Total Nitrogen Removal in the Hybrid Membrane-Biofilm Process

Robert Nerenberg
Department of Civil Engineering and Geosciences
University of Notre Dame

Metropolitan Water Reclamation District of Greater Chicago
August 22, 2008

Acknowledgements

Leon Downing

Kyle Bibby

- <u>Collaborators</u>: K. Esposito, B. Bodniewicz, T. Fascianella (*Metcalf & Eddy*)

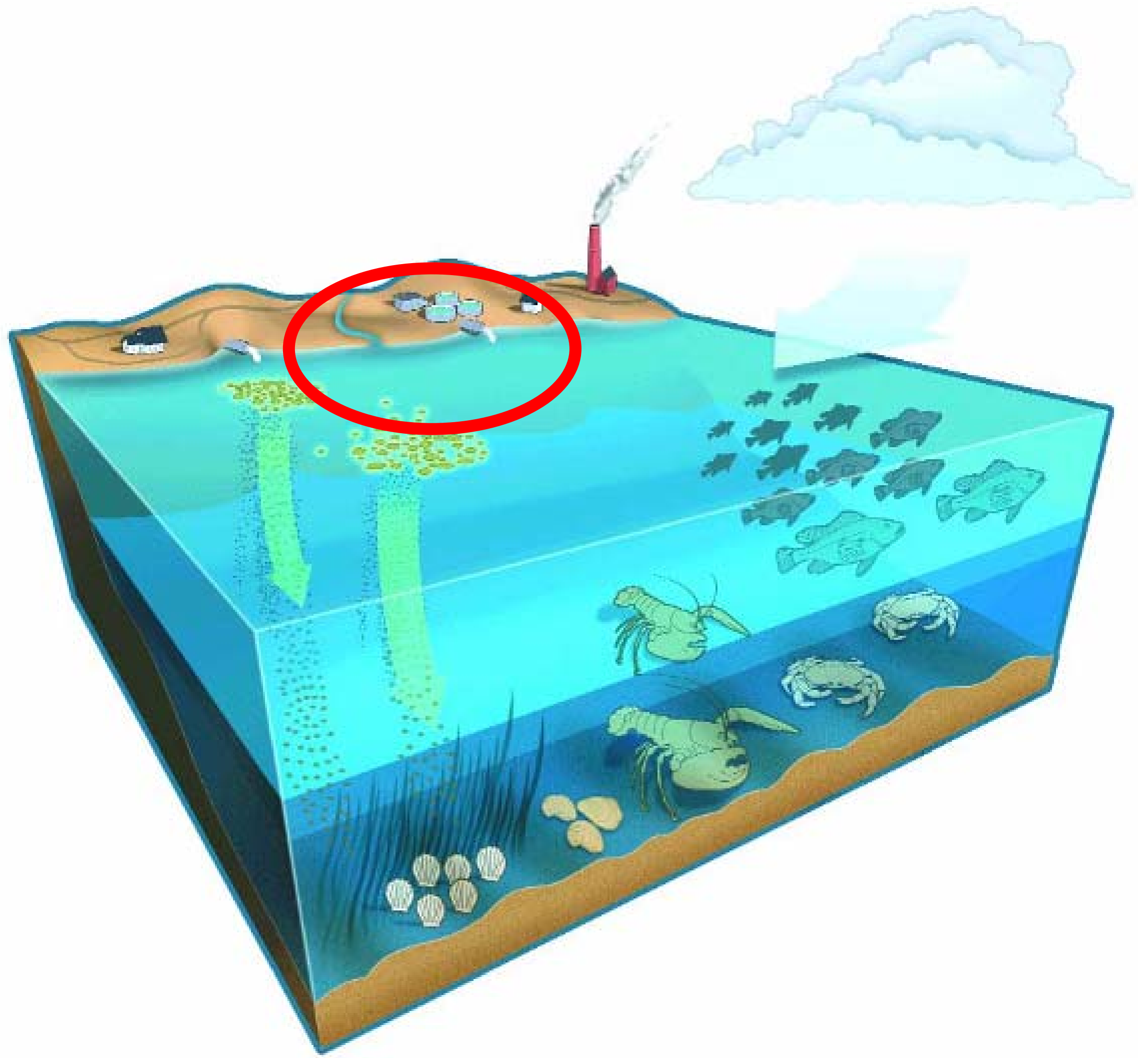
- **<u>Funding</u>:**

CICEET

NSF

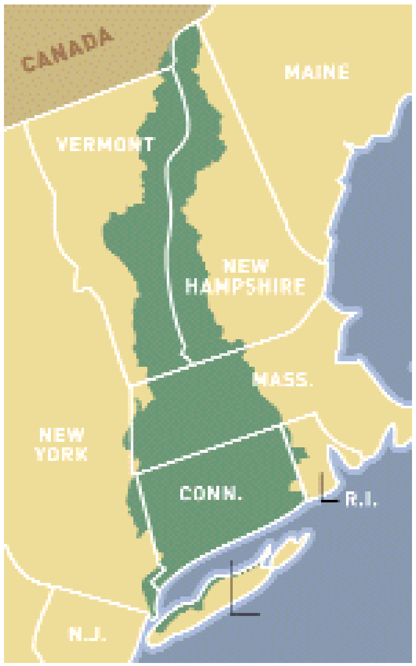
Introduction

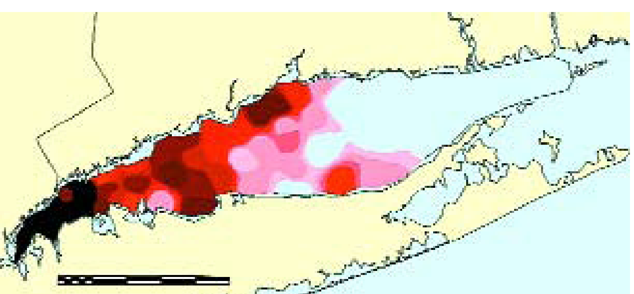
Problem: eutrophication



“Classic” Eutrophication Examples

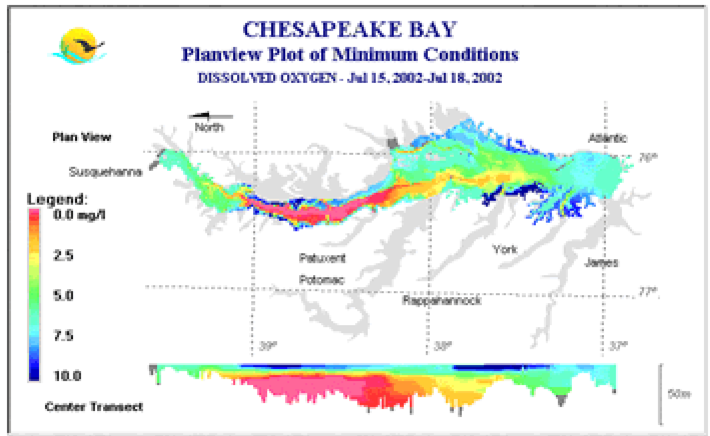
Long Island Sound

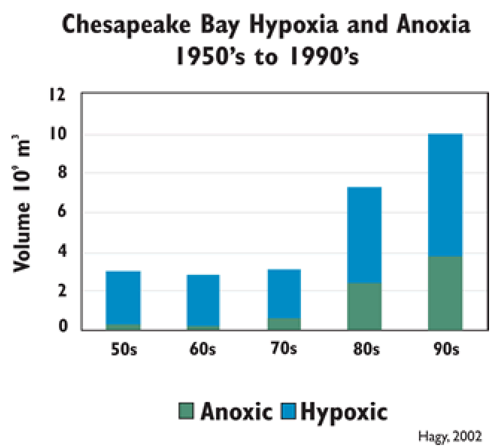




http://www.longislandsoundstudy.net/pubs/reports/sh03_p1.pdf

Chesapeake Bay





http://www.cbf.org/site/PageServer?pagename=resources_facts_deadzone

Gulf of Mexico

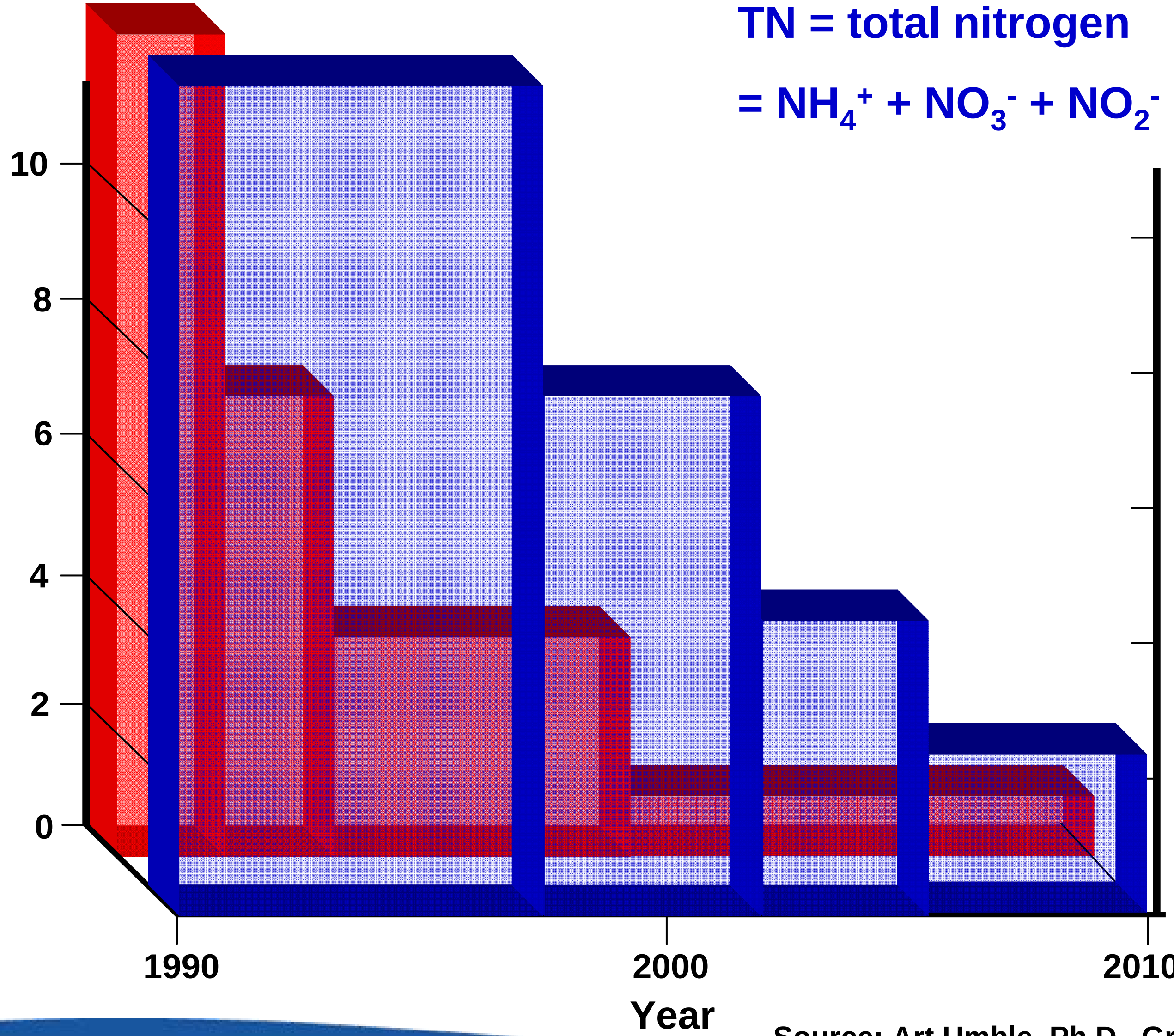
http://www.ncat.org/nutrients/hypoxia/hypoxia.html

The Dead Zone reached a recorded high of 7,728 square miles in 1999.

