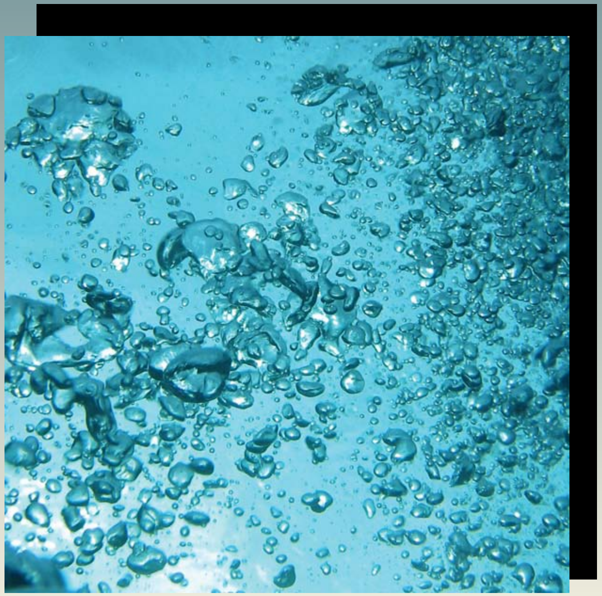
Exploring a New Aeration Technology

Is it Right for Your System?



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Presentation Overview

- Technology Background
- Process Fundamentals
- Traditional Aeration Technologies
- New Membrane Contactor Technology

Terminology

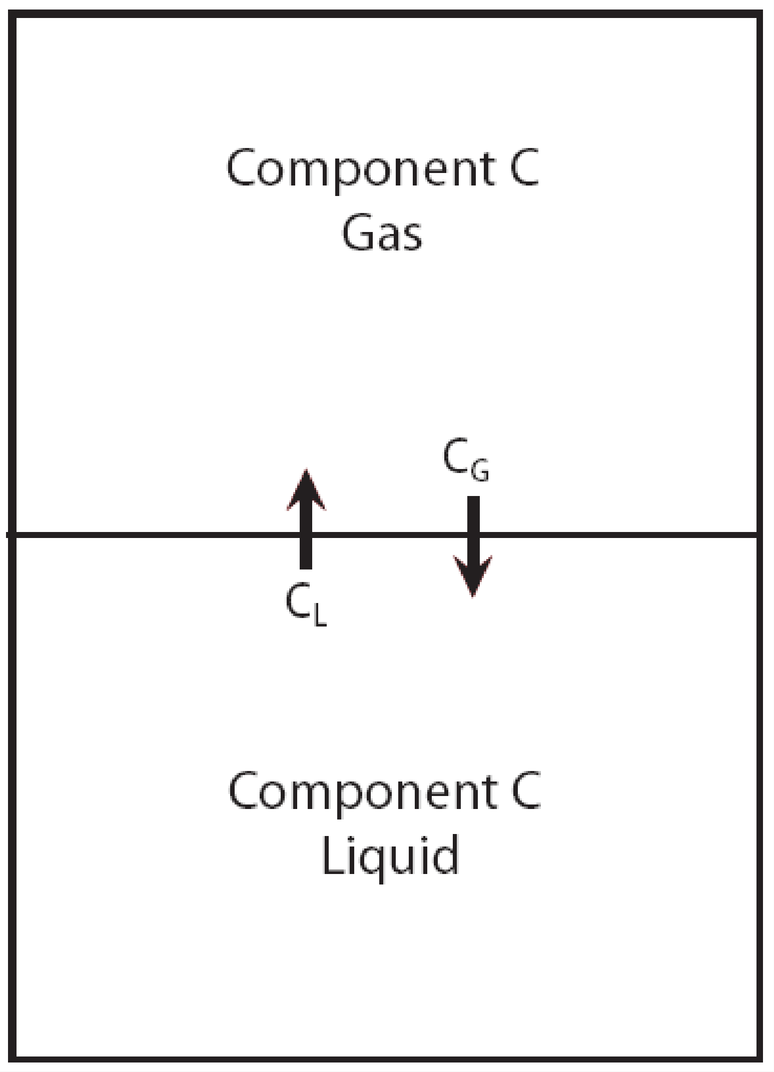
- Really talking about "Gas Transfer"
- Aeration vs. Degassing

Why Consider Aeration?

- Corrosion Control
- Remove Volatile Organic Compounds (VOCs)
- Remove Radon
- Remove THMs
- Oxygenation
- Remove Hydrogen Sulfide
- Remove Ammonia

Aeration Principles - Equilibrium

Component in solution tends to seek equilibrium with gas phase



Aeration Principles – Henry's Law

- Equilibrium reactions are described by Henry's Law
- Each gas has a Henry's Constant (or Coefficient)
- Higher Henry's Constant = easier to strip from solution
- Dimensionless Henry's Constant >0.01 can be effectively removed using aeration

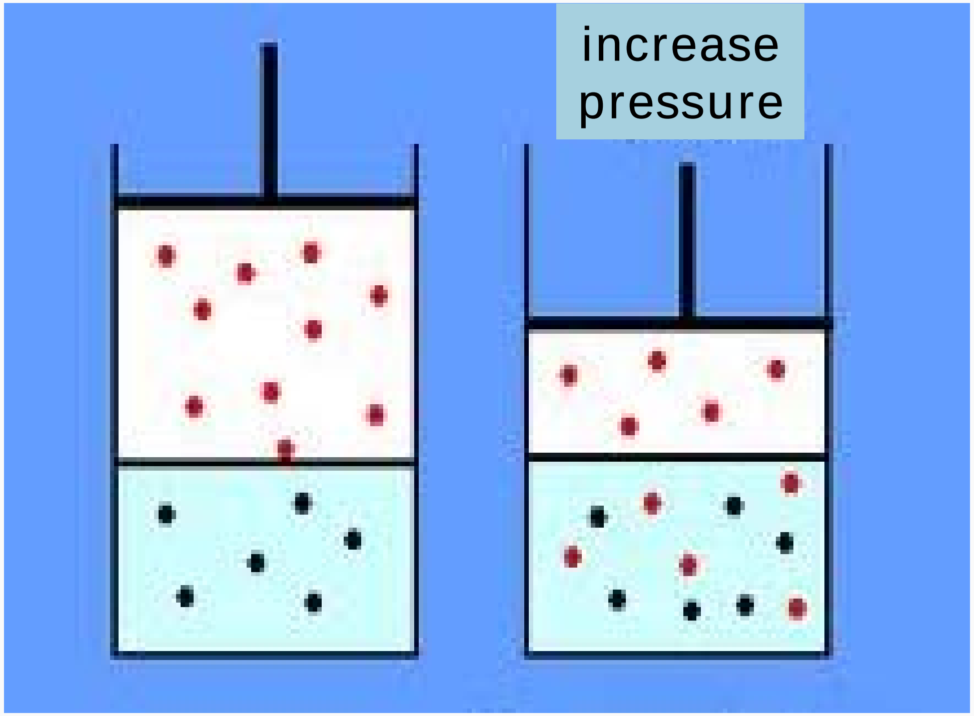
$$H = C_{gas}/C_{liquid}$$

Henry's Coefficients at 20°C

Constituent	Henry's Coefficient (units of L_w/L_a)
O_2	32.5
Radon	4.08
CO_2	1.14
PCE	0.586
H_2S	0.389
TCE	0.350
Chloroform	0.138
Ammonia	0.000574

Gas Solubility

Pressure



Temperature

↑T = ↑H = ↓Solubility

Process Fundamentals

Common Process Variables

- Liquid flow rate
- Air flow rate

} Air to Water Ratio

- Reaction surface area
- Contact time
- Driving force (concentration gradient)

Aeration Systems are “Percent Removal” Machines

Gas Transfer Approaches

- **Aeration**
  - Spray (nozzle)
  - Mechanical
  - Cascade
  - Diffused bubble
  - Tray
  - Packed Tower

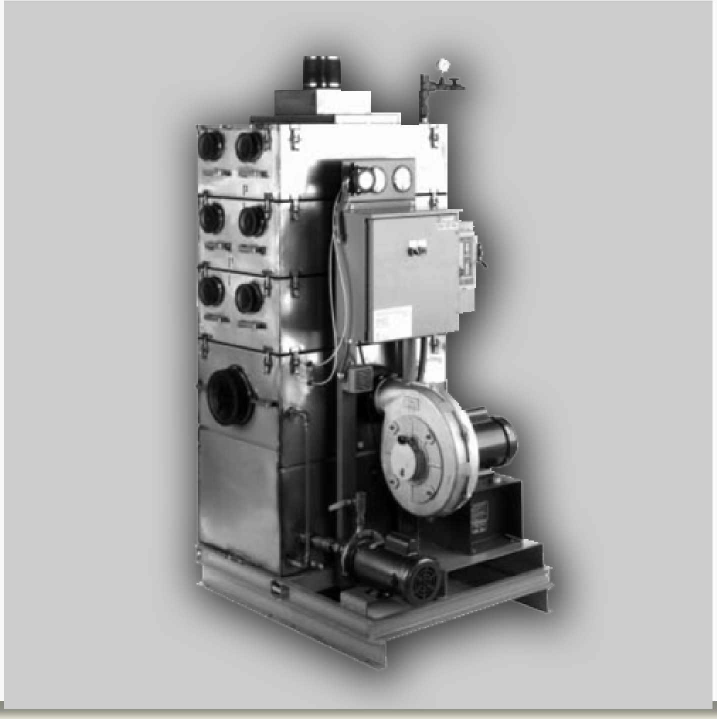
All aeration processes require exposure to atmospheric pressure

- **Degassing**
  - Membrane Contactor
  - Centrifugal/Vortex

Degassing can occur under system pressure or using vacuum

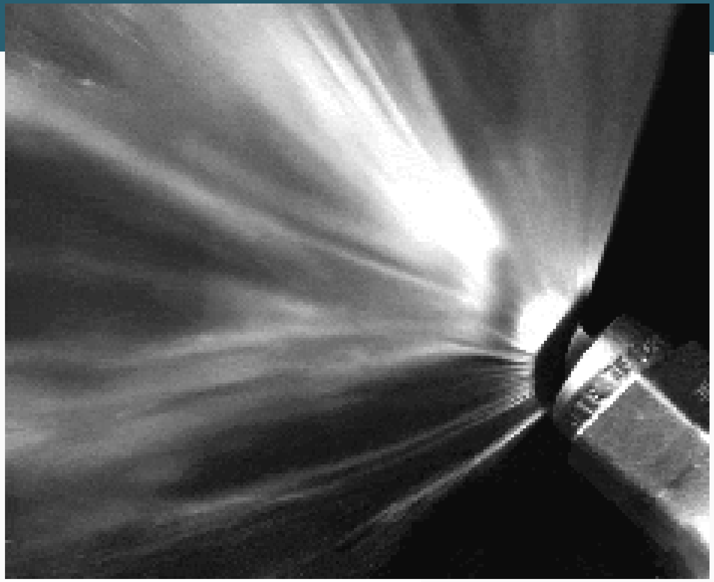
Tray Aeration

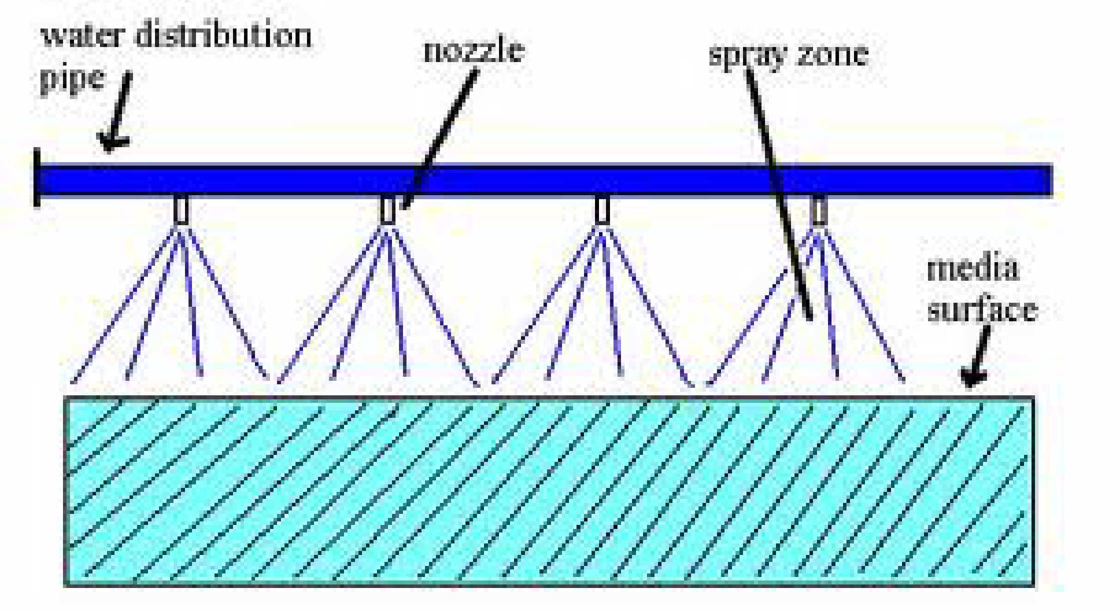
- Can use forced air or natural draft
- Must collect treated water and re-pump



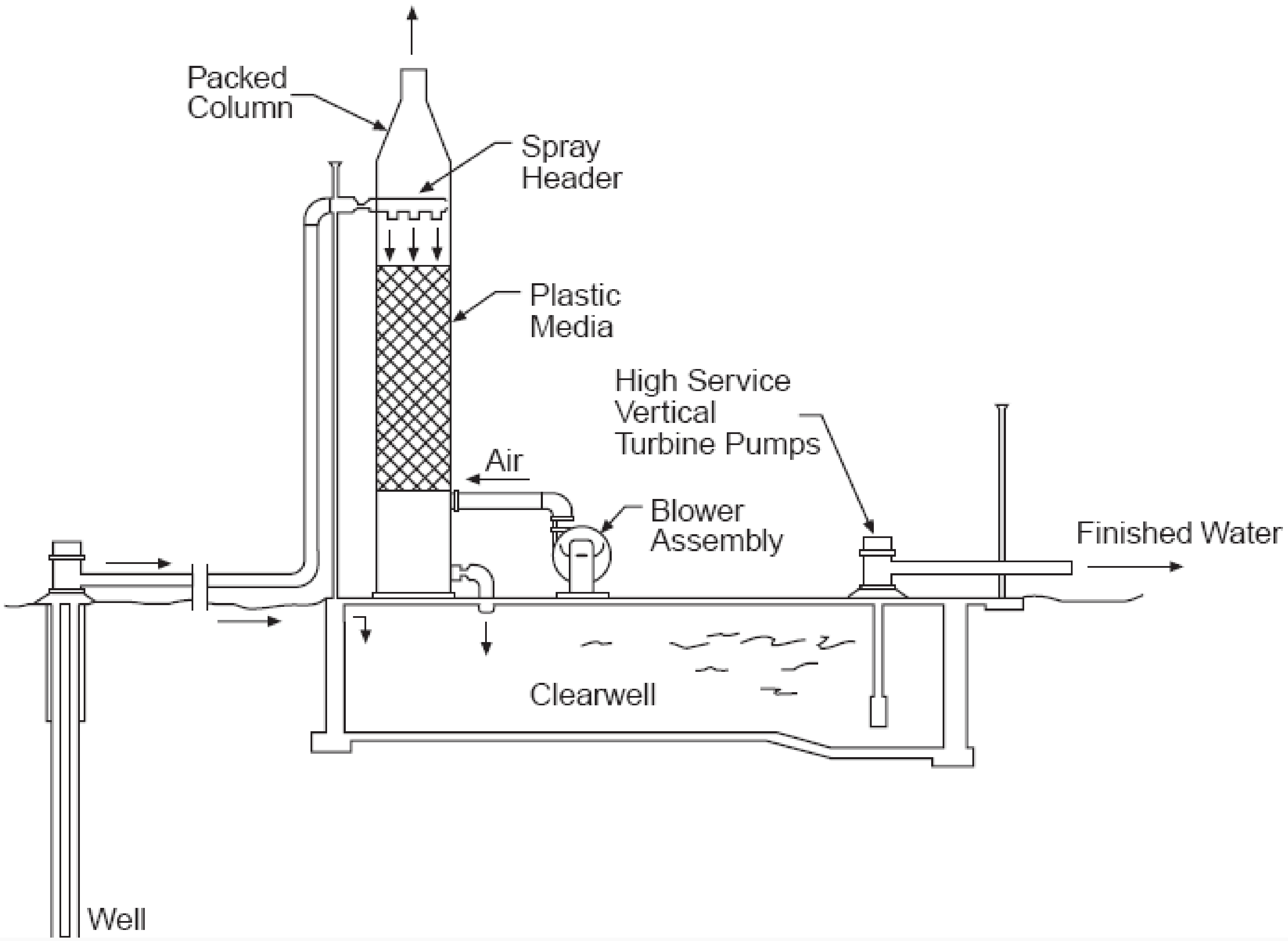
Spray (Nozzle) Aeration

- Low cost and complexity
- Low efficiency (≤ 50%)
- Can be installed in reservoirs



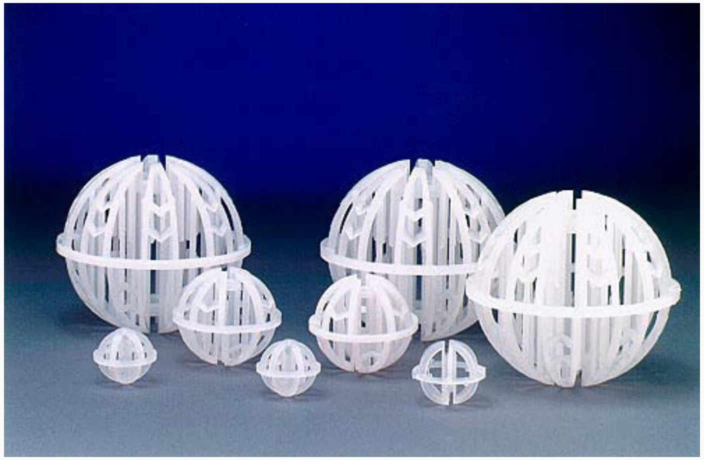


Packed Tower Aeration



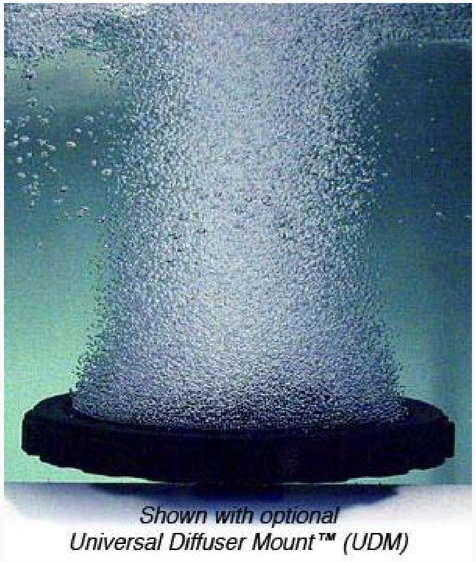
Packed Tower Aeration

- Highly efficient (>95%)
- Must collect treated water and re-pump

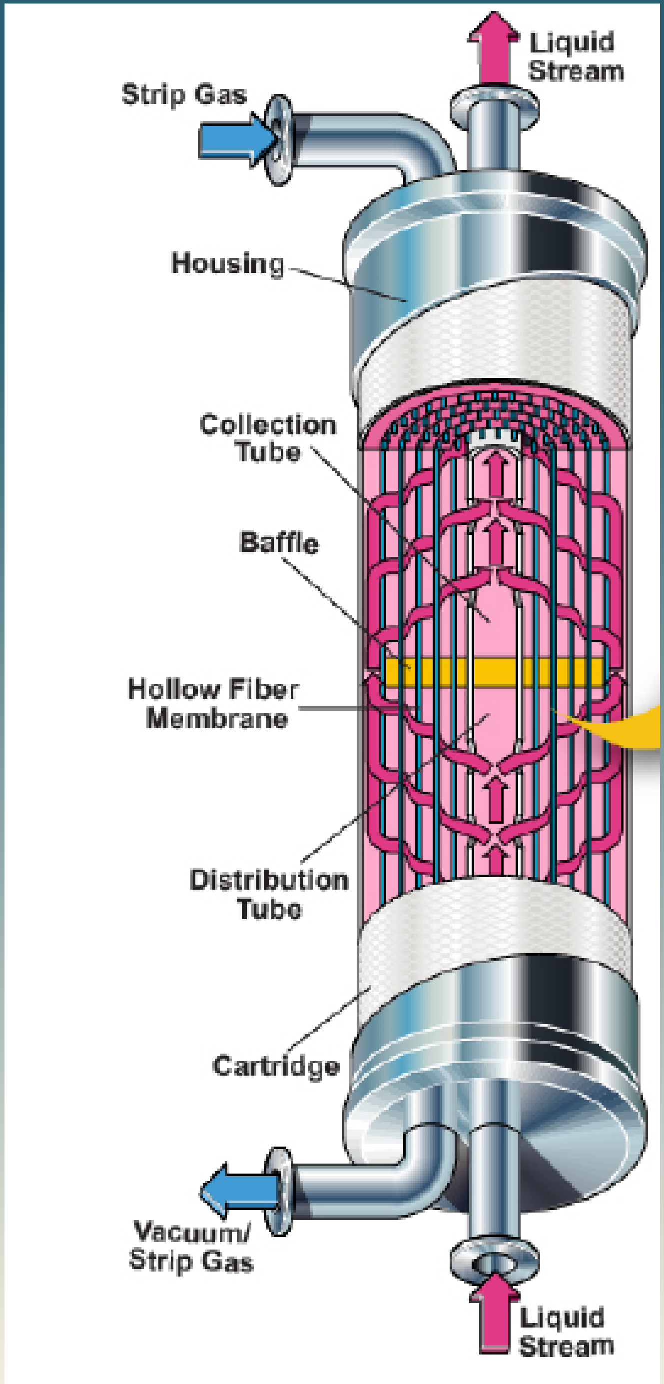


Diffused Bubble Aeration

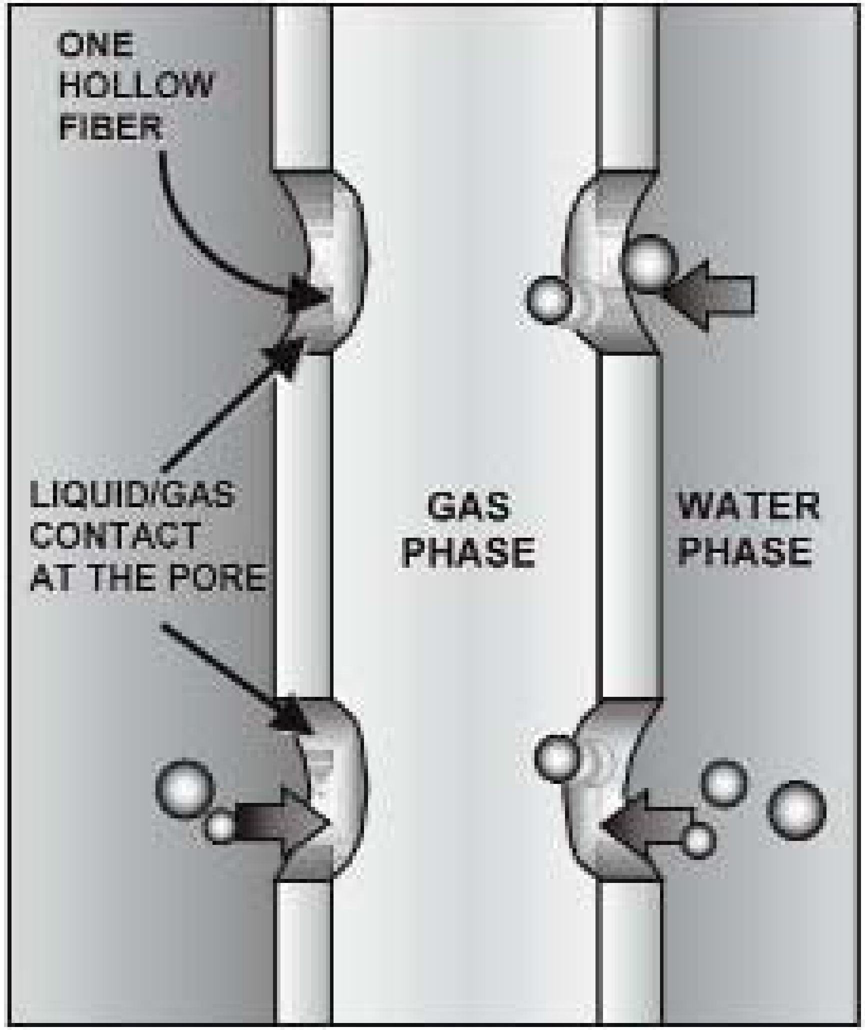
- Can be installed in reservoirs



Degassing Membrane Contactor (Liqui-Cel)



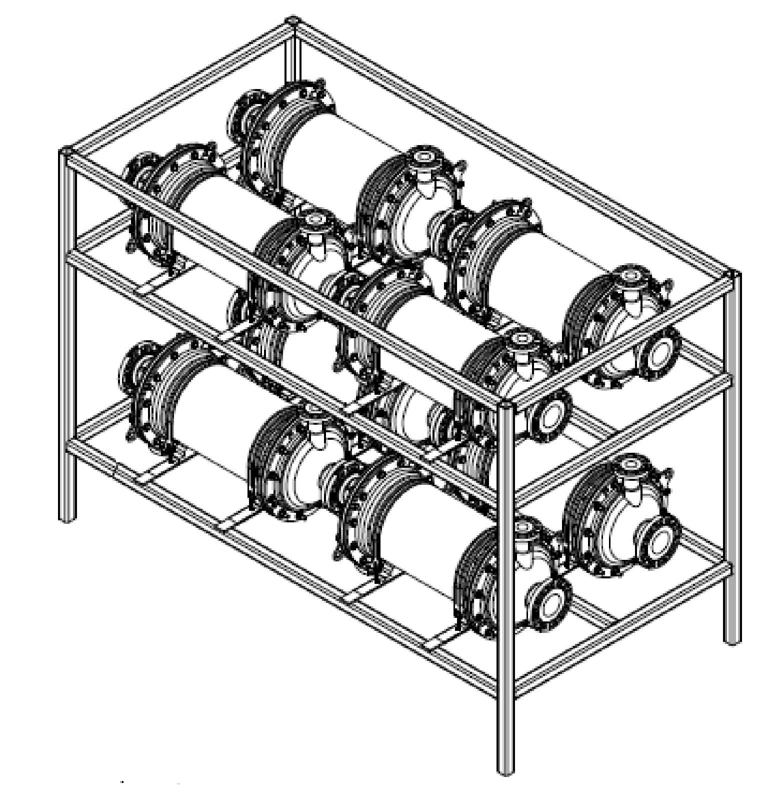
Liqui-Cel Treatment Technology



Membrane Contactor

Operational Modes

- Series – to improve treatment (% removal)
- Parallel – to meet total flow capacity needs



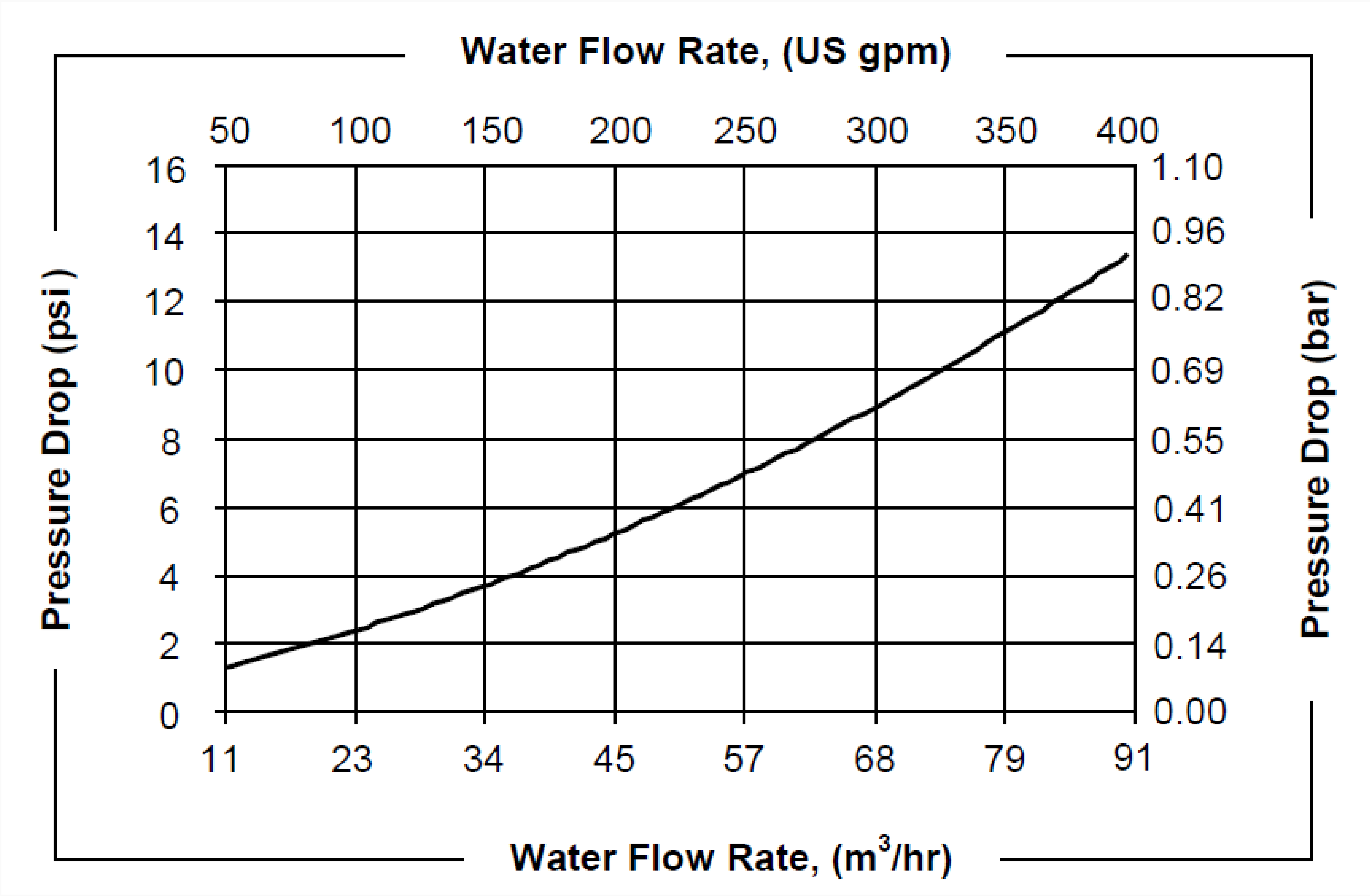
Fouling and Cleaning

- **Membrane surface / pores can become coated or blinded:**
  - Organics
  - Minerals
  - Metals
- **Chemical cleaning to remove (CIP)**
- **Site-specific pilot testing**
  - 1 to 2 months recommended

Membrane Life

- Contactor life is 5 - 10 years
- Chlorine exposure limit: 24,000 mg/L-hour
- Extended warranties case-by-case, may be tied to time since procurement

Contactor Head Loss (14x28-inch unit)



Installation and Operating History

- Product originally developed for industry
- Limited installations for drinking water
- NSF approval obtained in 2009

Aeration Process Attributes Summary

Process	Effectiveness	Energy Use	Capital Cost	Space Required
Diffused	Med	Varies	Med	Low
Packed Tower	Very High	High	High	High
Spray Nozzle	Low/Med	Low	Low	Low
Tray	Med/High	Med	Low/Med	Low
Mechanical	Low	Varies	Low	Low
Membrane Contactor	Very High	High	Med/High*	Very Low

*Application-specific

Conclusions

- **New alternative for aeration**
- **Has several attractive features**
- **Limited installation history in drinking water applications warrants site-specific testing**
- **Two case studies discussed in detail in next presentation (Shawn Kohtz, Andrew Hill)**

Questions?

