

# ELEMENTAL SULFUR ( $S^0$ ) AS A SUPPLEMENTAL ELECTRON DONOR FOR WASTEWATER DENITRIFICATION

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IWEA  
Nov. 18, 2010

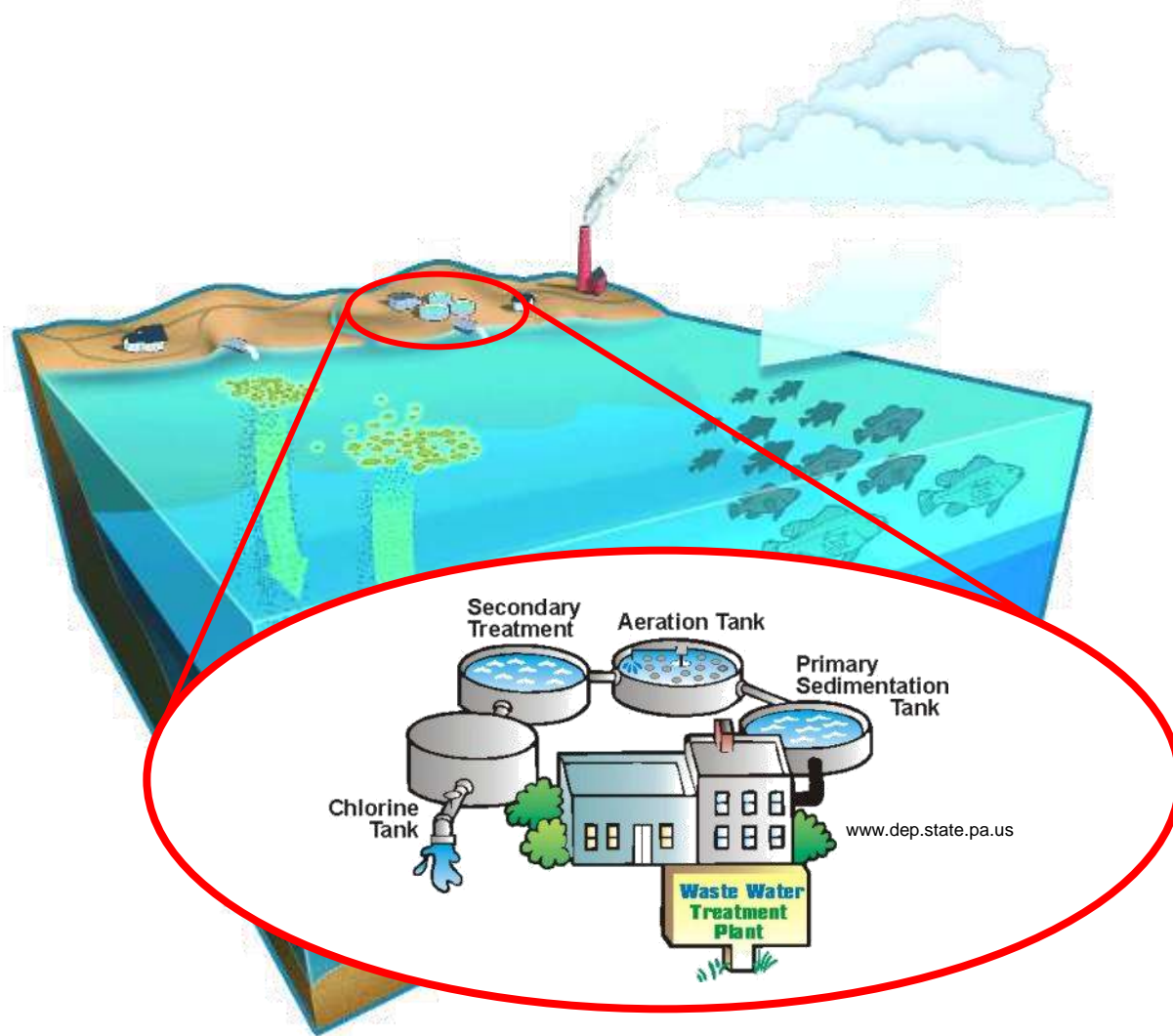
# Overview

- Introduction
- Objectives
- Methods
- Results
- Conclusions

# Introduction

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# Nutrients in the Environment



