0.02003		
0.0358	0.04413	0.04585	0.0381925	0.04133	0.04132	0.02593		
0.0351	0.03518	0.04487	0.0326975	0.04284	0.03836	0.03219		
0.01988	0.03304	0.02474	0.0287325	0.02182	0.03706	0.03491		
0.02267	0.03269	0.02092	0.034675	0.02120	0.03357	0.03180		
0.01987	0.02933	0.02098	0.030695	0.01975	0.03170	0.02640		
0.01555	0.02261	0.01749	0.0224775	0.01537	0.02915	0.01954		
0.03537	0.0285	0.02582	0.028975	0.02731	0.02921	0.02091		
0.02082	0.03176	0.03743	0.0247975	0.02767	0.02674	0.02253		
0.01329	0.03095	0.01202	0.02915	0.01260	0.02635	0.02074		
0.01192	0.04909	0.01224	0.0398325	0.00937	0.03069	0.01924		
0.01243	0.02208	0.01081	0.0211525	0.01109	0.02873	0.01518		
0.01773	0.03614	0.01997	0.03308	0.01938	0.03080	0.01311		
0.00644	0.0237	0	0.02465	0.00503	0.02968	0.01122		
0.00985	0.025	0.01123	0.0252975	0.00801	0.02605	0.01088		
0.02442	0.03457	0.00834	0.0345325	0.01429	0.02939	0.01168		
0.04446	0.05783	0.03748	0.0603825	0.04144	0.03622	0.01719		
0.03334	0.03434	0.03025	0.03509	0.02965	0.03883	0.02335		
0.01982	0.02922	0.02097	0.0216425	0.02181	0.03791	0.02680		
0.01251	0.03341	0.01466	0.03449	0.01475	0.03790	0.02691		

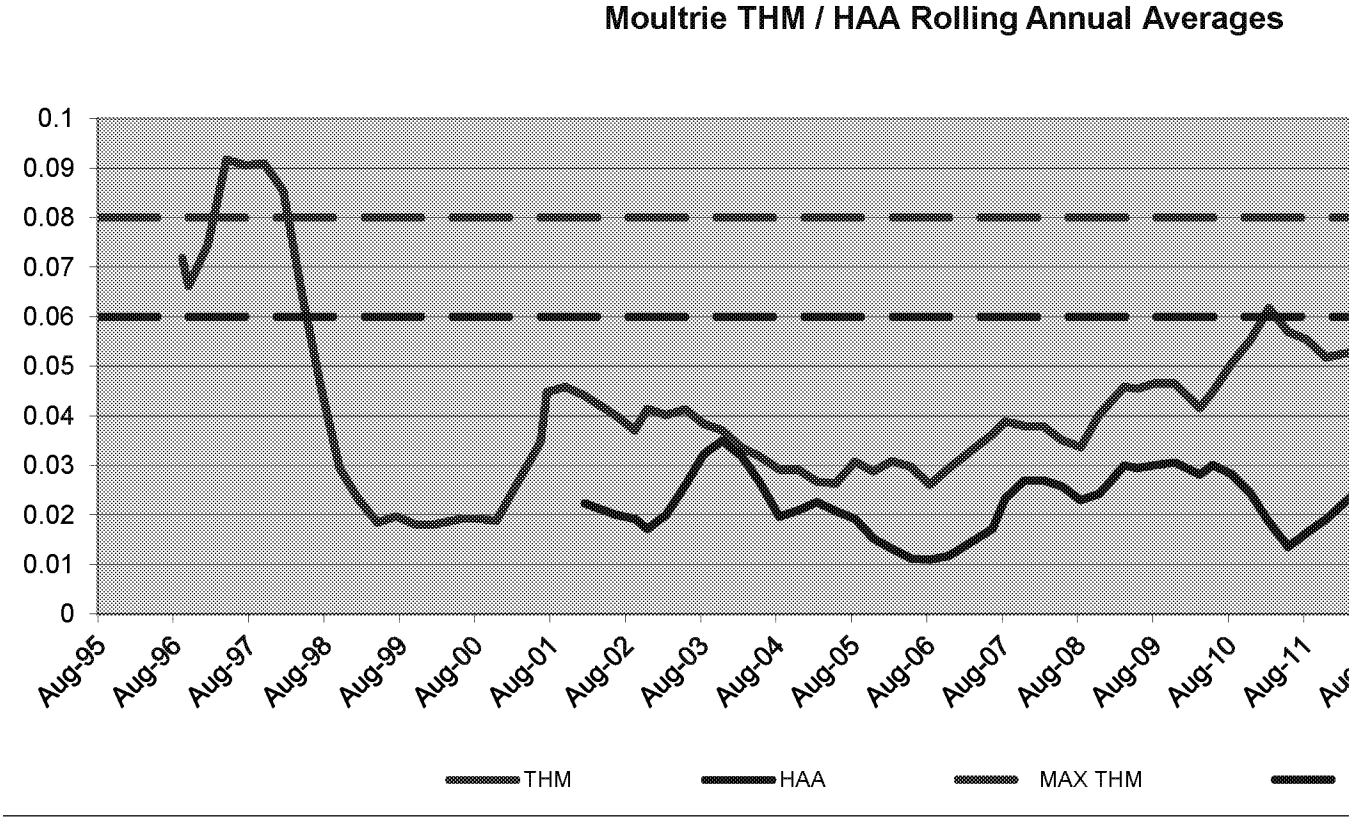
0.03752	0.0506	0.03914	0.0494025	0.03716	0.03516	0.02584		
0.01904	0.03291	0.0186	0.0291375	0.01812	0.03367	0.02296		
0.03927	0.03619	0.0207	0.0482325	0.02680	0.04032	0.02421		
0.05471	0.06373	0.05161	0.0564675	0.03763	0.04581	0.02993		
0.0512	0.03762	0	0.04808	0.03506	0.04548	0.02940		
0.02002	0.03231	0.02141	0.03355	0.02084	0.04658	0.03008		
0.02838	0.04954	0.03114	0.0475825	0.02898	0.04642	0.03063		
0.02662	0.03491	0.0282	0.0368325	0.02764	0.04151	0.02813		
0.03947	0.06325	0.04134	0.061325	0.04292	0.04482	0.03010		
0.01344	0.05606	0.01159	0.0563375	0.01351	0.05052	0.02826		
0.01219	0.07185	0.01506	0.0666425	0.01342	0.05528	0.02437		
0.00385	0.06451	0.0053	0.062805	0.00431	0.06178	0.01854		
0.02149	0.04203	0.02103	0.0418075	0.02297	0.05690	0.01355		
0.02574	0.04503	0.01923	0.050325	0.02487	0.05540	0.01639		
0.02365	0.05464	0.02331	0.0523225	0.02436	0.05182	0.01913		
0.02088	0.07435	0.02337	0.0666425	0.02238	0.05277	0.02364		
0.03464	0.06765	0.03534	0.0658	0.03531	0.05877	0.02673		
0.01709	0.04701	0.01841	0.048415	0.01648	0.05670	0.02468		
			0.03000	0.03939	0.03000	0.03939	0.03000	
			0.02963	0.02807	0.02963	0.02807	0.02963	
			0.02432	0.01586	0.02432	0.01586	0.02753	0.02048
			0.02736	0.01777	0.02736	0.01777	0.02815	0.01661
			0.03107	0.03263	0.03107	0.03263	0.03214	0.0319

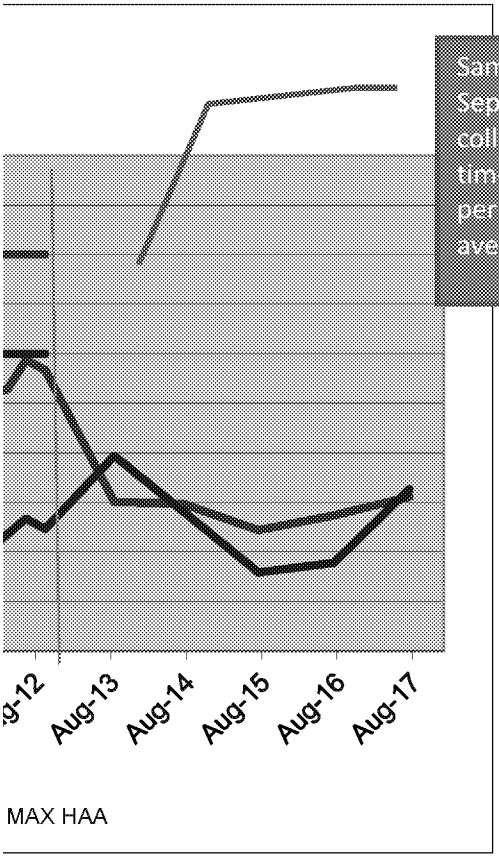
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
0.023949524	0.038775429	0.02235122	0.039029482	0.02288	#DIV/0!	#DIV/0!
-0.023949524	0.000254054	-0.02235122			#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

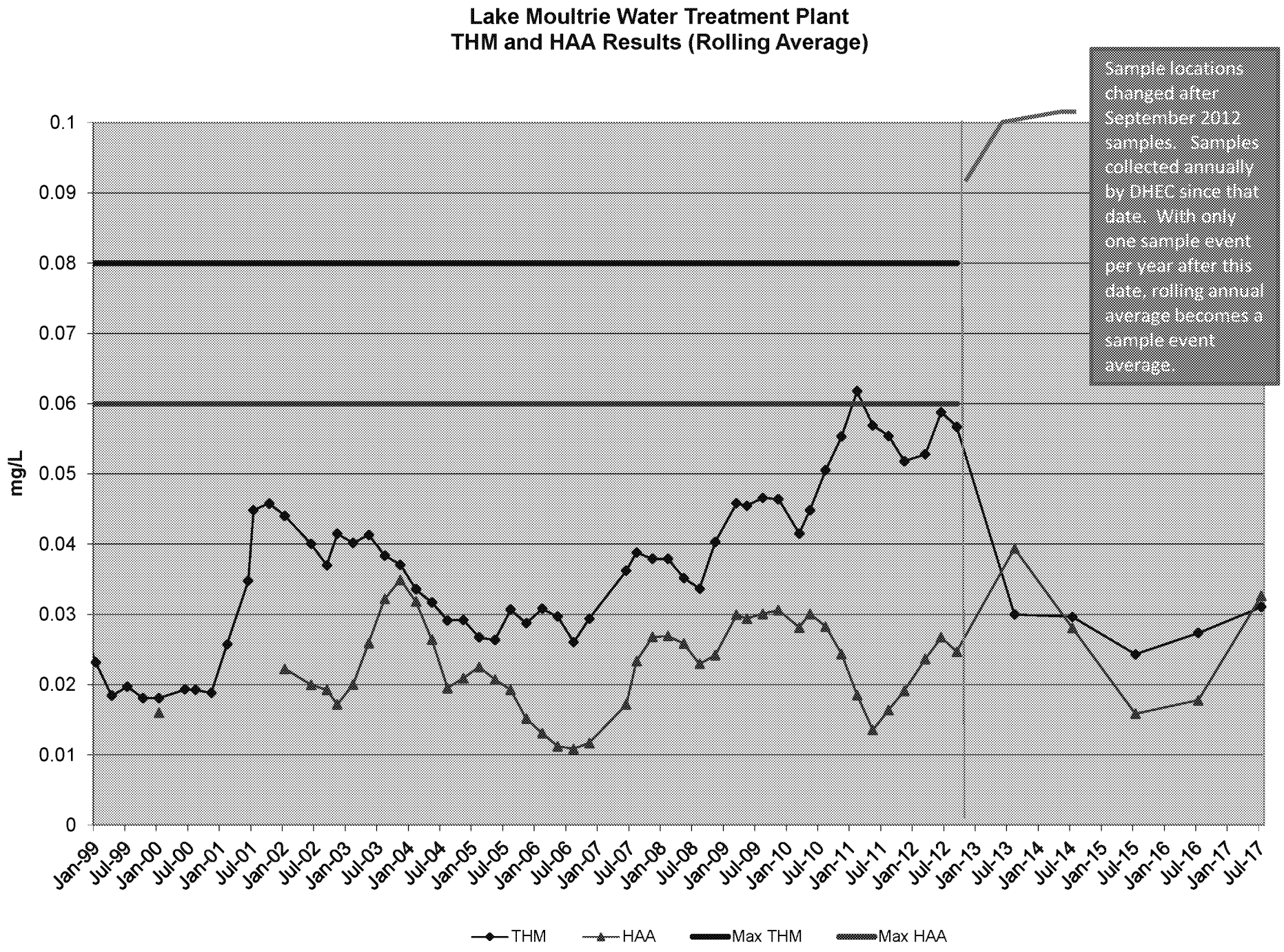
On Site Restroom		Maximum Level		
THM	HAA	MAX THM	MAX HAA	
		0.08	0.06	Sampling more than 4 sites until Jun 2000.
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	Sampling Reduced to these 4 sites.
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06	
		0.08	0.06

		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
		0.08	0.06
	0.03939		
	0.02807		
0.02111	0.01123		
0.02656	0.01892		
0.03	0.03335		





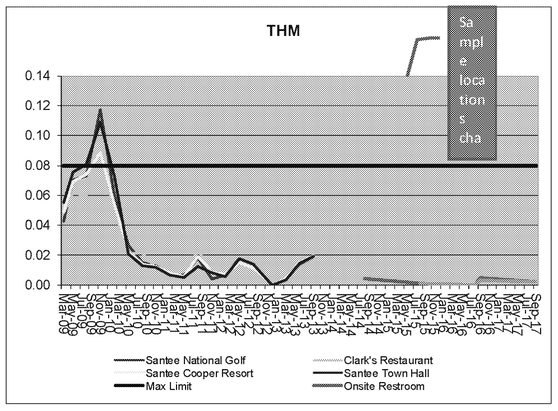
Sample locations changed after September 2012 samples. Sample collected annually by DHEC since that time. With only one sample event per year after this date, rolling annual average becomes a sample event

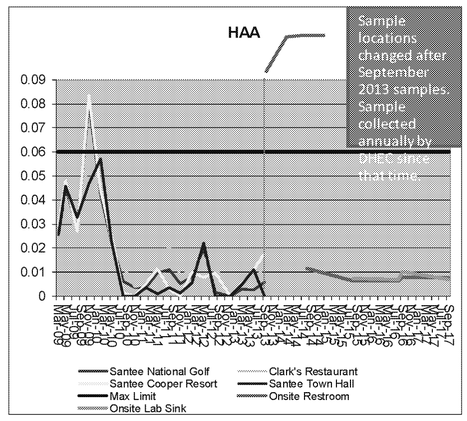

Lake Moultrie Water Treatment Plant
THM and HAA Results (Rolling Average)
Sample locations changed after September 2012 samples. Samples collected annually by DHEC since that date. With only one sample event per year after this date, rolling annual average becomes a sample event average.
mg/L
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14
Jul-14
Jan-15
Jul-15
Jan-16
Jul-16
Jan-17
Jul-17
THM
HAA
Max THM
Max HAA

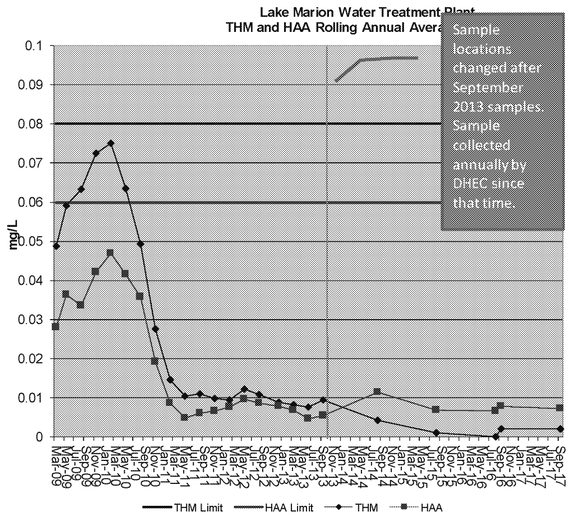
[Date]

		DBP-1		DBP-2		DBP-3		DBP-4							
	Sample	ee National Golf Pro S		Clark's Restaurant		Cooper Resort Gua		Santee Town Hall		Average		g Annual Av		THM Limit	HAA Limit
	Date	THM	HAA	THM	HAA	THM	HAA	THM	HAA	THM	HAA	THM	HAA	0.08	0.06
Previously	3/23/2009	0.04262	0.02571	0.04838	0.03071	0.04905	0.02967	0.05522	0.02576	0.04882	0.02796	0.049	0.028	0.08	0.06
Entered	5/13/2009	0.07036	0.04392	0.06216	0.04139	0.06934	0.04813	0.07563	0.04579	0.06937	0.04481	0.059	0.036	0.08	0.06
	8/5/2009	0.07284	0.02825	0.05943	0.02412	0.07377	0.02702	0.08096	0.03295	0.07175	0.02809	0.063	0.034	0.08	0.06
	11/5/2009	0.11743	0.08048	0.08375	0.06019	0.08884	0.08352	0.10882	0.04666	0.09971	0.06771	0.072	0.042	0.08	0.06
	2/2/2010	0.06009	0.04209	0.05043	0.04528	0.05433	0.04375	0.07292	0.0571	0.05944	0.04706	0.075	0.047	0.08	0.06
	5/4/2010	0.02631	0.02249	0.02148	0.02278	0.02278	0.02527	0.02095	0.02281	0.02288	0.02334	0.063	0.042	0.08	0.06
	8/5/2010	0.01479	0.00605	0.02137	0.01243	0.01388	0.00139	0.01308	0	0.01578	0.00497	0.049	0.036	0.08	0.06
	11/3/2010	0.0131	0.00364	0.0114	0.00396	0.01243	0	0.01206	0	0.01225	0.00190	0.028	0.019	0.08	0.06
	2/2/2011	0.00731	0.00365	0.00949	0.00519	0.00829	0.0052	0.00678	0.00351	0.00797	0.00439	0.015	0.009	0.08	0.06
	5/4/2011	0.00688	0.00972	0.00568	0.01215	0.00583	0.01134	0.0052	0.00105	0.00590	0.00857	0.010	0.005	0.08	0.06
	8/11/2011	0.018	0.01116	0.02333	0.02106	0.01915	0.00279	0.01219	0.00365	0.01817	0.00967	0.011	0.006	0.08	0.06
	11/3/2011	0.00414	0.00528	0.00906	0.00839	0.0088	0	0.00826	0.00146	0.00757	0.00378	0.010	0.007	0.08	0.06
	2/2/2012	0.00655	0.00821	0.00732	0.01111	0.00719	0.01011	0.00545	0.00558	0.00663	0.00875	0.010	0.008	0.08	0.06
	5/30/2012	0.01784	0.01968	0.01723	0.01599	0.01523	0.00794	0.01773	0.02205	0.01701	0.01642	0.012	0.010	0.08	0.06
	8/29/2012	0.01108	0.00174	0.01095	0.01158	0.01151	0.00984	0.01414	0	0.01192	0.00579	0.011	0.009	0.08	0.06
	12/5/2012	0	0	0	0.00306	0	0	0	0	0.00000	0.00077	0.009	0.008	0.08	0.06
	3/20/2013	0.0041	0.0029	0.0048	0.006	0.0045	0.0052	0.0033	0.0049	0.00418	0.00475	0.008	0.007	0.08	0.06
Newly	6/17/2013	0.0138	0.0025	0.0143	0.0059	0.0152	0.0112	0.0143	0.0109	0.01440	0.00763	0.008	0.005	0.08	0.06
Entered	9/11/2013	0.0186	0.0059	0.0186	0.0127	0.0199	0.018	0.0192	0	0.01908	0.00915	0.009	0.006	0.08	0.06
From	8/26/2014									0.00430	0.01140	0.004	0.011	0.08	0.06
DHEC	8/11/2015									0.00110	0.00685	0.001	0.007	0.08	0.06
Website	8/11/2016									0.00000	0.00660	0.000	0.007	0.08	0.06
	9/14/2016									0.00425	0.00910	0.002	0.008	0.08	0.06
	9/6/2017									0.00210	0.00735	0.002	0.007	0.08	0.06

DBP-20		DBP-21	
)n Site Restroon		On Site Lab Sink	
THM	HAA	THM	HAA
0.0043	0.0114		
0.0011	0.0065	0.0011	0.0072
0	0.0062	0	0.007
0.005	0.008	0.0035	0.0102
0.0021	0.0077	0.0021	0.007







Moultrie Data

		MO - 1 Kings Grant				
		Chloroform	Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs
Previously Entered	2/4/2008	0.00706	0.01254	0.01229	0.00171	0.0336
	5/8/2008	0.02146	0.0198	0.01579	0.00224	0.05929
	8/4/2008	0.00883	0.01057	0.00752	0	0.02692
	11/4/2008	0.01198	0.01561	0.01349	0.00268	0.04376
	2/17/2009	0.0163	0.01628	0.01198	0.00164	0.0462
	5/18/2009	0.023	0.01037	0.00425	0	0.03762
	8/17/2009	0.01613	0.01118	0.00393	0	0.03124
	11/19/2009	0.01798	0.01569	0.00849	0	0.04216
	3/3/2010	0.02173	0.01134	0.00241	0	0.03548
	5/19/2010	0.02752	0.02239	0.01334	0	0.06325
	8/18/2010	0.00653	0.01672	0.0221	0.01071	0.05606
	11/17/2010	0	0.01043	0.03089	0.03053	0.07185
	2/15/2011	0.0057	0.01769	0.02606	0.01506	0.06451
	5/19/2011	0.01357	0.01581	0.0113	0.00135	0.04203
	8/16/2011	0.01424	0.0177	0.01309	0	0.04503
	11/17/2011	0.00179	0.0106	0.02307	0.01918	0.05464
Newly Entered From DHEC Website	3/20/2012	0.00289	0.01376	0.03059	0.02711	0.07435
	6/6/2012	0.00362	0.01406	0.02798	0.02199	0.06765
	9/6/2012	0.00433	0.0129	0.01975	0.01003	0.0470
	8/5/2013					
	7/16/2014					
	7/20/2015					
	7/20/2016					
	7/17/2017					

Marion Data

		MA - 1 Santee National Pro Shop				
		Chloroform	Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs
Old	8/5/2009	0.02754	0.02389	0.01798	0.00343	0.07284
	11/5/2009	0.07956	0.02683	0.01104	0	0.11743
	2/2/2010	0.03971	0.01559	0.00479	0	0.06009
	5/4/2010	0.01623	0.00769	0.00239	0	0.02631
	8/5/2010	0.01274	0.00205	0	0	0.01479
	11/3/2010	0.00529	0.00431	0.0035	0	0.0131
	2/2/2011	0.00446	0.00285	0	0	0.00731
	5/4/2011	0.00498	0.0019	0	0	0.00688
	8/11/2011	0.00812	0.00712	0.00276	0	0.018
	11/3/2011	0.0023	0.00184	0	0	0.00414
	2/1/2012	0.02294	0.00186	0.00175	0	0.00655
Newly Entered From DHEC Website	5/30/2012	0.00443	0.0057	0.00506	0.00265	0.0178
	8/29/2012	0.00516	0.0037	0.00222	0	0.0111
	12/5/2012	0	0	0	0	0
	3/20/2013	0.0028	0.0013	0	0	0.0041
	6/17/2013	0.0073	0.0047	0.0018	0	0.0138
	9/11/2013	0.0133	0.0052	0.0014	0	0.099
	8/26/2014					

8/11/2015	
8/11/2016	
9/14/2016	
9/6/2017	

MO - 2 Oasis					
Chloroform	Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs	Chloroform
0.00772	0.01388	0.01393	0.00214	0.03767	0.00802
0.01383	0.01558	0.01151	0.00117	0.04209	0.01513
0.00984	0.01113	0.00765	0	0.02862	0.00942
0.01288	0.01689	0.01468	0.00276	0.04721	0.01702
0.02452	0.02253	0.01378	0.00104	0.06187	0.01895
0.02961	0.01806	0.00656	0	0.05423	0.02318
0.01692	0.01219	0.00429	0	0.0334	0.01887
0.02065	0.0176	0.00924	0	0.04749	0.02207
0.02664	0.013	0.00288	0	0.04252	0.01997
0.0301	0.02339	0.01473	0	0.06822	0.02318
0.00663	0.01797	0.02458	0.01226	0.06144	0.00644
0	0.00815	0.02608	0.02732	0.06155	0
0.00438	0.01599	0.02375	0.01256	0.05668	0.00539
0.01249	0.01611	0.0116	0.00156	0.04176	0.01298
0.01377	0.01958	0.01467	0	0.04802	0.01478
0.00173	0.01046	0.02099	0.01632	0.04950	0.00187
0.00248	0.01264	0.0264	0.02185	0.0634	0.00225
0.00371	0.01398	0.02682	0.01967	0.06418	0.00381
0.0034	0.01234	0.01969	0.01137	0.0468	0.00361

MA - 2 Clark's Restaurant					
Chloroform	Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs	Chloroform
0.01971	0.02014	0.01636	0.00322	0.05943	0.02918
0.05015	0.02275	0.01085	0	0.08375	0.05639
0.0334	0.01325	0.00378	0	0.05043	0.03616
0.0137	0.00585	0.00193	0	0.02148	0.01408
0.01282	0.00579	0.00276	0	0.02137	0.01149
0.00479	0.00394	0.00267	0	0.0114	0.00549
0.00476	0.00361	0.00112	0	0.00949	0.00436
0.00412	0.00156	0	0	0.00568	0.0043
0.01143	0.00823	0.00367	0	0.02333	0.00917
0.00397	0.00309	0.002	0	0.00906	0.004
0.0025	0.00249	0.00233	0	0.00732	0.00286
0.00439	0.00577	0.00484	0.00223	0.01723	0.0041
0.00433	0.00394	0.00268	0	0.01095	0.00483
0	0	0	0	0	0
0.0031	0.0017	0	0	0.0048	0.0029
0.0075	0.0049	0.0019	0	0.0143	0.0079
0.0122	0.0049	0.0015	0	0.0186	0.0133

MO - 3 MC CPW				M	
Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs	Chloroform	Bromodichloromethane
0.01238	0.01179	0.00109	0.03328	0.00742	0.01255
0.01652	0.01252	0.00146	0.04563	0.01798	0.01728
0.0112	0.00748	0	0.0281	0.01203	0.01229
0.02617	0.01897	0.00361	0.06577	0.00929	0.013
0.02109	0.0129	0.00113	0.05407	0.02369	0.02413
0.01396	0.00521	0	0.04235	0.03162	0.01915
0.0136	0.00478	0	0.03725	0.01646	0.0117
0.0191	0.00997	0	0.05114	0.02144	0.01849
0.01188	0.00257	0	0.03442	0.02199	0.01076
0.02169	0.01225	0	0.05712	0.02479	0.02012
0.01739	0.02444	0.01197	0.06024	0.00535	0.0139
0.01001	0.02614	0.02692	0.06307	0	0.01139
0.01849	0.02623	0.01304	0.06315	0.00616	0.01943
0.01587	0.01144	0.00139	0.04168	0.01353	0.01589
0.01995	0.01526	0	0.04999	0.01862	0.02295
0.01078	0.02163	0.01676	0.05104	0.00243	0.01048
0.01219	0.02571	0.02113	0.06128	0.00241	0.01318
0.01382	0.02601	0.01871	0.06235	0.00315	0.01372
0.01267	0.02057	0.0113	0.0482	0.00495	0.01417

MA - 3 Santee Cooper Resort Guard Shack				MA- 4	
Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs	Chloroform	Bromodichloromethane
0.02353	0.01773	0.00333	0.07377	0.03435	0.02546
0.02198	0.01047	0	0.08884	0.05799	0.03209
0.01421	0.00396	0	0.05433	0.05281	0.01636
0.0062	0.00219	0	0.02278	0.0136	0.00555
0.00239	0	0	0.01388	0.01071	0.00237
0.00406	0.00288	0	0.01243	0.00506	0.00404
0.0029	0.00103	0	0.00829	0.00396	0.00282
0.00153	0	0	0.00583	0.00379	0.00141
0.00736	0.00262	0	0.01915	0.00619	0.00483
0.00306	0.00174	0	0.0088	0.00334	0.00299
0.00219	0.00214	0	0.00719	0.00425	0.0021
0.00497	0.00416	0.002	0.015	0.00356	0.00578
0.00404	0.00264	0	0.01151	0.00637	0.00472
0	0	0	0	0	0
0.0016	0	0	0.0045	0.0023	0.001
0.0052	0.0021	0	0.0152	0.0074	0.0049
0.0052	0.0014	0	0.0199	0.0133	0.0047

IO- 4 GC Tank			On Site Lab Sink		
Dibromochloromethane	Bromoform	Total THMs	Chloroform	Bromodichloromethane	Dibromochloromethane
0.01194	0.0015	0.03341			
0.01369	0.00165	0.0506			
0.00859	0	0.03291			
0.01166	0.00224	0.03619			
0.01468	0.00123	0.06373			
0.00735	0	0.05812			
0.00415	0	0.03231			
0.00961	0	0.04954			
0.00216	0	0.03491			
0.0118	0	0.05671			
0.01922	0.00914	0.04761			
0.02878	0.02999	0.07016			
0.02682	0.01447	0.06688			
0.01118	0.00116	0.04176			
0.01669	0	0.05826			
0.02248	0.01872	0.05411			
0.02782	0.02416	0.06757			
0.02829	0.02386	0.06902			
0.02115	0.01143	0.05170			
			0.0156	0.01128	0.00308
			0.01502	0.01099	0.00362
			0.01244	0.01063	0.00446
			0.01414	0.01033	0.00368
			0.02007	0.00995	0.00212

· Santee Town Hall			On Site Lab Sink		
Dibromochloromethane	Bromoform	Total THMs	Chloroform	Bromodichloromethane	Dibromochloromethane
0.01782	0.00333	0.08096			
0.01757	0.00117	0.10882			
0.00375	0	0.07292			
0.0018	0	0.02095			
0	0	0.01308			
0.00296	0	0.01206			
0	0	0.00678			
0	0	0.0052			
0.00117	0	0.01219			
0.00193	0	0.00826			
0	0	0.00545			
0.0056	0.00279	0.0177			
0.00305	0	0.01414			
0	0	0			
0	0	0.0033			
0.002	0	0.0143			
0.0012	0	0.0192			

	0	0.0011	0
	0	0	0
	0.0035	0	0
	0.0021	0	0

		On Site Restroom				
Bromoform	Total THMs	Chloroform	Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs
0	0.0300					
0	0.02963					
0	0.02753	0.00955	0.00816	0.00340	0	0.02111
0	0.02815	0.01323	0.00982	0.00351	0	0.02656
0	0.03214	0.01878	0.00938	0.002	0	0.030

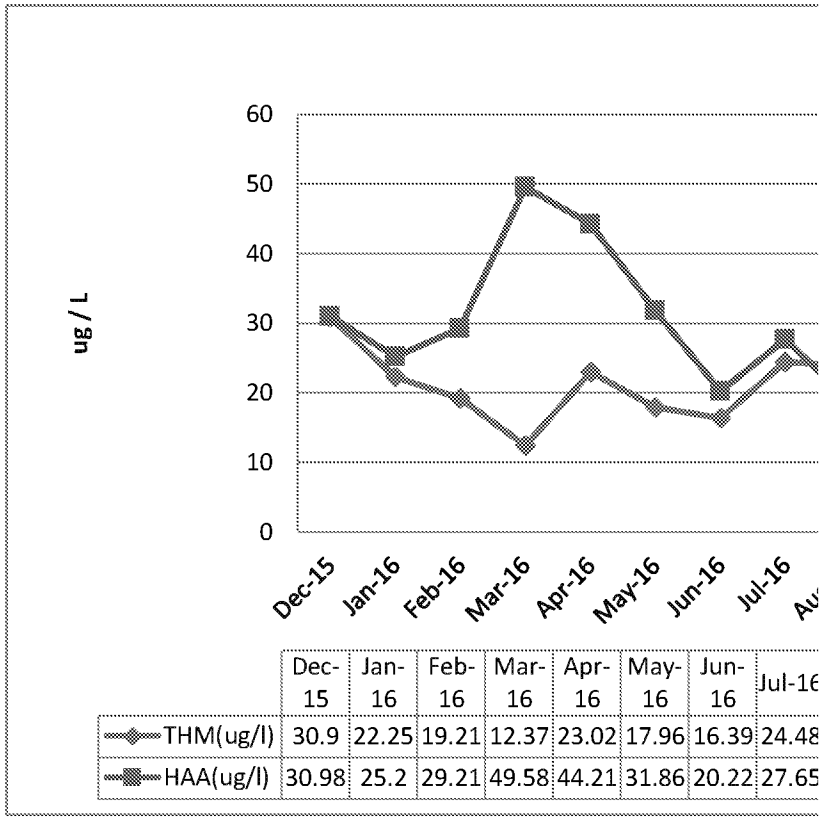
		On Site Restroom				
Bromoform	Total THMs	Chloroform	Bromodichloromethane	Dibromochloromethane	Bromoform	Total THMs
		0.0025	0.0018	0	0	0.0043

0	0.0011	0	0.0011	0	0	0.0011
0	0	0	0	0	0	0
0	0.0035	0.0038	0.0012	0	0	0.005
0	0.0021	0.0021	0	0	0	0.0021

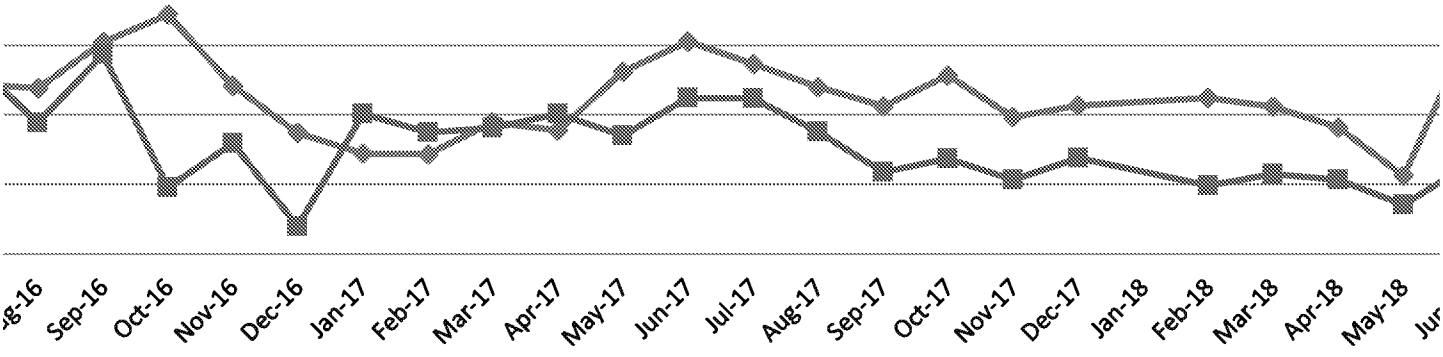
LAKE MOULTRIE "IN HOUSE"
THM / HAA STUDY

	THM(ug/l)	HAA(ug/l)
Dec-15	30.9	30.98
Jan-16	22.25	25.2
Feb-16	19.21	29.21
Mar-16	12.37	49.58
Apr-16	23.02	44.21
May-16	17.96	31.86
Jun-16	16.39	20.22
Jul-16	24.48	27.65
Aug-16	23.86	18.88
Sep-16	30.47	28.7
Oct-16	34.39	9.53
Nov-16	24.2	15.88
Dec-16	17.36	3.92
Jan-17	14.39	20.16
Feb-17	14.35	17.44
Mar-17	18.91	18.14
Apr-17	17.71	20.1
May-17	26.2	17
Jun-17	30.51	22.42
Jul-17	27.28	22.35
Aug-17	24	17.6
Sep-17	21.2	11.8
Oct-17	25.7	13.7
Nov-17	19.7	10.7
Dec-17	21.3	13.8
Feb-18	22.4	9.8
Mar-18	21.1	11.5
Apr-18	18.2	10.7
May-18	11.2	7.1
Jun-18	31.3	12.8

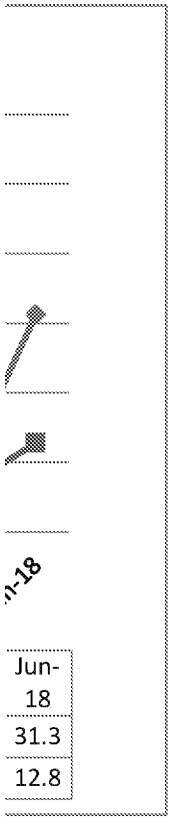
THM MCl = 80
HAA MCL = 60



LMO THM/HAA Study



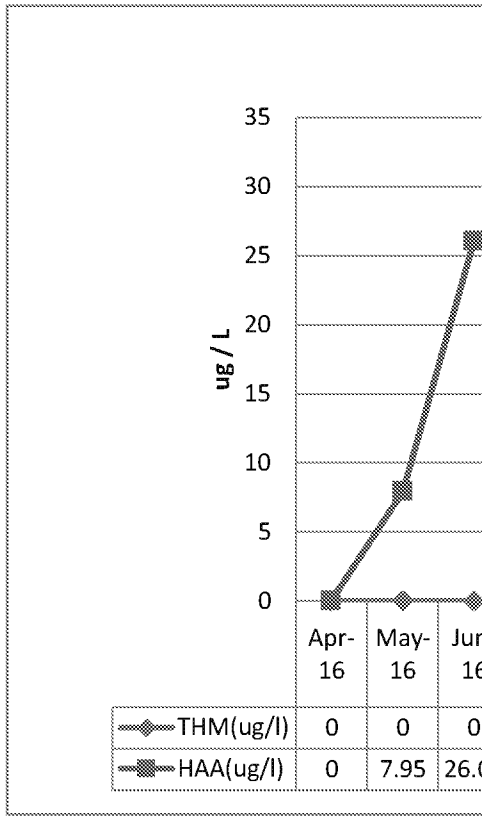
	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Feb-18	Mar-18	Apr-18	May-18
	23.86	30.47	34.39	24.2	17.36	14.39	14.35	18.91	17.71	26.2	30.51	27.28	24	21.2	25.7	19.7	21.3	22.4	21.1	18.2	11.2
	18.88	28.7	9.53	15.88	3.92	20.16	17.44	18.14	20.1	17	22.42	22.35	17.6	11.8	13.7	10.7	13.8	9.8	11.5	10.7	7.1

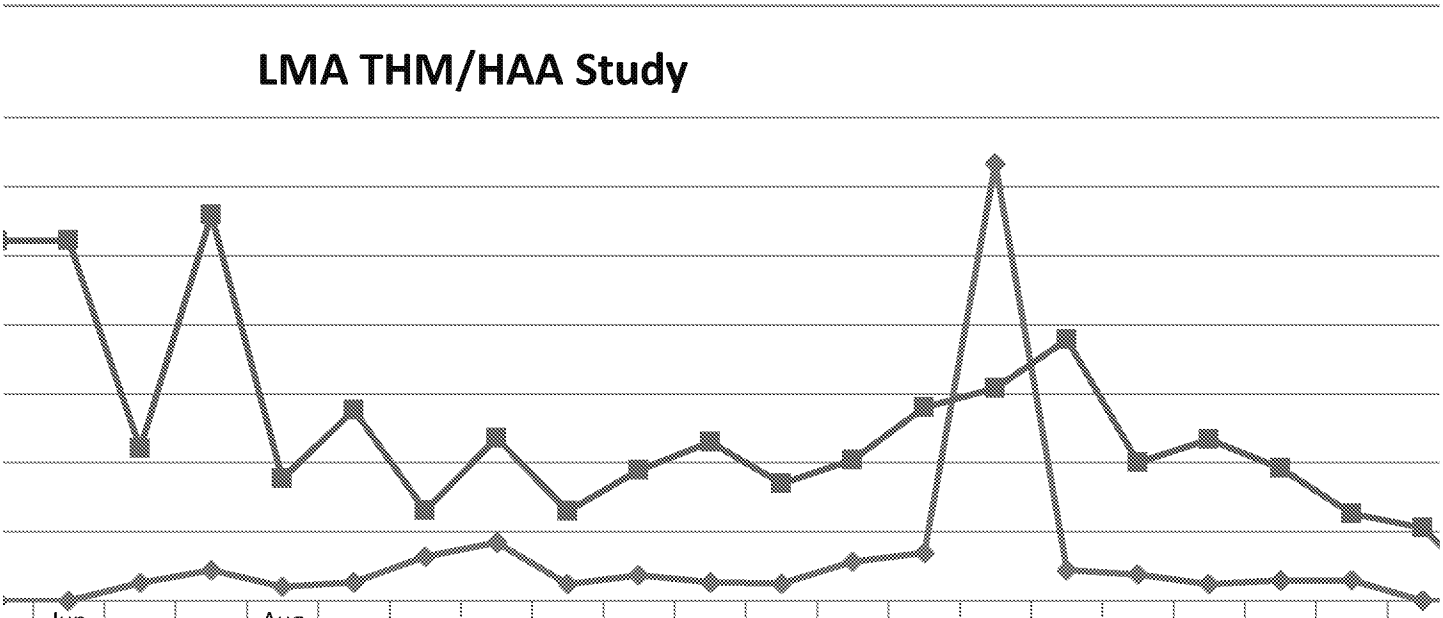

Jun-18
31.3
12.8

LAKE MARION "IN HOUSE"
THM / HAA STUDY

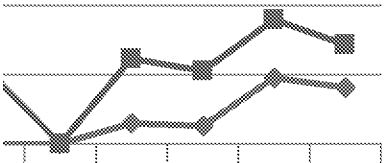
	THM(ug/l)	HAA(ug/l)	GAC in Use	Chlorophyll
Apr-16	0	0		
May-16	0	7.95		
Jun-16	0	26.07		
Jun 16 #2	0	26.12		
Jul-16	1.32	11.06		
Aug-16	2.24	27.96		
Aug 16 #2	1.03	8.86		
Sep-16	1.36	13.83		
Oct-16	3.22	6.53		
Nov-16	4.24	11.78		
Dec-16	1.23	6.49		
Jan-17	1.88	9.47		
Feb-17	1.37	11.5		
Mar-17	1.29	8.49		
Apr-17	2.85	10.2		
May-17	3.5	14		
Jun-17	31.66	15.38		
Jul-17	2.24	18.92		
Aug-17	1.9	10		
Sep-17	1.2	11.7		
Oct-17	1.5	9.6		
Nov-17	1.5	6.3		
Dec-17	0	5.3		
Feb-18	0	0		
Mar-18	1.5	6.2		
Apr-18	1.3	5.3		
May-18	4.8	9		
Jun-18	4.1	7.2		

THM MCl = 80
HAA MCL = 60





n- 5	Jun 16 #2	Jul-16	Aug-16	Aug 16 #2	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec 17
	0	1.32	2.24	1.03	1.36	3.22	4.24	1.23	1.88	1.37	1.29	2.85	3.5	31.66	2.24	1.9	1.2	1.5	1.5	0
07	26.12	11.06	27.96	8.86	13.83	6.53	11.78	6.49	9.47	11.5	8.49	10.2	14	15.38	18.92	10	11.7	9.6	6.3	5.3



-	Feb-18	Mar-18	Apr-18	May-18	Jun-18
	0	1.5	1.3	4.8	4.1
	0	6.2	5.3	9	7.2

Economic factors for use in evaluations

All evaluations will be performed to a commercial operation date of	7-Nov-16
Annual Discount Rate (2016 Levelized cost of capital)	4.93%
Plant Life	30 yr
Levelized Fixed Charge Rate(2016 Update):	
Insurance	0.05%
Property Taxes	0.00%
Interim Replacement	0.36%
Debt Service	7.05%
Total Percentage	7.46%
Coal Cost (2015 - Includes Transportation Source: Aligne)	$90.02/ton
Heating Value of Coal (Jan 2015 - April 2016 Avg Source: LabWorks)	12,381 Btu/lb
Cost of Fuel (2015 Source: Calculated)	$3.64/10^6 Btu
Net Generating Capacity (Winter/Summer Rating)	585 / 580 MW
Anticipated Load Factor (Jan 2015 - Mar 2016 Source: GADS NCF)	43.62%
Weighted Plant Heat Rate (Jan 2015 - March 2016 - Prog Report)	10,637 Btu/kWh
Generating Station Operating & Maintenance Personnel Cost (2001)	$31.42/hr
Generating Station Operating & Maintenance Personnel Cost (2006)	$36.42/hr
Projected Cost of Electricity @ 75% Load Factor & Weighted Plant Heat Rate	1.58 cents/kWh
Replacement Capacity Charge (Unit Capital Cost/Rated Net Capacity, 2001)	$1,163/kW
Value per kW (Fuel Cost + Capability Charge, PW)	$3,250/kW
Annual Escalation Rates	
Inflation	4%
Coal (2002-2006)	0.00%
Coal (beyond 2016)	2.00%
Operating Personnel (2016)	3%
Maintenance Supplies (2016)	3%
Polymer	4%
Water Treatment	4%
Electrical Energy (2016)	3%
Landfill	4%
Note: Consider listing derived (calculated) values in this table that are developed for individual contracts for reference	
Gypsum Sales Prices based on Quality	
Wallboard	$40/ton
Cement	$6/ton
Cost of Landfilling	$10/ton
Loading, Hauling and Landfilling Transportation Cost	$19/ton
Cost of Water Treatment	$0.01 gpm
O&M (2% of the Total Capital Costs)	2%

	Cross 1	Cross 2	Cross 3	Cross 4
Coal Cost (2015 - Includes Transportation Source: Aligne)	$90.02/ton	$92.54/ton	$90.36/ton	$90.33/ton
Heating Value of Coal (Jan 2015 - April 2016 Avg Source: LabWorks)	12,381 Btu/lb	12,258 Btu/lb	12,309 Btu/lb	12,305 Btu/lb
Cost of Fuel (2015 Source: Calculated)	$3.64/ 10^6 Btu	$3.77/ 10^6 Btu	$3.67/ 10^6 Btu	$3.67/ 10^6 Btu
Net Generating Capacity (Winter/Summer Rating)	585 / 580 MW	570 / 565 MW	610 / 610 MW	615 / 615 MW
Anticipated Load Factor (Jan 2015 - Mar 2016 Source: GADS NCF)	21.41%	11.45%	71.26%	70.36%
Weighted Plant Heat Rate (Jan 2015 - March 2016 - Prog Report)	10,637 Btu/kWh	10,716 Btu/kWh	9,922 Btu/kWh	9,929 Btu/kWh
Generating Station Operating & Maintenance Personnel Cost (2001)	$31.42/hr	$31.42/hr	$31.42/hr	$31.42/hr
Generating Station Operating & Maintenance Personnel Cost (2006)	$36.42/hr	$36.42/hr	$36.42/hr	$36.42/hr
Projected Cost of Electricity @ 75% Load Factor & Weighted Plant Heat Rate	1.58 cents/kWh	1.58 cents/kWh	1.58 cents/kWh	1.58 cents/kWh
Replacement Capacity Charge (Unit Capital Cost/Rated Net Capacity, 2001)	$1,163/kW	$1,163/kW	$1,163/kW	$1,163/kW
Value per kW (Fuel Cost + Capability Charge, PW)	$3,250/kW	$3,250/kW	$3,250/kW	$3,250/kW

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

BID ITEM NO.		DESCRIPTION	Evoqua Water Technologies LLC FGD Blowdown Wastewater Treatment System WINYAH-0-SW-KBE9C) Lump Sum Price	Suez Treatment Solutions Inc. FGD Blowdown Wastewater Treatment System WINYAH-0-SW-KBE9C) Lump Sum Price	WesTech Engineering Inc. FGD Blowdown Wastewater Treatment System WINYAH-0-SW-KBE9C) Lump Sum Price	Comments/Notes	
		ATTACHMENT A - SUMMARY OF EVALUATED PRICING				Veolia Water Technologies was an approved bidder for the Winyah FGD Blowdown WWTS. Bids were due on 9/15/2016 at 12 Noon EST to both Santee Cooper and WorleyParsons. Veolia's proposal was received on 9/16/2016 and in accordance with Santee Cooper procurement procedures, the bid was late and not evaluated.	
I.		BASE PRICING (AS-RECEIVED)					
	1.	Lump Sum Prices					
	A.	Design and Engineering	Included	Included	$1,387,733.00		
	B.	Material/Equipment (furnished and prepared to be delivered to Jobsite)	$15,282,799.00	$13,736,000.00	$9,874,097.00		
	C.	Spare Parts	Excluded	Included	Included		
	D.	Warranty of 1 Year after Final Acceptance	Included	Included	$587,238.00		
	E.	Taxes and Duties	See Note in column at right	See Note in column at right	See Note in column at right	Refer to Adjustments in Align category below for applicable South Carolina Sales and Use tax amounts	
		Subtotal - Engineering, Materials/Equipment, Spare Parts, Warranty, Taxes	$15,282,799.00	$13,736,000.00	$11,849,068.00		
	F.	Delivery to Jobsite and On-site Services	Included	Included	$838,279.00		
	G.	TOTAL FOR THE WORK	$15,282,799.00	$13,736,000.00	$12,687,347.00	Evoqua and Suez as-received pricing did not include a price breakdown as requested in the RFP; only a lump sum amount. Suez provided the following approximate breakdown: Engineering - 35%; Material - 60%; Freight - 4%; Site Services - 1%	$13,736,000.00
		Cost of Performance Security (Included in the above)	$122,400.00	$0.00	$0.00	Amount for Evoqua is for Base Scope only. Refer to Adjustments to Align category for Suez and WesTech	
	2.	RFP Optional Pricing-(Plus Discount for Combined System Award)	($230,731.00)	($320,000.00)	($59,317.00)	Optional Pricing is to control each system thru DCS **plus a credit for a combined Contract award.**	
	3.	Adjustments to Align to RFP (From As-Received Price)	$4,863,996.00	$1,523,930.14	$2,309,230.76		
		TOTAL (Equalized To Meet RFP)	$19,916,064.00	$14,939,930.14	$14,937,260.76		
II.		DESIGN DIFFERENCE/OTHER ADJUSTMENTS (Total Differential)	$0.00	$0.00	$0.00		
III.		EVALUATION FACTORS - ADDITIONAL COST (Total Differential)	$0.00	$0.00	$0.00		
		TOTAL EVALUATED PRICE (Overall)	$19,916,064.00	See Note in column at right	$14,937,260.76	Suez prpopsal deemed technically unacceptable and non-compliant since they were non-responsive to technical RFP requirements and the details for the advanced system subcontractors (Envirogen or GE ABMet) were not substantial enough in validating that Suez had a thorough understanding of the technology risks or the performance guarantees being requested.	
		Total Difference	$4,978,803.24		Base		
		Difference (%)	33.33%		Base		
		Bid Validity	6/30/2017		6/1/3017		

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

		DETAIL OF EVALUATED PRICING					
I.		BASE PRICING					
1.		LUMP SUM PRICING					
	A.	**Design and Engineering:**					
		1. Preliminary and final: (general arrangement, outlines, loadings, platform and foundation drawings; flow diagrams; Control Logic, Control Logic Drawings, P&ID's; performance curves, mechanical and electrical connection points; wiring diagrams; valve and instrument lists; etc. Installation Documents: preliminary and final. Shipping bills of materials, O&M manuals, test programs and reports, storage and handling procedures, etc.*)*.	Included	Included	$1,012,238.00		
		2. Preliminary, intermediate monthly updates, and final as built: 3-D model of the Contractor's design of all Equipment and associated structures, steel, electrical, instrument and instrument panel locations, and piping, maintenance and access envelopes, and platforming details including ladders, stairs, etc. Contractor's 3-D model shall be compatible with Intergraph PDS, Version 8.0 archived using the PDS Archival Manager.	$0.00	Included	$108,878.00	For Evoqua, refer to Adjustments to Align to RFP category	
		3. Project planning requirements, schedules and monthly progress reports	Included	Included	Included		
		4. Attending Design Review Meetings at Owner's Office in Moncks Corner, SC Jobsite, or Engineer's Reading, PA office; as required	Included - Four Total	Included	$261,032.00	Evoqua noted 4 total design review meetings included. Additional meetings may be Webinar or Skype meetings.	
		5. Develop and perform a Sampling Testing Program to confirm Contractor's Wastewater Treatment Systems can meet the performance requirements	See Note in column at right	Included	$5,585.00	Contractors shall perform wastewater sampling and testing to optimize chemical selection and dosing rates of their proposed wastewater treatment system. Evoqua noted plan development included; sampling and sampling equipment by others.	
		Subtotal Design and Engineering	Included	Included	$1,387,733.00		

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

B.	**B. Material/Equipment (furnished and prepared to be delivered to Jobsite):**					
	Equipment/materials, shop testing, packing for long term outdoor storage, special tools, and equipment required for installation of Winyah FGD Blowdown Wastewater Treatment Systems including:					
	1. Pumps (includes all vertical and horizontal centrifugal pumps with skid/module piping and valves)	Included	Included	$505,204.00		
	2. Chemical Skids and Tanks (includes all chemical skids and lime equipment with skid piping, tubing, and valves)	Included	Included	$923,268.00		
	3. Sludge System Including Holding/ Collection Tanks and Filter Press (includes skid/module piping, tubing and valves). Items to be included as applicable.	See Note in column at right	Included	$806,090.00	Evoqua provided RFP alignment to meet RFP requirement	
	4. Aeration Tank, Desaturation Tank, Coagulation Tank, Reaction Tank, Reactor Feed Tank, Clarifier Tanks, Thickener Tanks, Filter Tanks, Ion Exchange Tanks, UF System, and includes all Accessories. (includes skid/module piping, tubing and valves). Items to be included as applicable.	See Note in column at right	Included	$1,582,600.00	Evoqua provided RFP alignment to meet RFP requirement	
	5. Reactor (includes skid/module piping, tubing and valves)	Included	Included	$5,609,148.00		
	6. Instrumentation and Controls (includes startup and calibration chemicals)	Included	Included	$158,017.00		
	7. Electrical Components, including but not limited to, electrical panelboards, distribution centers and transformers , switchgear and motor control centers, interconnecting conduit, cable tray, cables and wiring for electrical, control and instrumentation between Contractor-provided skids and equipment, and between Contractor provided equipment and Owner supplied equipment; and electrical heat tracing / freeze protection for process piping, tubing and equipment	Excluded	Included	$289,770.00		
	8. Ladder and Platforms (All Equipment)	Included	Included	Included		
	9. Parts Required for Field assembly (plus 10 % spares)	Excluded	Included	Included	When questioned, WesTech confirmed that any miscellaneous parts required for field assembly will be provided.	
	10. Shop Painting (prime and finish coats on all supplied material)	Included	Included	Included	Evoqua noted some equipment not coated due to final field coating by others	
C.	**Spare Parts**					
	1. Construction/Start-up and Testing Spares (listed separately on appropriate spreadsheet tab (see tabs below)).	Excluded	Included	Included	Evoqua provided RFP alignment to meet RFP requirement	

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

D.	**Warranty of 1 year after Final Acceptance**				
	1. Warranty of 1 year after Final Acceptance	Included	Included	$587,238.00	Evoqua indicated 1 year from Final Acceptance; not to exceed six months from anticipated Final Acceptance date noted in RFP. Suez proposal noted tied to Final Acceptance; based on 24 months after delivery of Equipment or 12 months after Startup, whichever comes first.
E.	**Taxes and Duties**				
	1. Federal, State and Local Taxes or Import duty (if applicable)	Included	Included	Included	
	2. South Carolina Sales and Use Tax	Excluded	Not Included	$0.00	Refer to Adjustments to Align to RFP for price adder - Applies to Evoqua, Suez and WesTech
	Subtotal - Engineering, Material/Equipment, Spare Parts, Warranty, Taxes (Items A-E)	$15,282,799.00	$13,736,000.00	$11,849,068.00	Evoqua and Suez did not provide a price breakdown as requested in the RFP; only a Lump Sum amount was indicated on their pricing sheet
F.	**Delivery to Jobsite and On-Site Services**				
	1. Freight from Manufacturer's or Contractor's facility, whichever is applicable, to Cross Generating Station Jobsite (including risk of loss to 115% of value).	Included	Included	$300,810.00	
	On-Site Services				
	2. Site Technical Representation for installation overview and RFI resolution. Price is all inclusive: Per-Diem, Travel and Field Office.	Included	Included	$99,263.00	
	Number of onsite work days and trips for site Technical Representation to support field assembly and installation.	40 Days / 5 Trips	50 Days / 10 Trips	66 Days / 5 Trips	When questioned Suez Confirmed that total onsite services days are correct and noted days could increase due to close proximity of their offices and Jobsite
	3. Site Technical Representation for startup, field testing, and acceptance testing. Price is all inclusive: Per-Diem, Travel and Field Office.	Included	Included Above	$384,741.00	
	Number of onsite work days and trips for site Technical Representation to support startup, field testing, and acceptance testing	281 Days / 38 Trips	Included Above	164 Days / 14 Trips	
	4. Site Technical Representation for Operator Training. Price is all inclusive.	Included	Included Above	$53,465.00	
	Number of onsite work days and trips for site Technical Representation to support Operator Training	30 Days / 4 Trips	Included Above	20 Days / 4 Trips	
	Subtotal - Delivery to Jobsite and On-Site Services	Included	Included	$838,279.00	
G.	**TOTAL FOR THE LUMP SUM WORK (Items A thru F)**	$15,282,799.00	$13,736,000.00	$12,687,347.00	
	Cost of Performance Security included in the above	$122,400.00	$0.00	$0.00	Refer to Adjustments to Align to RFP for price adder - Applies to Suez and WesTech

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

2.	**Optional Pricing**				
A.	**RFP Optional Pricing**				
1.	Storage of Equipment at Manufacturer's or Contractor's facility, after the Contract Schedule Delivery date, if the Contract Schedule Delivery date is postponed by Owner.				
	a. Flat Fee	Did Not Quote	Two (2) months delay for free, cost for additional time to be provided later	Did Not Quote	
	b. Monthly Fee (Daily to be 1/30 of monthly cost.)	Did Not Quote		$12,000.00	
	c. Percentage of Material Price Stored	Did Not Quote		Did Not Quote	
	NOTE: Contractor shall provide maintenance (in accordance with Manufacturer's storage and maintenance recommendations) and insurance while Equipment is in storage. Owner will pay as if Equipment is delivered (except freight) and may file a UCC form or equivalent to establish ownership. Contractor is responsible for care, custody and control until delivery to Jobsite. Risk of Loss remains with Contractor while Equipment is in storage, during transportation of Equipment, and until delivery acceptance of Equipment at the Jobsite. Storage of Equipment must comply with the following: o Must be in a secure enclosed building or, at a minimum, fenced in area. o Enclosed storage areas must be protected against fire, i.e. monitored and sprinkled. o Must not be in any known flood zone				
2.	**Equipment Interface With Distributed Control System**				
	a. FGD Blowdown Wastewater Treatment System – Furnish a System that can be controlled automatically from the Owner's Distributed Control System (DCS), including the furnishing of the required interfaces for communication of the equipment with the Owner's DCS as well as all necessary local controls required for operation of the Equipment Reference Scope of Work CROSS-0-SW-KBE9C, Article 1.3.2	($230,731.00)	($320,000.00)	($59,317.00)	
3.	**Combined Award Savings to Owner**				
	Bidder is awarded Cross and Winyah FGD Blowdown Wastewater Treatment System (KBE9C)	Not Applicable	Not Applicable		
	TOTAL ACCEPTABLE RFP OPTIONS	($230,731.00)	($320,000.00)	($59,317.00)	

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

C.	Bidder Options - Not Recommended For Contract Award					
1.	Furnish a Contractor's Letter of Credit acceptable to the Owner for the faithful performance of the Contract, the value thereof to be ten percent (10%) of the Contract Price; valid thru Final Acceptance	Not Offered	$44,205.00	Not Offered	Not Recommended For Award; does not meet RFP/Contract requirements	
2.	On Demand Payment and Performance Bond - See Note	Not Offered	Included	Not Offered	Not Recommended for Award Suez offered at no additional cost - an 'On-Demand Bond' – a hybrid payment & performance bond with a 20% "on demand" feature. This hybrid will provides a full 100% P&P bond, plus an on demand feature that acts like an additional 20% LOC	
3.	Furnish a Letter of Credit for 100% of the Pironox component of the Equipment only (approx. $8M) to be provided upon delivery of the Equipment and valid thru Final Acceptance	$420,000.00	Not Offered	Not Offered	Not Recommended For Award; does not meet RFP/Contract requirements	
4.	Furnish a Winyah FGD Blowdown WWTS with Envirogen design and Equipment	Not Offered	($2,894,000.00)	Not Offered	Not Recommended for Award Suez's FGD Blowdown WWTS base bid is GE design and Equipment. The credit represents the difference between a GE and Envirogen FGD System. $10,842,000 price from Suez inlcuding Envirogen instead of GE ABMet	
5.	Change Envirogen design from 1 x 100% system to 2 x 50% system	Not Offered	$385,000.00	Not Offered	Not Recommended for Award	
6.	Price adder for additional equipment (blower and a pump skid) to support the Alternate 1 layout.	$65,507.00	Not Offered	Not Offered	Not Recommended for Award	
7.	Alternate 2 - Price adder to supply two (2) equalization tanks with mixers, revise pumps and supply above ground filtrate tank and pumps	To Follow	Not Offered	Not Offered	Not Recommended for Award	
8.	Additional cost for mixing of equalization tank (mixers and bridges)	$245,821.00	Not Offered	Not Offered	Not Recommended for Award	
9.	Provide 10% Contract value LOC in lieu of cash retention	Not Offered	Not Offered	$92,333.00	Not Recommended for Award	

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

3.	**Adjustments to Align to RFP**					
1	**Furnish a Contractor's Letter of Credit acceptable to the Owner for the faithful performance of the Contract, the value thereof to be one hundred percent (100%) of the Contract Price**	Not Offered	Not Offered	Not Offereed	All Bidders declined to provide a 100% Contract Value LOC; reasons are detailed on recommendation letter.	
2	Furnish a **Payment and Performance Bond** acceptable to the Owner for the faithful performance of the Contract, the value thereof to be one hundred percent (100%) of the Contract Price	Included	Included	$85,251.00		
3	South Carolina Sales and Use Tax to be included in Contract Price	$1,682,519.00	$1,003,428.14	$1,014,987.76	Suez noted South Carolina Sales and Use tax is approximately 7.2% of Contract value. Evoqua amount could change based upon final scope and selected options	
4	Furnish VFDs in accordance with Project Required Vendor List (Allen-Bradley PowerFlex)	$352,391.00	$68,550.00	$196,816.00	Suez indicated price adjustment includes furnish VFDs in NEMA 12 enclosures and VFDs omitted for GE bio system	
5	Furnish two (2) knocked down field erect carbon steel clarifier tanks for the FGD wastewater treatment system.	$2,314,043.00	Included	Included	Evoqua noted tank foundations, field erection and application of coating are by others.	
6	Furnish a knocked down field erect dirty backwash tank for the FGD wastewater treatment system	Included in Alignment #4	Included	Included	Evoqua noted tank foundations, field erection and application of coating are by others.	
7	Furnish a knocked down field erect sludge holding tank for the FGD wastewater treatment system	Included in Alignment #4	Included	Included	Evoqua noted tank foundations, field erection and application of coating are by others.	
8	Furnish construction and start-up spare parts for the FGD wastewater treatment system	$98,020.00	Included			
9	Furnish freeze protection (heat tape) and insulation for Sodium Hydroxide Storage tank	$59,927.00	Included			
10	Provide SAMA type logic drawings for Winyah FGD Blowdown WWTS	Included with DCS RFP optional price	Included	OPEN		
11	Furnish redundant instrumentation to avoid loss of any process measurement	$86,458.00	$35,100.00	$156,016.00		
12	Change materials of construction to rubber-lined carbon steel for HCl **Storage** Tank	Included	$27,000.00	$46,517.00		
13	**Change system design to 2 x 250 gpm 100% physical/chemical and advanced treatment trains**	$234,353.00	See Note	$198,096.00	For Evoqua, amount is to furnish flow splitter tank. Suez did not provide a response top the bid evalaution question. Suez noted in response: "SUEZ is working on a revision that will meet these requirements. There are three components involved: • The Physical Chemical System - meets requirement • The Bioreactors – SUEZ will work on an arrangement that achieves 2 x 100% (250 gpm) trains. • Ultrafiltration system – SUEZ will work on an arrangement that achieves 2 x 100% (250 gpm each) systems as required.	
13.A	**Add 2 x 50% desaturation tanks to meet design requirements**	**Not Applicable**	**$184,100.00**	**Not Applicable**		
14	Additional desaturation reaction tank to increase design to 2 x 100% system		$64,800.00		**DELETE ?? (To be confirmed)**	
15	Supply a 7,000 gallon Coagulant Tank	Included	Included	$10,446.00		
16	**Price adjustment for Suez Concrete Tanks**	Not Applicable	**Can this line be deleted?**	Not Applicable		
17	Furnish SS (A193, Grade B8M, Class 1) bolts/nuts in lieu of alloy bolts for SS 316/316L piping	Included	Included	Included		
18	Deletion of filtrate sump mixer and pumps and dirty backwash tank and pumps	($229,745.00)	Not Applicable	Not Applicable		
19	Increase the hydrochloric acid fume scrubber size	$25,134.00	Included	to follow - OPEN	Evoqua noted that still using vendor standard design	
20	Change the chemical storage tank material to FRP for hydrochloric acid, ferric chloride and ferrous chloride	($43,515.00)	Included	Included		
21	Furnish removable heater for sodium hydroxide tank	to follow				
21	Furnish a 10% LOC to be used in lieu od 10% cash retention on each each invoice; valid thru Final Acceptance		.	$92,333.00		
22	Change from two (2) 100% wastewater forwarding pumps to three (3) 50% - 300 gpm - pumps	$60,344.00	Included			
23	Furnish and install additional junction boxes	$63,676.00				
24	Provide 3-D modeling of Contractor's equipment	$67,954.00	Included	Included		
25	Furnish motor test reports for FGD System - **CROSS ALIGNMENT**	$42,927.00	Included	Included		
26	Change level ultrasonic controls to radar type level controls for FGD System - **CROSS ALIGNMENT**	$49,510.00				
27	Include equalization sump forwarding pumps discharge isolation valves	Included	Included	$9,088.00		
28	Include root valves for all instrumentation	Included	Included	$9,248.00		
29	Include back pressure valves, strainers, relief valves and pulsation dampeners for all chemical pumps (CPVC not allowed)	Included	Included	Included		
30	Include HCl pumps with PVDF materials of construction	Included	Included	$6,248.00		
31	Furnish injection quills where chemicals enter closed piping	Included	Included	$8,960.00		

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

32	Include isolation and control valves for all wastewater contact equipment as lined diaphragm or lined butterfly valves resistant to high level chlorides	Included	Included	Included		
33	Include all tanks(including chemical tanks) with isolation and drain valving	Included	Included	$26,838.00		
34	Furnish polymer feed system skid for filter presses		$62,000.00	$104,080.00		
35	Change HCl piping skid materials from PVDF or CPVC to PVDF lined carbon steel		$78,952.00	$78,952.00	SUEZ indicated a supplier could not be found to meet requirement; therefore the highest amount from the other bidders was used to equalize bids.	
36	Include 316L stainless steel for polymer feed piping			$118,384.00		
37	Include Portafeed Senior Totes for polymer and organo-sulfide chemical tanks		Included	Included		
38	Furnish all chemical metering pumps with speed less than 90 SPM	OPEN	OPEN	$146,970.00		
	TOTAL ADJUSTMENTS TO ALIGN TO RFP	$4,863,996.00	$1,523,930.14	$2,309,230.76		

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

II.		**DESIGN DIFFERENCES/OTHER ADJUSTMENTS** (Differential)					
	1.	Difference in field erection of concrete tanks versus erection of steel tanks since Suez could not provide steel tanks				The additional erection amount is comparable between steel and concrete and would only apply to Suez.	
		TOTAL FOR DESIGN DIFFERENCES/OTHER ADJUSTMENTS (Differential)	$0.00	$0.00	$0.00		
III.		**EVALUATION FACTORS** (Additional Cost)					
	1.	None - O&M Net Present Work Evaluation comparison Included with Matrix Evaluation	$0.00	$0.00	$0.00		
		TOTAL FOR EVALUATION FACTORS (Differential)	$0.00	$0.00	$0.00		

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

	RFP SUBMITTAL REQUIREMENTS			
A.	LUMP SUM PRICE (See Pricing Section 1A above)	See Pricing Above	See Pricing Above	See Pricing Above
B.	MEASUREMENT AND PAYMENT			
	Exceptions taken to measurement and payment criteria	Exceptions	Exceptions	Exceptions
D.	FIELD TECHNICAL SERVICE ADDITIONS AND DELETIONS			
	Daily rate for 10 hour day Monday through Friday	$2,406.25	$1,500.00	$1,200.00
	Daily rate for 10 hour day Saturdays	$2,625.00	$2,250.00	$1,800.00
	Daily rate for 10 hour day Sundays	$3,500.00	$3,000.00	$1,800.00
	Daily rate for 10 hour day Holidays	$5,250.00	$3,000.00	$1,800.00
	Nearest Service Office Location	Tampa, FL	Richmond, VA	Salt Lake City, UT
E.	CANCELLATION			
	Cancellation Schedule Provided	Yes	Yes	Yes
F.	LIQUIDATED DAMAGES			
	Liquidated Damages are as established in the RFP			
	LD#1 For failure of Contractor to complete items denoted as "Design Critical - Y" in the Supplier Data Requirements List – applies if one or more items are not submitted on schedule - $1,000.00/day	Not Offered	Per RFP	Per RFP
	LD#2 For failure of Contractor to deliver Equipment items (per item) denoted as "LD #2" in the Contract Schedule - $4,000.00/day	See LD Cap		Per RFP
	LD#3 For failure of Contractor to deliver Equipment to the degree of assembly shown on the drawings or listed in the Contract . Amount for LD #2 PLUS cost to assemble plus 20% administration fee/day to bring the Equipment to complete assembly in accordance with the Contract	See LD Cap	Per RFP	Per RFP
	LD#4 For Failure of Contractor's Equipment to operate to support test and startup (First Operation of Equipment or Initial Operation) (denoted as LD#4 in the Contract Schedule) $10,000.00/day	See LD Cap	Per RFP	Per RFP
	LD Cap	50% of Purchase Price Paid for Equipment	10% Contract Price	No Cap
G.	INSURANCE			
	Bidder conforms to Insurance requirements	Yes	Yes	Yes

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

	BONDS				
H.	Bid Bond provided	Yes	Yes	Yes	
	Performance Security	Payment and Performance Bond	Payment and Performance Bond	Payment and Performance Bond	All Bidders offering a Payment and Performance Bond
	Surety Name	Argonaut Insurance Company	American Home Assurance Company		
I.	DRUG-FREE WORKPLACE CERTIFICATION/DRUG SCREENING PROGRAM				
	Bidder has agreed to sign the Certification regarding Drug-Free Workplace Requirements	Yes	Yes	Yes	
J.	CONTRACT SCHEDULE				
	Bidder can comply with Contract Schedule	Yes	Yes	Yes	Veolia cannot submit engineering deliverables to support Project Schedule
K.	QUALITY ASSURANCE				
	Bidder has formal Quality Assurance Program	Yes	Yes	Yes	
	Bidder has submitted a copy of Quality Control Program	Yes	Yes	Yes	
	Bidder has a formal Positive Material Identification (PMI) Program	No	Yes	No - WesTech Fabricators have a PMI Program	
L.	SUBMITTALS AND INFORMATION				
	1. Bidder has provided submittals required from Technical Specifications.	Yes	Yes	Yes	
	2. Bidder has completed Data Sheets	Yes	Yes	Yes	
	3. Bidder has provided spare parts pricing with lead times	No - To be provided after Contract award	No - To be provided after Contract award	Yes	
	4. Bidder has provided Transportation Plan for delivery to the Jobsite.	No - To be provided after Contract award	No - To be provided after Contract award	No - To be provided after Contract award	
	5. Bidder has provided sizes and weights of Equipment and degree of assembly.	Yes	Yes	Yes	
	6. Bidder has provided list of Fabrication Facilities of Major Components.	Locations in Holland MI and Thomasville, GA	American Home Assurance Company	Various locations - United States	
	7. Bidder has provided Shop Testing Plan.	Yes	Yes	Yes	
	8. Bidder has provided Sound level information during normal operation.	No - To be provided after Contract award	No - To be provided after Contract award	Yes	
	9. Bidder has provided a Technical description of the Equipment to be supplied	Yes	Yes	Yes	
	10. Bidder has provided an itemized list of special tools to be furnished	None Required	None Required	None Required	
	11. Bidder has provided a storage plan a manufacturer's or contractor's facility	No	No	No	
	12. Bidders Organization				
	Project organization chart submitted	Yes	Yes	Yes	
	Corporate organization chart submitted	Yes	Yes	Yes	
	Key positions - personnel named and resumes provided	Yes	Yes	Yes	
	13. Bidder has listed Labor Agreements	Not Applicable	Not Applicable	Not Applicable	
M.	14. Bidder has listed Subcontractors as follows:	Not provided	Clarifiers and thickeners - Clearstream, Ovio, SPS Filter Press - Andritz, Bilfinger, Durco, Pumps - Flowserve, Goulds, Metering Pumps - Neptune, Prominent, Pulsafeeder Blowers - Gardner-Denver, Roots, Mixers - Chemineer, Lightin Steel Tanks - Kennedy Tank, Moon Tank, RECO, Strainers - Fluid Engineering, RP Adams, SP Kinney'	FRP Tanks - Diamond Fiberglass Steel Fabrication - Custom Fab., Pro Fab, Emerson Fab Pump Skid Assembly - MSS CChem Feeds - Jesco Filter Press - Micronics Drives - Copper Mountain	
	15. Detailed Work Plan Submitted	Yes	Yes	Yes	
N.	EXCEPTIONS				
	Bidder has provided a list of technical and commercial exceptions	Yes	Yes	Yes	
O.	RECEIPT OF DOCUMENTS				
	Addendum No. 1, 2, and 3 - Winyah FGD option	Yes	Yes	Yes	
	Pre-Bid Meeting Minutes	Yes	Yes	Yes	
	Replies to Bidder Questions and Scope Clarifications	Yes	Yes	Yes	

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

P.	PROPOSAL EXECUTION					
	Proposal signed	Yes	Yes	Yes		

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

7.20%
$988,992.00

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

$0.00

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

Comparison of Proposals
WINYAH-0-RQ-KBE9C
FGD Blowdown WWTS
Santee Cooper Winyah Generating Station

FGD COST SELENIUM BASIS

FGD COST SELENIUM BASIS

		Evoqua	Suez	WesTech	Veolia	Option 5	Option 6	Option 7
		FGD Blowdown	FGD Blowdown	FGD Blowdown	FGD Blowdown			
	Capital Costs							
	Lump Sum Price	$15,282,799	$13,736,000	$11,849,068	0.0	0.0	0.0	0.0
	Total (incl delivery)	Included	Included	$838,279	0.0	0.0	0.0	0.0
	RFP Options	($230,731)	($320,000)	($59,317)	0.0	0.0	0.0	0.0
	Align to RFP	$4,863,996	$1,523,930	$2,309,231	0.0	0.0	0.0	0.0
	Discounts	$0	$0	$0	0.0	0.0	0.0	0.0
	Total:	**$19,916,064**	**$14,939,930**	**$14,937,261**	**0.0**	**0.0**	**0.0**	**0.0**
1	30 Year Operating Costs							
	Chemical Cost	($81,224,000)	($116,533,000)	($79,044,000)		0.0	0.0	0.0
	Labor Cost	($36,601,000)	($39,263,000)	($39,263,000)		0.0	0.0	0.0
	Power Cost	($785,000)	($319,000)	($726,000)		0.0	0.0	0.0
	Maintenance	($24,481,000)	($24,947,000)	($24,946,000)	0.0	0.0	0.0	0.0
		$0	$0	$0	0.0	0.0	0.0	0.0
		$0	$0	$0	0.0	0.0	0.0	0.0
		$0	$0	$0	0.0	0.0	0.0	0.0
	Total:	**($143,091,000)**	**($181,062,000)**	**($143,979,000)**	**0.0**	**0.0**	**0.0**	**0.0**
	Grand Total:	**($163,007,064)**	**($196,001,930)**	**($158,916,261)**	**0.0**	**0.0**	**0.0**	**0.0**
	Selenium removed Wastewater/year	**1081.86**	**1068.72**	**1068.72**	**0.0**	**0.0**	**0.0**	**0.0**
30	Equivalent Yearly Operating Costs							
	Chemical Cost	($2,707,466.67)	($3,884,433.33)	($2,634,800.00)	0.0	0.0	0.0	0.0
	Labor Cost	($1,220,033.33)	($1,308,766.67)	($1,308,766.67)	0.0	0.0	0.0	0.0
	Power Cost	($26,166.67)	($10,633.33)	($24,200.00)	0.0	0.0	0.0	0.0
	Maintenance	($816,033.33)	($831,566.67)	($831,533.33)	0.0	0.0	0.0	0.0
		$0	$0	$0	0.0	0.0	0.0	0.0
		$0	$0	$0	0.0	0.0	0.0	0.0
		$0	$0	$0	0.0	0.0	0.0	0.0

FGD COST SELENIUM BASIS

Total:	**($4,769,700)**	**($6,035,400)**	**($4,799,300)**	**0.0**	**0.0**	**0.0**	**0.0**
PV Check	$163,007,064.00	$196,001,930.14	$158,916,260.76	0.0	0.0	0.0	0.0
Equivalent Annual Cost (EAC)	**($10,519,381)**	**($12,648,649)**	**($10,255,388)**	**0.0**	**0.0**	**0.0**	**0.0**
Evaluation Basis ($ per lb Se removed)	**($9,723.42)**	**($11,835.33)**	**($9,595.95)**				

FGD COST SELENIUM BASIS

Sensitivity anaylsis

	Evoqua FGD Blowdown	**Suez** FGD Blowdown	**WesTech** FGD Blowdown	**Veolia** FGD Blowdown
Capital Costs				
	$28,693,233	$28,693,233	$28,693,233	$0
RFP Conformance - Redundancy	$5,100,000	$11,100,000	$11,100,000	
Total including Redundancy:	**$53,709,297**	**$54,733,163**	**$54,730,494**	**$0**
Operating Costs				
	$0	**$0**	**$0**	**$0**
Total including Redundancy:	**($143,091,000)**	**($181,062,000)**	**($143,979,000)**	**$0**
Grand Total including Redundancy:	**($196,800,297)**	**($235,795,163)**	**($198,709,494)**	**$0**
				#DIV/0!
Delta				
Equivalent Annual Cost (EAC)	**($12,700,170)**	**($15,216,637)**	**($12,823,377)**	**$0**
Total Equivalent Annual Cost	**($12,700,170)**	**($15,216,637)**	**($12,823,377)**	**$0**
Evaluation Basis ($ per lb Se removed)	**($11,739.20)**	**($14,238.19)**	**($11,998.82)**	**$0.00**

FGD COST SELENIUM BASIS

	Evoqua	Suez	WesTech	Veolia	Option 5	Option 6	Option 6	Option 7	Option 7
	FGD Blowdown	FGD Blowdown	FGD Blowdown	FGD Blowdown	0	0	0	0	0
Capital Costs	$19,916,064	$14,939,930	$14,937,261						
Construction Estimate	$28,693,233	$28,693,233	$28,693,233						
Total:	$53,709,297	$54,733,163	$54,730,494	$0	$0	$0	$0	$0	$0
1 Operating Costs									
Chemical Cost	($81,224,000)	($116,533,000)	($79,044,000)	$0	$0	$0	$0	$0	$0
Labor Cost	($36,601,000)	($39,263,000)	($39,263,000)	$0	$0	$0	0	0	0
Power Cost	($785,000)	($319,000)	($726,000)	$0	$0	$0	$0	$0	$0
Maintenance	($24,481,000)	($24,947,000)	($24,946,000)	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total:	**($143,091,000)**	**($181,062,000)**	**($143,979,000)**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Grand Total:	**($196,800,297)**	**($235,795,163)**	**($198,709,494)**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
					-				
					-				
PV Check	$196,800,297.00	$235,795,163.14	$198,709,493.76	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Equivalent Annual Cost (EAC)	($12,700,169.83)	($15,216,636.68)	($12,823,376.57)	$ -	$ -	$ -	$ -	$ -	$ -
Evaluation Basis	($11,739.20)	($14,238.19)	($11,998.82)						
Delta		-18% Base	-16%						

Net Present Value (NPV) for 30-Year Costs:

	Chemical Cost
Production - $/1000 gal	23.5835
Volume of material - gpd	360,000
Load Factor, %	**100.0%**
Daily Costs - $/day	$ 8,490
Total Annual Costs - $/yr	$ 3,098,878.16
Escalation rate - %	4.00%
year	$/year
1	$ 3,222,833
2	$ 3,351,747
3	$ 3,485,816
4	$ 3,625,249
5	$ 3,770,259
6	$ 3,921,069
7	$ 4,077,912
8	$ 4,241,029
9	$ 4,410,670
10	$ 4,587,097
11	$ 4,770,581
12	$ 4,961,404
13	$ 5,159,860
14	$ 5,366,254
15	$ 5,580,904
16	$ 5,804,141
17	$ 6,036,306
18	$ 6,277,759
19	$ 6,528,869
20	$ 6,790,024
21	$ 7,061,625
22	$ 7,344,090
23	$ 7,637,853
24	$ 7,943,367
25	$ 8,261,102
26	$ 8,591,546
27	$ 8,935,208
28	$ 9,292,616
29	$ 9,664,321
30	$ 10,050,894
Discount Rate - %	4.93%
30-Year Cost - $	$81,224,000.00

Net Present Value (NPV) for 30-Year Costs:

