Biofilm Kinetics and the Performance of a Single Submerged Attached Growth Bioreactor for Simultaneous Removal of Organics and Nitrogen

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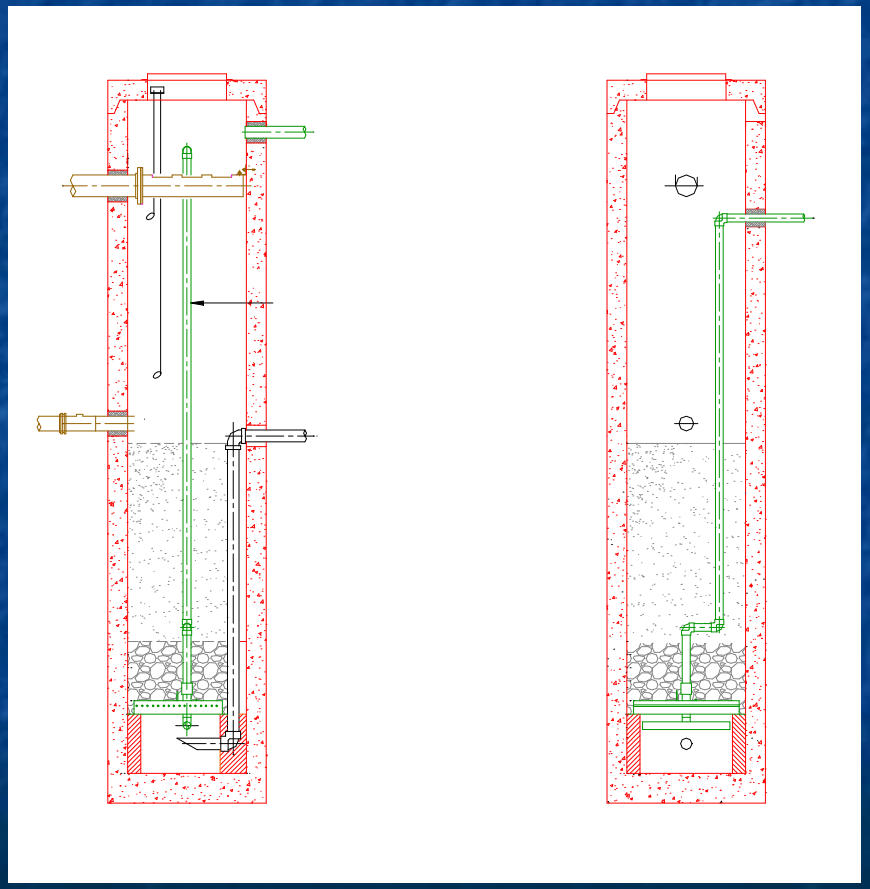
Outline

- Introduction
- Study Objective
- Pilot Plant & Experimental Design
- Results
  - Effluent Total Nitrogen
  - Oxidation of Organics & Nitrification
  - Denitrification
  - Biofilm Kinetics
  - Biomass Quantity
- Conclusions

Introduction

- Submerged Attached Growth Bioreactor (SAGB)
  - Media submerged in Flow
- Sand Filter



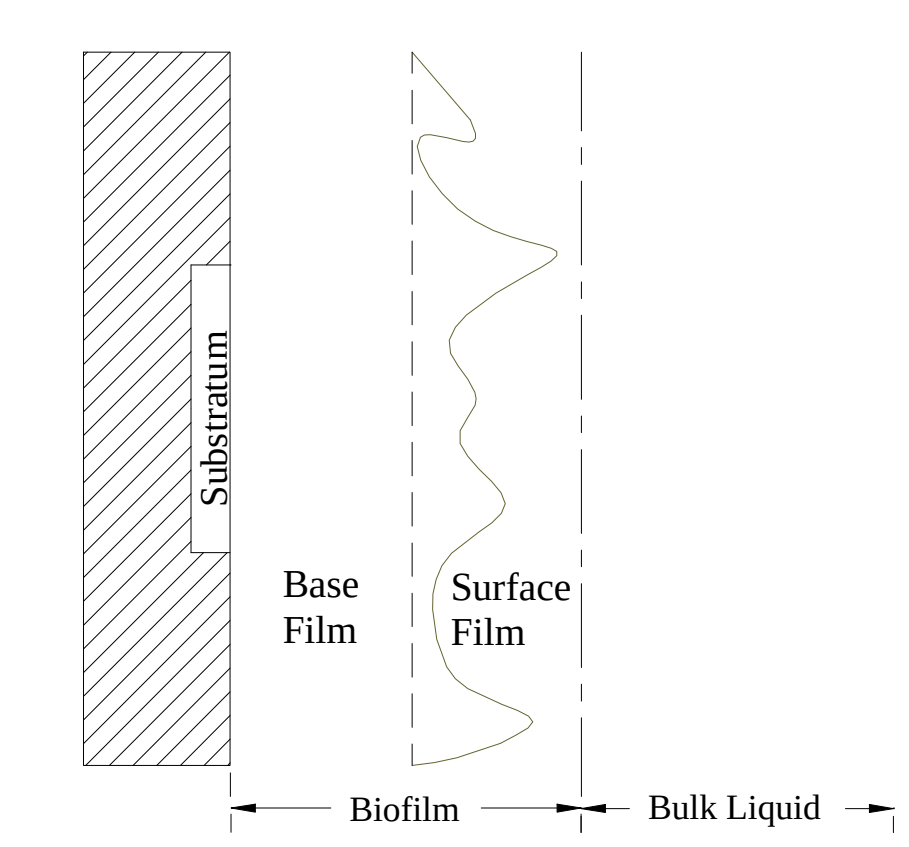
Introduction

- Biochemical Transformations (Normalized mass based)
  - $CH_2O + 0.309\ O_2 + 0.085\ NH_4^+ + 0.289\ HCO_3^- \Rightarrow 0.535\ C_5H_7O_2N + 0.633\ CO_2 + 0.515\ H_2O$ (aerobic)
  - $NH_4^+ + 3.30\ O_2 + 6.708\ HCO_3^- \Rightarrow 0.129\ C_5H_7O_2N + 3.373\ NO_3^- + 1.041\ H_2O + 6.463\ H_2CO_3$ (aerobic)
  - $NO_3^- + 0.324\ C_{10}H_{19}O_3N \Rightarrow 0.226\ N_2 + 0.710\ CO_2 + 0.087\ H_2O + 0.027\ NH_3 + 0.274\ OH^-$ (anoxic)

Introduction - Biofilms

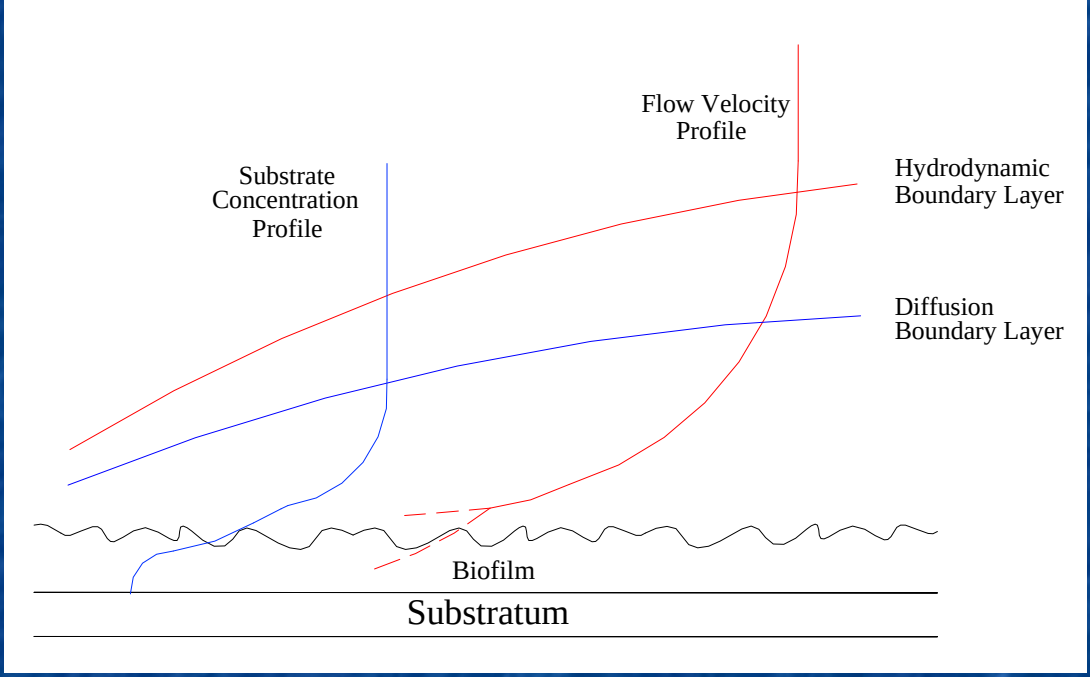
- Biofilm - organic polymer gel attached to a solid at solid-liquid interface
  - biopolymer building blocks
- Comprised of:
  - colonies of microorganisms
  - extra cellular polymeric substances (EPS)
  - inorganic particles
  - dissolved compounds

Introduction - Biofilms



- For analysis:
  - base film
  - surface film
  - bulk liquid
- Transport
  - base film - diffusion
  - surface film - convection

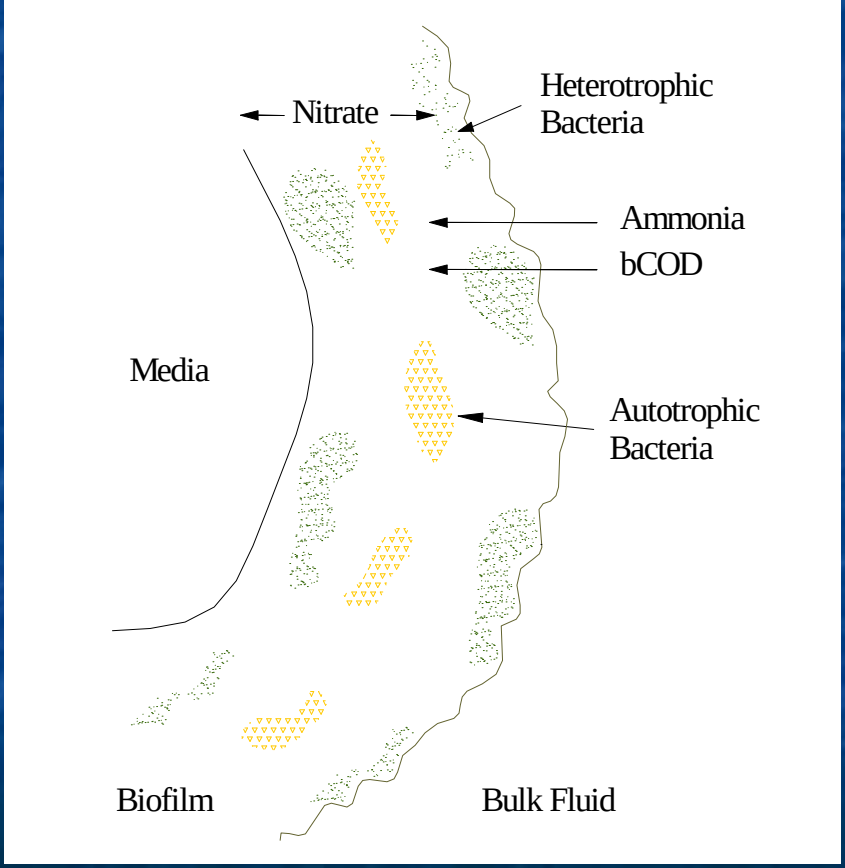
Introduction - Biofilms



Hydrodynamics and Kinetics in a Biofilm System

- Transport into biofilm
  - fluid velocity
  - substrate concentration

Introduction - Biofilms



- Multispecies biofilm
  - Heterotrophic bacteria
    - oxidation of organics
      - aerobic & anoxic
  - Autotrophic bacteria
    - nitrification
      - aerobic

