Performance of a Pilot-scale Nitrifying Trickling Filter treating Aerated Lagoon Effluent

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University of Idaho

Presentation Outline

- Project Background
- NTF Pilot Design
- Historical Trends
- Design Method
- Data Collection and Testing
- Model Comparison
- Conclusions

Washington
N
CANADA
Bellingham
Port Angeles
Everett
Kirkland
Bellevue
Bremerton
Seattle
WASHINGTON
Spokane
Wenatchee
Auburn
Tacoma
Aberdeen
Olympia
Ellensburg
Moses Lake
Colfax
48°
ID
Pacific Ocean
Yakima
Richland
Pasco
Kennewick
Longview
Walla Walla
46°
Vancouver
0 50 100 mi
0 50 100 km
OREGON
124°
122°
120°
118°
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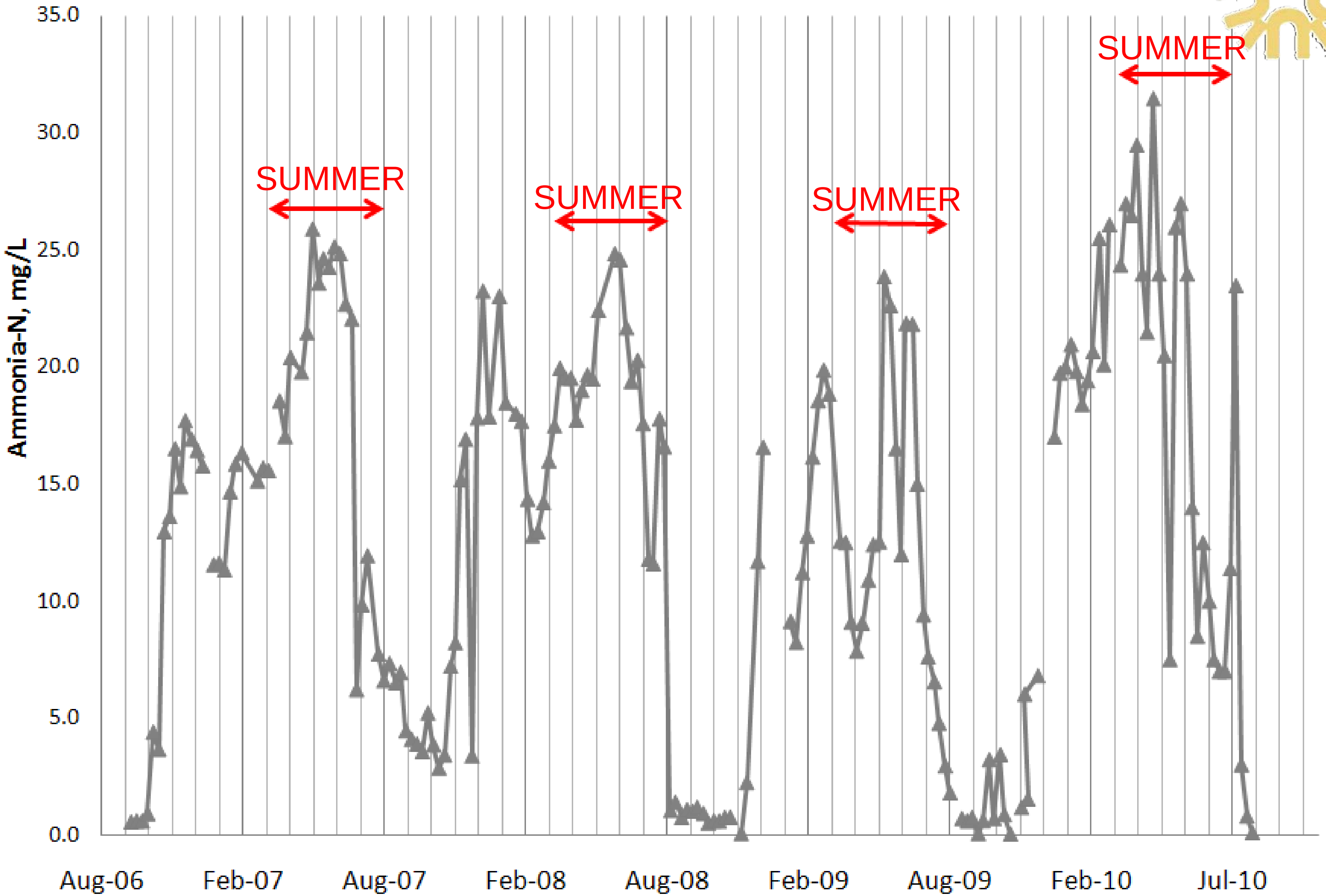
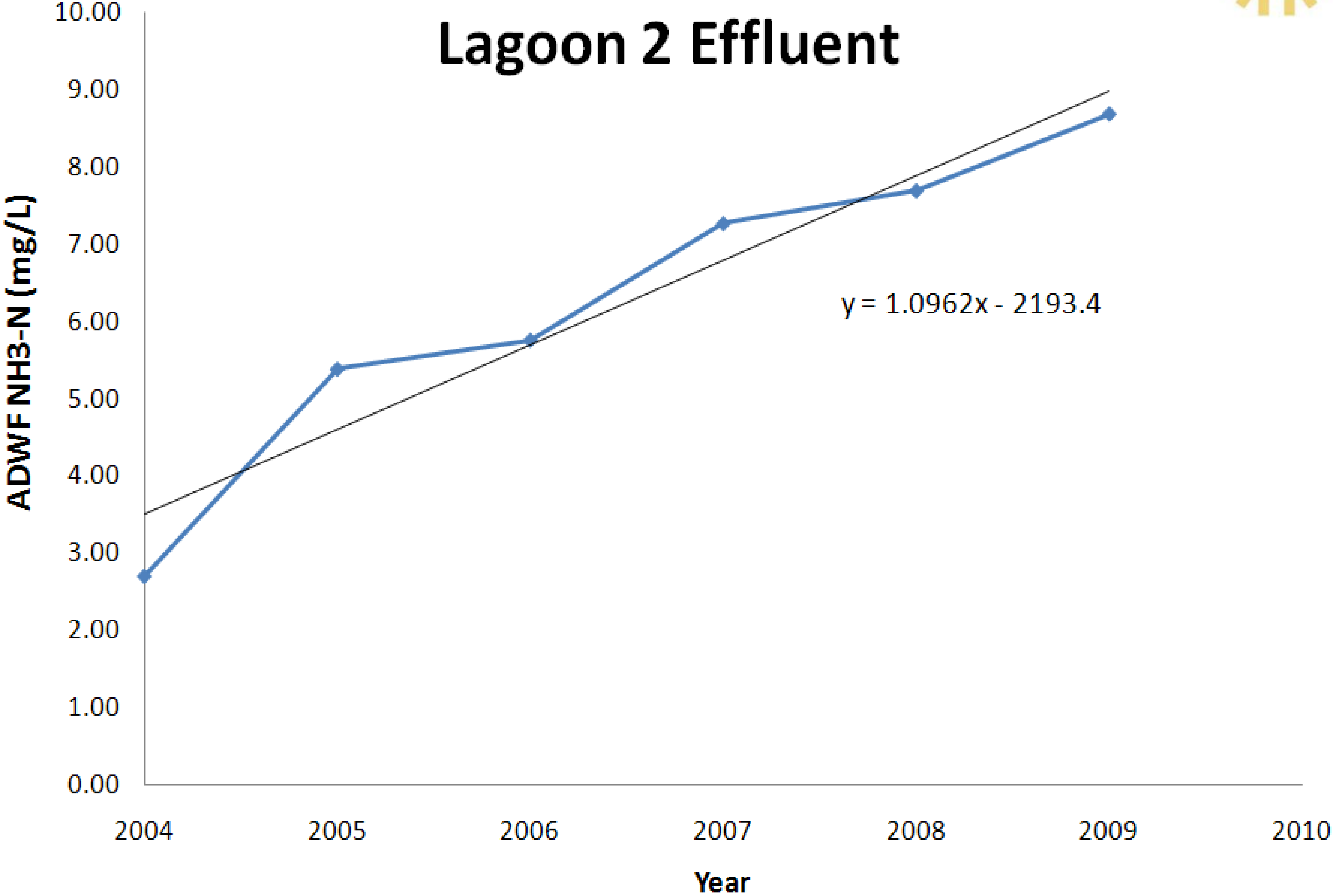
Project Background