	Labor Cost
Production - $/1000 gal	12.2222
Volume of material - gpd	360,000
Load Factor, %	**100.0%**
Daily Costs - $/day	$ 4,400
Total Annual Costs - $/yr	$ 1,606,000.00
Escalation rate - %	3.00%
year	$/year
1	$ 1,654,180
2	$ 1,703,805
3	$ 1,754,920
4	$ 1,807,567
5	$ 1,861,794
6	$ 1,917,648
7	$ 1,975,177
8	$ 2,034,433
9	$ 2,095,466
10	$ 2,158,330
11	$ 2,223,080
12	$ 2,289,772
13	$ 2,358,465
14	$ 2,429,219
15	$ 2,502,096
16	$ 2,577,159
17	$ 2,654,473
18	$ 2,734,107
19	$ 2,816,131
20	$ 2,900,615
21	$ 2,987,633
22	$ 3,077,262
23	$ 3,169,580
24	$ 3,264,667
25	$ 3,362,607
26	$ 3,463,486
27	$ 3,567,390
28	$ 3,674,412
29	$ 3,784,644
30	$ 3,898,184
Discount Rate - %	4.93%
30-Year Cost - $	$36,601,000.00

Net Present Value (NPV) for 30-Year Costs:

	Power Cost
Production - $/1000 gal	0.262
Volume of material - gpd	360,000
Load Factor, %	**100.0%**
Daily Costs - $/day	$ 94
Total Annual Costs - $/yr	$ 34,446.29
Escalation rate - %	3.00%
year	$/year
1	$ 35,480
2	$ 36,544
3	$ 37,640
4	$ 38,770
5	$ 39,933
6	$ 41,131
7	$ 42,365
8	$ 43,636
9	$ 44,945
10	$ 46,293
11	$ 47,682
12	$ 49,112
13	$ 50,586
14	$ 52,103
15	$ 53,666
16	$ 55,276
17	$ 56,934
18	$ 58,643
19	$ 60,402
20	$ 62,214
21	$ 64,080
22	$ 66,003
23	$ 67,983
24	$ 70,022
25	$ 72,123
26	$ 74,287
27	$ 76,515
28	$ 78,811
29	$ 81,175
30	$ 83,610
Discount Rate - %	4.93%
30-Year Cost - $	$785,000.00

Net Present Value (NPV) for 30-Year Costs:

Consumption - gpm
Cost of material - $/gpm
Load Factor, %
Annual Costs - $/yr
Total Annual Costs - $/yr
Escalation rate - %
year
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
Discount Rate - %
30-Year Cost - $

Water Use (ie Wastewater Produced)
0
$ 0.01
43.6%
$ -
$ -
4.00%
$/year
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
$ -
4.93%
$0.00

Net Present Value (NPV) for 30-Year Costs:

	Power
Power Consumption - KW	0
Cost of Power - $/kWhr	$0.02
Load Factor, %	**43.6%**
Annual Power Costs - $/yr	$ -
Total Annual Power Costs - $/yr	$ -
Escalation rate - %	3.00%
year	$/year
1	$ -
2	$ -
3	$ -
4	$ -
5	$ -
6	$ -
7	$ -
8	$ -
9	$ -
10	$ -
11	$ -
12	$ -
13	$ -
14	$ -
15	$ -
16	$ -
17	$ -
18	$ -
19	$ -
20	$ -
21	$ -
22	$ -
23	$ -
24	$ -
25	$ -
26	$ -
27	$ -
28	$ -
29	$ -
30	$ -
Discount Rate - %	4.93%
30-Year Cost - $	$0.00

Net Present Value (NPV) for 30-Year Costs:

	O&M
Capital Cost	$ 53,709,297
O&M Cost per year	$1,074,186
Annual Costs - $/yr	$ 1,074,186
Total Costs - $/yr	$ 1,074,186
Escalation rate - %	3.00%
year	$/year
1	$ 1,106,412
2	$ 1,139,604
3	$ 1,173,792
4	$ 1,209,006
5	$ 1,245,276
6	$ 1,282,634
7	$ 1,321,113
8	$ 1,360,747
9	$ 1,401,569
10	$ 1,443,616
11	$ 1,486,925
12	$ 1,531,532
13	$ 1,577,478
14	$ 1,624,803
15	$ 1,673,547
16	$ 1,723,753
17	$ 1,775,466
18	$ 1,828,730
19	$ 1,883,592
20	$ 1,940,099
21	$ 1,998,302
22	$ 2,058,251
23	$ 2,119,999
24	$ 2,183,599
25	$ 2,249,107
26	$ 2,316,580
27	$ 2,386,077
28	$ 2,457,660
29	$ 2,531,390
30	$ 2,607,331
Discount Rate - %	4.93%
30-Year Cost - $	$24,481,000.00

Net Present Value (NPV) for 30-Year Costs:

	Chemical Cost
Production - $/1000 gal	16.9177
Volume of material - gpd	**720,000**
Load Factor, %	**100.0%**
Daily Costs - $/day	$ 12,181
Total Annual Costs - $/yr	$ 4,445,963.32
Escalation rate - %	4.00%
year	$/year
1	$ 4,623,802
2	$ 4,808,754
3	$ 5,001,104
4	$ 5,201,148
5	$ 5,409,194
6	$ 5,625,562
7	$ 5,850,584
8	$ 6,084,608
9	$ 6,327,992
10	$ 6,581,112
11	$ 6,844,356
12	$ 7,118,131
13	$ 7,402,856
14	$ 7,698,970
15	$ 8,006,929
16	$ 8,327,206
17	$ 8,660,294
18	$ 9,006,706
19	$ 9,366,974
20	$ 9,741,653
21	$ 10,131,319
22	$ 10,536,572
23	$ 10,958,035
24	$ 11,396,356
25	$ 11,852,211
26	$ 12,326,299
27	$ 12,819,351
28	$ 13,332,125
29	$ 13,865,410
30	$ 14,420,026
Discount Rate - %	4.93%
30-Year Cost - $	$116,533,000.00

Net Present Value (NPV) for 30-Year Costs:

	Labor Cost
Production - $/1000 gal	6.5556
Volume of material - gpd	**720,000**
Load Factor, %	**100.0%**
Daily Costs - $/day	$ 4,720
Total Annual Costs - $/yr	$ 1,722,800.00
Escalation rate - %	3.00%
year	$/year
1	$ 1,774,484
2	$ 1,827,719
3	$ 1,882,550
4	$ 1,939,027
5	$ 1,997,197
6	$ 2,057,113
7	$ 2,118,827
8	$ 2,182,391
9	$ 2,247,863
10	$ 2,315,299
11	$ 2,384,758
12	$ 2,456,301
13	$ 2,529,990
14	$ 2,605,890
15	$ 2,684,066
16	$ 2,764,588
17	$ 2,847,526
18	$ 2,932,952
19	$ 3,020,940
20	$ 3,111,568
21	$ 3,204,915
22	$ 3,301,063
23	$ 3,400,095
24	$ 3,502,098
25	$ 3,607,161
26	$ 3,715,375
27	$ 3,826,837
28	$ 3,941,642
29	$ 4,059,891
30	$ 4,181,688
Discount Rate - %	4.93%
30-Year Cost - $	$39,263,000.00

Net Present Value (NPV) for 30-Year Costs:

	Power Cost
Production - $/1000 gal	0.0463
Volume of material - gpd	**720,000**
Load Factor, %	**100.0%**
Daily Costs - $/day	$ 33
Total Annual Costs - $/yr	$ 12,162.60
Escalation rate - %	4.00%
year	$/year
1	$ 12,649
2	$ 13,155
3	$ 13,681
4	$ 14,229
5	$ 14,798
6	$ 15,390
7	$ 16,005
8	$ 16,645
9	$ 17,311
10	$ 18,004
11	$ 18,724
12	$ 19,473
13	$ 20,252
14	$ 21,062
15	$ 21,904
16	$ 22,780
17	$ 23,692
18	$ 24,639
19	$ 25,625
20	$ 26,650
21	$ 27,716
22	$ 28,824
23	$ 29,977
24	$ 31,176
25	$ 32,424
26	$ 33,720
27	$ 35,069
28	$ 36,472
29	$ 37,931
30	$ 39,448
Discount Rate - %	4.93%
30-Year Cost - $	$319,000.00

Net Present Value (NPV) for 30-Year Costs:

	Water Use (ie Wastewater Produced)
Consumption - gpm	0
Cost of material - $/gpm	$ 0.01
Load Factor, %	43.6%
Annual Costs - $/yr	$ -
Total Annual Costs - $/yr	$ -
Escalation rate - %	4.00%
year	$/year
1	$ -
2	$ -
3	$ -
4	$ -
5	$ -
6	$ -
7	$ -
8	$ -
9	$ -
10	$ -
11	$ -
12	$ -
13	$ -
14	$ -
15	$ -
16	$ -
17	$ -
18	$ -
19	$ -
20	$ -
21	$ -
22	$ -
23	$ -
24	$ -
25	$ -
26	$ -
27	$ -
28	$ -
29	$ -
30	$ -
Discount Rate - %	4.93%
30-Year Cost - $	$0.00

Net Present Value (NPV) for 30-Year Costs:

	Power
Power Consumption - KW	0
Cost of Power - $/kWhr	$0.02
Load Factor, %	43.6%
Annual Power Costs - $/yr	$ -
Total Annual Power Costs - $/yr	$ -
Escalation rate - %	3.00%
year	$/year
1	$ -
2	$ -
3	$ -
4	$ -
5	$ -
6	$ -
7	$ -
8	$ -
9	$ -
10	$ -
11	$ -
12	$ -
13	$ -
14	$ -
15	$ -
16	$ -
17	$ -
18	$ -
19	$ -
20	$ -
21	$ -
22	$ -
23	$ -
24	$ -
25	$ -
26	$ -
27	$ -
28	$ -
29	$ -
30	$ -
Discount Rate - %	4.93%
30-Year Cost - $	$0.00

Net Present Value (NPV) for 30-Year Costs:

	O&M
Capital Cost	$ 54,733,163
O&M Cost per year	$1,094,663
Annual Costs - $/yr	$ 1,094,663
Total Costs - $/yr	$ 1,094,663
Escalation rate - %	3.00%
year	$/year
1	$ 1,127,503
2	$ 1,161,328
3	$ 1,196,168
4	$ 1,232,053
5	$ 1,269,015
6	$ 1,307,085
7	$ 1,346,298
8	$ 1,386,687
9	$ 1,428,287
10	$ 1,471,136
11	$ 1,515,270
12	$ 1,560,728
13	$ 1,607,550
14	$ 1,655,776
15	$ 1,705,450
16	$ 1,756,613
17	$ 1,809,312
18	$ 1,863,591
19	$ 1,919,499
20	$ 1,977,084
21	$ 2,036,396
22	$ 2,097,488
23	$ 2,160,413
24	$ 2,225,225
25	$ 2,291,982
26	$ 2,360,741
27	$ 2,431,563
28	$ 2,504,510
29	$ 2,579,646
30	$ 2,657,035
Discount Rate - %	4.93%
30-Year Cost - $	$24,947,000.00

Net Present Value (NPV) for 30-Year Costs:

	Chemical Cost
Production - $/1000 gal	11.4753
Volume of material - gpd	720,000
Load Factor, %	**100.0%**
Daily Costs - $/day	$ 8,262
Total Annual Costs - $/yr	$ 3,015,697.63
Escalation rate - %	4.00%
year	$/year
1	$ 3,136,326
2	$ 3,261,779
3	$ 3,392,250
4	$ 3,527,940
5	$ 3,669,057
6	$ 3,815,820
7	$ 3,968,452
8	$ 4,127,190
9	$ 4,292,278
10	$ 4,463,969
11	$ 4,642,528
12	$ 4,828,229
13	$ 5,021,358
14	$ 5,222,213
15	$ 5,431,101
16	$ 5,648,345
17	$ 5,874,279
18	$ 6,109,250
19	$ 6,353,620
20	$ 6,607,765
21	$ 6,872,075
22	$ 7,146,958
23	$ 7,432,837
24	$ 7,730,150
25	$ 8,039,356
26	$ 8,360,931
27	$ 8,695,368
28	$ 9,043,183
29	$ 9,404,910
30	$ 9,781,106
Discount Rate - %	4.93%
30-Year Cost - $	$79,044,000.00

Net Present Value (NPV) for 30-Year Costs:

	Labor Cost
Production - $/1000 gal	6.5556
Volume of material - gpd	720,000
Load Factor, %	**100.0%**
Daily Costs - $/day	$ 4,720
Total Annual Costs - $/yr	$ 1,722,800.00
Escalation rate - %	3.00%
year	$/year
1	$ 1,774,484
2	$ 1,827,719
3	$ 1,882,550
4	$ 1,939,027
5	$ 1,997,197
6	$ 2,057,113
7	$ 2,118,827
8	$ 2,182,391
9	$ 2,247,863
10	$ 2,315,299
11	$ 2,384,758
12	$ 2,456,301
13	$ 2,529,990
14	$ 2,605,890
15	$ 2,684,066
16	$ 2,764,588
17	$ 2,847,526
18	$ 2,932,952
19	$ 3,020,940
20	$ 3,111,568
21	$ 3,204,915
22	$ 3,301,063
23	$ 3,400,095
24	$ 3,502,098
25	$ 3,607,161
26	$ 3,715,375
27	$ 3,826,837
28	$ 3,941,642
29	$ 4,059,891
30	$ 4,181,688
Discount Rate - %	4.93%
30-Year Cost - $	$39,263,000.00

Net Present Value (NPV) for 30-Year Costs:

	Power Cost
Production - $/1000 gal	0.1054
Volume of material - gpd	720,000
Load Factor, %	**100.0%**
Daily Costs - $/day	$ 76
Total Annual Costs - $/yr	$ 27,710.44
Escalation rate - %	4.00%
year	$/year
1	$ 28,819
2	$ 29,972
3	$ 31,170
4	$ 32,417
5	$ 33,714
6	$ 35,063
7	$ 36,465
8	$ 37,924
9	$ 39,441
10	$ 41,018
11	$ 42,659
12	$ 44,365
13	$ 46,140
14	$ 47,986
15	$ 49,905
16	$ 51,901
17	$ 53,977
18	$ 56,136
19	$ 58,382
20	$ 60,717
21	$ 63,146
22	$ 65,671
23	$ 68,298
24	$ 71,030
25	$ 73,871
26	$ 76,826
27	$ 79,899
28	$ 83,095
29	$ 86,419
30	$ 89,876
Discount Rate - %	4.93%
30-Year Cost - $	$726,000.00

Net Present Value (NPV) for 30-Year Costs:

	Water Use (ie Wastewater Produced)
Consumption - gpm	0
Cost of material - $/gpm	$ 0.01
Load Factor, %	43.6%
Annual Costs - $/yr	$ -
Total Annual Costs - $/yr	$ -
Escalation rate - %	4.00%
year	$/year
1	$ -
2	$ -
3	$ -
4	$ -
5	$ -
6	$ -
7	$ -
8	$ -
9	$ -
10	$ -
11	$ -
12	$ -
13	$ -
14	$ -
15	$ -
16	$ -
17	$ -
18	$ -
19	$ -
20	$ -
21	$ -
22	$ -
23	$ -
24	$ -
25	$ -
26	$ -
27	$ -
28	$ -
29	$ -
30	$ -
Discount Rate - %	4.93%
30-Year Cost - $	$0.00

Net Present Value (NPV) for 30-Year Costs:

	Power
Power Consumption - KW	0
Cost of Power - $/kWhr	$0.02
Load Factor, %	43.6%
Annual Power Costs - $/yr	$ -
Total Annual Power Costs - $/yr	$ -
Escalation rate - %	3.00%
year	$/year
1	$ -
2	$ -
3	$ -
4	$ -
5	$ -
6	$ -
7	$ -
8	$ -
9	$ -
10	$ -
11	$ -
12	$ -
13	$ -
14	$ -
15	$ -
16	$ -
17	$ -
18	$ -
19	$ -
20	$ -
21	$ -
22	$ -
23	$ -
24	$ -
25	$ -
26	$ -
27	$ -
28	$ -
29	$ -
30	$ -
Discount Rate - %	4.93%
30-Year Cost - $	$0.00

Net Present Value (NPV) for 30-Year Costs:

	O&M
Capital Cost	$ 54,730,494
O&M Cost per year	$1,094,610
Annual Costs - $/yr	$ 1,094,610
Total Costs - $/yr	$ 1,094,610
Escalation rate - %	3.00%
year	$/year
1	$ 1,127,448
2	$ 1,161,272
3	$ 1,196,110
4	$ 1,231,993
5	$ 1,268,953
6	$ 1,307,021
7	$ 1,346,232
8	$ 1,386,619
9	$ 1,428,218
10	$ 1,471,064
11	$ 1,515,196
12	$ 1,560,652
13	$ 1,607,472
14	$ 1,655,696
15	$ 1,705,367
16	$ 1,756,528
17	$ 1,809,223
18	$ 1,863,500
19	$ 1,919,405
20	$ 1,976,987
21	$ 2,036,297
22	$ 2,097,386
23	$ 2,160,307
24	$ 2,225,117
25	$ 2,291,870
26	$ 2,360,626
27	$ 2,431,445
28	$ 2,504,388
29	$ 2,579,520
30	$ 2,656,905
Discount Rate - %	4.93%
30-Year Cost - $	$24,946,000.00

		EVOQUA			SUEZ - GE		SUEZ - Envirogen		WesTech		
Electrical											
Total load of system (kW-hr/d) Cost of electricity $/kWhr	$ 0.0158	By Supplier	5973	C	2,109	Y	Needs Confirmed	C	4805	Y	
Attach complete loadlist including motor data sheets			Needs Confirmed	C	Needs Confirmed	C	Needs Confirmed	C	After PO	C	
Cost @ $0.12 kW-hr/day		Needs Confirmed	Needs Confirmed		$253		Needs Confirmed		$556		
Chemical Consumption											
	$/lb		**lbs/day (Neat)**		**lbs/day (Neat)**				**gal/day**		sg - Product
Sodium Hydroxide 50%	0.2325	By Supplier	2400	Y	n/a	N/A	Needs Confirmed	C	n/a	N/A	1.54
Coagulant - Ferric Chloride 40%	0.19	By Supplier	750	Y	550	C	Needs Confirmed	C	86	Y	1.415
Hydrochloric Acid 35%	0.19	By Supplier	1700	Y	6850	C	Needs Confirmed	C	389	Y	1.2
Organo-sulfide neat	2.18	By Supplier	110	Y	925	C	Needs Confirmed	C	43	Y	1.35
Polymer neat	0.91	By Supplier	40	Y	140	C	Needs Confirmed	C	48	Y	1.07
Lime 15%	0.08	By Supplier	31000	Y	1800	C	Needs Confirmed	C	5212	Y	1
Ferrous Chloride 25%	0.13	By Supplier	2400	Y	n/a	N/A	Needs Confirmed	C	n/a	N/A	1.234
Polymer 2 neat	0.91	By Supplier	22	Y	n/a	N/A	Needs Confirmed	C	n/a	N/A	1.07
ZVI, lbs/day	1.08	By Supplier	1900	Y	n/a	N/A	Needs Confirmed	C	n/a	N/A	1
ZVI Conditioning Chemical		By Supplier	used at startup only	C	n/a	N/A	Needs Confirmed	C	n/a	N/A	1
Nutrient	0.5	By Supplier	n/a	N/A	210	Y	Needs Confirmed	C	522	Y	1
Citric Acid	0.27	By Supplier	n/a	N/A	Confirmed	C	Needs Confirmed	C	67	Y	1
Sodium Hypochlorite	3.4	By Supplier	n/a	N/A	Confirmed	C	Needs Confirmed	C	2.8	Y	1
Sodium Bisulfite	2.15	By Supplier	0	N/A	2695	C	Needs Confirmed	C			1
Cost per day		By Supplier	$5,543	N/A	$845	C	Needs Confirmed	C	$7,397	Y	1
Air Consumption											
Air operated pumps (inst. or plant)	scfm	By Supplier	330/plant	Y	Needs Confirmed	C	Needs Confirmed	C	85	Y	
Filter press (inst. or plant)	scfm	By Supplier	525/plant	Y	Confirmed	C	Needs Confirmed	C	480	Y	
Instruments & Air Operated Valves	scfm	By Supplier	75	Y	Needs Confirmed	C	Needs Confirmed	C	15	Y	

Electrical										
Total cost of load of system ($/000's gal) Cost of electricity $/kWhr	$ 0.0158	By Supplier	$ 0.26	C	$ 0.05	C		C	$ 0.11	Y
Attach complete loadlist including motor data sheets			Needs Confirmed	C	Needs Confirmed	C		C	After PO	C
Cost electricity/day		Needs Confirmed	$94		$33				$76	
Chemical Consumption										
	$/lb		**$/day**		**$/day**				**$/day**	
Sodium Hydroxide 50%	0.2325	By Supplier	1116.00	Y	0.00	N/A	0.00	C	0.00	N/A
Coagulant - Ferric Chloride 40%	0.19	By Supplier	375.00	Y	275.00	C	0.00	C	192.83	Y
Hydrochloric Acid 35%	0.19	By Supplier	922.86	Y	3718.57	C	0.00	C	739.69	Y
Organo-sulfide neat	2.18	By Supplier	239.80	Y	2016.50	C	0.00	C	1055.42	Y
Polymer neat	0.91	By Supplier	36.40	Y	127.40	C	0.00	C	389.79	Y
Lime 15%	0.08	By Supplier	2480.00	Y	144.00	C	0.00	C	3477.45	Y

Ferrous Chloride 25%	0.13	By Supplier	1248.00	Y		0.00	N/A	0.00	C	0.00	N/A
Polymer 2 neat	0.91	By Supplier	20.02	Y		0.00	N/A	0.00	C	0.00	N/A
ZVI, lbs/day	1.08	By Supplier	2052.00	Y		0.00	N/A	0.00	C	0.00	N/A
ZVI Conditioning Chemical		By Supplier	used at startup only	C		0.00	N/A	0.00	C	0.00	N/A
Nutrient	0.5	By Supplier	0.00	N/A		105.00	Y	0.00	C	2176.74	Y
Citric Acid	0.27	By Supplier	0.00	N/A		0.00	C	0.00	C	150.87	Y
Sodium Hypochlorite	3.4	By Supplier	0.00	N/A		0.00	C	0.00	C	79.40	Y
Sodium Bisulfite	2.15	By Supplier	0.00	N/A		5794.25	C	0.00	C	0.00	
			$8,490.08			$12,180.72		$0.00		$8,262.19	
Cost per day		By Supplier	$5,543	N/A		$845	C	Needs Confirmed	C	$7,397	Y
Air Consumption											
Air operated pumps (inst. or plant)	scfm	By Supplier	330/plant	Y		Needs Confirmed	C	Needs Confirmed	C	85	Y
Filter press (inst. or plant)	scfm	By Supplier	525/plant	Y		Confirmed	C	Needs Confirmed	C	480	Y
Instruments & Air Operated Valves	scfm	By Supplier	75	Y		Needs Confirmed	C	Needs Confirmed	C	15	Y

LABOR		$/Hr Rate	$/day			
CLASS A OPERATOR	1	50	1 400	5 2000	5 2000	5 2000
CLASS B OPERATOR	7	40	7 2240	3 960	3 960	3 960
SUPERVISOR (OPTIONAL)	1	45	1 360	1 360	1 360	1 360
MAINTENANCE	2	40	2 640	2 640	2 640	2 640
YARDWORK	2	30	2 480	2 480	2 480	2 480
LABORATORY TECHNICIAN	1	35	1 280	1 280	1 280	1 280
Hours per day	8	$ per day	4400	4720	4720	4720
		$/1000 gal	12.22	6.56	6.56	6.56
Treated water per day		gpm	250	500	500	500
		gpd	360000	720000	720000	720000
		$/1000 gal	$ 23.58	$ 16.92	$ 16.92	$ 11.48
Selenium	ppm	1		0.5	0.5	0.5
Influent	lbs per day		3.000	3.000	3.000	3.000
Effluent	lbs per day		0.036	0.072	0.072	0.072
	ppb	12				
Delta, removed	lbs per day		2.964	2.928	2.928	2.928

			EVOQUA		SUEZ - GE		SUEZ - Envirogen		WesTech	
			lbs/day (Neat)		lbs/day (Neat)				gals/day (Total as consumed)	
Chemical Consumption										
Sodium Hydroxide	gal/day	By Supplier	2400 as 100%	Y	n/a	N/A	Needs Confirmed	N/A	n/a	N/A
Coagulant	gal/day	By Supplier	750 as 100%	Y	550	Y	Needs Confirmed	N/A	86.4	C
Hydrochloric Acid	gal/day	By Supplier	1700 as 100%	Y	6850	Y	Needs Confirmed	N/A	388.8	Y
Organo-sulfide	gal/day	By Supplier	solution)	Y	925	Y	Needs Confirmed	N/A	43.2	Y
Polymer	gal/day	By Supplier	40 as neat solution	Y	140	Y	Needs Confirmed	N/A	48	Y
Lime	gal/day	By Supplier	31000 as 100%	Y	1800	Y	Needs Confirmed	N/A	5212	Y
Ferrous Chloride	gal/day	By Supplier	2400 as 100%	Y	n/a	N/A	Needs Confirmed	N/A	n/a	C
Polymer 2	gal/day	By Supplier	22 as neat solution	Y	n/a	N/A	Needs Confirmed	N/A	n/a	N/A
ZVI	gal/day	By Supplier	1900 (excludes startup)	Y	n/a	N/A	Needs Confirmed	N/A	n/a	N/A
ZVI Conditioning Chemical	gal/day	By Supplier	used at startup	Y	n/a	N/A	Needs Confirmed	N/A	n/a	N/A
Nutrient	gal/day	By Supplier	n/a	N/A	Needs Confirmed	C	Needs Confirmed	N/A	522	Y
Citric Acid	gal/day	By Supplier	n/a	N/A	n/a	N/A	Needs Confirmed	N/A	Varies	C
Sodium Hypochlorite	gal/day	By Supplier	n/a	N/A	n/a	N/A	Needs Confirmed	N/A	Varies	C
Sodium Bisulfite	gal/day	By Supplier	n/a	N/A	2695	Y	Needs Confirmed	N/A	Varies	C
Air Consumption										
Air operated pumps (inst. or plant)	scfh	By Supplier	330 / plant	C	Needs Confirmed	C	Needs Confirmed	N/A	Needs Confirmed	C
Filter press (inst. or plant)	scfh	By Supplier	(for air / core blow)	C	Needs Confirmed	C	Needs Confirmed	N/A	Needs Confirmed	C
Instruments & Air Operated Valves	scfh	By Supplier	75	Y	Needs Confirmed	C	Needs Confirmed	N/A	Needs Confirmed	C

WorleyParsons
resources & energy

2675 Morgantown Road
Reading PA 19607
USA

Telephone: +1 610 855 2000

www.worleyparsons.com
WorleyParsons

July 2018

Technical Memo FGD Blowdown Treatment System
Selenium Removal Economics
Santee Cooper

The technical memo is used to present the FGD Blowdown Treatment System cost evaluation to include the calculation of $ per pound of selenium removed from the FGD Blowdown wastewater and assuming compliance with the 2015 ELG regulatory discharge limits for selenium.

The source of the technical and cost inputs were received from a formal firm price bidding process conducted by WorleyParsons serving as the engineering services contractor for Santee Cooper.

A detailed design specification and Request for Proposal document was prepared and sent to the following four (4) bidders for their treatment system designs and pricing for equipment supply only, delivered to the Santee Cooper location.

- Suez Treatment Solutions aligned with biological advanced technology providers Envirogen or GE ABMet
- WesTech aligned with biological advanced technology provider Frontier Water Systems (SeHAWK)
- Evoqua Water Technologies with the Evoqua non-biological advanced technology (ZVI - Pironox)
- Veolia Water Technologies with the Veolia biological technology (Withdrew bid after submittal and not evaluated)

The as-received pricing was documented and an evaluation was performed to confirm compliance with the RFP requirements. Adjustments were made through clarification Q&A resulting in price adders and deducts.

	Evoqua FGD Blowdown	Suez FGD Blowdown	WesTech FGD Blowdown
Capital Costs			
Lump Sum Price	$15,282,799	$13,736,000	$11,849,068
Total (incl delivery)	Included	Included	$838,279
RFP Options	($230,731)	($320,000)	($59,317)
Align to RFP	$4,863,996	$1,523,930	$2,309,231
Discounts	$0	$0	$0
Total:	**$19,916,064**	**$14,939,930**	**$14,937,261**

The amount of selenium removed per year was calculated from a design basis wastewater concentration of 1 mg/l to achieve a 12 ppb discharge limit. The calculated pounds of selenium removed per year is:

	Evoqua FGD Blowdown	Suez FGD Blowdown	WesTech FGD Blowdown
Selenium removed pounds per year	**1081.86**	**1068.72**	**1068.72**

Operating consumables/chemicals consumption rates were requested with the proposals and supplied by the bidders. The chemical consumption were evaluated over a 30 year period using 4% escalation on cost of chemicals and discount rate of 4.93% to develop a present worth cost for chemicals. The power evaluation was not complete during the evaluation and was not significant in the cost evaluation.

The labor cost was developed based on additional operating staffing required to support the new treatment equipment. The labor cost was evaluated over a 30 year period using 3% escalation on rates and discount rate of 4.93% to develop a present worth cost for labor.

LABOR		$/Hr Rate	$/day
CLASS A OPERATOR	1	50	400
CLASS B OPERATOR	7	40	2240
SUPERVISOR (OPTIONAL)	1	45	360
MAINTENANCE	2	40	640
YARDWORK	2	30	480
LABORATORY TECHNICIAN	1	35	280
Hours per day	8	$ per day	4400

Maintenance costs were estimated using the standard industry practice, assuming 2% of capital reflecting the annual maintenance cost. The maintenance cost was evaluated over a 30 year period using 3% escalation on rates and discount rate of 4.93% to develop a present worth cost for maintenance

30 Year Operating Costs	Evoqua FGD Blowdown	Suez FGD Blowdown	WesTech FGD Blowdown
Chemical Cost	($81,224,000)	($116,533,000)	($79,044,000)
Labor Cost	($36,601,000)	($39,263,000)	($39,263,000)
Power Cost	($785,000)	($319,000)	($726,000)
Maintenance	($24,481,000)	($24,947,000)	($24,946,000)
Total:	**($143,091,000)**	**($181,062,000)**	**($143,979,000)**

The present worth for 30 years of operating costs and the evaluated bid total were added to develop an Equivalent Annual Cost basis for cost of treatment and calculating the $ per pound of selenium removed.

	Evoqua FGD Blowdown	**Suez** FGD Blowdown	**WesTech** FGD Blowdown
Grand Total:	($163,007,064)	($196,001,930)	($158,916,261)
Equivalent Annual Cost (EAC)	($10,519,381)	($12,648,649)	($10,255,388)
Evaluation Basis ($ per lb Se removed)	($9,723.42)	($11,835.33)	($9,595.95)

Additional sensitivity assessments were further evaluated to present a comprehensive all-inclusive cost of treatment.

The most contended item from the bidders was the issue to provide 100% redundancy for equipment sparing. The bidders approached the design as n+1 modular redundancy not 100% sparing.

An estimate was made in the evaluation for the redundancy adjustment required to bring the proposal prices into compliance with the original RFP.

- Both WesTech and Suez were requiring dilution water for treatment of the design basis FGD blowdown stream and neither increased the capacity of the 250 gpm design to a 500 gpm design due to dilution. The pricing for both technologies was increased by 75% to allow for a 100% increase in the size of the system design. The 75% factor was used rather than 100% as a standard industry adjustment to account for increased flow.
  - $14.9 M x 75% = $11.1 M adder to account for 100% increase in capacity
- Evoqua pricing continued to be based on 250 gpm as bid and no adjustments were required in the physical/chemistry treatment but the advanced technology required about 33% increase to allow for redundancy in the Pironox process.
  - $19.9 M - $4.4 M (allowance for phys/chem) = $15.5 M x 33% = $5.1 M adder to account for 2 x 250 gpm 100% redundancy of Pironox process

For a final complete assessment for cost of treatment, WorleyParsons developed an FGD Blowdown Treatment System construction cost estimate and added the cost of construction to the revised estimate total from the redundancy adder to have a Total Installed Cost basis to assess the cost of treatment.

The present worth for 30 years of operating costs and the revised constructed estimate total, including added redundancy cost were added to develop an Equivalent Annual Cost basis for cost of treatment and calculating the $ per pound of selenium removed.

	Evoqua FGD Blowdown	**Suez** FGD Blowdown	**WesTech** FGD Blowdown
Capital Costs (As bid, evaluated)	$19,916,064	$14,934,246	$14,937,261
Construction Estimate	$28,693,233	$28,693,233	$28,693,233
RFP Conformance - Redundancy	$5,100,000	$11,100,000	$11,100,000
Total including Redundancy:	**$53,709,297**	**$54,727,479**	**$54,730,494**
Operating Costs			
Total:	**($143,091,000)**	**($181,062,000)**	**($143,979,000)**
Grand Total including Redundancy:	**($196,800,297)**	**($235,795,163)**	**($198,709,494)**
Total Equivalent Annual Cost	**($12,700,169.83)**	**($15,216,636.68)**	**($12,823,376.57)**
Evaluation Basis ($ per lb Se removed)	**($11,739.20)**	**($14,238.19)**	**($11,998.82)**

Based on the basis presented, the above review is WorleyParsons' best assessment for the cost of selenium treatment in an FGD blowdown treatment system based on the assumption it would achieve the discharge requirements as included in the 2015 ELG regulations.

Regards

Jay A Weist
Senior Technical Consultant

Message

From: Benware, Richard [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=4B2E011A22A44312A04299F118CC4D11-BENWARE, RICHARD]
Sent: 6/5/2018 8:35:15 PM
To: Richard Benware [richard.j.benware@[redacted]
Subject: Read this over tonight for comments...
Attachments: CCR Phase One Final rule_5.31.18 OW ELG.docx

Importance: High

From: Hillyer, Kirsten
Sent: Tuesday, June 05, 2018 2:14 PM
To: Benware, Richard <Benware.Richard@epa.gov>
Subject: CCR Phase One Part 1 Final rule
Importance: High

Richard,

I heard you called Frank about having not seen the Deliberative Process / Ex. 5. I am sorry about that. Attached is the current draft I am working on and sending to PARMS/OP today. The ELG starts being mentioned on the bottom of page 24. We say that Deliberative Process / Ex. 5.

Please let me know ASAP if you have any issues with the language used in rule when referring to the ELG.
Thanks!

Kirsten Hillyer
Environmental Engineer
U.S. Environmental Protection Agency
Office of Resource Conservation & Recovery (ORCR)
Materials Recovery & Waste Management Division (MRWMD)
Cube:S-6834 Phone: (703) 347-0369

ELECTRIC POWER RESEARCH INSTITUTE

Closed-Loop Bottom Ash Transport Water: Costs and Benefits to Managing Purges

3002013706

Closed-Loop Bottom Ash Transport Water: Costs and Benefits to Managing Purges

3002013706

Technical Update, September 2018

EPRI Project Manager

P. Chu

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

REFERENCE HEREIN TO ANY SPECIFIC COMMERCIAL PRODUCT, PROCESS, OR SERVICE BY ITS TRADE NAME, TRADEMARK, MANUFACTURER, OR OTHERWISE, DOES NOT NECESSARILY CONSTITUTE OR IMPLY ITS ENDORSEMENT, RECOMMENDATION, OR FAVORING BY EPRI.

THE FOLLOWING ORGANIZATION, UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

CH2M HILL Engineers, Inc. (CH2M)

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Electric Power Research Institute, EPRI, and TOGETHER…SHAPING THE FUTURE OF ELECTRICITY are registered service marks of the Electric Power Research Institute, Inc.

Copyright © 2018 Electric Power Research Institute, Inc. All rights reserved.

ACKNOWLEDGMENTS

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

CH2M HILL Engineers, Inc. (CH2M)
155 Grand Avenue, Suite 800
Oakland, California, 94612

Principal Investigators
L. Reid, P.E.
M. Neumann, P.E.
D. Fink, P.E.

This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Closed-Loop Bottom Ash Transport Water: Costs and Benefits to Managing Purges. EPRI, Palo Alto, CA: 2018. 3002013706.

ABSTRACT

This study evaluates the challenges of existing bottom ash transport water systems in meeting the no-discharge limit of the U.S. Environmental Protection Agency's 2015 Effluent Limitations Guidelines (ELGs). Each of the systems evaluated in this report used remote bottom ash settling devices. Most sites recycle most of the water, but each required some water to be purged from the system and therefore the systems are not fully closed-loop (i.e., no-discharge) systems. The challenges include water imbalance (more water entering than can be contained in the loop); maintenance activities requiring draining parts of the loop; leaks; and water quality issues, which include acidity and corrosiveness, scaling, and presence of solids that abrade piping and equipment.

The study included an evaluation of 21 plants that had operational experiences ranging from over 20 years of operation of a partially closed-loop system, to operating less than one year, to systems under construction. The evaluation demonstrated that plants will find it problematic and/or costly to meet a no-discharge requirement for bottom ash transport water. Operational flexibility would be achieved if the ELGs allowed for a purge from these systems instead of only allowing water to be reused in scrubbers or other no-discharge applications. One approach to defining an allowable purge quantity would be to allow purging as a percent of the volume of the bottom ash loop on a regular basis for maintenance of system chemistry, averaged over a sufficient time period to account for variability in load and intake water quality. Additional purges should be allowed if needed for maintenance activities on tanks or other equipment containing large amounts of loop water.

Even though the 2015 ELGs allow the use of bottom ash transport water for scrubber makeup or other no-discharge uses, it is not clear that all of the purge water would be suitable for FGD makeup, and there may still be a need to allow a discharge of bottom ash transport water in order to provide for operational flexibility to ensure reliable generation assets.

Keywords
Bottom ash transport water
Closed loop
Effluent Limitations Guidelines
ELGs
Remote mechanical drag system

ELECTRIC POWER RESEARCH INSTITUTE

EXECUTIVE SUMMARY

Deliverable Number: 3002013706

Product Type: Technical Update

Product Title: Closed-Loop Bottom Ash Transport Water: Costs and Benefits to Managing Purges

---

PRIMARY AUDIENCE: Wastewater treatment engineers, environmental managers, and permit negotiators

KEY RESEARCH QUESTION

In 2015 the U.S. Environmental Protection Agency (EPA) issued Effluent Limitations Guidelines (ELGs), which included elimination of discharges of bottom ash transport water, except under very limited circumstances (e.g., use in scrubbers for makeup water or other no-discharge uses). Plants are challenged when trying to meet the ELGs' ban on discharge of bottom ash transport water through the use of a "closed loop" (no-discharge system) in which bottom ash is sluiced to a solids separation system and water is recycled back to the plant for additional bottom ash sluicing, or for flue gas desulfurization (FGD) makeup, without having the capability to discharge in order to maintain a water balance or closed-cycle chemistry. The primary goal of this document is to show the costs and benefits of having a purge from a remote bottom ash solids loop versus not having a purge.

RESEARCH OVERVIEW

Twenty-one plants were interviewed to characterize the purges from remote bottom ash loop systems that have been previously experienced or are anticipated. The costs and benefits of allowing a purge from remote bottom ash loop systems instead of maintaining the ELGs' ban on discharges of bottom ash transport water were evaluated.

KEY FINDINGS

- Plants will be challenged to completely eliminate a discharge of bottom ash transport water, even given the exception of being allowed to send discharges to the FGD scrubber or other no-discharge uses. Challenges include not being able to use the entire volume in the FGD scrubber or not having appropriate no-discharge uses; more water entering the system than can be contained; maintenance activities requiring draining of large quantities of water; leaks; and water quality issues in the closed loop system that necessitate a purge.
- Meeting the elimination of discharge requirement would be costly to plants and could restrict operational flexibility without a concomitant improvement in impacts to the environment.
- Operational flexibility would be improved by allowing a purge (i.e., discharge) from the bottom ash loop. Allowing a purge that is a fraction of the current bottom ash transport water discharge would achieve nearly all of the environmental benefits of a complete ban on transport water discharge. One approach to defining the allowable purge would be to allow purging as a percent of the volume of the bottom ash loop on a routine basis, averaged over a sufficient time period to account for variability, as well as allowing additional purges if needed for maintenance activities on tanks or other equipment containing large amounts of loop water.

WHY THIS MATTERS

Many drivers for needing to purge from bottom ash transport water "closed-loop" systems are explained. The high cost and low environmental benefit of eliminating purges are evaluated.

ELECTRIC POWER RESEARCH INSTITUTE

EXECUTIVE SUMMARY

HOW TO APPLY RESULTS

These results can be used by EPRI members in commenting on the ELGs.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- EPRI anticipates making this document available to the public to help inform sound decision making in the current reevaluation of the ELGs' ban on bottom ash transport water discharge.

EPRI CONTACTS: Paul Chu, EPRI Project Manager, pchu@epri.com

PROGRAM: Water Quality Program 196B Effluent Guideline and Plant Wastewater Monitoring

Together...Shaping the Future of Electricity®

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com
© 2018 Electric Power Research Institute (EPRI), Inc. All rights reserved. Electric Power Research Institute, EPRI, and TOGETHER...SHAPING THE FUTURE OF ELECTRICITY are registered service marks of the Electric Power Research Institute, Inc.

CONTENTS

ABSTRACT ..... **V**

EXECUTIVE SUMMARY ..... **VII**

***1* OVERVIEW** **1-1**

Setting Limits on Allowable Purges 1-17

Setting Allowable Purges based on Water Quantity Imbalance, Maintenance, and Leaks 1-17

Setting Allowable Purges based on Water Quality 1-18

Monitoring Purge Quantity 1-20

***2* HYPOTHETICAL CASE STUDY EXAMPLES AND ASSOCIATED COSTS TO ACHIEVE CLOSED-LOOP DESIGN** **2-1**

Hypothetical Case Study 1 ("Plant 1"): Cost of Additional Water Storage for Water Imbalances and Maintenance Events 2-3

Hypothetical Case Study 2 ("Plant 2"): Cost for Eliminating Purge due to Recirculated Water Quality Requirements 2-3

***3* ENVIRONMENTAL IMPACTS VERSUS COSTS TO CLOSE THE LOOP** **3-1**

Environmental Impact of Purges by Plant 3-2

***4* SUMMARY** **4-1**

***A* TWPE CALCULATION** **A-1**

LIST OF TABLES

Table 1-1 Summary of purges identified and potential solutions from interviews and/or study of 21 plants 1-4
Table 1-2 Estimated annualized purges as reported by plants interviewed, including as a percentage of the bottom ash recirculated water system's volume 1-8
Table 1-3 Estimated annualized purges (as reported by plants interviewed) evaluated as a percentage of the bottom ash transport water average flow[a] 1-13
Table 1-4 Summary of Chloride and TDS Data Compared to Conductivity Readings 1-19
Table 2-1 BPT limitations for bottom ash transport water 2-2
Table 2-2 Solids removal performance of dewatering systems 2-2
Table 3-1 Summary of costs versus economic benefits of eliminating purges 3-2
Table 3-2 Annual TWPE of estimated purges from partially closed-loop bottom ash dewatering systems 3-3

1 OVERVIEW

The 2015 Effluent Limitations Guideline (ELG) rule gives two compliance options for wet bottom ash: install either an under-the-boiler mechanical handling system or a "closed loop" configuration in which ash is sluiced to a remote ash removal system and then the water is returned to the bottom ash management system. The U.S. Environmental Protection Agency (EPA) uses the term "closed loop" in the ELG to describe a bottom ash system in which ash is transported to a location remote from the boiler where ash is settled, and water is reused rather than discharged to a permitted outfall. With the possible exception of being sent to a flue gas desulfurization (FGD) scrubber, no discharge is allowed except for discharges associated with certain minor maintenance events. Under-the-boiler mechanical handling systems are judged compliant with the 2015 ELG rule because no transport of bottom ash with water occurs; however, these systems are not feasible for many plants because vertical clearances are insufficient to allow additional equipment to be placed under the boiler, which forces these plants to install and operate remote closed-loop systems to eliminate the discharge of bottom ash transport water.

The Electric Power Research Institute's (EPRI) study of existing, partially-closed loop bottom ash transport water (BATW) systems has revealed several challenges with meeting the no-discharge limit for BATW. The term "partially-closed" is used throughout this document because while most ash transport water is returned for reuse in the systems evaluated, currently some water is discharged from the loop. While water is also lost from a partially-closed system through evaporation and the water entrained in the ash removed, there may still be a need to purge water from the loop. In general, the challenges facing each of the plants can be grouped into the following categories of drivers for needing a purge (i.e., discharge from the system):

- Water imbalance (WI), or more water entering than can be contained "in the loop" or bled to an FGD. Excess water may be due to continuous flows or intermittent flows; examples include adding wastestreams to the bottom ash loop or stormwater introduction.
- Maintenance-related activities (M) requiring draining parts of the loop; drivers include inspection or repair of structure interiors or critical conveyance equipment. Draining certain equipment can involve quantities of water in the range of hundreds of thousands of gallons.
- Leaks[1] (L) or flows not contained in the loop that are not currently explicitly defined in the ELG as "minor leaks," or
- Water quality (WQ) issues including:
  - Acidity and corrosiveness
  - Scaling
  - Abrading equipment due to solids carryover from the ash-settling device.

---

[1] Note that the 2015 ELG rule preamble identifies leaks as separate from maintenance events: "*Transport water does not include low volume, short duration discharges of wastewater from minor leaks (e.g., leaks from valve packing, pipe flanges, or piping) or minor maintenance events (e.g., replacement of valves or pipe sections) stated that bottom ash transport water.*" However, in the Technical Development Document, "minor leaks" are classified as an example of a "minor maintenance event."

Table 1-1 is a summary from the study of 21 plants with existing or planned partially closed-loop systems. This table includes estimates of purge volumes from the bottom ash systems at those plants, which can be continuous or intermittent. In **Table 1-1**, as well as subsequent tables, the continuous volumes are based on estimates and calculations and were not measured. Intermittent purges represent maintenance events that generally occur annually, or less frequently, such as emptying the entire closed-loop system or dewatering equipment for maintenance or inspection. Continuous purges were estimated from a combination of information provided by the plant and water chemistry as described in EPRI's 2016 guidance[2]. It is assumed that these continuous purges were linked to operations, assuming 350 days of operation per year, consistent with EPRI's assumptions when previously evaluating the industry's BATW volume. Intermittent purge volumes are estimates and based on site observations and interviews. For example, the volume of the closed-loop is estimated based on the calculated volume of the settling equipment (i.e., clarifiers, hoppers, water in piping etc.).

The table also includes reasons sites have needed to purge flows that would not be allowed under the 2015 no-discharge ELG requirements for BATW. In 2016, EPRI studied seven remote bottom ash dewatering systems at six coal-fired power plants, consisting of both remote mechanical drag systems (RMDS) (Plants A, B, and C) and ash dewatering bins (Plants D, E, and F). In addition, EPRI has data from a seventh plant (Plant G, ash dewatering bins) based on a pilot study of treating a purge from the bottom ash water loop. Additional information on these plants is included in Guidance Document for Management of Bottom Ash Handling Water in Compliance with the 2015 Effluent Limitations Guidelines (ELGs). EPRI, Palo Alto, CA, 2016. 3002008345. It should be noted that several systems listed in **Table 1-1** have little or no operating experience so they may not yet have experienced the issues necessitating purges. These include those systems under construction (Plants N, O, P, Q, R, and S), in commissioning (Plants J, K, L, and M), or operating less than 1 year at the time of this investigation (Plants T and U).

Five plants have reported scaling, but have been able to avoid an additional purge through pH control with sulfuric acid addition combined with other purges that have been routinely occurring. Scaling is difficult to predict based on standard scaling indices, which were not developed for the water quality typically found in ash transport water. Also, scaling is difficult to predict until equipment/system failures are observed. Once known/observed, scaling likely can be controlled with scale inhibitor (which only slows down the kinetics) or with pH control, usually sulfuric acid addition for preventing calcium scale (i.e., calcium carbonate). However, if the sulfuric acid demand is high enough, or is concentrated in the closed-loop via evaporation, then calcium sulfate (another scalant) could theoretically form. In this case, the plant would either need to use an alternative acid, such as hydrochloric acid (which could contribute to corrosivity issues), or purge water from the system to reduce the concentration of scaling ions.

In compliance with the 2015 ELG rule, purges could be fed into a FGD scrubber for use as makeup water; however, this may have its own practical challenges. Certain locations for introducing purge into FGD systems are not advisable because the quality of the bottom ash water would cause operational problems, such as in FGD mist eliminators. Mist eliminator injection would not be recommended because of challenges with the suspended or dissolved

---

[2] Electric Power Research Institute, Inc. (EPRI). 2016. *Guidance Document for Management of Closed-Loop Bottom Ash Handling Water in Compliance with the 2015 Effluent Limitations Guidelines (ELGs).* Product ID 3002008345.

solids in bottom ash water. Wet FGD systems may have higher water demands than dry, but only a fraction of the water needed may be able to be supplied by water such as BATW. Additionally, the chemistry of BATW, particularly the presence of aluminum, can negatively impact scrubber operations (e.g., aluminum-fluoride blinding) or gypsum water quality[3], requiring the purge volume to be further treated prior to use in a scrubber. Even with the ability to use the purge to the scrubber, there is still water that needs to be discharged. Also, not all facilities have a wet FGD or if one is present, it may not always be available to dispose of excess water from the bottom ash system. Plants with dry FGD systems may still have water demand but it is likely less than the purge volume needed.

Means of reducing purge volumes vary based on the reason for the purge. Possible means of controlling or eliminating purges are described in **Table 1-1**. Some purge-elimination steps may be relatively straightforward, while others are complex and involve significant changes within the power block. Treatment of purge water could cost millions of dollars, such as for reverse osmosis, evaporation, crystallization, etc., to eliminate water that fails loop chemistry requirements. Purges for bottom ash system maintenance events such as emptying major equipment could coincide with FGD scrubber outages, requiring the purge volume to be stored until either the bottom ash equipment or FGD system is back online. Purges due to leaks may require expensive infrastructure modifications to contain leaks that need to be accomplished without unintentionally mixing bottom ash transport water with non-transport waters and allowing these non-transport waters to enter the bottom ash loop. For example, certain activities associated with the bottom ash loop may involve flows that are currently routed to a station sump. These flows could be captured in theory to avoid that situation but depending upon the plant's configuration, that may be difficult to accomplish. Rerouting the station sump to the bottom ash system is not recommended because it introduces even more flows and possibly other constituents such as oil and grease.

[3] Electric Power Research Institute, Inc. (EPRI). 2017. *Water Management – Evaluation of Treatment for Closed-Loop Bottom Ash Purges to FGD.* Product ID 300201499.

Table 1-1
Summary of purges identified and potential solutions from interviews and/or study of 21 plants

Purge Driver/Description	Maximum Estimated Daily Purge Volume at Interviewed Plants[e]	Category[a]	Systems with Reported Issue (Blue are Dewatering Bins Systems, the others are RMDS Systems)																					Potential Mitigation Solutions (Some Solutions Already Implemented at Some Plants)
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	
Stormwater introduction above storage capacity of recirculated water supply	900,000 gallons	WI	●								●							●	●	●	●	●	●	– Yard improvements to redirect stormwater, which may include: regrading, repaving, curb additions, or addition of new sumps, pumps, and treatment processes. – Cover equipment or enclosure in building, including ash bunkers or ash dewatering pads. – Add storage capacity relative to volume and risk of concurrence with other events.[d]
Utilizing bottom ash dewatering equipment to treat other wastestreams (e.g., landfill leachate, NCMCWs)	32,500 gallons/day (average inputs from landfill leachate & coal pile runoff)	WI			●	●	●	●					●	●	●	●	●	●	●	●	●	●	●	– Design new treatment facilities for other wastewaters, so they will not enter the closed-loop. – Modify system and cleaning practices to redirect water during cleanings unless contact with transport water is unavoidable, in which case configure system to use recirculated water for wash (i.e., supply local area hoses dedicated only for this purpose). – Add storage capacity relative to volume and risk of concurrence with other events.[d]
Boiler tube leaks adding water to bottom ash hoppers	144,000 gallons	WI			●								●	●	●	●	●							– Add storage capacity relative to volume and risk of concurrence with other events.[d]
Use of service water (rather than bottom ash recirculated water) as cooling water for ash hopper(s) due to recirculated water supply being too hot	38,800 gallons/day	WI			●																			– Add heat exchangers and controls to cool recirculated water when needed.
Introduction of new water to the closed-loop due to cross-connections	Not reported, difficult to estimate	WI	●								●							●	●	●	●	●	●	– Replace and correct as discovered (typically during start-up and commissioning). – Design system such that all cross-connections are eliminated (i.e., only have service water added to dewatering system for water makeup).
Water introduction to bottom ash hopper area sump(s), such as area washdowns	Not reported, difficult to estimate	WI	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	– Redirect non-transport water to new sumps or modify existing sumps (if possible) to segregate ash transport water from non-transport water. This could require relocating equipment that drains to the sumps or modifying the trenches, piping, and sump pumps of other sumps that direct water to the hopper area sump. – Modify operation practices to minimize introduction of water. – Add storage capacity relative to volume and risk of concurrence with other events.[d]
Sluice line rupture	180,000 gallons	L	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	– To some extent unavoidable unless utilizing double-lined piping with leak monitoring or plant is able to otherwise contain and remove water from a rupture throughout the pipe length (such as a dedicated trench). However, water loss can be minimized utilizing other controls, specifically: – Have two sluice lines, such that sluices can be directed to the second line when a failure occurs on the initial line. However, this does not prevent a discharge if lines are near a receiving stream or storm drain and the flow is not stopped prior to reaching the receiving stream.

Table 1-1
Summary of purges identified and potential solutions from interviews and/or study of 21 plants

Purge Driver/Description	Maximum Estimated Daily Purge Volume at Interviewed Plants[e]	Category[a]	Systems with Reported Issue (Blue are Dewatering Bins Systems, the others are RMDS Systems)																					Potential Mitigation Solutions (Some Solutions Already Implemented at Some Plants)
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	
Failure of sluice door or grinder/crusher during operation which leads to a spill of transport water to floor sumps	3,000 gallons	L	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	– Tie-in hopper area sumps' discharge into closed-loop system. May include extra controls and piping, especially if multiple piping pathways are needed in case of failure of downstream equipment (such as interim pumps). May also include installing a new sump and/or segregating non-transport waters to prevent excess water introduction.
Leaks around hopper system flanges, joints, observation windows, etc.	6,000 gallons/day	L	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	– Replace and correct as discovered and as allowed by generation requirements (i.e., correct during outages). – Where feasible, tie-in drainage points (i.e., sumps) into the closed-loop system.
Draining hopper contents during scheduled maintenance, including refractory or steel hopper replacement	3,000 gallons	M	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	– Tie-in hopper area sumps' discharge into closed-loop system. May include extra controls and piping, especially if multiple piping pathways are needed in case of failure of downstream equipment (such as interim pumps). May also include installing a new sump and/or segregating not-transport waters to prevent excess water introduction.
Drain dewatering system component(s) to inspect interior	1,500,000 gallons	M	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	– Have a dedicated maintenance tank to hold contents of part, or all, of the closed-loop system. – Configure system such that spare equipment, such as a spare mechanical dewatering vessel, can be used to store water when another is taken offline.
Drain RMDS to replace/repair components (such as the chain)	250,000 gallons	M			●																			– Have a dedicated maintenance tank to hold contents of part, or all, of the closed-loop system. – Configure system such that spare equipment, such as a spare mechanical dewatering vessel, can be used to store water when other equipment is taken offline.
Failure of multiple conveyance pumps in hopper area resulting in flooding of water from area sump(s) that are incorporated in the closed-loop to other sumps/areas where the water could be discharged	170,000 gallons	M	●								●													– Add extra controls and piping to allow for multiple transfer pathways needed in case of failure of downstream equipment (such as interim pumps).
Purge to avoid corrosive conditions due to low pH water in bottom ash hopper overflow	500,000 gallons/day	WQ		●														●	●	●	●	●	●	– Add pH monitoring and control system (e.g., caustic injection). This may include controls and chemical addition systems at multiple locations in the closed-loop system, as acidic wastewater is sometimes associated with multiple units. Additionally, unless the system has a location with adequate mixing, multiple injections points may be necessary for precise pH control. – Add conductivity and/or corrosion monitoring. Corrosive conditions may still be observed because of salt addition from a caustic feed system. – Where feasible, include a purge to an FGD system. Where not feasible, the plant will need a salt-removal technology (RO, evaporation, crystallization, etc.).
Purge to avoid corrosive conditions from cycling up of makeup water supply's salts[b]	220,000 gallons/day	WQ							●	●		●												– Add conductivity and/or corrosion monitoring to set purge requirements to maintain non-corrosive conditions. – Where feasible, include a purge to an FGD system. Where not feasible, the plant will need a salt removal technology (RO, evaporation, crystallization, etc.).

Table 1-1
Summary of purges identified and potential solutions from interviews and/or study of 21 plants

Purge Driver/Description	Maximum Estimated Daily Purge Volume at Interviewed Plants[e]	Category[a]	Systems with Reported Issue (Blue are Dewatering Bins Systems, the others are RMDS Systems)																					Potential Mitigation Solutions (Some Solutions Already Implemented at Some Plants)
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	
Purge to avoid scaling conditions (*Some plants may experience scaling without realizing as it can go undiscovered for lengths of time*)[b,c]	N/A	WQ																						– Add pH monitoring/control and scaling control system (e.g., acid injection and antiscalant) to maintain water quality below scaling conditions. Unless the system has a location with adequate mixing, multiple injections points may be necessary for precise pH control. – Where feasible, include a purge to an FGD system. Where not feasible, the plant will need a softening or salt-removal technology (RO, evaporation, crystallization, etc.) to remove solids.
Purge to avoid corrosive conditions due to salt build-up from chemical addition to control pH and/or scaling (*expect some plants to experience as discharges from the partially closed-loop systems are eliminated*)[b]	N/A	WQ																						– Add conductivity and/or corrosion monitoring to set purge requirements to maintain non-corrosive conditions. – Where feasible, include a purge to an FGD system. Where not feasible, the plant will need a salt removal technology (RO, evaporation, crystallization, etc.).
Purge to remove fine solids from recirculated water supply not settled/removed by dewatering equipment[b]	N/A	WQ																						– Add turbidity monitoring to set purge requirements to maintain acceptable fine solids concentrations during non-sluicing conditions. – Add additional settling equipment (lamella plates, thickeners) and flocculants (polymers) for better solids removal. Effectiveness will be based on the characteristics (i.e., size, density) of the residual particulates. – Do not remove solids and perform increased maintenance to the closed-loop system because of solids accumulation in tanks and sumps, as well as plugging nozzles or small lines. – Include a purge to an FGD system and/or add filtration system to remove fines. The solids may need to be removed prior to the FGD because of the solids can have negative impacts on gypsum marketability or formation.

Notes:
[a] Category defines the purge driver as either: WI – Water imbalance issue due to excess water entering Loop, WQ – Purge to maintain water quality, M – Loss of water due to a maintenance event, L – leaks or line ruptures.
[b] Suspect that this may become a more frequent issue as "partially" closed-loop plants (most of the plants studied) implement further solutions to eliminate other purges, which assists with maintaining favorable water quality conditions.
[c] Five plants have reported scaling, but have been able to avoid a purge through pH control with sulfuric acid addition combined with other purges that have been routinely occurring. Scaling is difficult to predict based on standard scaling indices, which were not developed for the water quality typically found in ash transport water. Also, scaling is difficult to predict until equipment/system failures are observed. Once known/observed, scaling likely can be controlled with scale inhibitor (which only slows down the kinetics) or with pH control, usually sulfuric acid addition for preventing calcium scale (i.e., calcium carbonate). However, if the sulfuric acid demand is high enough, or is concentrated in the closed-loop via evaporation, then calcium sulfate (another scalant) could theoretically form. In this case, the plant would either need to use an alternative acid, such as hydrochloric acid (which could contribute to corrosivity issues), or purge water from the system to reduce the concentration of scaling ions.
[d] Storage capacity would need to be sufficient to hold excess water until that water can be bled into the loop as makeup water. Therefore, the amount of storage required will be dictated by frequency and magnitude of occurrences.
[e] The reported value shown is the maximum amount reported by the facilities interviewed. These values are often estimates or approximations; higher volumes could be observed. Actual flows are a range.

N/A = not applicable
NCMCW = nonchemical metal-cleaning waste
RMDS = Remote Mechanical Drag System
RO = reverse osmosis

For the seven systems at the six sites in the 2016 EPRI study, potential purge volumes for maintenance of equipment were estimated. The purge is shown relative to frequency and volume of recirculated water system or transport flow rate in **Tables 1-2** and **1-3**. Purge volumes as a percentage of the bottom ash recirculated water system's volume on a 30-day average are shown in **Table 1-2**. Examples of the calculations used in **Table 1-2** are described below:

- Purge volume averaged over 30 days, as percentage of recirculated water volume:
  Plant A's bottom ash system's volume is 560,000 gallons
  It is periodically drained (560,000 gallons/event)
  When drained, if averaged over 30 days: 560,000 gals ÷ 30 days = 18,667 gals/day
  18,667 gals/day ÷ 560,000 system volume = 3% purge/day as a % of system volume for system maintenance alone.

Table 1-3 summarizes the purge volumes as a percentage of the bottom ash transport water average flow, on annual 30-day average basis. An example of the calculations used for system maintenance alone in **Table 1-3** is described below:

- Percentage of average transport flow rate:
  Plant A's bottom ash system's average ash transport flow is 1,670,160 gals/day
  The ash system is periodically drained (560,000 gallons/event)
  It is drained every 5 years, so it occurs 0.2 times per year or once in any 30-day period
  560,000 gallons/event * 1 event (within 30 days) ÷ 30 days = 18,667 gals/day on average
  18,667 gals/day ÷ 1,670,160 gals/day = 1% average purge as a % of system flow

Table 1-2
Estimated annualized purges as reported by plants interviewed, including as a percentage of the bottom ash recirculated water system's volume
From interviews and/or study of seven plants

Plant	Volume of Recirculated Water System	Typical Purge Volume(s)	Potential Purge Frequencies	Purge Volume averaged over 30 days, as Percentage of Recirculated Water Volume
A	560,000 gallons	Dewatering system drain: 560,000 gals	1 per 5 years	3%
		Grinder/crusher or sluice door failure: 2,000-3,000 gals	2 times per year	<0.1%
		Active and spare hopper overflow tank pumps fail causing pumped overflow to sumps that discharge: 168,000 gals	1 per 5 years	1%
		Excess stormwater: 900,000 gals	1% chance annually for 24-hr, 100-yr event	5%[a]
		Flange/piping leaks: 14,200 gals (EPRI estimated)	1 per month	<0.1%[b]
		Sluice line rupture: 45,000 gals (EPRI estimated)	1 per 3 to 5 years	0.3%
B	2,000,000 gallons[c]	Hopper overflow: 504,000 gpd[c] (*amount could be reduced by addition of caustic system to treat acidity*)	Continuous[d]	25%

Table 1-2
Estimated annualized purges as reported by plants interviewed, including as a percentage of the bottom ash recirculated water system's volume
From interviews and/or study of seven plants

Plant	Volume of Recirculated Water System	Typical Purge Volume(s)	Potential Purge Frequencies	Purge Volume averaged over 30 days, as Percentage of Recirculated Water Volume
C	4,000,000 gallons	Service cooling water addition (recirculated BATW temperature too hot for economizer cooling water): 38,800 gpd[c] (250 gpm, instantaneous)	Continuous[d]	1%
		Grinder/crusher failure resulting in dumping the hopper contents: 15,000 gallons (EPRI estimated)	1 per year	<0.1%
		Sluice door leak: 4,320 or 5,760 gpd	Continuous[d]	0.1%
		Pump or other failure resulting in the overflow of interim tanks such as overflow tanks: 72,000 gallons (EPRI estimated)	1 per year	<0.1%
		Boiler tube leaks: 144,000 gallons (EPRI estimated)	1 per year	0.1%
		Sluice line rupture: 2,000 gpm for 30 to 90 minutes (EPRI estimated)	Once every 5 years	0.2%
		Chain jam during startup: 200,000 gallons	One-time event	2%

Table 1-2
Estimated annualized purges as reported by plants interviewed, including as a percentage of the bottom ash recirculated water system's volume
From interviews and/or study of seven plants

Plant	Volume of Recirculated Water System	Typical Purge Volume(s)	Potential Purge Frequencies	Purge Volume averaged over 30 days, as Percentage of Recirculated Water Volume
C	4,000,000 gallons	Maintenance of the RMDS system that requires a full or partial drain of equipment: 400,000 to 500,000 gallons	Once every 2 or 3 years	0.4%
		Inspect interior of RMDS: 200,000 gallons	1 per year	0.2%
		Plugged clarifier underflow pumps: 200,000 gallons	One-time event	0.2%
		Leaks around the hopper: 4,320 or 5,760 gpd (EPRI estimated)	Continuous[d]	0.1%
D	2,000,000 gallons	Settling and surge tank maintenance: 650,000 gallons per tank 1,300,000 gallons total[c]	1 per year	1%
E	2,000,000 gallons	Ash dewatering loop excess water purge: 17,200 gpd[c]	Continuous[d]	1%
		Settling and surge tank maintenance 650,000 gallons per tank 1,300,000 gallons total[c]	1 per year	1%

Table 1-2
Estimated annualized purges as reported by plants interviewed, including as a percentage of the bottom ash recirculated water system's volume
From interviews and/or study of seven plants

Plant	Volume of Recirculated Water System	Typical Purge Volume(s)	Potential Purge Frequencies	Purge Volume averaged over 30 days, as Percentage of Recirculated Water Volume
E	2,000,000 gallons	Purge of settling and storage tanks: 500,000 gallons total[c]	1 per year	2%
		Purge of settling and storage tanks: 600,000 gallons total[c]	1 per year	1%
F-1[e]	1,000,000 gallons	Purge of settling and storage tanks: 500,000 gallons total[c]	1 per year	2%
F-2[f]	2,000,000 gallons	Purge of settling and storage tanks: 600,000 gallons total[c]	1 per year	1%
G	2,000,000 gallons	Alternative 1: Corrosive conditions: 216,000 gpd (150 gpm) lake water as makeup water[c]	Continuous[d]	11%
		Alternative 2: Corrosive conditions: 2,160,000 gpd (1,500 gpm) using cooling tower blowdown as makeup water[c]	Continuous[d]	108%

Table Notes

[a] Assume a frequency of once per 30-days.

[b] Purge currently captured in the Plant's closed loop system. However, this can represent a typical purge at other plants. This purge is included in plant total volume calculation.

[c] Data from Electric Power Research Institute, Inc. (EPRI). 2016. Guidance Document for Management of Closed-Loop Bottom Ash Handling Water in Compliance with the 2015 Effluent Limitations Guidelines (ELGs).

Table 1-2
Estimated annualized purges as reported by plants interviewed, including as a percentage of the bottom ash recirculated water system's volume
From interviews and/or study of seven plants

Plant	Volume of Recirculated Water System	Typical Purge Volume(s)	Potential Purge Frequencies	Purge Volume averaged over 30 days, as Percentage of Recirculated Water Volume

[d] Continuous purge assumed to be 350 days per year and 1440 minutes per day.

gpd = gallons per day

[e] The bottom ash system also processes landfill leachate and non-chemical metal cleaning water. The flow of these waters into the loop is roughly 24,100 gpd. This inflow requires a similar purge flow, which accounts for 2% purge volume averaged over 30-days as a percentage.

[f] The bottom ash system also processes landfill leachate, coal-pile runoff, and non-chemical metal cleaning water. The flow of these waters into the loop is roughly 32,5000 gpd. This inflow requires a similar purge flow, which accounts for 2% purge volume averaged over 30-days as a percentage.

BA = bottom ash

gal/yr = gallons per year

gpd = gallons per day

gpm = gallons per minute

RMDS = Remote Mechanical Drag System

Table 1-3
Estimated annualized purges (as reported by plants interviewed) evaluated as a percentage of the bottom ash transport water average flow[a]
From interviews and/or study of seven plants

	Purge Event	Purge Event Details			Percentage of Average Transport Flow Rate	
Plant		**Frequency (times per year)[b]**	**Volume of Purge per Event (gallons)**	**Purge Averaged over 30-Days Flow Rate (gallons per day)**	**Average Transport Flow Rate (gallons per day)**	**Percentage of Average Transport Flow Rate**
A	Excess water, stormwater introduction	1[c]	900,000[c]	30,000	1,670,160	2%
	Leaks, flange/piping[d]	12	14,200[e]	473	1,670,160	<1%
	Loss around hopper, grinder/crusher or sluice door failure[d]	2	3,000	100	1,670,160	<1%
	Loss around hopper, active and spare hopper overflow tank pumps fail causing pumped overflow to sumps that discharge[d]	0.2	168,000	5,600	1,670,160	<1%
	Loss in transport, sluice line rupture	0.33	45,000[e]	1,500	1,670,160	<1%
	Maintenance requiring a full drain of equipment	0.2	560,000	18,667	1,670,160	1%
	Totals	***N/A***	***1,690,200***	***56,340***	***1,670,160***	***3%***
B	Corrosive conditions, acidic hopper overflow	350	504,000[e,f]	504,000	1,443,840	35%
	Totals	***N/A***	***504,000***	***504,000***	***1,443,840***	***35%***
C	Excess water, boiler tube leaks	1	144,000[e]	4,800	1,440,000	<1%
	Excess water, use of service water as hopper cooling water	350	38,800[e]	38,800	1,440,000	3%

Table 1-3
Estimated annualized purges (as reported by plants interviewed) evaluated as a percentage of the bottom ash transport water average flow[a]
From interviews and/or study of seven plants

	Purge Event	Purge Event Details			Percentage of Average Transport Flow Rate	
Plant		**Frequency (times per year)[b]**	**Volume of Purge per Event (gallons)**	**Purge Averaged over 30-Days Flow Rate (gallons per day)**	**Average Transport Flow Rate (gallons per day)**	**Percentage of Average Transport Flow Rate**
C	Leaks, miscellaneous around the hopper	350	5,760	5,760	1,440,000	<1%
	Loss around hopper, grinder/crusher failure resulting in dumping the hopper contents	1	15,000[e]	500	1,440,000	<1%
	Loss around hopper, pump or other failure resulting in the overflow of interim tanks such as overflow tanks	1	72,000[e]	2,400	1,440,000	<1%
	Loss around hopper, sluice door leak	350	5,760	5,760	1,440,000	<1%
	Loss in transport, sluice line rupture	0.2	180,000[e]	6,000	1,440,000	<1%
	Maintenance requiring a full or partial drain of equipment	0.5	500,000	16,667	1,440,000	1%
	Maintenance, chain jam during startup	1[g]	200,000	6,667	1,440,000	<1%
	Maintenance, inspect interior of RMDS	1	200,000	6,667	1,440,000	<1%
	Maintenance, plugged clarifier underflow pumps	1[g]	200,000	6,667	1,440,000	<1%
	Totals	***N/A***	***1,561,320***	***100,687***	***1,440,000***	***7%***
D	Maintenance, draining settling and surge tank	1	1,300,000	43,333	26,400	164%
	Totals	***N/A***	***1,300,000***	***43,333***	***26,400***	***164%***

Table 1-3
Estimated annualized purges (as reported by plants interviewed) evaluated as a percentage of the bottom ash transport water average flow[a]
From interviews and/or study of seven plants

	Purge Event	Purge Event Details			Percentage of Average Transport Flow Rate	
Plant		**Frequency (times per year)[b]**	**Volume of Purge per Event (gallons)**	**Purge Averaged over 30-Days Flow Rate (gallons per day)**	**Average Transport Flow Rate (gallons per day)**	**Percentage of Average Transport Flow Rate**
E	Excess water, refilling hydrobins with service water and processing of miscellaneous non-transport flows	350	17,200	17,200	2,000,000	<1%
	Maintenance, draining settling and surge tank	1	1,300,000	43,333	2,000,000	2%
	Totals	***N/A***	***1,317,200***	***60,533***	***2,000,000***	***3%***
F-1[h]	Maintenance, draining settling and surge tank	1	500,000	16,667	198,000	8%
	Totals	***N/A***	***500,000***	***16,667***	***198,000***	***8%***
F-2[i]	Maintenance, draining settling and surge tank	1	600,000	20,000	396,000	5%
	Totals	***N/A***	***600,000***	***20,000***	***396,000***	***5%***
G	Corrosive conditions (using cooling tower blowdown for makeup[j])	350	2,160,000	2,160,000	Not available	N/A
	Corrosive conditions (using lake water for makeup[j])	350	216,000	216,000	Not available	N/A
	Totals (using cooling tower blowdown for makeup[j])	***N/A***	***216,000***	***216,000***	***N/A***	***N/A***
	Totals (using lake water for makeup[hj])	***N/A***	***2,160,000***	***2,160,000***	***N/A***	***N/A***

Table 1-3
Estimated annualized purges (as reported by plants interviewed) evaluated as a percentage of the bottom ash transport water average flow[a]
From interviews and/or study of seven plants

Purge Event	Purge Event Details			Percentage of Average Transport Flow Rate	
Plant	**Frequency (times per year)[b]**	**Volume of Purge per Event (gallons)**	**Purge Averaged over 30-Days Flow Rate (gallons per day)**	**Average Transport Flow Rate (gallons per day)**	**Percentage of Average Transport Flow Rate**

Notes:

[a] Interviews are ongoing; information in this table may be updated to reflect new information and new plants.

[b] Time-weighted on an annual basis. For example, if the frequency of a purge occurs every 5 years, then the volume will be divided by 5 to determine an annual loss. Lowest frequency used for calculation (i.e., highest percentage calculated).

[c] Volume estimated by EPRI.

[d] Purge based on a 24-hour, 100-year storm event that has a 1 percent chance of occurring on a given year. It is assumed that this will occur once a year.

[e] Plant's system is currently configured such that this water is captured rather than discharged (purged). It has been included because this could represent a purge at other plants.

[f] It is anticipated that the purge volume from Plant B could be reduced, or eliminated, with the addition of a caustic system.

[g] Assumed to be a 1-time occurrence that will be prevented with operational modifications.

[h] The bottom ash system also processes landfill leachate and non-chemical metal cleaning water. The flow of these waters into the loop is roughly 24,100 gpd. This inflow requires a similar purge flow, which accounts for 12% purge volume averaged over 30-days as a percentage.

[i] The bottom ash system also processes landfill leachate, coal-pile runoff, and non-chemical metal cleaning water. The flow of these waters into the loop is roughly 32,5000 gpd. This inflow requires a similar purge flow, which accounts for 8% purge volume averaged over 30-days as a percentage.

[j] Plant G has two possible water makeup sources, with the cooling tower blowdown requiring higher purges because of its higher salinity.

RMDS = Remote Mechanical Drag System

Setting Limits on Allowable Purges

If EPA were to allow some discharge of water to be purged from the bottom ash loop, some means of regulating the purge may be needed. In considering how to regulate purges, it should be noted that the current 2015 ELG rule does allow for water to be sent from a remote bottom ash system because of "minor maintenance" and "minor leaks" to a National Pollutant Discharge Elimination System (NPDES) permitted discharge point. Possible approaches to modifying how purges would be regulated include:

- "Water quantity"-driven purges, i.e., setting a limit on the amount of water that can be purged from the bottom ash system (i.e., volumetric approach) due to both process water quantity and other quantity (e.g., storm events) issues.;
- Expanding the definition of "maintenance" and "leaks" that are allowed to be discharged from the loop beyond the current regulation to allow discharges of larger quantities of water that would be present in RMDS or other equipment to facilitate inspection and maintenance/repair of that equipment; and
- "Water quality"-driven purges, i.e., allowing for discharges to maintain water quality in the loop to prevent corrosion or scaling, per a prescribed metric.

Setting Allowable Purges based on Water Quantity Imbalance, Maintenance, and Leaks

Information from plant interviews on necessary water quantity purges provides insights on reasons for purges experienced in normal plant operations. The amount of purge from bottom ash loops at seven sites previously studied by EPRI ranged from 1.3 to 19 MG/yr, excluding purges driven by water quality.

A possible approach to setting allowable purges to account for differences in plant size is the purge as either a percentage of the volume of the BATW system or recirculating flow rate. Using percentage of volume of the BATW system is illustrated in **Table 1-2.** Using the purge as a percentage of the recirculating flow rate through the BATW system is illustrated in **Table 1-3**. In using either approach, it would be important to average the flow over a sufficient time period to account for infrequent-but-large purges.

At the seven sites included in **Table 1-2**, the largest single type of purge event at each plant ranged from 1 to 5 percent of the system volume if averaged over 30 days (the higher values at Plants B and G are related to water quality, not quantity). It is possible that multiple events could occur simultaneously, making the requisite purge higher (such as if at Plant A the system had to be drained when there was a large rain event, requiring a purge of 5 percent plus an additional 3 percent, or 8 percent of the volume). Because seven plants reflect a small portion of the hundreds of plants in the industry, it is assumed that some plants will require significantly more purging. If this metric were used to set allowable purge, the percent of the volume would ideally incorporate this limited data set to provide operational flexibility for the broader industry.

Setting a national limit on allowable purges based on planned outage frequency is problematic and would ideally account for an estimated number of unplanned outages as well as the number of "planned" outages, especially as the equipment ages. If a maximum purge rate for each site

were based on a set number of planned outages, then flows from unplanned outages would have to be stored to comply with the allowance.

Expanding the definition under the current regulations of allowable purges would include encompassing all possible leaks and maintenance conditions. Because of the lack of data on all potential leaks and maintenance conditions available, creating such a comprehensive list would be impossible. However, a comprehensive list would be required in order to minimize regulator interpretation of what is considered an allowable purge under the regulation. A disadvantage is that if a type of leak or maintenance was not included in list, it may limit operational flexibility.

Setting Allowable Purges based on Water Quality

Because water quality-driven purge flows can be significant, addressing them separately from maintenance or leak drivers can provide operational flexibility. For example, at Plant G the buildup of corrosive salts led to purging roughly 2 million gallons per day, which is several times the average daily purge rate driven by other drivers such as in-leakage from storm events.

The corrosivity of the transport water increases as the concentration of salts and the ionic strength cycle up due to repeated contact with ash, evaporation of clean water from the loop, and addition of chemical feeds (i.e., caustic or acid). Corrosion can be influenced by multiple factors, but chloride is a leading contributor to corrosion in recirculated water systems, including bottom ash systems. Three of the interviewed plants (Plants G, H, and J) reported associated issues with chlorides.

One plant interviewed was purging because of low pH conditions by discharging water and replacing it with fresh (more neutral) water, leading to large purges—up to an estimated 33 percent of the BATW flow rate (Plant B, **Table 1-3**). It may be possible to reduce purge volumes needed because of low or high pH by adding caustic or acid feeds. (which could lead to corrosion). However, purges driven by the buildup of salts that cause corrosion or scaling are more challenging because of complex and expensive treatment requirements. One example (Plant G) required purging roughly 220,000 gallons per day because of corrosive salt accumulation. This plant's influent water was from a water body with salinity on the higher end of the spectrum of salinity found in U.S. water bodies, so other plants likely would require less purging to maintain acceptable conditions. The quantity of water that must be purged to maintain water quality conditions in the bottom ash loop will be site-specific; it is recommended that these purges be based on a monitored parameter, such as conductivity as described below, particularly if the source water contains higher than average salinity.

Carbon steel is the predominant metallurgy in most bottom ash systems. The concentration of chlorides that creates a corrosion risk for carbon steel is influenced by multiple factors, including dissolved oxygen, water velocity, temperature, and pH.[4] It is also important to note that other metallurgies may exist in the closed-loop process (e.g., pumps, valves, elbows, meters); these will have different chloride tolerances than carbon steel, some of which may be less tolerant.

Defining how much water could be purged for such a water quality-driven need has some challenges, including:

---

[4] Winston, Revie R. 2011. *Uhlig's Corrosion Handbook*. John Wiley and Sons.

- Monitoring of water quality in the loop to predict the scaling or corrosion is challenging because of the complex water chemistry involved in scaling or corrosion. Chlorides are often targeted as corrosion markers but other constituents may be present that can cause scaling before corrosion occurs.
- Currently there are no known reliable, in-line, real-time chloride monitors to allow a purge simply by defining a chloride level in the BATW loop at which water could be purged. Therefore, frequent sampling of the water for analysis would be required. Alternately, some wet FGD operators have established an empirical correlation between density and chlorides (within certain ranges of coals) that may also be used as a surrogate here as well.
- Conductivity can be a good surrogate for chloride and other corrosive species, and may also give insight on scaling conditions. As shown in **Table 1-4**, the correlation between chloride (Cl-) concentrations and conductivity is somewhat inconsistent between plants. Conductivity targets could be determined on a plant-by-plant basis. However, conductivity targets may need to be adjusted if the composition of the water quality significantly changes, either due to seasonal service water quality differences, addition of other process waters (e.g., washes, cooling tower blowdown), coal switches, or generation swings (salts contributed by ash contact). This approach would require ongoing studies for most cost-fired plants due to changes in generation swings which is now the norm for most coal-fired plants.
- Alternatively, EPA could work with individual plants to define the conductivity at which water could be purged from the BATW loop. Because it appears that the need to purge due to water quality issues is limited to a subset of the industry, those plants affected could work with their permit writers to set a reasonable purge metric.

Table 1-4
Summary of Chloride and TDS Data Compared to Conductivity Readings

Plant	Cl (mg/L)	Conductivity (µS/cm)	Ratio of Conductivity to Chloride
A	30	804	27
B	7	321	46
C	6	360	60
C	11	400	36
C	19	412	22
D	73	3,690	51
D	106	4,866	46
E	3	1,137	379
F	80	1,700	21

Notes:
mg/L = milligrams per liter
µS/cm = microSiemens per centimeter

Monitoring Purge Quantity

If the 2015 ELG rule were modified to allow water to be purged from the loop and eventually discharged, a means of tracking the purge may be required. Possible means include:

- Water Quantity-Driven purges: Modify the system so that excess water primarily is purged from the bottom ash system through only a small number of points and is measured with a flow meter and totalizer[5] or rainfall quantity estimates.
- Measuring Losses from Maintenance-Related or Leak-Related Incidents: Estimate and log losses on a case-by-case calculation (e.g., water lost because of maintenance on a tank could be approximated by the amount of water stored in that tank).
- Water Quality-Driven purges: This would require monitoring of the water quality to indicate when purging is needed. Measuring the purged volume also could be done with a flow meter and totalizer.