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PNWS Annual Conference

May 3, 2012 – Yakima, WA

WHAT CAN MEMBRANE CONTACTOR TREATMENT TECHNOLOGY DO FOR YOU?

Two Pilot System Case Studies

Presented By:

Andrew Hill, P.E. and Shawn Kohtz, P.E.

MSA

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ACKNOWLEDGEMENTS

- **Sammamish Plateau Water and Sewer District**
  - Scott Jonas

- **United Water Idaho**
  - Dan Brown

PRESENTATION OVERVIEW

Background + Approach

Corrosion Control Case Study

PCE Reduction Case Study

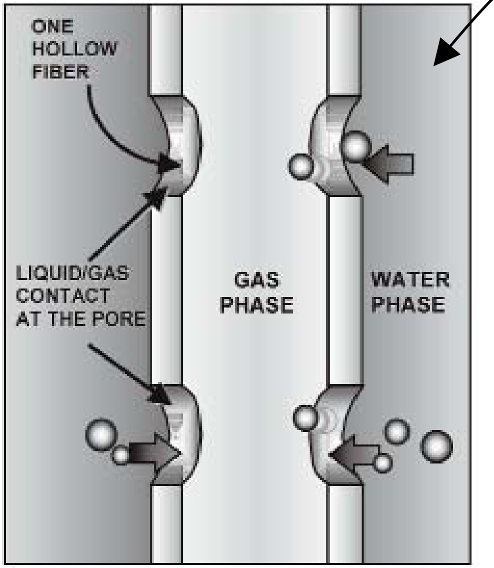
Summary

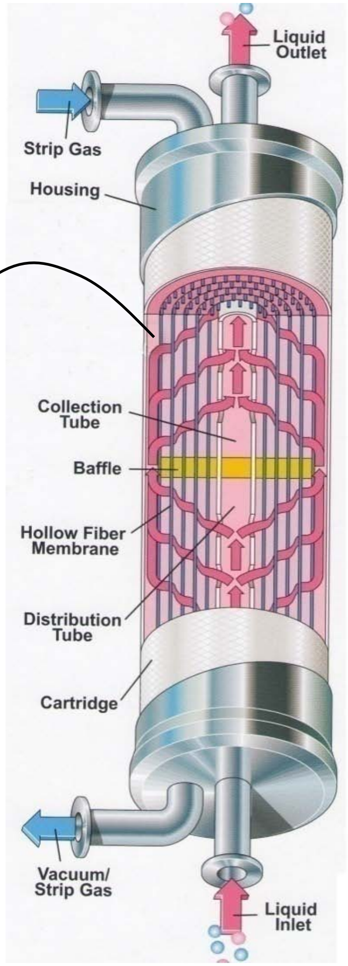
PRESENTATION OVERVIEW

- **Background + Approach**
- Corrosion Control Case Study
- PCE Reduction Case Study
- Summary

LIQUI-CEL TECHNOLOGY BACKGROUND

- ❑ **Previous Companion Presentation Reviewed Technology Fundamentals and Uses**
- ❑ **Degassing Membrane Contactor**
  - Single-supplier (Membrana)
  - Fully-contained pre-fabricated units
  - Largest unit has 550 gpm capacity
  - In-line operation





CASE STUDIES – Objectives and Approach

- **Treatment and Conceptual-Level Cost Evaluation to Support Process Selection**
  - Pilot test Liqui-Cel to characterize process performance
  - Establish design and operating criteria for scale-up
  - Develop full-scale integrated treatment concepts
  - Life-cycle cost analysis and comparison (NPW)

CASE STUDIES – Treatment Needs

Utility	Treatment Need	Role of Liqui-Cel	Comparison Alternative
SPWSD	pH Adjustment – Corrosion Control	CO_2 Stripping	Caustic Soda (currently used)
UWI	PCE Reduction – MCL Compliance	PCE Stripping	GAC

PRESENTATION OVERVIEW

- Background + Approach
- **Corrosion Control Case Study**
- PCE Reduction Case Study
- Summary

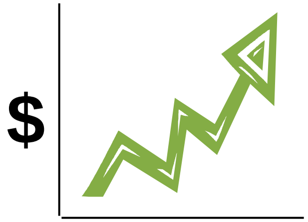
CORROSION CONTROL CASE STUDY – Sammamish Plateau Water and Sewer District

- **Emphasis on three Plateau Wells**
  - Used May – Oct to meet peak demands
  - 500 gpm capacity each
  - Corrosive: pH 6.2 – 7.1
- **Corrosion Control Treatment**
  - Finished WQ Goal: pH 7.8
  - Currently dose caustic soda to raise pH

Bulk storage of 50% caustic soda at District treatment site

CONCERNS WITH CAUSTIC SODA

- **Commodity Cost Trends**
  - Bulk price up 40% since 2008
  - Significant short-term volatility



- **Hazardous Chemical**
  - Handling and safety risks to District O&M staff
  - Deliveries/storage in residential neighborhoods

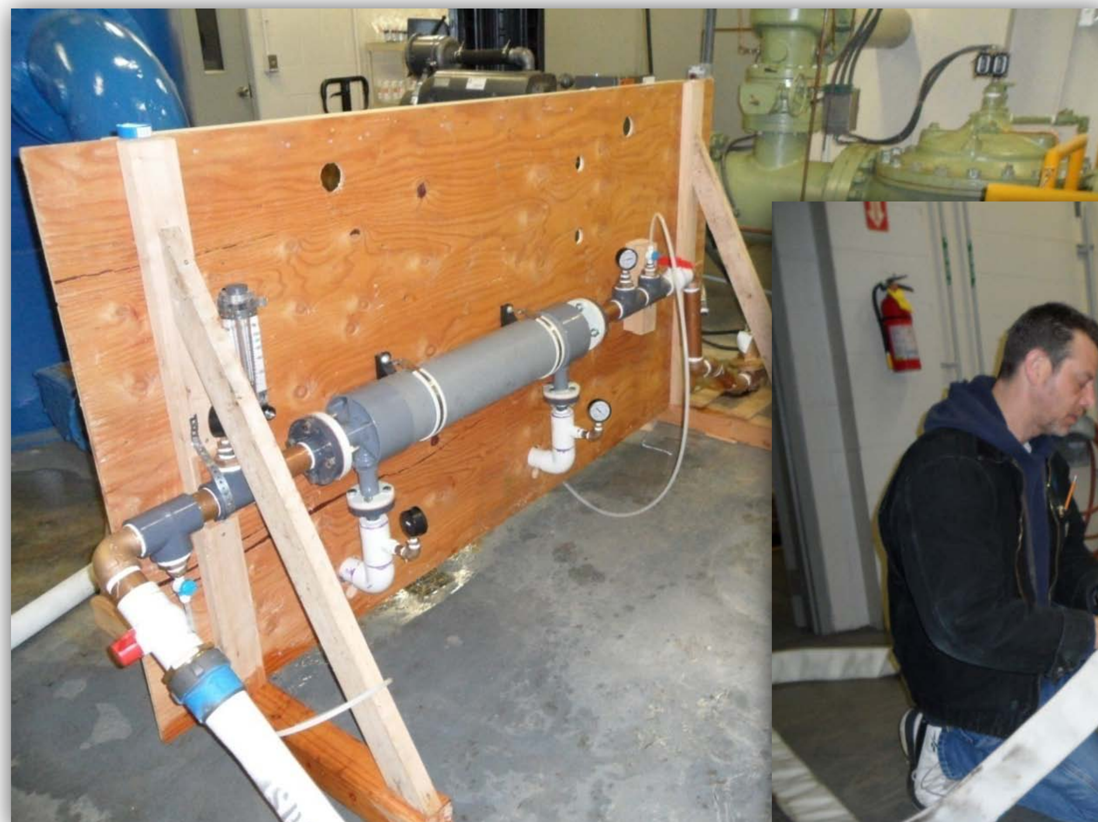
- **CO2 Stripping Presents an Attractive "Non-Chemical" Option for pH Adjustment**

DESKTOP FEASIBILITY ANALYSIS

- **Modeling of pH–CO2 System**
  - Supersaturated CO2 Levels Exist
  - Highly-Efficient Process Required

Source	Raw Water Quality			CO2 Stripping to pH 7.8	
	pH (units)	Alkalinity (mg/L)	Free CO2 (mg/L)	Free CO2 (mg/L)	Removal (%)
Well 1	6.8	100	35	3.5	90%
Well 2.1	6.2	61	86	2.1	97%
Well 10	7.1	85	14	3.0	78%

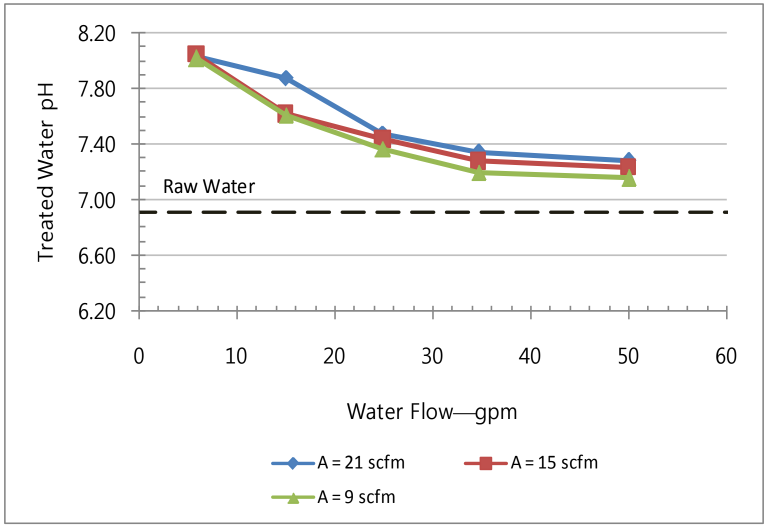
LIQUI-CEL PILOT TEST SETUP FOR WELL 1

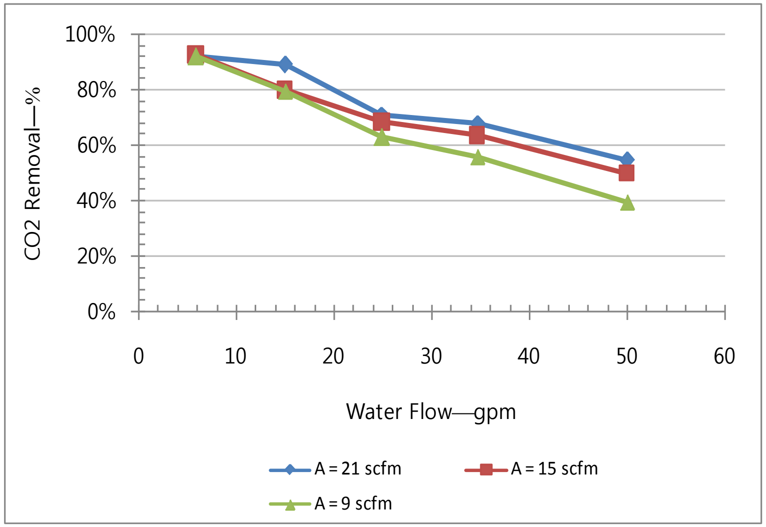


Liqui-Cel 6x28 Pilot Unit (5-50 gpm)
Tested at Well 1 Facility in Apr-2011

LIQUI-CEL PILOT TEST RESULTS FOR WELL 1

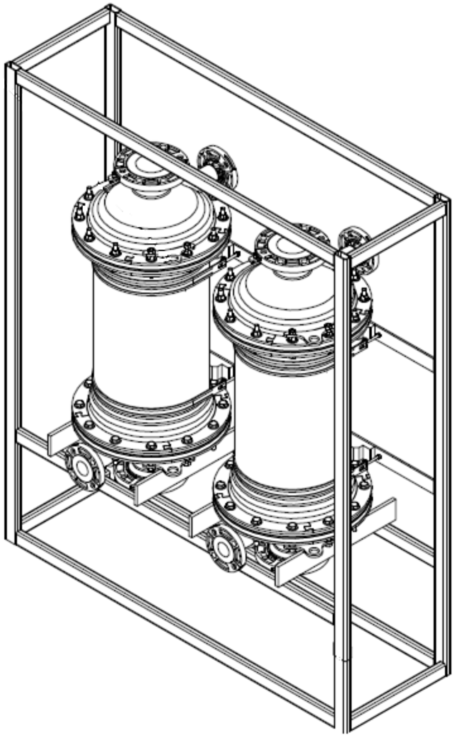
- ❑ **Capable of Raising pH ≥ 7.8**
- ❑ **CO_2 Removal of 40 to 90%**
- ❑ **Relatively Low Air Needs**
  - A/W of 1:1 at 25 inHg Vac





FULL-SCALE INTEGRATION CONCEPT FOR WELL 1

- **Skid-Mounted 2x2 Liqui-Cel System**
  - Two Stages: 68% – 68% = 90% Removal
  - Parallel Trains: 250 gpm each = 500 gpm
  - Vacuum Pump (20-hp)
- **Equipment Installed in Existing Wellhouse**
  - Remove Caustic Soda System
  - Estimated Footprint 100 ft^2
  - No Re-Pumping Required

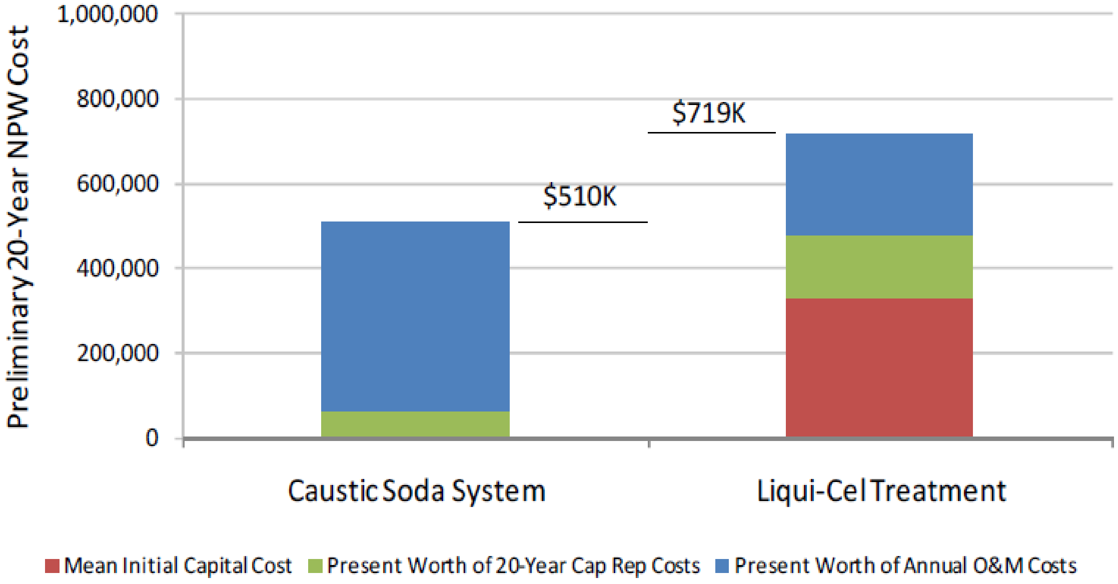


LIFE-CYCLE COST ANALYSIS FOR WELL 1 – Key Assumptions

- ❑ **20-Year Project Horizon**
- ❑ **Well Supply 90 MG/Year**
  - 75% Use May – Oct
- ❑ **5% Annual Discount Rate**
  - Capital Replacement
  - Comparative O&M
- ❑ **Other:**

Liqui-Cel Treatment	Caustic Soda System
• Membrane Contactor Life: 7 Year Average	• Existing Equipment Replaced at 10-Year Mark
• Chemical Cleaning On-Site by District – Once per Year	• Caustic Price $1,300/DST Year 1 (Escalation at 7.5% per Year)
Labor Needs Comparable (Assuming Frequent Cleaning is Not Needed)	

LIFE-CYCLE COST ANALYSIS FOR WELL 1 – Results



In this case, higher initial and replacement capital costs for Liqui-Cel are not "recovered" by its lower cost to produce water.

Parameter	Caustic Soda System	Liqui-Cel Treatment
Initial Capital Cost	$0 (E)	$330K
NPW of Capital Replacement	$64K	$151K
NPW of Comparative O&M	$446K	$238K
Overall 20-Year NPW Cost	$510K	$719K
Comparative Cost to Treat	$83/MG	$43/MG

Note: all figures in Y2011 dollars

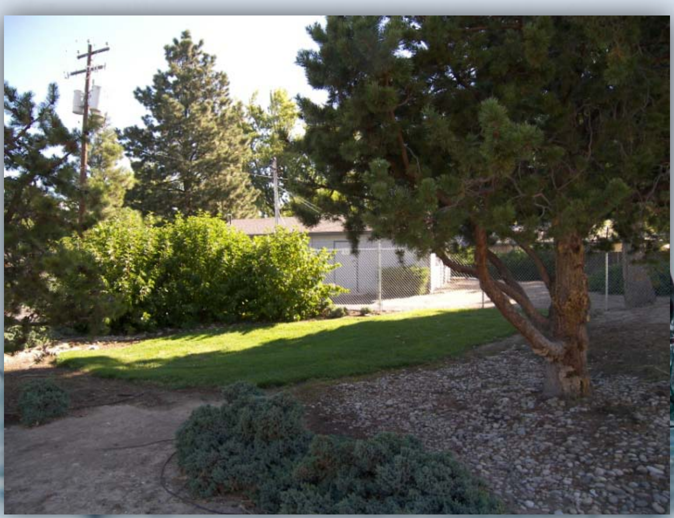
PRESENTATION OVERVIEW

- Background + Approach
- Corrosion Control Case Study
- **PCE Reduction Case Study**
- Summary

VOLATILE ORGANIC COMPOUND CASE STUDY

United Water Idaho

- **Emphasis on One Contaminated Well**
  - 2,000 gpm capacity
  - Tetrachloroethylene (PCE) contamination
- **Treatment Options**
  - Membrane Contactors
  - GAC
  - Packed column air stripper not considered due to advantage of membrane contactor



Well site in residential area

RAW WATER PCE DATA

Raw Water Sample (ug/L)	Sample Date
4.6	7/9/10
6.1	9/2/10
6.6	9/2/10
6.1	9/14/10
7.0	9/14/10
7.3	9/21/10
7.8	9/21/10
7.9	9/21/10

FULL SCALE DESIGN - Treatment Assumptions

- ❑ **PCE MCL = 5 ug/L***
- ❑ **Assumed Raw Water Concentration = 10-20 ug/L;**
- ❑ **Target Design Treatment Level 50-80% of MCL**

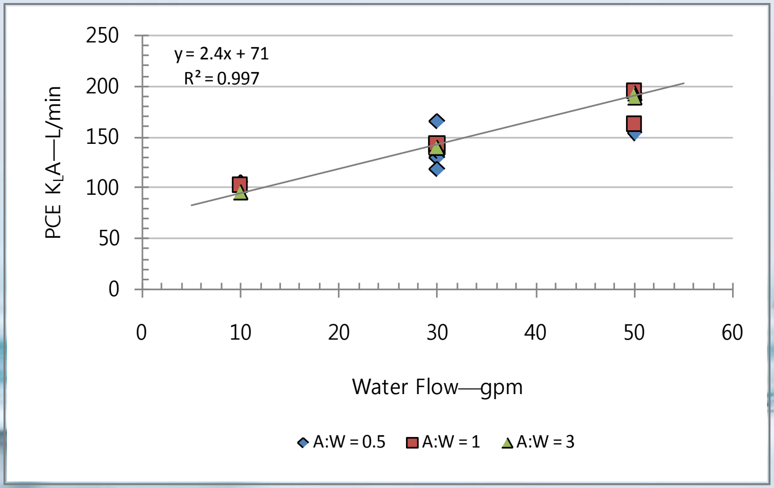
  - *The MCL is likely to be reduced by EPA in the next several years.

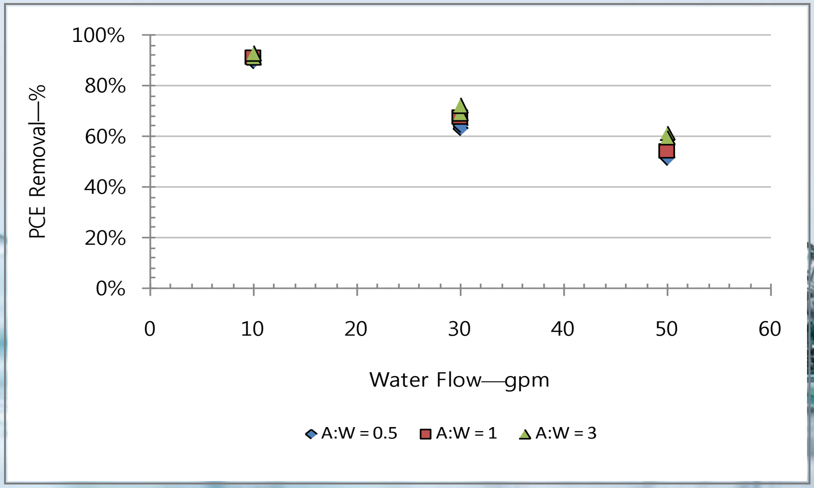
LIQUI-CEL PILOT TEST SETUP

Liqui-Cel 6x28 Pilot Membranes (5-50 gpm)
Tested at Well Facility in Sept-2011 and Summer-2010

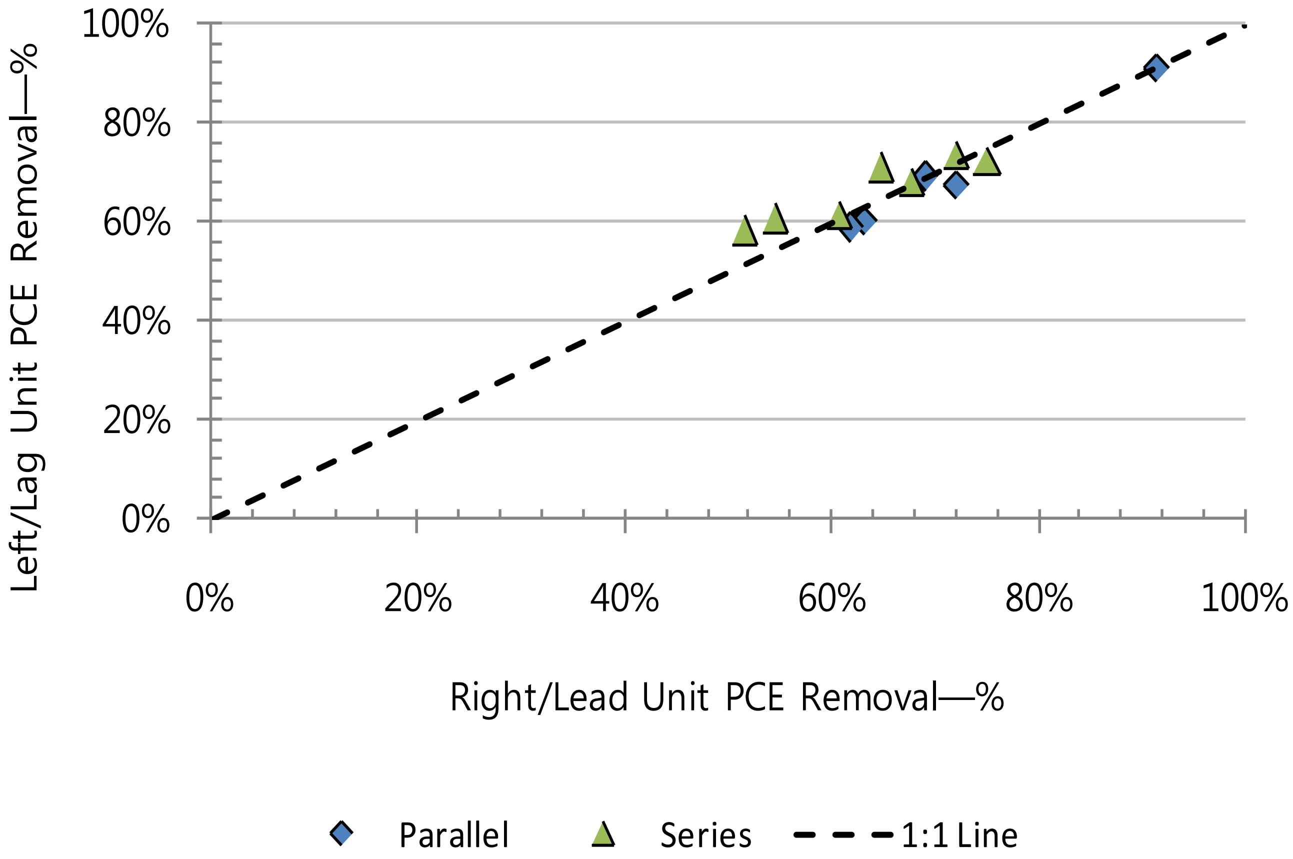
PILOT TEST RESULTS -
Impact Of Water Flow Rate

- ❑ **Intrinsic mass transfer rate positively related to water flow rate (velocity)**
- ❑ **Overall % removal ↓ as Q ↑ due to shorter residence time, which offsets effect of increased mass transfer rate**



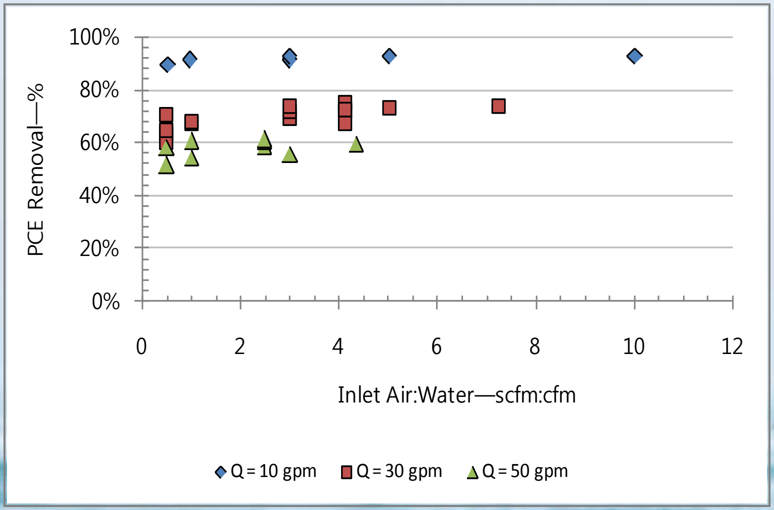


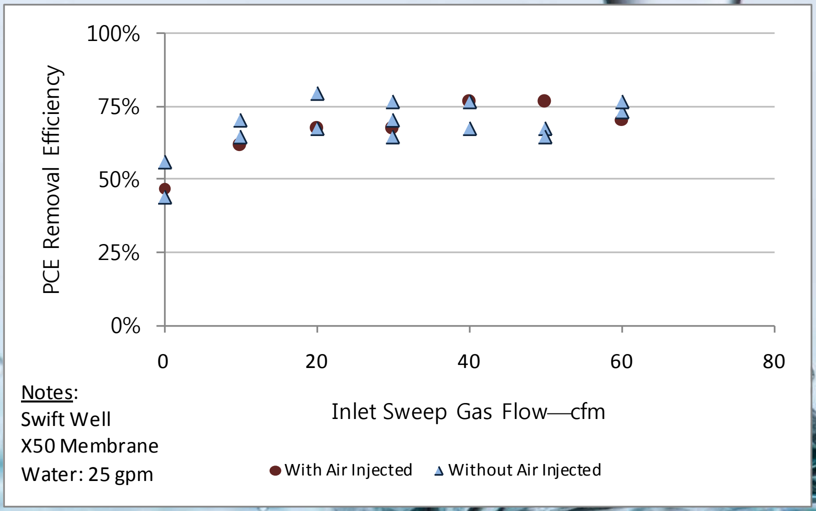
PILOT TEST RESULTS - Series and Parallel Performance



PILOT TEST RESULTS - Low Air Requirements

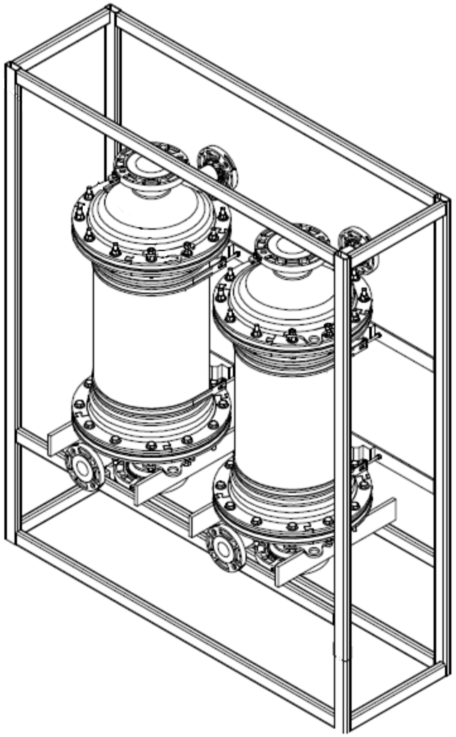
- **Relatively Low Air Needs**
  - Optimal A/W: 3:1
  - Vacuum 25 inHg