- Colfax's Population: **2,850 people**
- Plant Influent: **0.360 mgd**
  - Average Dry Weather Flow
- Removal Mechanisms: **Aerated Lagoons**
  Chlorination Basin
- Current Effluent Regulations: **BOD, Fecal Coliform**
- Future Effluent Regulations: **Ammonia-N**

Lagoon 2 Ammonia-N Concentration



NH3-N Historical Trend Lagoon 2 Effluent



Project Questions

- Are Nitrifying Trickling Filters a "good-fit" for Colfax?
- Which design model best fits the collected data?
- Based on the data collected how would our design change?

Number of Lagoons in Northwest

- **63 in Washington**
  - 27% of NPDES Permits- Municipal Lagoons
- **59 in Oregon**
- **40 in Idaho**
  - 50% of NPDES Permits- Municipal Lagoons

NTF Pilot Design

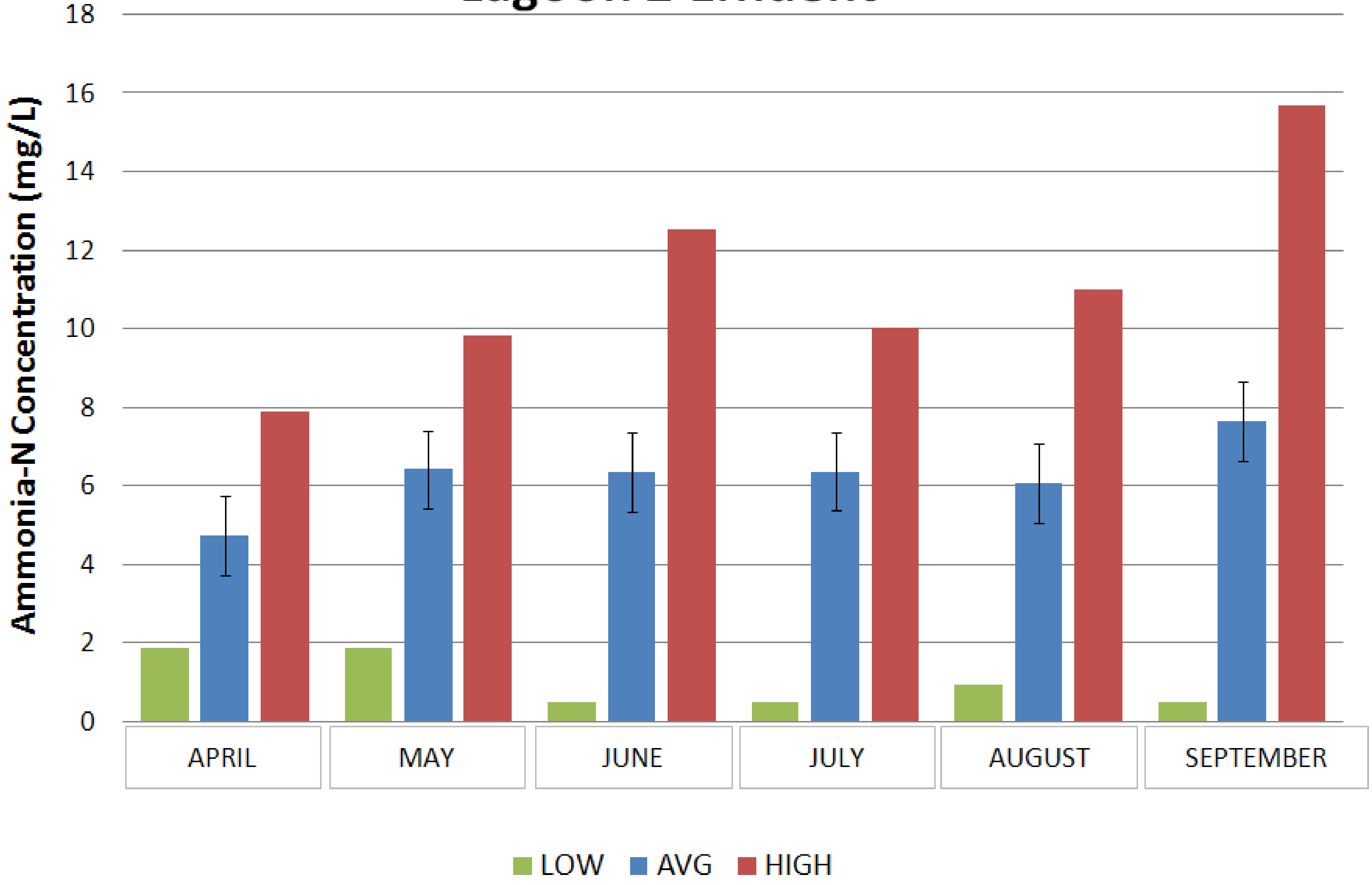
- Flow Rate
- Influent Characterization
- Design Method
- Media Selection
- Distribution System
- Oxygen Requirements

Average Dry Weather Flow

Flow Rate

- Anticipated Permit Season: Dry Weather Season
  - April through September
- Historically the ADWF 0.36 mgd
- Pilot influent 5% of total plant effluent
  - 12.5 gal/min
  - Low/Med hydraulic load for media type

Average Monthly Concentration 2004-2009
Lagoon 2 Effluent



Influent Characterization: NH_3

- **High NH_3:** **15.66 mg/L**
- **Average NH_3:** **6.26 mg/L**
- **Low NH_3:** **0.48 mg/L**
- **Design NH_3 influent:** **10-25mg/L**
- Steady increase in NH_3 concentrations
  - Increasing approximately **1.0mg/L** per year

Influent Characterization: BOD

- Major Concern for Biofilm Growth
  - Heterotrophic (BOD) vs. Autotrophic (NH_3)
  - **Heterotrophs will overtake at high BOD concentrations**
- Historical BOD Concentrations
  - **5.0-11.0 mg/L**
  - Therefore not a major concern

