UNRBA Technical Stakeholder Workshop

The UNRBA's Re-Examination of the Falls Lake Nutrient Management Strategy

August 1, 2023

The UNRBA's Approach to the Reexamination
10:35 AM

Upper Neuse River Basin (UNRBA)

- Members
  - Six counties
  - Seven municipalities
  - One water utility
  - Soil and water conservation districts
- Active External Stakeholders
  - Agriculture
  - Environmental groups
  - Land conservation organizations
  - NC DEQ/DWR
  - NC DOT
  - NC DA&CS

Falls Lake Designated Uses and Benefits

- Provides drinking water for over 500,000 customers
- No taste, odor, or disinfection byproduct concerns
- Minimizes downstream flooding
- Protects water quality downstream
- Sustains minimum flows
- Provides habitat (aquatic and terrestrial)
- No bloom-related fish kills since filling
- Provides regional recreational facility

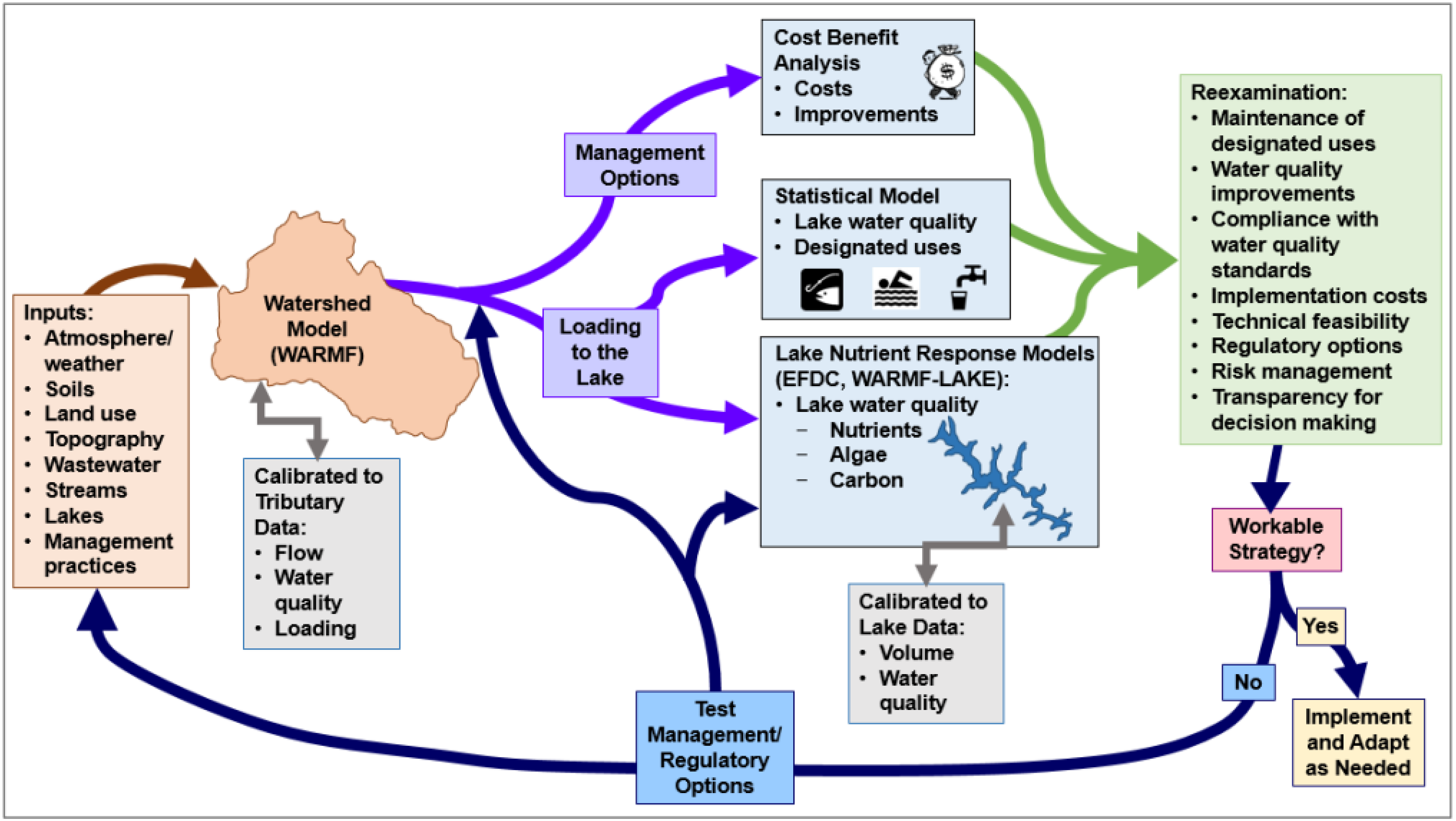
Current Falls Lake Regulatory Framework

- Falls Lake Nutrient Management Strategy passed by the State in 2011
- Two stages of nutrient reductions (relative to baseline year, 2006)
  - Stage I (20% TN, 40% TP)
  - Stage II (40% TN, 77% TP)
- Reductions assigned by sector
- Estimated costs over $1.5 billion
- Stage II requirements beyond technological limits
- Stage I fully implemented
- Adaptive management provision in Rules allows for re-examination of Stage II

UNRBA Approach to the Re-examination of Stage II

Science-based approach to water resource management

UNRBA Conceptual Modeling Plan



Watershed Data and Watershed Analysis Risk Management Framework (WARMF) Watershed Modeling

WARMF Watershed Model Development and Calibration

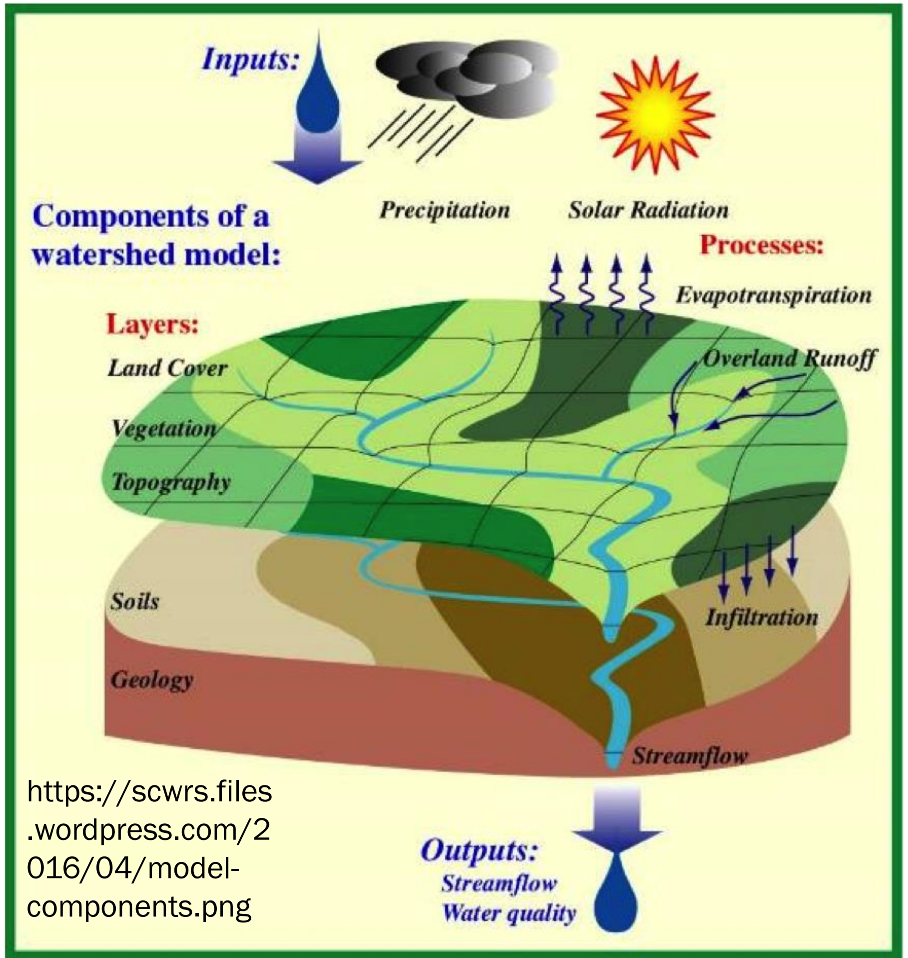
10:45 AM

Watershed Modeling Approach

Inputs
- Topography and hydrologic network
- Meteorology and atmospheric deposition
- Land use and soils (hydrologic and chemical)
- Nutrient application by month and land use
- WWTPs, OWTS, SSOs

Processes are simulated in
- Catchments (modeling subwatersheds)
  - Vegetation canopy
  - Soil surface
  - Individual soil layers
- Streams and rivers
- Upstream impoundments

Outputs
- Stream flow and water quality at 6-hr time steps
- Accounting of average annual nutrient loads delivered to Falls Lake by source



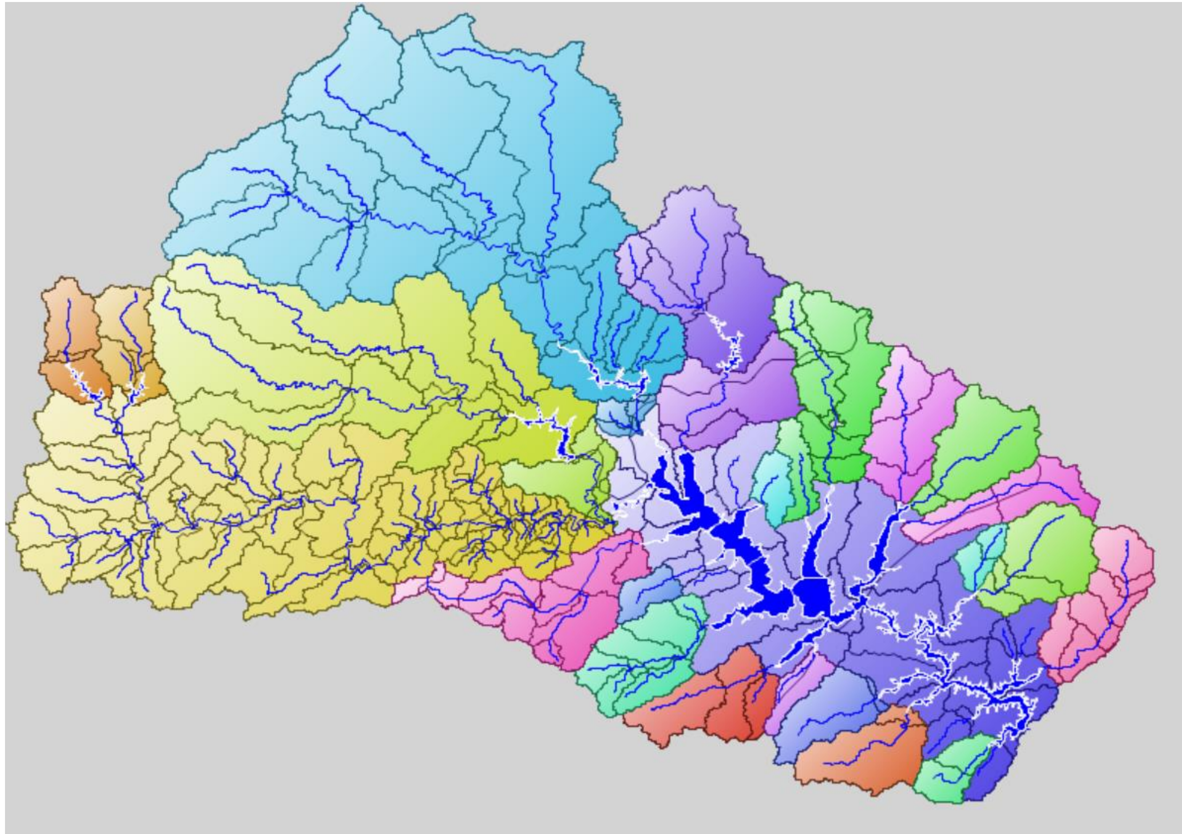
https://scwrs.files.wordpress.com/2016/04/model-components.png

The user does NOT prescribe runoff or groundwater concentrations by land use.

