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Assessing the Role of Turbulent Mixing on Phytoplankton Dynamics in Piedmont Reservoirs

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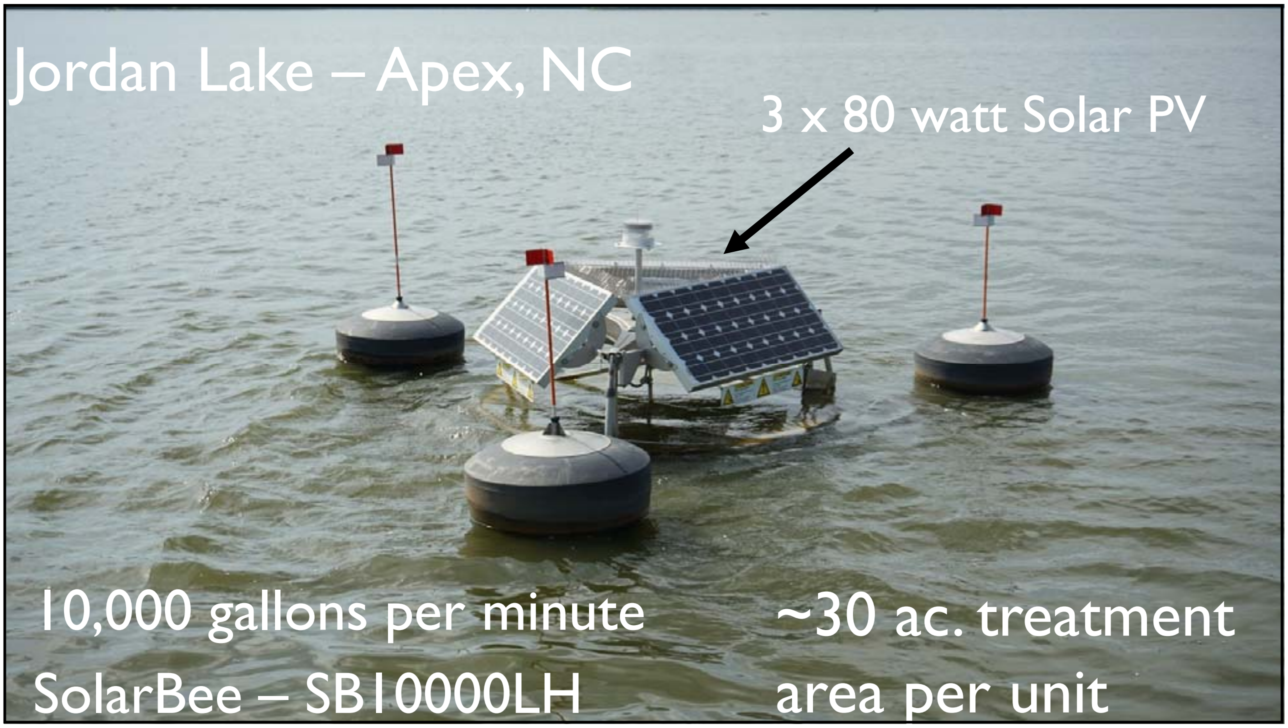
Harmful Algal Blooms – why do we care?

- Beneficial uses of reservoir
- Taste and odor in drinking water
- Toxin production
- Disinfection byproducts