Nitrogen Standards for Wastewater

TN = total nitrogen

= $NH_4^+ + NO_3^- + NO_2^-$ + org N



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

Biological Nitrogen Removal

1) Nitrification

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

$NH_4^+ + O_2 \rightarrow NO_2^-$

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

$NO_2^- + O_2 \rightarrow NO_3^-$

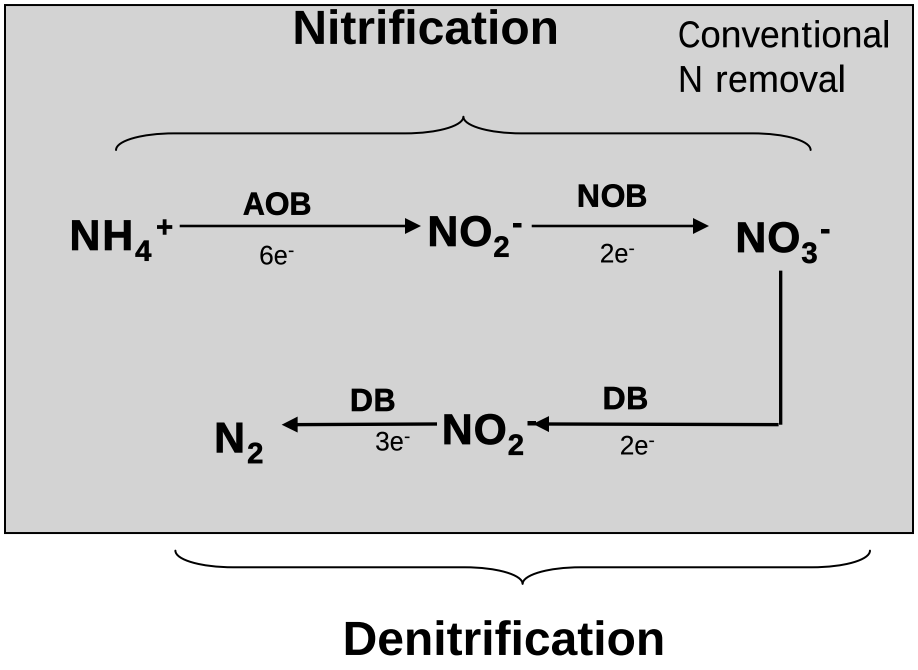
Biological Nitrogen Removal

2) Denitrification

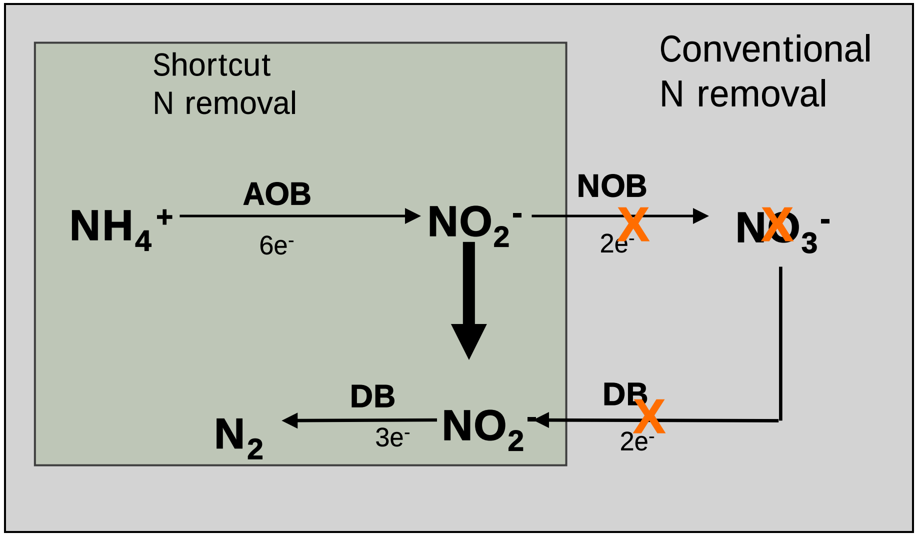
- Heterotrophic denitrifying bacteria (DB)

$$BOD + NO_3^- \ (NO_2^-) \rightarrow N_2$$

Biological Nitrogen Removal

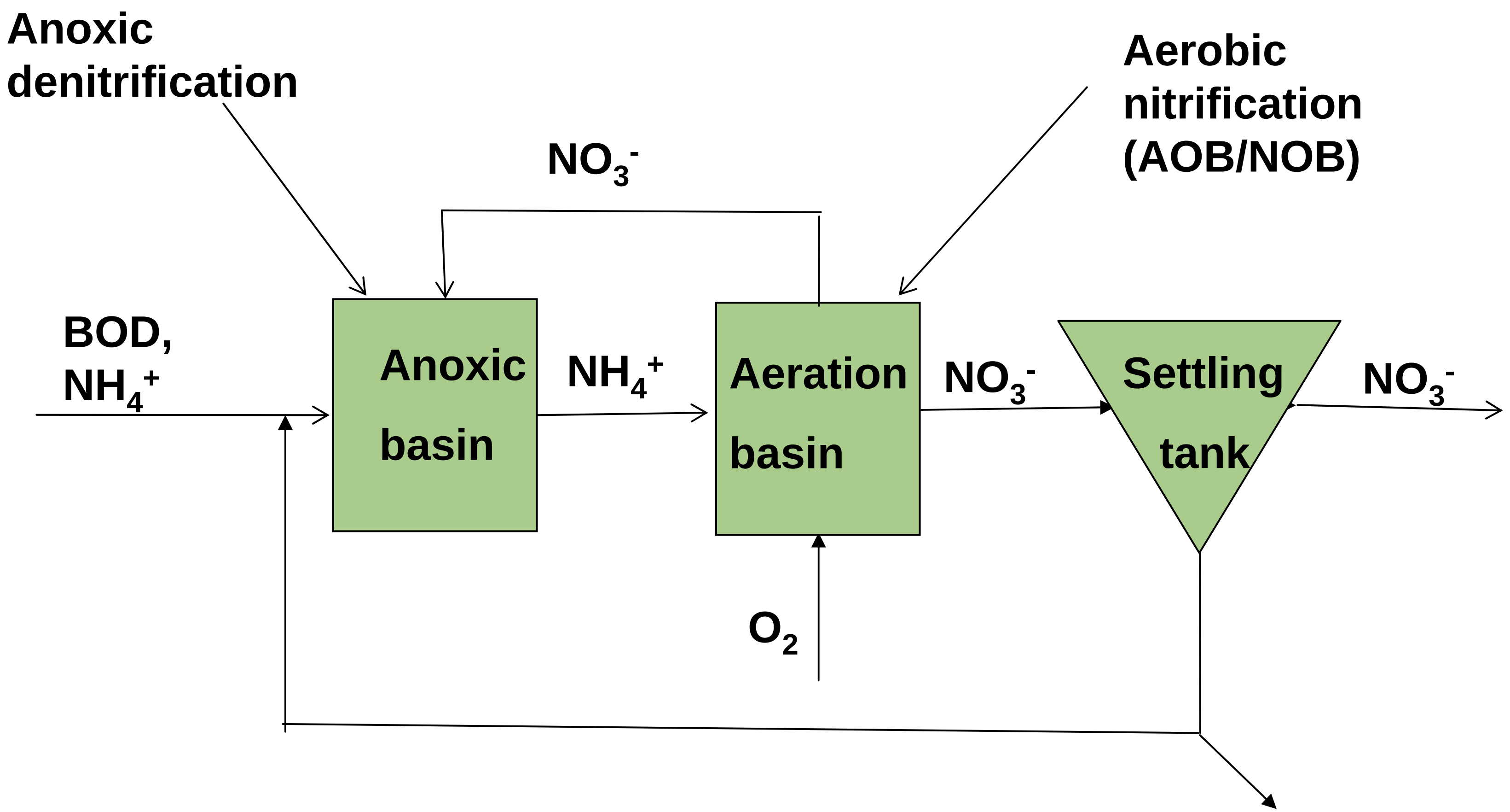


Shortcut Nitrogen Removal



- 25% reduction in oxygen
- 40% reduction in BOD
- Low DO favors AOB over NOB

Wastewater Treatment



Need high SRT!

