# Anaerobic biological treatment for removal of inorganic contaminants from drinking water

Workshop on Biological Drinking Water Treatment
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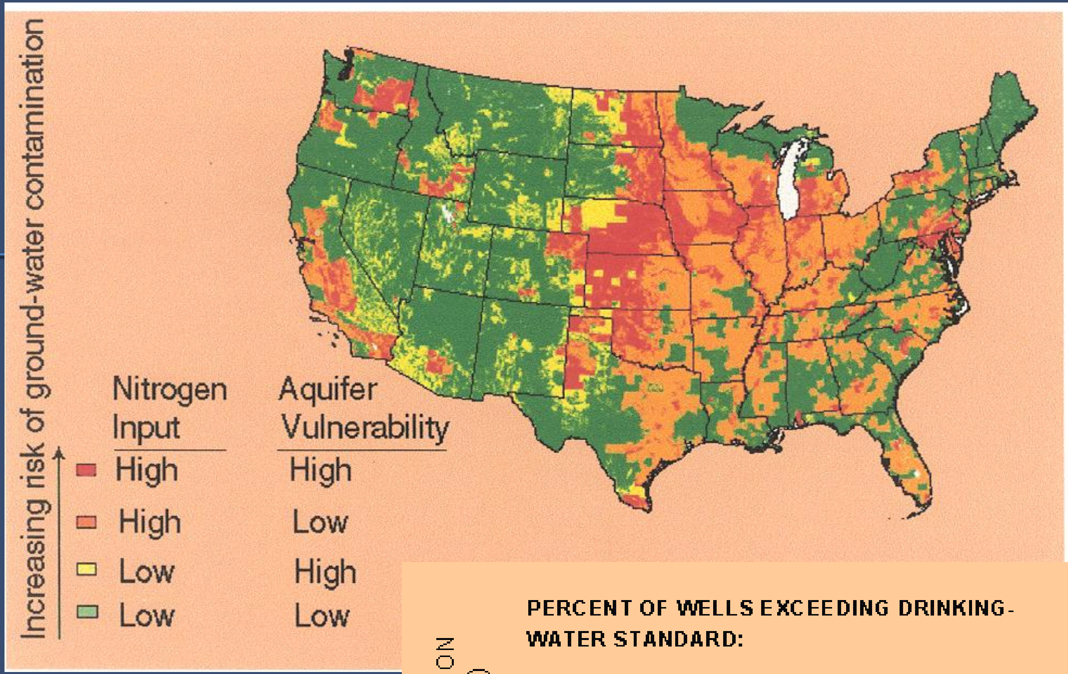
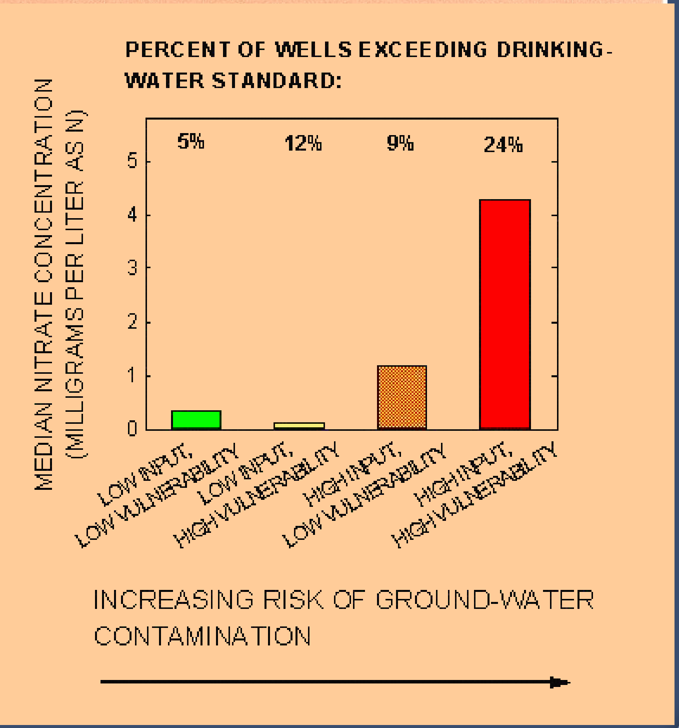
- Nitrate risk factors
  - Nitrate loading from agriculture, livestock operations
  - Aquifer vulnerability: sandy formation, shallow wells
- Affected communities
  - Small town or rural
  - Inland



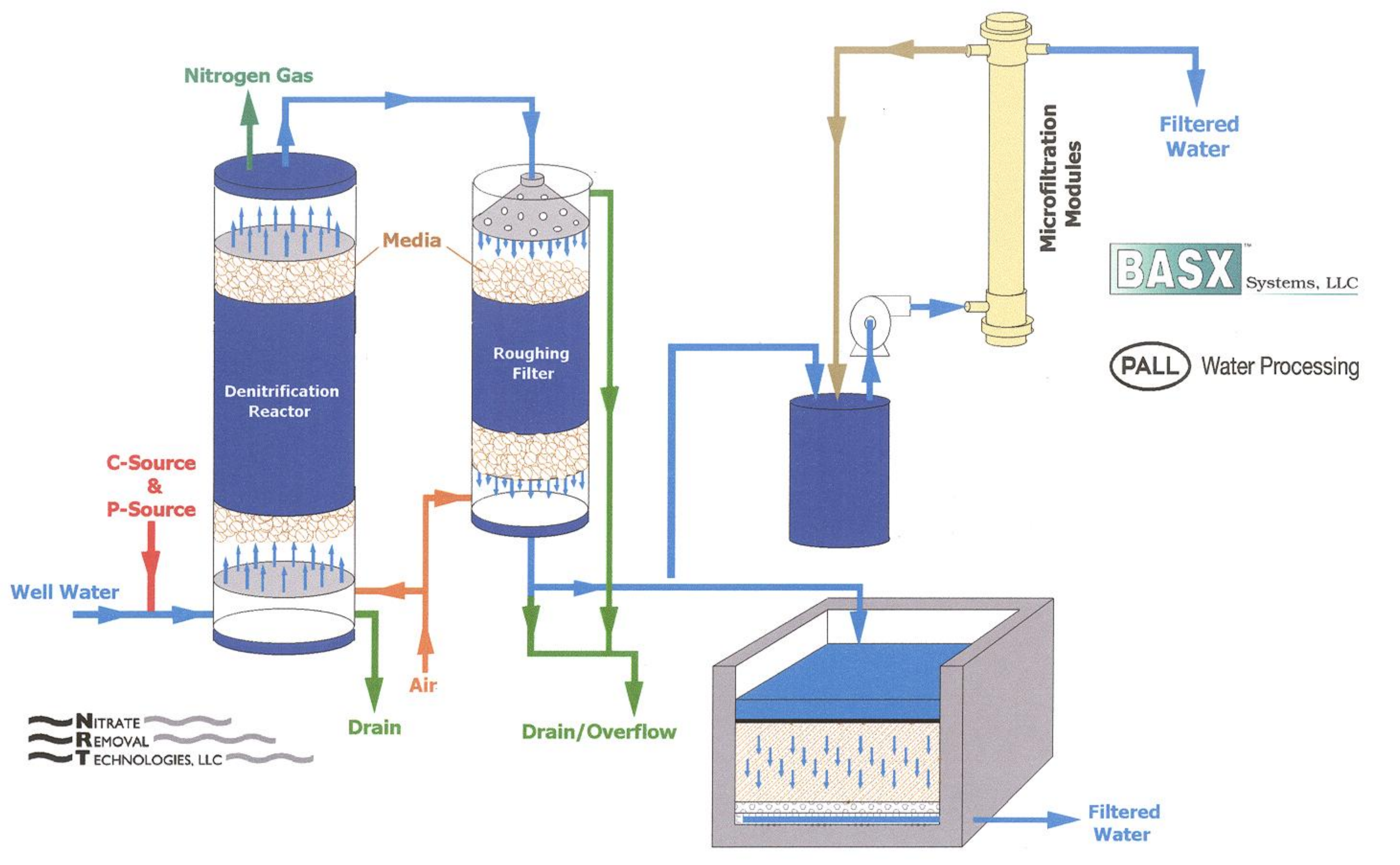




Nolan et al., USGS, 1997 survey of 1400 wells

# Objectives of drinking water denitrification studies

- Production of finished drinking water in field conditions and scale to meet regulatory and utility interests
- Demonstrate operability in small-utility settings
- Provide unit cost estimates of biological denitrification process
- Study nitrate-perchlorate competition for substrate

