UNC CHARLOTTE

The WILLIAM STATES LEE COLLEGE of ENGINEERING

Summary of Draft Report: Jordan Lake Water Quality Model Development

James Bowen

Associate Professor (Ret.)

Civil and Environmental Engineering Department

UNC Charlotte

JLOW/DWR Fall Stakeholder Meeting,

Nov 2, 2023

Summarizing Final Report (in draft)

NC DEQ Project - Task Order # CW28707

Project Title:
Jordan Lake Water Quality Model Development

September 2023 Final Report (Draft, Version 1)

Submitted by

James D. Bowen
Civil and Environmental Engineering Department
University of North Carolina at Charlotte

A Report to the NC Division of Water Resources
Raleigh, North Carolina

September 30, 2023

Study Objectives:

- Setup 3-d model of Jordan Lake
- Calibrate Model
- Investigate system functioning
- Test nutrient (N,P) reduction scenarios

Follow-up of UNC Collaboratory Project (2019, 2020)

Jordan Lake Responses to Reduced Nutrient Loading: Results from a New Three-Dimensional Mechanistic Water Quality Model

James D. Bowen, William Langley, and Babatunde Adeyeye
Department of Civil and Environmental Engineering, UNC Charlotte

December 2019

https://nutrients.web.unc.edu/files/2019/12/Reservoir-Model-UNC-Charlotte.pdf

Collaboratory Project Objectives:

a) Quantify and compare nutrient sources w/r to location and composition
b) Investigate how lake circulation affects delivery of nutrients to various regions of the lake
c) Compare the efficacy of various nitrogen and phosphorus watershed loading reductions for reducing algal levels in the reservoir.
d) Estimate how long it will take for the benefits of nutrient loading reductions to be fully realized.

Follow-up of UNC Collaboratory Project (2019, 2020)

Jordan Lake Responses to Reduced Nutrient Loading: Results from a New Three-Dimensional Mechanistic Water Quality Model

James D. Bowen, William Langley, and Babatunde Adeyeye
Department of Civil and Environmental Engineering, UNC Charlotte

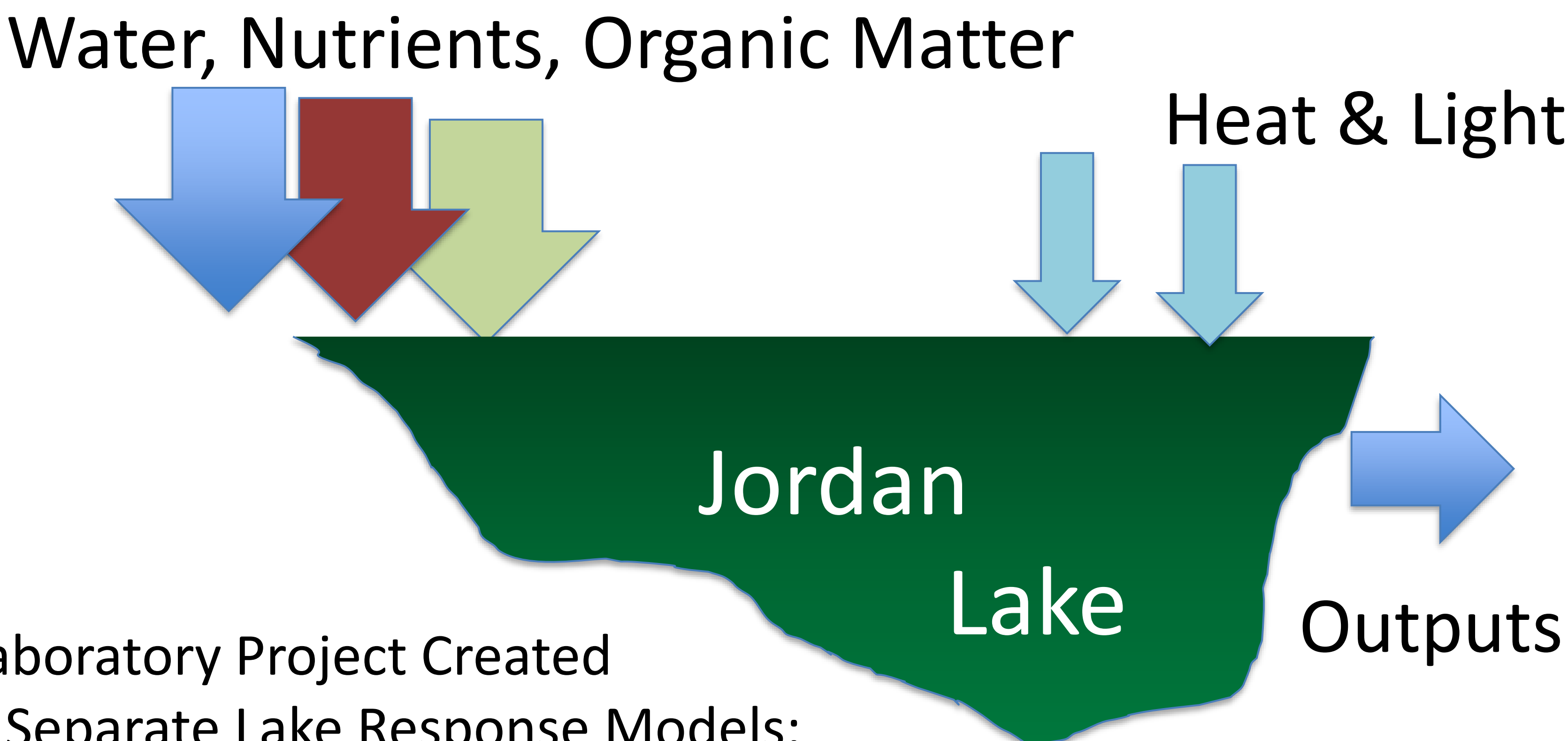
December 2019

https://nutrients.web.unc.edu/files/2019/12/Reservoir-Model-UNC-Charlotte.pdf

Collaboratory Project Objectives:

a) Quantify and compare nutrient sources w/r to location and composition
b) Investigate how lake circulation affects delivery of nutrients to various regions of the lake
c) Compare the efficacy of various nitrogen and phosphorus watershed loading reductions for reducing algal levels in the reservoir.
d) ~~Estimate how long it will take for the benefits of nutrient loading reductions to be fully realized.~~

Approach: Use a material-balance-based lake nutrient response model

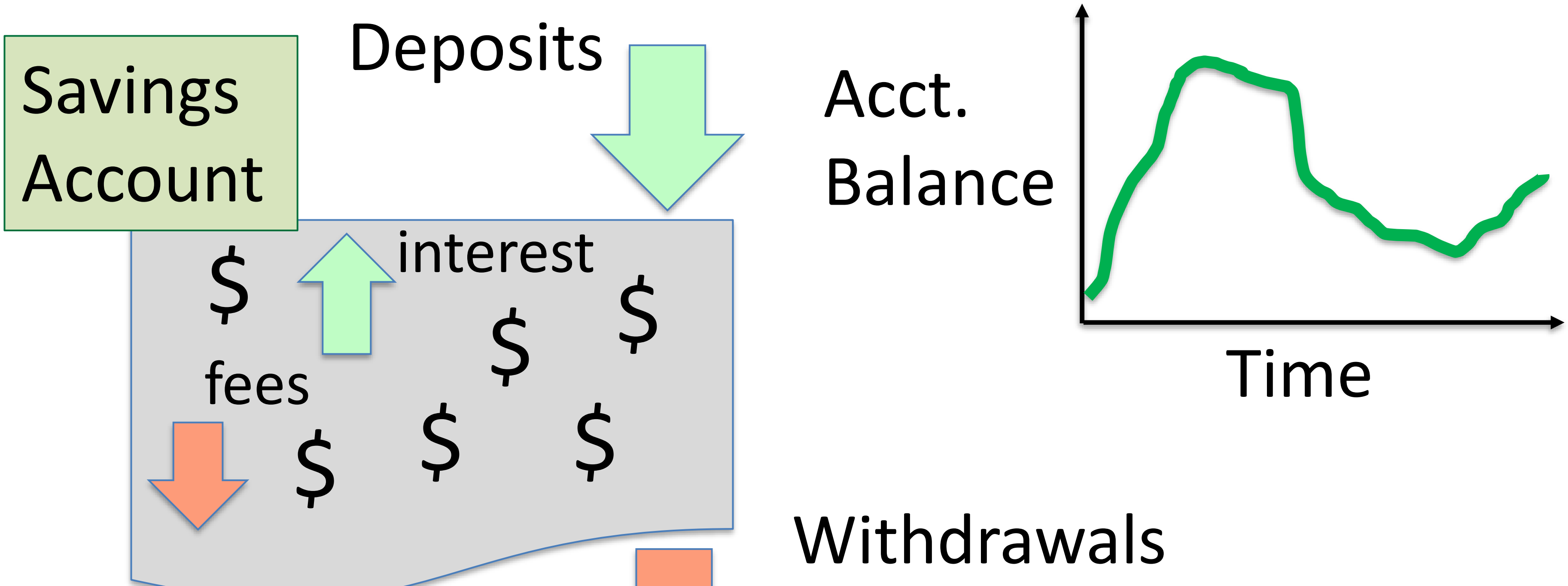


Collaboratory Project Created Two Separate Lake Response Models:

1. Three-dimensional mechanistic model (this model)
2. Bayesian-Mechanistic (Obenour et al. 2019)

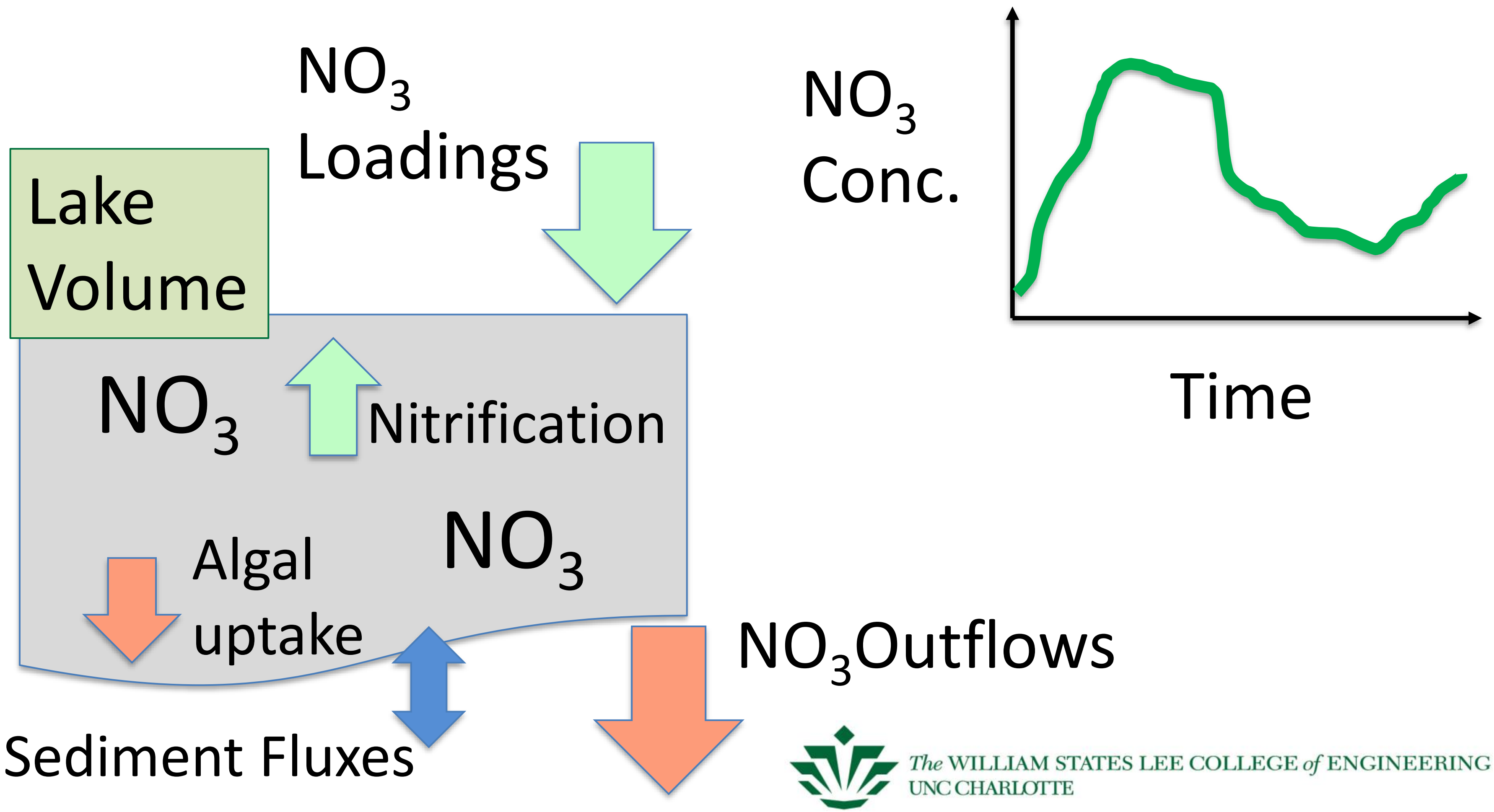
Modeling Approach: Create a Mechanistic Model Using Material Balances for Water, Heat, Momentum, Mass