Many older plants cannot achieve nitrification

- Short SRTs
- Landlocked

Upgrades:
- Space
- Capital costs
- Energy

Biofilms can retain nitrifiers

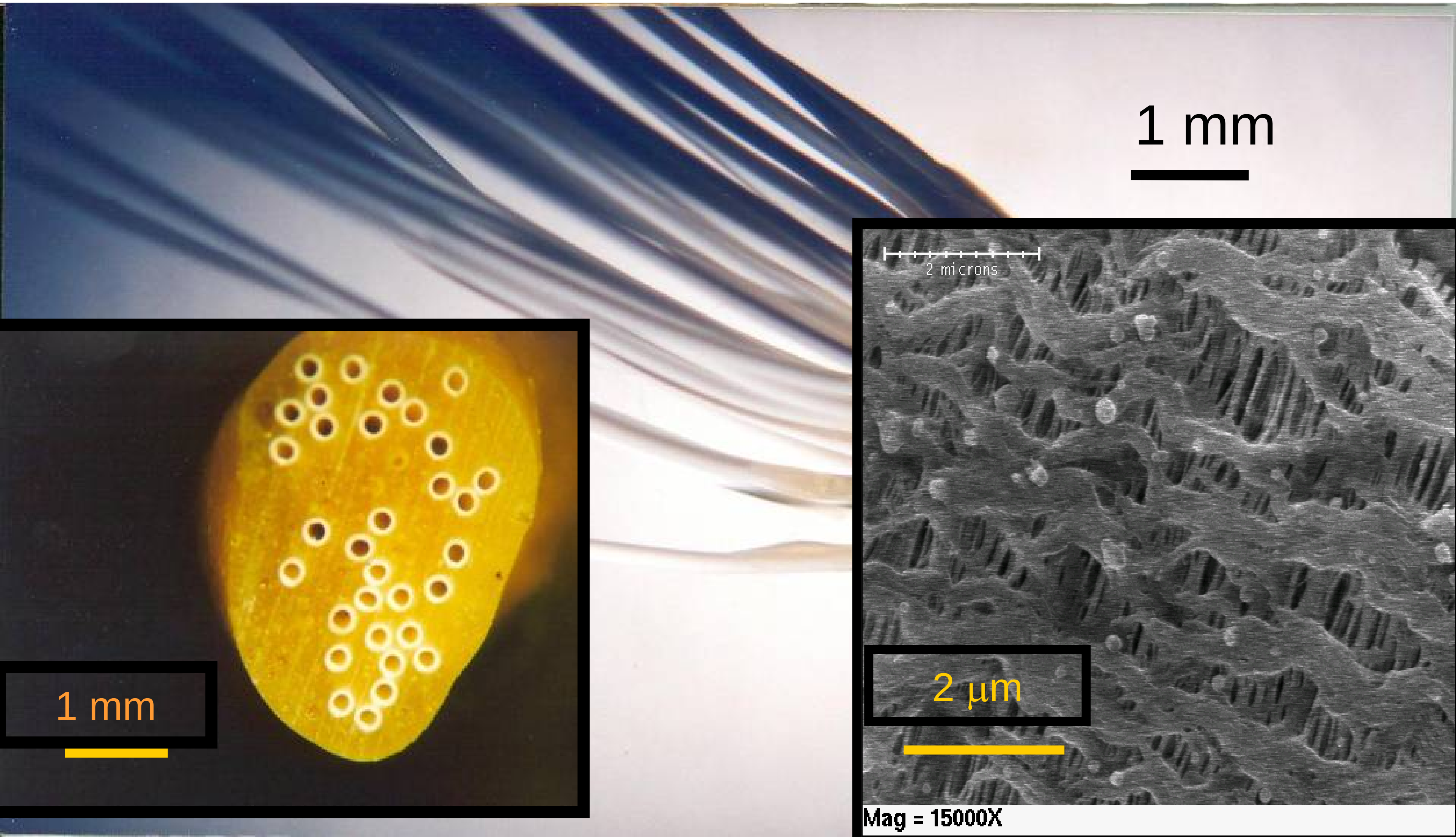
- IFAS, MBBR
- Limited denitrification

http://www.brentwood-ind.com/water/ifas_main.html

New approach

- Use air-filled hollow-fiber membranes
- Suppress bulk aeration

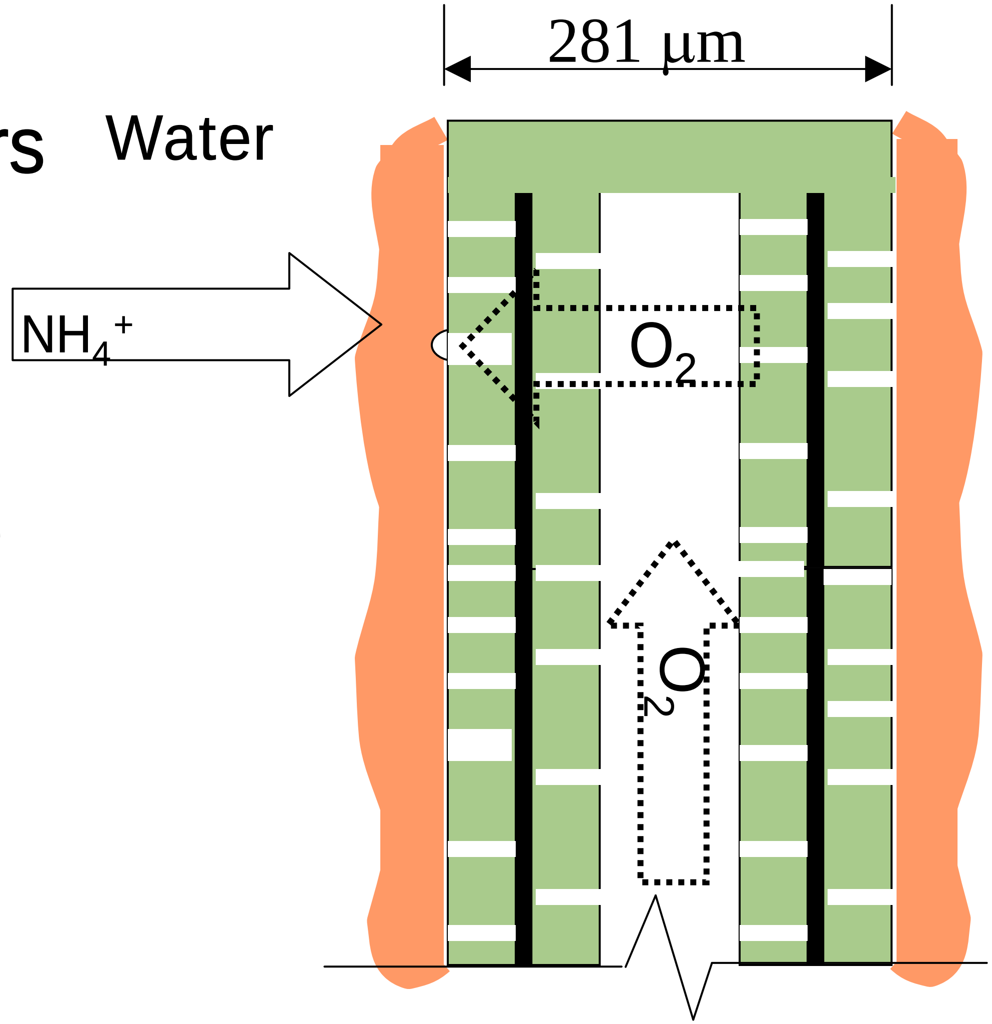
Hollow-Fiber Membranes for Gas Transfer



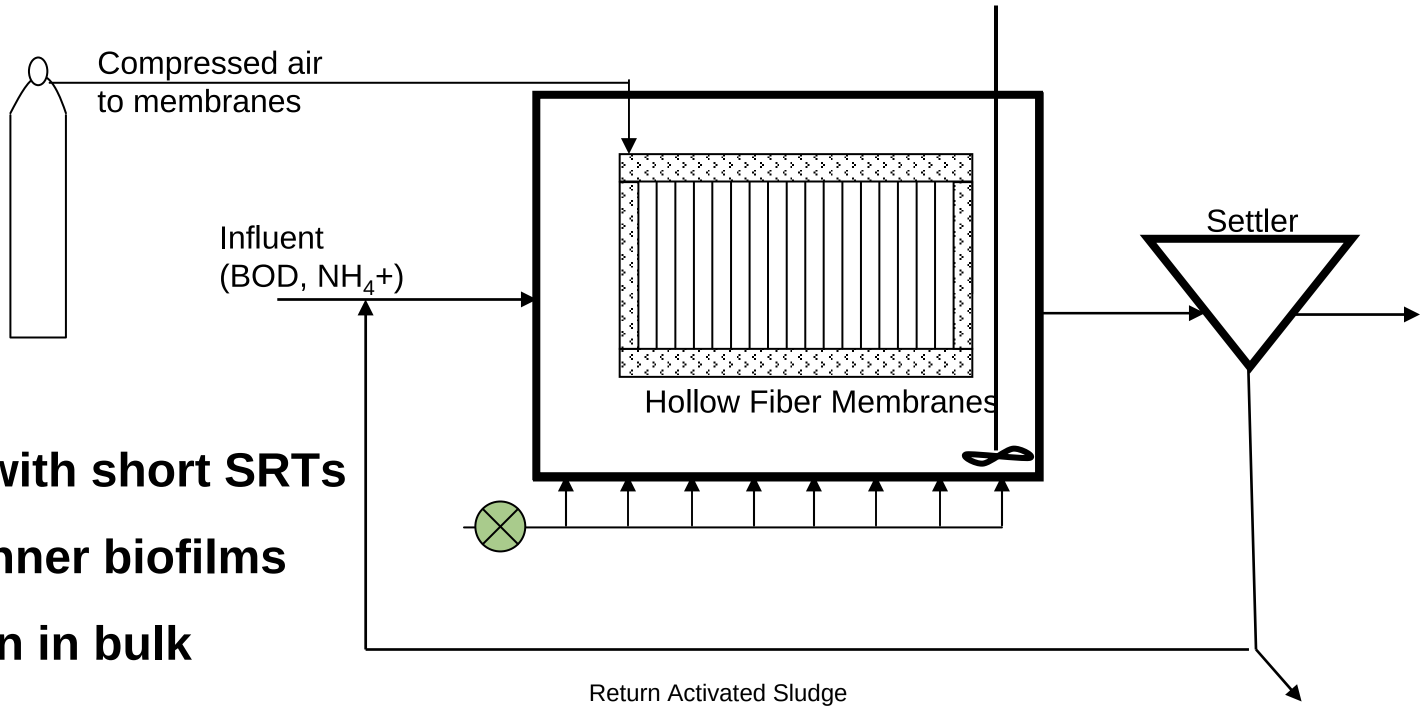
University of Notre Dame

Membrane-Biofilm Reactors

- Hydrophobic polymers
- High specific surface area
- Variable driving force
  - $J=K(C_L-C)$
- Low energy consumption



Hollow-Fiber Membrane Biofilm Process (HMBP)



- **Nitrification with short SRTs**
- **Hybrid → thinner biofilms**
- **Denitrification in bulk**
- **Passive aeration → save up to 70% on energy**

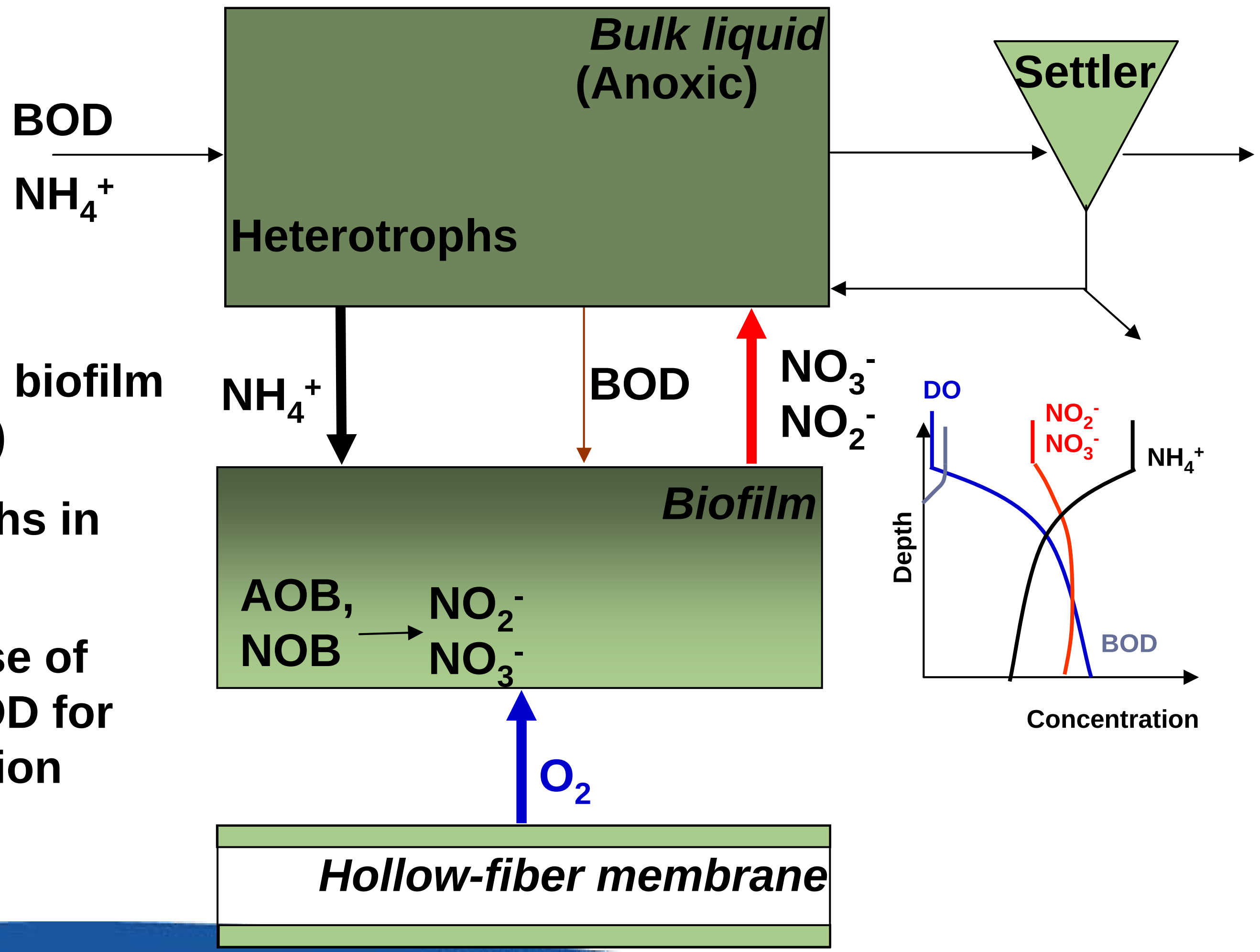
HMBP Conceptual Model

$$S = k\frac{1+b\theta_x}{Yq_{\max}\theta_x-(1+b\theta_x)}$$

$$X_a = \frac{\theta_x}{\theta}Y\frac{(S^o-S)}{(1+b\theta_x)}$$

S is insensitive to BOD loading

- **Nitrifiers in biofilm (AOB/NOB)**
- **Heterotrophs in bulk**
- **Maximal use of influent BOD for denitrification**