Jordan Lake – Apex, NC

3 x 80 watt Solar PV

10,000 gallons per minute

SolarBee – SB10000LH

~30 ac. treatment area per unit

Compressed Air Mixing

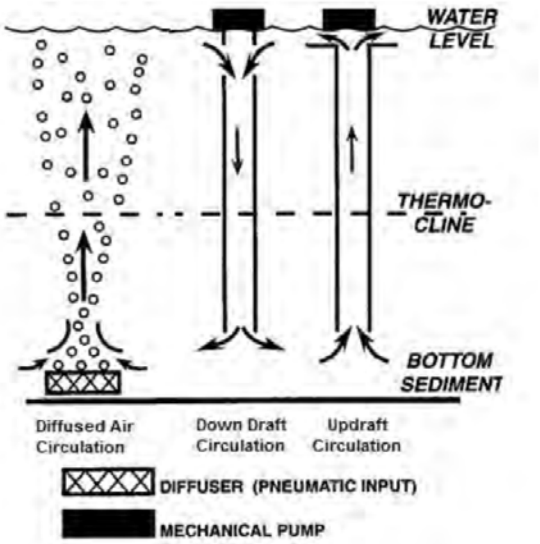
City Lake - High Point, NC

Source: Courtesy of WEARS

Figure 3.6 Views of components of the WEARS ResMix DDP system

Wagner, K. J. *Water Supply Reservoir Management Oxygenation and Circulation to Aid Water Supply Reservoir Management*; Denver, CO, 2015.

Circulation



Wagner, K. J. *Water Supply Reservoir Management Oxygenation and Circulation to Aid Water Supply Reservoir Management*; Denver, CO, 2015.

Mixing – A Tale of Two Lakes

- Solar Circulators – 240W solar PV per circulator (32 circulators)

  240W x 32 circulators x 12 hrs sunlight x 365 days/yr

  ~**34,000 kWh/yr (power delivered) (very favorable calculation)**

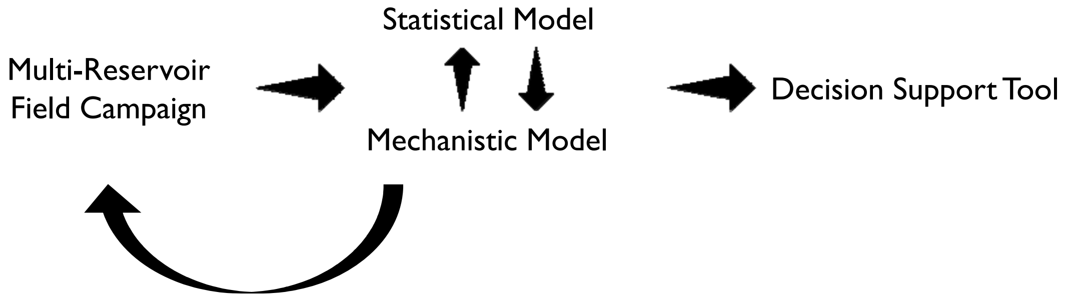
- City Lake Aeration – (from inquiry to City of High Point)

  52,618 kWh/month → **631,416 kWh/yr (delivered)**

Big Questions:

- How does mixing (natural and artificial) affect phytoplankton community structure?
  - What about toxin production? – Astrid Schnetzer
- What levels of mixing are needed (and when) to suppress HAB formation?
- Can we predict bloom formation or phytoplankton community composition based on mixing?

WRRI Grant Study Objectives



Multi-Reservoir
Field Campaign

Statistical Model

Mechanistic Model

Decision Support Tool

Field Campaign

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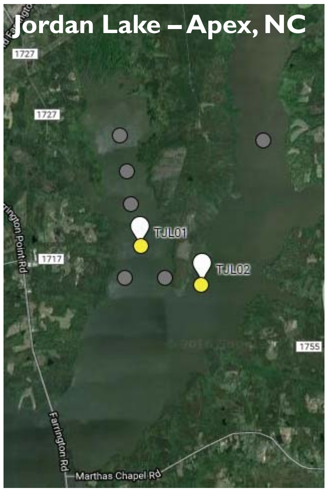
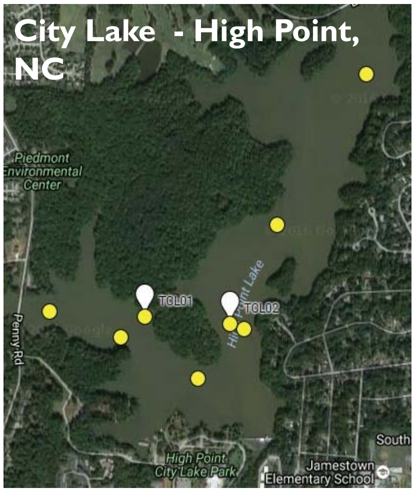
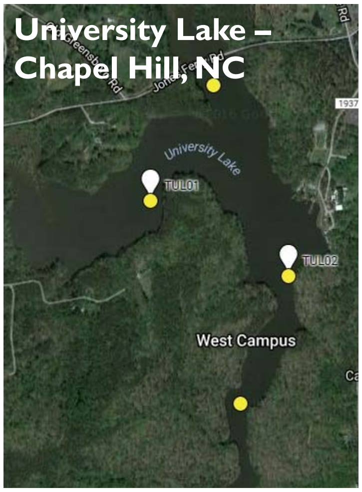

