

# Using a Recirculating Aeration System to Remove Bromoform and Other THMs

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# Presentation Outline

Plant background & DBP history

Description of pilot efforts

- Carbon

- Aeration

Discussion of pilot results

Conclusions

# Eagle Cove Homeowners Association

San Juan Island – NW Washington

~30 residential connections

All residential

Well

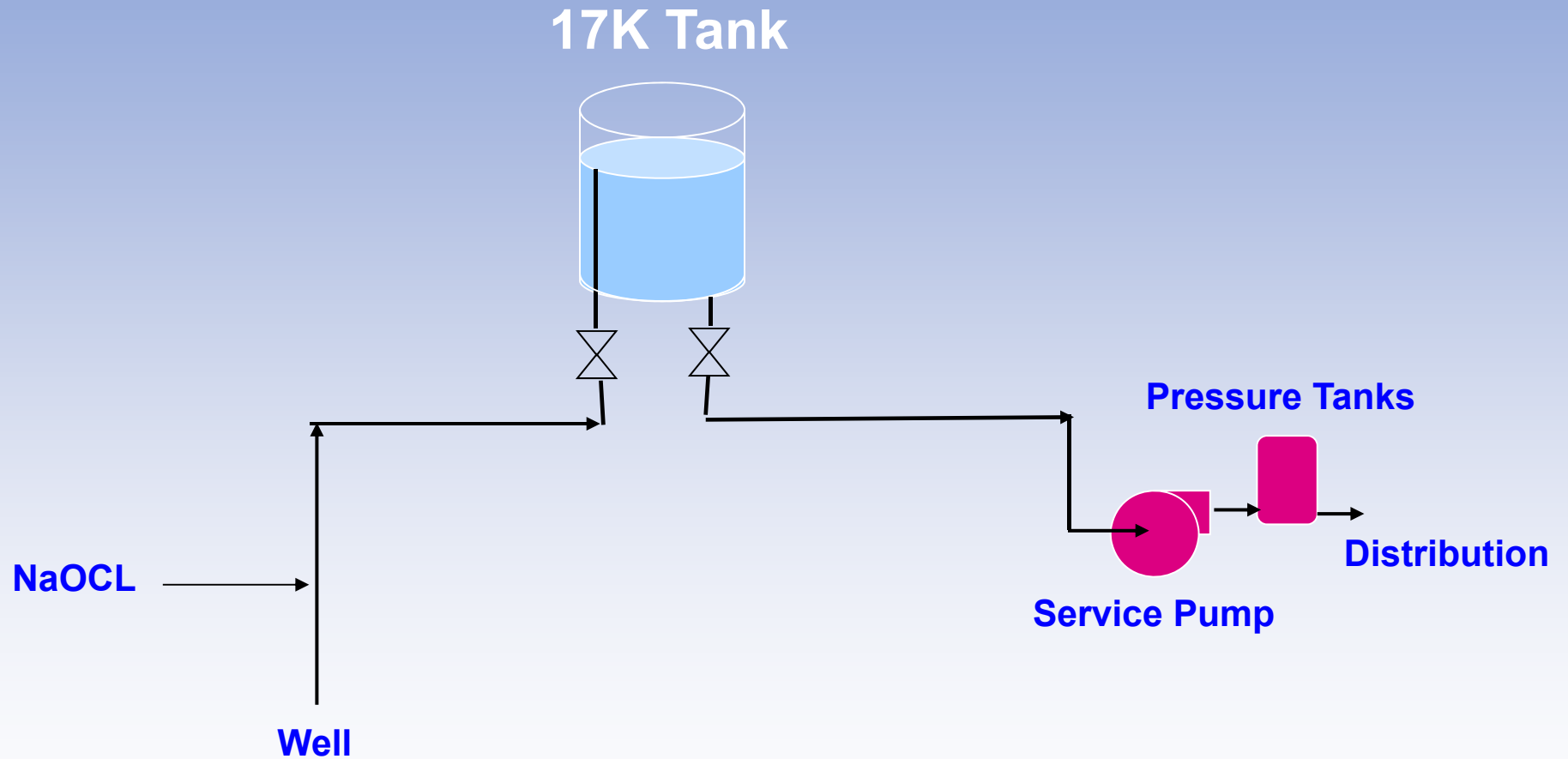
10 gpm capacity

NaOCl added

17,000 gallon reservoir

Booster station

# System Schematic



# Eagle Cove Homeowners Well Source

## Raw well water quality

pH = 7.7-7.8

TOC Average = 3.4 mg/L Range 2.7-4.5 mg/L

Mn = 0.14 mg/L

## Disinfection by-products

High THMs

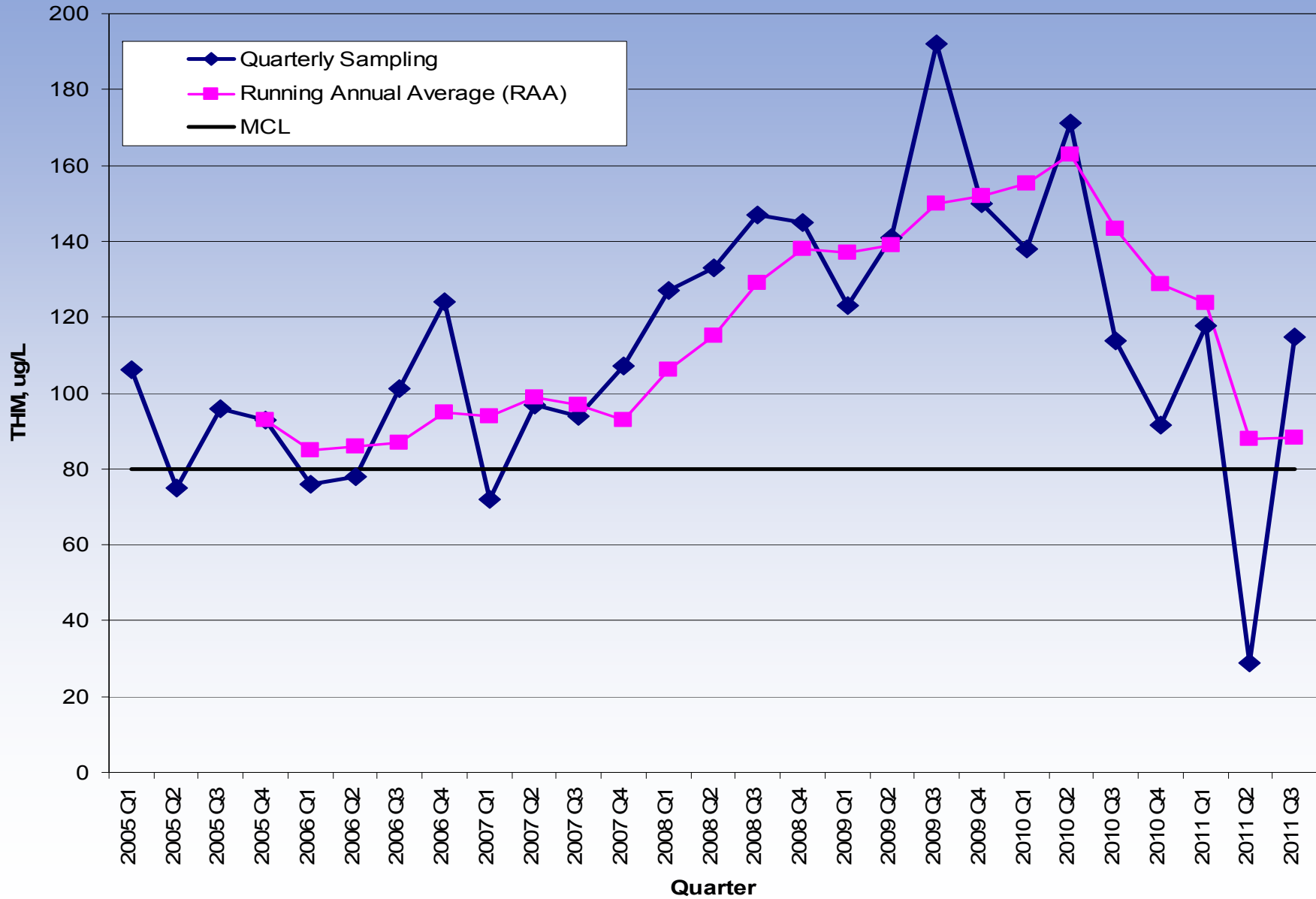
Low HAA5s

## Pb/Cu

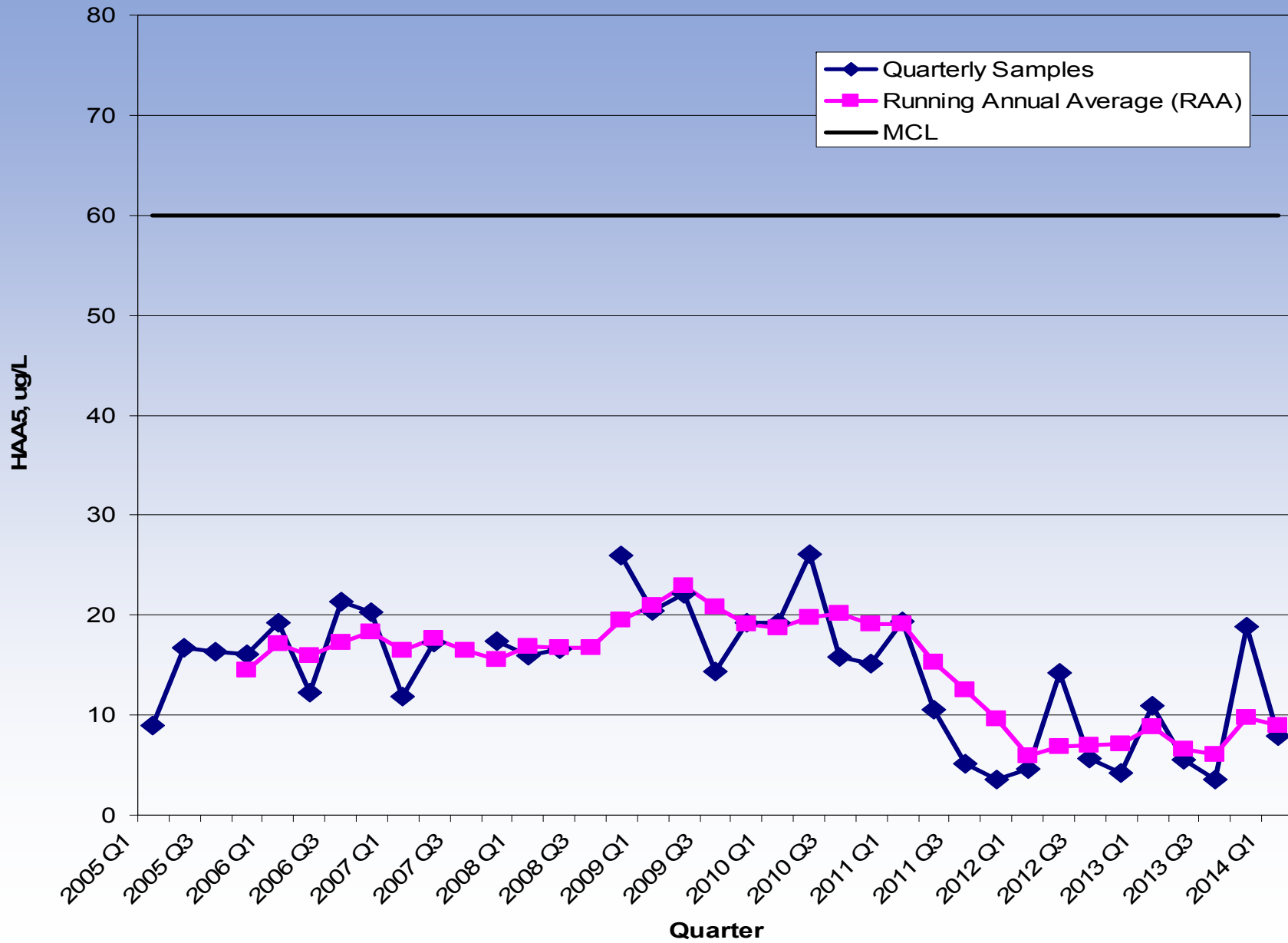