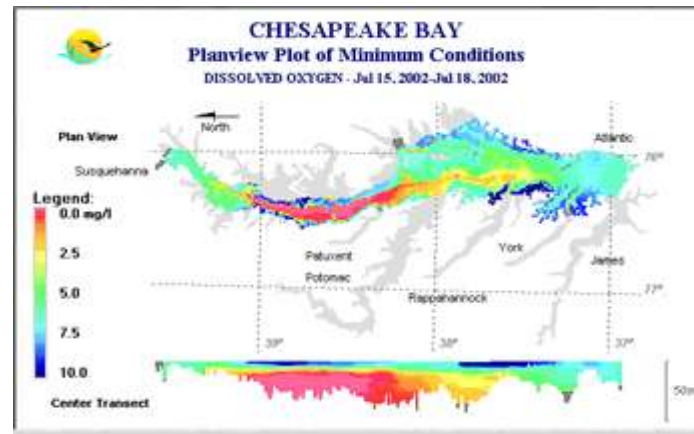
# Examples

## Long Island Sound



[http://www.longislandsoundstudy.net/pubs/reports/sh03\\_p1.pdf](http://www.longislandsoundstudy.net/pubs/reports/sh03_p1.pdf)

## Chesapeake Bay



[http://www.cbf.org/site/PageServer?pagenam=resources\\_facts\\_deadzone](http://www.cbf.org/site/PageServer?pagenam=resources_facts_deadzone)

## Gulf of Mexico

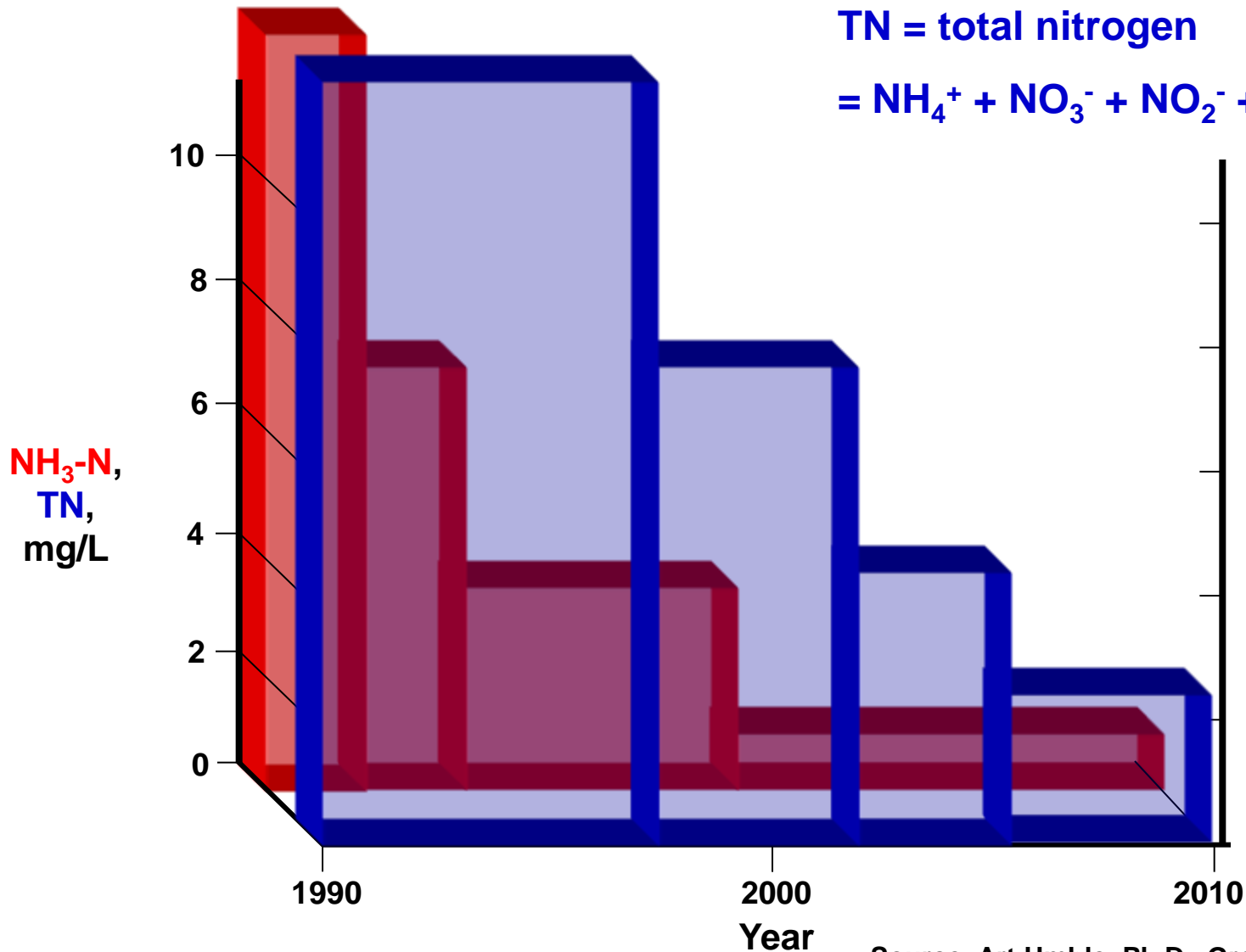


<http://www.ncat.org/nutrients/hypoxia/hypoxia.html>

# Nitrogen Standards for Wastewater

TN = total nitrogen

=  $\text{NH}_4^+$  +  $\text{NO}_3^-$  +  $\text{NO}_2^-$  + org N

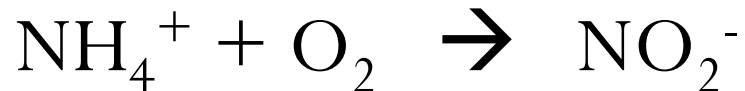


Source: Art Umble, Ph.D., Greeley and Hansen

# Biological Nitrogen Removal

## 1) Nitrification

- Ammonia oxidizing bacteria (AOB)  
(*Nitrosomonas*)