Jordan Lake – Apex, NC

2 current sites (yellow) and 2 thermistors (white). Summer sites were taken until August 2016 (grey)


City Lake - High Point, NC

8 sites (yellow) and 2 thermistors (white)


University Lake – Chapel Hill, NC

4 sites (yellow) and 2 thermistors (white)

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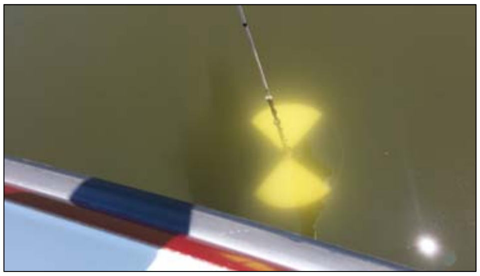
Field Campaign

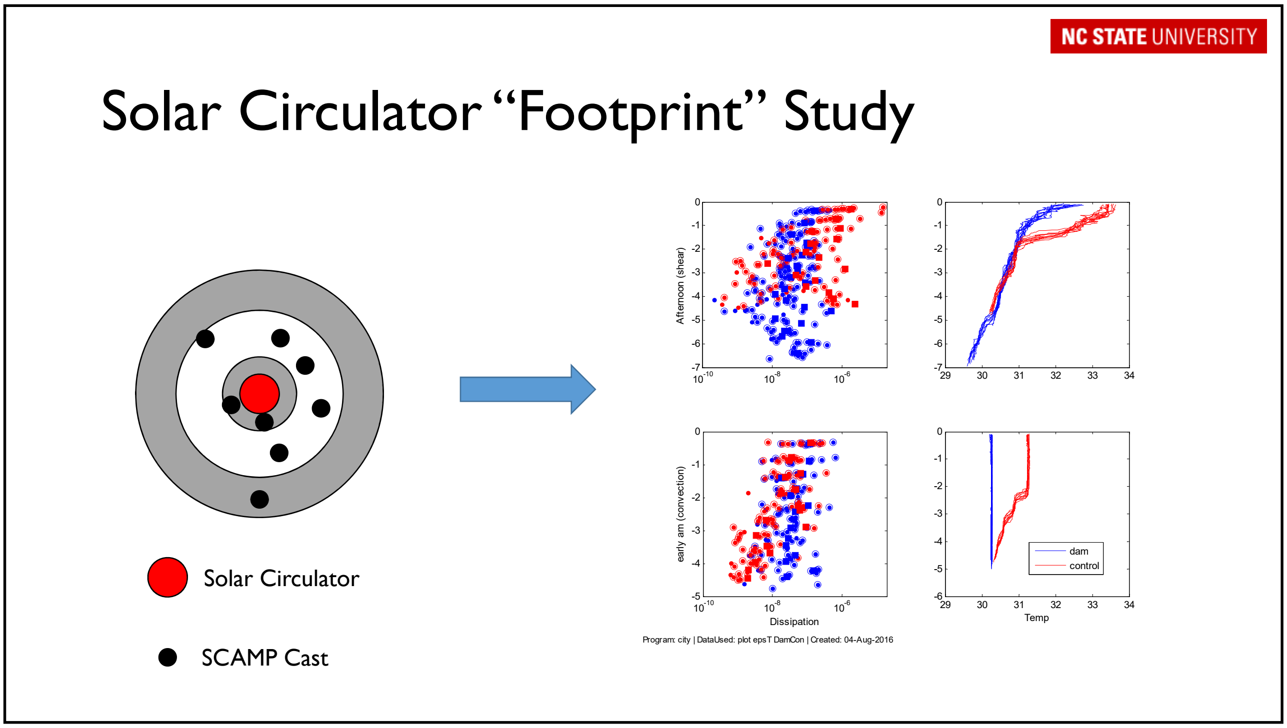
Data Set	2015	2016
Jordan Lake	✓	✓
University Lake		✓
High Point City Lake		✓
Monthly Sonde Data (Temperature, LDO, pH, Conductivity, Chlorophyll Fluorescence, and Phycocyanin Fluorescence)	✓	✓
Hourly Temperature Logs (Thermistor String)	✓	✓
SCAMP (turbulent diffusion measurement)	✓	✓
Dye Tests (turbulent diffusion measurement)	✓	✓
Monthly Assemblage Grab Samples		✓
Water Quality Samples		✓