# Denitrification-Post-Treatment Process Flow Diagram



# Plant Characteristics

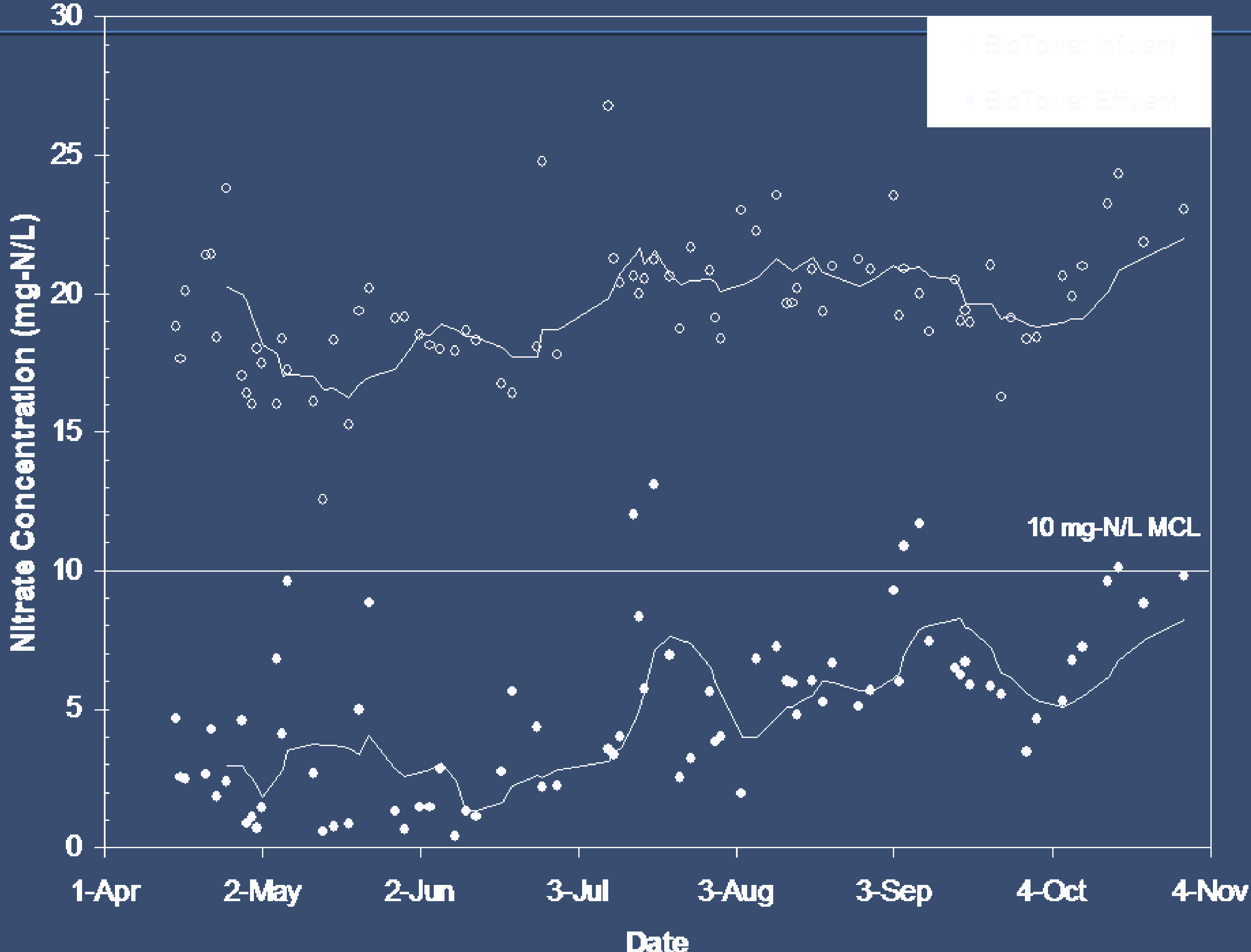
| Location | Purpose | Configuration | Flow (lpm) | Influent $NO_3$ (mg/L-N) | Duration (days) |
|---|---|---|---|---|---|
| Wiggins | Demo. | Denitrify - SSF | 38 | 15-25 | 365 (180 data) |
| Suffolk Mt. Sinai | Demo. | Denitrify - SSF, MF | 30 (DN) 8 (MF, SSF) | 9 | 243 (151 data) |
| Coyle | Drinking Water[1] | Denitrify -SSF | 106 (cap), 53 (DN) | 10 | 758 (24 data) |