Analogous to a Bank Account

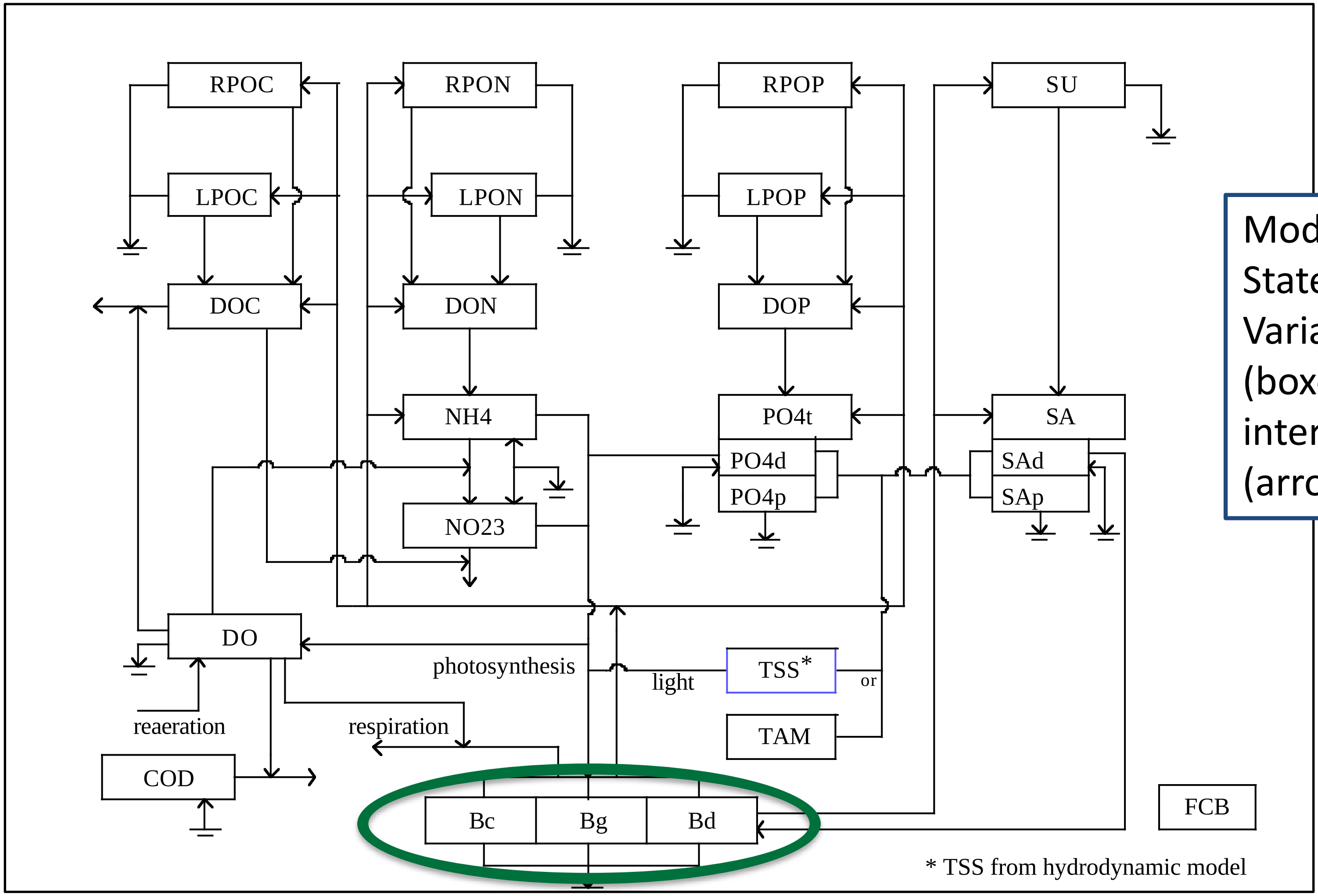


Qu: What are Material Balances?

NO_3 Material Balance



Model (EFDC) includes 3 Algal Functional Groups

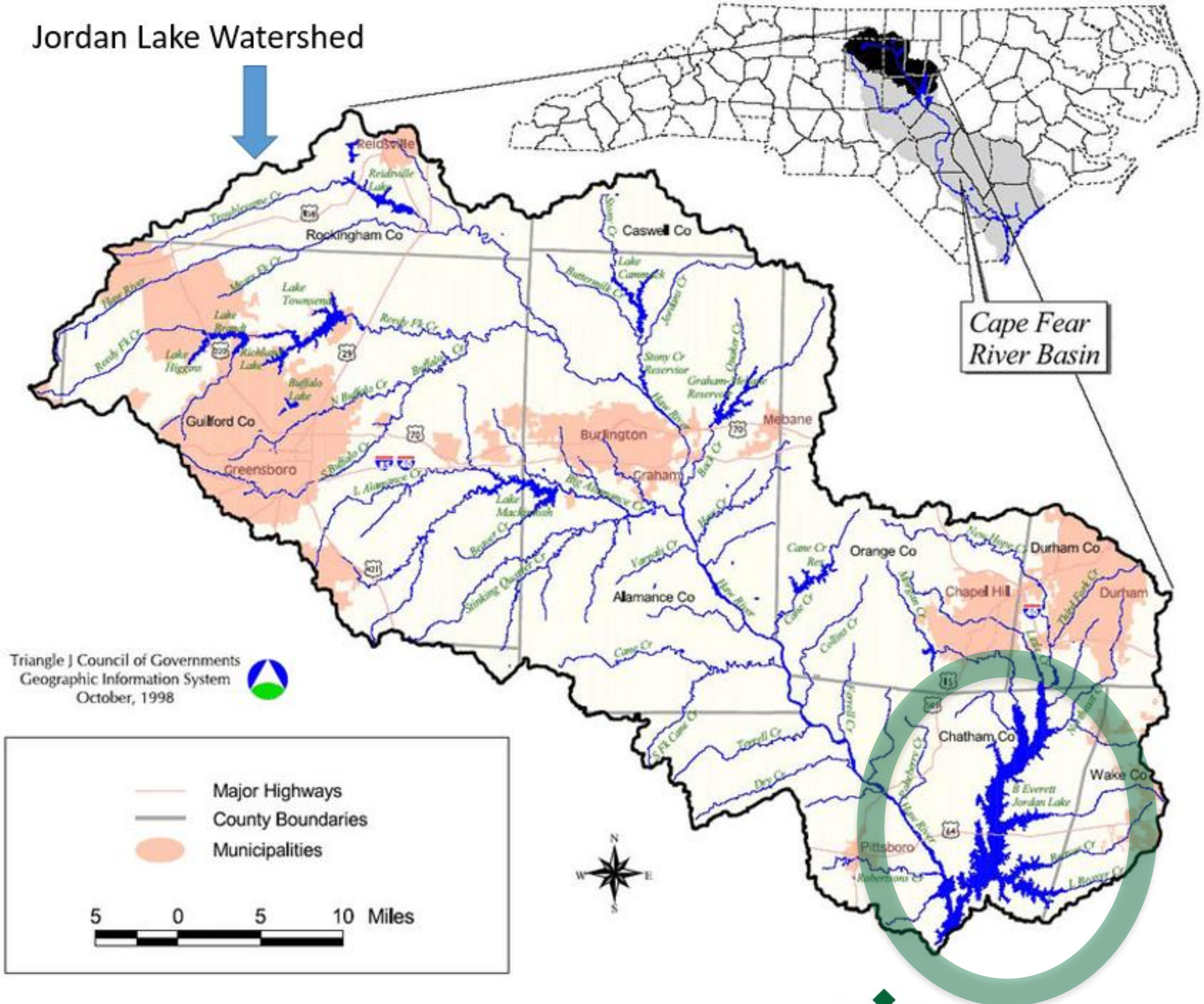


Model State Variables (boxes) w/ interactions (arrows)

The WILLIAM STATES LEE COLLEGE of ENGINEERING
UNC CHARLOTTE

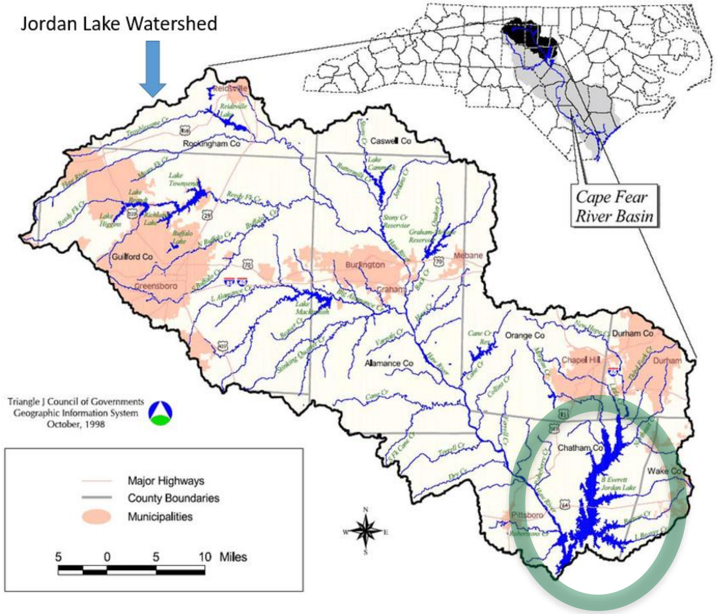
Jordan Lake: Not Your Typical Reservoir

Jordan Lake Watershed



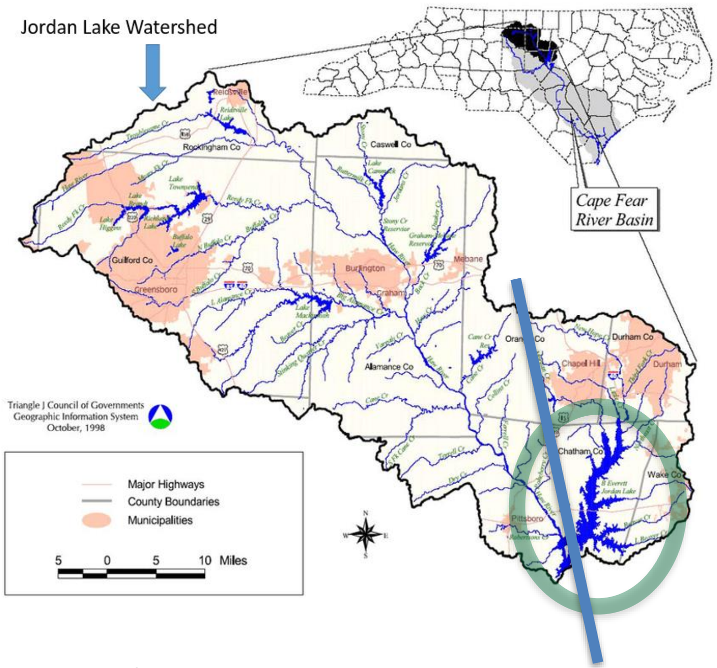
The WILLIAM STATES LEE COLLEGE of ENGINEERING
UNC CHARLOTTE

