

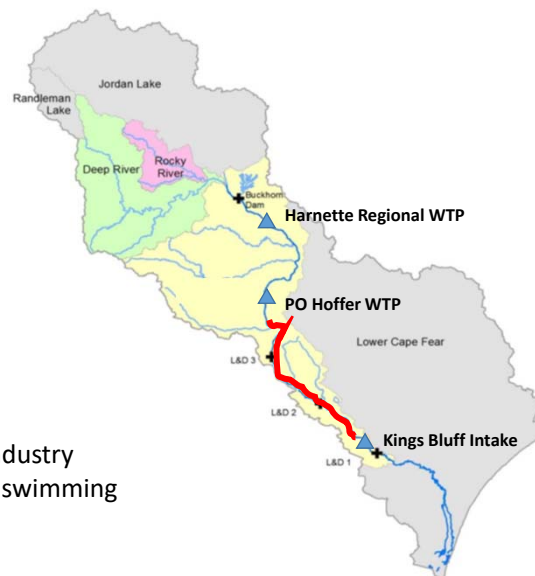
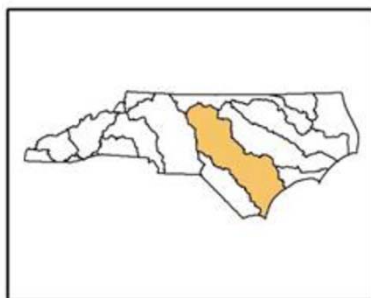


## Unraveling dual influences of increasing nutrients and changing flow regimes on bloom potentials along the middle Cape Fear River

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### The Middle Cape Fear River



- 1) Water supply: >0.5 million & industry
- 2) Recreation: boating, fishing, & swimming

## Three Bloom Requirements: Nutrients, Light, & Time to Grow All Three Modulated by River Flow

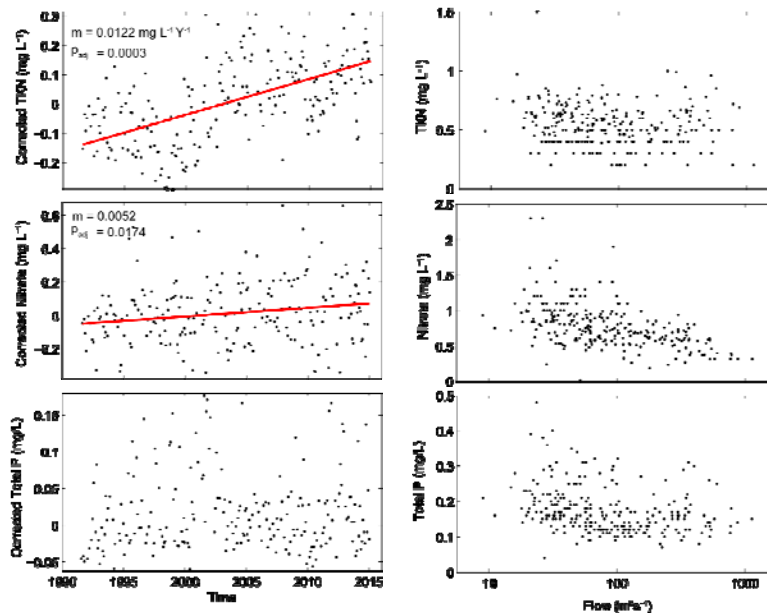
“the appropriate combination of environmental factors necessary to favor proliferation of Cyanobacteria seems unlikely to occur in the middle CFR”  
(Dubbs and Whalen 2008)