[5] A flow totalizer logs a running total of how much liquid has passed by the flow meter within a given time.

2
HYPOTHETICAL CASE STUDY EXAMPLES AND ASSOCIATED COSTS TO ACHIEVE CLOSED-LOOP DESIGN

In the following sections, EPRI estimates total installed costs to implement solutions that eliminate one or more of the purges identified in **Table 1-1** in order for an existing dewatering system to comply with the 2015 ELG rule. Also included is the cost of treating and discharging a purge, if such a discharge were to be allowed in EPA's reconsidered rule. The costs developed are screening level estimations; actual cost estimates would need to account for challenges unique to a given site. Therefore, the estimated costs can vary widely and EPRI members may have estimated or actual costs for their individual systems that exceed the values listed in the following sections.

The costs for some solutions, such as modifications around the bottom ash hopper, were not estimated because of the potential order-of-magnitude differences between costs by plant. The cost estimates presented are developed using the methodology for a Class 4 estimate as defined by Association for the Advancement of Cost Engineering International (AACEI) 2011 guidance, including factored equipment costs and parametric models. Typically, the accuracy range for a Class 4 estimate for the process industries is as broad as +50 percent/-30 percent to as narrow as +20 percent/-15 percent, depending on the technical complexity of the project, the availability of appropriate cost reference information, the degree of project definition, and the inclusion of appropriate contingency determination. Costs have been developed using cost curves and vendor quotes. Allowances have been assumed for other direct and indirect costs to calculate a total installed cost. The final costs of a project will depend on actual labor and material costs, competitive market conditions, actual site conditions, final project scope, implementation schedule, continuity of personnel and engineering, and other variable factors. Annualized costs were calculated by adding annual operations and maintenance (O&M) costs to the capital costs annualized assuming 20-year life and 7 percent interest.

It is assumed that to be discharged, at a minimum, purge waters would need to comply with best practicable control technology (BPT) limits for BATW on total suspended solids (TSS) and oil and grease (O&G)—most notably the 30 milligrams per liter (mg/L) TSS limit (**Table 2-1**). O&G presumably would be controlled through good operational practices.

Table 2-1
BPT limitations for bottom ash transport water

Parameter	Monthly Average Limit (mg/L)	Daily Maximum Limit (mg/L)
TSS	30	100
O&G	15	20

Based on available EPRI TSS data of bottom ash systems (**Table 2-2**), most purge waters would require further treatment for TSS removal.

Table 2-2
Solids removal performance of dewatering systems

Plant	Time Weighted TSS[a] (mg/L)	Number of Analyses
A	190	3
B	232	1
C	81[b]	2
D	253	2
E	462	2
F-1	4	1
F-2	21	1
G	28	9

Notes:

[a] TSS is calculated using the respective maximum TSS data recorded during periods of ash sluicing and in-between ash sluicing. These maximum concentrations were multiplied by the fraction of time the equipment processed either sluicing or in-between ash sluicing conditions to estimate the water quality of a 24-hour composite (i.e., $TSS_{sluicing}$ × time fraction sluicing + $TSS_{not\text{-}sluicing}$ × time fraction between sluices). This calculation could not be performed on Plant G because of the lack of operations information on sample collection (i.e., could be during or between sluicing conditions); the value shown is the average of the available data and may not be representative of daily variability.

[b] System was designed to achieve TSS limits in **Table 2-1**; it is assumed performance could be improved through chemical optimization.

The amount of treatment required for a purge stream, and therefore cost, is dependent on several factors. One consideration is whether the ash dewatering system can settle solids out of the recirculated ash water sufficiently to meet the BPT limits. Another consideration is whether a plant has a separate tank-based treatment system or a coal combustion residual (CCR)-compliant impoundment that has capacity to treat the bottom ash purge sufficiently to reduce TSS to the BPT limits. If either the dewatering system meets TSS limits or an existing solids removal treatment system has capacity for the purge, then additional treatment costs likely would be minimal. However, if the purge needs further TSS removal and there are no existing treatment facilities (or the facility is using ponds that are being closed to comply with the CCR rule), costs likely will be considerable and will depend on the flow and on the quantity of solids that need to

be removed. For estimating the cost of treating this purge, EPRI has considered the purge drivers, solids loading, and availability of other existing treatment facilities to estimate the equipment needed to treat the purge. These are outlined in the hypothetical case studies below.

Hypothetical Case Study 1 ("Plant 1"): Cost of Additional Water Storage for Water Imbalances and Maintenance Events

Hypothetical Plant 1 can experience multiple water imbalance and maintenance purge drivers from **Table 2-1**, including draining the dewatering system for maintenance (1,500,000 gallons), local stormwater addition (900,000 gallons), and boiler tube leaks (144,000 gallons). There is a risk that all three events could occur at the same time. A possible approach to eliminate water discharge would be for the plant to install tanks capable of holding the total volume of the individual events (approximately 2,600,000 gallons). This would cost roughly $9 million, assuming two 1,300,000-gallon tanks. Annual O&M costs are estimated as $110,000. Annualized costs would be $960,000 per year. Alternately, the plant may be able to implement lower cost best management practices to address some of the stormwater addition, thus lowering costs to eliminate the purge.

Hypothetical Case Study 2 ("Plant 2"): Cost for Eliminating Purge due to Recirculated Water Quality Requirements

Hypothetical Plant 2's dewatering system dewaters economizer ash and bottom ash. Cooling water for the ash hoppers, a non-transport water, must be incorporated into a recirculated, closed-loop system since this water exits with the ash during sluicing (ash transport) operations. This leads to excess water in the closed-loop system because water temperatures exiting the dewatering system can be as high as 120 degrees Fahrenheit (°F) because of the short residence time in the dewatering equipment. These water temperatures are too high to use the recirculated water as makeup for cooling water for the economizer ash hoppers, thus fresh service water is introduced into the loop. The amount of excess water that is purged out of the loop is approximately 38,800 gpd.

A possible approach to address the recirculated water temperature issue so that 'fresh' excess water is not needed would be to add two heat exchanges and cooling water supply/piping such that ash loop water can be used for cooling the ash hoppers. The estimated cost would be $230,000, with annual O&M costs of approximately $30,000. Annualized costs would be $52,000 per year.

3
ENVIRONMENTAL IMPACTS VERSUS COSTS TO CLOSE THE LOOP

An environmental benefit is defined as the reduction or elimination of the amount of pollutants in the wastewater from additional treatment compared to no additional treatment. EPA has traditionally used the metric, cost per toxic-weighted pound equivalents removed annually ($/TWPE) in ELG rulemakings to estimate cost-benefit of regulatory change. The environmental benefit of eliminating most BATW purge discharges is small, especially when solutions cost in the hundreds of thousands to millions of dollars.

Table 3-1 summarizes costs to eliminate the purge from each of the two case studies in Section 2 compared to the environmental benefit. Costs are shown in current dollars as well as 1981 cost-equivalent, because EPA has used 1981 dollars for cost-comparisons in other ELG evaluations. The environmental benefit was calculated assuming 3.11×10^{-6} TWPE per gallon bottom ash water; this is based on the median concentration data from a limited set of partially closed-loop systems' bottom ash transport water after subtracting out the service water contributions (Appendix A summarizes the data supporting the median concentration). The additional cost to eliminate these purges and maintain closed-loop operations in compliance with the 2015 ELG rule can be tens of millions of $/TWPE removed annually for simple solutions (e.g., caustic injection system), but can be much higher, for complex solutions (e.g., building and maintaining storage tanks for equipment maintenance such as RMDS). These $/TWPE removed are well above what EPA has used historically as a reasonable cost effectiveness as demonstrated by Plant 1's costs.

Estimating cost-effectiveness for addressing other purge discharges is difficult because their volumes, and therefore environmental benefits, are low. For example:

- Upgrading sluice line piping (two ruptures per year would be approximately 360,000 gallons or 1 TWPE per year)
- Boiler modifications (two of each leak, maintenance, or failure event around the boiler described in Table 1-1 annually would be approximately 2,112,000 gallons or 7 TWPE per year)
- Purge to control corrosive salt accumulation (77,000,000 gallons or approximately 240 TWPE per year)

Table 3-1
Summary of costs versus economic benefits of eliminating purges

Case Study	Description of Approach to Eliminate Purge	Annualized Cost[a]	Gallons Per Year	Environmental Benefit (TWPE per Year)	Cost Per TWPE Removed
#1	Addition of maintenance tanks and return pumps	Current $: 960,000 198 $: 318,000	5,600,000	17[b]	Current $: $55,000 1981 $: $18,000
#2	Addition of heat exchangers to provide water temperatures needed for economizer ash hopper cooling water	Current $: 52,000 198 $: 17,000	13,600,000	42[c]	Current $: $1,200 1981 $: $400

Notes:
[a] Calculated based on 20 years and 7 percent interest.
[b] Assumes that each purge event (stormwater introduction, boiler tube leaks, draining dewatering system) occurs twice a year.
[c] Assumes 350 days per year operation.

Environmental Impact of Purges by Plant

As another means of demonstrating the small environmental benefit of completely eliminating purges from a closed-loop bottom ash system versus a high recycle system bottom ash system, EPRI has calculated the TWPE of the purge water based on data collected at seven sites **(Table 3-2)**. Purge flow and bottom ash water data were used to calculate the TWPE of current purges after then subtracting the mass of TWPE contributed by the system makeup water, where data were available. Several notable observations were made:

- Plants D and E have the highest TWPE concentration (per volume purged); however, these systems receive other wastewaters that were not analyzed separately and therefore could not be subtracted with the makeup water contributions to determine net TWPE discharges due to the introduction of bottom ash.
- Plant F's two systems (F-1 and F-2) process wastewaters such as landfill leachate and coal pile runoff along with bottom ash transport water; for F-2, the coal pile runoff water is estimated to account for approximately 20 percent of the TWPE.
- With the exception of Plant A, aluminum was a significant contributor (approximately 20 to 75 percent) of the TWPE from the six sites (Plants A – F); subsequent data suggest much of this aluminum is particulate in nature and could be removed through further settling or treatment such that a differential benefit between no discharge and high recycle would be smaller.

- The average of TWPE per year of purge water as shown in **Table 3-2** was calculated to be 125, or only 3 percent of EPA's[6] calculated TWPE per year of 4,183 on average per plant.
- The average of TWPE per year of purge water, (accounting for background water quality where known) is 106, or 2.5 percent of EPA's calculated values as shown in **Table 3-2.**

Table 3-2
Annual TWPE of estimated purges from partially closed-loop bottom ash dewatering systems

Site	Total Purge Volume	Purge Water (TWPE/yr)	Purge Minus Make-Up Water Contributions (TWPE/yr)
A	1,186,000	6	3
B	169,200,000	456	455
C	17,960,000	51	42
D	1,300,000	19	19
E	7,316,000	143[b]	Insufficient data[b]
F-1[c]	8,422,000	11	9
F-2[c]	11,381,000	48	37
G	75,600,000	264	181[d]
Average	**31,120,000**	**125**	**106**

Notes:

[a] Assumes 350 days of operation.

[b] Plant E frequently uses low-volume wastewaters as makeup water, such as demineralizer wastewater, or reverse osmosis reject wastewater. These wastewaters were not analyzed and therefore are not accounted for in the calculation subtracting out the TWPE mass from makeup water contributions.

[c] Plant F frequently uses its dewatering systems to process coal-pile runoff, landfill leachate, and non-chemical metal cleaning water. With the exception of coal-pile runoff, EPRI was unable to quantify the TWPE mass contributions of these non-bottom ash contributions. Therefore, the value included is an overestimate of TWPE for Plant F.

[d] Plant G's makeup adjusted calculation is based on use of cooling tower blowdown as the makeup supply water with an estimated flow loading of 150 gpm (the actual makeup demand was not measured). Cooling tower water is one of two sources of makeup water to the bottom ash loop. The other is plant service water. The net TWPE was computed for the cooling tower water as source scenario only.

TWPE/yr = toxic-weighted pound equivalent per year

[6] EPA's calculated value based on 481,000 TWPE/yr divided by 115 plants as displayed in Table 10-14 in U.S. Environmental Protection Agency (EPA). 2015 Technical Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category

4
SUMMARY

There are multiple challenges to implementing the 2015 ELG rule's requirement of no discharge of BATW. Plants will find it costly to completely eliminate all discharges if excess water cannot be repurposed to the FGD or other no discharge uses in order to comply with a no discharge requirement for BATW. Costs to eliminate many of the purges are disproportionately high (millions of dollars in initial capital cost range) compared to volumes and pollutant loading of these purges. The amount of BATW purge(discharge) in a high recycle system would be a small fraction of the amount of bottom ash water discharged at plants not recycling their bottom ash transport water, even if purges at these plants were allowed under the revised ELG. In the U.S. Environmental Protection Agency's (EPA) 2015 Technical Development Document , the average per plant BATW discharge is reported as 2.1 million gallons per day averaged over the course of a year, or 750 million gallons per year. The amount in a purge sufficient to give operational flexibility would be one to two orders of magnitude lower than this.

Operational flexibility and environmental protection could be achieved by modifying the 2015 ELG to both:

- Allow a purge as a percent of the volume of the bottom ash loop, averaged over a sufficient period of time, and
- At those plants that need additional purging, such as due to the source water's salinity being sufficient to cycle up to corrosive conditions, allow for a purge if the water reaches levels that are corrosive to the metallurgy of the loop.

A
TWPE CALCULATION

		EPRI Bottom Ash Closed-Loop Study Plant A									EPRI Bottom Ash Closed-Loop Study Plant B								
		Bituminous									Bituminous								
		Second (In Series) SFC									Overflow from Active SFC								
		Source Water		BA Closed-Loop Water			Purge Water	Ash Solids	BA Subtracting out Source Water	BA Subtracting out Source Water and adjusting to purge volume*	Source Water		BA Closed-Loop Water			Purge Water	Ash Solids	BA Subtracting out Source Water	BA Subtracting out Source Water and adjusting to purge volume*
Flow rate, gpd:		29,920					3,389	3,379		3,389	14,952					104,000	3,293		
Frequency, dpy:		365					365	365			365					365	365		
Flow rate, Mgpy		9.6					1.2	1.1		1.2E-06	5.4					37.9	1.2		
Fraction of Sluicing/Non sluicing				0.75	0.25								0.50	0.50					
Additional description				Non Sluicing	Sluicing	Time Adjusted (Aw)							Non Sluicing	Sluicing	Time Adjusted (Aw)				
Analyte	TWF	Concentration (ug/L)	TWPE/year	Concentration (ug/L)	Concentration (ug/L)	Concentration (ug/L)	TWPE/year	TWPE/year	Concentration (ug/L)	TWPE/year	Concentration (ug/L)	TWPE/year	Concentration (ug/L)	Concentration (ug/L)	Concentration (ug/L)	TWPE/year	TWPE/year	Concentration (ug/L)	TWPE/year
Aluminum	0.064691216	939	5	1,993	2,588	1,866.88	1	1	526	0	12	0	1,270	3,240	2,255	235	1	2,243	0
Antimony	0.01225									0									0
Arsenic	4.041333333	0.5	0	84.9	83.3	84.49	3	4	84	0	0.3	0	21.7	29.9	26	153	1	25	0
Barium	0.000990757									0									0
Beryllium	1.016609774									0									0
Boron	0.008341867	34	0	476	467	473.25	0	0	439	0	87	0	129	161	145	2	0	58	0
Cadmium	23.1358	0.0	0	0.1	0.2	0.10	0	0	0	0	0.0	0	0.2	0.4	0	11	0	0	0
Calcium	0.000028	6,410	0	41,733	41,950	41,787.50	0	0	35,378	0	46,700	0	48,800	50,900	48,850	2	0	3,150	0
Chromium	0.075696708									0									0
Cobalt	0.114285714									0									0
Copper	0.634823222									0									0
Iron	0.0051	1,040	0	793	2,095	1,103.50	0	0	54	0	20	0	1,280	3,150	2,220	58	0	2,200	0
Lead	2.24									0									0
Magnesium	0.000865533	2,735	0	3,883	3,585	3,433.75	0	0	719	0	7,900	0	7,980	8,240	8,135	30	0	235	0
Manganese	0.070432298	36	1	39	67	45.88	0	0	-	0	8	0	22	29	25	3	0	37	0
Mercury	117.1180238	0	0	0	0	0.00	0	0	-	0	0	0	0	0	0	1	0	0	0
Molybdenum	0.200438848									0									0
Nickel	0.108914308									0									0
~~Potassium~~	0.000052843									0									0
Selenium	1.121348	0.3	0	2.8	2.7	2.80	0	0	1	0	0.1	0	1.1	1.2	1	2	0	1	0
Silver	16.47072824									0									0
Sodium	0.00000548	14,500	0	33,700	35,500	34,150.00	0	0	19,650	0	4,710	0	4,790	4,930	4,850	0	0	140	0
Thallium	1.027058824									0									0
Tin	0.900075268									0									0
Titanium	0.029319372									0									0
Vanadium	0.035									0									0
Zinc	0.046886									0									0
Chloride	<0.0000248	11,800	0	24,700	25,900	24,975.00	0	0	13,175	0	7,020	0	7,140	7,130	7,125	0	0	105	0
Sulfate	<0.0000051	9,800	0	65,350	68,900	66,462.50	0	0	56,663	0	18,500	0	27,400	28,600	28,500	0	0	10,000	0
Nitrate/Nitrite	0.0095			1,230	1,140	1,192.50	0	0		0	3,350	0	1,960	1,980	1,970	5	0	20	0
Ammonia-N	0.001111									0									0
Fluoride	0.035	67	0	183	149	174.63	0	0	106	0	320	0	320	320	320	36	0		0
Sulfide (as S)	2.800466667	22	5	22	58	31.13	1	1	9	0	4	0	4	4	4	36	0	-	0
Cyanide	1.116923077	2	0	3	4	2.90	0	0	1	0	0	0	0	0	0	0	0	-	0
Hexavalent Chromium	0.516557576									0									0
TOTAL			12				6	6		3		2				456	3		455

Flag Descriptions:

< – Result below the MDL.

Note 2 - Hg results determined by the least sensitive methods, Methods 245.1 and 245.2, were all reported as non-detect (< 0.2 ppb). Only Hg measurements using the most sensitive methods were used.

Calculation Description:

* - BA Subtracting out Source Water and adjusting to purge volume (M_p) was calculated using the following formular:

$$M_p = \frac{T_p}{Q_p \cdot T_{ext}} \left(Q_p \cdot A_w - Q_s \cdot T_s \cdot A_s + Q_{ext} \cdot T_{ext} \cdot A_s \right)$$

Q_p - Purge flow rate
Q_{ext} - Water exiting with dewatered ash solids flow rate
T_p - Purge frequency
A_w - Weighted closed-loop water quality based on non-sluicing and sluicing conditions
Q_s - Source water flow rate
T_s - Source water frequency
A_s - Source water analyte
T_{ext} - Water exiting with dewatered ash solids frequency

		EPRI Bottom Ash Closed-Loop Study Plant C									EPRI Bottom Ash Closed-Loop Study Plant D								
		Bituminous									Sub-Bituminous (PRB)								
		Overflow from Thickener									Overflow from Surge Tank								
		Source Water		BA Closed-Loop Water			Purge Water	Ash Solids	BA Subtracting out Source Water	BA Subtracting out Source Water and adjusting to purge volume*	Source Water		BA Closed-Loop Water			Purge Water	Ash Solids	BA Subtracting out Source Water	BA Subtracting out Source Water and adjusting to purge volume*
Flow rate, gpd:		89,062					51,372	2,203			1,737					3,562	955		
Frequency, dpy:		365					365	365			365					365	365		
Flow rate, Mgpy		32.5					18	0.8			0.6					1.3	0.3		
Fraction of Sluicing/Non sluicing				0.75	0.25								0.92	0.08					
Additional description				Non Sluicing	Sluicing	Time Adjusted (Aw)							Non Sluicing	Sluicing	Time Adjusted (Aw)				
Analyte	TWF	Concentration (ug/L)	TWPE/year	Concentration (ug/L)	Concentration (ug/L)	Concentration (ug/L)	TWPE/year	TWPE/year	Concentration (ug/L)	TWPE/year	Concentration (ug/L)	TWPE/year	Concentration (ug/L)	Concentration (ug/L)	Concentration (ug/L)	TWPE/year	TWPE/year	Concentration (ug/L)	TWPE/year
Aluminum	0.064892218	54	1	862	816	849.28	8	0	796	0	26	0	9,129	12,455	9,398	7	1	9,372	0
Antimony	0.03229									0									0
Arsenic	4.04193333	0.4	0	34.8	26.3	33.25	20	1	33	20	0.8	0	22.8	24.0	23	1	0	22	0
Barium	0.001990757									0									0
Beryllium	1.056609774									0									0
Boron	0.008341867	30	0	280	305	286.25	0	0	276	0	36	0	25,800	25,500	25,317	2	0	25,281	0
Cadmium	23.3168	0.0	0	0.3	0.1	0.07	0	0	0	0	0.2	0	0.2	0.2	0	0	0	-	0
Calcium	0.0000038	34,600	0	39,050	41,650	39,700.00	0	0	5,100	0	163,500	0	728,000	725,500	727,792	0	0	586,292	0
Chromium	0.075686709									0									0
Cobalt	0.114285714									0									0
Copper	0.634822222									0									0
Iron	0.0058									0	240	0	4,280	5,815	4,408	0	0	4,168	0
Lead	2.24									0									0
Magnesium	0.000865333	10,450	2	10,750	10,500	10,787.50	1	0	138	0	89,050	0	104,350	103,350	104,267	1	0	15,217	0
Manganese	0.07043298	53	3	83	88	84.40	1	0	32	0	15	0	37	47	38	0	0	23	0
Mercury	117.1180038	0	0	0	0	0.00	0	0	0	0	3	2	0	0	0	0	0	-	0
Molybdenum	0.201438848									0									0
Nickel	0.108514308									0									0
Potassium	0.000052632									0									0
Selenium	1.121344	0.4	0	7.8	7.7	7.67	1	0	7	0	1.8	0	17.7	18.4	18	0	0	16	0
Silver	16.47072824									0									0
Sodium	0.00000598	6,325	0	5,690	10,215	9,821.25	0	0	3,496	0	38,100	0	446,000	449,000	446,250	0	0	408,150	0
Thallium	1.007058824									0									0
Tin	0.026075168									0									0
Titanium	0.009319172									0									0
Vanadium	0.032									0									0
Zinc	0.046886									0									0
Chloride	0.0000043	5,375	0	8,540	8,450	8,762.50	0	0	3,388	0	33,150	0	98,050	103,500	98,504	0	0	65,354	0
Sulfate	0.0000056	19,300	0	63,000	90,850	18,932.50	0	0	50,863	0	353,500	0	2,605,000	2,600,000	2,604,583	0	0	2,453,084	0
Nitrate/Nitrite	0.0032	560	0	650	750	675.00	0	0	115	0	3,600	0	104,800	102,450	104,604	4	1	101,004	0
Ammonia-N	0.00113									0									0
Fluoride	0.035	165	2	315	450	348.75	2	0	184	0	285	0	1,520	2,120	1,570	3	0	1,285	0
Sulfide (as S)	1.801466667	4	3	37	39	37.15	16	1	33	20	4	0	104	108	104	3	0	100	0
Cyanide	1.136923077	0	0	0	0	0.00	0	0	0	0	0	0	0	0	0	0	0	-	0
Hexavalent Chromium	0.516557576									0									0
TOTAL			10				51	2		42		3				19	3		19

		EPRI Bottom Ash Closed-Loop Study Plant E									EPRI Bottom Ash Closed-Loop Study Plant F-1								
		Sub-Bituminous (PRB)									Bituminous/Sub-Bituminous (PRB)								
		Overflow from Surge Tank									Overflow from Surge Tank								
		Source Water		BA Closed-Loop Water			Purge Water	Ash Solids	BA Subtracting out Source Water	BA Subtracting out Source Water and adjusting to purge volume*	Source Water		BA Closed-Loop Water			Purge Water	Ash Solids	BA Subtracting out Source Water	BA Subtracting out Source Water and adjusting to purge volume*
Flow rate, gpd:		61,074					26,844	684			30,000					26,844	185		
Frequency, dpy:		365					365	365			365					365	365		
Flow rate, Mgpy		22.3					7.3	0.22			10.5					9.8	0.04		
Fraction of Sluicing/Non sluicing				0.83	0.17								0.83	0.17					
Additional description				Non Sluicing	Sluicing	Time Adjusted Avg							Non Sluicing	Sluicing	Time Adjusted Avg				
Analyte	TWF	Concentration (ug/L)	TWPE/year	Concentration (ug/L)	Concentration (ug/L)	Concentration (ug/L)	TWPE/year	TWPE/year	Concentration (ug/L)	TWPE/year	Concentration (ug/L)	TWPE/year	Concentration (ug/L)	Concentration (ug/L)	Concentration (ug/L)	TWPE/year	TWPE/year	Concentration (ug/L)	TWPE/year
Aluminum	0.064691216	13	0	12,520	26,815	14,586	53	2	14,972	0	15	0	1,040	3,650	1,475	7	0	1,460	0
Antimony	0.01225									0									0
Arsenic	4.041313333	0.1	0	0.8	2.2	1	0	0	1	0	0.5	0	0.9	2.3	1	0	0	1	0
Barium	0.001940757									0									0
Beryllium	1.056603774									0									0
Boron	0.008341667	19	0	1,455	2,730	1,668	1	0	1,649	0	10	0	527	1,950	764	0	0	754	0
Cadmium	23.1388	0.0	0	0.02	0.02	0	0	0	-	0	0.0	0	0.0	0.0	0	0	0	-	0
Calcium	0.000028	58,350	0	173,500	278,000	190,917	0	0	112,567	0	14,300	0	65,600	219,000	81,167	0	0	76,867	0
Chromium	0.075696709									0									0
Cobalt	0.114285714									0									0
Copper	0.634822022									0									0
Iron	0.0058	1,509	2	6,053	12,840	7,194	2	0	5,676	0	120	0	206	322	227	0	0	107	0
Lead	2.24									0									0
Magnesium	0.000865533	31,700	5	28,150	28,500	28,208	1	0	-	0	2,970	0	5,220	13,800	6,337	0	0	3,947	0
Manganese	0.07004298	63	1	45	54	46	0	0	-	0	8	0	10	23	12	0	0	4	0
Mercury	157.1130259	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Molybdenum	0.201418848									0									0
Nickel	0.108814808									0									0
~~Potassium~~	0.001052632									0									0
Selenium	1.323348	0.2	0	2.3	4.7	3	0	0	3	0	0.2	0	6.2	23.4	9	1	0	3	0
Silver	15.47072828									0									0
Sodium	0.000003549	2,095	0	60,350	107,000	68,125	0	0	66,030	0	2,900	0	35,000	127,000	50,333	0	0	47,433	0
Thallium	1.027058824									0									0
Tin	0.301075268									0									0
Titanium	0.029310172									0									0
Vanadium	0.095									0									0
Zinc	0.046886									0									0
Chloride	0.0000043	1,330	0	2,765	4,600	3,073	0	0	2,741	0	1,860	0	8,440	36,000	11,367	0	0	9,501	0
Sulfate	0.0000058	19,050	0	315,500	688,000	394,250	0	0	374,600	0	1,670	0	83,500	629,000	174,417	0	0	170,747	0
Nitrate/Nitrite	0.0092	30	0	3,155	6,770	3,958	1	0	3,747	0	440	0	920	2,850	1,242	0	0	802	0
Ammonia-N	0.00111									0									0
Fluoride	0.035	179	1	390	575	404	1	0	226	0	68	0	150	430	209	1	0	135	0
Sulfide (as S)	2.801466667	4	2	410	612	444	76	2	440	0	4	1	4	4	4	1	0	0	0
Cyanide	1.116813077	0	0	0	0	0	0	0	0	0	0	0		0	0.00	0	0	-	0
Hexavalent Chromium	0.516577576									0									0
TOTAL			11				143	4		136		2				11	0		9

		EPRI Bottom Ash Closed-Loop Study Plant F-2									EPRI Bottom Ash Closed-Loop Study Plant G						BA Close Loop Water				BA Close Loop Water Subtracting out Source Water			
		Sub Bituminous (PRB)																						
		Overflow from Surge Tank																						
		Source Water		BA Closed-Loop Water			Purge Water	Ash Sluice	BA Subtracting out Source Water	BA Subtracting out Source Water and Coal Run off and adjusting to purge volume*	Source Water		BA Closed-Loop Water		BA Subtracting out Source Water	BA Subtracting out Source Water								
Flow rate, gpd:		12,384					32,895	368			736,896		216,000											
Frequency, day:		365					365	365			365		365											
Flow rate, Mgy		5					12	0.13			269		79											
Fraction of Sluicing/Non sluicing				0.95	0.05												Mean	Median	Mean	Median	Mean	Median	Mean	Median
Additional description				Non Sluicing	Sluicing	Time Adjusted (Ave																		
Analyte	TWF	Concentration (ug/L)	TWF*g/year	Concentration (ug/L)	Concentration (ug/L)	Concentration (ug/L)	TWF*g/year	TWF*g/year	Concentration (ug/L)	TWF*g/year	Concentration (ug/L)	TWF*g/year	Concentration (ug/L)	TWF*g/year	Concentration (ug/L)	TWF*g/year	ug/l	ug/L	TWF*ug/l	TWF*ug/L	ug/L	ug/L	TWF*ug/l	TWF*ug/L
Aluminum	0.064001136	31	5	4,210	1,600	4,372.50	10	1	4,364	0	147	10	3,330	177	4,084	0	2,587	2,193	165	221	4,820	3,709	181	265
Antimony	0.07125										7	0	5	0	-	0	5	5	0	0	0	0	0	0
Arsenic	0.240330143	0.5	0	2.1	2.3	2.15	1	0	1	0	76	202	16	3	-	0	22	13	38	32	21	12	84	48
Barium	0.007995757										75	6	418	2	763	0	418	418	2	2	763	763	2	2
Beryllium	1.016827148										2	1	0	0	-	0	0	0	0	0	0	0	0	0
Boron	0.008340167	10	0	2,200	2,340	2,262.50	1	0	2,251	0	12,308	26	7	0	-	0	4,416	764	37	5	4,347	764	37	5
Cadmium	21.1368	0.0	0	0.0	0.0	0.00	0	0	-	0	2	15	0.7	1	-	0	0	0	1	2	0	-	1	0
Calcium	0.006008	14,300	0	307,000	284,000	297,500.00	1	0	299,299	0	604,134	21	297,500	2	-	0	166,727	133,042	1	2	126,524	88,222	1	1
Chromium	0.071694108										38	3	35.5	0.7	-	0	16	16	1	1	0	-	0	0
Cobalt	0.115867134										17	1	2	0	-	0	2	2	0	0	0	-	0	0
Copper	0.034882122										30	10	14	10	-	0	24	24	25	15	0	-	0	0
Iron	0.4758	100	0	741	705	723.50	0	0	200	0	501	2	2,150	3	1,643	0	2,536	2,150	24	12	2,028	1,649	11	8
Lead	2.24										1	1	1	2	0	0	1	1	3	3	0	0	0	0
Magnesium	0.006861338	2,900	0	7,280	7,340	7,310.00	1	0	4,848	0	6,312,297	2,486	47,750	16	-	0	17,681	9,451	23	8	8,825	5,05	1	0
Manganese	0.050041148	3	0	5	8	6.50	0	0	-	0	914,470	47,313	70	3	-	0	94	57	2	1	10	5	1	0
Mercury	1.[illegible]	0	0	0	0	0.00	0	0	0	0	1	40	0	0	-	0	0	0	0	0	0	0	0	0
Molybdenum	0.251484848										57	8	30	1	-	0	30	30	8	4	0	-	0	0
Nickel	0.208019108										162	12	9	1	-	0	9	9	3	3	0	-	0	0
Potassium	0.002551142																							
Selenium	1.121114	0.2	0	17.0	16.6	16.80	1	0	17	0	2,140	1,208	140	1	-	0	8	5	3	3	7	2	3	1
Silver	18.43277826										4	20				0								
Sodium	0.0002549	2,500	0	140,000	130,000	134,500.00	0	0	141,600	0	715,134	3	48,750	0	-	0	100,347	45,344	1	0	85,822	39,622	0	0
Thallium	1.027553624										38	16	45	1.1	-	0	5	5	5	5	0	-	0	0
Tin	0.035271183										269	14				0								
Titanium	0.078814177										17	6	406	1	963	0	424	424	12	11	386	199	11	11
Vanadium	0.03																							
Zinc	0.001186										19	1												
Chloride	0.0000543	3,800	0	14,500	14,500	14,500.00	0	0	12,910	0	1,301,231	43	80,000	1	-	0	13,676	11,063	1	0	13,276	8,747	0	0
Sulfate	0.0000858	3,670	0	185,000	790,000	488,200.00	0	0	486,580	0	17,976,473	16	672,500	1	-	0	107,636	295,193	3	2	105,232	103,108	3	1
Alkalinity	0.0002	200	0	8,150	5,170	6,160.00	0	0	5,730	0	177,278	113	-	0	-	0	11,023	1,070	54	2	10,071	2,214	50	1
Ammonia-N	0.0011										41,028	24												
Fluoride	0.035	68	0	420	460	440.00	1	0	391	0	18,660	655				0	489	349	17	11	328	194	11	6
Sulfide (as S)	1.802446867	4	1	23	44	33.50	8	0	43	0	0	0				0	33	11	261	30	37	25	241	19
Cyanide	1.131802677	0	0	0	0	0.00	0	0	-	0	44	11				0	0	0	0	0	0	-	0	0
Hexavalent Chromium	0.515705176															0								
TOTAL			5				48	1		37				264		183	976,079	586,791	887	480	735,396	248,665	798	373

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI members represent 90% of the electric utility revenue in the United States with international participation in 35 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together…Shaping the Future of Electricity

© 2018 Electric Power Research Institute (EPRI), Inc. All rights reserved. Electric Power Research Institute, EPRI, and TOGETHER…SHAPING THE FUTURE OF ELECTRICITY are registered service marks of the Electric Power Research Institute, Inc.

3002013706

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

Appointment

From: Shapiro, Mike [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=2C70AF880BA747B5A8B6BAA45A040125-MSHAPIRO]
Sent: 5/9/2017 2:43:53 PM
To: Shapiro, Mike [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=2c70af880ba747b5a8b6baa45a040125-MShapiro]; Greenwalt, Sarah [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=6c13775b8f424e90802669b87b135024-Greenwalt,]; Southerland, Elizabeth [Southerland.Elizabeth@epa.gov]; Wood, Robert [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=b2676c137cf54db0a5d98df232901821-Wood, Robert]; Matuszko, Jan [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=94eefc2788084d73a97caf80d30a0e24-JMatuszk]; Jordan, Ronald [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=b7b8e2766b3e4f29a86a3893d65023ff-RJordan]; Neugeboren, Steven [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=cfd837ac503949a9820715b53ba921e6-SNEUGEBO]; Fotouhi, David [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=febaf0d56aab43f8a9174b18218c1182-Fotouhi, Da]; Levine, MaryEllen [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=f59ef87b9924425897c750435bad5522-MLEVINE]; Zomer, Jessica [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=a5c30484c1704ec79addf362bf776ed6-Hall, Jessica]; Dravis, Samantha [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=ece53f0610054e669d9dffe0b3a842df-Dravis, Sam]; Bolen, Brittany [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=31e872a691114372b5a6a88482a66e48-Bolen, Brit]
CC: Rees, Sarah [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=Rees, Sarah]; Brown, Byron [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=9242d85c7df343d287659f840d730e65-Brown, Byro]; Thundiyil, Karen [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=25cfc85adc76406db1ddf8a5232eb5e8-KTHUNDIY]; Covington, James [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=37b66364a2a84cf494c686173ee51f53-JCOVIN02]; Benware, Richard [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=4b2e011a22a44312a04299f118cc4d11-Benware, Richard]; Allen, Ashley [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=38f541491ef94ce5ae934b78a9e3b2a6-AAllen]; Sawyers, Andrew [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=49214552a00b4ab7b168ec0edba1d1ac-Sawyers, Andrew]; Sandy Evalenko [s.evalenko@yahoo.com]; Pritts, Jesse [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=377a4bb09a164281921d55ab06e188ae-JPritts]; Forsgren, Lee [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=a055d7329d5b470fbaa9920ce1b68a7d-Forsgren, D]; Best-Wong, Benita [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=6ee79b3d0fc0429b99f2c05481b0b957-bbestwon]; Zobrist, Marcus [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=844deb75a43b4d319c6adcaf8a5b2e4b-mzobrist]

Subject: Reconsideration of Steam Electric ELGs
Attachments: Reconsideration of Steam Electric ELGs.pdf_7_10-13_2017.pdf; Reconsiderbrief4July17.pptx
Location: 3233 WJCE Call in 1-866-299-3188 passcode 2025640516

Start: 7/17/2017 7:00:00 PM
End: 7/17/2017 8:00:00 PM
Show Time As: Tentative

LITIGATION DURING REGULATORY CHANGE: THE CLEAN WATER ACT, ADMINISTRATIVE PROCEDURE ACT AND STEAM ELECTRIC ELG RULE

JESSICA HALL ZOMER

WATER LAW OFFICE

NOVEMBER 9, 2017

2015 STEAM ELECTRIC EFFLUENT LIMITATIONS GUIDELINES & STANDARDS (2015 STEAM ELECTRIC RULE)

- Established first nationally applicable limits on amount of toxic pollutants that may be discharged from the largest wastewater sources at steam electric power plants.
  - Estimated to reduce pollutant discharges by 1.4 billion pounds annually; reduce water withdrawals by 57 billion gallons annually.
- Before 2015 rule, regulations hadn't been updated in over 30 years. This industry responsible for approx. one-third of pollutants discharged collectively from all industrial point sources.
- Limitations and standards based on what the "best available technology economically achievable" can achieve, not on water quality impacts.
- Published in November 2015, effective January 2016.
  - Certain requirements not applicable until November 2018 at the earliest.

LITIGATION OVER 2015 STEAM ELECTRIC RULE

- Section 509(b) of the Clean Water Act: review of EPA action in promulgating any effluent limitation or other limitation under section 301 of the Act, any new source performance standard under section 306, and any pretreatment standard under 307 lies in the Circuit Courts of Appeals.
- 7 petitions for review filed in 4 different Circuit Courts of Appeals by:
  - industry,
  - environmental group, and
  - drinking water utility interests
- Consolidated in 5th Circuit.
- Petitioners' merits briefs filed in December 2016.

PETITIONS FOR RECONSIDERATION OF 2015 STEAM ELECTRIC RULE

- Two petitions for reconsideration received in March/April 2017:
  - Utility Water Act Group (litigant in 5th Cir.)
  - Small Business Administration Office of Advocacy
- Requested reconsideration on a number of aspects of the 2015 rule, including the final limitations and standards applicable to discharges from two of the largest power plant wastestreams (flue gas desulfurization wastewater and bottom ash transport water).
  - Also requested an administrative stay of the rule pursuant to Section 705 of the Administrative Procedure Act.

ADMINISTRATOR DECISION TO RECONSIDER THE 2015 STEAM ELECTRIC RULE

- On April 12, 2017, Administrator Pruitt sent a letter to UWAG and SBA saying:
  - "After considering your petitions, I have decided that it is appropriate and in the public interest to reconsider the rule."
- On April 14, 2017, before EPA's merits brief was due, EPA asked the 5th Circuit to hold the case in abeyance for 120 days to give EPA time to determine which, if any, portions of the rule to potentially request a remand on in order to conduct further rulemaking.
  - Court granted request over opposition from environmental groups and drinking water utilities on April 24.

ADMINISTRATIVE STAY OF 2015 STEAM ELECTRIC RULE

- Decision was made to stay those parts of the rule with future compliance deadlines for existing sources pursuant to Section 705 of the APA at the same time as we conduct a notice-and-comment rulemaking to provide relief to regulated parties from the upcoming compliance deadlines in the rule.
- On April 25, 2017, EPA published a notification in the FR announcing an administrative postponement of certain compliance dates in the 2015 steam electric rule.
  - Section 705 of the APA provides, in part, "[w]hen an Agency finds that justice so requires, it may postpone the effective date of action taken by it, pending judicial review."
  - FR Notice: "In light of the capital expenditures that facilities incurring costs under the Rule will need to undertake to meet the compliance deadlines for the [limits] . . . in the Rule . . . the Agency finds that justice requires it to postpone the compliance dates of the Rule that have not yet passed, pending judicial review. This will reserve the regulatory status quo with respect to the wastestreams subject to the rule's [limits] . . . while the litigation is pending and the reconsideration is underway. While EPA is not making any concession of error with respect to the rulemaking, the far-ranging issues contained in the reconsideration petitions warrant careful and consideration review of the Rule."

LITIGATION OVER ADMINISTRATIVE STAY OF STEAM ELECTRIC RULE

- Complaint filed by Clean Water Action and 7 other plaintiffs in U.S. District Court for District of Columbia on May 3, 2017.
- 6 claims for relief:
  - failing to make required findings for a stay under section 705;
  - staying the rule for purposes of reconsidering it;
  - staying the rule where the effective date has already passed;
  - staying portions of the rule, while leaving others in effect;
  - failing to provide adequate justification and consider relevant factors;
  - failing to provide notice and an opportunity for comment.
- Summary judgment briefing concluded on September 11.

LITIGATION OVER ADMINISTRATIVE STAY OF STEAM ELECTRIC RULE

- EPA's main arguments:
  - The court should dismiss the action or transfer it to the 5th Circuit because jurisdiction is lacking pursuant to Section 509 of the CWA and *Telecommunications Research and Action Ctr. v. FCC* ("*TRAC*"), 750 F.2d 70, 75 (D.C. Cir. 1984) ("any suit seeking relief that might affect the Circuit Court's future jurisdiction is subject to the *exclusive* review of the Court of Appeals.").
  - EPA properly exercised its authority under Section 705 of the APA.
- Before summary judgment briefing was completed, two adverse decisions came out in the N.D. Cal. regarding agencies' authority to use Section 705 to stay rules whose "effective date" had already passed.
- Plaintiffs filed a protective petition for review in D.C. Circuit in August 2017.
- Petitioners moved to hold D.C. Cir. case in abeyance pending decision by district court, and Court granted request in October. EPA took no position on the motion, but reserved the opportunity to seek termination of any such abeyance on jurisdictional or other grounds.

DC Circuit 1984: any suit seeking relief that might affect the Circuit Court's future jurisdiction is subject to the exclusive review of the Court of appeals.

ADMINISTRATOR DECISION ON WHAT PARTS OF 2015 RULE TO CONDUCT FURTHER RULEMAKING ON

- On August 11, the Administrator sent a second letter to UWAG and SBA stating:
  - "After carefully considering your petitions, I have decided that it is appropriate and in the public interest to conduct a rulemaking to potentially revise the new, more stringent best available technology economically achievable effluent limitations and pretreatment standards for existing sources in the 2015 Rule that apply to bottom ash transport water and flue gas desulfurization wastewater."

FIFTH CIRCUIT LITIGATION OVER MERITS OF 2015 RULE

- On August 14, 2017, EPA filed a motion to govern further proceedings requesting that the court sever and hold in abeyance all aspects of the litigation relating to those parts of the 2015 rule that EPA intends to conduct a further rulemaking on.
  - Also requested some time to confer with the other parties as to a briefing schedule for those litigation issues not held in abeyance.
  - Court granted request over environmental groups' opposition.
- On September 26, the parties filed a joint proposed briefing schedule in which the parties agreed that only the environmental groups' claims will be briefed at this time; the other claims are stayed or will not be pursued.
  - Under the schedule, which was approved by the Court, EPA's merits brief is due on December 15, 2017.

POSTPONEMENT RULE

- June 6, 2017: EPA published a proposed rule to postpone certain compliance dates in the 2015 steam electric rule; compliance dates would be postponed until EPA completes reconsideration of the 2015 rule.
- September 18, 2017: EPA published final rule.
  - Effective immediately, pursuant to APA section 553(d)(1) exception for rules that "relieve[] a restriction."
  - Postpones only 2 of the 5 wastestreams proposed to be postponed, in line with Administrator's decision to conduct further rulemaking relating to these 2 wastestreams.
  - Formally withdraws the 705 stay.
- After publication of final rule, EPA filed a motion to dismiss the district court litigation on mootness grounds.
- Plaintiffs in district court litigation filed a motion to amend their complaint to add claims related to the postponement rule. EPA has opposed on the grounds that the amendment is futile, as jurisdiction over such claims lies in the Courts of Appeals pursuant to Section 509 of the CWA.
- The same plaintiffs also filed a second protective petition for review, this time of the postponement rule, in the D.C. Circuit.
- In Oct. 2017, the Center for Biological Diversity sent EPA a notice of intent to sue relating to the Agency's alleged failure to comply with the Endangered Species Act in issuing the postponement rule.

NEXT STEPS

- The U.S. District Court for the District of Columbia will likely schedule a hearing soon on the jurisdictional and other issues raised in the section 705 litigation.
- EPA will likely move to transfer one or both D.C. Circuit cases to the 5th Circuit.
- EPA is working on its merits brief in the 5th Circuit defending against the environmental group petitioners' claims, which is due on December 15.
- CBD likely to file new district court complaint involving ESA compliance in issuing the postponement rule in early December.
- EPA must produce records concerning EPA's decision to reconsider the 2015 rule by the end of December 2017 as a result of related FOIA litigation, *Waterkeeper Alliance et al. v. EPA* (S.D.N.Y).

QUESTIONS?

Please provide the type and source of coal used at the plant each day starting one month b
The spreadsheet currently allows for information to be provided for five different coals use

Date			
	Type of Coal	Chlorine Content (specify units)	Bromine Content (specify units)

before the pilot test through the end of the pilot test.
ed on the same day. If more than five coals are used on any one day, please copy and paste as many additional sets

Coal 1				
Iodine Content (specify units)	Sulfur Content (specify units)	Percentage of Coal Blend	Type of Coal	Chlorine Content (specify units)

of columns are needed to accompany the number of coals used.

Coal 2			
Bromine Content (specify units)	Iodine Content (specify units)	Sulfur Content (specify units)	Percentage of Coal Blend

Coal 3			
Type of Coal	Chlorine Content (specify units)	Bromine Content (specify units)	Iodine Content (specify units)

Sulfur Content (specify units)	**Percentage of Coal Blend**	**Type of Coal**	**Chlorine Content (specify units)**	**Bromine Content (specify units)**

Coal 4				
Iodine Content (specify units)	Sulfur Content (specify units)	Percentage of Coal Blend	Type of Coal	Chlorine Content (specify units)

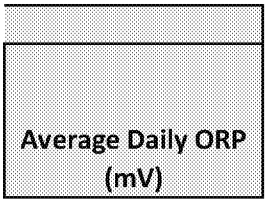
Coal 5			
Bromine Content (specify units)	Iodine Content (specify units)	Sulfur Content (specify units)	Percentage of Coal Blend

Please provide the following information for each FGD scrubber system for each day within the range of sampling

Please provide the FGD system information based on the FGD System IDs used in the 2009 Steam Electric ICR.

Date	FGD 1			
	Average Daily Chloride Concentration (mg/L)	Average Daily Bromide Concentration (mg/L)	Average Daily Iodide Concentration (mg/L)	Average Daily pH (S.U.)

data that are being



Identify all chemicals added to each of the pretreatment technologies and technologies evaluated as part of the pilot t
identify where the chemical is added, the dates the chemical was added, and the target dosage rate. If the target dosa
time, include multiple entries for each dosage rate and identify the period associated with each dosage rate.

Treatment Technology	Chemical Addition Start Date	Chemical Addition End Date	Chemical Added	Chemical Supplier	Location of Addition

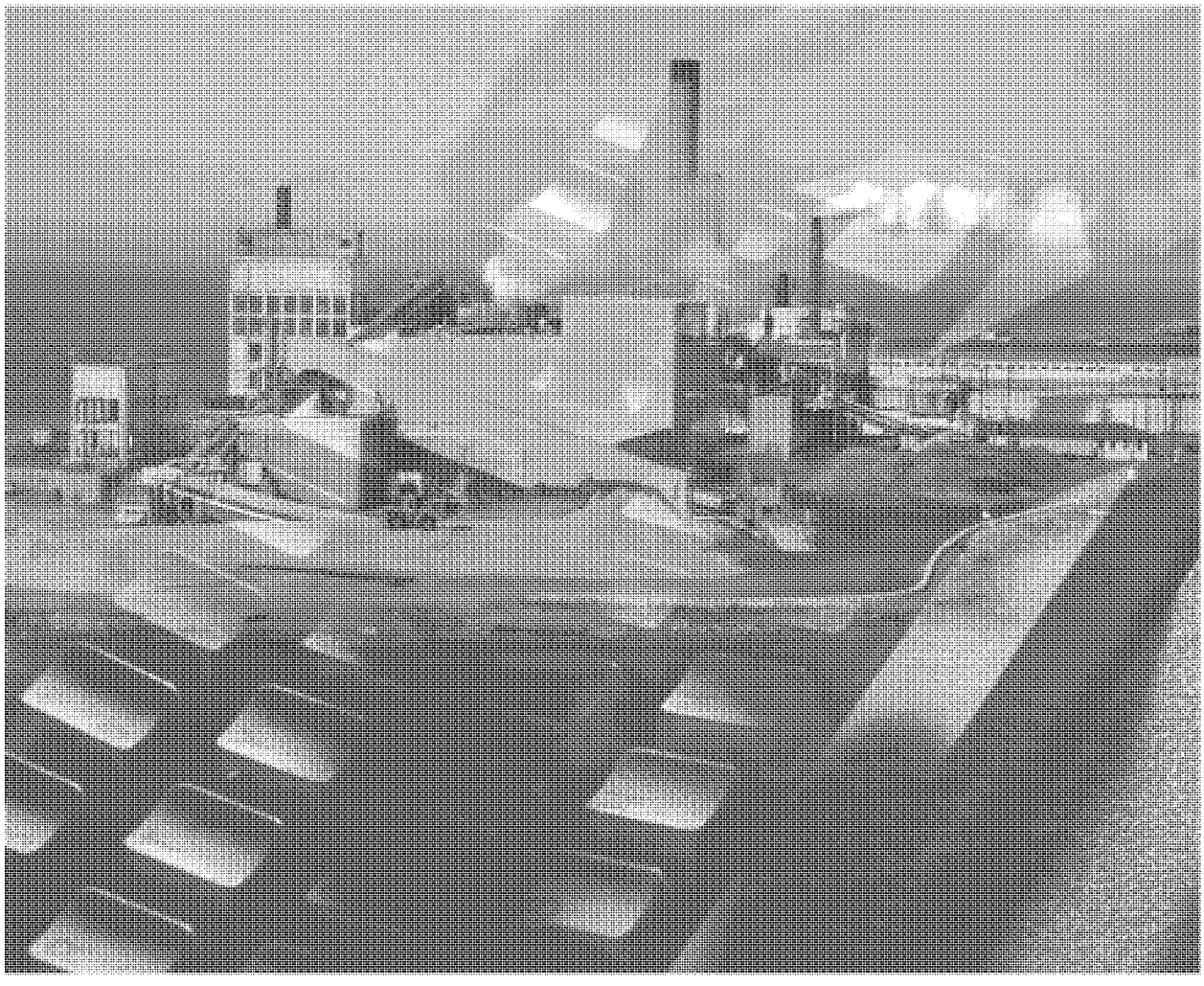
:est. Additionally,
ıge rate changed over

Target Dosage Rate (ppm)

ELECTRIC POWER RESEARCH INSTITUTE

Flue Gas Desulfurization (FGD) Wastewater Chemical Precipitation Bench-Scale Treatability Study

3002004893



Flue Gas Desulfurization (FGD) Wastewater Chemical Precipitation Bench-Scale Treatability Study

3002004893

Technical Update, August 2015

EPRI Project Manager

P. Chu

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

REFERENCE HEREIN TO ANY SPECIFIC COMMERCIAL PRODUCT, PROCESS, OR SERVICE BY ITS TRADE NAME, TRADEMARK, MANUFACTURER, OR OTHERWISE, DOES NOT NECESSARILY CONSTITUTE OR IMPLY ITS ENDORSEMENT, RECOMMENDATION, OR FAVORING BY EPRI.

THE FOLLOWING ORGANIZATION, UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

CH2M Hill Engineers, Inc. (CH2M)

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Electric Power Research Institute, EPRI, and TOGETHER…SHAPING THE FUTURE OF ELECTRICITY are registered service marks of the Electric Power Research Institute, Inc.

Copyright © 2015 Electric Power Research Institute, Inc. All rights reserved.

ACKNOWLEDGMENTS

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

CH2M Hill Engineers, Inc. (CH2M)
155 Grand Avenue Suite 800
Oakland, California 94612

Principal Investigators
L. Reid, P.E.
C. Joiner
D. Fink, P.E.
T. Higgins, P.E.
M. McCloud

This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Flue Gas Desulphurization (FGD) Wastewater Chemical Precipitation Bench-Scale Treatability Study. EPRI, Palo Alto, CA, 2015. 3002004893.

PRODUCT DESCRIPTION

This report will help coal-fired power plants evaluate how well different chemical precipitation treatment conditions remove arsenic and mercury. The report also summarizes the bench-scale laboratory evaluation of removal of selenite, nitrate, and other trace metals that are in flue gas desulphurization (FGD) wastewaters.

Background

The United States Environmental Protection Agency (EPA) has proposed new effluent limitations guidelines (ELGs) for the steam-electric-power-generating industry. In the proposed ELGs, EPA cited chemical precipitation using iron and organosulfide addition as the basis for the best available technology (BAT) for mercury and arsenic removal from FGD wastewater.

Objectives

- To characterize the effectiveness of arsenic and mercury removal using chemical precipitation.
- To evaluate the impact of selenium and arsenic species on treatability.
- To characterize selenite capture using chemical precipitation.
- To evaluate removal of other trace metals using chemical precipitation.
- To evaluate factors that influence treatment effectiveness of mercury and arsenic to levels in compliance with proposed limits.
- To evaluate the general benefit of bench-scale studies as a tool to optimize removal of trace metals in FGD wastewater treatment (WWT) systems.

Approach

The information contained in this report is based on laboratory studies using FGD water samples from coal-fired power plants, as well as the personal experience of the investigators, and previous studies. CH2M conducted laboratory tests using samples from five plants to evaluate whether trace metals removal could be optimized at varying treatment conditions such as pH. The results from this laboratory study are intended for further evaluation in larger scale pilot and full-scale studies.

Results

Jar tests included treatment with pH adjustment, ferric chloride (iron co-precipitation) addition, and organosulfide addition, followed by settling of solids. Overall, the results helped provide information on improved physical/chemical treatment for the various metals. Because of the small number of samples tested and the bench-scale nature of the tests, all results and conclusions are intended to develop future strategies for further evaluation in larger scale pilot- and full-scale evaluations. Much more research is needed before any of the conclusions from the jar tests could be applied to an individual facility or to facilities in general.

Applications, Values, and Use

This report will help utilities meet the proposed ELGs for mercury and arsenic, and also end-of-pipe discharge limits on mercury and arsenic based on water-quality based effluent limits (WQBELs). It will also help utilities understand the impact of FGD wastewater variations on treatment performance, and the impact of pH and organosulfide dose on removal of various

pollutants. The report will also provide insights into planning jar tests and interpreting performance of mercury capture.

The intent of these studies was to develop general strategies for the overall optimization of trace metals removal. Laboratory studies are relatively inexpensive and many different test conditions can be easily evaluated. However, there are known issues with scaling to full-scale "real" FGD wastewater treatment systems. Thus these studies are meant to screen potential treatment strategies for larger systems in the future that could then be further evaluated in pilot- as well as full-scale studies.

Keywords
Flue gas desulphurization (FGD)
Physical/chemical treatment
Chemical precipitation
Wastewater treatment
Arsenic
Mercury
Selenium

ABSTRACT

This study focuses on physical/chemical wastewater treatment used to remove various metals from flue gas desulphurization (FGD) wastewater. The scope of this study includes bench-scale FGD wastewater treatment for mercury, arsenic, selenite, and other trace metals. Laboratory tests were done using samples from five plants. The tests included treatment with pH adjustment, ferric chloride (iron co-precipitation) addition, and organosulfide addition, followed by settling of solids.

EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) has proposed new effluent limitations guidelines (ELGs) for the steam-electric-power-generating utility industry. The proposed rule would establish specific technology-based limits for wastewater from the flue gas desulfurization (FGD) process. The guidelines propose numeric limits for arsenic, selenium, mercury, and nitrate/nitrite in FGD wastewater. Chemical precipitation using iron and organosulfide addition is the primary treatment for mercury and arsenic removal; it was cited by the EPA in the proposed ELGs as the basis for the best available technology economically achievable (BAT) for their removal.

CH2M conducted bench-scale testing using FGD wastewater samples collected from five facilities. Jar tests included treatment with pH adjustment, ferric chloride (iron co-precipitation) addition, and organosulfide addition, followed by settling of solids. The primary goal of these jar tests was to better characterize and optimize arsenic and mercury removal using various chemical precipitation treatment conditions. Selenium removal was added as a secondary goal because it is understood that some forms of selenium need treatment beyond chemical precipitation to meet the proposed ELG limits. Treatability of other trace metals was also evaluated. See **Table 2-3** for a full list on constituents analyzed.

Note that full-scale wastewater treatment plants were also characterized as part of EPRI ongoing research. Because further sites are being evaluated at the time of this report, this information will be compiled in a later report.

Summary of FGD Wastewater Characterization and Treatability

Mercury Findings

- Based on the limited data of this jar testing, some sites with physical/chemical treatment may have compliance challenges with the proposed ELGs.
- All plants had significant particulate (>0.45 micrometer [µm]) and soluble/small particulate (defined in this report as that portion which passes through a 0.45-µm filter) mercury in untreated, unsettled FGD wastewater samples. Therefore, treatment would likely need to remove both particulate and soluble mercury to meet proposed ELGs.
- Mercury was best removed at pH 8.5 for all plants. Significant removal was also observed at pH 6.5. At both pH conditions, soluble/small particulate mercury was driven below the proposed ELG of 119 parts per trillion for four of the five plants. Note that three of the five plants had soluble/small particulate mercury below the proposed ELG in the control (settling with no chemical addition, no pH adjustment).
- Limited mercury removal (26 to 99 percent) was observed at pH 4.0. Soluble/small particulate (<0.45 µm) mercury was driven below the proposed ELG for three of the five plants. The two plants evaluated at pH 10.5 showed poor settling characteristics and soluble mercury concentrations above the proposed ELG.
- Most plants had significant particulate and soluble/small particulate mercury in jar test effluent.

- Mercury is expected to settle out better in full-scale plants than jar test results indicate because of better flocculation from factors, such as sludge recirculation, which are difficult to replicate in lab-scale settings [1].
- Water complexity (total dissolved solids [TDS]) seemed to be an indicator of difficulty in driving mercury into particulate form.

Arsenic Findings

- Arsenic in untreated, unsettled FGD wastewater influent samples was mostly particulate.
- Particulate (>0.45 μm) arsenic was removed well in jar tests.
- There was little or no removal of soluble (<0.45 μm) arsenic in jar tests.
- Soluble arsenic in untreated FGD wastewater (and jar test effluent) was below the proposed ELG of 6 parts per billion (ppb) for all but one of the five plants. Therefore, the testing of soluble arsenic removal was limited.
- A general trend was observed where concentrations of soluble arsenic increased with higher FGD scrubber residence times. This suggests that higher soluble arsenic concentration could occur if plants elect to reduce their FGD flow via higher recirculation of the scrubber.
- The five FGD waters generally have low levels of soluble arsenic, thus the arsenic speciation data were generally near or below the analytical detection limit. For the one plant with soluble arsenic above 6 ppb, the arsenic appeared to be present mainly as arsenate, arsenite, and dimethylarsinic acid (DMA); there was also a significant portion of "unaccounted" arsenic (the difference between total soluble arsenic reading and detected arsenic species), which indicates that there may be some organic arsenic compounds.

Selenium Findings

- Selenium in untreated FGD wastewater influent was above the proposed monthly average ELG of 10 ppb for all five plants.
- Soluble (<0.45 μm) selenium in jar test effluent appeared to have been present mainly as selenate and selenite; there was also a significant portion of other selenium compounds, including organo-selenium compounds and "unaccounted" selenium (the difference between total soluble selenium reading and detected selenium species).
- Selenate in jar test effluent was above the proposed ELG of 10 ppb for all five plants. Selenite in jar test effluent was above the proposed ELG of 10 ppb for four of the five plants. This was expected, because selenium is not removed well by chemical precipitation, especially selenate. Concentrations of other selenium compounds, including "unaccounted" selenium, were above the proposed ELG of 10 μg/L for all five plants, both in untreated FGD wastewater influent and in jar test effluent; therefore, these forms will also need to be removed in order to achieve the proposed ELG.
- All forms of soluble selenium were generally ineffectively captured in jar tests. Limited selenite removal was observed even at lower pHs, which are the conditions expected based on past research to be best for selenite precipitation. Removal of soluble selenium ranged from 0 to 58 percent, with the largest removal at pH 4 and the majority of removal primarily as selenite.

- Selenium will likely require additional treatment (such as biological or zero-valent iron [ZVI] treatment) to comply with the proposed ELGs. This may need to include removal of organic selenium species.

Nitrate/Nitrite Findings

- The proposed ELGs would regulate nitrate and nitrite, but only nitrate was significantly present in the FGD wastewater tested.
- Nitrate in untreated FGD wastewater influent was above the proposed monthly average ELG of 0.13 milligram per liter (mg/L) as N for all five plants.
- No nitrate removal was observed in jar tests and nitrate in jar test effluent was above the proposed ELG of 0.13 mg/L as N for all five plants. This was expected because nitrate is not removed by chemical precipitation.

Other Trace Metals Findings

- Metals that settle out or form sulfide precipitates (arsenic, mercury, cadmium) were effectively reduced in jar tests. Selenium, boron, magnesium, and manganese are trace metals that were present in the FGD water after iron and sulfide precipitation.

ACRONYMS AND ABBREVIATIONS

°F	degree Fahrenheit
BAT	best available technology economically achievable
DMA	dimethylarsinic acid
DRC	Dynamic Reaction Cell
ELGs	effluent limitations guidelines
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
$FeCl_3$	ferric chloride
FGD	flue gas desulfurization
L	liter
mg/L	milligram per liter
µg/L	microgram per liter
mL	milliliter
µm	micrometer
MMA	monomethylarsonic acid
MS	matrix spike
MSD	matrix spike duplicate
MW	molecular weight
N	nitrogen
ng/L	nanograms per liter
ppb	parts per billion
ppm	parts per million
ppmv	parts per million by volume
PRB	Powder River Basin
rpm	revolution per minute
RPD	relative percent difference

TDS	total dissolved solids
TSS	total suspended solids
WQBEL	water quality-based effluent limitation
WWT	wastewater treatment
ZVI	zero-valent iron

CONTENTS

1 NTRODUCTION 1-1
Regulatory Background 1-1
Objectives 1-1
Approach 1-2
Study Limitations 1-2
2 APPROACH 2-1
Approach to FGD Wastewater Collection 2-1
Approach to FGD Wastewater Jar Testing 2-2
pH Setpoints, Temperature, and Chemical Addition 2-3
Jar Test Procedures 2-5
Approach to FGD Wastewater Treatability Evaluation 2-6
3 FGD WASTEWATER TREATABILITY 3-1
Role of Physical/Chemical Treatment in the Proposed ELGs 3-1
Physical/Chemical Treatment Fundamentals 3-1
Chemical Precipitation 3-2
Organosulfide Addition 3-2
Iron Co-precipitation 3-3
Clarification 3-3
Filtration 3-4
Effect of Chemical Precipitation and Settling on Metals Removal 3-4
Mercury Removal 3-5
Mercury in Untreated FGD Water 3-5
Removal of Large Particulate Mercury by Settling 3-6
Removal of Soluble and Small Particulate Mercury by Settling 3-7
Removal of Large Particulate Mercury by Chemical Addition 3-7
Removal of Soluble and Small Particulate Mercury by Chemical Addition 3-9
Particle Size Distribution of Effluent Mercury 3-10
Effect of pH on Mercury Removal 3-11
Arsenic Speciation and Removal 3-13
Arsenic in Untreated FGD Water 3-13
Removal of Particulate Arsenic by Settling 3-15
Removal of Soluble Arsenic by Settling 3-15
Removal of Particulate Arsenic by Chemical Addition 3-15
Removal of Soluble Arsenic by Chemical Addition 3-15
Selenium Speciation and Removal 3-18
Selenium in Untreated FGD Water 3-18
Removal of Particulate Selenium by Settling 3-19
Removal of Soluble Selenium by Settling 3-20
Removal of Particulate Selenium by Chemical Addition 3-20

Removal of Soluble Selenium by Chemical Addition 3-20
Nitrate Removal 3-22
Other Trace Metals 3-23
Lessons Learned and Recommendations for Future Research 3-25
4 DATA QUALITY EVALUATION 4-1
Data Evaluation Conclusions 4-1
Data Evaluation Methods 4-1
Plant Operations 4-2
Analytical Quality Control Results 4-2
Precision 4-2
Duplicate Samples 4-2
Inter-Laboratory Split Samples 4-3
Accuracy 4-5
Blank Effects 4-6
5 REFERENCES 5-1
A EPRI FGD WATER CHEMICAL PRECIPITATION BENCH-SCALE TREATABILITY STUDY PLAN A-1
B FGD TREATABILITY TESTING DATA SUMMARY B-1
C ANALYTICAL QUALITY CONTROL RESULTS C-1

LIST OF FIGURES

Figure 2-1 Example of robust floc generation and settling 2-5
Figure 2-2 Laboratory equipment set-up 2-6
Figure 3-1 FGD wastewater treatment system process flow diagram 3-2
Figure 3-2 Removal of effluent soluble mercury appears affected by TDS 3-9
Figure 3-3 Effluent mercury (<30,000 MW) at varying pH and high organosulfide dose (80 ppm) 3-12
Figure 3-4 Total effluent mercury at varying pH and high organosulfide dose (80 ppm) 3-12
Figure 3-5 Comparison of effluent arsenic to EPA sampling for ELG development 3-18
Figure 3-6 Selenium speciation in influent (control) and treated effluent at pH 6.5 3-21
Figure 3-7 Selenium and selenite removal from plants at pH 6.5 3-22

LIST OF TABLES

Table 1-1 Draft ELG Discharge Permit Limits on FGD Wastewater 1-1
Table 2-1 Untreated FGD Wastewater Influent Comparison 2-2
Table 2-2 Jar Test Matrix[a] 2-3
Table 2-3 FGD Wastewater Jar Test (Supernatant) Sampling Parameters 2-8
Table 3-1 Influent Mecury in Control (Settled) 3-6
Table 3-2 Influent and Effluent Mercury 3-7
Table 3-3 Comparison of Jar Test Effluent and Full-scale FGD WWTP Effluent Mercury (from not yet published EPRI report) 3-8
Table 3-4 Influent and Effluent Supernatant Turbidity 3-8
Table 3-5 Soluble Mercury Concentration in Effluent Compared to TDS 3-10
Table 3-6 Influent and Effluent Mercury 3-11
Table 3-7 Effluent Mercury at Varying pH and High Organosulfide Dose (80 ppm) 3-13
Table 3-8 Influent Arsenic in the Control (Settled) 3-14
Table 3-9 Relationship Between Scrubber HRT and Influent Soluble/Small Particulate Arsenic 3-14
Table 3-10 Influent and Effluent Arsenic 3-15
Table 3-11 Arsenic Speciation in 0.45-µm Filtered Water 3-17
Table 3-12 Influent Selenium 3-19
Table 3-13 Influent and Effluent Selenium 3-19
Table 3-14 Iron Addition in Jar Tests 3-20
Table 3-15 Selenite Removal 3-21
Table 3-16 Nitrate Removal 3-22
Table 3-17 Influent and Effluent Trace Metals 3-24
Table 4-1 Laboratory Duplicate Samples 4-3
Table 4-2 Laboratory Duplicate Precision Outside of Criteria 4-3
Table 4-3 Laboratory Split Samples 4-4
Table 4-4 Laboratory Split Precision Outside of Criteria 4-5

1 INTRODUCTION

Regulatory Background

The United States Environmental Protection Agency (EPA) sets technology-based standards, termed "effluent limitations guidelines (ELGs)", by industry category based on what it determines as the best available technology economically achievable (BAT). EPA has proposed new ELGs for the steam-electric-power-generating industry to include BAT limits on flue gas desulfurization (FGD) wastewater. The draft rule was published in June 2013; the final rule is scheduled to be signed by September 30, 2015. The proposed BAT technologies that EPA has cited in development of ELGs for FGD wastewater are based on physical/chemical and biological treatment technologies. The focus of this report is the physical/chemical treatment technology.

EPA's proposed ELGs for FGD wastewater are shown in **Table 1-1**. These include ELGs for arsenic, mercury, selenium, and nitrate/nitrite prior to comingling. The proposed selenium and nitrate/nitrite ELGs are based on using biological treatment technology for FGD wastewater treatment; selenium and nitrate/nitrite are not anticipated to be removed by the physical/chemical treatment technology to the levels proposed in the ELGs.

In addition, site-specific water quality-based effluent limitations (WQBELs) for mercury and arsenic may necessitate treatment of FGD wastewater.

Table 1-1
Draft ELG Discharge Permit Limits on FGD Wastewater

Parameter	Discharge Limits	
	Average Monthly	Daily Maximum
Arsenic, µg/L	6	8
Mercury, µg/L	0.119	0.242
Selenium, µg/L	10	16
Nitrate/Nitrite (as N), mg/L	0.13	0.17

Source [14]
µg/L – microgram per liter
mg/L – milligram per liter

Objectives

FGD wastewater is a very complex matrix, and contains trace metals such as mercury and arsenic captured from the flue gas stream. Treatment of FGD wastewater may be required to meet discharge limits. The goals of this study are to:

1. Characterize the effectiveness of arsenic and mercury removal using chemical precipitation.
2. Evaluate the impact of selenium and arsenic species on treatability.

3. Characterize selenite capture using chemical precipitation.
4. Evaluate removal of other trace metals with chemical precipitation.
5. Evaluate factors that influence treatment effectiveness of mercury and arsenic to levels in compliance with proposed limits.
6. Evaluate the general benefit of bench-scale studies as a tool to optimize removal of trace metals in FGD wastewater treatment (WWT) systems.

The understandings gleaned from this study are to be used in follow-on work to improve removal of mercury and arsenic from FGD wastewaters.

Approach

Untreated FGD wastewater from five coal-fired power plants, with a range of operations, coal sources, and FGD scrubber operations, was sampled and analyzed at a laboratory that specializes in low level trace metals analyses, including mercury and arsenic in industrial water, and has significant previous experience with FGD wastewater. Grab samples were collected for initial characterization and screening. A bulk sample was collected for bench-scale laboratory testing. Samples were collected of hydrocyclone overflow at a point ahead of any chemical addition, solids removal, or mixing with recirculation streams. Bench-scale testing included jar tests involving chemical addition (iron, organosulfide, flocculant, and pH adjustment compounds) and settling.

Study Limitations

The study is limited by the number of facilities tested, the conditions at the time of sample collection, and the inherent limitations in representing full-scale treatment using bench-scale laboratory testing. The number of samples or data points from each facility also limited the study. FGD wastewater is known from past Electric Power Research Institute (EPRI) studies to be highly variable both between plants and over time at any given plant [4 through 15]. Therefore, insights may not be applicable to FGD wastewater at all or even a majority of plants.

2
APPROACH

The purpose of this chapter is to summarize the approach to evaluating FGD wastewater treatability used in this project. A detailed test plan is included in **Appendix A**.

Approach to FGD Wastewater Collection

During a single sampling event, untreated FGD wastewater influent samples were collected from five facilities with a range of operations, coal sources, and FGD scrubber operations. Sampling was done between September 22 and November 10, 2014. Samples were collected at a point ahead of any chemical addition, solids removal, or mixing with recirculation streams.

Grab samples were collected for initial characterization and screening; in addition a bulk sample was collected for bench-scale laboratory testing. Grab samples were collected directly into bottles provided by the laboratory, which were cleaned in accordance with EPA Method 1669, "Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels" double-bagged as appropriate, and filled with the correct preservative in sufficient supply for sampling. Samples for metals analysis were collected in accordance with the standard operating procedure for ultraclean metals sampling ("clean hands, dirty hands"). Samples for soluble metals analysis were allowed to settle for roughly 1 hour, and then field-filtered using bottles, syringes, and filters provided by the laboratory. Bulk samples were collected directly into unused, clean, unpreserved containers provided by the laboratory. Samples were shipped to the laboratory without ice within 24 hours of collection by overnight delivery.

Plant conditions at the time of sampling are summarized in **Table 2-1**. All of the facilities sampled have forced oxidation scrubbers. Three of the plants burned bituminous coal, one burned sub-bituminous Powder River Basin (PRB) coal, and one burned a blend of the two. None of the samples collected are representative of lignite coal. Total dissolved solids (TDS) ranged from 6,970 to 43,600 milligram per liter (mg/L); chloride ranged from 940 to 19,100 mg/L; and nitrate ranged from 18 to 250 mg/L as nitrogen (N).

Table 2-1
Untreated FGD Wastewater Influent Comparison

Plant	Coal Source	Estimated Scrubber System HRT	pH [c]	TSS [b], mg/L	TDS [c], mg/L	0.45µm filtered Cl [b], mg/L	0.45 µm filtered SO_4 [b], mg/L	NO_3/NO_2 [b], mg/L as N
Plant 1	Primarily bituminous, some PRB	6-7 days	6.7	23,000	28,000	8,000	3,970	37
Plant 2[a]	Bituminous	10-20 hours (single pass)	7.1	203,000	6,970	940	2,390	24
Plant 3	PRB	18 days	6.4	10,900	43,600	5,540	19,700	251
Plant 4	Bituminous	8 days	7.0	15,700	36,500	19,100	4,640	181
Plant 5	Bituminous	3 days [d]	6.8	20,300	21,000	5,730	5,210	18

Notes:

HRT – hydraulic residence time

NO_2 – nitrite

NO_3 – nitrate

SO_4 – sulfate

TSS – total suspended solids

[a] FGD sample was collected upstream of hydrocyclone because of the organosulfide addition at the hydrocyclone. To simulate the FGD wastewater stream that goes to the treatment system (hydrocyclone overflow), the collected sample was settled for two minutes and rapidly decanted to remove heaviest solids in the lab, and the supernatant (including solids) was collected for laboratory tests.

[b] These results were taken from field-collected samples (samples collected for specific analytes following method protocol for sampling, container materials, and preservatives, versus the bulk sample for jar testing).

[c] These results were taken from the jar test control (supernatant from jar test that was settled with no chemical addition).

[d] Scrubber volume was not reported for this plant. It was estimated using information from similarly sized plants along with the flow information that this plant sent to EPA, which was available via the ELG Information Collection Request database.

Approach to FGD Wastewater Jar Testing

Samples were delivered to the laboratory. Samples collected for initial characterization and screening were processed on the day of receipt, and jar testing was performed on the remaining sample volume. Screening involved a 1-day turnaround for arsenic (EPA Method 200.8M with Dynamic Reaction Cell [DRC]) and mercury (EPA Method 245.1). The initial characterization also involved the remaining parameters, but with a standard turnaround time.

On the day of receipt of treatability samples from a given plant, the laboratory combined the wastewater samples (if in multiple sample containers), adequately mixed the combination, and

collected a small portion for polymer selection. The combined sample was then split between the jars for testing. Jar testing was conducted within 48 hours of field collection (within 24 hours of receipt by laboratory) to minimize water quality changes and help ensure data quality. A matrix of tests is shown in **Table 2-2**.

Table 2-2
Jar Test Matrix [a]

pH Target [b]	10-25 ppm Organosulfide [d] ("Low Dose")	50 ppm Organosulfide [d] ("Med Dose")	80 ppm Organosulfide [d] ("High Dose")
4 or 5.5	--	--	Tested
6.5	Tested	Tested (later dropped)	Tested
8.5	Tested	Tested (later dropped)	Tested
10.5 [c]	Tested (later dropped)	Tested (later dropped)	Tested (later dropped)

Notes:
ppm – part per million.
[a] All tests included a 200-ppm dosage of ferric chloride by volume, to promote flocculation/settling.
[b] Target pH was achieved during jar test, in conjunction with other chemical additions.
[c] Used lime until reaching pH of 8.5, then switched to caustic to reach 10.5.
[d] Organosulfide - Nalmet 1691.

pH Setpoints, Temperature, and Chemical Addition

The following pH setpoints were used:

- 4.0 – A single low pH test was conducted to evaluate selenite removal at the lower pH range.
- 6.5 – This pH was considered, based on past research and treatment, to be a good target for removal of metals, such as arsenic and selenium, which can exist as anions in water.
- 8.5 – This pH was considered, based on past research and treatment, to be a good target for removal of mercury and other cations (note that cations are removed at alkaline conditions, but the high buffering capacity of the wastewater makes it impractical to raise pH above 8.5 because of high chemical demand and high solids generation).
- 10.5 – This pH was included to evaluate if cation removal would improve at a higher pH than 8.5. This pH setpoint was eliminated after 2 plants because of poor mercury capture and settling.

All tests included iron addition in the form of ferric chloride ($FeCl_3$) to promote flocculation and settling. A dosage of 200 parts per million by volume (ppmv) commercial-grade $FeCl_3$ was used in all jar tests; this relatively high dose was selected specifically to promote arsenic and selenium removal. Based on CH2M's experience, the ideal target iron addition is 500 to 1,000 pounds of iron per pound of arsenic or 500 to 1,200 pounds of iron per pound of selenium; because $FeCl_3$ solution is roughly 10 percent iron, this equates to roughly 5,000 to 10,000 ppmv of neat $FeCl_3$ solution per part per million (ppm) of arsenic (or 5 to 10 ppmv of neat $FeCl_3$ solution per part per billion [ppb] of arsenic) and roughly 20,000 ppmv $FeCl_3$ solution per ppm of selenium. This is not additive; both arsenic and selenium participate. An iron dosage is calculated for each target

ratio (iron-to-selenium and iron-to-arsenic) and the higher of the two is selected (in FGD water, selenium usually controls). Additionally, not all forms are removed; arsenate and selenite are the main forms that participate and are removed and help set the needed dosage of iron. However, speciation data take too long to obtain prior to jar testing and total soluble arsenic and selenium concentration are typically used to calculate the iron dosage for jar tests (i.e., all of the total soluble selenium concentration is assumed to be present as selenite).

Note that speciation results indicated that one of the plants (Plant 3) had higher selenite levels than anticipated. Because these analytical results were not expedited, the iron addition was not adjusted and was below the target ratio for this sample (as shown in **Table 3-14**).

All tests also included organosulfide addition in the form of Nalmet 1691. Dosages of 20, 50, and 80 ppm were applied at each pH setpoint (6.5, 8.5, and 10.5). These dosages were based on CH2M's experience with FGD wastewaters. The 50-ppm dosage was eliminated after the first two plants because of minimal performance differences between that feed rate and either the low or high dosages.

Polymer was added to all jars. Polymer is often used to help combine small particles into larger ones that can be better settled out in a treatment system. Polymer performance varies widely based on the type of polymer and the water chemistry. To determine the best polymer for each jar test, up to 5 polymers, 3 anionic and 2 cationic, were initially evaluated at 5 ppmv (neat basis) for each wastewater at each pH setpoint (up to 20 tests per plant). The tests involved adding the polymer, slow mixing (20 revolutions per minute [rpm]) for approximately 15 minutes, followed by 60 minutes of settling. Visual observations of the results were documented, and photos were taken of the resulting supernatant; the polymer that produced the clearest supernatant and most robust floc, as judged by the tester (who was experienced with chemical precipitation), was used for the laboratory tests. See **Figure 2-1** for an example of robust floc generation and settling.

All tests were heated to 140 degrees Fahrenheit (°F) to simulate FGD blowdown conditions. In post-test discussion with EPRI members, it was found that their typical FGD blowdown conditions were closer to 100 to 120°F, following equalization. However, the higher temperature should not have affected metals removal.

A baseline sample was run and tested at the same time as the other jar tests for comparison to the initial wastewater characterization. This sample had no chemical addition and no pH adjustment, but was heated to the operating temperature (140°F), mixed, and settled. Therefore, the settled baseline sample ("control") was representative of sedimentation only, without chemical precipitation. The water from Plant 1 was mixed during the laboratory testing with stir bars. Because of concerns with shearing precipitated solids into smaller solids that would not settle out of solution, the testing of the other four plants involved paddle bars at a speed of approximately 20 rpm. The paddle bars reduced shearing, but it should be noted that they could still have resulted in some shearing, because polymer-formed precipitated floc can be fragile.