Jordan Lake: Not Your Typical Reservoir



- Lake has two arms (Haw, New Hope)
- Most of watershed in Haw arm
- Most of lake volume in New Hope arm
- Causeways in New Hope arm restrict circulation
- Large fluctuations in water
- surface (~6 m 2014-2016)

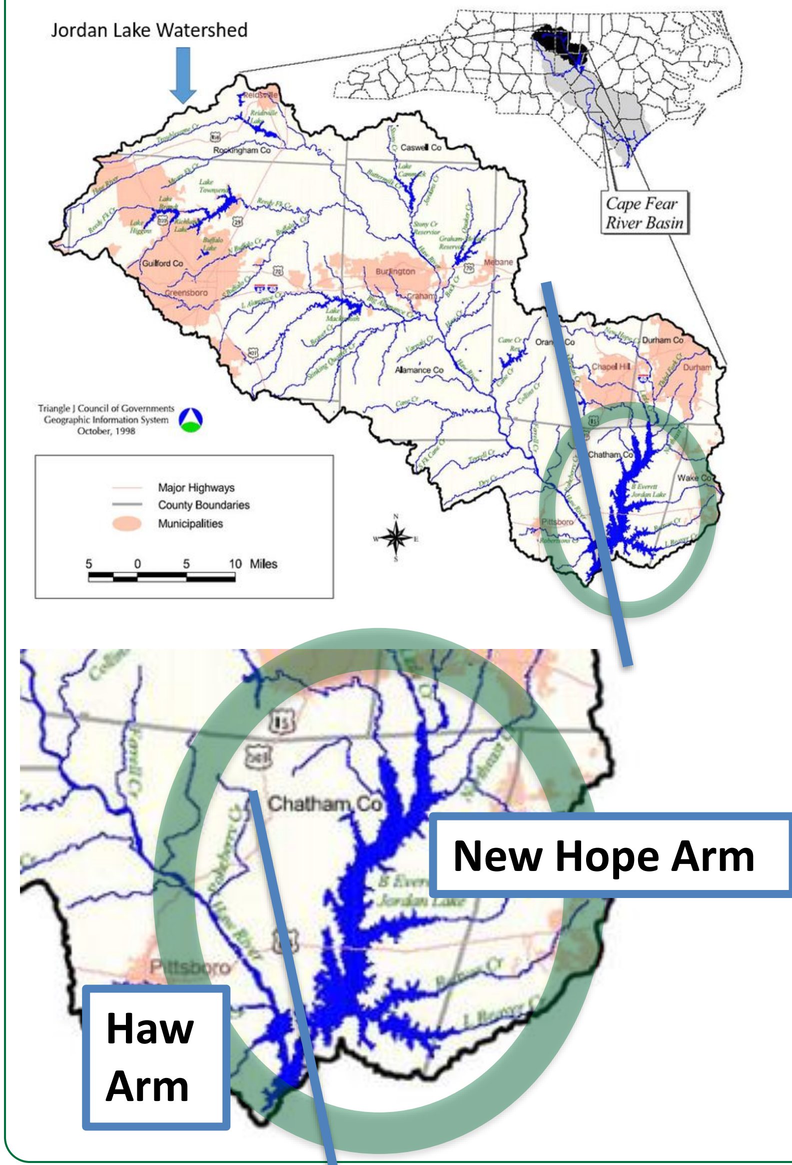
Jordan Lake: Not Your Typical Reservoir



Haw/New Hope Watershed Divide

- Lake has two arms (Haw, New Hope)
- Most of watershed in Haw arm
- Most of lake volume in New Hope arm
- Causeways in New Hope arm restrict circulation
- Large fluctuations in water
- surface (~6 m 2014-2016)

Jordan Lake: Not Your Typical Reservoir

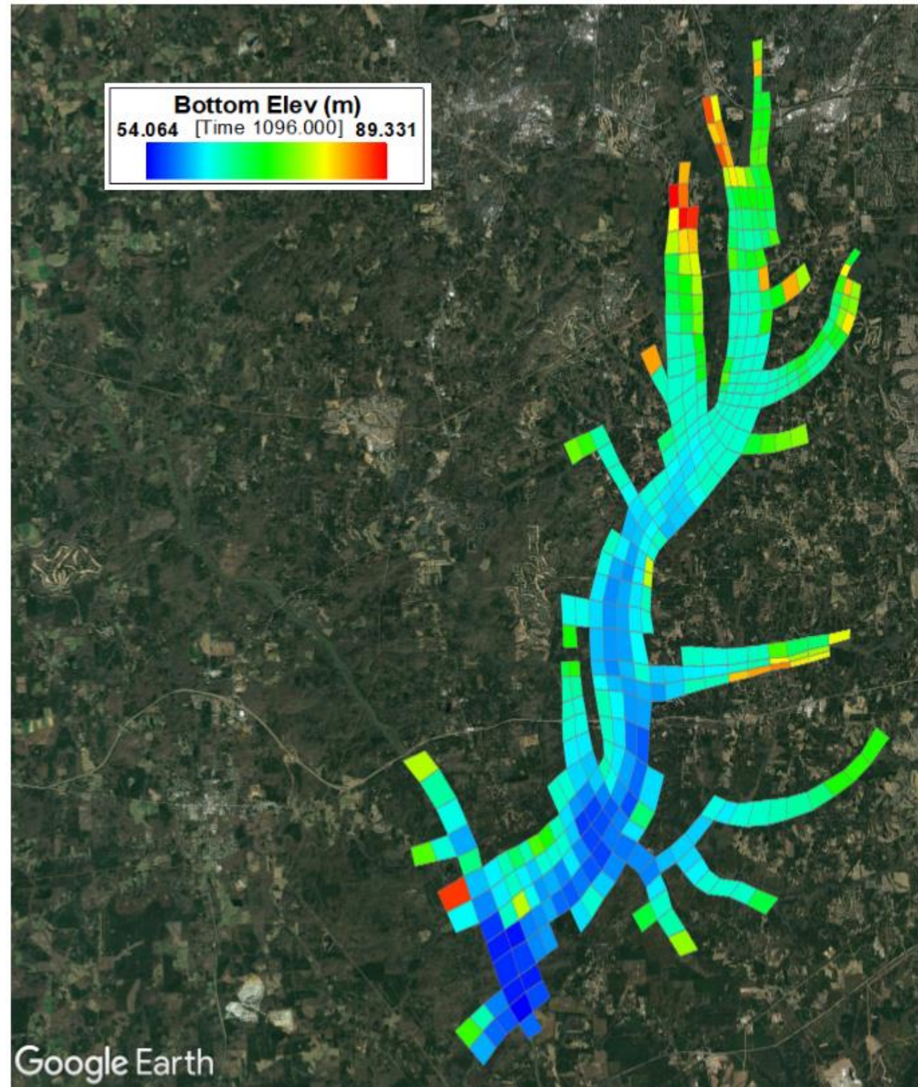


- Lake has two arms (Haw, New Hope)
- Most of watershed in Haw arm
- Most of lake volume in New Hope arm
- Narrows & Causeways in New Hope arm restrict circulation
- Large fluctuations in water
- surface (~6 m 2014-2016)

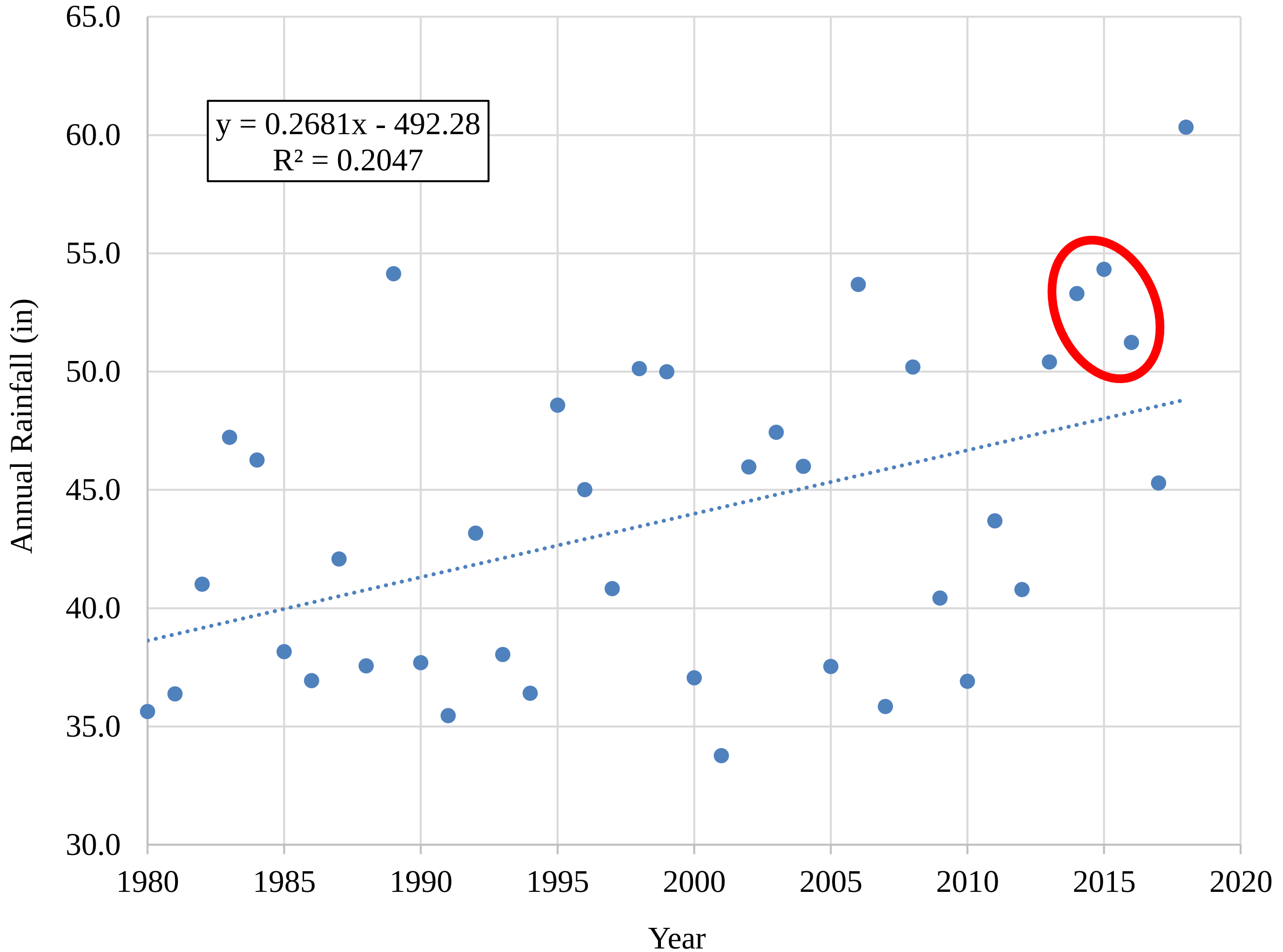
The WILLIAM STATES LEE COLLEGE of ENGINEERING
UNC CHARLOTTE