Introduction - Nitrification

- Parameters effecting nitrifying biofilms:
  - Dissolved oxygen
  - Bicarbonate alkalinity & pH
  - Carbon to Nitrogen (C/N) ratio
    - Simultaneous oxidation of organics and nitrification occurs according to criterion:

$$\frac{\nu_s D_s}{D_o} \cdot \frac{S_s}{S_o} = 1$$

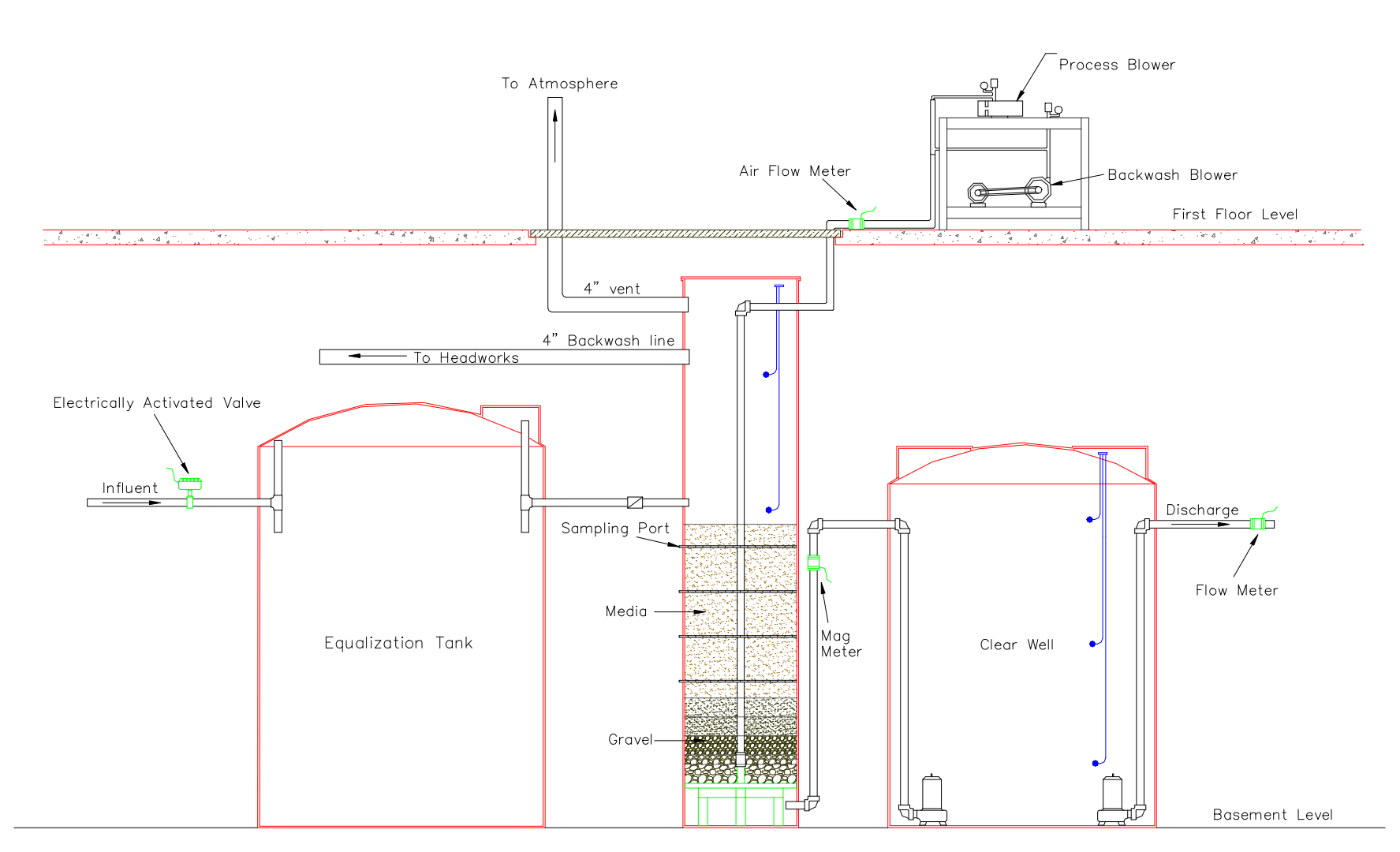
Study Objective

- Achieve simultaneous oxidation of carbonaceous matter and nitrogen removal in a single submerged attached growth bioreactor (SAGB) reactor.
  - BOD_5 & TSS < 30 mg/l
  - Total Nitrogen (TN) < 10 mg/l

Experimental Design

- SAGB pilot plant

Experimental Design



Experimental Design

Sagb39.exe

Experimental Design

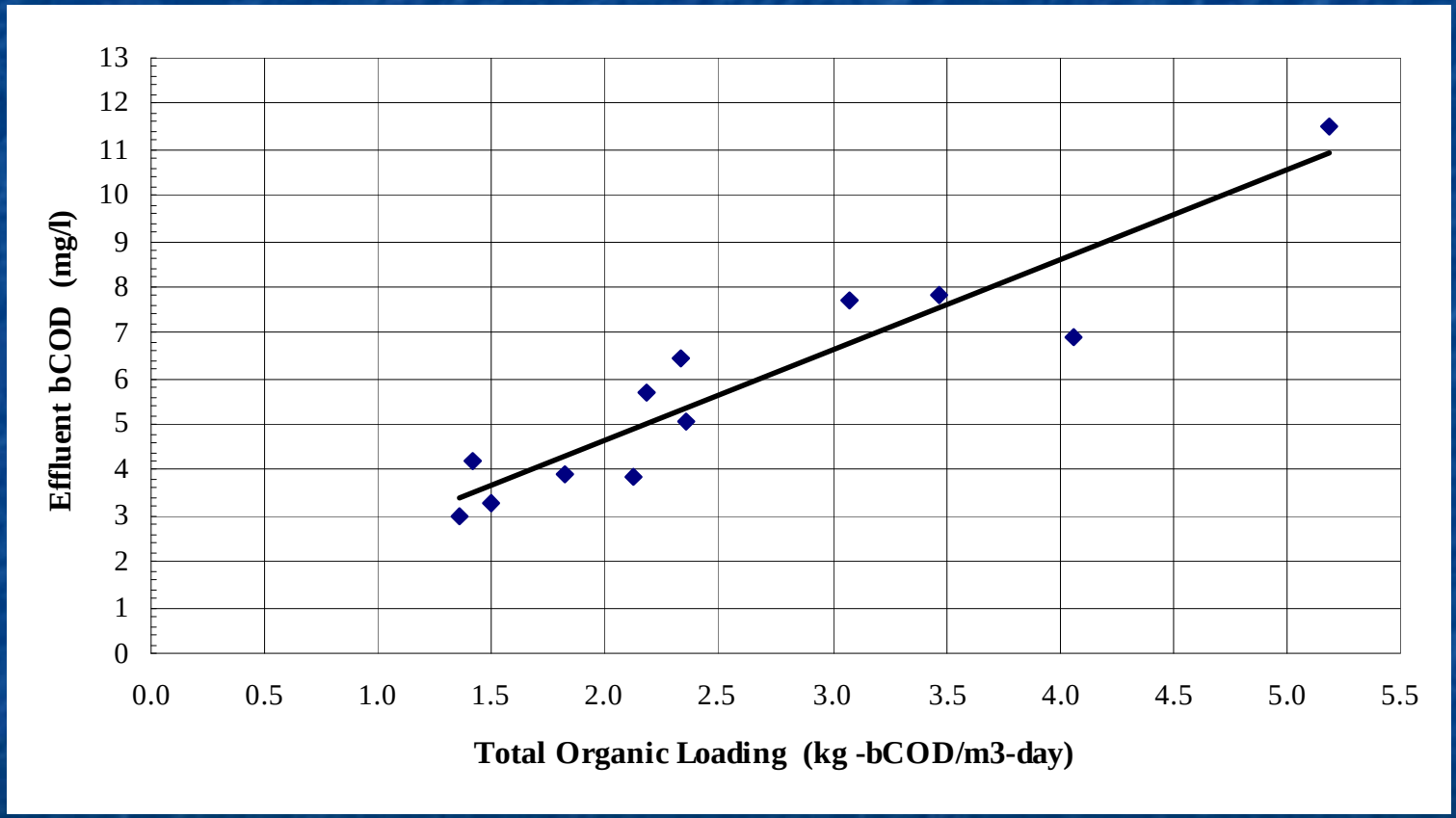
- Objectives
  - Quantify removal of organics (bCOD) & nitrogen
  - Determine removal rates
  - Determine concentration profiles
    - bCOD, NH_3, NO_3^- & TKN
  - Examine kinetics
  - Determine quantity of biomass

Experimental Design

- 4 different flow conditions tested
  - 8.3 m^3/d (2,148 gpd)
  - 4.5 m^3/d (1,191 gpd)
  - 4.1 m^3/d (1,089 gpd)
  - 3.2 m^3/d (840 gpd)

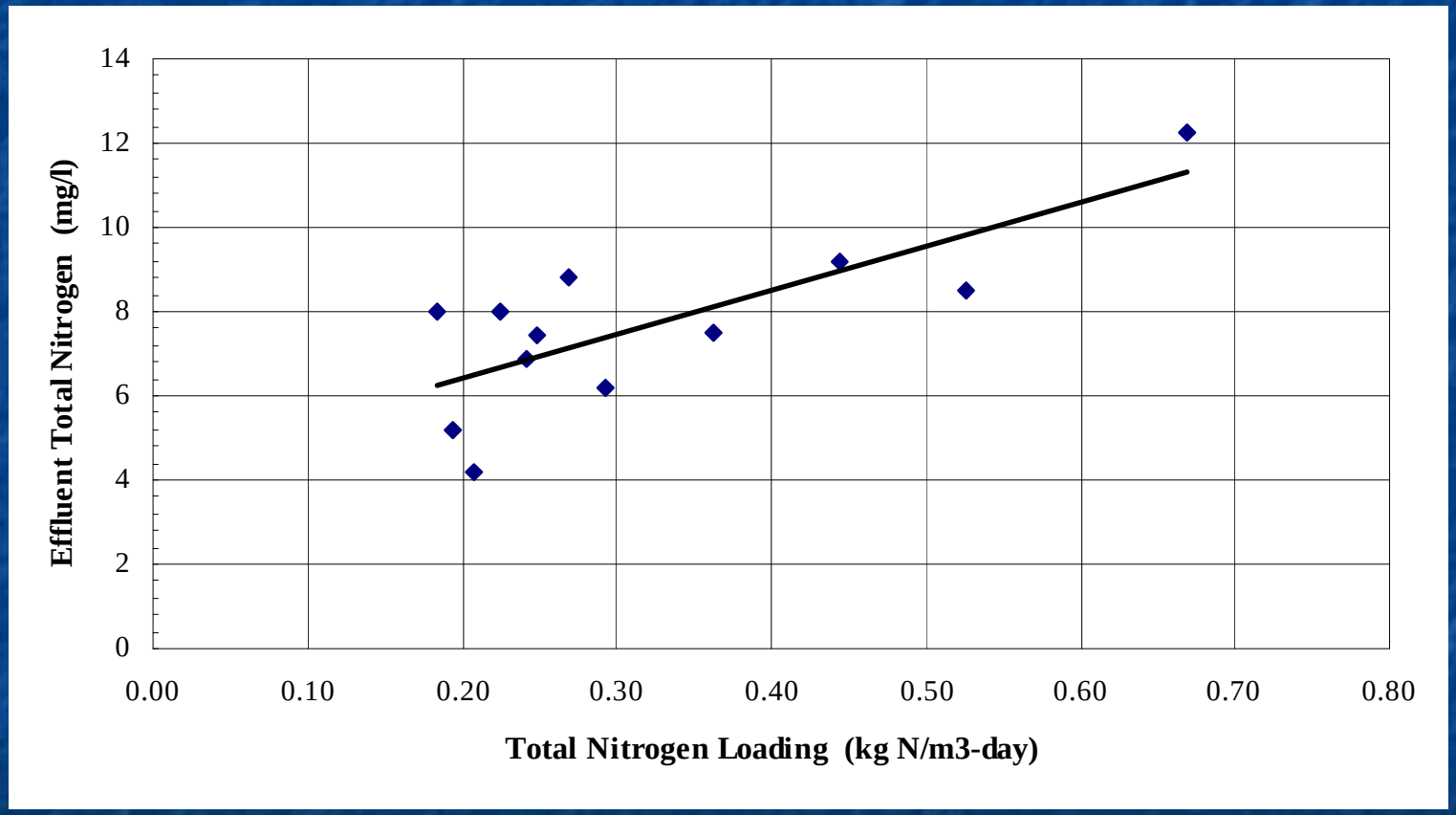
Parameter	TCOD	BOD_5	TKN	Nitrate & Nitrite
Average (mg/l)	213.0	97.0	20.4	0.0191
STD	41.2	31.4	4.1	0.0096

Results - Total Organic Loading



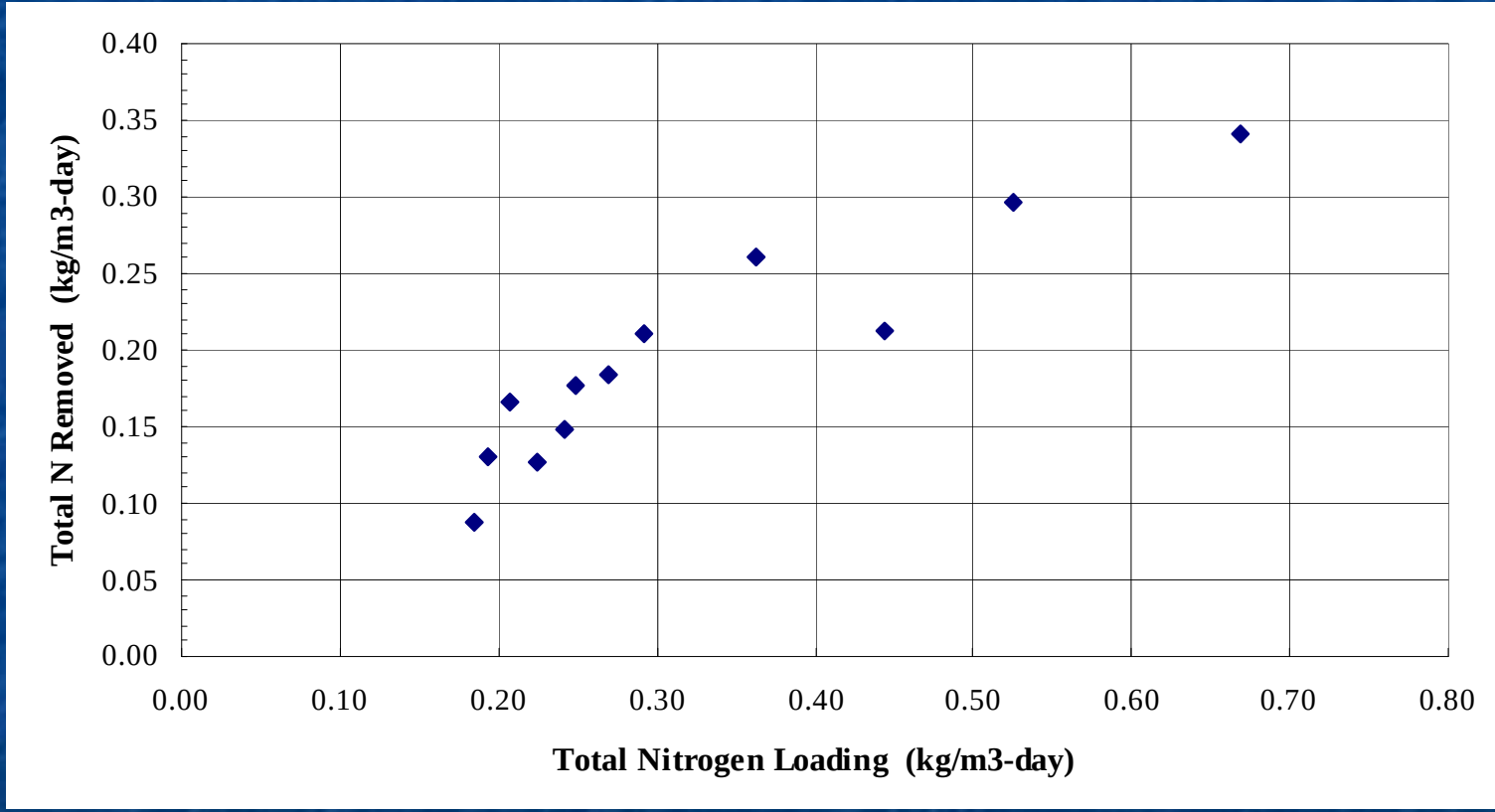
Removal of organics to levels below 51 mg/l bCOD.