Self-Contained Autonomous Microstructure Profiler (SCAMP)

Robyn Smyth

SCAMP



Solar Circulator "Footprint" Study

● Solar Circulator

● SCAMP Cast

Program: city | DataUsed: plot epsT DamCon | Created: 04-Aug-2016

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Additional Sampling

BAE Environmental Analysis Lab and CAAE Lab
- Chlorophyll a
- Total Density
- Total Keldahl Nitrogen
- Nitrate-Nitrite
- Ammonia
- Total Phosphorous
- Orthophosphate

In Situ Measurements (Hydrolabs Sonde)
- Chl a, phycocyanin, DO, pH, Temp

Couple to Ongoing Monitoring Efforts
- Municipalities, DWR, EPA STORET

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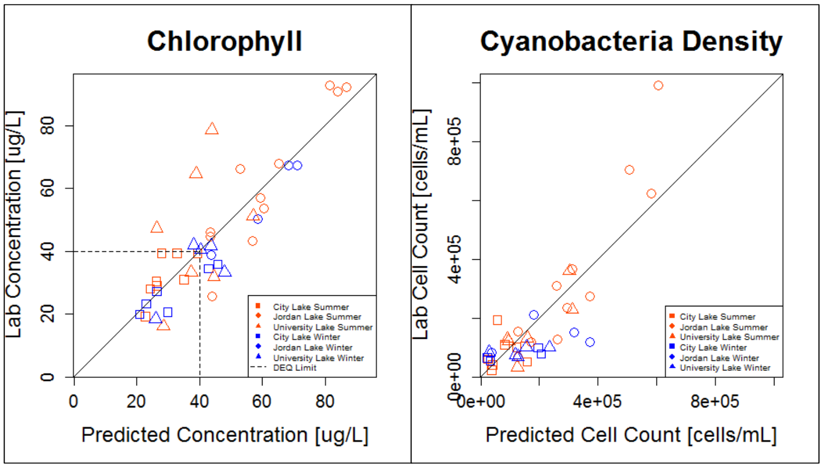
Regression Modeling

$Bloom\ Metric \sim C_{sf} + P_{sf}$

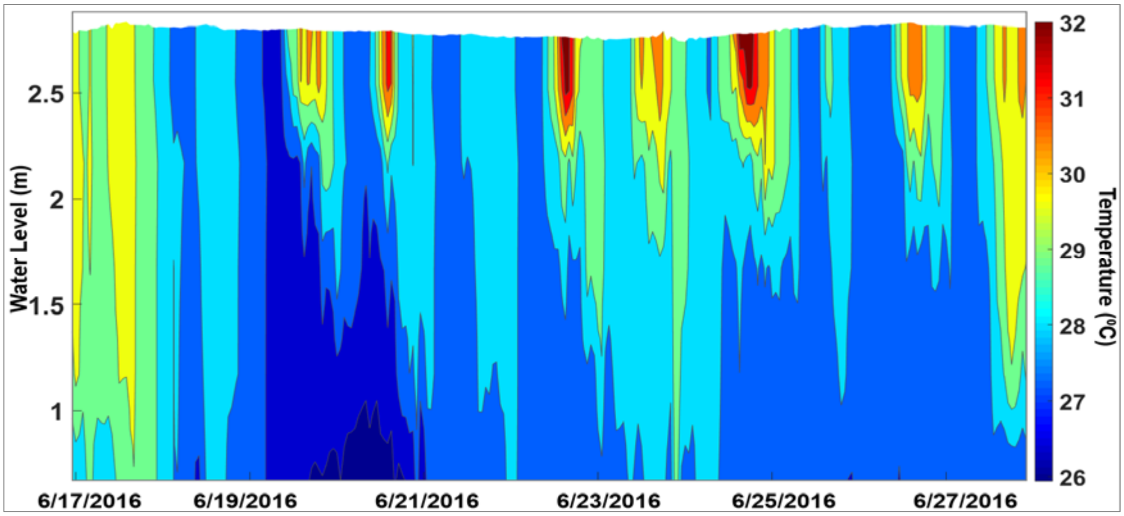
- C_{sf} ~ Sonde Fluorescence of Chlorophyll α [μg/L]
- P_{sf} ~ Sonde Fluorescence of Phycocyanin [cells/mL]