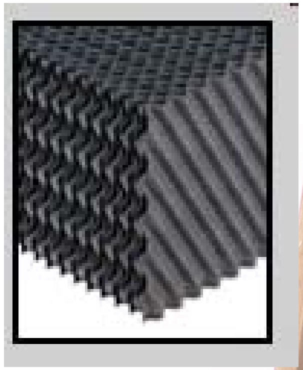
Pilot Design Method

- NTF Design Methods
  - Albertson and Okey Procedure
  - Line Fit Equation
  - Metcalf and Eddy
  - Gujer and Boller Equation
- **New Project Objective**
  - Compare and Contrast Methods with Data

Pilot Design

- Followed: **Metcalf and Eddy guidance**
- Constants and Assumptions
  - Nitrification Rates
  - Half-velocity Constant (K_n =1.5mg/L Ammonia-N)
  - Constant describing the decrease in rates as a function of depth ($k = 0.2m^{-1}$)
  - Transition Concentrations (N_T)

Media Selection



- Requirements:
  - High Specific Surface Area (ft^2/ft^3)
  - Durable
  - Minimize Clogging
  - Maximize Air Flow
- Cross-Flow Media
  - Yielded positive results for NH_3 removal
- Brentwood Industries CF-1900

Distribution System

- Target Hydraulic Loading Rate (HLR)
  - Brentwood Industries
  - Metcalf Eddy Design HLR
- Translate to Upscale
- Tipping-Bucket Design
  - Mimic distribution arm
  - Even distribution- Trough System

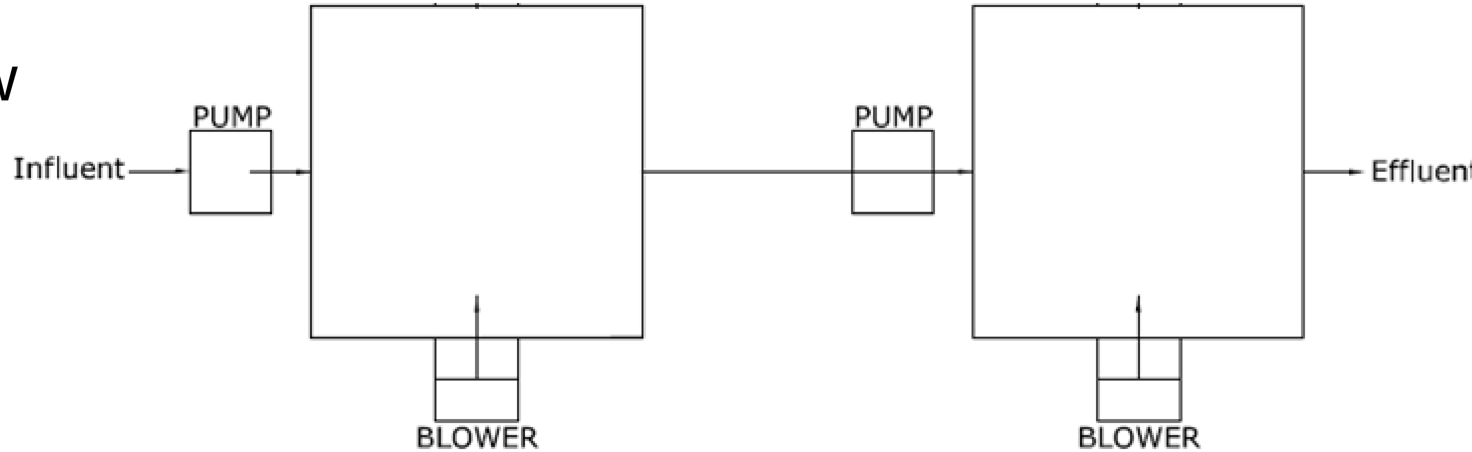
Oxygen Requirement

- Estimated: 3.7 ft^3/min Airflow
- Prevent oxygen from being the limiting factor
- Data Collected:
  - Influent: **4.0-5.0** O_2 mg/L
  - Effluent NTF: **7.0-8.0** O_2 mg/L
- Data shows **sufficient oxygen**

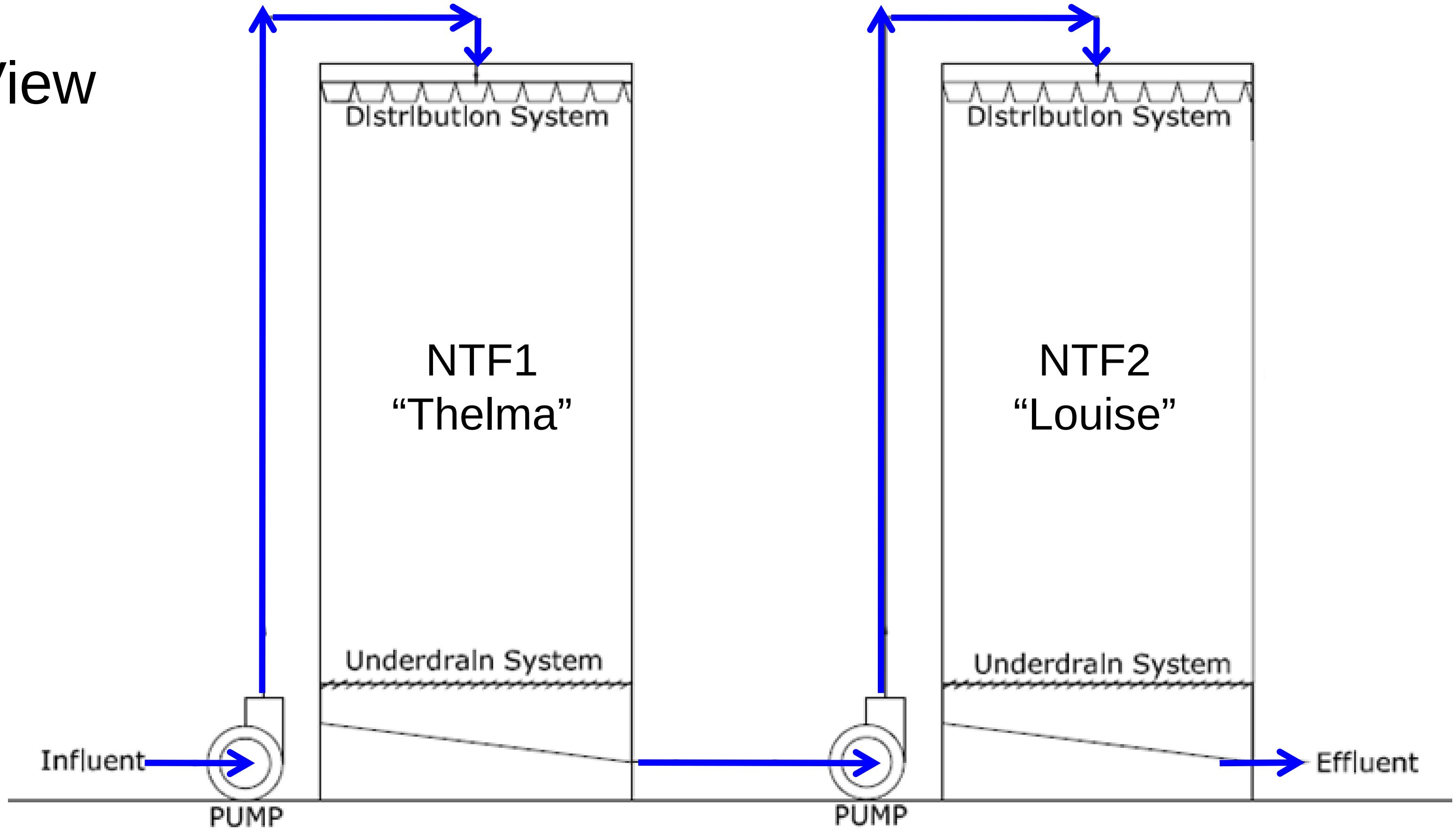
Final Design

- Two NTFs in series
- **Media Depth:** 8.0ft each
  - Total: 16.0ft
- **Width:** 4.0ft
- **Length:** 4.0ft
- **HLR:** 0.781 gpm/ft^2
  - Flowrate: 12.5gpm