[1] 290 residents, 400 schoolchildren

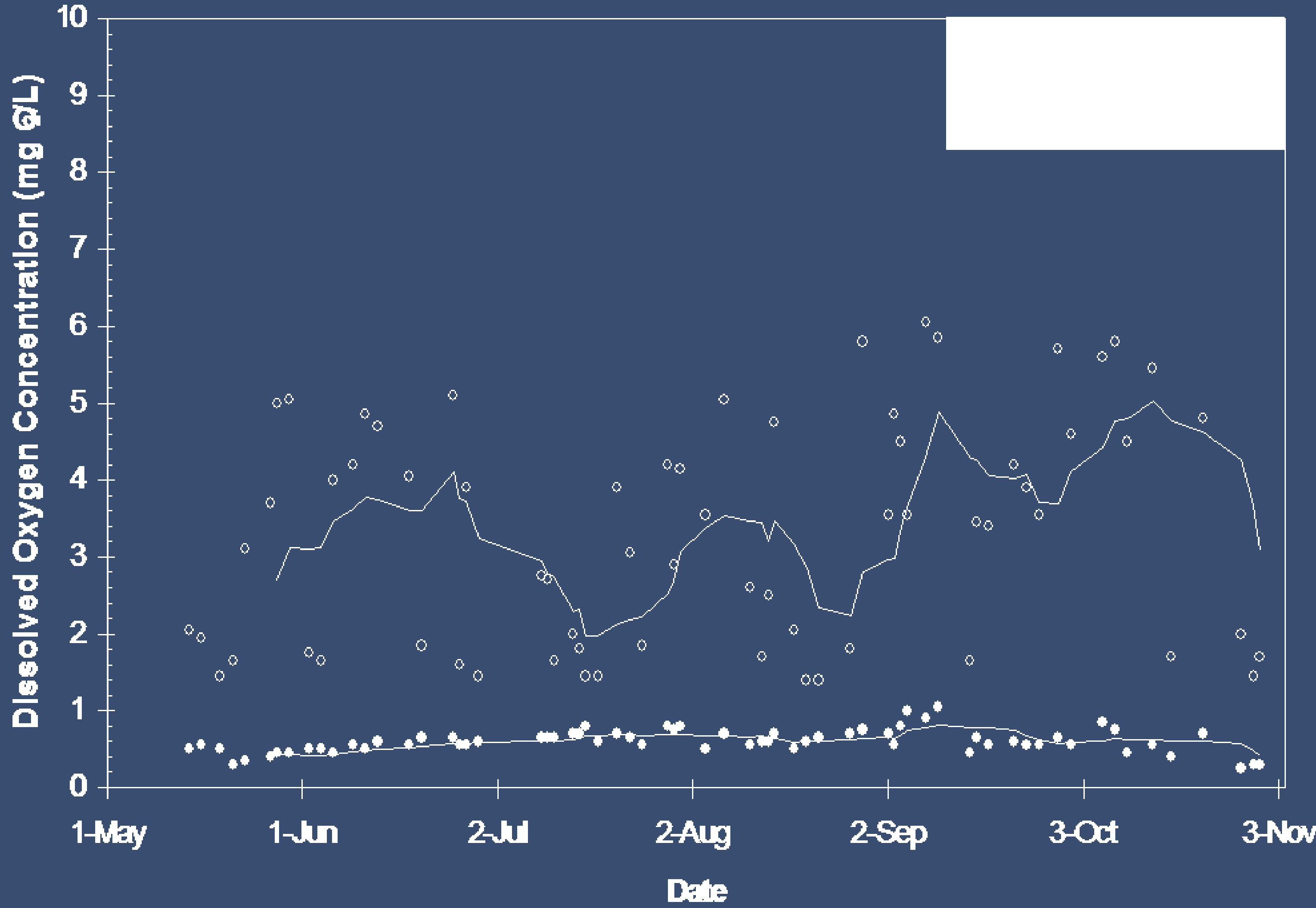
# Wiggins, Colorado Well Pump House (left) and Demonstration Plant Building (right)

Wiggins demonstration plant: (right) anoxic denitrifying biotowers and aerobic prefilter; (left) slow sand filter.

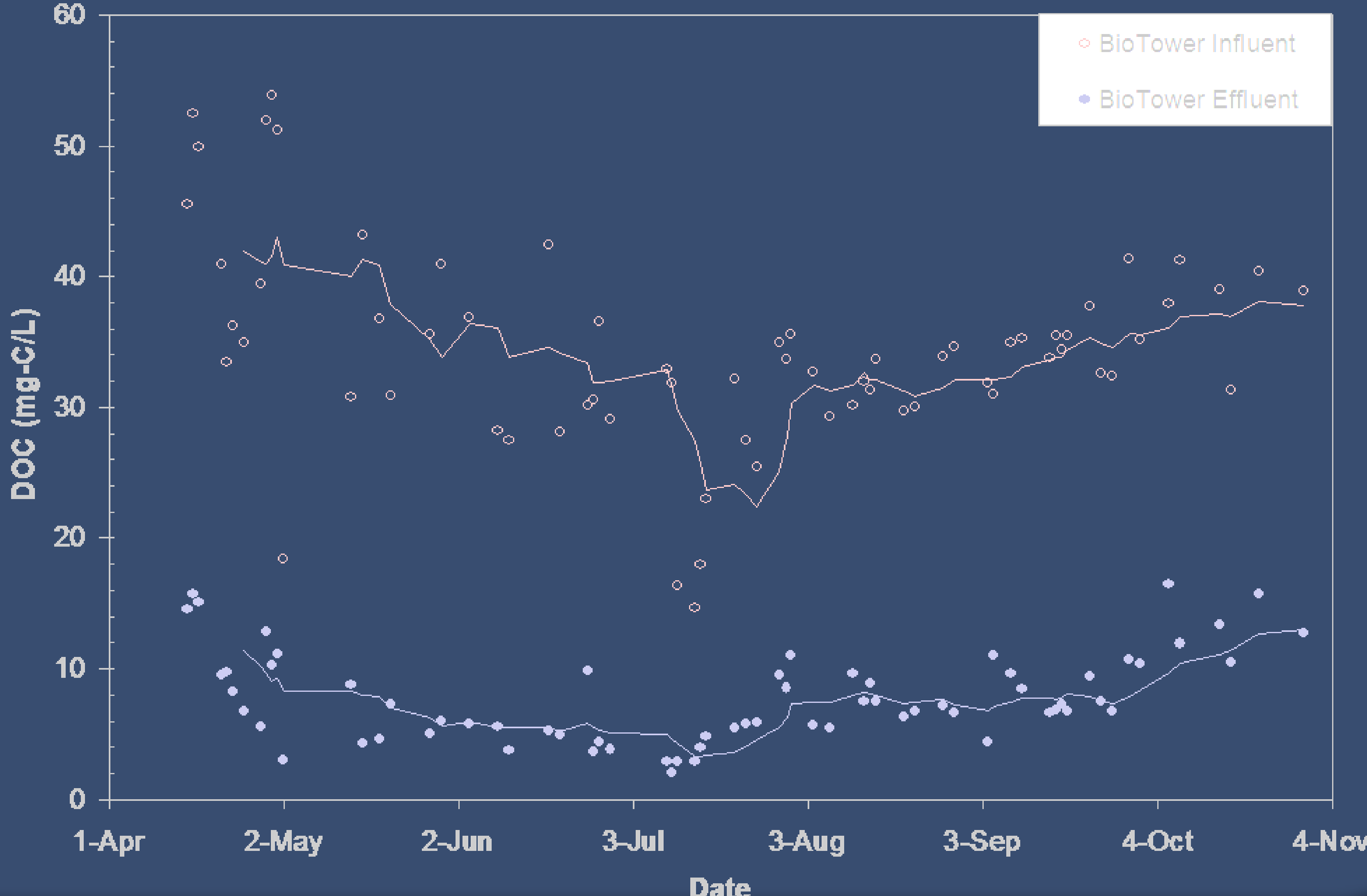
# Wiggins biotower influent and effluent nitrate (lines are 14-day moving averages)