Model Setup, 3-d Mechanistic, a New Grid

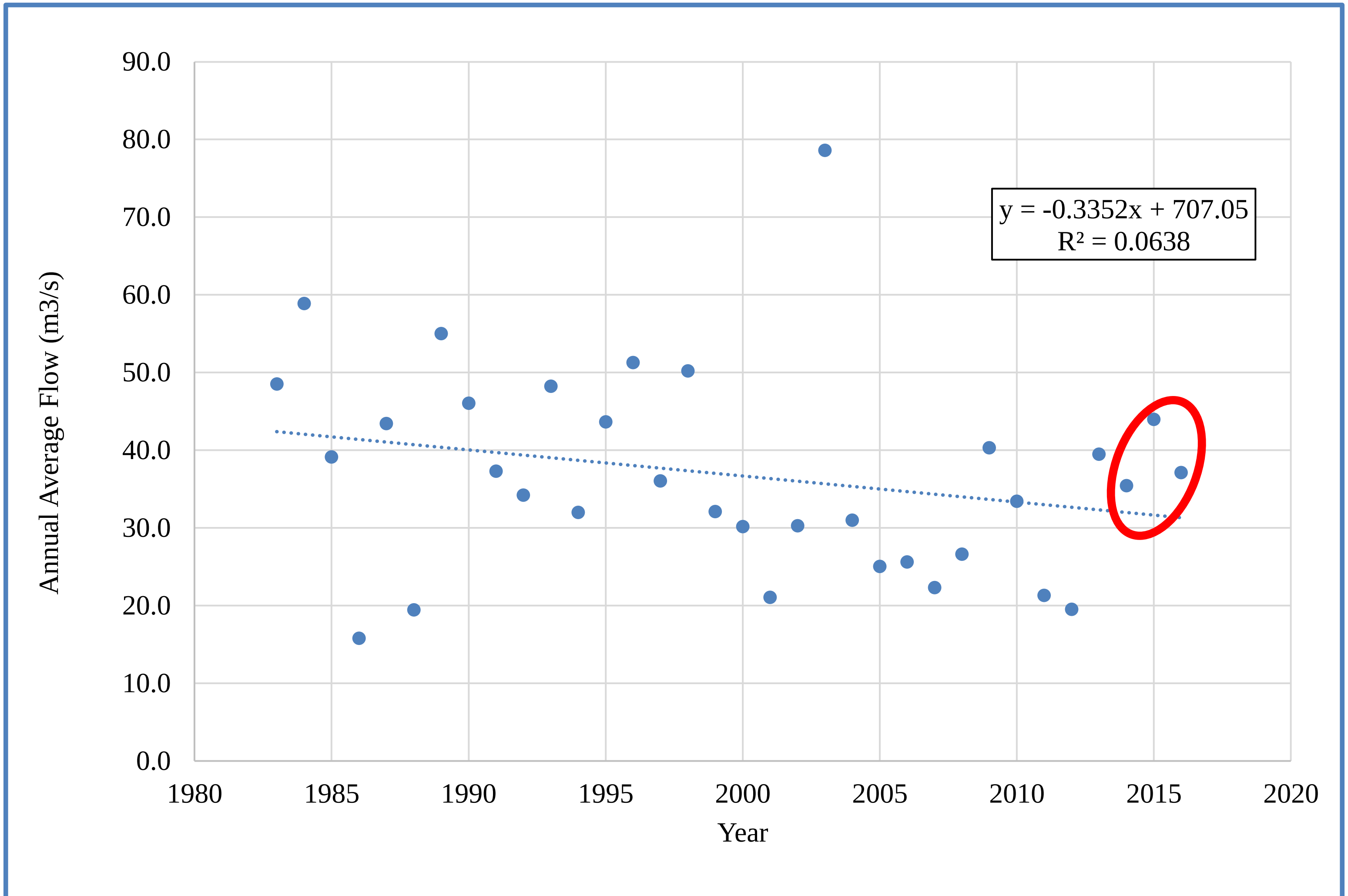
- Lake divided into 407 cells horizontally
- Each cell divided vertically into up to 25 layers (~.4 m), using a z-grid layering method
- Bottom elevations use new bathymetry plus LIDAR data
- Model time period (2014-2016) is recent and has good chlorophyll data coverage
- Lake is modeled for 2+ years (Jan. '14-Feb. '16) at a ~100 second time step



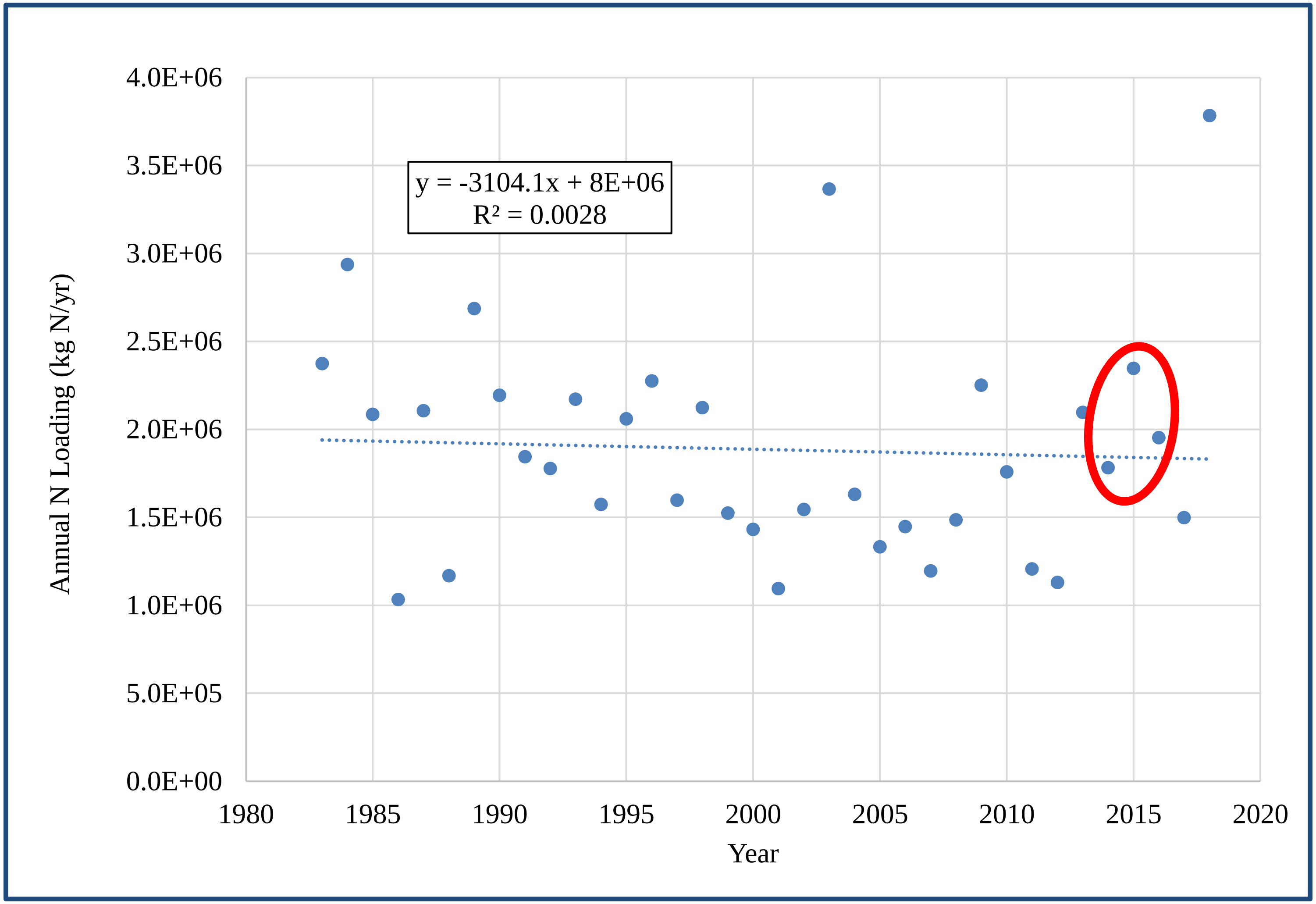
Hydrologic Analysis (comparison to historical): 2014-2016 model time period: Yearly Rainfall



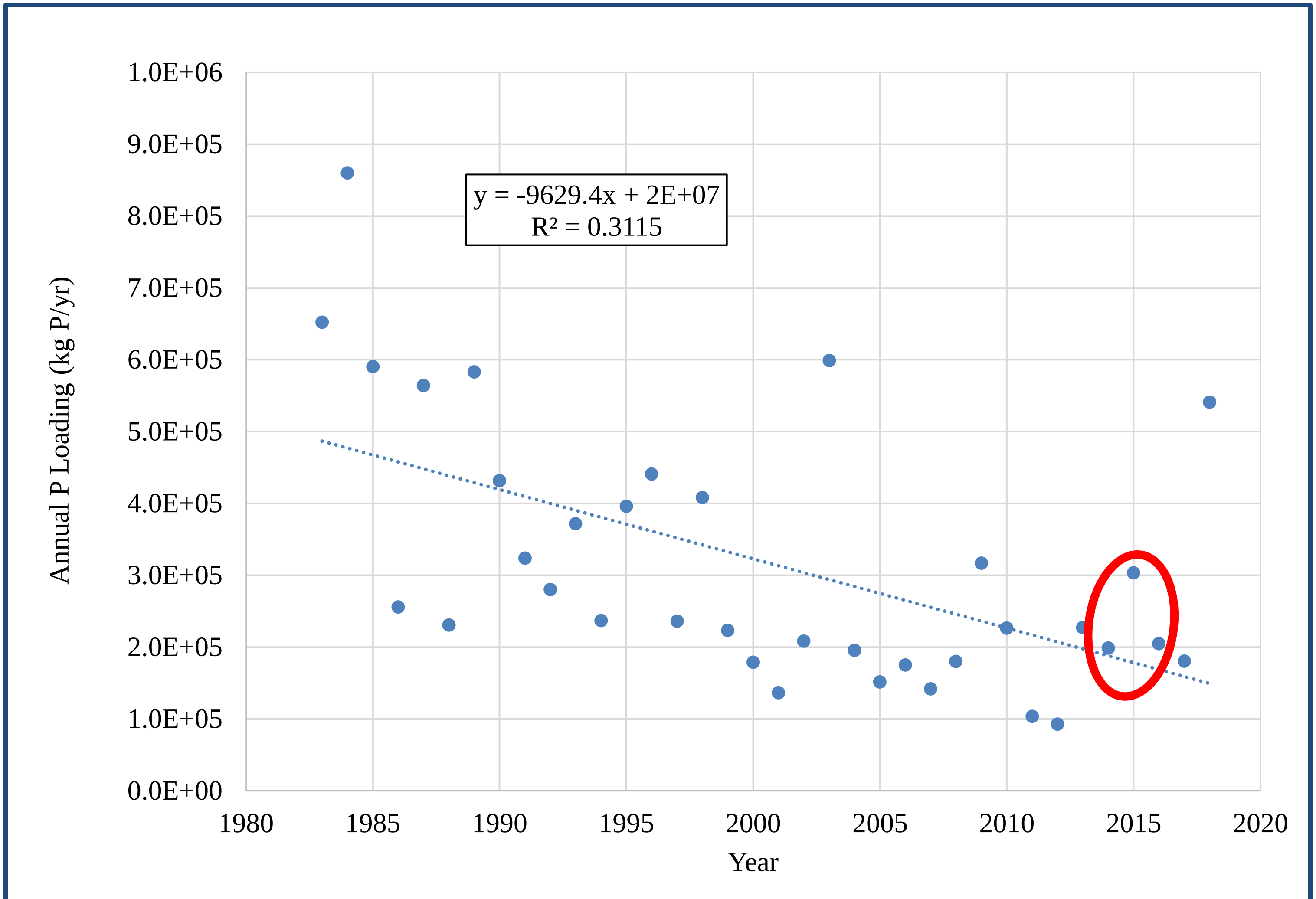
Hydrologic Analysis (comparison to historical): 2014-2016 model time period: Average Streamflows