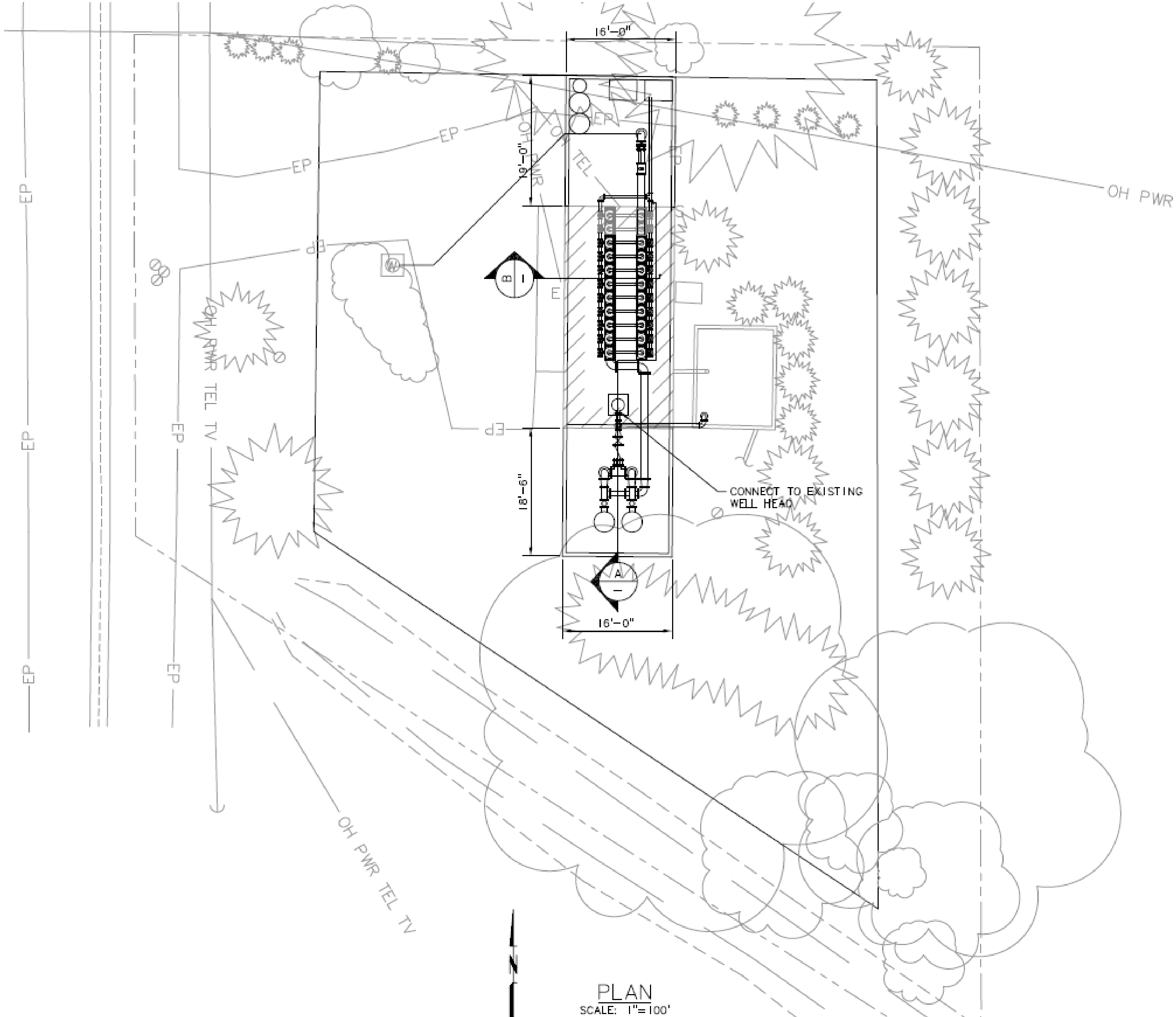




FULL-SCALE INTEGRATION CONCEPT

- **9x2 Membrane Contactor System**
  - Two Stages: 65% – 65% = 80% Removal
  - Parallel Trains: 225 gpm each
  - Total Vacuum Pump hp = 75
  - Pre-filtration (10 um)
  - Leave space for additional four membrane units
  - GAC gas scrubbing, if necessary
- **Expand existing well facility**

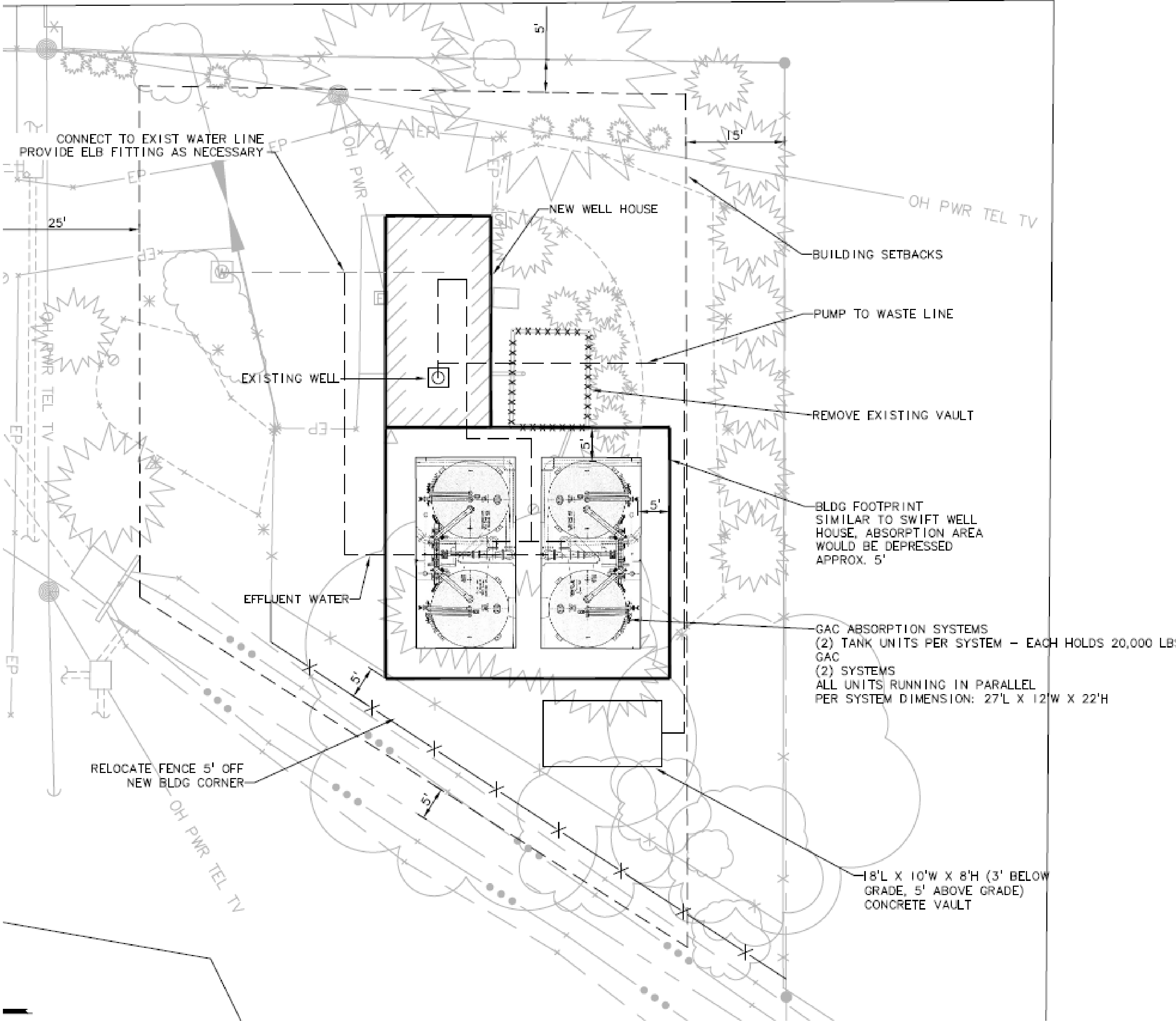




PLAN
SCALE: 1"=100'

GAC PRESSURE FILTRATION - Design Comparison Basis

- **System Configuration**
  - 80,000 lbs total GAC
  - Four Treatment Vessels, each containing 20,000 lbs GAC
  - Empty-Bed-Contact-Time = 9 minutes
- **New Building**


CONNECT TO EXIST WATER LINE
PROVIDE ELB FITTING AS NECESSARY
NEW WELL HOUSE
BUILDING SETBACKS
PUMP TO WASTE LINE
EXISTING WELL
REMOVE EXISTING VAULT
BLDG FOOTPRINT
SIMILAR TO SWIFT WELL
HOUSE, ABSORPTION AREA
WOULD BE DEPRESSED
APPROX. 5'
EFFLUENT WATER
GAC ABSORPTION SYSTEMS
(2) TANK UNITS PER SYSTEM - EACH HOLDS 20,000 LBS
GAC
(2) SYSTEMS
ALL UNITS RUNNING IN PARALLEL
PER SYSTEM DIMENSION: 27'L X 12'W X 22'H
RELOCATE FENCE 5' OFF
NEW BLDG CORNER
18'L X 10'W X 8'H (3' BELOW
GRADE, 5' ABOVE GRADE)
CONCRETE VAULT
OH PWR TEL TV
OH PWR
OH TEL
25'
15'
5'

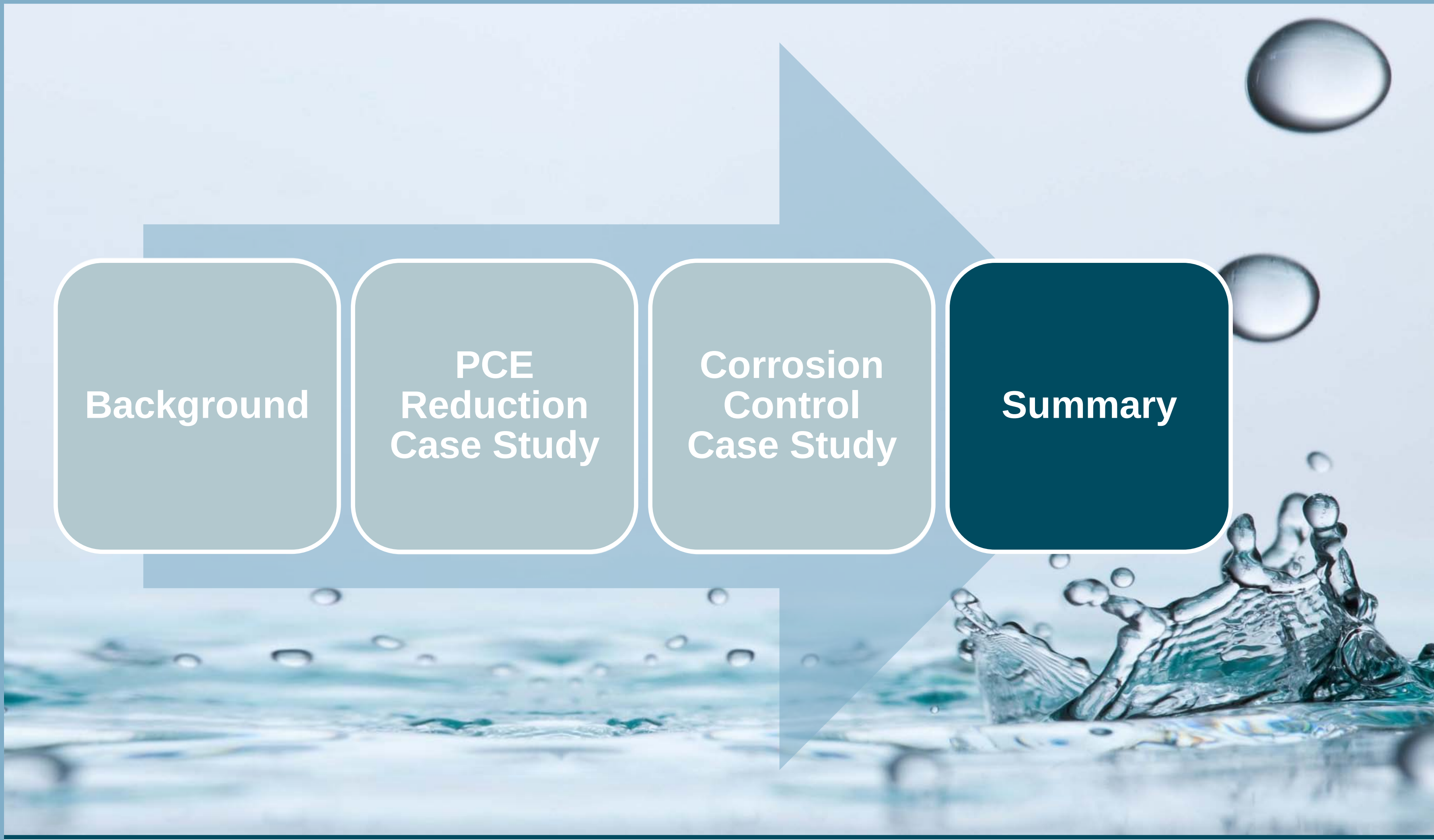
LIFE-CYCLE COST ANALYSIS - Key Assumptions

- **20-Year Project Horizon**
- **Well Supply:**
  - Pump 24 hours per day throughout the year
- **8.49% Annual Discount Rate**
  - Capital Replacement
  - Comparative O&M
- **GAC Replacement:**
  - Replace 80,000 lbs every 4 years
- **Membrane Contactors:**
  - Membrane life: 6.5 years

COST COMPARISON

Item	Membrane Contactors	GAC
Capital Costs	$1,461,000	$2,076,000
Capital Replacement Costs (NPV)	$472,000	$415,000
Annual Additional O&M Costs	$25,000	$4,000
Total NPV* *Includes conversion of Annual O&M Costs to NPV	$2,170,000	$2,529,000

PRESENTATION OVERVIEW



SUMMARY

- Degassing membrane contactors present a new alternative to traditional treatment technologies for volatile contaminants
- Offers benefits including: safety, low O&M cost, in-line operation, compact, expandable, low pumping head
- Relative cost-attractiveness is <u>application-specific</u> and depends on:
  - Contaminant/treatment needs
  - Membrane life
  - Fouling potential (cleaning needs)
  - Space availability
  - Hydraulic profile

QUESTIONS?

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Residuals – The Dark Side of Water Treatment



PNWAWWA 2012

Residuals Quantities per MG Treated (Surface Water)

- Residual Quantities depend on turbidity and coagulant dose
- Seasonal Peaking Factor typically 1.5 . . . Not for PNW

Type	Average (lb/MG)	Peak (lb/MG)
“Textbook” WTP		
Reservoirs	120	180
Rivers	540	810
PNW		
Everett - L. Chaplain	34	50
JWC - Tualatin River	100	13,000

PNW Conditions Unique – Function of Climate

Two Types of Residuals from Conventional Treatment Plants

Clarifier Residuals

- Solids (0.5-2.0)
- Small Volume
- Large percentage of solids (98%)
- Difficult to thicken
- Difficult to dewater
- Decant recyclable

Filter Backwash Residuals

- Low Solids (40-500 mg/L)
- High volume (3 to 10% of flow)
- High Instantaneous flow for short periods (15-30 mgd for 8-15 minutes)
- Recyclable

Ground Water Plant Residuals

Filter Backwash Residuals
Highly Variable

- Variable Solids (20 to 6,000 mg/L)
- Volume 0.3 to 1 percent of plant production
- Sludge typically iron and manganese oxides
- By Stokes Law settle at about 3 to 4 ft/hr

Groundwater Plants Typically Produce Less Residuals

Ultimate Disposal Technique Drives Dewatering Needs

Ultimate Disposal Drives Dewatering Needs

- Monofill
- Landfill
- Land Application
- Sewer

Ultimate Disposal Drives Dewatering Needs

- Monofill – 10%
- Landfill
- Land Application
- Sewer

Ultimate Disposal Drives Dewatering Needs

- Monofill
- **Landfill – 35%**
- Land Application
- Sewer

Ultimate Disposal Drives Dewatering Needs

- Monofill
- Landfill
- **Land Application - Varies**
- Sewer

Ultimate Disposal Drives Dewatering Needs

- Monofill
- Landfill
- Land Application

- **Sewer – no dewatering needed**

Dewatering Options

Lagoons

- Low Cost
- 6 to 15% solids
- Typically 3 Cells or more
  - Fill one cell (active)
  - One cell dewatered for solids removal
  - 1 cell solids removed
- Sized for peak year, not peak day

Engineered Pond

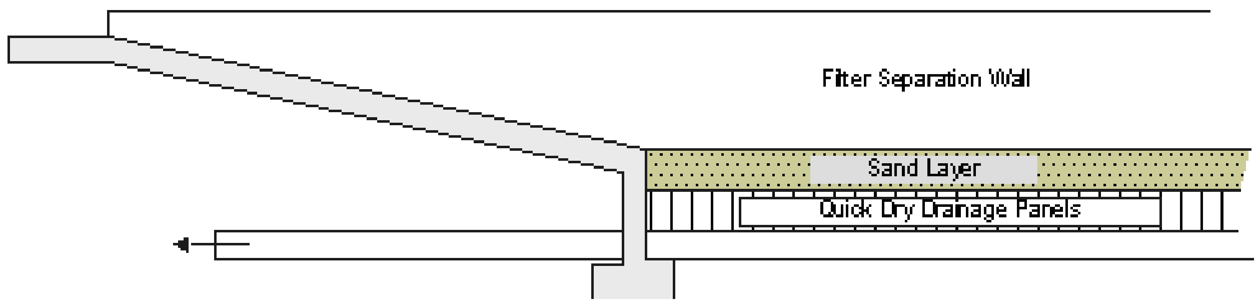
- Concrete Lined
- Polymer addition
- Settling Zone
- Easier Sludge Removal

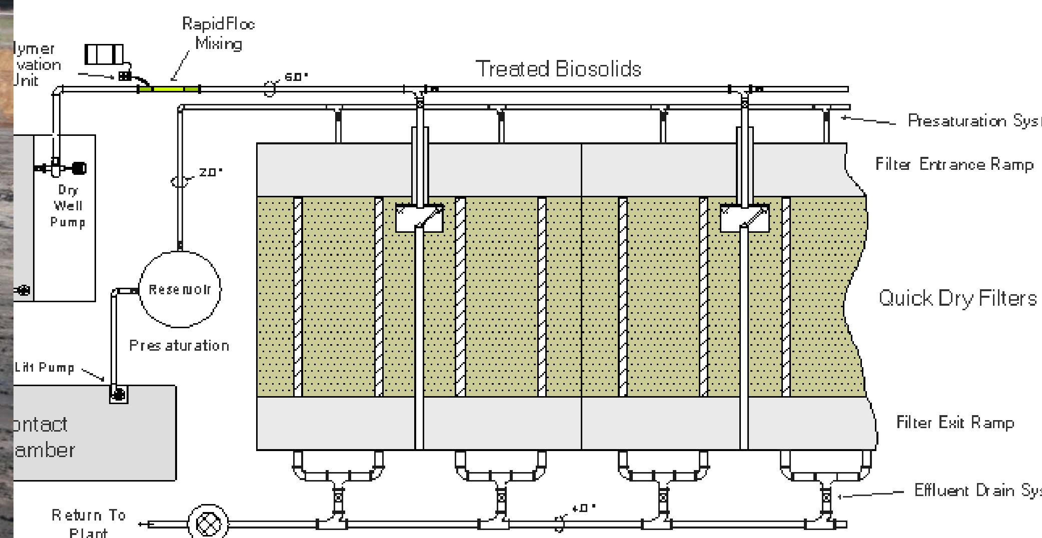
Lagoons

- **Advantages**
  - Low O&M requirements, energy
  - Multi-purpose (storage, thickening, dewatering, drying)
  - Forgiving, Can handle variable loadings
- **Disadvantages**
  - Large land area requirements
  - Removal equipment
  - Low solids concentration
  - Pest controls for insects and birds
  - Still requires final disposal

Engineered Drying beds

- Smaller Foot Print
- Faster Drying
- 15% to 20% Solids





Drying Beds Advantages and Disadvantages

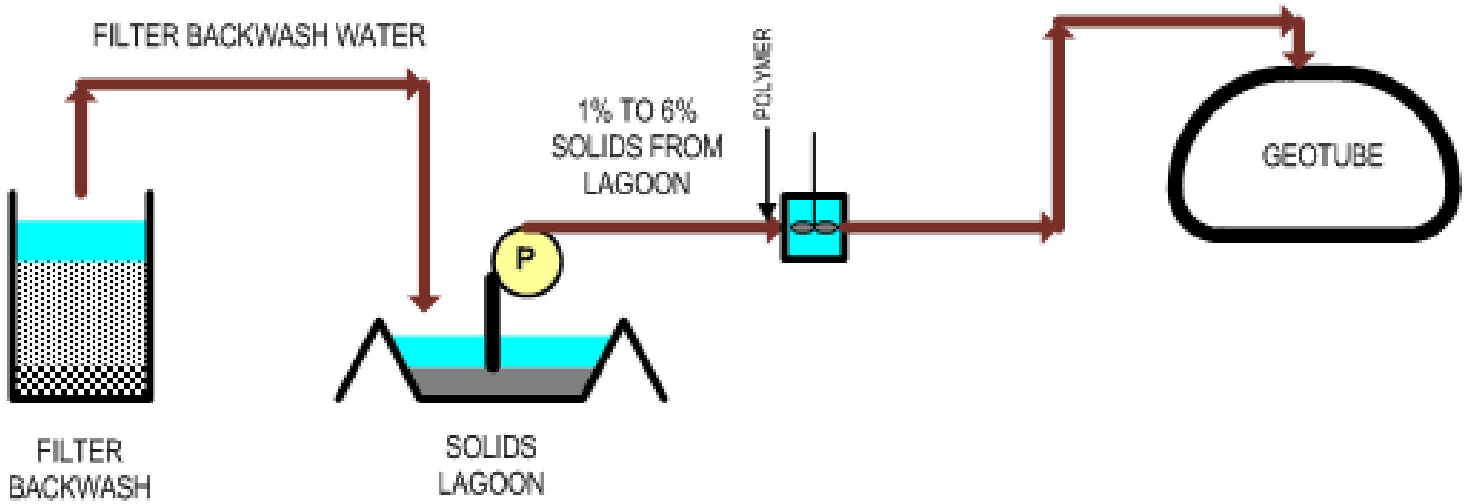
- **Advantages**
  - Proven technology
  - Minimal O&M requirements
  - Low capital costs
  - Can handle variable loadings

- **Disadvantages**
  - More Effective in Dry Climates
  - Large land requirements
  - Manual removal of residuals

Geotexile Tube

- Geotexile Tube (Geotube®) - high strength polypropylene geotextile.
- High flow rate allows liquid to dewater, while containing chemically conditioned solids.
- Geotextile tubes are custom fabricated with seaming techniques that resist pressures during pumping operations.

Geotube –Everett WA Experience



- Geotubes can accept straight BW water up to 6% solids
- Water passes through the geotube fabric
- Solids retained and w/o polymer clog fabric
- Be sure to think of drainage

Polymer Required for Good Performance

- Everett dose: 0.2 to 0.6 mg polymer per mg solids
- At 2% avg solids (Everett) dose works out to be about 60 mg/L
- Nonionic polyacrylamide polymer worked best (also the filter aid polymer)

Geotubes

- Pump into geo tube
- Geotube retains solids and passes water
- Geotubes come in different sizes
- 10% solids in 3 to 5 days

Geotubes have Flexibility

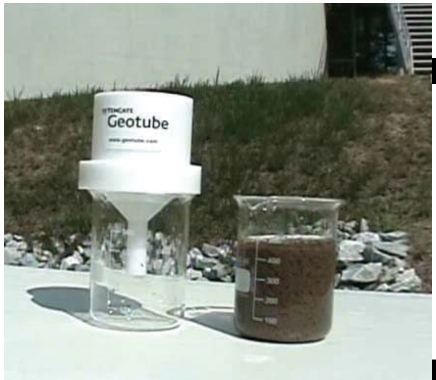
- Tubes can be stacked on one another to limit area needs
- At 10 percent solids can open and dry out further
- 20 to 25% solids possible

Geotexile Tubes Advantages and Disadvantages

- **Advantages**
  - Low capital costs and operating costs
  - Simple operations with no special requirements
  - Effective high volume containment

- **Disadvantages**
  - Large land area requirements
  - Manual removal and equipment required
  - Limited experience in Water Tment
  - Tubes must be replaced after using
  - 15-45 days of drying required for 25% solids

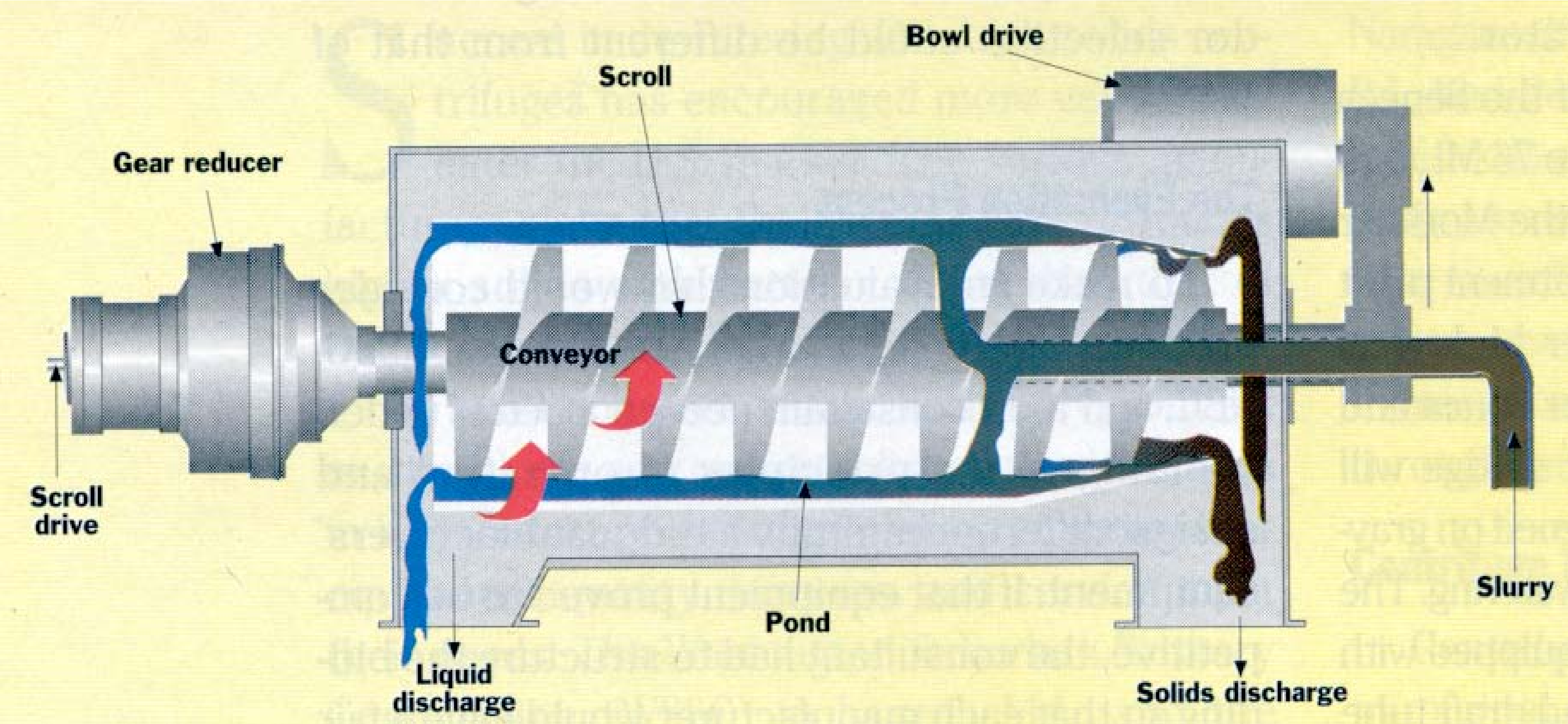
Geotexile Tube Bench and Pilot Testing



- Rapid Dewatering Test (RDT) or Cone Test
  - Evaluate polymers
  - Predicts percent solids, effluent quality, & volume reduction
- Geotube® Dewatering Test
  - More accurate than RDT and Cone Test
  - Determines retention and flow rate of residuals through tube

Centrifuge

- Solids Concentration
  - Coagulant Residuals - 20-30%

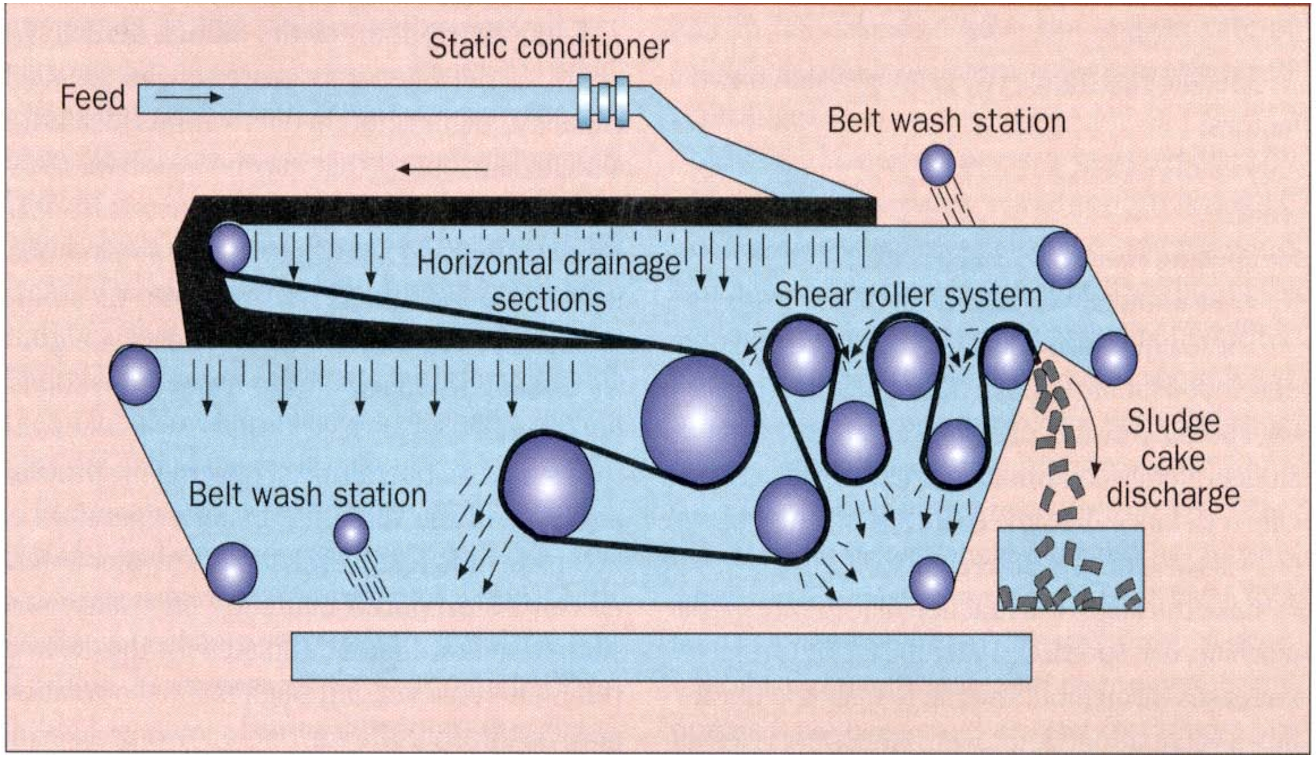


Centrifuge Advantages and Disadvantages

- **Advantages**
  - Proven technology
  - Recent advances in backdrive technology: higher throughput and solids concentrations
  - Relatively small space requirements
  - Relatively low operating cost
  - Clean operations
  - Performance is somewhat independent of solids loading
- **Disadvantages**
  - High energy costs
  - Comparatively high capital cost
  - Major maintenance requirements
  - Centrate may be high in suspended solids
  - Size for peak day solids

Belt Filter Press

- Solids Concentration
  - Coagulant Residuals -15-25%



Belt filter press

Belt Filter Press Advantages and Disadvantages

- Advantages
  - Proven technology
  - Lower capital costs

- Disadvantages
  - Moderate space requirement
  - Poor solids capture
  - Cake may not meet disposal requirements
  - Alum solids can be difficult to dewater

Supernatant has Issues

Supernatant Must Meet Permit when Released to Natural Water

- Chlorine
- Arsenic
- Temperature
- pH
- TSS

Supernatant Issues –Recycling

- Contaminant Recycling
  - Giardia/Cryptosporidium
  - Arsenic
  - Iron/Manganese
  - DBP precursors
- Treatment Upsets
  - Polymer
  - Simply Changing Water

Discussion

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Innovations in Biological Treatment: Three Case Studies

PNWS
IDAHO • OREGON • WASHINGTON

GO WITH THE FLOW
2012 PNWS • YAKIMA, WA

Rebecca Venot, PE

Kerry Meyer, PE

Enoch Nicholson, PE

Biological Treatment Overview

- Free Labor!
  - Takes advantage of the capacity of bacteria to metabolize contaminants of interest
- Sustainable
  - Destroys contaminant rather than concentrates
  - Lower greenhouse gas production
  - Increased finished water quality
  - Reduced waste stream

Basics of Biological Treatment

- Fixed or suspended growth of bacteria that “breathe” or “eat” contaminants
- Bacteria oxidize electron-donor substrate
  - Send fraction of electrons to an electron-donor substrate to gain energy.
  - Invest most of the electrons in synthesizing new biomass.