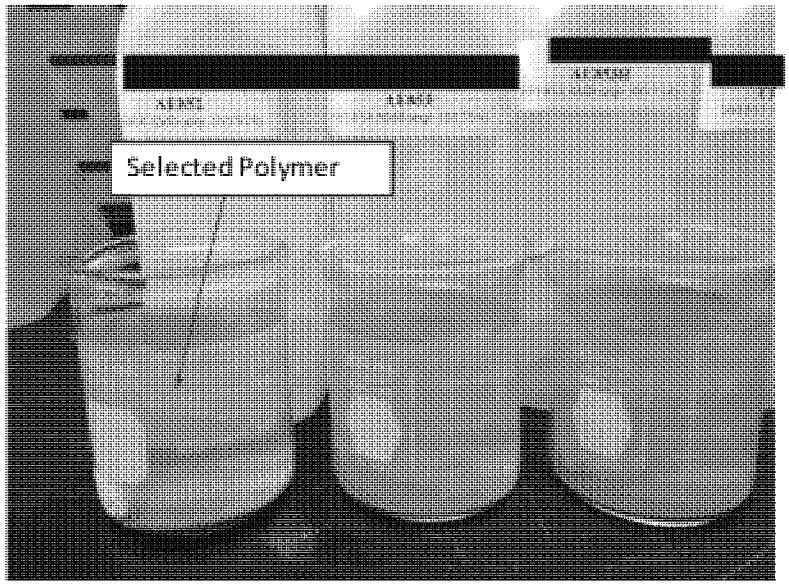


Figure 2-1
Example of robust floc generation and settling

Jar Test Procedures

The laboratory tests had one phase of testing, with the settled effluent analyzed after being passed through different filters to determine whether the metals passing the standard 0.45-µm filters were truly soluble or were particulates smaller than 0.45 µm. **Figure 2-2** illustrates the laboratory equipment set-up. Jar testing was conducted in accordance with the following procedures:

1. Document each step, as well as any observations or anomalies, in a log book or on a bench sheet and later transcribe to an electronic copy of the test log.
2. Mix the untreated wastewater sample well to re-suspend any solids that may have settled. Tests should be conducted on the FGD wastewater as the FGD wastewater treatment plant would receive it, with all of the solids re-suspended.
3. Measure 1 liter (L) of untreated sample with a graduated cylinder, and transfer to a 1-L beaker.
4. Place the beaker on a paddle stirrer. Turn on the paddle stirrer at 20 rpm, which is used throughout. (The Plant 1 test was mixed using stir bars. Because of concerns with shearing, the other four plants used paddle bars at a speed of approximately 20 rpm.)
5. Place a pH probe in the sample to monitor pH throughout the test. Record the initial pH and temperature.
6. Prior to testing, perform a pH adjustment on a small amount of water (with the appropriate $FeCl_3$ dose) and record the amount of lime/caustic (if initial pH is too low) or sulfuric acid (if initial pH is too high) required to reach each target pH (4.0, 6.5, 8.5, and 10.5). During testing, add 90 percent of the calculated dosage from these tests and follow with smaller adjustments to reach the target pH.
7. Add all chemical dosages together ($FeCl_3$, organosulfide, and 90 percent of anticipated sulfuric acid/lime/caustic demand) and mix at 20 rpm for 20 minutes. Record the pH after

chemical addition before further adjustment. Monitor pH throughout the 20-minute mixing period and adjust pH as necessary. Add 1.0 N sulfuric acid or hydrated lime (or 1.0 N sodium hydroxide once lime is ineffective) to achieve the target pH (+/- 0.1 pH units). Record the amount of acid or base added and mix for 5 minutes.

8. Add the flocculant polymer last and mix the sample at 20 rpm for an additional 20 minutes.
9. Record any visual observations (such as precipitate/flocculant formation, color changes, odors, and heat generation) during the test. Take digital pictures before adding chemicals, after 20 minutes of first-stage chemical addition, then after polymer addition and 20 minutes of flocculation, and after settling and filtering sample.
10. At the end of the mixing period, collect a sample of approximately 250 milliliters (mL), which should be reserved for TDS and total suspended solids (TSS) analysis, then remove the beaker from the stirring apparatus.
11. Settle for 30 minutes before collecting and filtering (as needed) the supernatant for metals analysis. Samples will be collected as:
    a. Settled, for total metals analysis
    b. Filtered using 0.45-micrometer filters
    c. Filtered using 30,000- molecular weight (MW) filters
    d. Filtered using 3,000- MW filters
12. Submit samples for analysis.

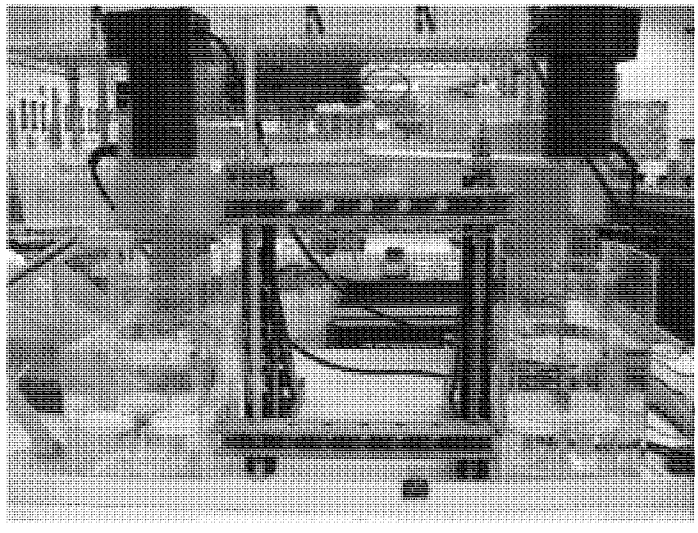


Figure 2-2
Laboratory equipment set-up

Approach to FGD Wastewater Treatability Evaluation

Table 2-3 lists the parameters that were measured and the corresponding detection limits. The parameters of primary concern were arsenic and mercury. Although filtered, or "soluble," data are typically represented by a sample filtered through a 0.45-micrometer (μm) filter, mercury particulates can be very small, especially mercury-sulfide compounds, and may require

additional analysis to quantify the portion that is truly soluble. Arsenic was filtered and analyzed similarly to determine if similar results were observed. Jar test supernatant was analyzed for total, 0.45-µm-filtered, 30,000-MW-filtered (centrifuge filtration), and 3,000-MW-filtered (centrifuge filtration) arsenic and mercury. Results were defined using the following terminology:

- Large particulate (>0.45 µm)
- Larger submicron particles (30,000 MW to 0.45 µm) – macromolecular range, would require advanced filtration (microfiltration or ultrafiltration) to remove
- Smaller submicron particles (3,000 MW to 30,000 MW) – molecular range, would require advanced filtration (ultrafiltration or nanofiltration) to remove
- "Truly soluble" (<3,000 MW)

The parameters of secondary concern were selenium, nitrate and nitrite, and other trace metals that are present in FGD wastewaters (boron, cadmium, magnesium, and manganese). These parameters were selected because they, along with mercury and arsenic, contribute 95 percent of total toxicity in settled FGD effluent; this information is based on EPA's data, which were collected at 12 plants to understand settled FGD water. Jar test supernatant was analyzed for total and 0.45-µm-filtered selenium, boron, cadmium, magnesium, and manganese. Select jars were also analyzed for arsenic and selenium speciation.

Quality control included process blanks, jar test duplicates, analytical duplicates, and matrix spike/matrix spike duplicate samples. Some samples were also split and sent to two laboratories for confirmation. Results were all within target ranges, with the exception of a few split samples that did not meet the precision goal but those did not change conclusions presented in this report. A combination of high dilutions (which make small instrument readings equate to large changes in the recorded sample result) and matrix interferences may have resulted in the differences between the split samples.

Table 2-3
FGD Wastewater Jar Test (Supernatant) Sampling Parameters

Parameter	Method	Preservative	Holding Time
Total suspended solids	SM2540D	Unpreserved	7 days
Total dissolved solids	SM2540C	Unpreserved	48 hours
Mercury, total	E245.1/E1631 [d]	Unpreserved	180 days
Mercury, low-level, 0.45-µm filtered	E1631	Unpreserved	180 days
Mercury, low-level, 3,000-MW filtered	E1631	Unpreserved	180 days
Mercury, low-level, 30,000-MW filtered [a]	E1631	Unpreserved	180 days
Arsenic, total	EPA200.8/6020	HNO_3	180 days
Arsenic, 0.45-µm filtered [a]	EPA200.8/6020	HNO_3	180 days
Arsenic, 3,000-MW filtered	EPA200.8/6020	HNO_3	180 days
Arsenic, 30,000-MW filtered	EPA200.8/6020	HNO_3	180 days
Arsenic speciation, 0.45-µm filtered [b,c]	Laboratory SOP ASC-085	Unpreserved	180 days
Selenium, 0.45-µm filtered [a]	EPA200.8/6020	HNO_3	180 days
Selenium, total	EPA200.8/6020	HNO_3	180 days
Selenite (Se speciation, no headspace, 0.45-µm filtered) [b]	Laboratory SOP ASC-084	Unpreserved	180 days
Nitrate-nitrite	E353.2	H_2SO_4	28 days
Iron, 0.45-µm filtered	EPA200.7	HNO_3	180 days
Boron, 0.45-µm filtered	EPA200.7	HNO_3	180 days
Cadmium, 0.45-µm filtered [a]	EPA200.8/6020	HNO_3	180 days
Magnesium, 0.45-µm filtered	EPA200.7	HNO_3	180 days
Manganese, 0.45-µm filtered	EPA200.7	HNO_3	180 days
Boron, total	EPA200.7	HNO_3	180 days
Cadmium, total	EPA200.8/6020	HNO_3	180 days
Magnesium, total	EPA200.7	HNO_3	180 days

Notes:
HNO_3 – nitric acid
H_2SO_4 – sulfuric acid
[a] Split samples for these parameters were sent to CH2M's Applied Sciences Laboratory (ASL) and Brooks Rand Laboratory for duplicate sampling. The results that are presented in Section 3 of this report are from ASL; however, a comparison of the results from the two labs is presented in Section 4.
[b] Samples were sent to Applied Speciation Laboratory for analysis. This included ONLY two jar tests (JT3-1 and JT3-4).
[c] Arsenic speciation was not conducted if the total arsenic concentration from the initial sampling was less than 6 micrograms per liter.
[d] Total mercury samples were first screened using method E245.1. If results were below detection, samples were then analyzed using the low-level method (E1631).

3
FGD WASTEWATER TREATABILITY

The purpose of this chapter is to summarize the FGD wastewater treatability results. This section focuses on the main parameters of concern (mercury and arsenic); it also examines removal of selenium, nitrate, and other trace metals. Detailed results are included in **Appendix B**.

Role of Physical/Chemical Treatment in the Proposed ELGs

The proposed BAT treatment technologies that EPA has cited in development of proposed ELGs for FGD wastewater are based on physical/chemical and biological treatment technologies. Physical/chemical treatment can be used to help remove various metals, including mercury and arsenic, which are in soluble form or are small particles that would otherwise not be removed by settling or filtration alone.

EPA calculated an average concentration from selected data for untreated FGD wastewater, settled FGD wastewater, and chemical precipitation effluent in *Technical Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category* [15]. Using values that have been averaged across multiple facilities can be misleading, but it is noteworthy that settled FGD water (as estimated by sampling from pond effluent) had less than 2 percent of the concentration of arsenic and mercury of unsettled FGD water. Chemical precipitation effluent (as measured at some plants' physical chemical treatment plants) had even lower concentrations of arsenic and mercury. Many parameters are removed by over 99 percent through settling combined with chemical precipitation treatment and nearly all of the removal occurs through settling.

The proposed selenium and nitrate/nitrite limits are based on using biological treatment technology for FGD wastewater treatment; they are not anticipated to be removed by the physical/chemical treatment technology to the levels in the proposed ELGs.

Physical/Chemical Treatment Fundamentals

Figure 3-1 shows a typical FGD wastewater physical/chemical treatment system. Typically, an FGD wastewater treatment plant that employs chemical precipitation includes the following unit processes: equalization, desaturation, clarification, and chemical addition. Plants that require additional metals polishing may also include filtration to remove solids that pass through the clarifier. The concentration of TSS in the untreated wastewater ranged from hundreds of ppm to over 7 percent. When TSS in the untreated wastewater is in the percent range, there is a tendency to remove solids in two stages, using primary and secondary clarifiers – the primary to remove the bulk of solids and the secondary to remove metals precipitated. This is site-specific and based on settleability of the solids as well as the balance between capital costs and operating costs [4]. Previous EPRI reports have focused on FGD wastewater management options for these unit processes, including design and operational considerations [2 through 12].

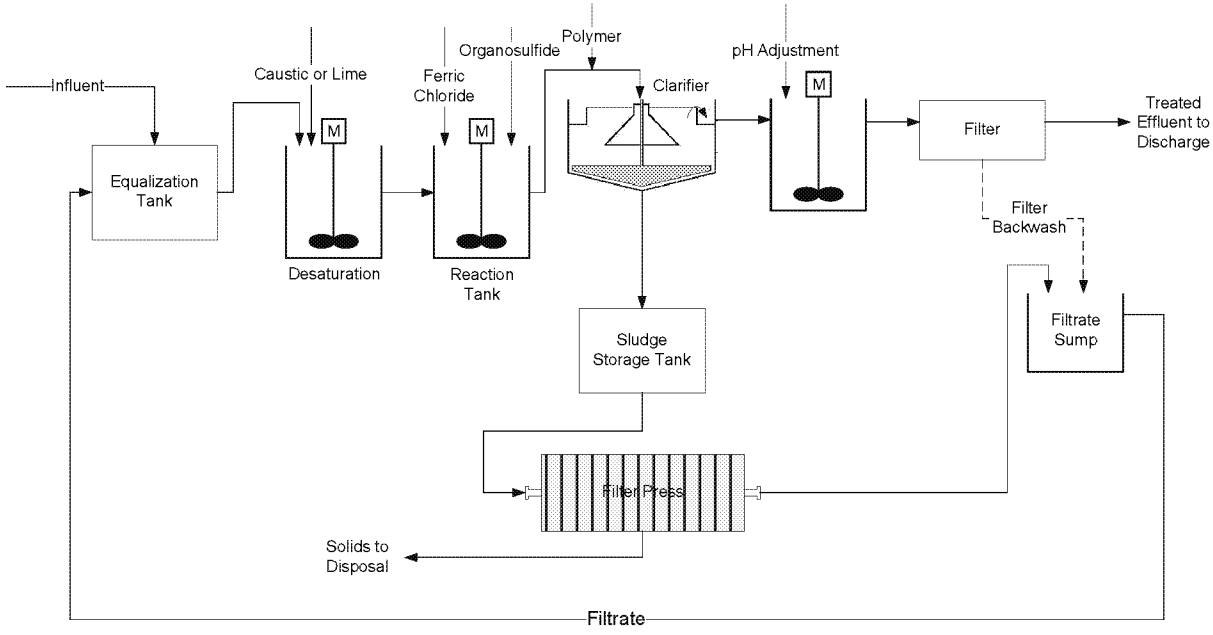


Figure 3-1
FGD wastewater treatment system process flow diagram

Chemical Precipitation

Chemical precipitation can be used to help remove metals that are in soluble form or present as small particles that would otherwise not be removed by settling or filtration alone. Chemical precipitation is driven by effluent concentration, as opposed to percent removal. While large particulates are removed via settling (and their removal is highly dependent on polymer selection, solids recirculation, and clarifier sizing/operation), soluble/small particulate metals are removed through chemical precipitation, and their removal is highly dependent on pH and chemical addition. Although some process wastewater treatment facilities may only require removal of suspended solids, adding the capacity for chemical precipitation may be needed to meet present or future discharge permit limits.

Chemical precipitation may include addition of iron, polymers, acids or bases, and sulfide compounds to improve precipitation. Trace elements precipitate at varying pHs; in this study, chemical precipitation through pH adjustment, iron co-precipitation, and organosulfide addition was evaluated in laboratory testing.

Organosulfide Addition

When metals removal is required to levels below those that can be met using iron co-precipitation and filtration, organosulfide metals precipitation can be used to help remove many trace metals. Organosulfide addition is typically used to enhance mercury removal in power plant wastewater. Organosulfide compounds are polymers with thio- (sulfide) functional groups that bond with monovalent and divalent cationic metals; they are used to counter the solubility of mercury and other cationic metal-chloride complexes, and form precipitates of mercury that can be removed. Organosulfides are typically ineffective at removing anions (such as arsenic and selenium) or trivalent cations (such as ferric iron or alumin) from solution. Various organosulfides are available from vendors (Nalco's Nalmet-1689, Evonik's TMT-15,

and GE's MetClear MR2405). Organosulfides are currently used at numerous power plants for mercury removal from FGD wastewater.

Dissolved mercury can be precipitated into a solid by addition of sulfides. Mercury-sulfide precipitates are very insoluble and precipitate rapidly, so colloidal particles tend to form, which are difficult to remove. Addition of large organic molecules with sulfide or thio- functional groups can form larger particles that are easier to remove. Removal of precipitated mercury is enhanced by addition of a coagulant (such as iron). Polymer addition may be needed after organosulfide precipitation to enhance flocculation.

Iron Co-precipitation

In the iron co-precipitation process, a bulk iron hydroxide compound is formed that precipitates with the addition of an iron source, such as $FeCl_3$. Other ions in solution adsorb to the bulk compound and are thus co-precipitated. Iron is added for precipitation of metals and coagulation of suspended solids. The following is the simplified chemical equation to represent this iron hydroxide formation reaction.

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_{3(solid)} + 3H^+ \qquad \text{(Eq. 3-1)}$$

Dissolved metals concurrently adsorb and precipitate with the ferric hydroxide solid developed during this reaction. Heavy metals form their insoluble hydroxide products and attach to the highly charged, relatively dense ferric hydroxide precipitate. $FeCl_3$ is a common coagulant used to remove suspended particulate material in wastewater. An advantage of using $FeCl_3$ over other coagulants for suspended solids removal is that the formed ferric hydroxide solid also binds and precipitates dissolved metals. Optimal bulk iron hydroxide formation and manipulation of the pH can enhance treatment performance.

Clarification

Clarifiers are used to settle solids in wastewater. Wastewater should not be pumped, but rather should flow by gravity to a clarifier so that solids formed by coagulation and flocculation are not sheared into smaller particles that settle slowly. Traditional circular clarifiers are equipped with a clarifier mechanism and flocculation zone. The clarifier mechanism is equipped with rake arms used to remove settled solids. The flocculator provides gentle mixing of the solids and polymer to promote particle growth that enhances settling of the solids. The flocculated mixture passes below the skirt of the flocculation zone and enters the clarification zone. Solids settle to the conical, sloped bottom of the clarifier; clarified liquid rises to the top, and exits as overflow from the clarifier. Clarifier types other than circular clarifiers are also in use in FGD wastewater treatment; these types include those that have packs of inclined plates to increase effective surface area. These lamella clarifiers need to be sized large enough to account for the high solids loading in FGD wastewater treatment.

Particles smaller than 20 micrometers are poorly removed by settling. Settling efficiency is based on the particles' density, size, and shape. Coagulation and flocculation are needed to build large, dense particles.

Clarifier performance can be enhanced by adding polymers. Polymer is often used to help flocculate solids before clarification. A flocculation well is therefore often included in the

primary clarifier to provide the ability to add polymer at this point. Polymer doses vary widely based on the type of polymer and water chemistry. Polymer may be added to the mix tank effluent pipe to provide initial mixing in the gravity line to the clarifier.

Additional information on clarifier design and operation is included in a past EPRI document [4].

Filtration

Filtration is used to remove TSS and heavy metals in particulate form. Filtration will typically not be used in process wastewater applications unless metals limits cannot be met with chemical precipitation and clarification. Sand filters can typically reduce FGD wastewater TSS to below 10 ppm and remove solids that are 5 micrometers or larger. Membrane technologies, such as microfiltration, ultrafiltration, nanofiltration, or reverse osmosis could be used to remove smaller solids particles from process wastewater. However, these technologies have not been commercially applied to FGD wastewater and there are concerns with potential membrane scaling.

Effect of Chemical Precipitation and Settling on Metals Removal

Metals, such as mercury and arsenic, can be precipitated as either hydroxide or sulfide particulates in FGD wastewater. The solubility for each metal varies over different pH ranges; in general, for cationic metals, a higher pH results in lower solubility and greater precipitation. Plants often use lime for pH adjustment. The lime is typically added in the metals removal step to achieve a pH of approximately 8.5, which is as high a pH as lime can achieve under plant conditions, as FGD wastewater tends to be supersaturated with calcium sulfate. Sand filters have been found to be difficult to maintain due to scaling of the sand.

Many factors can affect mercury concentration in FGD wastewater and its treatment, including the composition of coal that is burned, FGD design and operation, whether gypsum fines are washed to the treatment system, and the presence of compounds that prevent the precipitation of mercury from dissolved to particulate form. Mercury treatment is affected by the effectiveness of chemical addition for mercury precipitation, liquid/solids separation, water temperature, controlling pH, and numerous other treatment system operational variables [10].

Organic matter, often measured as dissolved organic carbon, also appears to affect the ability to remove mercury with conventional chemical precipitation processes. In past EPRI research [10], higher dissolved organic carbon concentrations correlated to higher dissolved mercury concentrations in jar test effluents, and lower percent removal of mercury. It was theorized that organic acids acted as complexing agents for mercury, which increased mercury solubility by incorporating the metal in the soluble organic molecule.

Some metals, such as selenium and arsenic, are present as anions in solutions and cannot be removed by hydroxide or sulfide precipitation, but may be removed, in part, under some conditions by adsorption or co-precipitation with iron hydroxide. It is important to understand the speciation of selenium and arsenic, as some forms (selenite and arsenate) can be removed by physical/chemical treatment under the right conditions, while other species (selenate and arsenite) have much less removal by physical/chemical treatment. This is complicated by the fact that the favored form of selenium (selenite) is the chemically reduced form, while the favored form of arsenic (arsenate) is oxidized. Providing oxidation or reduction to favor one anion is at

the expense of adversely impacting removal of the other. Arsenic and selenium are generally removed best at neutral or slightly acidic pH. With metals being regulated to microgram per liter (µg/L) or nanogram per liter (ng/L) levels, it may be difficult to have an optimum pH for precipitation of all metals of concern. Unlike metal hydroxide precipitation, organosulfide precipitation is effective over a broad pH range, although it appears to be more efficient, and in some cases more effective, at slightly alkaline pH. To treat arsenic and selenium along with cationic metals, precipitation using iron salts and organosulfide is likely to be most effective at neutral to slightly acidic pH.

Treatment levels achieved by a technology at one plant may not be achieved by that same technology at another plant. Additionally, because of the changing nature of FGD wastewater, the treatment levels achieved by a technology at a plant will likely not be achieved consistently.

Mercury Removal

Mercury in Untreated FGD Water

The proposed ELG contains a monthly average mercury value of 119 ng/L and a daily maximum mercury value of 242 ng/L for FGD wastewater. As shown in **Table 3-1**, FGD wastewater influents sampled have mercury concentrations well above the proposed ELGs, with total concentrations ranging from 1,390 ng/L to 266,000 ng/L, and soluble/small particulate (<0.45 µm) concentrations ranging from 40 ng/L to 19,500 ng/L. Because mercury is present in both soluble/small particulate (<0.45 µm) and large particulate (>0.45 µm) forms, treatment would likely need to remove both forms well to meet the 119-ng/L ELG.

Three of the five plants had soluble/small particulate mercury well below the ELG in untreated FGD water. The other two plants had much more soluble/small particulate mercury. The large variation in soluble/small particulate mercury is likely a result of changes in the mercury content of coal, and factors that affect the solubility of mercury (which may include dissolved organic acids) [10] and MATS additives.

Estimated FGD scrubber residence times are included in **Table 2-1**. Unlike soluble arsenic, FGD scrubber residence time does not appear, from this limited data set, to impact soluble mercury concentration. For example, Plant 2, which has the shortest estimated FGD scrubber residence time of the five plants, had the highest soluble (<3,000 MW) mercury concentration; whereas Plant 3, which had the longest estimated FGD scrubber residence time, had the second highest soluble mercury concentrations (**Table 3-1**).

Table 3-1
Influent Mercury in Control (Settled)

Site	Mercury, Total	Mercury, 0.45-µm Filtered	Mercury, 30,000-MW Filtered	Mercury, 3,000-MW Filtered	Mercury, > 0.45 µm	Mercury, 30,000 MW to 0.45 µm	Mercury, 3,000 MW to 30,000 MW	Mercury, <3,000 MW
	Measured Concentration (ng/L)				Calculated Values in Each Size Range (ng/L)			
Plant 1	166,000	41	44	--	165,956	*	44	
Plant 2	20,800	19,500	19,400	18,000	1,300	100	1,400	18,000
Plant 3	266,000	4,110	4,630	3,770	261,890	*	860	3,770
Plant 4	7,580	61	38	20	7,519	23	18	20
Plant 5	1,390	44	36	14 J	1,346	8	22	14 J

Notes
J – estimated value
µm – micrometer
MW – molecular weight
ng/L – nanograms per liter
* Little or no mercury appears to be present in the given size range.

Removal of Large Particulate Mercury by Settling

Influent and effluent mercury concentrations from the laboratory tests are included in **Table 3-2**. As can be seen in the difference between the untreated samples and the jar test controls, in which the only treatment is by settling (i.e., no chemical addition), a large percentage (88 to 99 percent) of particulate mercury was removed by settling for four of the five plants. The results for Plant 1 showing as much mercury in water after settling as without settling are likely because of the use of stir bars for mixing, which appeared to cause shearing. However, the amount of large particulate (>0.45 µm) mercury remaining after settling is still significant enough (1,350 to 262,000 ng/L) to be one to three orders of magnitude higher than the proposed ELG limit.

Table 3-2
Influent and Effluent Mercury

Site	Untreated, Not Heated			Control (Settled)			Best Effluent		
	Total	Large Particulate (>0.45 µm)	Soluble and Small Particulate (<0.45 µm)	Total	Large Particulate (>0.45 µm)	Soluble and Small Particulate (<0.45 µm)	Total	Large Particulate (>0.45 µm)	Soluble and Small Particulate (<0.45 µm)
	ng/L			ng/L			ng/L		
1	126,000	125,950	50	166,000	165,959	41	237	225	12 J
2	211,000	203,790	7,210	20,800	1,300	19,500	406	393	13 J
3	2,110,000	2,107,300	2,700	266,000	261,890	4,110	3,830	2,873	957
4	373,000	372,975	25	7,580	7,519	61	608	582	26
5	104,000	103,954	46	1,390	1,346	44	771	762	9

Notes:

J – estimated value

Large particulate (>0.45 µm) concentrations were calculated by subtracting the soluble/small particulate (<0.45 µm) concentration from the total.

Removal of Soluble and Small Particulate Mercury by Settling

As would be expected, settling did not remove soluble or small particulate mercury. In fact, higher concentrations were reported after settling for water from Plants 2, 3, and 4. This may be partly a result of particle shearing caused by mixing energy.

Removal of Large Particulate Mercury by Chemical Addition

Adding iron, organosulfide, and polymer removed mercury well past the concentrations achieved only by settling. This is seen by comparing the total mercury in the jar test control to the lowest concentration achieved in jar testing (**Table 3-3**, "Best Effluent" column). However, the concentration of large particulate (>0.45 µm) mercury was still greater than the proposed ELG of 119 ng/L for all plants (230 to 2,900 ng/L). Large particulate mercury is expected to settle out better in full-scale plants than these jar test results indicate, especially in full scale systems with sludge recirculation, which is not replicable in the lab. Sludge recirculation produces large granular particles; without sludge recirculation, light, fluffy solids are produced that settle poorly and are fragile. The better removal with sludge recirculation is evidenced by lower treatment plant effluent mercury results from full-scale FGD wastewater treatment plants, which were sampled in a concurrent EPRI project at Plants 1, 3, and 5, as shown in **Table 3-3** (data are analyzed in a not yet published report).

Table 3-3
Comparison of Jar Test Effluent and Full-scale FGD WWTP Effluent Mercury (from not yet published EPRI report)

Site	Best Effluent from Jar Tests			Full-scale WWTP Effluent		
	Total	Large Particulate (>0.45 µm)	Soluble and Small Particulate (<0.45 µm)	Total	Large Particulate (>0.45 µm)	Soluble and Small Particulate (<0.45 µm)
	ng/L			ng/L		
Plant 1 – Sample 1	237	225	12 J	1,430	1,337	93
Plant 1 – Sample 2	--	--	--	80	50	30
Plant 1 – Sample 3	--	--	--	25	16	9
Plant 3 – Sample 1	3,830	2,873	957	202	85	117
Plant 3 – Sample 2	--	--	--	157	65	92
Plant 3 – Sample 3	--	--	--	112	53	59
Plant 5 – Sample 1	771	762	9 J	< 9	0	< 9
Plant 5 – Sample 2	--	--	--	< 12	0	< 12
Plant 5 – Sample 3	--	--	--	131	122	9

Notes:

< - not detected at shown detection limit.

Large particulate (>0.45 µm) concentrations were calculated by subtracting the soluble/small particulate (<0.45 µm) concentration from the total.

Further optimization of polymer type and dose could likely have achieved better particulate removal. (Polymer optimization was not fully explored because of the limited scope of this study.) Polymer screening was limited to five polymers for each wastewater at each pH setpoint (up to 20 tests per plant). The polymer that produced the clearest supernatant and most robust floc, as judged by the tester (who was experienced with chemical precipitation), was used for the laboratory tests. However, in some cases, the polymer produced a supernatant with some turbidity remaining, which may have contained fine particulate mercury, as shown in **Table 3-4** ("Best Effluent" column).

Table 3-4
Influent and Effluent Supernatant Turbidity

Site	Control (Settled)Control (Settled)	Best Effluent
	Turbidity (NTU)	
Plant 1	--29	7
Plant 2	29	3
Plant 3	1,254	5
Plant 4	8374	11
Plant 5	74	35

Notes:
NTU – nephelometric turbidity units

Removal of Soluble and Small Particulate Mercury by Chemical Addition

As shown in **Table 3-5,** the removal of soluble and small particulate (<0.45 µm) mercury varied significantly between plants. At four of the five sites, chemical precipitation was able to drive the soluble/small particulate (<0.45 µm) concentration down to 9 to 26 ng/L (below the proposed ELGs), while the Plant 3 water was only treated down to 960 ng/L. This higher effluent soluble/small particulate mercury concentration was also seen in Plant 3's full-scale treatment plant samples (**Table 3-5**), which had 59 to 117 ng/L in three EPRI sample events conducted in 2014. This result may be because of the relatively large amount of mercury in the Plant 3 water before treatment; if just a small percentage of the 266,000 ng/L of total mercury is present after settling in difficult-to-remove form, then there would be significant mercury remaining in the bench-scale test effluent.

Water complexity (TDS) seemed to be another indicator of how difficult it is to drive mercury into particulate form; difficulty capturing soluble and small particulate mercury was observed in samples with high TDS concentrations as shown in **Figure 3-2** and **Table 3-5**. For example, Plants 2 and 3 had high influent soluble mercury, but Plant 2 achieved much lower soluble mercury in the jar testing. However, Plant 3 had much higher TDS than Plant 2, which may have contributed to Plant 3 having the significantly higher soluble mercury in the jar test effluent.

Other potential contributing factors to less removal of soluble and small particulate mercury are the presence of organics, particle shearing, and insufficient iron particle aggregation.

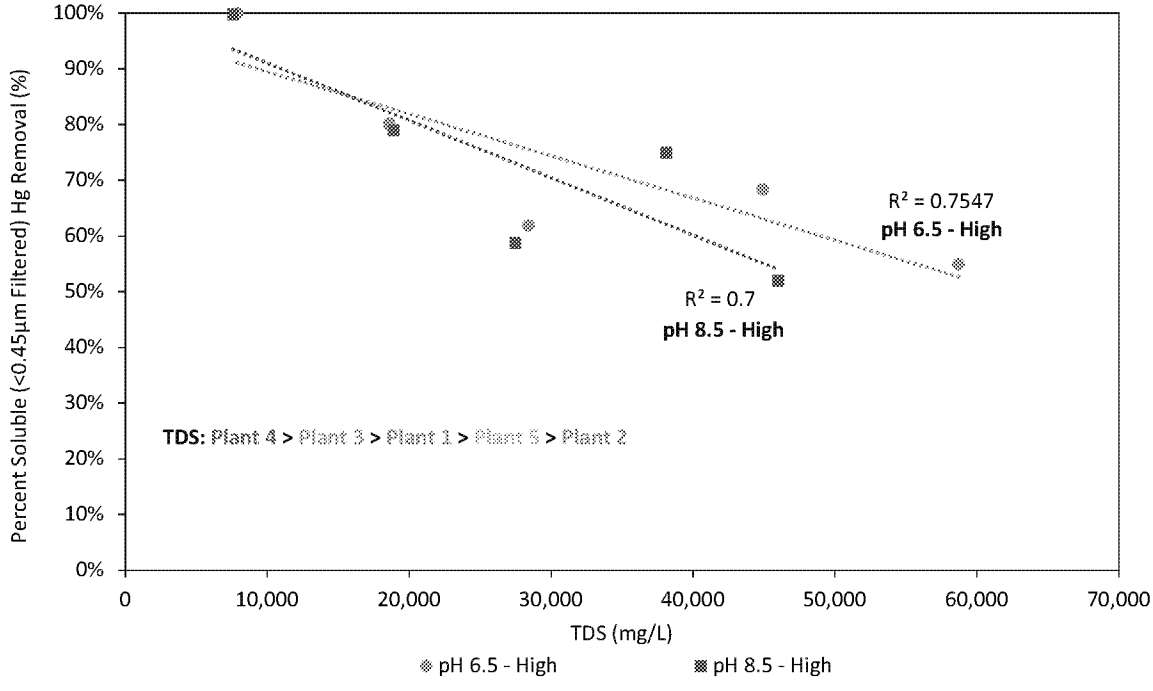


Figure 3-2
Removal of effluent soluble mercury appears affected by TDS

Table 3-5
Soluble Mercury Concentration in Effluent Compared to TDS

Site	Control (Settled)		pH 8.5 – High Organosulfide (80-ppm) Dose	
	TDS (mg/L)	Chloride (mg/L)	Mercury (<0.45 µm) (ng/L)	Mercury (<0.45 µm) (ng/L)
Plant 4	54,100	19,100	61	29
Plant 3	44,300	5,540	4,110	1,030
Plant 1	21,900	8,000	41	17 J
Plant 5	19,700	5,730	44	9 J
Plant 2	7,500	940	19,500	47

Notes:
J – estimated value

Particle Size Distribution of Effluent Mercury

Mercury concentrations by size fraction are included in **Table 3-6**. Roughly half of the soluble/small particulate (<0.45 µm) mercury present in the Plant 3 effluent was present as "truly soluble" (<3,000 MW) mercury. Plants 1, 2, and 5 had a similar particle size distribution, with 46 to 63 percent of the soluble/small particulate mercury present as "truly soluble." Only about 20 percent of the soluble/small particulate mercury present in the Plant 4 effluent was present as "truly soluble."

Table 3-6
Influent and Effluent Mercury

Site	Total	Large Particles (>0.45 µm)	Larger Submicron Particles (30,000 MW to 0.45 µm)	Smaller Submicron Particles (3,000 MW to 30,000 MW)	Soluble (<3,000 MW)
	Mercury, ng/L				
Control (Settled)					
Plant 1	166,000	165,959	*	*	*
Plant 2	20,800	1,300	100	1,400	18,000
Plant 3	266,000	261,890	*	860	3,770
Plant 4	7,580	7,519	23	18	20
Plant 5	1,390	1,346	8	22	14
Organosulfide Dose: High (80 ppm); Target pH: 6.5					
Plant 1	1,990	1,975	*	8	7
Plant 2	633	620	7	*	7
Plant 3	19,500	18,200	344	124	832
Plant 4	1,050	1,023	16	5	6
Plant 5	1,190	1,181	*	7	6
Organosulfide Dose: High (80 ppm); Target pH: 8.5					
Plant 1	463	446	1	8	8
Plant 2	525	478	13	4	30
Plant 3	3,830	2,800	309	119	602
Plant 4	608	579	19	4	6
Plant 5	883	874	4	*	6

Notes:
* Little or no mercury appears to be present in the given size range (based on no difference or a negative difference between the two filtration results).

Effect of pH on Mercury Removal

Removal of soluble/small particulate mercury was comparable at pH 6.5 and 8.5 (**Figure 3-3**). Total mercury was better removed at pH 8.5 in all five waters (**Figure 3-4**), this was likely because of better iron solids formation.

As shown in **Table 3-7**, limited removal was also observed at pH 4.0.

The two plants evaluated at pH 10.5 showed poor settling characteristics and soluble mercury concentrations well above the proposed ELG.

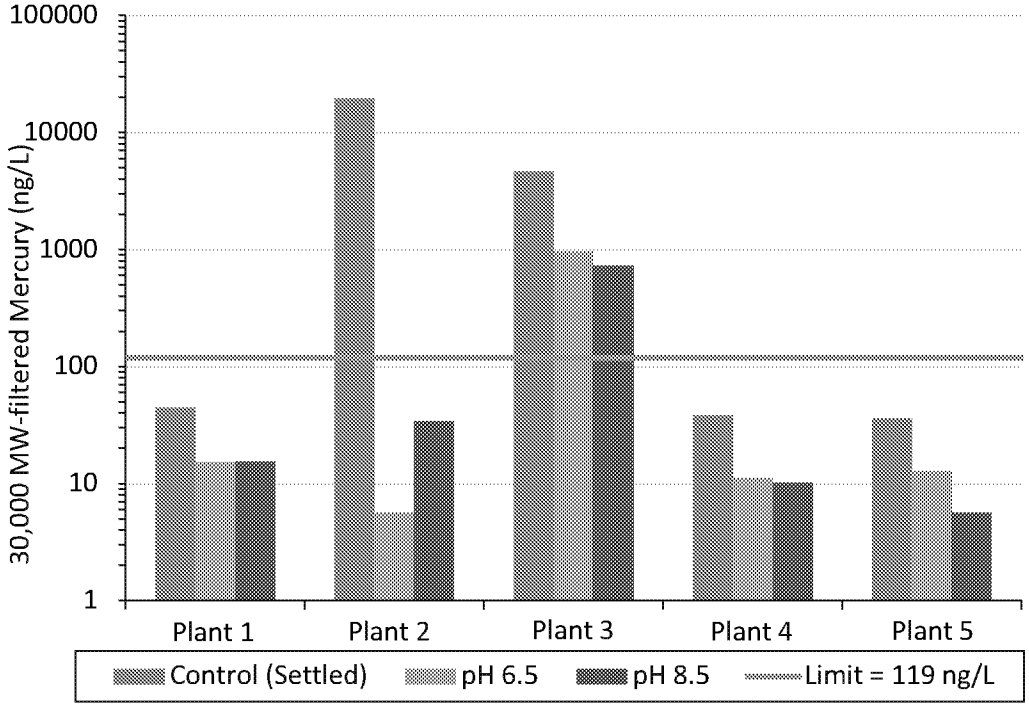


Figure 3-3
Effluent mercury (<30,000 MW) at varying pH and high organosulfide dose (80 ppm)

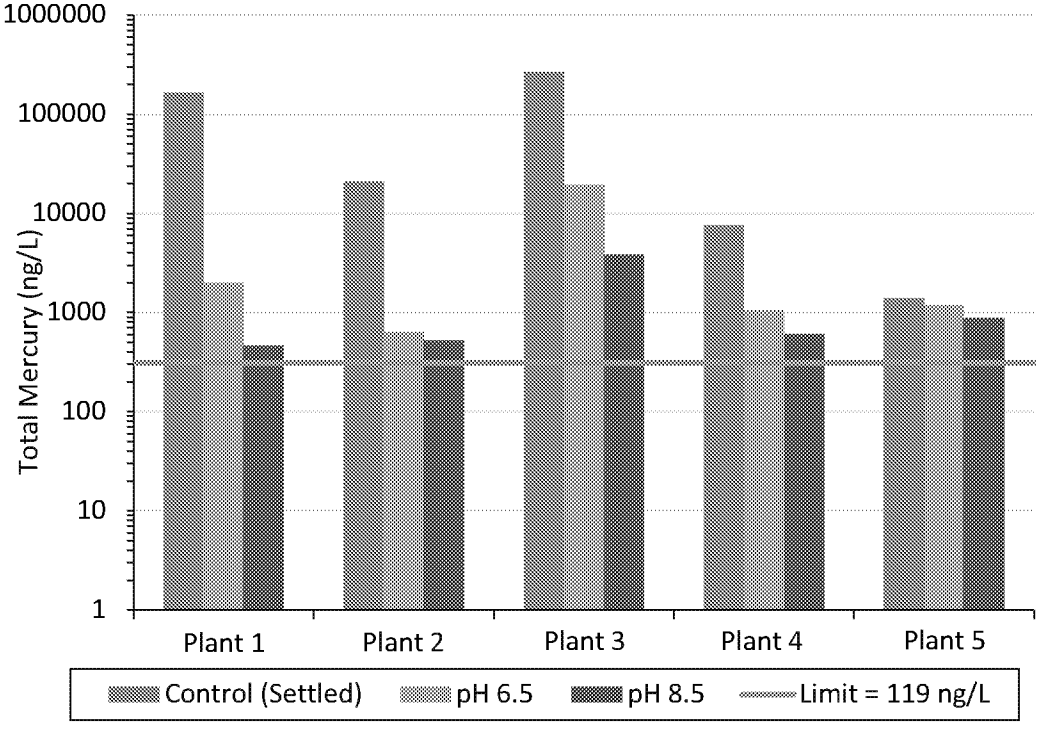


Figure 3-4
Total effluent mercury at varying pH and high organosulfide dose (80 ppm)

Table 3-7
Effluent Mercury at Varying pH and High Organosulfide Dose (80 ppm)

Site	Total Mercury, ng/L					Mercury <30,000 MW, ng/L				
	Control (Settled)	Jar Test pH 4.0	Jar Test pH 6.5	Jar Test pH 8.5	Jar Test pH 10.5	Control (Settled)	Jar Test pH 4.0	Jar Test pH 6.5	Jar Test pH 8.5	Jar Test pH 10.5
1	166,000	1,130	1,990	463	NA	44	14 J	15 J	15 J	909
2	20,800	1,020	633	525	961	19,400	10 J	< 6	34	923
3	266,000	34,500	19,500	3,830	NA	4,630	19,700	956	721	NA
4	7,580	1,810	1,050	608	NA	38	112	11 J	10 J	NA
5	1,390	1,030	1,190	883	NA	36	7 J	13 J	< 6	NA

Notes:
J – estimated value
MW – molecular weight
NA – not analyzed
< – not detected at shown detection limit.

Arsenic Speciation and Removal

Arsenic in Untreated FGD Water

The proposed ELGs would set a monthly average arsenic limit of 6 µg/L and a daily maximum arsenic limit of 8 µg/L for FGD wastewater. As shown in **Table 3-8**, in water that had been settled in the jar test, three of the five plants had arsenic concentrations that were above the proposed ELGs. Arsenic in untreated FGD wastewater influent samples was mostly particulate with very low concentrations of material passing a 0.45-µm filter.

To evaluate if the arsenic passing the 0.45-µm filter was small particulate or truly soluble, the water was filtered with very small pore size filtration. By observing that the concentration passing the smallest filter (3,000 MW, or 1.5 nanometer) is essentially the same as that passing the 0.45-µm filter, it appears that the arsenic that does pass a 0.45-µm filter is truly soluble.

Soluble (<0.45 µm) arsenic in untreated FGD water was below the proposed monthly average ELG of 6 µg/L for all but one plant, with concentrations ranging from non-detect to 9 µg/L.

Table 3-8
Influent Arsenic in the Control (Settled)

Site	Arse-nic, Total	Arsenic, 0.45-µm Filtered	Arsenic, 30,000-MW Filtered	Arsenic, 3,000-MW Filtered	Arsenic, > 0.45 µm	Arsenic, 30,000 MW to 0.45 µm	Arsenic, 3,000 MW to 30,000 MW	Arsenic, <3,000 MW
	Measured Concentration (µg/L)				Calculated Values in Each Size Range			
Plant 1	261	3.0	NA	NA	258	3.0		
Plant 2	2.6	< 0.8	0.9 J	NA	1.7	*	0.9 J	
Plant 3	28	8.8	9.9	9.7	19	*	0.2	9.7
Plant 4	7.6	4.7	5.2	4.7	2.9	*	0.5	4.7
Plant 5	3.3	1.3 J	1.6 J	1.6 J	2.0	*	0.1	1.6 J

Notes:

J – Estimated value

NA – not available

< – not detected at shown detection limit

* Little or no arsenic appears to be present in the given size range (based on no difference or a negative difference between the two filtration results).

As shown in **Table 3-9**, higher soluble arsenic concentrations were observed at plants with longer FGD scrubber residence times. The plant with the highest soluble arsenic concentration had the highest FGD scrubber hydraulic residence time (18 days), which was twice that of the next highest residence time (Plant 4, over 8 days). Longer residence times are indicative of higher recirculation of the scrubber, implicating that higher soluble arsenic concentration could occur if plants reduce their FGD flow via higher recirculation of the scrubber. The plant with the highest soluble arsenic was also the only plant burning solely PRB coal.

Table 3-9
Relationship Between Scrubber HRT and Influent Soluble/Small Particulate Arsenic

Site	Estimated Scrubber HRT (days)	Arsenic, 0.45-um filtered [a] (µg/L)
Plant 3	18	8.8
Plant 4	8	4.7
Plant 1	6-7	3.0
Plant 5	3 [c]	1.3 J
Plant 2	less than 1 [b]	< 0.8

Notes:

[a] Control (settled)

[b] Single pass

[c] Scrubber volume was not reported for this plant. It was estimated using information from similarly sized plants along with EPA reported data for flow rates.

J – estimated value

< – not detected at shown detection limit.

Removal of Particulate Arsenic by Settling

Influent and effluent arsenic concentrations from the laboratory tests are included in **Table 3-10.** As can be seen in the difference between the untreated samples and the jar test controls (in which the only treatment is by settling, with no chemical addition), a large percentage (90 to 99 percent) of particulate arsenic was removed by settling for four of the five plants (the results for Plant 1, where arsenic after setting was as high as before settling, are likely because of the use of stir bars for mixing, which appeared to cause shearing). However, the amount of large particulate (>0.45 µm) arsenic remaining after settling was still higher than the proposed ELG for three of the five plants (7.6 to 261 µg/L).

Table 3-10
Influent and Effluent Arsenic

Site	Untreated, Not Heated			Control (Settled)			Best Effluent		
	Total	Particulate (>0.45 µm)	Soluble (<0.45 µm)	Total	Particulate (>0.45 µm)	Soluble (<0.45 µm)	Total	Particulate (>0.45 µm)	Soluble (<0.45 µm)
	Arsenic, µg/L								
1	267	264	3.1	261	258	3.0	1.7	0.2	1.5
2	194	193	1.4	2.6	1.7	< 0.8	< 0.3	*	< 0.3
3	200	191	9.0	28	19	8.8	7.9	1.3	6.6
4	202	197	5.2	7.6	2.9	4.7	4.1	0.9	3.2
5	144	143	< 0.8	3.3	2.0	1.3 J	1.8 J	1.0	< 0.8

Notes:

J – estimated value

< – Not detected at shown detection limit

Particulate (>0.45 µm) concentrations were calculated by subtracting the soluble (<0.45 µm) concentration from the total.

Removal of Soluble Arsenic by Settling

As would be expected, settling alone did not remove soluble or small particulate (<0.45 µm) arsenic.

Removal of Particulate Arsenic by Chemical Addition

Adding iron, organosulfide, and polymer removed particulate arsenic well past the concentrations achieved only by settling. This is seen by comparing the total arsenic in the jar test control to the lowest concentration achieved (**Table 3-10**, "Best Effluent" column). The concentration of particulate (>0.45 µm) arsenic was driven below the proposed ELG limit of 6 µg/L for all plants, ranging from 0.2 to 1.3 µg/L.

Removal of Soluble Arsenic by Chemical Addition

As shown in **Table 3-10** there was little or no removal of soluble (<0.45 µm) arsenic in jar tests. Soluble arsenic was not substantively removed at any of the test conditions and there was little to no difference between the different pHs tested.

Water from one plant had higher influent selenite levels than anticipated and the iron addition was below the target iron-to-selenium ratio for this sample. However, the iron addition was well above the target iron-to-arsenic ratio for all samples.

As shown in **Table 3-11**, arsenic speciation analysis was conducted to determine the concentrations of arsenate, arsenite, DMAs, and monomethylarsonic acids (MMAs). The "unaccounted" arsenic was calculated from the difference between total soluble arsenic reading and detected arsenic species. The "unaccounted" arsenic was not effectively removed with physical/chemical treatment; this indicates that there may be some organic arsenic. The significant amount of "unaccounted" arsenic may also be a result of analytical variability due to low arsenic concentrations and sampling and analysis "noise".

The chemicals used in laboratory treatability testing, specifically iron, presented additional challenges with obtaining accurate arsenic speciation data. Matrix spikes on the samples collected showed poor recovery for arsenate. Arsenate is adsorbed by iron hydroxide. It is thought that colloidal iron hydroxide was present in the samples and/or ferric iron was getting caught in the speciation separation column; both processes adsorbing arsenate caused analytical challenges with getting a correct measurement for this parameter. However, it should be noted that the speciation results from the control samples, in which iron was not present, were consistent with jar test results and all were below or near the method detection level.

Table 3-11
Arsenic Speciation in 0.45-µm Filtered Water

Site	Arsenic (µg/L)					
	Total < 0.45 µm Arsenic	Arsenate (V)	Arsenite (III)	DMAs	Sum of Species	Unaccounted Arsenic
Control (Settled)						
Plant 1	3.0	1.4	1.2	< 1.0	2.6	0.4
Plant 2	< 0.8	< 1.4	1.1	< 1.0	1.1	N/A
Plant 3	8.8	< 1.4	0.7	1.2	1.8	7.0
Plant 4	4.7	< 1.4	< 0.6	2.0	2.0	2.7
Plant 5	1.3 J	< 1.4	< 0.6	< 1.0	0.0	1.3
Jar Test pH 6.5 – High Organosulfide Dose						
Plant 1	2.2	< 1.4	1.6	< 1.0	1.6	0.6
Plant 2	0.9	< 1.4	< 0.6	< 1.0	0.0	0.9
Plant 3	10.0	< 1.4	< 0.6	< 1.0	0.0	10.0
Plant 4	4.9	< 1.4	0.8	1.7	2.6	2.3
Plant 5	< 0.8	< 1.4	< 0.6	< 1.0	0.0	N/A
Jar Test pH 8.5 – Low Organosulfide Dose						
Plant 1	1.9	NA	NA	NA	NA	NA
Plant 2	1.5	< 1.4	< 0.6	< 1.0	0.0	1.5
Plant 3	7.0	< 1.4	0.8	2.1	2.9	4.1
Plant 4	4.2	< 1.4	< 0.6	2.0	2.0	2.2
Plant 5	1.2	< 1.4	< 0.6	< 1.0	0.0	1.2

Notes:

J – estimated value

NA - Not Analyzed

< - Not detected at shown detection limit

MMAs not detected in any test. Unaccounted arsenic is the difference between the <0.45 filtered arsenic and the sum of the detected species. Note that this calculation of "unaccounted" may be skewed by non-detect values (for example, at Plant 3, arsenate is some value less than 1.4 µg/L, but is considered to be 0 µg/L in calculating the sum of species).

The plants sampled by EPA for ELG development also had little or no soluble arsenic in the full-scale treatment plant effluent, as shown in **Figure 3-5**. EPRI commented on the 2013 proposed ELG that EPA should better characterize removal of soluble arsenic in setting ELGs [13].

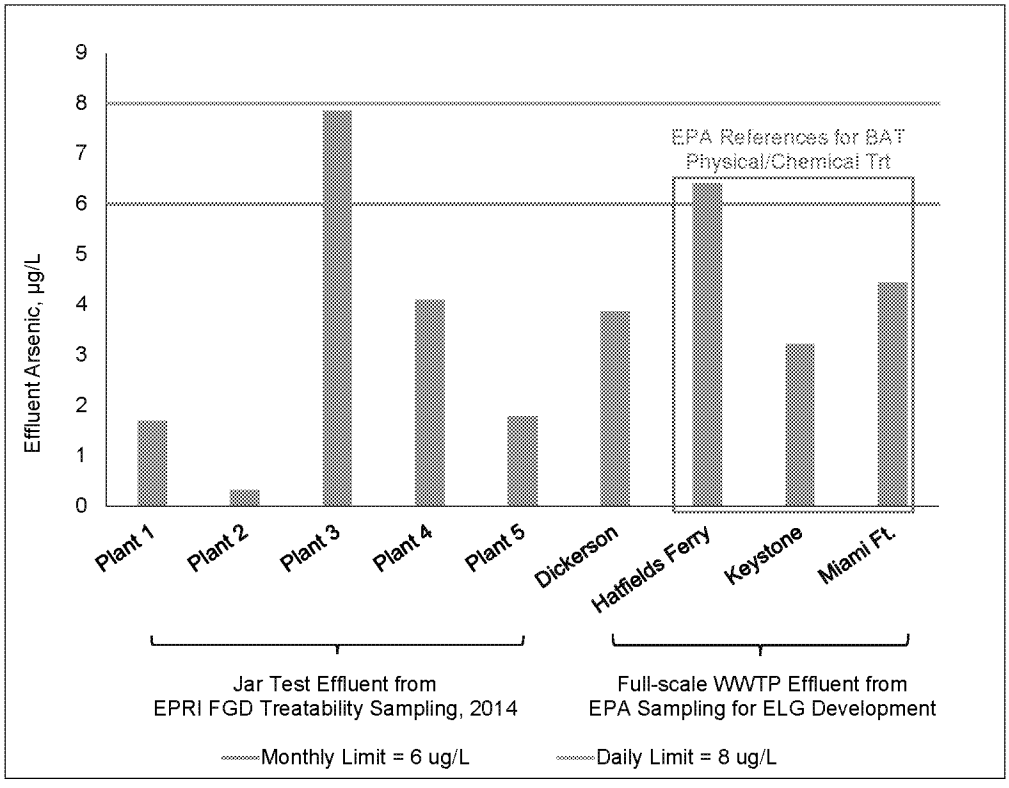


Figure 3-5
Comparison of effluent arsenic to EPA sampling for ELG development

Selenium Speciation and Removal

Selenium in Untreated FGD Water

The proposed ELGs would set a monthly average selenium value of 10 µg/L and a daily maximum selenium value of 16 µg/L for FGD wastewater. As shown in **Table 3-12**, all of the five plants had selenium concentrations in untreated FGD wastewater that were well above the proposed ELGs, with total concentrations ranging from 919 µg/L to 15,800 µg/L, and soluble (<0.45 µm) concentrations ranging from 239 µg/L to 4,520 µg/L. As with mercury, because selenium is present in both soluble (<0.45 µm) and particulate (>0.45 µm) forms, treatment must remove both forms well to meet the proposed ELGs.

Table 3-12
Influent Selenium

Site	Selenium, Total	Selenium, >0.45 µm	Selenium, <0.45 µm
	Untreated, Not Heated		
	µg/L		
Plant 1	919	676	243
Plant 2	1,950	890	1,060
Plant 3	15,800	11,280	4,520
Plant 4	1,290	1,051	239
Plant 5	1,550	1,232	318

Removal of Particulate Selenium by Settling

Influent and effluent selenium concentrations from the laboratory tests are included in **Table 3-13**. As can be seen in the difference between the untreated samples and the jar test controls (in which the only treatment is by settling, with no chemical addition), a large percentage (41 to 84 percent) of particulate selenium was removed by settling for four of the five plants (the higher results for Plant 1 are likely from the use of stir bars for mixing, which appeared to cause shearing). However, the amount of particulate (>0.45 µm) selenium remaining after settling was still higher than the proposed ELGs for two of the five plants (798 to 1,580 µg/L).

Table 3-13
Influent and Effluent Selenium

Site	Untreated, Not Heated			Control (Settled)			Best Effluent		
	Total	Particulate (>0.45 µm)	Soluble (<0.45 µm)	Total	Particulate (>0.45 µm)	Soluble (<0.45 µm)	Total	Particulate (>0.45 µm)	Soluble (<0.45 µm)
	µg/L			µg/L			µg/L		
1	919	676	243	937	798	139	109	14	95
2	1,950	890	1,060	1,160	*	1,300	1,080	30	1,050
3	15,800	11,280	4,520	6,620	1,580	5,040	2,960	210	2,750
4	1,290	1,051	239	210	8.0	202	75	*	85
5	1,550	1,232	318	331	5.0	326	288	10	278

Notes:

* Little or no selenium appears to be present as particulate (based on no difference or a negative difference between total and soluble selenium measured results).

Particulate (>0.45 µm) concentrations were calculated by subtracting the soluble (<0.45 µm) concentration from the total.

Removal of Soluble Selenium by Settling

As would be expected, settling did not remove soluble (<0.45 µm) selenium. In fact, higher concentrations were reported after settling for water from Plants 2 and 3. This may be partly a result of particle shearing caused by mixing energy.

Removal of Particulate Selenium by Chemical Addition

Adding iron, organosulfide, and polymer removed particulate (>0.45 µm) selenium well past the concentrations achieved only by settling. This is seen by comparing the particulate selenium in the jar test control to the lowest concentration achieved (Table 3-13, "Best Effluent" column). However, the concentration of particulate selenium was still greater than the proposed monthly average ELG of 10 µg/L for three of the five plants (14 to 210 µg/L).

Removal of Soluble Selenium by Chemical Addition

As shown in **Table 3-13**, soluble (<0.45 µm) selenium was generally not effectively captured in jar tests. Removal of soluble selenium ranged from 15 to 58 percent, with the largest removal at pH 4.0. Selenium in jar test effluent was above the proposed ELGs for all five plants.

Plants 2 and 3 had the highest effluent soluble selenium. They both had higher influent soluble selenium levels than anticipated. Since these analytical results were not expedited, the iron addition was not adjusted and was below the target iron-to-selenium ratio for these samples, as shown in **Table 3-14**.

Table 3-14
Iron Addition in Jar Tests

Site	Control (Settled) Total Soluble Selenium (µg/L)	Theoretical Iron Required (mg/L)	Control (Settled) Selenite (µg/L)	Theoretical Iron Required (mg/L)	Actual Iron Dosage Used in Jar Tests (mg/L)
Plant 1	139	37	33	9	40
Plant 2	1,300	346	4	1	40
Plant 3	5,040	1,340	2,060	548	40
Plant 4	202	54	111	30	40
Plant 5	326	87	57	15	40

If only selenite, which is the main form of soluble selenium that is removed by chemical precipitation, is considered, only Plant 3 was below the target iron-to-selenium ratio. A higher iron dose may have resulted in additional selenium removal for this plant. However, Plant 2 had very low influent and effluent selenite concentrations, indicating that additional treatment was needed to drive selenium below the proposed ELGs. Therefore, selenium will likely require additional treatment (such as biological or ZVI treatment) to comply with the proposed ELGs.

Soluble selenium in jar test effluent appears to have been present mainly as selenate and selenite; as shown in **Figure 3-6**. However, there is also a significant portion of other selenium compounds, including "unaccounted" selenium. The "unaccounted" selenium was calculated from the difference between total soluble selenium reading and detected selenium species.

Concentrations of other selenium compounds, including "unaccounted" selenium, were above the lower proposed ELG of 10 µg/L in jar test effluent from all five plants; these forms will also need to be removed in order to achieve the ELG. Little or no difference in selenium speciation was observed at different pHs and organosulfide doses.

Past research has shown that some selenite treatment can be achieved by chemical precipitation using iron addition and pH control (best results have been seen at slightly acidic conditions). However, limited selenite removal was observed even at lower pHs; selenite removal ranged from 27 to 56 percent, as shown in **Table 3-15** and **Figure 3-7**. Little or no removal was observed for selenium species other than selenite.

Table 3-15
Selenite Removal

Site	Selenite		
	Control (Settled), µg/L	Best Effluent, µg/L	Percent Removal
Plant 1	33	20	40%
Plant 2	3.7	4.0	--
Plant 3	2,060	1,410	32%
Plant 4	111	49	56%
Plant 5	57	41	27%

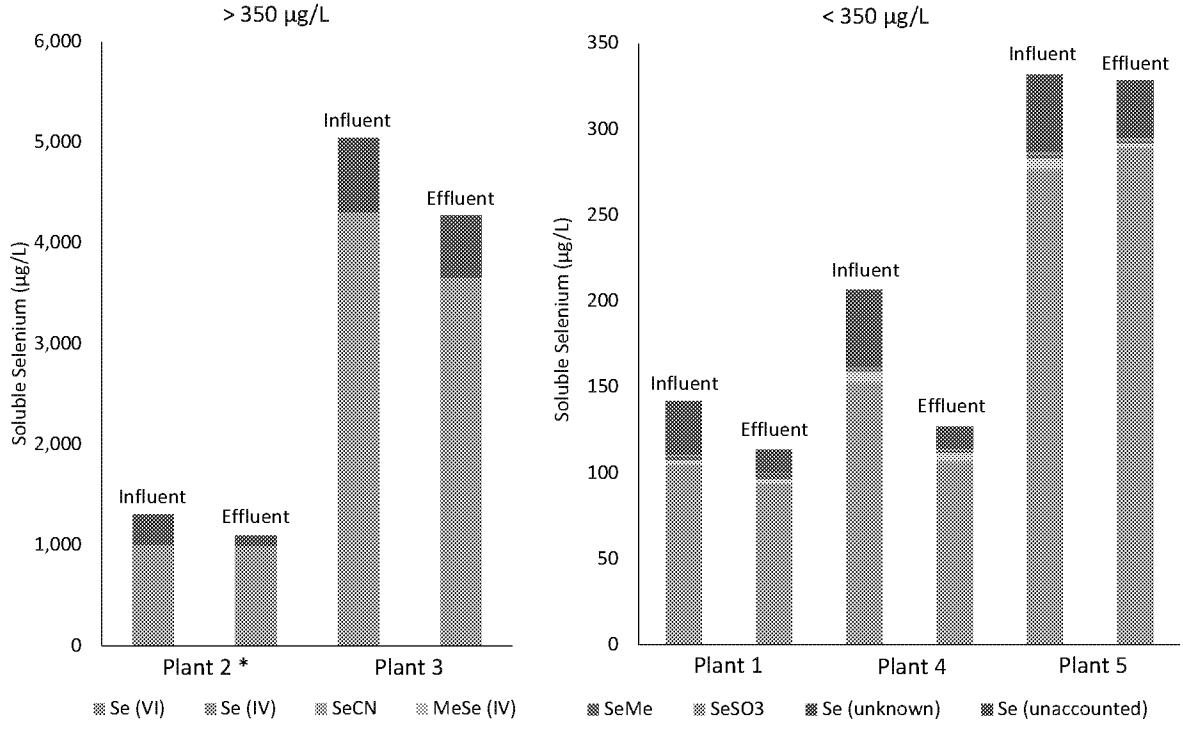


Figure 3-6
Selenium speciation in influent (control) and treated effluent at pH 6.5

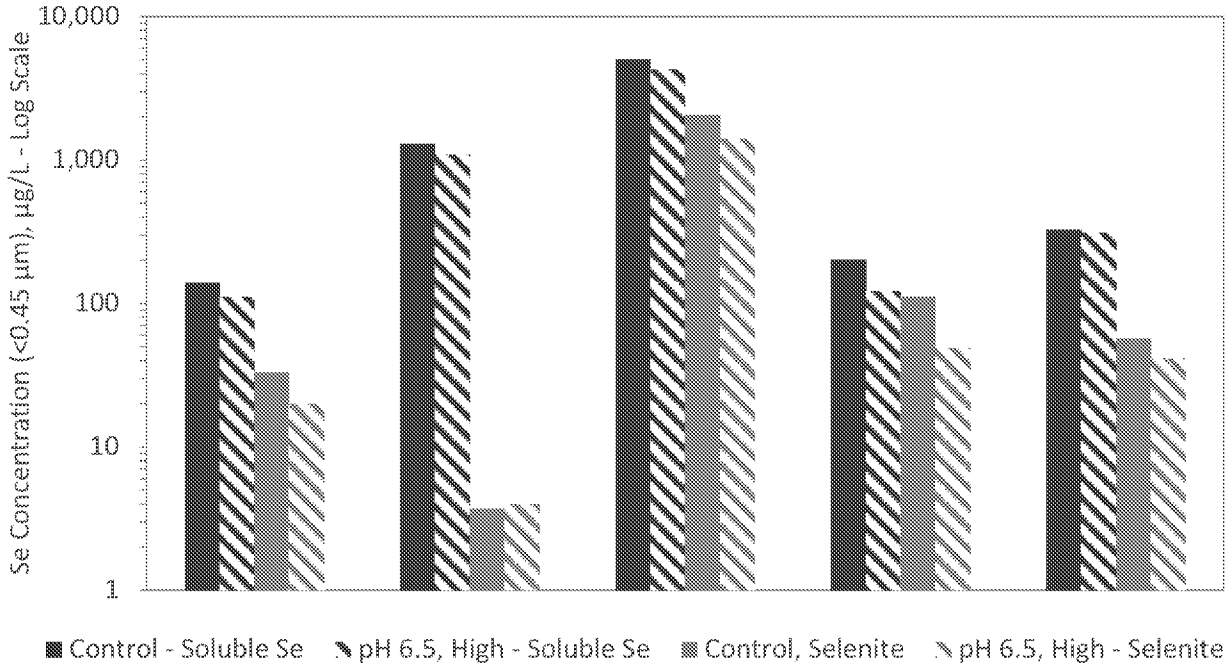


Figure 3-7
Selenium and selenite removal from plants at pH 6.5

Nitrate Removal

The proposed ELGs would set a monthly average nitrate value of 0.13 mg/L as N, and a daily maximum value of 0.17 mg/L as N for FGD wastewater. As shown in **Table 3-16**, all five of the plants had nitrate concentrations above the proposed ELGs in untreated FGD wastewater influent and jar test effluent. Nitrate is not removed by chemical precipitation and no nitrate removal was observed in the jar tests. Nitrate will likely require additional treatment to comply with the proposed ELGs; the current state-of-the-art for nitrate removal is biological reduction. It should be noted that nitrate must be removed before leading selenium-removal technologies (biological and ZVI) can remove selenium.

Table 3-16
Nitrate Removal

Site	Nitrate Capture, mg/L as N		
	Untreated	Control (Settled)	Best Effluent
Plant 1	37	38	36
Plant 2	24	26	24
Plant 3	251	273	263
Plant 4	181	195	177
Plant 5	18	22	20

Other Trace Metals

In addition to arsenic, mercury, selenium, and nitrate, several other parameters (boron, cadmium, magnesium, and manganese) were evaluated, as shown in **Table 3-17**. Reducing these and other trace metals may reduce overall toxicity. Metals that settle out or form hydroxide and/or sulfide precipitates (arsenic, mercury, and cadmium) were effectively reduced in jar tests. However, selenium, boron, magnesium, and manganese were not well removed.

- Cadmium was effectively removed at pH 6.5 and 8.5. Total cadmium in jar test effluent was near or below detection levels.
- Some boron removal was observed at pH 8.5 and 10.5, possibly due to ettringite removal. The tests at pH 10.5 were limited to two plants.
- Magnesium was effectively removed at pH 10.5, but mercury precipitation was poor at this pH. The tests at pH 10.5 were limited to two plants.
- Some manganese removal was observed at pH 8.5 and above. This is consistent with results from full-scale treatment systems.

Table 3-17
Influent and Effluent Trace Metals

Site	Total Cadmium, µg/L			Total Boron, µg/L			Total Magnesium, µg/L			Total Manganese, µg/L		
	Untreated, Not Heated	Control (Settled)	Best Effluent	Untreated, Not Heated	Control (Settled)	Best Effluent	Untreated, Not Heated	Control (Settled)	Best Effluent	Untreat-ed, Not Heated	Control (Settled)	Best Effluent
Plant 1	32	33	< 0.6	330,000	321,000	217,000	3,560,000	3,470,000	2,320,000	57,100	54,200	114 J
Plant 2	81 J	52	< 0.6	25,600	27,600	16,700	1,170,000	784,000	2,260	4,640	56 J	< 5.0
Plant 3	33 J	14	< 0.6	22,600	20,300	10,300	7,310,000	7,050,000	5,680,000	92,300	88,900	16,700
Plant 4	37	34	2.5 J	720,000	759,000	468,000	7,440,000	7,890,000	5,570,000	36,100	35,400	1,000
Plant 5	129	96	0.9 J	242,000	271,000	218,000	2,800,000	3,040,000	2,450,000	46,500	47,500	3,090

Notes

J – Estimated value

< – Not detected at shown detection limit

Lessons Learned and Recommendations for Future Research

Several lessons were learned during the various FGD treatability efforts including:

- Mixing efficiency – The water from Plant 1 was mixed during the laboratory testing with stir bars. Because of concerns with shearing precipitated solids into smaller solids that would not settle out of solution, the testing of the other four plants used paddle bars at a speed of approximately 20 rpm.
- Iron addition – Because of the addition of selenite removal testing to this study, the iron addition was increased from 50 ppm to 200 ppm (of $FeCl_3$ by volume). The 200-ppm dose was selected specifically to promote arsenic and selenium removal and was set based on a target iron addition of 500 to 1,000 pounds per pound of arsenic and 2,000 pounds per pound of selenium. Speciation results indicated that two of the plants had higher selenium levels than anticipated, so the iron addition was below the target ratio for these samples. Therefore, in the future it would be best to have initial arsenic and selenium data before jar testing to adjust the iron dosage.
- Temperature selection – All tests were heated to 140°F to simulate FGD blowdown conditions. Typical FGD blowdown conditions may be closer to 100 – 120°F. The higher temperature should not have impacted metals removal.
- Analytical challenges made it difficult to assess mercury removal. A combination of high dilutions and matrix interferences may have resulted in some differences between the split samples. In the future, it will be important to work with laboratories to optimize dilution and analysis to get the most accurate data and to make sure matrix spikes are done with sensitive samples.
- Arsenic and selenium speciation – total soluble arsenic and selenium analyses were not conducted by the speciation lab. Therefore, "unaccounted" arsenic and selenium was calculated by subtracting the sum of known species, as reported by the speciation lab, from the total soluble concentration, as reported by the primary analytical lab. In the future, it will be important to have the speciation lab also run total soluble analyses so that "unaccounted" arsenic and selenium can be accurately calculated given variance between labs.

Potential future research topics include:

- Arsenic: Evaluate soluble arsenic at sites where it is above the proposed ELG.
  - Characterize speciation.
  - Test oxidation step prior to chemical precipitation to see if it improves treatment of soluble arsenic.
  - Test polishing adsorption media to verify if it can remove the soluble arsenic that passes through chemical precipitation.
  - Evaluate soluble arsenic removal in biological treatment systems; this may require spiking the test water depending on the soluble arsenic in the test site's FGD water.
- Selenium and nitrate removal with biological and zero valent iron (ZVI) technologies are being evaluated in separate EPRI research projects.

4
DATA QUALITY EVALUATION

Data Evaluation Conclusions

Data collected during the study were evaluated for usability. Results of the data evaluation include:

- Based on discussions with plant personnel, no unusual operating conditions occurred during the sampling visits.
- Laboratory duplicate samples showed that, overall, precision values fell within established limits: of 104 laboratory duplicate relative percent difference (RPD) values, seven were outside typical target range. But the poor RPDs were likely caused by the results being at or near the reporting limits and therefore well below quantitation levels.
- Inter-lab split samples showed that, overall, precision values fell within established limits: of 59 laboratory split RPD values, 20 were outside typical target range. With the exception of the Plant 3 filtered mercury results, the poor RPDs were likely caused by the results of one or both laboratories being at or near the reporting limits and therefore well below quantitation levels.
- The poor inter-lab RPDs for Plant 3 filtered mercury may have been the result of a combination of high dilutions (which make small instrument readings equate to large changes in the recorded sample result) and matrix interferences (Plant 3 water had the highest TDS, an indicator of water complexity).
- Matrix spike and matrix spike duplicate recoveries, overall, fell within the established target ranges: of 104 matrix spike recoveries, 17 were outside the range. These were nearly all caused by the analyte concentrations in the samples being significantly higher than the added spike concentrations.
- Boron was detected in the Plant 3 method blank at a value just above the detection limit and well below the reporting limit. Selenium was detected in the Plant 2 method blank at a value just above the detection limit and below the reporting limit. This blank contamination did not affect conclusions, as the FGD wastewater samples had concentrations orders-of-magnitude above the concentrations found in the blanks.

Data Evaluation Methods

Plant personnel provided information about plant operations during each sampling event to identify unusual operating conditions. Data QC procedures, such as duplicates, matrix spikes, blanks, and split samples, were used to evaluate the analytical quality of the data. These procedures included:

- Assessing the effect of the overall analytical process on the usability of the data.
- Evaluating the performance of the laboratory for compliance with the method requirements.
- Evaluating matrix interferences. This evaluation is more nuanced and involves analyzing several areas of results, including the results of matrix spike recoveries, contamination, and

duplicate samples. Precision and accuracy measurements are based primarily on the actual sample matrices. Analytical precision and accuracy are unique to each sample matrix.

Measures of quality control include the "PARCCs" defined below:

- **Precision**—Is defined as the agreement between duplicate results, and was estimated by comparing the results of duplicate matrix spike recoveries, native duplicates, and field duplicate samples.
- **Accuracy**—Is a measure of the agreement between an experimental determination and the true value of the parameter being measured. Each test sample was spiked with a known reference material before digestion. This approach provides a measure of the matrix effects on the analytical accuracy.
- **Representativeness**—This criterion is a qualitative measure of the degree to which sample data accurately and precisely represent a characteristic environmental condition. Representativeness is a subjective parameter and is used to evaluate the efficacy of the sampling plan design. Representativeness was demonstrated by providing full descriptions of the sampling techniques and the rationale used for selecting sampling locations in the project scoping documents.
- **Completeness**—Is defined as the percentage of measurements that are judged to be valid compared to the total number of measurements made.
- **Comparability**—Is another qualitative measure designed to express the confidence with which one data set may be compared to another. Factors that affect comparability are sample collection and handling techniques, sample matrix type, and analytical method. Comparability is limited by the other PARCC parameters because data sets can be compared with confidence only when precision and accuracy are known.

Plant Operations

Plant personnel provided information about plant operations during each sampling event to identify unusual operating conditions. Examples of operational variety include changes in load, changes in number of units on-line, and type of coal being fired. No unusual operating conditions occurred during the sampling visits.

Analytical Quality Control Results

Precision

Duplicate Samples

The water generated through the jar tests included three duplicates per plant. The duplicate samples included analysis of filtered mercury (EPA Method 1631, 30,000-MW filtered); filtered arsenic, selenium, and cadmium (EPA Method 200.8M, 0.45-µm filtered); and filtered boron, magnesium, and manganese (EPA Method 200.7, 0.45-µm filtered) as shown in **Table 4-1.** The smaller filtration size for mercury was selected to remove solids that could cause discrepancies between laboratories.

Table 4-1
Laboratory Duplicate Samples

Site	ID of First Test Used to Generate Duplicate	ID of Second Test Used to Generate Duplicate (pH, organosulfide dose)	ID of Third Test Used to Generate Duplicate (pH, organosulfide dose)
Plant 1	Control (JT1.0)	8.5 su, 10 ppm (JT1.2)	10.5 su, 80 ppm (JT3.3)
Plant 2	Control (JT1.0)	8.5 su, 25 ppm (JT1.2)	10.5 su, 80 ppm (JT3.3)
Plant 3	Control (JT1.0)	8.5 su, 25 ppm (JT1.2)	6.5 su, 80 ppm (JT3.1)
Plant 4	Control (JT1.0)	8.5 su, 25 ppm (JT1.2)	6.5 su, 80 ppm (JT3.1)
Plant 5	Control (JT1.0)	8.5 su, 25 ppm (JT1.2)	6.5 su, 80 ppm (JT3.1)

Table C-1 in Appendix C lists all calculated RPDs for duplicate samples regardless of the native concentration levels. Many of the measurements at or near the reporting limits will reflect biased RPDs because of the deviation in measurements inherent at these levels. All precision measurements were evaluated using a goal of 35 percent RPD or less. Duplicates with poor RPDs were screened to evaluate if the poor precision was caused by either the native or duplicate result being at or near the reporting limits and therefore well below quantitation levels. **Table 4-2** indicates screened values outside of the precision goal.

Table 4-2
Laboratory Duplicate Precision Outside of Criteria

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL Result	ASL Duplicate	ASL DL	ASL RL	RPD
Mercury, Filtered (ng/L) [a]	Plant 1	JT1.0	Control	28	44	6	20	45%

Notes:
[a] EPA Method 1631, 30,000-MW filtered
ASL – CH2M's Applied Sciences Laboratory
DL – Detection Limit
RL – Reporting Limit
RPD – Relative Percent Difference

Overall, precision values fell within established limits: of 104 laboratory duplicate RPD values, seven were greater than 35 percent. And of those, only one was not caused by the results being at or near the reporting limits and therefore well below quantitation levels. All matrix spike duplicate (MSD) precision was within the method target acceptance ranges. Therefore, ASL's precision was not considered as affecting the project results.

Inter-Laboratory Split Samples

The water generated through the jar tests included three inter-laboratory splits per plant. The split samples included analysis of filtered mercury (EPA Method 1631, 30,000-MW filtered), arsenic, selenium, and cadmium (EPA Method 200.8M, 0.45-µm filtered) in the effluent for the jar tests

as shown in **Table 4-3**. The smaller filtration size for mercury was selected to remove solids that could cause discrepancies between laboratories.

Table 4-3
Laboratory Split Samples

Site	ID of First Test Used to Generate Split	ID of Second Test Used to Generate Split (pH, organosulfide dose)	ID of Third Test Used to Generate Split (pH, organosulfide dose)
Plant 1	Control (JT1.0)	8.5 su, 10 ppm (JT1.2)	10.5 su, 80 ppm (JT3.3)
Plant 2	Control (JT1.0)	8.5 su, 25 ppm (JT1.2)	10.5 su, 80 ppm (JT3.3)
Plant 3	Control (JT1.0)	8.5 su, 25 ppm (JT1.2)	6.5 su, 80 ppm (JT3.1)
Plant 4	Control (JT1.0)	8.5 su, 25 ppm (JT1.2)	6.5 su, 80 ppm (JT3.1)
Plant 5	Control (JT1.0)	8.5 su, 25 ppm (JT1.2)	6.5 su, 80 ppm (JT3.1)

Table C-2 in Appendix C lists all calculated RPDs for split samples regardless of the native concentration levels. Many of the measurements at or near the reporting limits will reflect biased RPDs because of the deviation in measurements inherent at these levels. All precision measurements were evaluated using a goal of 35 percent RPD or less. Splits with poor RPDs were screened to evaluate if the poor precision was caused by either result being at or near the reporting limits and therefore well below quantitation levels. Most split samples showed good precision. **Table 4-4** indicates screened values outside of the precision goal. Plant 3 had four instances where the split samples did not meet precision goals; further investigation noted that there was a large difference in dilutions used by each laboratory, such that small matrix interferences may become more magnified, which is one possible explanation for the observed differences. The matrix spike for Brooks Rand laboratory showed a slight positive bias for the arsenic which may explain the higher reported arsenic concentrations. The matrix spike was only conducted on the control, making it difficult to determine if this was true for other tests. It does not change the conclusions of the report as (1) both labs show arsenic as above the ELG of 6.0 µg/L for Plant 3 and below the ELG for Plants 1 and 4 and (2) neither lab's results showed appreciable removal of soluble arsenic.

ASL had a slight negative bias for the two mercury samples shown in **Table 4-4**; the control (JT1.1, not shown in the table) did not show any matrix interference. Brooks Rand similarly showed no interference on the control (JT1.0), but no matrix spikes were conducted on either JT1.2 or JT3.1 making it difficult to assess if matrix interference can account for part of the differences observed here. As both labs show soluble and small particulate mercury levels above the ELG of 119 ng/L, this does not affect the report's conclusions.

Table 4-4
Laboratory Split Precision Outside of Criteria

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL Result	ASL DL	ASL RL	BR Result	BR DL	BR RL	RPD
Mercury, Filtered (ng/L) [a]	Plant 3	JT1.2	8.5 su, 25 ppm	**615**	6	20	**248**	0.5	2	85%
	Plant 3	JT3.1	6.5 su, 80 ppm	**956**	6	20	**236**	0.5	2	121%
Arsenic, Filtered (µg/L) [b]	Plant 1	JT3.3	10.5 su, 80 ppm	**1.6**	0.3	1.0	**2.3**	0.3	0.8	39%
	Plant 3	JT1.0	Control	**8.8**	0.3	5.0	**19.0**	0.3	0.8	73%
	Plant 3	JT1.2	8.5 su, 25 ppm	**7.0**	0.3	5.0	**19.4**	0.3	0.8	94%
	Plant 3	JT3.1	6.5 su, 80 ppm	**8.6**	0.3	5.0	**20.0**	0.3	0.8	79%
	Plant 4	JT1.2	8.5 su, 25 ppm	**3.4**	0.8	2.5	**5.2**	0.3	0.8	41%

Notes:
[a] EPA Method 1631, 30,000-MW filtered
[b] EPA Method 200.8M, 0.45-µm filtered
ASL – CH2M's Applied Sciences Laboratory
BR – Brooks Rand Laboratory
DL – Detection Limit
RL – Reporting Limit
RPD – Relative Percent Difference

Overall, precision values fell within established limits: of 59 inter-laboratory split RPD values, 20 were outside of the RPD target. And of those, only a few were not caused by the results of one or both laboratories being at or near the reporting limits and therefore below quantitation levels.

The poor RPDs for Plant 3 filtered mercury may have been the result of a combination of high dilutions (which make small instrument readings equate to large changes in the recorded sample result) and matrix interferences (Plant 3 water had the highest TDS, an indicator of water complexity). ASL performed matrix spike/matrix spike duplicate (MS/MSD) analyses on the Plant 3 filtered mercury split samples to evaluate accuracy. Recovery ranged from 79 to 81 percent, which is within ASL's QC limits (71 to 125 percent). Brooks Rand did not perform MS/MSD analyses on the Plant 3 filtered mercury split samples and therefore did not capture matrix interferences specific to the Plant 3 water.

Accuracy

Table C-3 in Appendix C lists all calculated matrix spike recoveries regardless of the native concentration levels. The matrix spikes were evaluated using a 70 to 130 percent window.

Overall, MS/MSD recoveries fell within the established limits: of 104 matrix spike recoveries, 17 were outside the target range. Of those, they were all caused by the analyte concentrations in the samples being significantly higher than the added spike concentrations.

Blank Effects

Method blanks, which are generated from jar tests using DI water with chemicals added, to test for contamination from equipment/chemicals, were submitted to the analytical laboratory with the jar test effluent samples. None of the results were above the reporting limits.

