



Moorhead Public Service

Case Study: Moorhead, MN

Ozone Water Treatment Plant

by Cliff McLain & Troy Hall

Moorhead Ozone Case Study Outline

- Background
- Ozone System Operations Issues
- System Improvements
- Ozone Disinfection By-product Research

Moorhead Water Treatment Plant : 10 MGD



Background

- Drought 1988-1989
 - Peak Demand: 9.2 MGD
 - Plant Capacity: 9.0 MGD
 - Source Capacity: 8.5 MGD
- 1986 Amendments to SDWA
 - THMs
 - Average: 55 ug/l
 - Range: 6 - 180 ug/l

Background (cont'd)

- 1986 Amendments to SDWA (cont'd)
 - Turbidities
 - Average: 0.2 - 0.3
- Taste and odor problems
- Limited ground water supplies
 - Slow decline in ground water levels

Red River Water Quality

- Total Alkalinity- Average: 214 mg/L
 - Range: 80 - 289 mg/L as CaCO_3
- Total Hardness- Average: 286 mg/L
 - Range: 131 - 527 mg/L as CaCO_3
- Calcium Hardness- Average: 146 mg/L
 - Range: 82 - 279 mg/L as CaCO_3
- pH- Average: 8.20
 - Range: 7.04 - 8.89

Red River Water Quality

- Turbidity- Average: 107 NTU
 - Range: 1.7 - 909 NTU
- Temperature- Average: 52°F
 - Range: 32°F - 86°F
- Total Organic Carbon- Avg.: 9.63 mg/L
 - Range: 5.59 - 19.20 mg/L
- Total Coliform- Avg.: 207 per 100 ml
 - Range: 0 - 6800 per 100 ml

Goals for New Water Treatment Plant

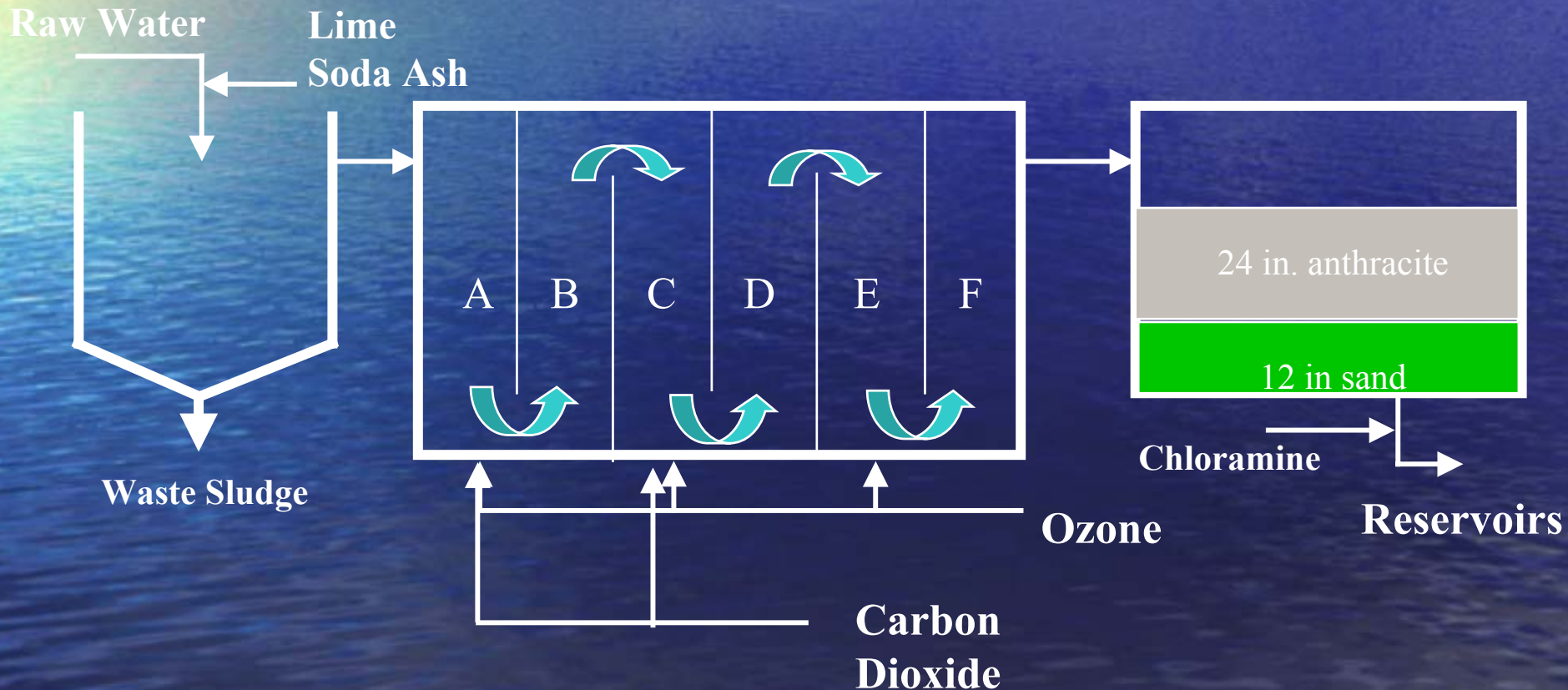
- Increase capacity to 16 MGD
- Improve Water Quality
 - Lower chlorinated by-products
 - Lower turbidities
 - Eliminate taste & odor problems
- Increase use of surface water

Schematic of the MWTP Processes

Softening Basins

Ozone Contact Chambers

Filters



Softening Basin

(Two 5 MGD Units)



Ozone Generators

(Two 400 pound/day units)



PSA System

(4 tons of oxygen/day)



Why Ozone?

- Inconsistent success with KMnO_4 and PAC for taste & odor reduction
- Ozone: powerful oxidant for T&O reduction
- Ozone: effective disinfectant
- Ozone: with chloramines = low THMs
- Pilot study
 - Effective reduction in THMs
 - Effective taste & odor removal
- Low electric rates in Moorhead

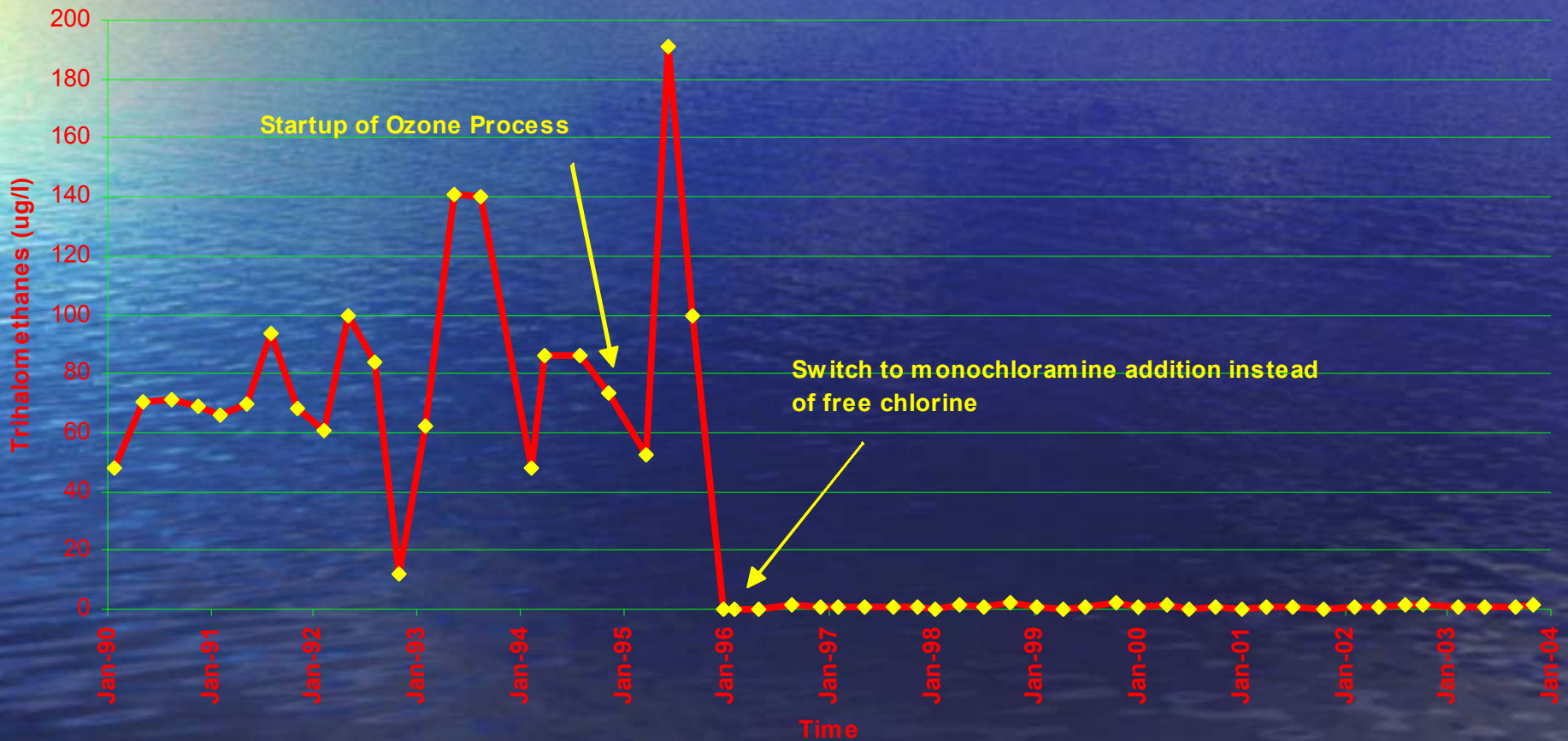
Ozone Dosages

- Overall Dose
 - Average: 4.99 mg/L
 - Range: 1.30 to 15.59 mg/L
- Summer Dose (June through August)
 - Average: 7.99 mg/L
 - Range: 2.25 to 15.59 mg/L
- Winter Dose (December through February)
 - Average: 2.23 mg/L
 - Range: 1.30 to 4.80 mg/L

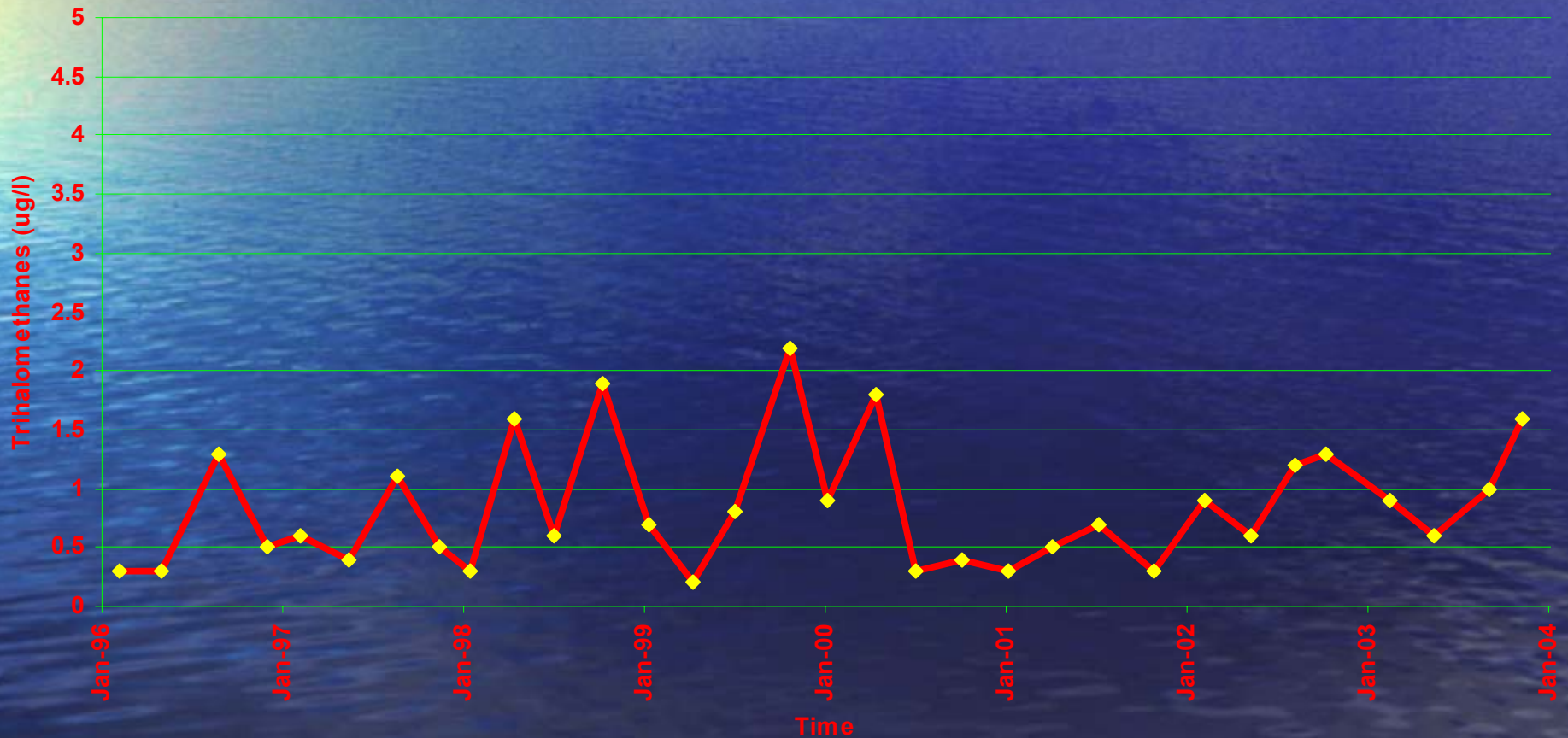
Energy Usage of Ozone System

- Ozone Generators
 - 4.24 kW-hr per pound of ozone
- PSA System for Oxygen
 - 6.88 kW-hr per pound of ozone
- Overall Electrical Cost of Ozone Process
 - \$18,660 in 2003 (746,560 kW @ \$0.025/kW)
 - \$51/day for 4.10 MG

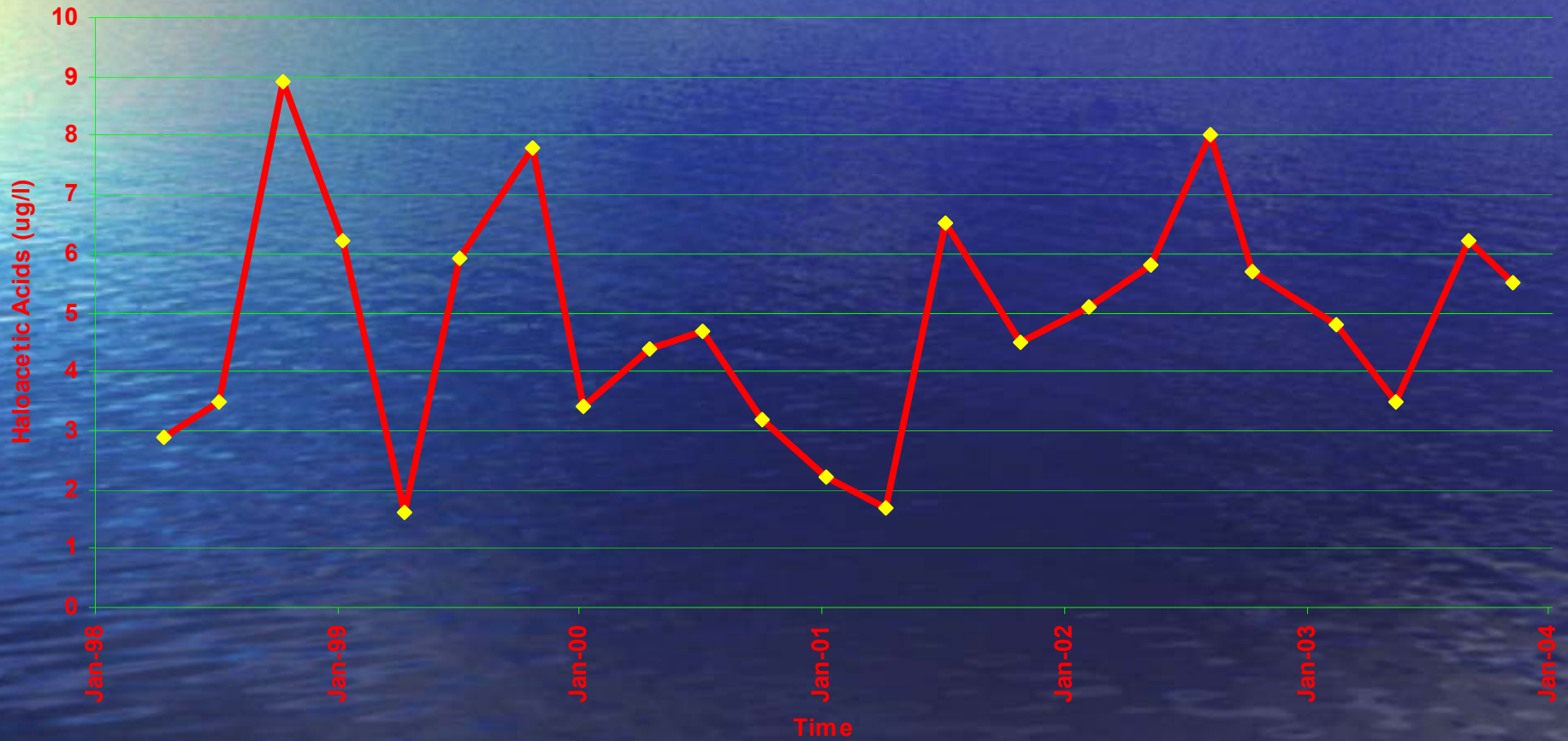
THM Data (1990-present)