Watershed Analysis Risk Management Framework (WARMF)

UNRBA selected the WARMF model

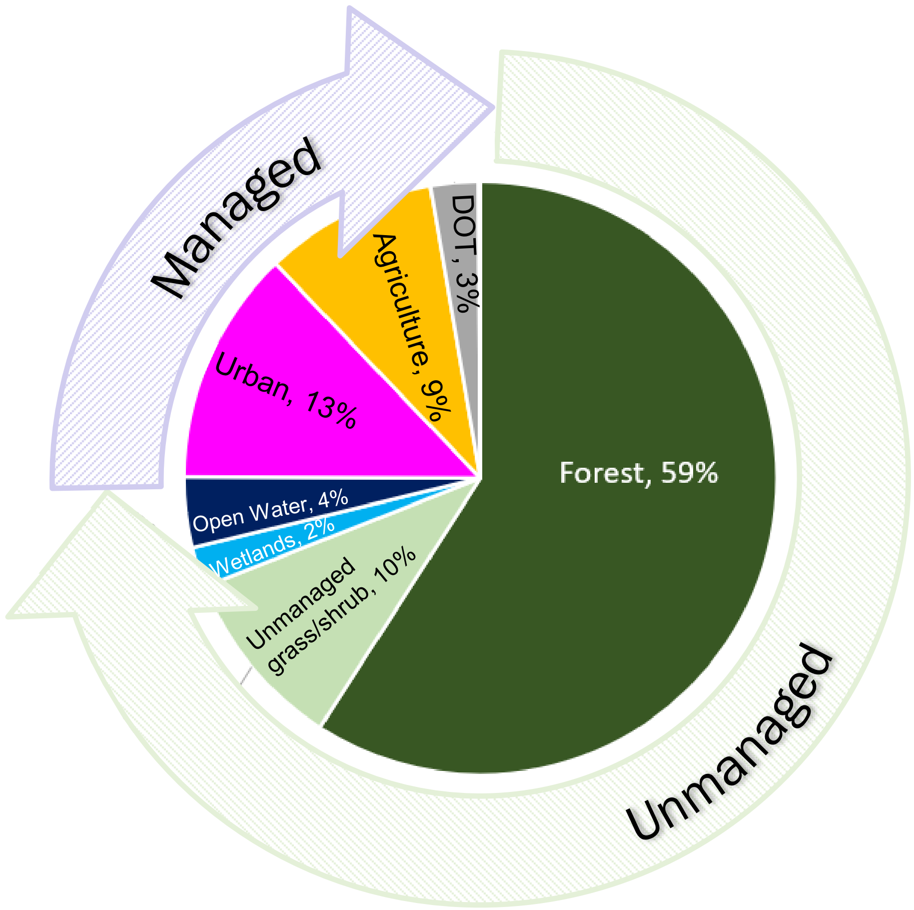
- 2015 to 2018
- 6-hr time step
- 264 modeling catchments
- Delivered nutrient loads by source
- Stream flows and pollutant concentrations delivered to Falls Lake



The UNRBA model selection process is documented online at https://unrba.org/reexamination

Land Use Composition of the Falls Lake Watershed

- 75% unmanaged land
- 13% urban
  - 68% developed open space and non-DOT road rights of way
  - 20% low intensity existing development
  - 12% medium and high intensity development (1.5% of the total watershed area)
  - Over 350 existing development retrofits installed by Dec. 2015
- 9% agriculture
  - Mostly small family farms
    - ~26,000 acres of pasture
    - ~20,000 acres of crops
  - Acreage decreased by 44% since 2006 (baseline)
  - NC Department of Agriculture indicates that further significant reductions of loading from agriculture are not feasible



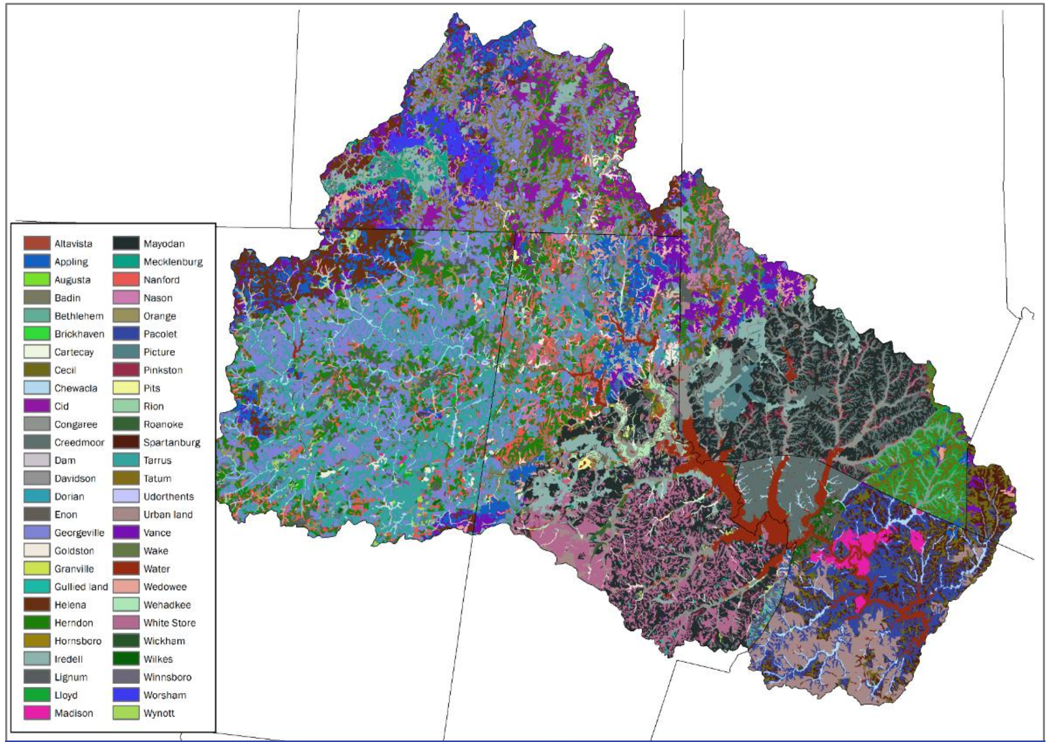
Soils - Data Sources and Contributors

Hydrologic Properties (5 soil layers)

- US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO)

Chemical Properties

- USDA National Cooperative Soil Survey (NCSS)
- US Geological Survey (USGS) Geochemical and Mineralogical Data for Soils of the Conterminous United States



Soil chemistry is extremely important to the storage and cycling of nutrients in the watershed and Falls Lake.

Separate Land Use / Soil Simulations

- WARMF's default model simulates all soils in a modeling catchment as one unit representing the average condition for overlying land uses
- There is an option in WARMF to separate soils under each land use, but initial soil concentrations have to be set uniformly for the catchment

Forest	Development	Crops	Pasture	Wetlands
Initially, WARMF has uniform soils under all the land uses				

Model start

Forest	Development	Crops	Pasture	Wetlands
Soils	Soils	Soils	Soils	Soils

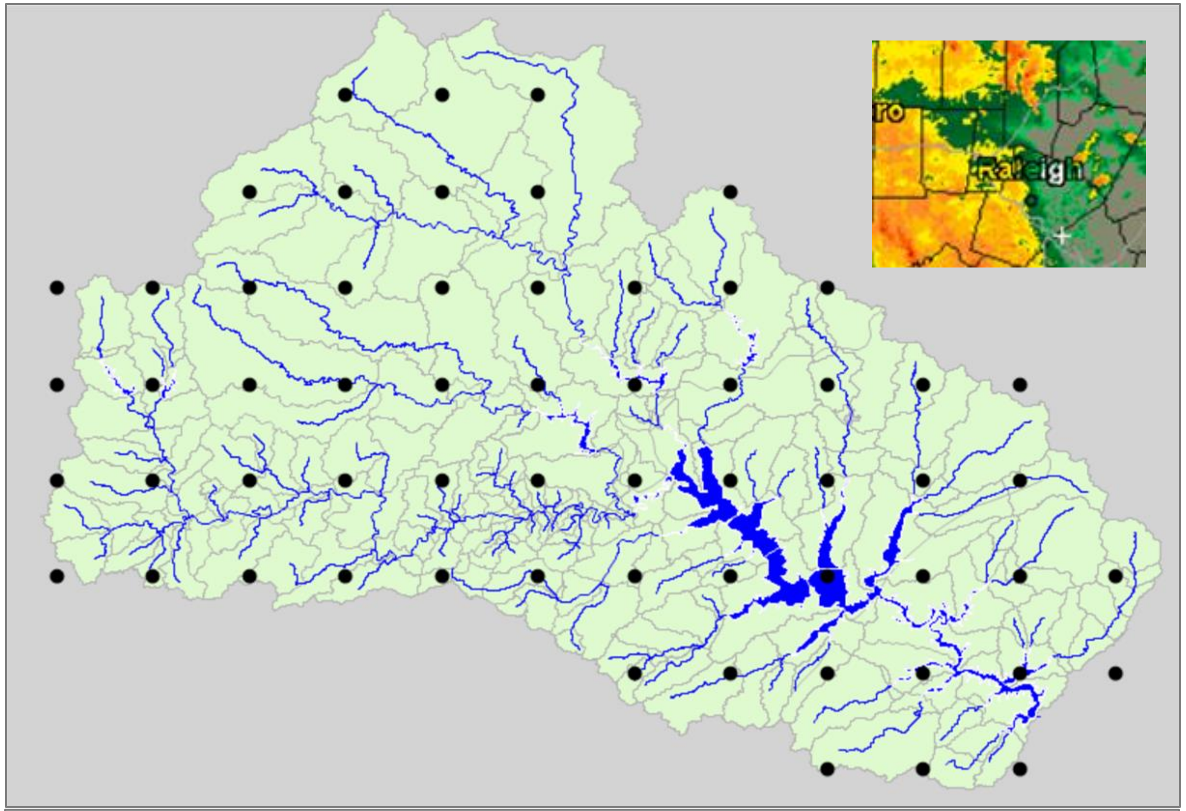
Multiple iterations

- Given the soil chemistry in the watershed, a five-year model period (one model iteration) is not long enough for initial soil conditions to separate by land use and output distinguishable loads by land use
- The WARMF model has to be run fives times to stabilize this separation and generate land use specific areal loading rates for nitrogen, phosphorus, and total organic carbon

Rainfall - Data Sources and Contributors

Radar Precipitation Data (NEXRAD):

- 6-hour rainfall data
- 78 locations
- 2015-2018
- NCDOT facilitated UNRBA acquisition of this data through the NC State Climate Office

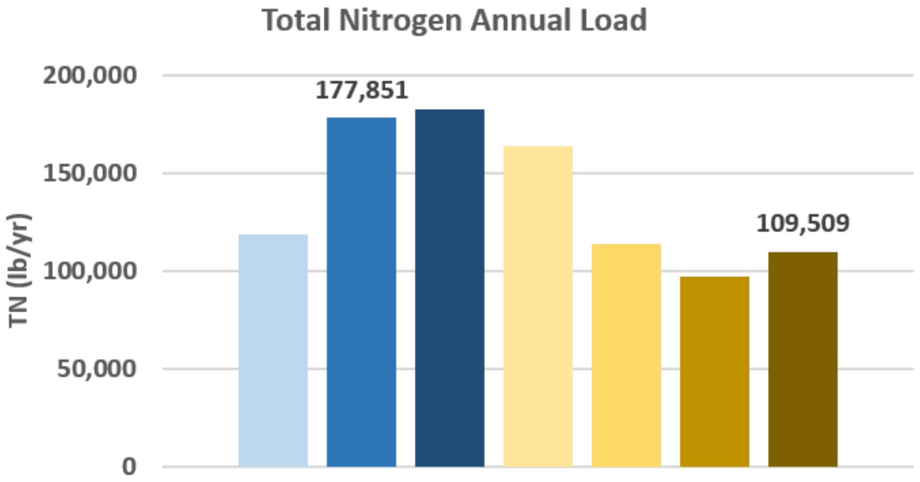


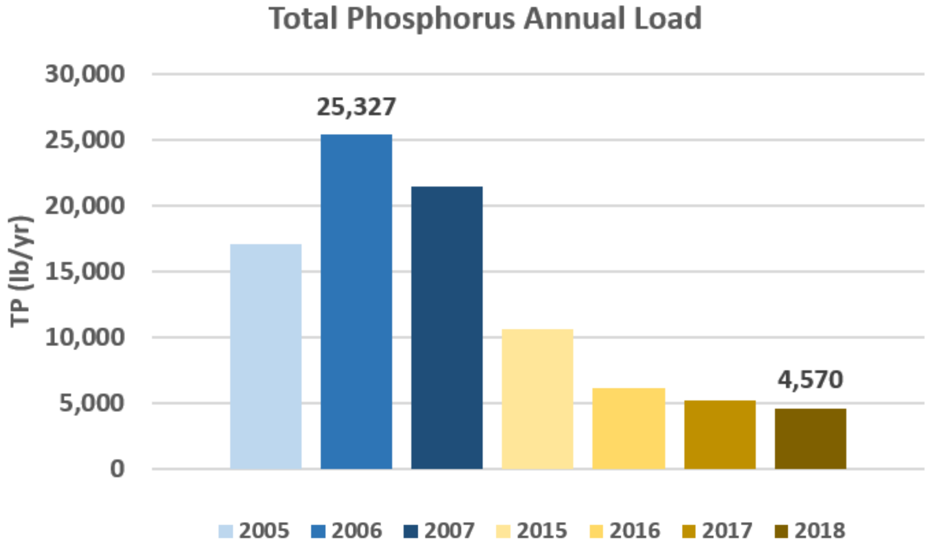
Precipitation is highly variable across this 770 square-mile watershed, especially during hurricanes and tropical storms.