Biological Treatment History

- 1804 - First used in slow sand filter in Scotland
- 1870 – Slow sand filter in New York
- 1892 – Riverbank filtration in Germany
- 1970's – Ozone and GAC (BAC)
- 1990's – end of chlorination in the Netherlands due to extensive biological treatment
- 2000's (early) – development of perchlorate and nitrate reduction in USA
- 2008 – AWWA initiates Biological Drinking Water Committee

Case Study Projects

Biological Iron Removal

Ruth Burnett Sport Fish Hatchery

Fairbanks, Alaska

Biological Nitrate Removal

Tailored Collaboration with Water Research Foundation

Glendale, Arizona

Biological DBP Precursor Removal

Large Midwestern Water Treatment Plant

Ohio, USA

Case Study Projects

- Biological Iron Removal
  - Ruth Burnett Sport Fish Hatchery
  - Fairbanks, Alaska
- Biological Nitrate Removal
  - Tailored Collaboration with Water Research Foundation
  - Glendale, Arizona
- Biological DBP Precursor Removal
  - Large Midwestern Water Treatment Plant
  - Ohio, USA

Conventional Iron Removal

- Oxidation followed by precipitation and filtration
  - Oxidants: oxygen, chlorine, ozone, permanganate
- Oxidation on filtration media
  - Media: greensand, manganese dioxide (pyrolusite)
- Softening/Ion Exchange
- Biological Treatment

Biological Iron Removal

- All Proteobacteria
  - Mostly: *Gallionella* and *Leptothrix*
- Combination of intracellular & extracellular mechanisms
- Thrive at
  - Neutral pH
  - Redox Potential: 0.1-0.4 Eh-V
- Low redox potential of iron → challenging kinetics

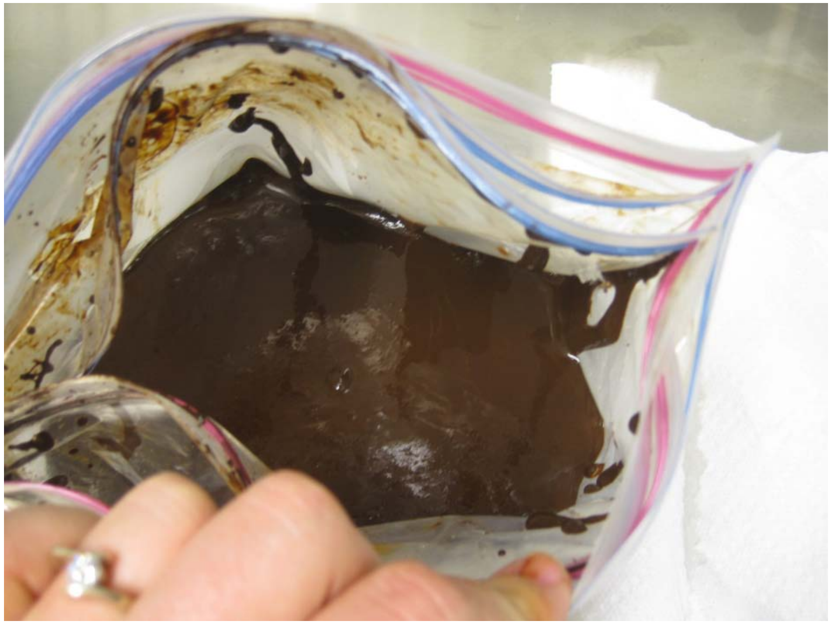
$$4Fe^{2+} + O_2 + 10H_2O \rightarrow 4Fe(OH)_3(s) + 8H^+ + \text{energy}$$

Ruth Burnett Sport Fish Hatchery

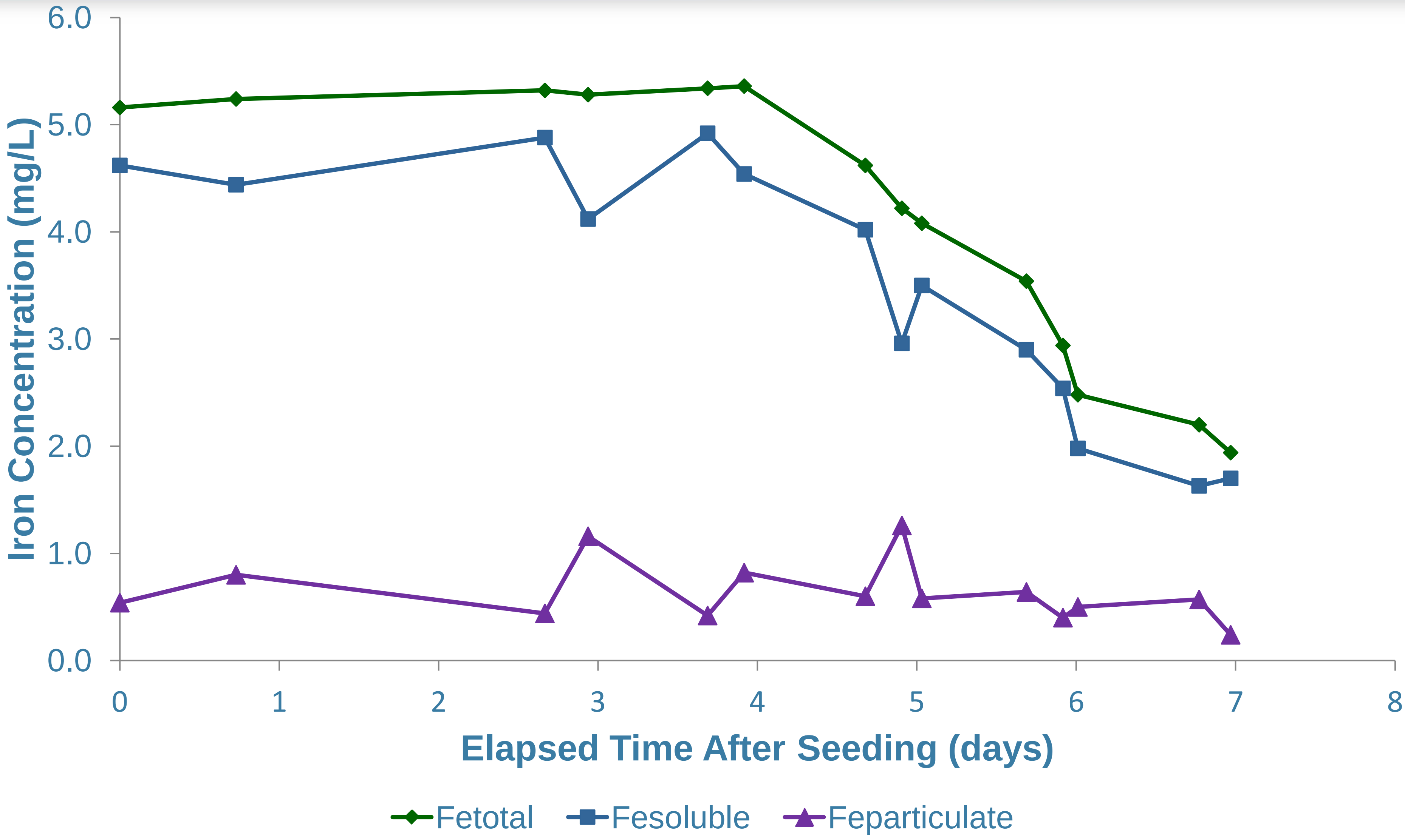
- Groundwater treatment to support sport fish rearing in interior Alaska
- Raw Iron: 7 mg/L
- Raw Manganese: 0.7 mg/L
- Temperature: 0.3 C
- 820 gpm
- Iron Goal: <0.1 mg/L
- Manganese Goal: <0.05 mg/L

Biological Treatment Implementation

- Two stage filtration
  - Biological first stage
  - Permanganate for manganese reduction in second stage
- Startup challenges
  - Inconsistent iron removal
  - Competitive oxidation
  - Excessive backwash

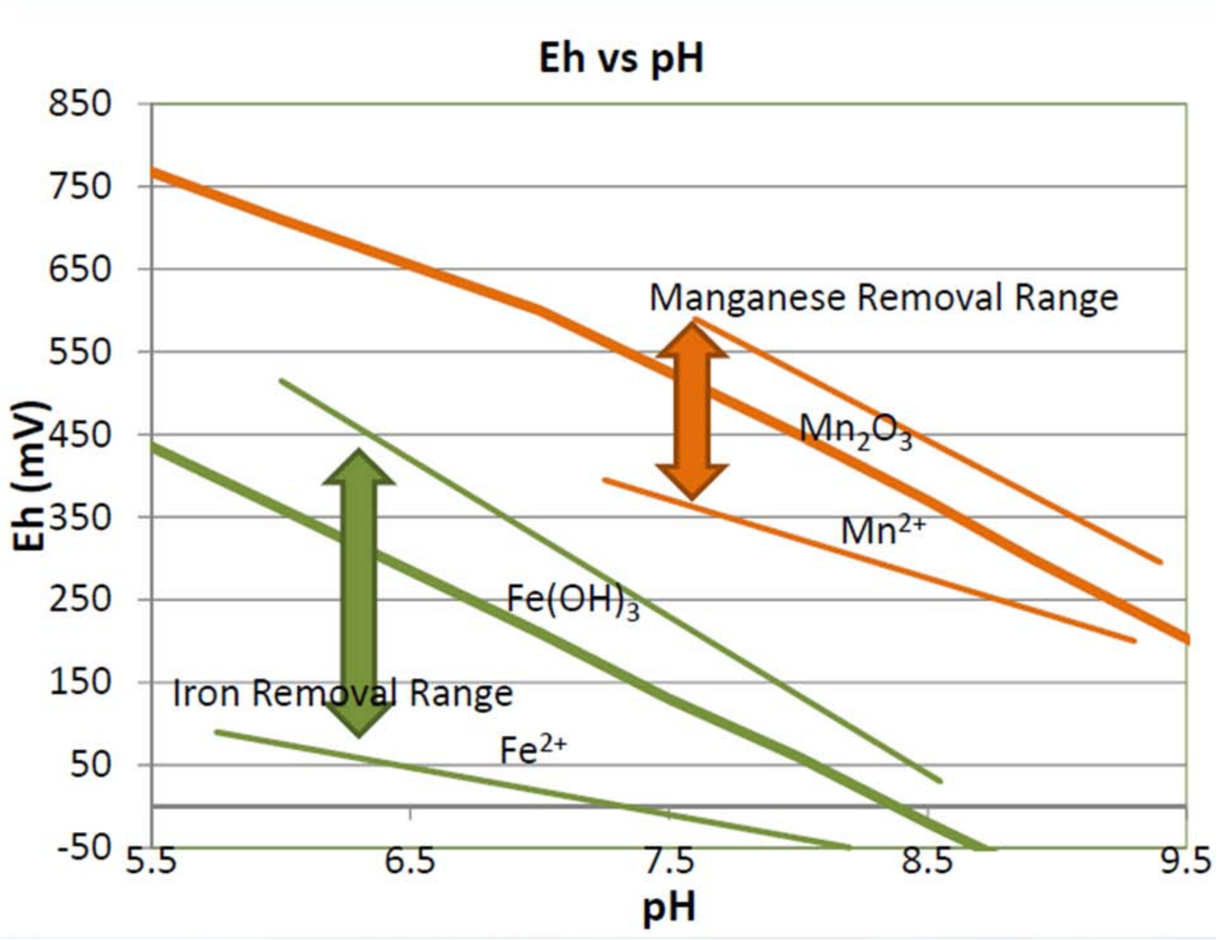


Biological Treatment Results



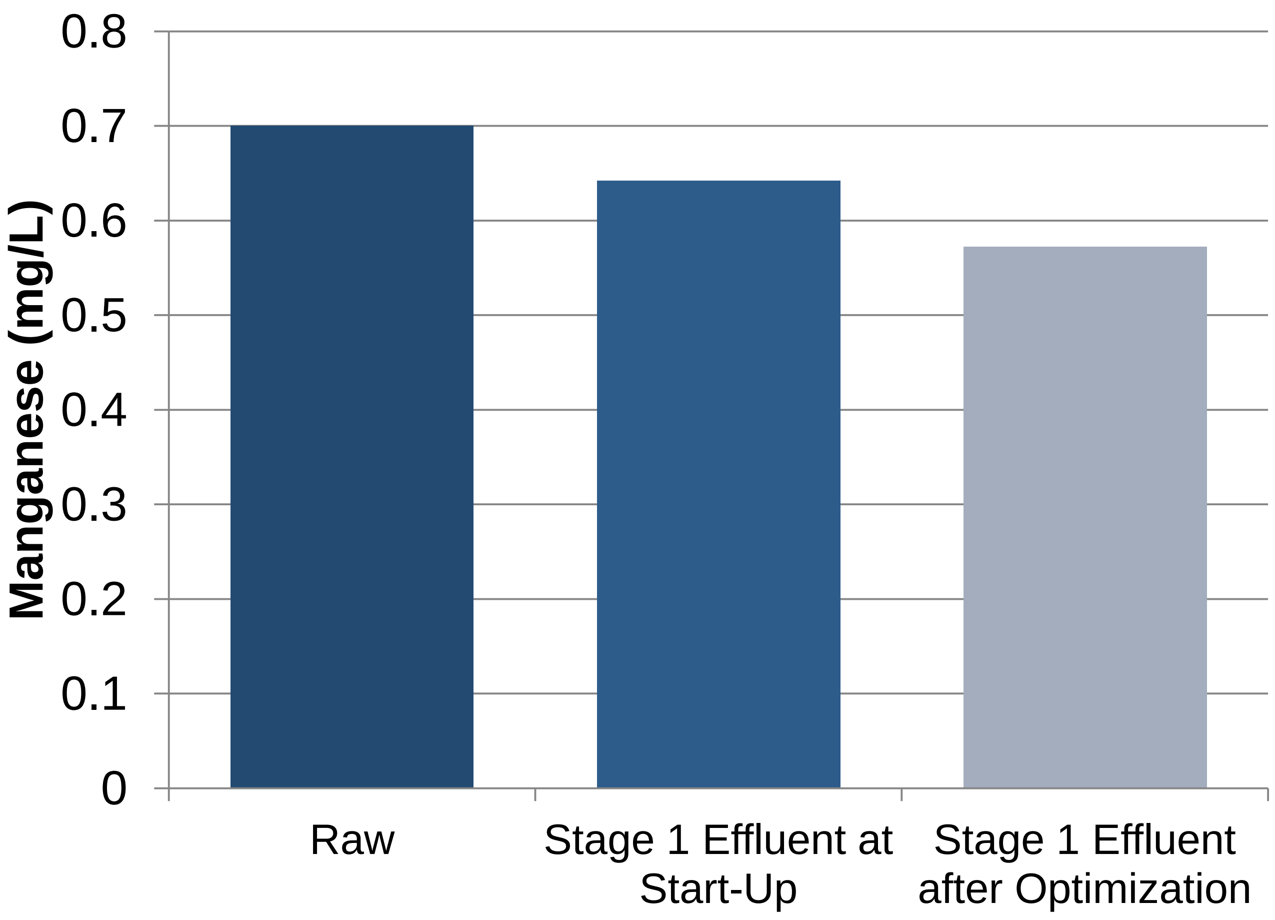
What About Manganese?

- Not critical for fish health
- Can be a maintenance nuisance
- Some biological removal with correct redox conditions



What About Manganese?

- Some biological removal with correct redox conditions
- Balance of manganese removed with permanganate addition



Biological Iron Removal Cost

- Traditional oxidation-adsorption: $37,000/year
- Biological iron removal: $26,500/year

Case Study Projects

Biological Iron Removal

- Ruth Burnett Sport Fish Hatchery
- Fairbanks, Alaska

Biological Nitrate Removal

- Tailored Collaboration with Water Research Foundation
- Glendale, Arizona

Biological DBP Precursor Removal

- Large Midwestern Water Treatment Plant
- Ohio, USA

Conventional Nitrate Removal

- Second most common contaminant above MCL in survey of private drinking water wells
- Typically Removed by
  - Reverse Osmosis
  - Ion Exchange

Biological Nitrate Removal

- No brine, targets more than nitrate, sustainable
- Not widely used in US, may require regulatory proof of compliance, typically requires substrate addition
- Treated water is anoxic
  - Contains some dissolved organic carbon from soluble microbial products
  - Biofilm detachment causes an increase in heterotrophic plate count
- It's good practice for an aerobic biologically active filtration process to follow biological denitrification of drinking water

$NO_3^- \rightarrow N_2(g)$ *(4 step process mediated by 4 enzymes)*

Glendale, Arizona

- Growing community reliant on groundwater
- High nitrate
  - 12 mg/L in raw water
  - 6 mg/L blended target
- Temp: 21-34 C, pH 7.1-7.9
- TDS: 723 mg/L
- Sulfate = 108 mg/L
- Dissolved Oxygen = 4.5 mg/L
- Treatment Goal = <2 mg/L NO_3-N

Glendale, Arizona

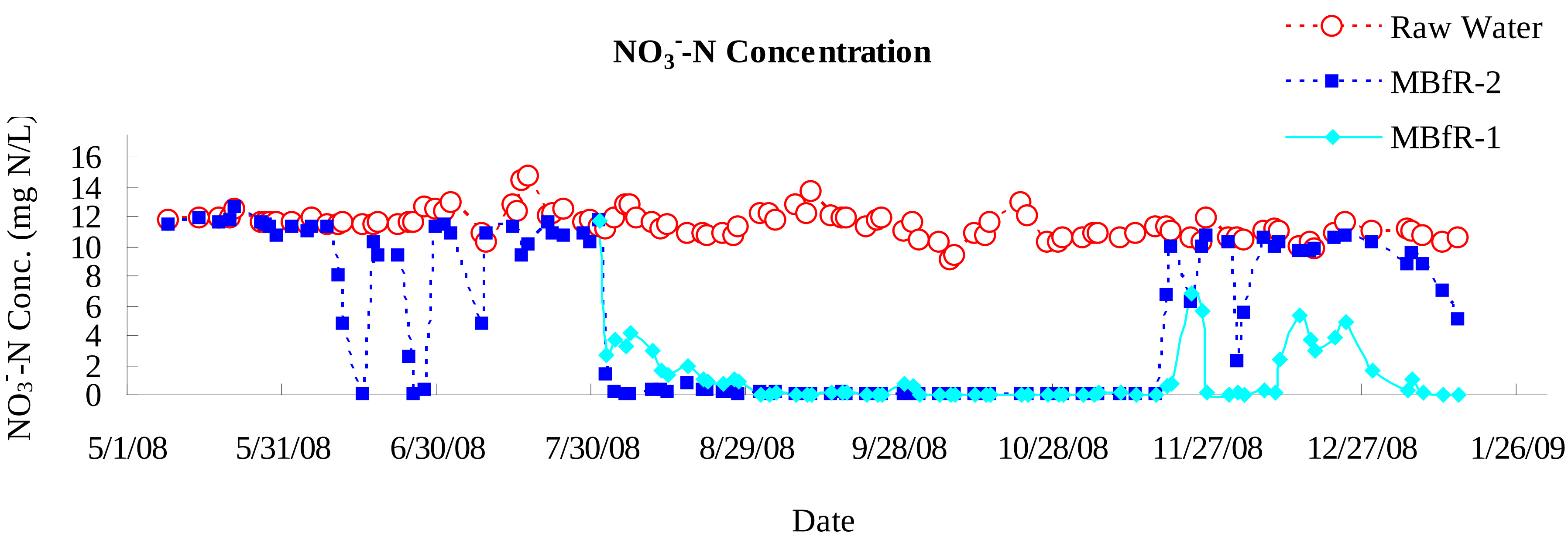
- Pilot Study Goals
  - Characterize the performance of biological nitrate removal technology
  - Identify co-contaminant treatment
  - Evaluate ongoing ion-exchange pilot performance
  - Identify environmental issues for each technology
  - Develop cost comparison
  - Evaluate biological and ion-exchange systems based on criteria including the triple bottom line of sustainability

Glendale Tailored Collaboration Study

- Biological Nitrate Reduction
  - Train 1 – Autotrophic Membrane Biofilm Reactor (MBfR)
  - Train 2 – Heterotrophic bioreactor – upflow bioreactor with plastic media
- Post Treatment
  - Ozone Biological Activated Carbon

Results

- No innooculation was required with favorable operation conditions
- Nitrate was removed to much less than the goal
  - Removal rates were at or above the published data
- Nitrate loading rate was a key parameter

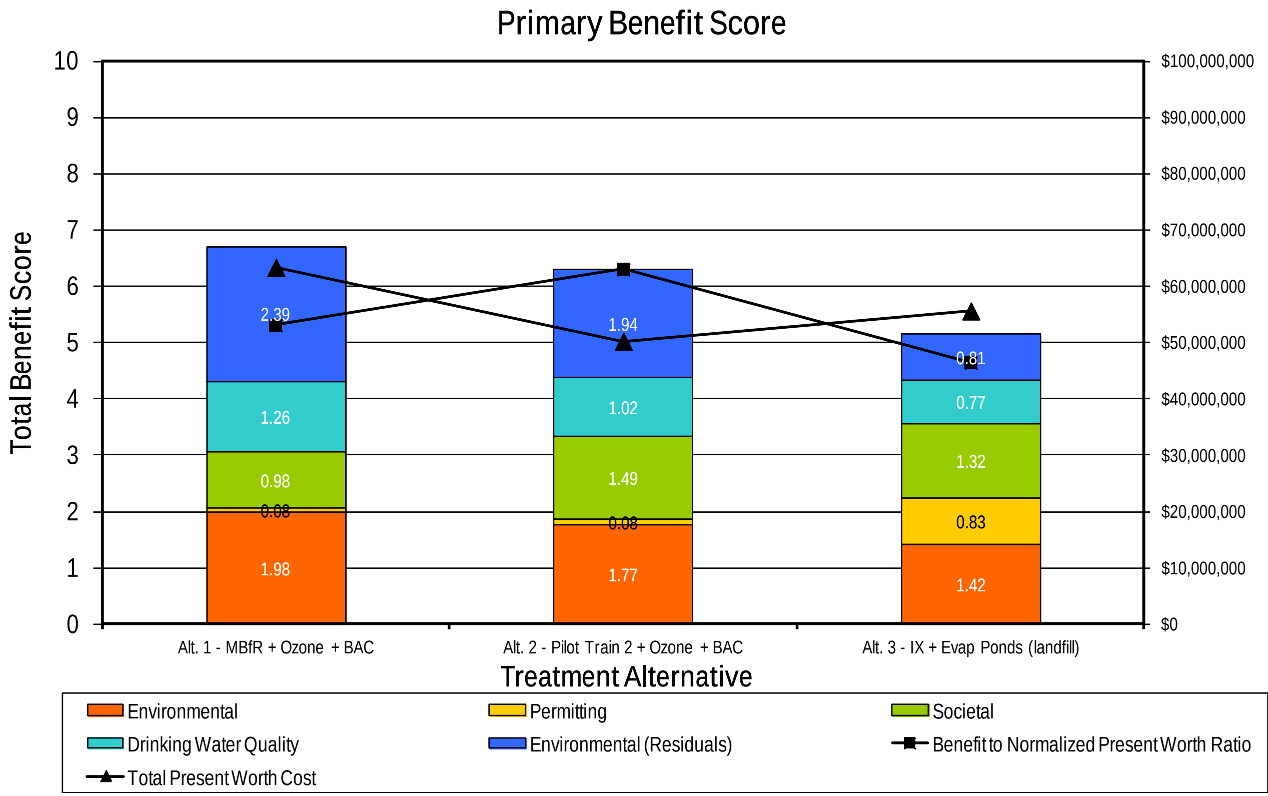


Results

- Ozonation/BAC
  - Increased DO
  - Reduced DOC
  - Achieved SWTR turbidity goals
  - Mitigated Nitrite carryover
  - Decreased Heterotrophic Plate Count
- Conclusions
  - Identification of target carbon and nutrient requirements is critical
  - The turbidity introduced through biological treatment was removed through post-treatment
  - Effluent dissolved organic carbon (DOC) and phosphate concentrations were well-controlled
  - Finished water met SWTR and IESWTR requirements.