- Nitrite oxidizing bacteria (NOB)  
(*Nitrobacter*, *Nitrospira*)

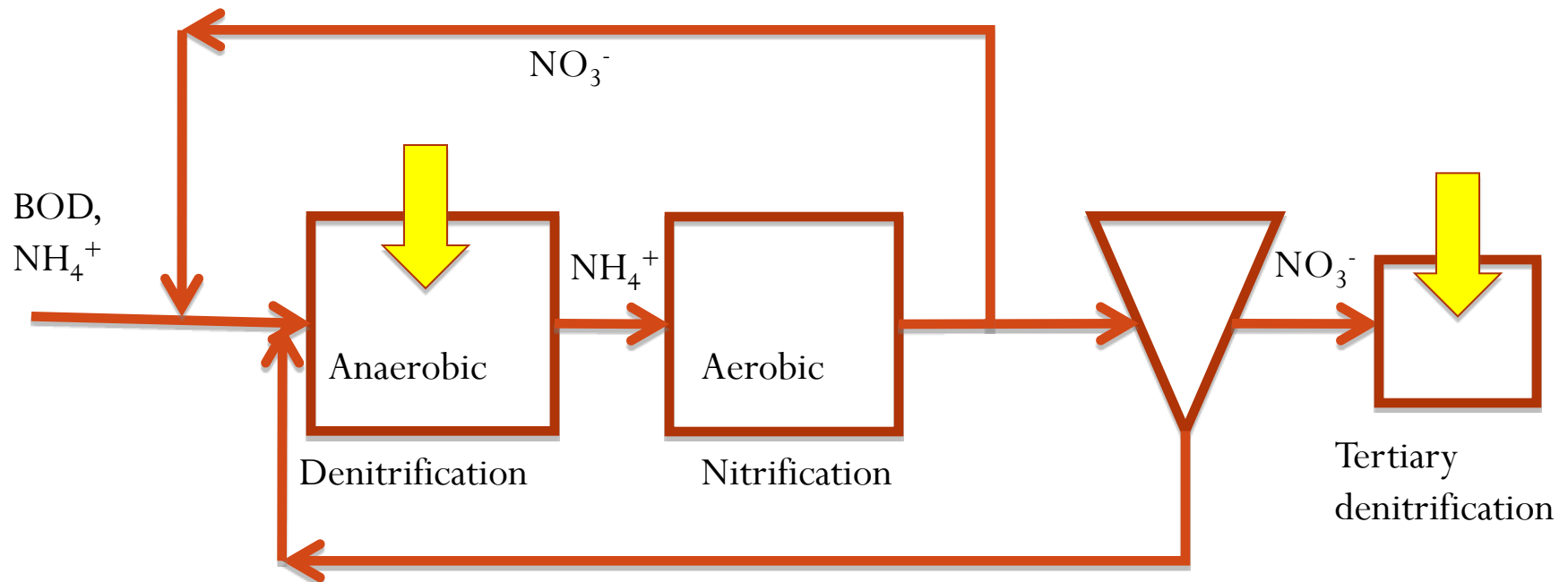


# Biological Nitrogen Removal

2) Denitrification - Heterotrophic denitrifying bacteria (DB)



# Nitrogen Removal in Wastewater Treatment



MLE Process

# Heterotrophic and Autotrophic Denitrification

- **Heterotrophic denitrification (organic donor)**
  - Methanol, ethanol, acetate, sucrose, primary fermentate
  - **Proprietary: MicroC, UnicarbDN**
    - Efficient
    - Expensive
    - More sludge produced
- **Autotrophic denitrification (inorganic donor)**
  - **Hydrogen (MBfR, APTwater, Inc.)**
    - No need for external organic carbon source
    - Less sludge produced