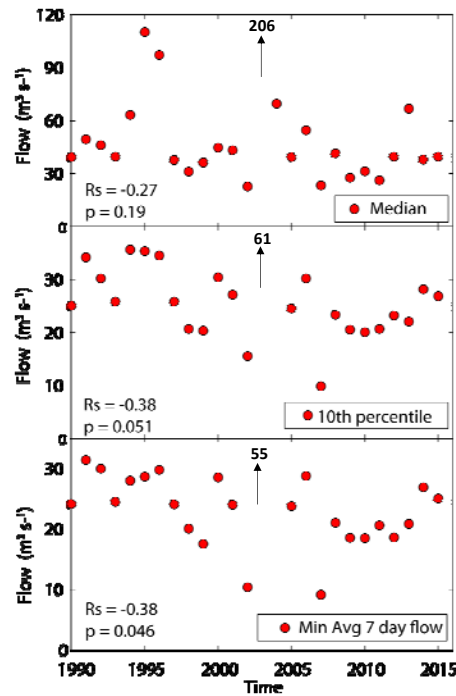
Photo credit: Stephanie Pettergarrett, NCDENR-DWR

Major blooms started the next summer in 2009, then 2010, 2011, 2012

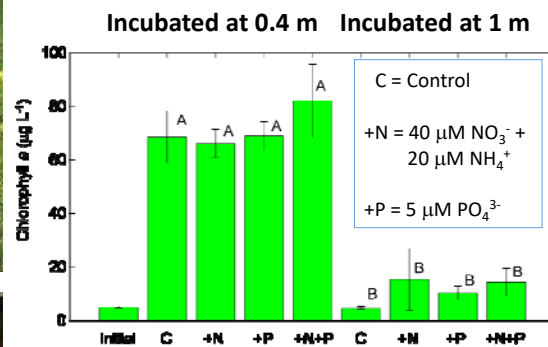
## Nutrients: N Has Increased Over Time & Nutrient Availability is Higher Under Low Flows