Biological Nitrate Removal Cost

- Triple Bottom Line Analysis
  - Environment, Society, Economic
- 3 Options Evaluated
  - Pilot 1 (Mbfr), ozone, BAC
  - Pilot 2 (upflow bioreactor) ozone, BAC
  - Ion Exchange, evaporation pond, landfill



Case Study Projects

Biological Iron Removal

- Ruth Burnett Sport Fish Hatchery
- Fairbanks, Alaska

Biological Nitrate Removal

- Tailored Collaboration with Water Research Foundation
- Glendale, Arizona

Biological DBP Precursor Removal

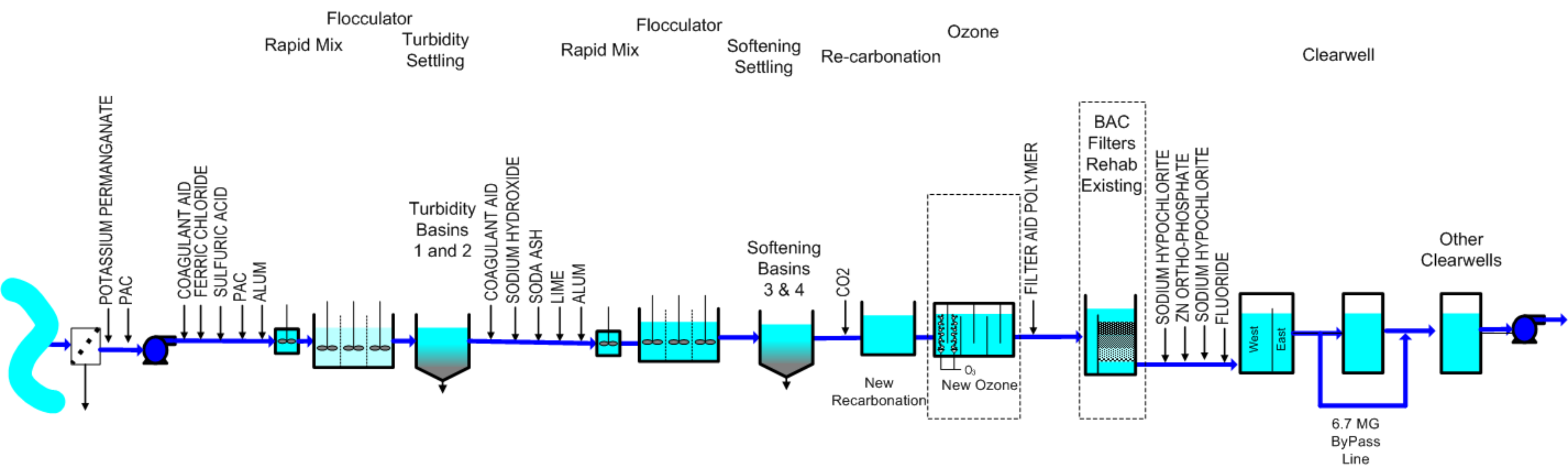
- Large Midwestern Water Treatment Plant
- Ohio, USA

Conventional DBP Precursor Removal

- Enhanced coagulation/settling
- Increase contact time/decrease residual
- GAC adsorption
- Convert to chloramines

Biological DBP Precursor Removal

- Enhance filter performance to support biology to remove TOC



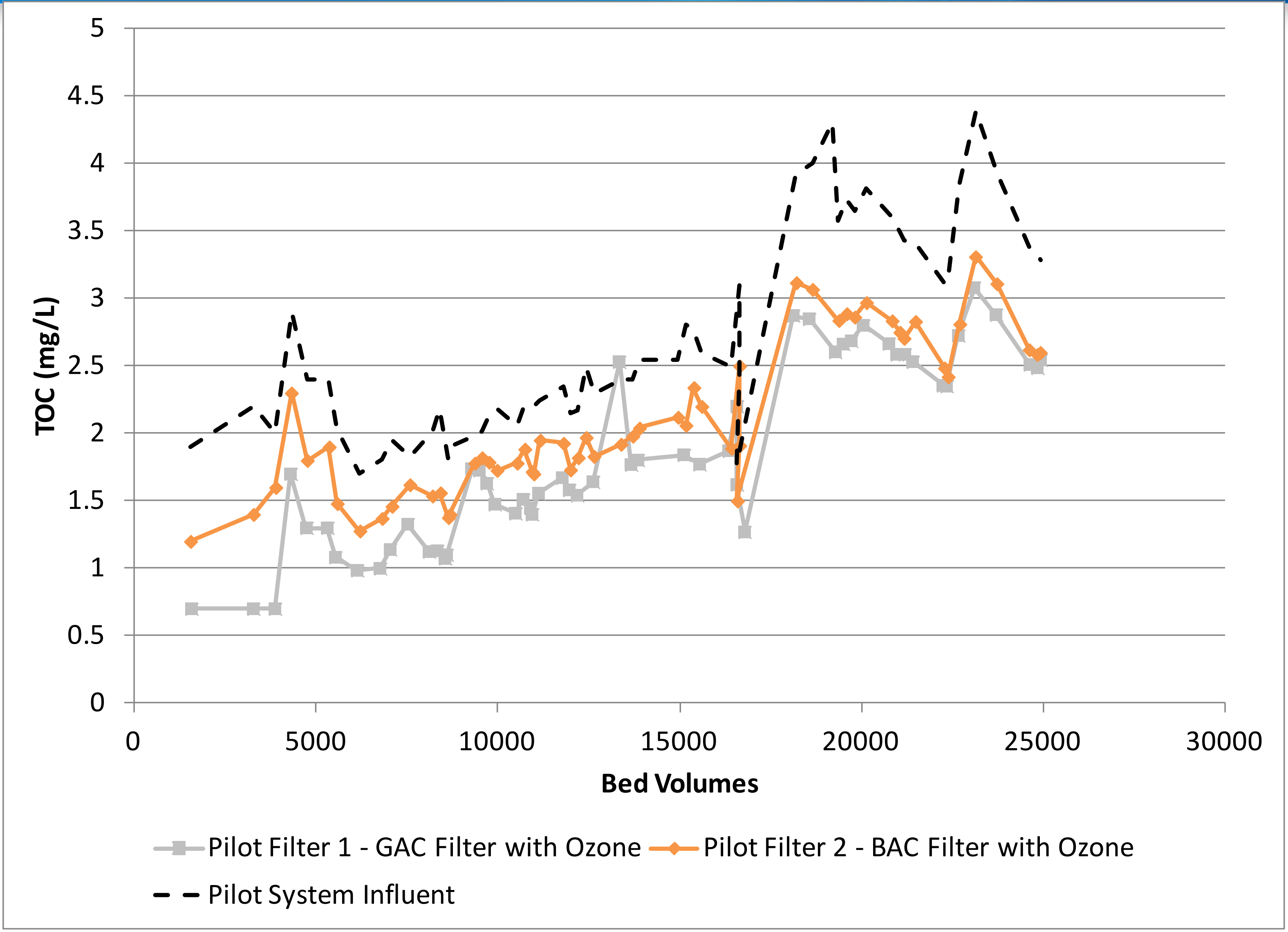
Large Midwestern City Pilot Program

- **Pilot Options**
  - **GAC in Existing Filters**
  - **GAC Post-filter Contactors**
  - **Ozone/BAC in Existing Filters**
- **Goal**
  - **TOC: <2.0 mg/L**
  - **Turbidity reduction**
  - **Cost effective Stage 2 DBP Compliance:**
    - **Target 80% of Locational Running Annual Average (LRAA)**
    - **Comply with all primary drinking water regulations**

Large Midwestern City Pilot Program

Filter #	Nickname	Upstream Process	Media Configuration
Filter 1	GAC with Ozone	Ozone	36” GAC over 6” Filter Sand
Filter 2	BAC with Ozone	Ozone	36” BAC over 6” Filter Sand
Filter 3	Anthracite with Ozone	Ozone	18” Anthracite over 12” Filter sand over 3” Torpedo Sand
Filter 4	GAC, no Ozone	Recarbonation	36” GAC over 6” Filter Sand
Filter 6 (Existing)	Anthracite, no Ozone	Recarbonation	18” Anthracite over 12” Filter sand over 3” Torpedo Sand
Filter 7	GAC Contactor with Ozone	Ozone and Filter 3	120” GAC
Filter 8	GAC Contactor, no Ozone	Recarb and Filter 6	120” GAC

Large Midwestern City Pilot Results



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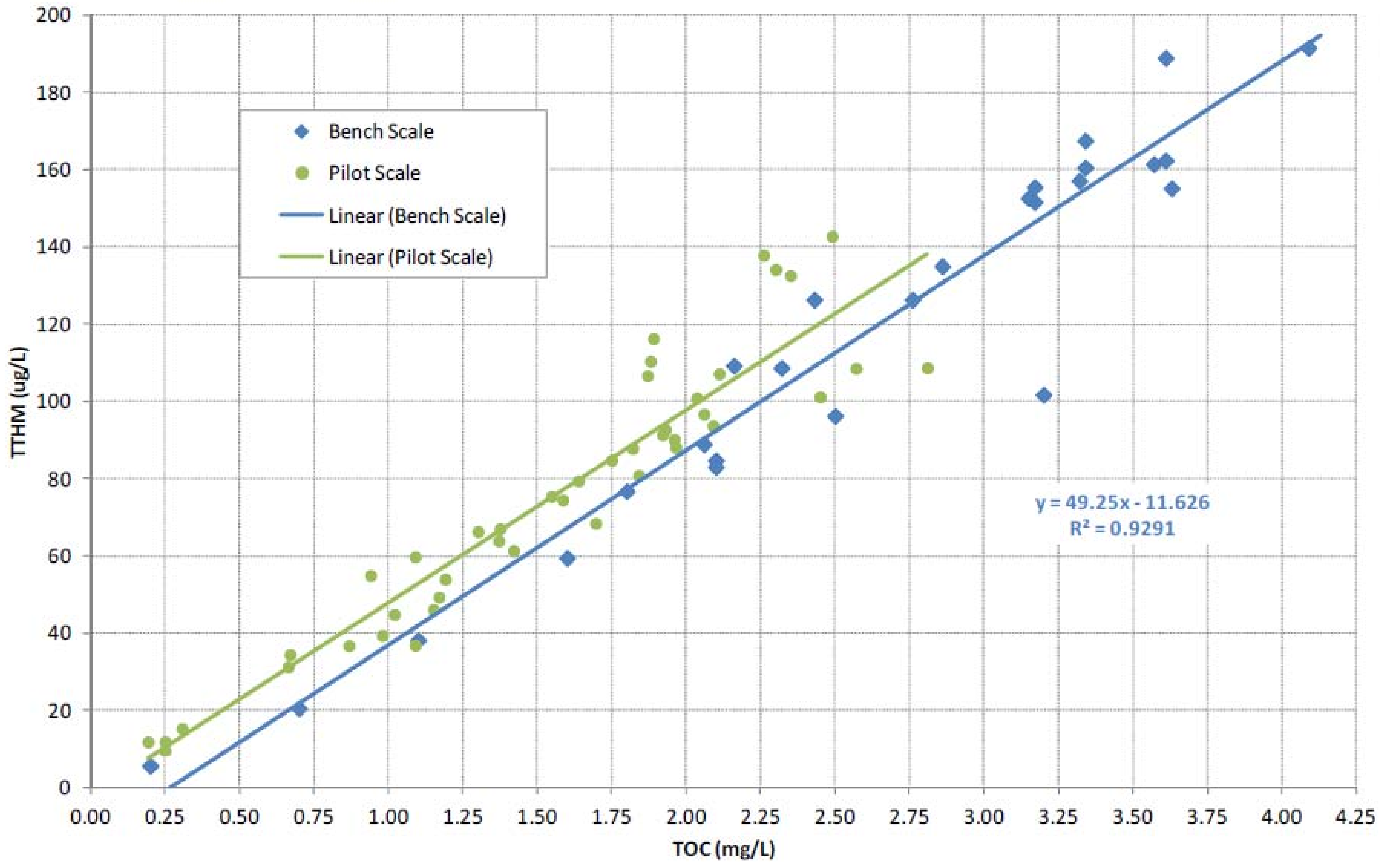
Large Midwestern City Pilot Results



Large Midwestern City Pilot Results

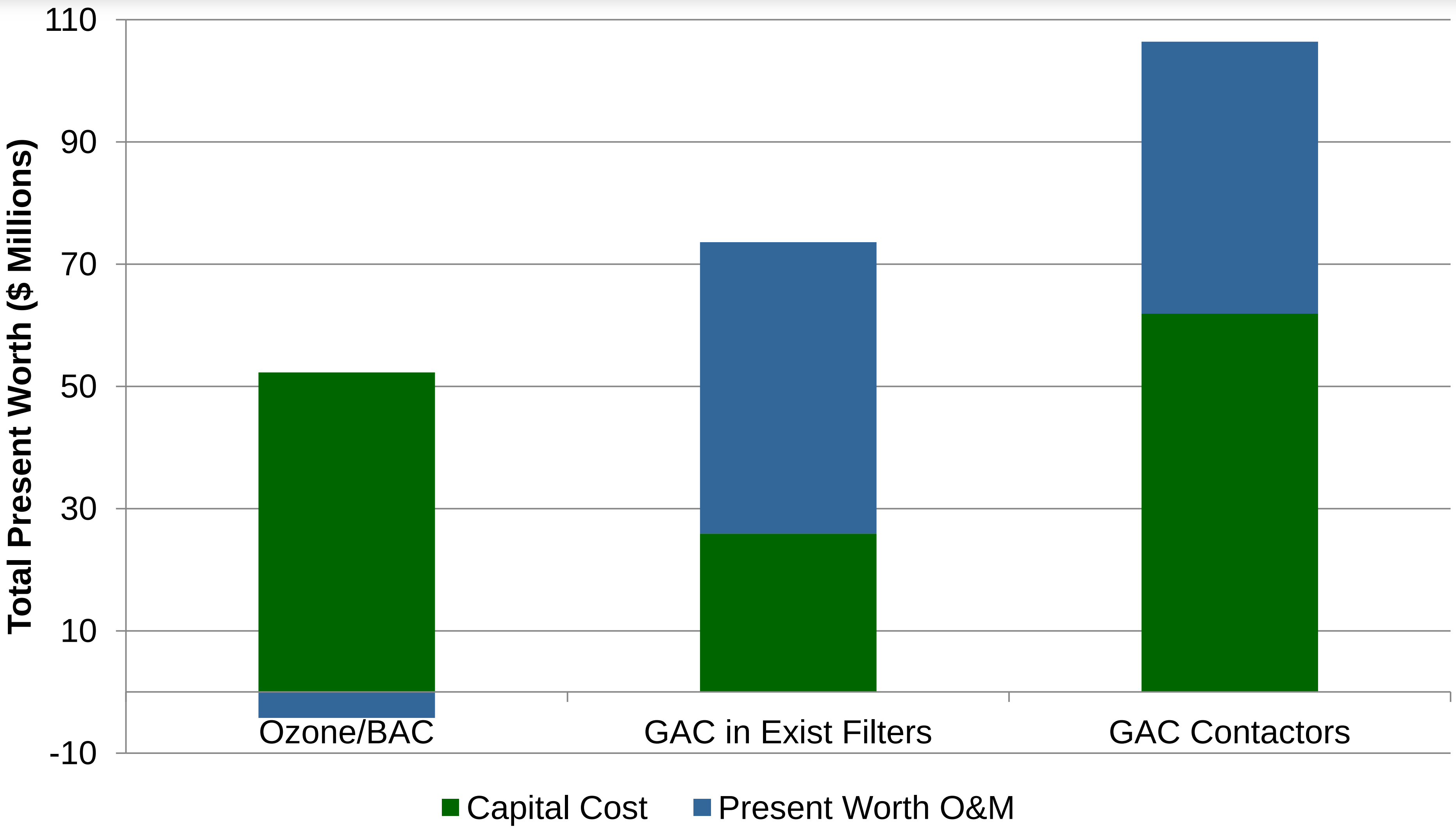
- **Bench and pilot results support ozone and BAC filters as most cost effective DBP control technologies**
- **Filter loading rates on BAC filters (36” GAC over 6” sand) were proven**
  - **With and without ozone**
  - **At 3.4 gpm/sf or equivalent of 110 MGD**
  - **Approximately 24 weeks of operational data**
- **Requesting approval from regulators at 3.1 gpm/sf or equivalent to 100 mgd with 6” sand**

Biological DBP Precursor Removal Cost

Alternative	DBP Compliance	Water Quality	O&M	Construct-ability	Environ-mental	Construction $(million)	+ Annual O&M $(million)	Present Worth $(million)
O3/BAC	⊙	○	⊙	◉	○	$52.3	$-0.37	$48
GAC Filter	⊙	◉	●	⊙	⊙	$25.9	$4.2	$73
GAC Contactor	○	⊙	⊙	●	◉	$61.9	$3.9	$106

- ○ Excellent
- ⊙ Good
- ◉ Fair
- ● Poor

Biological DBP Precursor Removal Cost



Current Regulatory Issues

Current Regulatory Climate

- Biological treatment is covered by existing EPA drinking water treatment *regulations* however *permitting* biological drinking water processes can still be challenging

- Anoxic biological treatment is under more scrutiny than aerobic processes

Summary & Conclusions

Biological Treatment Is:

- Becoming more widely accepted in the United States
- Often a sustainable approach
- Can be used on a wide variety of contaminants
- Effective with surface water and groundwater

- Not always the right fit, but part of a toolbox of treatment options

Acknowledgements

- Alaska Department of Fish and Game
  - Ruth Burnett Sport Fish Hatchery Staff
- Water Research Foundation Report 4131
  - City of Glendale, AZ
  - Arizona State University Biodesign Institute
  - Applied Process Technology (Vendor)
- Large Midwestern City

Questions?

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Brown AND Caldwell

PNWS AWWA Conference – Yakima Washington

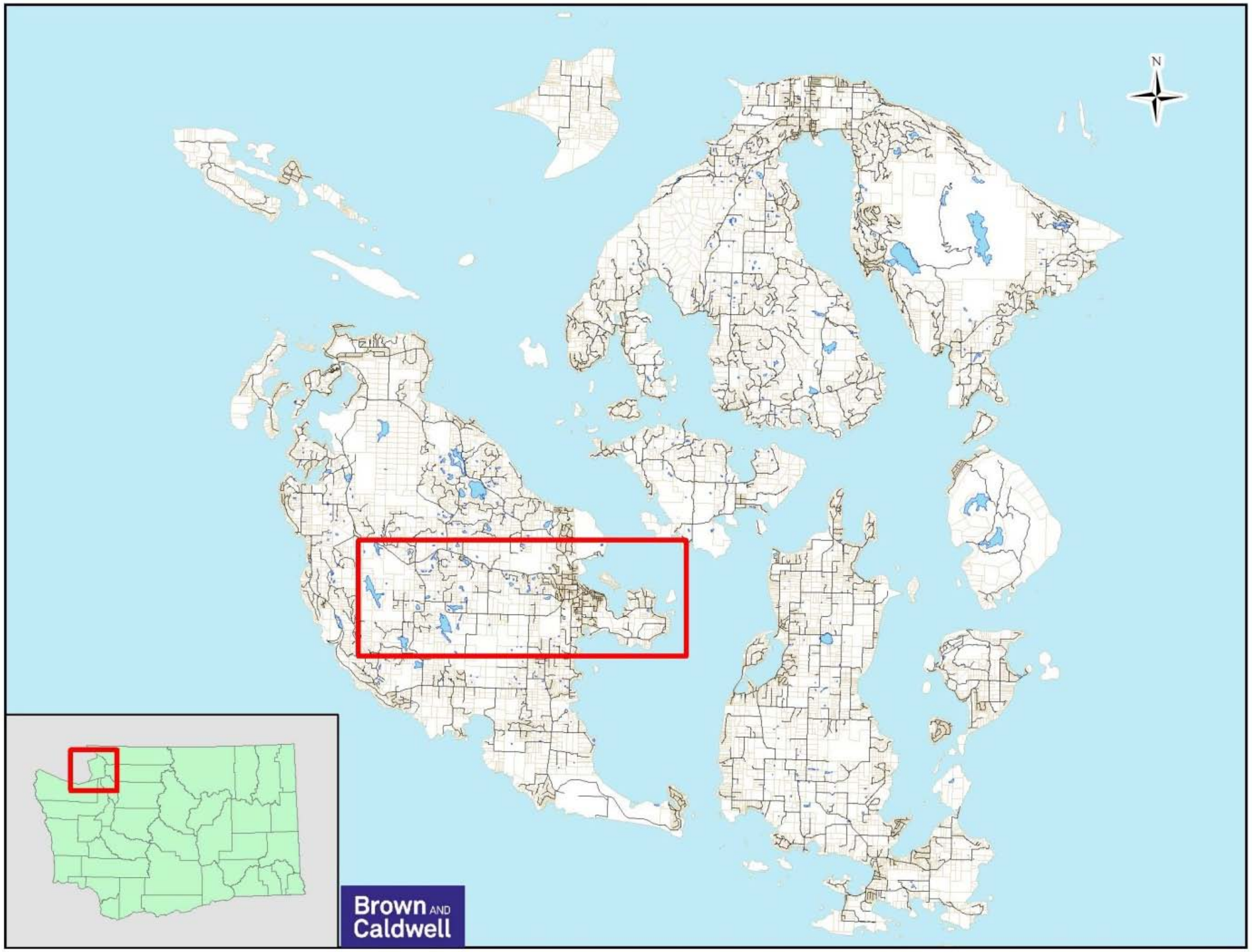
Implementing GAC Surface Water Treatment for Organics and DBP Control

Matt Maring, P.E. – May 3, 2012

Presentation Overview

- The Community, Water System, and Treatment Facilities
- The Water Quality Problem
- The Solution Alternatives
- The Final Solution – GAC Filtration/Adsorption

Town of Friday Harbor and San Juan Islands

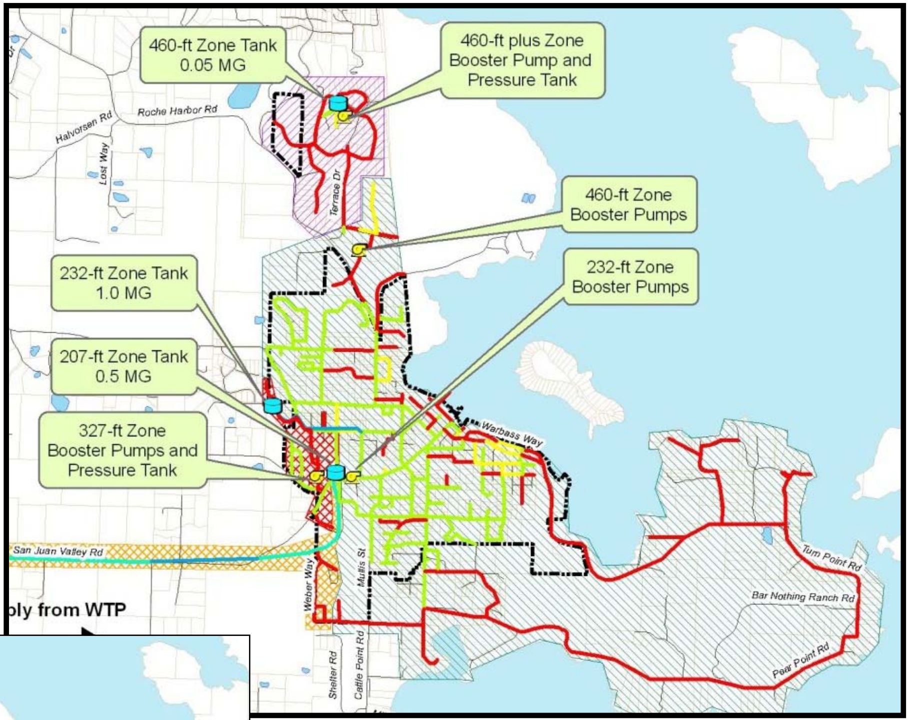


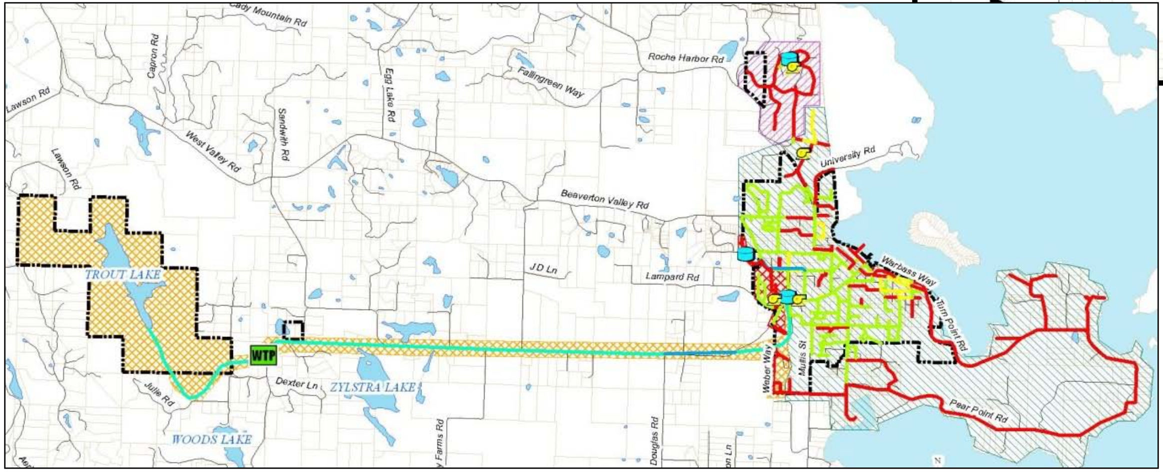
The Town of Friday Harbor Community

- Located on San Juan Island
- Summer tourism destination
- Resident water service population of totals approximately 3,300
  - 2,300 in town
  - 900 in surrounding unincorporated areas

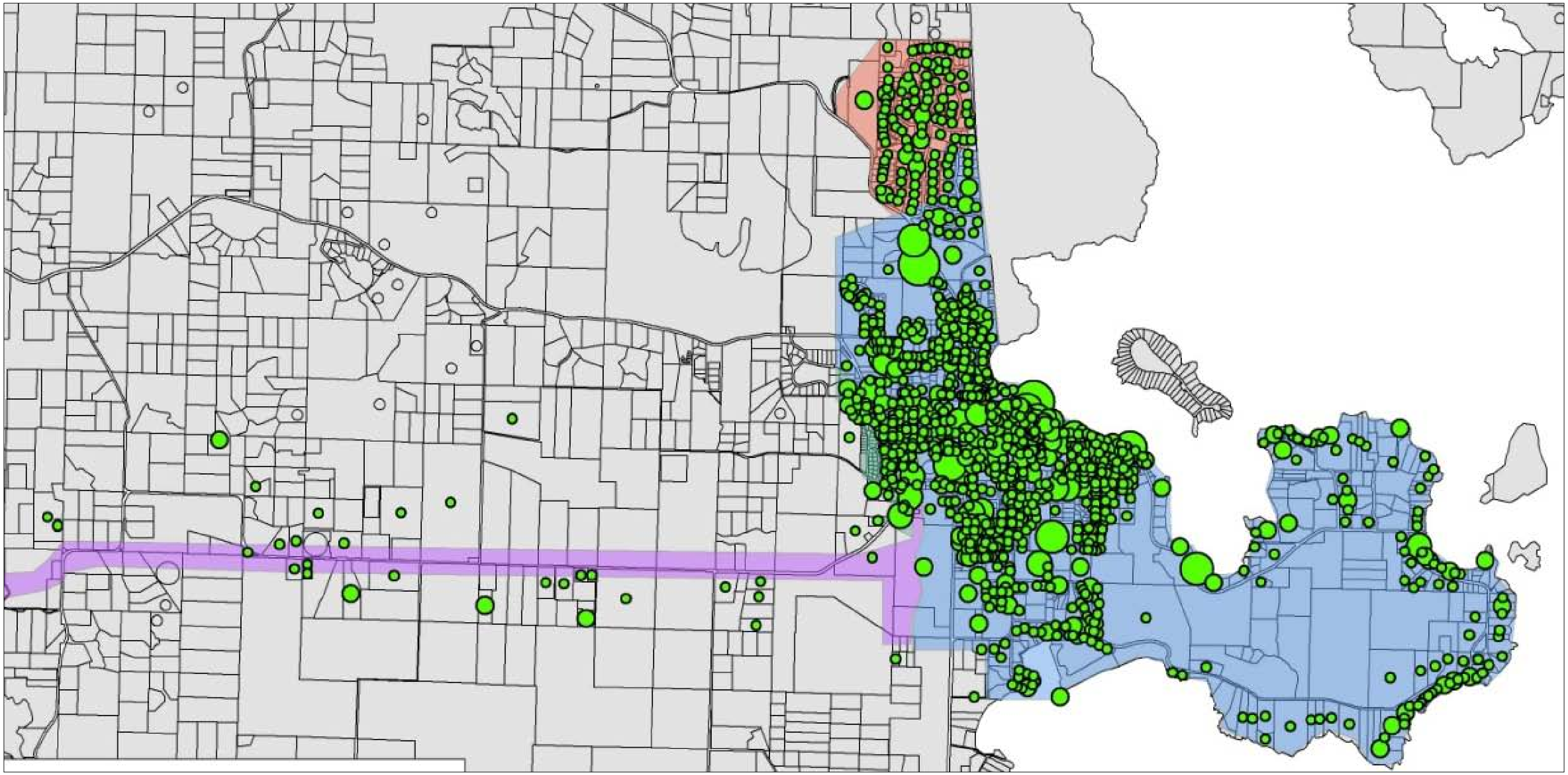
Friday Harbor Water Supply System

- Surface water supply
- Direct filtration WTP w/ chlorine disinfection
- 35+ miles of water mains
- 1.55 MG water storage
- 5 pressure zones





Water Demand Distribution



Trout Lake Surface Water Supply Source

- Concrete arch dam constructed in 1928
- AUG 1 and 2 supplemental seasonal surface water supplies pumped to Trout Lake storage
- Forested and vegetated watershed

Trout Lake Surface Water Supply and Watershed

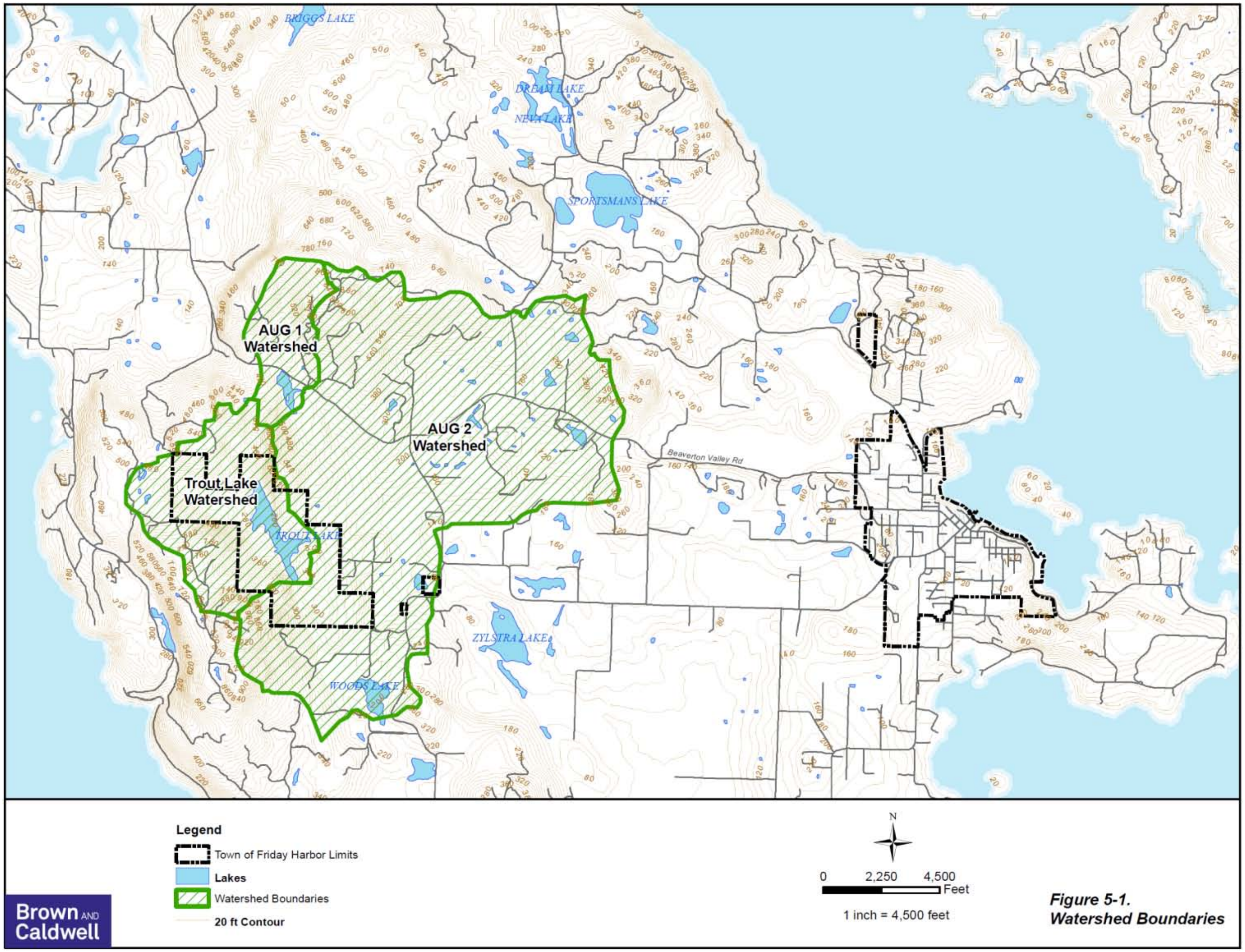
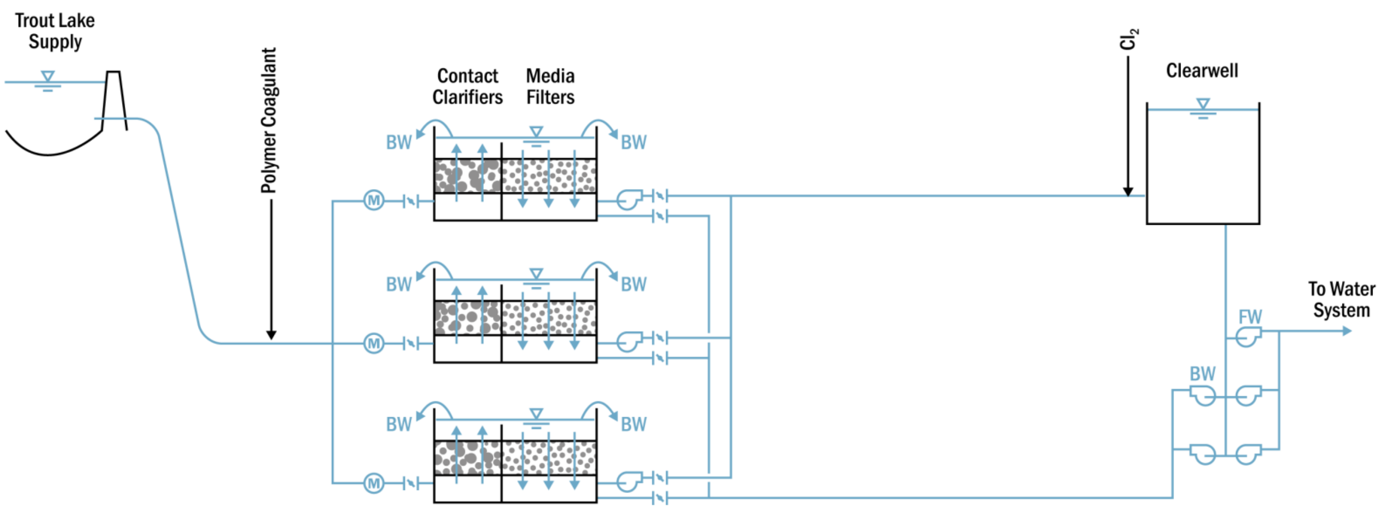