- Linear regression modeling was used to relate the sonde fluorescence data to the grab sampling data.
- This data will be used in a hierarchical modeling framework



Mechanistic and Statistical Modeling (preliminary results)

Observed Temperature in Jordan Lake (thermistor chains)



Mechanistic Model - Approximating Mixing with Thermistor Chain

We are developing a one dimensional hydrodynamics model for predicting the vertical distribution of temperature, density, and diffusion in lakes and reservoirs.

- Governing equation

$$\frac{\partial T}{\partial t} = \underset{\text{Diffusion}}{\boxed{\frac{1}{A(z)}\frac{\partial}{\partial z}\left\{A(z)[\alpha + E(z,t)]\frac{\partial T}{\partial z}\right\}}} + \underset{\text{Meteorology}}{\boxed{\frac{1}{A(z)}\frac{1}{C_p}\frac{1}{\rho}\frac{\partial[\Phi A(z)]}{\partial z}}}$$

- Turbulent Diffusion, E

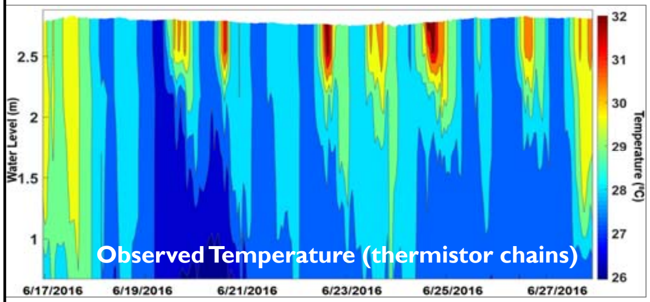
$$\mathrm{E}(z,t) = f(Uw, \rho, z)$$

wind speed

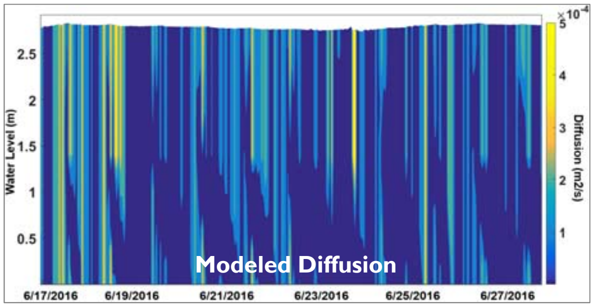
density

depth

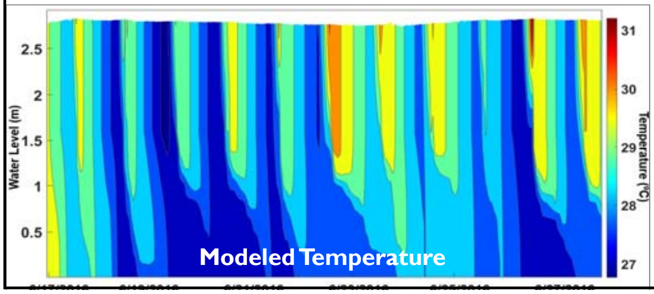
Mathematical Heat Model



Observed Temperature (thermistor chains)