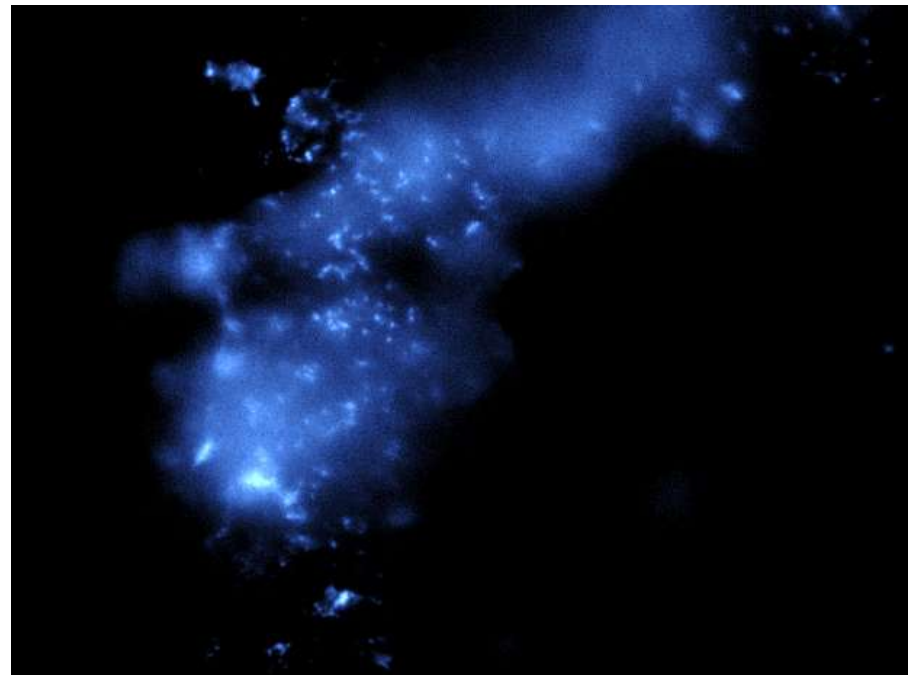
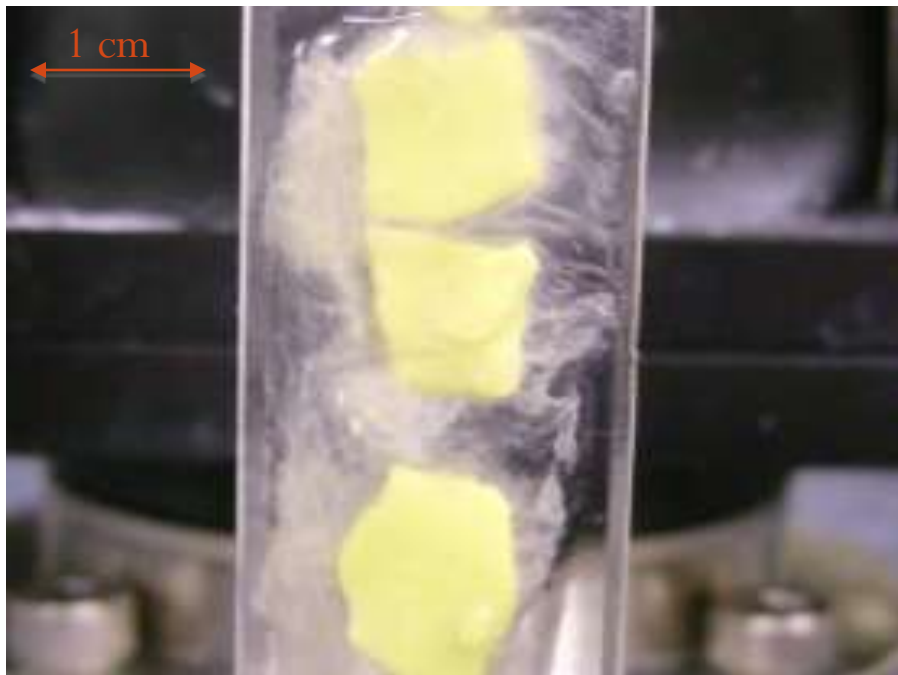
# Elemental sulfur ( $S^0$ ) as donor?



# Elemental sulfur

## Biofilm process

Film of bacteria growing on  $S^0$  particle



# Elemental sulfur

- **Advantages**

- Lower cost
- Non-toxic, easy handling
- Lower biomass yields
- Cannot overdose, no donor residual left in water

- **Potential Disadvantages**

- Need for specialized  $S^0$ -oxidizing bacteria
- Slow growth rates, longer startup time
- Consumes alkalinity
- Sulfate formation