Figure 5-1. Watershed Boundaries

Friday Harbor and Watershed

Preexisting Water Treatment Process

- 1.0 mgd direct filtration package treatment system
- Constructed in 1995 for SWTR compliance
- Upflow contact clarifiers
- Rapid sand media filters
- Chlorine disinfection



The Water Quality Problem

- TOC – high Total Organic Carbon levels
- DBP – Disinfection Byproduct formation
  - TTHM – Total Trihalomethanes
  - HAA5 – Haloacetic Acids
  - MCL – some Maximum Contaminant Level violations
- T&O – Taste and Odor from seasonal algae blooms

Friday Harbor Water Quality History

Constituent	*Concentration*	*MCL*
Raw water TOC	6 – 8 mg/L	– –
Finished water TTHM	0.080 – 0.125 mg/L	0.080 mg/L
Finished water HAA5	0.040 – 0.050 mg/L	0.060 mg/L

Water Quality Improvement Approach

1. Study and assess solution alternatives
2. Implement expedient low cost solutions to achieve water quality regulatory compliance
3. Review and implement additional measures to further improve water quality as appropriate

2001 – Ranked Solution Options

- Suspend prechlorination
- More frequent distribution system cleaning and flushing
- Oxidize DBP precursor and T&O compounds with potassium permanganate
- Adsorb DBP precursor and T&O compounds with powdered activated carbon
- New coagulants and enhanced coagulation
- Air strip chloroform THM species
- Reduce algae formation in Trout Lake
- Adsorptive granular activated carbon (GAC) cap on existing filters
- Inline GAC filtration/adsorption treatment
- Switch from free chlorine disinfection to chloramination
- Chlorine dioxide disinfection
- Ultraviolet (UV) disinfection
- Ozone disinfection system to oxidize DBP precursor and T&O compounds

2003 – Initial Solutions Implementation

- Suspend prechlorination
- More frequent distribution system flushing
- Solar Bee mixers installed to limit Trout Lake algae formation
- Implement potassium permanganate preoxidation

- TTHMs reduced to just below 0.080 mg/L MCL

Intermediate Assessments

- 2006 – Prefiltration ozone pilot
  - Effective at DBP and T&O reduction
  - Full scale implementation costs >$1.0M, relatively expensive
  - Complex operations
- 2008 – Enhanced coagulation
  - Limited effectiveness at DBP reduction in optimization trials
- 2009 – Air stripping analysis
  - Chloroform THM removal
  - Effective DBP reduction
  - THM reformation potential
  - No T&O benefits

2010 – Implement GAC Filtration System

Process selection factors:

- Performance and effectiveness with DBP and T&O reduction
  - GAC media adsorption removes organics (DBP precursor and T&O compounds)
- Operational and hydraulic simplicity
  - Largely passive operation
  - Monitor hydraulics and water quality
  - Clean periodically via backwashing
  - GAC media is replaced when saturated
- Cost/benefit balance
- Analogous success at Roche Harbor

GAC System Sizing

Design Parameter	*Design Sizing*
Peak design flow	1.0 mgd
Media quantity	40,000 lbs
Empty bed contact time	14.7 minutes
Filter configuration	2x 10’ diameter pressure tanks
Operation modes	• Dual series lead-lag operation (normal) • Dual parallel operation (peak flows) • Single operation (during media replacement/maintenance)
Backwash loading rate (25% GAC bed expansion)	8.5 gpm/sf = 700 gpm
Expected media life to saturation	8 – 12 months

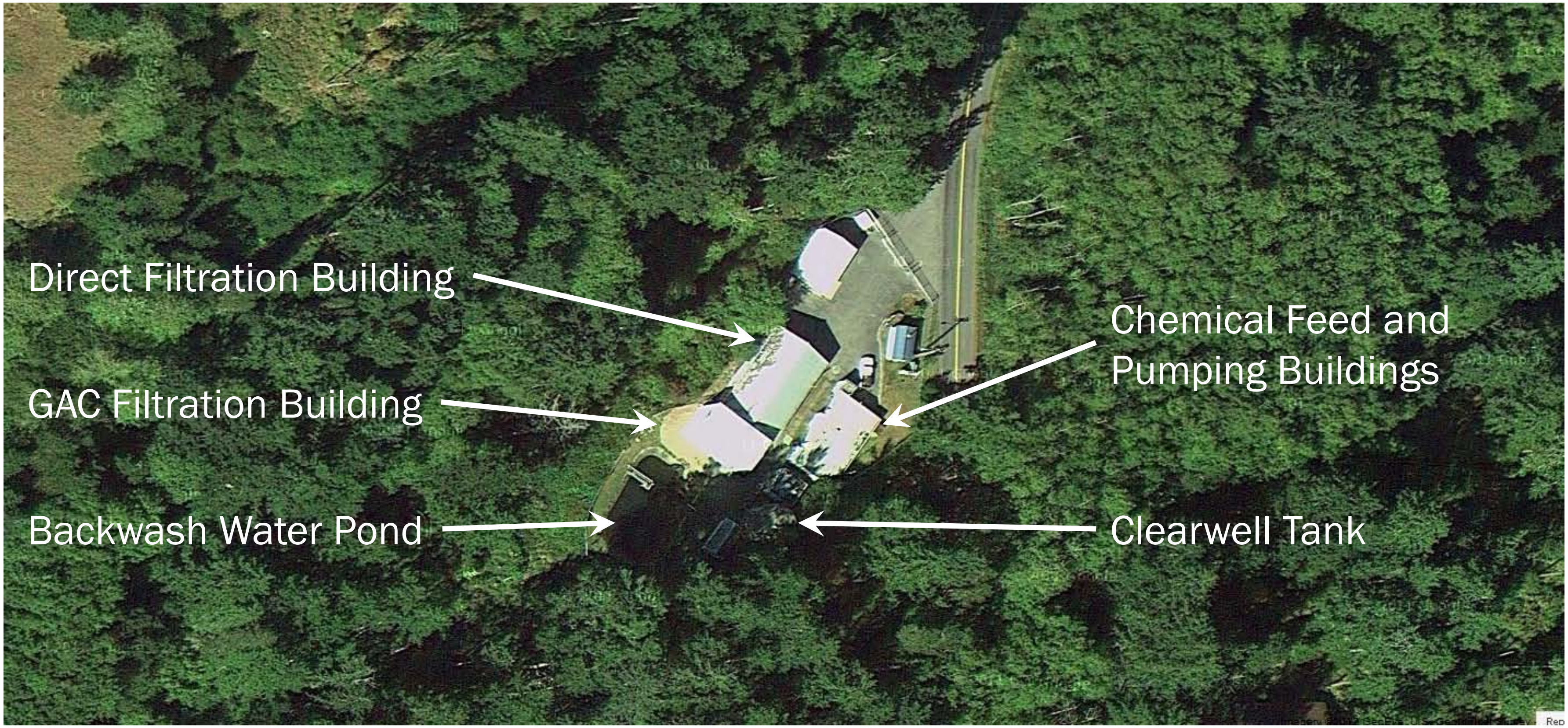
GAC Media Characteristics

Parameter	*Value*
Iodine number	1,000 mg/g (min)
Effective size	0.55 – 0.75 mm
Trace adsorption capacity	10 mg/cc (min)
Apparent density	0.5 g/cc
Ash content	9%

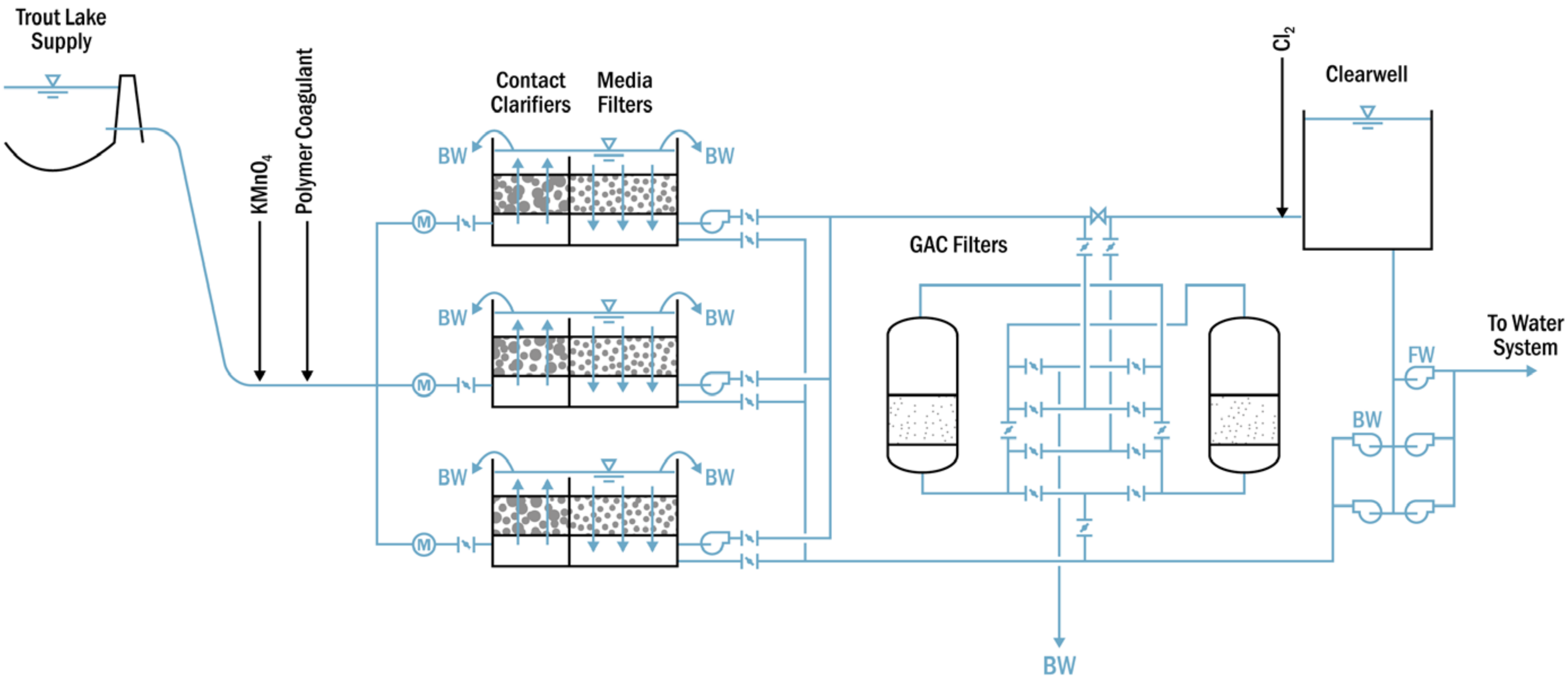
GAC Process Performance Monitoring

- Hydraulics
  - Treatment flowrate
  - Pressures – inlet, intermediate, outlet
  - Differential headloss – determines backwashing frequency
- Water quality
  - UV absorbance (DBP precursor surrogate measure) – inlets, GAC media mass transfer saturation/adsorption zone, outlets
  - TOC concentrations and removal
  - pH
  - DBP levels (TTHM and HAA5)

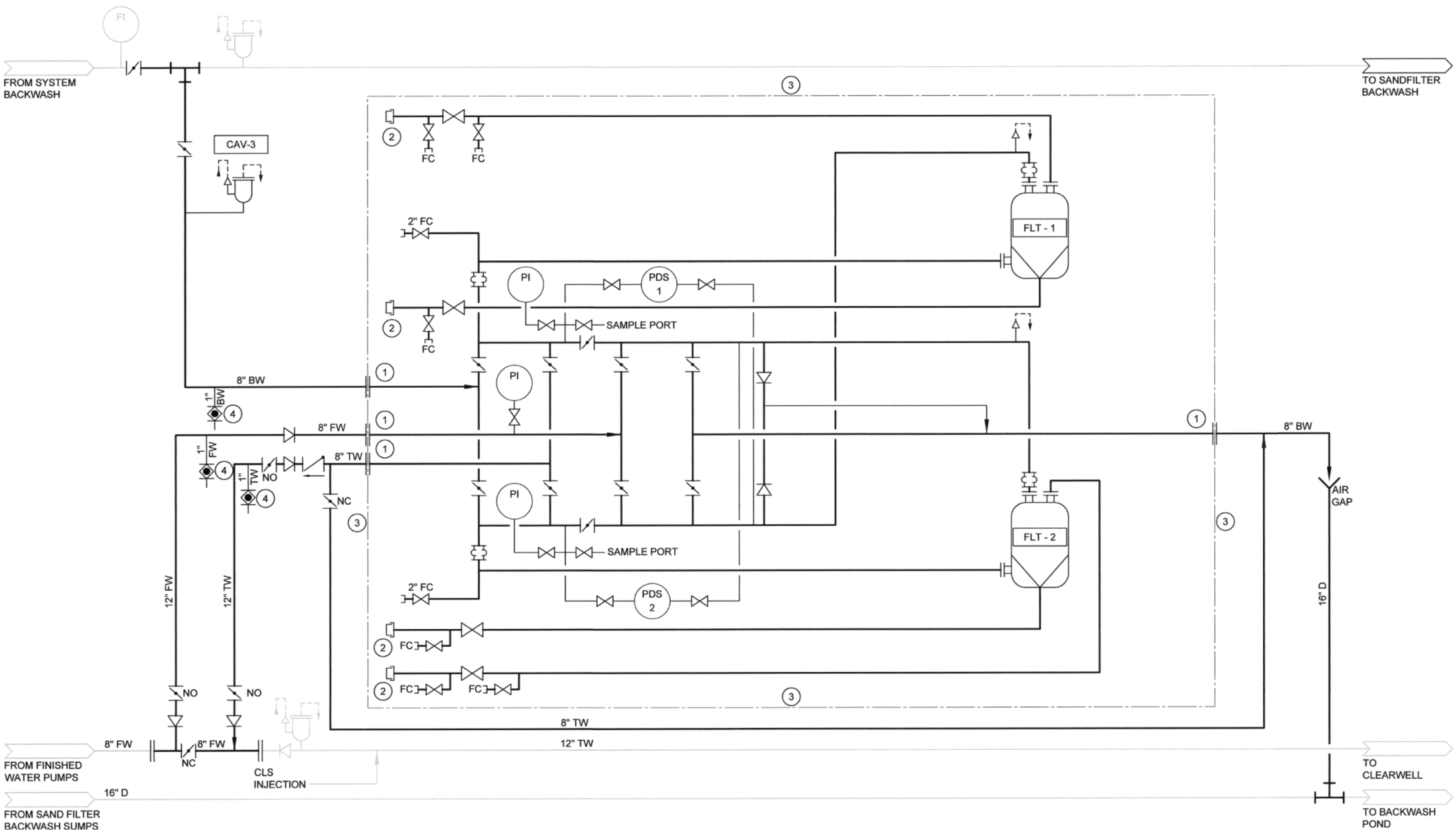
Water Treatment Plant Site Integration



GAC Water Treatment Process Integration



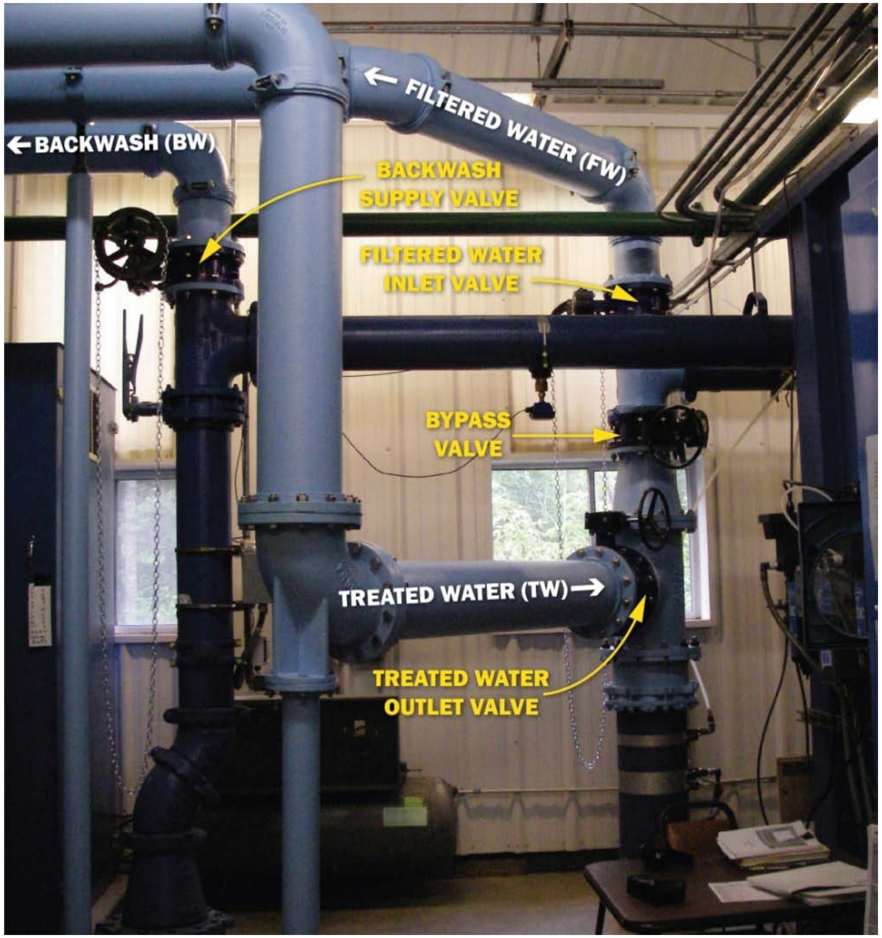
GAC Process and Instrumentation Diagram



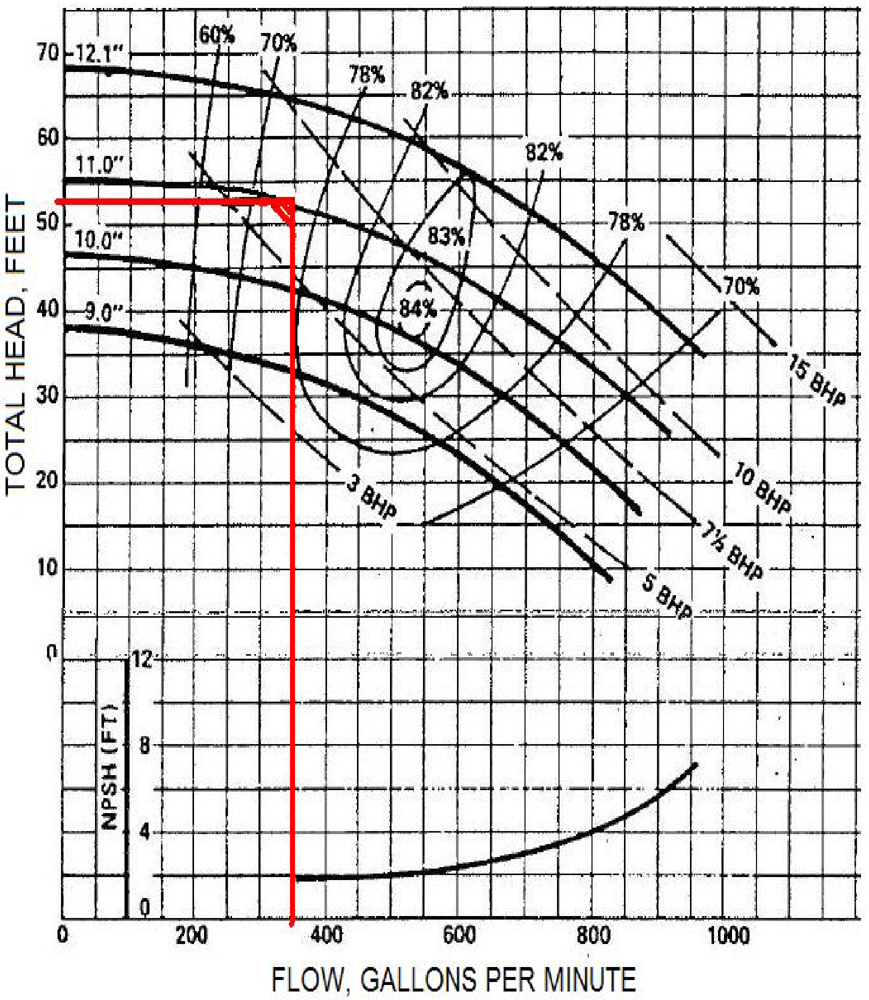
GAC System Piping Integration

Preexisting piping

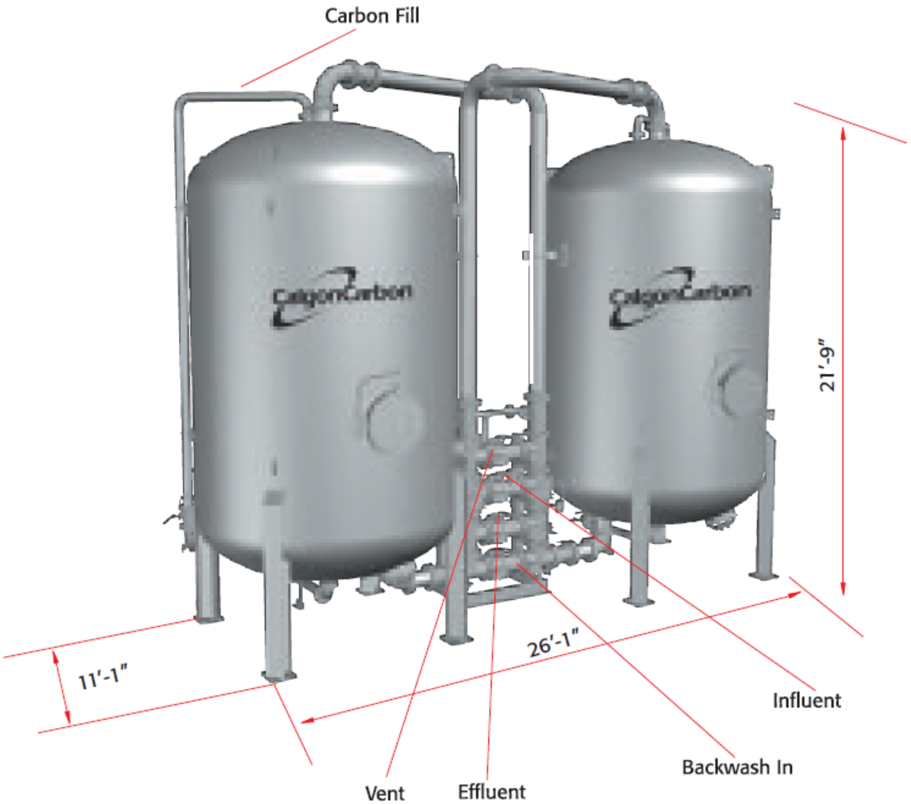
GAC system connections

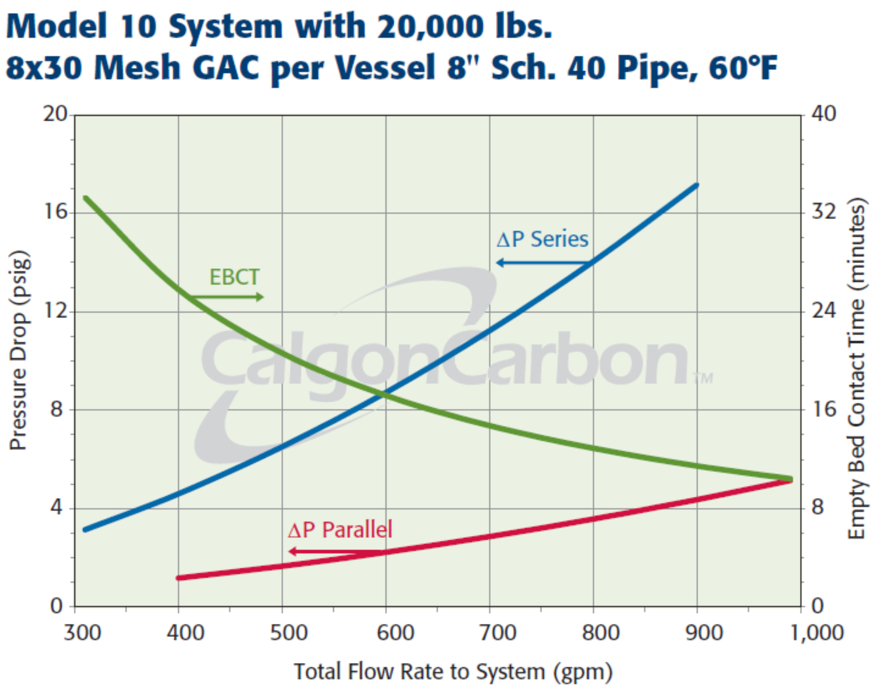


Existing Filtered Water Pump Performance

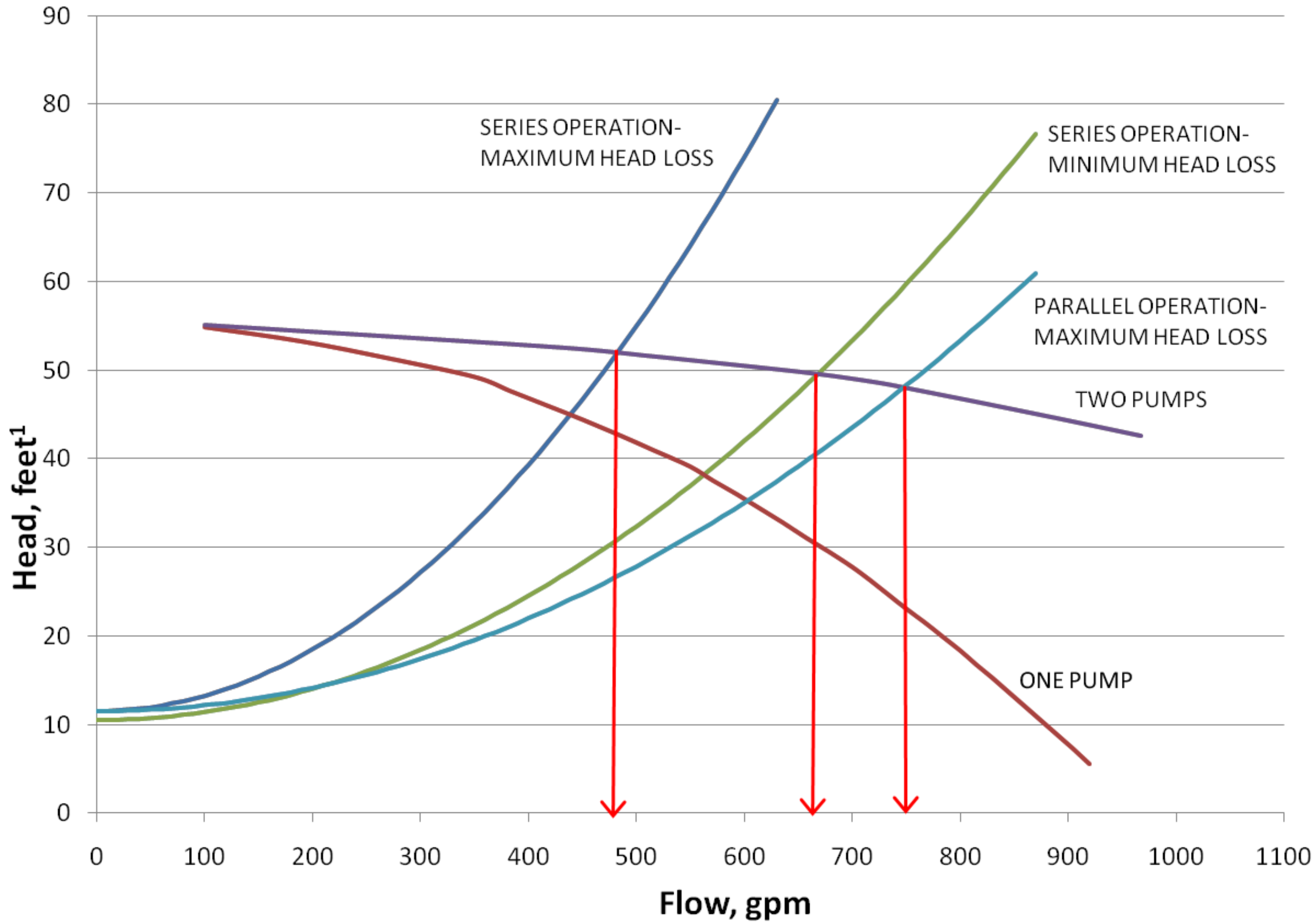


GAC System and Hydraulic Performance





GAC System Pump Performance



Note 1. Total head indicated is less than actual head because pump curve head is reduced by the loss incurred in the individual branch piping of each pump.