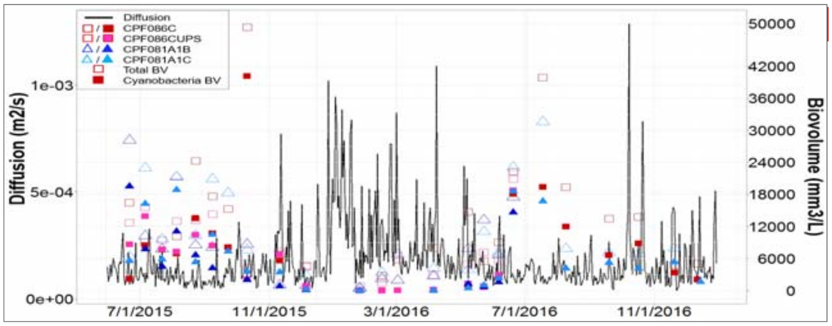


Modeled Diffusion



Modeled Temperature

Potential Relationships



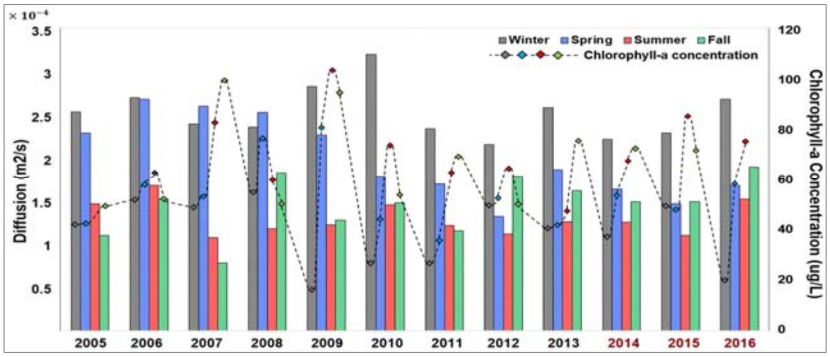


Figure 2(a): Plots of estimated diffusion rates with biovolume (includes total biovolume and cyanobacteria biovolume) with a two-year period from 2015 to 2016.

Figure 2(b): Averaged seasonal diffusion rates and chlorophyll-a concentration with a 12-year period.

Multiple Linear Regression (early results)

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- **Model mainly based on following predictor variables with a prediction of Chlorophyll-a concentration**

$$Chla \sim log(Q) + log(E) + log(J_{sn})$$

Chla – Chlorophyll-a Concentration (ug/L);
Q – Flowrate (cfs);
E – Diffusion (m^2/s);
J_{sn} – Solar Radiation (W/m^2)

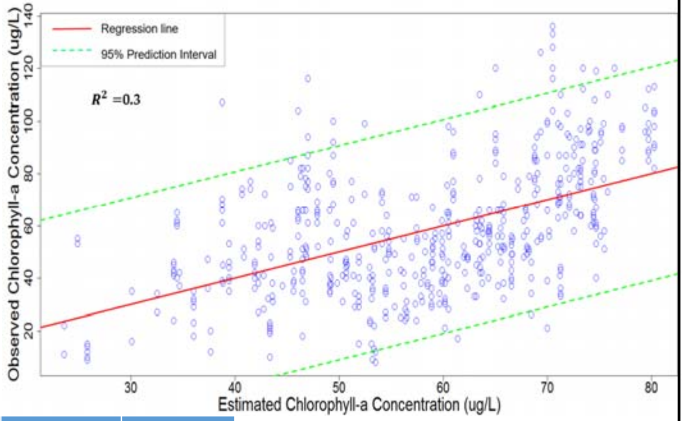


Table 1: Sign of the parameters and significance for the variables.