Boron was detected in the Plant 3 method blank at a value just above the detection limit and well below the reporting limit. Similarly, selenium was detected in the Plant 2 method blank at a value just above the detection limit and below the reporting limit. This blank contamination did not affect conclusions, as the FGD wastewater samples had concentrations orders-of-magnitude above the concentrations found in the blanks.

5
REFERENCES

1. CH2M HILL. 2013. *Meeting Part-per-trillion Mercury Limits for Power Plant Wastewater*.
2. Electric Power Research Institute (EPRI). 2006. *Flue Gas Desulfurization (FGD) Wastewater Characterization: Screening Study*. Product 1010162.
3. Electric Power Research Institute (EPRI). 2006. *EPRI Technical Manual: Guidance for Assessing Wastewater Impacts of FGD Scrubbers*. Product 1013313.
4. Electric Power Research Institute (EPRI). 2008. *Flue Gas Desulfurization (FGD) Water Blowdown Characterization and Management: 2007 Update*. Product 1014073.
5. Electric Power Research Institute (EPRI). 2008. *Multi-Media Fate of Selenium and Boron at Coal-Fired Power Plants Equipped with SCR and Wet FGD Controls*. Product 1015615.
6. Electric Power Research Institute (EPRI). 2008. *Multimedia Mercury Fate at Coal-Fired Power Plants Equipped with SCR and Wet FGD Controls*. Product 1014095.
7. Electric Power Research Institute (EPRI). 2009. *Flue Gas Desulfurization (FGD) Water Characterization: 2008 Update*. Product 1015588.
8. Electric Power Research Institute (EPRI). 2009. *Impact of Wet FGD Design and Operating Conditions on Selenium Speciation*. Product 1017952.
9. Electric Power Research Institute (EPRI). 2009. *Review of Water Treatment Technologies for Selenium Removal Implemented at Power Plants*. EPRI, Palo Alto, CA. Product ID: 1020813.
10. Electric Power Research Institute (EPRI). 2010. *Evaluation of Mercury Speciation and Its Treatment Implication in Flue Gas Desulphurization (FGD) Waters*. EPRI, Palo Alto, CA. Product ID: 1019867.
11. Electric Power Research Institute (EPRI). 2010. *Pilot-Scale and Full-Scale Evaluation of Treatment Technologies for the Removal of Mercury and Selenium in FGD Water*. Palo Alto, CA. Product ID: 1017955.
12. Electric Power Research Institute (EPRI). 2010. *Evaluation of Technologies Implemented for Treatment of Mercury from FGD Wastewater*. EPRI, Palo Alto, CA. Product ID: 1019867.
13. Electric Power Research Institute (EPRI). 2013. *EPRI Comments on Proposed Effluent Limitations Guidelines Rule*. EPRI, Palo Alto, CA. Product ID: 3002002231.
14. U.S. Environmental Protection Agency (EPA). 2013. "Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category," Proposed Rule. *Federal Register*, Volume 78, Number 110, Friday, June 7.
15. U.S. Environmental Protection Agency (EPA). 2013. *Technical Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category*. EPA-HQ-OW-2009-0819-2257, DCN SE01964.

A

EPRI FGD WATER CHEMICAL PRECIPITATION BENCH-SCALE TREATABILITY STUDY PLAN

Flue Gas Desulfurization Water Chemical Precipitation Bench-Scale Treatability Study Plan

Prepared for

Electric Power Research Institute

October 2014

CH2MHILL

Contents

Contents iii

Acronyms and Abbreviations v

1 Introduction 1-1
- 1.1 Background 1-1
- 1.2 Objectives 1-1
- 1.3 Project Outcomes 1-2

2 Sample Collection 2-1
- 2.1 Sampling Location Selection and Sampling Collection Methodology 2-1
  - 2.1.1 FGD Influent Sampling 2-1
- 2.2 Sample Labeling, Filtering, and Preservation 2-2
- 2.3 Quality Control 2-3
- 2.4 Sample Packing, Custody, and Shipping 2-4

3 Laboratory Equipment & Configuration 3-1
- 3.1 Preparation of Stock Solutions 3-1
- 3.2 Laboratory Equipment 3-2

4 Treatability Testing 4-1
- 4.1 Approach 4-1
- 4.2 Treatability Testing 4-2
- 4.3 Jar Test Procedures 4-3

5 Analytical Requirements for Samples 5-1

6 Sampling Implementation 5
- 6.1 Sampling Personnel and Training 5
- 6.2 Personnel Safety 5
- 6.3 Laboratory Coordination 5

Tables

4-1 Phase I FGD Jar Test Matrix[a,b] 4-2
5-1 FGD Wastewater Initial Sampling Parameters (for QA/QC) 5-1
5-2 FGD Wastewater Jar Test (Supernatent) Sampling Parameters 5-2

Acronyms and Abbreviations

BAT	best available technology
COC	chain of custody
ELGs	effluent limitation guidelines
EPA	[U.S.] Environmental Protection Agency
EPRI	Electric Power Research Institute
FGD	flue gas desulfurization
MW	molecular weight
QA/QC	quality assurance/quality control
TDS	total dissolved solids
TSS	total suspended solids
TWPEs	toxic-weighted pound equivalents

SECTION 1

Introduction

1.1 Background

The U.S. Environmental Protection Agency (EPA) has proposed new effluent limitations guidelines (ELGs) for the steam electric utility industry. The guidelines significantly reduce the amount of arsenic, selenium, mercury, and nitrate/nitrite permitted to be released from flue gas desulfurization (FGD) wastewater at power plants. Chemical precipitation using iron and organosulfide addition is the primary treatment used for mercury and arsenic removal. Chemical precipitation can also remove many other pollutants that contribute to the toxic-weighted pound equivalents (TWPEs) of FGD water.

The purpose of the treatability study proposed here is to determine how well different treatment conditions remove arsenic and mercury, in terms of total TWPEs, from FGD wastewater. Electric Power Research Institute (EPRI) has retained CH2M HILL to coordinate the study.

1.2 Goals and Objectives

EPRI is generating data on the treatability of wastewaters generated by coal-fired steam-powered electric power plants. The data generated primarily consider FGD wastewater treatment consistent with EPA's definition of an optimized physical/chemical system, which includes removing metals by adding iron and an organosulfide.

The primary goal of the bench-scale treatability tests proposed here is to characterize the effectiveness of various arsenic and mercury treatment options, in addition to selenite removal. A secondary goal is to determine which power-plant tests may indicate how to minimize TWPE in FGD physical/chemical treatment system effluent.

Objectives of this testing are to increase understanding of:

- Using iron and organosulfide addition effectively to precipitate arsenic and mercury to meet limits set by the upcoming ELGs on FGD water
- Using iron and organosulfide addition effectively to precipitate selenite
- Minimizing toxicity of FGD blowdown after chemical precipitation (which would decrease pollutants remaining to be removed by biological and other forms of treatment)
- How to provide additional data the EPA would accept for consideration during its final rulemaking on ELGs concerning setting the best available technology (BAT) limits on FGD discharge (EPRI has not yet decided whether the information will be provided to EPA; however, the program will be set up so that the dataset will be of quality appropriate for submittal to EPA)
- How and why treatment effectiveness varies between FGD waters

It is anticipated that EPRI and EPRI members can use these results to provide insight into optimal conditions for iron and organosulfide precipitation chemistry. Insights that can be applied will include managing pH and chemical dose, impact on various pollutants, and how wastewater variations can impact treatment. Using jar tests will allow study of multiple plants over a short time and will provide quick feedback on the degree to which metal precipitation chemistry can vary under tests that are similar to each other. These insights will be communicated with other EPRI treatability projects so that lessons are shared.

Because the optimization of metal removal in a full-scale system typically requires jar-testing to fine-tune chemical dosages, supplying a procedure for the jar testing can be an applied value to EPRI members.

1.3 Project Outcomes

Wastewater from up to five plants will be used in the proposed treatability tests. The test results will be compiled from all facilities into one comprehensive report. Facility confidentiality will be maintained as requested by participating plants.

SECTION 2

Sample Collection

2.1 Determining the Sampling Location and Collection Methodology

Grab samples will be collected during a single sampling event. CH2M HILL will coordinate with each plant to determine the schedule. Samples will be collected at the FGD treatment system influent or directly from FGD blowdown. Influent samples will be collected at a sampling point ahead of any chemical addition, solids removal, or mixing with recirculation streams. The sampling location may be the treatment system equalization tank if no recirculated water is sent back to that tank. If water (such as from solids dewatering filter press filtrate) is recirculated, the influent sample will be collected upstream of the equalization tank.

The logistics of sample collection necessitate use of grab samples. In most cases, plants do not have sampling locations at which it is safe or feasible to set up a composite sampling device. CH2M HILL considers a grab sample to be representative of FGD water because the long residence time in the FGD adsorber (typically weeks) equalizes day-to-day variation. Grab samples will be collected directly into unused, clean bottles provided by the laboratory. Metals samples (for quality assurance/quality control [QA/QC]; see Section 2.3) will be field-filtered using bottles, syringes, and filters provided by the laboratory. Samples will be analyzed as outlined in Section 5. The tests and analyses required may necessitate use of various laboratories. The "treatability laboratory" will conduct jar testing, and the "analytical laboratory" will analyze the waters generated by the treatability laboratory's jar testing.

2.1.1 FGD Influent Sampling

Treatability testing requires only FGD influent samples, which are expected to have high suspended solids content. Determining the concentration of filtered metals in the FGD influent will be important. Filtered metals results from influent samples filtered in the field would be preferable, though results from samples filtered by the lab would be acceptable. Therefore, sampling approaches will be different for samples to be analyzed for dissolved metals analysis than for samples to be used in the treatability tests.

The sampling kits supplied to the site will include the following:

- 2, 2.5 gallon cubitainers for the treatability sample
- 2, 250 mL poly bottles with HNO_3 preservative for total and filtered metals analysis
  - One bottle will be filled with a fully mixed sample
  - One bottle will be filled with filtered effluent, raw sample can be allowed to settled as noted in Section 2.1.1.2
- 2, 250 mL glass bottles with no preservative for total and filtered mercury analysis for the initial screening using EPA Method 1631
  - One bottle will be filled with a fully mixed sample
  - One bottle will be filled with filtered effluent, raw sample can be allowed to settled as noted in Section 2.1.1.2
- 1, 250 mL poly bottle with H_2SO_4 preservative for nitrate-nitrate analysis
- 2, 250 mL poly bottles with no preservative – one for arsenic and selenium speciation and the other for sulfate and chloride analysis (no filtration required for either)
- 1, 1000 mL poly bottle with no preservative for total suspended solids and total dissolved solids analysis
- 2, 60 mL syringes
- 10, 0.45 µm syringe filters

- 3 pairs of nitrile gloves
- 2 coolers
- 2 sharpies
- 1 extra cubitainer cap
- Return Chain-of-Custody (COCs) and FedEx forms
- A copy of the sampling instructions (to be emailed as well)

Bottles will already be preprinted with analysis and preservatives. Contact information for the CH2M HILL field sampling coordinator, Susan Shamis, will also be included with sampling kits. She can be reached at (937) 220-2960 (office) or at Susan.Shamis@ch2m.com.

2.1.1.1 Water to be Used in Treatability Tests

The water collected for the treatability tests, including water to be analyzed for total metals, will be collected and shipped unpreserved and unfiltered to the treatability laboratory. Preferably at least 5 gallons should be shipped. The lab will provide 2, 2.5 gallon cubitainers for this sample.

2.1.1.2 Field Collected Samples for Initial Characterization and Screening

Samples will be collected in the field for laboratory analysis. These will be used to immediately start a sampling screening upon receipt of the samples, as well as be used as a check against the baseline samples. Similar to the treatability samples, these samples should **not be placed on ice** as discussed in Section 2.2. The samples collected for filtered metals analysis by field filtering will be allowed to settle for roughly 1 hour, and the sampling team will then filter the supernatant. Settling helps reduce fouling of the filters. This will include two samples that will be measured in accordance with those parameters shown in **Table 5-1.** Sample containers will be provided as noted earlier. It is expected that metals concentrations in the wastewater will be high enough so that low-level analytical methods will not be required.

2.2 Sample Labeling, Filtering, and Preservation

Sample labeling, filtering, preservation, and storage will be completed in accordance with the requirements in this section. Sample labels will be preprinted or handwritten and placed on the container or the outer bag before the bottles are filled.

Sample labels will bear:

- Sample name
- Sampling site name
- Pollutants/analytes to be analyzed for
- Preservative, if any
- Initials of person collecting the sample
- Date and time of collection

Site-specific sample names will be assigned before sampling. Sample labels will be filled out before their arrival in the field with the sample name, site name, bottle required, analytes, and preservative. At the time of sampling, the sampler will fill in his or her initials and the date and time. Bottles will be pre-preserved as required for the health and safety of the samplers. Samples will be placed in a cooler stored under atmospheric conditions. **The standard procedure for these analyses is to store and ship the samples on ice to keep samples at 4 °C; however, this is <u>not</u> recommended for these because the sample matrixes will be primarily inorganic and the analyses will be to determine concentrations of metals, and because the treatability testing itself will be conducted at room temperature. Furthermore, temperature changes can affect the solubility of metals in unpreserved samples, which could skew the treatability test results.**

Therefore, samples should not be placed on ice. It is expected that sampling will take 1 day. FedEx and UPS shipping deadlines at power plants commonly are in the early afternoon, so samples should be collected in the morning so they can be shipped the same day and received by the laboratory the day after sampling. CH2M HILL will coordinate with the treatability laboratory so it can begin testing upon receipt, and will arrange for samples generated from the treatability testing to be sent to the analytical laboratory.

2.3 Quality Control

To obtain high-quality samples, the samplers will be briefed on the methods to be used. Samplers typically use standard methods for sample collection, with fresh containers to minimize risk of sample contamination. Since the samples will only be untreated FGD blowdown, it is not necessary to use low-level metal sampling methods.

To minimize the risk of changes in water chemistry producing non-representative results, samples will be shipped overnight express and treatability testing will be started on receipt. EPRI will use a laboratory certified and trusted for low-level analysis of FGD water (CH2M's Applied Sciences Laboratory). The laboratory will use low-level analytical methods to obtain high-quality data to measure treatment effectiveness, and will use methods consistent with those used in previous EPA sampling and analytical efforts. A single-phase approach will be used for testing to identify optimal operating conditions for mercury and arsenic removal.

The treatability laboratory will generate duplicate and blank samples when preparing samples for the analytical laboratory. QC sampling will also include field-filtered samples for metal analysis to compare to lab-filtered results to determine whether results are consistent. The contract laboratories will provide the containers, syringes, and filters. These QC analysis will include those shown in Table 2-1.

TABLE 2-1
QC Analysis

Analytical Method	Process Blank[a]	Jar Test Duplicate[b]	Analytical Duplicate	MS and MSD[c]
SM2540C	1	1	n/a	n/a
E1631 (Hg)	1	1	1	1
EPA 200.8/6020 (As & Se)	1	1	1	1
EPA 200.7	1	1	1	1

Notes
[a] Process Blank = Jar Test using DI water with chemicals added, to test for contamination from equipment/chemicals; Process blank is one per 5 plants tested, not one per plant
[b] Jar Test Duplicate = Jar Test using same chemical dosing as another jar, to evaluate reproducibility
[c] MS/MSD samples for quality control should be taken from the same sample bottle that is vigorously shaken to homogenize.

2.3.1 Split Analysis on Treatability Jar Test Effluent

The water generated through the jar tests will include at least 3 splits per plant between two analytical labs (CH2M's Applied Sciences Laboratory and Brooks Rand Laboratory) for the first two sampling events. The results of the first two sites will be compared and reviewed to make a determination on analytical laboratories used moving forward.

The split samples will include analysis on dissolved mercury (EPA Method 1631, 30,000 MW filtered), arsenic, selenium, and cadmium (EPA Method 200.8 metals will be 0.45 µm filtered) in the effluent for the jar tests as shown in Table 5-2. The lower filtration for mercury is to remove solids that could cause discrepancies between laboratories. Splits will be taken from the following jar test conditions:

- JT0-0 – Baseline

- JT1-2 – 8.5 pH, 20 ppm organosulfide
- JT3-3 – 10.5 pH, 80 ppm organosulfide

For QC, each lab should also include one MS and MSD.

2.4 Sample Packing, Custody, and Shipping

Samples must be under chain of custody (COC) protocols at all times. COC protocols must include restricted access to all sample containers and samples before, during, and after sample collection. Sampling materials that are not in the direct possession of a project team member must be locked or sealed in a secure area to prevent tampering. After the samples have been collected, proceed with sample shipment preparations. The steps for shipping samples are:

1. Check that the sample container caps are sealed and tight. If the shipping cooler is equipped with drain holes, tape them shut with duct tape, inside and out.
2. Place mailing label on lid of cooler, cover with clear protective tape, and place a copy of the tracking number and the laboratory address inside the cooler.
3. Fill the bottom of the cooler with bubble wrap or other temperature- and shock-insulating material.
4. Examine each sample bottle. Make sure each bottle is appropriately labeled as outlined above and that the bottle caps are securely fastened.
5. Place a cooler bag or contractor-grade trash bag inside the cooler.
6. Arrange bottles inside the cooler bag so they fit snugly. **Do not add ice to cooler.**
7. List all samples packaged inside the cooler on the COC.
8. Fill remaining spaces with packing material to prevent contents from shifting during shipping.
9. Twist the cooler bag closed and tape it down.
10. Make sure all pertinent fields on the COC are filled out. Sign the COC and record the time and date.
11. Complete the shipping airbill. If appropriate, record the airbill tracking number on the COC form. Attach airbill or airbill receipt to the top of the sample cooler.
12. Separate the copies of the COC. Seal the laboratory's copy in a resealable plastic bag and tape the bag to the inside of the cooler lid.
13. Close and secure the cooler lid.
14. Carefully peel custody seals from backings and place them intact over lid openings, one in front and one in back. Cover the seals with clear protection tape.
15. Tape cooler shut on both ends, making several complete revolutions. Do not cover mailing label or airbill with tape. The cooler is now ready to be relinquished to the shipping carrier.
16. Keep sampler's copies of the COC and shipper's copy of the airbill together. Put receipts in a binder for storage. If a COC does not have triplicate forms, photocopy or take a picture with a smartphone and e-mail a copy to the sample coordinator.
17. The sample coordinator must confirm that samples were received each day that samples are shipped.

SECTION 3

Laboratory Equipment and Configuration

3.1 Preparation of Stock Solutions

Treatability testing chemicals are to be of commercial, **not lab-grade**, quality to be representative of real conditions. Required chemicals are:

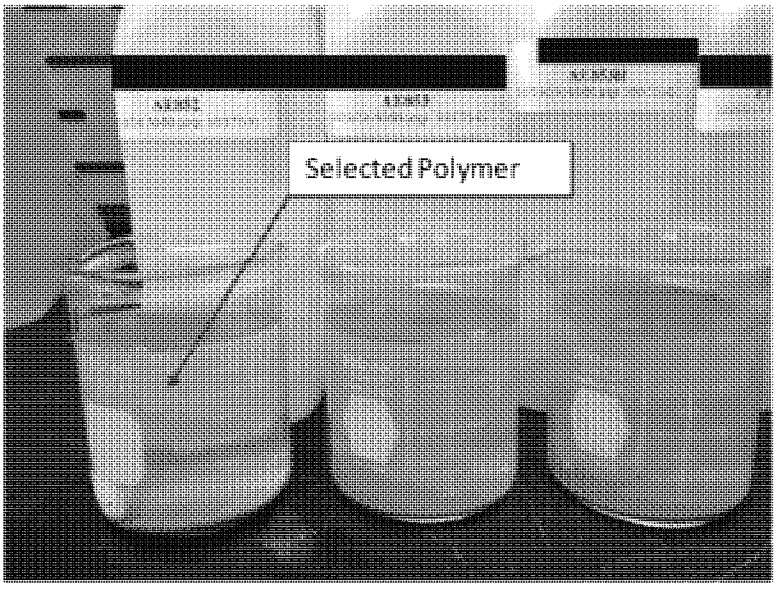
- Ferric chloride – Using a technical grade product, Kemira PIX-311, containing approximately 40 percent ferric iron.
  Note that commercial ferric chloride can contain trace amounts of arsenic. The total arsenic concentration will be measured and recorded for the proposed product.
- Organosulfide – Nalmet 1691
- Polymer (will select one after initial settling tests):
  Hychem AE852 (medium charge density, high MW, anionic)
  Hychem AE853 (high charge density, high MW, anionic)
  Hychem AE853H (high charge density, very high MW, anionic)
  Note: Predilute the polymer 1:100 with DI water to unwind the polymer
- Hydrated lime technical grade – 5 percent slurry
- Sodium hydroxide – Use commercial grade 25% sodium hydroxide
- Sulfuric acid – Use commercial grade 93% sulfuric acid

Chemicals are to be added neat (without dilution) using micropipettes. Exceptions will be for emulsion polymers that require some level of dilution to "unwind" the polymer. Fresh chemicals should be obtained, especially the organosulfide, which can have a short (6-month) shelf life.

Polymer. Up to three anionic polymers will be evaluated at doses of 1, 5, and 10 ppmv (neat basis) on the initial FGD wastewater (not the jar test effluent). The tests will involve slow mixing (20 rpm) the effluent with the selected dosage for approximately 15 minutes, followed by 60 minutes of settling. Visual observations of the results will be documented, and photos will be taken of the resulting supernatant; the polymer and dosage that produces the clearest supernatant and most robust floc, as judged by someone experienced with chemical precipitation, will be used for the treatability tests. See Figure 3-1 for an example of robust floc generation and settling. If a suitable polymer cannot be found after twenty tests, then treatability tests will be conducted without polymer addition after approval from the project technical lead, Laura Reid. She can be reached at (704) 543-3277 (office) or at Laura.Reid@ch2m.com.

Prepare a 1% solution of emulsion polymers by weighing pipetting 1 mL neat polymer into 100 mL of deionized water in a 250 mL bottle. Shake vigorously for 15 to 20 seconds but no longer than 20 seconds. Allow the solution to age for 1 to 2 hours before use, and label with the contents and date of preparation. Make fresh daily.

Figure 3-1: Example of Robust Floc Generation and Settling



Organosulfide. Obtain either Nalmet 1691 or MetClear MR2403 for this study. Organosulfide solutions are odorous and should be prepared in a fume hood or ventilated area. Keep solutions capped when not in use. Liquids to be fed by volume at a dosing ratio of 1 ppmv.

Ferric chloride. Use a standard, commercially available solution (generally 35% ferric chloride) for the tests, adding it to sample volumes using micropipettes.

Hydrated lime. Use a standard, commercially available hydrated lime powder (not pellets). A 5 percent slurry should be made from the powder and used for chemical addition to the jar tests.

Sulfuric acid. Use a standard, commercially available solution (generally 93% sulfuric acid) for the tests, adding it to sample volumes using micropipettes.

Sodium hydroxide. Use a standard, commercially available solution (generally 25% sodium hydroxide) for the tests, adding it to sample volumes using micropipettes.

3.2 Laboratory Equipment

The following laboratory equipment should be available and ready to start using on tests immediately upon receipt of the FGD samples:

- 1-L glass beakers (x 7)
- 1 L glass volumetric flasks (x 1)
- Deionized water – for rinsing
- 1-L plastic graduated cylinder (x 13)
- Paddle stirrer mechanisms (x 12)
- Micropipettes (x 100) and disposable pipette tips
- Waterproof labels
- Permanent markers
- 60-mL syringes (x 5)
- 0.45-micron Millipore Sterivex[1] syringe filters (x 100)
- 3,000-molecular weight (MW) syringe filters (x 100)

[1] Because some filters contain trace amounts of mercury, CH2M HILL's laboratory has investigated and tested several filters for trace mercury and has selected Millipore Sterivex (or, if Millipore Sterivex is unavailable, Whatman Puradisc Aqua 30) cartridge filters for use because they have minimal, if any, trace mercury. Since mercury is one of the metals of concern, these selected filters will be used for all sample collection.

- pH probe/meter
- pH buffers for calibrations
- Analytical balance
- Plastic weigh boats
- Lab soap and brushes
- Sample bottles
- Lab gloves
- Face masks
- 30,000-MW syringe filters (x 100)
- 100-mL glass volumetric flasks (x 4)
- 1-L glass volumetric flasks (x 6)
- 100-mL glass graduated cylinders (x 2)
- Glass bottles for chemical solutions (x 9)
- Neat chemicals –polymer
- Commercial grade chemicals - NaOH, H_2SO_4, $FeCl_3$
- Organosulfides (TMT, Nalmet™ and Metclear™ products)
- Deionized water – for equipment blanks

SECTION 4

Treatability Testing

NOTE: Some changes were made between the first tests and the later tests. These changes are summarized below:

- The water from Plant 1 was mixed during the laboratory testing with stir bars. Because of concerns with shearing precipitated solids into smaller solids that would not settle out of solution, the testing of the other four plants involved paddle bars at a speed of approximately 20 rpm.
- The control jar from Plant 1 was not heated during the laboratory testing. In order to isolate the impact of chemical addition, control jars for the other four plants were heated to 140°F.
- The 10.5 pH setpoint was eliminated from laboratory testing after the first two plants because of poor mercury capture and settling.
- The 50-ppm organosulfide dosage was eliminated after the first two plants because of minimal performance differences between it and either the low or high dosages.

4.1 Approach

This plan proposes using jar tests to evaluate treatment performance for chemical precipitation. Jar testing, a bench-scale evaluation of chemical/physical treatment, can be a useful tool to evaluate process performance and process optimization. Jar tests can be carried out on small aliquots (500 to 1,000 mL) of sample in a beaker, with chemical doses and treatment conditions varied to investigate differences in the results of various treatment schemes.

Samples from up to five power plants will be delivered to EPRI's treatability laboratory. Samples collected for screening and initial characterization will be processed immediately, and jar testing will be performed upon receipt of the remaining samples. Screening will involve a 1-day turnaround for arsenic (EPA Method 200.8) and mercury (EPA Method 1631). If the levels are below reporting limits (0.5 ppb for As and 0.5 ppt for Hg), CH2M HILL and EPRI may elect not to analyze the effluent from the jar tests if significant removal cannot be shown. The initial characterization will involve the remaining parameters listed in Table 5-1 but with a standard turnaround time. The treatability tests will have one phase of testing, with the settled effluent sampled using different filters to determine whether the remaining metals are filtered or small particulates. Testing will also include a baseline sample (one with no chemical addition) for comparison the initial wastewater characterization.

Chemical precipitation of metals is typically influenced by a number of factors including:

- Operating pH
- Organosulfide addition
- Enmeshment of metals within a flocculant (iron in most cases)

Metal precipitate as either hydroxide or sulfide particulates in FGD wastewater. The solubility curve for each metal varies over different pH ranges; in general, for cationic metals, higher pH results in lower solubility and greater precipitation. Some metals, such as selenium, are present as anions in solutions and cannot be removed by hydroxide or sulfide precipitation, but can be removed by absorption or co-precipitation with iron hydroxide. These are generally removed best at lower pH ranges. Plants often use lime for pH adjustment. The lime is typically added in the metals removal step to achieve a pH of approximately 8.5, which is as high a pH as lime can achieve under plant conditions. CH2M HILL proposes testing pHs in the jar tests of up to 10.5, which will be achieved with caustic after exhausting lime addition.

Organosulfides are polymeric compounds with active sulfide sites to promote formation of sulfide precipitates and settling. They are specialized chemicals and tend to be costly, so it is important to optimize

dosage in order to manage operations budgets. Iron addition provides a coagulant that enmeshes and helps settle out particulates in a clarification step. For these treatability tests, the focus is on optimizing operating pH and organosulfide addition, though polymer and iron addition will be necessary to generate a "clarified" effluent. Iron dosage is of lesser concern as iron's real-life performance is more difficult to replicate in jar testing because jar tests do not include recycling iron hydroxide solids that improve their performance. Sludge recirculation is included in most physical/chemical operations.

Treatment effectiveness will be evaluated by the levels of mercury and arsenic achieved from each set of operating conditions relative to the proposed limits in the draft ELGs. A secondary determination will be the overall removal of TWPE. In past FGD data evaluations, physical/chemical treatment effluent TWPE is primarily contributed by pollutants that can be removed by precipitation (magnesium, manganese, cadmium) and those not typically well removed by precipitation treatment (boron and selenium).

4.2 Treatability Testing

Upon receiving wastewater samples from a given plant, the treatability laboratory will immediately combine the wastewater if it is sent in multiple containers, adequately mix it, and collect a small portion for polymer selection, as noted in Section 3.2. The combined sample will then be split between the jar test apparati for the tests. A matrix of tests and name identifications is shown in **Table 4-1**.

The pH will be operated at the following setpoints:

- Baseline – A baseline sample will be run and tested at the same time as the other jar tests. This sample will have no chemical addition or pH adjustment, but will be heated to the operating temperature.
- 4.0 – A single low pH test will be conducted to evaluate selenite removal at the lower pH range
- 6.5 – Optimum for removal of metals that can exist as anions in water, such as arsenic and selenium
- 8.5 – Optimum for removal of mercury and other cations when using lime
- 10.5 – Best cation removal, but requires addition of caustic and may be difficult for plants to operate

Organosulfide dosages of 20, 50, and 80 ppm will be applied at each pH. These dosages are based on CH2M HILL's experience with FGD wastewaters. Testing at three doses and three pHs, as well as an unadjusted control results in 10 tests. Tests will be conducted at 130 degrees Fahrenheit to simulate summer conditions.

TABLE 4-1
Phase I FGD Jar Test Matrix[a,b]

PH Target[c]	Baseline	20 ppm Organosulfide	50 ppm Organosulfide	80 ppm Organosulfide
No pH Adjustment	JT0-0	Not tested	Not tested	Not tested
5.5	Not tested	Not tested	Not tested	JT3-4[d]
6.5	Not tested	JT1-1	JT2-1	JT3-1[d]
8.5	Not tested	JT1-2	JT2-2	JT3-2
10.5	Not tested	JT1-3	JT2-3	JT3-3

Notes
[a] All tests will include a 200-ppm dosage of $FeCl_3$ by volume) to promote flocculation/settling.
[b] Target pH should be achieved during jar test in conjunction with other chemical additions.
[c] Target pH should be achieved during jar test in conjunction with other chemical additions. Apply lime until reaching pH of 8.5; then switch to caustic.
[d] These jar tests will have additional samples collected and sent to Applied Speciation for selenium speciation.

Jar testing will be conducted in accordance with the procedures in Section 4.5 and analysis methods noted in Section 5.

4.3 Jar Test Procedures

The following procedures will be used in each test phase. Testing conditions, observations, and results will be documented in the test log.

1. Document each step, as well as any observations or anomalies, in a log book or on a bench sheet and later transcribe to an electronic copy of the test log.
2. Mix the untreated wastewater sample well to re-suspend any solids that may have settled. Tests should be conducted on the FGD wastewater as the plant would receive it, with all of the solids re-suspended.
3. Measure 1 L of untreated sample with a graduated cylinder, and transfer to a 1-L beaker.
4. Place the beaker on a paddle stirrer. Turn on the paddle stirrer at 20 rpm, which is used throughout.
5. Place a pH probe in the sample to monitor pH throughout the test. Record the initial pH and temperature.
6. Prior to testing, perform a pH adjustment on a small amount of water and record the amount of lime, caustic, ferric chloride, and sulfuric acid required to reach pH of 6.5, 8.5, and 10.5 (H_2SO_4 test should be done on a separate water than the base chemicals). During testing, add 90% of the calculated dosage from these tests and follow with smaller adjustments to reach the target pH.
7. Add all chemical dosages together (ferric chloride, organosulfide, and 90% of anticipated sulfuric acid/lime/caustic demand) and mix at 20 rpm for 20-minutes. Record the pH after chemical addition before further adjustment. Monitor pH throughout the twenty minute mixing period and adjust pH as necessary. Add 1.0 N sulfuric acid or hydrate lime (or 1.0 N sodium hydroxide once lime is ineffective) to achieve the target pH (+/- 0.1 pH units). Record the amount of acid or base added and mix for 5-minutes.
8. Add the flocculant polymer last and mix the sample at 20 rpm for an additional 20 minutes.
9. Record any visual observations (take digital pictures before adding chemicals after 20 minutes of first stage chemical addition, then after polymer addition and 20 minutes of flocculation, and after settling and filtered sample) during the test (such as precipitate/flocculant formation, color changes, odors, heat generation).
10. At the end of the mixing period, collect a sample of approximately 250 mL, which should be reserved for total dissolved solids (TDS) and total suspended solids (TSS) analysis, then remove the beaker from the stirring apparatus.
11. Settle for 20 minutes before collecting and filtering (as needed) the supernatant for metals analysis. Samples will be collected as:
    a. Settled – for total metals analysis
    b. Filtered using 0.45-micron filters – typically considered the filtered or soluble fraction, includes speciation samples.
    c. Filtered using 3,000-MW filters
    d. Filtered using 30,000-MW filters
12. Prepare samples for shipment to analytical lab using procedures noted in Section 2.4.

SECTION 5

Analytical Requirements for Samples

Tables 5-1 and 5-2 list the parameters to be analyzed and give specific requirements for the analytical laboratory. The analytical methods and detection limits used must conform to the EPA method specified. The analytical laboratory will need this information to prepare the sampling kits. The laboratory should provide all sample containers needed for the sampling event plus at least one spare set of containers, preservatives, COC forms, shipping coolers, packing material, and absorbent necessary to properly collect and ship samples to the laboratory.

Either the treatability or the analytical laboratory will supply bottles cleaned in accordance with EPA Method 1669, "Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels" (1996), for collecting the samples from the treatability tests. The CH2M HILL sample coordinator will coordinate with the treatability laboratory so that bottles are the correct type, are cleaned in accordance with Method 1669, and are double-bagged as appropriate, and that they contain the correct preservative in sufficient supply for sampling. Arrangements should be made with the contract laboratory so that sample kits are available prior to treatability testing.

Samples should be shipped to the analytical laboratory within 24 hours of collection for overnight delivery. Samples should not be collected or shipped on a Friday to avoid delays in testing.

TABLE 5-1
FGD Wastewater Initial Sampling Parameters (for QA/QC and Characterization)

Parameter	Method	Preservative	Holding Time
Total suspended solids	SM2540D	None	7 days
Total dissolved solids	SM2540C	None	48 hours
Mercury, total	E1631	HCl	180 days
Mercury, 0.45µm filtered	E1631	HCl	180 days
Arsenic, total	EPA200.8/6020	HNO_3	180 days
Arsenic, 0.45 µm filtered	EPA200.8/6020	HNO_3	180 days
Arsenic speciation, no headspace and unfiltered[a,d]	Laboratory SOP ASC-085	None	180 days
Selenium, 0.45µm filtered	EPA200.8	HNO_3	180 days
Selenium, total	EPA200.8/6020	HNO_3	180 days
Selenite (Se speciation, no headspace, 0.45µm filtered [a,c])	Laboratory SOP ASC-084	None	180 days
Nitrate-Nitrite	EPA 353.2	H_2SO_4	28 days
Boron, 0.45µm filtered	EPA200.7	HNO_3	180 days
Cadmium, 0.45µm filtered	EPA200.8/6020	HNO_3	180 days
Magnesium, 0.45µm filtered	EPA200.7	HNO_3	180 days
Manganese, 0.45µm filtered	EPA200.7	HNO_3	180 days
Boron, total	EPA200.7	HNO_3	180 days
Cadmium, total	EPA200.8/6020	HNO_3	180 days
Magnesium, total	EPA200.7	HNO_3	180 days

TABLE 5-1
FGD Wastewater Initial Sampling Parameters (for QA/QC and Characterization)

Parameter	Method	Preservative	Holding Time
Manganese, total	EPA200.7	HNO_3	180 days
Calcium, 0.45µm filtered	EPA200.7	HNO_3	180 days
Sodium, 0.45µm filtered	EPA200.7	HNO_3	180 days
Sulfates, 0.45µm filtered	E300.0	None	28 days
Chlorides, 0.45µm filtered	E300.0	None	28 days

Notes
°C = degrees Celsius
[a] The analyte may be removed from the sampling and analysis plan prior to execution. Note these samples will be tested by Applied Speciation Laboratory.
[c] Sample will be sent to Applied Speciation laboratory for analysis.
[d] Arsenic speciation will not be conducted if the total arsenic concentration is less than 6 micrograms per liter.

TABLE 5-2
FGD Wastewater Jar Test (Supernatant) Sampling Parameters

Parameter	Method	Preservative	Holding Time
Total suspended solids	SM2540D	None	7 days
Total dissolved solids	SM2540C	None	48 hours
Mercury, total low-level[a,]	E1631/6020	HCl	180 days
Mercury, low-level, 0.45µm filtered	E1631	HCl	180 days
Mercury, low-level, 3,000 MW filtered	E1631	HCl	180 days
Mercury, low-level, 30,000 MW[b] filtered	E1631	HCl	180 days
Arsenic, total[a]	EPA200.8/6020	HNO_3	180 days
Arsenic, 0.45µm filtered[b]	EPA200.8/6020	HNO_3	180 days
Arsenic, 3,000 MW filtered	EPA200.8/6020	HNO_3	180 days
Arsenic, 30,000 MW filtered	EPA200.8/6020	HNO_3	180 days
Arsenic speciation, 0.45µm filtered[d]	Laboratory SOP ASC-085	None	180 days
Selenium, 0.45µm filtered[b]	EPA200.8/6020	HNO_3	180 days
Selenium, total[a]	EPA200.8/6020	HNO_3	180 days
Selenite (Se speciation, no headspace, 0.45µm filtered[c])	Laboratory SOP ASC-084	None	180 days
Nitrate-Nitrite	EPA 353.2	H_2SO_4	28 days
Iron, 0.45 µm filtered	EPA200.7	HNO_3	180 days
Boron, 0.45µm filtered	EPA200.7	HNO_3	180 days
Cadmium, 0.45µm filtered[b]	EPA200.8/6020	HNO_3	180 days
Magnesium, 0.45µm filtered	EPA200.7	HNO_3	180 days

TABLE 5-2
FGD Wastewater Jar Test (Supernatant) Sampling Parameters

Parameter	Method	Preservative	Holding Time
Manganese, 0.45µm filtered	EPA200.7	HNO_3	180 days
Boron, total[a]	EPA200.7	HNO_3	180 days
Cadmium, total[a,]	EPA200.8	HNO_3	180 days
Magnesium, total[a]	EPA200.7	HNO_3	180 days
Manganese, total[a]	EPA200.7	HNO_3	180 days

Notes
[a] Total samples will be measured from the "settled" effluent.
[b] Split samples for these parameters will be sent to BrooksRand for duplicate sampling.
[c] Samples will be sent to Applied Speciation laboratory for analysis. This will include ONLY two jar tests (JT3-1 and JT3-4).
[d] Arsenic speciation will not be conducted if the total arsenic concentration from the initial sampling is less than 6 micrograms per liter.

SECTION 6

Sampling Implementation

This section outlines basic guidelines for sampling implementation, describing personnel and training requirements, safety precautions, and laboratory coordination. The laboratory contact and a CH2M HILL sample coordinator will be designated in plant-specific information.

6.1 Sampling Personnel and Training

Plant sample technicians will collect samples. Samplers should be experienced in sampling industrial (process) wastewater discharges. The sampling team should be familiar with:

- Identification of sampling locations
- Equipment needed and proper use
- Grab sample collection methodology
- Sampling parameters, associated container types, and volume requirements
- Delivering analytical samples to the laboratory
- Forms to be completed during sampling events

All sample containers must be labeled before any sample is collected. The date, time, location, and preservative must be provided on each sample bottle.

6.2 Personnel Safety

Samplers should work under their company's health and safety procedures.

Precautions should be taken for the safety of the sampling team members. Sampling will be performed in accordance with the facility safety practices to decrease the likelihood of a serious accident and to enhance QC. If any sampling team member judges that sampling cannot be conducted safely, the team should cease work and immediately contact the sampling coordinator. In all situations during sampling, team members must be observant and alert and use common sense.

6.3 Laboratory Coordination

Sampling kits will be preassembled at the contracted laboratories before the actual sampling event. The kits will contain the necessary number and types of containers needed to collect samples for the parameters listed in Table 5-1, as well as collapsible cubes to collect enough water for treatability testing. A plant will need to inform CH2M HILL if the sampling locations require dippers or other equipment. The volumes, preservative requirements, and types of container to be used in transporting the samples should be provided by the contract laboratories.

B
FGD TREATABILITY TESTING DATA SUMMARY

Project Name	FGD Treatability
Sample Source	Plant 1
Sample Description	FGD Influent
Sample Collection Date	9/22/2014

Conditions	Units	Field Collected Sample	Jar Test Control JT1.0	Jar Test 4.0 - 80 JT4.4	Jar Test 6.5 - 20 JT1.1	Jar Test 6.5 - 50 JT2.1	Jar Test 6.5 - 80 JT3.1	Jar Test 6.5 - 80 DUP JT2.4	Jar Test 8.5 - 10 JT1.2	Jar Test 8.5 - 50 JT2.2	Jar Test 8.5 - 80 JT3.2	Jar Test 10.5 - 10 JT1.3	Jar Test 10.5 - 50 JT2.3	Jar Test 10.5 - 80 JT3.3
Jar Test Conditions														
Temperature	°C	--	Ambient	54	54	54	54	54	54	54	54	54	130	130
pH Target	s.u.	--	Ambient	4.00	6.5	6.5	6.5	6.5	8.5	8.5	8.5	10.5	10.5	10.5
pH after coagulant addition	s.u.	--	0.0	5.6	6.6	0.0	7.0	6.7	8.4	6.6	8.4	9.1	8.4	9.1
pH after adjustment	s.u.	--	0.0	4.2	6.6	6.6	7.0	6.8	8.5	8.5	8.5	10.5	10.5	10.5
HCl Dose	mL	--	0	35	0	0	0	0	0	0	0	0	0	0
NaOH Dose	mL	--	0	0	0	0	0	0	0	0	0	28	27	28
Ca(OH)2 Dose, 5% slurry	mL	--	0	0	1	1	2	1	57	56	47	40	40	40
Organosulfide Dose	ppm	--	0	80	20	50	80	80	10	50	80	10	50	80
FeCl3*6 H2O Dose	ppm	--	0	200	200	200	200	200	100	200	200	200	200	200
Anionic Polymer (AE 852) Dose	ppm as Product	--	0	5	5	5	5	5	5	5	5	0	0	0
Jar Test Results														
Total suspended solids	mg/L	23,000	10,500	12,300	15,300	13,600	11,800	13,800	17,200	13,300	14,900	26,100	28,700	16,200
Total dissolved solids	mg/L	28,000	21,900	32,500	21,600	22,900	28,400	22,200	20,900	21,200	27,500	14,600	20,500	21,600
Supernatent turbidity	NTU	--	0	33.2	78.8	104	75.6	77.7	9.15	7.12	20.1	No supernatant	No supernatant	No supernatant
Mercury, total	ng/L	126,000	166,000	1,130	2,010	2,780	1,990	1,760	274	237	463	--	--	--
Mercury, 0.45µm filtered	ng/L	50.3	40.7	22.9	22.1	11.6 J	15.5 J	13.4 J	26.3	20.8	16.8 J	140	1,260	1,520
Mercury, 30,000 MW filtered	ng/L	--	44.1	14.3 J	19.6 J	13.4 J	15.2 J	19.9 J	29.3	16.4 J	15.4 J	67.7	909	--
Mercury, 3,000 MW filtered	ng/L	--	--	5.62 U	14.0 J	8.89 J	6.93 J	6.77 J	--	11.4 J	7.67 J	59.2	669	402
Arsenic, total	µg/L	267	261	2.53	5.51	6.18	5.12	4.11	2.01	1.70	2.64	--	--	--
Arsenic, 0.45µm filtered	µg/L	3.06	2.97	1.54	1.88	1.82	2.15	1.90	1.86	1.87	1.50	1.74	1.96	1.56
Arsenic, 30,000 MW filtered	µg/L	--	--	1.54	1.75	1.75	2.25	1.80	1.91	1.85	1.81	2.12	1.88	--
Arsenic, 3,000 MW filtered	µg/L	--	--	2.00	1.80	1.72	2.84	2.53	--	2.75	2.72	1.92	2.10	1.94
Arsenate, 0.45µm filtered	µg/L	--	0.84 U	0.84 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U
Arsenite, 0.45µm filtered	µg/L	--	0.84 U	0.84 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U
Arsenate (V), 0.45µm filtered (AS)	µg/L	--	1.40	--	--	--	1.40 U	--	--	--	--	--	--	--
Arsenite (III), 0.45µm filtered (AS)	µg/L	--	1.17	--	--	--	1.55	--	--	--	--	--	--	--
MMAs (AS)	µg/L	--	0.99 U	--	--	--	0.99 U	--	--	--	--	--	--	--
DMAs (AS)	µg/L	--	0.99 U	--	--	--	0.99 U	--	--	--	--	--	--	--
Selenium, total	µg/L	919	937	109	131	126	120	104	109	116	114	--	--	--
Selenium, 0.45µm filtered	µg/L	243	139	110	118	117	111	114	112	115	113	140	127	94.6
Selenate (Se VI), 0.45µm filtered	µg/L	--	71.5	--	--	--	73.8	--	--	--	--	--	--	--
Selenite (Se IV), 0.45µm filtered	µg/L	--	33.0	--	--	--	19.9	--	--	--	--	--	--	--
SeCN	µg/L	--	0.83 U	--	--	--	0.83 U	--	--	--	--	--	--	--
MeSe (IV)	µg/L	--	2.13	--	--	--	2.16	--	--	--	--	--	--	--
SeMe	µg/L	--	2.44	--	--	--	2.54	--	--	--	--	--	--	--
SeSO3	µg/L	--	0.90 U	--	--	--	0.90 U	--	--	--	--	--	--	--
Se (unknown)	µg/L	--	0.90 U	--	--	--	0.90 U	--	--	--	--	--	--	--
Nitrate/Nitrite	mg/L as N	36.6	38.4	39.1	38.0	38.0	37.7	38.1	36.6	35.6	36.1	--	--	--
Boron, total	µg/L	330,000	321,000	316,000	304,000	306,000	295,000	264,000	217,000	226,000	234,000	--	--	--
Boron, 0.45µm filtered	µg/L	330,000	344,000	323,000	310,000	326,000	353,000	293,000	233,000	215,000	235,000	201,000	193,000	225,000
Cadmium, total	µg/L	31.8	32.5	6.39 J	2.24 J	0.60 U	0.60 U	0.60 U	0.60 U	0.60 U	0.60 U	--	--	--
Cadmium, 0.45µm filtered	µg/L	22.3	20.3	6.88 J	1.56 J	0.60 U	0.60 U	0.60 U	0.60 U	0.60 U	0.60 U	0.60 U	0.60 U	0.45 J
Magnesium, total	µg/L	3,560,000	3,470,000	3,260,000	3,160,000	3,150,000	3,070,000	2,730,000	2,320,000	2,430,000	2,460,000	--	--	--
Magnesium, 0.45µm filtered	µg/L	3,550,000	3,670,000	3,300,000	3,190,000	3,320,000	3,610,000	3,020,000	2,480,000	2,280,000	2,520,000	5,000 U	5,000 U	5,000 U
Manganese, total	µg/L	57,100	54,200	52,500	48,300	48,100	45,600	41,600	114 J	190 J	899 J	--	--	--
Manganese, 0.45µm filtered	µg/L	53,200	53,900	53,000	48,600	50,800	53,500	45,800	71.3 J	140 J	870 J	50.0 U	50.0 U	50.0 U
Iron, 0.45µm filtered	µg/L	--	--	--	--	--	--	--	--	--	--	--	--	--
Calcium, 0.45µm filtered	µg/L	--	--	--	--	--	--	--	--	--	--	--	--	--
Sodium, 0.45µm filtered	µg/L	--	--	--	--	--	--	--	--	--	--	--	--	--
Sulfates, 0.45µm filtered	mg/L	3,970	--	--	--	--	--	--	--	--	--	--	--	--
Chlorides, 0.45µm filtered	mg/L	8,000	--	--	--	--	--	--	--	--	--	--	--	--

U - not detected at the applied dilution
J - Estimated value
-- Not analyzed
DMA - dimethylarsinic acid
MMA - monomethylarsonic acid
SeCN - Selenocyanate
(AS) - Applied speciation results

Project Name	**FGD Treatability**
Sample Source	**Plant 2**
Sample Description	**FGD Influent**
Sample Collection Date	**10/14/2014**

Jar Test Conditions											
Conditions	**Units**	**Field Collected Sample**	**Jar Test Control JT1.0**	**Jar Test 4.0 - 80 JT3.4**	**Jar Test 6.5 - 25 JT1.1**	**Jar Test 6.5 - 80 JT3.1**	**Jar Test 8.5 - 25 JT1.2**	**Jar Test 8.5 - 25 Dup JT1.4**	**Jar Test 8.5 - 80 JT3.2**	**Jar Test 10.5 - 20 JT1.3**	**Jar Test 10.5 - 80 JT3.3**
Temperature	°C	--	54	54	54	54	54	54	54	54	54
pH Target	s.u.	--	7.1	4.0	6.5	6.5	8.5	8.5	8.5	10.5	10.5
pH after coagulant addition	s.u.	--	N/A	4.2	6.2	6.1	8.2	8.2	8.0	9.7	9.0
pH after adjustment	s.u.	--	N/A	4.0	6.5	6.5	8.5	8.5	8.5	10.5	--
HCl Dose	mL	--	0	3	0	0	0	0	0	0	0
NaOH Dose	mL	--	0	0	0	0	0	0	0	10	10
Ca(OH)2 Dose, 5% slurry	mL	--	0	0	1	2	5	4	5	7	7
Organosulfide Dose	ppm	--	0	80	25	80	25	25	80	20	80
FeCl3*6 H2O Dose	ppm	--	0	200	200	200	200	200	200	200	200
Anionic Polymer (AE 852) Dose	ppm as Product	--	0	0	0	0	5	5	5	0	0
CE 1950 Dose	ppm as Product	--	0	5	0	0	0	0	0	0	0
CE 834 Dose	ppm as Product	--	0	0	5	5	0	0	0	0	0
Jar Test Results											
Total suspended solids	mg/L	203,000	2,070	108	30.9	32.7	23.3	37.6	32.1	6,910	11,300
Total dissolved solids	mg/L	6,970	7,500	8,210	7,890	7,900	7,830	7,620	7,600	6,490	6,450
Supernatent turbidity	NTU	--	28.7	15.3	7.27	6.36	4.47	4.65	6.51	3.28	4.27
Mercury, total	ng/L	211,000	20,800	1,020	632	633	406	405	525	1,930	961
Mercury, 0.45µm filtered	ng/L	7,210	19,500	19.0 J	16.2 J	12.7 J	68.2	72.2	47.4	1,580	909
Mercury, 30,000 MW filtered	ng/L	--	19,400	10.4 J	21.8	3.62 U	61.0	43.7	34.0	401	923
Mercury, 3,000 MW filtered	ng/L	--	18,000	5.62 U	7.58 J	7.28 J	--	37.2	30.0	248	714
Arsenic, total	µg/L	194	2.58	0.33 U	1.25 J	1.52 J	1.95 J	1.44 J	1.63 J	1.45 J	0.84 U
Arsenic, 0.45µm filtered	µg/L	1.36	0.84 U	0.33 U	0.90 J	0.89 J	1.46	1.19	0.91 J	0.73 J	0.57 U
Arsenic, 30,000 MW filtered	µg/L	--	0.91 J	0.57 J	0.33 U	0.56 J	--	1.10	1.46	0.64 J	0.33 U
Arsenic, 3,000 MW filtered	µg/L	--	--	0.63 J	0.71 J	0.52 J	--	1.04	0.70 J	0.79 J	0.45 J
Arsenate (V), 0.45µm filtered (AS)	µg/L	--	1.40 U	--	--	1.40 U	--	1.40 U	--	--	--
Arsenite (III), 0.45µm filtered (AS)	µg/L	--	1.12	--	--	0.61 U	--	0.61 U	--	--	--
MMAs (AS)	µg/L	--	0.99 U	--	--	0.99 U	--	0.99 U	--	--	--
DMAs (AS)	µg/L	--	0.99 U	--	--	0.99 U	--	0.99 U	--	--	--
Selenium, total	µg/L	1,950	1,160	1,110	1,100	1,140	1,160	1,110	1,120	1,090	1,080
Selenium, 0.45µm filtered	µg/L	1,060	1,300	1,050	1,100	1,090	1,110	1,080	1,080	1,050	1,060
Selenate (Se VI), 0.45µm filtered	µg/L	--	1,000	--	--	983	--	966	--	--	--
Selenite (Se IV), 0.45µm filtered	µg/L	--	3.71	--	--	3.98	--	6.83	--	--	--
SeCN	µg/L	--	0.83 U	--	--	0.83 U	--	0.83 U	--	--	--
MeSe (IV)	µg/L	--	0.90 U	--	--	0.90 U	--	0.90 U	--	--	--
SeMe	µg/L	--	0.90 U	--	--	0.90 U	--	0.90 U	--	--	--
SeSO3	µg/L	--	0.90 U	--	--	0.90 U	--	0.90 U	--	--	--
Se (unknown)	µg/L	--	0.90 U	--	--	0.90 U	--	0.90 U	--	--	--
Nitrate/Nitrite	mg/L as N	24.1	26.0	25.6	25.0	25.5	24.2	25.4	25.3	25.0	24.8
Boron, total	µg/L	25,600	27,600	27,500	28,300	28,000	26,800	--	25,900	20,500	16,700
Boron, 0.45µm filtered	µg/L	27,200	28,400	28,400	27,300	27,400	27,300	25,900	25,700	18,100	16,600
Cadmium, total	µg/L	81.4 J	52.0	54.2	4.73 J	0.60 U	0.60 U	0.60 U	0.60 U	0.60 U	0.60 U
Cadmium, 0.45µm filtered	µg/L	62.4	51.2	52.4	4.55 J	0.60 U	0.60 U	0.60 U	0.60 U	0.60 U	0.60 U
Magnesium, total	µg/L	1,170,000	784,000	771,000	777,000	795,000	751,000	--	742,000	2,260	12,100
Magnesium, 0.45µm filtered	µg/L	707,000	764,000	805,000	761,000	776,000	751,000	728,000	727,000	1,610 J	9,780
Manganese, total	µg/L	4,640	55.5 J	535 J	289 J	374 J	50.0 U	--	58 J	6.98 J	5.00 U
Manganese, 0.45µm filtered	µg/L	253 J	50.0 U	538 J	205 J	342 J	50.0 U	50.0 U	50 U	5.00 U	5.00 U
Iron, 0.45µm filtered	µg/L	--	1,000 U	1,000 U	1,000 U	1,000 U	1,000 U	1,000 U	1,000 U	100 U	100 U
Calcium, 0.45µm filtered	µg/L	--	--	--	--	--	--	--	--	--	--
Sodium, 0.45µm filtered	µg/L	--	--	--	--	--	--	--	--	--	--
Sulfates, 0.45µm filtered	mg/L	2,390	--	--	--	--	--	--	--	--	--
Chlorides, 0.45µm filtered	mg/L	940	--	--	--	--	--	--	--	--	--

U - not detected at the applied dilution
J - Estimated value
-- Not analyzed
DMA - dimethylarsinic acid
MMA - monomethylarsonic acid
SeCN - Selenocyanate
(AS) - Applied speciation results

Project Name	**FGD Treatability**
Sample Source	**Plant 3**
Sample Description	**FGD Influent**
Sample Collection Date	**10/21/2014**

Conditions	Units	Field Collected Sample	Jar Test Control JT1.0	Jar Test 4.0 - 80 JT3.3	Jar Test 6.5 - 25 JT1.1	Jar Test 6.5 - 80 JT3.1	Jar Test 8.5 - 25 JT1.2	Jar Test 8.5 - 25 Dup JT1.3	Jar Test 8.5 - 80 JT3.2
Jar Test Conditions									
Temperature	°C	--	54	54	54	54	54	54	54
pH Target	s.u.	--	6.4	4.0	6.5	6.5	8.5	8.5	8.5
pH after coagulant addition	s.u.	--	0.0	4.1	6.4	6.5	8.3	8.3	8.4
pH after adjustment	s.u.	--	0.0	4.0	6.6	6.5	8.5	8.5	8.5
HCl Dose	mL	--	0	3	0	0	0	0	0
NaOH Dose	mL	--							
Ca(OH)2 Dose, 5% slurry	mL	--	0	0	4	3	81	80	70
Organosulfide Dose	ppm	--	0	80	25	80	25	25	80
FeCl3*6 H2O Dose	ppm	--	0	200	200	200	200	200	200
Anionic Polymer (AE 852) Dose	ppm as Product	--	0	5	0	0	0	0	0
CE 834 Dose	ppm as Product	--	0	0	5	5	5	5	5
Jar Test Results									
Total suspended solids	mg/L	10,900	9,720	10,300	11,400	10,400	15,840	17,120	18,500
Total dissolved solids	mg/L	43,600	44,300	45,800	43,500	44,900	38,900	38,400	38,100
Supernatent turbidity	NTU	--	1,254	98.8	106	109	5.07	6.77	6.33
Mercury, total	ng/L	2,110,000	266,000	34,500	19,700	19,500	3,840	3,150	3,830
Mercury, 0.45µm filtered	ng/L	2,700	4,110	25,700	1,890	1,300	957	855	1,030
Mercury, 30,000 MW filtered	ng/L	--	4,630	19,700	1,660	956	615	698	721
Mercury, 3,000 MW filtered	ng/L	--	3,770	21,300	1,280	832	490	463	602
Arsenic, total	µg/L	200	27.8	7.85	9.65	10.2	8.45	8.46	8.32
Arsenic, 0.45µm filtered	µg/L	9.01	8.82	6.64	7.48	10.0	7.01	8.12	8.42
Arsenic, 30,000 MW filtered	µg/L	--	9.92	6.30	8.01	9.70	8.05	8.24	9.6
Arsenic, 3,000 MW filtered	µg/L	--	9.70	6.14	8.03	7.56	8.27	8.13	7.27
Arsenate, 0.45µm filtered	µg/L	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U	2.50 U
Arsenite, 0.45µm filtered	µg/L	2.67	2.50 U	3.11	3.78	2.85	3.21	2.73	3.66
Arsenate (V), 0.45µm filtered (AS)	µg/L	--	1.40 U	--	--	1.40 U	1.40 U	--	--
Arsenite (III), 0.45µm filtered (AS)	µg/L	--	0.66	--	--	0.61 U	0.79	--	--
MMAs (AS)	µg/L	--	0.99 U	--	--	0.99 U	0.99 U	--	--
DMAs (AS)	µg/L	--	1.18	--	--	0.99 U	2.09	--	--
Selenium, total	µg/L	15,800	6,620	2,960	5,080	4,410	5,060	4,900	4,890
Selenium, 0.45µm filtered	µg/L	4,520	5,040	2,750	4,700	4,270	4,860	4,640	4,860
Selenate (Se VI), 0.45µm filtered	µg/L	--	2,240	--	--	2,240	2,150	--	--
Selenite (Se IV), 0.45µm filtered	µg/L	--	2,060	--	--	1,410	1,970	--	--
SeCN	µg/L	--	1.50 U	--	--	1.50 U	1.50 U	--	--
MeSe (IV)	µg/L	--	2.90	--	--	1.80	1.90	--	--
SeMe	µg/L	--	1.10 U	--	--	1.10 U	1.10 U	--	--
SeSO3	µg/L	--	1.10 U	--	--	1.10 U	1.10 U	--	--
Se (unknown)	µg/L	--	6.60	--	--	7.40	5.80	--	--
Nitrate/Nitrite	mg/L as N	251	273	280	276	277	265	263	263
Boron, total	µg/L	22,600	20,300	20,300	20,700	19,600	11,000	10,300	10,600
Boron, 0.45µm filtered	µg/L	19,500 J	21,000	20,600	19,400	20,300	10,800	10,400	10,300
Cadmium, total	µg/L	33.0 J	14.4	8.58 J	2.23 J	0.60 U	1.10 J	0.60 U	0.60 U
Cadmium, 0.45µm filtered	µg/L	11.5	11.9	8.58 J	2.28 J	0.60 U	1.35 J	0.60 U	0.60 U
Magnesium, total	µg/L	7,310,000	7,050,000	6,920,000	6,940,000	6,830,000	6,000,000	5,680,000	5,880,000
Magnesium, 0.45µm filtered	µg/L	6,830,000	7,210,000	6,930,000	6,540,000	6,730,000	5,850,000	5,730,000	5,620,000
Manganese, total	µg/L	92,300	88,900	89,300	83,700	84,500	16,700	17,200	17,700
Manganese, 0.45µm filtered	µg/L	87,500	90,200	89,400	78,700	83,300	16,000	17,000	16,800
Iron, 0.45µm filtered	µg/L	--	1,000 U	5,650 J	1,000 U	1,000 U	1,000 U	1,000 U	1,000 U
Calcium, 0.45µm filtered	µg/L	639,000	--	--	--	--	--	--	--
Sodium, 0.45µm filtered	µg/L	886,000	--	--	--	--	--	--	--
Sulfates, 0.45µm filtered	mg/L	19,700	--	--	--	--	--	--	--
Chlorides, 0.45µm filtered	mg/L	5,540	--	--	--	--	--	--	--

U - not detected at the applied dilution
J - Estimated value
-- Not analyzed
DMA - dimethylarsinic acid
MMA - monomethylarsonic acid
SeCN - Selenocyanate
(AS) - Applied speciation results

Project Name	**FGD Treatability**
Sample Source	**Plant 4**
Sample Description	**FGD Influent**
Sample Collection Date	**10/27/2014**

Jar Test Conditions								
Conditions	**Units**	**Jar Test Control JT1.0**	**Jar Test 4.0 - 80 JT3.3**	**Jar Test 6.5 - 25 JT1.1**	**Jar Test 6.5 - 80 JT3.1**	**Jar Test 8.5 - 25 JT1.2**	**Jar Test 8.5 - 25 Dup JT1.3**	**Jar Test 8.5 - 80 JT3.2**
Temperature	°C	53	52	53	54	52	52	53
pH Target	s.u.	7.0	4.0	6.5	6.5	8.5	8.5	8.5
pH after coagulant addition	s.u.	0.0	5.1	6.5	6.5	8.3	8.4	8.3
pH after adjustment	s.u.	0.0	4.0	6.5	6.5	8.5	8.5	8.5
HCl Dose	mL	0	14	2	2	0	0	0
Ca(OH)2 Dose, 5% slurry	mL	0	0	0	0	132	118	158
Organosulfide Dose	ppm	0	80	25	80	25	25	80
FeCl3*6 H2O Dose	ppm	0	200	200	200	200	200	200
Anionic Polymer (AE 853) Dose	ppm as Product	0	0	5	5	0	0	0
CE 834 Dose	ppm as Product	0	5	0	0	5	5	5

Jar Test Results								
Total suspended solids	mg/L	7,760	900	175	1,810	41.9	44.7	54.8
Total dissolved solids	mg/L	54,100	55,100	48,100	58,700	47,100	47,500	46,000
Supernatent turbidity	NTU	82.6	33.3	64.2	18.8	15.2	19.7	11.4
Mercury, total	ng/L	7,580	1,810	4,380	1,050	962	952	608
Mercury, 0.45µm filtered	ng/L	60.6	138	49.4	27.3	25.6	25.3	29.1
Mercury, 30,000 MW filtered	ng/L	38.1	112	8.82 J	11.1 J	11.5 J	6.24 J	10.2 J
Mercury, 3,000 MW filtered	ng/L	20.1	99.4	5.74 J	5.62 U	6.02 J	5.84 J	6.36 J
Arsenic, total	µg/L	7.61	4.09	5.75	4.95	4.72	4.73	4.19
Arsenic, 0.45µm filtered	µg/L	4.70	3.17	4.03	4.85	4.18	3.98	4.60
Arsenic, 30,000 MW filtered	µg/L	5.17	3.34	3.84	3.80	3.93	3.85	4.36
Arsenic, 3,000 MW filtered	µg/L	4.67	3.21	4.54	4.87	3.96	4.54	3.62
Arsenate (V), 0.45µm filtered (AS)	µg/L	1.40 U	--	--	1.40 U	1.40 U	--	--
Arsenite (III), 0.45µm filtered (AS)	µg/L	0.61 U	--	--	0.84	0.61 U	--	--
MMAs (AS)	µg/L	0.99 U	--	--	0.99 U	0.99 U	--	--
DMAs (AS)	µg/L	1.99	--	--	1.74	2.03	--	--
Selenium, total	µg/L	210	74.8	168	122	198	192	222
Selenium, 0.45µm filtered	µg/L	202	85.3	126	122	199	181	199
Selenate (Se VI), 0.45µm filtered	µg/L	40.5	--	--	56.7	39.1	--	--
Selenite (Se IV), 0.45µm filtered	µg/L	111	--	--	48.9	97.6	--	--
SeCN	µg/L	1.50 U	--	--	1.50 U	1.50 U	--	--
MeSe (IV)	µg/L	6.15	--	--	4.62	5.08	--	--
SeMe	µg/L	1.10 U	--	--	1.10 U	1.10 U	--	--
SeSO3	µg/L	1.10 U	--	--	1.10 U	1.10 U	--	--
Se (unknown)	µg/L	1.10 U	--	--	1.10 U	1.10 U	--	--
Nitrate/Nitrite	mg/L as N	195	190	195	195	180	181	177
Boron, total	µg/L	759,000	633,000	752,000	739,000	544,000	575,000	468,000
Boron, 0.45µm filtered	µg/L	730,000	692,000	712,000	706,000	521,000	523,000	455,000
Cadmium, total	µg/L	33.7	21.2	8.00 J	2.83 J	2.52 J	4.18 J	2.70 J
Cadmium, 0.45µm filtered	µg/L	32.1	20.4	7.35 J	2.90 J	2.12 J	2.07 J	2.32 J
Magnesium, total	µg/L	7,890,000	6,470,000	7,820,000	7,660,000	6,170,000	6,360,000	5,570,000
Magnesium, 0.45µm filtered	µg/L	7,510,000	7,060,000	7,350,000	7,250,000	5,860,000	5,800,000	5,390,000
Manganese, total	µg/L	35,400	30,600	35,200	34,300	1,790	7,520	1,000
Manganese, 0.45µm filtered	µg/L	33,700	33,300	33,200	32,700	1,360	6,640	746
Iron, 0.45µm filtered	µg/L	1,000 U	5,750 J	1,000 U	1,000 U	1,000 U	1,000 U	1,000 U
Calcium, 0.45µm filtered	µg/L	--	--	--	--	--	--	--
Sodium, 0.45µm filtered	µg/L	--	--	--	--	--	--	--
Sulfates, 0.45µm filtered	mg/L	--	--	--	--	--	--	--
Chlorides, 0.45µm filtered	mg/L	--	--	--	--	--	--	--

U - not detected at the applied dilution

J - Estimated value

-- Not analyzed

DMA - dimethylarsinic acid

MMA - monomethylarsonic acid

SeCN - Selenocyanate

(AS) - Applied speciation results

Project Name	**FGD Treatability**
Sample Source	**Plant 5**
Sample Description	**FGD Influent**
Sample Collection Date	**11/10/2014**

Jar Test Conditions								
Conditions	**Units**	**Jar Test Control JT1.0**	**Jar Test 4.0 - 80 JT3.3**	**Jar Test 6.5 - 25 JT1.1**	**Jar Test 6.5 - 80 JT3.1**	**Jar Test 8.5 - 25 JT1.2**	**Jar Test 8.5 - 25 Dup JT1.3**	**Jar Test 8.5 - 80 JT3.2**
Temperature	°C	54	54	54	54	54	54	54
pH Target	s.u.	6.8	4.0	6.5	6.5	8.5	8.5	8.5
pH after coagulant addition	s.u.	--	4.2	6.6	6.4	8.4	8.3	8.2
pH after adjustment	s.u.	--	4.0	6.4	6.8	8.5	8.5	8.5
HCl Dose	mL	--	22.9	0.9	0	0	0	0
Ca(OH)2 Dose, 5% slurry	mL	--	0	1.8	2.1	44	48	54
Organosulfide Dose	ppm	--	80	25	80	25	25	80
FeCl3*6 H2O Dose	ppm	--	200	200	200	200	200	200
Anionic Polymer (AE 852) Dose	ppm as Product	--	5	5	5	5	5	5
Jar Test Results								
Total suspended solids	mg/L	19,900	15,100	23,300	15,300	15,300	12,800	11,500
Total dissolved solids	mg/L	19,700	18,500	20,300	18,600	18,900	19,000	18,900
Supernatent turbidity	NTU	73.7	50.6	47.1	58.9	36.4	35.1	51.2
Mercury, total	ng/L	1,390	1,030	1,280	1,190	771	656	883
Mercury, 0.45µm filtered	ng/L	44.0	9.74 J	16.0	8.72 J	15.2 J	13.4 J	9.24 J
Mercury, 30,000 MW filtered	ng/L	35.7	7.34 J	13.2 J	12.7 J	20.2	11.3 J	5.62 U
Mercury, 3,000 MW filtered	ng/L	14.2 J	5.62 U	5.62 U	5.62 U	5.62 U	5.62 U	5.62 U
Arsenic, total	µg/L	3.30	2.26 J	2.23 J	2.14 J	1.79 J	1.41 J	2.54
Arsenic, 0.45µm filtered	µg/L	1.33 J	1.39 J	0.85 J	0.84 U	1.18 J	1.22 J	1.62 J
Arsenic, 30,000 MW filtered	µg/L	1.63 J	1.36 J	1.22 J	1.11 J	1.46 J	1.74 J	1.58 J
Arsenic, 3,000 MW filtered	µg/L	1.57 J	0.98 J	1.06 J	1.17 J	1.31 J	1.37 J	1.33 J
Arsenate (V), 0.45µm filtered (AS)	µg/L	1.40 U	--	--	1.40 U	1.40 U	--	--
Arsenite (III), 0.45µm filtered (AS)	µg/L	0.61 U	--	--	0.61 U	0.61 U	--	--
MMAs (AS)	µg/L	0.99 U	--	--	0.99 U	0.99 U	--	--
DMAs (AS)	µg/L	0.99 U	--	--	0.99 U	0.99 U	--	--
Selenium, total	µg/L	331	288	304	293	335	314	303
Selenium, 0.45µm filtered	µg/L	326	290	300	309	321	318	278
Selenate (Se VI), 0.45µm filtered	µg/L	219	--	--	205	211	--	--
Selenite (Se IV), 0.45µm filtered	µg/L	56.9	--	--	41.3	78.1	--	--
SeCN	µg/L	1.10 U	--	--	1.10 U	1.10 U	--	--
MeSe (IV)	µg/L	6.30	--	--	4.00	1.60 U	--	--
SeMe	µg/L	1.60 U	--	--	1.60 U	1.60 U	--	--
SeSO3	µg/L	1.60 U	--	--	1.60 U	1.60 U	--	--
Se (unknown)	µg/L	1.60 U	--	--	1.60 U	1.60 U		
Nitrate-Nitrite	mg/L as N	22.3	20.6	21.8	21.1	19.6	21.1	21.5
Boron, total	µg/L	271,000	265,000	261,000	254,000	223,000	218,000	218,000
Boron, 0.45µm filtered	µg/L	269,000	253,000	254,000	248,000	223,000	219,000	214,000
Cadmium, total	µg/L	96.4	8.71 J	14.4	1.40 J	1.19 J	1.52 J	0.92 J
Cadmium, 0.45µm filtered	µg/L	92.0	8.14 J	13.2	1.31 J	0.60 U	0.60 U	0.60 U
Magnesium, total	µg/L	3,040,000	2,960,000	2,910,000	2,840,000	2,520,000	2,460,000	2,450,000
Magnesium, 0.45µm filtered	µg/L	2,970,000	2,810,000	2,830,000	2,740,000	2,500,000	2,450,000	2,400,000
Manganese, total	µg/L	47,500	49,700	45,700	43,200	4,910	3,090	6,220
Manganese, 0.45µm filtered	µg/L	46,500	47,300	44,200	41,500	4,750	2,980	5,950
Iron, 0.45 µm filtered	µg/L	1,000 U	14,100	1,000 U	1,000 U	1,000 U	1,000 U	1,000 U
Calcium, 0.45µm filtered	µg/L	--	--	--	--	--	--	--
Sodium, 0.45µm filtered	µg/L	--	--	--	--	--	--	--
Sulfates, 0.45µm filtered	mg/L	--	--	--	--	--	--	--
Chlorides, 0.45µm filtered	mg/L	--	--	--	--	--	--	--

U - not detected at the applied dilution
J - Estimated value
-- Not analyzed
DMA - dimethylarsinic acid
MMA - monomethylarsonic acid
SeCN - Selenocyanate
(AS) - Applied speciation results

C
ANALYTICAL QUALITY CONTROL RESULTS

Table C-1
Laboratory Duplicate Precision

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL Result	ASL Duplicate	ASL DL	ASL RL	RPD
Mercury, Filtered (ng/L) [a]	Plant 1	JT1.0	Control	28	44	6	20	45%
		JT1.2	8.5 su, 10 ppm	13 J	29	6	20	80%
	Plant 2	JT1.0	Control	19,400	19,200	112	400	1%
		JT1.2	8.5 su, 25 ppm	58	61	6	20	6%
		JT3.3	10.5 su, 80 ppm	923	879	6	20	5%
	Plant 3	JT1.0	Control	4,370	4,630	112	400	6%
		JT1.2	8.5 su, 25 ppm	615	602	6	20	2%
		JT3.1	6.5 su, 80 ppm	956	932	6	20	3%
	Plant 4	JT1.0	Control	32	38	6	20	19%
		JT1.2	8.5 su, 25 ppm	< 6	12 J	6	20	69%
		JT3.1	6.5 su, 80 ppm	8 J	11 J	6	20	36%
	Plant 5	JT1.0	Control	36	35	6	20	1%
		JT1.2	8.5 su, 25 ppm	20	17 J	6	20	18%
		JT3.1	6.5 su, 80 ppm	9 J	13 J	6	20	33%
Arsenic, Filtered (µg/L) [b]	Plant 1	JT1.0	Control	3.0	2.6	0.8	2.5	15%
		JT1.2	8.5 su, 10 ppm	1.9	1.9	0.3	1.0	1%
		JT3.3	10.5 su, 80 ppm	1.6	1.7	0.3	1.0	8%
	Plant 2	JT1.0	Control	< 0.8	< 0.8	0.8	2.5	0%
		JT1.2	8.5 su, 25 ppm	1.0	1.5	0.3	1.0	35%
		JT3.3	10.5 su, 80 ppm	0.6 J	< 0.3	0.3	1.0	53%
	Plant 3	JT1.0	Control	8.8	7.0	0.3	5.0	24%
		JT1.2	8.5 su, 25 ppm	7.0	5.9	0.3	5.0	18%
		JT3.1	6.5 su, 80 ppm	8.6	10.0	0.3	5.0	14%
	Plant 4	JT1.0	Control	4.7	3.9	0.8	2.5	18%
		JT1.2	8.5 su, 25 ppm	3.4	4.2	0.8	2.5	20%
		JT3.1	6.5 su, 80 ppm	4.2	4.9	0.8	2.5	14%
	Plant 5	JT1.0	Control	1.1 J	1.3 J	0.8	2.5	24%
		JT1.2	8.5 su, 25 ppm	1.0 J	1.2 J	0.8	2.5	20%
		JT3.1	6.5 su, 80 ppm	< 0.8	< 0.8	0.8	2.5	0%
Selenium, Filtered (µg/L) [b]	Plant 1	JT1.0	Control	139	139	1.5	2.5	0%
		JT1.2	8.5 su, 10 ppm	111	112	0.6	1.0	1%
		JT3.3	10.5 su, 80 ppm	92	95	0.6	1.0	3%

Table C-1
Laboratory Duplicate Precision

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL Result	ASL Duplicate	ASL DL	ASL RL	RPD
Selenium, Filtered (µg/L) [b]	Plant 2	JT1.0	Control	1,190	1,300	29	50	9%
		JT1.2	8.5 su, 25 ppm	1,110	1,090	0.6	1.0	2%
		JT3.3	10.5 su, 80 ppm	1,060	1,040	0.6	1.0	2%
	Plant 3	JT1.0	Control	5,040	4,850	2.9	50	4%
		JT1.2	8.5 su, 25 ppm	4,760	4,860	2.9	50	2%
		JT3.1	6.5 su, 80 ppm	4,220	4,270	2.9	50	1%
	Plant 4	JT1.0	Control	202	200	1.5	25	1%
		JT1.2	8.5 su, 25 ppm	199	190	1.5	25	5%
		JT3.1	6.5 su, 80 ppm	122	121	1.5	25	1%
	Plant 5	JT1.0	Control	326	318	1.5	25	2%
		JT1.2	8.5 su, 25 ppm	321	312	1.5	25	3%
		JT3.1	6.5 su, 80 ppm	309	300	1.5	25	3%
Cadmium, Filtered (µg/L) [b]	Plant 1	JT1.0	Control	20	20	0.6	10	1%
		JT1.2	8.5 su, 10 ppm	< 0.6	< 0.6	0.6	10	0%
		JT3.3	10.5 su, 80 ppm	0.5 J	< 0.6	0.6	10	29%
	Plant 2	JT1.0	Control	51	50	0.6	10	3%
		JT1.2	8.5 su, 25 ppm	< 0.6	< 0.6	0.6	10	0%
		JT3.3	10.5 su, 80 ppm	< 0.6	< 0.6	0.6	10	0%
	Plant 3	JT1.0	Control	12	12	0.6	10	2%
		JT1.2	8.5 su, 25 ppm	1.4 J	1.0 J	0.6	10	27%
		JT3.1	6.5 su, 80 ppm	< 0.6	< 0.6	0.6	10	0%
	Plant 4	JT1.0	Control	32	32	0.6	10	1%
		JT1.2	8.5 su, 25 ppm	2.1 J	1.7 J	0.6	10	23%
		JT3.1	6.5 su, 80 ppm	2.0 J	2.9 J	0.6	10	38%
	Plant 5	JT1.0	Control	92	92	0.6	10	0%
		JT1.2	8.5 su, 25 ppm	< 0.6	< 0.6	0.6	10	0%
		JT3.1	6.5 su, 80 ppm	1.3 J	0.9 J	0.6	10	37%
Boron, Filtered (mg/L) [c]	Plant 1	JT1.0	Control	344	331	2	10	4%
		JT1.2	8.5 su, 10 ppm	233	231	2	10	1%
		JT3.3	10.5 su, 80 ppm	225	222	2	10	1%
	Plant 2	JT1.0	Control	27	28	2	10	6%
		JT1.2	8.5 su, 25 ppm	26	27	2	10	4%

Table C-1
Laboratory Duplicate Precision

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL Result	ASL Duplicate	ASL DL	ASL RL	RPD
Boron, Filtered (mg/L) [c]	Plant 2	JT3.3	10.5 su, 80 ppm	17	17	2	10	1%
	Plant 3	JT1.0	Control	20	21	2	10	4%
		JT1.2	8.5 su, 25 ppm	11	10	2	10	4%
		JT3.1	6.5 su, 80 ppm	20	20	2	10	1%
	Plant 4	JT1.0	Control	730	724	2	10	1%
		JT1.2	8.5 su, 25 ppm	518	521	2	10	1%
		JT3.1	6.5 su, 80 ppm	698	706	2	10	1%
	Plant 5	JT1.0	Control	257	269	2	10	5%
		JT1.2	8.5 su, 25 ppm	216	223	2	10	3%
		JT3.1	6.5 su, 80 ppm	245	248	2	10	1%
Magnesium, Filtered (mg/L) [c]	Plant 1	JT1.0	Control	3,670	3,540	5	50	4%
		JT1.2	8.5 su, 10 ppm	2,480	2,450	5	50	1%
		JT3.3	10.5 su, 80 ppm	5	5	5	50	0%
	Plant 2	JT1.0	Control	764	763	5	50	0%
		JT1.2	8.5 su, 25 ppm	751	738	5	50	2%
		JT3.3	10.5 su, 80 ppm	10	10	5	50	0%
	Plant 3	JT1.0	Control	7,210	6,900	5	50	4%
		JT1.2	8.5 su, 25 ppm	5,850	5,730	5	50	2%
		JT3.1	6.5 su, 80 ppm	6,730	6,730	5	50	0%
	Plant 4	JT1.0	Control	7,510	7,450	5	50	1%
		JT1.2	8.5 su, 25 ppm	5,840	5,860	5	50	0%
		JT3.1	6.5 su, 80 ppm	7,170	7,250	5	50	1%
	Plant 5	JT1.0	Control	2,870	2,970	5	50	3%
		JT1.2	8.5 su, 25 ppm	2,440	2,500	5	50	2%
		JT3.1	6.5 su, 80 ppm	2,710	2,740	5	50	1%
Manganese, Filtered (µg/L) [c]	Plant 1	JT1.0	Control	53,900	52,200	50	1,000	3%
		JT1.2	8.5 su, 10 ppm	71 J	71 J	50	1,000	1%
		JT3.3	10.5 su, 80 ppm	< 50	< 50	50	1,000	0%
	Plant 2	JT1.0	Control	< 50	< 50	50	1,000	0%
		JT1.2	8.5 su, 25 ppm	< 50	< 50	50	1,000	0%
		JT3.3	10.5 su, 80 ppm	< 5	< 5	5	100	0%
	Plant 3	JT1.0	Control	90,200	87,300	50	1,000	3%

Table C-1
Laboratory Duplicate Precision

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL Result	ASL Duplicate	ASL DL	ASL RL	RPD
Manganese, Filtered (µg/L) [c]	Plant 3	JT1.2	8.5 su, 25 ppm	16,000	15,300	50	1,000	4%
		JT3.1	6.5 su, 80 ppm	83,200	83,300	50	1,000	0%
	Plant 4	JT1.0	Control	33,700	33,400	50	1,000	1%
		JT1.2	8.5 su, 25 ppm	1,360	1,360	50	1,000	0%
		JT3.1	6.5 su, 80 ppm	32,200	32,700	50	1,000	2%
	Plant 5	JT1.0	Control	45,000	46,500	50	1,000	3%
		JT1.2	8.5 su, 25 ppm	4,620	4,750	50	1,000	3%
		JT3.1	6.5 su, 80 ppm	41,200	41,500	50	1,000	1%