Research Objectives

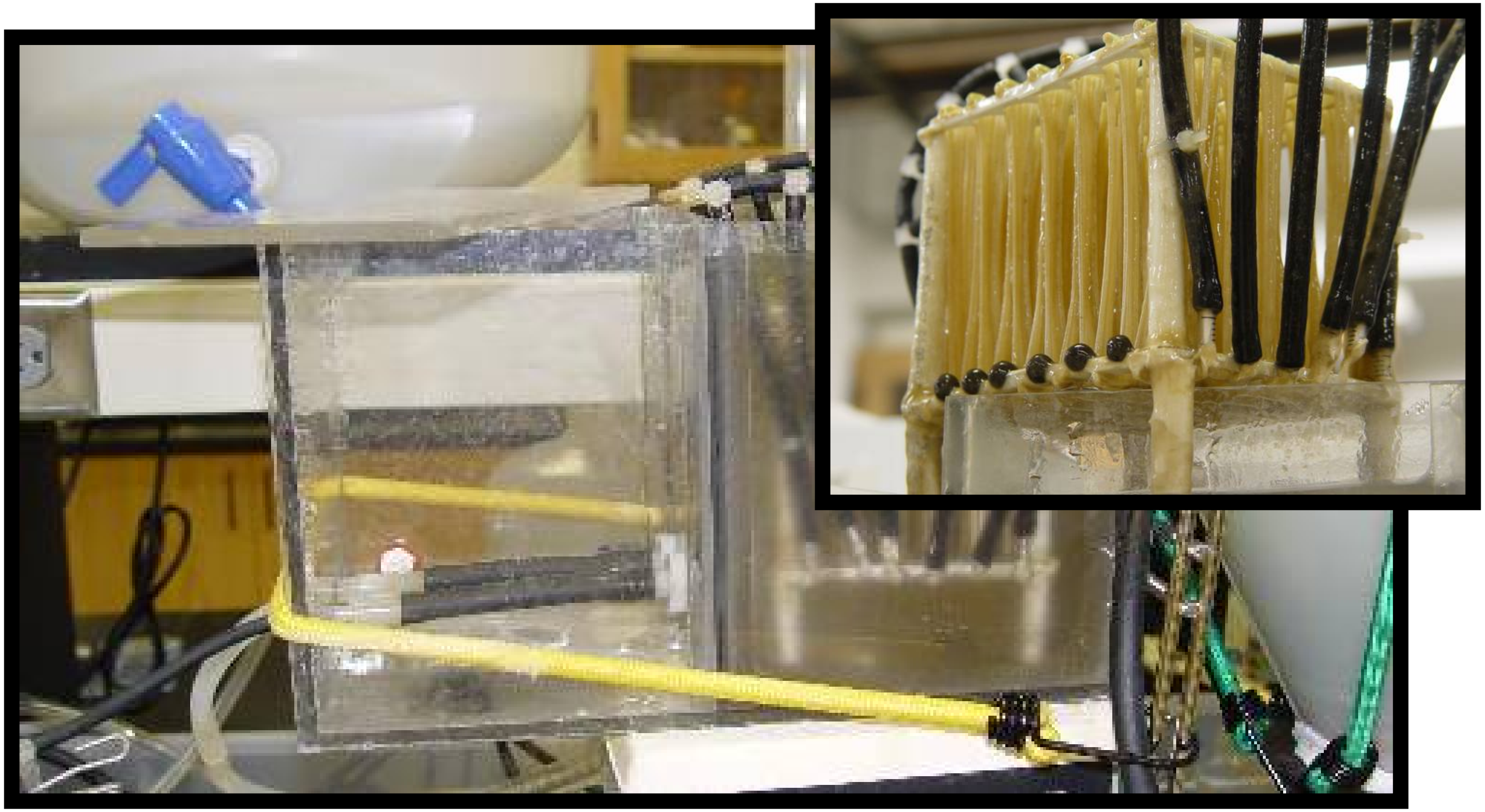
1. Test HMBP concept
2. Explore effects of membrane DO and bulk BOD on nitrification rates
3. Can the HMBP be scaled up?

Results

1. Test HMBP Concept

Performance of a bench-scale HMBP

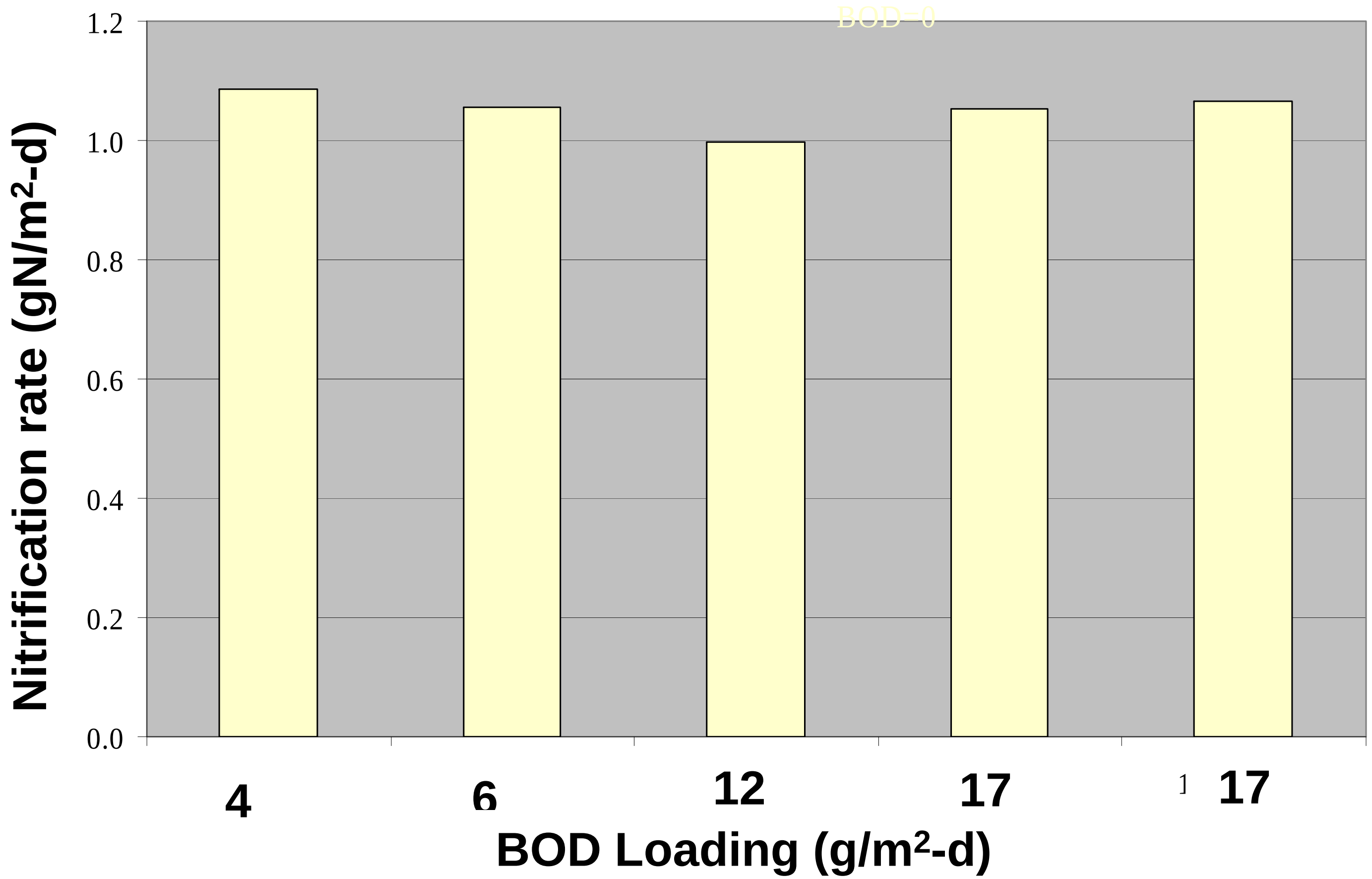
Bench Scale HMBP



Performance Tests

- Test HMBP for a variety of NH_4^+ and BOD loadings
- Determine location and activity of AOB, NOB, and Heterotrophs

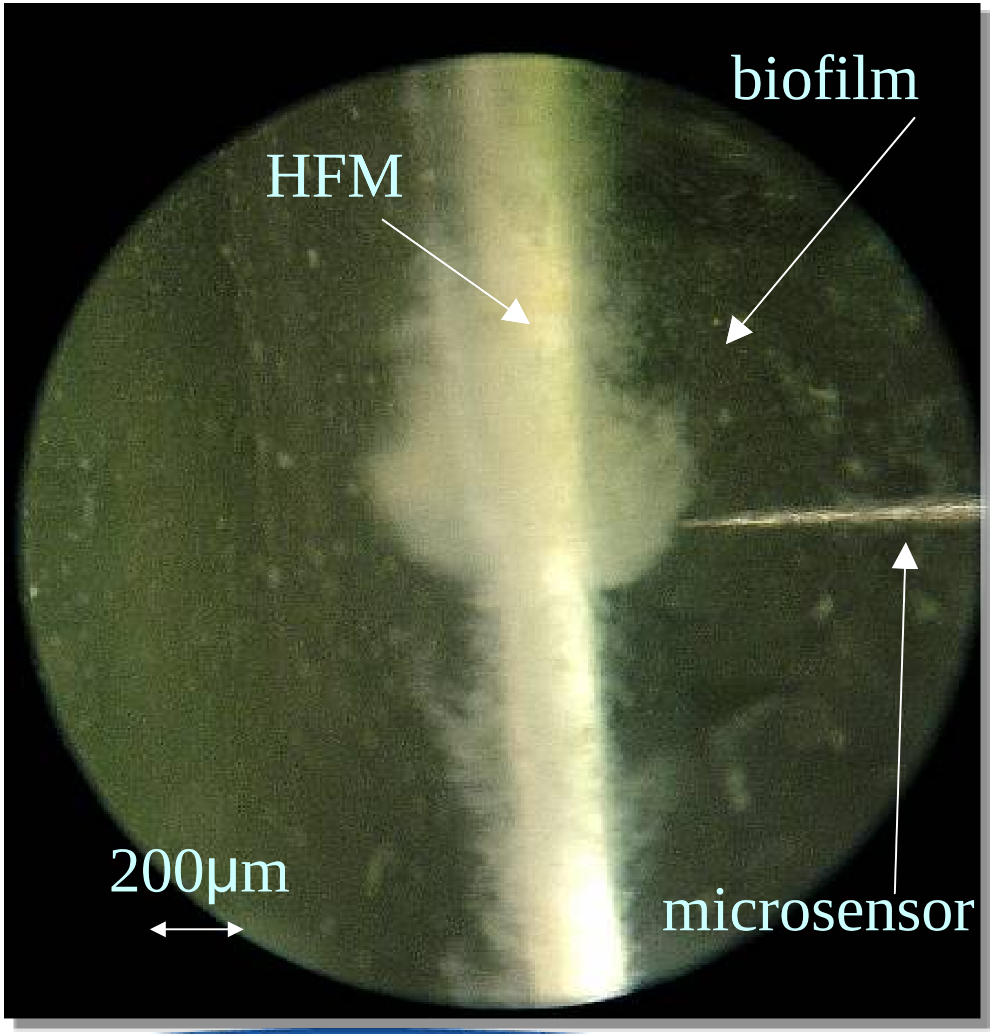
Vary Influent BOD Concentration



Nitrification rates are is insensitive to influent BOD concentrations

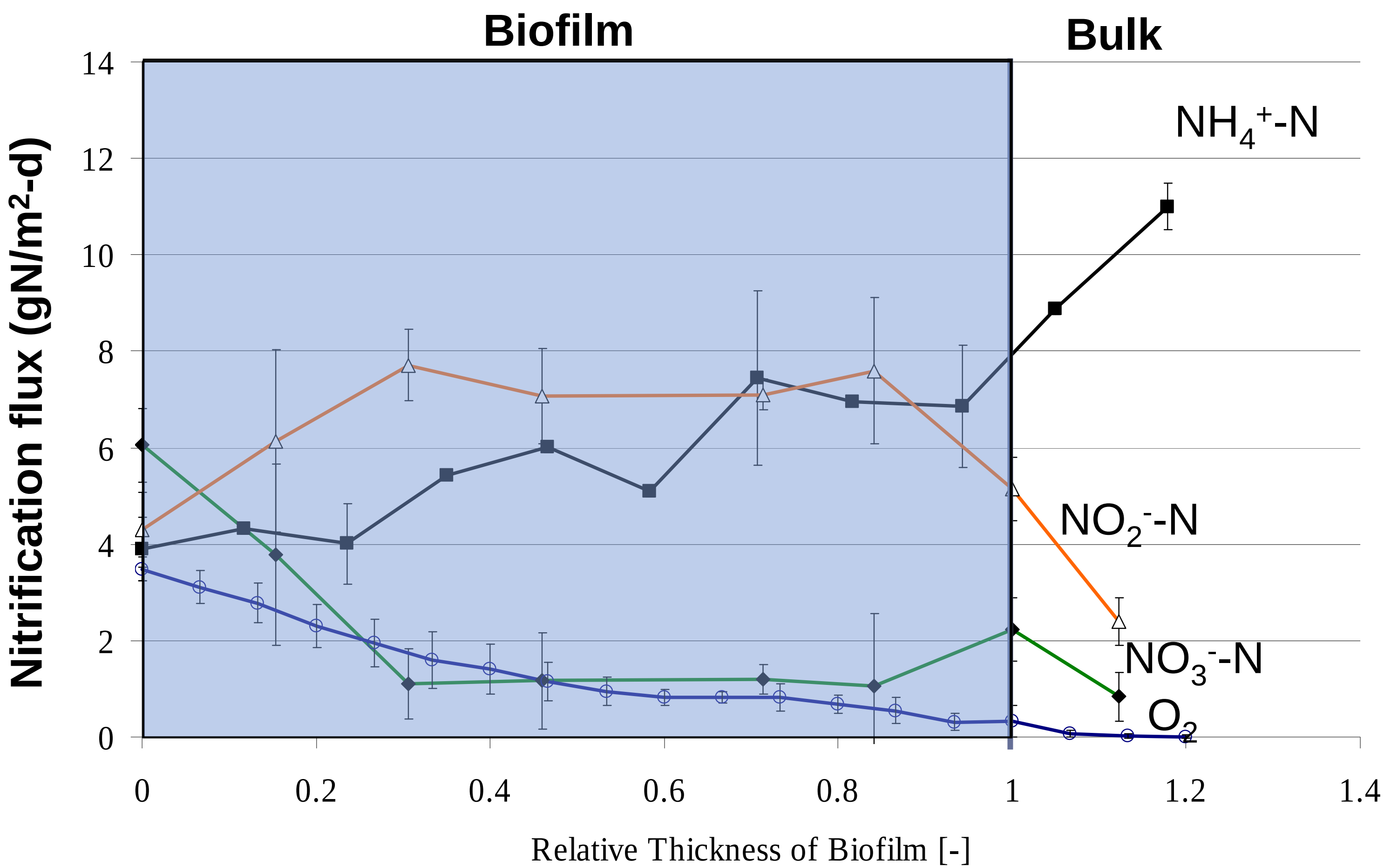
Downing and Nerenberg (in press) *Water Research*