THM Data (1996-present)



HAA Data (1998-present)



Success with Ozone & Chloramine

- 2003 THM Levels
 - Average: 1.0 ug/l
 - Range: 0.6 - 1.6 ug/l
- 2003 HAA Levels
 - Average: 5.0 ug/l
 - Range: 3.5 - 6.2 ug/l
- Eliminate Taste & Odor Complaints

Success with Ozone (cont'd)

- Optimize surface water sources
 - 85 - 90% Surface water
 - 60% Reduction in groundwater usage
 - Increased ground water levels

Ozone System Operation Issues

- Ozone Contactor Sample Line Location
- pH Control
- Ozone Residual Monitoring
- Ozone Residual Present in Filter Influent During Winter Months.
- Bromate Formation

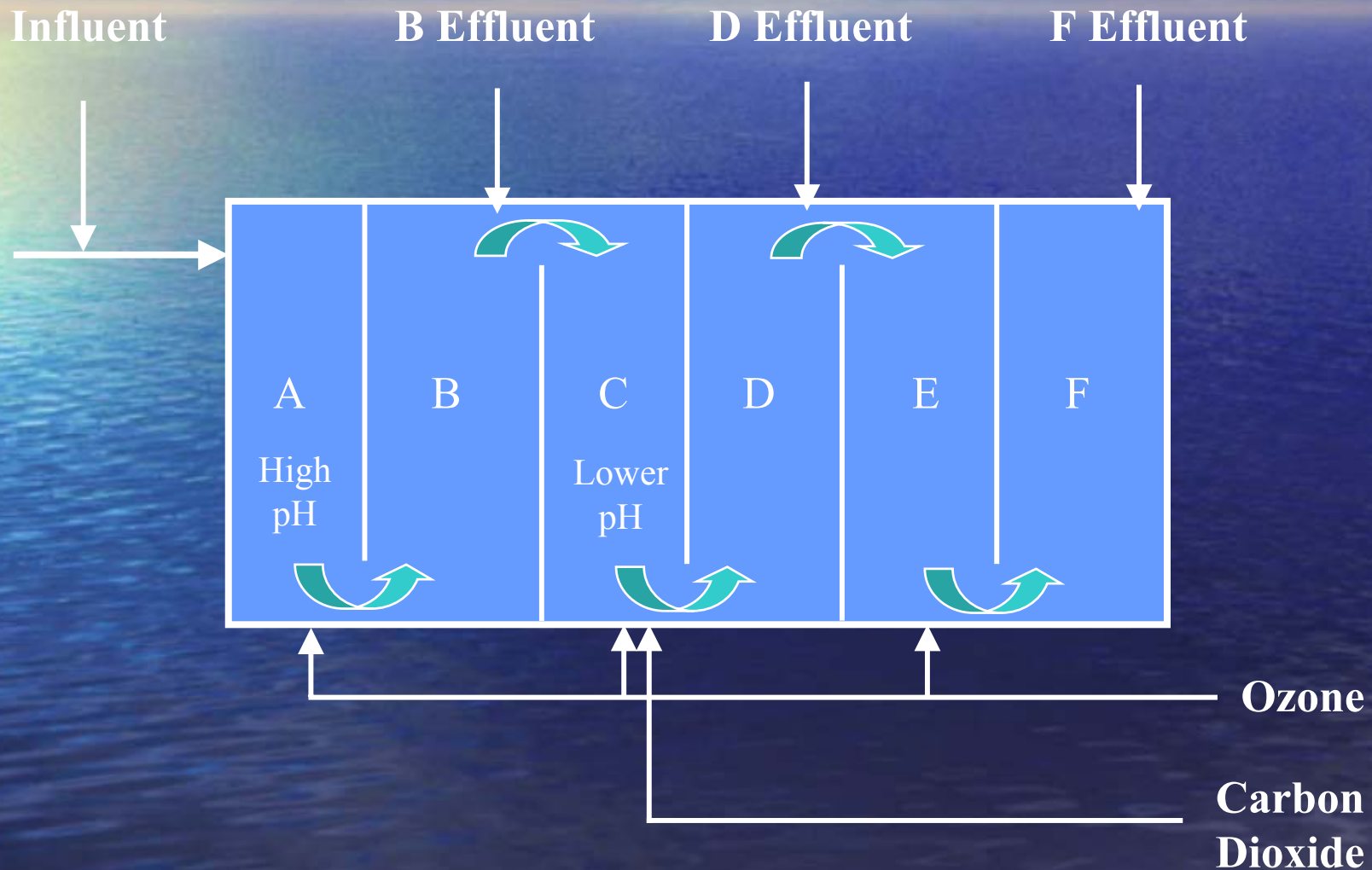
Ozone Contactor Sample Line Location

- Problem: Measured higher ozone residuals at ozone contactor outlet than at the contactor sample points.
- Solution: Extend sample lines from contactor wall out 18 inches.

pH Control

- Problem: Unacceptable variation in pH and ozone residuals. Ozone dosage is very dependant on pH.
- Solution: Replaced in-contacter pH probe with a flow-thru pH probe and installed a sample pipe cross. The new sample pipe collects sample from a cross-section of the contactor, rather than a single point.

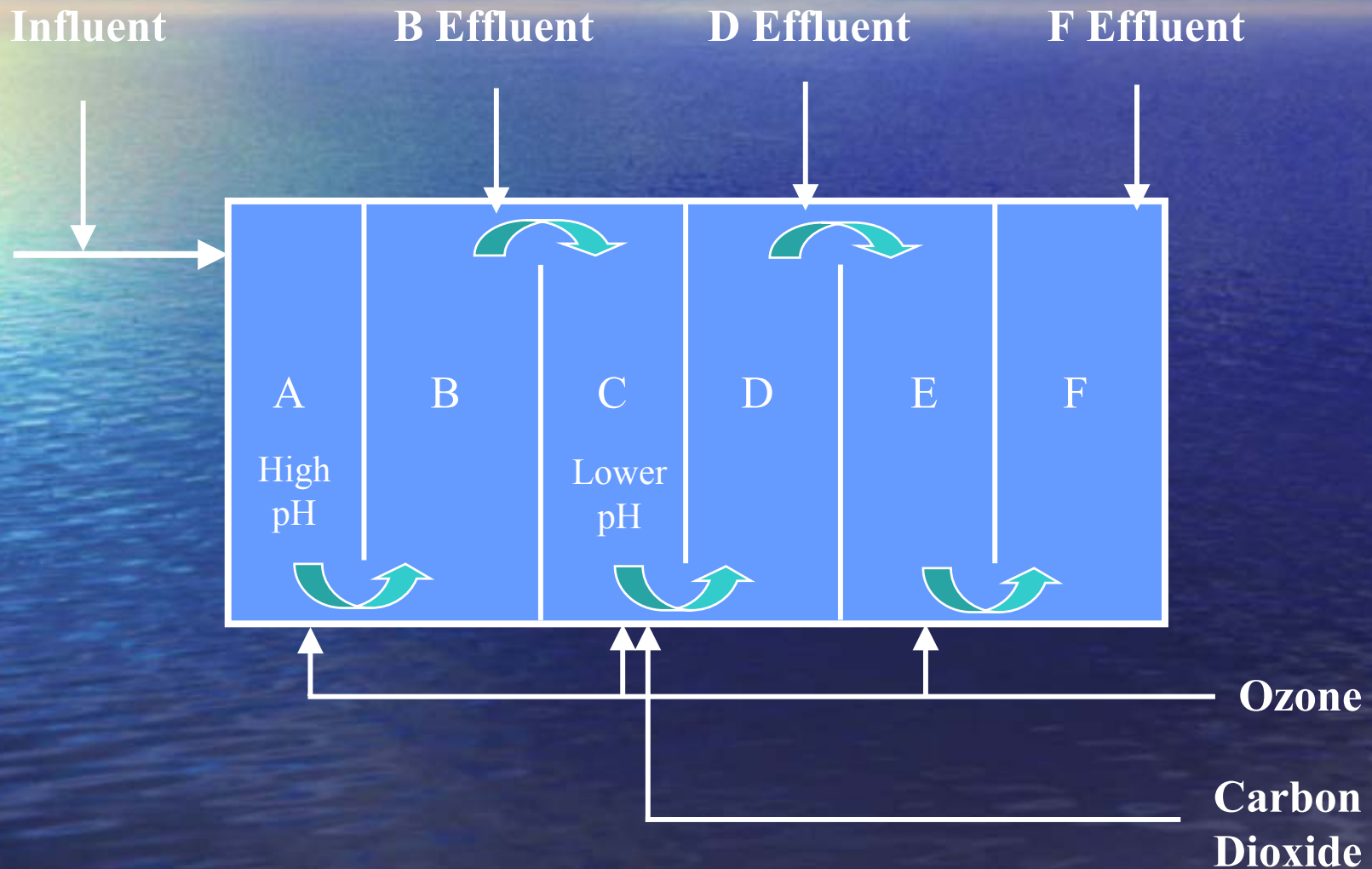
Sample Locations



Ozone Residual Monitoring

- Problem: Original design used one on-line analyzer for each contactor effluent point. Needed to monitor two of the three chamber for CT credit.
- Solution: Install an additional on-line ozone analyzer and sample pump for each contactor.

Sample Locations



Ozone Residual Present in Filter Influent During Winter Months.

- Problem: Ozone Present in Filter Inffluent Brought Ozone into Filter Room.
- Solution: Add Reducing Agent to Ozone Effluent to Neutralize Ozone in the Water. Calcium Thiosulfate is Used as Reducing Agent.

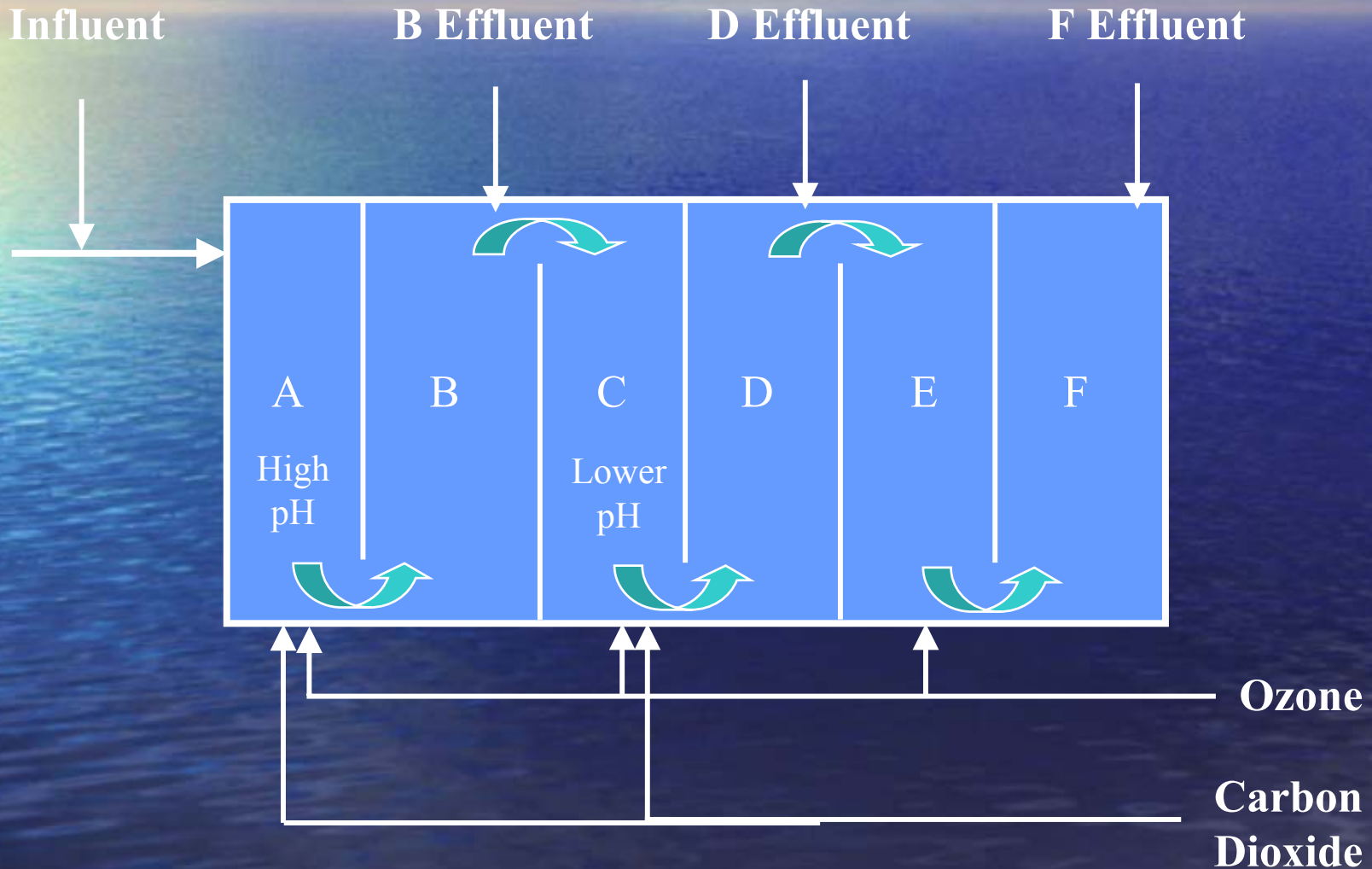
Reducing Agents

- Winter time operation only; ozone decays slower and higher ozone residuals (CT) are required.
- Reducing agent used to quench ozone residual before filters.
- Ozone analyzer in lab measures filter influent stream.
- Sodium Metabisulfite or Calcium Thiosulfate used as reducing agent.

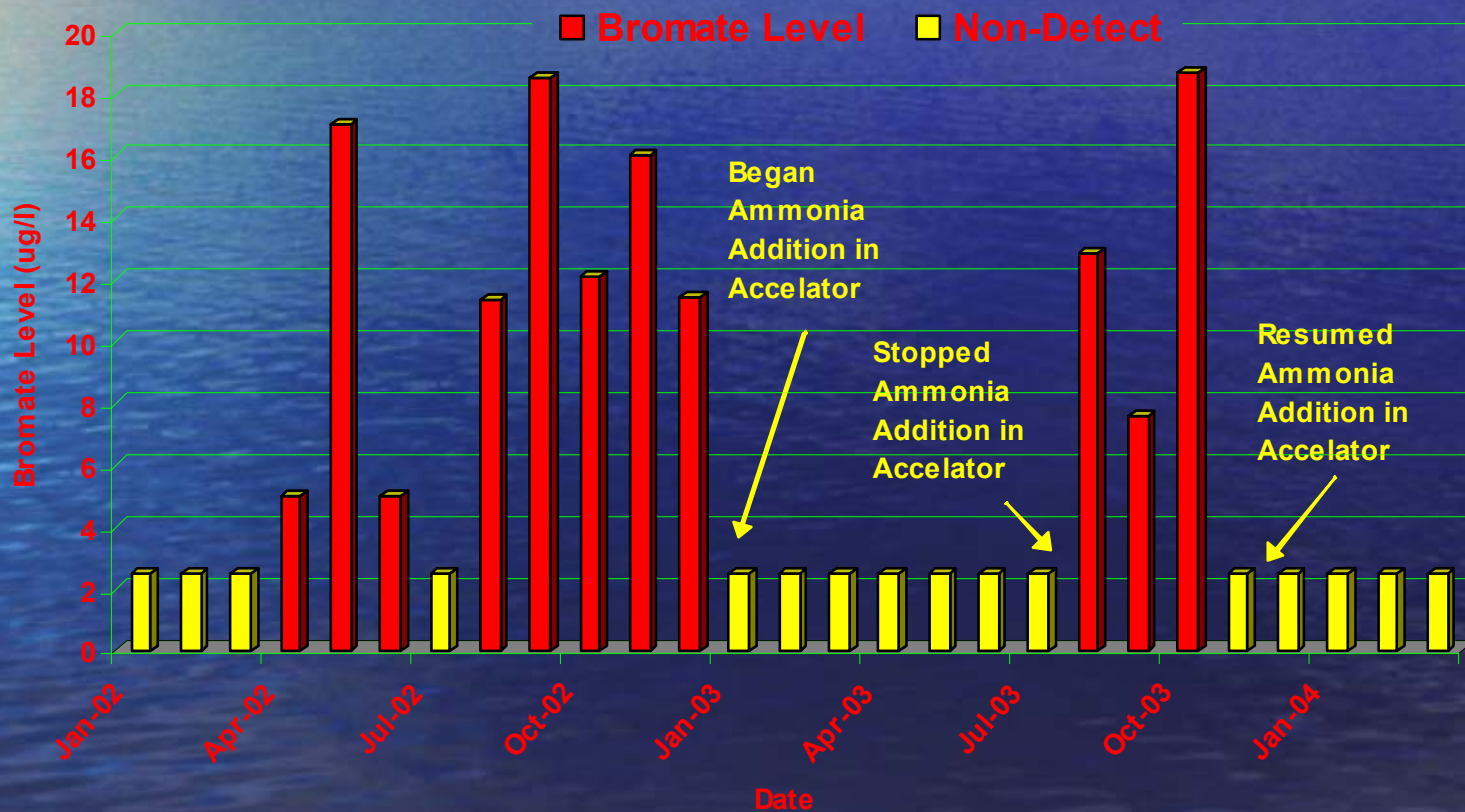
Bromate Formation

- Problem: Stage 1 Disinfectants and Disinfection Byproducts Rule MCL of 0.010 ug/l running annual average. Summer ozone doses produce bromate concentrations greater than 10 ug/l.
- Solution: Reduce pH, move CO₂ feed point from middle chamber to first chamber, feed CO₂ through ozone diffusers, and feed ammonia before ozone contactor.