# Objectives

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# Objectives

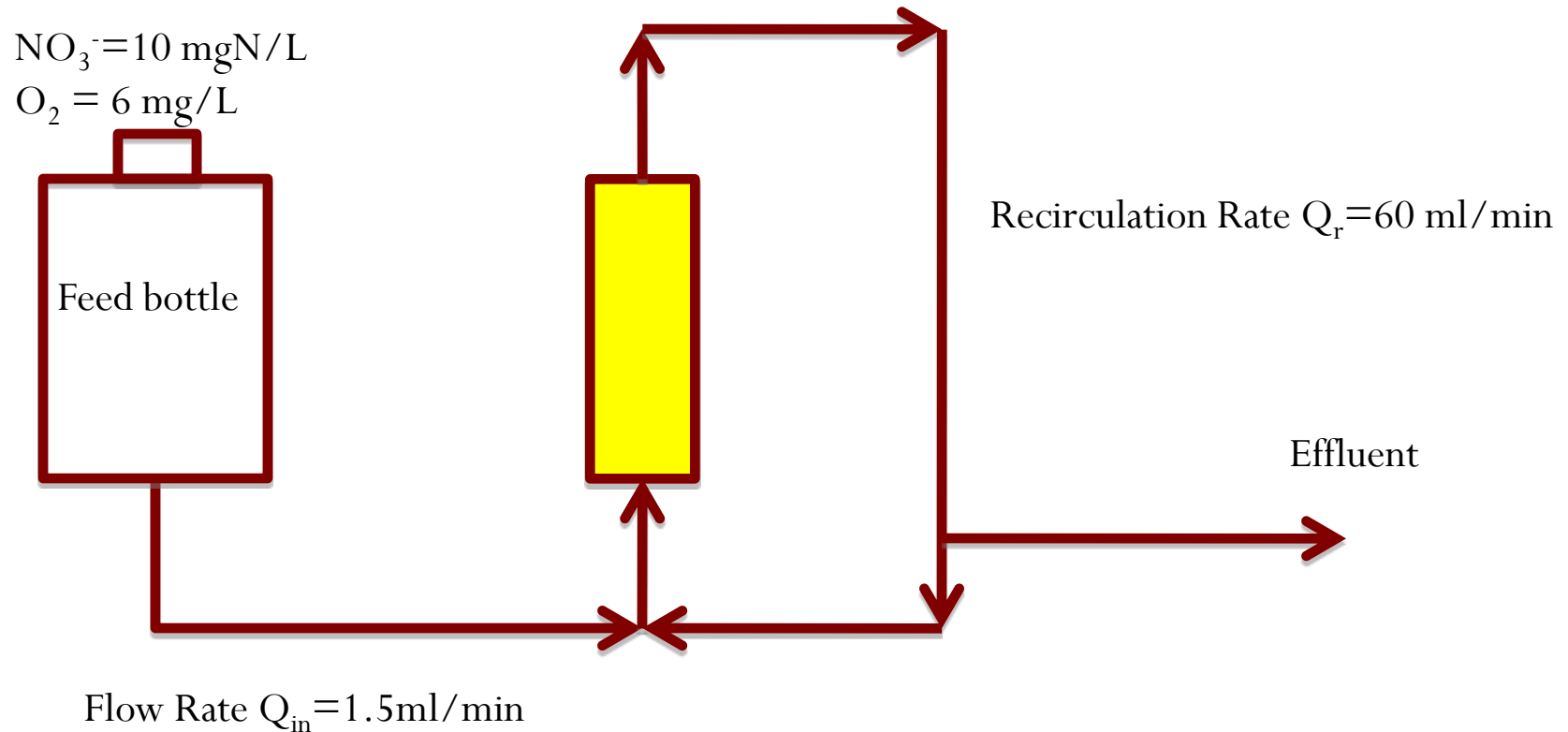
Determine:

- 1.Startup time
- 2.Effects of long-term operation
- 3.Effects of backwashing
- 4.Denitrification fluxes
- 5.Costs

# Methods

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# Reactor setup – upflow fixed bed



# Two reactors run concurrently



# Reactor Characteristics

	Reactor 1	Reactor 2
Sulfur source	Industrial grade, 99.5% purity	Agricultural grade, 90% purity
Sulfur mass in reactor (g)	40g	48.5g
Sulfur specific gravity	2	2
Sulfur area (m <sup>2</sup> )	0.054	0.065
Specific surface area (m <sup>2</sup> /m <sup>3</sup> )	947	1017
Baseline flow (mL/min)	1.5	1.5
HRT (min)	48	79
Recirculation ratio (Q <sub>r</sub> /Q <sub>in</sub> )	40	40