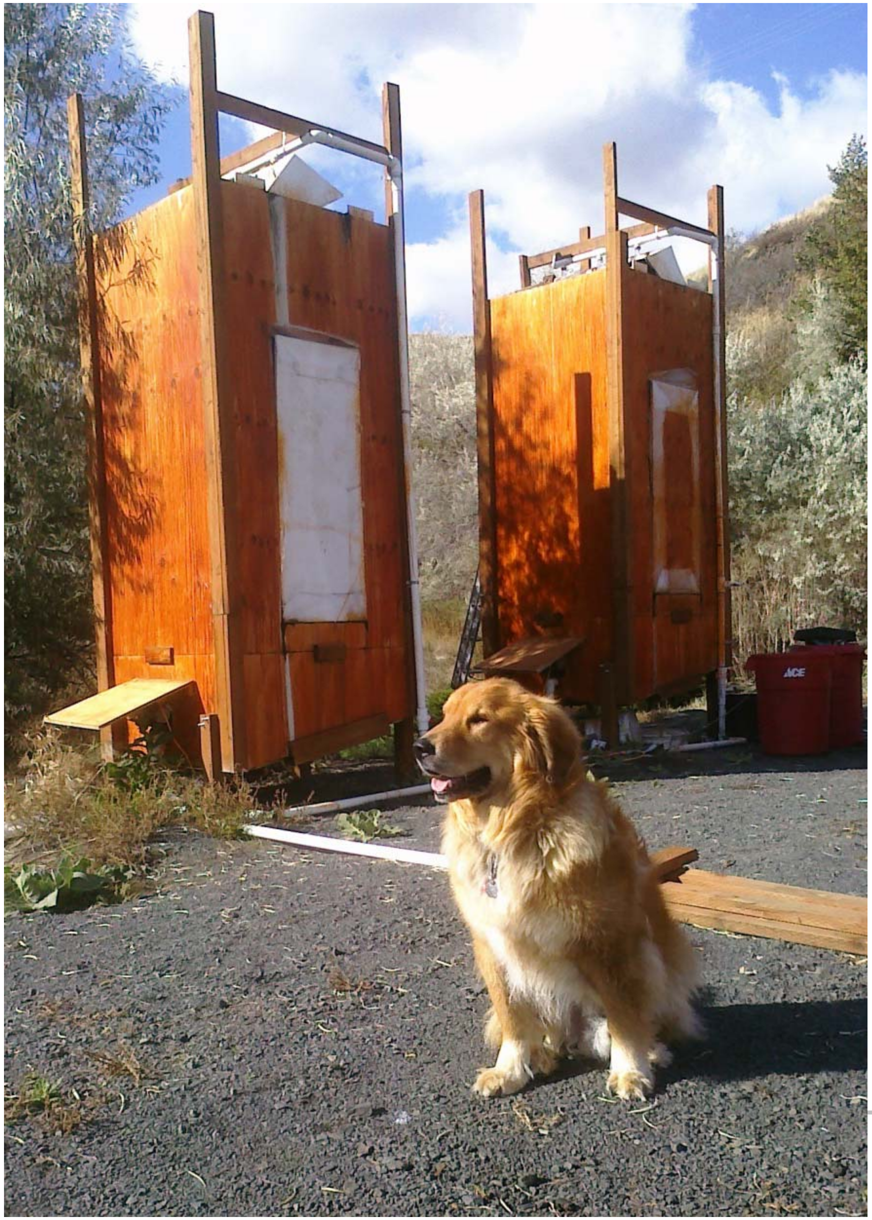
Plan View



Section View

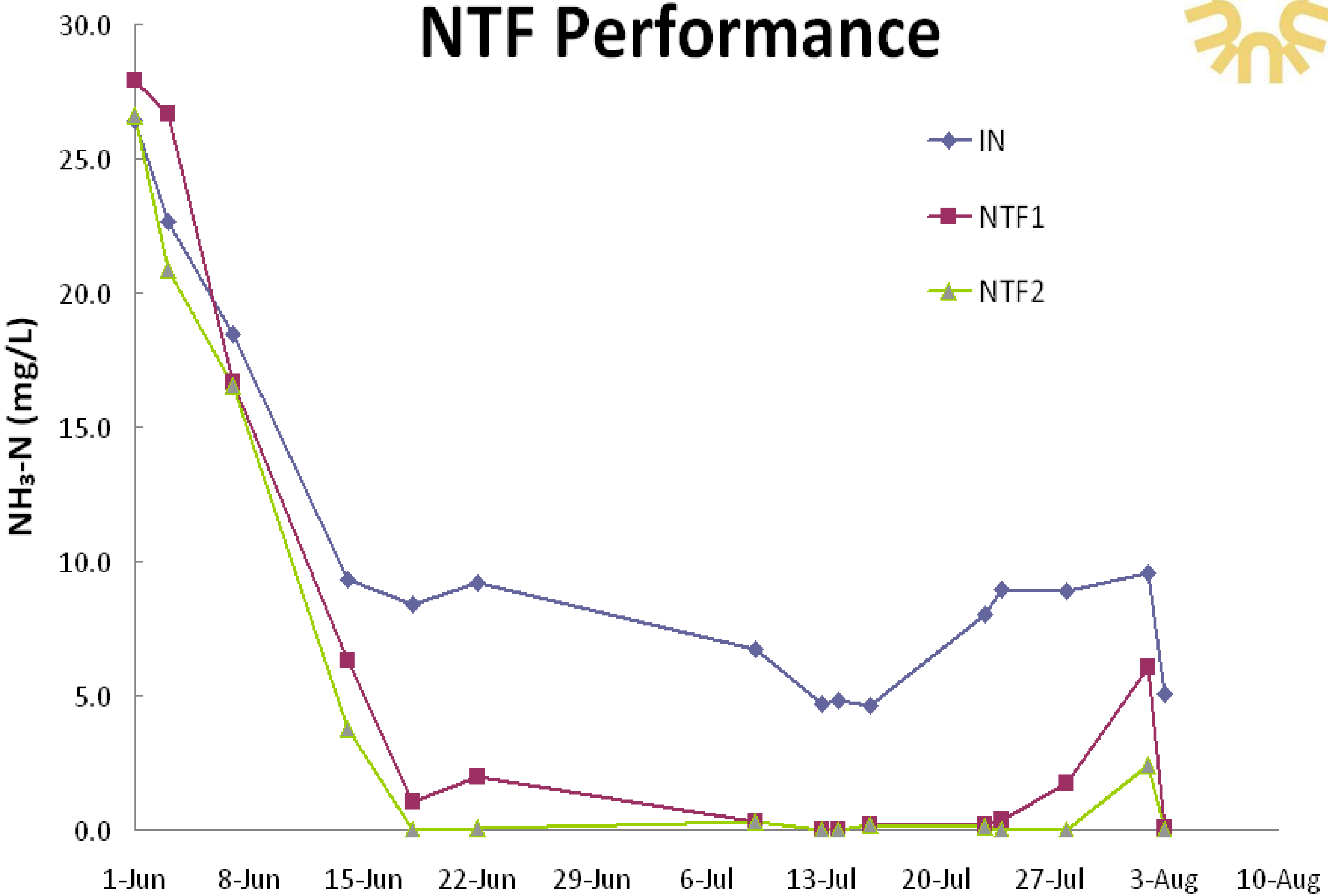


Data Collection



- Sampling began May 30th 2010
- Parameters Tested:
  - Temperature
  - Dissolved Oxygen
  - Ammonia-N
  - Phosphorous
  - Alkalinity
- Three Locations
  - Influent, Effluent NTF1 and Effluent NTF2