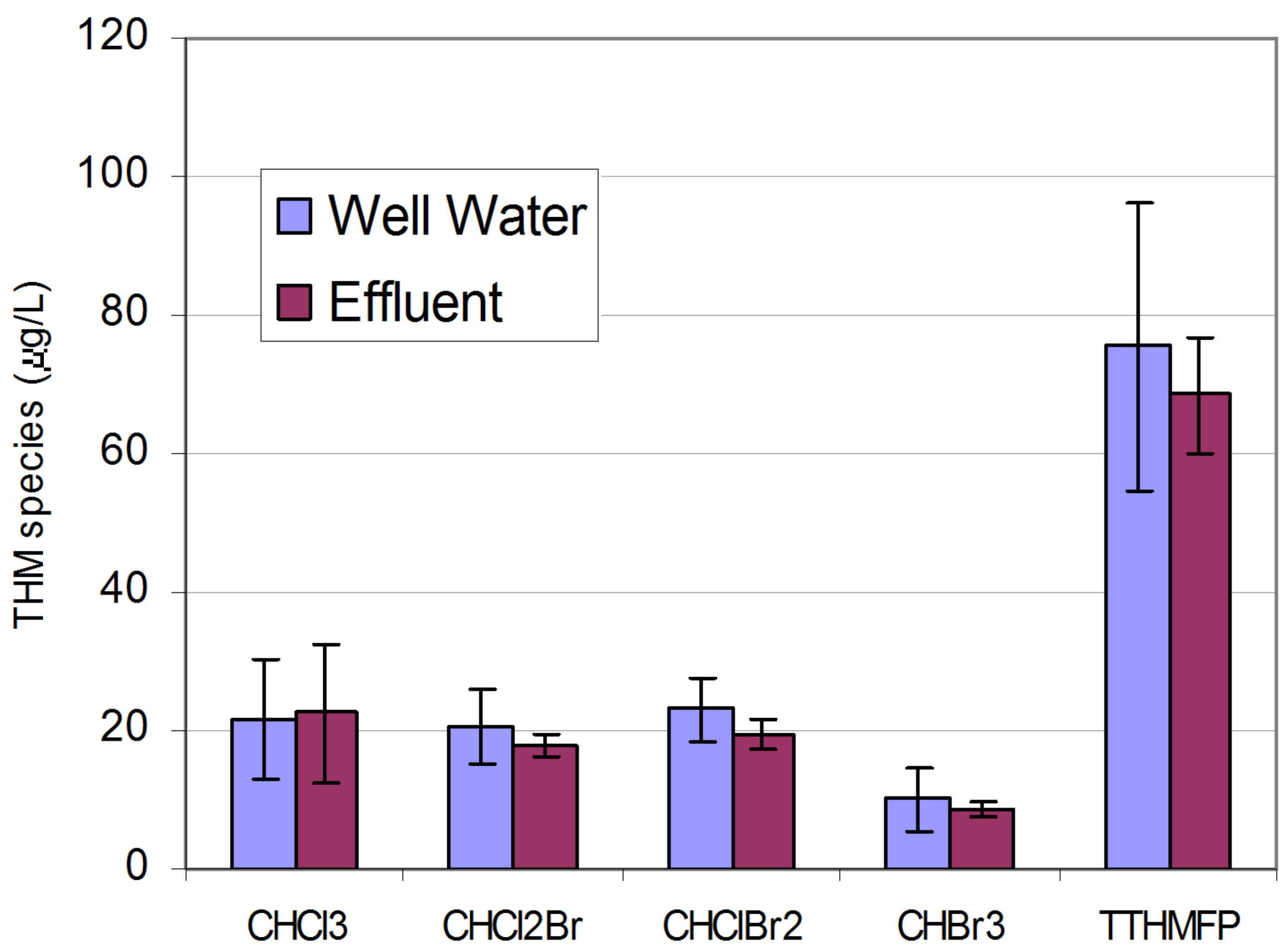
# Biotower Influent and Effluent Dissolved Oxygen at Wiggins Plant (lines are 14-day moving averages)



# Influent (after corn syrup addition) and effluent TOC at Wiggins plant (lines are 14-day moving averages)



# Individual Species and Total Trihalomethane Formation Potential in Wiggins Plant Influent and Effluent

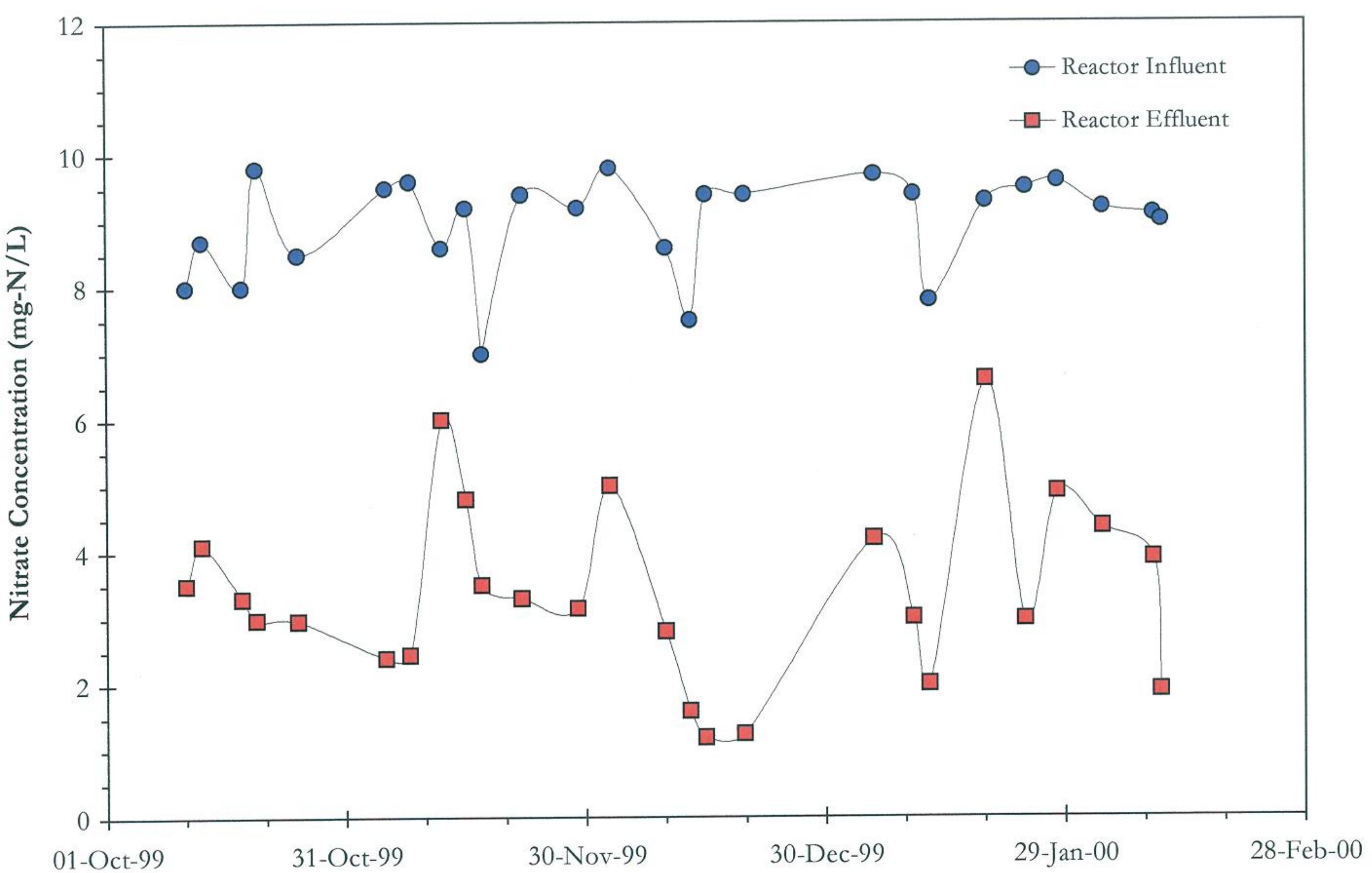


# Summary of Wiggins Demonstration

- Consistent denitrification achieved from average 19.6 to 4.3 mg/L N @ C:N = 1.3:1
- Influent dissolved oxygen 2 – 6 mg/L did not affect performance
- No significant change in DBP precursors
- Significant increase in Cl-demand from 0.6 to 4.5 ppm
- Corn syrup associated with high biomass growth, TOC, clogging, high effluent coliform and HPC bacteria, and $NH_4$ in effluent

# Left: ceramic microfiltration system (BASX Systems). Right: hollow fiber membrane microfiltration system (Pall Corp.) used at Suffolk Demonstration Plant