Hydrologic Analysis (comparison to historical): 2014-2016 model time period: Cumulative Nitrogen Loading to Lake

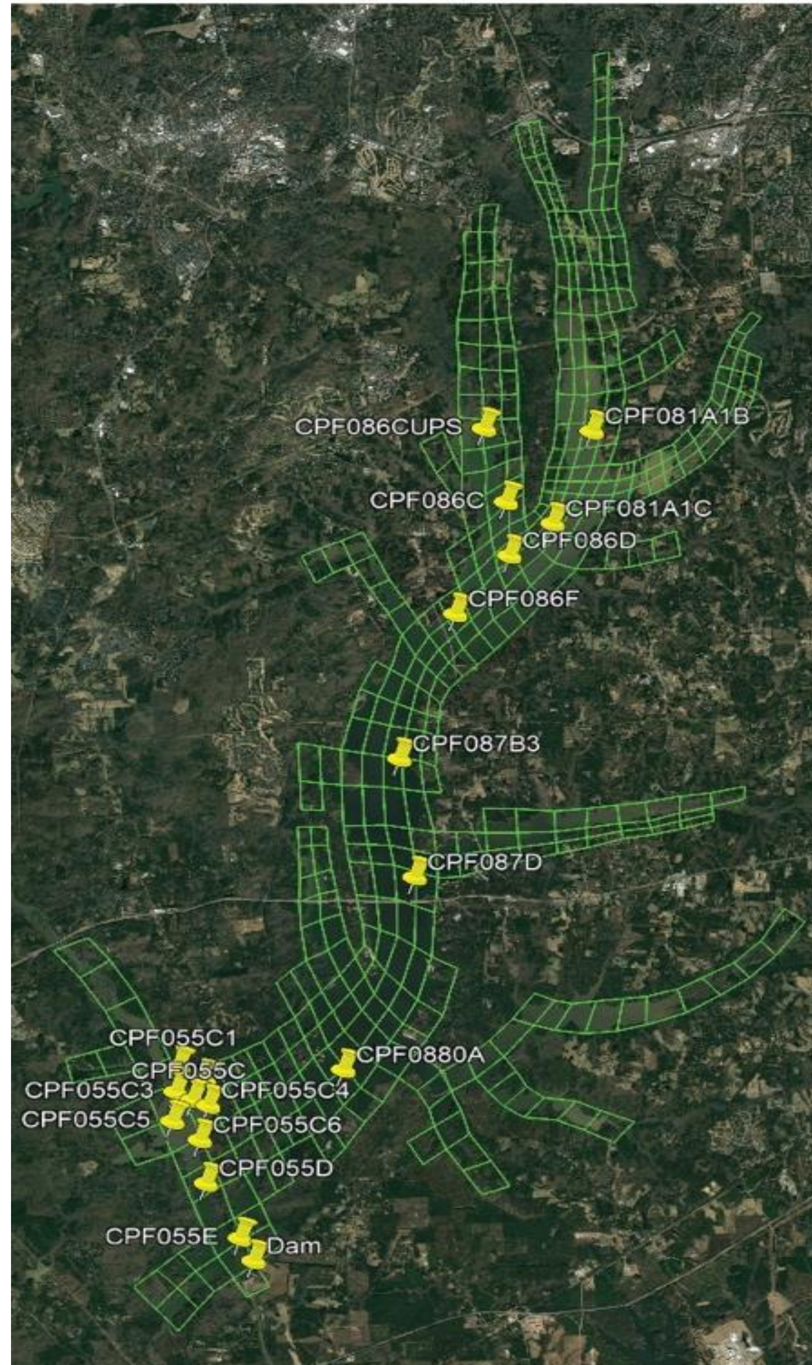


Hydrologic Analysis (comparison to historical): 2014-2016 model time period: Cumulative Phosphorus Loading to Lake

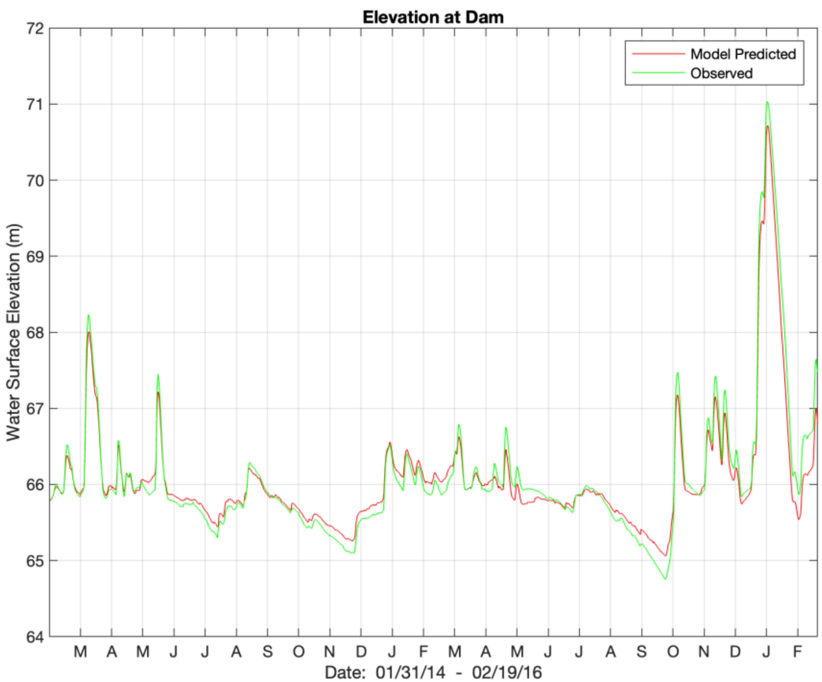


Model Predictions Compared to DWR Temp, Nutrients, DO, Chl-a Data

- Long-term monitoring data available for Jordan Lake
- 18 stations in both Haw River and New Hope Creek arms of lake
- Data available since the 1980's



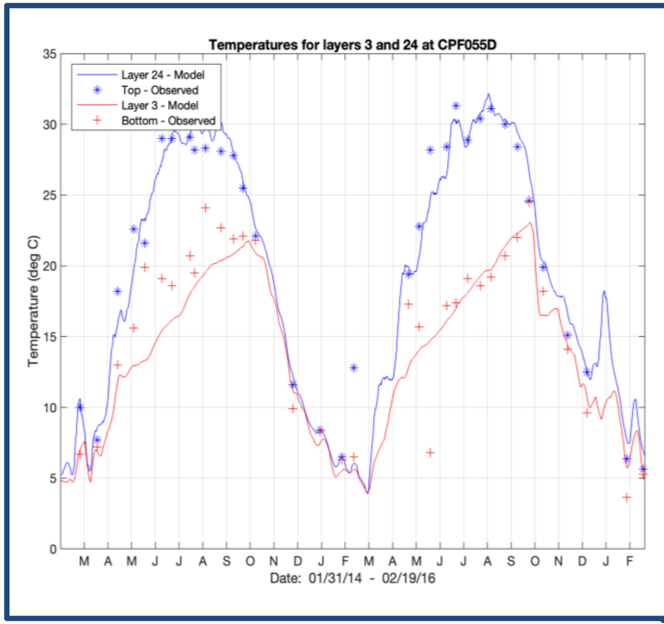
Model Calibration: Elevation @ Dam, Time Series, Calibration Stats

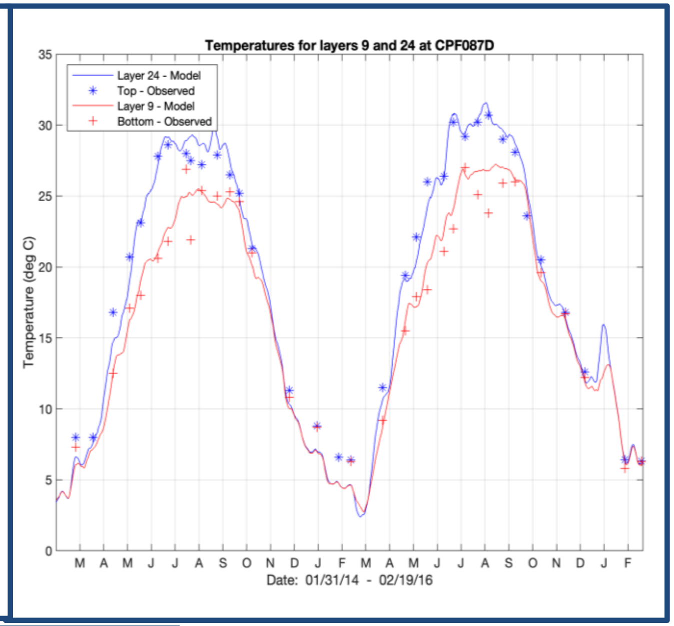


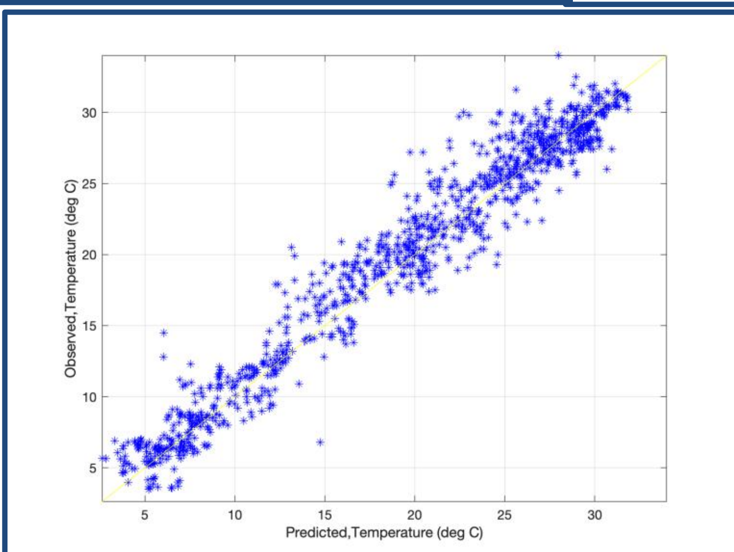
- Note ~6 m range in water surface elevation
- Model meets calibration performance criteria

Calibration Statistic	Value for 2014-2016 time period	Units
Mean Error (predicted – observed)	-0.02	m
Normalized Mean Error	-0.0%	%
Root Mean Square Error	0.23	m
Normalized Root Mean Square Error	0.3%	%
Mean Absolute Error	0.16	m
Normalized Mean Absolute Error	0.2%	%
Coefficient of determination (R^2)	95.7%	%
Number of Model/Data Comparisons	749	-
Nash-Sutcliffe Model Efficiency	93.5%	%

Model Calibration: Temperatures – Time Histories, Scatter Plot, Calibration Stats