Biofilm Activity: Microsensors

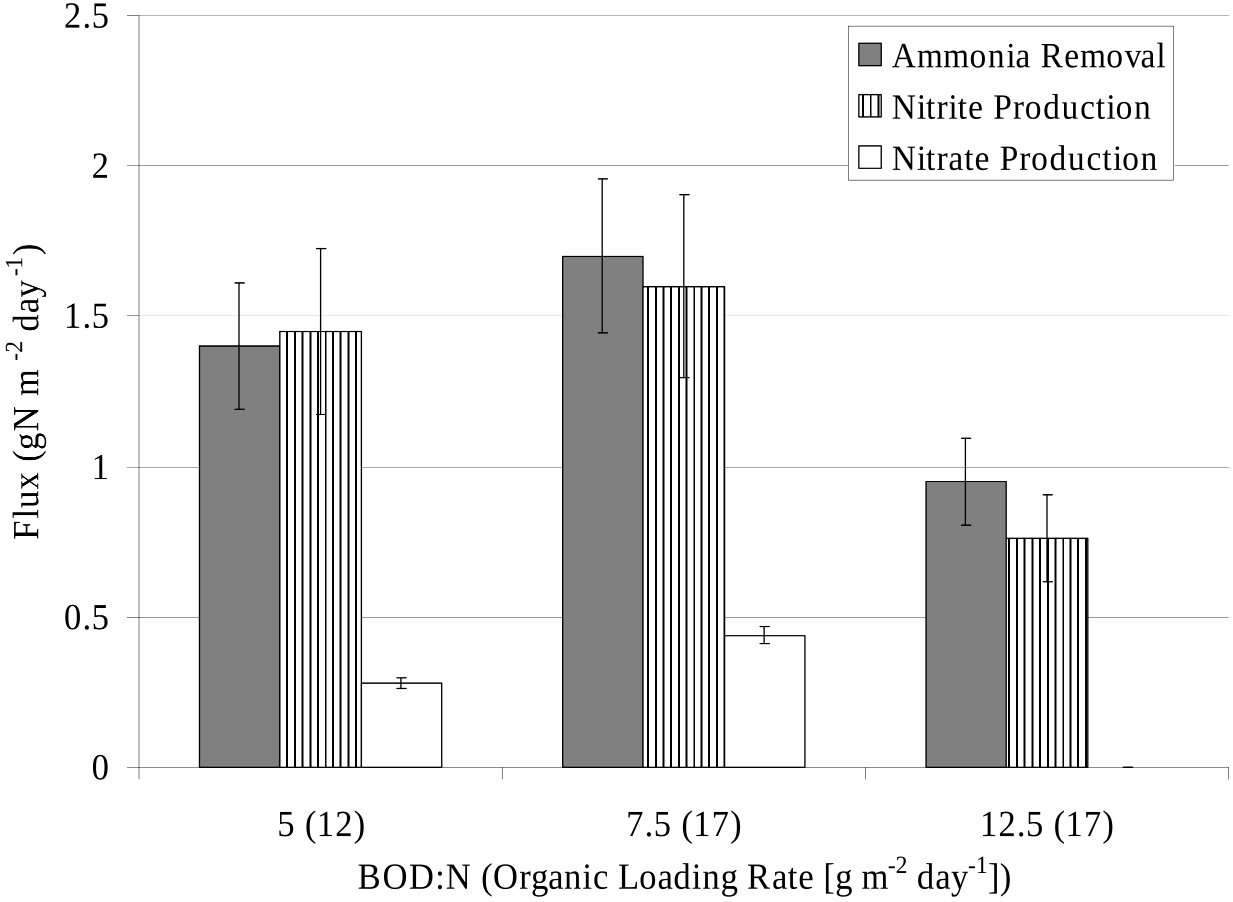


- Measure gradients through the biofilm
  - DO, NH_4^+, NO_3^-, NO_2^-,
- Determine fluxes into or out of the biofilm

Biofilm Gradients



Nitrite and Nitrate Production in Biofilm

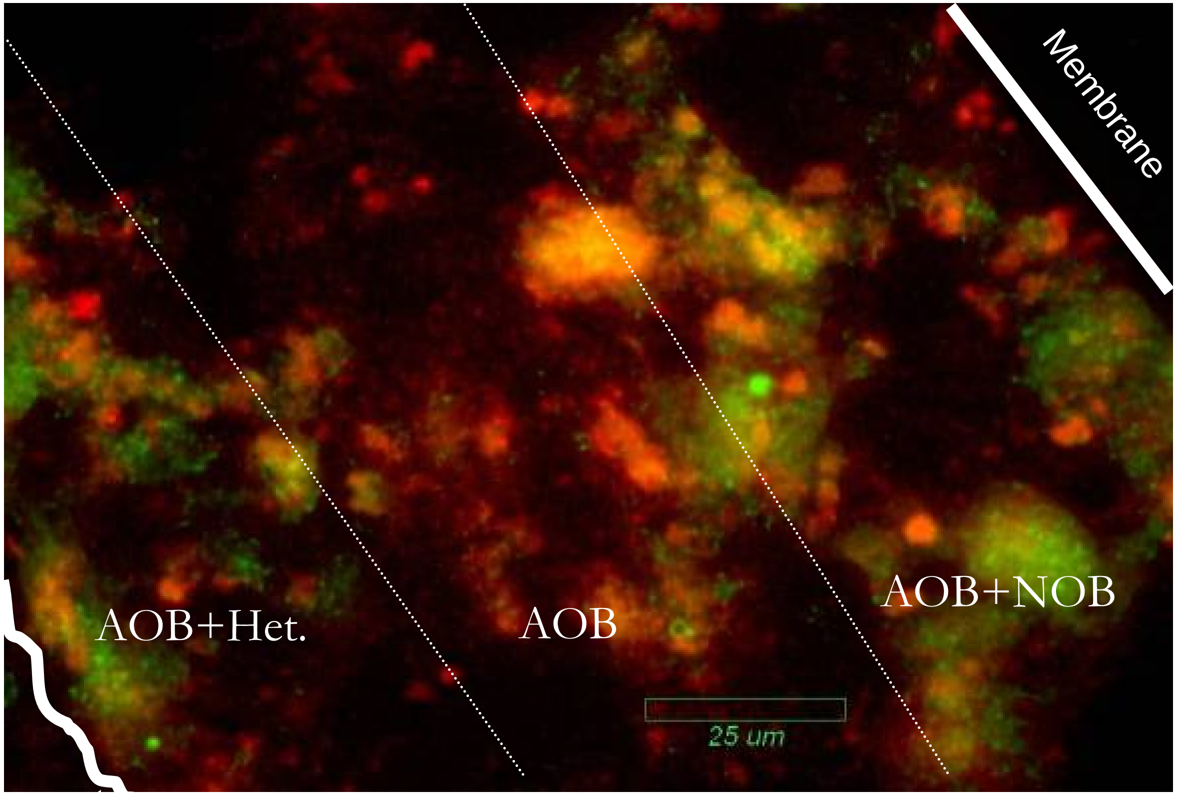


Mainly nitrite production (shortcut)

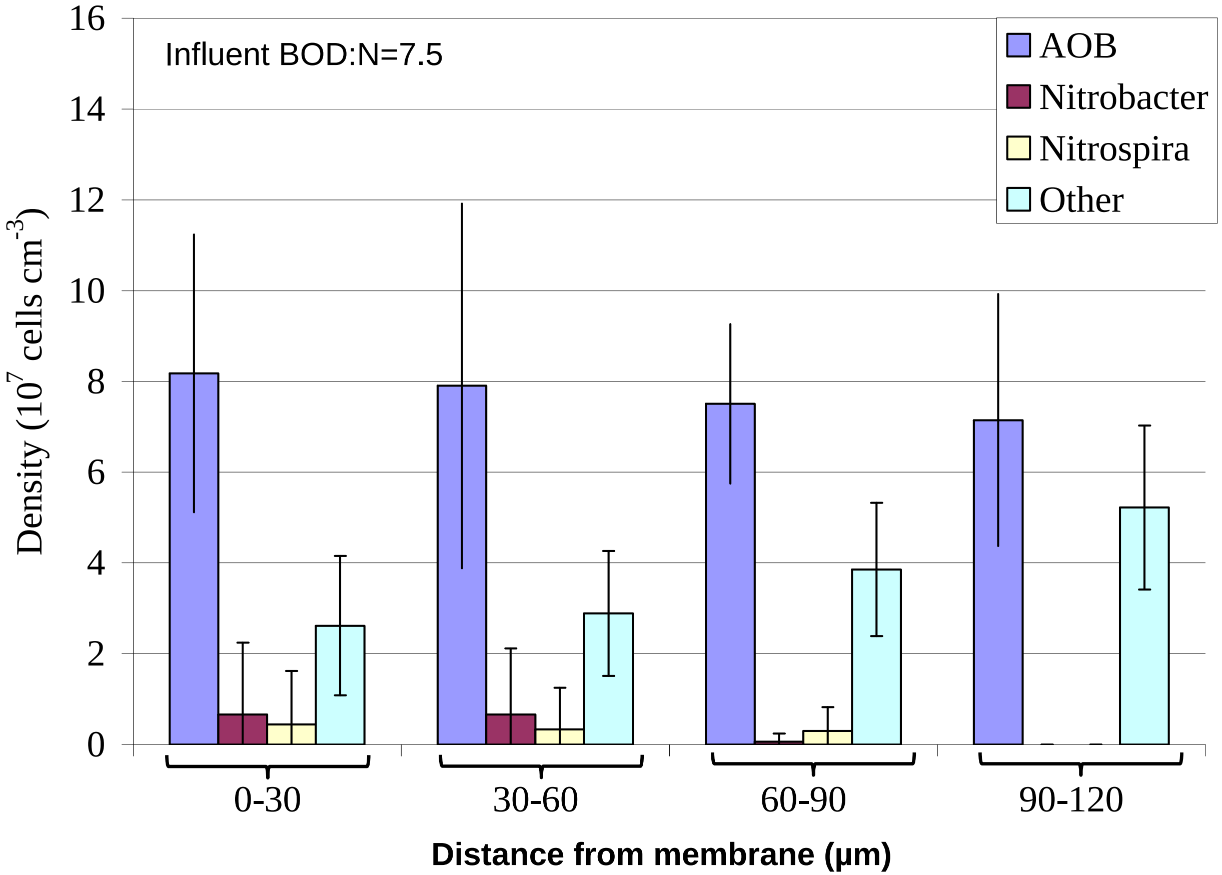
Downing and Nerenberg (in press) *Water Research*