Point Source Dischargers and Sanitary Sewer Overflows

Wastewater treatment plants (WWTPs)

- Three major WWTPs (>1 MGD)
  - North Durham Water Reclamation Facility
  - Town of Hillsborough
  - South Granville Water and Sewer Authority (SGWASA)
- Four minor WWTPs (< 1 MGD)
  - NC DWR
- Facility upgrades and optimization have reduced nutrient loads significantly; comparing 2006 to 2018:
  - 38 percent reduction in total nitrogen (TN)
  - 81 percent reduction in total phosphorus (TP)





Nutrient Application and Land Use Changes

Since the baseline year (2006)

- Acreages of agriculture and nutrient application have declined by 40 to 55 percent
- New development rules in place since 2012 with limits of 2.2 lb-N/ac/yr and 0.33 lb-P/ac/yr
- Over 350 stormwater control measures and best management practices have been installed

KEY DATASETS:

Urban areas land use, percent impervious cover, stormwater control measures, and fertilizer application

- USGS National Land Cover Data
- Local government development records
- Two homeowner fertilizer use surveys

County-level agricultural acres and nutrient application

- Falls Lake (FL) Watershed Oversight Committee
- NC Dept. Ag. and Consumer Services and local advisory councils

Forests lands and nutrient loading rates

- USGS National Land Cover Data
- US Forest Service multi-year monitoring study in forested headwaters of FL watershed (Boggs et al. 2013)

State lands

- NC Dept. of Transportation (DOT) provided rights of way and percent impervious cover
- NC Wildlife Resources Commission provided wildlife impoundments acreage

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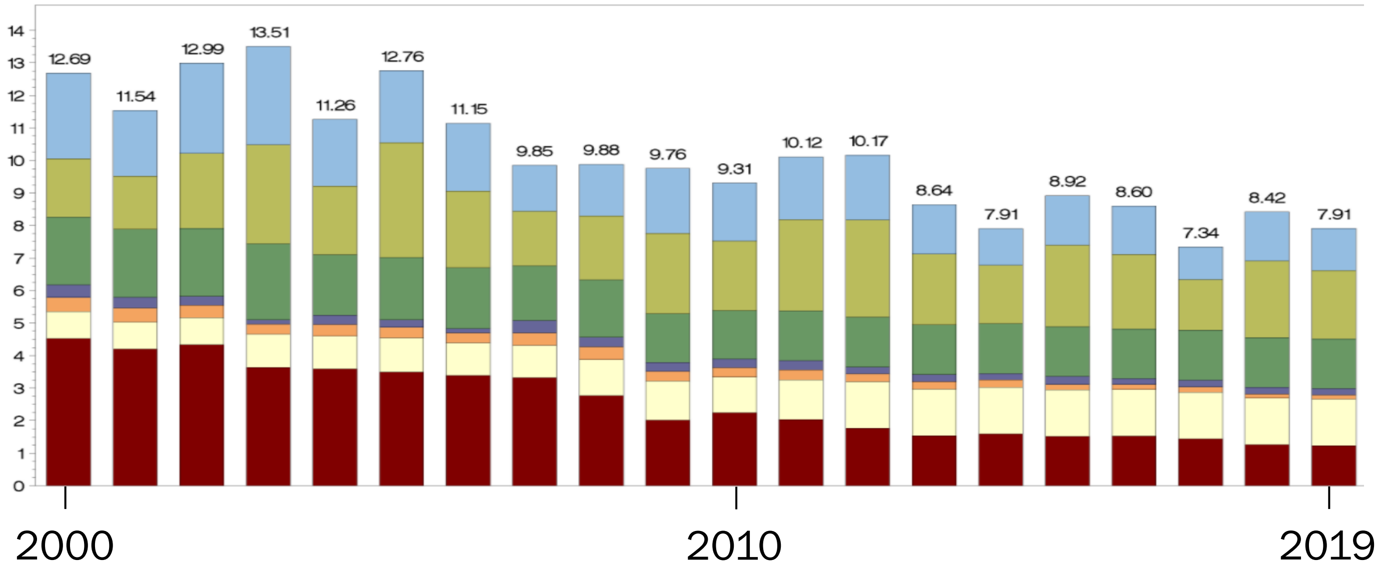
Atmospheric Deposition

- Since baseline year (2006), atmospheric deposition of total nitrogen has declined 25%
- Affects all lands and waters in the basin

Wet and Dry Atmospheric Deposition

- NADP, CASTNET (national datasets)
- Duke Forest Monitoring
- City of Durham Monitoring

Rates of Total Nitrogen Deposition (wet plus dry) to Watershed



11.25 kg-N/hectare/year (2005 to 2007)
8.32 kg-N/hectare/year (2015 to 2018)
26 percent reduction comparing averages for these two periods

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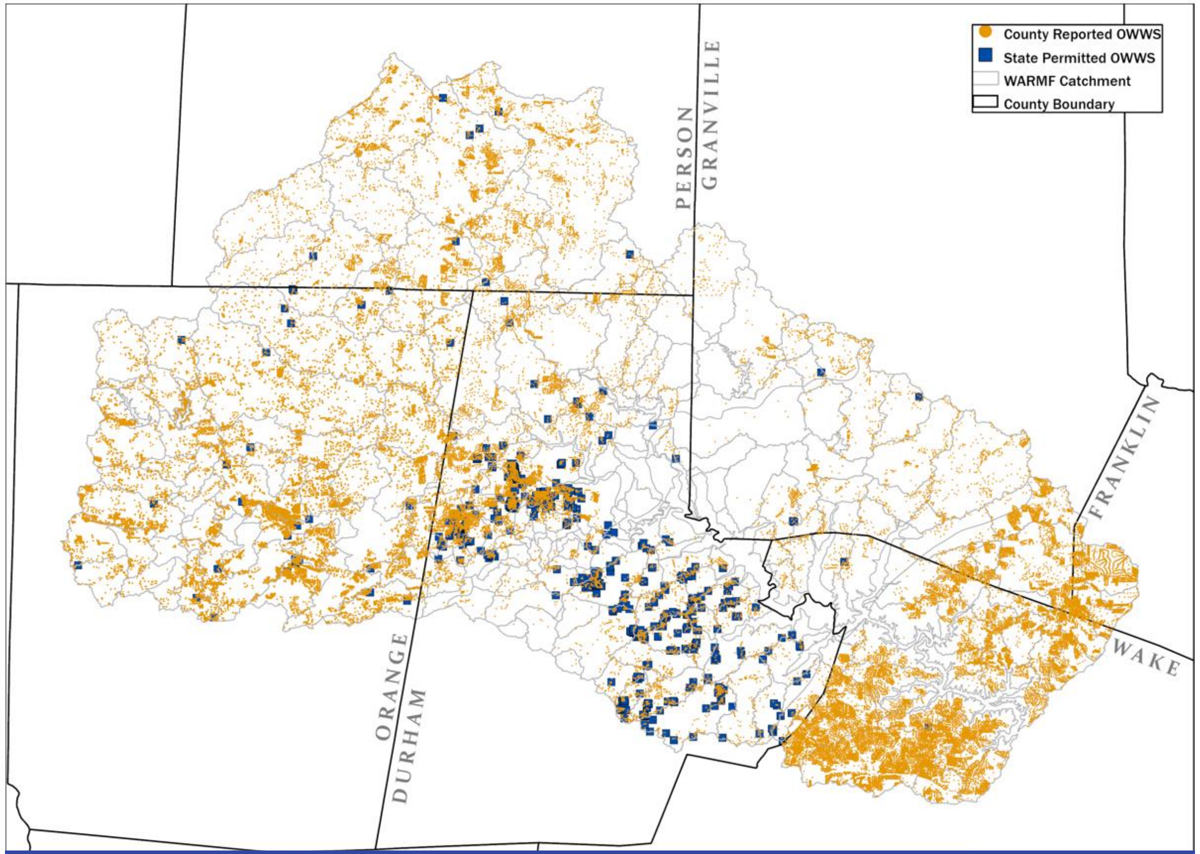
Onsite Wastewater Treatment Systems (OWTS)

County-level system types, counts, and failure rates

- Wake, Durham, Orange, Person, Granville, Franklin Counties
- NC Collaboratory Researchers

Effluent discharge rates and effluent quality by type and status (functioning or malfunctioning)

- NC Collaboratory Researchers



There are ~50,000 OWTSs in the watershed. Their relative contribution to the delivered nutrient load to Falls Lake has been a source of controversy.

Observed Stream Flows and Water Quality for Model Calibration

USGS 15-minute stream flow data

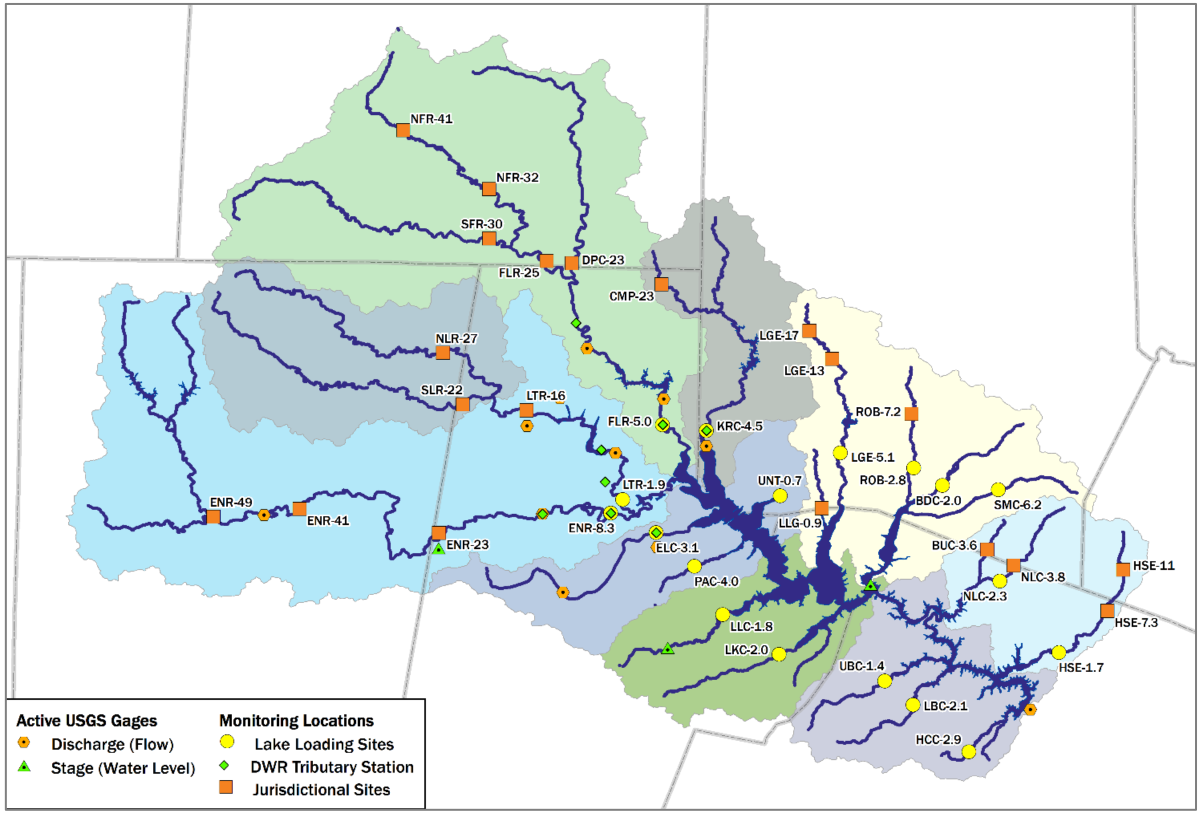
- 10 gages
- 5 largest tributaries

UNRBA monthly water quality sampling

- 17 tributaries near Falls Lake
- 21 additional tributary monitoring stations upstream at jurisdictional boundaries

DWR monthly water quality sampling

- 5 tributaries near Falls Lake



Comprehensive report describing these data for the UNRBA study period is available online at https://unrba.org/monitoring-program.

Evaluation of Model Performance

- DWR-approved UNRBA Modeling Quality Assurance Project Plan available online at https://unrba.org/reexamination
- Describes model development and evaluation of model performance
- Several statistical evaluations were performed with a focus on percent bias (compares the average of observations to the average of simulated values)
- Visual assessments are also important
- **Extensive vetting by subject matter experts and third-party reviewers greatly improved the model and helped the UNRBA prepare for DWR review.**

WARMF Model Performance Targets:

Parameter	Percent Bias Criteria		
	Very Good	Good	Fair
Sediment	< ± 20	± 20-30	± 30-45
Water Temperature	< ± 7	± 8-12	± 13-18
Water Quality/Nutrients	< ± 15	± 15-25	± 25-35

Performance Summary for “Big 5” Tributaries (2015-18)

Parameter	Ellerbe	Eno	Flat	Knap	Little
Total Flow[1]	Very good	Very good	Good	Very good	Very good
Temperature	Very good	Good	Good	Good	Good
TN[2]	Very good	Very good	Very good	Good	Good
TP	Very good	Very good	Good	Low/very good[3]	Very good
TOC	Very good	Very good	Very good	Very good	Very good
Chlorophyll-a	Low[4]	Good	Very good	Very good	Very good