# Measurements

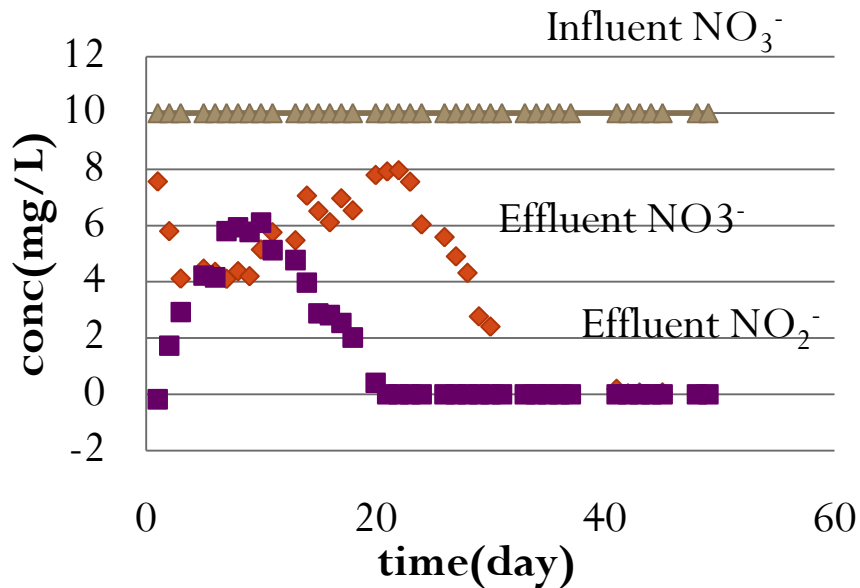
- Monitor
  - DO
  - Nitrate
  - Nitrite
  - Sulfate
  - pH
- Use flowrate to adjust nitrate loading
- Use short-term tests to assess flux vs. nitrate concentration

# Results

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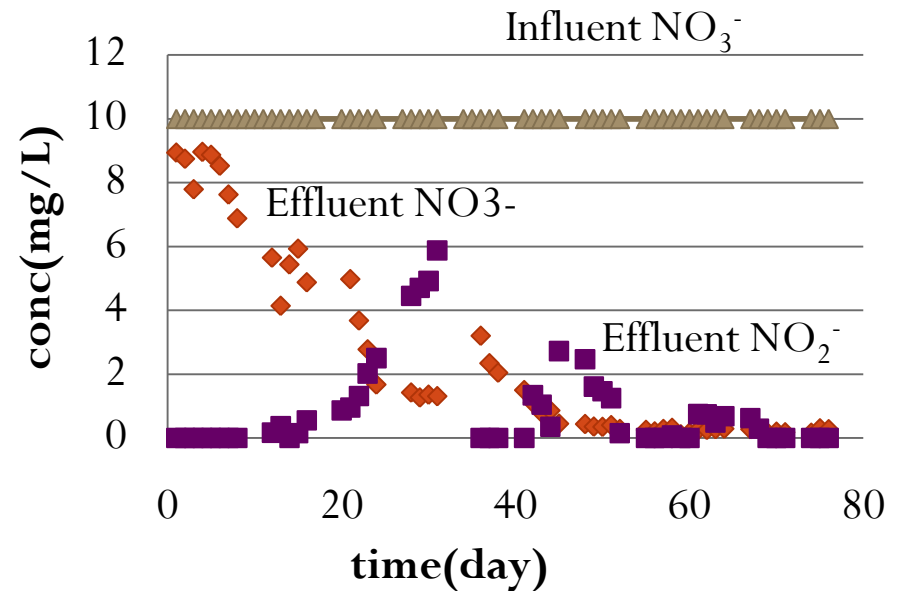
# 1. Startup time