NTF Performance



Data Collection

- Removal began within **two weeks** of operation

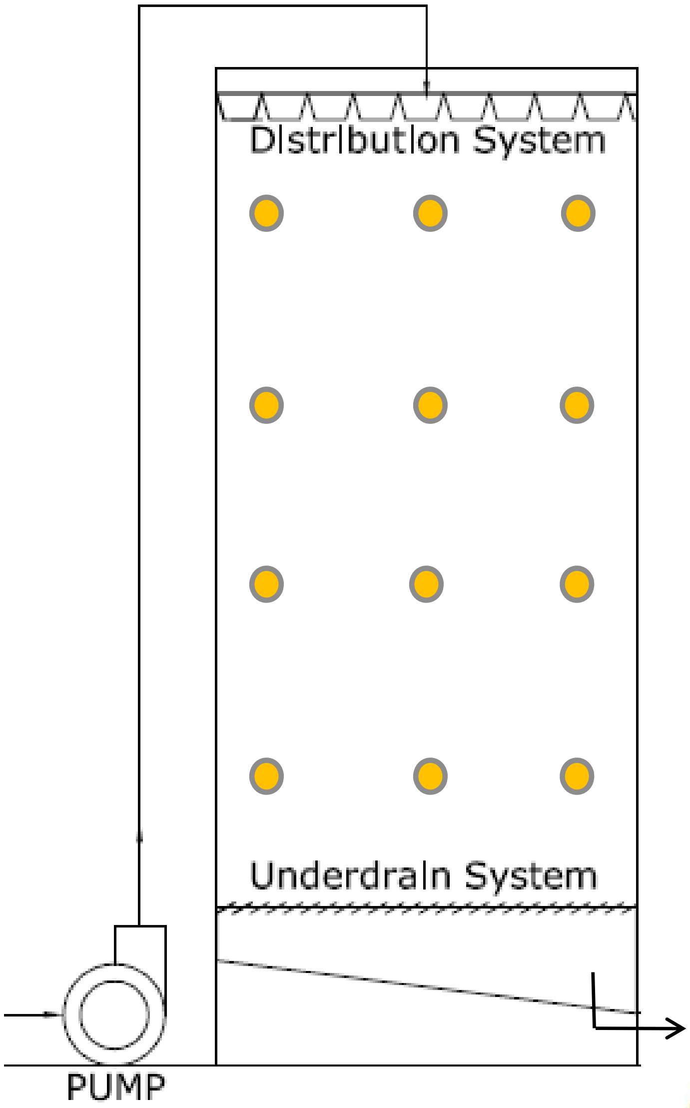
- **Full removal occurred in three weeks**
  - 95-98% removal occurred in **NTF1**

Project Questions

- **Are Nitrifying Trickling Filters a "good-fit" for Colfax?**
  - **YES! The design yielded FULL removal in 3 weeks.**
- Which design model best fits the collected data?
- Based on the data collected how would our design change?

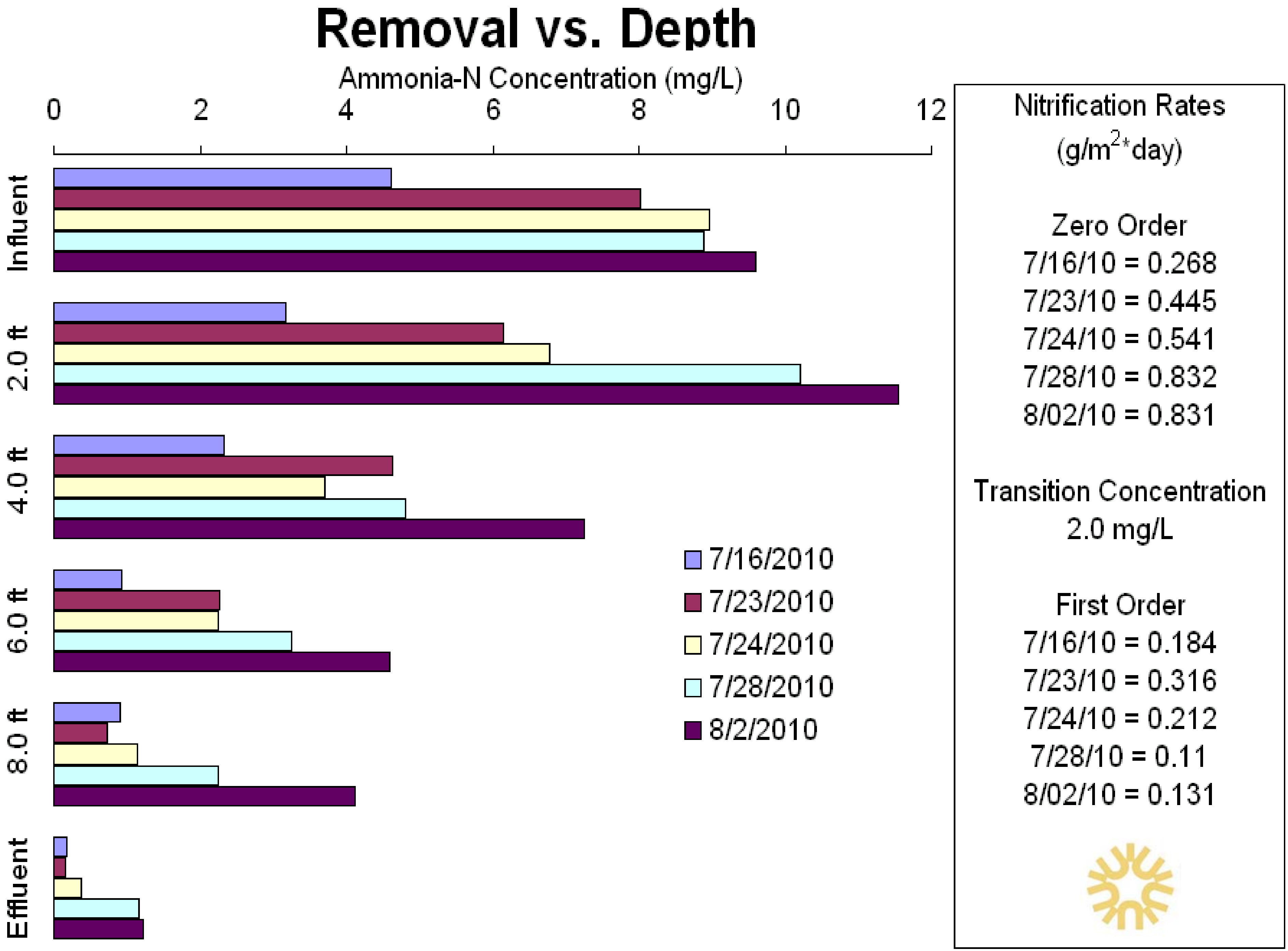
Vertical Testing

- Began vertical sampling in NTF1
  - Calculate nitrification rate as function of depth
  - Zero and first order kinetics
- Holes drilled every 1.5-2.0ft
- Two weeks of testing