Preexisting Water Treatment Site

GAC Treatment System Site

Foundation Complete

GAC Components Ready for Delivery

GAC Components Arrive on Site

Unloading GAC Filter Tank 1

Righting GAC Filter Tank 1

Righting GAC Filter Tank 1

Righting GAC Filter Tank 1

Placing GAC Filter Tank 1

GAC Filter Tanks in Place

GAC Manifold and Piping Installation

Preengineered Metal Building Framing

GAC System Manifold Connections

GAC Building Rollup Access Door

Filling GAC Filter Tanks with Media

Project Complete and Operational – June 2011

GAC Filtration System Costs (1.0 mgd capacity)

- Preconstruction estimates
  - $800K capital
  - $200K design, administration, construction management
- Construction bidding
  - 10 bidders
  - $792K high bid
  - $572K low bid/awarded (Faber Brothers Construction)
- Final project costs
  - $568K (including GAC equipment @ $250K)
  - $200K design, administration, construction management
  - $80K – $120K annual operating costs
    (GAC media replacement)

Treatment and GAC System Performance

Parameter	*Performance*
Backwash frequency (GAC differential pressure build up)	Required every 2 – 3 months
Initial DBP reductions	• TTHMs reduced from 0.080 down to less than 0.020 mg/L • HAA5 reduced from 0.045 down to less than 0.015 mg/L
Annual DBP levels	• TTHMs reduced from 0.080 down to 0.025 – 0.045 mg/L • HAA5 reduced from 0.045 down to 0.020 – 0.025 mg/L
Annual TOC treatment removal	50% – 90% removal
Chlorine use and demand	Reduced by 50% – 60%
Chlorine residual maintenance	Increased from 0.2 – 0.5 mg/L up to 0.5 – 1.0 mg/L

Summary

- GAC provides:
  - Effective DBP control
  - Excellent T&O performance and water quality aesthetics
  - Good cost/benefit balance
  - Reasonable media longevity
  - Straightforward operations and maintenance
  - Utility and customer satisfaction
  - Peace of mind

Questions and Discussion

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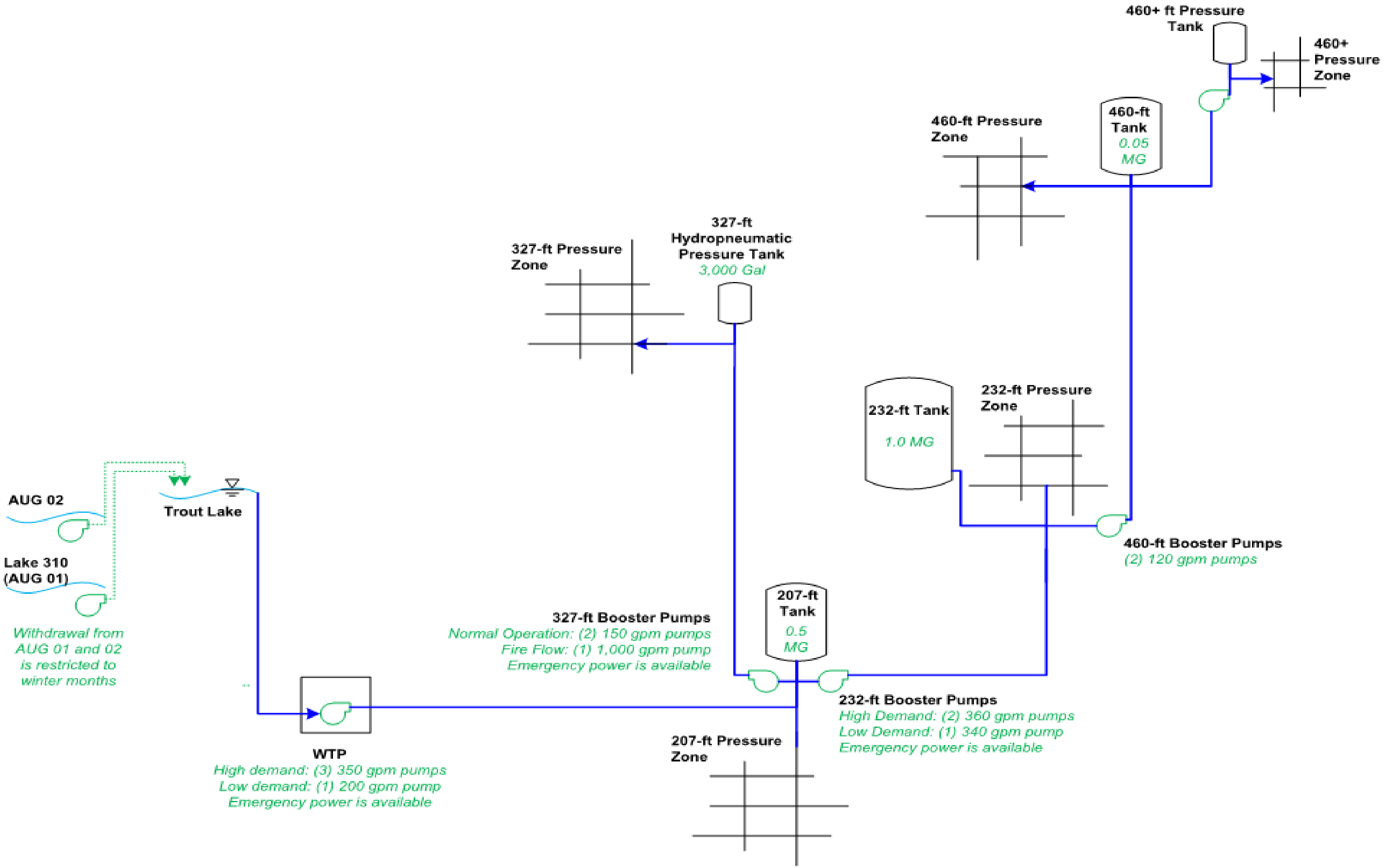
- Matt Maring: mmaring@brwncald.com
- Bill Persich: bpersich@brwncald.com
- Jon Beer: jbeer@brwncald.com

Acknowledgements:

- C. King Fitch, Town of Friday Harbor
- Mike Wilks, Town of Friday Harbor
- Mike Deegan, Town of Friday Harbor

Reserve Slides to Follow

Water System Schematic



Watershed Land Use
Forest Resource and Rural Farm Forest

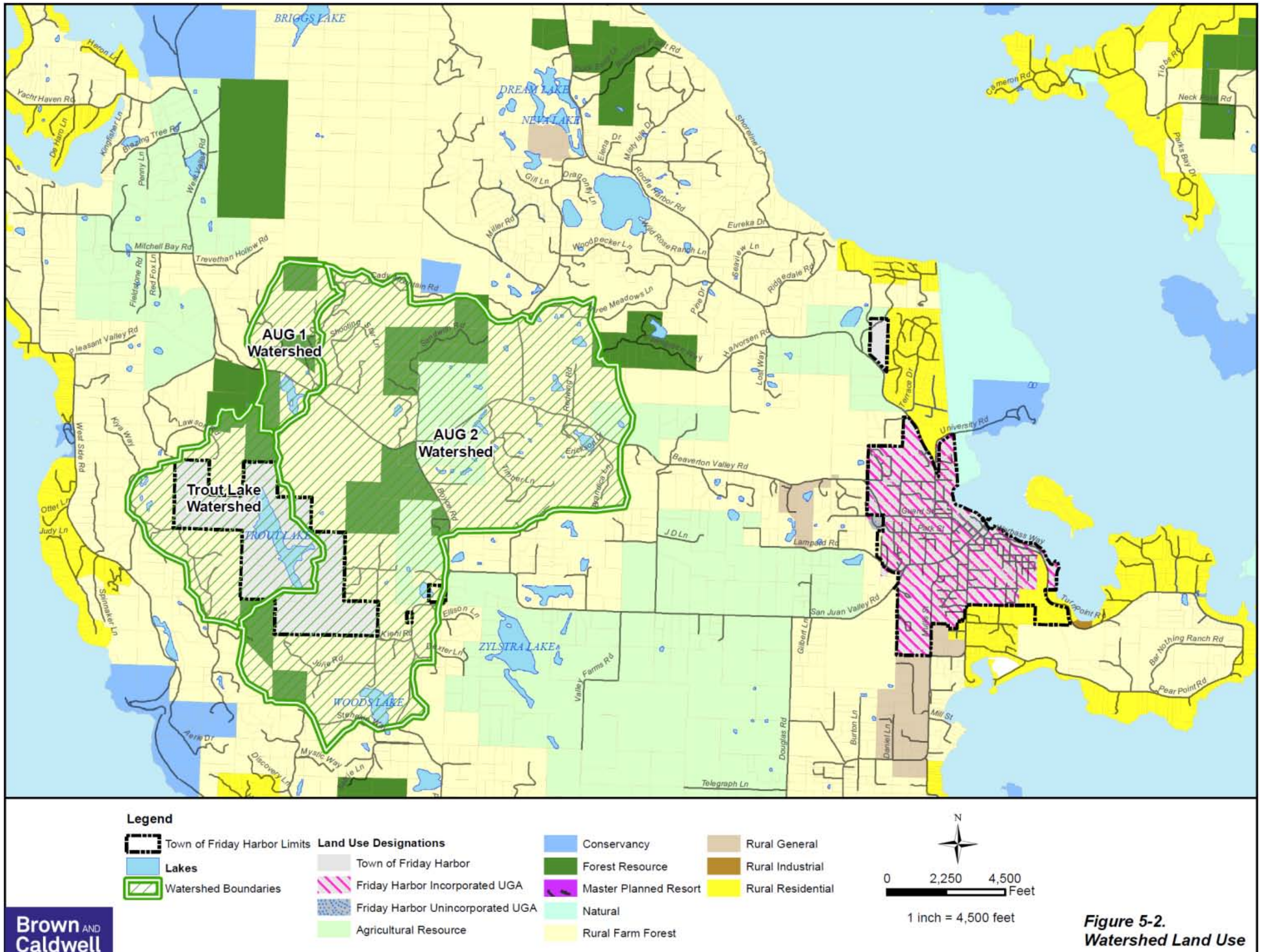


Figure 5-2. Watershed Land Use

Construction Access Corridor

Site Preparation and Grading

Forming Foundation Footing Walls

Foundation and Backwash Drain

Ready for Floor Slab

Pouring Floor Slab

Backing into the Treatment Plant Site

Backing between Treatment Buildings

Righting GAC Filter Tank 2

Righting GAC Filter Tank 2

Preengineered Metal Building Framing

Preengineered Metal Building Construction

Preengineered Metal Building Construction

Submitted to
PNWS-AWWA 2012 Conference
Yakima, WA

Secondary Membranes for Backwash Recovery

Establishing design criteria, demonstrating performance expectations, and implementation

Mark Graham

May 3, 2012

CITY OF NANAIMO
THE HARBOUR CITY

Associated Engineering

MWH
BUILDING A BETTER WORLD

Acknowledgements

MWH

- Carolyn Spehr
- Michael McWhirter
- Karla Kinser
- Geno Lehman

Associated Engineering

- Quinn Crosina
- Matt Henney

CITY OF NANAIMO
THE HARBOUR CITY

- Bill Simms

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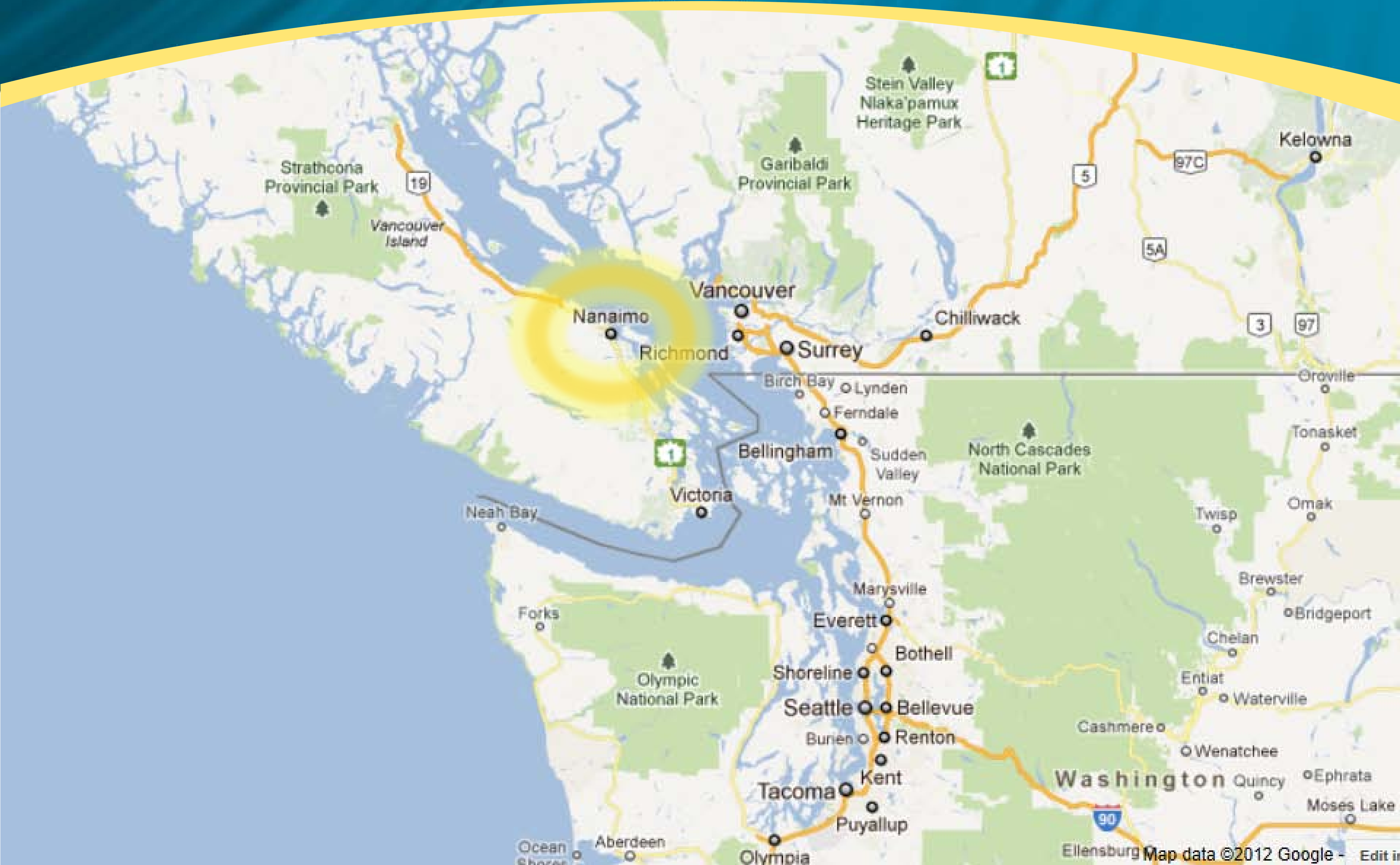
Water & Process Technologies

- Bill Legge
- Anthony Amendola
- David Swerdylk

Background

City of Nanaimo, British Columbia



City of Nanaimo Water Demands

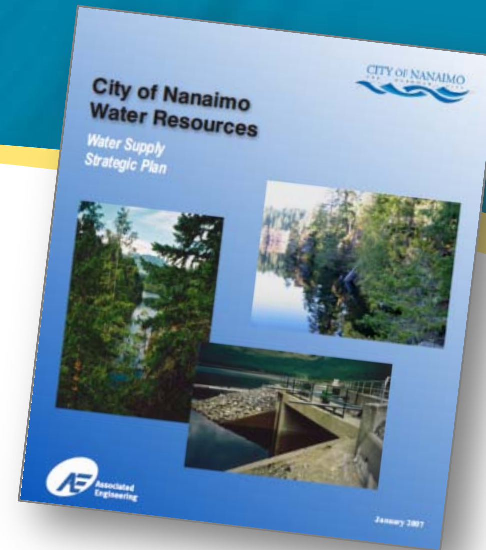
	Current	2035	2055
Population	84,000	124,200	167,300
Peak Day Demand, ML/d (MGD)	90 (24)	116 (31)	156 (41)
Average Day Demand, ML/d (MGD)	50 (13)	63 (17)	85 (23)

Nanaimo's Water System Today

- Pristine water supply
  - Typically < 2 NTU
- Open reservoirs
- Unfiltered. Coarse screening, chlorine disinfection
- Water Quality Issues:
  - Turbidity excursions – "flashy" and "twitchy" (frequent and short duration)
  - Colour visible to customers
  - Organics leading to elevated HAAs

South Fork Dam

Preparations for the Future



Goal 1 – Provide Safe Drinking Water

Goal 2 – Ensure a Sustainable Water Supply

Goal 3 – Provide Cost Effective Water Delivery

- Regulations requiring water to be filtered
- Address aesthetic issues (colour, T&O)
- Potential for increased logging in catchment
- Construction of another reservoir
  - Possible elevated organics during construction
  - Future increased algae
- Climate change?

South Fork Water Treatment Plant

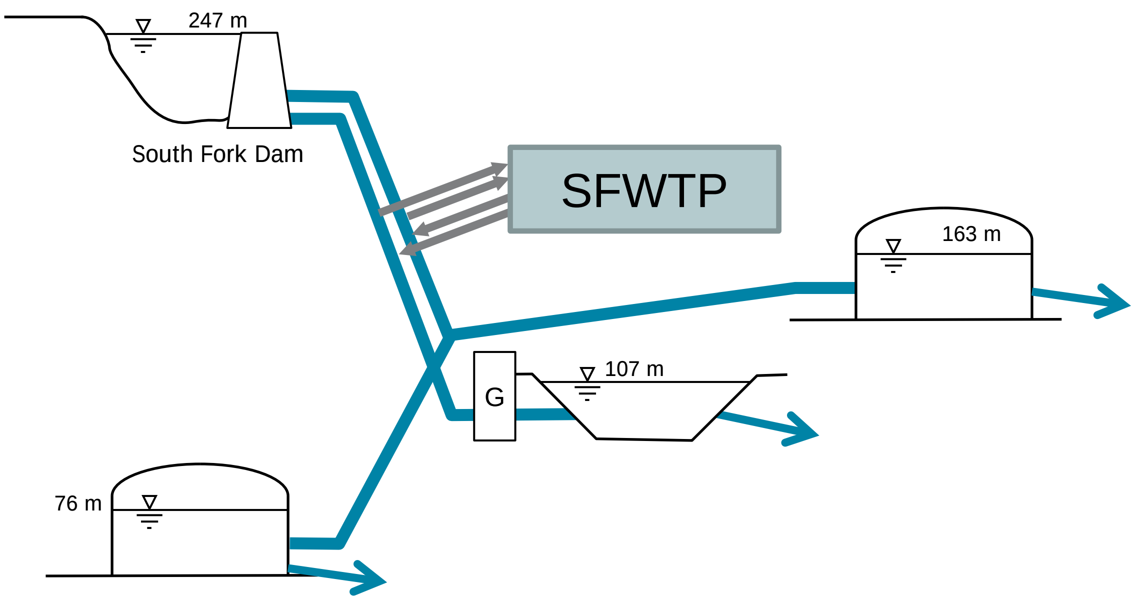
Key Drivers in Treatment Process Selection

- Ease of operation
- Reduce chemical use
- Minimize pumping
- Robust, reliable process
- Colour removal
- Minimize residuals

After pilot testing direct filtration, DAF and membrane filtration, **submerged membranes** were recommended.

Limited Hydraulic Head Drove Process Design

- Existing water supply flows by gravity to distribution system
- Power generation at Reservoir 1
- Only ~13-18 m of head available for treatment process



Submerged membranes were capable of accommodating hydraulic constraints

Remote Site Drove Residuals Treatment

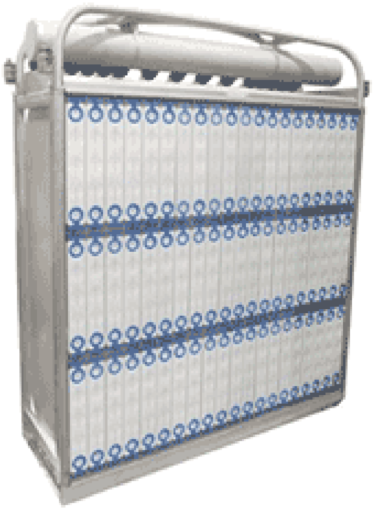
- No sewer for disposal
  - Waste streams must be handled on-site
- Chemical deliveries twice per week
- New power supply required
- Possibly unattended operation
- Low impact on area desired

Secondary membranes were required to minimize residuals

- Mechanical dewatering will be used

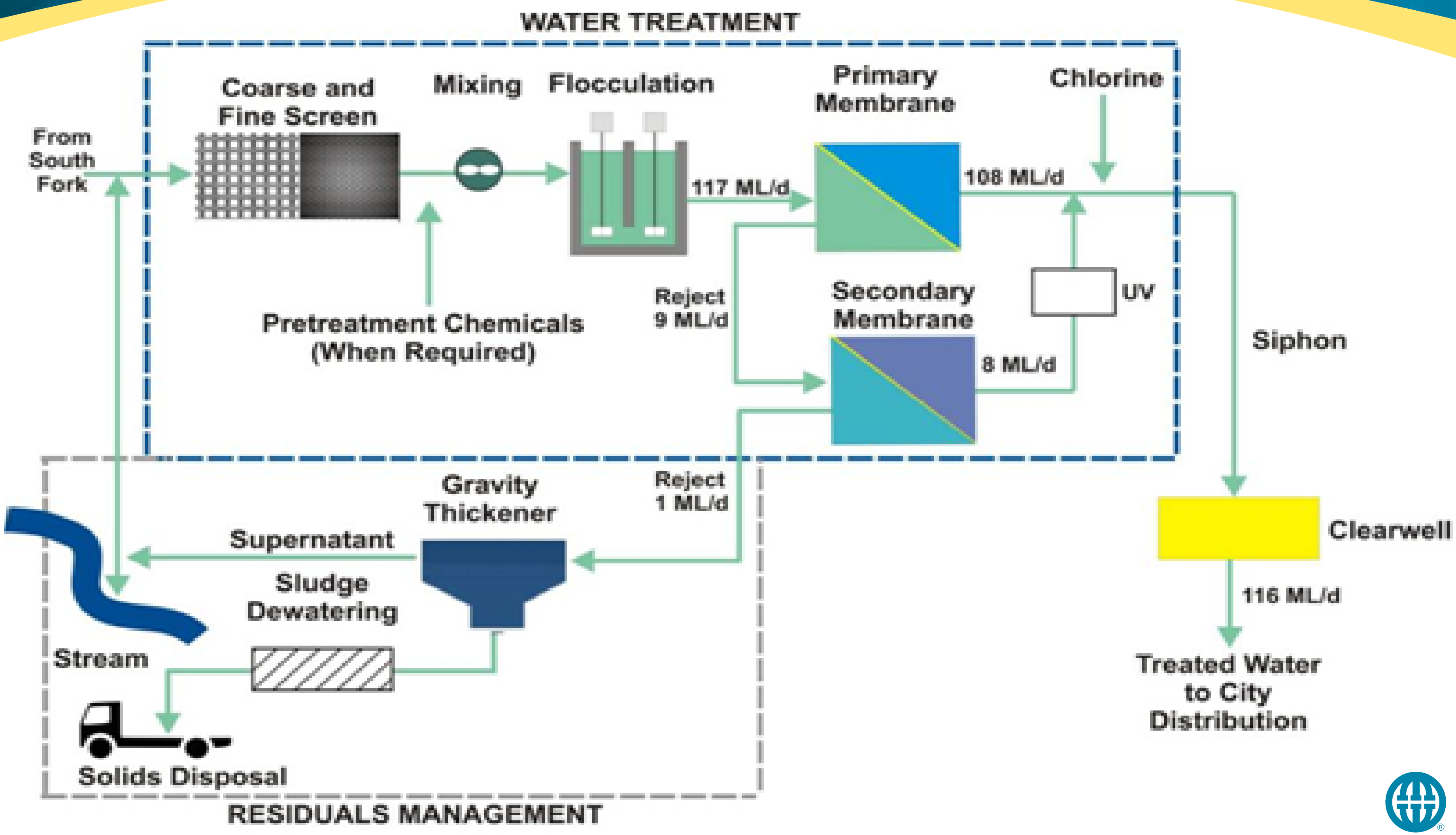
Membrane Filtration Objectives

- Water Quality
  - Turbidity ≤ 0.1 NTU; NTE 0.3 NTU
  - 4-log virus reduction
  - 3-log *Giardia lamblia* and *Cryptosporidium* reduction
  - Organics and algae removal to below aesthetic objectives (w/ coagulant as needed)
  - DBP and Aluminum reduction
  - Free chlorine residual of 0.2 mg/L
- Backwash recovery to achieve overall plant recovery of 99%
- Filtrate from second stage to contribute to overall plant production capacity



ZeeWeed 1000 Ultrafiltration Membrane

South Fork WTP Process



Stage 1 Membrane System Design

Parameter	Value	Comments
Stage 1 Permeate Flow	111.3 MLD	
Number of Stage 1 Trains	8	Initially membranes for 7
Stage 1 Recovery	97%	
Stage 1 Design Flux	44 lmh @ 20degC 29 lmh @ 3degC	28 gfd; Two trains out of service 18 gfd; Two trains out of service
Permeate Driving Force	Siphon	
Installed membranes per train	5 cassettes with 84 modules each	ZW1000 V4. Spare spaces for 12 more modules.
Backwash period	49 to 77 minutes	
Maintenance Clean Period	2 to 14 days	Hypochlorite cleans and HCl cleans
Recovery Clean Period	30 to 60 days	Hypochlorite cleans and Citric/HCl cleans

Secondary Membrane System

Secondary Membrane System

- Design considerations
  - Highly dependent on ability to project backwash water quality of primary stage
  - Use lower flux rates and more robust membrane
  - UV disinfection required as supplemental treatment for direct addition to plant effluent
- Pilot & demonstration testing
  - Presents challenges since secondary system capacity is much smaller than primary system
- Conservative design criteria
  - Established based on industry standards and representative feed water quality

ZeeWeed 500 Reinforced Membrane

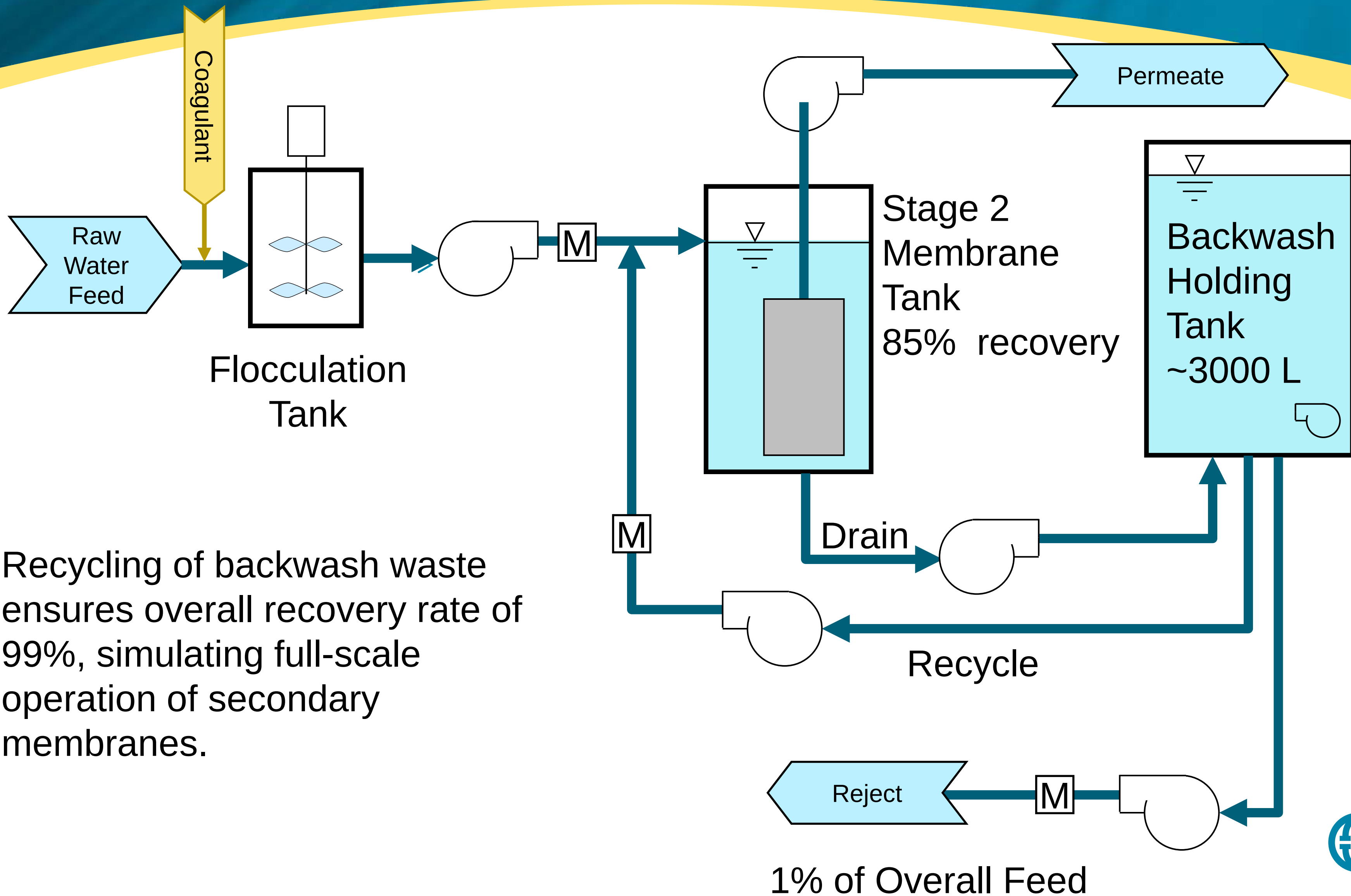
Stage 2 Membrane System Design

Parameter	Value	Comments
Stage 2 Permeate Flow	4.78 MLD	
Number of Stage 2 Trains	4	Initially membranes for 4.
Stage 2 Recovery	85%	
Stage 2 Design Flux	31 lmh @ 20degC 20 lmh @ 3degC	19 gfd; One train out of service 13 gfd; One train out of service
TMP Range	17 to 76 kPa	
Permeate Driving Force	Siphon	Primary reject pumped
Installed membranes per train	1 cassettes with 54 modules each	Spare spaces for 8 additional modules if needed
Backwash period	52 to 118 minutes	
Maintenance Clean Period	2 to 7 days	Hypochlorite cleans
Recovery Clean Period	30 to 60 days	Hypochlorite cleans and Citric/HCl cleans