Notes:
[a] EPA Method 1631, 30,000-MW filtered
[b] EPA Method 200.8M, 0.45-µm filtered
[c] EPA Method 200.7, 0.45-µm filtered
ASL – CH2M's Applied Sciences Laboratory
DL – Detection Limit
RL – Reporting Limit
RPD – Relative Percent Difference
< – not detected at the applied dilution
J – Detected by the instrument, the result is > the DL but < or = to the RL. Result is reported and considered an estimate.
RPD > 35 percent

Table C-2
Inter-laboratory Split Precision

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL Result	ASL DL	ASL RL	BR Result	BR DL	BR RL	RPD
Mercury, Filtered (ng/L) [a]	Plant 1	JT1.0	Control	28	6	20	31	0.5	2	11%
		JT1.2	8.5 su, 10 ppm	13 J	6	20	16	0.5	2	21%
		JT3.3	10.5 su, 80 ppm	-	-		1,320	0.5	2	-
	Plant 2	JT1.0	Control	19,400	112	400	21,300	51	204	9%
		JT1.2	8.5 su, 25 ppm	58	6	20	56	0.5	2	3%
		JT3.3	10.5 su, 80 ppm	923	6	20	927	0.5	2	0%
	Plant 3	JT1.0	Control	4,370	112	400	3,940	53	211	10%
		JT1.2	8.5 su, 25 ppm	615	6	20	248	0.5	2	85%
		JT3.1	6.5 su, 80 ppm	956	6	20	236	0.5	2	121%
	Plant 4	JT1.0	Control	32	6	20	30	0.5	2	5%
		JT1.2	8.5 su, 25 ppm	< 6	6	20	7	0.5	2	28%
		JT3.1	6.5 su, 80 ppm	8 J	6	20	5	0.5	2	49%
	Plant 5	JT1.0	Control	36	6	20	31	0.5	2	14%
		JT1.2	8.5 su, 25 ppm	20	6	20	9	0.5	2	80%
		JT3.1	6.5 su, 80 ppm	9 J	6	20	6	0.5	2	45%
Arsenic, Filtered (µg/L) [b]	Plant 1	JT1.0	Control	3.0	0.8	2.5	3.8	0.3	0.8	25%
		JT1.2	8.5 su, 10 ppm	1.9	0.3	1.0	2.4	0.3	0.8	25%
		JT3.3	10.5 su, 80 ppm	1.6	0.3	1.0	2.3	0.3	0.8	39%
	Plant 2	JT1.0	Control	< 0.8	0.8	2.5	2.3	0.3	0.8	92%
		JT1.2	8.5 su, 25 ppm	1.0	0.3	1.0	1.6	0.3	0.8	45%
		JT3.3	10.5 su, 80 ppm	0.6 J	0.3	1.0	0.9	0.3	0.8	41%
	Plant 3	JT1.0	Control	8.8	0.3	5.0	19.0	0.3	0.8	73%
		JT1.2	8.5 su, 25 ppm	7.0	0.3	5.0	19.4	0.3	0.8	94%
		JT3.1	6.5 su, 80 ppm	8.6	0.3	5.0	20.0	0.3	0.8	79%
	Plant 4	JT1.0	Control	4.7	0.8	2.5	6.5	0.3	0.8	32%
		JT1.2	8.5 su, 25 ppm	3.4	0.8	2.5	5.2	0.3	0.8	41%
		JT3.1	6.5 su, 80 ppm	4.2	0.8	2.5	5.1	0.3	0.8	19%
	Plant 5	JT1.0	Control	1.1 J	0.8	2.5	1.6	0.6	1.5	43%
		JT1.2	8.5 su, 25 ppm	1.0 J	0.8	2.5	1.4 J	0.6	1.5	33%
		JT3.1	6.5 su, 80 ppm	< 0.8	0.8	2.5	1.3 J	0.6	1.5	41%
Selenium, Filtered (µg/L) [b]	Plant 1	JT1.0	Control	139	1.5	2.5	148	0.6	1.8	6%
		JT1.2	8.5 su, 10 ppm	111	0.6	1.0	118	0.6	1.8	6%

Table C-2
Inter-laboratory Split Precision

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL Result	ASL DL	ASL RL	BR Result	BR DL	BR RL	RPD
Selenium, Filtered (µg/L) [b]	Plant 1	JT3.3	10.5 su, 80 ppm	92	0.6	1.0	114	0.6	1.8	22%
	Plant 2	JT1.0	Control	1,190	29	50	1,240	0.6	1.8	4%
		JT1.2	8.5 su, 25 ppm	1,110	0.6	1.0	1,240	0.6	1.8	11%
		JT3.3	10.5 su, 80 ppm	1,060	0.6	1.0	1,210	0.6	1.8	13%
	Plant 3	JT1.0	Control	5,040	2.9	50	5,950	0.6	1.8	17%
		JT1.2	8.5 su, 25 ppm	4,760	2.9	50	5,740	0.6	1.8	19%
		JT3.1	6.5 su, 80 ppm	4,220	2.9	50	4,940	0.6	1.8	16%
	Plant 4	JT1.0	Control	202	1.5	25	233	0.6	1.8	14%
		JT1.2	8.5 su, 25 ppm	199	1.5	25	215	0.6	1.8	8%
		JT3.1	6.5 su, 80 ppm	122	1.5	25	137	0.6	1.8	12%
	Plant 5	JT1.0	Control	326	1.5	25	335	1.2	3.5	3%
		JT1.2	8.5 su, 25 ppm	321	1.5	25	334	1.2	3.5	4%
		JT3.1	6.5 su, 80 ppm	309	1.5	25	306	1.2	3.5	1%
Cadmium, Filtered (µg/L) [b]	Plant 1	JT1.0	Control	20	0.6	10	22	0.1	0.2	8%
		JT1.2	8.5 su, 10 ppm	< 0.6	0.6	10	0.4	0.1	0.2	N/A
		JT3.3	10.5 su, 80 ppm	0.5 J	0.2	2.5	< 0.07	0.1	0.2	144%
	Plant 2	JT1.0	Control	51	0.6	10	50	0.2	0.5	3%
		JT1.2	8.5 su, 25 ppm	< 0.6	0.6	10	< 0.2	0.2	0.5	N/A
		JT3.3	10.5 su, 80 ppm	< 0.6	0.6	10	0.5 J	0.2	0.5	27%
	Plant 3	JT1.0	Control	12	0.6	10	11.2	0.2	0.5	6%
		JT1.2	8.5 su, 25 ppm	1.4 J	0.6	10	0.4 J	0.2	0.5	118%
		JT3.1	6.5 su, 80 ppm	< 0.6	0.6	10	0.5 J	0.2	0.5	N/A
	Plant 4	JT1.0	Control	32	0.6	10	31	0.2	0.5	3%
		JT1.2	8.5 su, 25 ppm	2.1 J	0.6	10	0.3 J	0.2	0.5	145%
		JT3.1	6.5 su, 80 ppm	2.0 J	0.6	10	0.8	0.2	0.5	82%
	Plant 5	JT1.0	Control	92	0.6	10	91	0.2	0.5	2%
		JT1.2	8.5 su, 25 ppm	< 0.6	0.6	10	0.2 J	0.2	0.5	N/A
		JT3.1	6.5 su, 80 ppm	1.3 J	0.6	10	0.9	0.2	0.5	35%

Table C-2
Inter-laboratory Split Precision

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL Result	ASL DL	ASL RL	BR Result	BR DL	BR RL	RPD

Notes:
[a] EPA Method 1631, 30,000-MW filtered
[b] EPA Method 200.8M, 0.45-µm filtered
ASL – CH2M's Applied Sciences Laboratory
BR – Brooks Rand Laboratory
DL – Detection Limit
N/A – Not Applicable
RL – Reporting Limit
RPD – Relative Percent Difference
< – not detected at the applied dilution
J – Detected by the instrument, the result is > the DL but < or = to the RL. Result is reported and considered an estimate.
RPD > 35 percent

Table C-3
Matrix Spike Recoveries

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL MS %Recovery	ASL MSD %Recovery
Mercury, Filtered [a]	Plant1	JT1.0	Control	92%	94%
		JT1.2	8.5 su, 10 ppm	89%	94%
		JT3.3	10.5 su, 80 ppm	-	-
	Plant 2	JT1.0	Control	116%	117%
		JT1.2	8.5 su, 25 ppm	93%	93%
		JT3.3	10.5 su, 80 ppm	99%	89%
	Plant 3	JT1.0	Control	104%	108%
		JT1.2	8.5 su, 25 ppm	79%	81%
		JT3.1	6.5 su, 80 ppm	81%	80%
	Plant 4	JT1.0	Control	101%	98%
		JT1.2	8.5 su, 25 ppm	97%	100%
		JT3.1	6.5 su, 80 ppm	101%	101%
	Plant 5	JT1.0	Control	102%	104%
		JT1.2	8.5 su, 25 ppm	103%	102%
		JT3.1	6.5 su, 80 ppm	105%	106%
Arsenic, Filtered [b]	Plant1	JT1.0	Control	98%	101%
		JT1.2	8.5 su, 10 ppm	96%	96%
		JT3.3	10.5 su, 80 ppm	98%	95%
	Plant 2	JT1.0	Control	99%	104%
		JT1.2	8.5 su, 25 ppm	101%	106%
		JT3.3	10.5 su, 80 ppm	97%	99%
	Plant 3	JT1.0	Control	99%	96%
		JT1.2	8.5 su, 25 ppm	97%	97%
		JT3.1	6.5 su, 80 ppm	98%	100%
	Plant 4	JT1.0	Control	102%	98%
		JT1.2	8.5 su, 25 ppm	100%	101%
		JT3.1	6.5 su, 80 ppm	101%	101%
	Plant 5	JT1.0	Control	97%	94%
		JT1.2	8.5 su, 25 ppm	100%	101%
		JT3.1	6.5 su, 80 ppm	99%	100%
Selenium, Filtered [b]	Plant1	JT1.0	Control	98%	92%
		JT1.2	8.5 su, 10 ppm	104%	105%

Table C-3
Matrix Spike Recoveries

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL MS %Recovery	ASL MSD %Recovery
Selenium, Filtered [b]	Plant 1	JT3.3	10.5 su, 80 ppm	95%	92%
	Plant 2	JT1.0	Control	106%	103%
		JT1.2	8.5 su, 25 ppm	36%	45%
		JT3.3	10.5 su, 80 ppm	45%	19%
	Plant 3	JT1.0	Control	156%	15%
		JT1.2	8.5 su, 25 ppm	155%	165%
		JT3.1	6.5 su, 80 ppm	82%	133%
	Plant 4	JT1.0	Control	94%	91%
		JT1.2	8.5 su, 25 ppm	93%	97%
		JT3.1	6.5 su, 80 ppm	91%	90%
	Plant 5	JT1.0	Control	75%	71%
		JT1.2	8.5 su, 25 ppm	85%	89%
		JT3.1	6.5 su, 80 ppm	60%	61%
Cadmium, Filtered [b]	Plant1	JT1.0	Control	94%	95%
		JT1.2	8.5 su, 10 ppm	95%	95%
		JT3.3	10.5 su, 80 ppm	93%	92%
	Plant 2	JT1.0	Control	97%	98%
		JT1.2	8.5 su, 25 ppm	99%	100%
		JT3.3	10.5 su, 80 ppm	101%	100%
	Plant 3	JT1.0	Control	97%	96%
		JT1.2	8.5 su, 25 ppm	96%	95%
		JT3.1	6.5 su, 80 ppm	96%	95%
	Plant 4	JT1.0	Control	97%	96%
		JT1.2	8.5 su, 25 ppm	102%	99%
		JT3.1	6.5 su, 80 ppm	101%	101%
	Plant 5	JT1.0	Control	99%	100%
		JT1.2	8.5 su, 25 ppm	101%	101%
		JT3.1	6.5 su, 80 ppm	101%	101%
Boron, Filtered [c]	Plant 1	JT1.0	Control	100%	88%
		JT1.2	8.5 su, 10 ppm	110%	100%
		JT3.3	10.5 su, 80 ppm	96%	102%
	Plant 2	JT1.0	Control	105%	104%

Table C-3
Matrix Spike Recoveries

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL MS %Recovery	ASL MSD %Recovery
Boron, Filtered [c]	Plant 2	JT1.2	8.5 su, 25 ppm	104%	111%
		JT3.3	10.5 su, 80 ppm	109%	107%
	Plant 3	JT1.0	Control	107%	107%
		JT1.2	8.5 su, 25 ppm	105%	104%
		JT3.1	6.5 su, 80 ppm	106%	105%
	Plant 4	JT1.0	Control	93%	59%
		JT1.2	8.5 su, 25 ppm	111%	124%
		JT3.1	6.5 su, 80 ppm	131%	111%
	Plant 5	JT1.0	Control	110%	113%
		JT1.2	8.5 su, 25 ppm	110%	117%
		JT3.1	6.5 su, 80 ppm	106%	107%
Magnesium, Filtered [c]	Plant1	JT1.0	Control	0%	0%
		JT1.2	8.5 su, 10 ppm	110%	40%
		JT3.3	10.5 su, 80 ppm	96%	95%
	Plant 2	JT1.0	Control	86%	73%
		JT1.2	8.5 su, 25 ppm	71%	99%
		JT3.3	10.5 su, 80 ppm	99%	98%
	Plant 3	JT1.0	Control	240%	0%
		JT1.2	8.5 su, 25 ppm	0%	60%
		JT3.1	6.5 su, 80 ppm	360%	340%
	Plant 4	JT1.0	Control	0%	0%
		JT1.2	8.5 su, 25 ppm	70%	170%
		JT3.1	6.5 su, 80 ppm	270%	110%
	Plant 5	JT1.0	Control	110%	130%
		JT1.2	8.5 su, 25 ppm	130%	180%
		JT3.1	6.5 su, 80 ppm	80%	90%
Manganese, Filtered [c]	Plant1	JT1.0	Control	96%	96%
		JT1.2	8.5 su, 10 ppm	101%	99%
		JT3.3	10.5 su, 80 ppm	95%	96%
	Plant 2	JT1.0	Control	102%	101%
		JT1.2	8.5 su, 25 ppm	101%	103%
		JT3.3	10.5 su, 80 ppm	103%	102%

Table C-3
Matrix Spike Recoveries

Parameter	Site	Sample ID	Test Condition (pH, organosulfide dose)	ASL MS %Recovery	ASL MSD %Recovery
Manganese, Filtered [c]	Plant 3	JT1.0	Control	95%	90%
		JT1.2	8.5 su, 25 ppm	94%	95%
		JT3.1	6.5 su, 80 ppm	96%	94%
	Plant 4	JT1.0	Control	97%	91%
		JT1.2	8.5 su, 25 ppm	103%	105%
		JT3.1	6.5 su, 80 ppm	100%	99%
	Plant 5	JT1.0	Control	104%	105%
		JT1.2	8.5 su, 25 ppm	101%	103%
		JT3.1	6.5 su, 80 ppm	103%	104%

Notes:
[a] EPA Method 1631, 30,000-MW filtered
[b] EPA Method 200.8M, 0.45-µm filtered
[c] EPA Method 200.7, 0.45-µm filtered
ASL – CH2M's Applied Sciences Laboratory
MS – matrix spike
MSD – matrix spike duplicate
%Recovery outside of acceptable recovery window

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent approximately 90 percent of the electricity generated and delivered in the United States, and international participation extends to more than 30 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together…Shaping the Future of Electricity

© 2015 Electric Power Research Institute (EPRI), Inc. All rights reserved. Electric Power Research Institute, EPRI, and TOGETHER…SHAPING THE FUTURE OF ELECTRICITY are registered service marks of the Electric Power Research Institute, Inc.

3002004893

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

January 25, 2018

Jim Dougherty
Babcock Power Environmental
26 Forest Street, Suite 300
Marlborough, MA 01752

Dear Mr. Dougherty:

Thank you for taking the time to discuss approaches for minimizing flue gas desulfurization (FGD) flows at steam electric power plants. EPA has drafted notes summarizing the topics we discussed during our meeting on November 16, 2017. We ask that you review these notes for accuracy and provide any corrections that may be warranted.

The information discussed during the meeting will help further enhance EPA's understanding of FGD flow optimization. Although it is in the public's interest to have as much of this information available in the public record as possible, we understand you may consider some data to be confidential business information (CBI). Federal regulations at Title 40, Part 2 of the Code of Federal Regulations specify how to assert a business confidentiality claim covering all or part of the information you submit. Please see the enclosed document for more information on what may be considered CBI and how to assert a claim of business confidentiality. Following receipt of your feedback on the draft notes, including identifying what information you consider CBI, EPA will finalize the notes for the public record.

The information you provide will aid EPA's assessment of the treatability of FGD wastewater. We appreciate your interest in EPA's efforts and thank you in advance for providing the information requested. Please provide your comments on the draft meeting notes by **February 15, 2018.**

Sincerely,

Ronald Jordan
Engineering and Analysis Division

Recycled/Recyclable • Printed with Vegetable Oil Based Inks on 100% Recycled Paper (40% Postconsumer)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

January 25, 2018

Earl Jones
Heartland Water Technology, Inc.
43 Broad St
Hudson MA, 01749

Dear Mr. Jones:

Thank you for taking the time to provide an overview of Heartland's technology for treating flue gas desulfurization (FGD) wastewater from steam electric power plants. EPA has drafted notes summarizing the topics we discussed during our meeting about the LM-HT concentrator on October 17, 2017. We ask that you review these notes for accuracy and provide any corrections that may be warranted. The notes also highlight some follow-up questions on the topics discussed.

In addition, EPA previously requested certain cost and performance data associated with the HWT LM-HT concentrator. Below is a listing of the information EPA requested during our meeting:

- Detailed process flow diagram of the LM-HT concentrator.
- EPRI Report associated with the Plant Bowen pilot study.
- Performance data and operation data for the systems operating at Iatan, Plant Bowen, and the West Virginia power plant. EPA requests these data for the influent, effluent, and any other intermediate monitoring points within the system.

The information requested above will further enhance EPA's understanding of the applicability, efficacy, and cost for Heartland's LM-HT concentrator for treating FGD wastewater. Although it is in the public's interest to have as much of this information available in the public record as possible, we understand you may consider some data to be confidential business information (CBI). Federal regulations at Title 40, Part 2 of the Code of Federal Regulations specify how to assert a business confidentiality claim covering all or part of the information you submit. Please see the enclosed document for more information on what may be considered CBI and how to assert a claim of business confidentiality. Following receipt of your feedback on the draft notes and responses to follow-up questions, including identifying what information you consider CBI, EPA will finalize the notes for the public record.

Recycled/Recyclable • Printed with Vegetable Oil Based Inks on 100% Recycled Paper (40% Postconsumer)

The information you provide will aid EPA's assessment of the treatability of FGD wastewater. The cost and performance data you provide are valued and will be taken into account as EPA reconsiders the effluent limitations guidelines established by the 2015 rule. Please provide the requested cost and performance data, as well as your comments on the draft meeting notes, by **February 15, 2018**.

We appreciate your interest in EPA's efforts and thank you in advance for providing the information requested.

Sincerely,

Ronald Jordan
Engineering and Analysis Division

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

January 25, 2018

Song Wu
Chief Technology Officer
Mitsubishi Hitachi Power Systems Americas, Inc.
645 Martinsville Road
Basking Ridge, New Jersey 07920

Dear Dr. Wu:

Thank you for taking the time to provide an overview of Mitsubishi's technologies for treating flue gas desulfurization (FGD) wastewater from steam electric power plants. EPA has drafted notes summarizing the topics we discussed during our meeting about the Wastewater Spray Dryer (WSD) on December 18, 2017. We ask that you review these notes for accuracy and provide any corrections that may be warranted. The notes also highlight some follow-up questions on the topics discussed.

In addition, EPA previously requested certain cost and performance data associated with the WSD. Below is a listing of the information EPA requested during our meeting:

- A copy of the WSD costs previously discussed with EPA.
- Information on any available off-setting costs (i.e., cost savings), such as energy usage.

The information requested above will help further enhance EPA's understanding of the applicability, efficacy, and cost for Mitsubishi's WSD technology for treating FGD wastewater. Although it is in the public's interest to have as much of this information available in the public record as possible, we understand you may consider some data to be confidential business information (CBI). Federal regulations at Title 40, Part 2 of the Code of Federal Regulations specify how to assert a business confidentiality claim covering all or part of the information you submit. Please see the enclosed document for more information on what may be considered CBI and how to assert a claim of business confidentiality. Following receipt of your feedback on the draft notes and responses to follow-up questions, including identifying what information you consider CBI, EPA will finalize the notes for the public record.

The information you provide will aid EPA's assessment of the treatability of FGD wastewater. The cost and performance data you provide are valued and will be taken into account as EPA reconsiders the effluent limitations guidelines established by the 2015 rule.

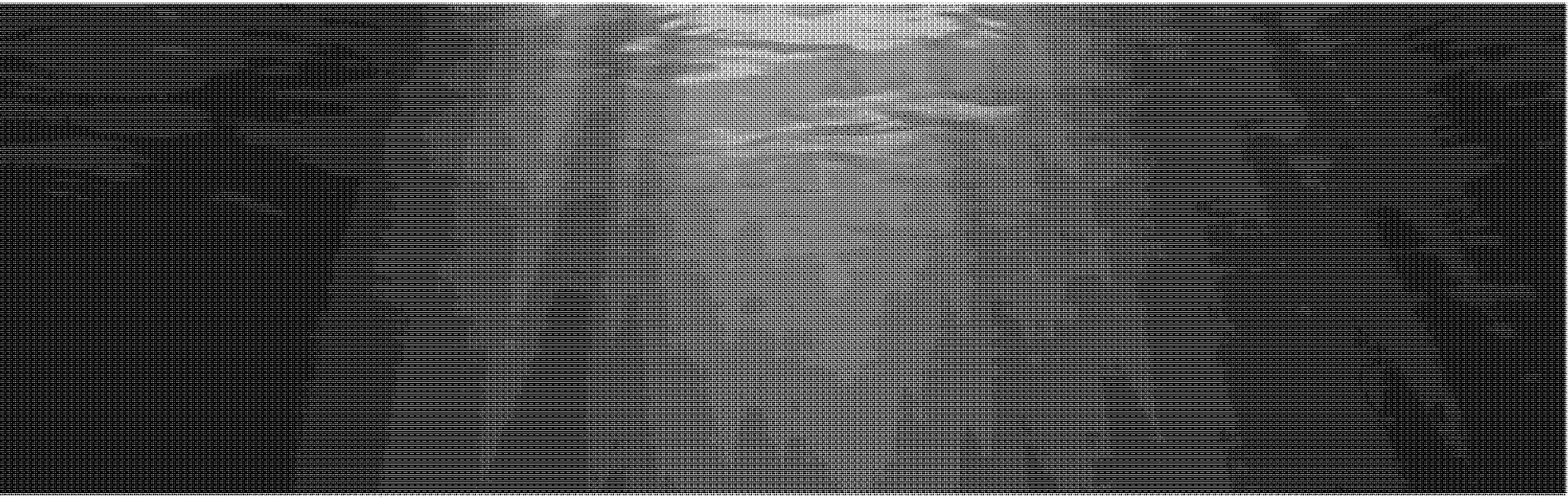
Recycled/Recyclable • Printed with Vegetable Oil Based Inks on 100% Recycled Paper (40% Postconsumer)

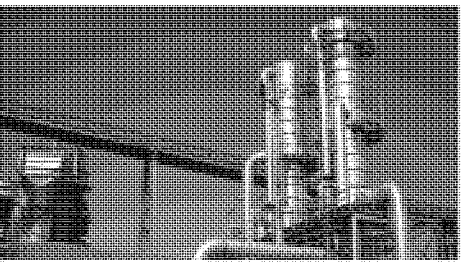
Please provide the requested cost and performance data, as well as your comments on the draft meeting notes, by **February 15, 2018**.

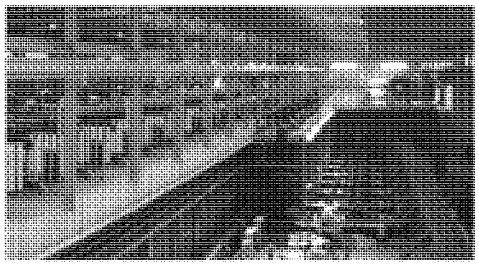
We appreciate your interest in EPA's efforts and thank you in advance for providing the information requested.

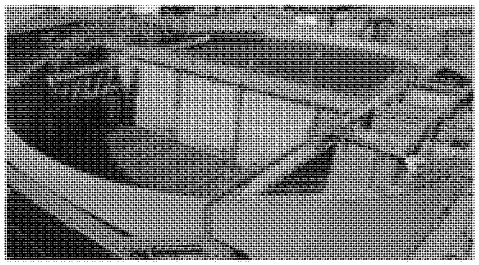
Sincerely,

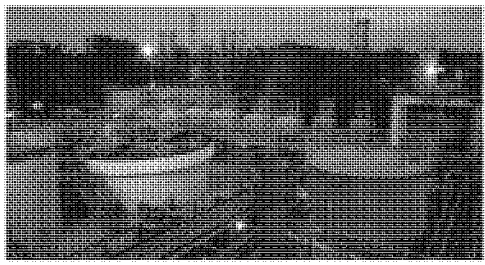
Ronald Jordan
Engineering and Analysis Division











Presentation to Environmental Protection Agency, Wash. DC (Jan 17, 2018)

From Innovation Flows Leadership

Aquatech

Agenda

Introduction

1. Technology Overview

- Process Treatment Options
- ZLD Configurations

2. FGD ZLD Treatment Experience

- FGD ZLD Experience
- Project Profiles

3. True Cost of ZLD

- Cost Curves
- Observations

Conclusions/Discussions

-

Aquatech

Introduction

Aquatech

Aquatech at a Glance

Over **1,500** installations in **60** countries

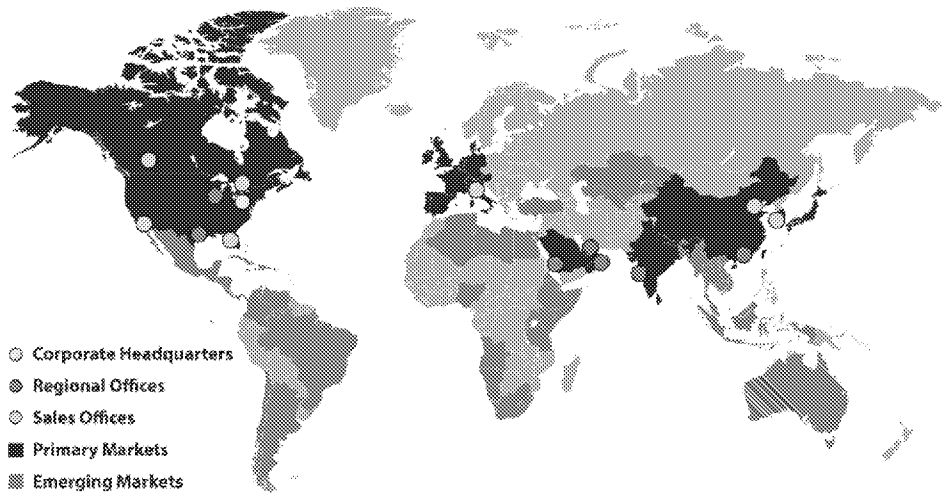
Solely focused on water since its founding in 1981

Offices in North America, Europe, the Middle East, India, and China

More than **600** global employees

State-of-the-art laboratory, piloting, and R&D capabilities

High percentage of repeat business



Aquatech

Primary Industries

- Oil and Gas
- Petrochemicals and Refining
- Power
- Mining and Metals
- Infrastructure

Aquatech

Complete Solutions

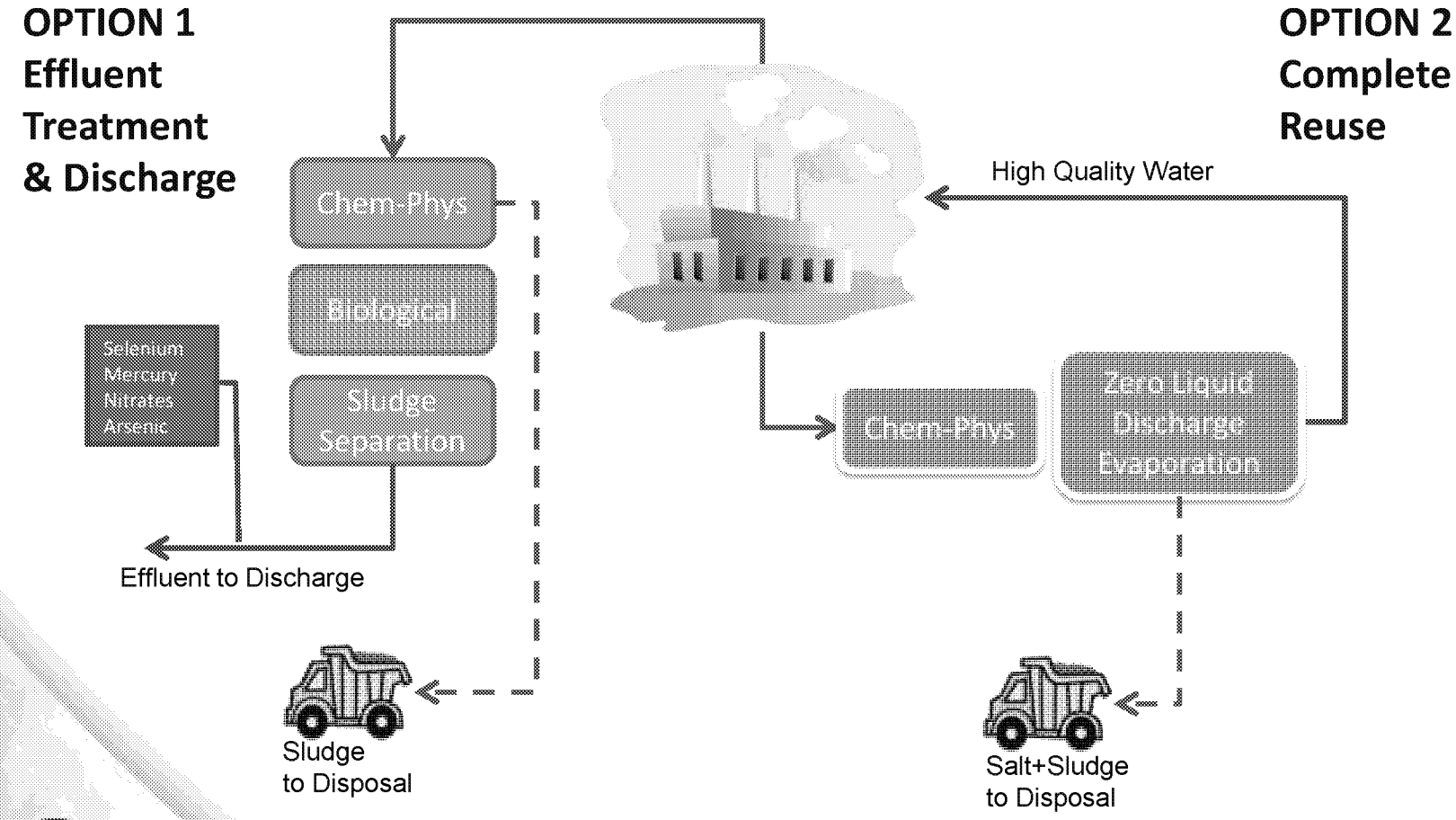
- Zero Liquid Discharge (ZLD)
- Desalination – Thermal/Membrane
- Wastewater Treatment, Recycle & Reuse
- Industrial Process Water (Demineralization)

Aquatech

1. Technology Overview

Aquatech

Process Treatment Options



Aquatech

Process Treatment Options - Comparison

Biological

PROS

- Proven Technology
- Lower life cycle cost for larger capacities
- Highly automated operation

CONS

- Few suppliers offer performance guaran
- FGD BD chemistry variations impact performance
- Biomass can die off due to various factors
- Replacement biomass requires substantial time for acclimation
- Redundancy required

Thermal

PROS

- Proven Technology
- Eliminates waste water discharge and future NPDES permitting concerns
- High quality water is produced for recycle/reuse
- Highly automated operation
- Redundancy not required … provide storage

CONS

- Higher life cycle cost for larger capacities
- High maintenance requirement perception
- Fewer experienced operators

Aquatech

FGD ZLD Treatment Objective (wrt Compliance)

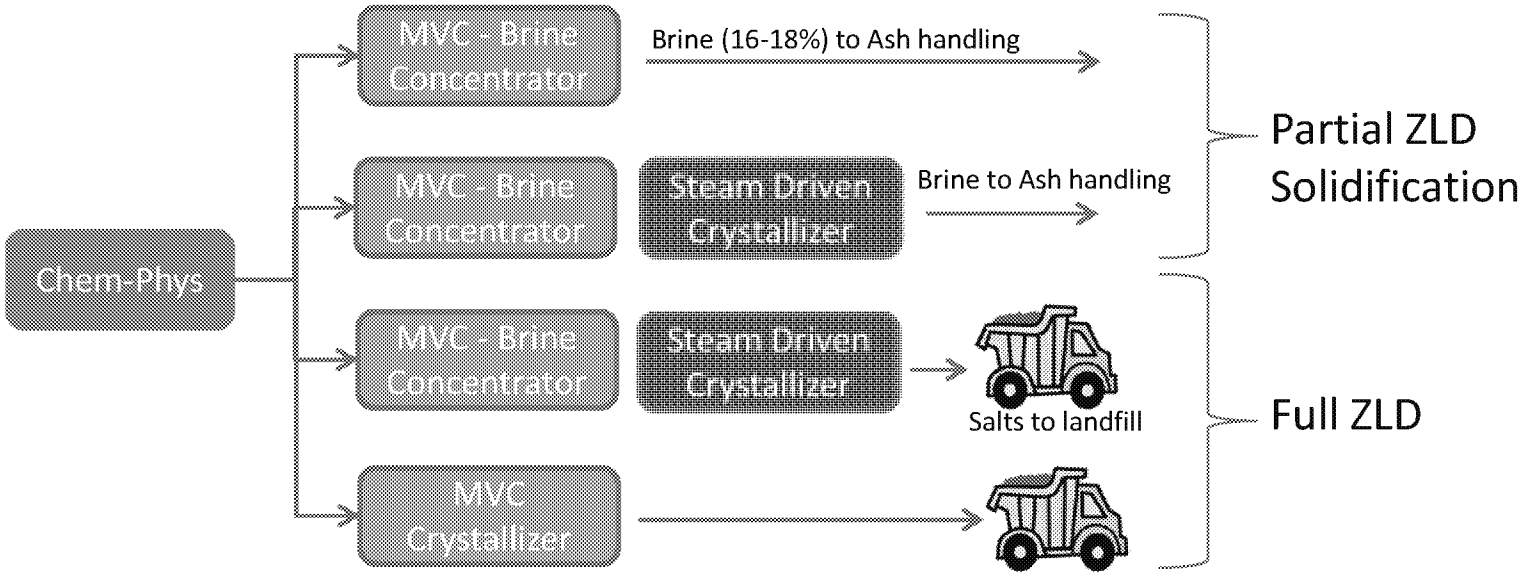
Effluent limitations for New Sources

Pollutant	Daily Maximum Limitation	Monthly Average Limitation
Arsenic (ppb)	4	NA
Mercury (ppt)	39	24
Selenium (ppb)	5	NA
TDS (ppm)	50	24

These limits essentially can only be met by implementation of thermal ZLD technology

Aquatech

ZLD Configurations



	Solidification		Full ZLD	
Option	**1** BC + Purge	**2** BC+CRY + Purge	**3** BC+CRY	**4** (**) CRY
Capital Investment (*)	$	$$	$$$	$$$$
Power Consumption	**	***	****	*
Steam Consumption	*	**	***	****
Sludge Production (*)	*	*	***	***

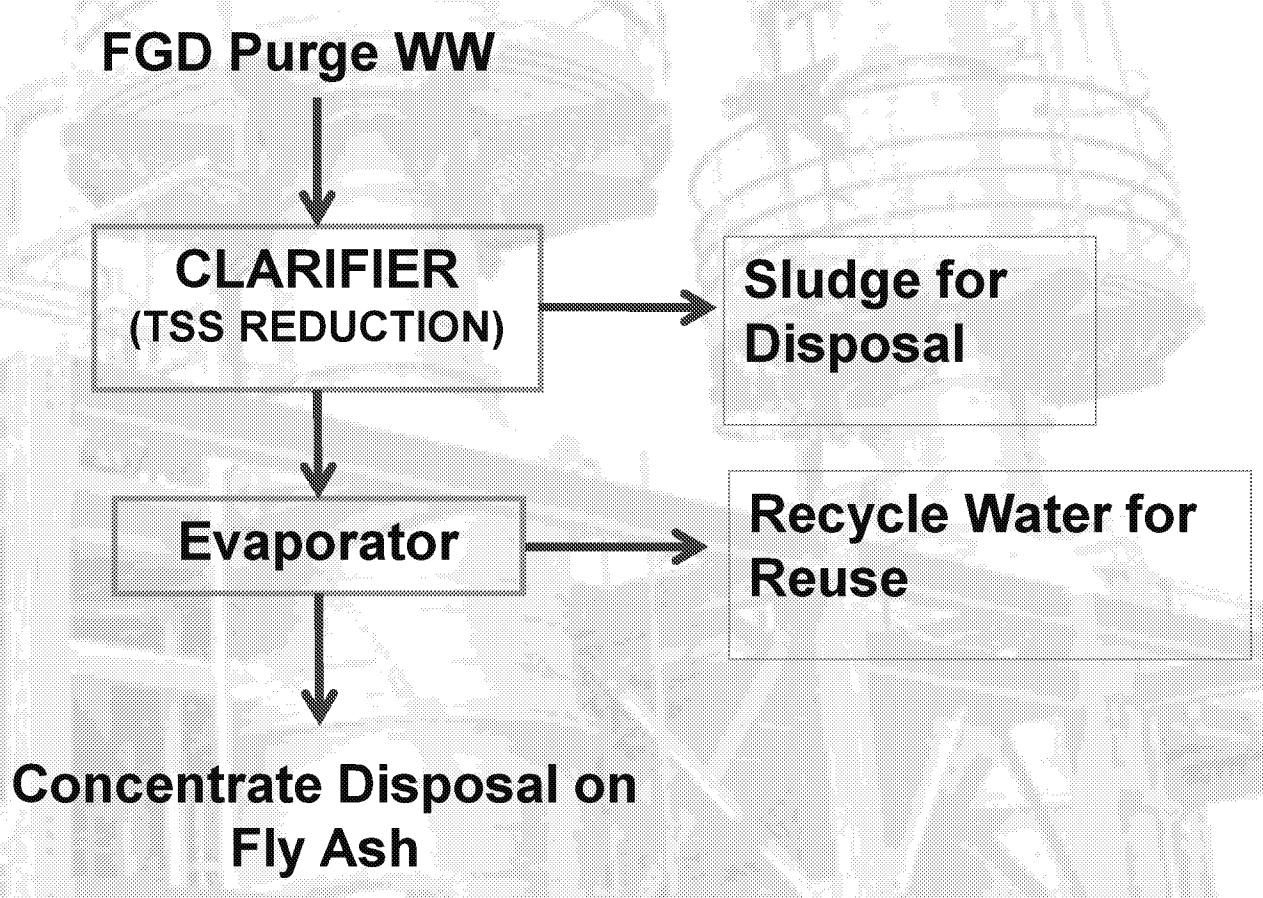
Aquatech

(*) The above indications are just a simplification. Chemistry and flow eventually to be defined in order to assess the overall set of options

(**) A stand alone Crystallizer may be a realistic option for flows below 30 gpm

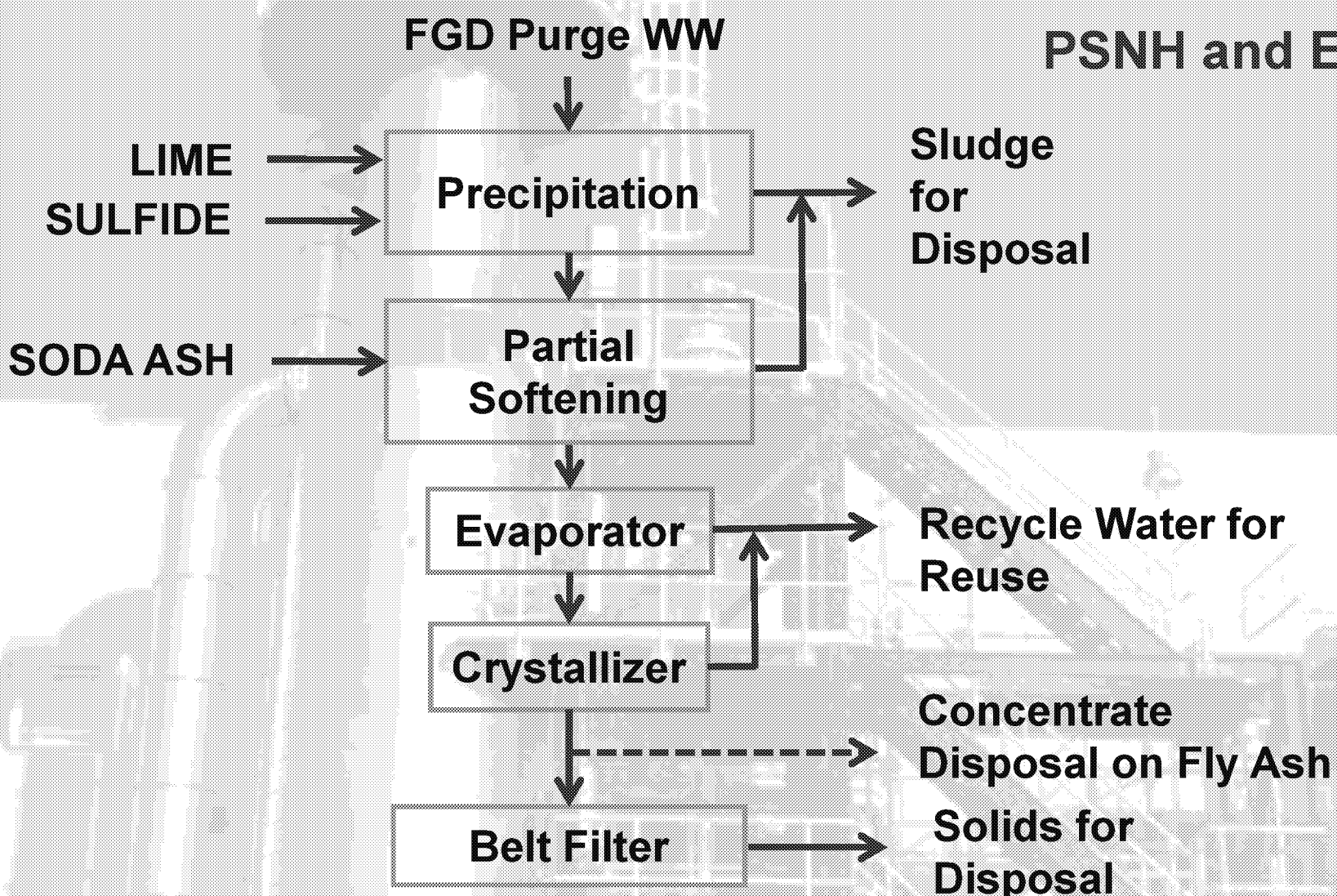
Solidification

Iatan and Springfield



Full Zero Liquid Discharge

PSNH and ENEL



2. FGD ZLD Treatment Experience

Aquatech

FGD ZLD Experience

PSNH Merrimack Station	FGD	1 Unit	USA	2011
Kansas City Power & Light – Iatan Plant	FGD	2 Units	USA	2009
ENEL – Brindisi Plant	FGD	2 Units	Italy	2008
ENEL – Fusina Plant	FGD	2 Units	Italy	2008
ENEL – Sulcis Plant	FGD	1 Unit	Italy	2008
ENEL – La Spezia Plant	FGD	1 Unit	Italy	2008
ENEL – Torrevaldaliga Plant	FGD	2 Units	Italy	2009
CWLP Springfield Power Plant	FGD	2 Units	USA	2007
Mannheim Power Plant	FGD	Pilot	Germany	1994

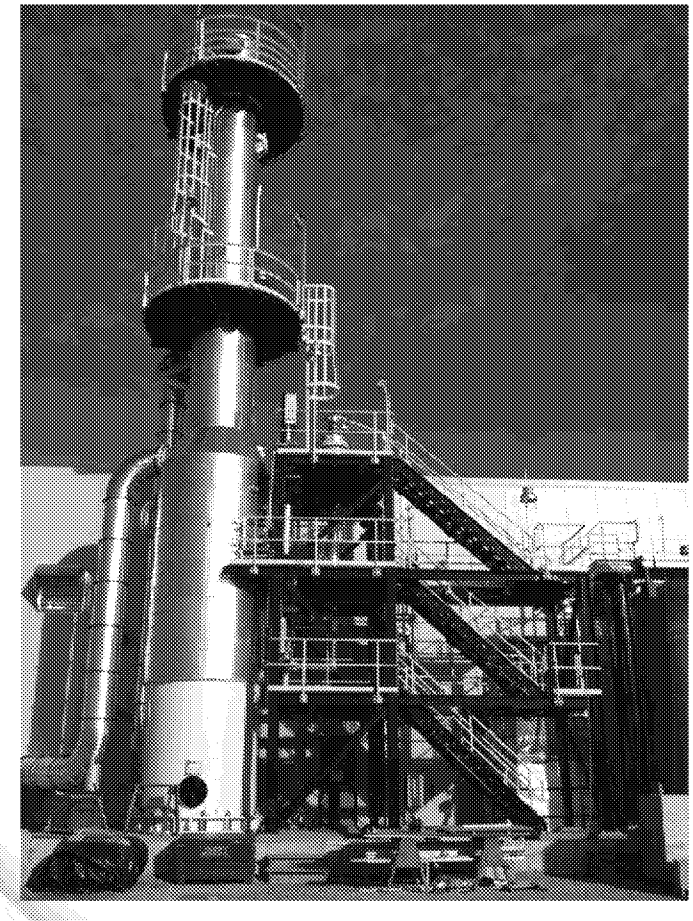
Aquatech

FGD ZLD Experience - Problems Solved with ZLD

- CWLP Springfield – Boron mitigation
- ENEL – Multiple sites, corporate decision
- KCPL – Permitting time and cost
- PSNH – Limits could not be met with Bio

Aquatech

Project Profile: PSNH – FGD ZLD



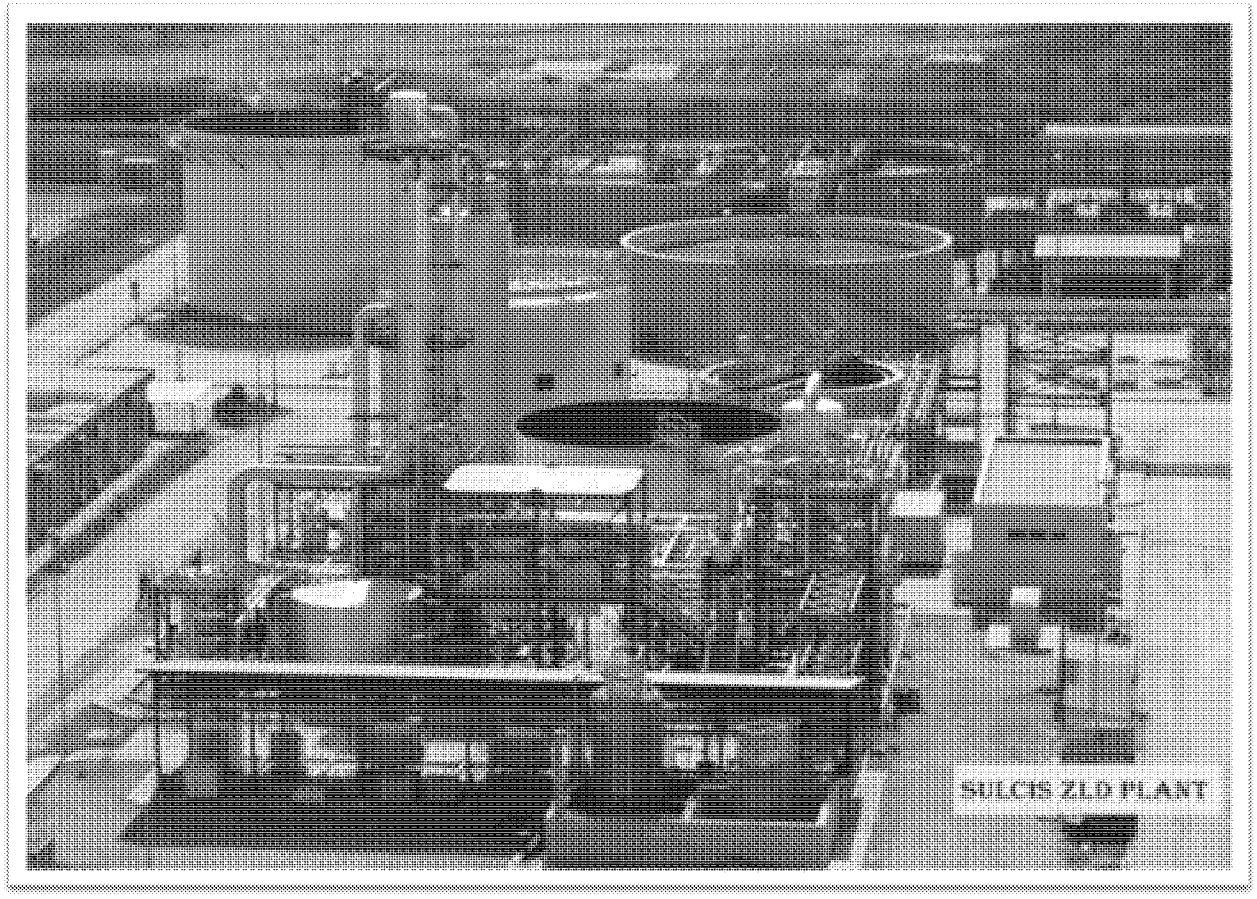
- **Project:**
  Merrimack Power Plant
- **Client:**
  Public Service New Hampshire
- **Location:**
  Bow, NH
- **Type of Plants:**
  Supercritical Coal Fired
- **Equipment Supplied:**
  Clarifier, Brine Concentrator, Crystallizers
- **Capacity:**
  1 x 65 GPM
- **Design, Supply + O&M**

Aquatech

Project Profile: ENEL – FGD ZLD

- **Projects:**
  Brindisi, Fusina, Sulcis, Torrevaldaliga, La Spezia
- **Client:**
  ENEL Power
- **Location:**
  Various sites in Italy
- **Type of Plant:**
  FGD Wastewater for Coal Fired Power
- **Equipment Supplied:**
  Physical, Chemical, Brine Concentrator, FC, BFP
- **Capacity:**
  55 GPM to 310 GPM range feed
- **Design, Build + O&M**

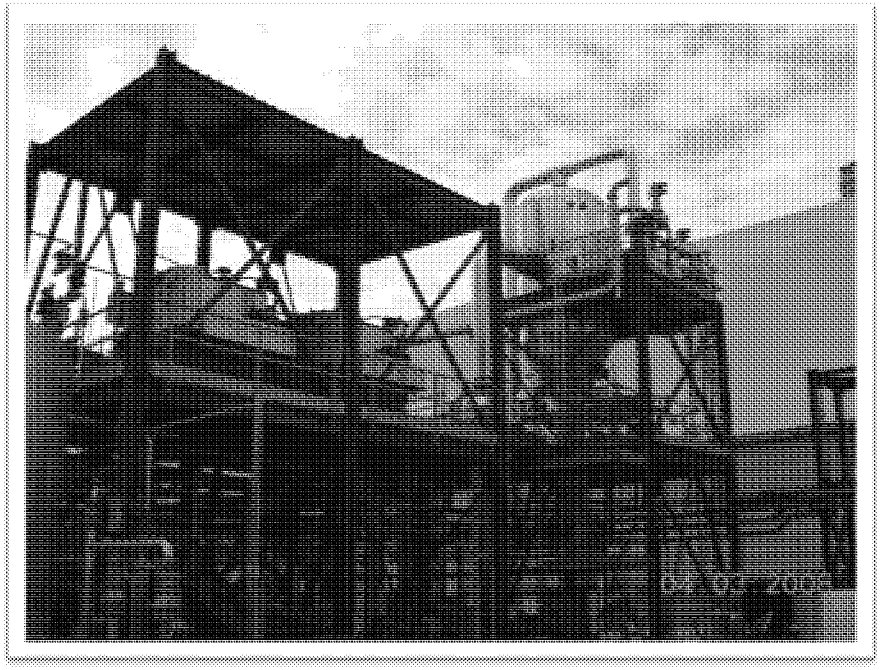
Aquatech



WASTEWATER ZLD SYSTEM
ENEL - SULCIS, ITALY

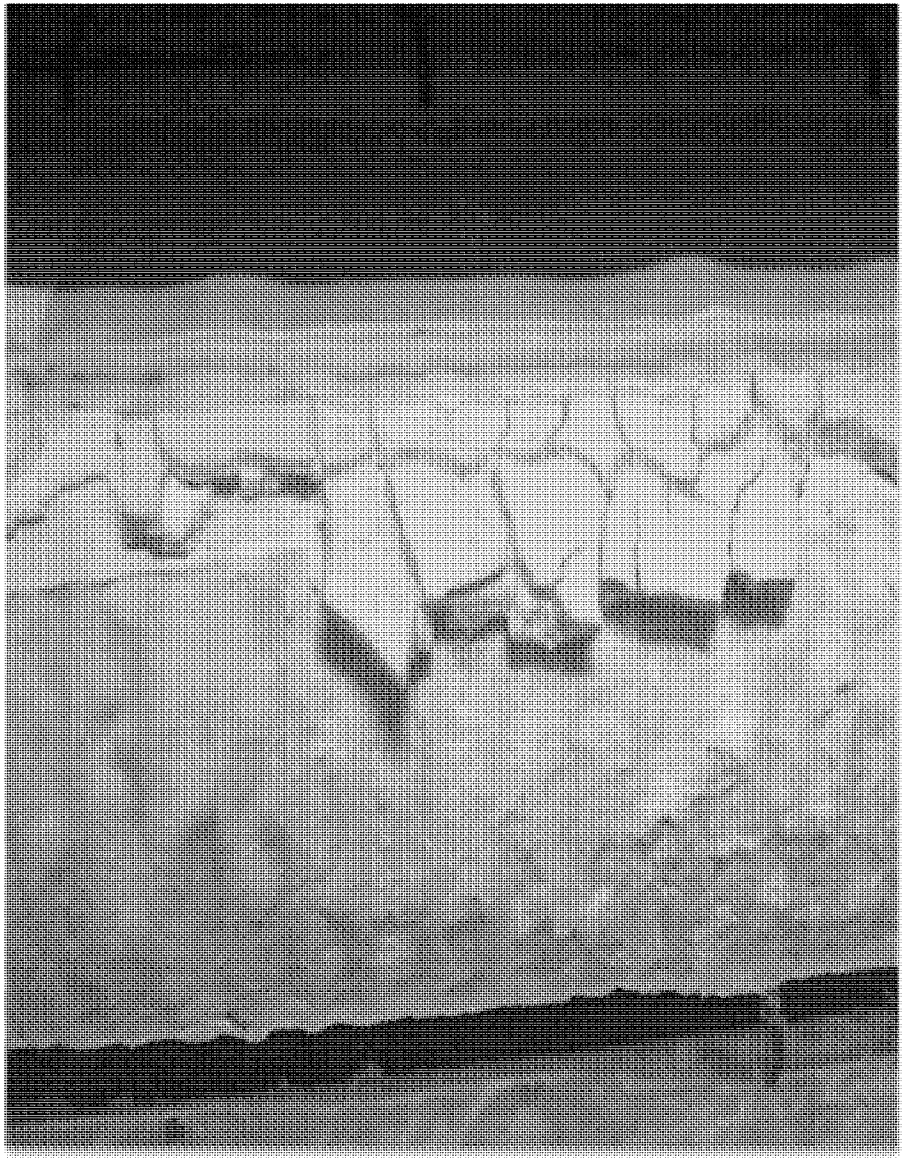
WASTEWATER ZLD SYSTEM
ENEL - SULCIS, ITALY

Crystallizer



ZLD Salt Cake for Disposal

SALT CAKE



3. True Cost of ZLD

Aquatech

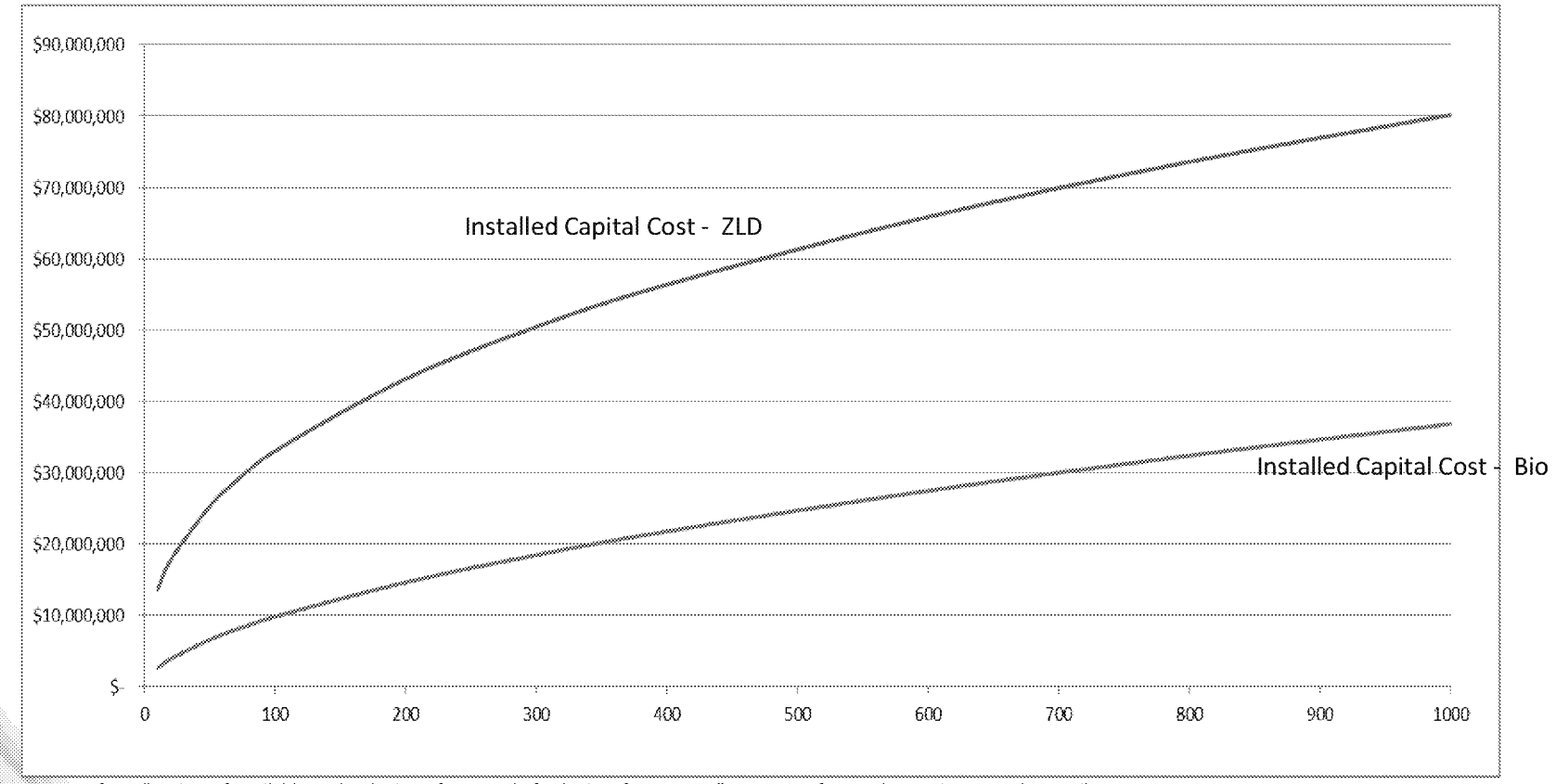
Cost Curves

- Building Cost Curves is hard because every case is different and there are diverse actual conditions that may affect the process and the initial investment costs. To name a few: **quality of the feed** (impact on material of construction, pretreatment and process), **redundancy requirements**, **operational benefits** (i.e. on the selection of a full of partial ZLD scheme), **possible retrofit** of existing equipment, **modularization**…

- However, in 2010 CH2M published a paper with a tentative cost curves for FGD Wastewater treatment technologies.

Aquatech

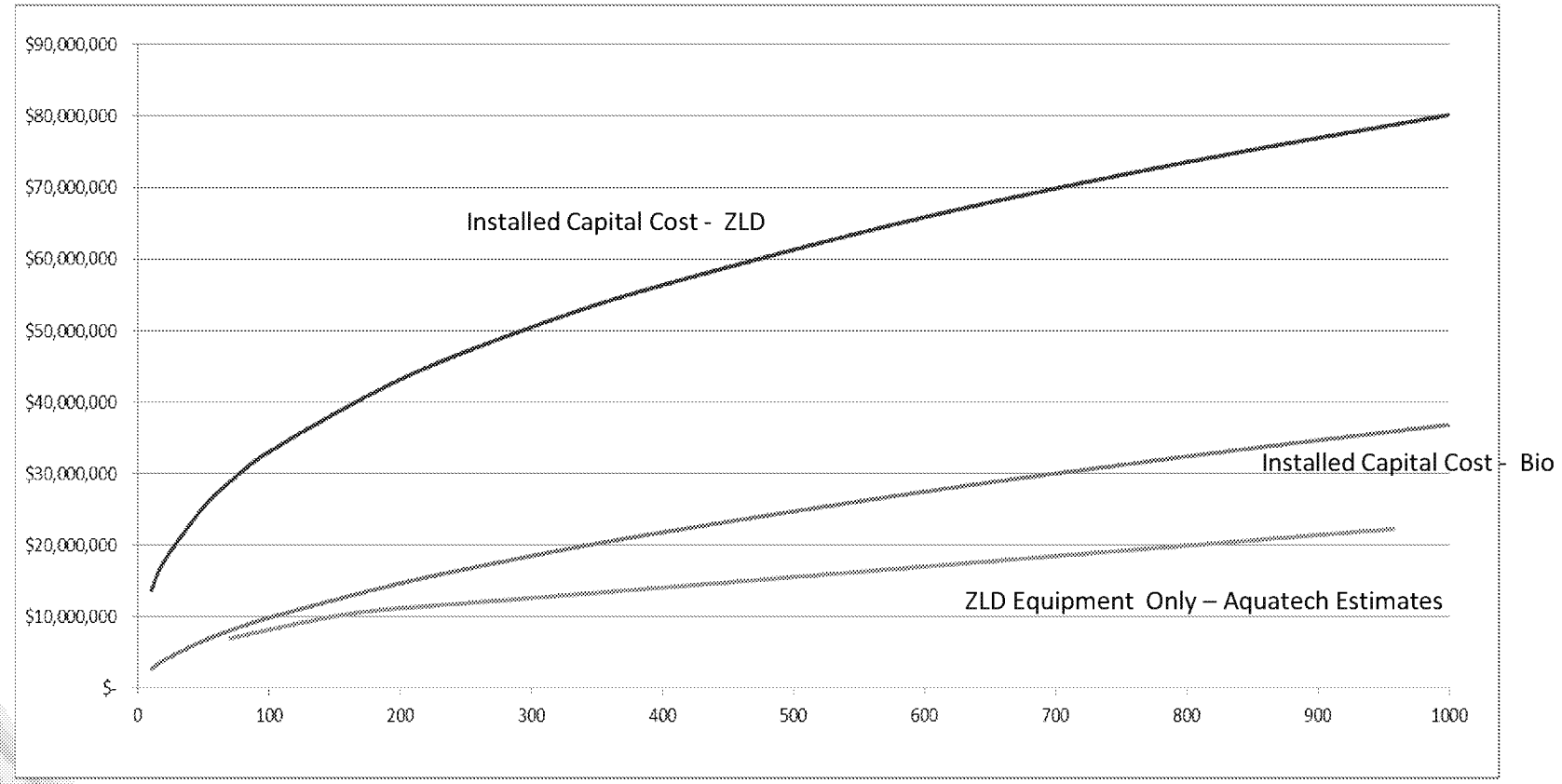
Cost Curves (cont'd)



Data from "Review of Available Technologies of Removal of Selenium from Water" CH2MHILL for North American Metal Council, June 2010

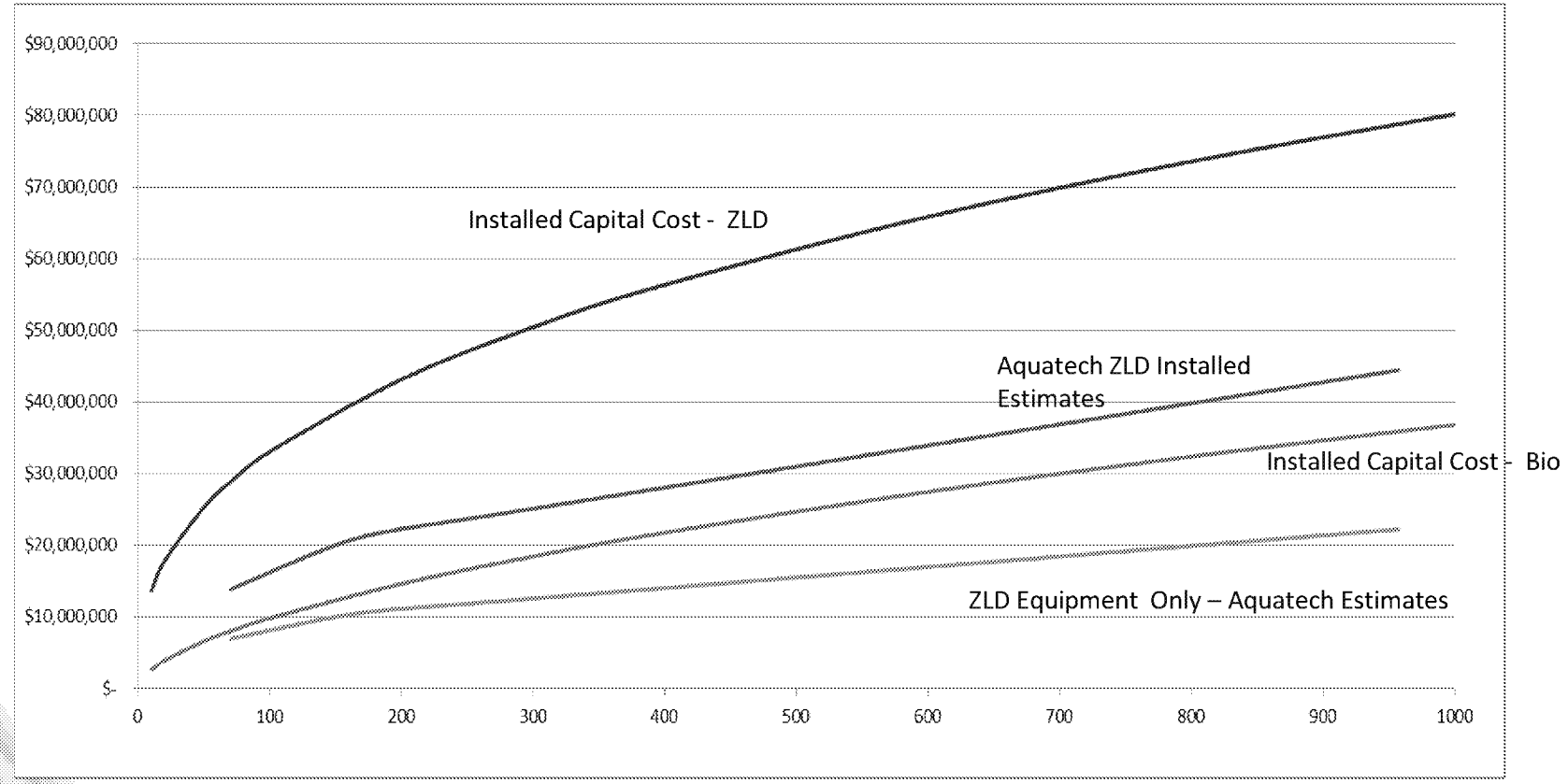
Aquatech

Cost Curves (cont'd)



Aquatech

Cost Curves (cont'd)



Aquatech

Cost Curves – Observations

- We can say that **the trend of the curves from different sources seems to be similar and consider a good representation**.
- Looking at the all the curves and how they compare with the suppliers' data, it seems that the overall cost impact is overestimated
- Especially, the ZLD Capital Investment seems to be heavily overestimated. While more expensive, it is not as much as originally portrayed.
- However, while the data about the Bio are quite close and then consistent, the ZLD figures considered by engineering consulting firms are very different.
- Again, predicting the cost of a ZLD is proving to be harder than expected and the perception, especially compared with the actual Aquatech data, seems to be misleading.
- The ZLD has to be evaluated case by case and integrated with the existing facilities and actual scenario.

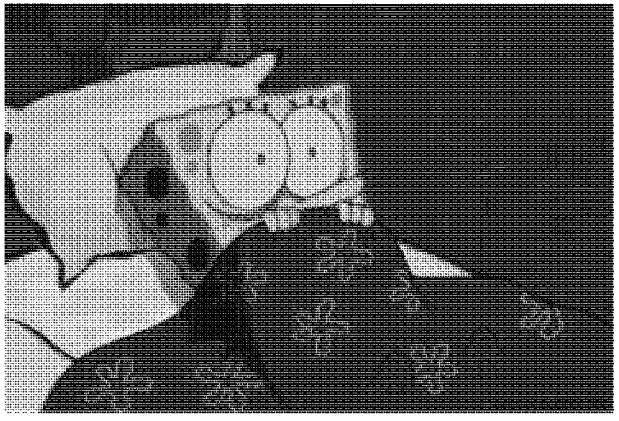
Aquatech

Some final thoughts……

ZLD

EPA Regs

Bugs



Weather

Turndown

Variability

Br, Cl, TDS

Se

Aquatech

Conclusions / Discussion Points

- ZLD cost misperception in the market place……How can this be overcome?
- Recycle / Reuse of Distillate…..Can this become a requirement under ELGs?
- What is the direction wrt the ELGs…timing?
- Evaluation Criteria for BAT?
-

Aquatech

Contacts

Ashwin Thakkar
Regional Sales Manager
Email: thakkara@[redacted]
Tel: [redacted](cell)

Alan R. Daza, P.Eng.
VP – Sales & BD
Americas & Europe Regions
Email: dazaa@[redacted]
Tel: [redacted] (cell)

Daniel Bjorklund
VP – Operations
ICD – Industrial Concentration Division
Email: bjorklundd@a[redacted]
Tel: [redacted](cell)

Aquatech

IWC 14-59

Pilot Studies for the Treatment of a Highly Oxidized Flue Gas Desulphurization Wastewater

Joseph Chwirka, Tetra Tech, Jean-Claude Younan, SCANA, and Paul Chu, Electric Power Research Institute

Keywords: Flue gas desulphurization, wastewater, selenium, mercury, nitrate, oxidants, treatment.

ABSTRACT

The treatment of flue gas desulphurization (FGD) wastewater is a relatively new area of wastewater treatment. Although physical/chemical treatment with iron and/or sulfide precipitation has been used for FGD treatment, it has focused extensively on solids removal. The Environmental Protection Agency (EPA) has proposed new Effluent Limitation Guidelines (ELG) which would require treatment of the FGD wastewater for selenium, mercury, arsenic, and nitrates. To meet these proposed ELG's, SCANA and Electric Power Research Institute (EPRI) implemented an extensive program of pilot treatment technologies at a coal fired power plant in South Carolina. The treatment technologies piloted included three biological systems, as well as two zero valent iron chemical technologies. The FGD wastewater was highly oxidized as characterized by oxidation reduction potential (ORP) levels exceeding 500 mv, selenium at 2,500 ug/L, mercury up to 150 ug/L, and pH values as low as 2.9. Due to operational changes with the plants wet flue gas desulphurization absorber, there were two distinct water quality phases. The phases were gradually separated around early January 2014. This paper will examine the FGD water quality characteristics and their impacts on the performance of the piloted technologies .

INTRODUCTION

On June 7, 2013, the EPA released the proposed rule, 40 CFR Part 423 Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category. This rule is expected to be promulgated by September 30, 2015, or sooner. Of specific interest to coal fired power plants utilizing wet flue gas desulphurization (FGD) absorbers, this proposed rule will limit contaminants discharged from FGD wastewater.

In 2012, SCANA recognized they may soon need to treat the FGD wastewater generated at their power plants. In an effort to identify technologies that can treat FGD wastewater, SCANA and the Electric Power Research Institute (EPRI) initiated a large pilot program to test technologies side by side with a produced FGD wastewater. A pilot testing program was started in June 2013 and lasted until May 2014. The treatment goals for the pilot studies were based on the proposed ELG limits which are presented in Table 1.

Table 1. Proposed EPA ELG Limits

Contaminant of Concern	EPA Draft ELGs (Daily Max/Avg)
As	8/6 ug/L
Hg	0.242/0.191 ug/L
Se	16/10 ug/L
NO_3/NO_2	0.17/0.13 mg/L

During the pilot testing period, significant changes in FGD water quality were observed and quantified. The FGD wastewater generated proved to be very challenging to treat, especially for selenium. The FGD wastewater was generated by processing the absorber purge slurry through a primary hydroclone where the majority of gypsum solids are removed and sent to a belt filter press. The overflow from the primary hydroclone is sent to a secondary hydroclone where the solids are conveyed to a plate and frame press, and the remaining FGD wastewater is sent to a series of ponds. The ponds consist of two forebay ponds, a second stage pond, and finally a third pond. The FGD wastewater is solids free after the forebay ponds

The purpose of this pilot study was to characterize the FGD wastewater and to identify how different treatment technologies would perform. The technologies selected for pilot testing included:

- Anaerobic Membrane Bioreactor (AnMBR): ADI
- Fluidized Bed Reactor/Anaerobic Membrane Bioreactor(FBR/MBR): Envirogen
- Attached growth biofilter, ABMet: GE
- Zero valent iron reactor, Pironox: Evoqua (formally Siemens)
- Zero valent iron attached to support: Liberty Hydro, Inc.

This paper will present the characterization of the FGD wastewater, and the performance of the treatment technologies tested. All of the figures are in Appendix A of this paper.

FGD WATER QUALITY CHARACTERISTICS

The FGD wastewater used in this pilot has a complex chemistry. Initial measurements of pH indicated a pH of less than 3. Operations staff reported the ponds would at times smell like a swimming pool (i.e., chlorine). If the FGD were to be splashed on clothing, it would cause a mark similar to a bleach stain.

Daily monitoring the FGD pond consisted of parameters available on a YSI multiparameter sonde including temperature, conductivity, dissolved oxygen, oxidation reduction potential (ORP), and pH.

It should be noted in December 2013, the absorber was removed from service for repair work. In January of 2014, the absorber control points were reprogramed. The changes in the operation of the absorber as well as changes in the coal appear to be responsible for the changes in FGD water quality. There were two distinct phases of FGD water quality characterized by a period of high oxidation referred to as Phase 1, and period of low oxidation referred to as Phase 2. The phases were separated by a gradual change in water quality which occurred around the first part of January 2014.

The pH and ORP of the FGD pond water exhibited an inverse relationship. When the ORP of the FGD wastewater increased, the pH would drop. The pH and ORP data for the

pilot operation is shown in Figure 1. The variation in pH and ORP is significant over the period of time the pilots were operated.

The FGD pilot feed water selenium concentration also varied significantly. The influent Se concentration is shown in Figure 2. Two analytical methods were used for total selenium concentrations. The first was an ICP-CRC-MS method used by the laboratory Applied Speciation. The collision reaction cell (CRC) method is recommended by the EPA for the analysis of FGD wastewater because it eliminates interferences. The interference can be caused by polyatomic species such as Ar_{40}-Ar_{40} which have a similar mass to Se_{80}. The second method used by a local laboratory is EPA 200.7 (ICP-AES). The 200.7 method was used on a daily basis in an effort to get turnaround times of around a week versus two to four weeks for Applied Speciation. The results of the two methods are shown on Figure 2.

The selenium data presented in Figure 2 shows that after the absorber was removed from service in December 2013, the FGD wastewater selenium concentration began to decrease. During Phase 1 of the pilot, the FGD selenium concentration averaged around 1,800 ppb. After the absorber changes and into Phase 2, the selenium concentration dropped to around 200 ppb, almost a 10-fold decrease.

There is a strong correlation between ORP and Se concentration. As the ORP drops, we see a corresponding drop in the selenium concentration. The selenium concentration and ORP are shown in Figure 3. This correlation has been observed in other FGD wastewaters (Brown et al, 2013). It has been observed that when the ORP of the scrubber slurry is less than 300 mv, the selenium typically occurs in the selenite form, and when the ORP is greater than 300 mv the selenium is oxidized to the selenate form (Brown, 2013).

The concentration of manganese also varied significantly over the two phases. In Phase 1, the manganese concentration in the FGD wastewater was very low, around 0.2 mg/L. In Phase 2, the manganese concentration increased significantly to over 90 mg/L. In a strongly oxidizing environment, the manganese likely exists as a solid form of MnO_2, which is removed with the other solids as observed in Phase 1. During Phase 2, the manganese was not oxidized, and therefore; remained in the soluble Mn^{+2} form, which cannot act as a catalyst for selenium oxidation. The manganese and selenium concentrations of the FGD wastewater are shown in Figure 4. EPRI research has shown that MnO_2 is an effective catalyst that will oxidize selenium to selenate when oxygen is present. This appears to be the primary mechanism of selenium oxidation in absorbers.

The FGD mercury concentration also changed during the pilot study as shown in Figure 5. The dissolved mercury concentration decreased from a high of over 160 ug/L in Phase 1 to less than 100 ng/L in Phase 2. The decrease in dissolved mercury correlates well with a decrease in ORP. This observation has also been documented (Brown, 2013) and is believed to be caused by the mercury adsorbing to the slurry solids at an ORP less than 300 mv and above 300 mv the mercury is in the dissolved Hg^{+2} form.

In addition, the FGD nitrate concentration appears to correlate with ORP. The nitrate concentrations and ORP data is presented in Figure 6. The nitrate as nitrogen concentration varies from over 80 mg/L to around 25 mg/L. Nitrate concentrations are important for two reasons, first it is listed in the proposed ELG Rule with a numeric limit and secondly because the nitrates must be removed before the selenium can be removed.

The FGD feed water also contained high concentrations of oxidants. The Babcock and Wilcox oxidant test (Babcock and Wilcox, 2010) was used several times to measure non-specific oxidants using a ferrous ammonium sulfate method. When the ORP was measured in the 400 to 500 mv, the concentration of oxidants was measured in the range of 1.5 g/L. When the ORP was around 200 mv, the oxidant concentration was essentially zero.

The water quality characteristics of the FGD wastewater appear to be related to the oxidation state of the water. To summarize the water quality changes from Phase 1 to Phase 2, Table 2 presents the general water quality characteristics of each phase.

Table 2. Phase 1 and Phase 2 FGD Water Quality Summary

Water Quality Parameter	Phase 1	Phase 2
pH	~3.5	~6.9
ORP	~450 mv	~250 mv
Selenium	~1,800 ug/L	~200 ug/L
Mercury	~100 ug/L	~0.4 ug/L
Nitrate as N	~65 mg/L	~30 mg/L

The variations in FGD water quality observed here are beginning to be observed at other power plants and may not be considered abnormal in the universe of coal fired power plants operated with wet FGD systems.

PERFORMANCE OF PILOT TREATMENT TECHNOLOGIES

The five pilot treatment technologies were operated with the FGD wastewater discussed above. The performance of the pilots is presented below by the contaminant of concern. The performance of each technology is generally related to the water quality of the FGD wastewater. However, as with all pilot efforts mechanical issues such as pump failure, leaks, air binding, etc. can occur. It is beyond the intent of this paper to attempt to define the day to day issues and relate them to performance. The reader is encouraged to review the data in general terms related to trends. It can be seen that all the technologies performed in generally the same way even though they all had occasional mechanical issues.

The performance data presented in this paper is for selenium, mercury, and nitrates which are limited in the proposed ELG Rule. The arsenic concentrations in the FGD wastewater were well below the proposed ELG limits of 6 ug/L on an average basis, typically less than 3 ug/L. As such, arsenic removal is not discussed here.

Presented in Appendix A are graphs showing pilot performance for selenium removal. The graphs all show total selenium in the feed water and the effluent from the pilot systems. The inset graph on each figure shows the Phase 2 performance with an expanded vertical scale for better review. Figure 7 presents the performance of the AnMMR pilot for selenium removal.

The pilot process performance graphs (Figures 7-11) show that selenium removal was relatively good for all the treatment processes, yet the proposed ELG limit of 10 ug/L on an average basis was difficult to achieve. It was only in the second phase that the treatment technologies showed more consistent results with effluent concentrations near the proposed ELG limits. The biological process performed better than the chemical processes during Phase 1 when the FGD wastewater was highly oxidized. During the latter part of Phase 1, the FGD wastewater was better stabilized by pH and ORP controls which resulted in better biological process performance.

Both of the ZVI process (Pironox and LHI) performed less effectively for selenium removal than the biological processes in Phase 1. However, during Phase 2, the Pironox process performed quite well, meeting the proposed ELG limit most of the time.

Presented in the Appendix are the graphs for mercury removal for the various pilots. The performance of the AnMBR process for mercury removal is shown in Figure 12.

Mercury removal was generally very good for all of the technologies. The biological technologies rely on sulfide production to precipitate the mercury from solution as well as other precipitation reactions. With a slightly more negative ORP, it is believed that the biological processes may be able to reach the proposed ELG mercury limits of 119 ng/L on an average basis. The Pironox process was very effective with mercury removal.