High Cu - 90% Percentile 0.73-2.15 mg/L

Pb well below action level

# THM History



# HAA5 History



# THMs

## Predominantly bromoform and bromonated THMs

Bromoform,  $\text{CHBr}_3$  – 64%

Dibromochloro methane,  $\text{CHBr}_2\text{Cl}$  – 25%

Chlorodibromo methane,  $\text{CHBrCl}_2$  – 9%

Chloroform,  $\text{CHCl}_3$  – 2%

## Most systems are predominantly chloroform (Another San Juan system, for example)

Bromoform,  $\text{CHBr}_3$  – <1%

Dibromochloro methane,  $\text{CHBr}_2\text{Cl}$  – 2%

Chlorodibromo methane,  $\text{CHBrCl}_2$  – 19%

Chloroform,  $\text{CHCl}_3$  – 79%

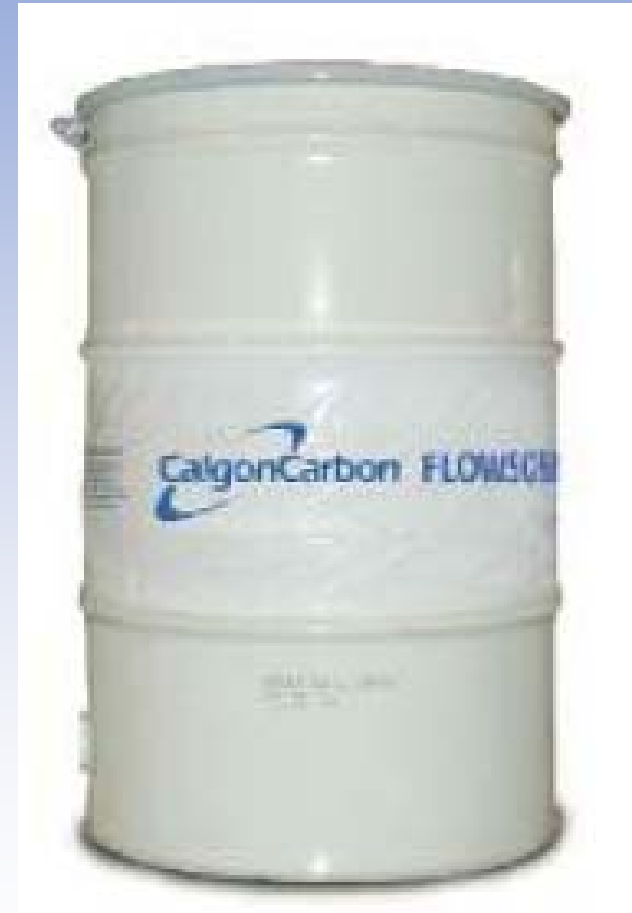


# Initial Pilot Efforts

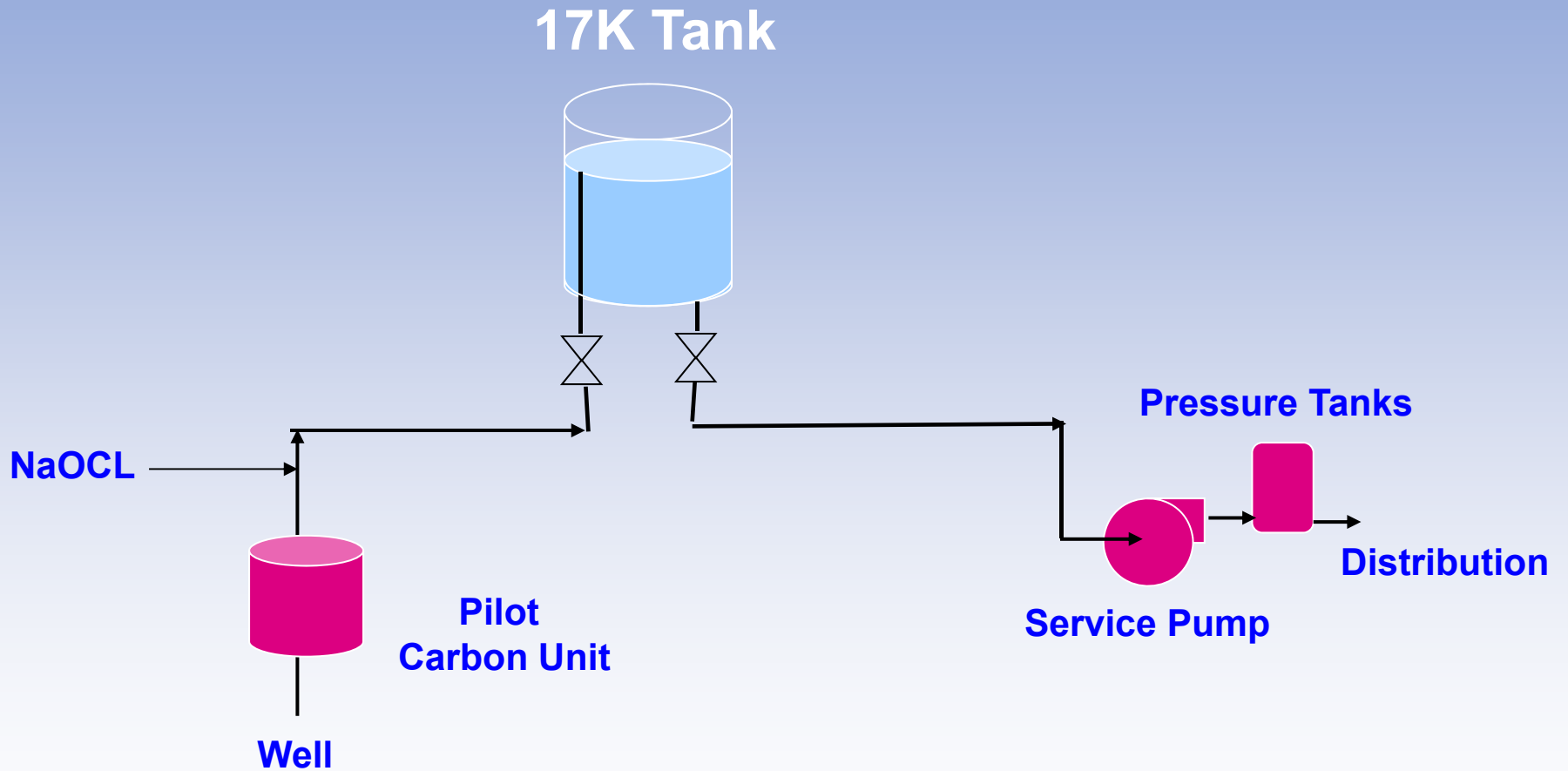
Investigate activated carbon.

Full-scale using carbon filter  
in a 55-gallon drum.