Results - Total Nitrogen



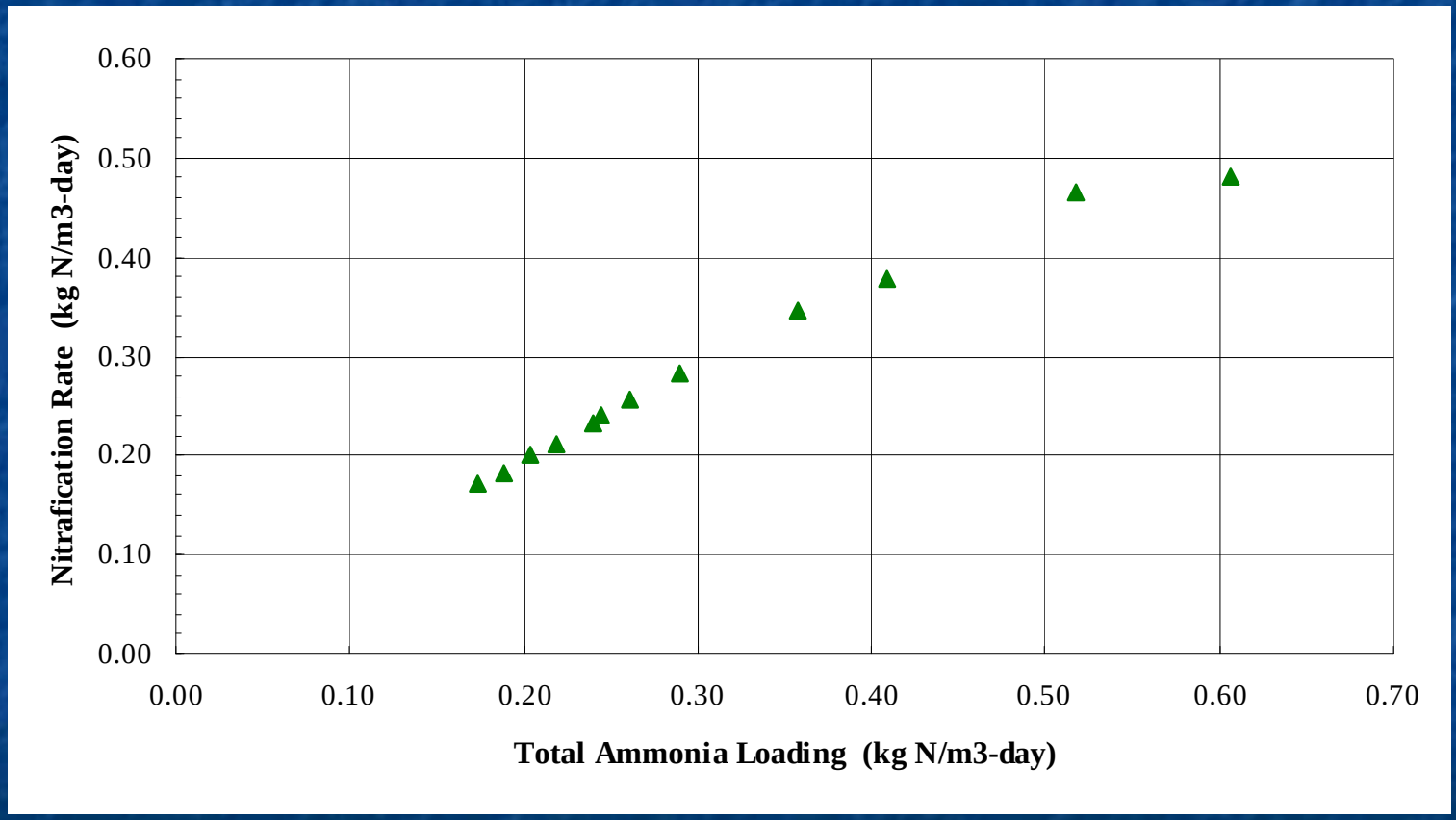
Effluent concentration below 10 mg/l.

Results - Total Nitrogen Loading



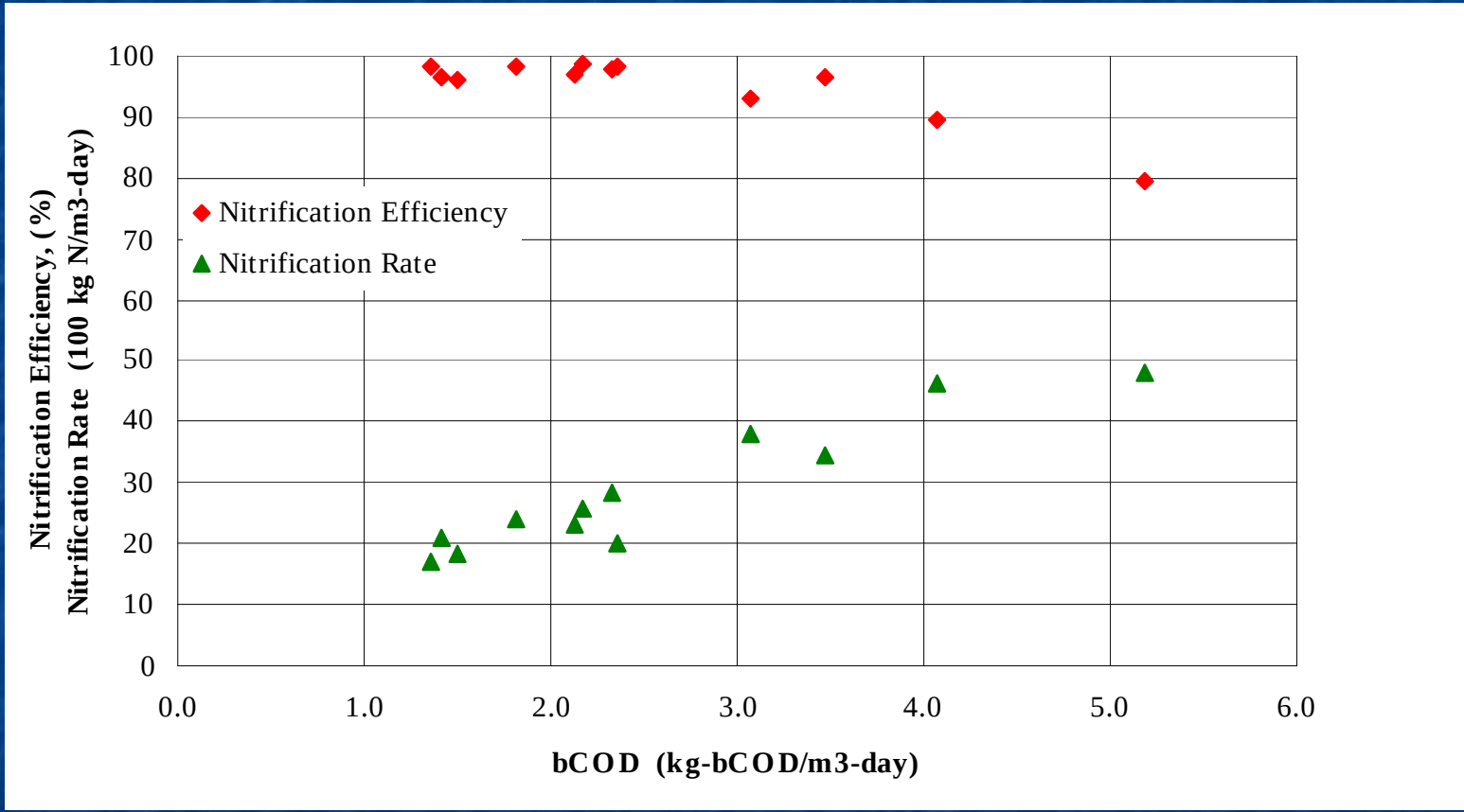
Loading and removal in agreement with data reported by Holbrook et al.

Results - Total Ammonia Loading



Loading and removal in agreement with data reported for 10 nitrification BAFs

Results - Organics & Nitrification



Loading and removal in agreement with data reported by Rogalla et al.

Results - Organics & Nitrification

- Diffusion Equation

$$\frac{\partial S}{\partial t} = D\nabla^2 S$$

- Oxidant & Reductant

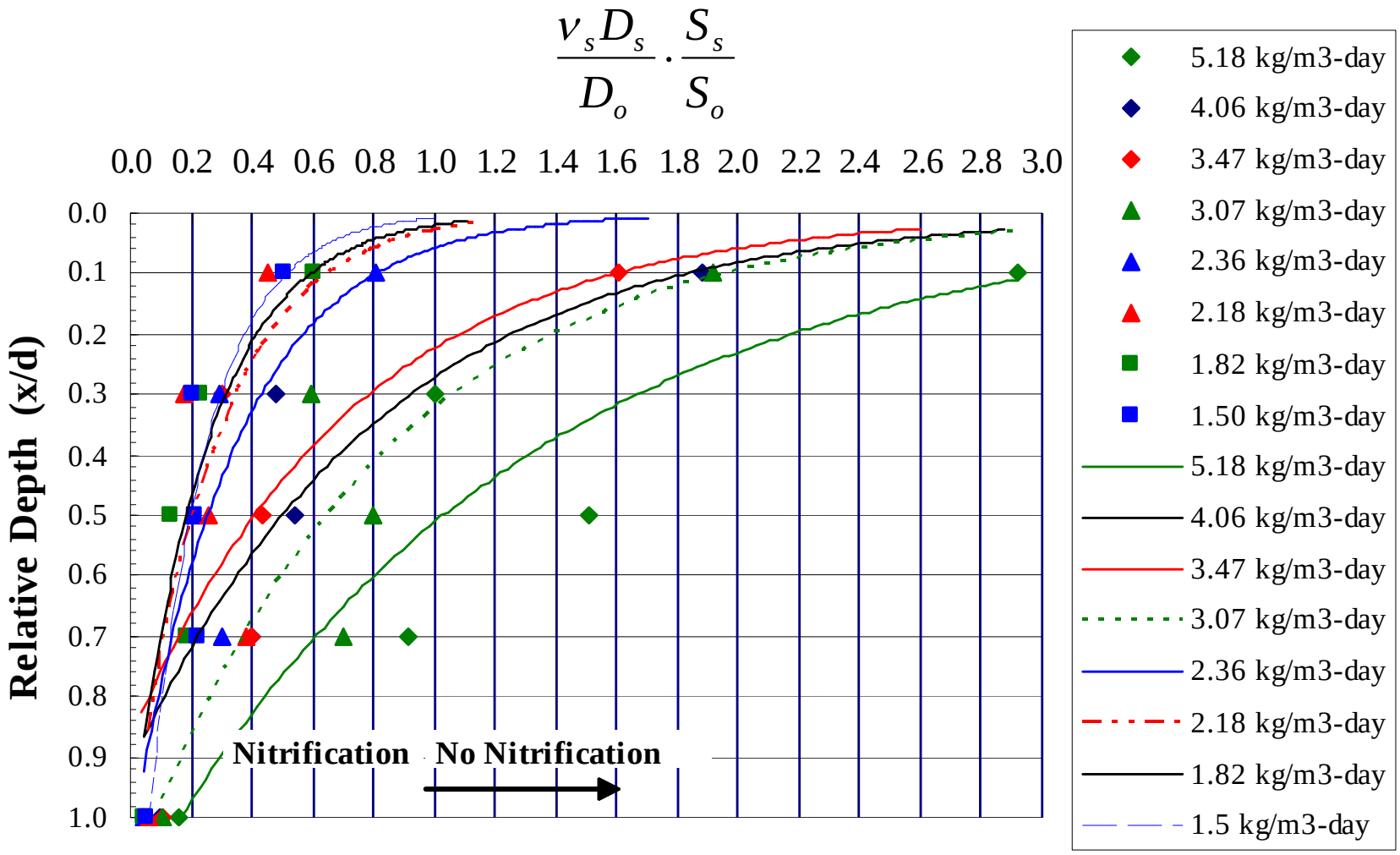
$$\frac{S_{ox}}{S_{red}} \overset{>}{<} \frac{D_{red}}{D_{ox}} \cdot \frac{k_{0,ox}}{k_{0,red}} = \frac{D_{red}}{D_{ox}} \cdot \frac{1}{\nu_{ox,red}}$$