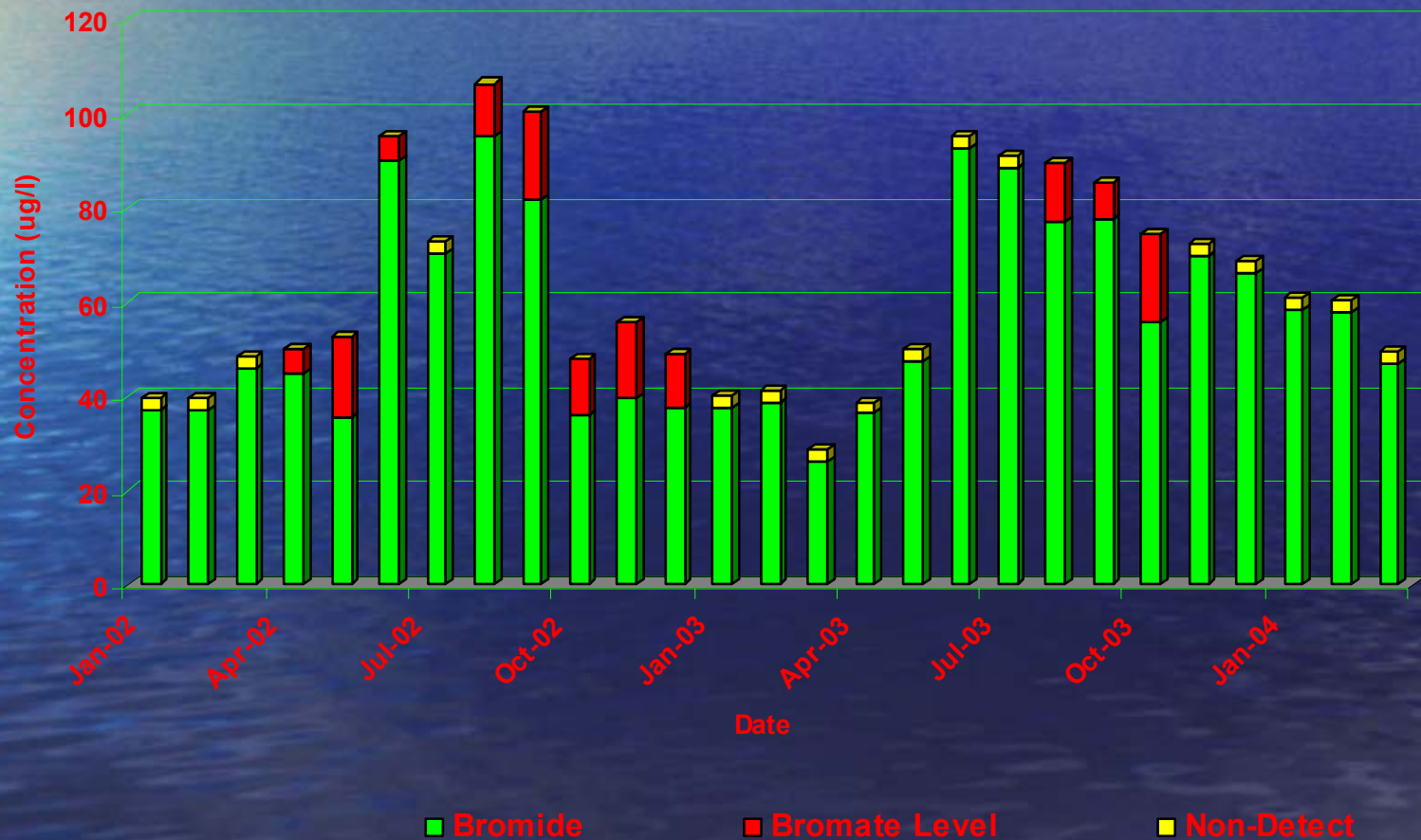
Sample Locations



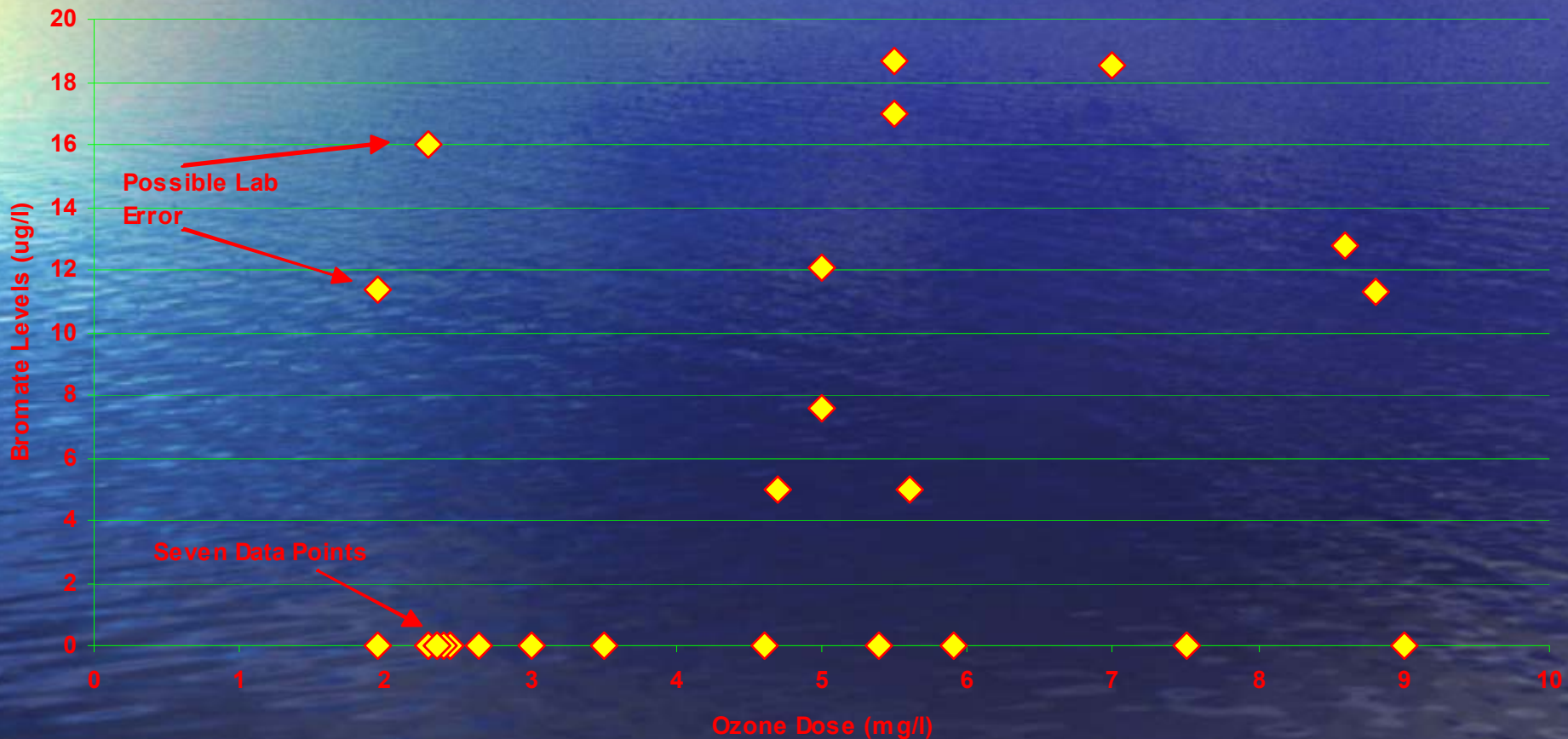
Bromate Levels (2002 to Present)



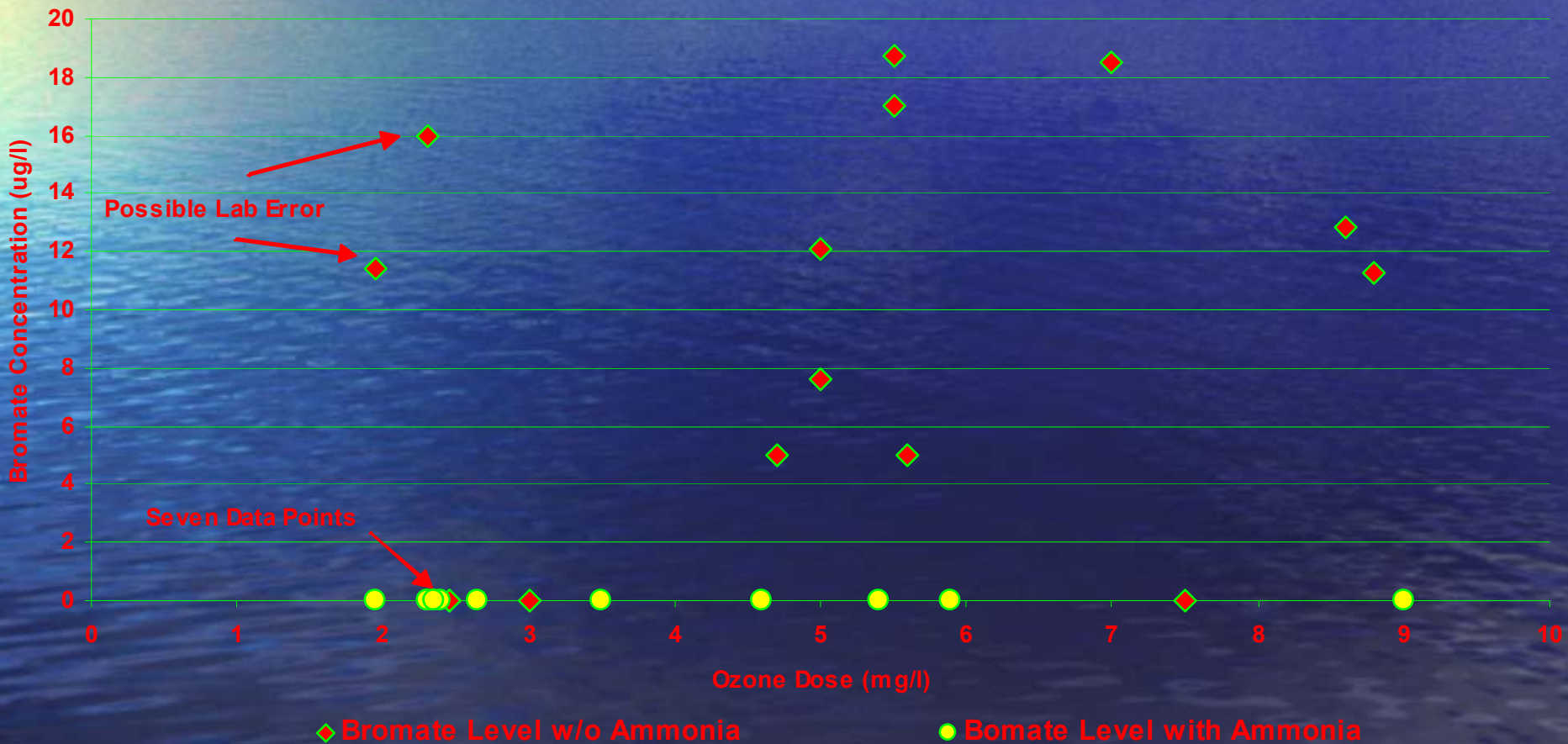
Bromide and Bromate Relation



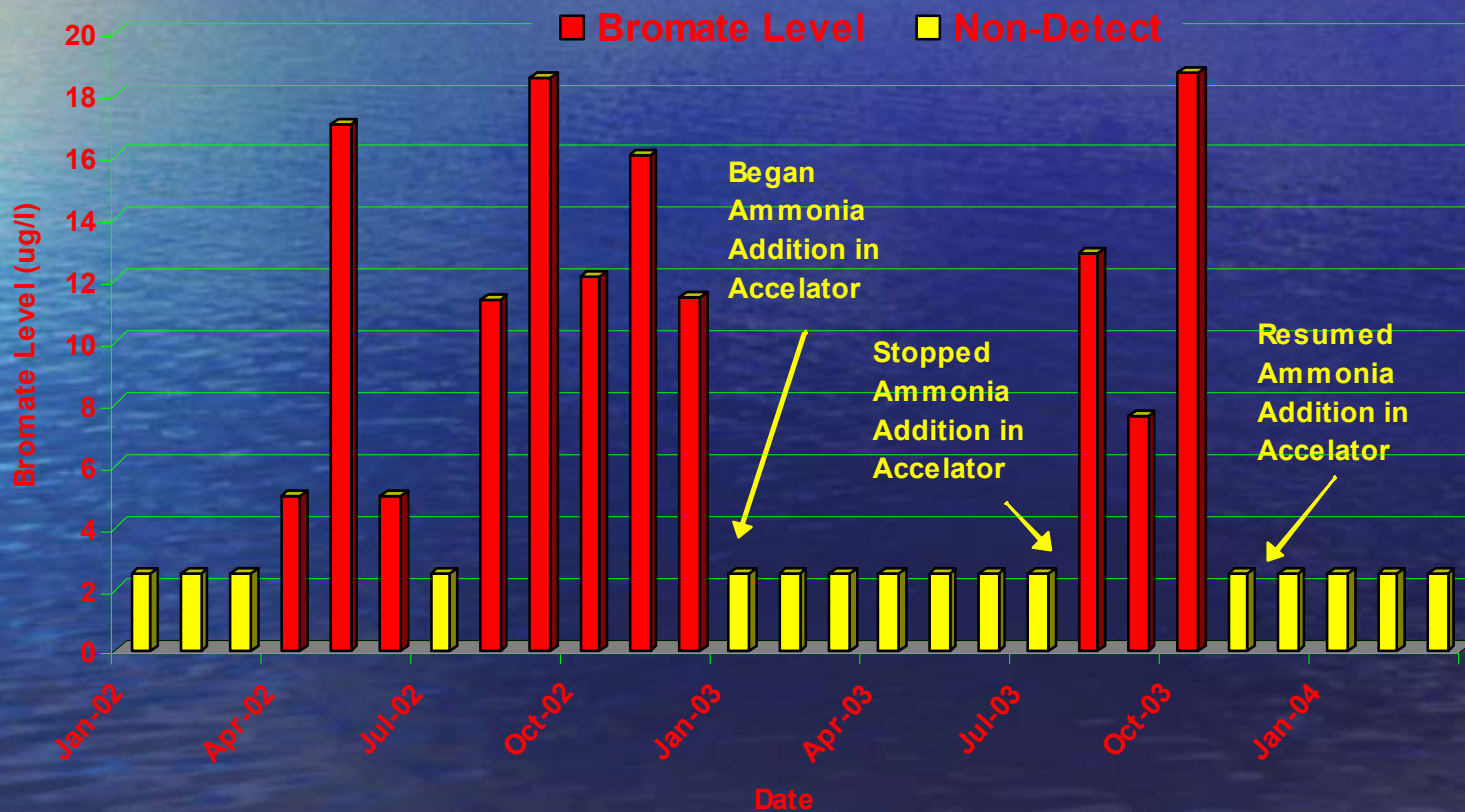
Bromate Concentration vs. Ozone Dose (January 2002 to Present)



Bromate Concentration vs. Ozone Dose (January 2002 to Present)



Bromate Levels (2002 to Present)



System Improvements

- Carbon Dioxide Control: Added Second pH Controller and CO₂ Control Valve.
- Installed Additional Ozone Residual Analyzers and Sample Pumps.
- Real-time Calculation and Trending of Ozone Residual CT Value.

Carbon Dioxide (CO₂)

- Two parallel contact chambers for CO₂ and ozone addition.
- Operators had to control splitting CO₂ and ozone dosages between the two contactors.
- Running both contactors was very tricky in past. Operators had to spend a lot of time monitoring ozone and recarbonation systems.