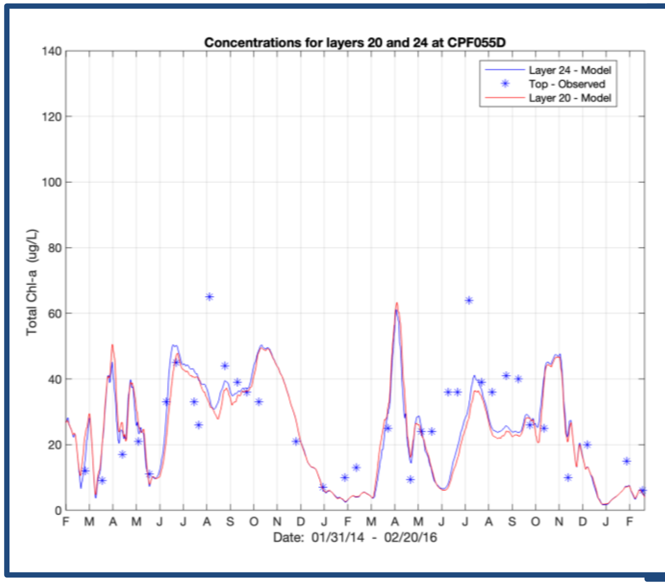


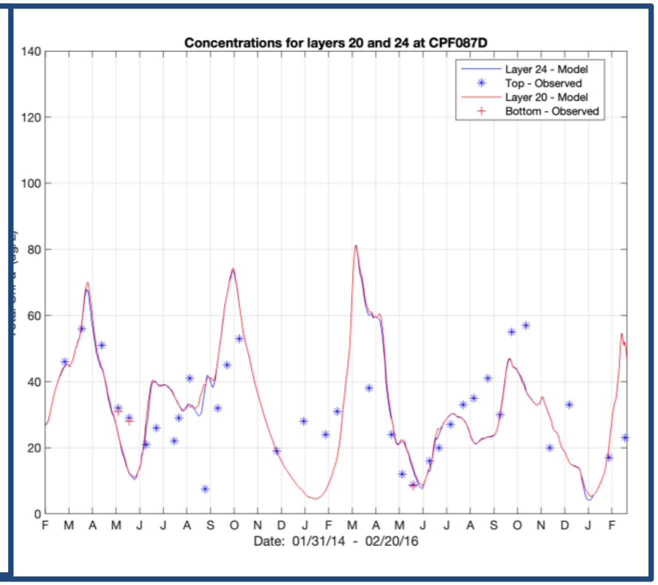


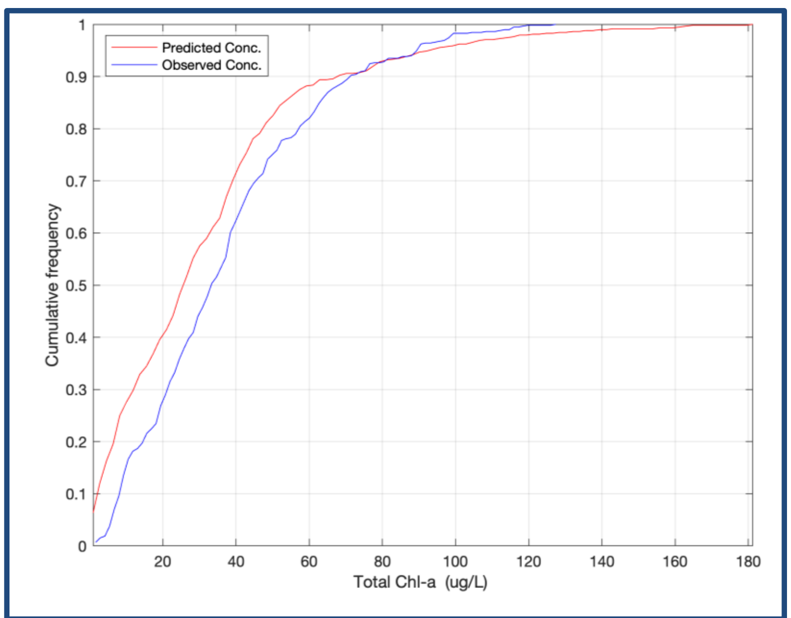
Model meets calibration performance criteria

Calibration Statistic	Value for 2014-2016 time period	Units
Mean Error (predicted – observed)	-0.54	Deg C
Normalized Mean Error	-2.7%	%
Root Mean Square Error	1.91	Deg C
Normalized Root Mean Square Error	9.7%	%
Mean Absolute Error	1.42	Deg C
Normalized Mean Absolute Error	7.2%	%
Coefficient of determination (R^2)	95.2%	%
Number of Model/Data Comparisons	1075	-
Nash-Sutcliffe Model Efficiency	94.7%	%

Model Calibration: Chorophyll-a – Time Histories, CDF, Calibration Stats



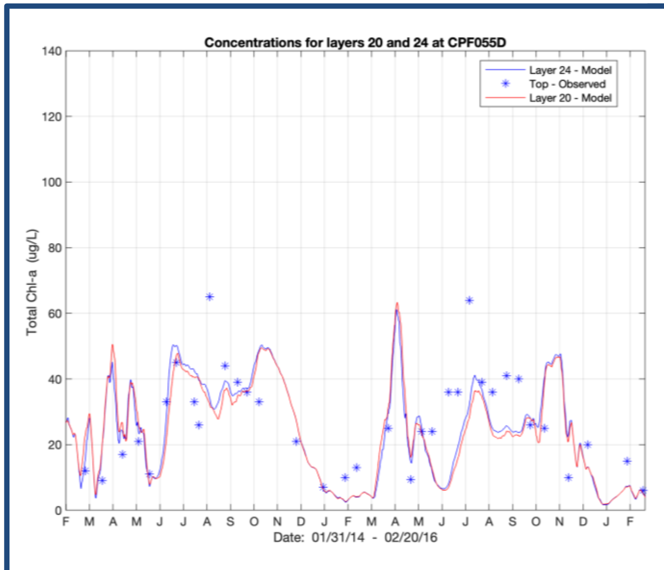


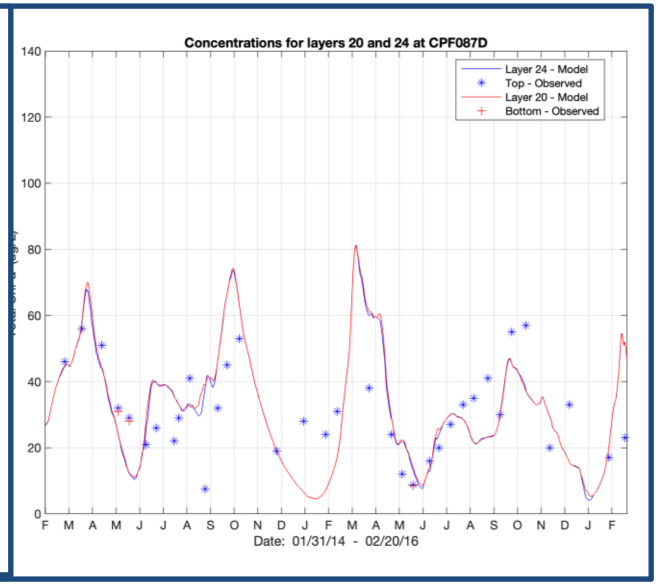


Model meets calibration performance criteria

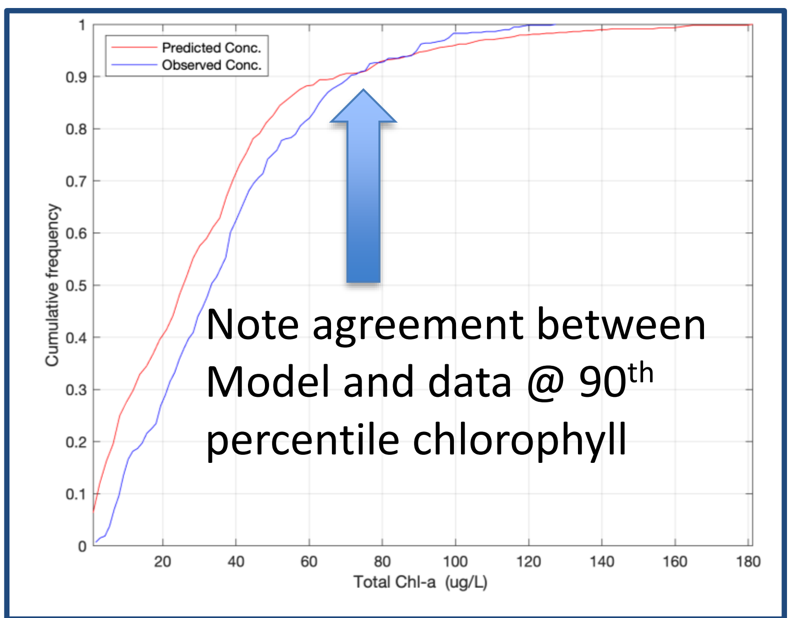
Calibration Statistic	Value for 2014-2016 time period	Units
Mean Error (predicted – observed)	-5.37	ug/L
Normalized Mean Error	-14.2%	%
Root Mean Square Error	27.2	ug/L
Normalized Root Mean Square Error	72.1%	%
Mean Absolute Error	18.9	ug/L
Normalized Mean Absolute Error	49.9%	%
Coefficient of determination (R^2)	28.3%	%
Number of Model/Data Comparisons	584	-
Nash-Sutcliffe Model Efficiency	-0.184	-

Model Calibration: Chorophyll-a – Time Histories, CDF, Calibration Stats





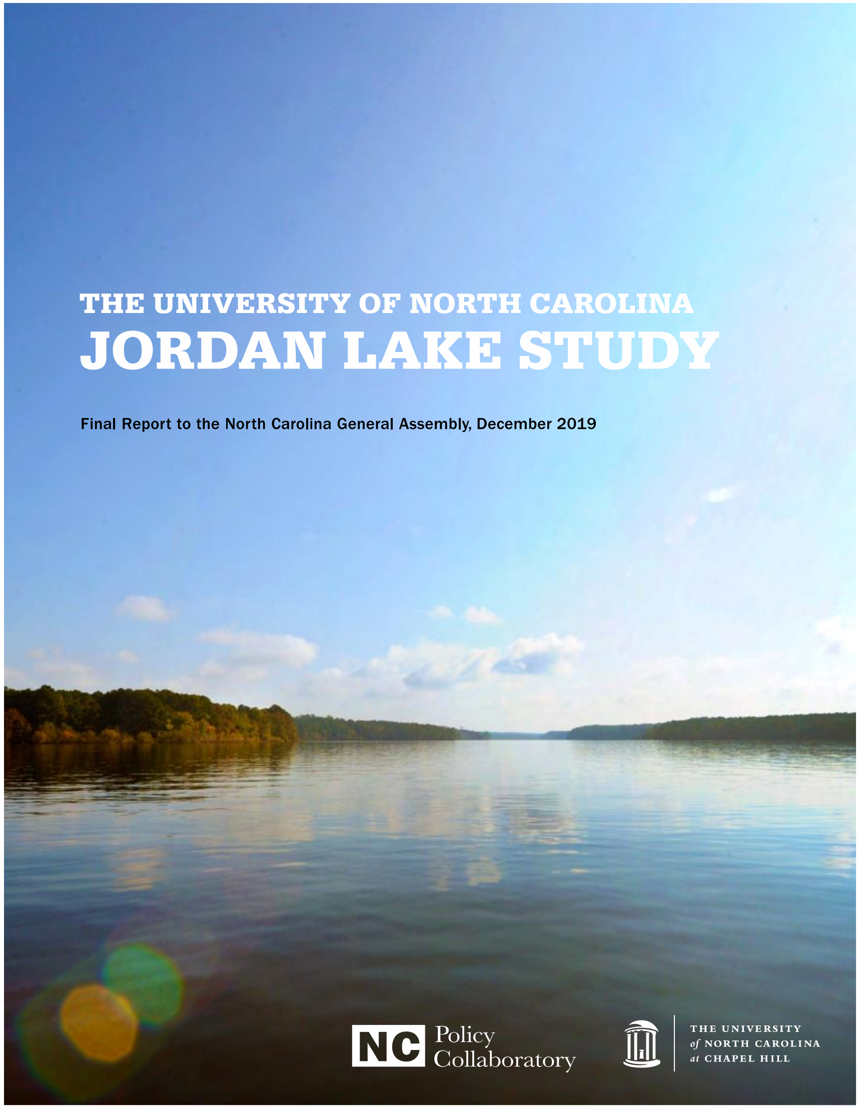
Model meets calibration performance criteria