# Biotower Influent and Effluent Nitrate at Suffolk Plant (acetate carbon addition to achieve 3 mg/L-N in effluent)



# Biotower Comparison

| Parameter | Wiggins | Mt. Sinai |
|---|---|---|
| Carbon source | Corn Syrup | Acetate |
| Nitrate Removal Rate (kg-N/m$^3$-media/d) | 0.34 | 0.40 |
| Effluent Nitrite (mg/L-N) | 1.4 | 0.04 |
| Effluent TOC (mg/L) | 7.7 | 6 |
| Effluent Turbidity (NTU) | 2.52 | 0.9 |
| Effluent Total Coliform (cfu/100 mL) | $5.1 \times 10^6$ | 65 |
| HPC (cfu/100mL) | $6.6 \times 10^7$ | $2.4 \times 10^5$ |

# Suffolk Filter Comparison

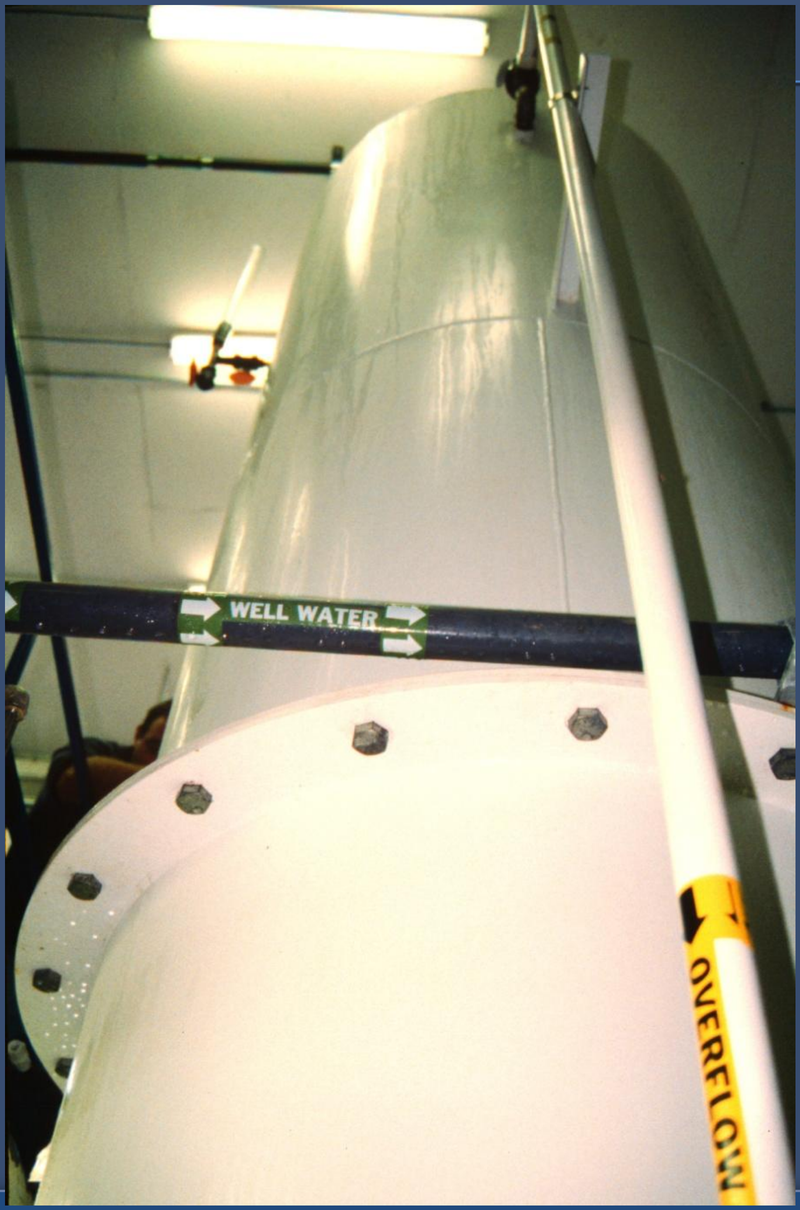
| Parameter | Slow Sand Filter | Ceramic Microfilter | Hollow Fiber Memb. MF |
|---|---|---|---|
| Effluent TOC (mg/L) | 0.4 | 1.5 | 0.4 |
| Effluent Turbidity (NTU) | 0.3 | 0.27 | 0.03 |
| Effluent Total Coliform (cfu/100 mL) | 1 | ND | ND |
| Effluent HPC (cfu/100 mL) | 2,900 | 170 | 1 |
| Chlorine Demand (mg/L) | 0.55 | 0 | 0 |