Carbon Dioxide (CO₂)

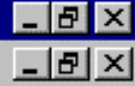
- Installed independent pH control for each contact chamber in July 2003.
- Used digital controller instead of analog.
- CO₂ is now fed with ozone through the ozone diffusers (better mixing and bromate control).
- Results: Smoother plant startups/shut downs, easier contactor startups.

Carbon Dioxide (CO₂) Controller

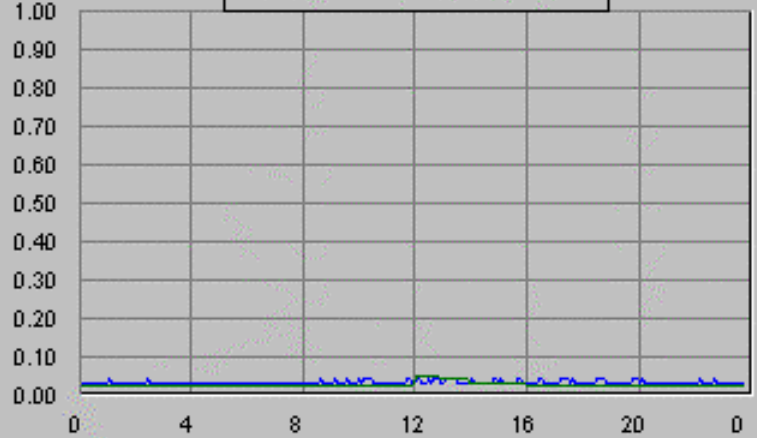


Carbon Dioxide Control Valves





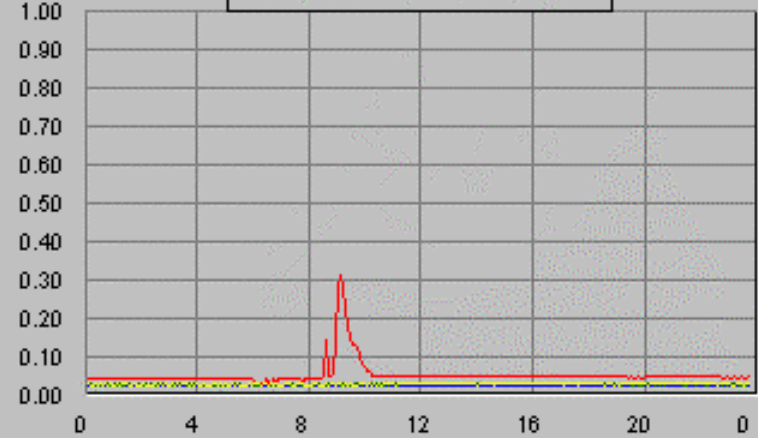
PLANT TURBIDITIES



0: 0: 0
March 3, 2003

0: 0: 0
March 4, 2003

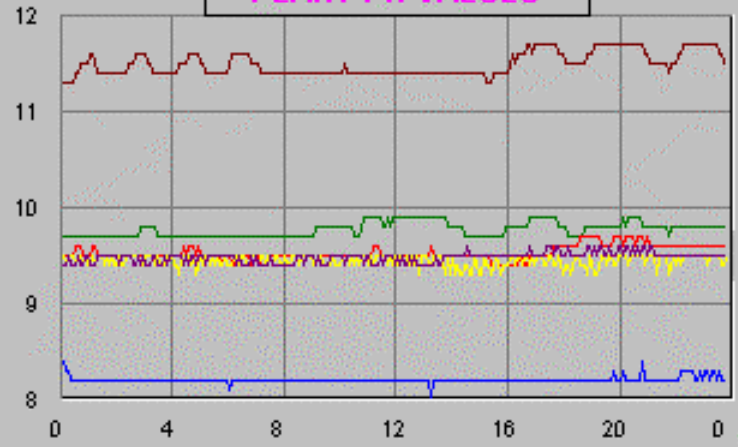
FILTER TURBIDITIES



0: 0: 0
March 3, 2003

0: 0: 0
March 4,

PLANT PH VALUES



0: 0: 0
March 3, 2003

0: 0: 0
March 4, 2003

PLANT TURBIDITIES

RIVER	51.50
CLEARWELL	0.04
EAST RESERVOIR	0.03
FILTER TURBIDITIES	
FILTER #1	0.03
FILTER #2	0.03
FILTER #3	0.04
FILTER #4	0.03

PLANT PH VALUES

RIVER	4.00
ACCELATOR	6.00
RECARBONATION	9.70
FILTER INFLUENT	9.60
CLEARWELL	9.50
EAST RESERVOIR	9.40

ROSEMOUNT PH

RIVER TURB.

- [MAIN MENU](#)
- [TRENDING MENU](#)
- [TIMERS](#)
- [FILTER](#)
- [CHEMICALS](#)
- [DOSAGE](#)
- [CITY LEVELS](#)
- [RIVER CONTROL](#)
- [EAST BOOSTERS](#)
- [WEST BOOSTERS](#)

CHEMICAL FLOWS

WEST PLANT

CHLORINE/AMMON

OZONE/CT VALUE

LEVELS/FLOWS

BOOSTER/TOWER

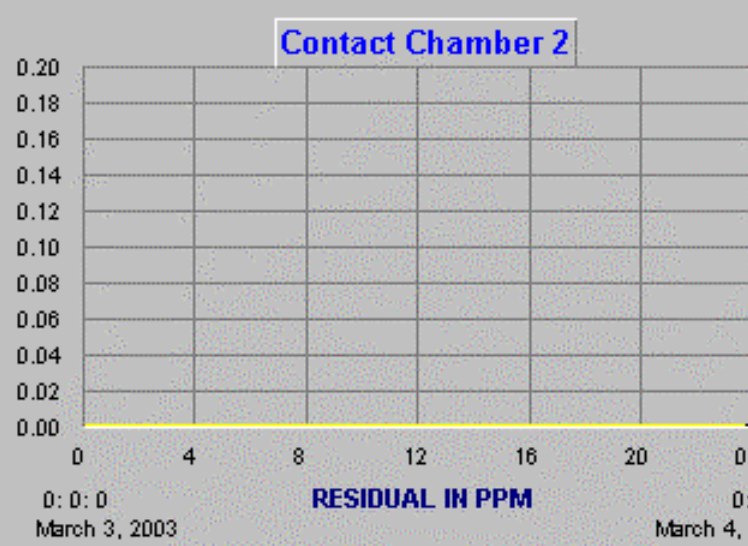
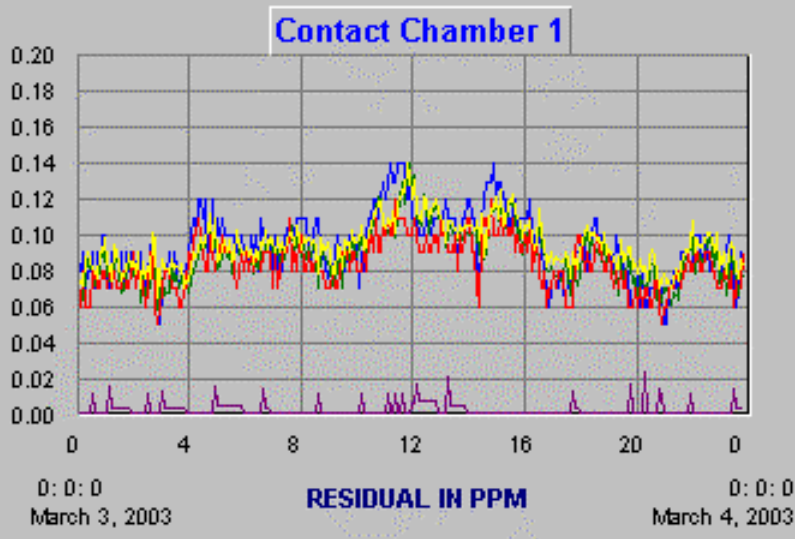
RIVER STATUS

- <--HR HR-->
- <--8 HR 8 HR-->
- <--16 HR 16 HR-->
- <--DAY DAY-->
- <--WEEK WEEK-->

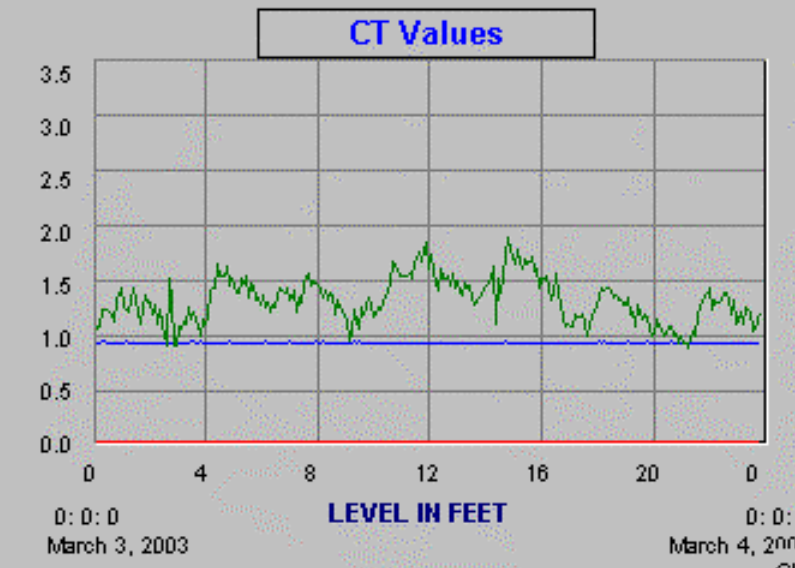
1 HOUR SPAN

8 HOUR SPAN

1 DAY SPAN



- [MAIN MENU](#)
- [TRENDING MENU](#)
- [TIMERS](#)
- [FILTER](#)
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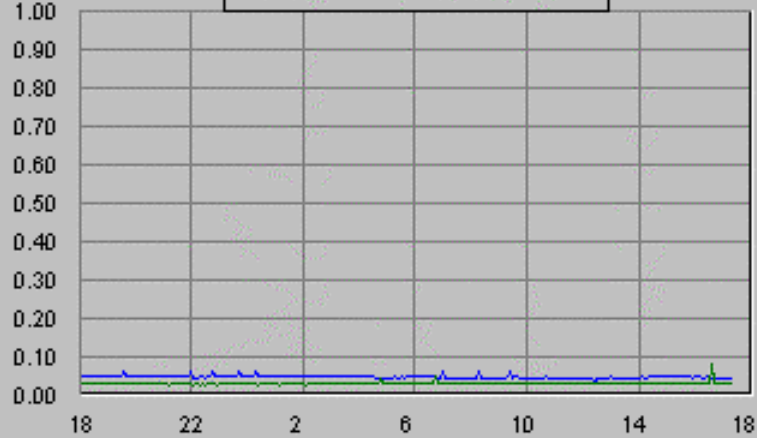


Ozone Chamber 1 (West)		Ozone Chamber 2 (East)	
CELL D high	0.000	CELL D high	0.070
CELL F high	0.000	CELL F high	0.046
CELL D high (Backup)	0.000	CELL D high (Backup)	0.080
CELL F high (Backup)	0.000	CELL F high (Backup)	0.059
Filter Influent Orbis.	0.00	OZONE SETUP SCREEN	
Chamber Flow	0	Chamber Flow	2721
Required CT Value	0.540	Required CT Value	0.540
Current CT Value	-0.020	Current CT Value	0.910
CHAMBER #1 DOSE		5.00	CHAMBER #2 DOSE
			5.00

- [CHEMICAL FLOWS](#)
- [WEST PLANT](#)
- [CHLORINE/AMMON](#)
- [BOOSTER/TOWER](#)
- [LEVELS/FLOWS](#)
- [TURBIDITY / pH](#)
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- [--HR](#) [HR-->](#)
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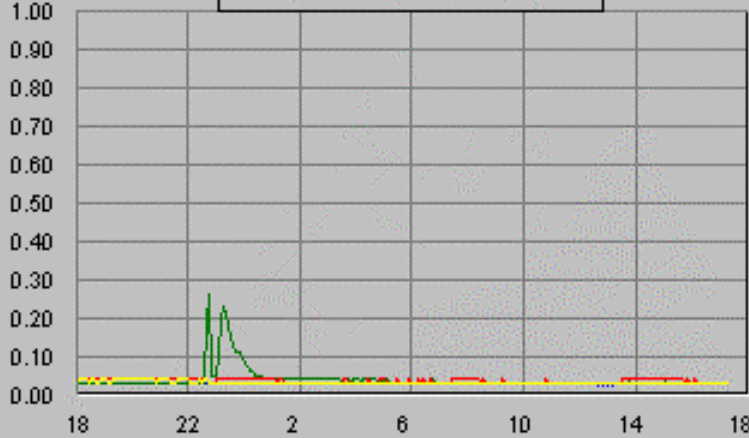


PLANT TURBIDITIES



18: 0: 0 April 22, 2004 18: 0: 0 April 23, 2004

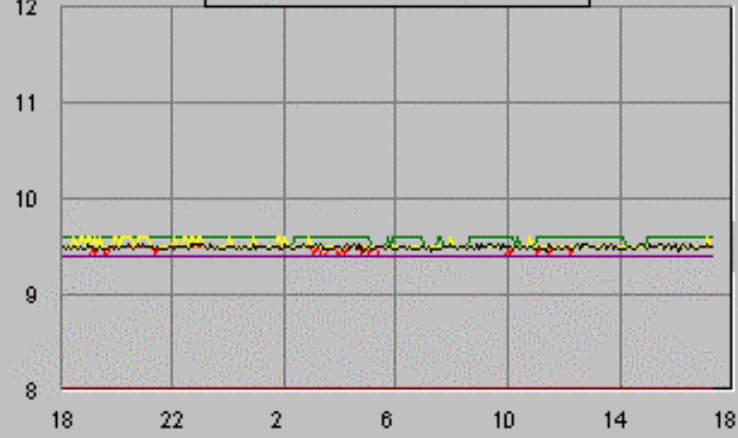
FILTER TURBIDITIES



18: 0: 0 April 22, 2004 18: 0: 0 April 23, 2004

- [MAIN MENU](#)
- [TRENDING MENU](#)
- [TIMERS](#)
- [FILTER](#)
- [CHEMICALS](#)
- [DOSAGE](#)
- [CITY LEVELS](#)
- [RIVER CONTROL](#)
- [EAST BOOSTERS](#)
- [WEST BOOSTERS](#)

PLANT PH VALUES



18: 0: 0 April 22, 2004 18: 0: 0 April 23, 2004

PLANT TURBIDITIES

RIVER	56.70
CLEARWELL	0.04
EAST RESERVOIR	0.03
FILTER TURBIDITIES	
FILTER #1	0.03
FILTER #2	0.03
FILTER #3	0.03
FILTER #4	0.03

PLANT PH VALUES

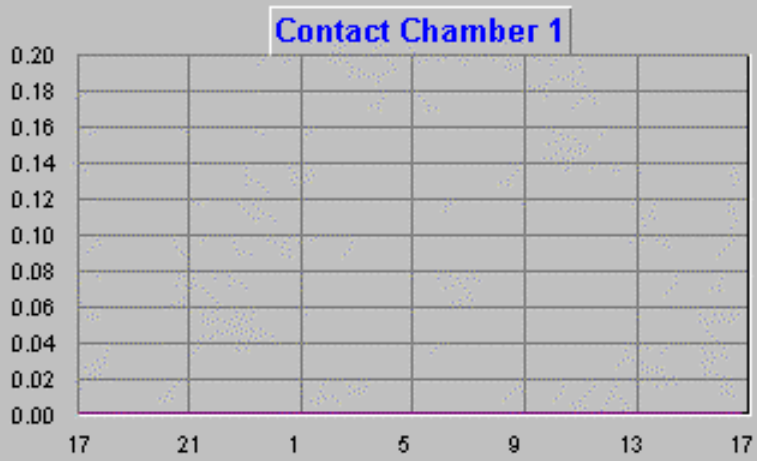
RIVER	4.00
ACCELATOR	6.00
RECARBONATION	9.70
FILTER INFLUENT	9.60
CLEARWELL	9.50
EAST RESERVOIR	9.40
ROSEMOUNT PH	9.51

CHEMICAL FLOWS

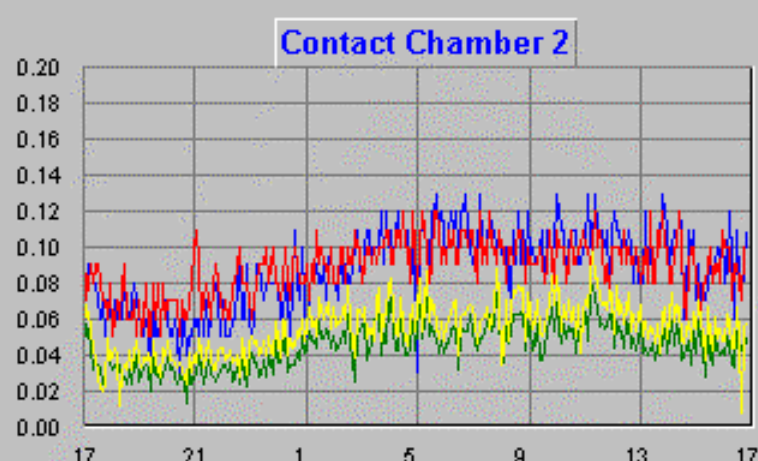
- [WEST PLANT](#)
- [CHLORINE/AMMON](#)
- [OZONE/CT VALUE](#)
- [LEVELS/FLOWS](#)
- [BOOSTER/TOWER](#)
- [RIVER STATUS](#)
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- [<--8 HR](#) [8 HR-->](#)
- [<--16 HR](#) [16 HR-->](#)
- [<--DAY](#) [DAY-->](#)
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RIVER TURB.