Calibration Statistic	Value for 2014-2016 time period	Units
Mean Error (predicted – observed)	-5.37	ug/L
Normalized Mean Error	-14.2%	%
Root Mean Square Error	27.2	ug/L
Normalized Root Mean Square Error	72.1%	%
Mean Absolute Error	18.9	ug/L
Normalized Mean Absolute Error	49.9%	%
Coefficient of determination (R^2)	28.3%	%
Number of Model/Data Comparisons	584	-
Nash-Sutcliffe Model Efficiency	-0.184	-

Results Summary, A Look Back

Key Takeaways in NC Policy Collaboratory Report



https://collaboratory.unc.edu/files/2020/01/2019-jordan-lake-final-report.pdf

The WILLIAM STATES LEE COLLEGE of ENGINEERING
UNC CHARLOTTE

3-d Mechanistic Model – Key Takeaways

- The majority of nutrients (N and P) entering the lake are from watershed sources, primarily from the Haw River. These nutrients are mostly in particulate and organic forms that are not immediately available to phytoplankton.
- Only a very small fraction of inflowing Haw River water makes its way to the region above the two causeways in the New Hope Creek arm of the lake. In this region, local inflows (Morgan Creek, New Hope Creek, Northeast Creek) supply the majority of nutrient inputs.
- The benthic sediments of Jordan Lake act as a sink for the particulate fraction of organic nutrients, nitrate, and dissolved oxygen. Benthic sediments are also the major source of bioavailable nutrients, providing more than 75% of phosphate and 90% of ammonia to the lake.

Results from Simulated Dye Introduction to Haw River Inflow

- Haw River Contributes >90% of water in Haw Arm
- Haw River Contributes only ~1% of water in Upper New Hope Arm

Jordan Lake Region	Station	Time-Average Contribution from Haw River Water (%)	
		2014-2015	2017-2018
Haw River	CPF055C	100%	100%
	CPF055D	100%	100%
	CPF055E	100%	100%
	Average	93.5%	93.1%
Above Causeways	CPF086C	0.0%	1.0%
	CPF086D	0.8%	2.8%
	CPF086F	1.0%	3.2%
	Average	0.0%	1.2%
Between Causeways	CPF087B3	12.0%	20.1%
	CPF087D	20.1%	30.0%
	Average	16.0%	25.0%
Below Causeways	CPF0880A	59.2%	70.4%
	Average	59.2%	70.4%

Results from Simulated Dye Introduction to Haw River Inflow

- Haw River Contributes >90% of water in Haw Arm
- Haw River Contributes only ~1% of water in Upper New Hope Arm

Jordan Lake Region	Station	Time-Average Contribution from Haw River Water (%)	
		2014-2015	2017-2018
Haw River	CPF055C	100%	100%
	CPF055D	100%	100%
	CPF055E	100%	100%
	Average	93.5%	93.1%
Above Causeways	CPF086C	0.0%	1.0%
	CPF086D	0.8%	2.8%
	CPF086F	1.0%	3.2%
	Average	0.0%	1.2%
Between Causeways	CPF087B3	12.0%	20.1%
	CPF087D	20.1%	30.0%
	Average	16.0%	25.0%
Below Causeways	CPF0880A	59.2%	70.4%
	Average	59.2%	70.4%

3-d Mechanistic Model – Key Takeaways, cont'd

- For the five-year time period studied (2014-2018), the observed 90th percentile photic-zone chlorophyll a concentration at eighteen monitoring stations across Jordan Lake was 72 µg/l, which is 44% above the North Carolina water quality criteria value of 40 µg/l.

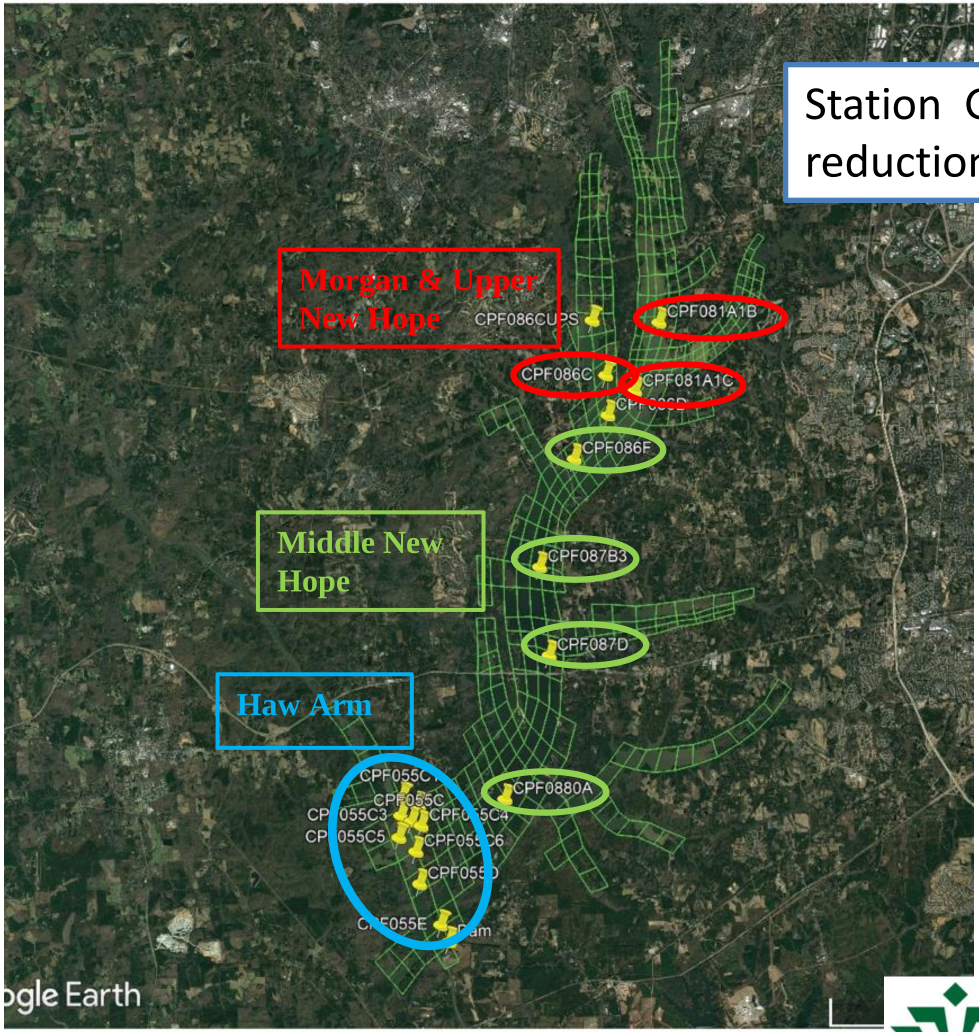
Analysis of 2014-2018 Chl a Data

Lake Region	Station	Number of Chl a samples	Chl a median concentration (µg/L)	90th percentile Chla a concentration (µg/L)	Reduction needed for 90th percentile Chl a concentration at 40 µg/L
Haw River	CPF055C	74	29.0	63.7	37%
	CPF055D	72	25.0	44.9	11%
	CPF055E	73	28.0	44.0	9%
Above Causeways	CPF081A1C	74	57.5	90.4	56%
	CPF086C	74	58.5	89.0	55%
	CPF086F	74	52.5	81.7	51%
Between Causeways	CPF087B3	74	34.0	52.4	24%
	CPF087D	74	29.5	53.0	25%
Below Causeways	CPF0880A	74	28.0	42.0	5%
Jordan Lake	All 18 Stations	1004	36.0	72.0	44%

Results from 2023 Model – Nutrient Reduction Scenario Tests

- Watershed loadings of organic & inorganic N & P loading reduced from 0% to 70% (63 cases + base)
- Compared chlorophyll-a concentrations and fraction of values above 40 ug/L (criteria value)
- Analyzed entire lake + 3 regions (Haw, Upper New Hope & Morgan, Middle New Hope)
- Adjusted chlorophyll-a for regions so model agrees w/ data @ 90th percentile

Results from 2023 Model – Nutrient Reduction Scenario Tests



Station Groupings for N,P reduction scenario tests

Chl-a adjust factors for N,P reduction scenario tests

Station Group	Chl-a to C Adjustment Factor
All Stations	1.00
Haw Arm	1.12
Morgan & Upper New Hope	0.89
Middle New Hope	0.80

The WILLIAM STATES LEE COLLEGE of ENGINEERING
UNC CHARLOTTE

Results: Lake Responds to Reduced N and/or P Loading (all stations) (NB: N given as frac in med)

Med chl-a (ug/L)

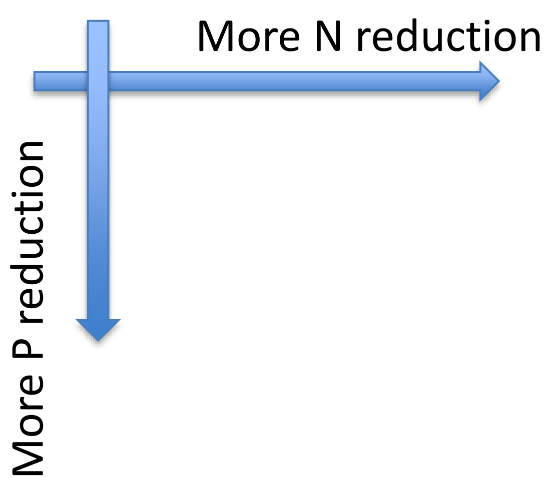
Station Set: All Stations

P loading reduction (%) × Nitrogen Loading Reduction (%)

	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
0%	31.2	30.4	29.5	28.2	26.8	25.1	21.7	17.3
10%	30.0	29.3	28.4	27.2	25.8	24.4	21.2	17.2
20%	28.7	28.1	27.3	26.2	24.8	23.5	20.8	17.0
30%	27.2	26.7	26.0	25.1	23.8	22.6	20.1	16.7
40%	25.6	25.2	24.7	23.9	22.8	21.6	19.3	16.3
50%	23.9	23.7	23.3	22.6	21.6	20.4	18.6	15.8
60%	22.2	22.0	21.7	21.2	20.3	19.2	17.7	15.1
70%	20.1	20.0	19.8	19.5	18.9	18.0	16.7	14.4

Color Scale

0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0



Frac. > 40 ug/L

Station Set: All Stations

P loading reduction (%) × Nitrogen Loading Reduction (%)

	0%	10%	20%	30%	40%	50%	60%	70%
0%	0.37	0.35	0.32	0.30	0.28	0.24	0.20	0.10
10%	0.35	0.33	0.30	0.28	0.25	0.22	0.17	0.10
20%	0.31	0.29	0.27	0.25	0.22	0.19	0.15	0.09
30%	0.29	0.27	0.24	0.22	0.20	0.15	0.12	0.07
40%	0.27	0.26	0.23	0.21	0.19	0.14	0.10	0.06
50%	0.26	0.24	0.22	0.20	0.17	0.13	0.09	0.05
60%	0.24	0.23	0.20	0.18	0.16	0.12	0.08	0.04
70%	0.23	0.21	0.19	0.17	0.15	0.12	[illegible]	0.04

Color Scale

0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Results: Lake Response More Sensitive to N than P (P reduction effect is smaller) – All Stations

Med chl-a (ug/L)