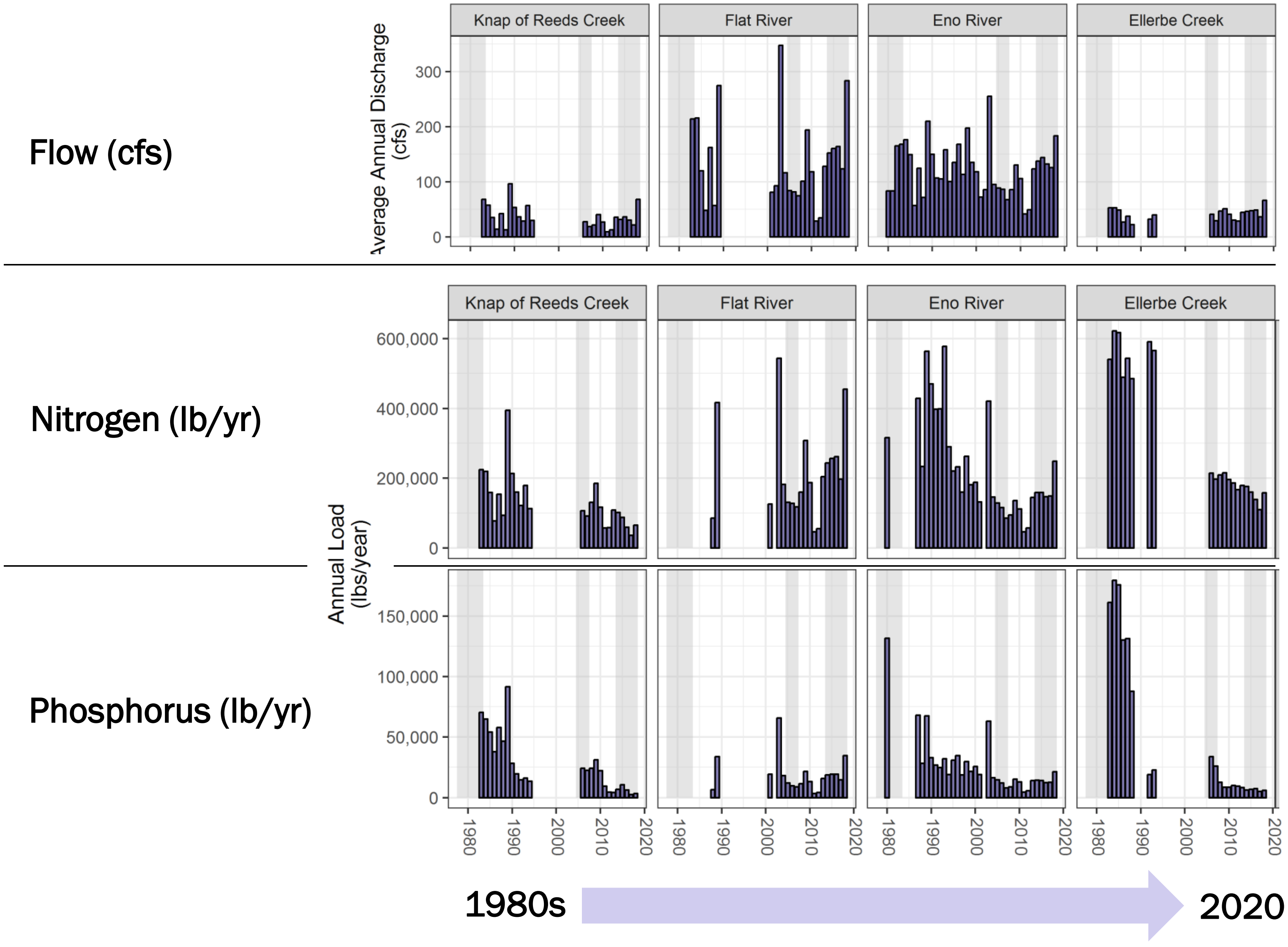
1. Additional flow statistics are presented in the February 4, 2020, MRSW meeting materials available online at https://unrba.org/meetings. Peak, high, low, and seasonal flow targets are good to very good at each gage.
2. Additional nitrogen species are presented in the August 27, 2021, special meeting of the MRSW available online at https://unrba.org/meetings.
3. The model underpredicts phosphorus concentrations during a period in late 2015 and early 2016 in Knap of Reeds Creek. A period of high phosphorus concentrations was observed in the creek as part of the UNRBA Monitoring Program at this location. The model performance is “very good” at this location for the validation years (2017 and 2018).
4. Average of observed chlorophyll-a concentrations in Ellerbe Creek is 3.6 µg/L; simulated mean is 1.2 µg/L. The percent bias is -66 percent, but this is not an ecologically important difference.

Delivered Nutrient Loading to Falls Lake

11:05 AM

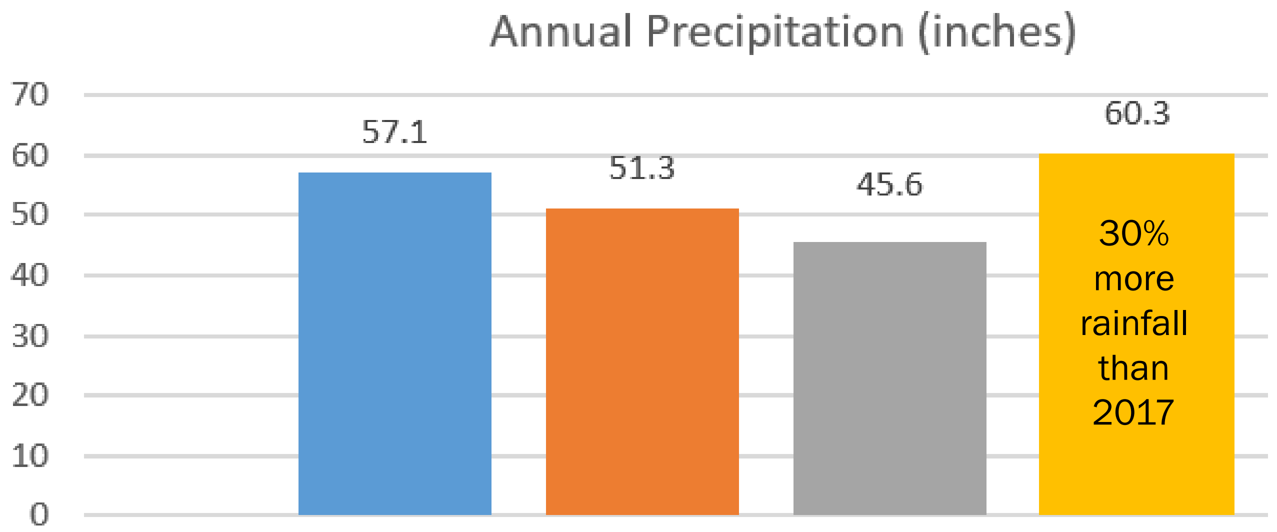
Nutrient Loads to Falls Lake have declined since reservoir was filled

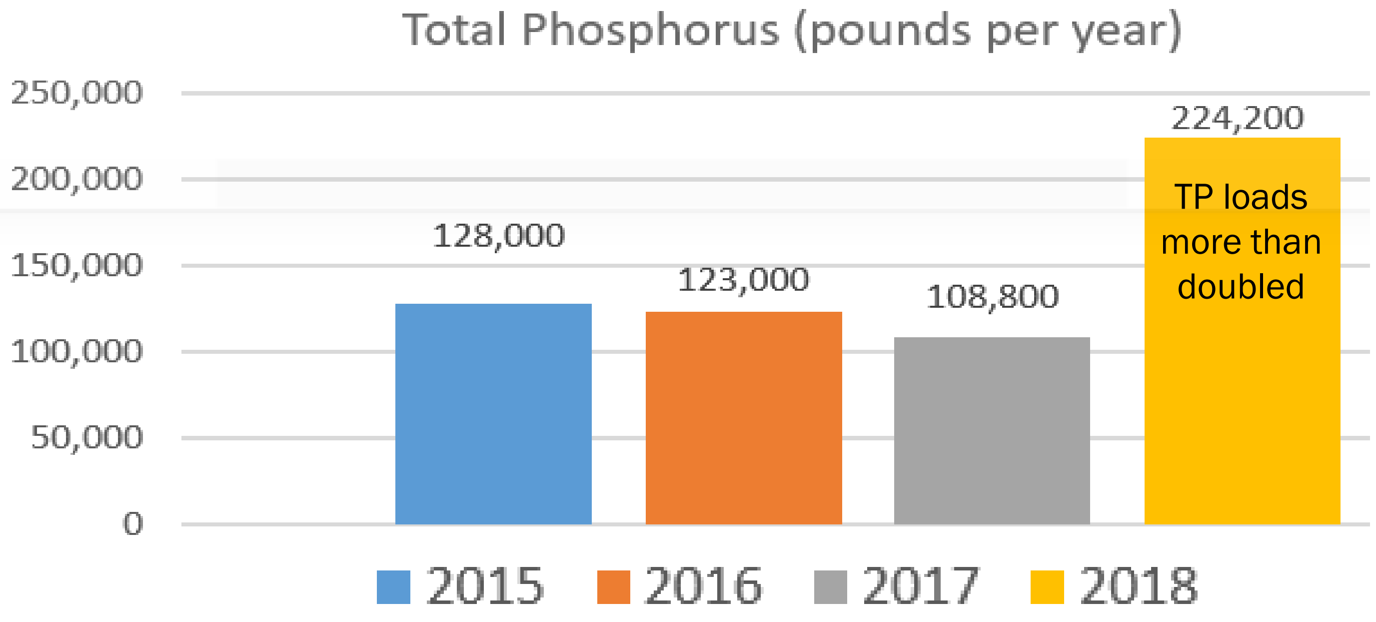
Based on long-term stream flow data (USGS) and water quality monitoring data (DWR)



Importance of Precipitation on Delivered Loading

- Load is a function of stream flow and concentration
- Nutrient loads are highly variable from year to year based on precipitation
    - Loads to Falls Lake more than doubled in 2018 compared to 2017
    - Precipitation increased by 30%





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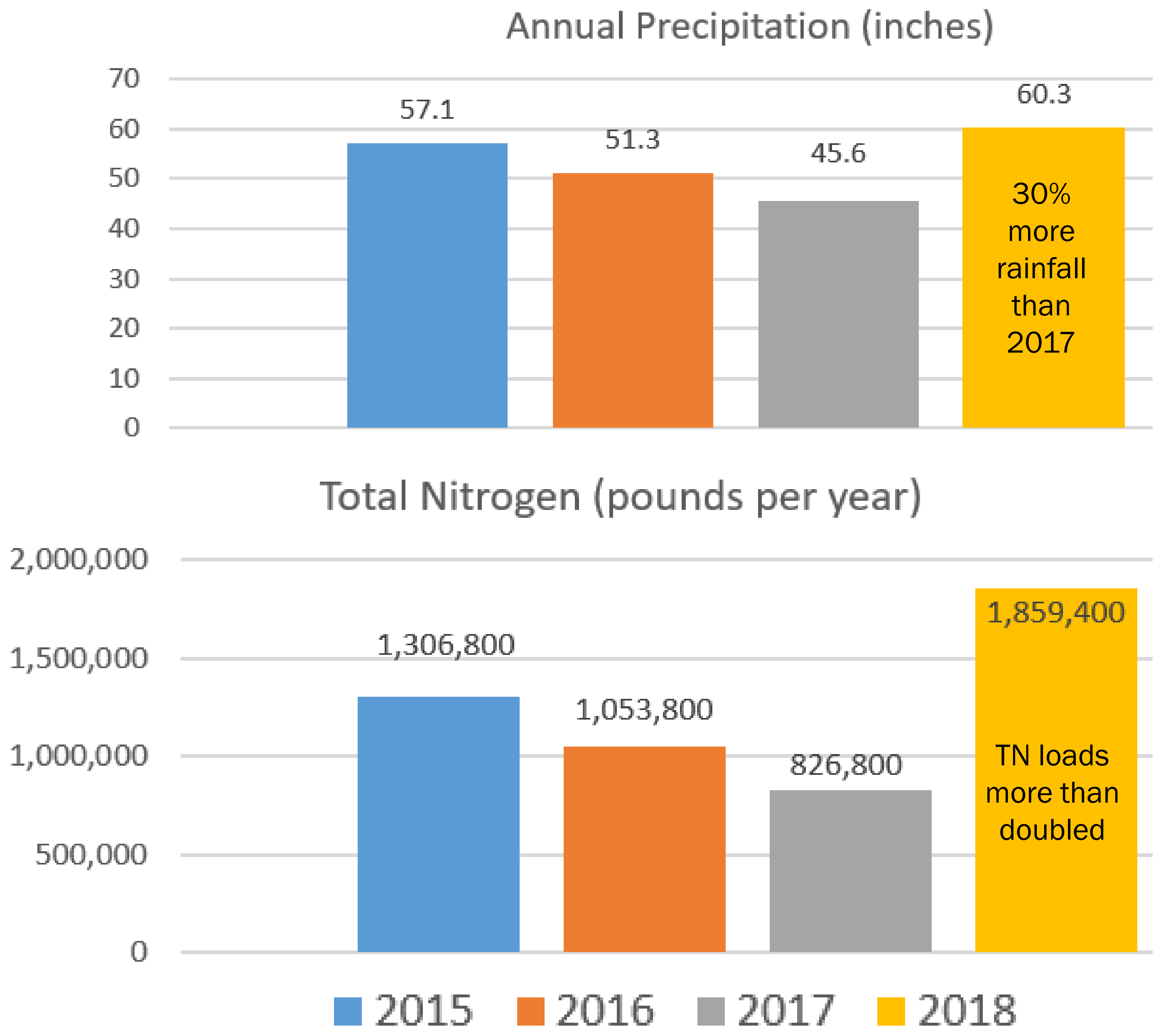
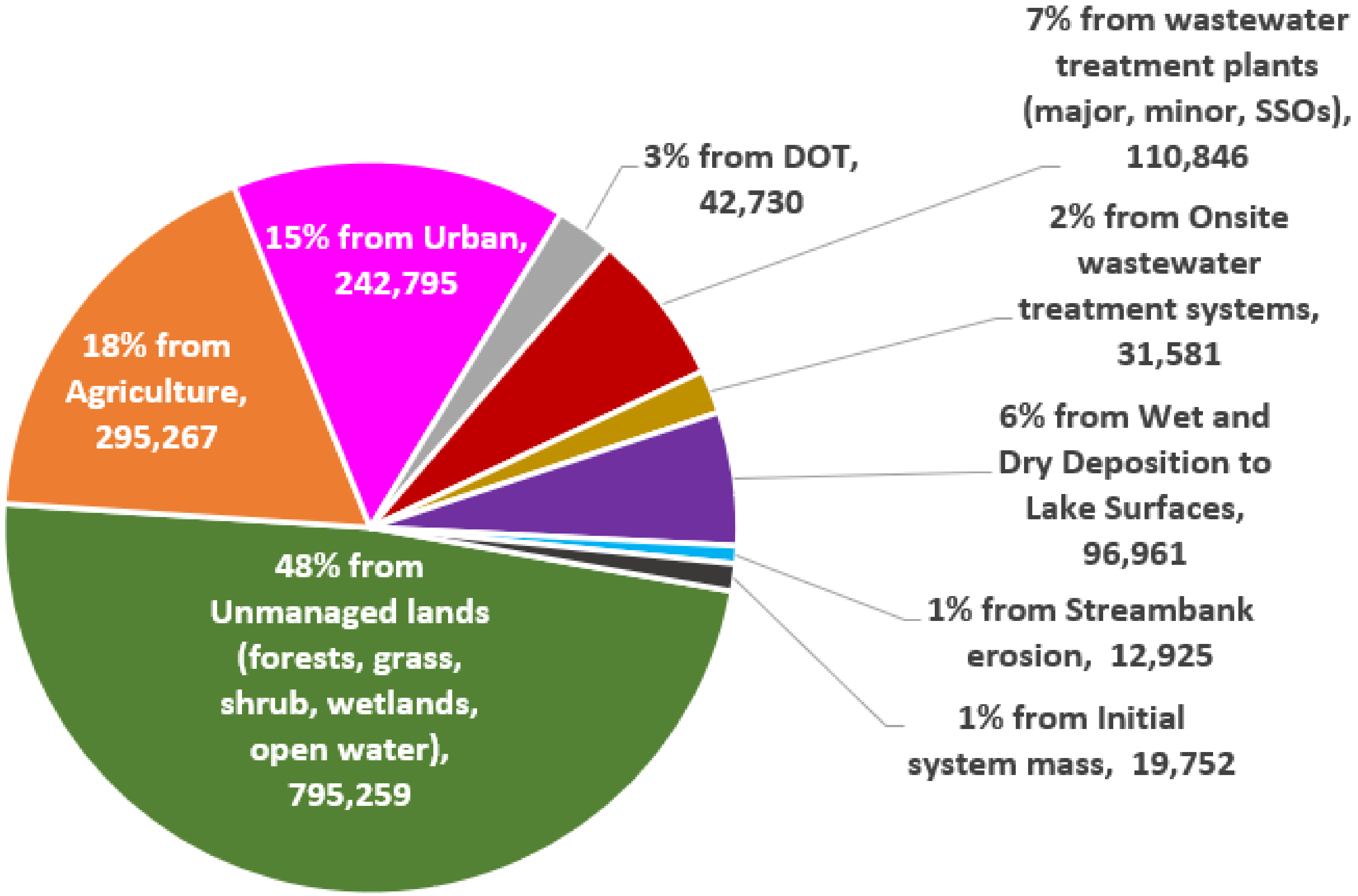