- [1 HOUR SPAN](#)
- [8 HOUR SPAN](#)
- [1 DAY SPAN](#)

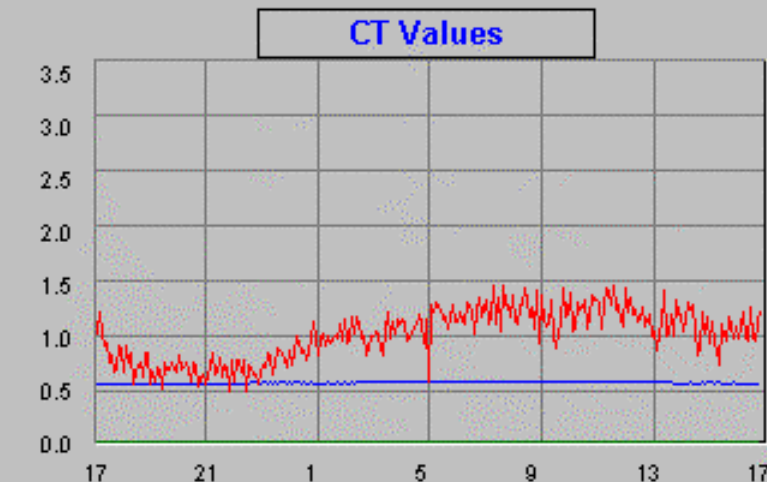


17: 0: 0 April 22, 2004 **RESIDUAL IN PPM** 17: 0: 0 April 23, 2004



17: 0: 0 April 22, 2004 **RESIDUAL IN PPM** 17: 0: 0 April 23, 2004

- [MAIN MENU](#)
- [TRENDING MENU](#)
- [TIMERS](#)
- [FILTER](#)
- [CHEMICALS](#)
- [DOSAGES](#)
- [CITY TANKS](#)
- [RIVER CONTROL](#)
- [EAST BOOSTERS](#)
- [WEST BOOSTERS](#)



17: 0: 0 April 22, 2004 **LEVEL IN FEET** 17: 0: 0 April 23, 2004

Ozone Chamber 1 (West) **Ozone Chamber 2 (East)**

CELL D high	0.000	CELL D high	0.080
CELL F high	0.000	CELL F high	0.030
CELL D high (Backup)	0.000	CELL D high (Backup)	0.080
CELL F high (Backup)	0.000	CELL F high (Backup)	0.041
Filter Influent Orbis.	0.00	OZONE SETUP SCREEN	
Chamber Flow	0	Chamber Flow	2723
Required CT Value	0.540	Required CT Value	0.540
Current CT Value	-0.020	Current CT Value	0.830

CHAMBER #1 DOSE **5.00** CHAMBER #2 DOSE **5.00**

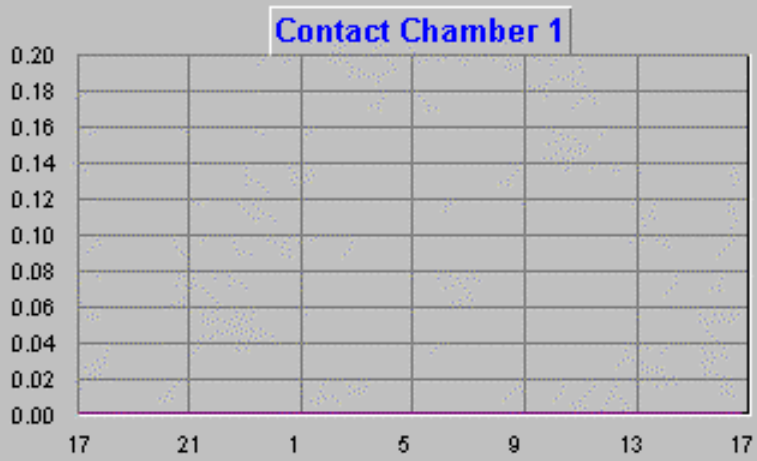
- [CHEMICAL FLOWS](#)
- [WEST PLANT](#)
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- [BOOSTER/TOWER](#)
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- [TURBIDITY / pH](#)
- [RIVER STATUS](#)
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- <--DAY DAY-->
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- 1 HOUR SPAN
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Ozone Residual Monitoring

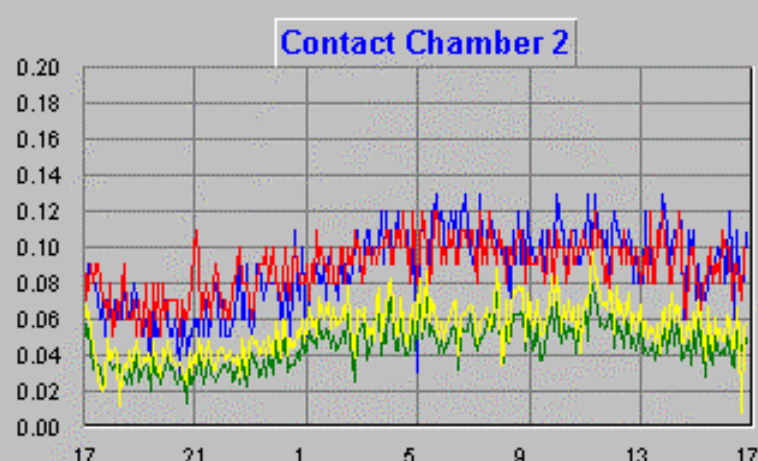
- Operators adjust ozone dose, pH, and water temperature (blend of river and groundwater) to attain required CT value.
- On-line ozone analyzers measure ozone residuals in each contact chamber.
- SCADA system calculates water temperatures using ratio of river and groundwater flows into the plant.

Ozone Operation

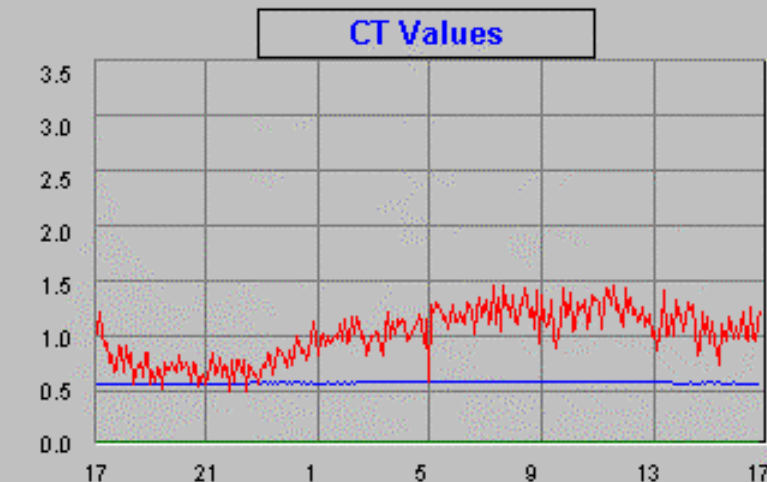
- The river temperature is measured with an on-line analyzer and 50°F is used for groundwater temperature.
- SCADA calculates the CT value.
- CT values are added for the sampling points.
- Current calculated CT values are compared to the required CT.



17: 0: 0 April 22, 2004 **RESIDUAL IN PPM** 17: 0: 0 April 23, 2004



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17: 0: 0 April 22, 2004 **LEVEL IN FEET** 17: 0: 0 April 23, 2004

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CELL D high	0.000	CELL D high	0.080
CELL F high	0.000	CELL F high	0.030
CELL D high (Backup)	0.000	CELL D high (Backup)	0.080
CELL F high (Backup)	0.000	CELL F high (Backup)	0.041
Filter Influent Orbis	0.00	OZONE SETUP SCREEN	
Chamber Flow	0	Chamber Flow	2723
Required CT Value	0.540	Required CT Value	0.540
Current CT Value	-0.020	Current CT Value	0.830

CHAMBER #1 DOSE **5.00** CHAMBER #2 DOSE **5.00**

- MAIN MENU**
- TRENDRING MENU**
- TIMERS**
- FILTER**
- CHEMICALS**
- DOSAGES**
- CITY TANKS**
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- <--HR HR-->
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	Signal	Chamber Flow	Chamber Signals
Contact Chamber 1 (West)	1	3747	0 - Chamber Off
Contact Chamber 2 (East)	0	0	1 - Only Chamber Running 2 - Both Chambers Running

Total Plant Flow: 3748

River Temp. (F): 56.4

Combined Temp. (F): 56.1

Required CT Value: 0.510

Current Chamber 1 CT: 1.170

Current Chamber 2 CT: -0.020

Ozone Monitoring Point	Signal	Ozone Reading	Ozone Monitor Signals
Chamber 1 (West) Cell Dhigh	1	0.090	0 - No Analyzer
Chamber 1 (West) Cell Fhigh	4	0.106	1 - Orbisphere (O3 Room): 0.090
Chamber 1 (West) Cell Dhigh Extra	2	0.090	2 - In USA Analyzer: 0.080
Chamber 1 (West) Cell Fhigh Extra	3	0.110	3 - Rosemount #1: 0.110
Chamber 2 (East) Cell Dhigh	0	0.000	4 - Rosemount #2
Chamber 2 (East) Cell Fhigh	0	0.000	
Chamber 2 (East) Cell Dhigh Extra	0	0.000	
Chamber 2 (East) Cell Fhigh Extra	0	0.000	

- [MAIN MENU](#)
- [TRENDING MENU](#)
- [WHT CHART MENU](#)
- [TIMERS](#)
- [FILTER](#)
- [CHEMICALS](#)
- [DOSAGES](#)
- [RIVER CONTROL](#)
- [EAST BOOSTERS](#)
- [WEST BOOSTERS](#)

- [CITY TANKS](#)
- [BOOSTER/TOWER](#)
- [LEVELS/FLOWS](#)
- [TURBIDITY / pH](#)
- [RIVER STATUS](#)

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<--DAY DAY-->

<--WEEK WEEK-->

- 1 HOUR SPAN
- 8 HOUR SPAN
- 1 DAY SPAN

CHAMBER #1 DOSE: **5.00**

CHAMBER #2 DOSE: **5.00**

OZONE ROOM: **0.02**

Filter Int. Ozone/Orb: **0.00**

O3 RES. NEEDED: **0.04**

CURRENT CT: **0.27**

REQUIRED CT: **0.27**

Ozone Analyzers



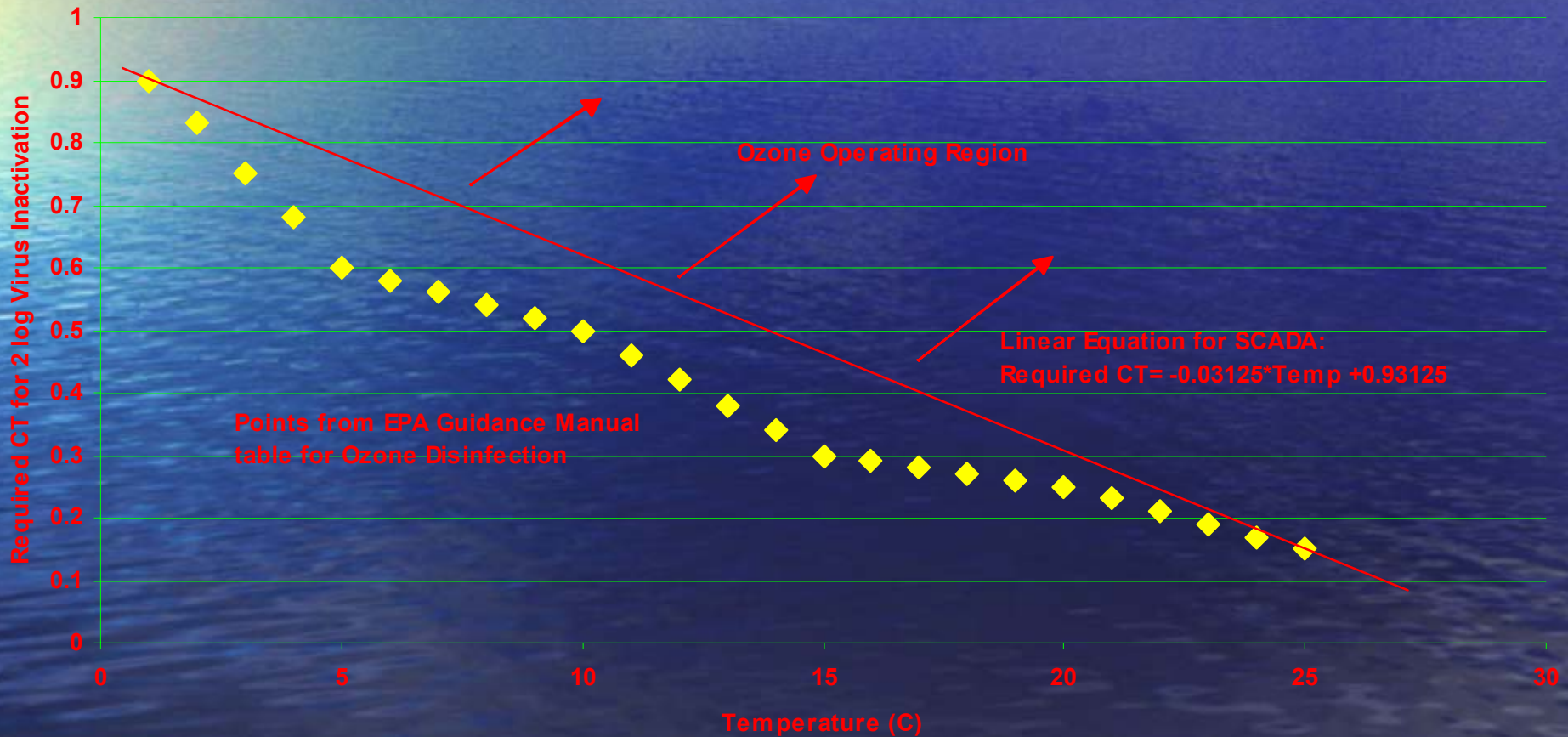
Ozone Distribution & Sampling

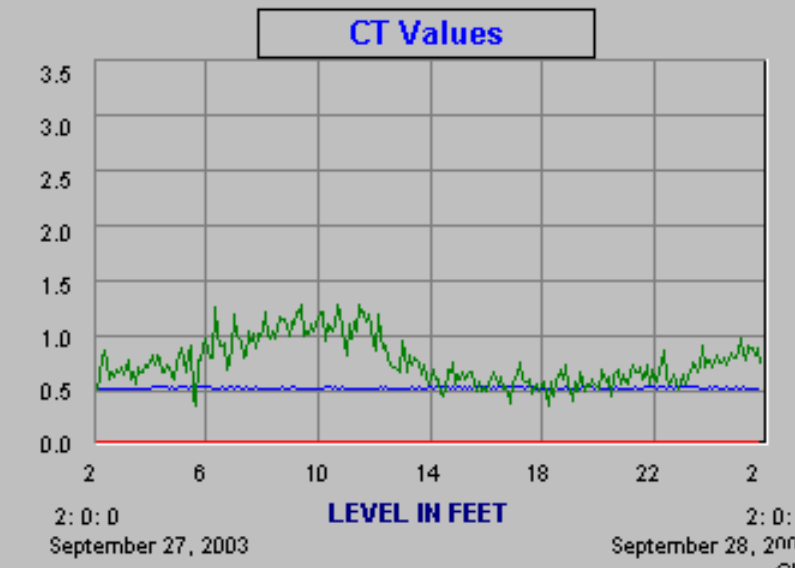
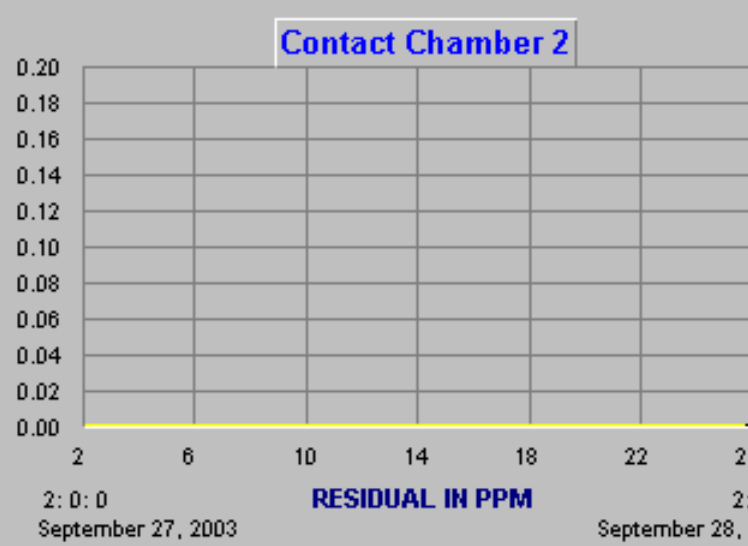
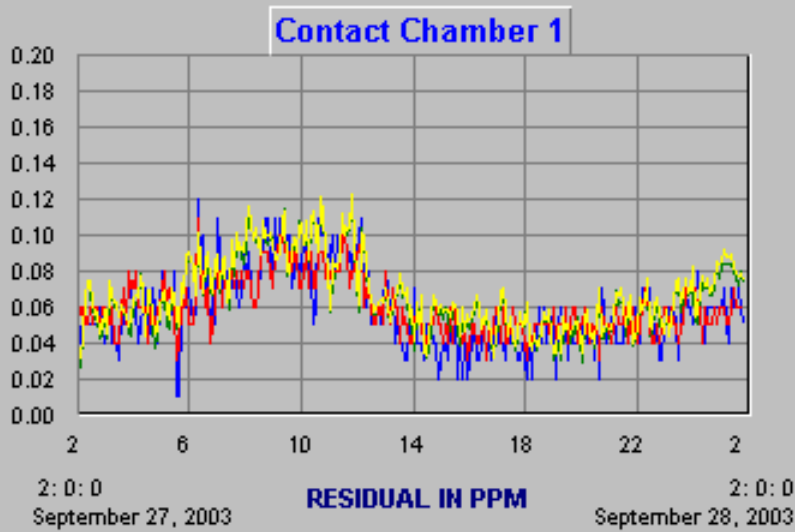


Real-time Calculation and Trending of Ozone Residual CT Value

- Real-time calculation and trending of CT value (Concentration * time).
- CT based on EPA Tables: 0.5 log Giardia Cysts and **2 log virus inactivation**
- PLC programming is a conservative, linear calculation of required CT value for simplicity.
- Temperature: Real-time river temperature and fixed groundwater temperature.