Presented in Figures 13 to 21 are the nitrate removal performance of the pilot technologies. Nitrate is limited in the proposed ELG Rule to 130 ug/L on an average basis. Presented in Figure 17 is the performance of the AnMBR process with respect to nitrate as nitrogen.

The biological process appears to be better suited for efficient denitrification than the ZVI processes. All of the biological processes were able to remove nitrate down to the proposed ELG limit of 130 ug/L fairly consistently. It is interesting to note that nitrate removal was achieved even when selenium removal is compromised.

The ZVI processes were able reduce nitrate, but not to the extent as the biological processes. Both the Pironox and the LHI processes were not able to meet the proposed

ELG limits. It should also be noted that the ZVI processes will convert nitrate to ammonia which can be toxic to fish.

SUMMARY

The FGD characterization and the pilot studies conducted were very important from the standpoint of understanding the impacts of FGD water quality on chemical and biological treatment processes. The following general observations can be made from these studies:

- FGD wastewater quality varies significantly. There are numerous factors that will influence the water quality of the FGD wastewater including slurry hydraulic residence time, number of generation units served by the absorber, coal quality, and perhaps to a lesser extent oxidation air. As the ORP of the absorber slurry increase above 300 mv, there is a tendency to see higher selenium and mercury concentrations and a lower pH in the FGD wastewater.
- Selenium oxidation to the dissolved Se^{+6} species appears to be related MnO_2 formation. EPRI has done extensive work with bench scale absorber studies. These studies have shown that MnO2 is the predominate mechanism for the oxidation of selenium to selenate in the FGD slurry. The pilot studies here confirmed that the dissolved manganese concentrations in Phase 1 were very low, around 0.2 mg/L. During Phase 2, the manganese concentrations exceeded 90 mg/L. It is believed that during Phase 1, the manganese was oxidized to the solid form, MnO_2 which acted as a catalyst for the oxidation of selenium to selenate. During Phase 2, the manganese was not oxidized and therefore was not catalyzing the oxidation of selenium. Consequently, in less oxidizing conditions, the selenium is either in the elemental form or Se^{+4}, both of which would then have adsorbed to iron in the FGD slurry.
- When the FGD wastewater is highly oxidized, the biological processes appear to perform better for selenium removal. It is thought that the high concentration of oxidants or nitrates may interfere with the ZVI processes. However, during the highly oxidized Phase 1, none of the technologies produced effluent selenium levels that met the proposed ELG limits of 10 ug/L.
- When the FGD wastewater became less oxidized as in Phase 2, the Pironox process did meet the ELG limits most of the time. All of the biological processes performed better in Phase 2, but still did not meet the proposed ELG limits.
- The biological processes were able to achieve excellent nitrate removal throughout the entire pilot testing program. It is interesting that denitrification was not inhibited by the FGD wastewater as selenium removal was. This may be attributed to two factors. First, the denitrification process occurs at a much higher redox potential and doesn't require the low ORP values needed for selenate and sulfate reduction. It was not affected by the presence of strong mixed oxidants in the FGD wastewater. Second, denitrification is mediated by facultative heterotrophic organisms that grow in distinctly different chemical environments than the obligate anaerobes frequently associated with selenate and sulfate reduction. Most of these organisms will not grow in aerobic environments and may sensitive to the presence of chemical oxidants.
- Mercury concentrations in the FGD wastewater are influenced by the oxidation state of the FGD slurry. A higher scrubber ORP causes the mercury occur in the soluble form.
- All of the piloted technologies were relatively effective at reducing mercury, however; the Pironox process appeared to meet the proposed ELG limit of 119 ng/L most of the time.
- FGD nitrate concentrations were also significantly variable. During the highly oxidized Phase 1, the nitrate as N concentration was typically in the 60 mg/L range. During Phase 2, the nitrate as N concentration dropped to less than 30 mg/L.

- Only the biological systems were able to denitrify the nitrates to low enough levels to meet the proposed ELG limits. The chemical ZVI technologies were generally not able to consistently achieve effluent nitrate as N concentrations less than 1.0 mg/L. In addition, the ZVI technologies converted nitrate to ammonia which can be toxic to fish.

REFERENCES

Babcock and Wilcox (2010), *Redox Titration Method for Determination of Total Strong Oxidizer in WFGD Absorber,* (BWRC-TP-1715-00)

Brown, S.R. (2013), *ORP Measurement in FGD Water Chemistry, EPRI Workshop on Managing FGD Water Discharges*, Charleston, SC

Brown, S.R., DeVault, R.F., Johnson, D.B. (2013), *ORP as a Predictor of WFGD Chemistry and Wastewater Treatment*, Power

APPENDIX A

Figure 1. FGD Feed ORP vs pH

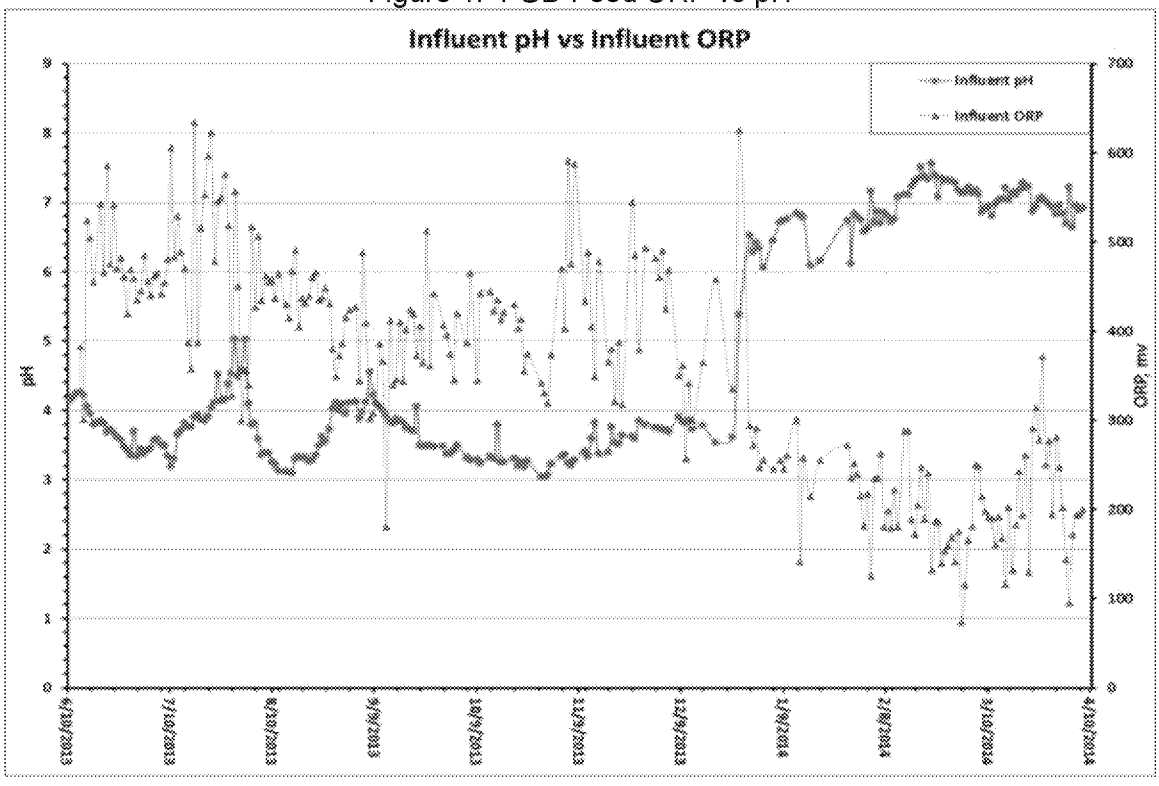
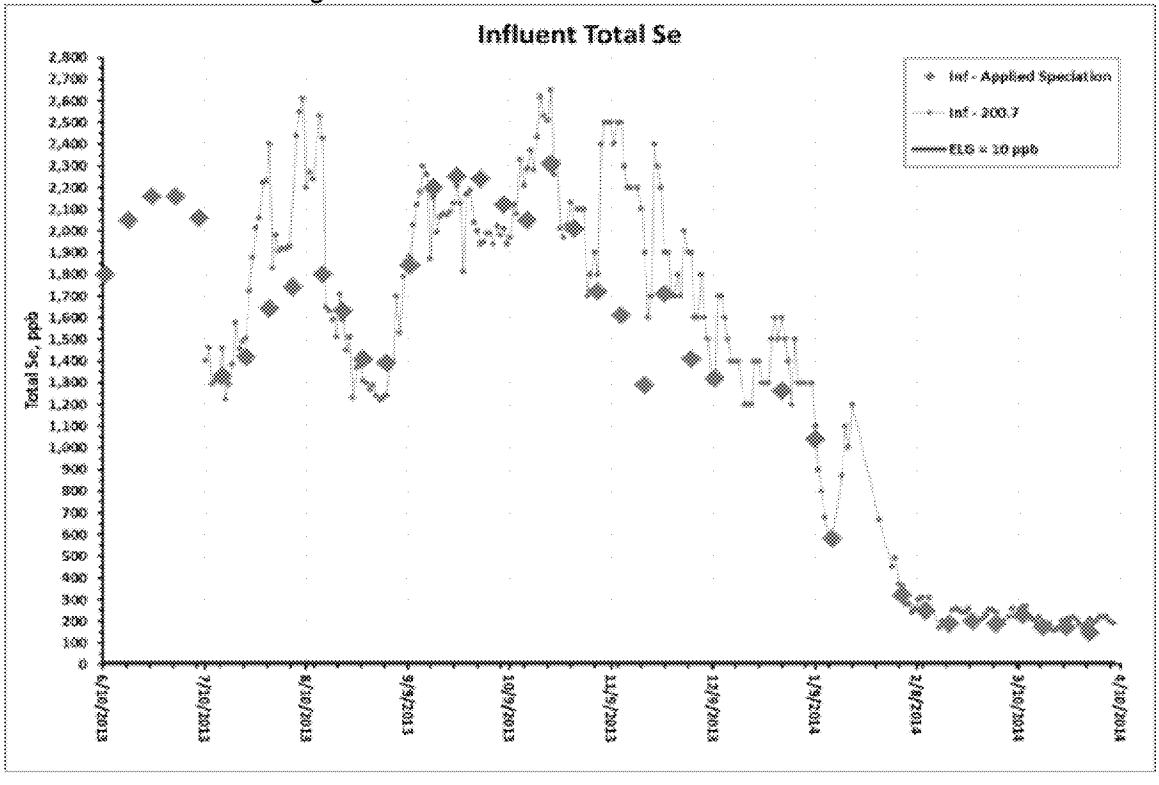


Figure 2. FGD Feed Selenium Concentration



IWC 14-59

Figure 3. FGD Selenium Concentration and ORP

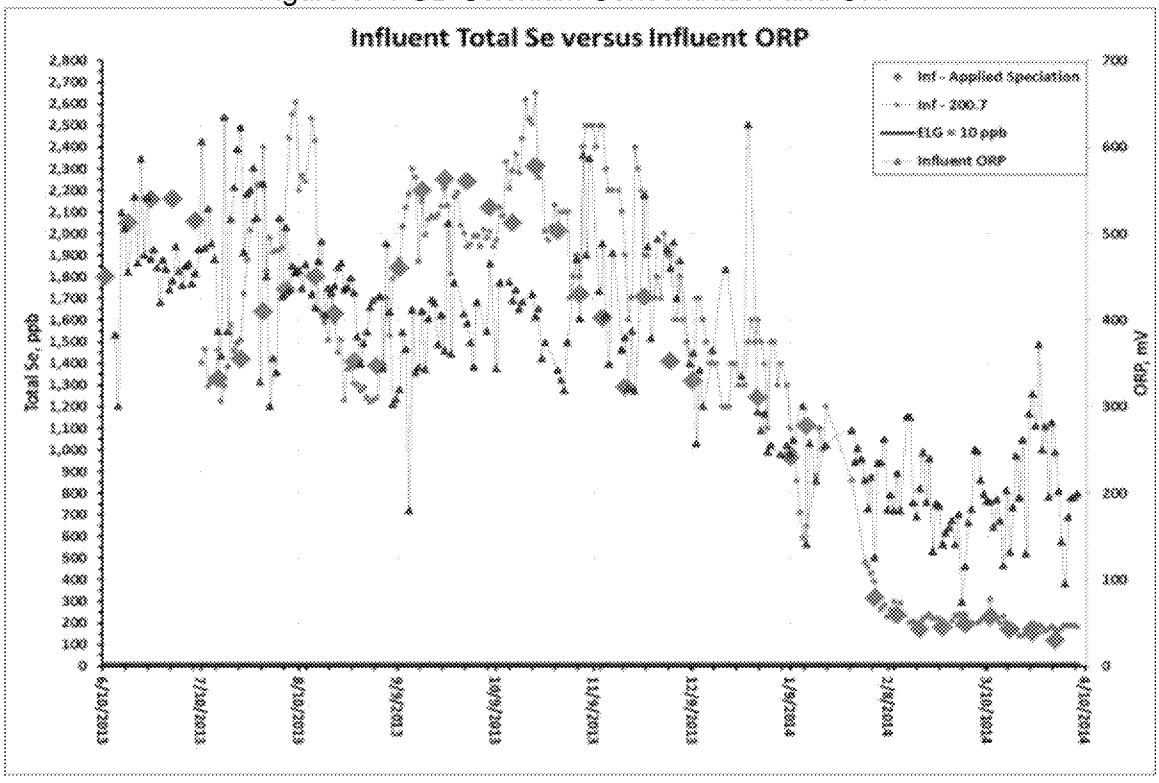
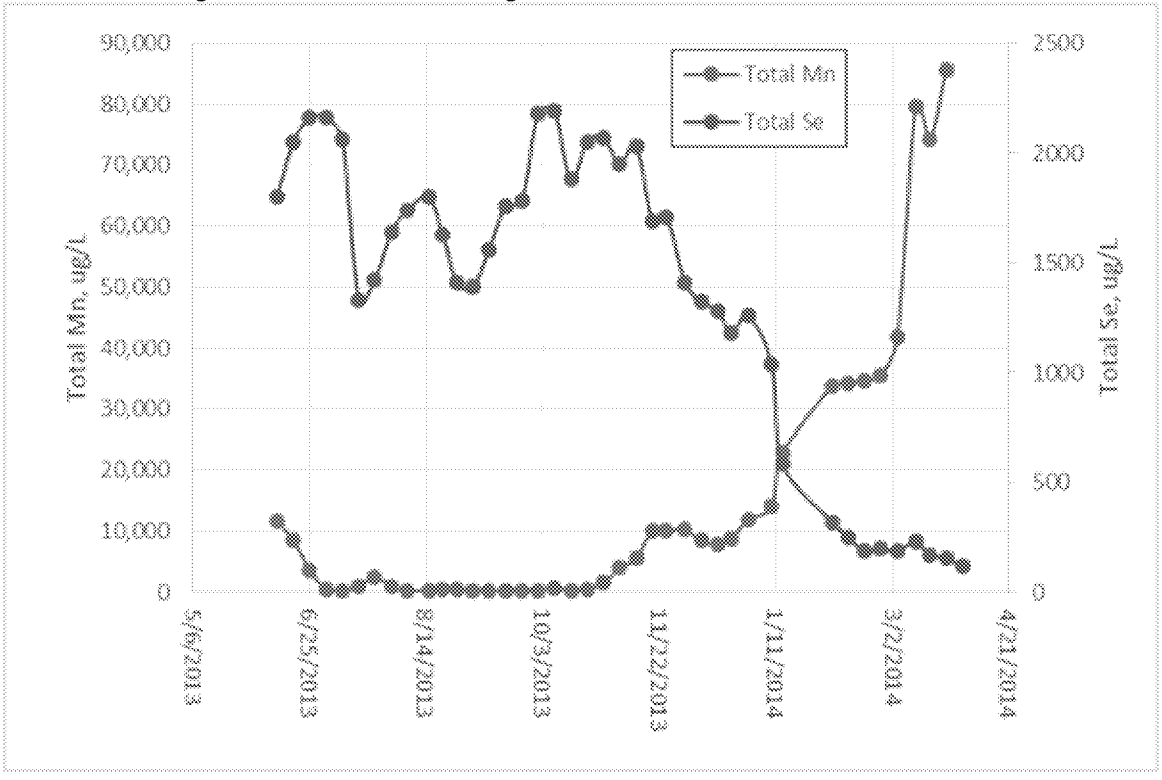


Figure 4. FGD Feed Manganese and Selenium Concentrations



IWC 14-59

Figure 5. FGD Dissolved Mercury and ORP

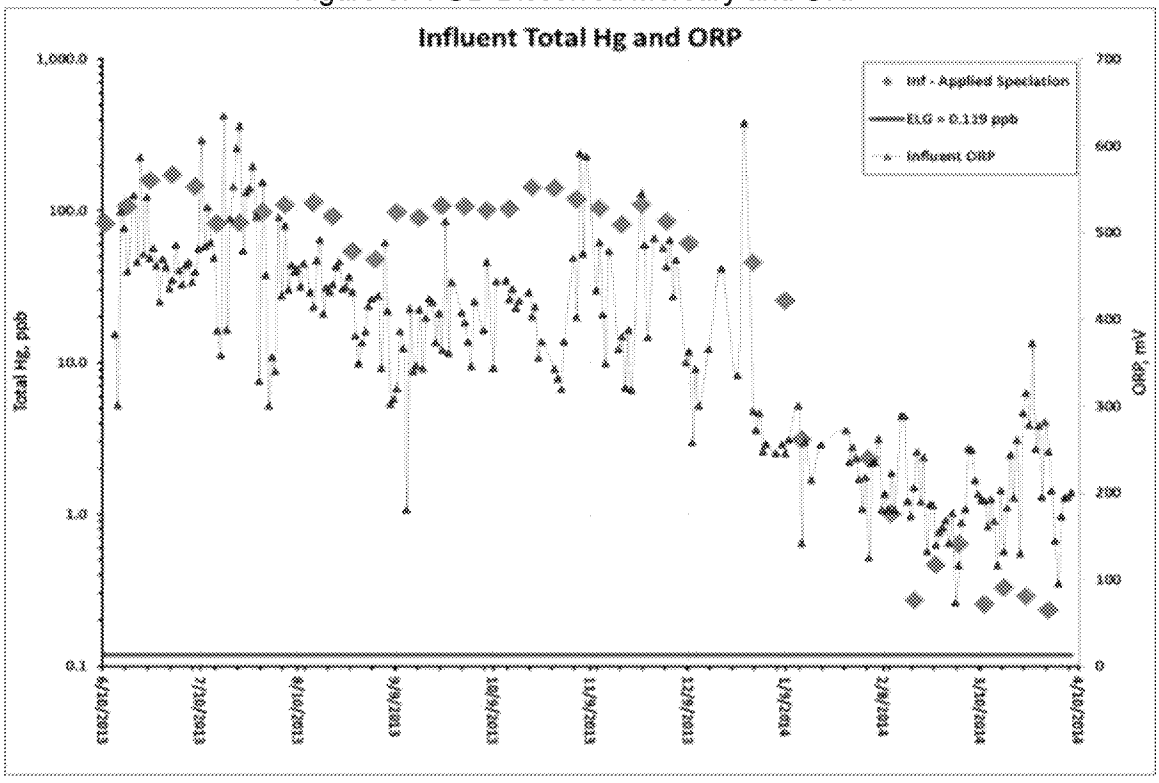
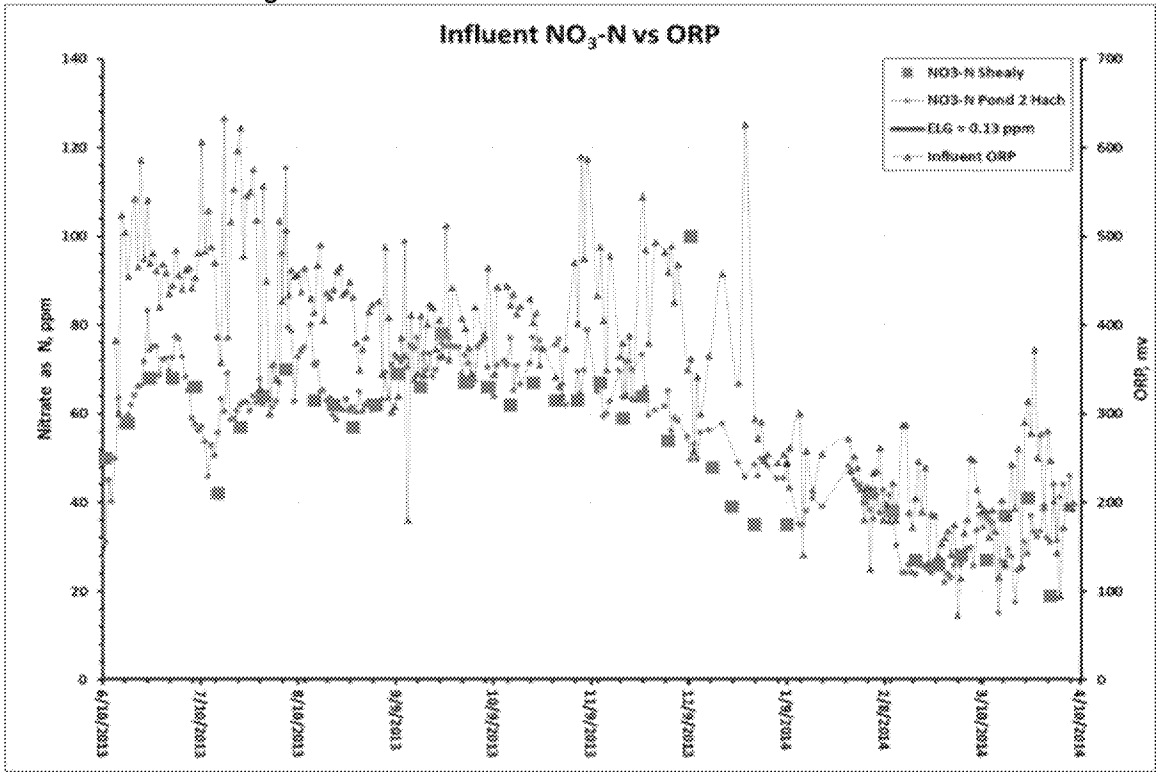


Figure 6. FGD Feed Nitrate Concentration and ORP



IWC 14-59

Figure 7. AnMBR Influent and Effluent Selenium Concentrations

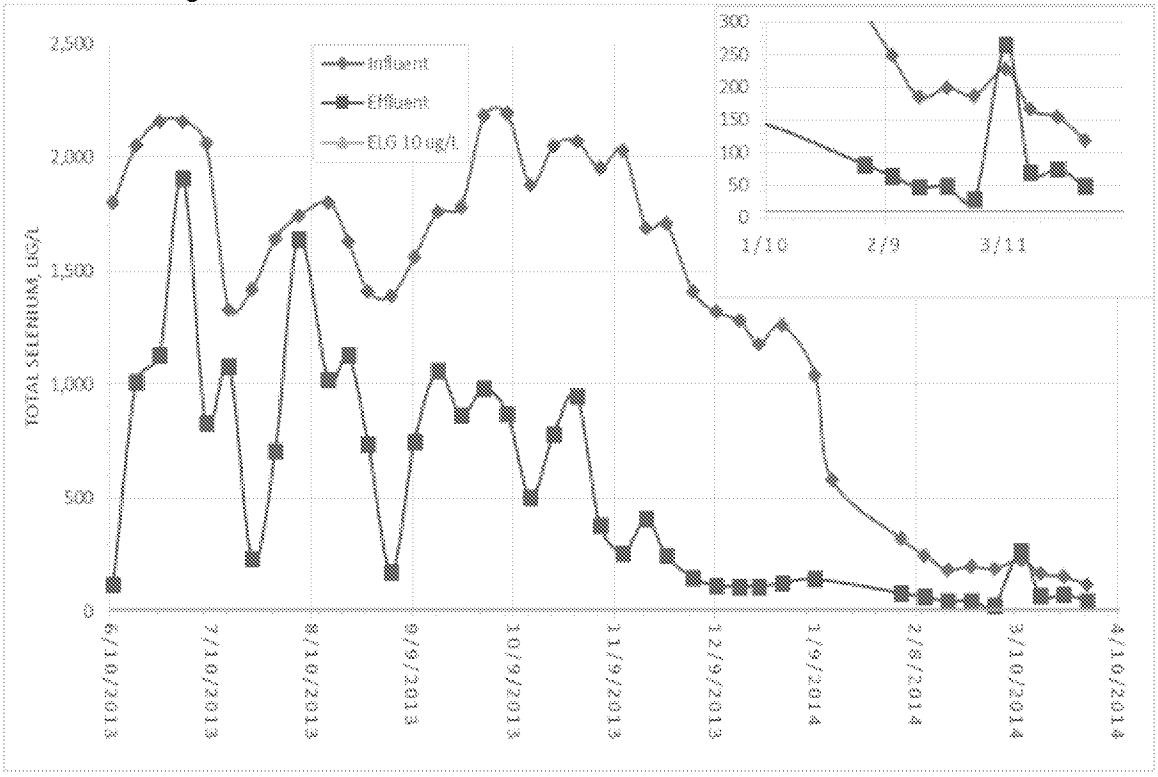
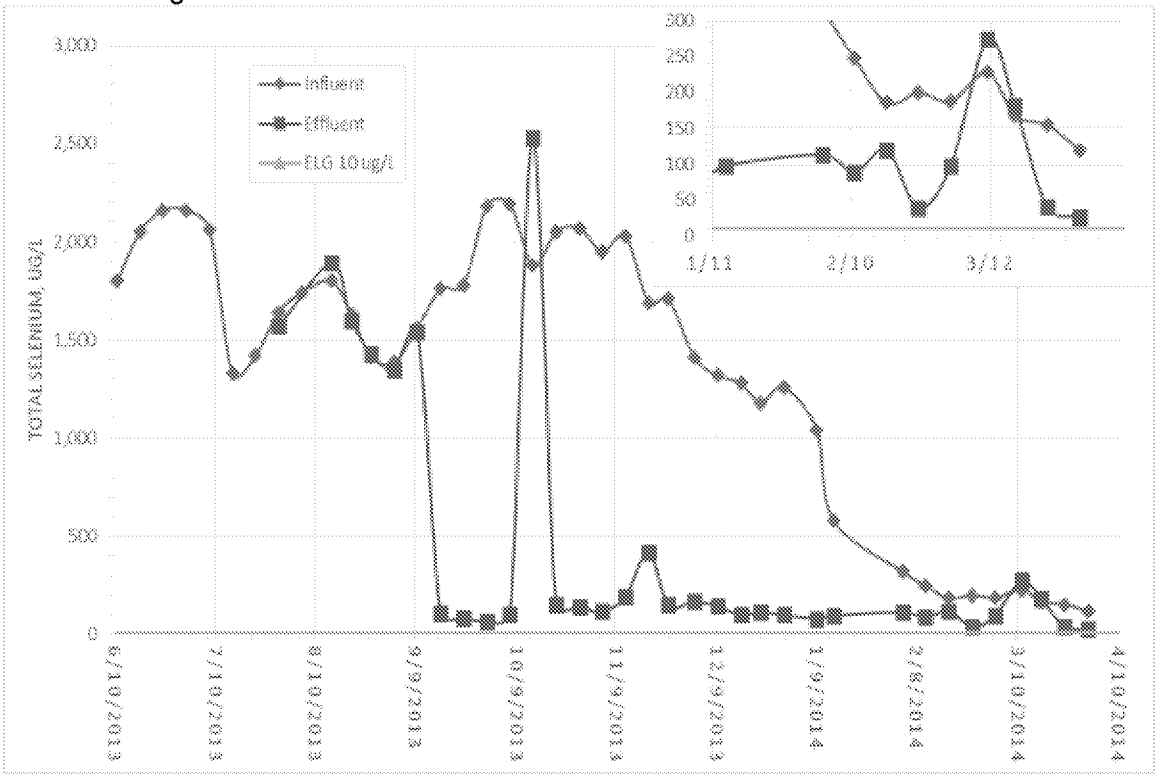


Figure 8. FBR/MBR Influent and Effluent Selenium Concentrations



IWC 14-59

Figure 9. ABMet Influent and Effluent Total Selenium Concentrations

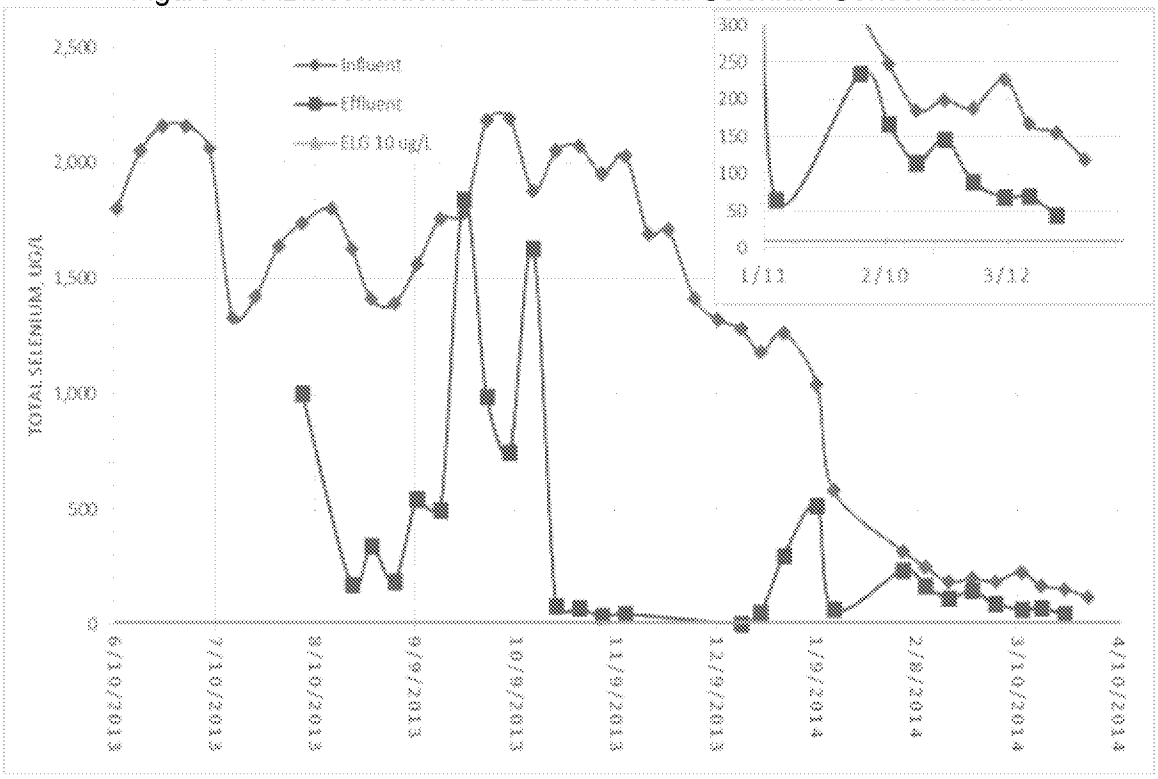
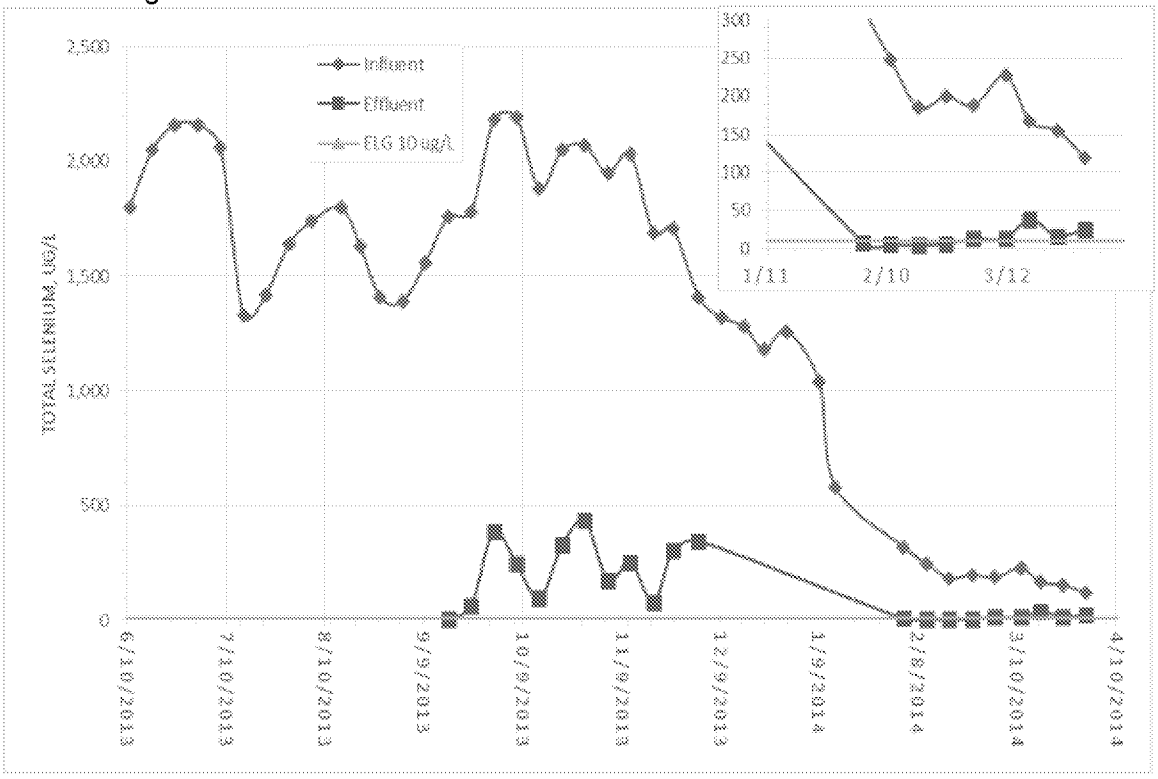


Figure 10. Pironox Influent and Effluent Total Selenium Concentrations



IWC 14-59

Figure 11. LHI Influent and Effluent Total Selenium Concentrations

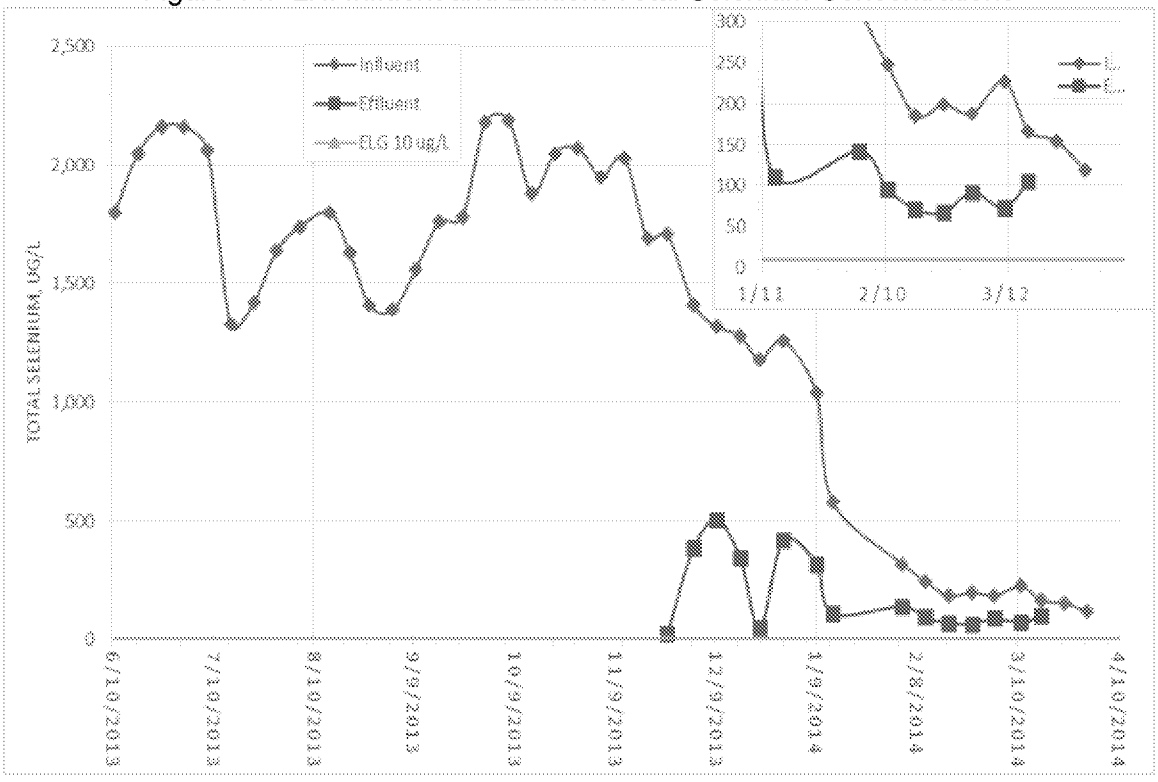


Figure 12. AnMBR Influent and Effluent Total Mercury Concentrations

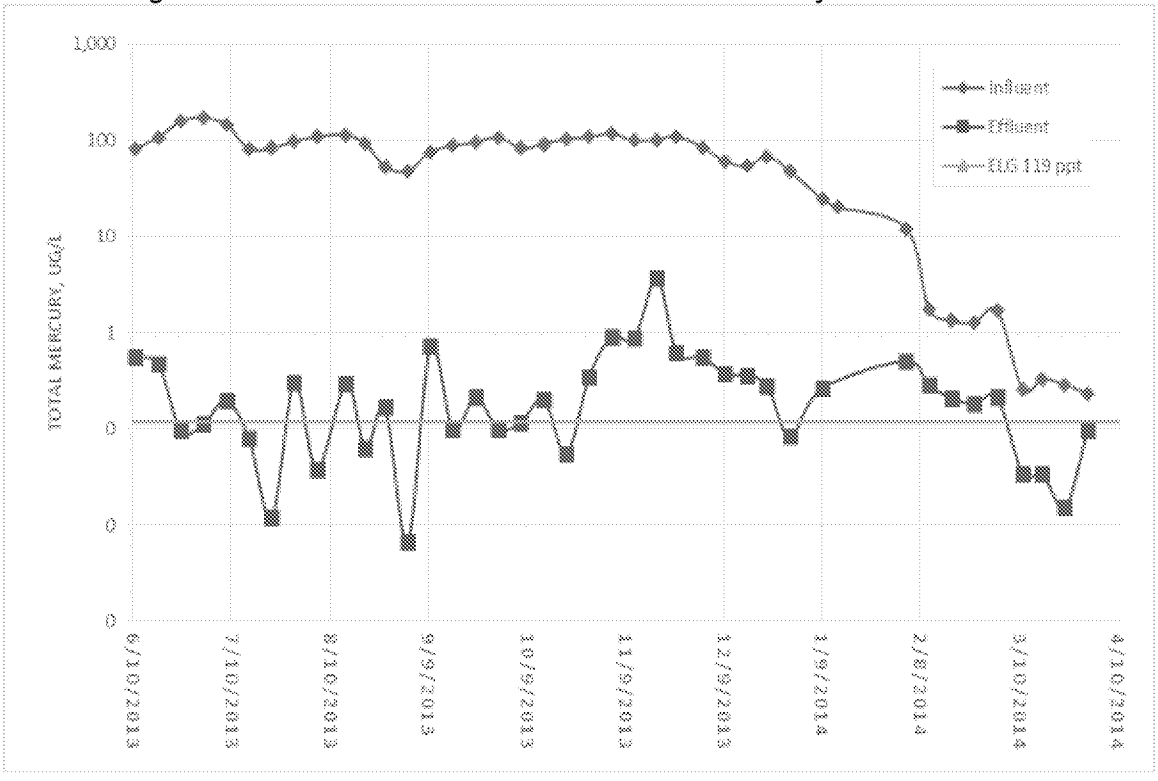


Figure 13. FBR/MBR Influent and Effluent Total Mercury Concentrations

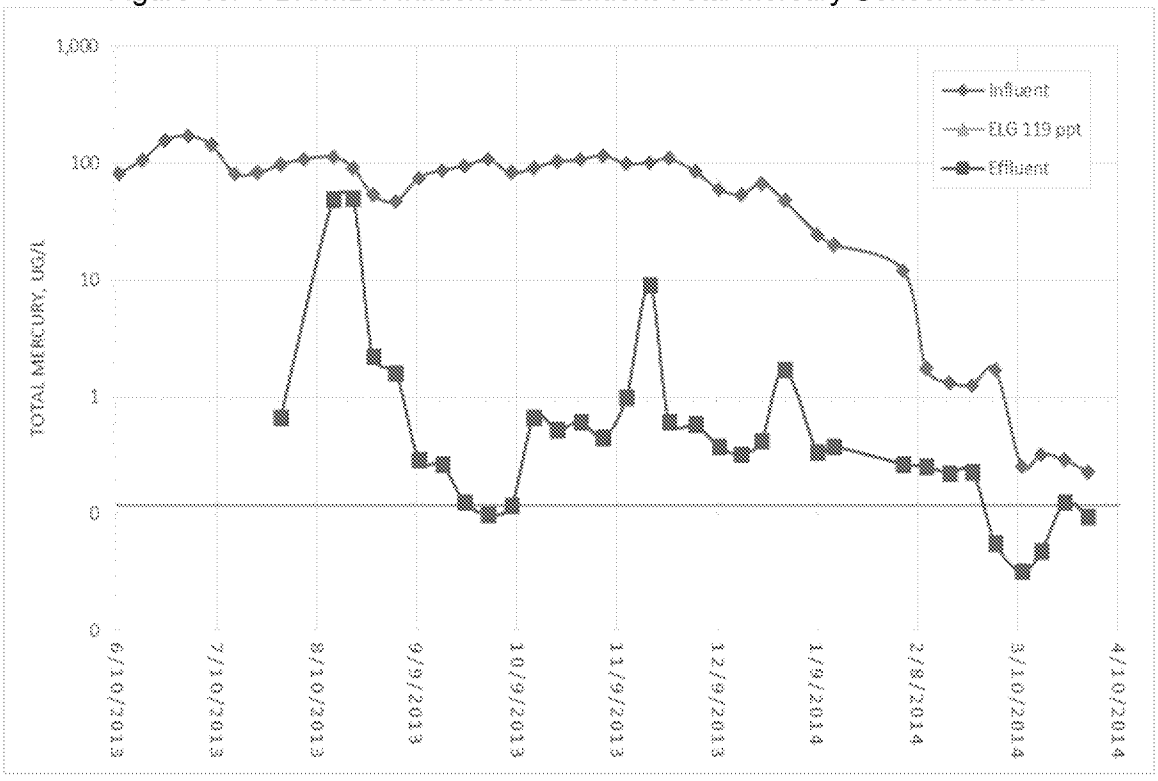
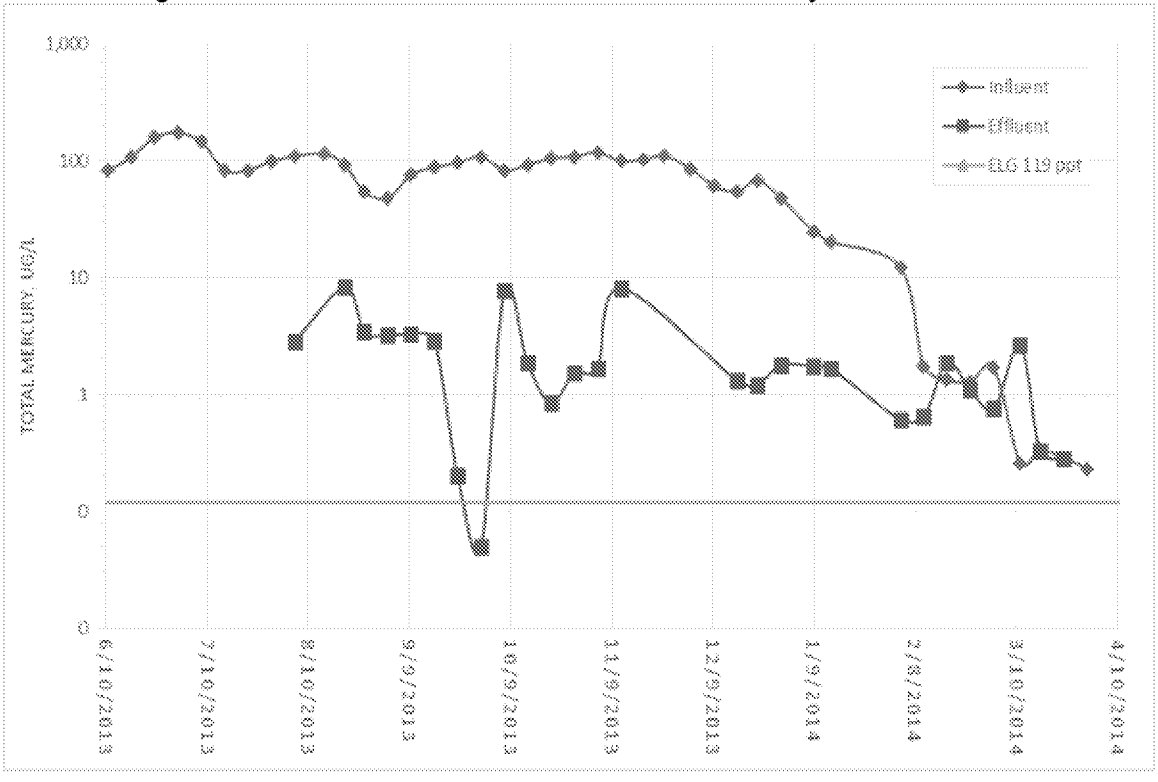


Figure 14. ABMet Influent and Effluent Total Mercury Concentrations



IWC 14-59

Figure 15. Pironox Influent and Effluent Total Mercury Concentrations

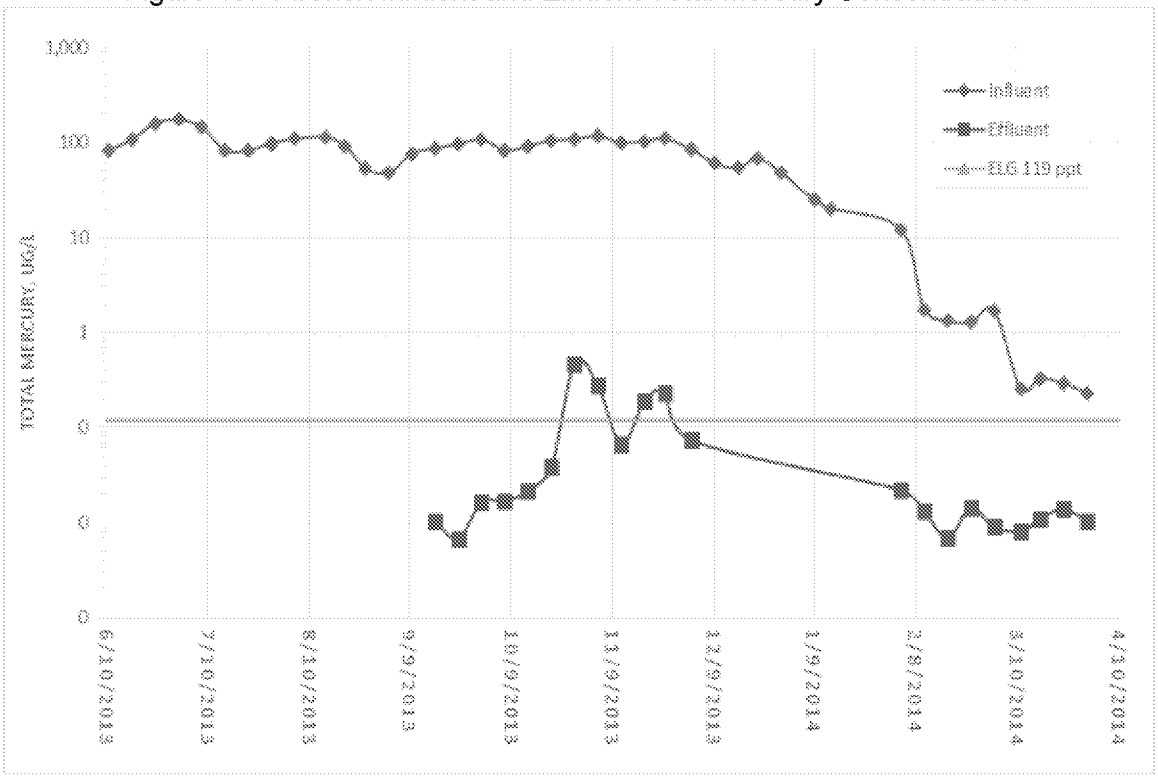
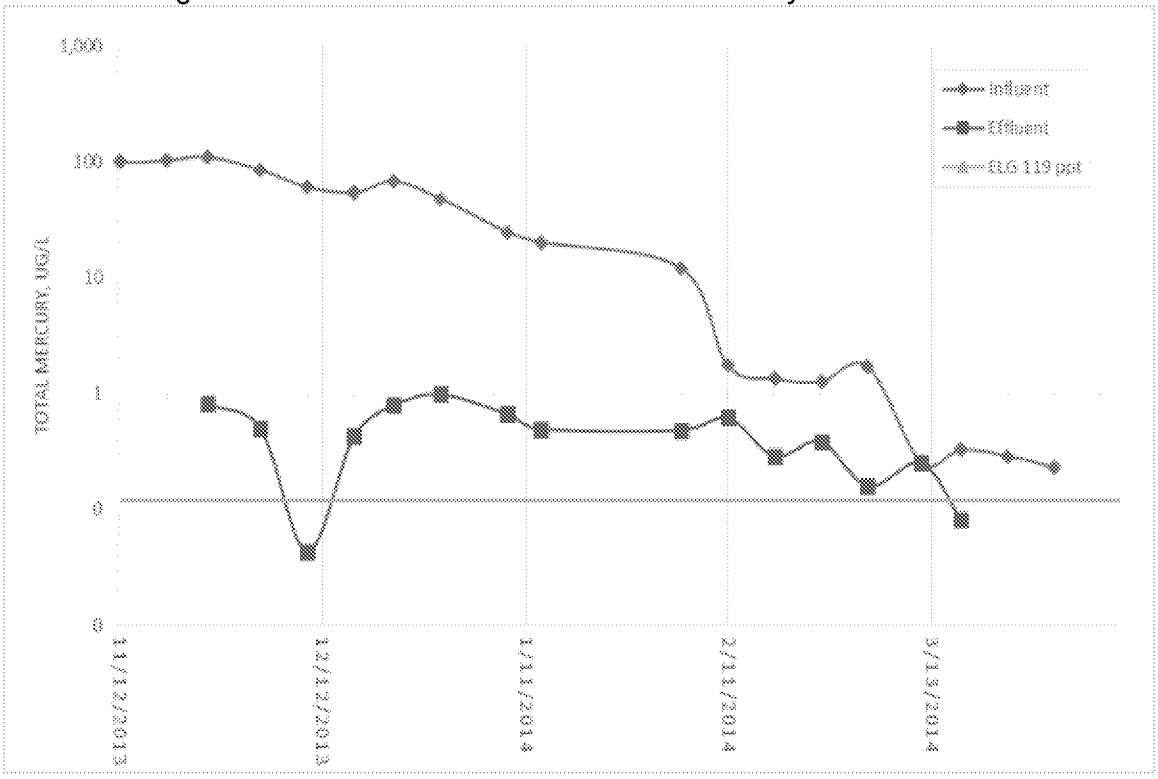


Figure 16. LHI Influent and Effluent Total Mercury Concentrations



IWC 14-59

Figure 17. AnMBR Influent and Effluent Nitrate as N Concentrations

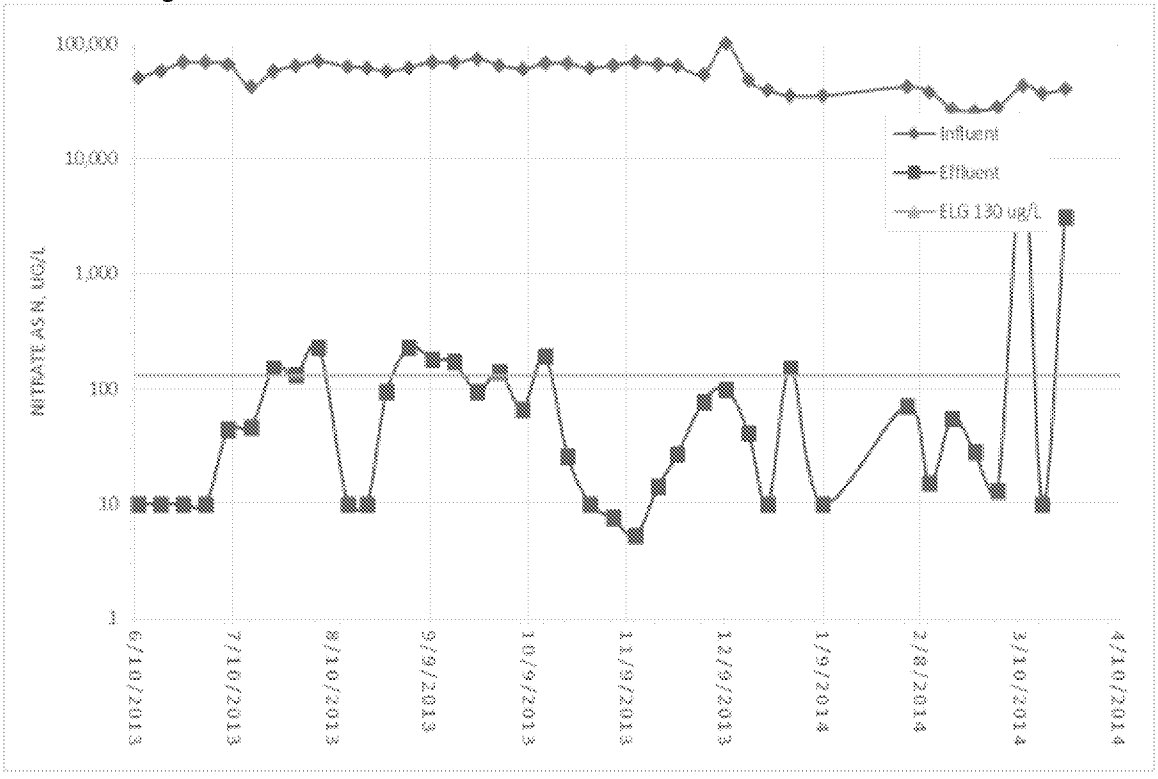
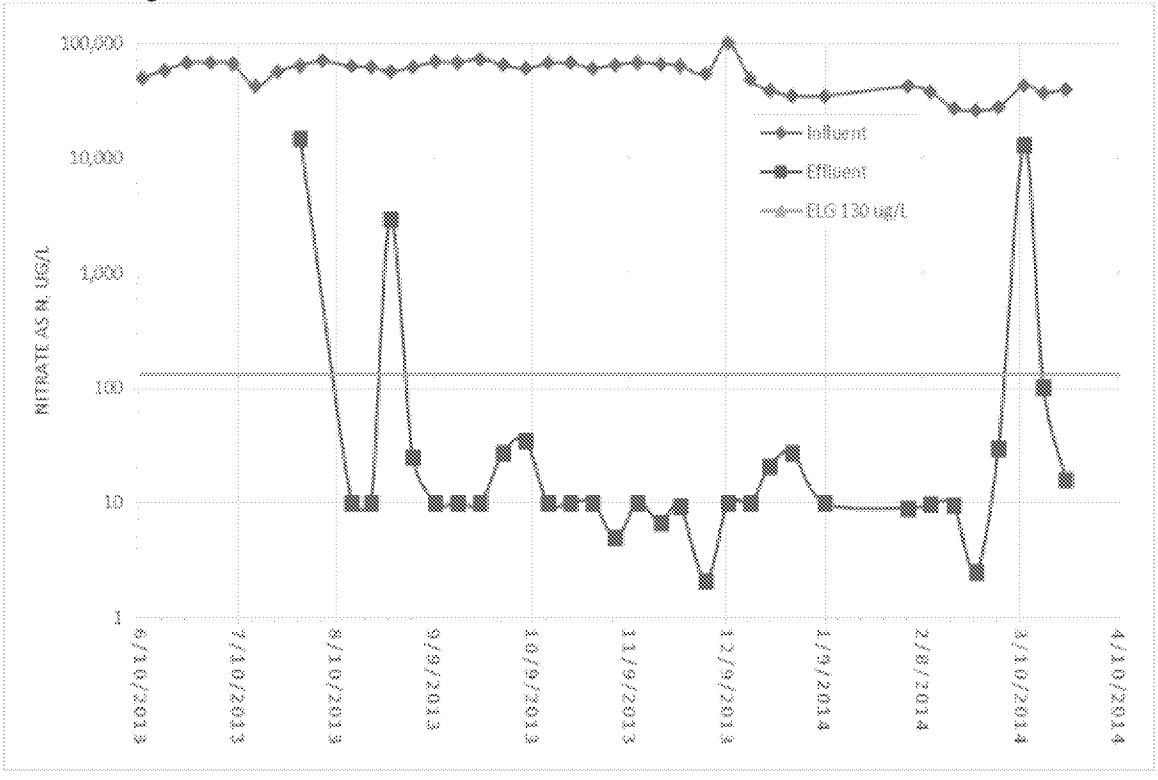


Figure 18. FBR/MBR Influent and Effluent Nitrate as N Concentrations



IWC 14-59

Figure 19. ABMet Influent and Effluent Nitrate as N Concentrations

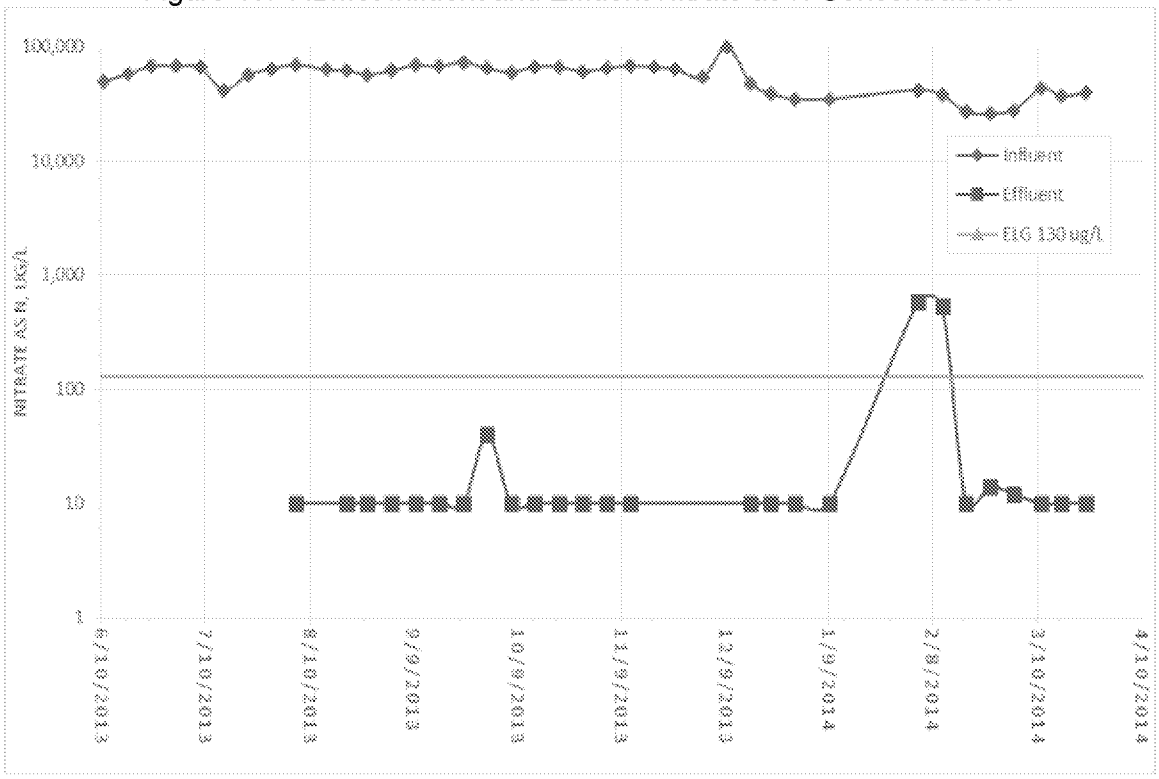
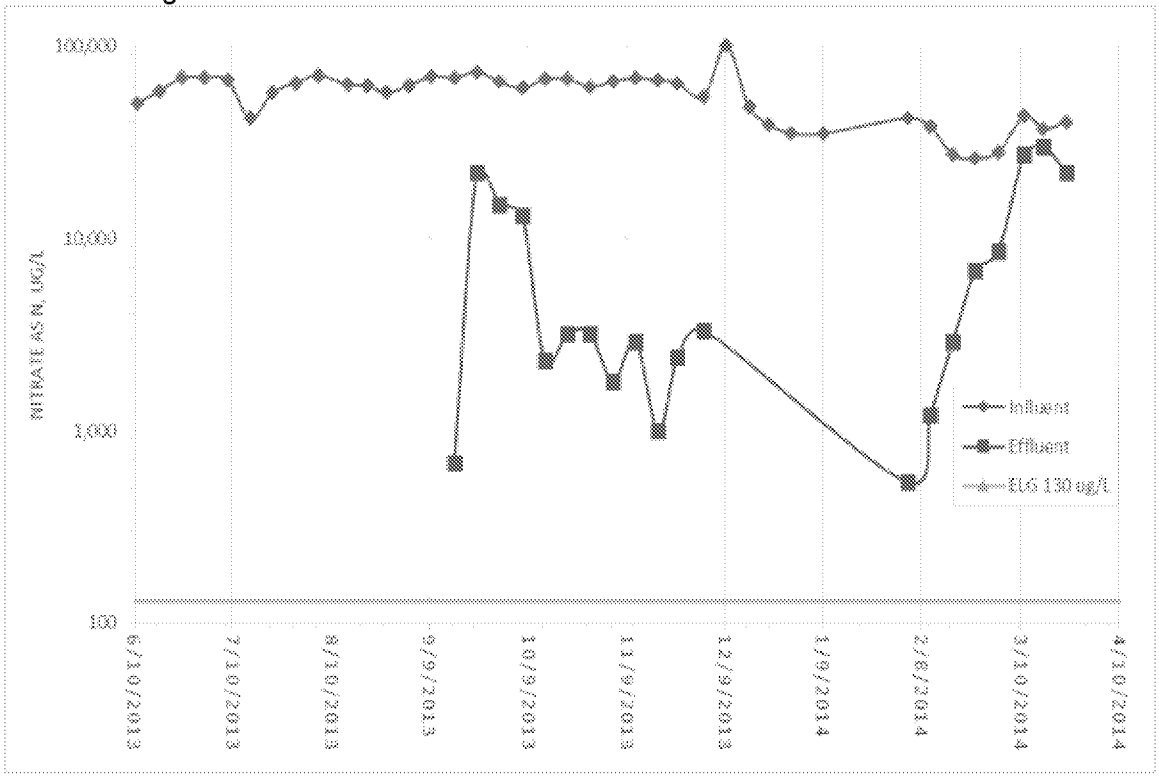
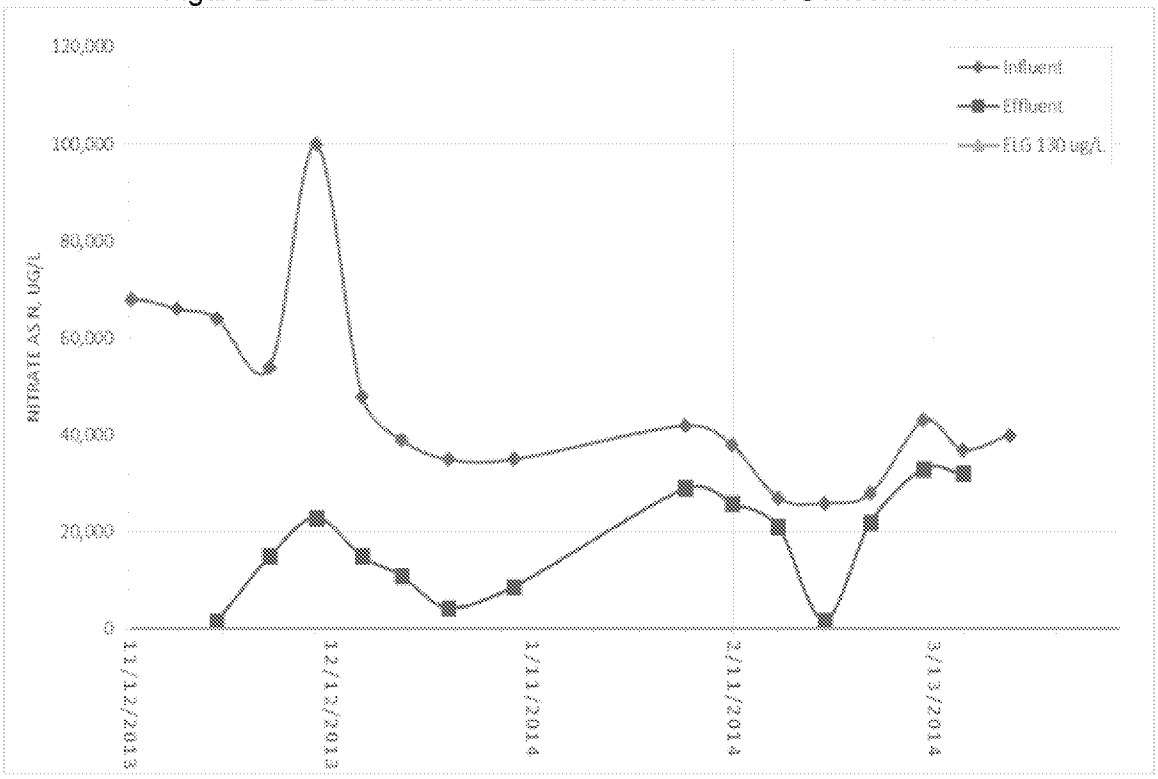


Figure 20. Pironox Influent and Effluent Nitrate as N Concentrations



IWC 14-59

Figure 21. LHI Influent and Effluent Nitrate as N Concentrations



IWC 14-59

Prepared Discussion of:

Pilot Studies for the Treatment of Highly Oxidized Flue Gas Desulphurization Wastewater

JIM BENINATI
HDR Engineering, Inc.
Pittsburgh, PA

OVERVIEW

The paper being discussed summarizes a series of pilot tests from Fall 2013 through Spring 2014 where several FGD wastewater treatment technologies were tested at a South Carolina coal-fired power plant. The technologies in question focus on pending ELG guidelines, specifically addressing arsenic, selenium, mercury, and nitrate. The following discussion examines the paper and its conclusions.

COMMENTS ON PAPER'S GENERAL STRUCTURE AND THEME

The paper essentially covers two main themes.

The first theme is an extensive background discussion on the changing FGD wastewater quality during the test period, stemming from changes in scrubber chemistry and operations. There are two main periods of operation during the pilot testing; Fall 2013 during original scrubber operation, then a December shutdown and Spring 2014 period of modified scrubber chemistry.

The second theme of the paper follows the paper's title; the evaluation of the pilot technologies' ability to treat the FGD wastewater for removal of ELG contaminants.

While the changes in FGD wastewater chemistry play a key role in the outcome of the study, it also complicates the comparison of the treatment technologies by adding additional variables that are extensively explained by the authors.

The paper was a very interesting case study in that it not only compared the performance of several treatment technologies, but also evaluated their comparative performance under two distinctly different operational conditions.

However, an extensive amount of time was spent discussing the changes in FGD wastewater chemistry due to scrubber modifications. This space may have been more well-used if it instead had been dedicated to more detailed background discussions of the various treatment technologies being tested. As currently structured, the paper jumps quickly into the results of the testing, without a description of what makes these technologies work. Such a background discussion could have added some context to why these technologies performed the way they did. Without this background, some readers will be forced to consult outside references just to understand even the most basic aspects of these technologies.

Given that the focus of this paper is a comparison of wastewater treatment technologies, this will also be the focus of this discussion. Changes in FGD scrubber operation and chemistry will be addressed secondarily.

SCRUBBER QUESTIONS

The paper provides extensive analysis of the changing FGD wastewater chemistry, but little discussion on what scrubber changes led to this. It would be interesting to have at least a few sentences on what scrubber operational changes led to these variations in wastewater chemistry.

It appears that the fundamental changes in scrubber operation produced a much more treatable wastewater stream. If this is the case, then why not spend more time discussing this very critical observation from a scrubber operations perspective? It appears that scrubber operation itself may be as critical as what wastewater treatment technology is selected with regard to ELG compliance.

Were there any changes in coal type throughout the test that would also contribute to variations in wastewater chemistry? Or do the authors attribute most of these wastewater changes to scrubber operation?

PRETREATMENT QUESTIONS

There is little discussion as to whether any of these treatment technologies were preceded by any pretreatment. All of these technologies are recognized as polishing systems to remove specific contaminants that only recently are being regulated (As, Se, Hg, and NO_3), It would be unusual, and probably discouraged by the respective vendors, to install these technologies on raw FGD wastewater whose only pretreatment is pond sedimentation.

If pretreatment was excluded from the treatment train during these tests, is that an accurate reflection of pending permit requirements? Or would other metals and chemical constituents also require the implementation of physical/chemical pretreatment?

Do the various technology vendors have standard influent criteria when proposing full-scale systems? If so, did the influent characteristics during this study meet those criteria? Or were SCANA, EPRI, TetraTech, and the vendors simply testing the boundaries of the technology?

The most problematic characteristics of this influent FGD wastewater are the potentially high concentrations of scalants and the high oxidation potential. Did any of the technology vendors individually pretreat for these conditions in a way that other providers may not have, through filtration or chemical reduction? If so, this could have created a “false” advantage not reflected in the performance of the other technologies not employing these pretreatment steps, in that such pretreatment is universally available and is not integral to the core technology being evaluated.

PILOT OPERATIONAL QUESTIONS

Given the apparent lack of pretreatment, it seems that the potential for scaling was fairly high, especially in the media-based treatment systems. Was any data collected on fouling, loss of throughput, and related effluent production trends for the pilot systems? Treatment efficiency (as measured by effluent concentrations) becomes almost secondary if the flow rate slows to a trickle.

If media fouling was observed, did it differ between technologies, and did the MBR systems fair better? If so, what filtration material and style was used in the MBR system?

Was any data collected on breakthrough rate or media consumption for the Zero Valent Iron (ZVI) technologies?

SPECIFIC CHEMISTRY COMMENTS

The authors provide much up-front discussion on the cause-effect relationship between various FGD chemical constituents. While a fairly detailed discussion of manganese and selenium interaction is provided, it would be useful to also have similar analyses on other interacting parameters as well, such as ORP and pH, and ORP and selenium. This would help the reader more fully appreciate how these changes in wastewater chemistry affect treatability of the target constituents.

The presentation slides (and to a lesser extent the paper) provide a detailed breakdown of the selenium species exiting each pilot system. It is interesting how different technologies allow a different composition of selenium to break through. Can the authors expand on that?

The substantial decrease in Redox potential halfway through the test phase greatly benefited all the treatment technologies. How do these variations in influent ORP compare to influent requirements recommended by the technology vendors?

The period from June 2013 to late October 2013 shows a wide variation in pilot system selenium effluent concentrations. These wide-ranging fluctuations seem to mirror, yet exceed the magnitude of, the influent selenium fluctuations. Was this a result of bio-acclimation?

For the biological treatment systems, what period of bio-acclimation was allowed before effluent data was collected?

In the slide presentation, there are several slides that show selenium speciation by technology. The authors should clarify that this is “effluent” speciation, and that all systems received the same influent, assuming that is the case.

Selenium speciation slides are provided for the AnMBR (biological) and Pironox (ZVI) systems but for no other

technologies. Was effluent speciation performed for any of the other technologies?

The selenium speciation data is very interesting in that the biological system (AnMBR) shows great variety in the species that break though the system. Yet the ZVI system (Pironox) breakthrough consists almost exclusively of dissolved selenate. A detailed discussion from authors on this difference would add great value to the paper.

The selenium speciation slide for AnMBR shows a profound increase in dissolved selenite in the pilot system's effluent for at least a week in March 2014. Do the authors have an explanation for this?

The effluent mercury and arsenic slides in the presentation show the ABMet system discharging levels of Se and As in excess of the influent concentrations. Do the authors have an explanation for this?

The authors point out the very crucial limitation of ZVI: that it does not provide for denitrification. Nitrate and nitrite were converted to ammonia during the testing. Any use of the ZVI system would therefore have to be preceded or followed by denitrification.

DISCUSSER CONCLUSIONS

This was an excellent paper. It is very relevant to the mission of the IWC, and contained a thorough presentation of the research methods and results. However, it would be very useful to provide a more detailed description of the technical basis of each of the treatment technologies pilot tested here. Also useful would be a description of what scrubber changes led to the observed changes in FGD wastewater chemistry.

It was very interesting to see the various strengths and weaknesses of the two types of technologies; biological and non-biological (ZVI). Rather than viewing the technologies as competing technologies, perhaps it would be more useful to view them as complementary. For example, a two stage system utilizing both technologies could consist of a biological system to denitrify and remove most selenium, followed by a ZVI system to polish for selenium, arsenic, and mercury down to ELG concentrations.

OASYS WATER

Oasys Water Overview

John Tracy | Senior Director, Marketing
MaryTheresa Pendergast | Director, R&D

19 October 2017

© 2017 Oasys Water, Inc. | Confidential

Presentation Outline

OASYS WATER

Oasys Introduction & Overview
Mission and strategy

Oasys Technology Platform
FO-based brine concentration enabled by membranes, draw solutions, and systems integration

Oasys Commercial Projects
System design and project references

© 2017 Oasys Water, Inc. | Confidential

OASYS WATER

Helping to Solve the World's Water Challenges with Innovative Technologies

Oasys develops innovative, sustainable, end-to-end solutions that transform the world's most abused waters into valuable freshwater resources.

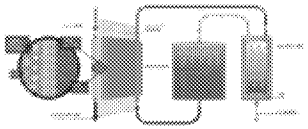
© 2017 Oasys Water, Inc. | Confidential

A Brief History of Oasys Water

OASYS WATER

Founding and FO Development
2008 – 2011

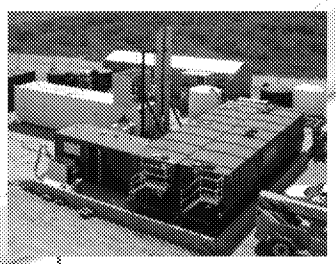
Oasys formed around technology from Yale University combining FO membrane, a unique draw solution, and a recovery system



Piloting and Proving
2011 – 2013

US pilots on produced water and a Chinese pilot on power industry effluent prove performance of the Oasys MBC™ (Membrane Brine Concentrator)

Marcellus Pilot
2011



Permian Basin Pilot
2011-12

Commercial Momentum
2013 – Present

Commercial projects in China Power and Chemicals, US Oil & Gas have led to broader adoption in a range of industries and geographies

NATIONAL OILWELL VARCO

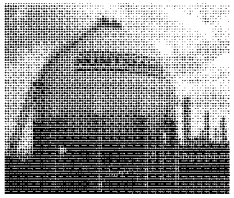
NOV Wellsite MBC System
2013

WOTEER 沃特尔

Changxing Power w/ Beijing Woteer
2013

NEXO Capital
Rifle, CO Produced Water Disposal DBO project
2016

Huntsman Chemical
FEED for ZLD plant design
2017



US Power Pilots
2016 and 2017

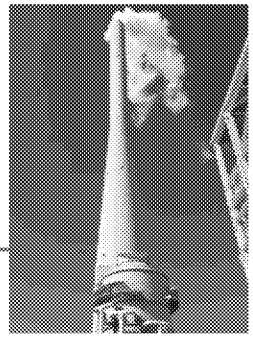
EPRI ELECTRIC POWER RESEARCH INSTITUTE

nrg

Sinopec Corp.