Sources of Total Nitrogen (TN) Delivered to Falls Lake

Annual average loading for 2015 to 2018:

- 8.6 million pounds of TN applied, deposited, or discharged to watershed each year
- ~20% reaches Falls Lake (1.65 million lb/yr)
- Unmanaged lands contribute the most (48%) because they comprise 75% of drainage



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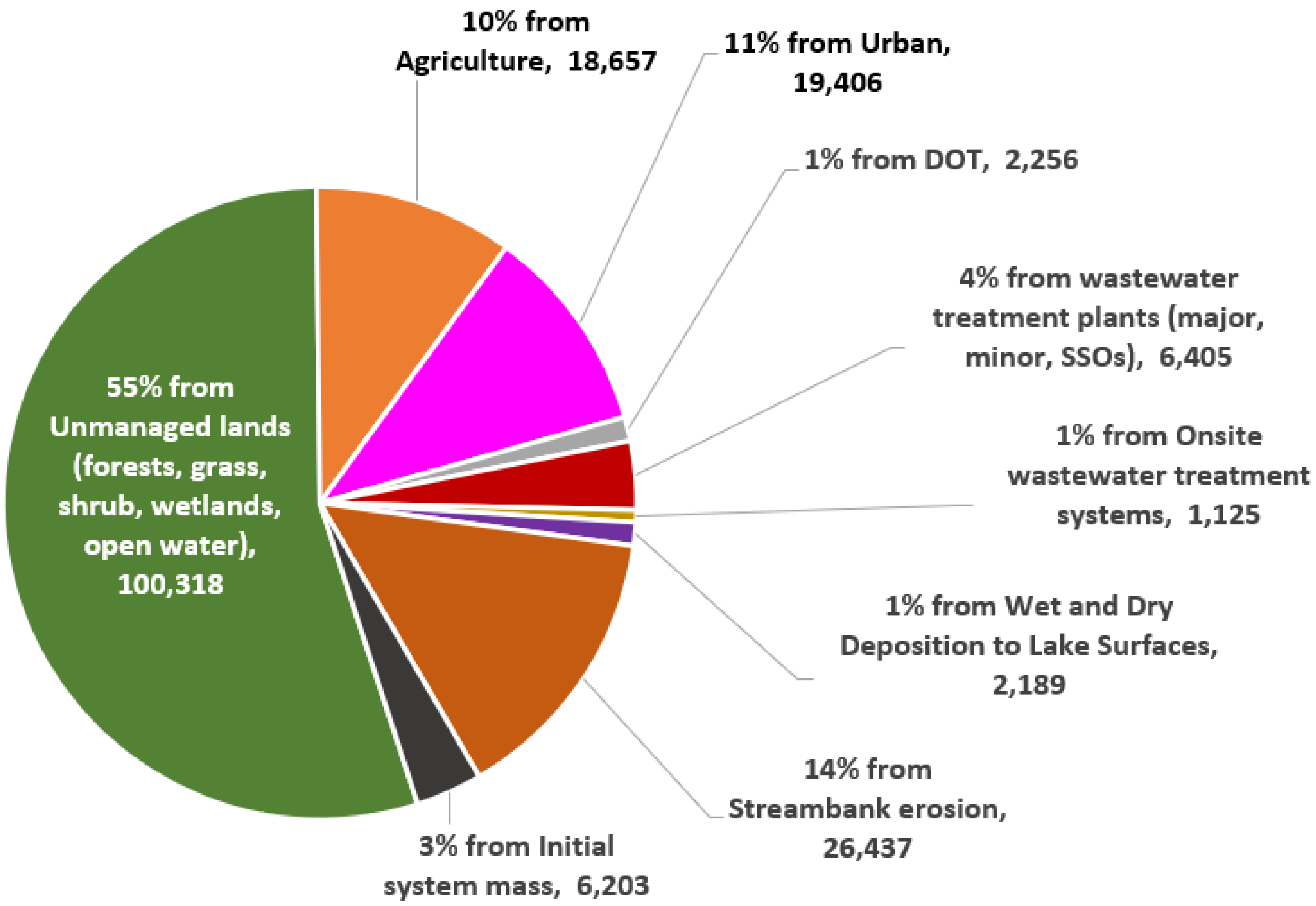
Sources of Total Phosphorus (TP) Delivered to Falls Lake

Annual average loading for 2015 to 2018:

- 1.1 million pounds of TP are applied, deposited, or discharged to the watershed each year
- ~20% reaches Falls Lake (183,000 lb/yr)
- Unmanaged lands contribute the most (55%) because they comprise 75% of the drainage
- Streambank erosion contributes ~14%



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WARMF Watershed Scenarios
11:15 AM

Evaluation of Scenarios

- Once the model is developed and calibrated, it can be used to evaluate scenarios and ask questions
- The UNRBA formed a Scenario Screening Workgroup (SSG) to prioritize and select which scenarios to evaluate with the model
- SSG included UNRBA members and representatives of agriculture, NC DOT, NC DWR, and environmental advocacy groups
- For the watershed model, scenarios focused on how nutrient and total organic carbon loading to Falls Lake could change given changes in the following:
  - Rainfall
  - Rates of atmospheric deposition
  - Land use change to forest with removal of human inputs (i.e., “All Forest”)
  - Testing changes to vertical hydraulic conductivity for All Forest in densely urbanized areas

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Watershed Model Scenarios Variants Table

Short Name	Land use	Rainfall	Human Inputs	Atm. Dep.	Vertical hydraulic conductivity
UNRBA Study Period	2015-18	Avg. to wet	2015-18	2015-18	Calibrated model
25% less atm. dep	2015-18	Avg. to wet	2015-18	**-25%**	Calibrated model
25% more atm. dep	2015-18	Avg. to wet	2015-18	**+25%**	Calibrated model
20% less rainfall	2015-18	**Dry to avg.**	2015-18	2015-18	Calibrated model
20% more rainfall	2015-18	**Very wet**	2015-18	2015-18	Calibrated model
All Forest, study period rainfall	**Forest**	Avg. to wet	**None**	2015-18	Calibrated model
All Forest, 20% less rainfall	**Forest**	**Dry to avg**	**None**	2015-18	Calibrated model
All Forest, study period rainfall, increased vertical conductivity	**Forest**	Avg. to wet	**None**	2015-18	**Increased in Ellerbe Creek**

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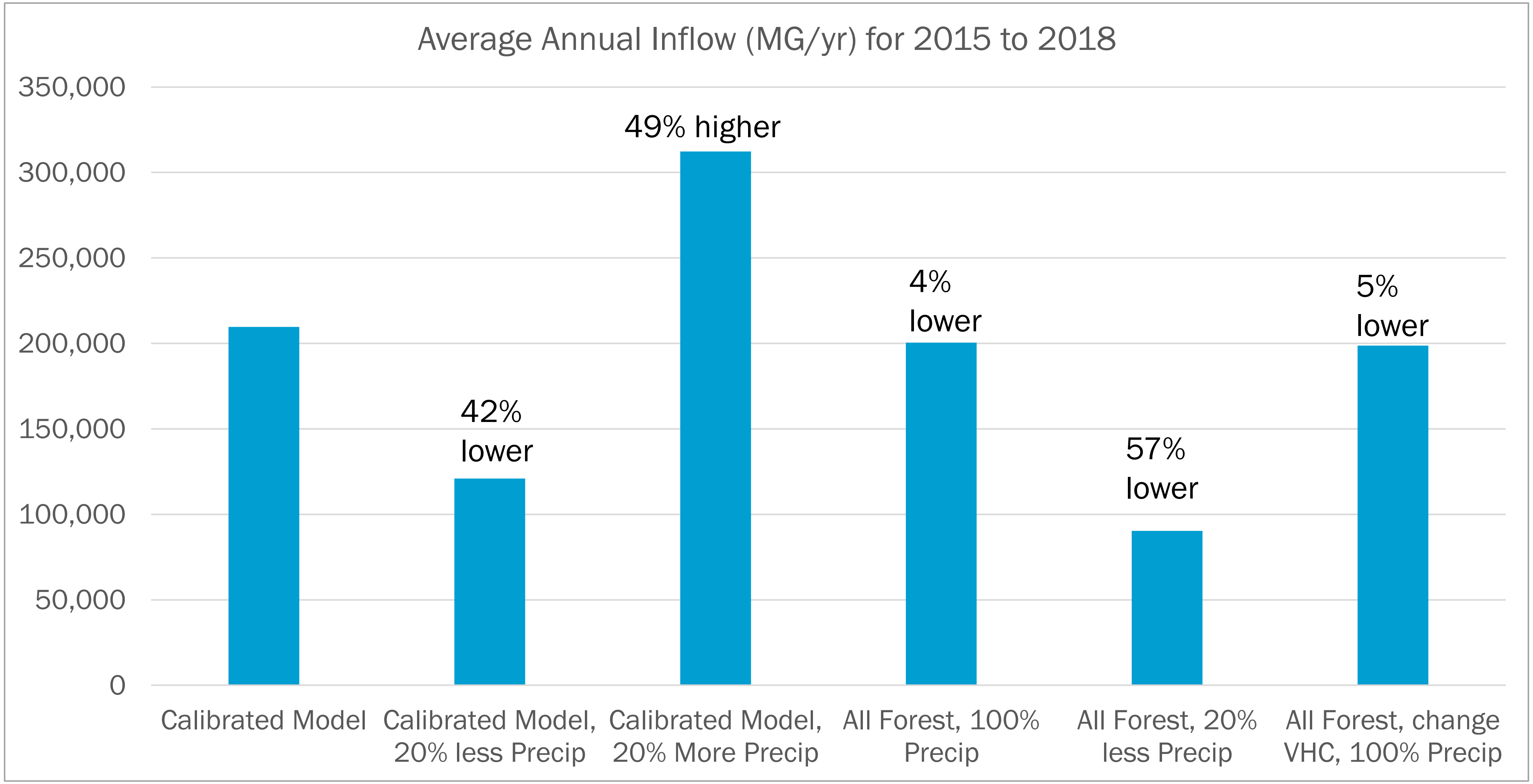
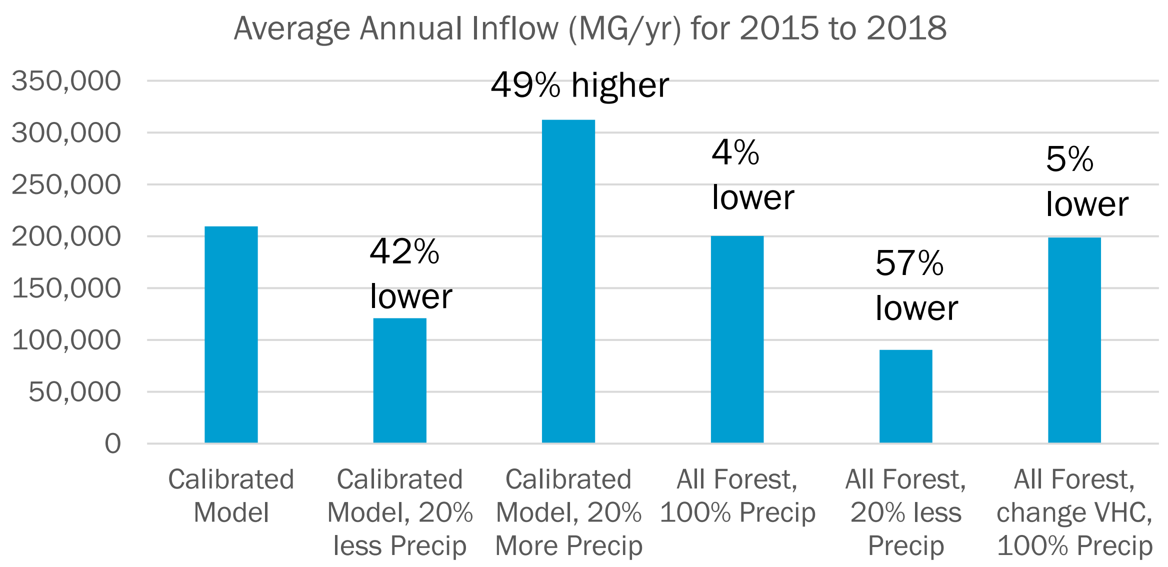
Comparison of Delivered Flows for Scenarios