Ozone Operation





Ozone Chamber 1 (West)		Ozone Chamber 2 (East)	
CELL D high	0.050	CELL D high	0.000
CELL F high	0.086	CELL F high	0.000
CELL D high (Backup)	0.060	CELL D high (Backup)	0.000
CELL F high (Backup)	0.086	CELL F high (Backup)	0.000
Filter Influent Orbis.	0.02	OZONE SETUP SCREEN	
Chamber Flow	3186	Chamber Flow	0
Required CT Value	0.560	Required CT Value	0.560
Current CT Value	0.970	Current CT Value	-0.020
CHAMBER #1 DOSE	4.30	CHAMBER #2 DOSE	4.30

- MAIN MENU**
- TRENDING MENU**
- TIMERS**
- FILTER**
- CHEMICALS**
- DOSAGES**
- CITY TANKS**
- RIVER CONTROL**
- EAST BOOSTERS**
- WEST BOOSTERS**
- CHEMICAL FLOWS**
- WEST PLANT**
- CHLORINE/AMMON**
- BOOSTER/TOWER**
- LEVELS/FLOWS**
- TURBIDITY / pH**
- RIVER STATUS**
- <--HR HR-->
- <--8 HR 8 HR-->
- <--16 HR 16 HR-->
- <--DAY DAY-->
- <--WEEK WEEK-->
- 1 HOUR SPAN
- 8 HOUR SPAN
- 1 DAY SPAN

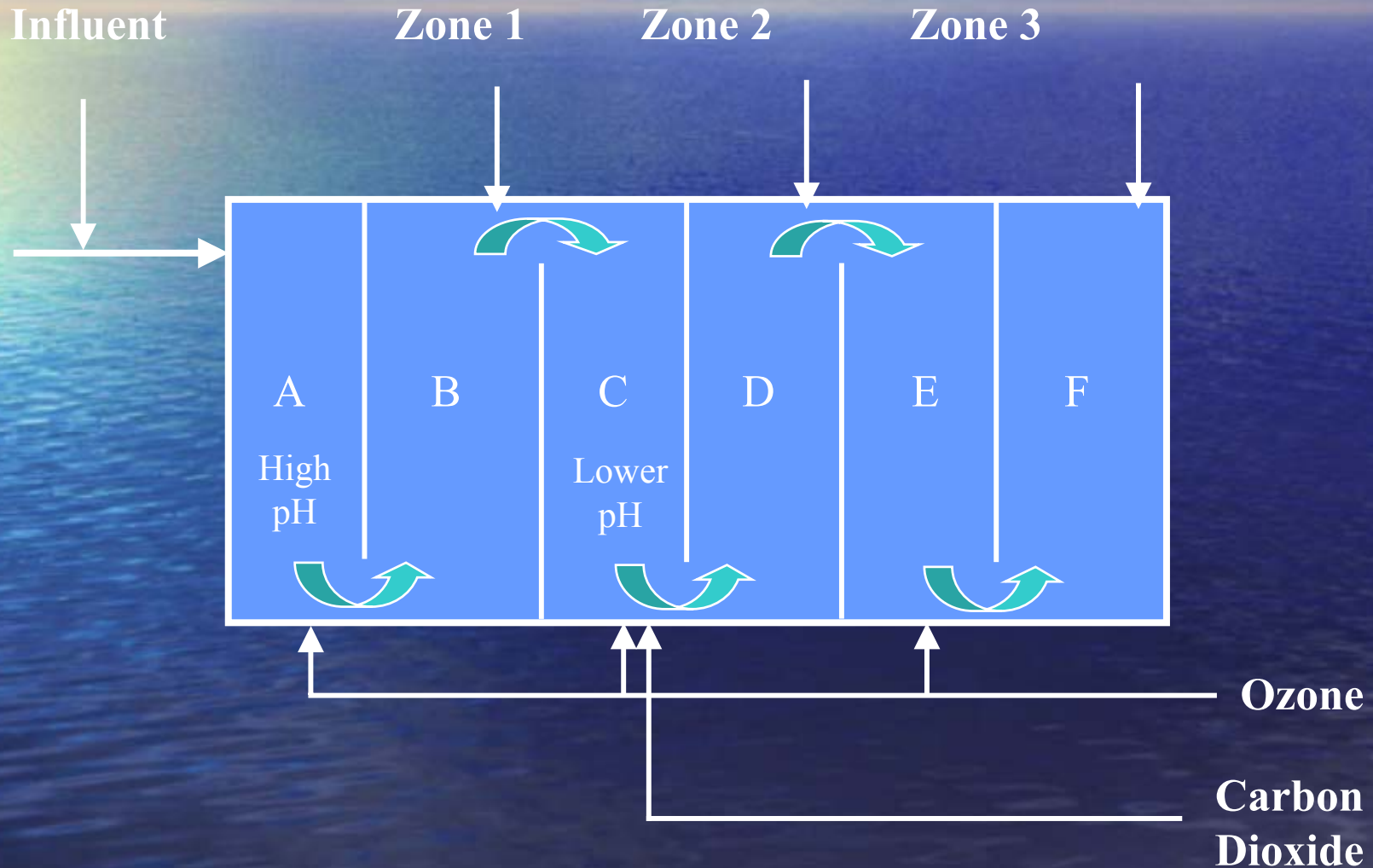
Chloramine CT Credit

- In future, we will include real-time CT calculations for chloramine disinfection in plant reservoirs.