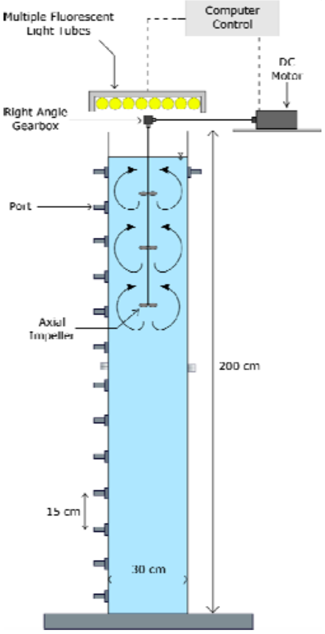
	Intercept	Log(Q)	Log(E)	Log(J_{sn})
Averaging Period (day)	NA	30	30	10
Sign of Trend Coeff.	−	−	−	+
Significance	***	***	***	***

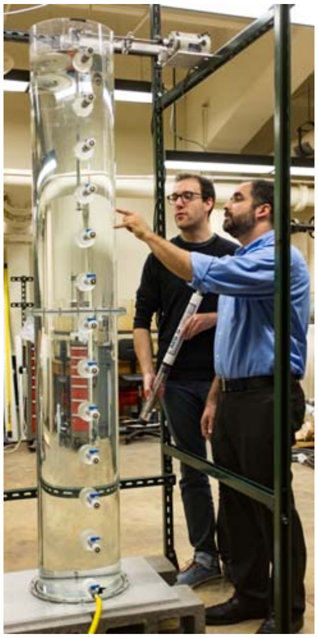
Note: Significant codes: 0 '***'

On the horizon

- Continued monitoring
- Additional tweaking of mechanistic model
- Deeper analysis with statistical modelling
- Experimental configuration to study water column dynamics…

The Water Column Reactor





NC State Seed Grant in collaboration with Dan Obenour and Astrid Schnetzer

<u>Components</u>:

1. Reactor design (13 ports)
2. Mixing (axial impellers)
3. Light (fluorescents/LEDs)
4. Biology (cultured *Microcystis*)

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The People

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The Municipalities/Organizations/People

- NC DEQ: Water Resources – Jason Green and crew
- NSF
- NC WRRI and Urban Water Consortium
- NC State Office of Research Innovation and Economic Development (ORIED)
- OWASA
- City of High Point
- US Army Corps
- Bill Frazier

Questions?

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Dye Test Model

$$\frac{\partial C}{\partial t} = E * \frac{\partial^2 C}{\partial z^2}$$

- E = Diffusivity (m^2/s)
- C = Concentration of Rhodamine WT Dye (g/m^3)
- t = time (sec) ; z = depth (m)

$$C_i^{n+1} = C_i^n + \frac{E * \Delta t}{\Delta z^2}\left(C_{i+1}^n - 2C_i^n + C_i^n\right)$$

- Forward-time, center-space finite differencing model for time “n” at depth “i”

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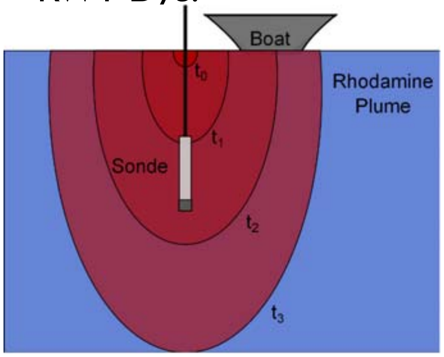
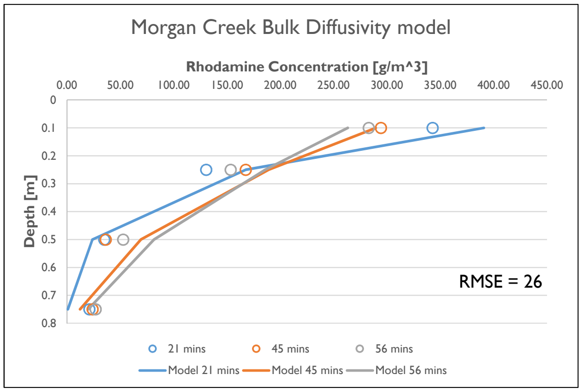
Dye Test Modeling

- Dye tests on Jordan Lake with RWT Dye.