- Established Criterion

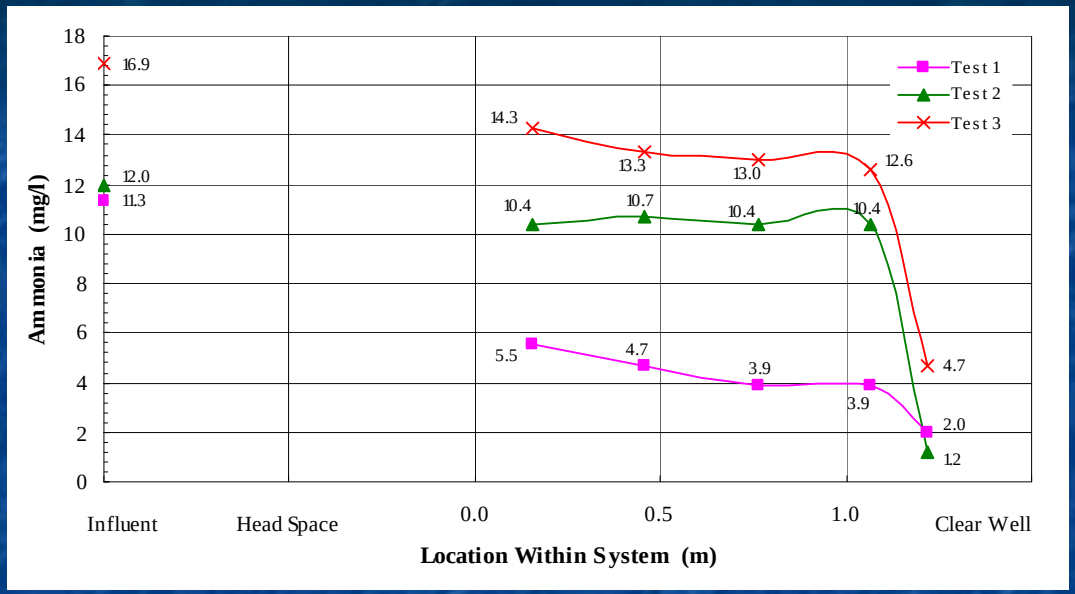
$$\frac{\nu_s D_s}{D_o} \cdot \frac{S_s}{S_o} = 1$$

  - (Williamson and McCarty 1976, Gönenc and Harremoës 1985, Gönenc and Harremoës 1990 and Henze et al. 2000)

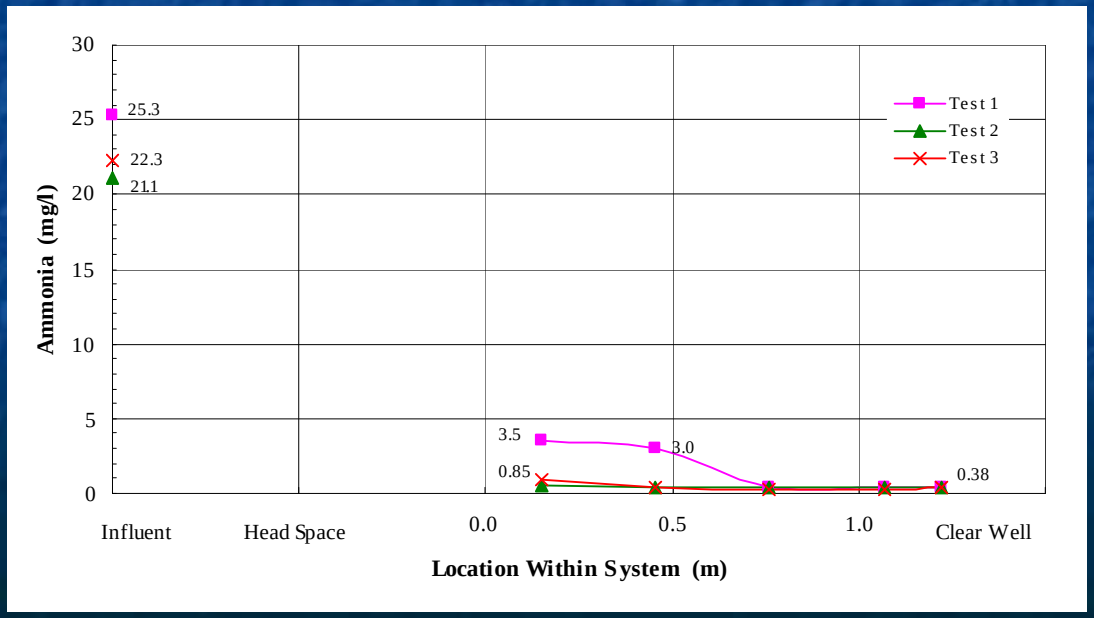
Results - Organics & Nitrification



Results - Organics & Nitrification

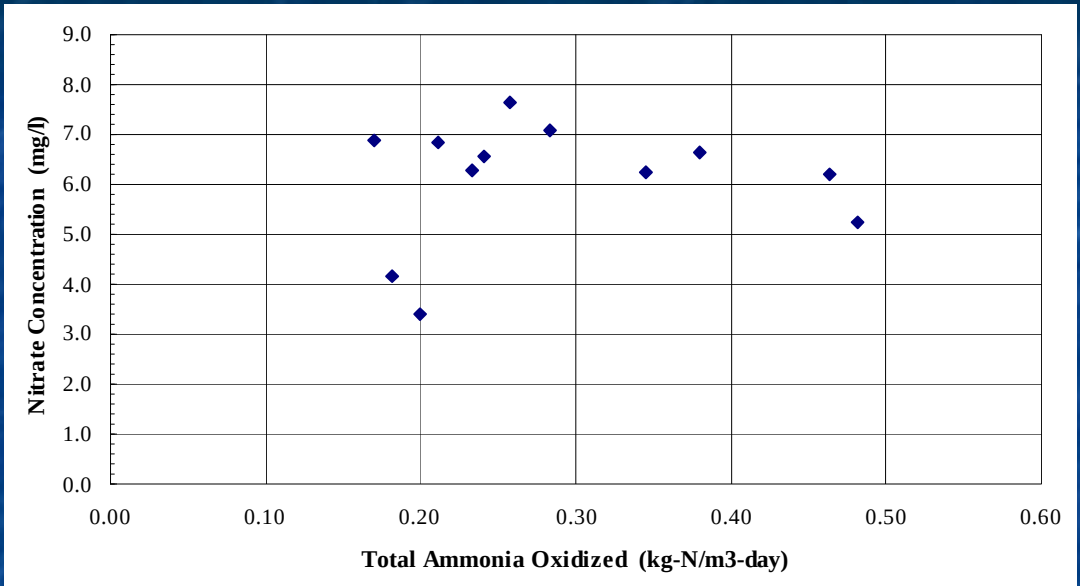


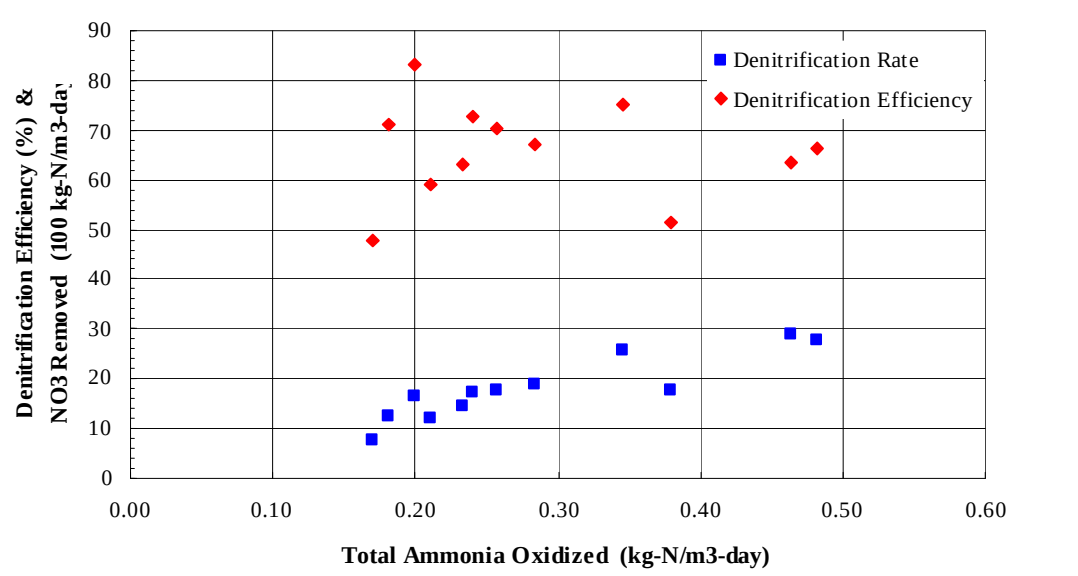
- Concentration Profiles
  - Organic Loading
  - 3.47 - 5.18 kg/m^3- day



- Concentration Profiles
  - Organic Loading
  - 1.5 - 2.18 kg/m^3- day

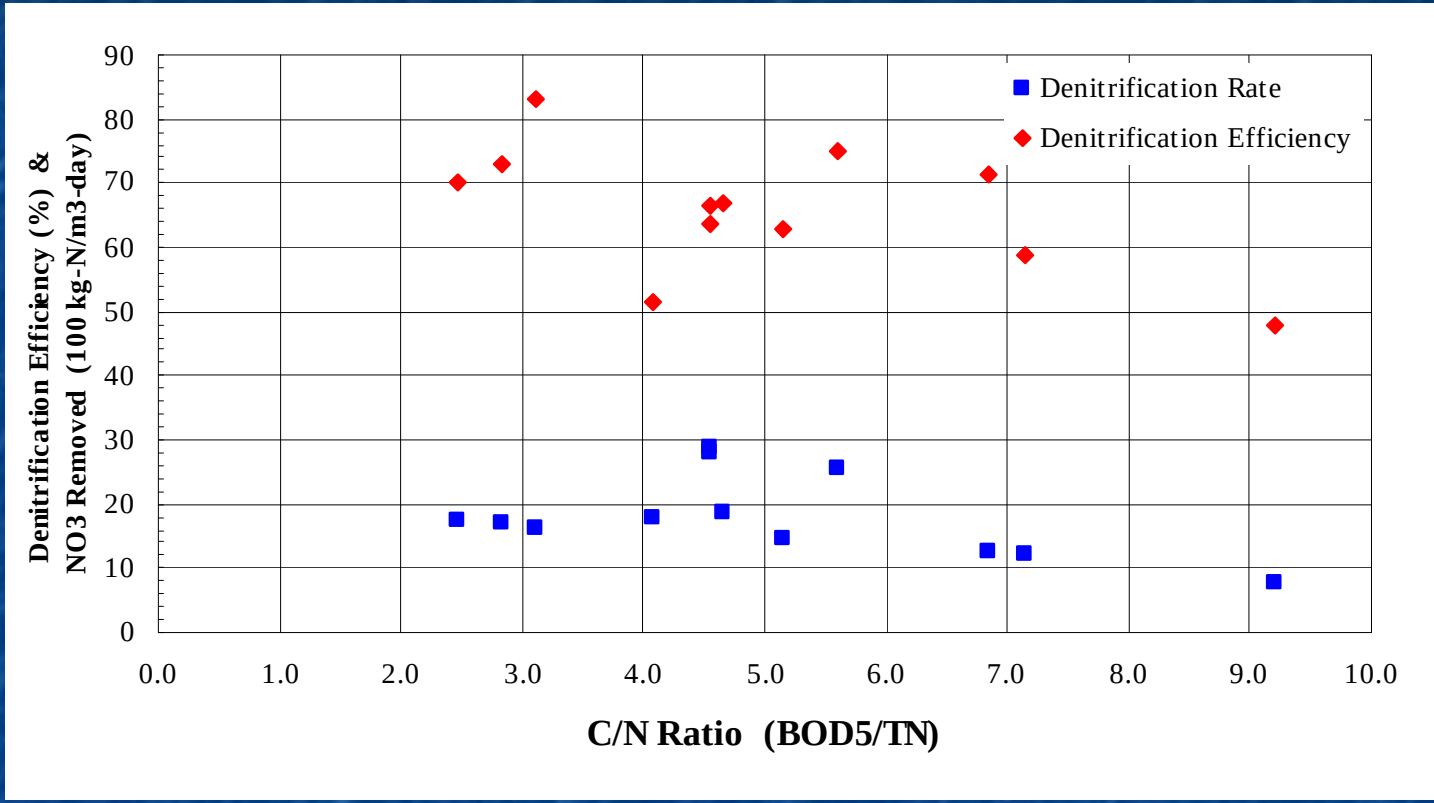
Results - Denitrification





- Effluent nitrate concentration high
- Rates: 0.077 - 0.29 kg/m^3 - day
- Efficiency 48 -83%