Biofilm Structure: FISH

- AOB
- *Nitrobacter*
- *Nitrospira*



Biofilm Microbial Structure



AOB throughout, *Nitrobacter* near membrane

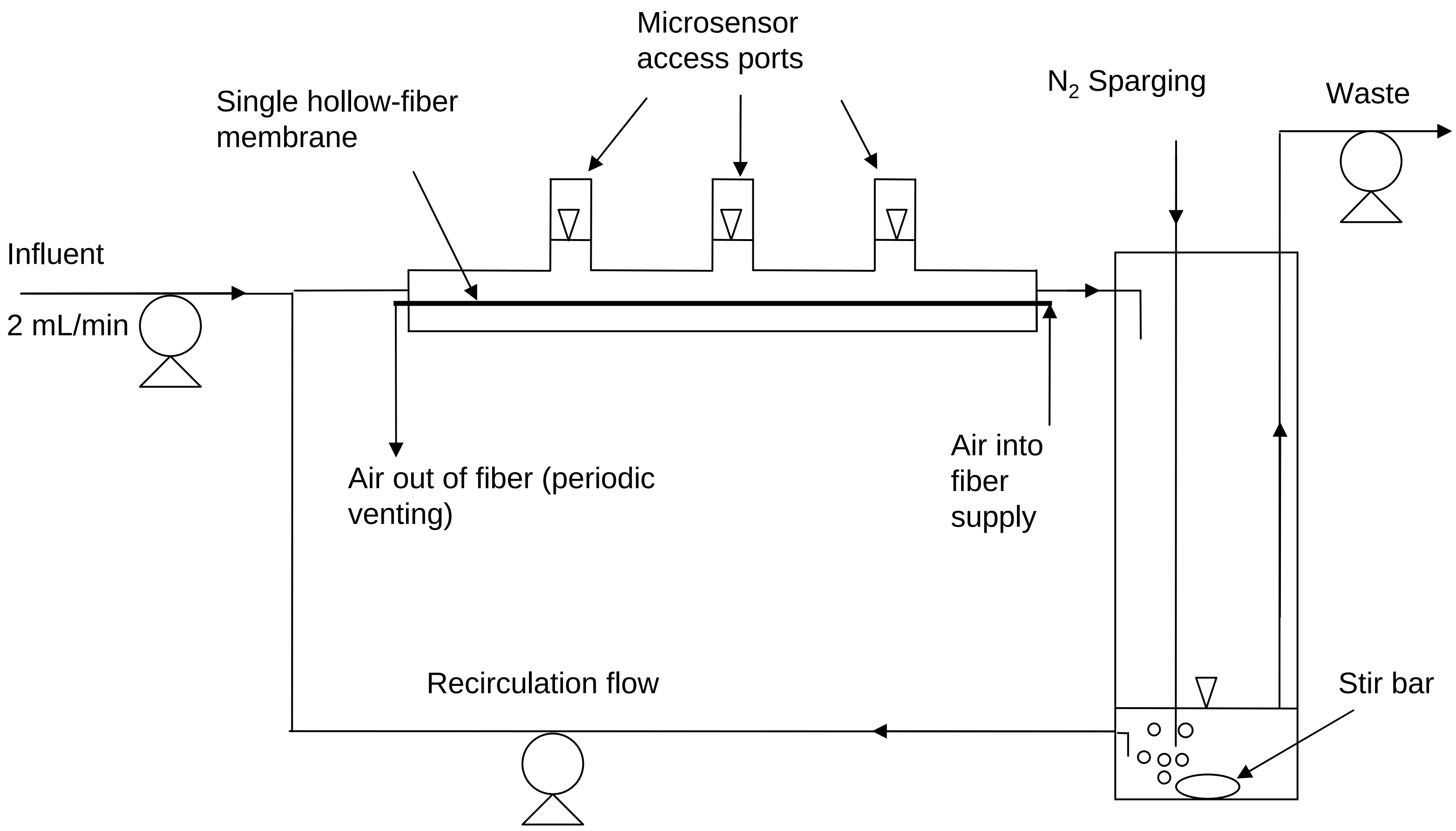
Downing and Nerenberg (in press) *Water Research*

2. Effects of DO and BOD

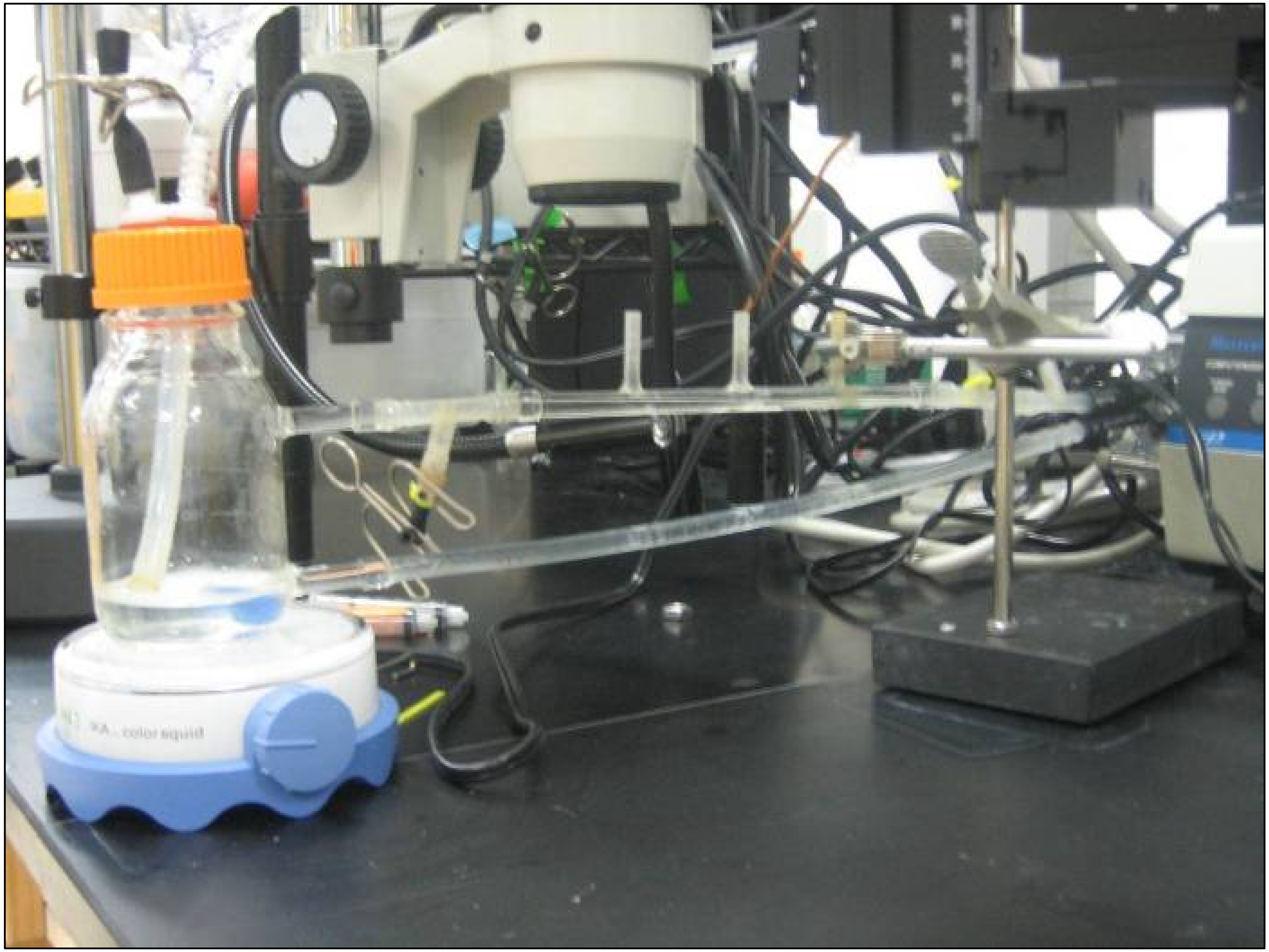
How does the membrane DO affect performance?

How much bulk BOD can be tolerated?