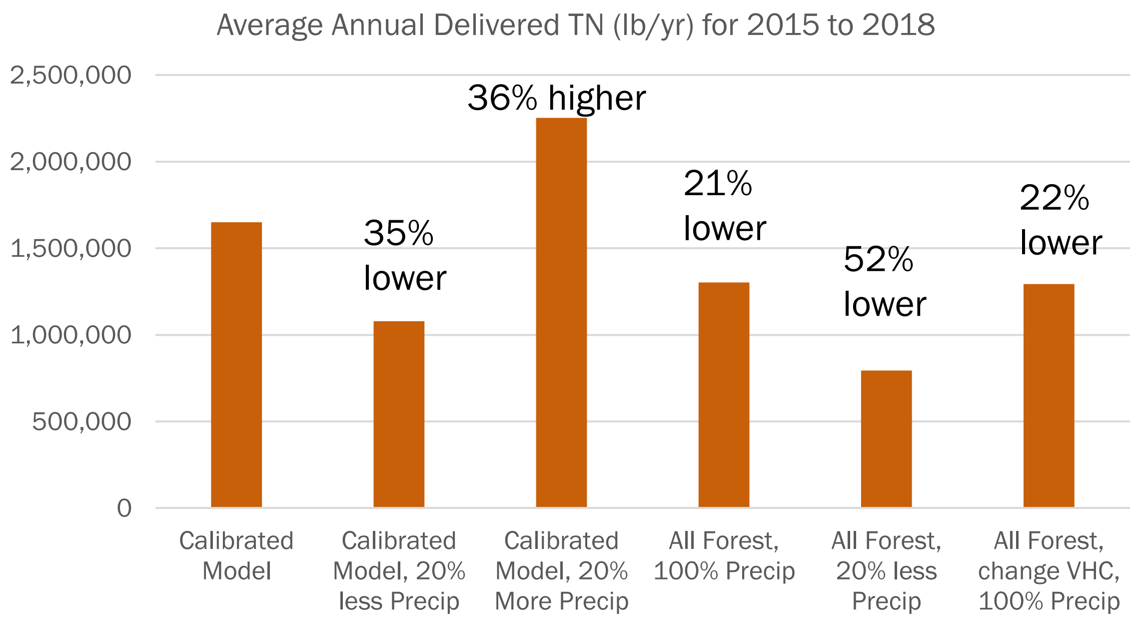


The change to vertical hydraulic conductivity (VHC) only applies to Ellerbe Creek subwatershed where VHC had been adjusted down relative to other subwatersheds in the Triassic Basin.

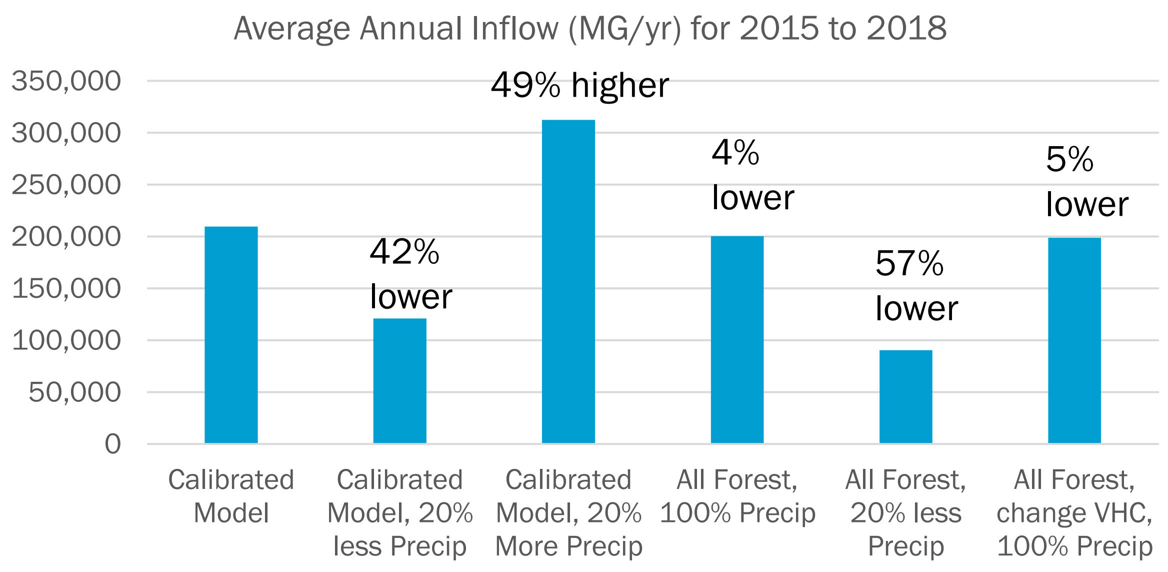
Delivered Flow



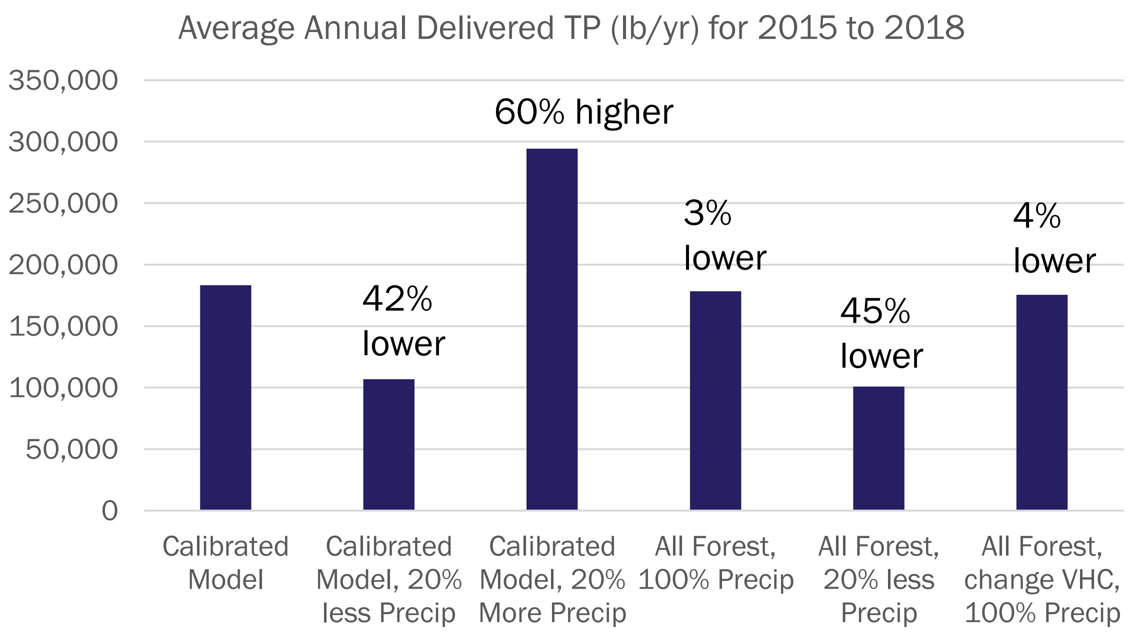
Delivered TN Load



Delivered Flow

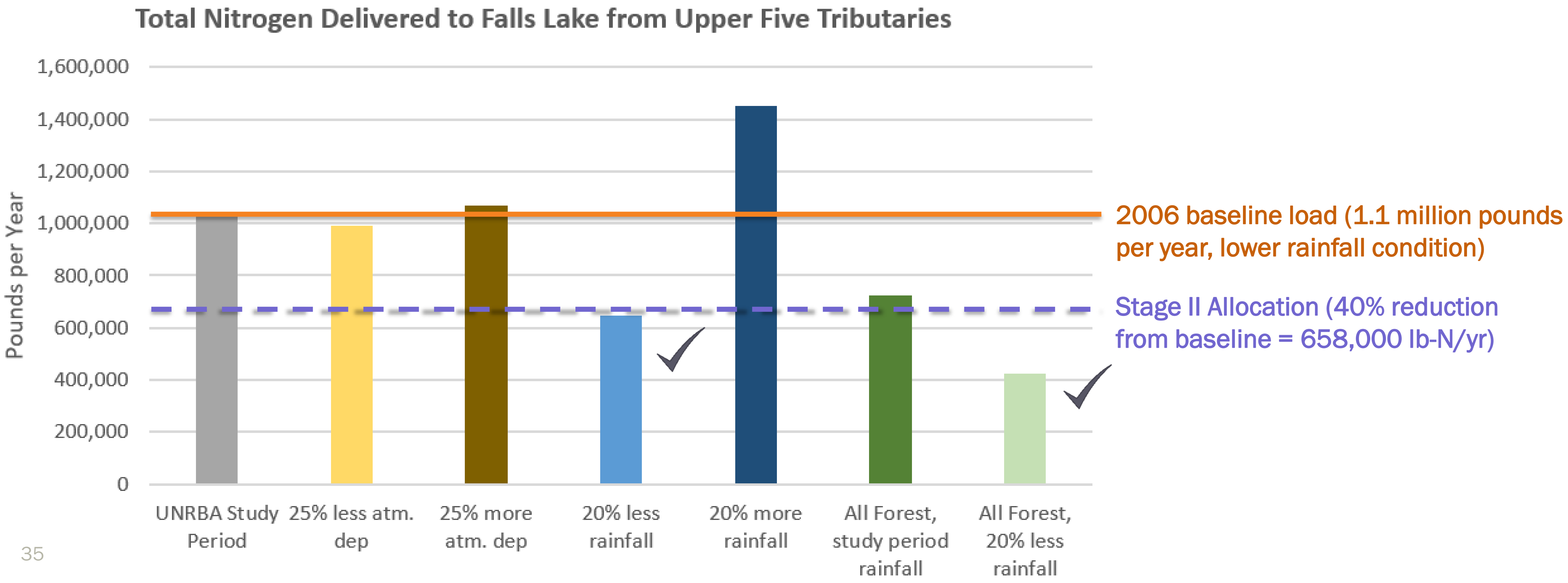


Delivered TP Load



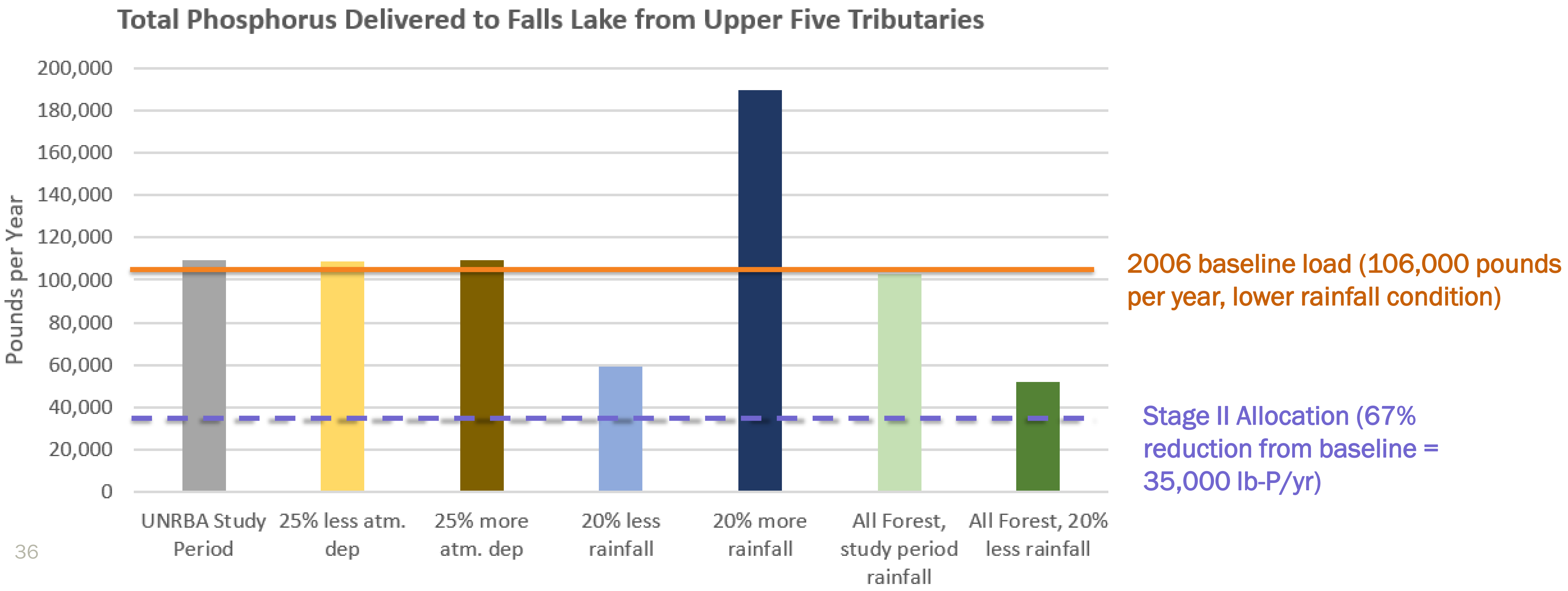
Comparison of Delivered Total Nitrogen to Falls Lake (Five Tributaries)

- Loads during UNRBA study period similar to baseline despite having higher rainfall (indicates improvements)
- **With 20% less rainfall, current watershed activities <u>would meet</u> the Stage II allocation**
- Land conversion to "All forest" with 2015 to 2018 rainfall does not meet the Stage II allocation unless rainfall is also reduced



Comparison of Delivered Total Phosphorus to Falls Lake (Five Tributaries)