### Trend toward lower summertime (June – September) low flows

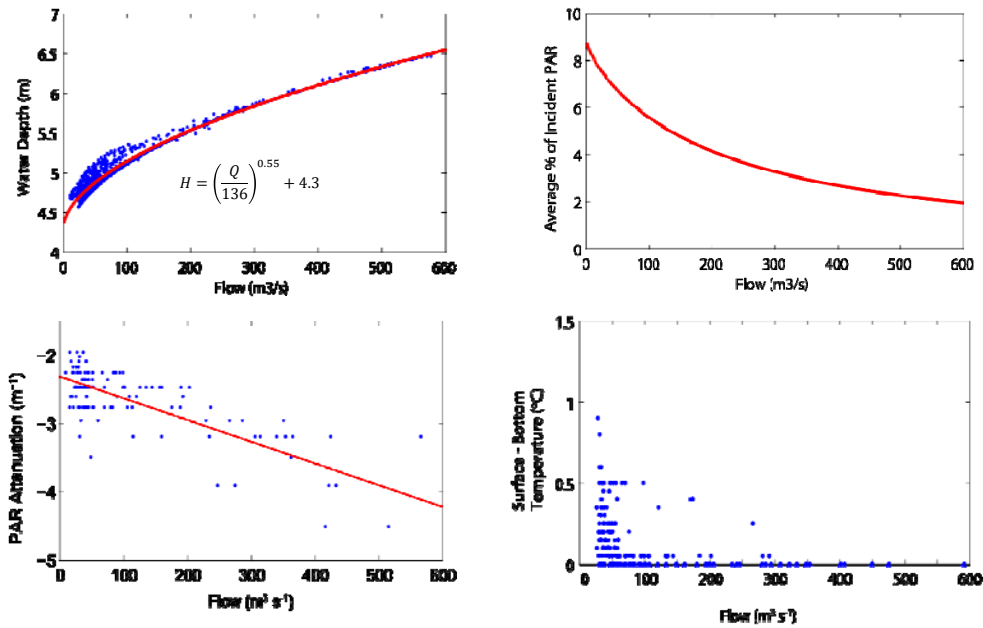


### *In Situ* Nutrient Addition Bioassay at Two Different Depths July 2017

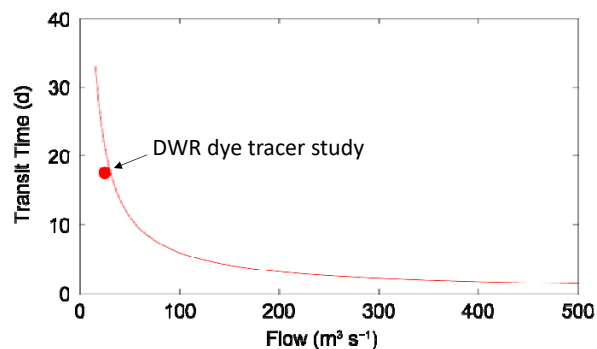
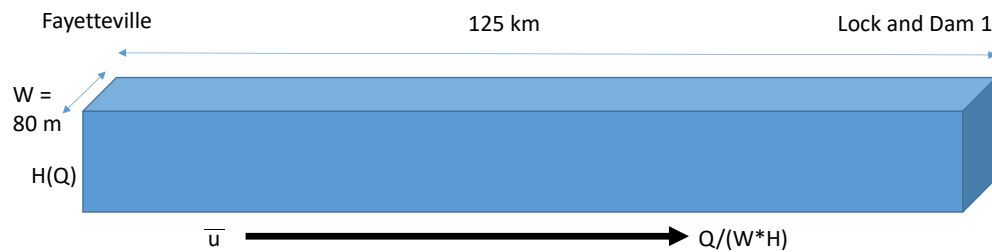


**Corroborated Nutrient Replete/  
Light-Limited Growth Reported  
by Dubbs & Whalen (2008)**

**Light availability:** Strongly flow related due to depth, light attenuation, and mixing/ stratification

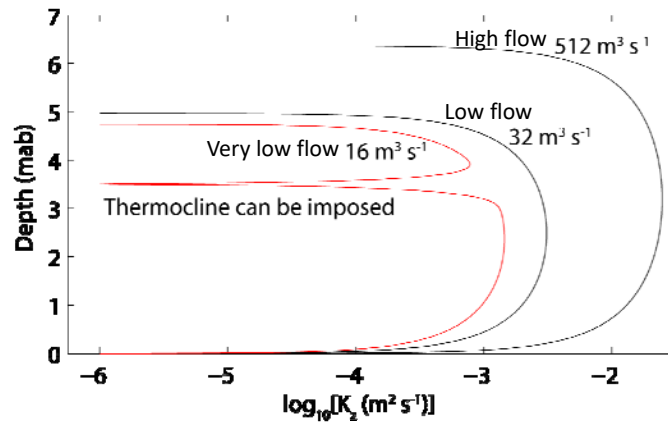


**Time to Grow:** Time of travel determined by flow and river morphology



## The Physics

### Mixing Determined by Bed Stress



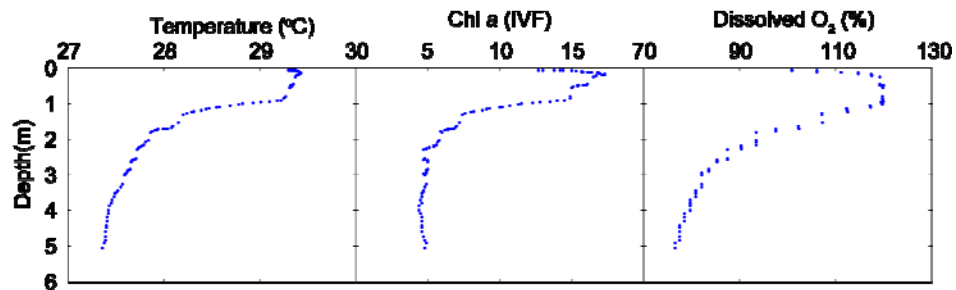
### Phytoplankton Vertical Position Determined by Random Walk

$$z_{n+1} = z_n + \underbrace{w_p \Delta t}_{\text{motility}} + \underbrace{K'(z_n) \Delta t}_{\text{deterministic term}} + \underbrace{R \left[ \frac{2K(z_n + \frac{1}{2} K'(z_n) \Delta t) \Delta t}{r} \right]^{1/2}}_{\text{random term}}$$