Results - Denitrification

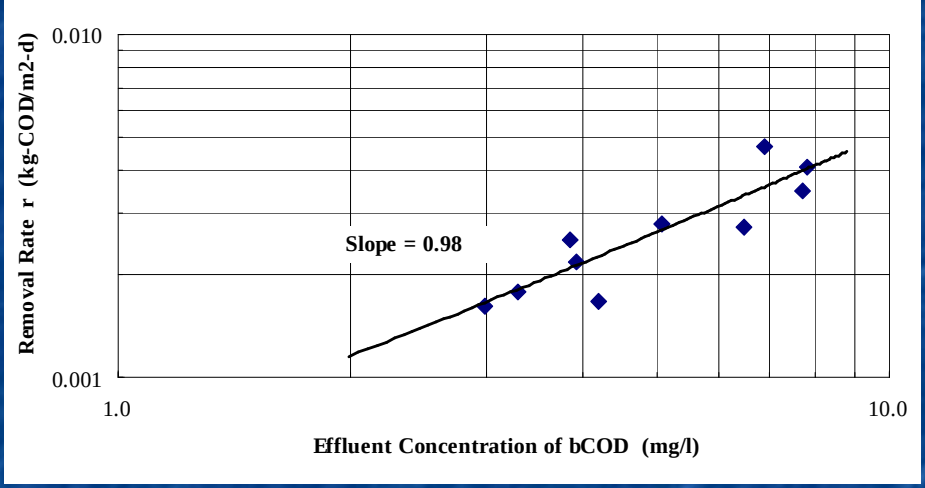


- Sufficient Carbon
- Excess DO

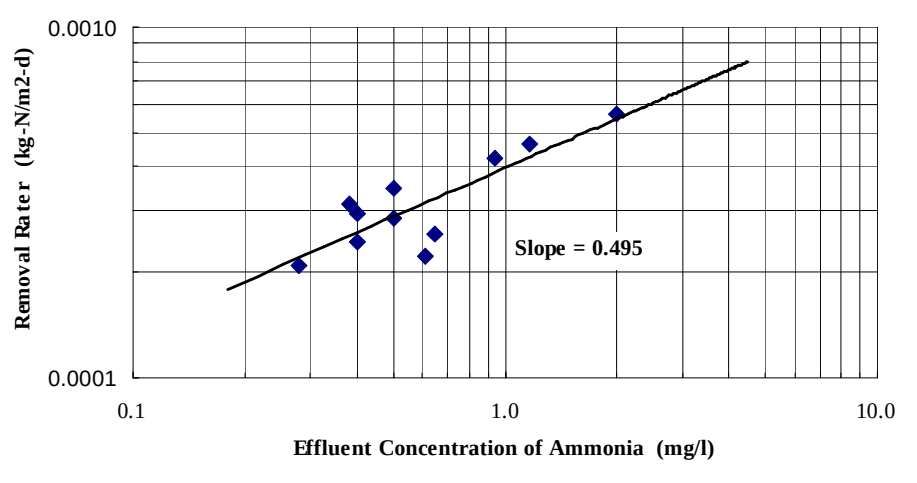
Results - Biofilm Kinetics

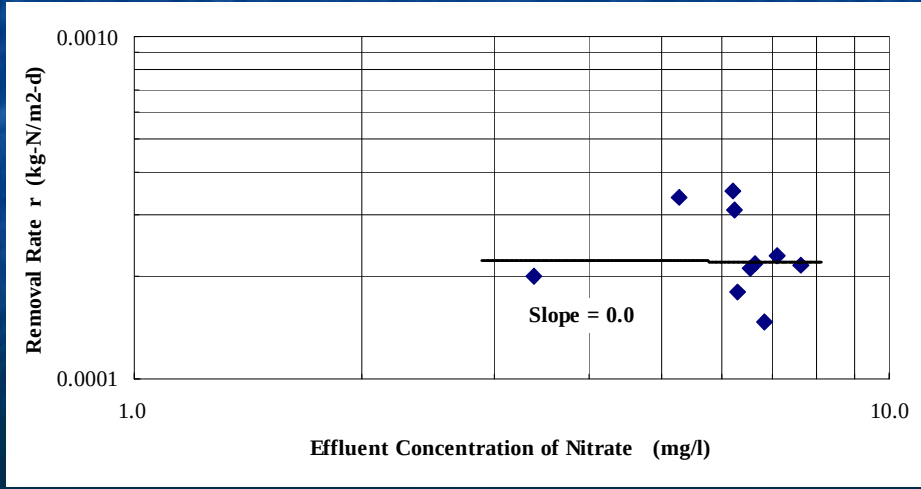
- Organics, ammonia and nitrate
- Log-log plot of removal rate per surface area as a function of concentration
  - slope of line indicates reaction order
    - (Harremoës 1976, Harremoës 1978, and Henze et al. 2000)

Results - Biofilm Kinetics

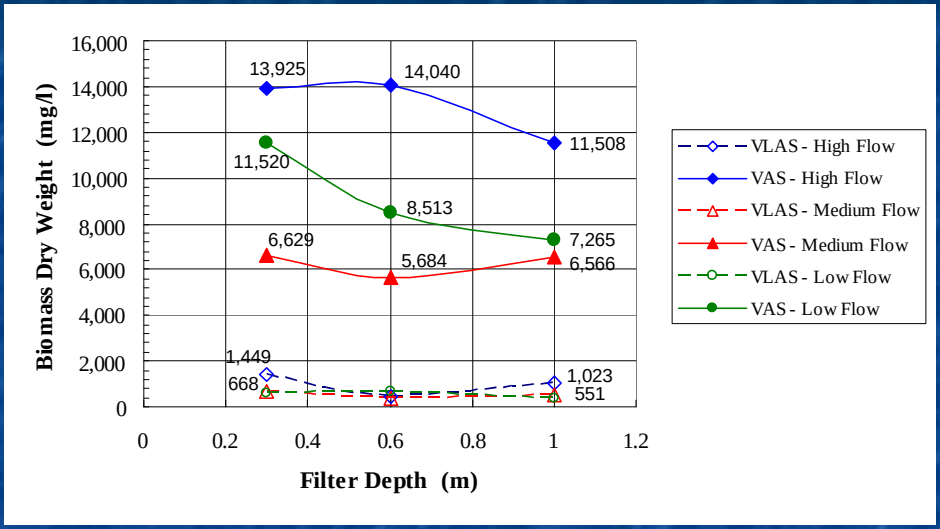


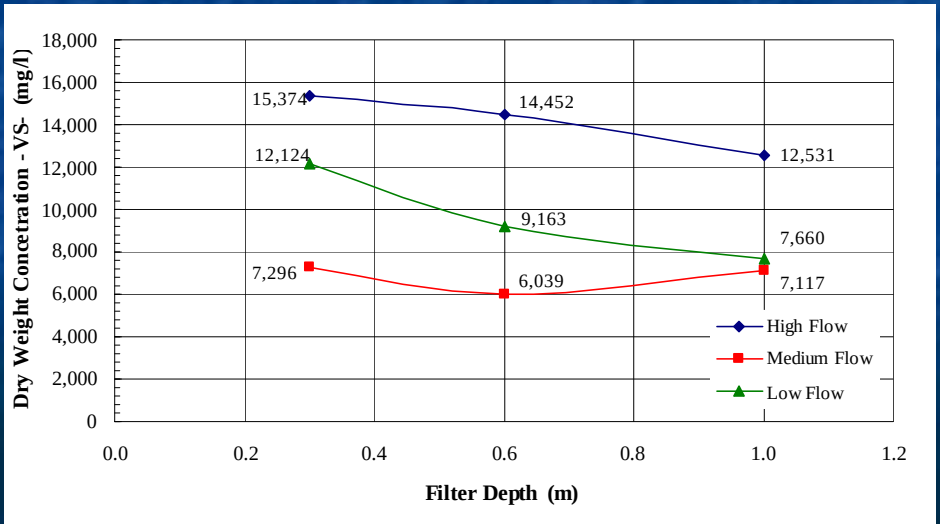
- Removal of organics
  - first order kinetics
- Nitrification
  - half order kinetics
- Denitrification
  - zero order kinetics





Results - Biomass





- Dry mass of biofilm
  - VLAS
  - VAS
  - VSS within interstitial volume was negligible

Conclusions

- Simultaneous oxidation of organics and nitogen removal achieved,
- Intermittent aeration created adequate environment, but could be improved
  - control of aeration
    - ORP or DO probes
    - online analysis of nitrate and ammonia
- Determine optimum biofilm thickness
  - may improve denitrification
- Study backwash effects on biofilm

Acknowledgments

- Professor Hameed Methgalchi, Northeastern U.
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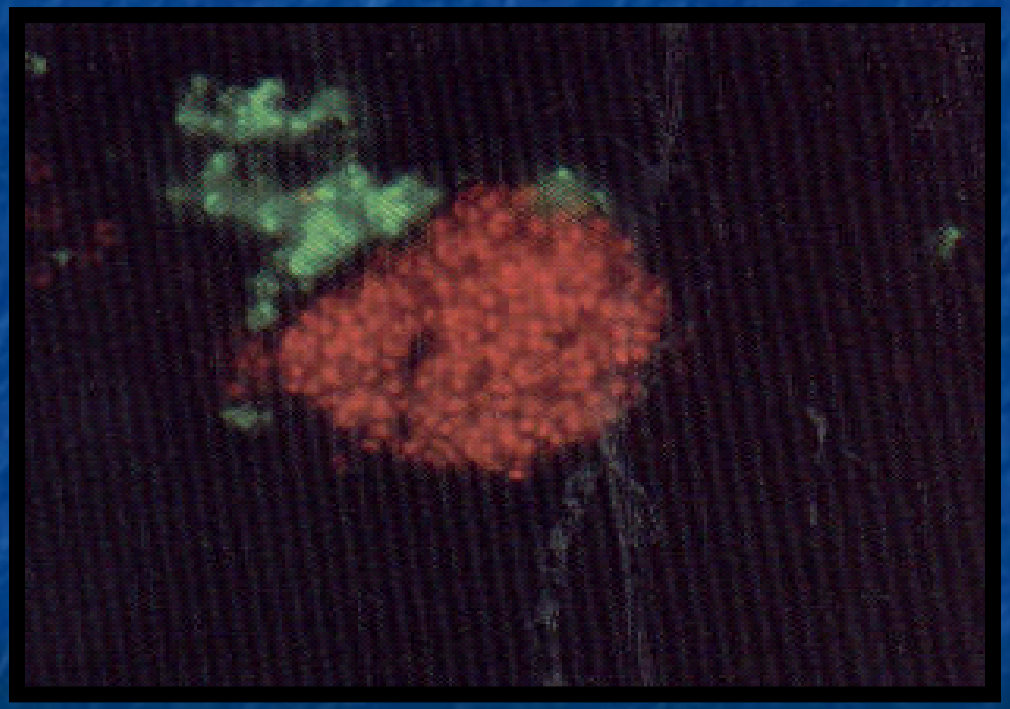
- Mr. Bernard Beamster, ASA Chemscan
- HOMA Pump Technology
- Liquid Milltronics

Thank You & Questions

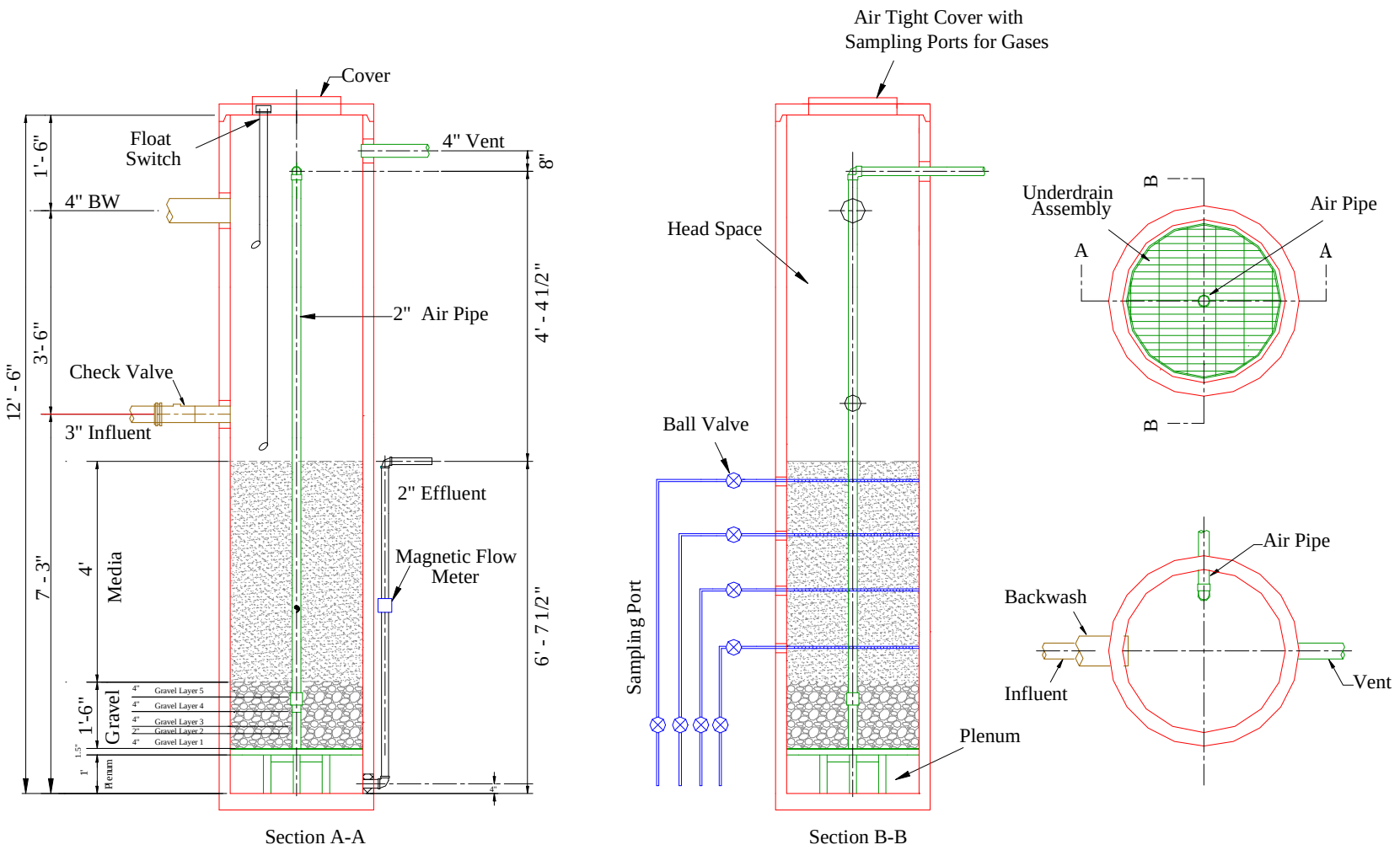


Nitrifying Bacteria

Introduction

- Previous applications of SAGBs
  - oxidation of carbonaceous matter (organics)
  - nitirification
  - denitirification
  - simultaneous oxidation of organics and nitrification