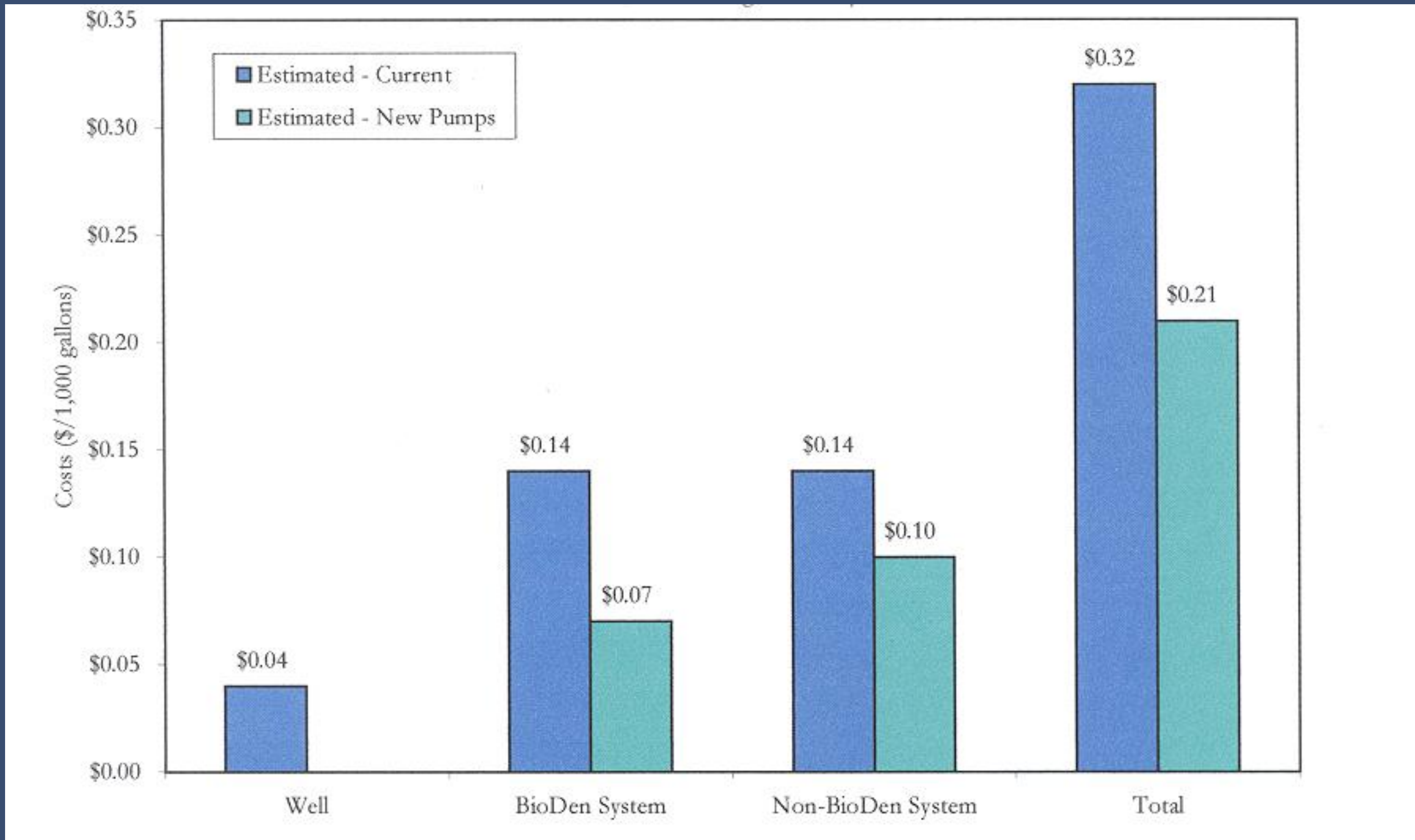
# Suffolk Study Summary

- Use of acetate as carbon source reduces biotower effluent bacteria, turbidity and nitrite.
- Microfiltration produces bacteria-free low turbidity product water
- 90% of DOC was removed in SSF and hollow fiber MF
- Residuals from MF = 3% of product water
- Chlorine injection to prevent fouling may account for rise in THMFP after MF treatment