Ross and Sharples (2008)

## Observed Effects of Stratification

June 20, 2016. Upstream of Lock and Dam 1 near Elwell Ferry



## The Biology



Floating Cyanobacteria  
 $w_s = +0.5 \text{ m/h}$

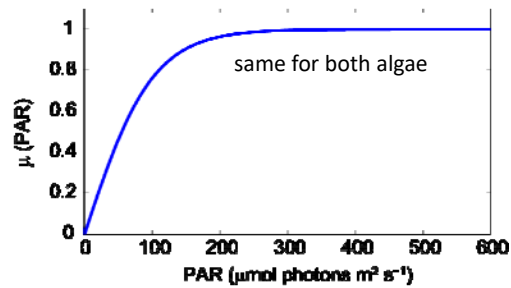
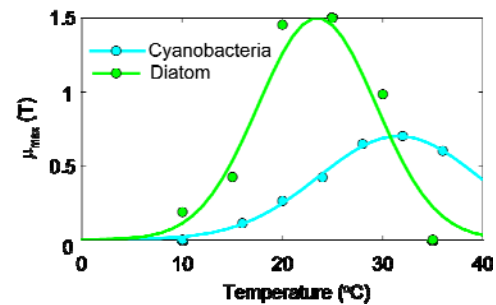
Sinking Diatom  
 $w_s = -0.5 \text{ m/d}$

$$\mu = \mu_{\max}(T) * \mu(I) - 0.05 * \mu_{\max}(T)$$

Light and temperature limited growth  
with loss of 5%  $\mu_{\max}$

$$PAR = PAR_0 \exp(-K_{PAR}Z); K_{PAR} = K_{BG} + K_{chl}$$

light attenuation due to background and  
self shading



## Position of Cyanobacteria During Model Run, Flow = 20 m<sup>3</sup>s<sup>-1</sup>

Command Window

```

>> LagrangianMovie
Cannot find an exact (case-sensitive) match for 'Movie'
The closest match is: movie in C:\Program Files\MATLAB\R2013a\toolbox\matlab\specgraph\movie.m

Error in LagrangianMovie (line 162)
Movie(F,5)
Operation terminated by user during getframe (line 104)

In LagrangianMovie (line 160)
F(j) = getframe(gcf);

>> LagrangianMovie
Operation terminated by user during LagrangianMovie (line 153)

>> LagrangianMovie
Operation terminated by user during LagrangianMovie (line 153)

>> LagrangianMovie
Operation terminated by user during LagrangianMovie (line 153)

>> addpath C:\Proposals\WRI2015\ProjectStuff\WRI2015Conference2017
>> LagrangianMovie
Operation terminated by user during LagrangianMovie (line 153)

>> LagrangianMovie
Operation terminated by user during LagrangianMovie (line 153)

>> LagrangianMovie
Operation terminated by user during LagrangianMovie (line 153)

>> LagrangianMovie
Operation terminated by user during LagrangianMovie (line 153)

```

Workspace

Name	Value
F	<1x199 struct>
H	4.6489
Io	1.8561e+01
K	<100x1 double>
K2	<100x1 double>
Ko	1.0000e+06
Kprime	<100x1 double>
Kprime2	<100x1 double>
P	<100x140 double>
P2	<100x140 double>
PAR	<11528x2 double>
Pa	<100x1 double>
Po	<100x1 double>
R	<100x1 double>
R2	<100x1 double>
X	<100x140 double>
X2	<100x140 double>
Xs	<100x1 double>
Xs2	<100x1 double>
Ys	<100x1 double>
Ys2	<100x1 double>
Z	<100x1 double>