Vertical Testing Results

- Calculated Zero and First Order Nitrification Rates
- Estimated transition concentration (2.0 mg/L)
  - Between zero and first order
- Estimated the change in removal rate as function of depth ($k=0.2m^{-1}$)
- Used data to compare/contrast design methods



Removal vs. Depth
Ammonia-N Concentration (mg/L)
0
2
4
6
8
10
12
Influent
2.0 ft
4.0 ft
6.0 ft
8.0 ft
Effluent
7/16/2010
7/23/2010
7/24/2010
7/28/2010
8/2/2010
Nitrification Rates
(g/m2*day)
Zero Order
7/16/10 = 0.268
7/23/10 = 0.445
7/24/10 = 0.541
7/28/10 = 0.832
8/02/10 = 0.831
Transition Concentration
2.0 mg/L
First Order
7/16/10 = 0.184
7/23/10 = 0.316
7/24/10 = 0.212
7/28/10 = 0.11
8/02/10 = 0.131

Pilot Design Methods

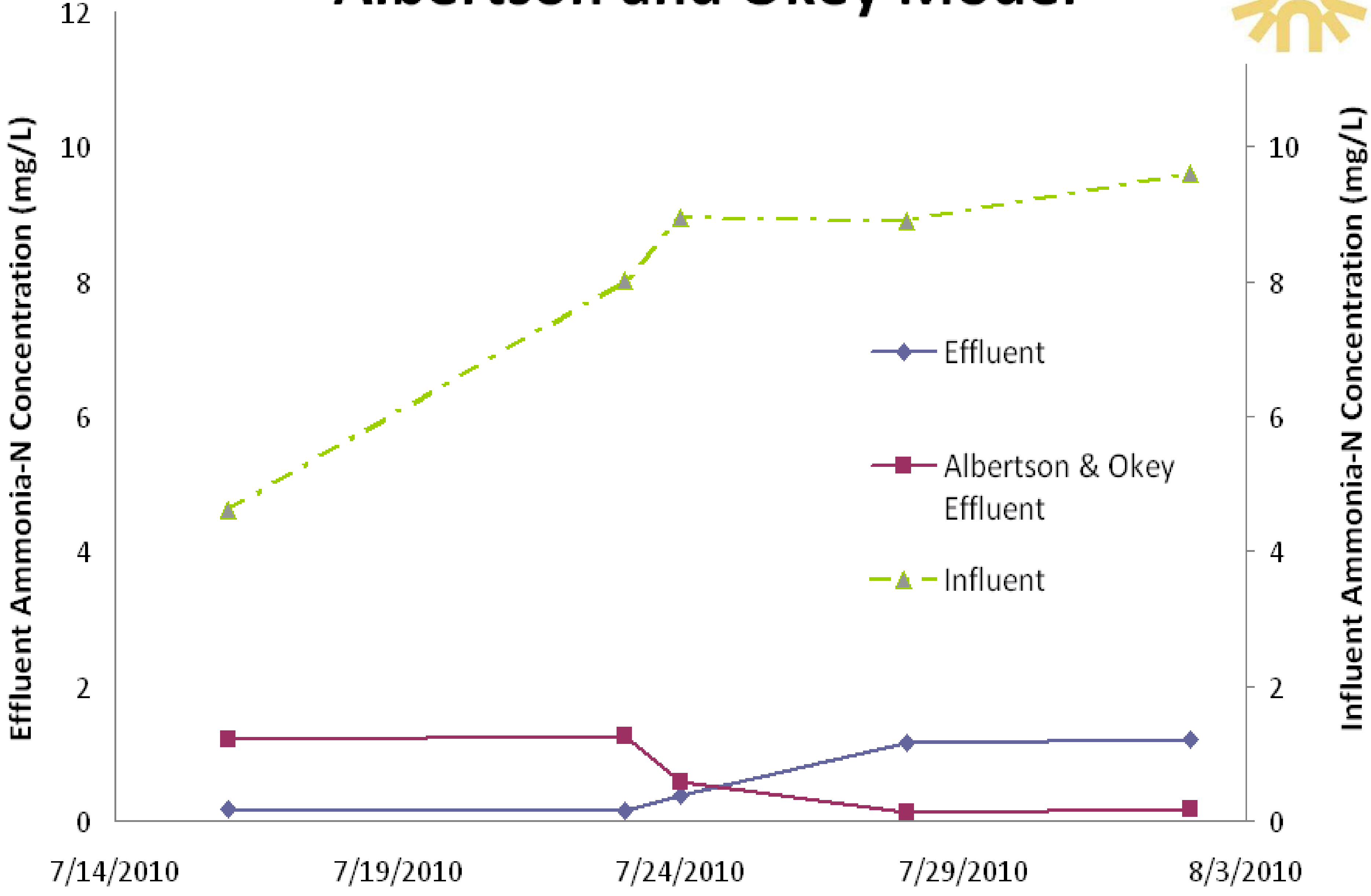
- Compare and Contrast Models with Collected Data
  - Albertson and Okey Procedure
  - Line Fit Equation
  - Metcalf and Eddy
  - Gujer and Boller Equation

Albertson and Okey Design

$$k_{n1} = k_{n0} \cdot \left(\frac{N_e}{N_T} \right)^{0.75}$$

- Similar to Metcalf and Eddy Model
- One Assumption: Transition Concentration (N_T)
  - Transition between Zero and First Order N-Rate
  - Data collected found N_T = 2.0mg/L
- Used the model to estimate Ammonia-N effluent concentration