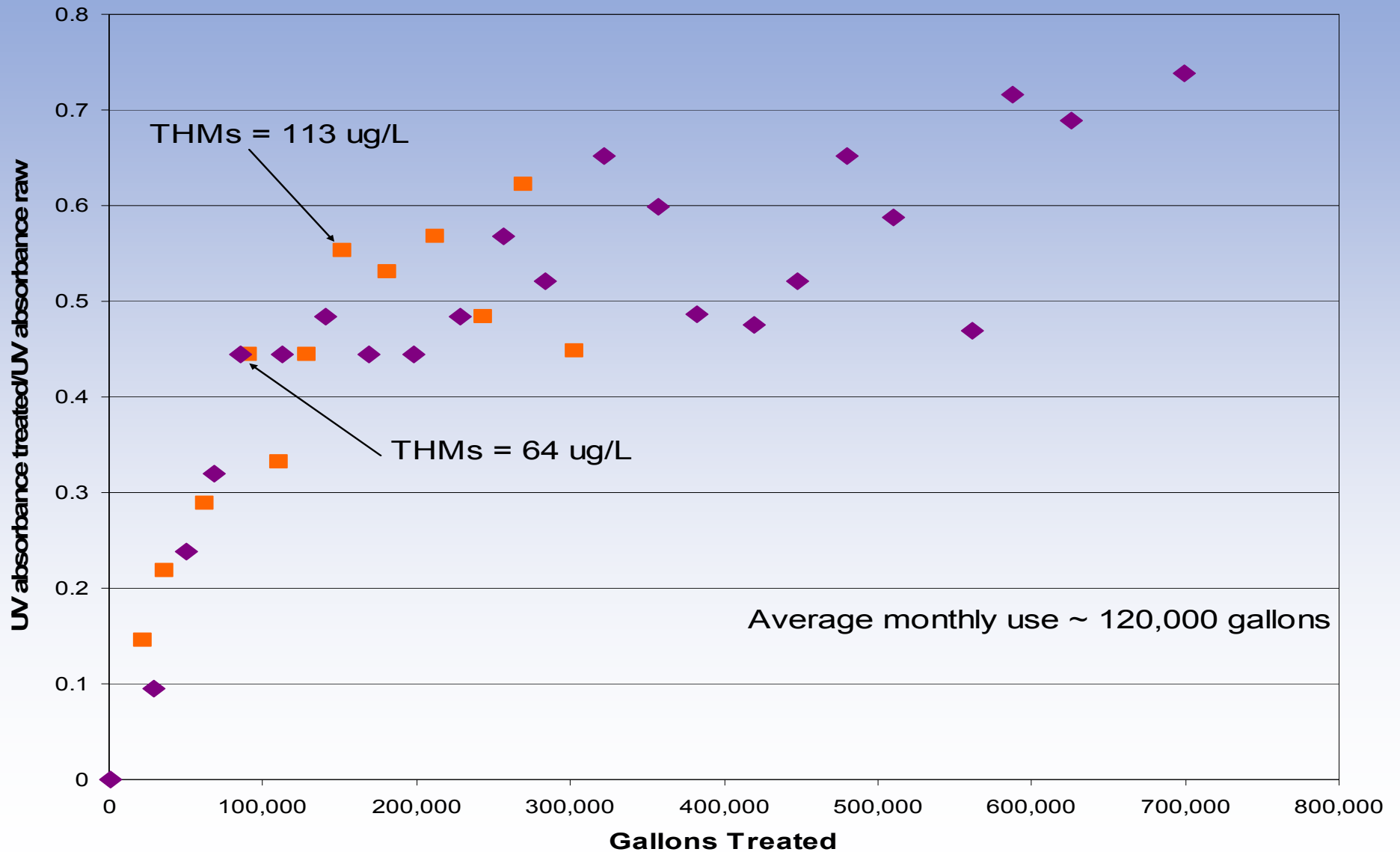
UV 254 and THM testing for  
performance



# System Schematic



# Carbon was used up quickly – each barrel lasted only about a month



# THM Data

A few days after startup, total THMs in the distribution system were sampled at 64  $\mu\text{g/L}$ .

A month after startup, total THMs in the distribution system were sampled at 113  $\mu\text{g/L}$ .

Carbon not the answer – cost too prohibitive to change drums frequently.

# Second Pilot - Aeration

Aeration has been used effectively on THMs.

Aeration also can raise the pH for Cu/Pb.

Theoretical pH rise given pH and alkalinity would be from 7.7 to 8.2.

# Second Pilot - Aeration

Dissolved gases in water governed by Henry's Law generically given as:

$$p = Hc$$

Where:

$p$  = Constituent pressure in gas

$H$  = Henry's constant

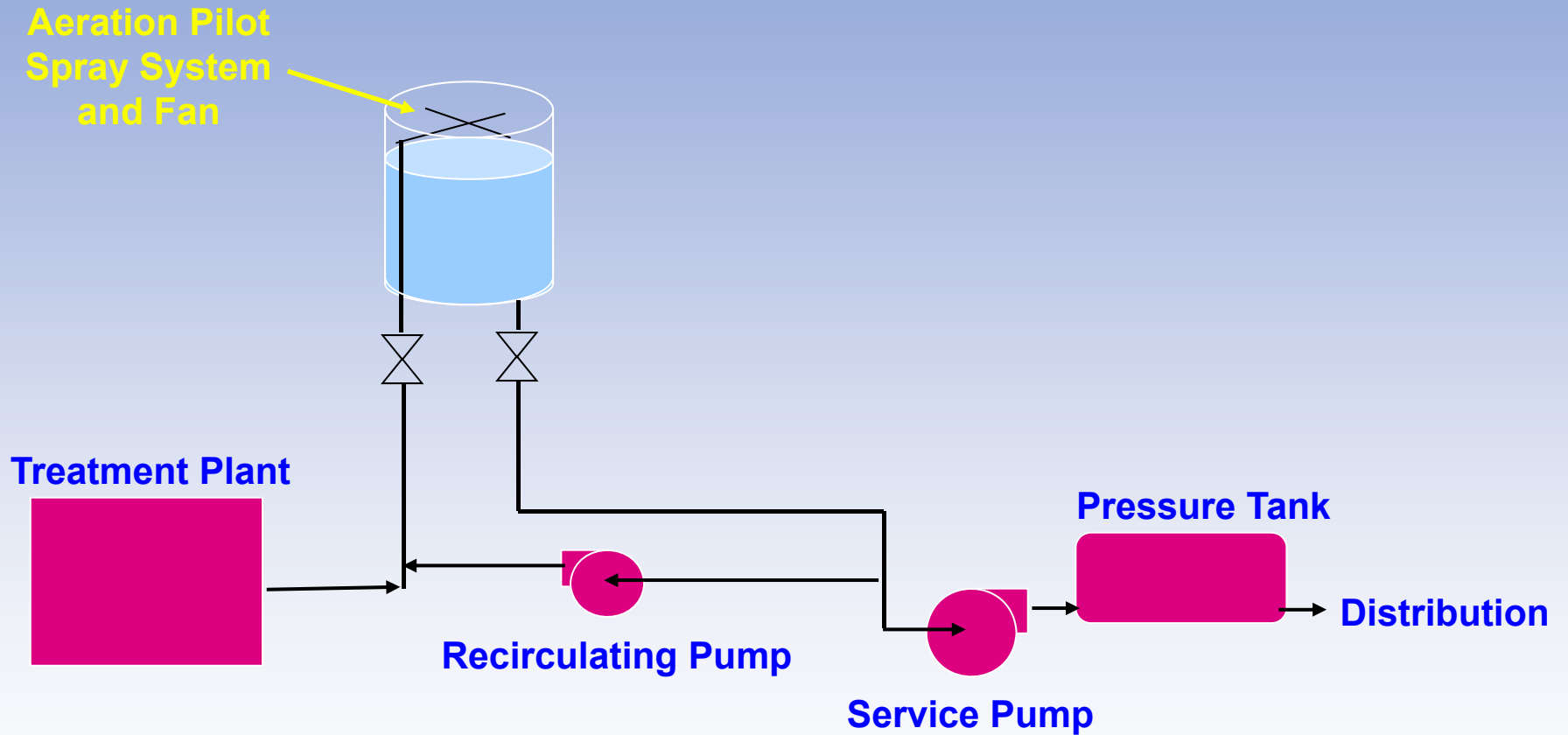
$c$  = Constituent concentration in liquid

## Henry's Law Constants Reflect Volatility of Gasses in Water

DBP	H - atm
Chloroform	200
Dichlorobromomethane	121
Dibromochloromethane	56
Bromoform	35
$\text{CH}_2\text{ClCOOH}$	0.00051
$\text{CHCl}_2\text{COOH}$	0.00046
$\text{CCl}_3\text{COOH}$	0.00075
$\text{CH}_2\text{BrCOOH}$	0.00037
$\text{CHBr}_2\text{COOH}$	0.00024

**THMs volatile but bromoform much less volatile than chloroform.**

# Orcas Island Example – System Schematic Using Recirculating Aeration





# Simple Spray Header with Recirculation 60% Removal – But Mostly Chloroform (78%)



# Aeration Pilot

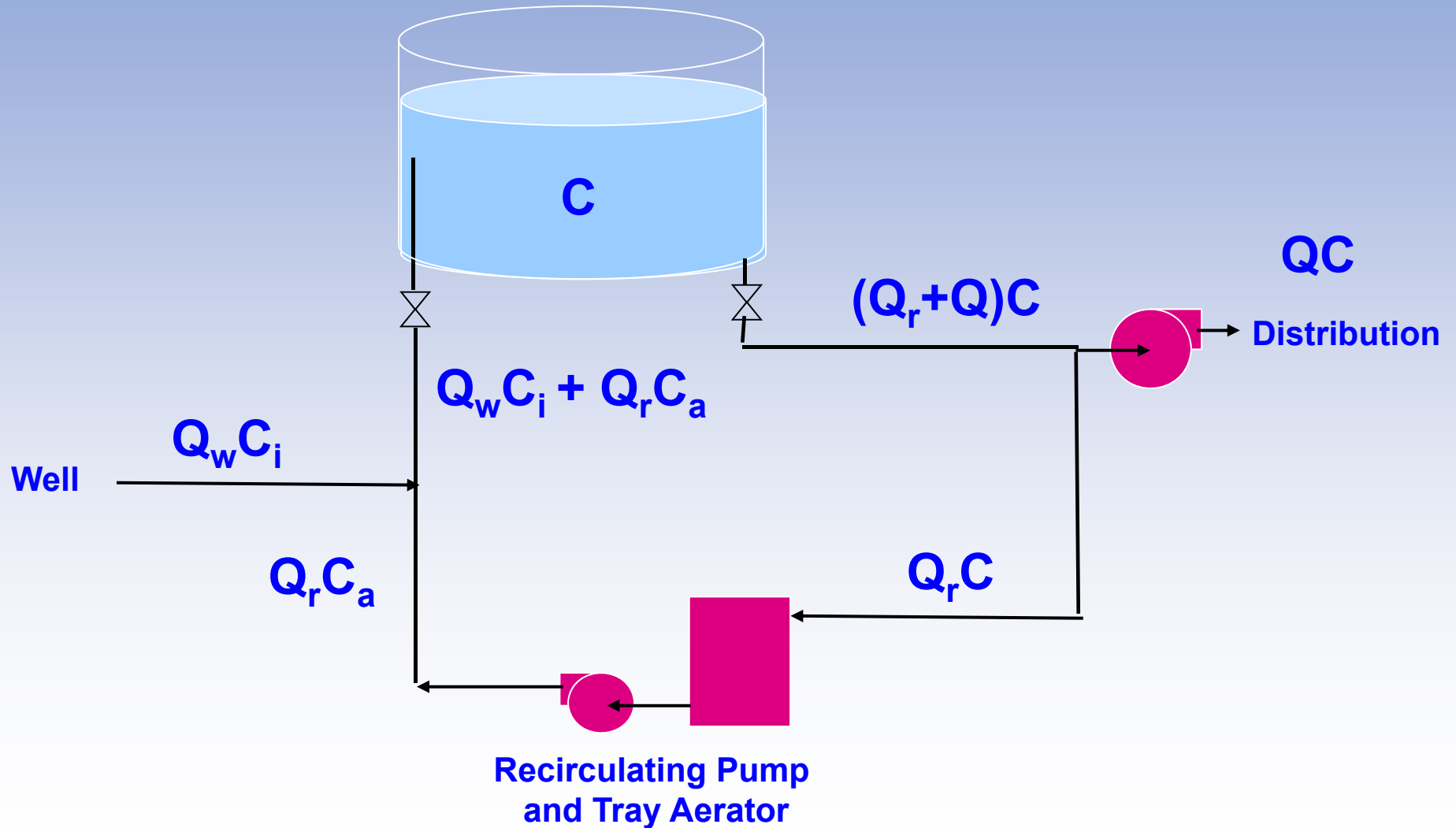
Something more efficient than spray aeration would be needed.