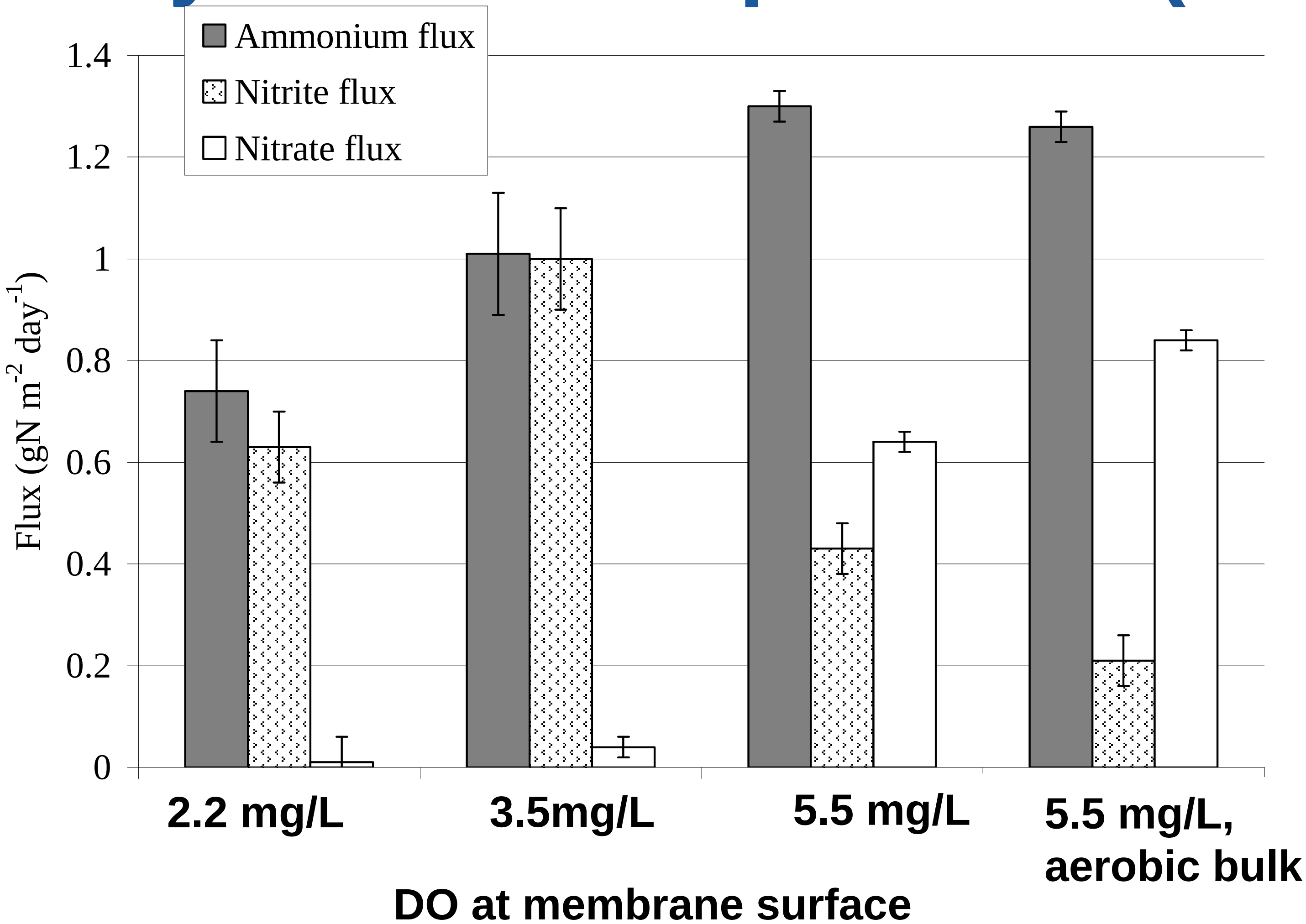
Experimental System



Experimental System



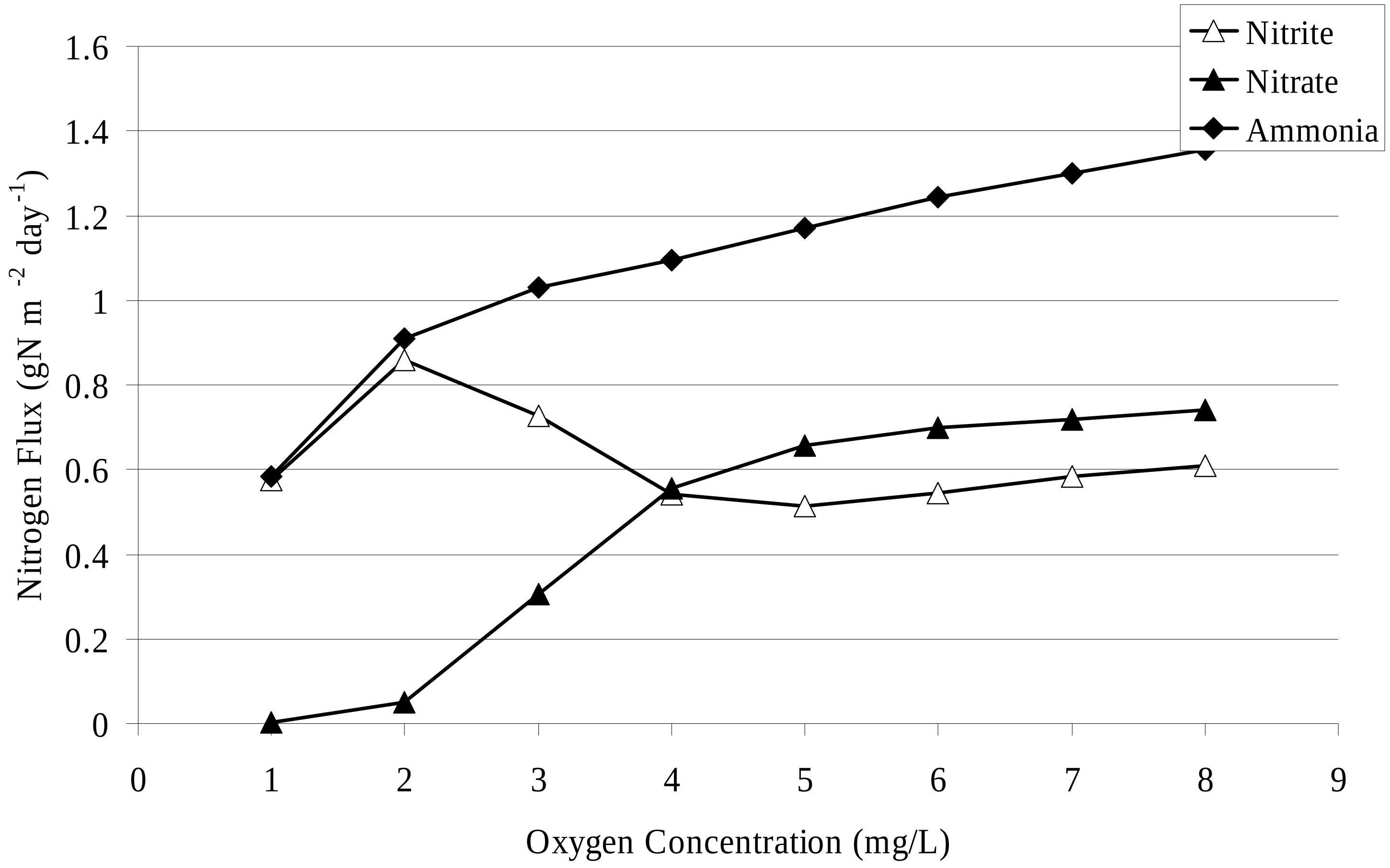
Vary membrane pressure (DO)



Tradeoff: high shortcut vs. high nitrification rates

Downing and Nerenberg (in press)
Biotechnology and Bioengineering

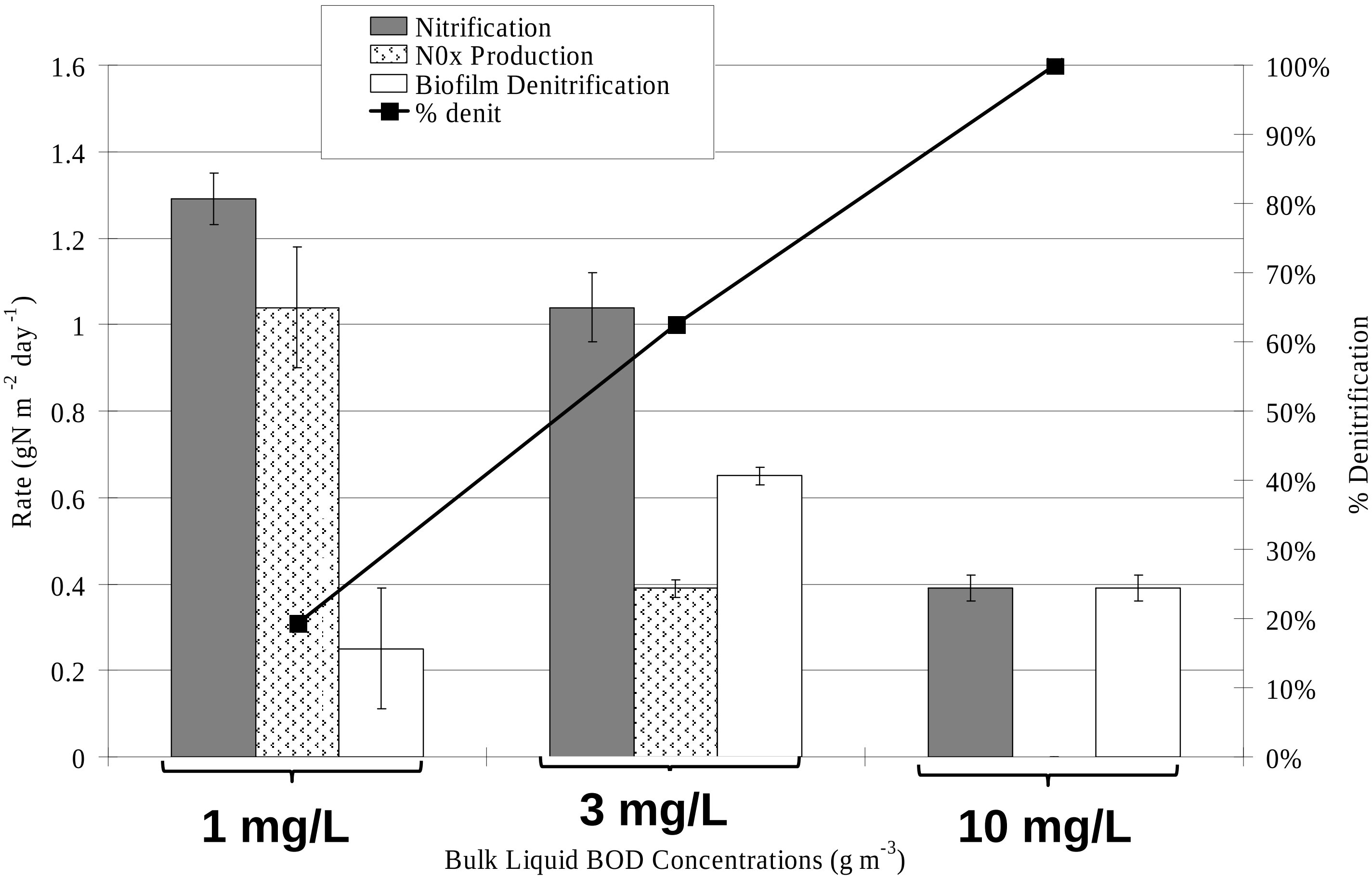
Variable DO - modeling



Tradeoff exists, but still some shortcut at high DO

Downing and Nerenberg (in press)
Biotechnology and Bioengineering

Impact of BOD

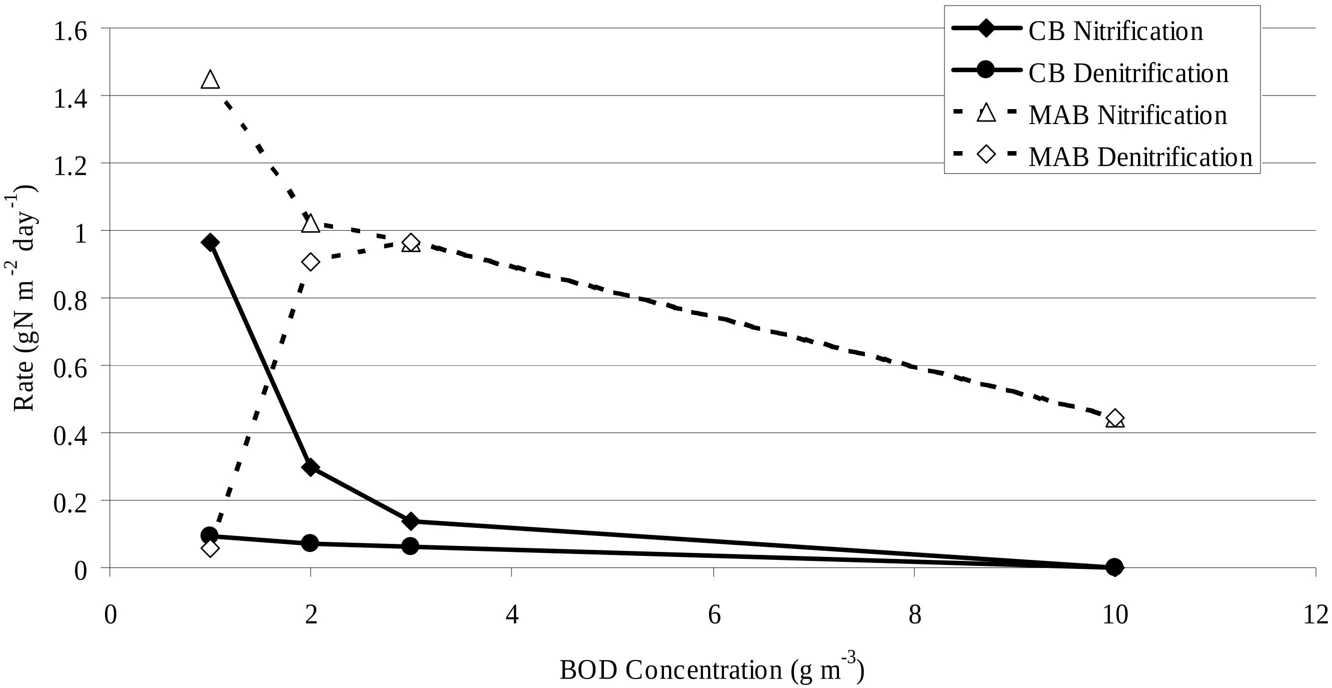


BOD slows nitrification, but increases denitrification

Downing and Nerenberg (accepted) *Applied Microbiology and Biotechnology*

Conventional vs membrane biofilm (Model)

- CB- Conventional Biofilm
- MAB- Membrane Aerated Biofilm



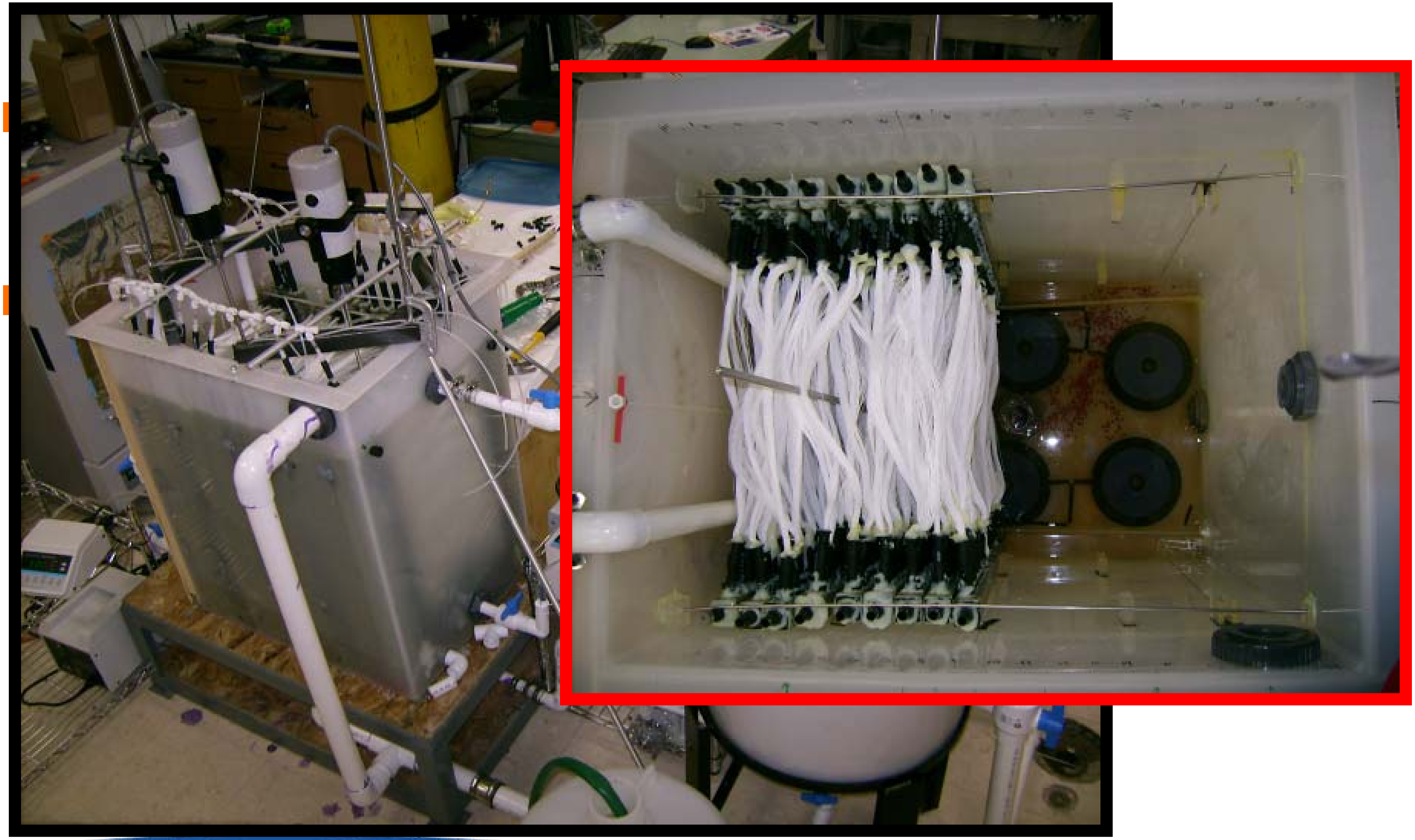
Membrane-aerated biofilm much less sensitive to BOD