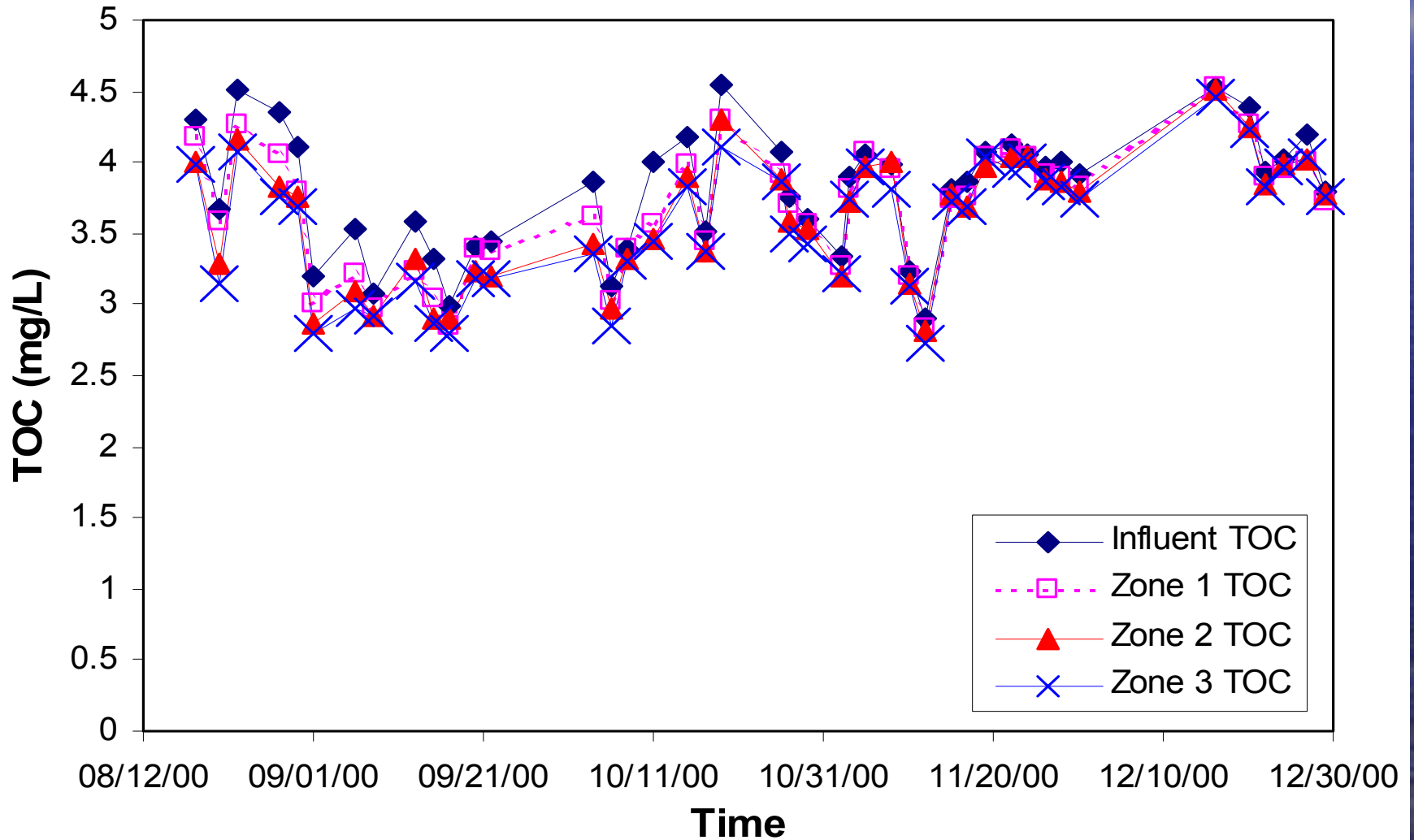
Stuart Hurley's Research

- AN INVESTIGATION OF THE DISINFECTION BY-PRODUCT FORMATION AND REMOVAL AT THE MOORHEAD WATER TREATMENT PLANT

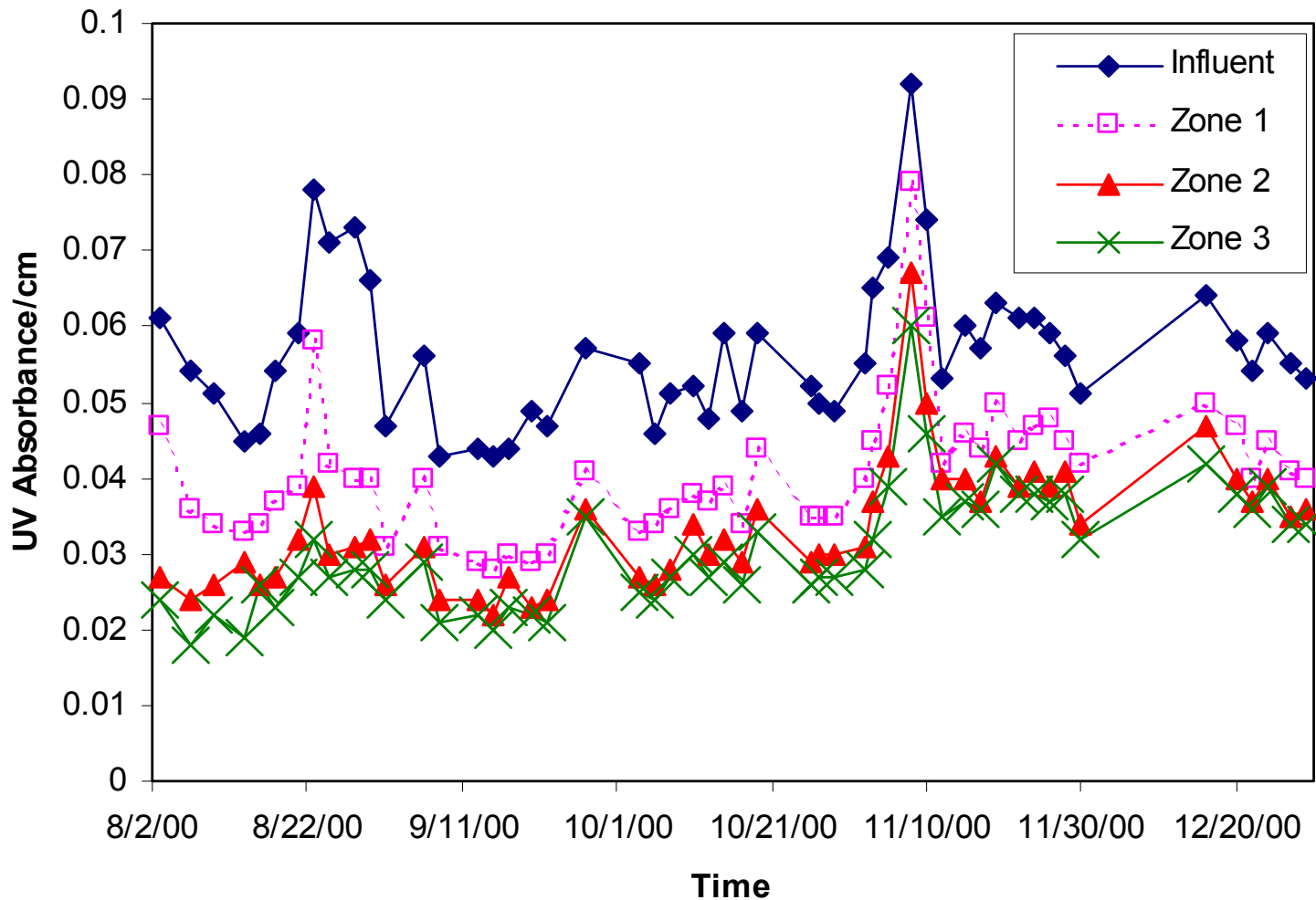
Sample Locations



Complete Oxidation



Incomplete Oxidation

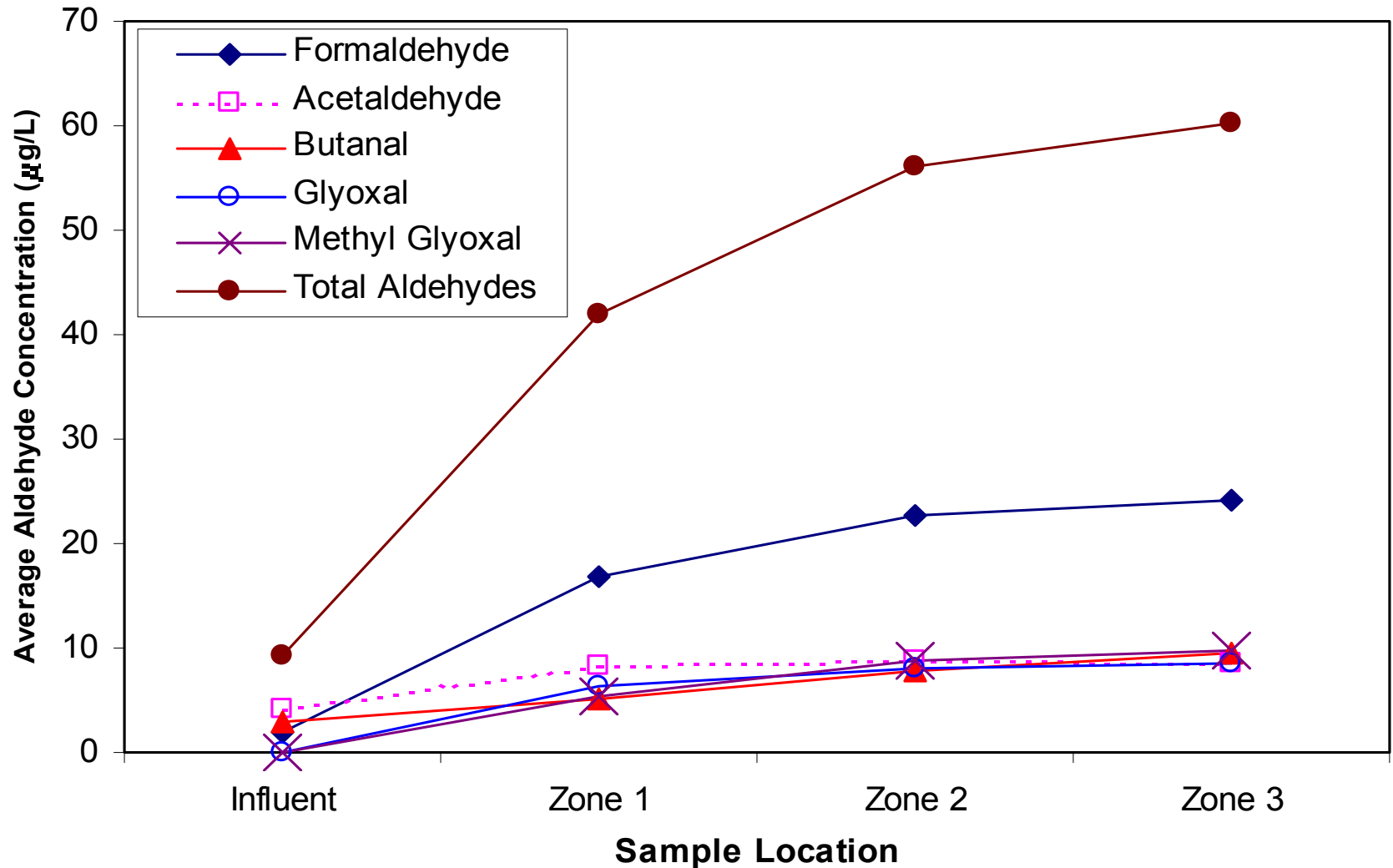


Task 3

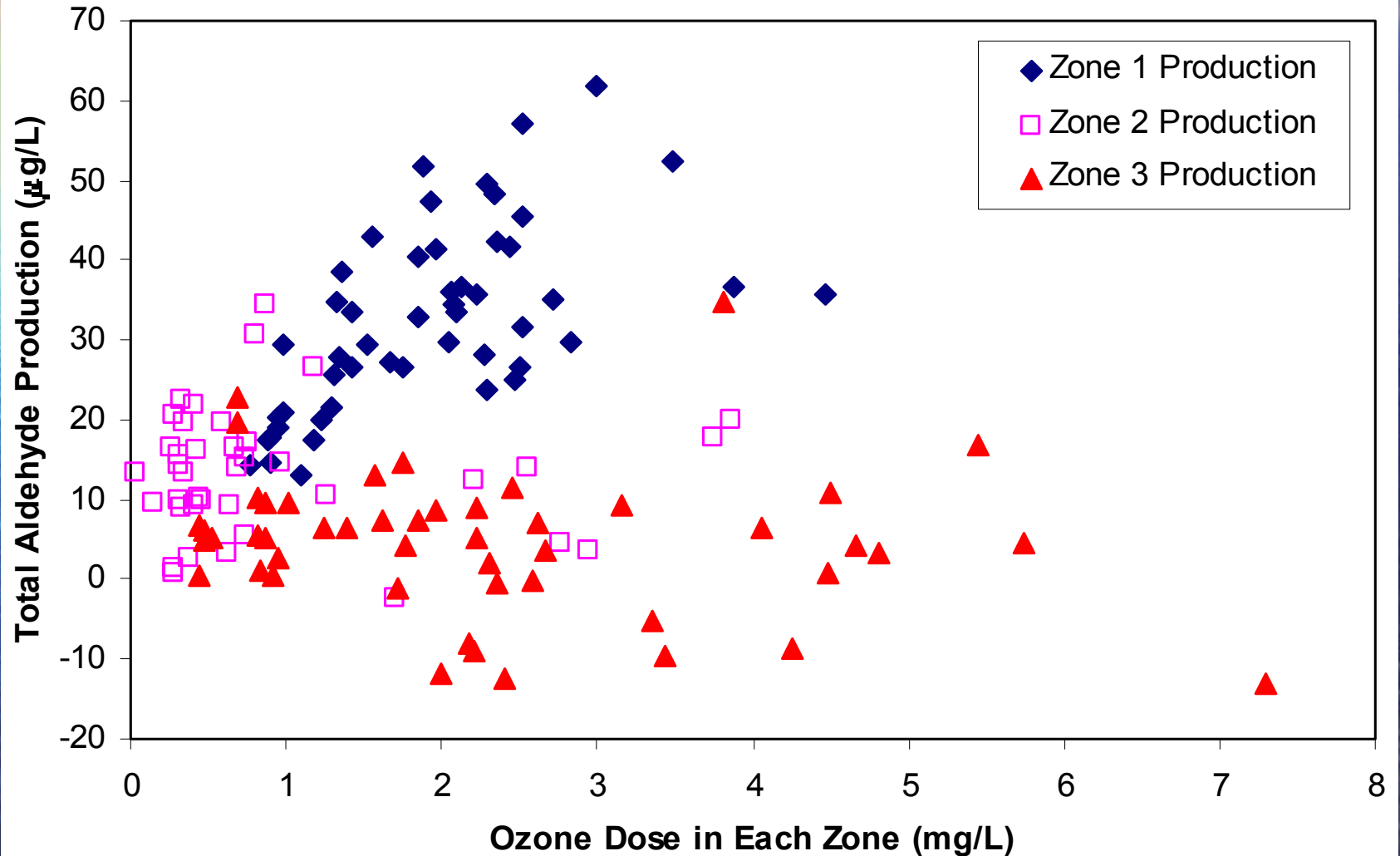
- Volatile compound analysis
 - No volatile compounds were identified
- Carbonyl Compound Analysis
 - Main ozone DBPs formed are:
 - Formaldehyde, Acetaldehyde, Butanal, Glyoxal, and Methyl Glyoxal