Albertson and Okey Model



Albertson and Okey Design

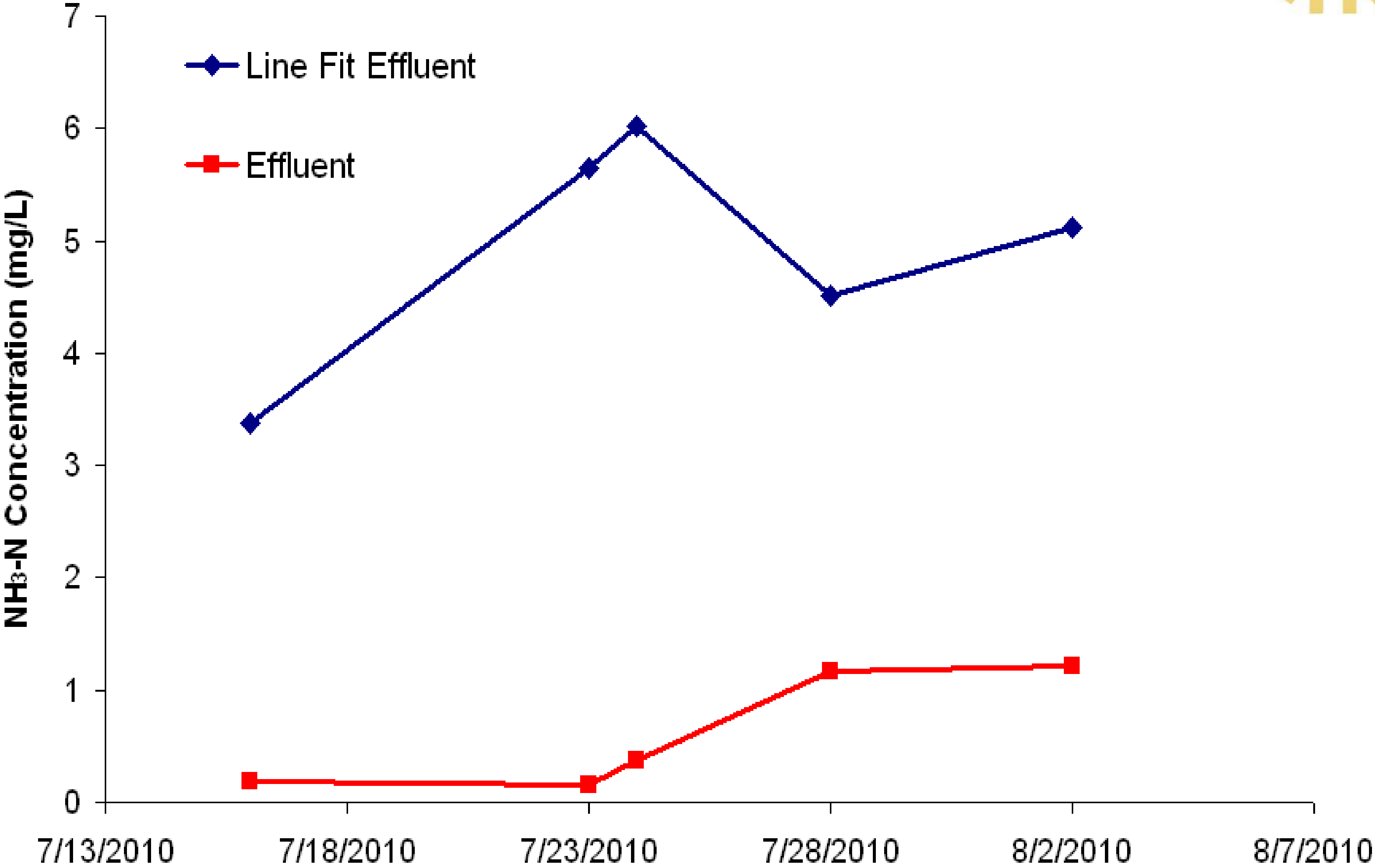
- Reasonable representation of data
- Model is highly dependent on zero-order Nitrification Rate
- **Over estimated** removal capacity at **high influent concentrations**
- **Under estimated** removal capacity at **low influent concentrations**

Line Fit Equation

$$\frac{a \cdot jn_{max}(T)}{k \cdot V_n} \cdot \left(1 - e^{-k \cdot z}\right) = S_{ni} - S_n + N \cdot \ln\left(\frac{S_{ni}}{S_n}\right)$$

- Three empirical constants
  - N = Saturation Parameter (mg/L)
  - S_n = Bulk Liquid Ammonia-N Concentration (mg/L)
  - k = empirical parameter describing decrease of rate with depth (m^{-1})
- Estimated Effluent Concentration

Line Fit Equation Model



Line Fit Equation

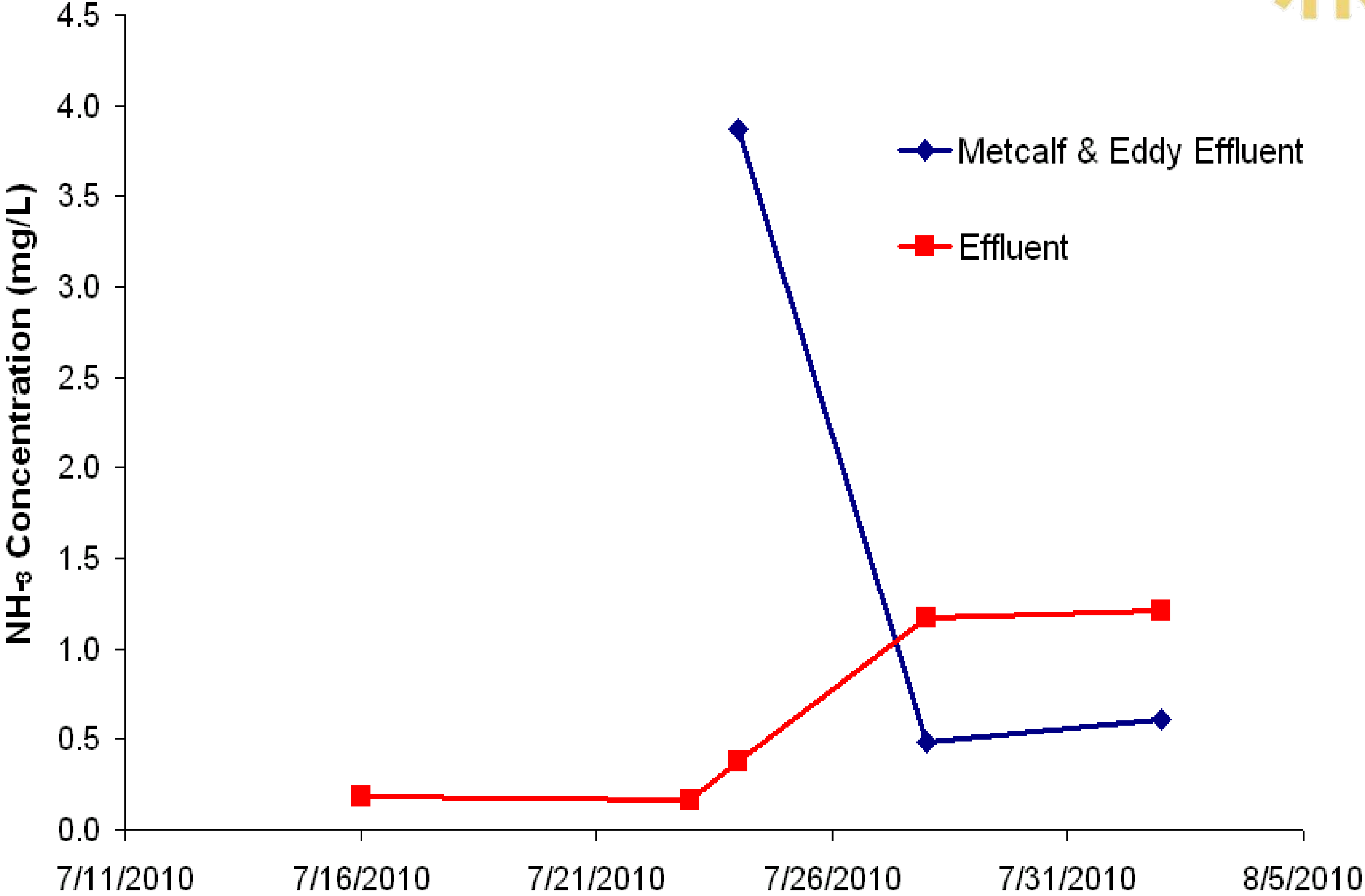
- Under estimated removal capacity
- Not representative of Colfax NTF
- Overly conservative estimation