Downing and Nerenberg (in press)
Biotechnology and Bioengineering

3. Pilot-Scale Tests

Performance of a larger system with real wastewater

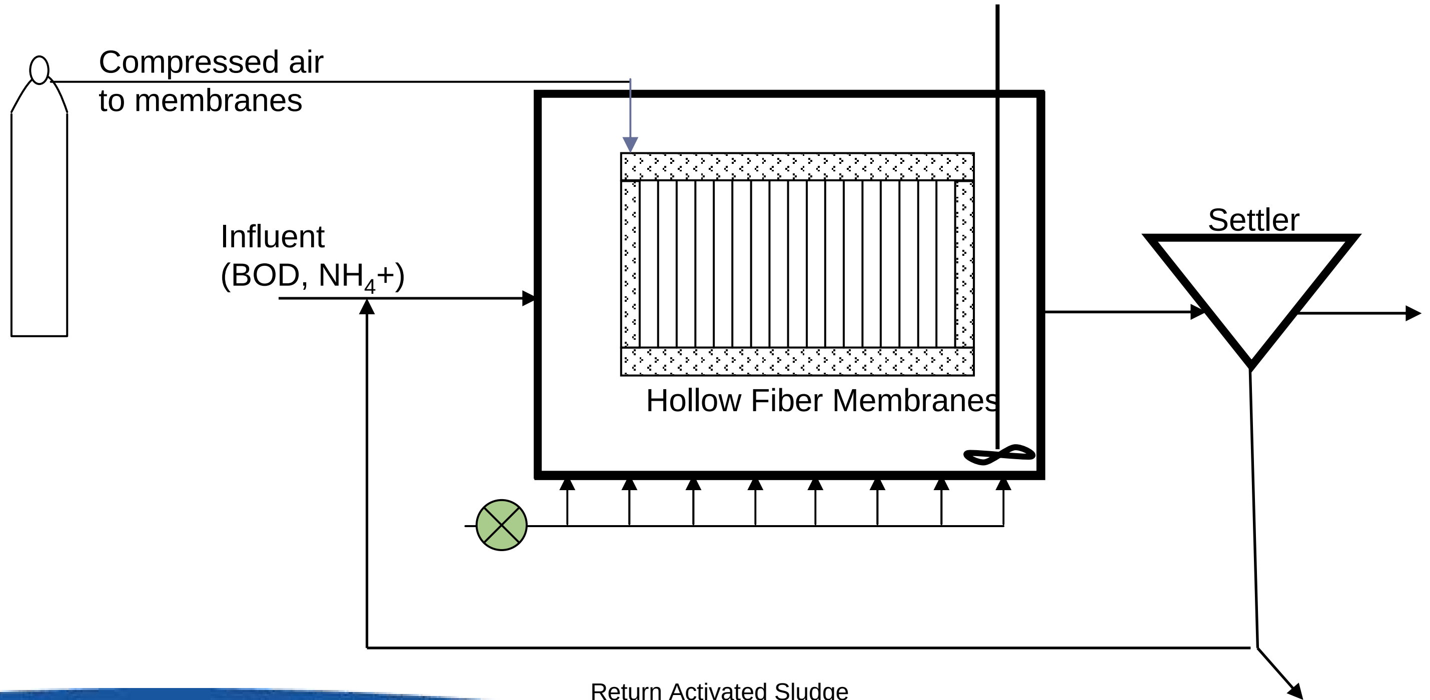
Pilot Scale Testing



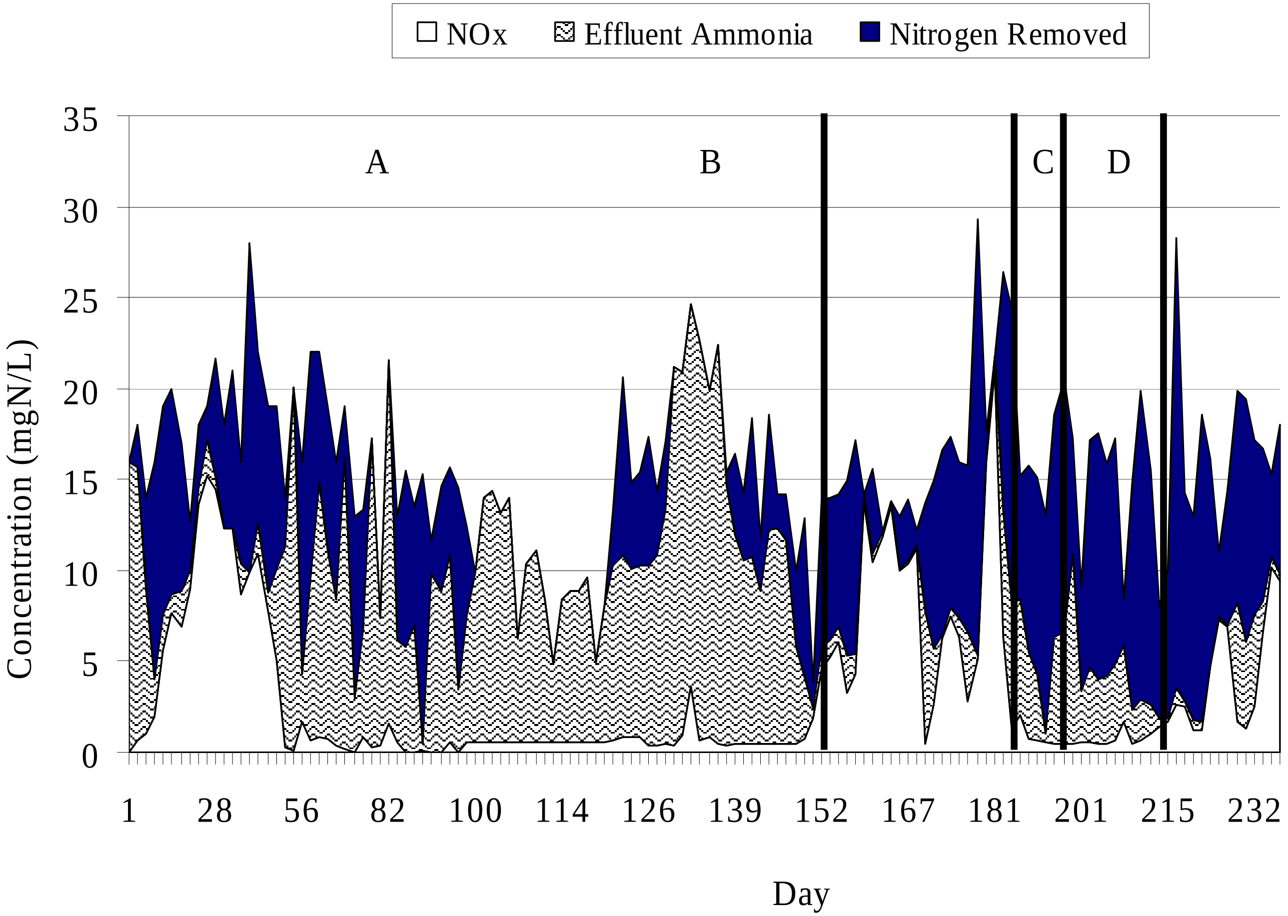
Images from NYC (PO-55a)

Reactor System

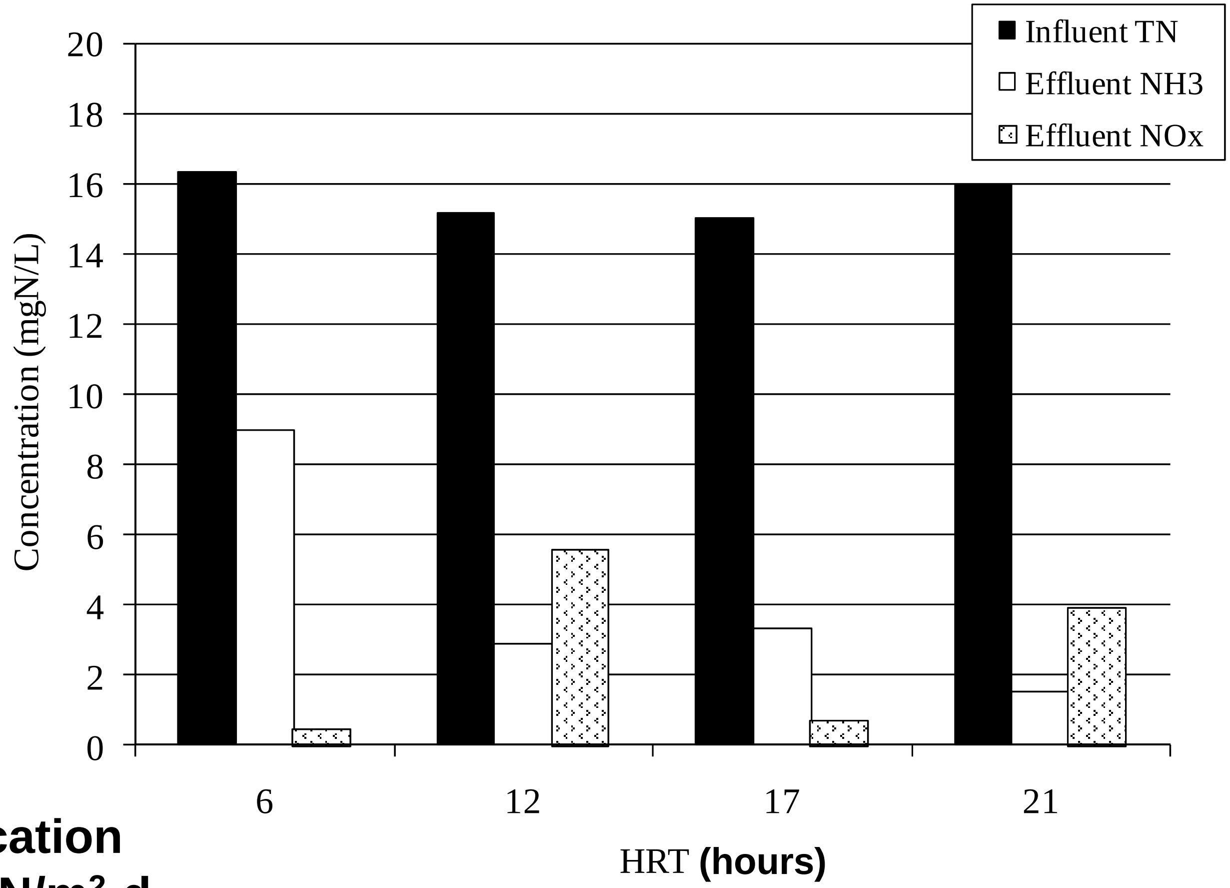
- 10 hour HRT
- 120 L active volume
- 2.5 day bulk SRT
- 0.2 m^2 membrane surface area
- Infl. ammonia: 15-20 mgN/L
- Infl. BOD: 40-150 mg/L



Pilot Scale Testing



Pilot Scale Testing



Avg. nitrification rate: 0.35 gN/m^2-d

Significant levels of TN removal at higher HRTs

Issues for scaleup

- Membrane materials
- Membrane packing density
- Mixing
- Biofilm management
- Cost analysis

CONCLUSIONS

- **The HMBP is effective for TN removal**
  - **Retrofit**
  - **Short bulk SRTs**
  - **Minimal Donor**
  - **Save energy**
- **Nitrification insensitive to influent BOD, but sensitive to bulk BOD**
- **Tradeoff exists between nitrification rates and extent of shortcut**
- **Promising results, further research needed for scaleup**

Thank you!