## Options

Packed tower

Tray aerator – chosen option

# Predictive Mass Balance Model



# Mass Balance Model Assumptions

Continuously mixed reservoir with concentration  $C$

$$C_{(T=n+1)} = C_{(T=n)} + \text{inputs} - \text{outputs} + d\text{THM}/dt$$

$$\text{Aerator efficiency } (\eta) = (C - C_a)/C$$

$C_i$  is amount formed between chlorination at well and reservoir

$Q_w$  (well) =  $Q$  (distribution system), Use average day flow in gpm

Some THMs form in distribution system after the reservoir

# Mass Balance Model Assumptions

Calibrate (as best as possible) with existing system with no aeration system

- $C_i = \sim 50 \mu\text{g/L}$
- $d\text{THM}/dt$  adjusted to have appropriate  $C$
- Final tap is  $C + \sim 10 \mu\text{g/L}$

Example model without aeration conditions

$C_i = 50 \mu\text{g/L}$ ,  $C = 140 \mu\text{g/L}$ , and tap concentration is  $150 \mu\text{g/L}$

# Mass Balance Model Predictions

Recirculating aeration system can be added after calibration.

$Q_r$  and  $\eta$  varied to size unit to achieve desired final THM.

25 gpm ( $Q_r$ ), 5-tray aerator ( $\eta = 55\%$ ) was selected.

HOA leased/purchased a used unit from a groundwater remediation company.

# Initial Pilot Testing

HOA initially leased the unit for a month to test.

Initial single pass test with flow to waste to verify manufacturer's performance claim ( $\eta = 55\%$ ).

Contaminant	Average Influent Concentration ( $\mu\text{g/L}$ )	Average Effluent Concentration ( $\mu\text{g/L}$ )	Removal Efficiency (%)	Manufacturer Predicted Removal (%)
Bromoform	68.2	36.7	46	31
Chlorodibromomethane	38.8	9.1	77	55
Bromodichloromethane	13.6	1.1	93	85
Chloroform	3.8	ND	100	93
<b>TOTAL</b>	<b>124.4</b>	<b>46.8</b>	<b>62</b>	-