Metcalf and Eddy

$$r_n(N, Z) = r_{nmax} \cdot \left(\frac{N}{K_n + N} \right) \cdot e^{-r \cdot Z}$$

- Model used for Pilot Design
- Very similar to Albertson and Okey
- Constants: Determined by the data
  - Half-Velocity Constant **(K_n) = 2.0 mg/L**
  - Empirical parameter describing decrease of rate with depth **(r) = 0.2 m^{-1}**
- Calculated effluent concentration to compare and contrast

Metcalf and Eddy Model



Metcalf and Eddy

- Omitted 7/16/10 and 7/23/10 data points
- Sensitive to low zero order removal rates
- As zero order approaches first order model does not represent data well
- Sensitive to Zero: First Order Ratio
  - As you approach 1 the model becomes unrepresentative of data

Gujer and Boller Equation

$$h = \left(\frac{1}{-k_x}\right)\cdot \ln\left[\frac{1 - k_x \cdot v_h}{a \cdot k_{nmax} \cdot e^{0.044(T-10)}}\left(N_i - N_o + N_s \cdot \ln\left(\frac{N_i}{N_o}\right)\right)\right]$$

- Model estimated design height **34.0ft**
  - Compared to 8.0ft, more than **triple** the height
- Similar empirical variables
  - Saturation Parameter (Ns) = **2.0mg/L**
  - Empirical parameter describing decrease of rate with depth (k) =**0.2m^{-1}**
- Overly conservative for Colfax

Project Questions

- Are Nitrifying Trickling Filters a "good-fit" for Colfax?
- **Which design model best fits the collected data?**
  - **Simple models with few empirical constants. Metcalf & Eddy and Albertson & Okey appear to best fit, but more data needs to be collected.**
  - **Further illustrates the importance of PILOTS!**
- Based on the data collected how would our design change?

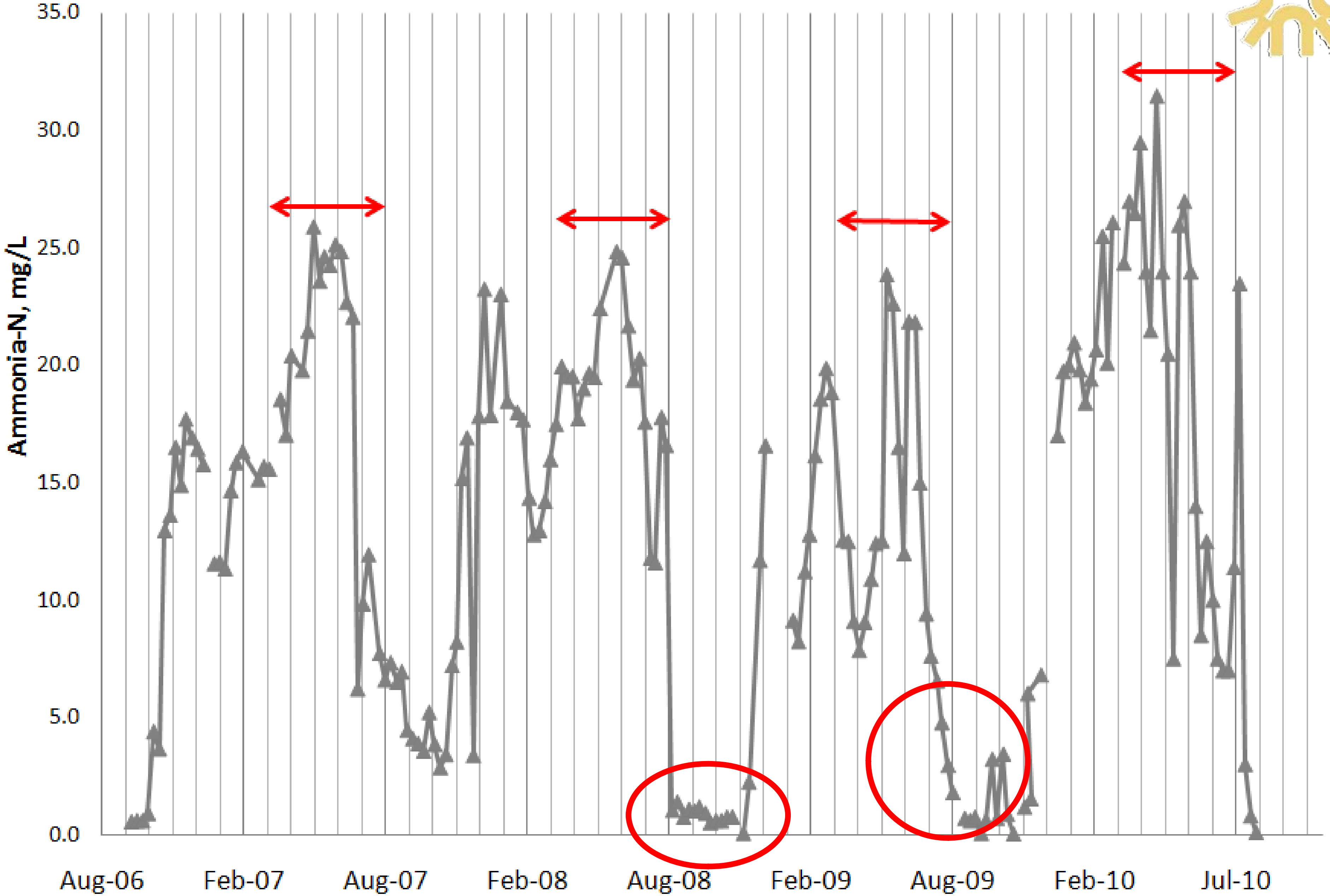
NTF Conclusions

- Pilot has shown NTF's are an excellent option for Colfax
- Established empirical constants
  - Half-Velocity Constant **(K_n) = 2.0 mg/L**
  - Transition Concentration **(N_T) = 1.5 mg/L**
  - Empirical parameter describing decrease of rate with depth **(r or k) = 0.2 m^{-1}**
- Further Data Collection

Original Summer 2010 Plans for Colfax

- **Double Hydraulic Loading Rate to 25gpm**
  - NTF1 achieved 95-98% removal at 12.5 gpm
- **However: Lagoons Nitrified (next slide)**
  - Complete ammonia-N removal observed in Lagoons beginning in August
  - Therefore our NTFs were starved
  - Historically NOT abnormal….but complete nitrification not previously observed

Lagoon 2 Ammonia-N Concentration



Future Plans for Colfax

- **Increase Hydraulic Loading Rate 25gpm**
  - Provide Colfax with an operating range – Upscale
- **Continue collecting data in 2011 (beginning in April)**

Project Questions

- Are Nitrifying Trickling Filters a "good-fit" for Colfax?
- Which design model best fits the collected data?
- **Based on the data collected how would our design change?**
  - **Increase the hydraulic capacity of the entire system to test NTF2.**

Questions?