Experimental Design



Submerged Attached Growth Bioreactor

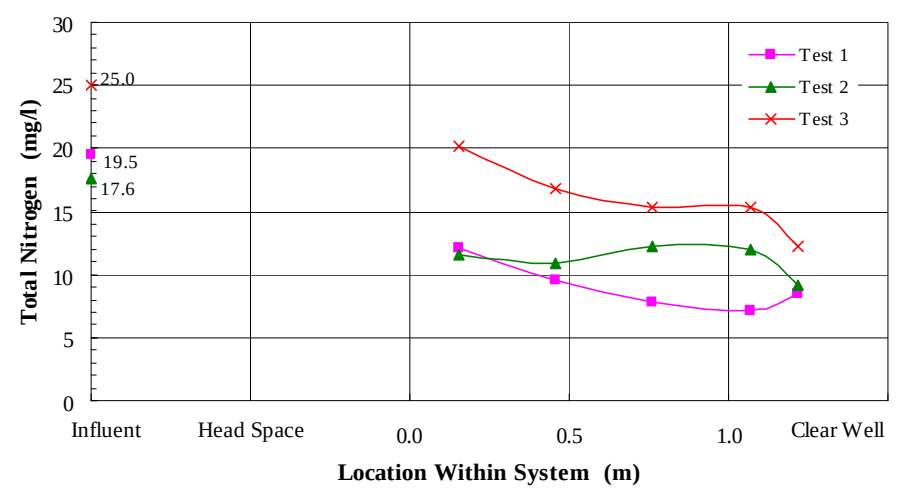
Experimental Design

- Environmental conditions within reactor were achieved by:
  - Intermittent aeration
  - Alkalinity feed
  - Constant air and water velocities

Experimental Results

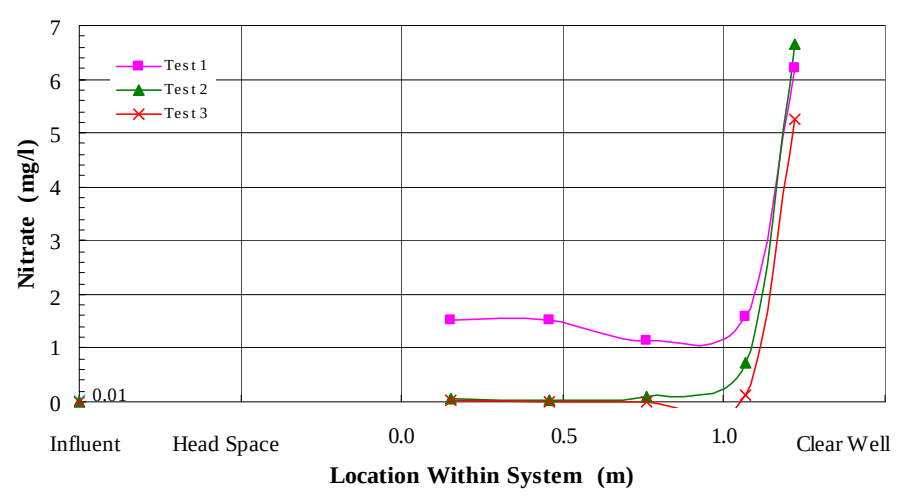
- System characteristics of CMSTR
- SAGB characteristics of plug flow reactor
- Location within filter where nitrification occurred, related to organic load
- TN < 10 mg/l was achieved in all cases

Experimental Results

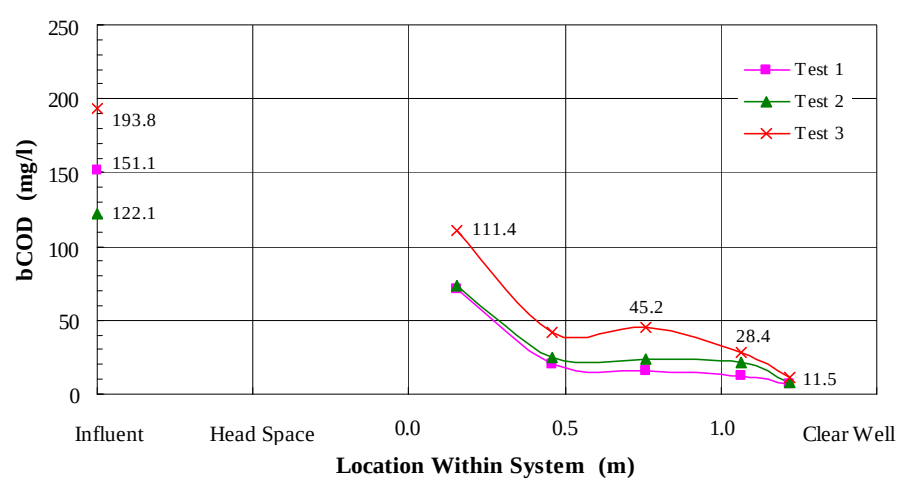


Ammonia Concentration

- Flow 8.3 m^3/d
  - organics removal in upper portion of filter
  - flat ammonia & nitrate profile within media
  - nitrification in gravel layer

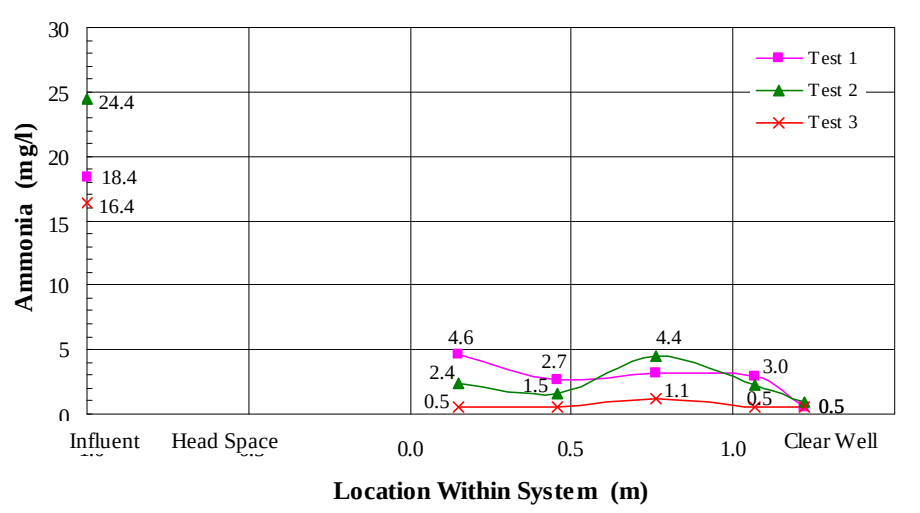


Nitrate Concentration



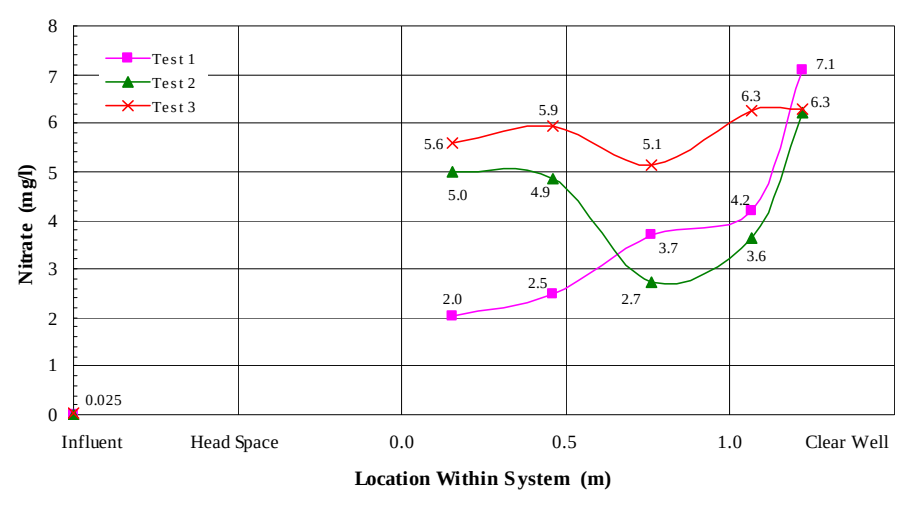
bCOD Concentration

Experimental Results

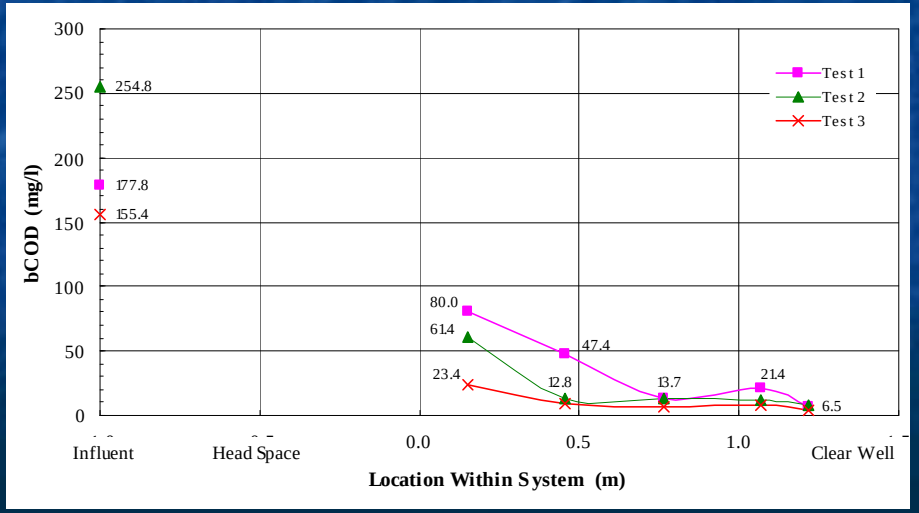


Ammonia Concentration

- Flow 4.5 m^3/d
  - organics removal in upper portion of filter
  - flat ammonia & nitrate profile within media
  - nitrification in gravel layer