# Pilot Test Phase 2

Full scale recirculating system - Temporary piping





# Pilot Test Phase 2-Full Scale Operation

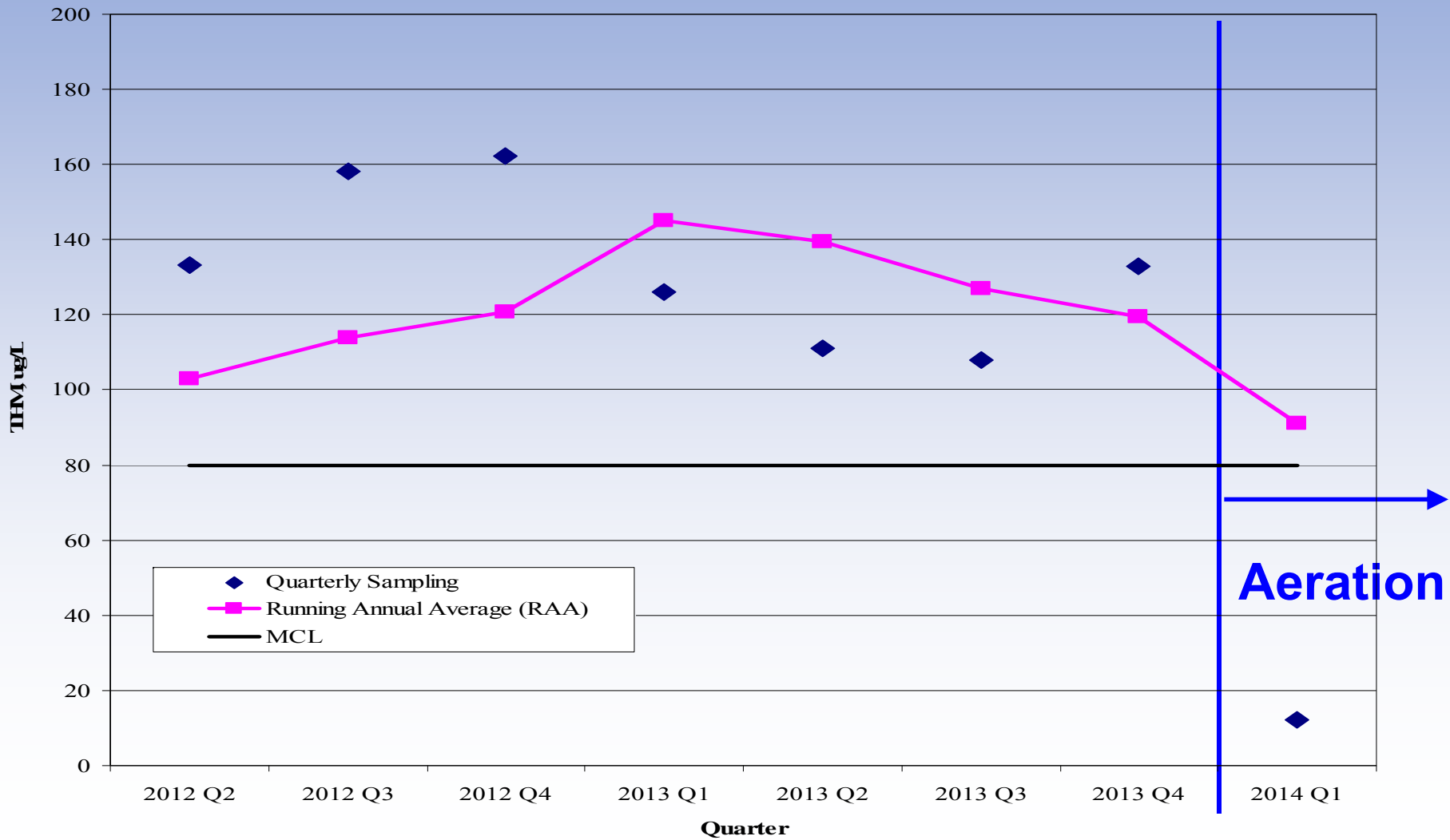
Day	Finished pH	Distribution THMs, $\mu\text{g/L}$
0	7.7	132
4	8.0	63.3
5	8.1	-
6	8.2	-
9	8.1	27.1 55.5

# Pilot Test Phase 2-Full Scale Operation

HOA decided to purchase the unit and built a permanent installation.



# Compliance Sampling – 12.3 $\mu\text{g/L}$ THM



# Regulatory Full Scale Considerations

Washington regulates VOC releases through WAC 173-460.

WAC 173-460 regulates Acceptable Source Impact Limit (ASIL) for toxic compounds.

ASIL for Chloroform =  $0.0435 \mu\text{g}/\text{m}^3$

Emitters must stay below ASIL as proven by analysis.

WAC 173-460 sets Small Quantity Emission Rates (SQER) and de minimis amounts in lieu of analysis.

# Emission Rate Limits for THMs

Compound	SQER, lb/yr
Chloroform	8.35
Bromoform	174
Bromodichloromethane	5.18
Chlorodibromomethane	7.1

# Eagle Cove Compliance

For analysis assume:

2 MG Annual Water Use

150 µg/L THM

100% Removal

65% Bromoform

2.5 lb/yr (174 lb/yr limit)

25% DiBromochloromethane

0.6 lb/yr (7.1 lb/yr limit)

9% Bromodichloromethane

0.2 lb/yr (5.18 lb/yr limit)

2% Chloroform

0.05 lb/yr (8.35 lb/yr limit)

All values < SQER

Eagle Cove is in compliance.

# Eagle Cove Compliance – Pb/Cu

Raw Water pH = 7.7

Aerated Water = pH 8.1-8.2

Pb/Cu scheduled for May 2014

Distribution pH used to verify aeration system operating.

# Conclusions

Aeration is effective at reducing THMs at Eagle Cove.

~ 130  $\mu\text{g/L}$  reduced to  $<20 \mu\text{g/L}$

Higher efficiency unit required for bromoform –tray aerator still only achieved ~50% removal single pass.

Effect of pH elevation on Pb and Cu remains to be seen.



# Questions?

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## Acknowledgements

Eagle Cove HOA

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