Zhongtian CTX ZLD Project
2014

YangMei CTX ZLD Project
2015

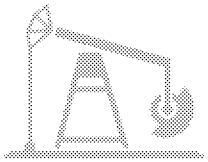


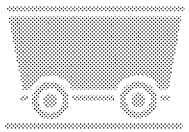
Wangqu Power FGD Treatment
2016

© 2017 Oasys Water, Inc. | Confidential

Focus on Difficult Industrial Waters

OASYS WATER



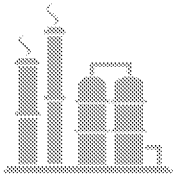


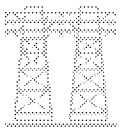
"Naturally" Occurring

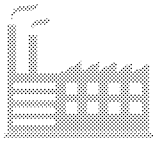
Waters from hyper saline aquifers

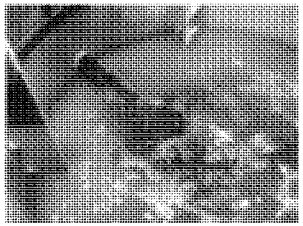
Process Concentrates

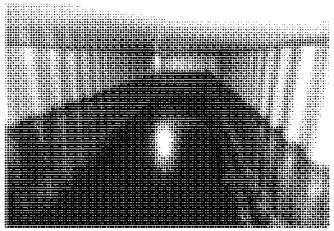
Waters from ground and surface water cycling processes

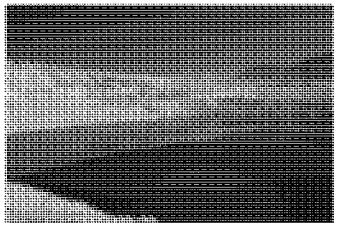


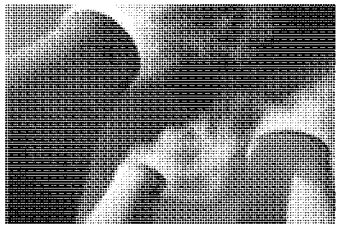


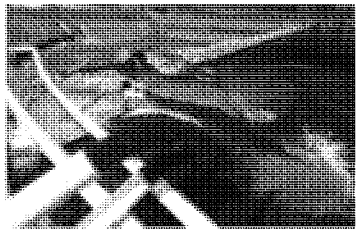








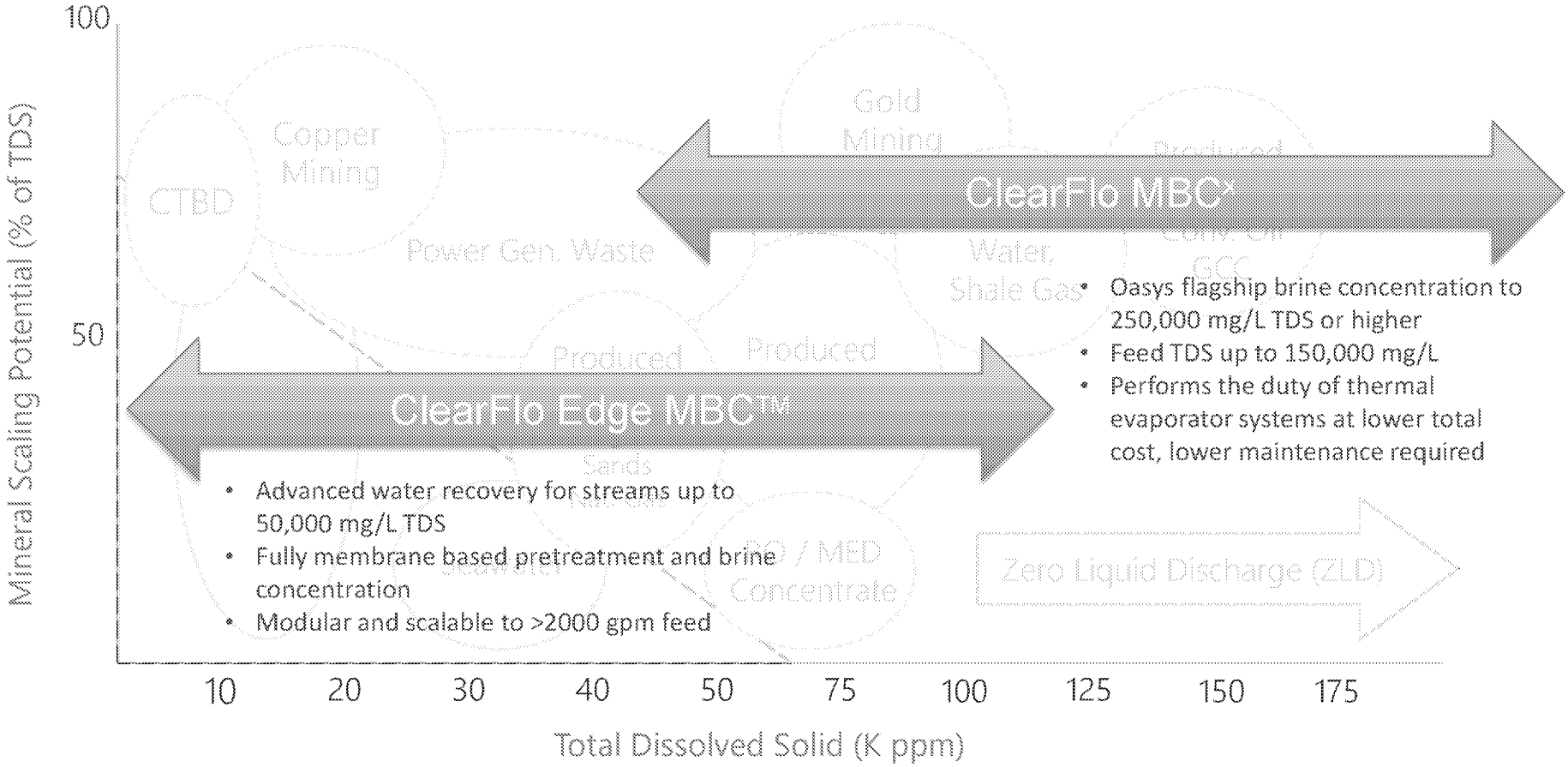




© 2017 Oasys Water, Inc. | Confidential

Innovative Approaches to Treating Difficult Waters

Oasys Targets High Salinity Streams in Power, Oil & Gas, Manufacturing

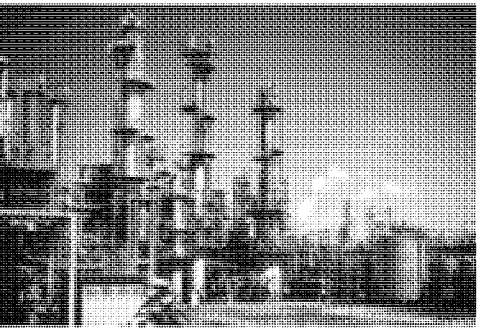


© 2017 Oasys Water, Inc. | Confidential

Shifting the Paradigm Towards Custom Solutions for Customer Needs

OASYS WATER

Oasys end-to-end solutions are designed to transform water for reuse at the lowest total cost and highest possible reliability



Lower CapEx

Materials

Installation

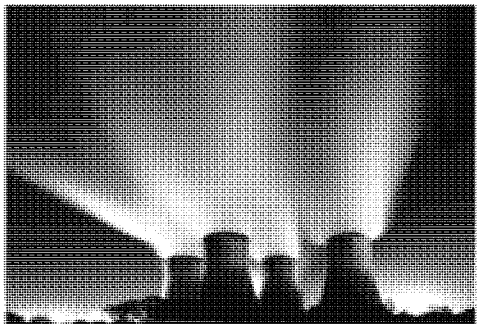
Modularity

Lower OpEx

Energy

Consumables

High Purity Brine



Higher Recovery

Waste Minimization

Lower Flow to ZLD

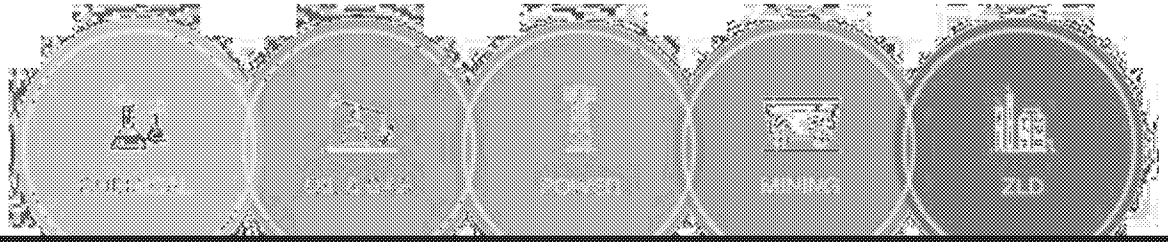
Lower OPEX per Unit

Higher Uptime

Decreased Fouling

On-Line CIP

Flexible Operation



© 2017 Oasys Water, Inc. | Confidential

Presentation Outline

OASYS WATER

Oasys Introduction & Overview
Our Mission and Strategy

Oasys Technology Platform
FO-based brine concentration enabled by membranes, draw solutions, and systems integration

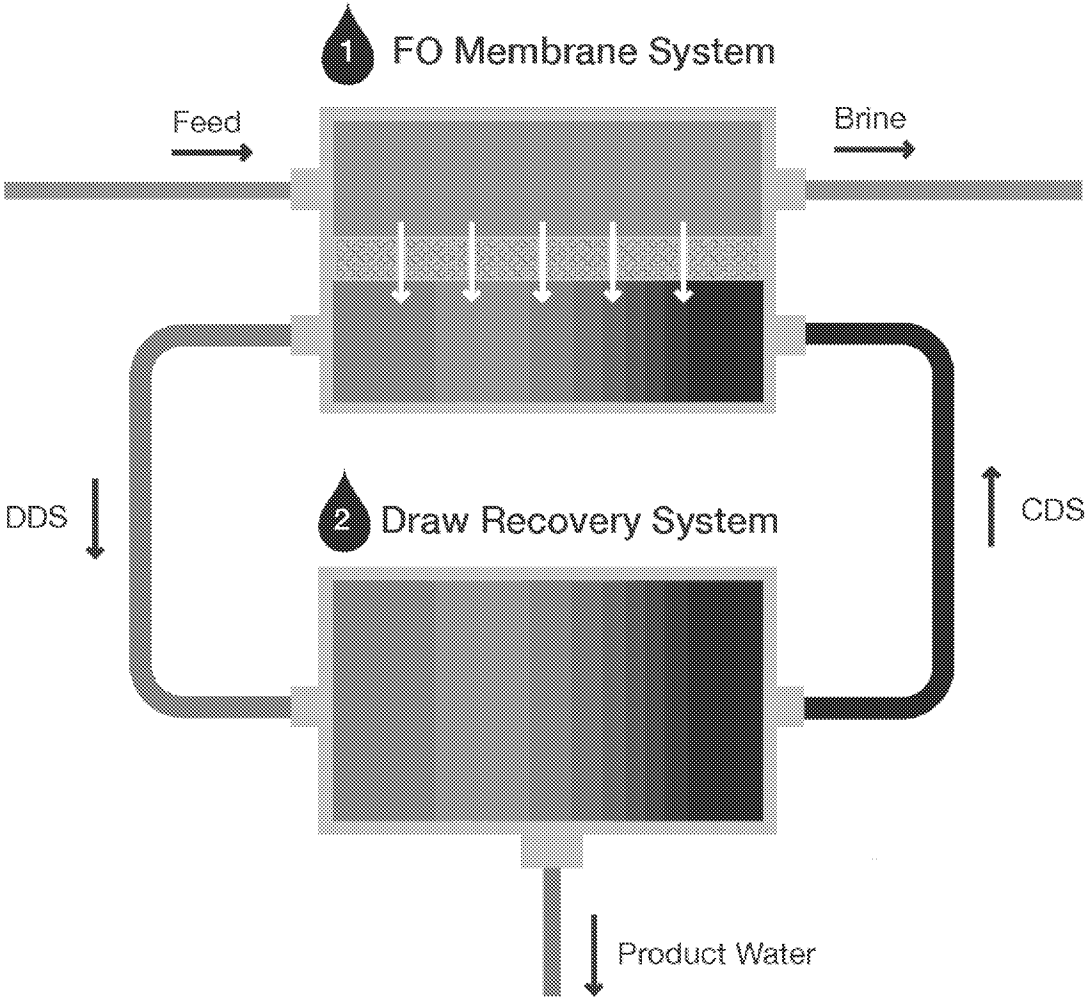
Oasys Commercial Projects
System design and project references

© 2017 Oasys Water, Inc. | Confidential

Technology Platform

Expertise in the key components of FO

OASYS WATER



3

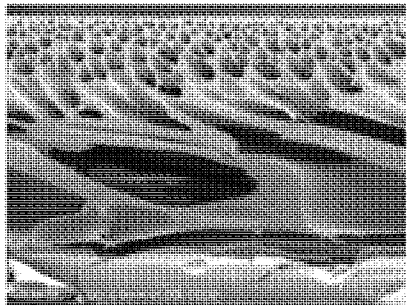
Systems Integration

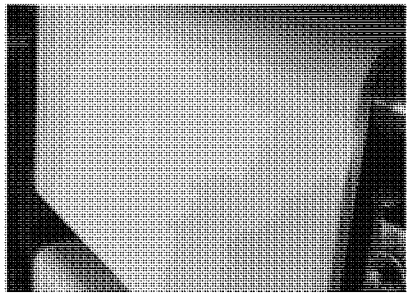
19 Issued U.S. Patents | 23 Pending U.S. Applications,
92 Issued Non-U.S. Patents | 187 Non-U.S. Applications

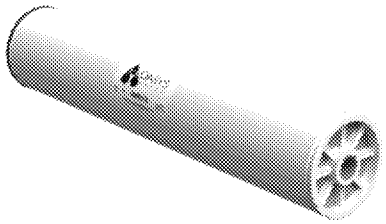
© 2017 Oasys Water, Inc. | Confidential

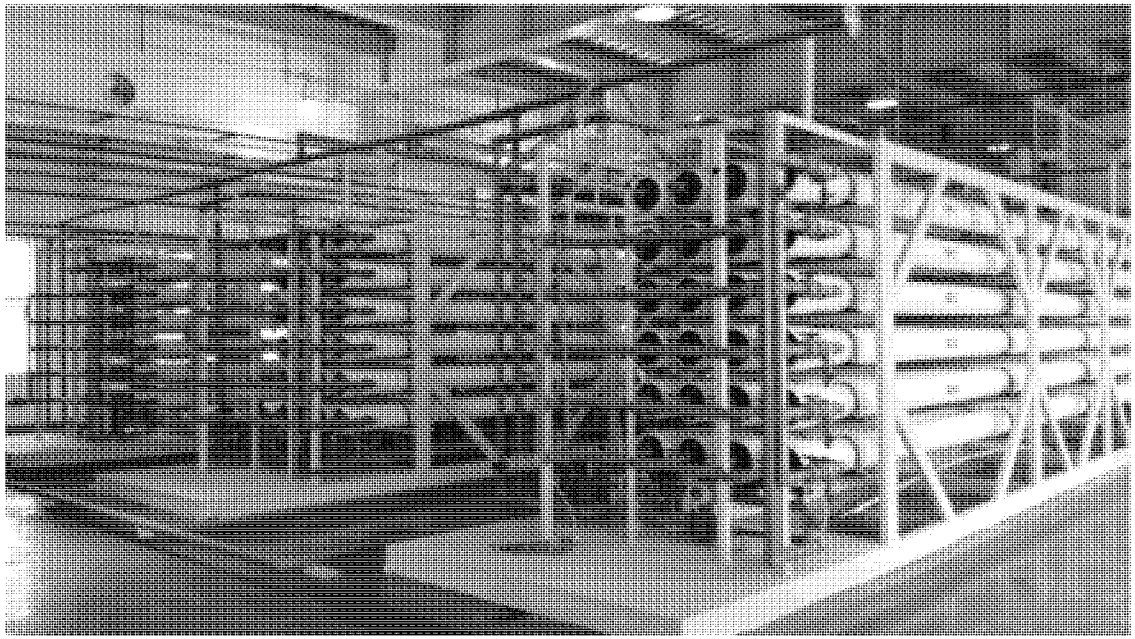
FO Membrane Technology

Core of the Oasys platform is a highly optimized membrane





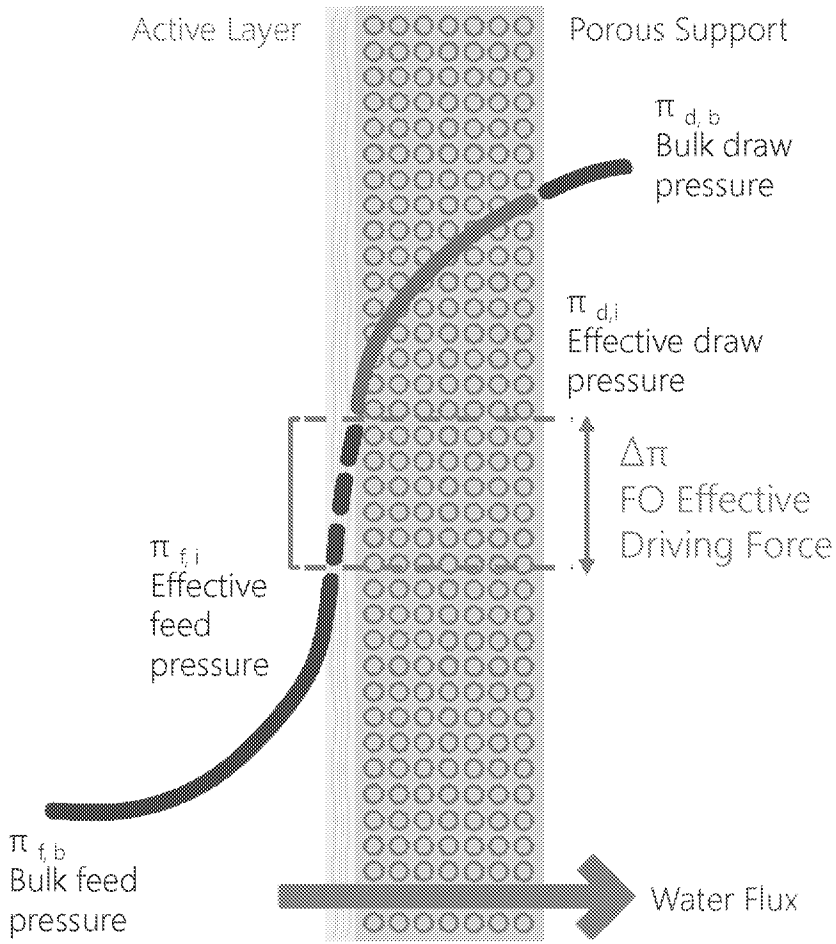




© 2017 Oasys Water, Inc. | Confidential

Forward Osmosis Membranes

Specific requirements for successful transport



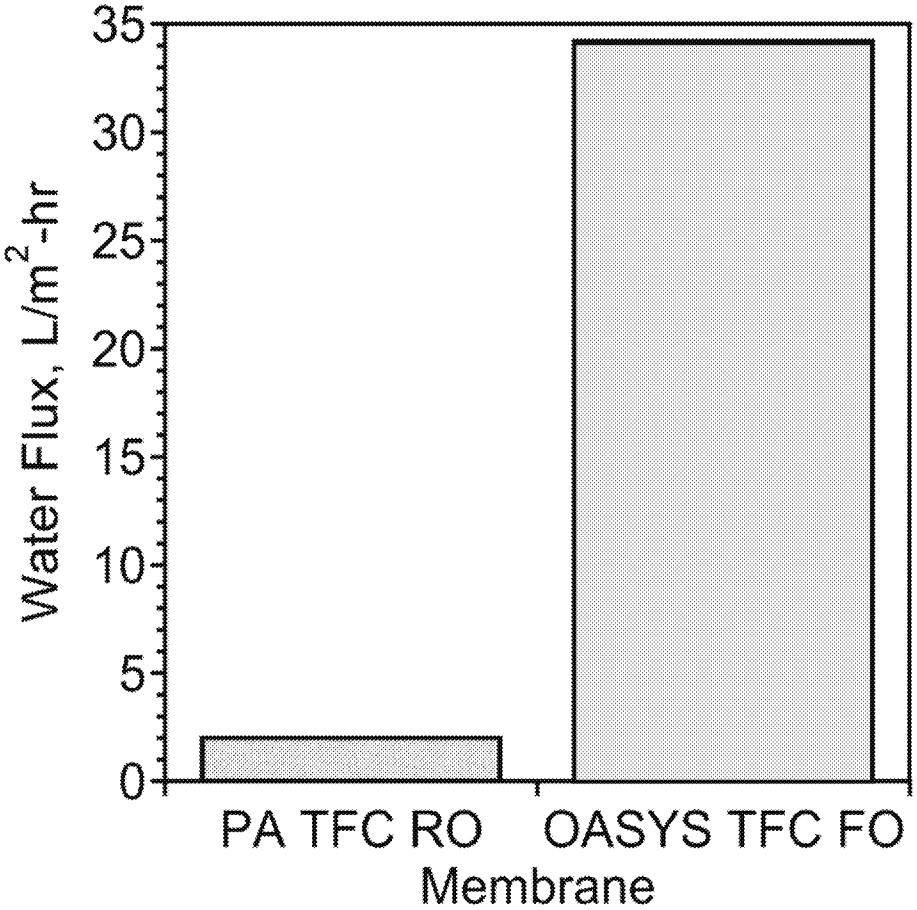
Transport through osmotic membranes limited by boundary layer effects

- Reverse Osmosis (RO)
  - Concentrative external concentration polarization
- Forward Osmosis (FO)
  - Concentrative external concentration polarization
  - Dilutive internal concentration polarization
  - Dilutive external concentration polarization

© 2017 Oasys Water, Inc. | Confidential

Oasys Membrane Technology

Custom engineered for performance in forward osmosis



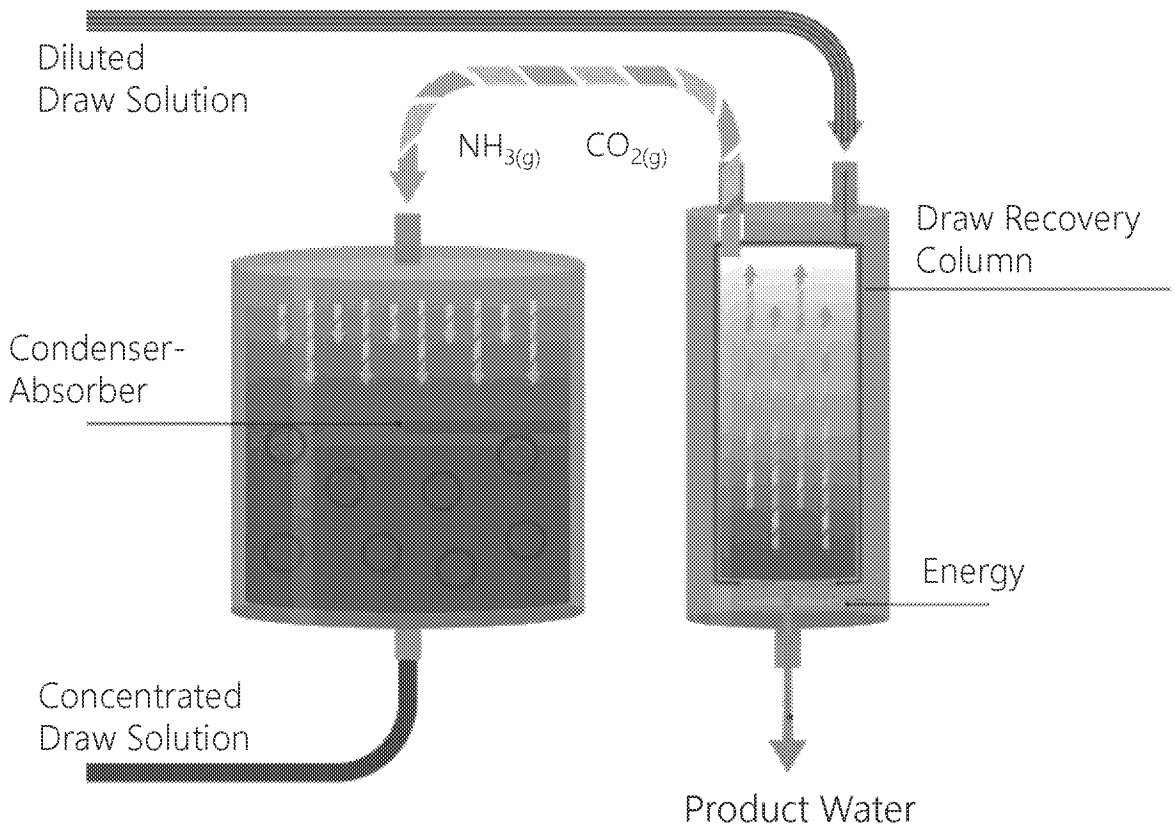
Conditions:

- Bench-scale
- Draw Solution: 6 M-C
- Feed: 28 g/L (0.5 M) NaCl
- Temperature: 25 ˚C
- Cross flow velocity: 15 cm/s

© 2017 Oasys Water, Inc. | Confidential

Thermolytic Draw Solution

Membrane performance is enabled by efficient draw solution



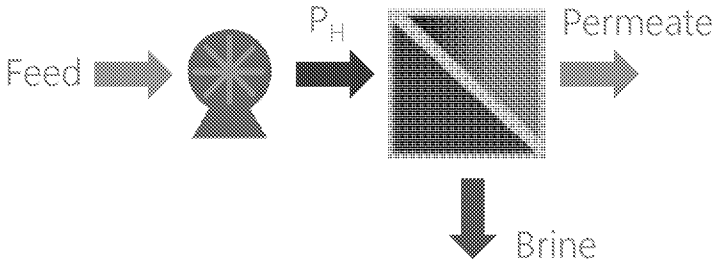
Highly soluble (> 30%) | Potent driving force (>6,000 psi)
Readily recoverable with heat | Safe & non-toxic

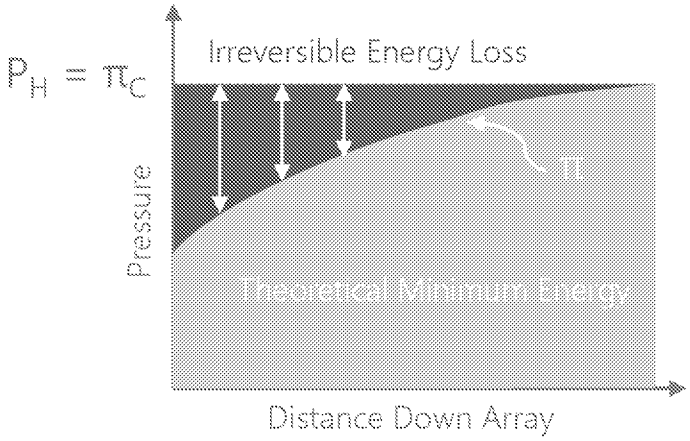
© 2017 Oasys Water, Inc. | Confidential

RO vs. FO System Design

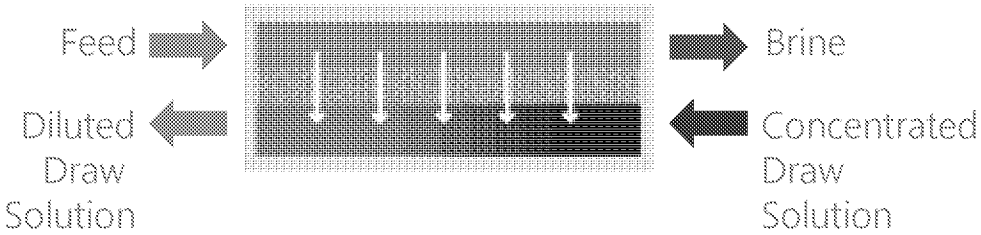
OASYS WATER

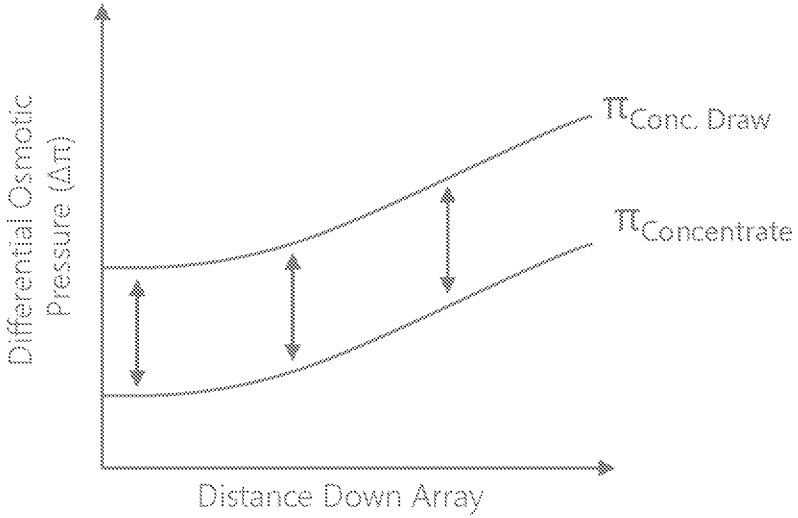
Reverse Osmosis (RO)





Forward Osmosis (FO)



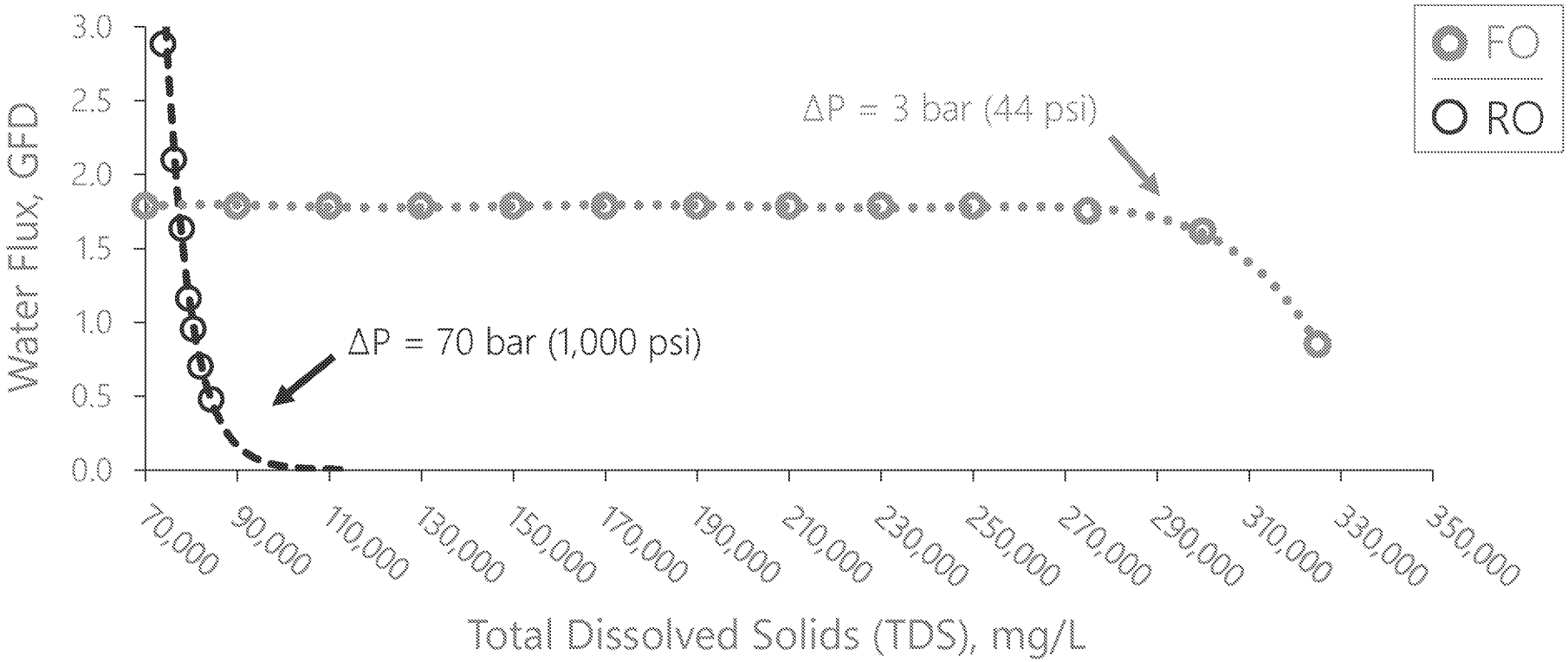


© 2017 Oasys Water, Inc. | Confidential

Rethink Water Flux

OASYS WATER

Reverse Osmosis (RO)	Forward Osmosis (FO)
Water Flux = A ($\Delta P - \Delta\pi$)	Water Flux = A ($\Delta\pi - \Delta P$)

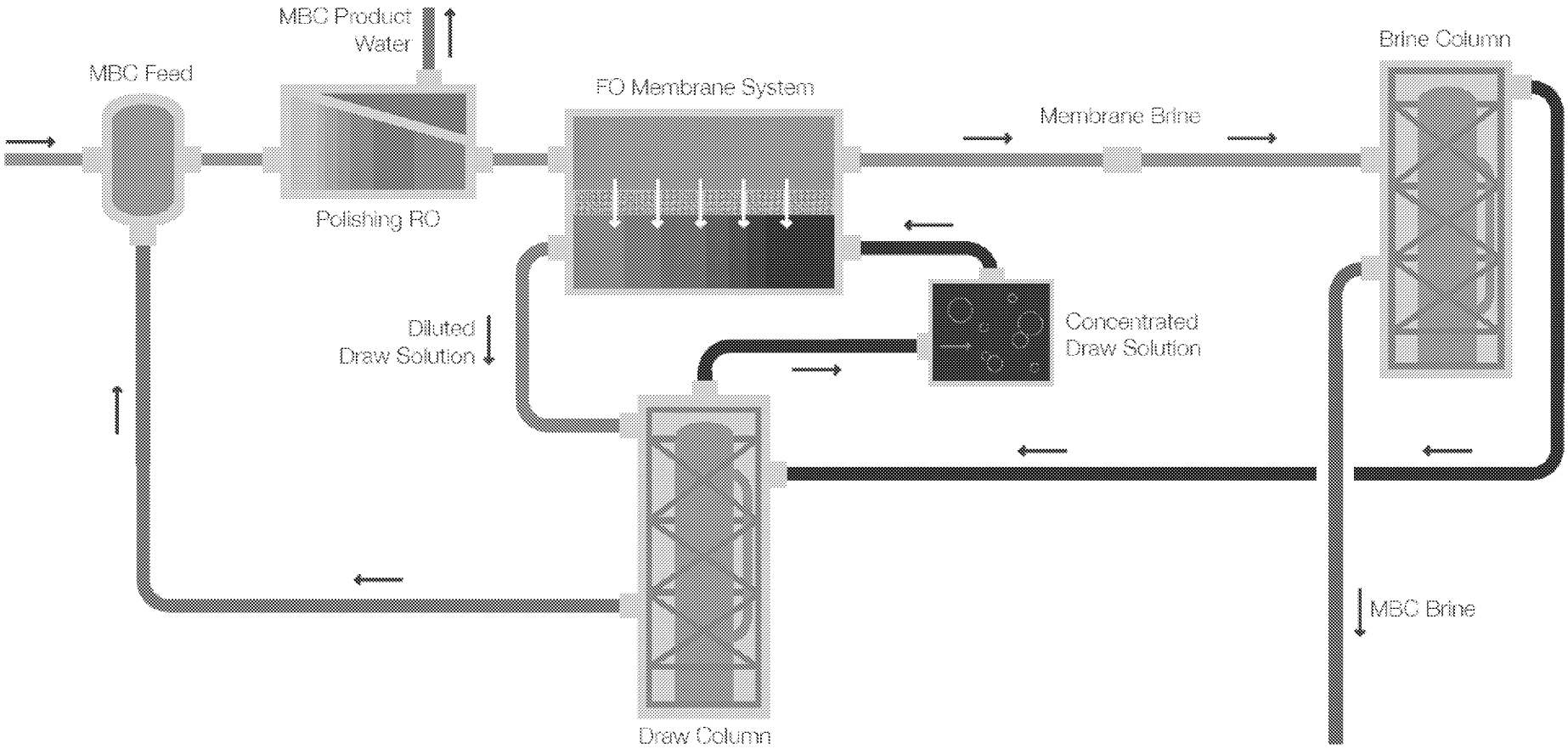


© 2017 Oasys Water, Inc. | Confidential

Membrane Brine Concentrator (MBC™)

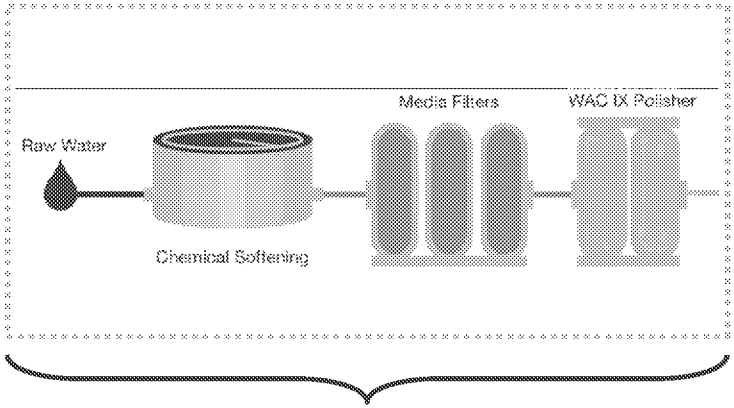
OASYS WATER

Integrated process design enables 100% recovery of draw species for high reliability, flexibility, and low OPEX

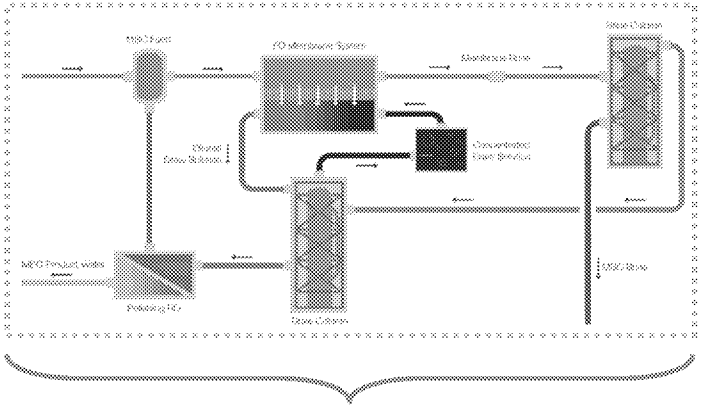


© 2017 Oasys Water, Inc. | Confidential

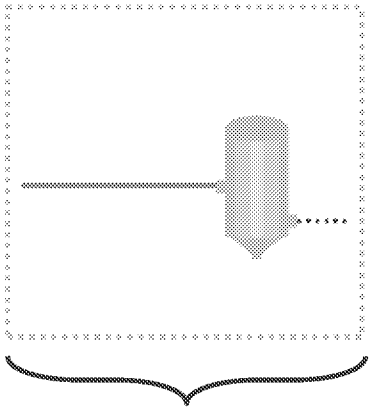
Delivering Complete Solutions



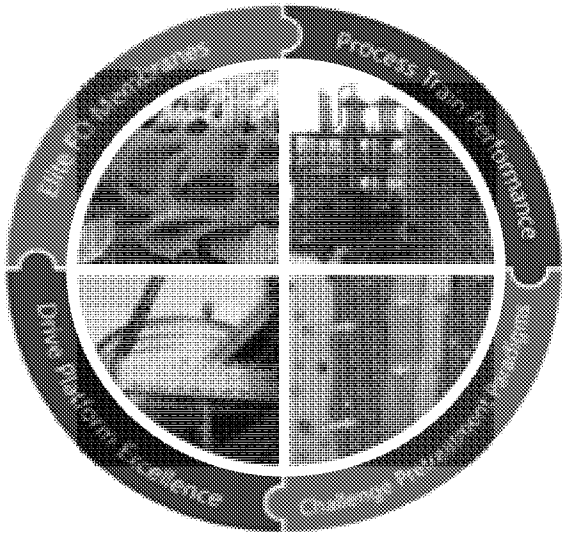
Pretreatment

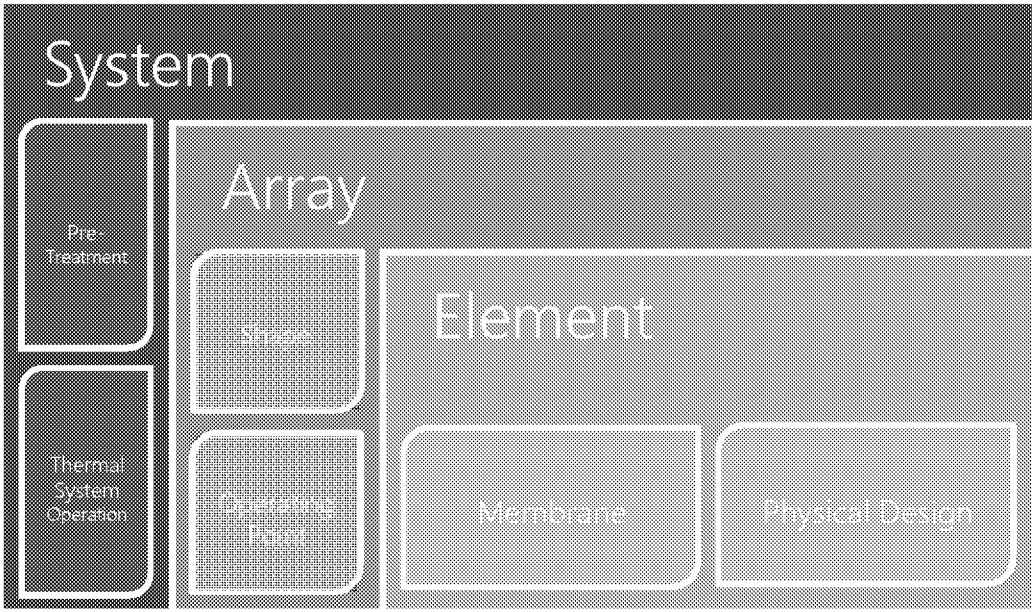


Oasys Water ClearFlo MBC



Crystallizer



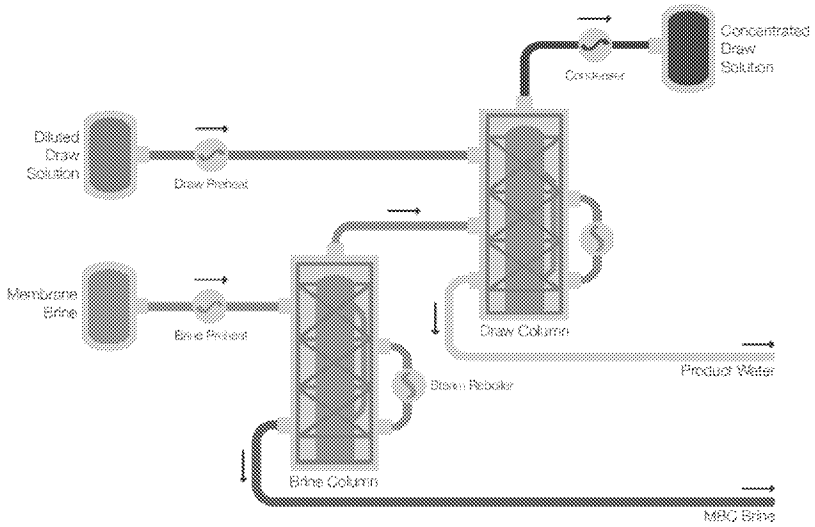


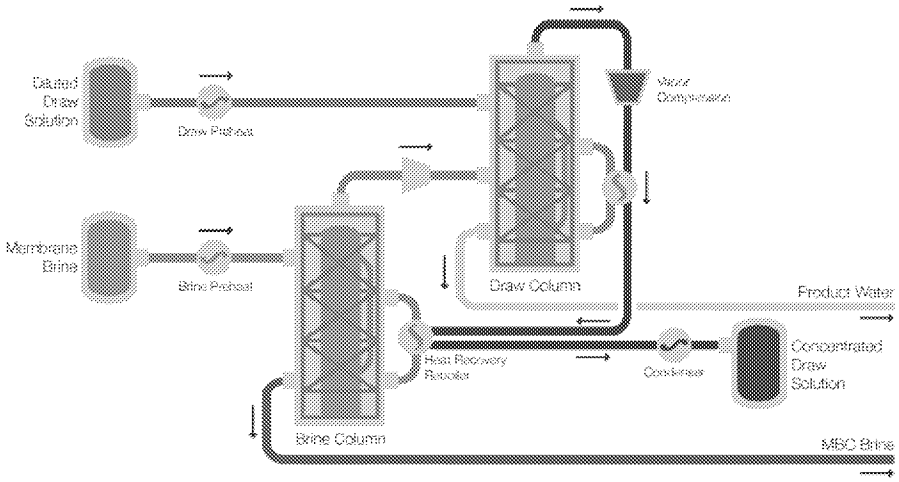
© 2017 Oasys Water, Inc. | Confidential

Versatile Design Enabled by FlexFuel™

OASYS WATER

- Draw Recovery System is thoroughly integrated for minimum energy use
- Oasys has particular expertise in the thermos-physical properties of our draw solution and in the kinetically limited steps of condensation and absorption
- Systems can be configured for a variety of energy sources
  - Low pressure steam is directly used to drive the draw recovery process where available
  - Mechanical compression enables the enthalpy of the process vapor to be utilized as the heating media for the recovery process





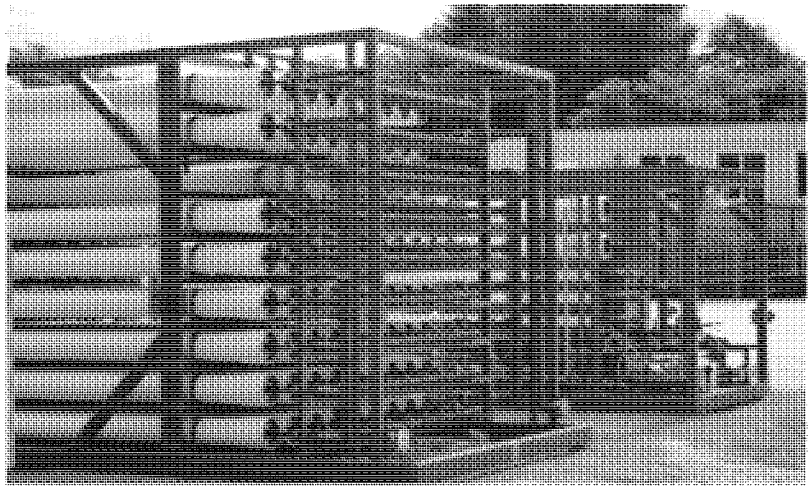
© 2017 Oasys Water, Inc. | Confidential

Versitle Design Enabled by Modularity

Oasys offers the capability to design technology solutions for any industrial application, creating customized design flexibility that can meet customer needs

OASYS WATER

Skid-Mounted Design



- Smaller footprint, portable system
- Faster installation, lower cost to install

NATIONAL OILWELL VARCO

Fixed Design

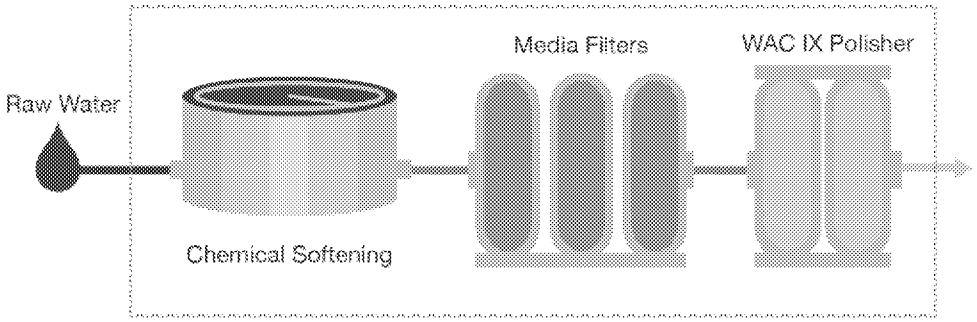
- Integrated, build-in-place technology
- Customized, bespoke design

WOTEER

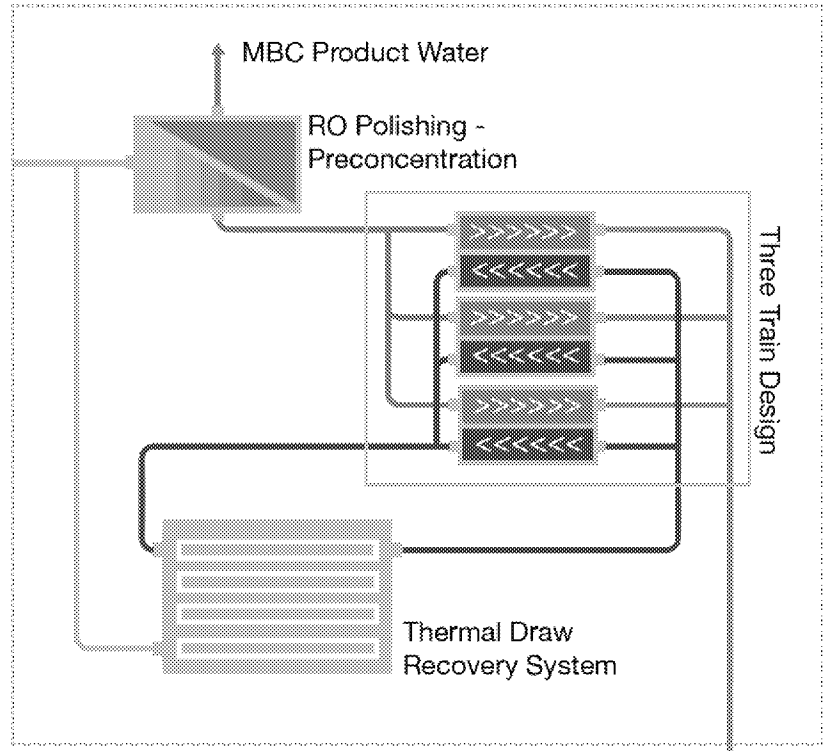
© 2017 Oasys Water, Inc. | Confidential

MBC-Based Designs

Offering Reliability with Modular, Integrated Systems

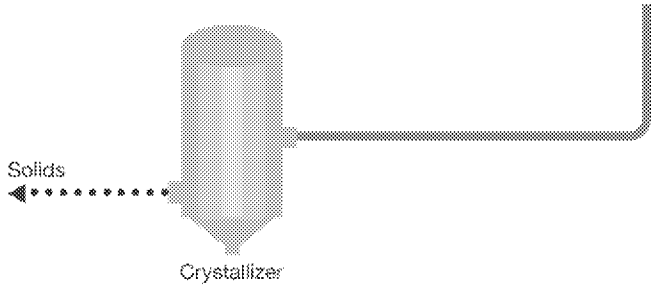


Pretreatment System



ClearFlo MBC System

MBC Product Brine



Wastewater treatment demands a flexible system design

- Pretreatment design tailored to meet the specific needs of the raw water and the MBC
- RO designed for expanded duty on low TDS incoming feed water
- FO operates as multiple trains to handle flow and quality variation
- A single draw recovery system supports multiple FO trains to minimize cost
- Integrate system delivers a more stable feed to the final processing step (e.g., crystallizer)

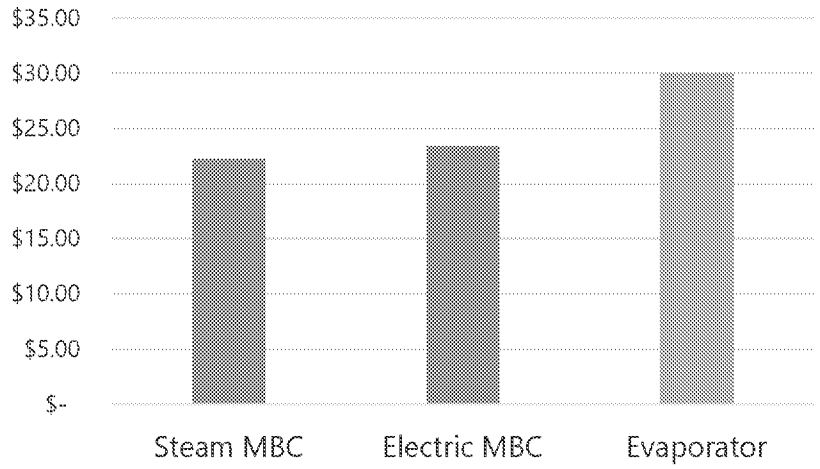
© 2017 Oasys Water, Inc. | Confidential

Competitive Analysis

Based on a partner's evaporator-based ZLD design

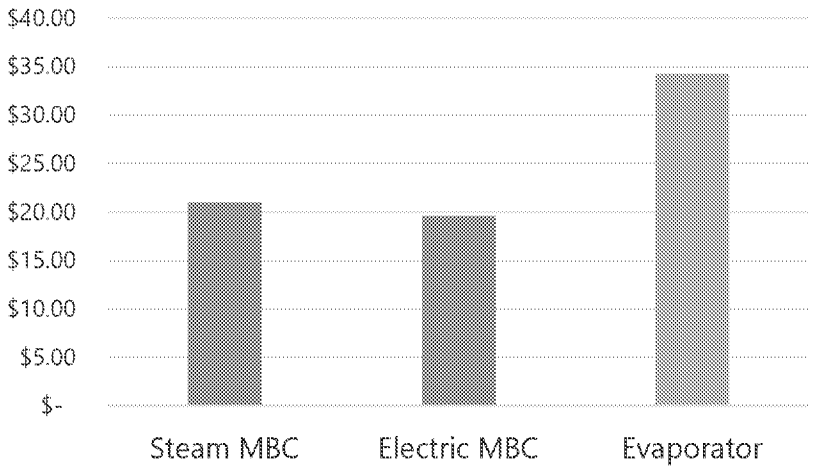
OASYS WATER

Installed CAPEX (MM USD)



- The MBC-based ZLD treatment train shows a 22-26% lower installed capital cost due to membrane-based brine concentration design
- Steam-driven MBC will be lower CAPEX, but requires slightly higher OPEX unless low pressure steam is available at low or no cost on site

OPEX (USD/m^3)



- MBC-based ZLD treatment train shows a 39-43% lower operating cost due to lower energy & chemical requirements
- Pretreatment approach demonstrated by Oasys also provides lower OPEX than competitor's approach

© 2017 Oasys Water, Inc. | Confidential

Presentation Outline

OASYS WATER

Oasys Introduction & Overview
Our Mission and Strategy

Oasys Technology Platform
FO-based brine concentration enabled by membranes, draw solutions, and systems integration

Oasys Commercial Projects
System design and project references

© 2017 Oasys Water, Inc. | Confidential

Oasys Project References

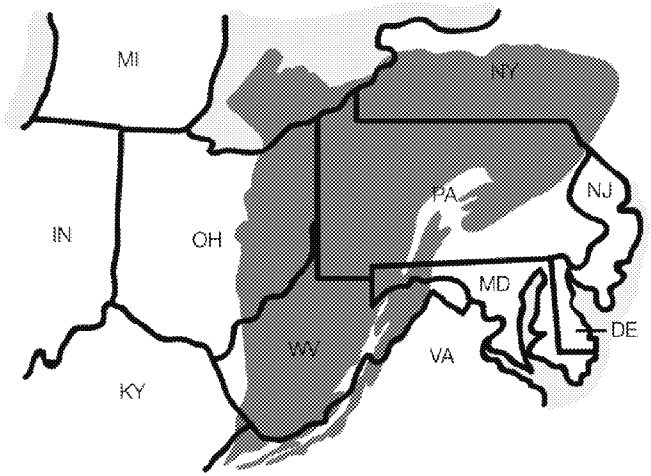
OASYS WATER

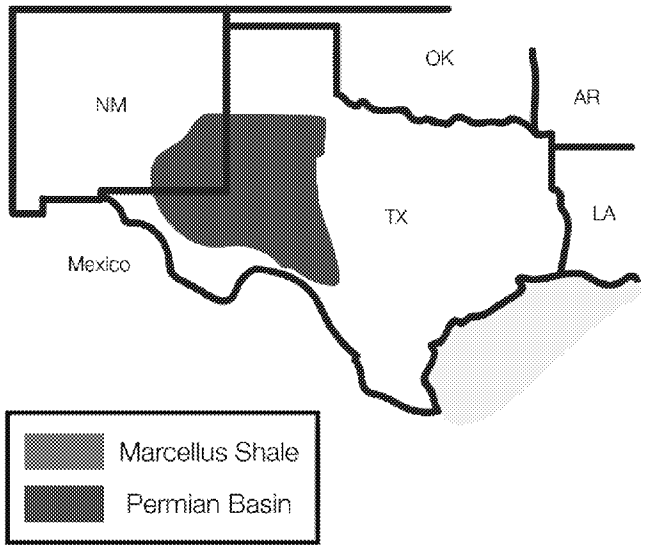
Customer	Application	Commission Date	Flow m^3/day (BPD)	Scale
Piceance Basin Produced Water Treatment Plant, Mountain West United States	Produced Water	Q2 2017	398 (210000)	Commercial
Sinopec-China Coal JV, Zhongtian Coal-to-Olefins Uxin, Ordos, Inner Mongolia Region, PRC	CTX Wastewater	Q3 2017	5,760 (36,230)	Commercial
Shanxi Lujin, Wangqu Power Station Lucheng City, Shanxi Province, PRC	FGD Wastewater	Q2 2017	288 (1,815)	Commercial
Yangmei Taihua CTX Taiyuan, Shanxi Province, PRC	CTX Wastewater	Q2 2017	1,200 (7,554)	Commercial
Water Research Center Cartersville, GA, USA	FGD Wastewater	2016	18 (113)	Pilot
Huaneng Group, Changxing Station Changxing, PRC	FGD Wastewater	2015	600 (3,775)	Commercial
National Oilwell Varco Permian Basin, Texas, USA	Produced Water	2014	630 (4,000)	Commercial
Guohua Electric Pwr., Huanghua Station Guangdong Province, PRC	MED Concentrate	2014	16 (100)	Pilot
Highland Environmental Marcellus Basin, PA, USA	Produced Water	2012	16 (100)	Pilot
Select Energy Services Permian Basin, TX, USA	Produced Water	2012	16 (100)	Pilot

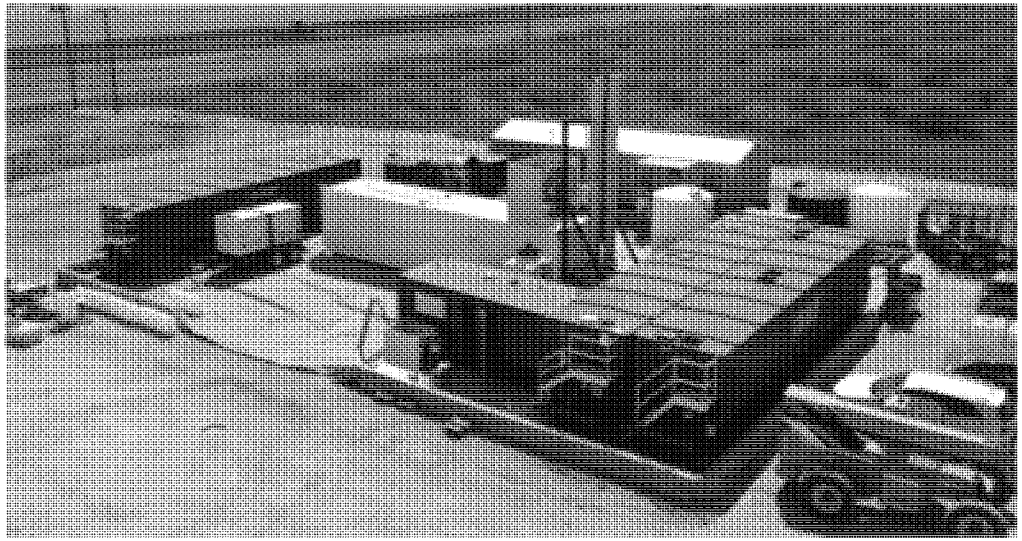
© 2017 Oasys Water, Inc. | Confidential

MBC Demonstrations for US Oil & Gas

OASYS WATER







- Variety of medium-high TDS and waters handled
- 50 – 150,000 TDS feed, 3 – 15,000 Hardness range treated
- High recovery, robust, and high availability demonstrated
- Membrane life and resilience validated
- 2 years / 4,000+ hours of operation
- Testing, continuous and shift-based regimes
- Varying conditions and locations
- Movability of system demonstrated and improved

Pilot demonstration of the NH_3-CO_2 forward osmosis desalination process on high salinity brines

The 2013 Global Water Awards: Shortlisted entries

INDUSTRIAL WATER PROJECT OF THE YEAR

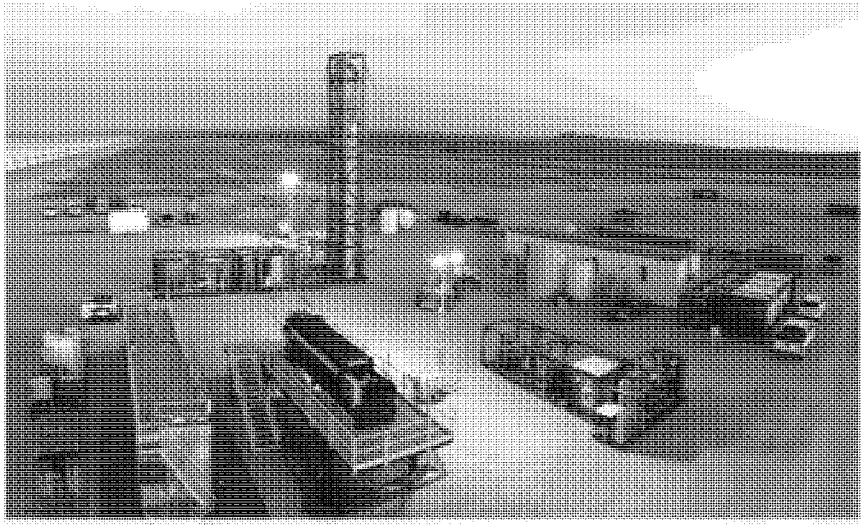
© 2017 Oasys Water, Inc. | Confidential

Delivering Best-In-Class O&G Solutions

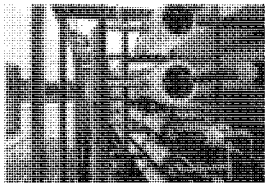
OASYS WATER

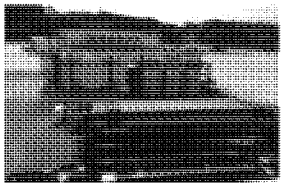
Oasys Water's Field Deployable ClearFlo MBC system for NOV

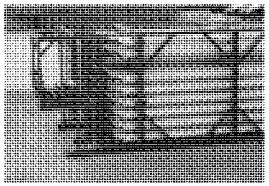
- Strategic partnership with National Oilwell Varco (NOV)
  - Oasys and NOV jointly work to design, build, and deliver O&G systems
  - NOV owns and operates the joint Oasys-NOV systems for O&G producers across North America
- ClearFlo MBC System Features for O&G:
  - Moveable
  - Robust
  - Flexible Feed Range
  - Fully Contained
  - Electric-driven

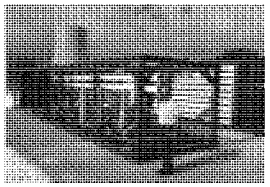


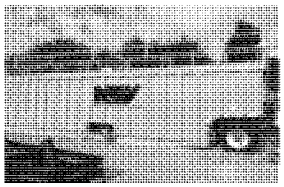
Electric-Powered ClearFlo MBC system Treats 4000 BPD of Produced Water

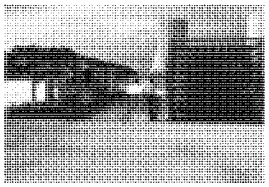










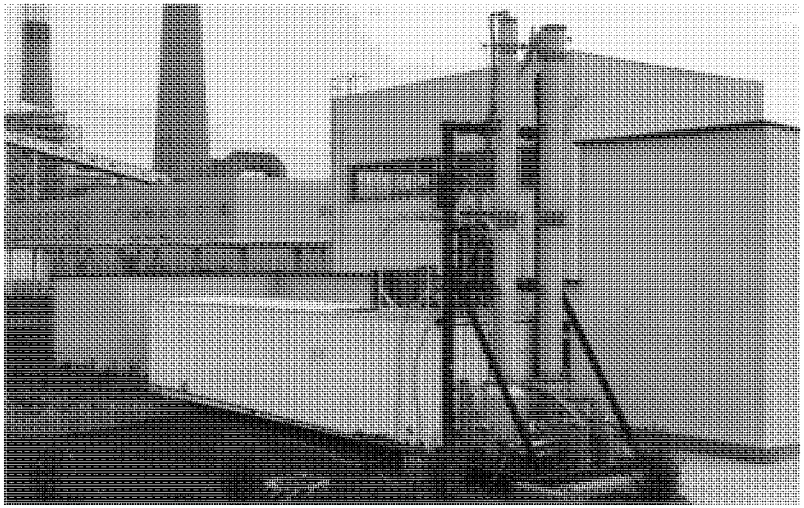


© 2017 Oasys Water, Inc. | Confidential

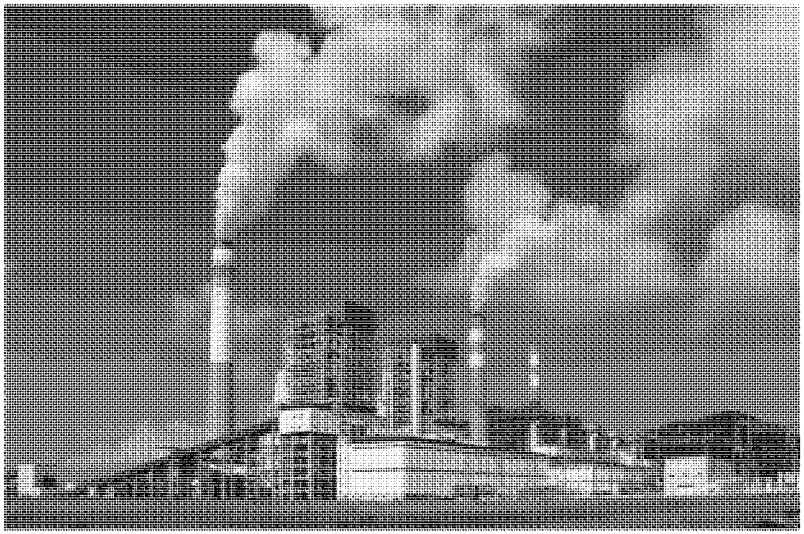
MBC Demonstration for China

OASYS WATER

- Located at the Guohua Huanghua Powerplant to demonstrated Oasys technology to Sinopec, PetroChina, and others
- Operated Q4 2014 - Q1 2015
- Treating MED effluent from the power plant
- Jointly deployed with partner company, Beijing Woteer, who led the pretreatment system operation



Oasys MBC Pilot System Deployed in China



Guohua Huanghua Powerplant

© 2017 Oasys Water, Inc. | Confidential

Commercial Projects in China

OASYS WATER

Oasys FO-based solutions gaining momentum in China's Power & Energy industries

1 Changxing coal fired power plant

- Huaneng Group
- ZLD for FGD wastewater
- 600 m^3/day feed

2 Yangmei Taihua Coal-to-Chemical

- Taiyuan, Shanxi Province
- ZLD for steam boiler makeup water plant streams
- 1,200 m^3/day feed

3 Zhongtian Coal-to-Olefins

- Sinopec – China Coal JV
- Uxin, Ordos, Inner Mongolia region
- Combined process unit streams
- 6,000 m^3/day feed

4 Shanxi Lujin Wangqu Power

- Lucheng City, Shanxi
- ZLD for FGD wastewater
- 300 m^3/day feed

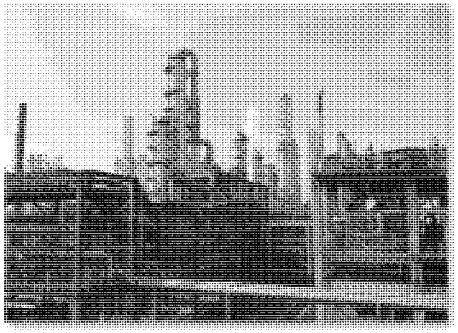
© 2017 Oasys Water, Inc. | Confidential

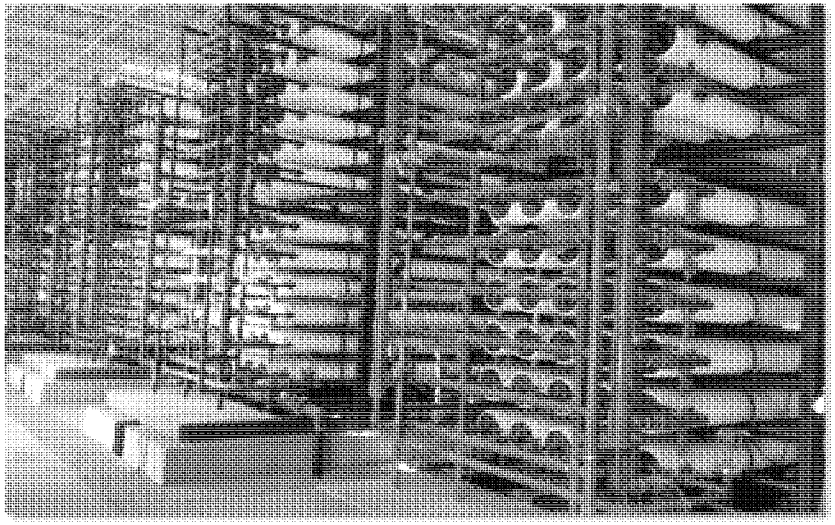
Zhongtian Hechuang CTX ZLD Project

Largest MBC Project to Date – designed to API standards

OASYS WATER

- Third Oasys-Woteer commercial project treats a combined process wastewater stream at SinoPec /China Coal JV CTX complex to ZLD
- Located in Uxin, Ordos, Inner Mongolia region
- Demonstrates scalability of the MBC
- Commissioning Q3 2017
- Process includes
  - 5,760 m^3/d overall capacity
  - Pretreatment includes chemical softening + filtration
  - Two trains of MBC, at 91% recovery
  - 490 m^3/d crystallizer

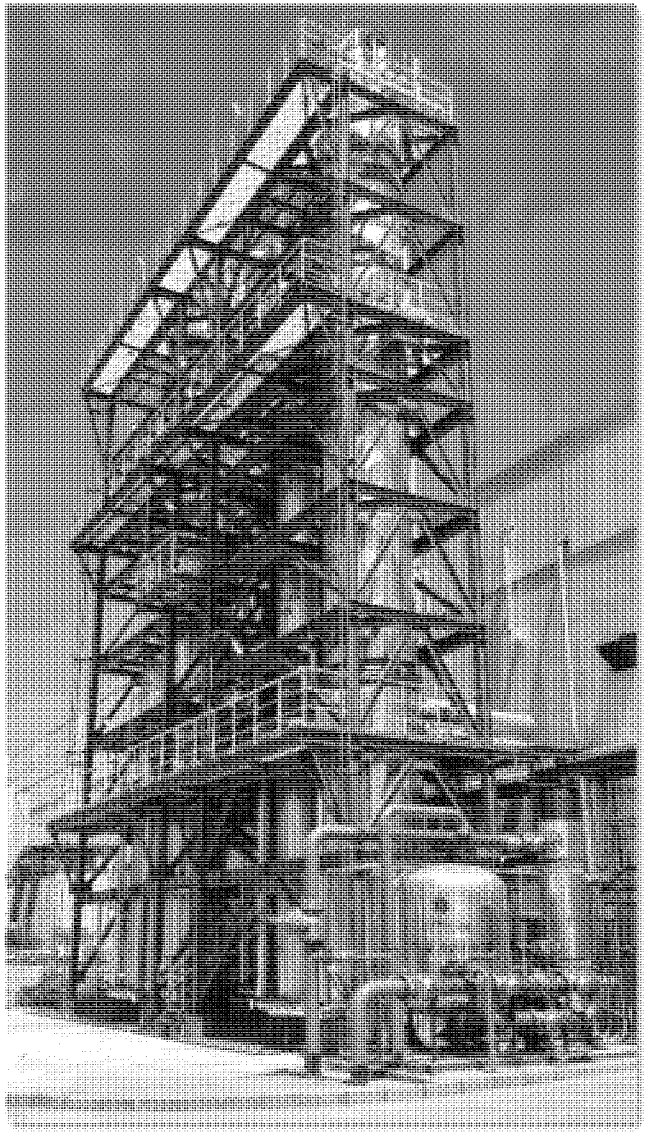


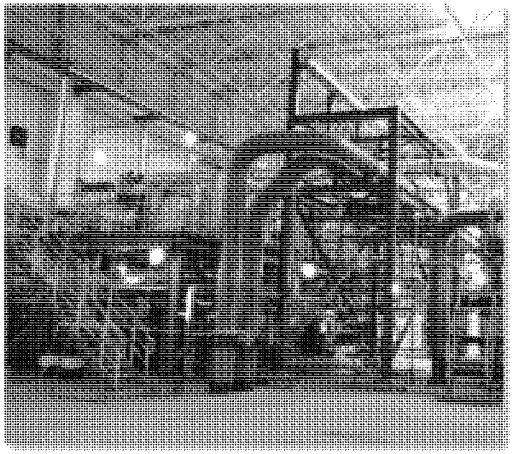


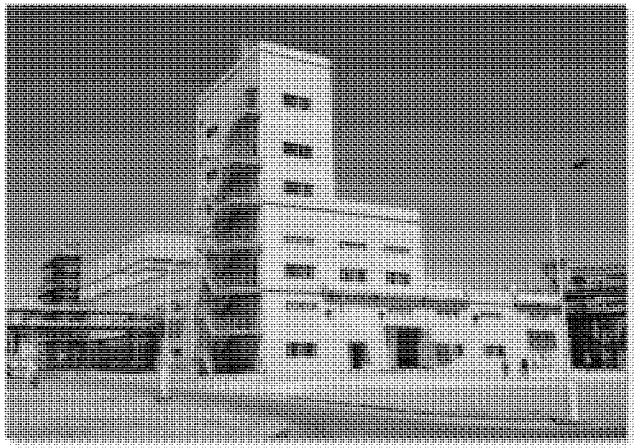
© 2017 Oasys Water, Inc. | Confidential

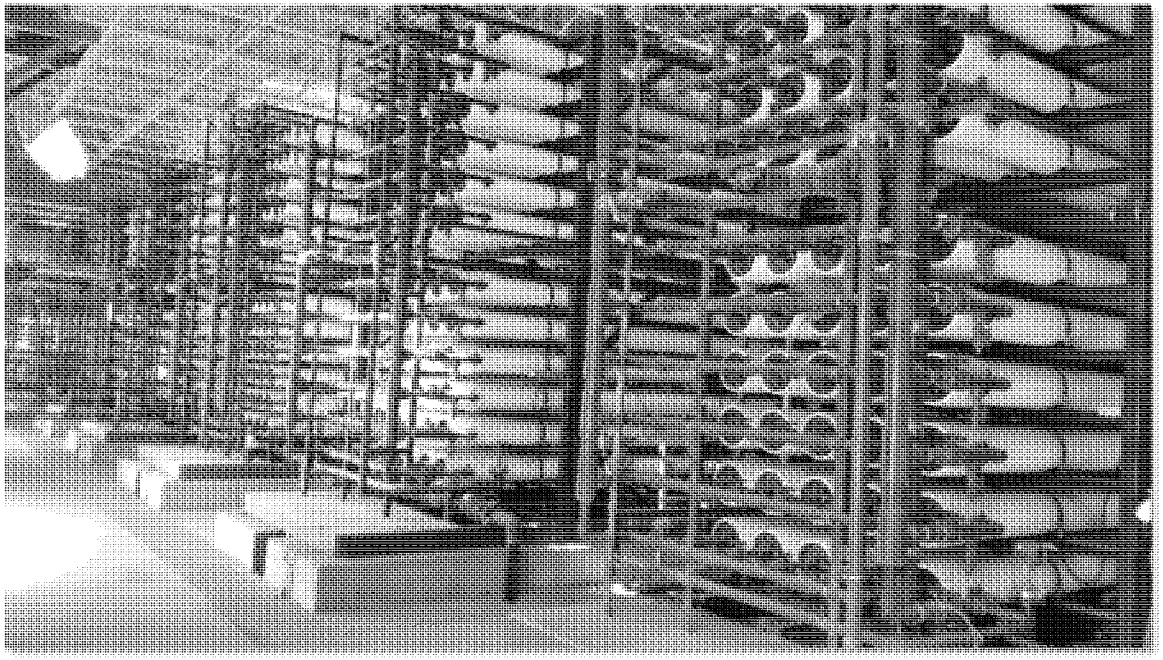
Zhongtian Hechuang CTX ZLD Project

Largest MBC Project to Date – designed to API standards









© 2017 Oasys Water, Inc. | Confidential

Changxing Power FGD ZLD Project

OASYS WATER

End User: China Huaneng Group

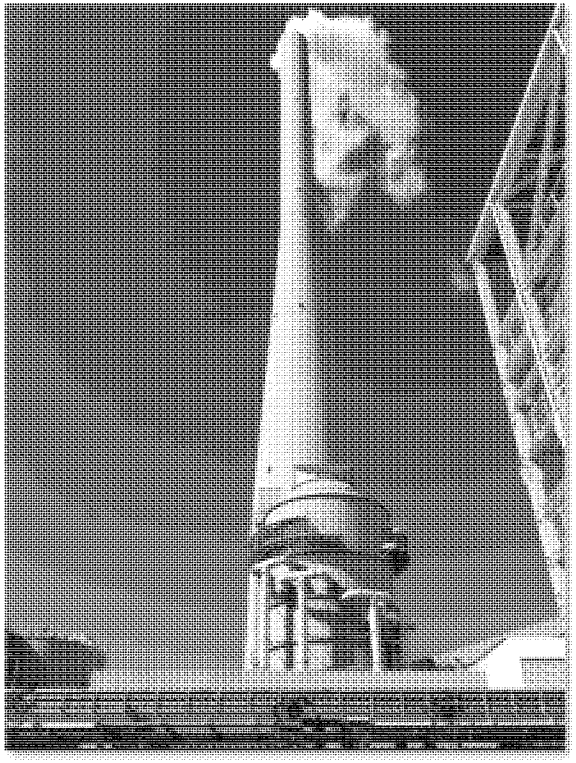
- One of 5 largest state owned electric (SOE) utilities
- First High Efficiency Ultra-Supercritical project utilizing domestic 2x660MW coal-fired generation units

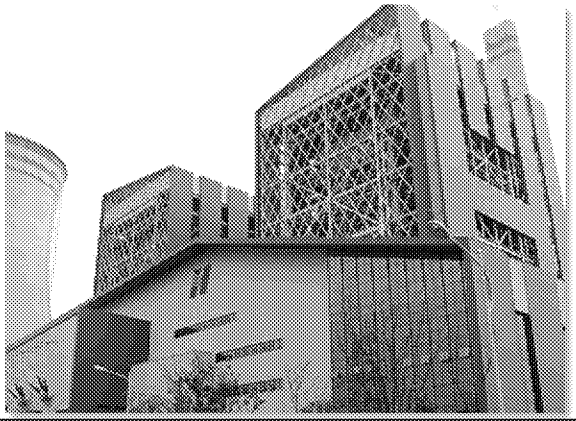
Project

- First in the world FO based ZLD plant
- 25 m^3/h of Flue Gas Desulfurization (FGD) wastewater
- Draw solution recovery powered by low pressure (5 bar) steam

Oasys Offering Includes:

- End-to-end engineering and design
- Technology package
- Supply chain development
- Control system and HMI panels
- FO elements
- Column design and packing
- Procurement & fabrication oversite
- Commissioning, startup, and training





中国华能集团公司 CHINA HUANENG GROUP

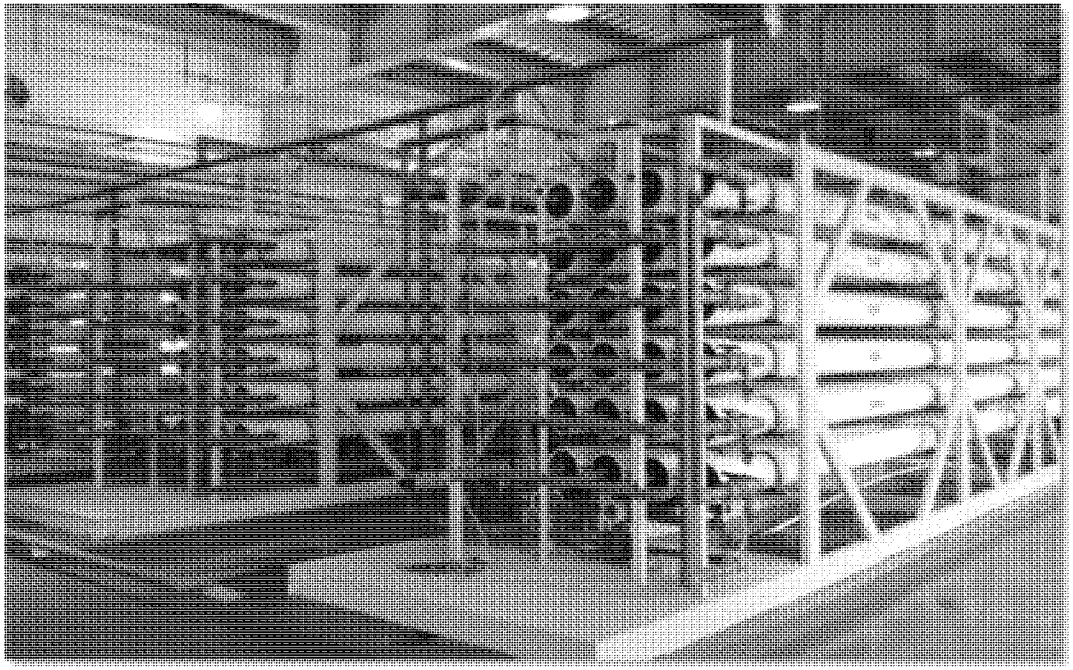
WOTEER 沃特尔

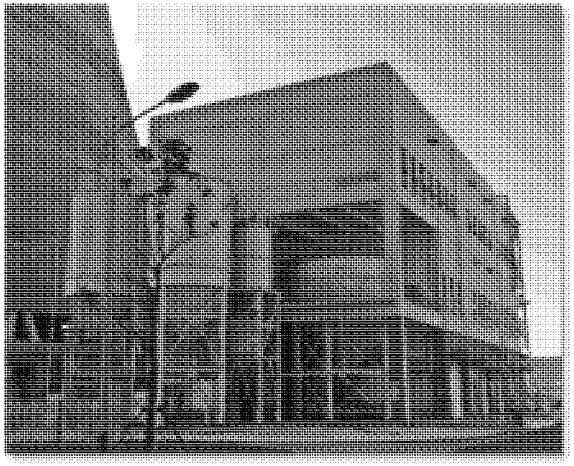
© 2017 Oasys Water, Inc. | Confidential

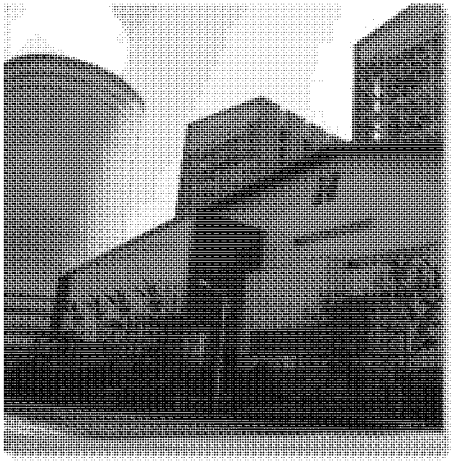
Huaneng Changxing Power Plant

World's First FO-Based ZLD Solution

OASYS WATER



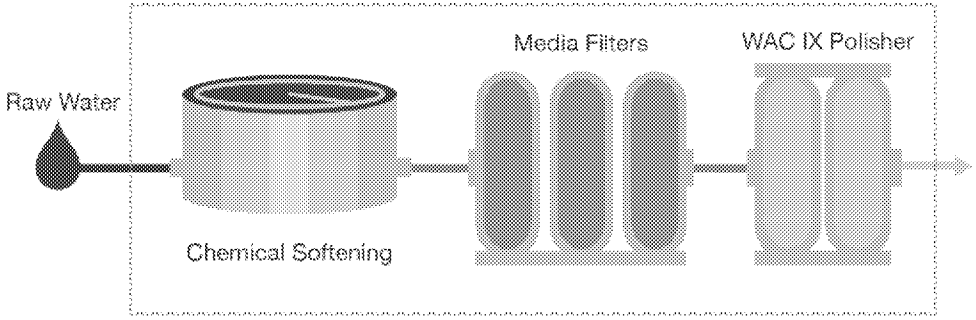




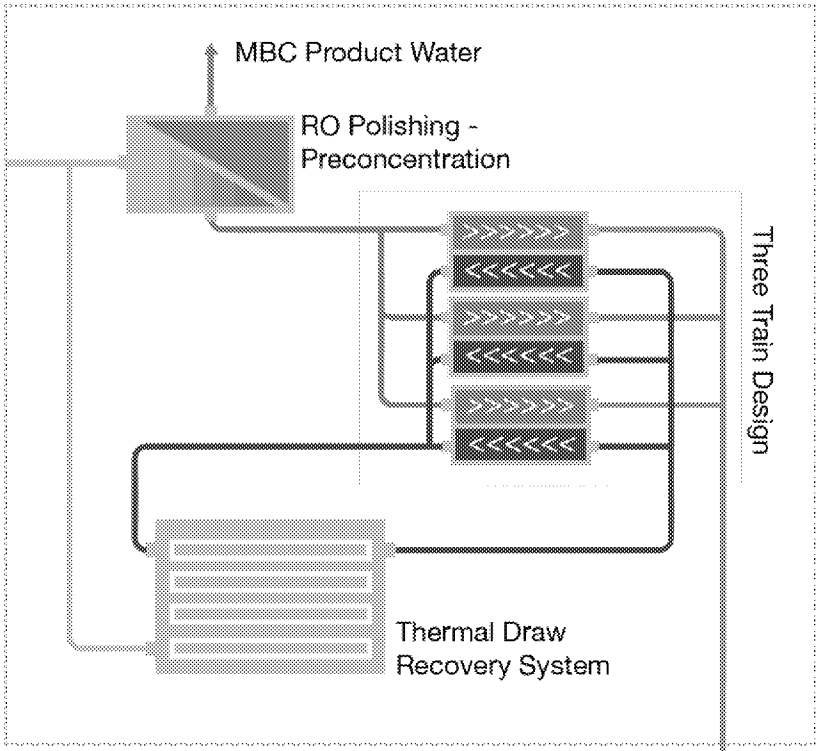
WOTEER 沃特尔

© 2017 Oasys Water, Inc. | Confidential

Proven Operational Flexibility

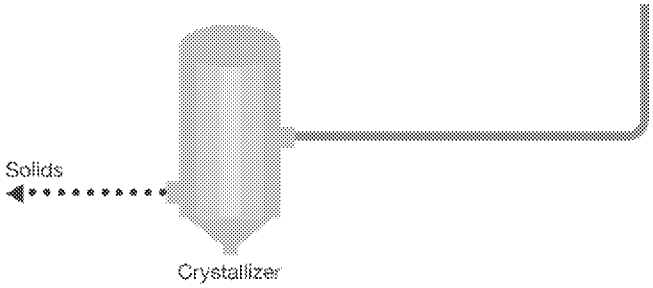


Pretreatment System



ClearFlo MBC System

Parameter	Design Specifications	Operational Data
Raw feed flow	15.0-26.4 m^3/h (66-116 gpm)	27.0-30.0 m^3/h (119-132 gpm)
Raw feed TDS	25,000-40,000 mg/L	8,600-9,500 mg/L
MBC brine TDS	>220,000 mg/L	>220,000 mg/L
MBC product water TDS	<100 mg/L	35-50 mg/L
Overall water recovery	79 – 88%	93-97 %



© 2017 Oasys Water, Inc. | Confidential