- Loads during the UNRBA study period were similar to baseline loads despite having higher rainfall
- **No scenario meets the Stage II Allocation for TP, not even the hypothetical land conversion to "all forest" with removal of all human inputs and a 20% reduction in rainfall**
- No scenario meets the chlorophyll-a criterion in Falls Lake above I-85 (discussed in lake modeling section)



Questions/Discussion Regarding Watershed Data and Modeling

11:25 AM

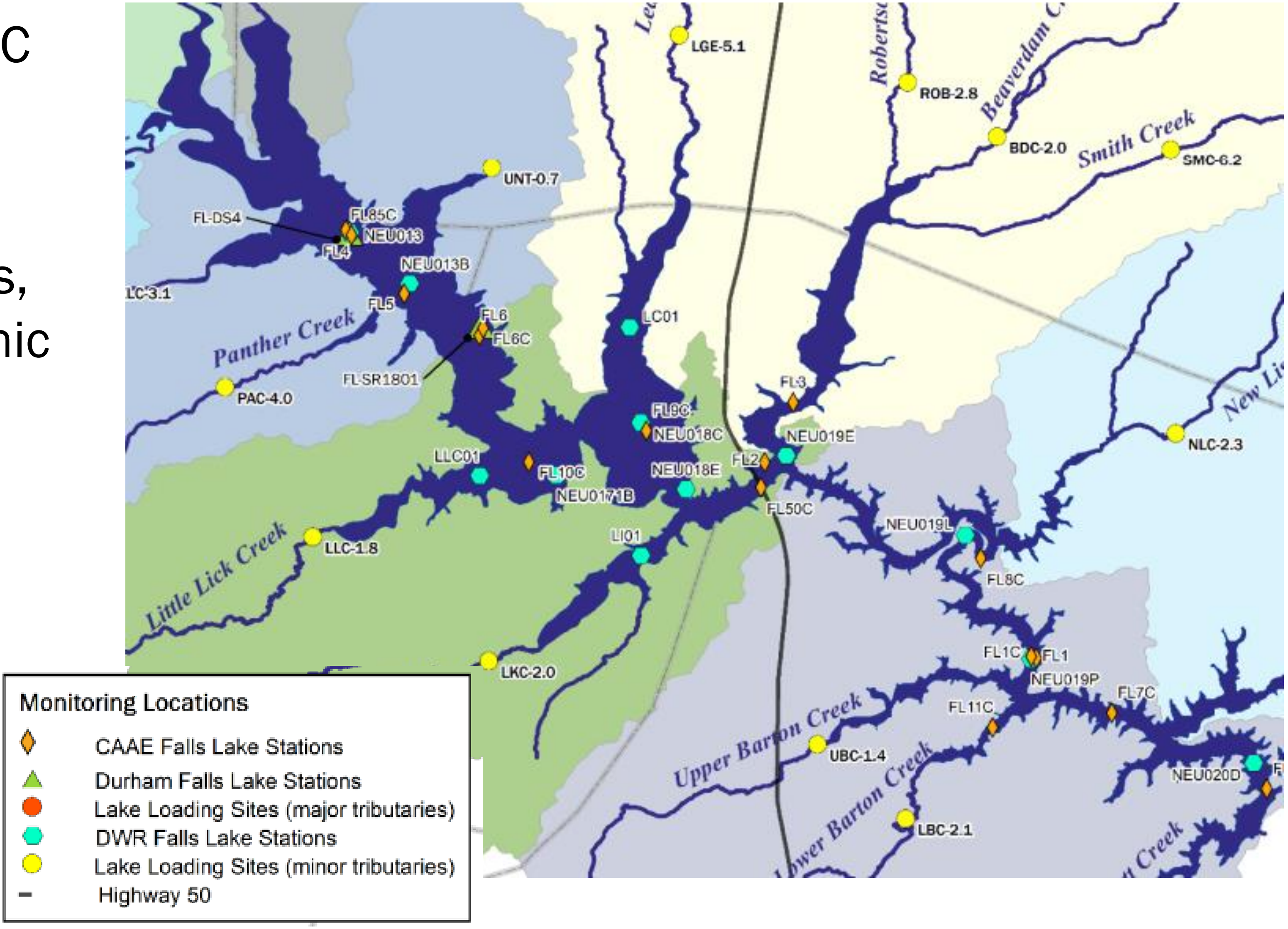
Lake Data and Lake Modeling – Part 1

Lake Monitoring Data and Research Studies

11:35 AM

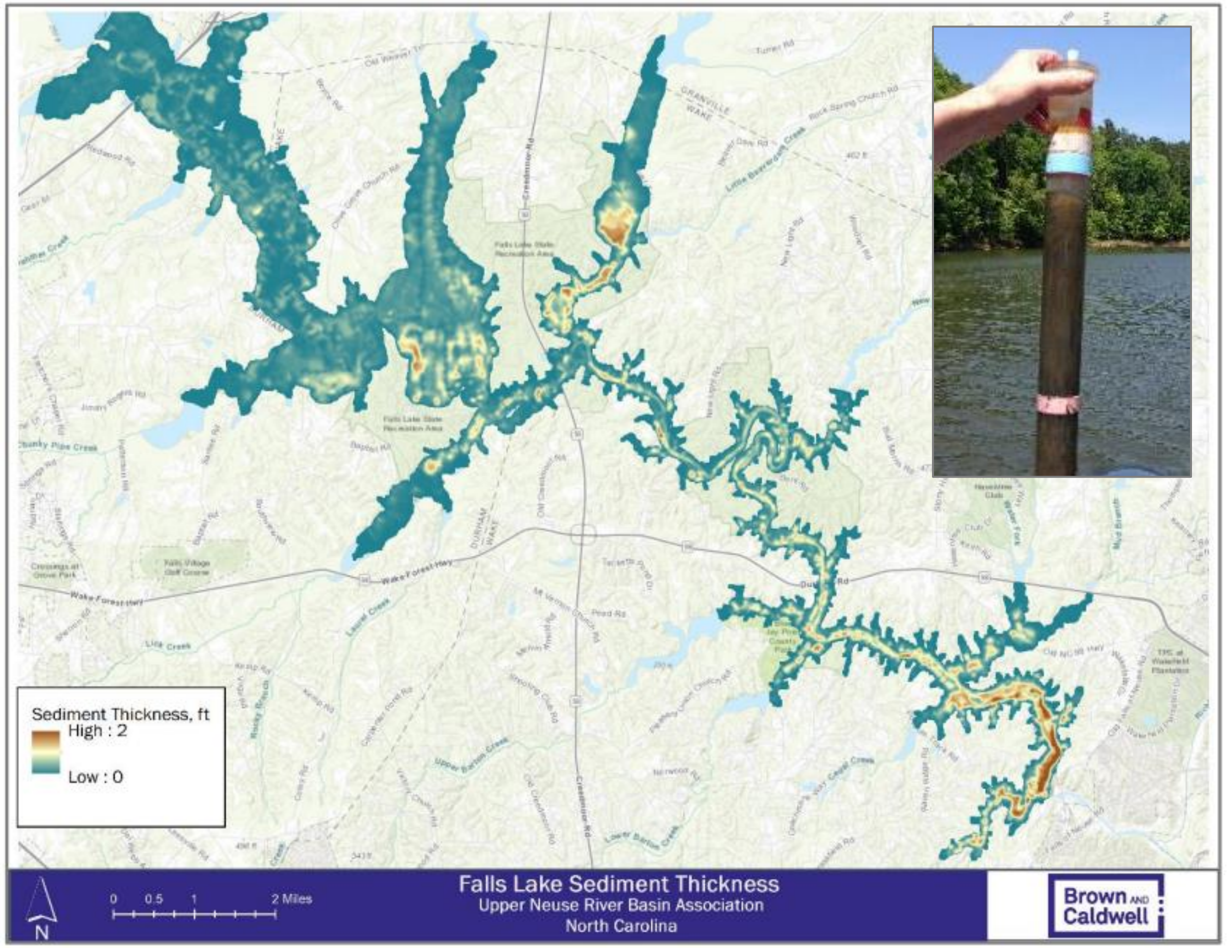
Falls Lake: The Most Studied Reservoir in North Carolina

- Most studied reservoir in NC
- Seven organizations
- 30 monitoring stations
- Routine sampling (nutrients, algal biovolume, total organic carbon, chlorophyll-a)
- Special studies (sediment nutrient fluxes, water movement, light extinction, nutrient balances, etc.)



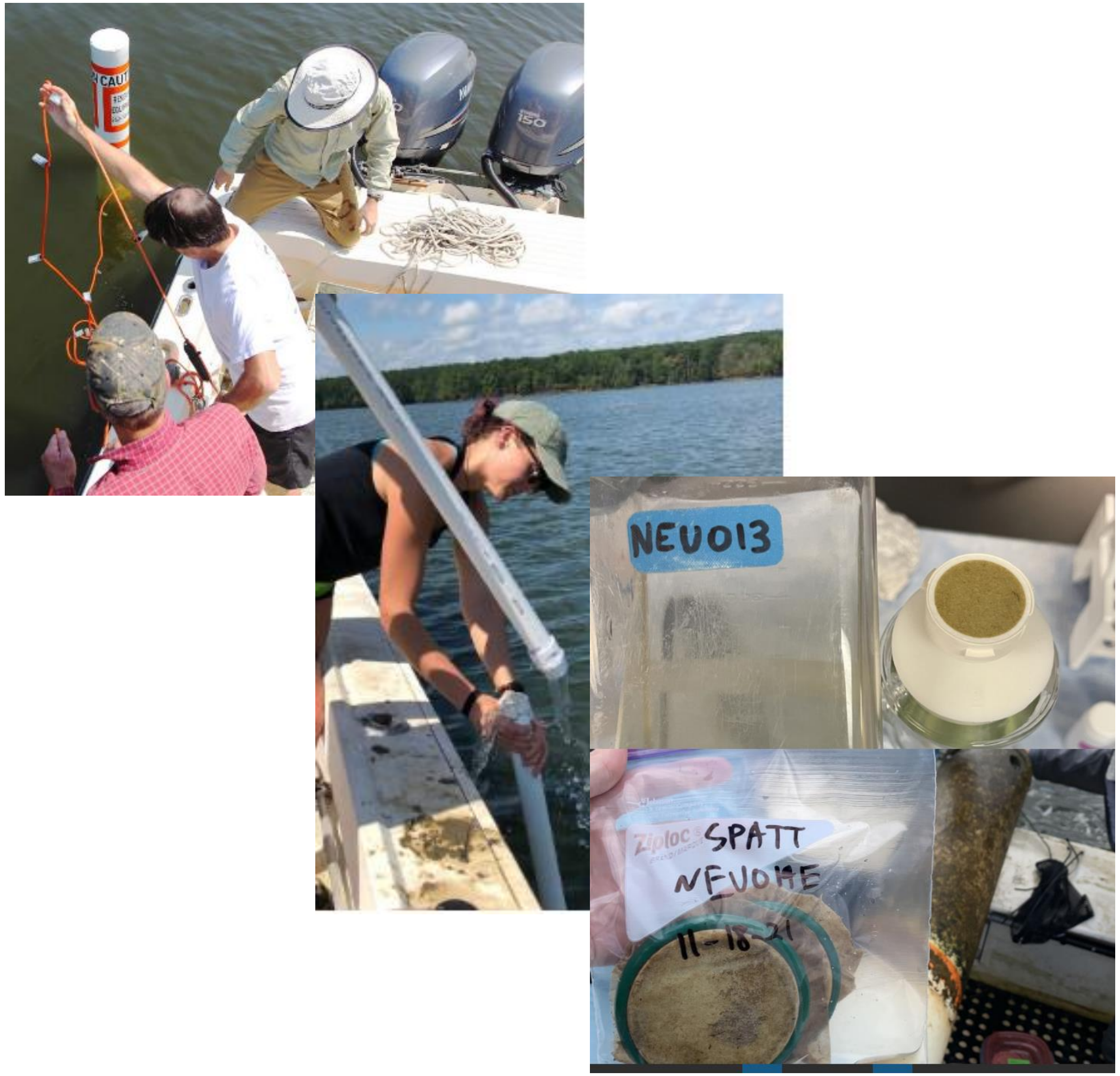
UNRBA Sediment Depth, Quality, and Bathymetric Surveys

- Bathymetric survey of Falls Lake informed model development
  - EFDC model grid
  - WARMF Lake model segments
- Sediment depth and quality studies
  - Initial conditions
  - Sediment diagenesis modeling
  - Estimates of nutrient releases from lake sediments into the water column
- **Continued releases of nitrogen for 10 to 40 years even if all other nutrient inputs are ZERO**



NC Collaboratory Falls Lake Research Studies (link)

- The UNRBA has been coordinating with the NC Collaboratory since it was formed in 2016 on research efforts in the watershed and Falls Lake
- Researchers have been providing input on model development and third-party review
- **This collaboration has ensured the models are based on the best science**



NC Collaboratory Falls Lake Research Key Findings (link)