Station Set: All Stations

P loading reduction (%)	Nitrogen Loading Reduction (%) 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
0%	31.2	30.4	29.5	28.2	26.8	25.1	21.7	17.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20%	28.7	28.1	27.3	26.2	24.8	23.5	20.8	17.0
30%	27.2	26.7	26.0	25.1	23.8	22.6	20.1	16.7
40%	25.6	25.2	24.7	23.9	22.8	21.6	19.3	16.3
50%	23.9	23.7	23.3	22.6	21.6	20.4	18.6	15.8
60%	22.2	22.0	21.7	21.2	20.3	19.2	17.7	15.1
70%	20.1	20.0	19.8	19.5	18.9	18.0	16.7	14.4

Color Scale

0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0

More N reduction

More P reduction

Frac > 40 ug/L

Station Set: All Stations

P loading reduction (%)	Nitrogen Loading Reduction (%) 0%	10%	20%	30%	40%	50%	60%	70%
0%	0.37	0.35	0.32	0.30	0.28	0.24	0.20	0.10
10%	0.35	0.33	0.30	0.28	0.25	0.22	0.17	0.10
20%	0.31	0.29	0.27	0.25	0.22	0.19	0.15	0.09
30%	0.29	0.27	0.24	0.22	0.20	0.15	0.12	0.07
40%	0.27	0.26	0.23	0.21	0.19	0.14	0.10	0.06
50%	0.26	0.24	0.22	0.20	0.17	0.13	0.09	0.05
60%	0.24	0.23	0.20	0.18	0.16	0.12	0.08	0.04
70%	0.23	0.21	0.19	0.17	0.15	0.12	0.07	0.04

Color Scale

0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Results: N vs. P sensitivity varies from Haw to New Hope (P limited in Haw, N limited in New Hope)

Haw - Med chl-a (ug/L)

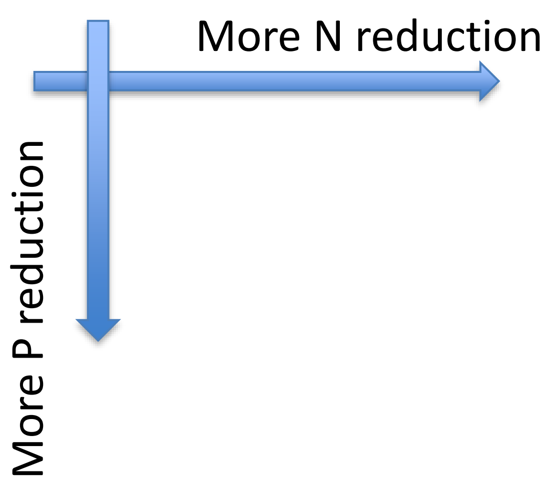
Station Set: Haw Stations

Nitrogen Loading Reduction (%)

P loading reduction (%)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
0%	28.4	28.4	28.1	27.9	27.5	27.2	25.5	21.8
10%	26.9	26.9	26.7	26.4	26.2	25.6	24.5	21.3
20%	25.3	25.2	25.1	24.8	24.8	24.0	23.3	20.6
30%	23.5	23.6	23.5	23.3	23.2	22.6	21.8	19.7
40%	21.7	21.7	21.6	21.5	21.3	21.2	20.2	18.7
50%	19.6	19.6	19.6	19.5	19.3	19.6	18.5	17.4
60%	17.5	17.5	17.5	17.3	17.2	17.4	17.1	15.7
70%	15.2	15.3	15.2	15.2	15.1	15.3	15.7	14.2

Color Scale

0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0



N.H. - Med chl-a (ug/L)

Station Set: Morgan & Upper New Hope

Nitrogen Loading Reduction (%)

P loading reduction (%)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
0%	33.6	31.5	28.9	25.3	21.5	17.0	13.1	9.2
10%	32.9	30.3	28.0	24.9	21.3	16.9	13.1	9.2
20%	31.6	29.3	27.2	24.3	20.9	16.8	13.0	9.2
30%	30.7	28.4	26.0	23.7	20.4	16.8	12.9	9.2
40%	29.5	27.3	25.1	22.7	20.0	16.5	12.8	9.1
50%	27.7	25.8	24.0	21.8	19.3	16.3	12.6	9.0
60%	25.8	24.2	22.6	20.8	18.7	16.0	12.6	8.9
70%	23.8	22.4	20.9	19.3	17.6	15.5	12.2	8.8

Color Scale

0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0

Results: N vs. P sensitivity varies from Haw to New Hope (P sensitive in Haw, N sensitive in New Hope)

Haw - Med chl-a (ug/L)

Station Set: Haw Stations

P loading reduction (%)	Nitrogen Loading Reduction (%) 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
0%	28.4	28.4	28.1	27.9	27.5	27.2	25.5	21.8
10%	26.9	26.9	26.7	26.4	26.2	25.6	24.5	21.3
20%	25.3	25.2	25.1	24.8	24.8	24.0	23.3	20.6
30%	23.5	23.6	23.5	23.3	23.2	22.6	21.8	19.7
40%	21.7	21.7	21.6	21.5	21.3	21.2	20.2	18.7
50%	19.6	19.6	19.6	19.5	19.3	19.6	18.5	17.4
60%	17.5	17.5	17.5	17.3	17.2	17.4	17.1	15.7
70%	15.2	15.3	15.2	15.2	15.1	15.3	15.7	14.2

Color Scale

0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0

More N reduction

More P reduction

Note higher chl-a values in NH vs Haw (15% - 40% difference)

N.H. - Med chl-a (ug/L)

Station Set: Morgan & Upper New Hope

P loading reduction (%)	Nitrogen Loading Reduction (%) 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
0%	33.6	31.5	28.9	25.3	21.5	17.0	13.1	9.2
10%	32.9	30.3	28.0	24.9	21.3	16.9	13.1	9.2
20%	31.6	29.3	27.2	24.3	20.9	16.8	13.0	9.2
30%	30.7	28.4	26.0	23.7	20.4	16.8	12.9	9.2
40%	29.5	27.3	25.1	22.7	20.0	16.5	12.8	9.1
50%	27.7	25.8	24.0	21.8	19.3	16.3	12.6	9.0
60%	25.8	24.2	22.6	20.8	18.7	16.0	12.6	8.9
70%	23.8	22.4	20.9	19.3	17.6	15.5	12.2	8.8

Color Scale

0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0

Results: Significant Load Reductions Needed to Get to Frac > 40 ug/L < 0.10 (w.q. criteria)

Station Set: All Stations

P loading reduction (%) / Nitrogen Loading Reduction (%)

	0%	10%	20%	30%	40%	50%	60%	70%
0%	0.37	0.35	0.32	0.30	0.28	0.24	0.20	0.10
10%	0.35	0.33	0.30	0.28	0.25	0.22	0.17	0.10
20%	0.31	0.29	0.27	0.25	0.22	0.19	0.15	0.09
30%	0.29	0.27	0.24	0.22	0.20	0.15	0.12	0.07
40%	0.27	0.26	0.23	0.21	0.19	0.14	0.10	0.06
50%	0.26	0.24	0.22	0.20	0.17	0.13	0.09	0.05
60%	0.24	0.23	0.20	0.18	0.16	0.12	0.08	0.04
70%	0.23	0.21	0.19	0.17	0.15	0.12	0.07	0.04

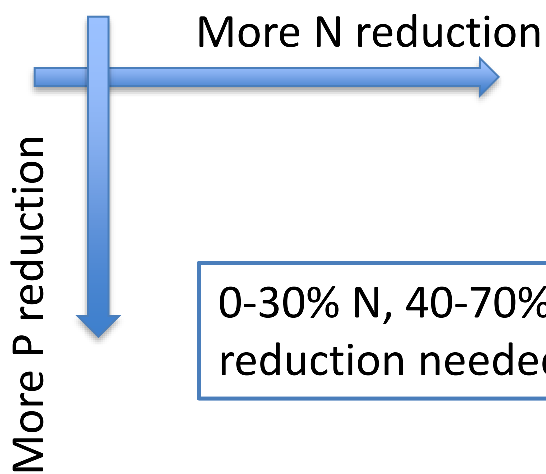
All Stations: Frac > 40 ug/L

60-70% N, 10-40% P reduction needed

Color Scale

0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Haw Stations: Frac > 40 ug/L



0-30% N, 40-70% P reduction needed

Station Set: Haw Stations

P loading reduction (%) / Nitrogen Loading Reduction (%)

	0%	10%	20%	30%	40%	50%	60%	70%
0%	0.31	0.31	0.29	0.27	0.27	0.28	0.28	0.17
10%	0.28	0.27	0.26	0.24	0.24	0.24	0.25	0.16
20%	0.24	0.23	0.22	0.20	0.19	0.20	0.20	0.14
30%	0.18	0.18	0.16	0.15	0.13	0.14	0.14	0.11
40%	0.14	0.13	0.12	0.10	0.08	0.07	0.08	0.07
50%	0.12	0.12	0.10	0.08	0.07	0.05	0.04	0.04
60%	0.11	0.10	0.09	0.07	0.06	0.04	0.02	0.02
70%	0.10	0.09	0.08	0.06	0.05	0.03	0.01	0.00

Results: Significant Load Reductions Needed to Get to Frac > 40 ug/L < 0.10 (w.q. criteria)

Station Set: Morgan & Upper New Hope

Up NH & Morg Stations: Frac > 40 ug/L

Nitrogen Loading Reduction (%) / P loading reduction (%)

P loading reduction (%)	0%	10%	20%	30%	40%	50%	60%	70%
0%	0.45	0.44	0.42	0.39	0.35	0.26	0.17	0.07
10%	0.45	0.43	0.41	0.39	0.35	0.26	0.17	0.07
20%	0.43	0.42	0.40	0.38	0.34	0.26	0.16	0.07
30%	0.42	0.40	0.39	0.37	0.33	0.25	0.16	0.07
40%	0.40	0.39	0.37	0.36	0.32	0.25	0.16	0.07
50%	0.38	0.37	0.36	0.34	0.31	0.24	0.16	0.07
60%	0.37	0.35	0.34	0.33	0.30	0.23	0.15	0.07
70%	0.35	0.34	0.33	0.31	0.28	0.22	0.15	0.07

70% N, 0% P reduction needed

Color Scale

0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

More N reduction

More P reduction

Middle NH Stations: Frac > 40 ug/L

Station Set: Middle New Hope

Nitrogen Loading Reduction (%) / P loading reduction (%)

P loading reduction (%)	0%	10%	20%	30%	40%	50%	60%	70%
0%	0.26	0.24	0.22	0.17	0.13	0.11	0.08	0.03
10%	0.25	0.23	0.20	0.17	0.12	0.10	0.07	0.03
20%	0.23	0.21	0.19	0.16	0.12	0.09	0.06	0.02
30%	0.22	0.20	0.18	0.15	0.11	0.09	0.06	0.02
40%	0.21	0.19	0.17	0.14	0.10	0.08	0.05	0.02
50%	0.18	0.16	0.14	0.12	0.09	0.07	0.05	0.02
60%	0.16	0.14	0.13	0.10	0.07	0.05	0.04	0.01
70%	0.14	0.13	0.11	0.09	0.06	0.05	0.03	0.01

30-50% N, 10-60% P reduction needed

Color Scale

0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Summary and Conclusions

- New 3-d model of Jordan Lake developed and used to test nutrient reduction scenarios
- Model meets calibration criteria for key state variables
- The lake is less sensitive overall to P vs. N load reductions, but not for all regions (Haw P sensitive, UNH insensitive to P load reduction)
- Significant reductions needed to meet chl-a criteria, but differ in arms of lake (Haw: 20% N, 50% P; UNH: 70% N, 0 % P)
- Model to undergo peer review in coming year