Schematic of the Dye Release Test



Results of the most recent dye test. Diffusivity was found to be **0.16 cm²/s**

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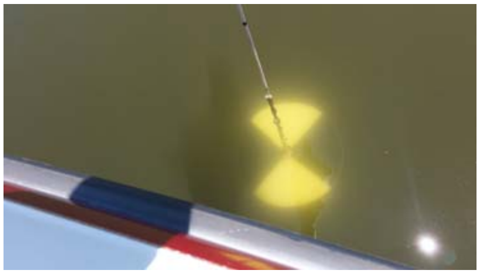
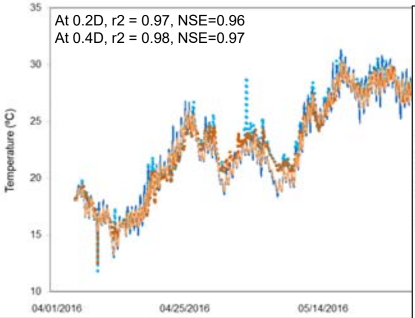
Multi-year Monitoring Effort

- Summer 2015 (Jordan Lake):
  - Monthly in-situ physical, chemical, and biological measurements
    - Temperature, LDO, pH, Conductivity, Chlorophyll Fluorescence, Phycocyanin Fluorescence
  - Hourly temperature logs from thermistor strings
  - SCAMP deployments
  - Dye tests
- Since Summer 2016:
  - Jordan Lake, University Lake, High Point Lake
  - Monthly in-situ physical, chemical, and biological measurements
    - Temperature, LDO, pH, Conductivity, Chlorophyll Fluorescence, Phycocyanin Fluorescence
  - Monthly phytoplankton assemblage and extracted chlorophyll grab samplings.
  - Hourly temperature logs from thermistor strings
  - SCAMP deployments
  - Dye Tests





At 0.2D, r2 = 0.97, NSE=0.96
At 0.4D, r2 = 0.98, NSE=0.97

Figure 1: Observed temperature and predicted temperature at 0.2D and 0.4D from Apr. 1st to July 28th, respectively.

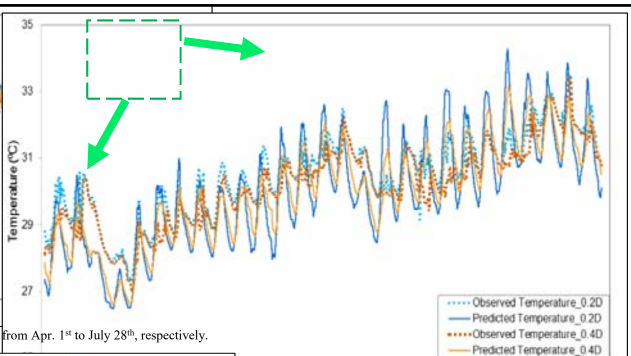


Figure 2: Observed temperature and predicted temperature at 0.2D and 0.4D from July 1st to July 28th, respectively.

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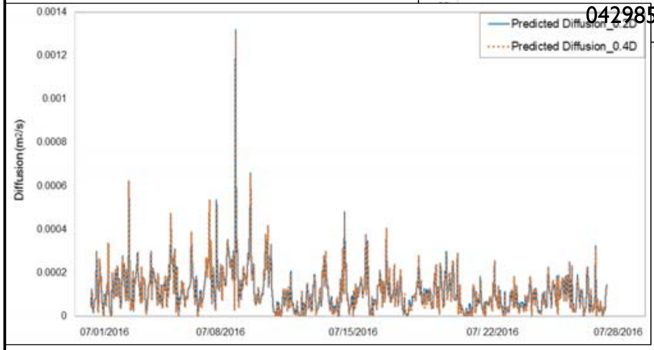

Figure 3: Predicted diffusion at 0.2D and 0.4D from July 1st to July 28th, respectively.

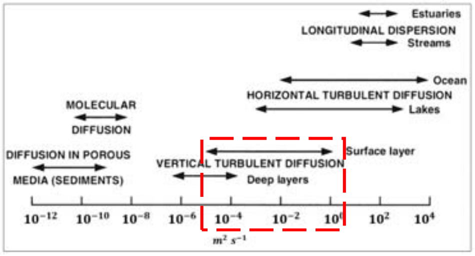

Figure 4: Typical ranges of the diffusion coefficient in natural waters and sediments (Chapra, 2008).