Demonstration Testing

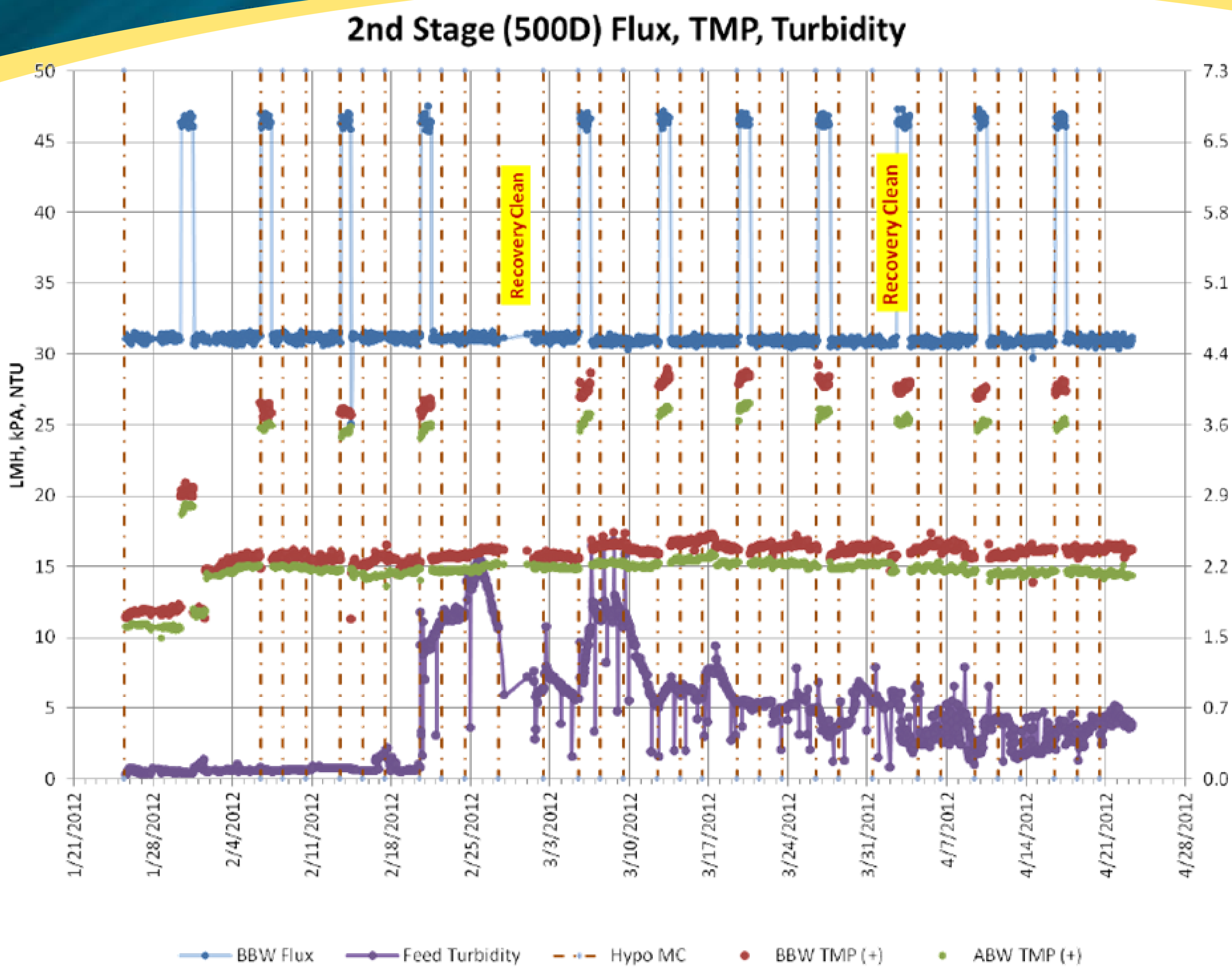
- Evaluates equipment proposed by selected membrane manufacturer
  - Prove design fluxes
  - Prove chemical cleaning frequencies
  - Allow evaluation of permeate and reject quality from the secondary stage membranes to allow design of downstream equipment
    - UV
    - Solids handling
- Additional time allowed for pilot testing following demonstration testing
- Second stage testing is challenging, because first stage produces a limited volume of reject.
- Second round of demonstration testing scheduled for summer/fall to evaluate performance with algae in water supply

Demonstration Testing
2nd Stage Process Flow Diagram



Recycling of backwash waste ensures overall recovery rate of 99%, simulating full-scale operation of secondary membranes.

Demonstration Testing Results



Flux: 6 days at N-1 and 1 day at N-2

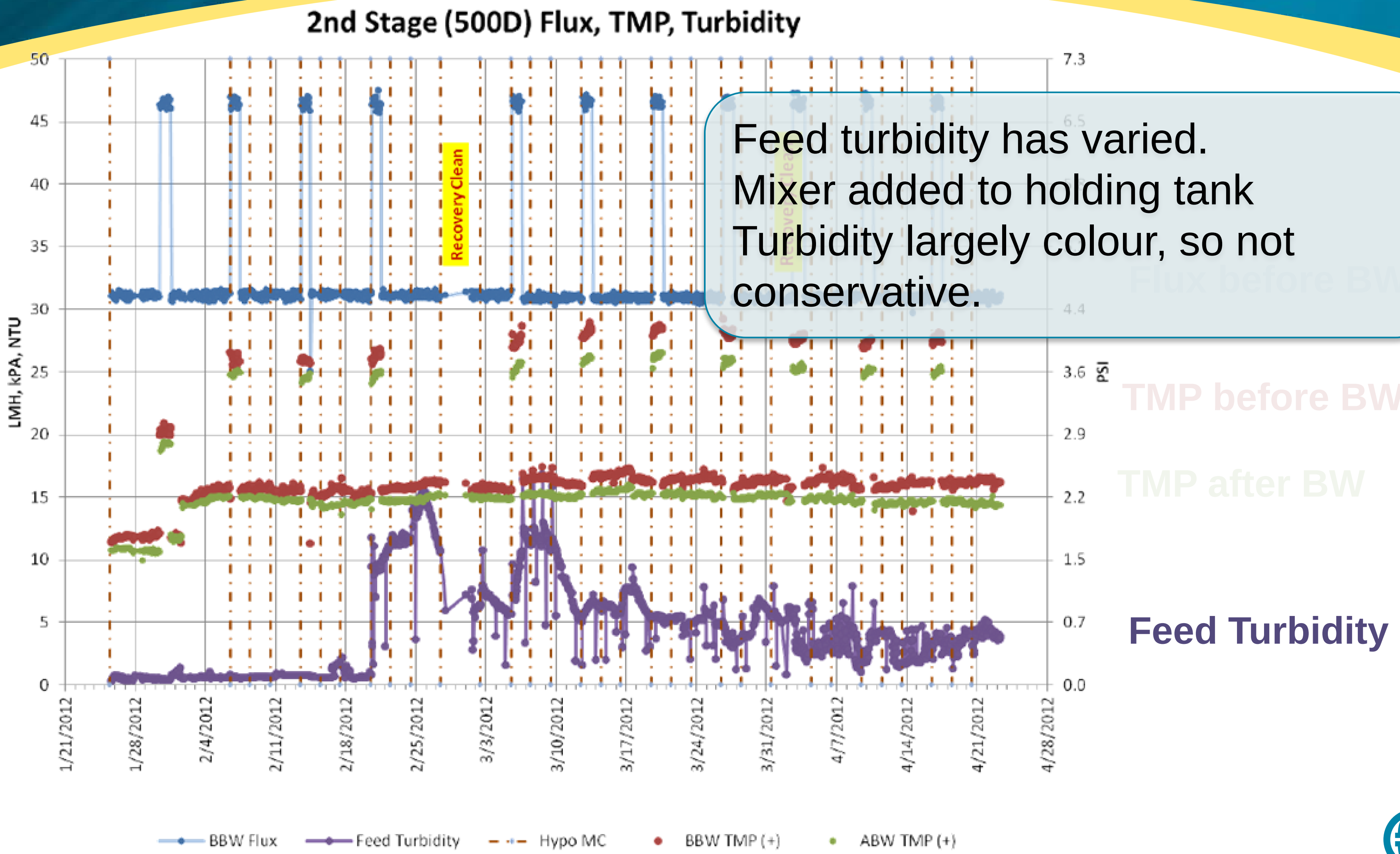
Flux before BW

TMP before BW

TMP after BW

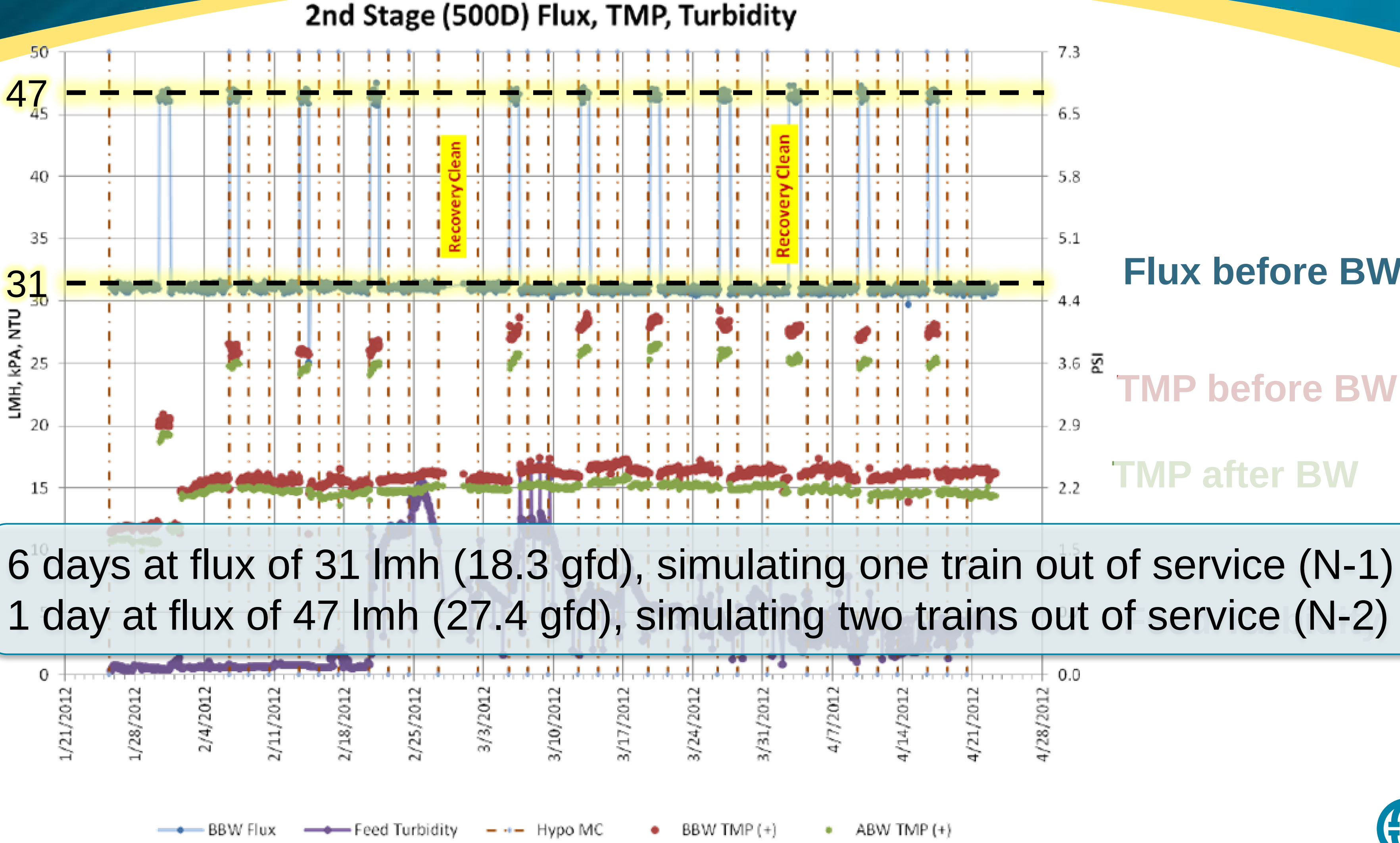
Feed Turbidity

Demonstration Testing Results



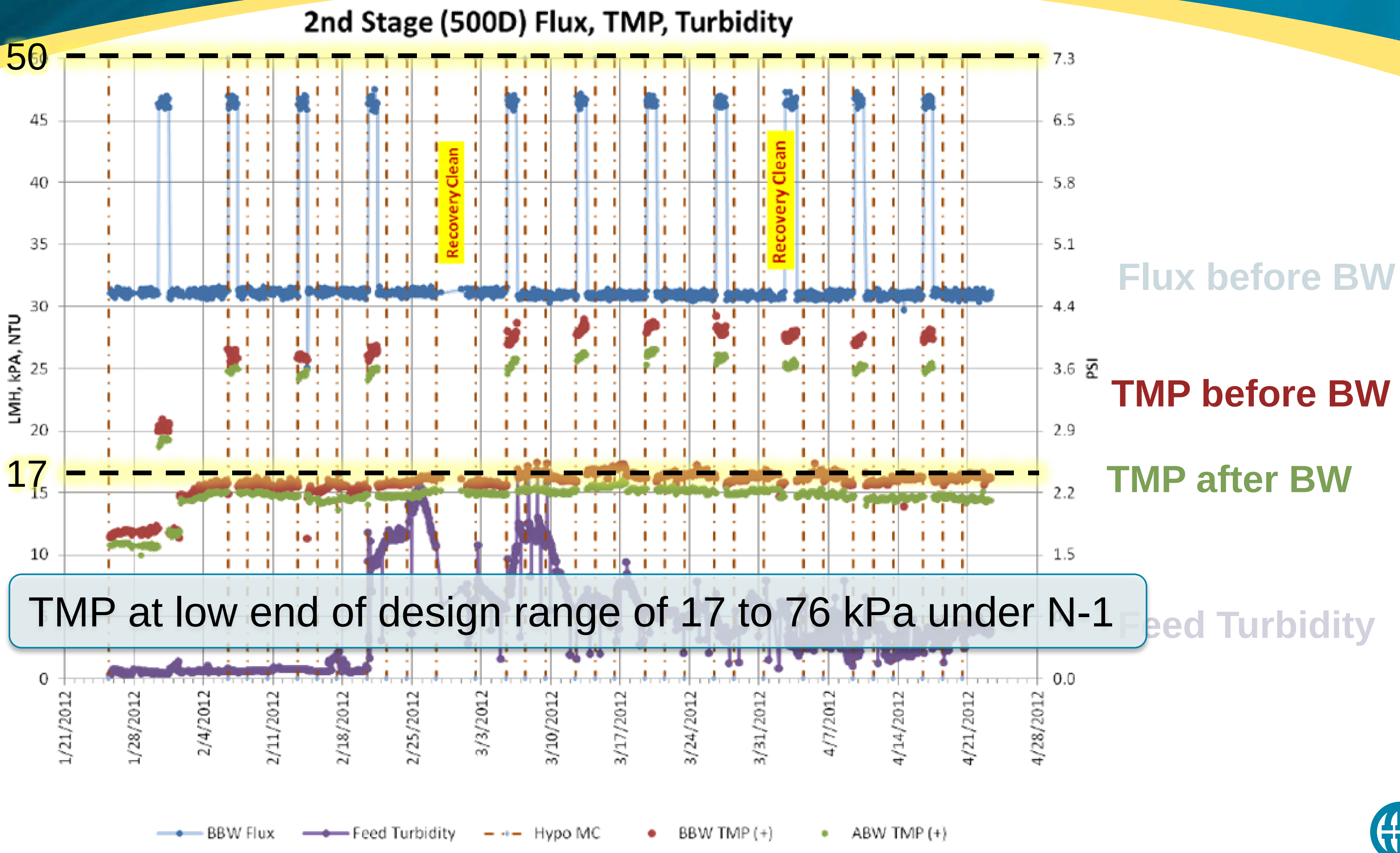
Feed turbidity has varied.
Mixer added to holding tank
Turbidity largely colour, so not conservative.

Demonstration Testing Results



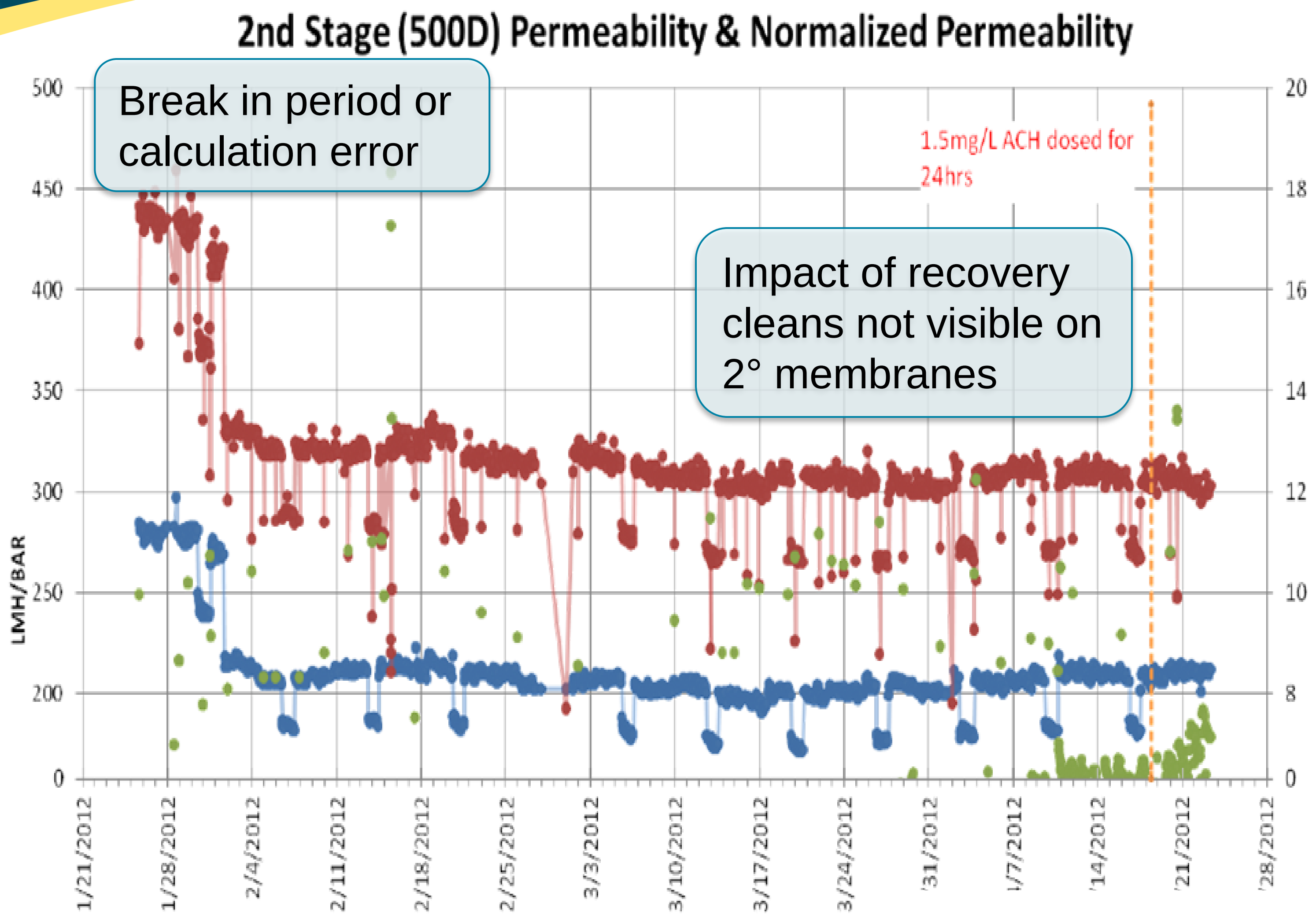
6 days at flux of 31 lmh (18.3 gfd), simulating one train out of service (N-1)
1 day at flux of 47 lmh (27.4 gfd), simulating two trains out of service (N-2)

Demonstration Testing Results



TMP at low end of design range of 17 to 76 kPa under N-1

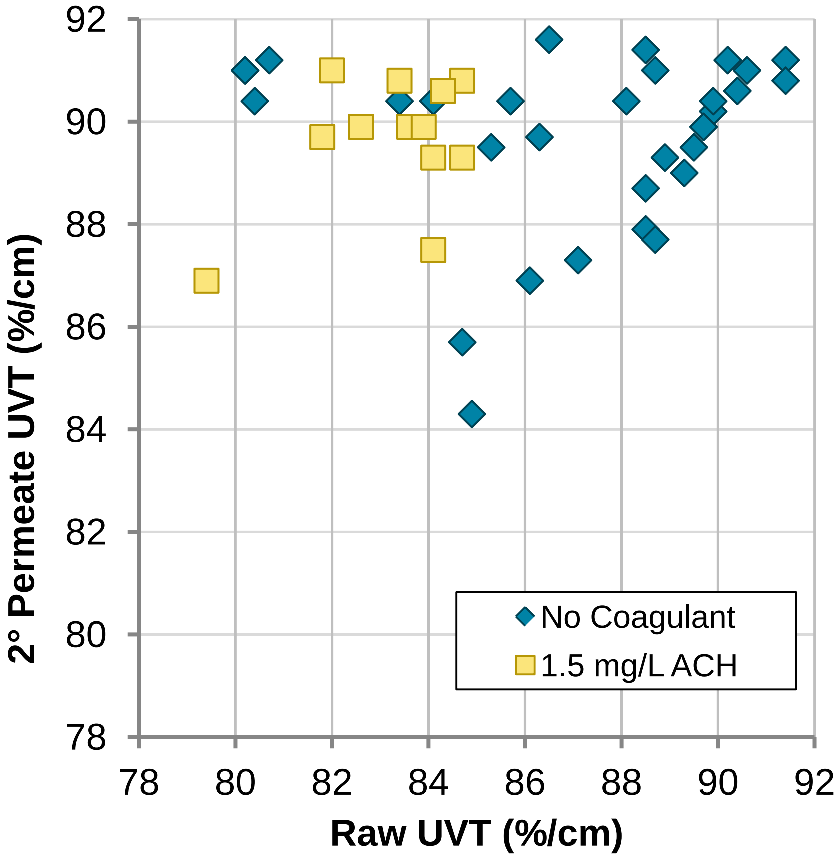
Demonstration Testing Results – Stage 2



Normalized Permeability after BW

Permeability after BW

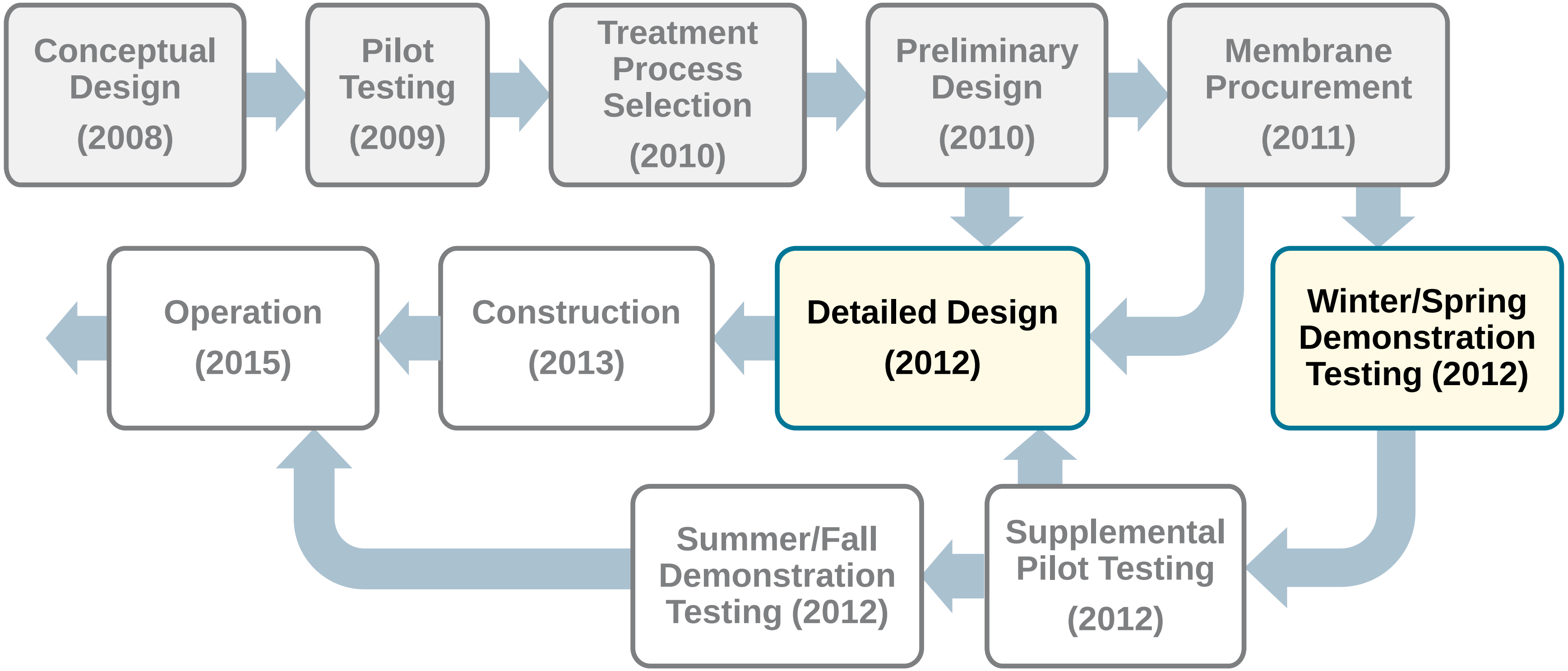
UV Disinfection of Stage 2 Permeate



- To meet regulatory requirements, permeate from second-stage membranes will be disinfected with UV light ahead of clearwell
- Reasonable UVT values are achieved in permeate, and can be enhanced with coagulant addition.

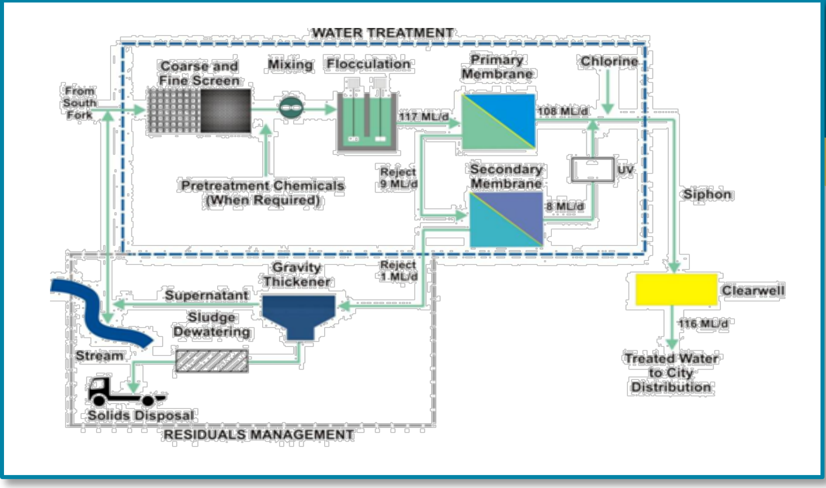
Next Steps

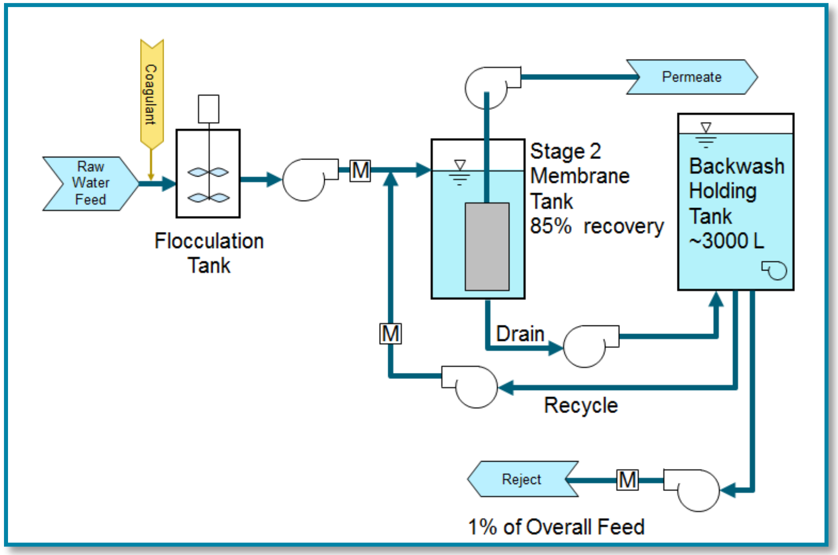
Overall project is on-schedule



Key Findings and Remaining Challenges

- 2-stage siphon membrane system is effective and efficient
  - Coagulant addition effective for colour removal
- Use of recycle holding tank effective at simulating 2nd stage membrane filtration
  - Design assumptions have been confirmed
  - Coagulant addition has not caused fouling
- Design criteria for gravity thickening and mechanical dewatering
  - Evaluate during summer/fall pilot testing





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