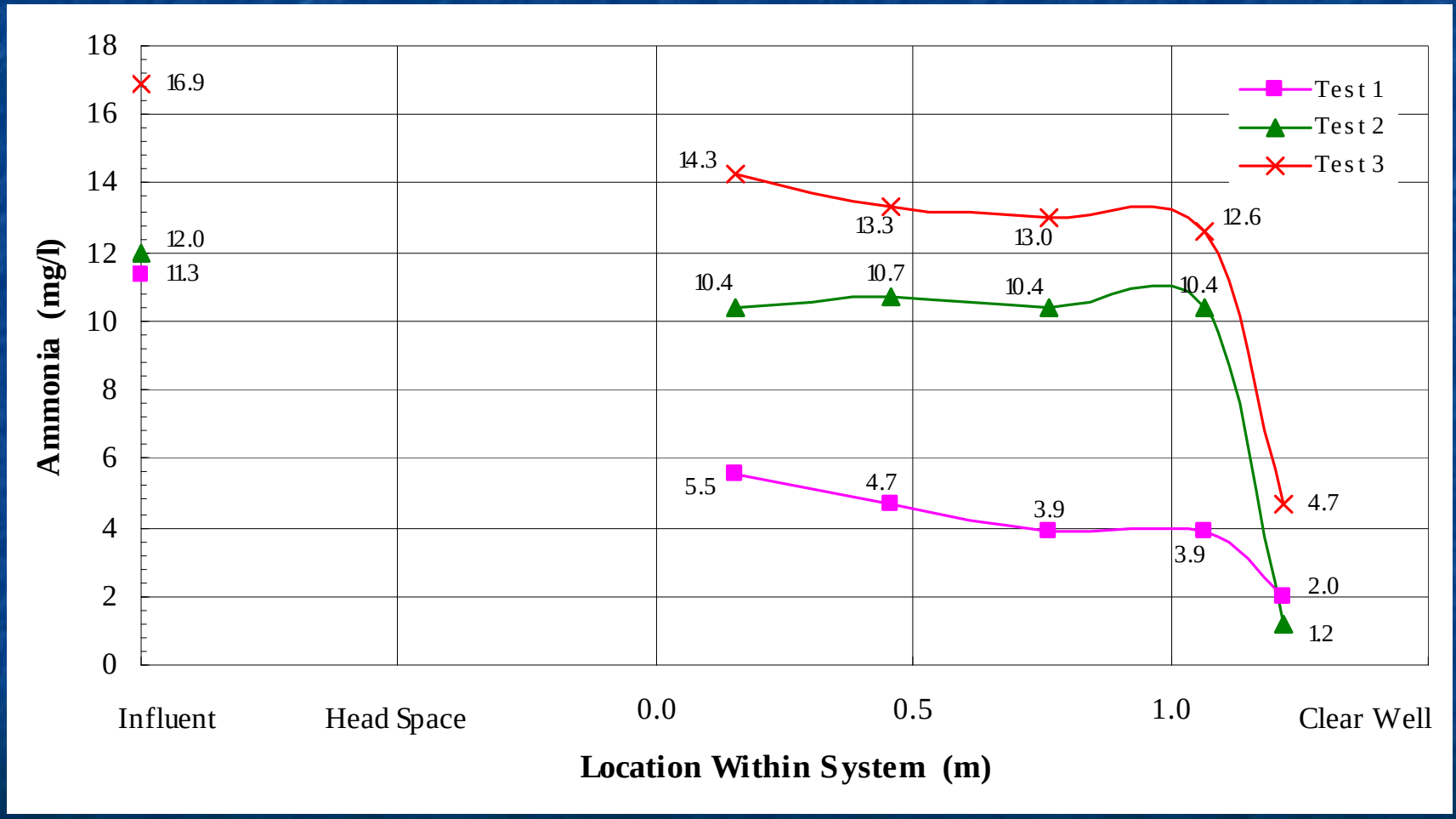


Nitrate Concentration



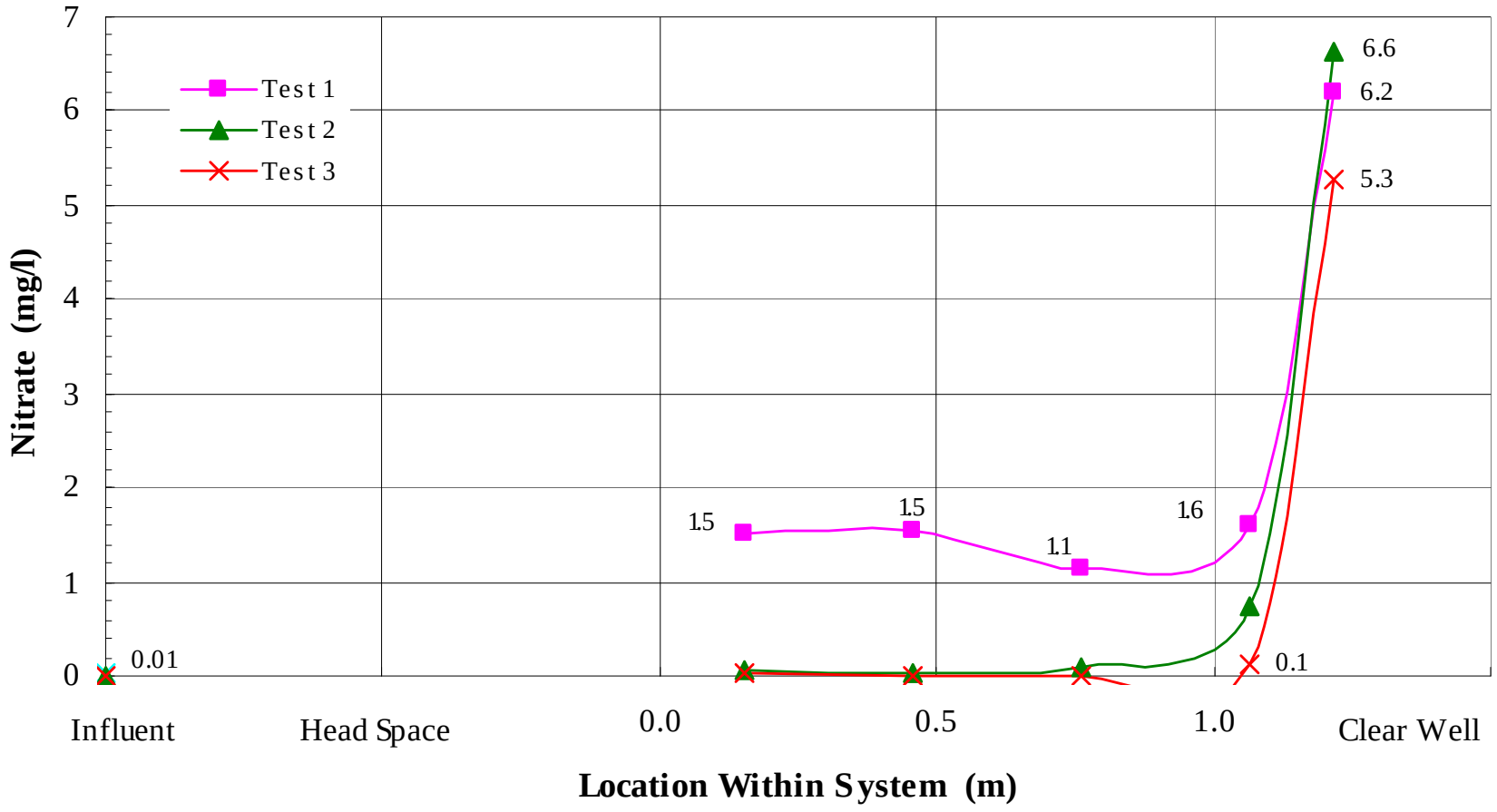
bCOD Concentration

Experimental Results



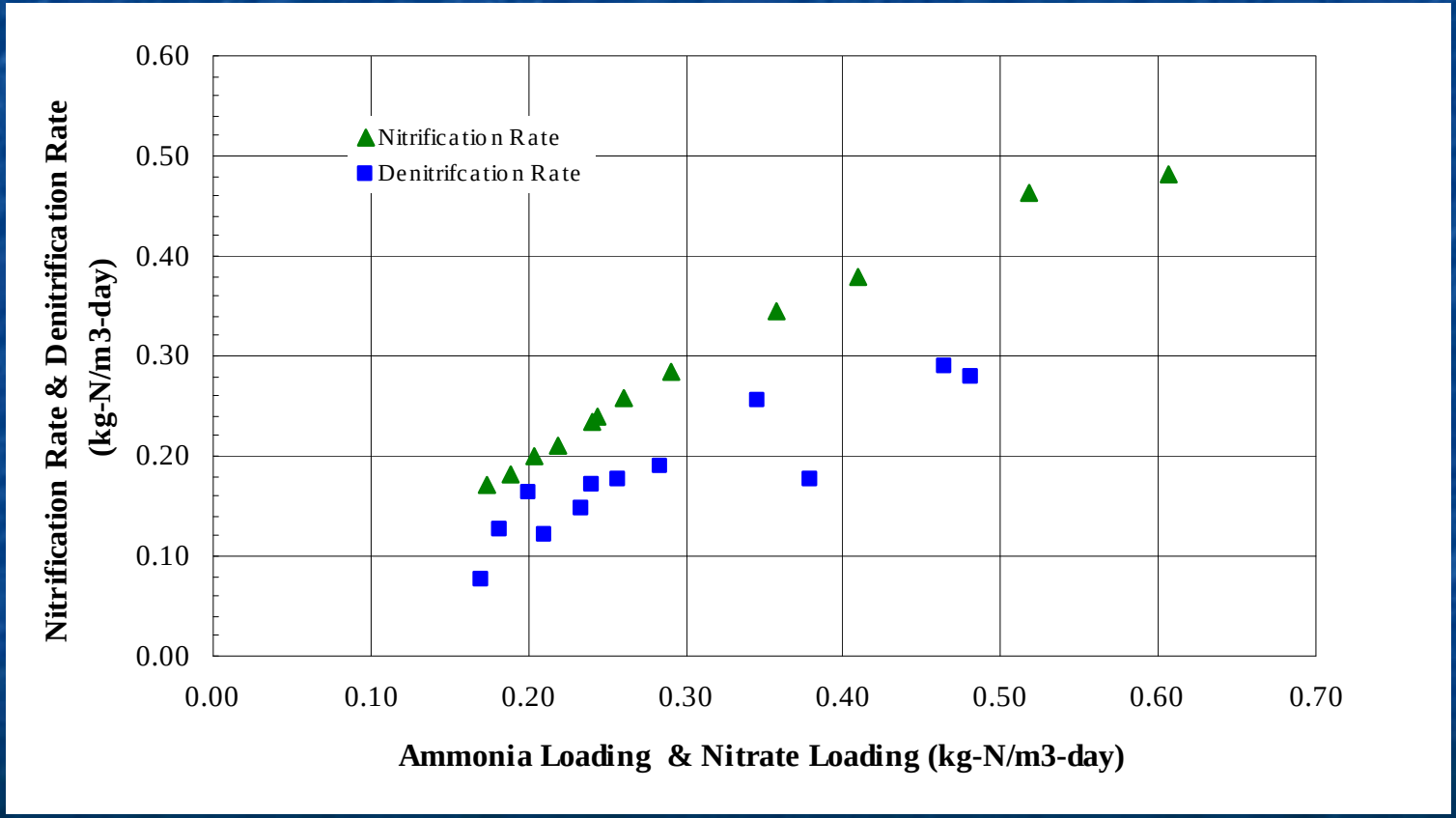
Ammonia Concentration - 8.3 m^3/d

Experimental Results

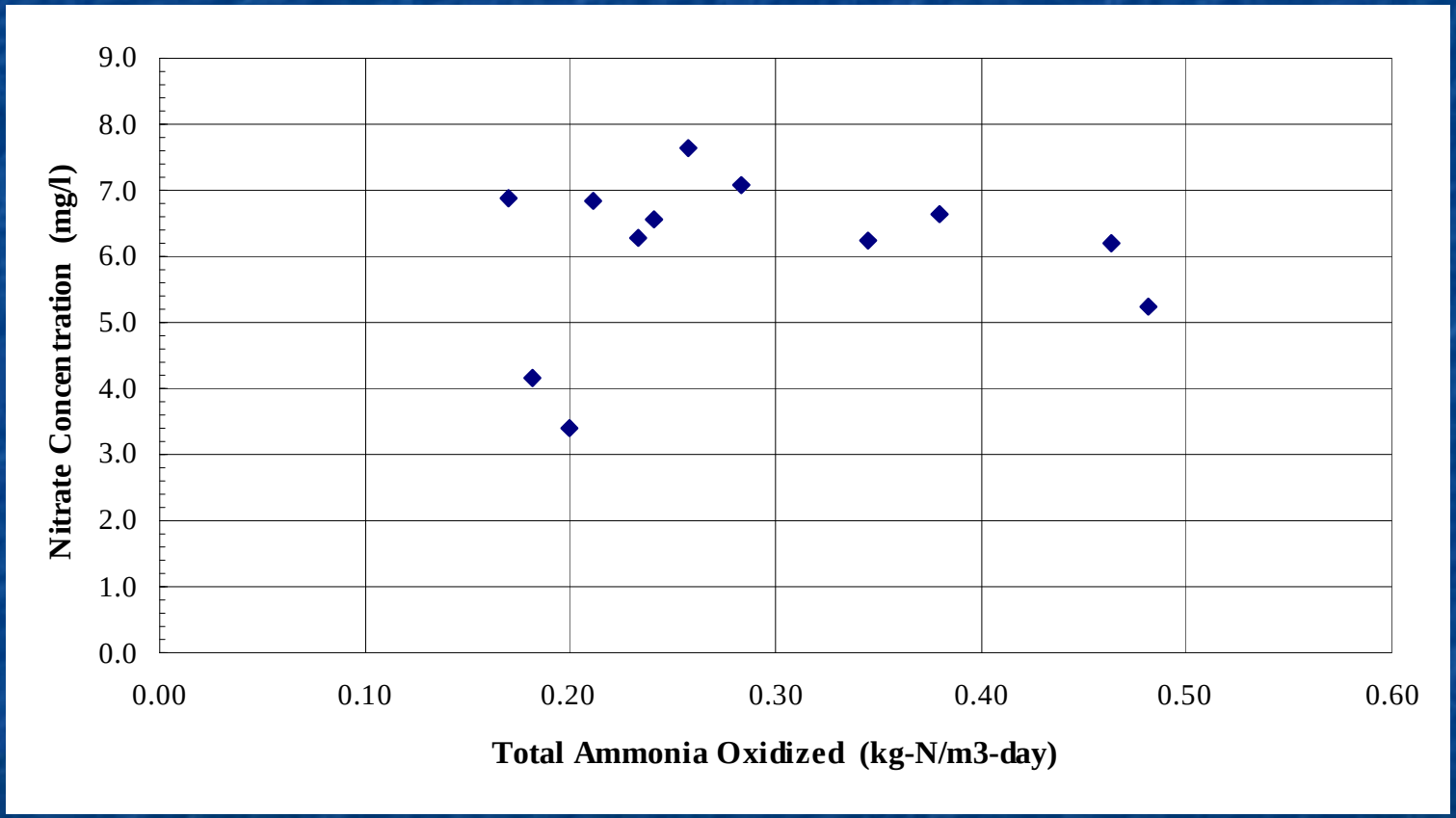


Nitrate Concentration - 8.3 m^3/d

Experimental Results

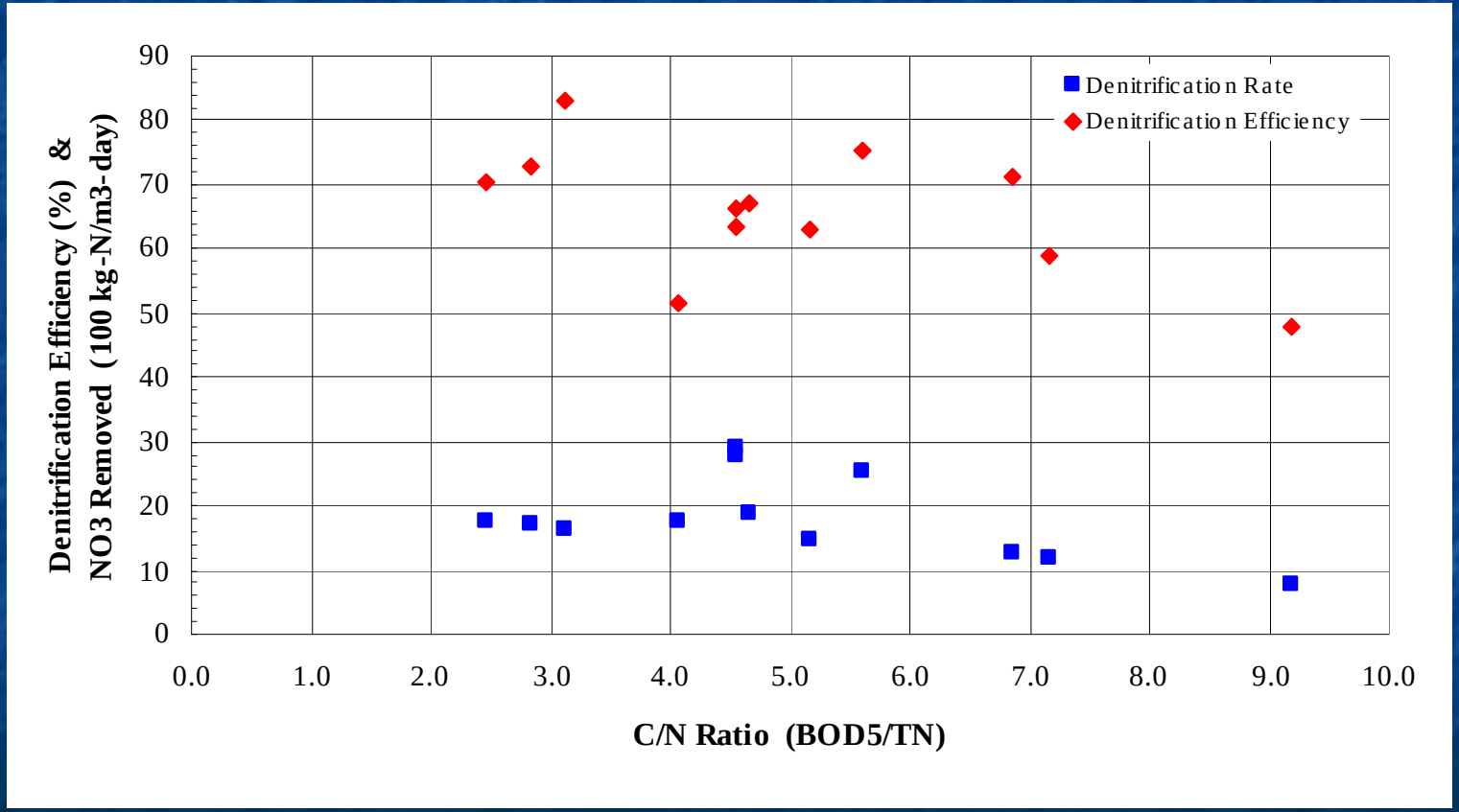


Experimental Results - Nitrates

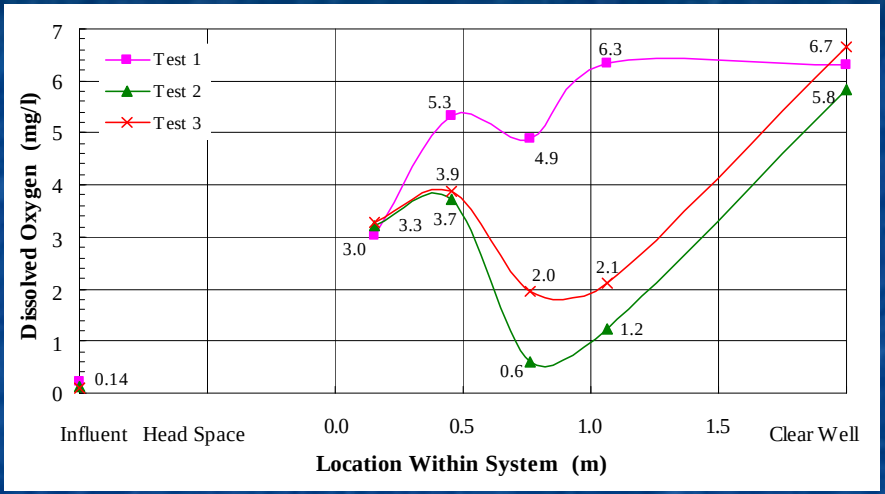


Denitirification rate and efficiency vs. nitrate loading.

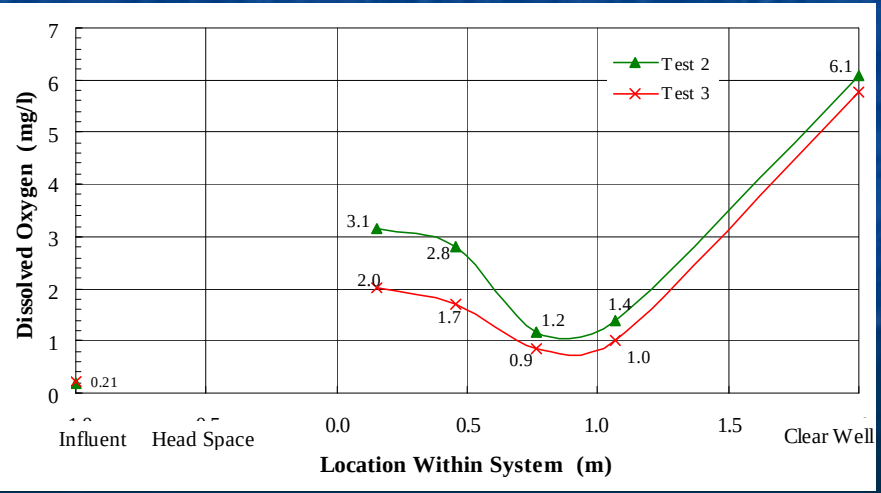
Experimental Results - Nitrates



Experimental Results - Nitrate

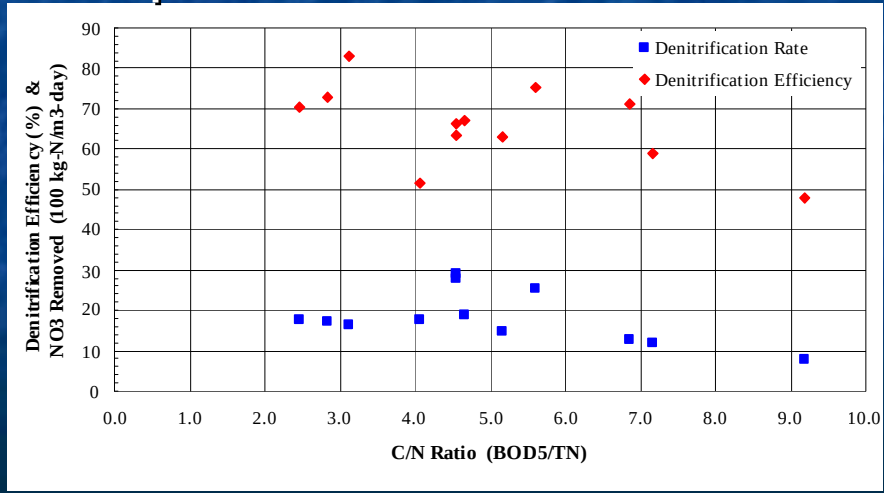


DO Concentration - 4.5 m^3/d



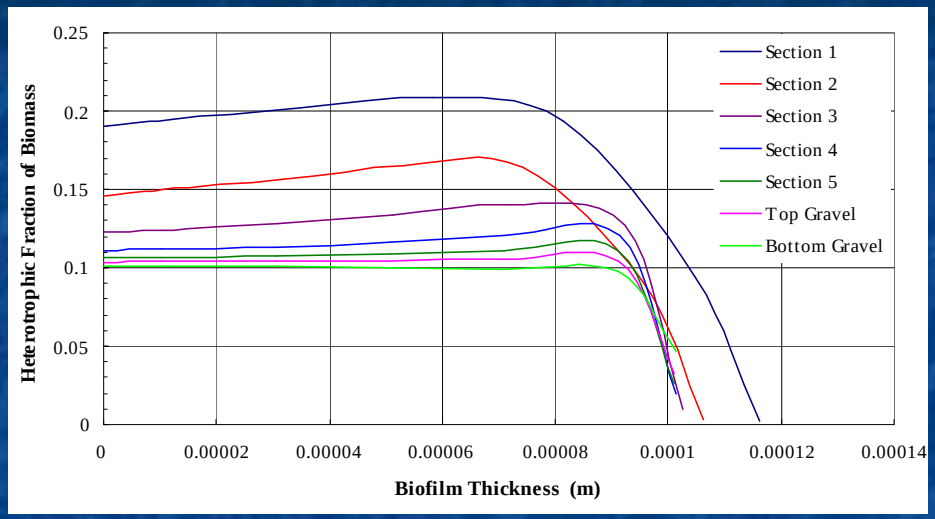