Task 3

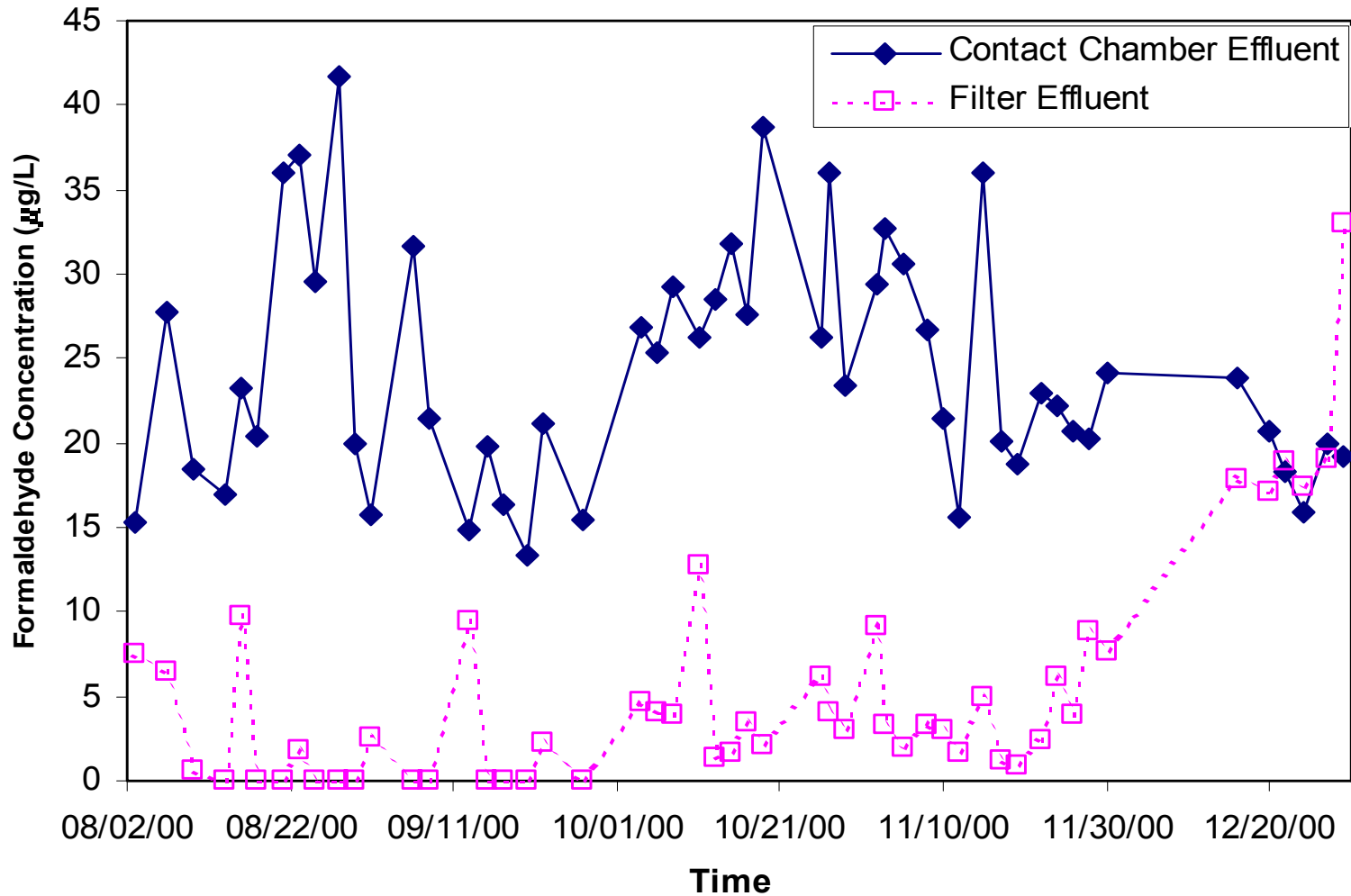
Aldehyde Production



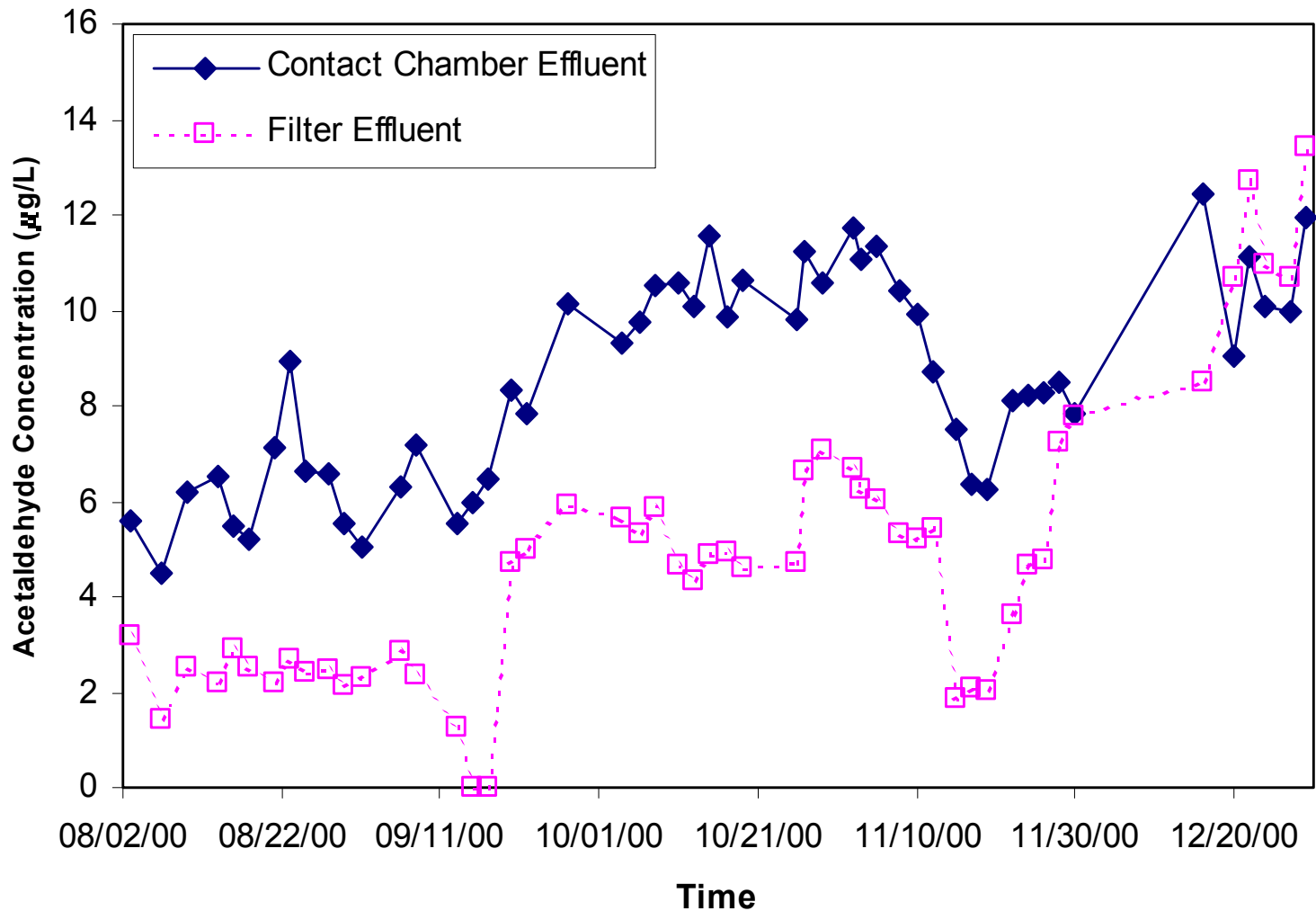
Aldehyde Production vs Ozone Dose



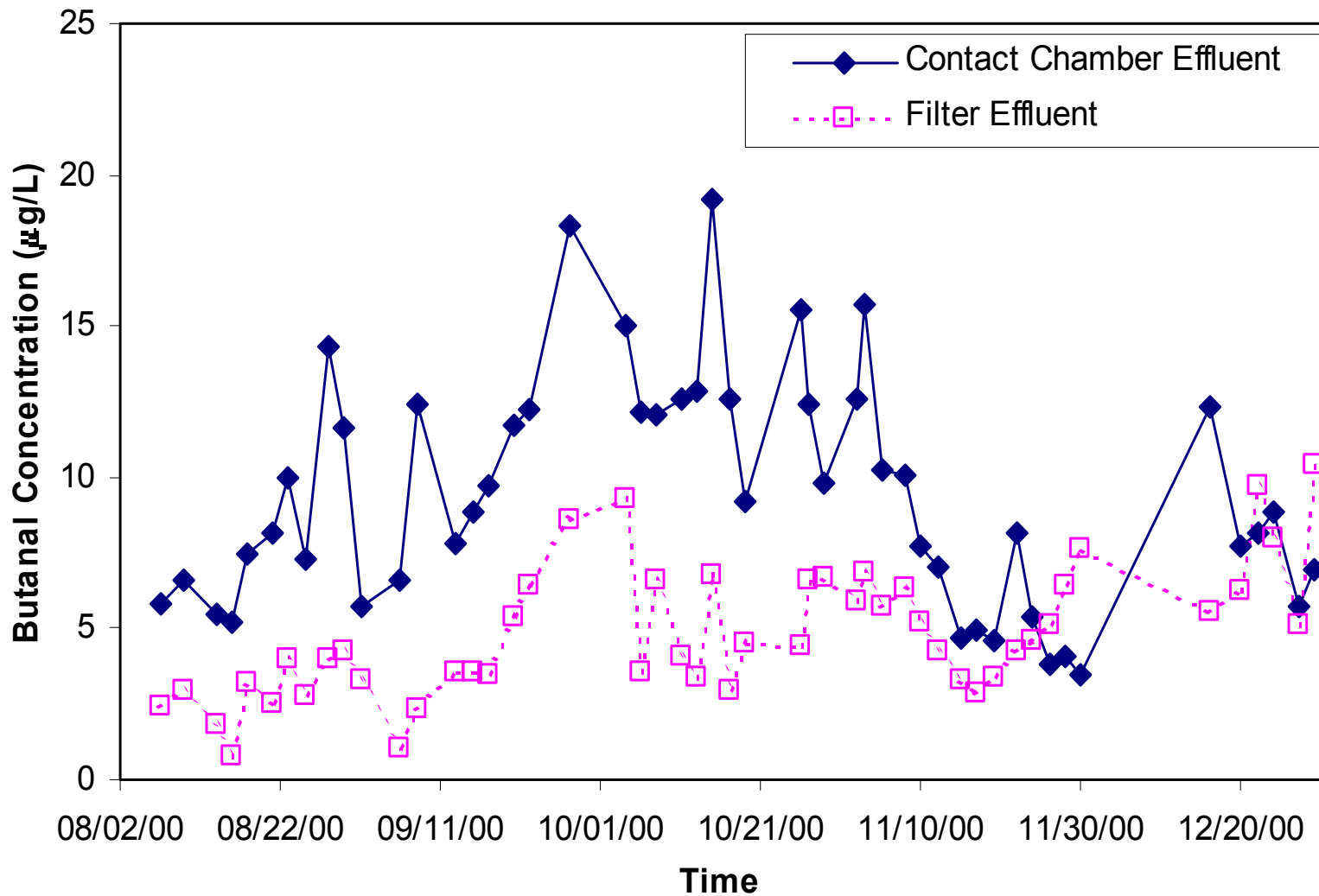
Formaldehyde Removal



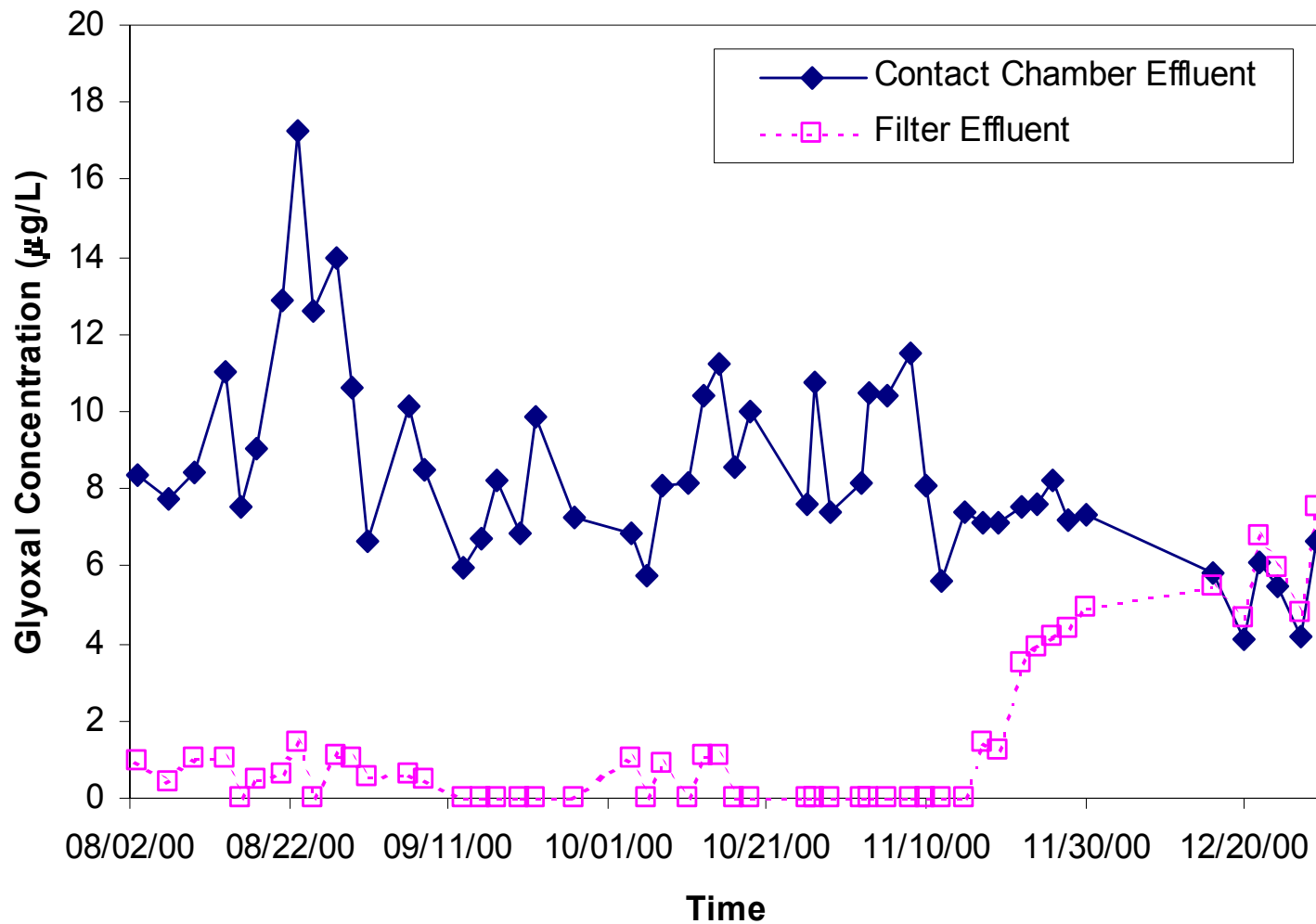
Acetaldehyde Removal



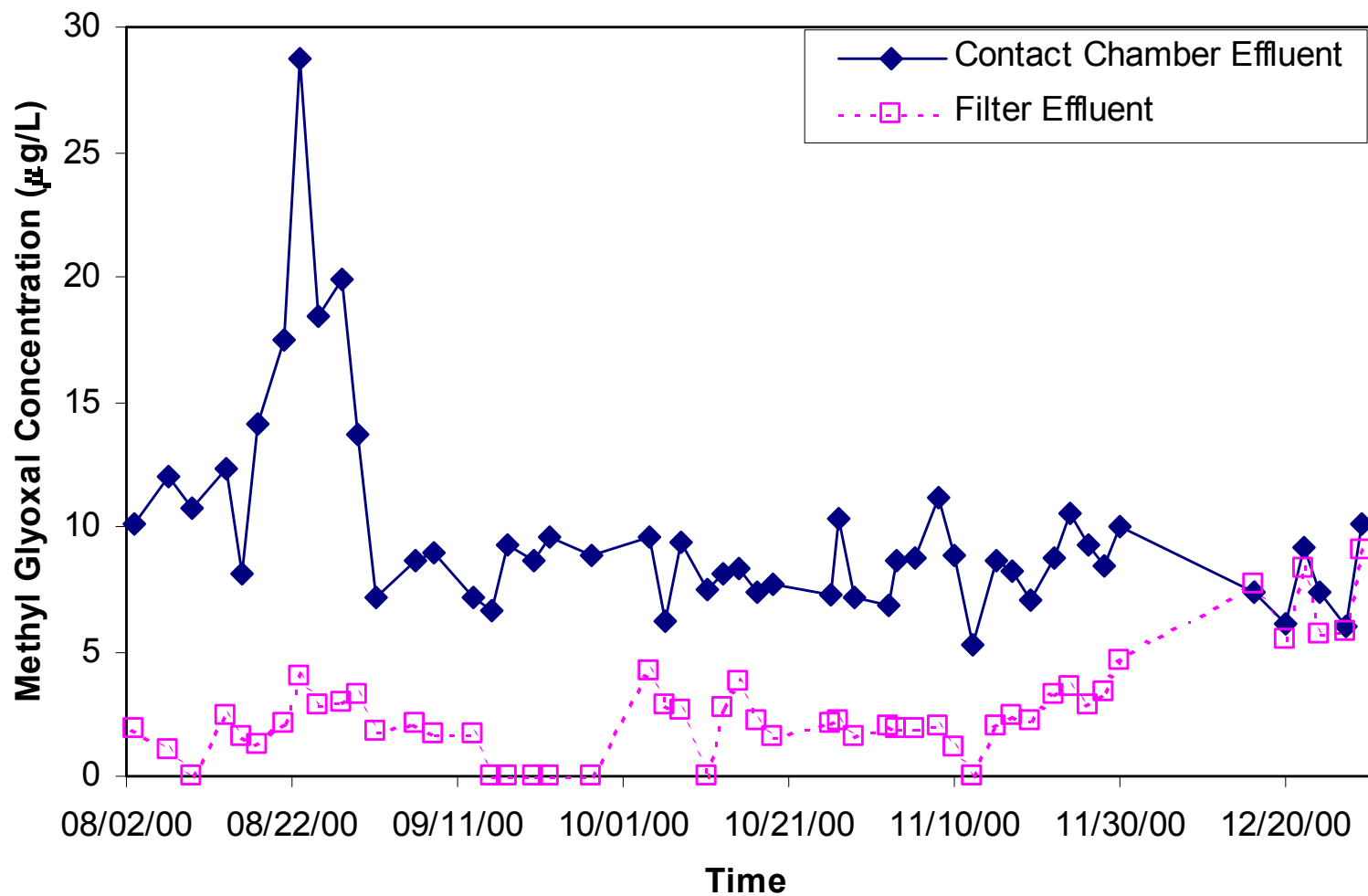
Butanal Removal



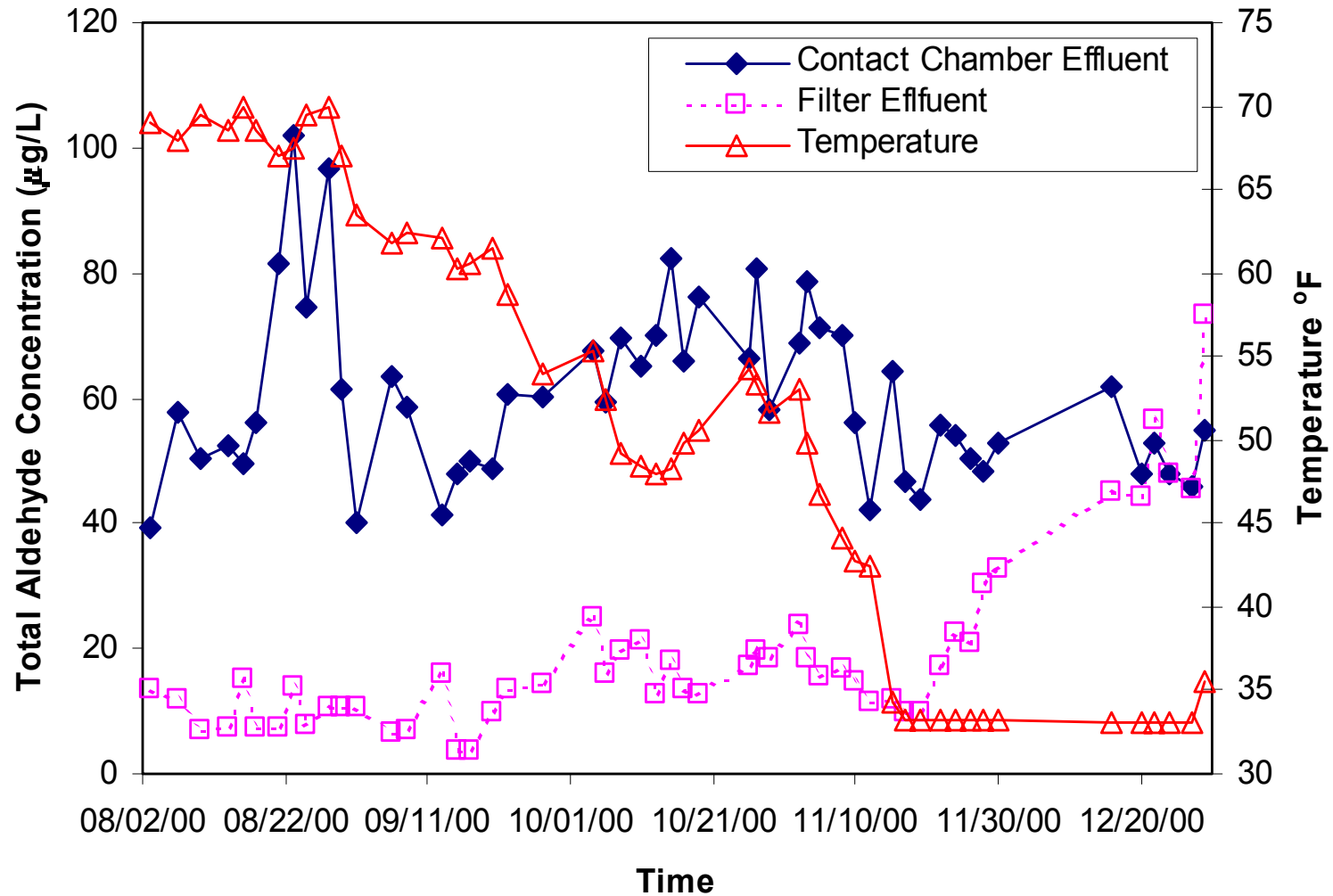
Glyoxal Removal



Methyl Glyoxal Removal



Total Aldehyde Removal



Acknowledgements

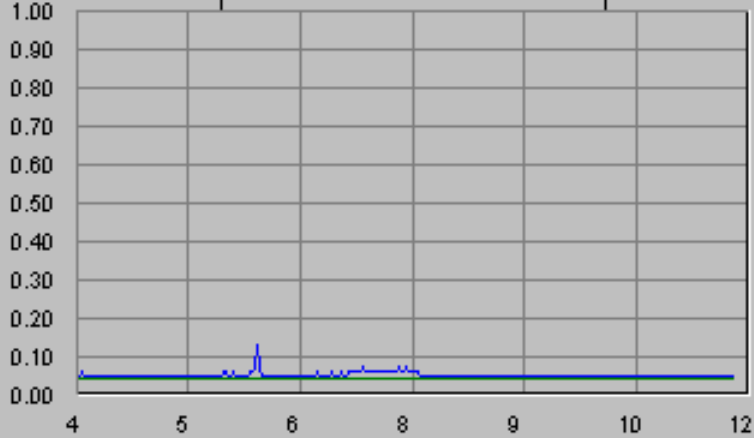
- Troy Hall, Water Plant Supervisor
- MPS Water Plant Operators
- Stuart Hurley, NDSU Graduate Student
- Dr. Wei Lin, Major Professor, North Dakota State University



Questions ?

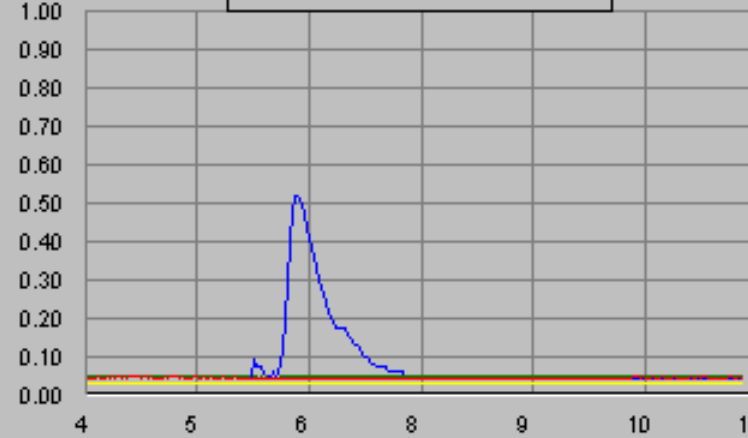


PLANT TURBIDITIES



4: 0: 0 12: 0: 0
September 27, 2003 September 27, 2003

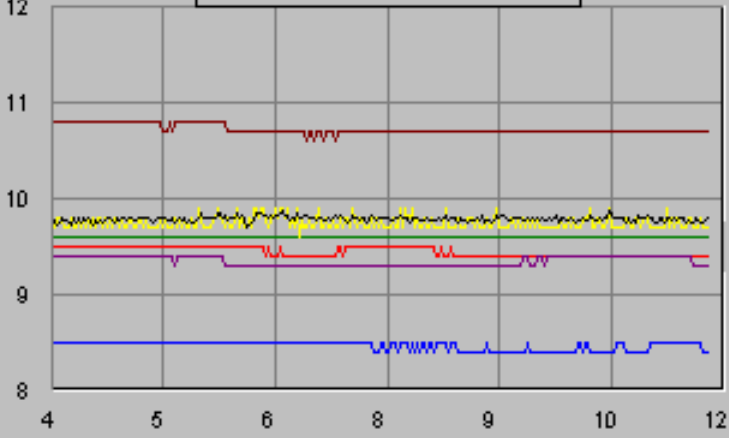
FILTER TURBIDITIES



4: 0: 0 12: 0: 0
September 27, 2003 September 27, 2003

- [MAIN MENU](#)
- [TRENDING MENU](#)
- [TIMERS](#)
- [FILTER](#)
- [CHEMICALS](#)
- [DOSAGE](#)
- [CITY LEVELS](#)
- [RIVER CONTROL](#)
- [EAST BOOSTERS](#)
- [WEST BOOSTERS](#)

PLANT PH VALUES



4: 0: 0 12: 0: 0
September 27, 2003 September 27, 2003

PLANT TURBIDITIES

RIVER	141.10
CLEARWELL	0.05
EAST RESERVOIR	0.04
FILTER TURBIDITIES	
FILTER #1	0.04
FILTER #2	0.05
FILTER #3	0.04
FILTER #4	0.03

PLANT PH VALUES

RIVER	8.40
ACCELATOR	10.70
RECARBONATION	9.70
FILTER INFLUENT	9.60
CLEARWELL	9.40
EAST RESERVOIR	9.30
ROSEMOUNT PH	9.75

- [CHEMICAL FLOWS](#)
- [WEST PLANT](#)
- [CHLORINE/AMMON](#)
- [OZONE/CT VALUE](#)
- [LEVELS/FLOWS](#)
- [BOOSTER/TOWER](#)
- [RIVER STATUS](#)
- [<--HR](#) [HR-->](#)
- [<--8 HR](#) [8 HR-->](#)
- [<--16 HR](#) [16 HR-->](#)
- [<--DAY](#) [DAY-->](#)
- [<--WEEK](#) [WEEK-->](#)

RIVER TURB.

- [1 HOUR SPAN](#)
- [8 HOUR SPAN](#)
- [1 DAY SPAN](#)