# Coyle, Oklahoma Drinking Water Denitrification Plant

# Town of Coyle, Oklahoma
# Drinking Water Treatment Plant



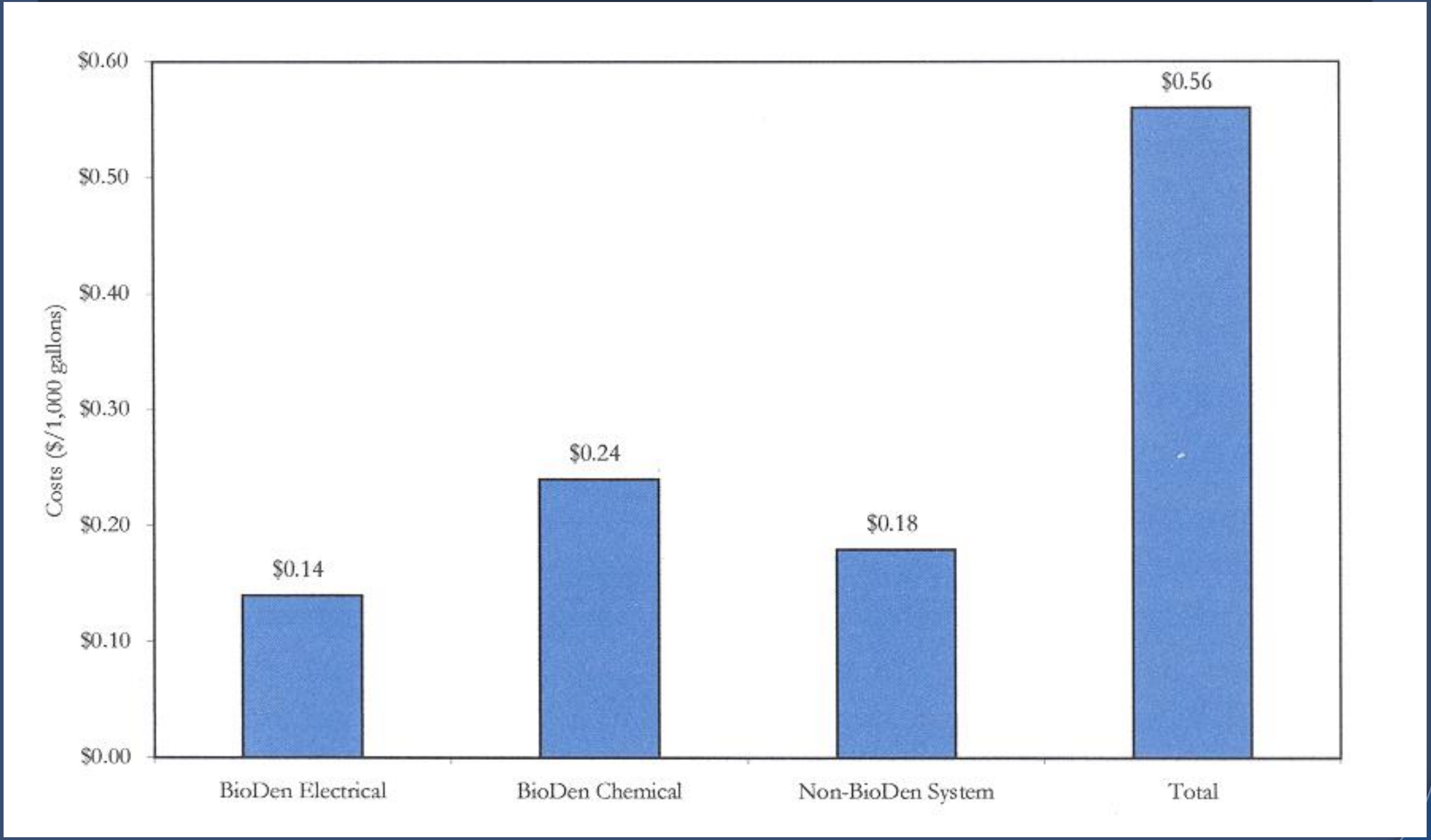

# Power Cost at Coyle Denitrification Plant

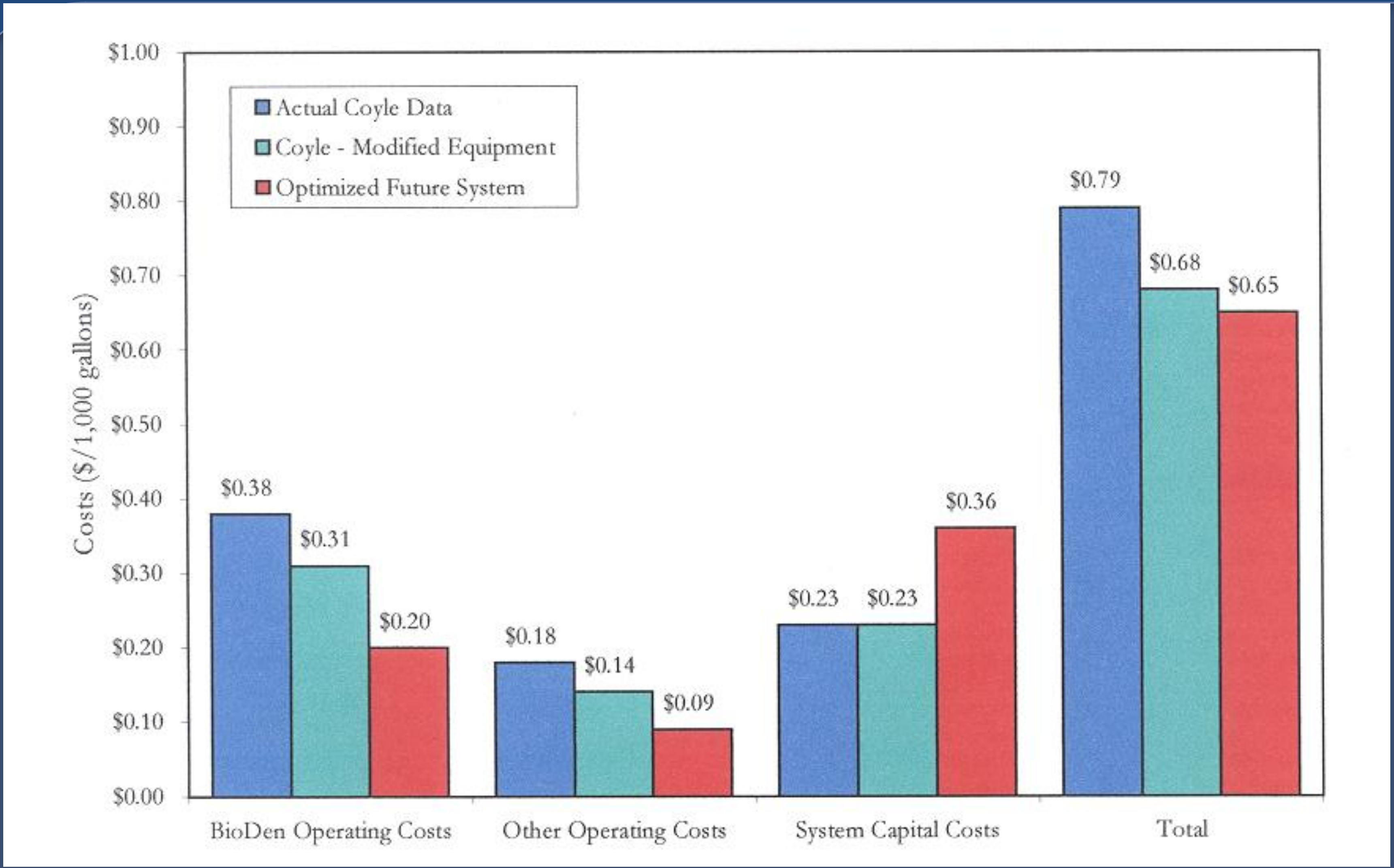
Unit electric power cost: $0.0532/kwh

# Chemical Costs

| Chemical | Before Blending (/1,000 gallons) | After Blending (/1,000 gallons) |
|---|---|---|
| Vinegar (acetate) | $0.36 | $0.18 |
| Phosphate | $0.10 | $0.05 |
| Other (analytical) | $0.02 | $0.01 |
| Total | $0.48 | $0.24 |

# Total Operating Costs at Coyle Plant






# TOTAL COSTS

Usage: 15 million gallons per year (28 gpm)
Coyle plant: $130,000 capital (67% grant), 20 years, 5%
Future system: $130,000 capital, no grant, 20 years, 5%

# Cost Study Summary

- Total unit cost (capital, O & M) for drinking water treatment (including well pumping) was $0.79/1,000 gallons (with 67% capital financing grant from State of Oklahoma)
- Chemical costs are approximately 30% of total. Carbon (vinegar) is 75% of chemical cost.
- Power costs are approximately 40% of treatment total
- Estimated unit cost with future system of equal capacity assuming pump replacement and plant configuration changes, and <u>no grants</u> is $0.65/1,000 gallons

# Acknowledgements

Nitrate Removal Technologies (NRT)
National Water Research Institute
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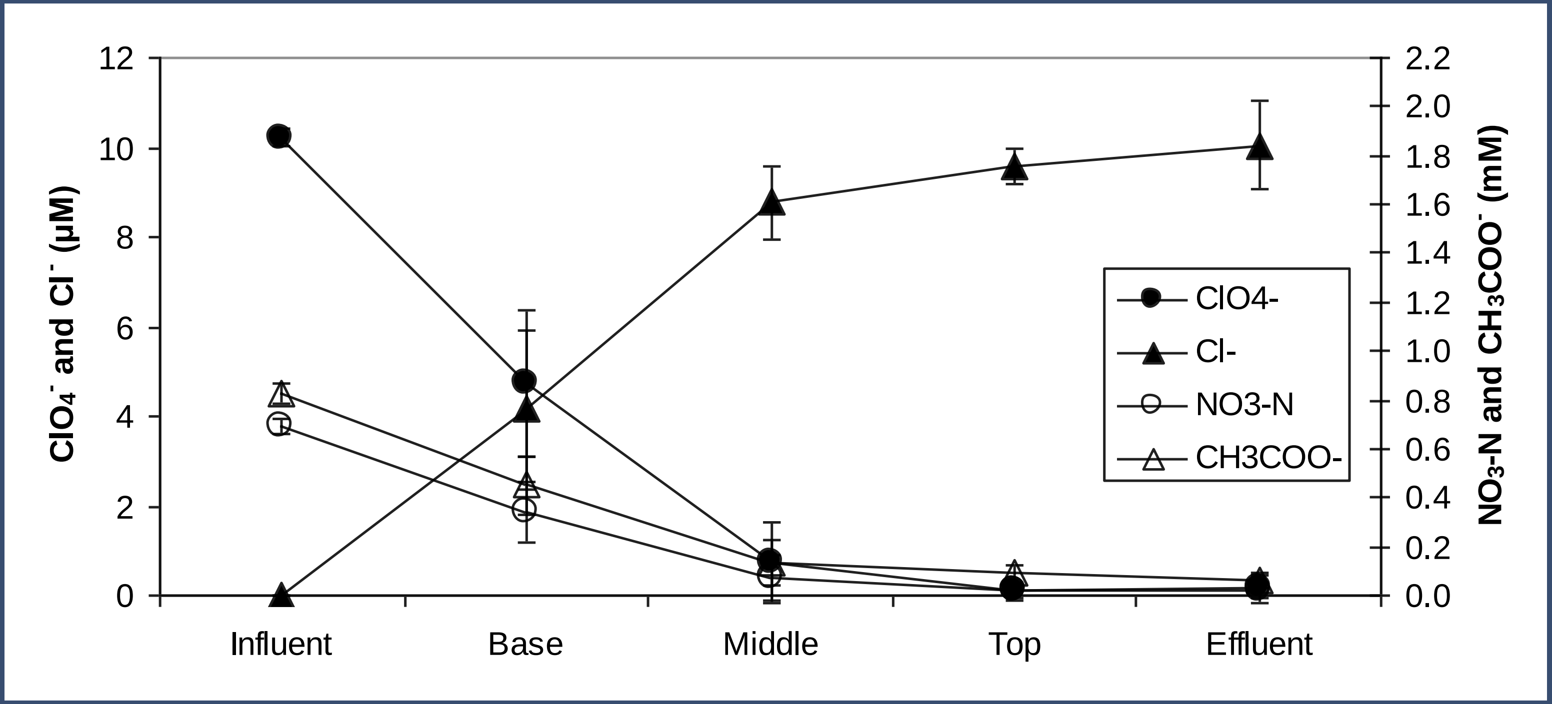
Colorado Dept. Local Affairs
Town of Brighton, CO, Town of Wiggins, CO
Suffolk County Water Authority (SCWA), Town of Mt. Sinai, New York , Town of Coyle, OK
BASX
Pall Corp.
Colorado Dept. Public Health & Environment
Oklahoma Dept. Environmental Quality