## Reactor 1



33 days for full startup

## Reactor 2



40 days for full startup

## 2. Effects of long-term operation – Reactor 1

New Sulfur



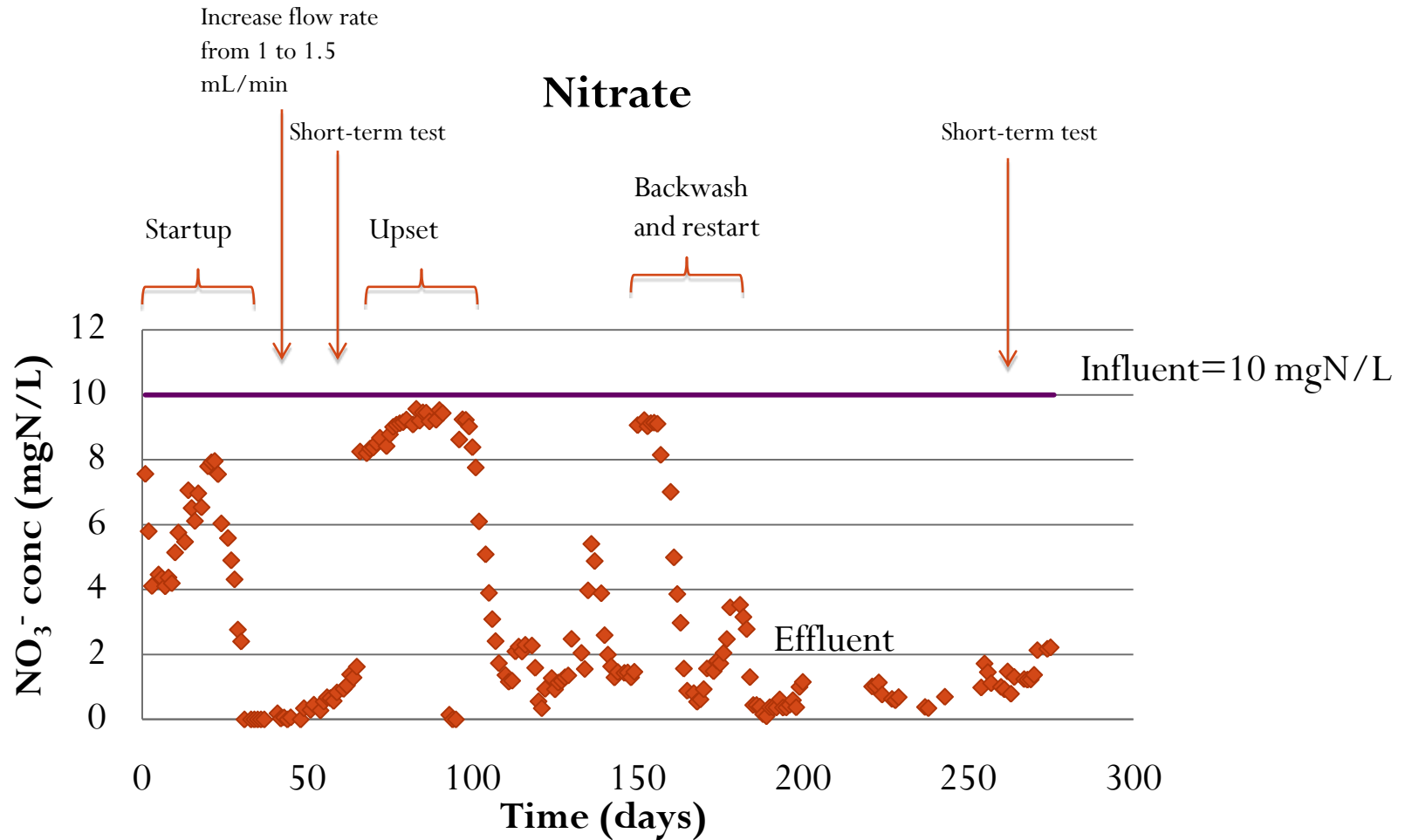
40 days



100+ days



# Results – Reactor 1



# 3. Effects of Backwashing – Reactor 1

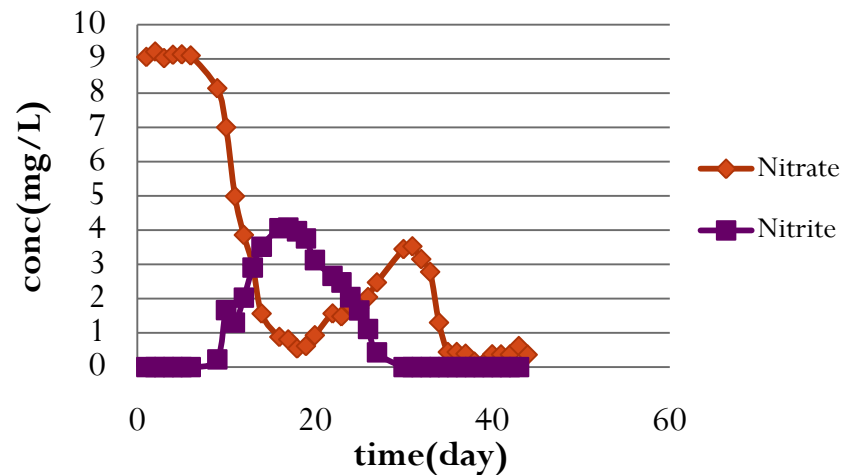
Before Backwashing



After Backwashing



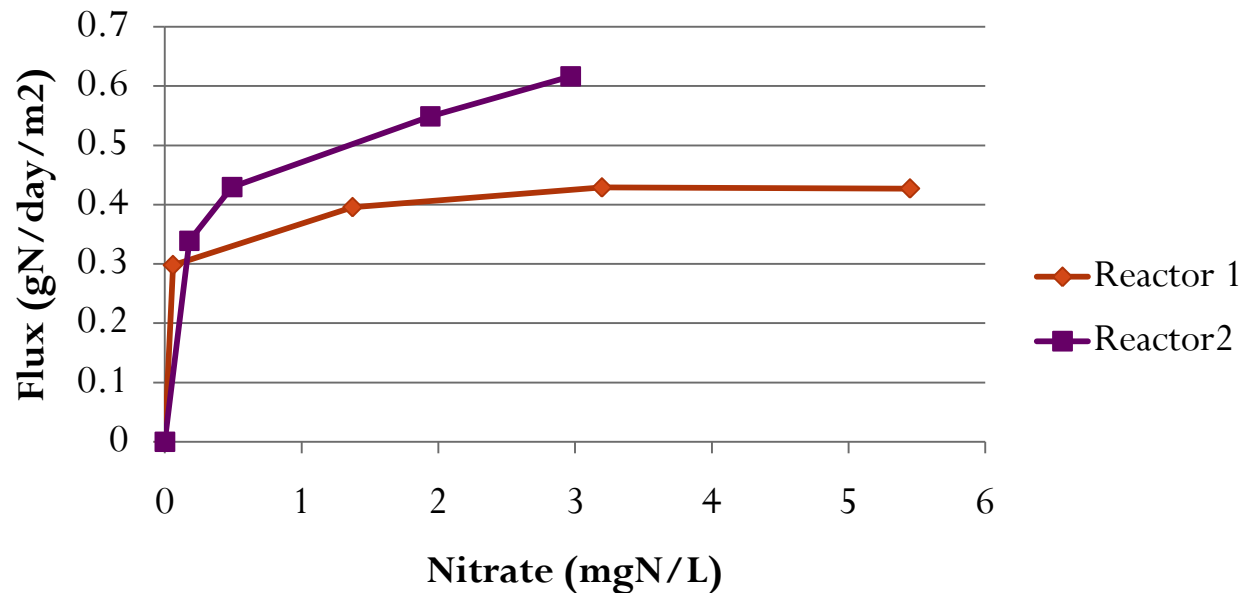
After Backwash



Recovery time = 33 days,  
 Similar to startup

# 4. Denitrification Fluxes

Fluxes as a function of nitrate concentration



Apparent half-saturation constant  $K_{app} < 0.2$  mgN/L

# 5. Costs

## Elemental Sulfur

Unit cost: \$220/metric ton.

Based on a stoichiometry<sup>1</sup> of 2.5 gS/gNO<sub>3</sub><sup>-</sup> N, cost is:

**\$0.6/kg NO<sub>3</sub>-N**

## Methanol

Unit cost: \$1.1/gal

Based on stoichiometry<sup>2</sup> of 3.2 gMeOH/gNO<sub>3</sub>-N:

**\$1.2/kg NO<sub>3</sub>-N**

Sulfur may have a significant cost advantage over methanol.

<sup>1</sup>Batchelor and Lawrence (1976)

<sup>2</sup>Metcalf & Eddy

# Conclusions

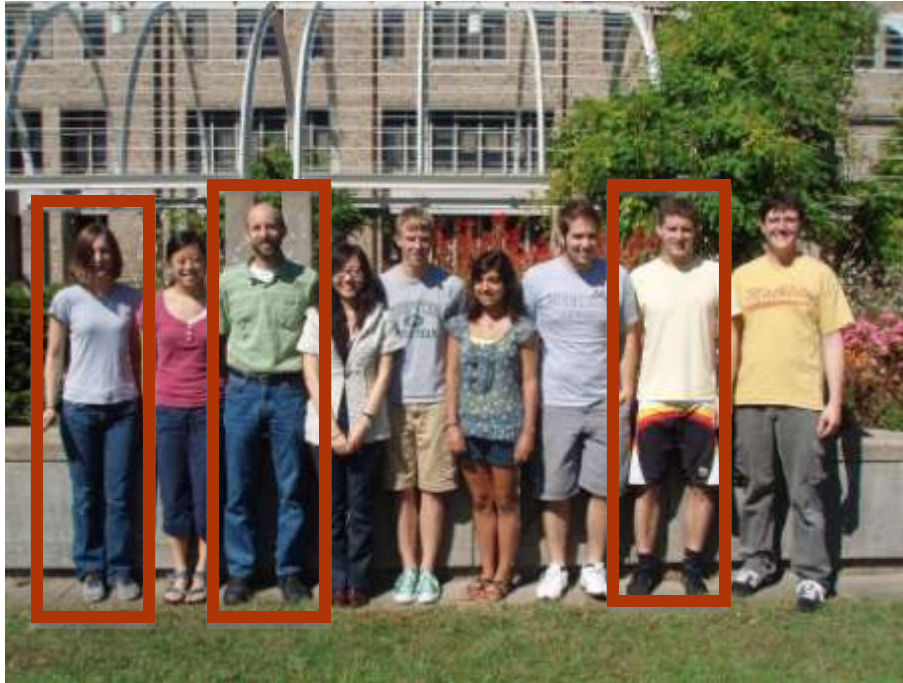
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# Conclusions

- Startup time: 30 – 40 days
- Fluxes: 0.4 - 0.6 gN/day/m<sup>2</sup>
- Backwashing: Need to optimize
- Appears cost-competitive
- Future work:
  - Biofilm formation/detachment, effects on flux
  - Effects of BOD on microbial community
  - S<sup>o</sup> particle size, shape, and crystal structure
  - Upsets

# Acknowledgments

- Nerenberg research group



- Funding: Hampton Roads Sanitation District