Command History

```

plot(Xs,Ys,'og','markerfacecolor','g')
axis ij
drawnow
F(j) = getframe;
end
LagrangianMovie
movie(F,5)
LagrangianMovie
help movie
movie(F,1)

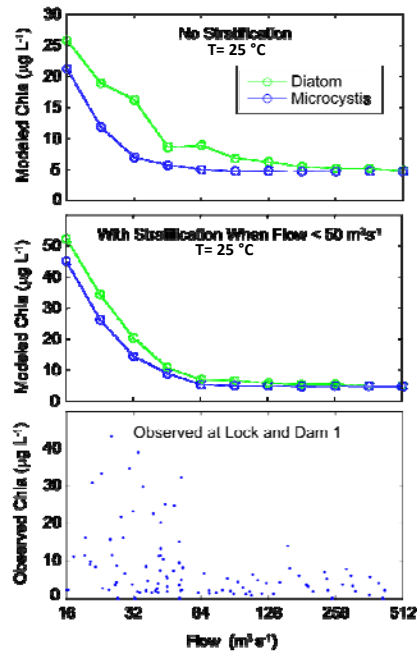
```

3/14/2017 1:18 PM -->

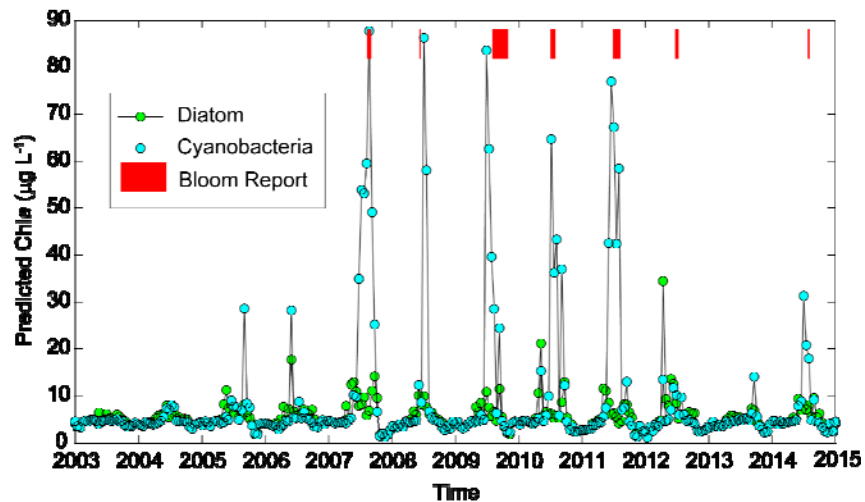
addpath C:\Proposals\WRI2015\WRI2015Conference2017
addpath C:\Proposals\WRI2015\ProjectStuff\WRI2015Conference2017
LagrangianMovie
addpath C:\Proposals\WRI2015\ProjectStuff\WRI2015Conference2017
LagrangianMovie

RECORDED WITH SCREENCAST MONITOR

## Model Captures Relation of Biomass to Flow



## Hind Casts of Reported Blooms



Flow from USGS at Lock and Dam1

Water Temperature from Interpolated Biweekly Observations DEQ/MCFRBA

Air Temperature and Incident Light from RAWs Turnbull Cr. Station

### Conclusions/ Comments

- 1) Recent, extreme, summertime low-flow events provide sufficient light and travel times for bloom development
- 2) Stratification likely plays an important role in determining overall phytoplankton biomass and competitive dominance by positively buoyant cyanobacteria
- 3) Recent increase in blooms likely related to flow rather than increasing nutrient concentrations because nutrients are, and have been, replete for a long time
- 4) Reducing the magnitude of blooms along the Middle Cape Fear will likely require thinking about managing nutrient concentrations rather than loads.
  - a) Loads are strongly influenced driven by high flow events when conditions disfavor blooms
  - b) Point sources ensure nutrient satiety during low flows.

Tarheel plant: 0.1 m<sup>3</sup>/s flow, 120 mg/L of TN      ~12,000 mg/s

River: 1.5 mg/L of TN flux at flow of 20 m<sup>3</sup>/s      ~24000 mg/s