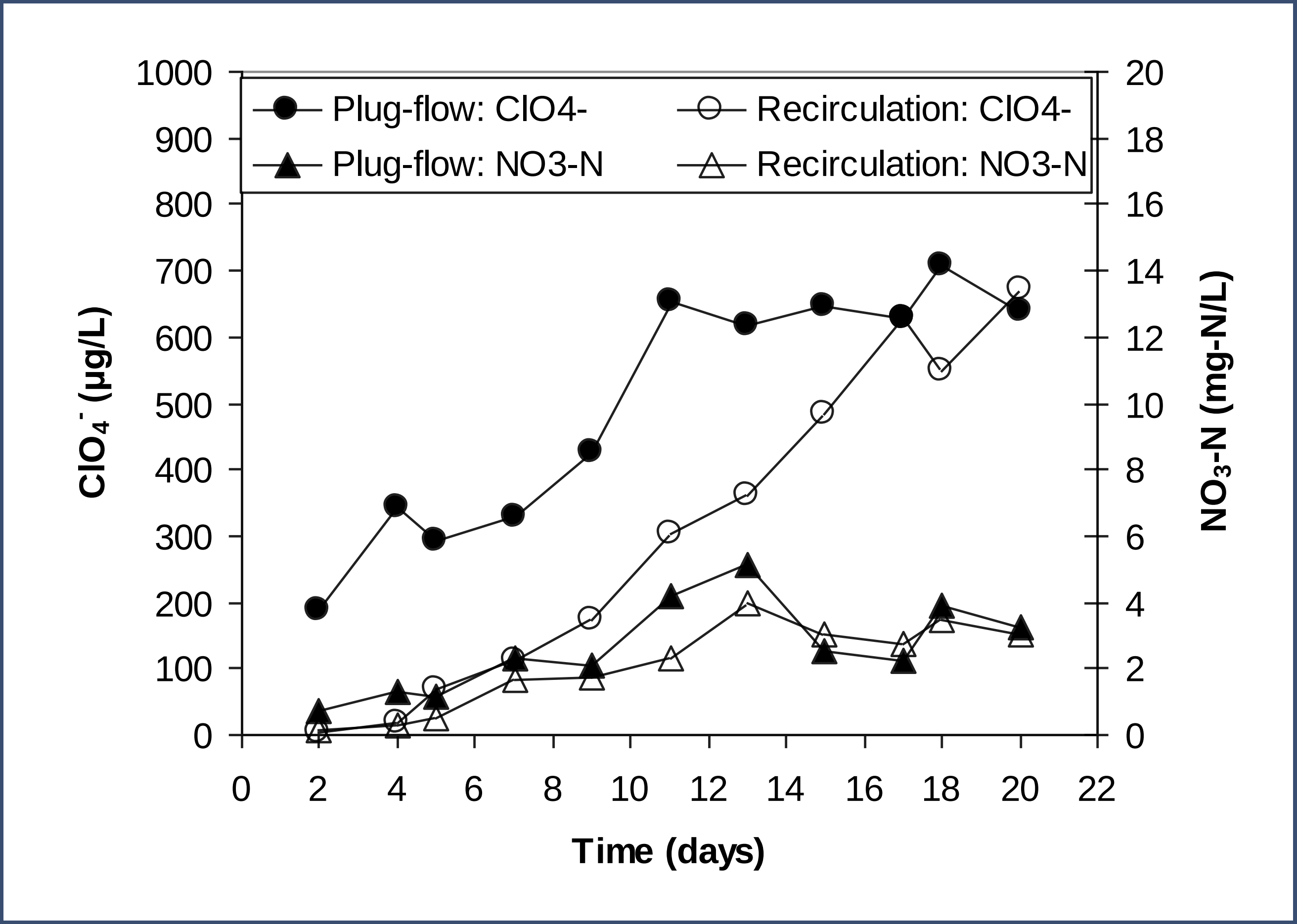
# Biological reduction of mixed nitrate and perchlorate influent in biofilm reactor

# Biofilm reactor profiles. C:(N+$ClO_4$) = 1.8:1



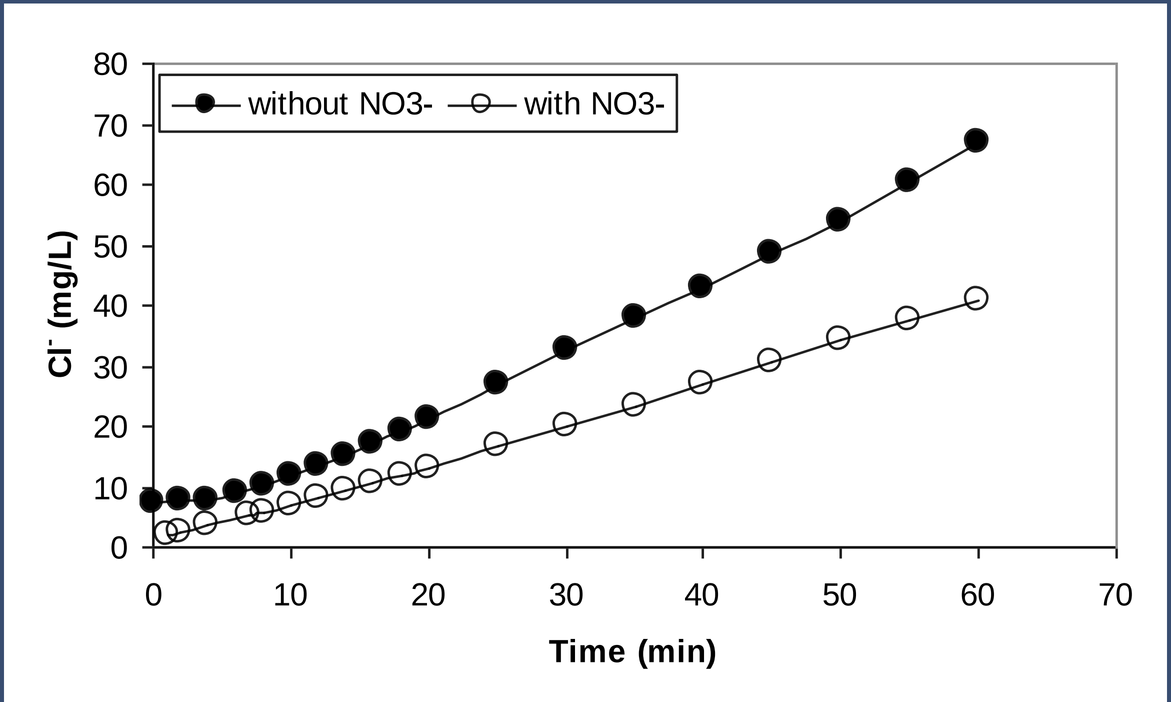

$ClO_4^-$, $NO_3^-$, $CH_3COO^-$, and $Cl^-$ concentration profiles in the biofilm reactor receiving 10 mg.$L^{-1}$ $NO_3$-N and 1,000 µg.$L^{-1}$ $ClO_4^-$, and 42 mg.$L^{-1}$ $CH_3COO^-$.

# Biofilm reactor effluent. C:(N+$ClO_4$) = 1.2:1




Influent contained 1,000 µg.$L^{-1}$ $ClO_4$, 16 mg.$L^{-1}$ $NO_3$-N and 52 mg.$L^{-1}$ acetate.

# Effect of nitrate on chloride evolution in suspended cultures with excess acetate




Effect of 2 mM (28 mg/L) nitrate-N on reduction of 2 mM (200 mg/L) perchlorate in flasks inoculated with perchlorate-reducing culture, average MLSS in flasks was 5 g.L$^{-1}$. 16.7 mM acetate was added to both flasks. C:($ClO_4$+N)>1.8

# Biofilm reduction of mixed perchlorate-nitrate influent

- Perchlorate and nitrate are reduced simultaneously along bioreactor flow path when sufficient acetate added $C:(ClO_4+N)>1.8$.
- Low substrate conditions $C:(ClO_4+N)<1.2$ decreases perchlorate reduction more than denitrification
- Perchlorate-reducing cultures reduced nitrate without acclimation
- Nitrate competed with perchlorate for substrate electrons even when mass ratio of $ClO_4:N = 7$ g/g