DO Concentration - 4.1 m^3/d

- Factors affecting rate
  - C/N ratio > 3
  - linear reduction in denitrification rate proportional to the DO concentration to half power

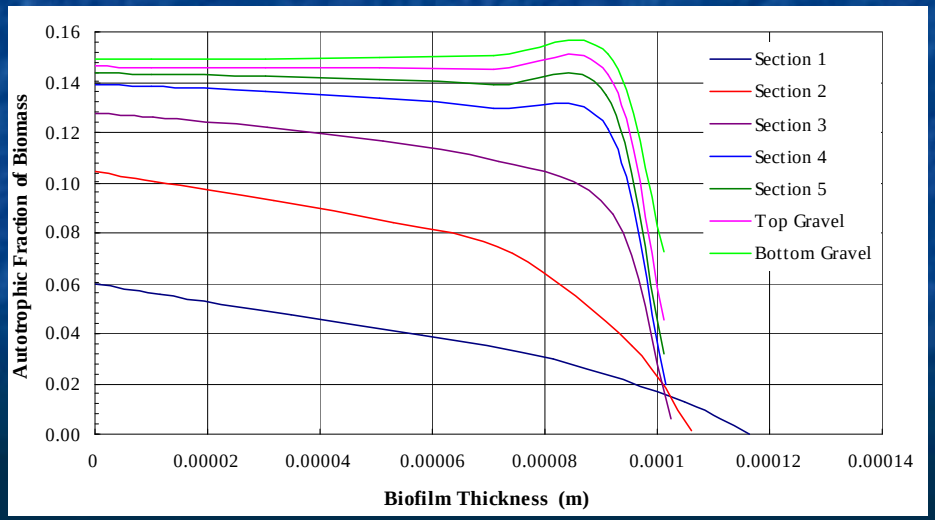


Denitrification rate and C/N ratio

Numerical Simulation Results

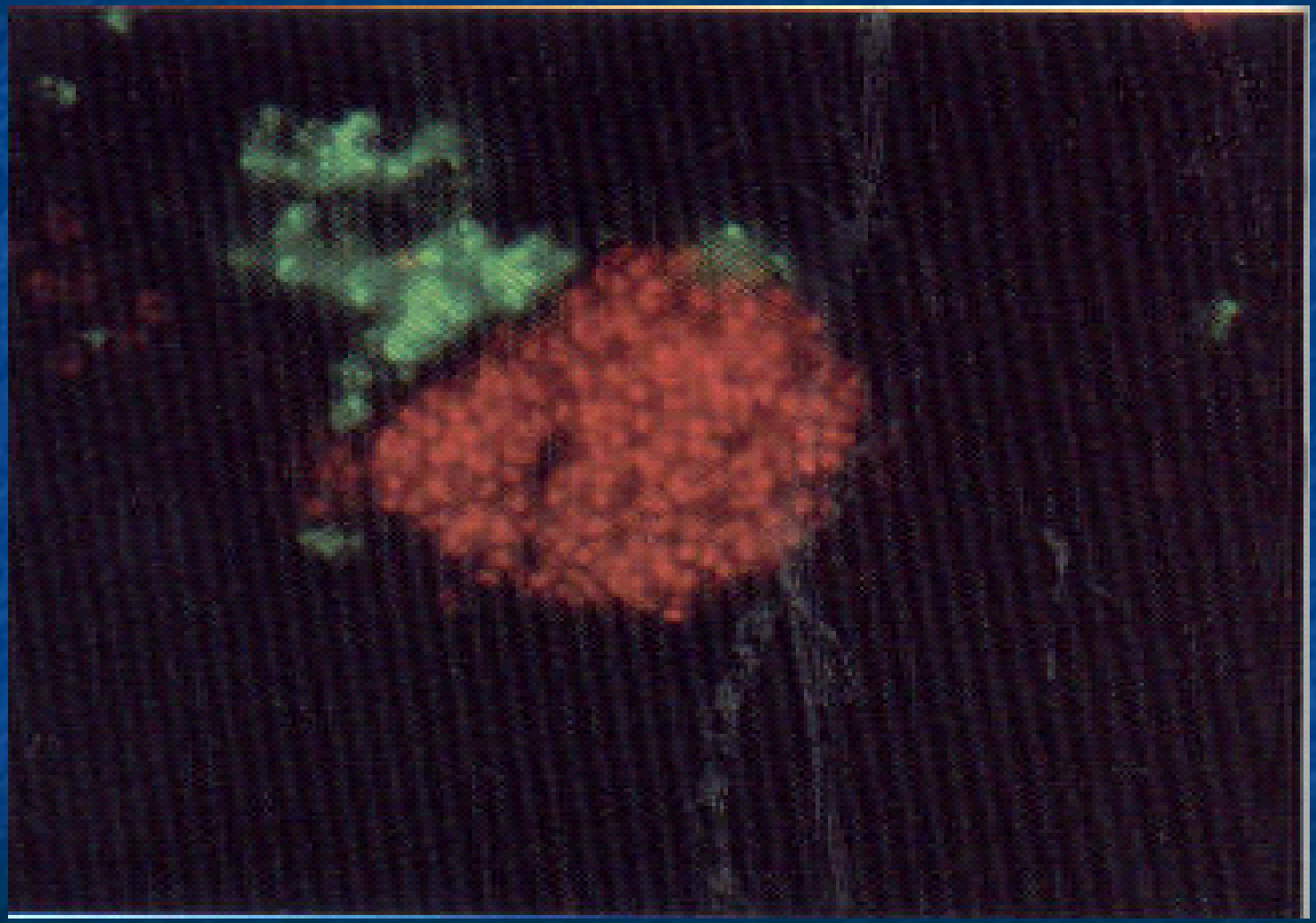


Fraction of Heterotrophs



Fraction of Autotrophs

- Model Results
  - heterotrophs dominant in upper portion of filter
  - supports concentration profiles



Thank You

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  - Northeastern University
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  - EWAG
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  - FR Mahony & Associates