Nutrient releases from lake sediments

- Used for comparison to model simulations

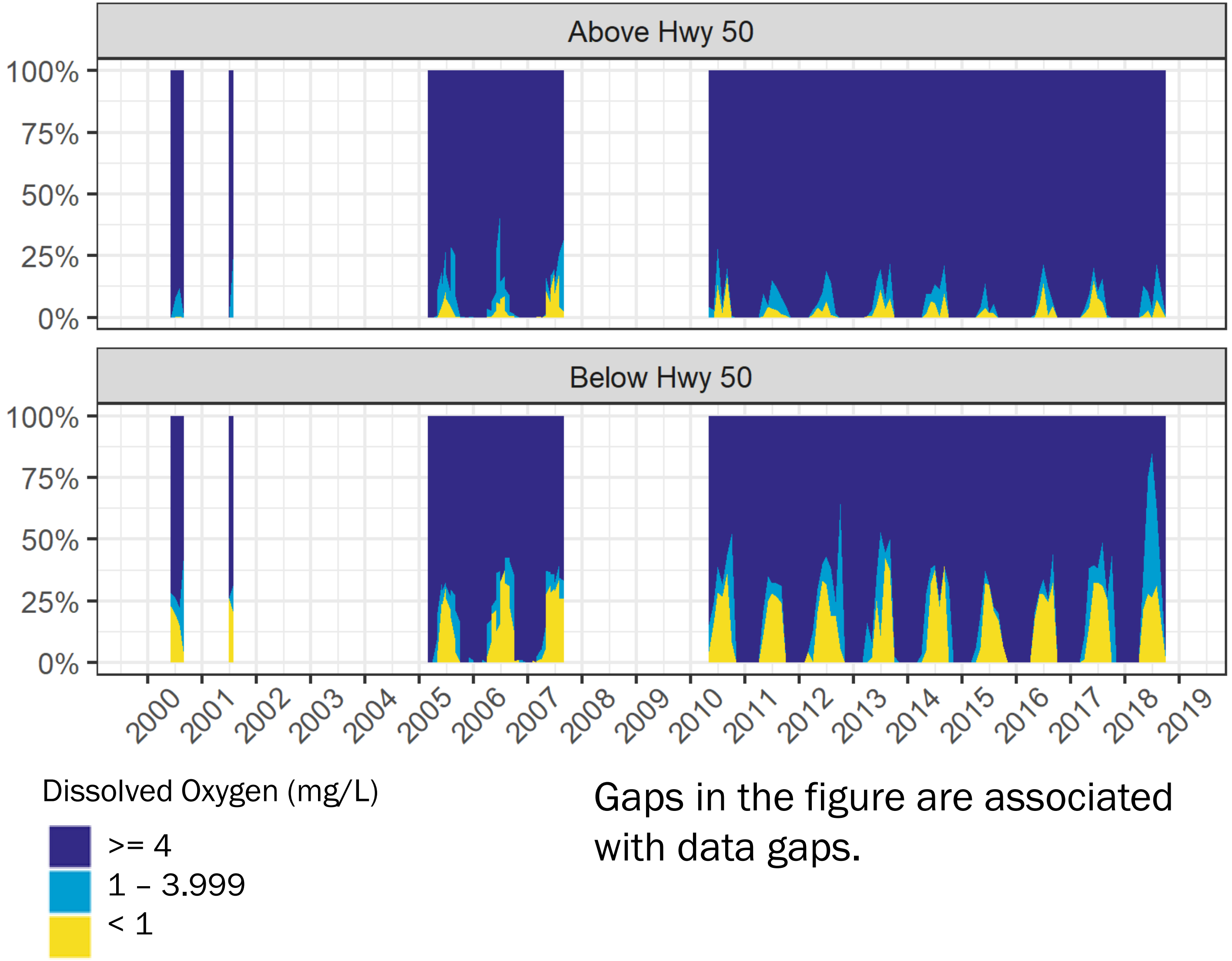
NC Collaboratory Falls Lake Research Key Findings (link)

Carbon cycling and climate change

- Falls Lake stores significant amounts of carbon

Volume of Lake Relative to Dissolved Oxygen (DO) Criterion

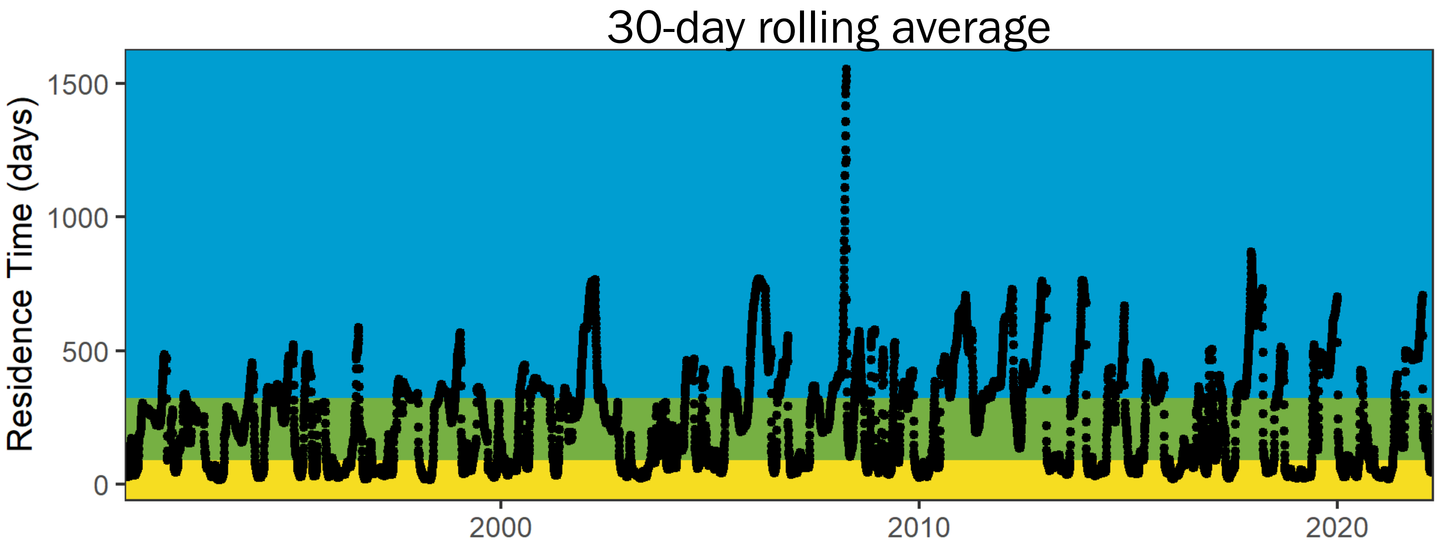
- Monthly mean DO volume as a percent of total lake volume
  - UNRBA bathymetric survey
  - Lake profile data
- Volume of lake above and below Highway 50 are similar
- Majority of lake volume is always above 4 mg/L, with brief exception in summer 2018
  - 4 mg/L is the instantaneous minimum criterion
- **Well oxygenated waters are always present**



Gaps in the figure are associated with data gaps.

Residence Time

- Residence time is the amount of time water is estimated to remain in the lake
  - Controls phytoplankton density
  - Longer residence times allow for more growth
- USACE controls releases from Falls Lake for flood control and downstream minimum flows
- Residence time can change rapidly and can vary from a couple of days to 1500 days.
- The median of the 30-day rolling average is 215 days

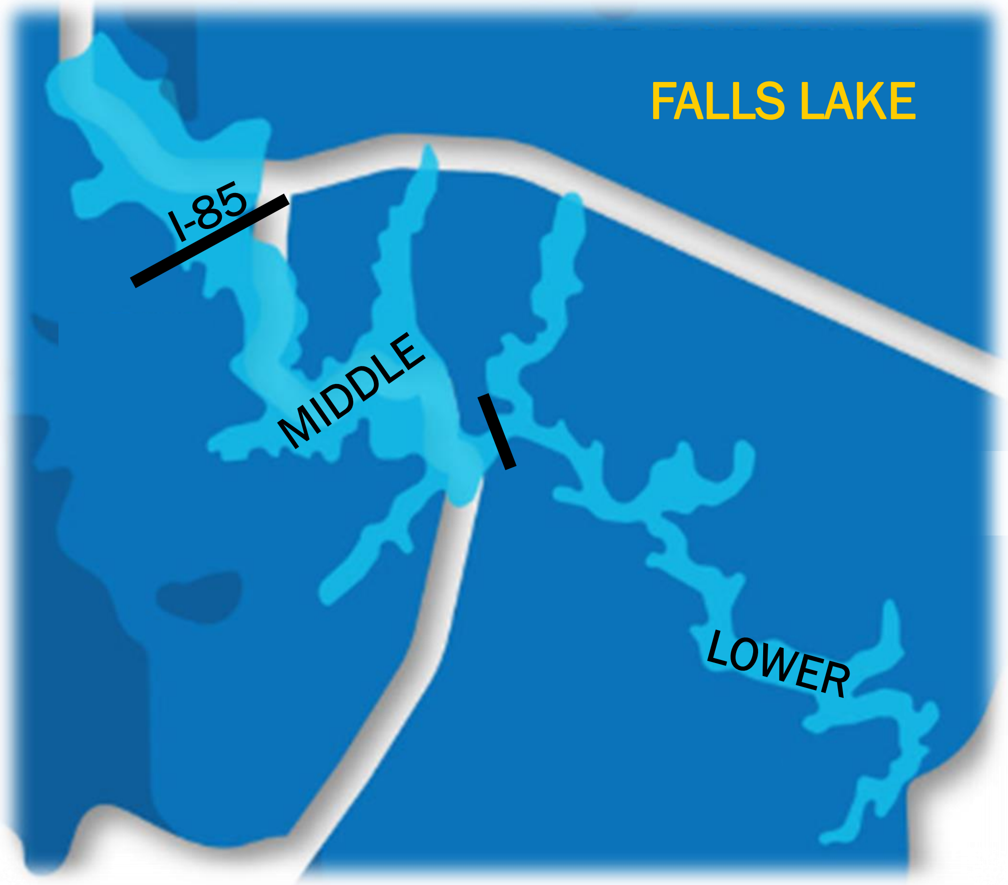


An equal number of observations are assigned to each bin on this figure

- **Yellow** (< 90 days)
- **Green** (90 – 323 days)
- **Blue** (> 323 days)

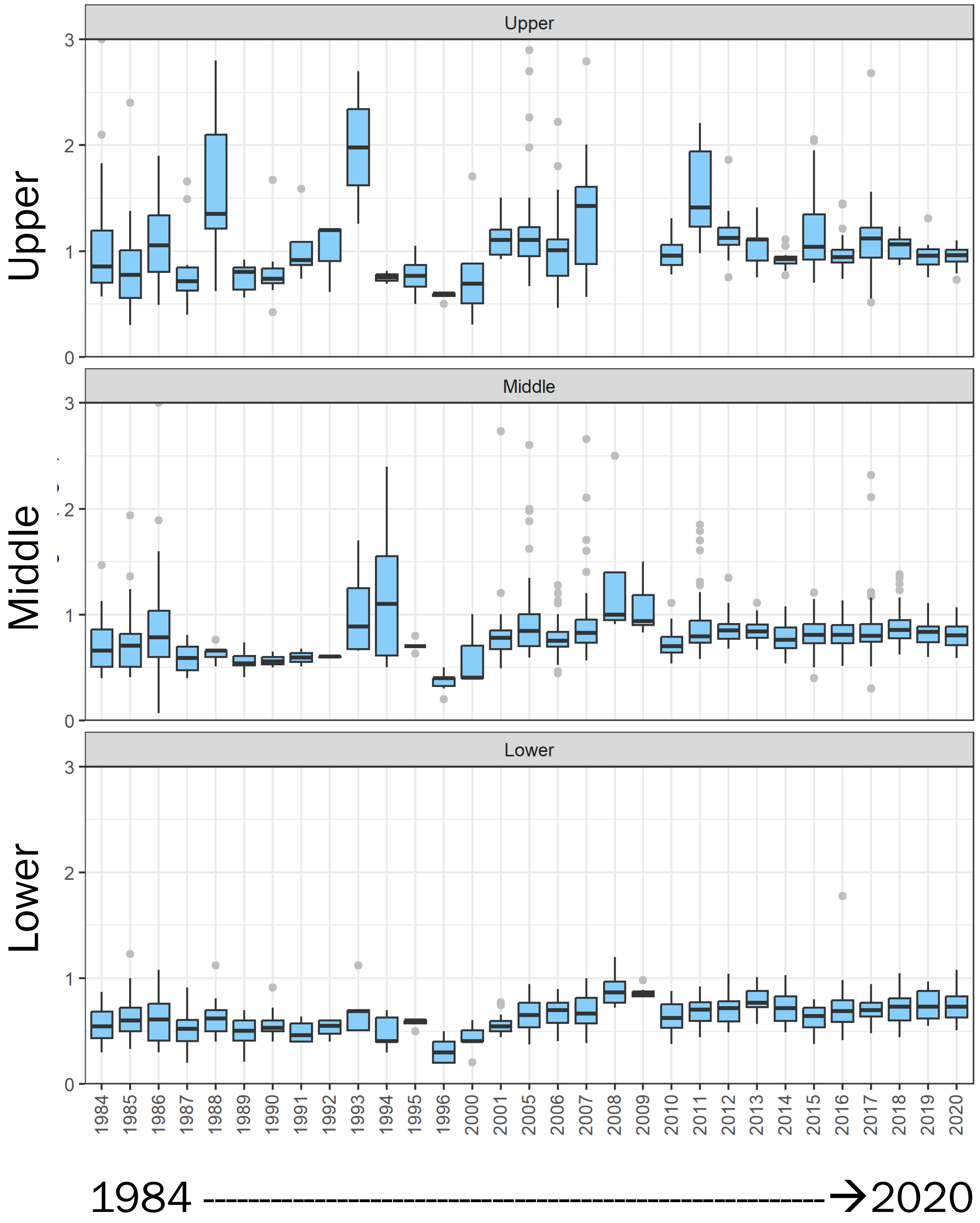
Nutrients and Chlorophyll *a*

- Data summarized by segment
  - Upper, above Interstate 85 (I-85)
  - Middle, between I-85 and Highway 50 (H-50)
  - Lower, between H-50 and the dam
- Organizations sampling water quality
  - DWR
  - City of Durham
  - City of Raleigh
  - Center for Applied Aquatic Ecology
  - USGS
  - NC Collaboratory funded researchers



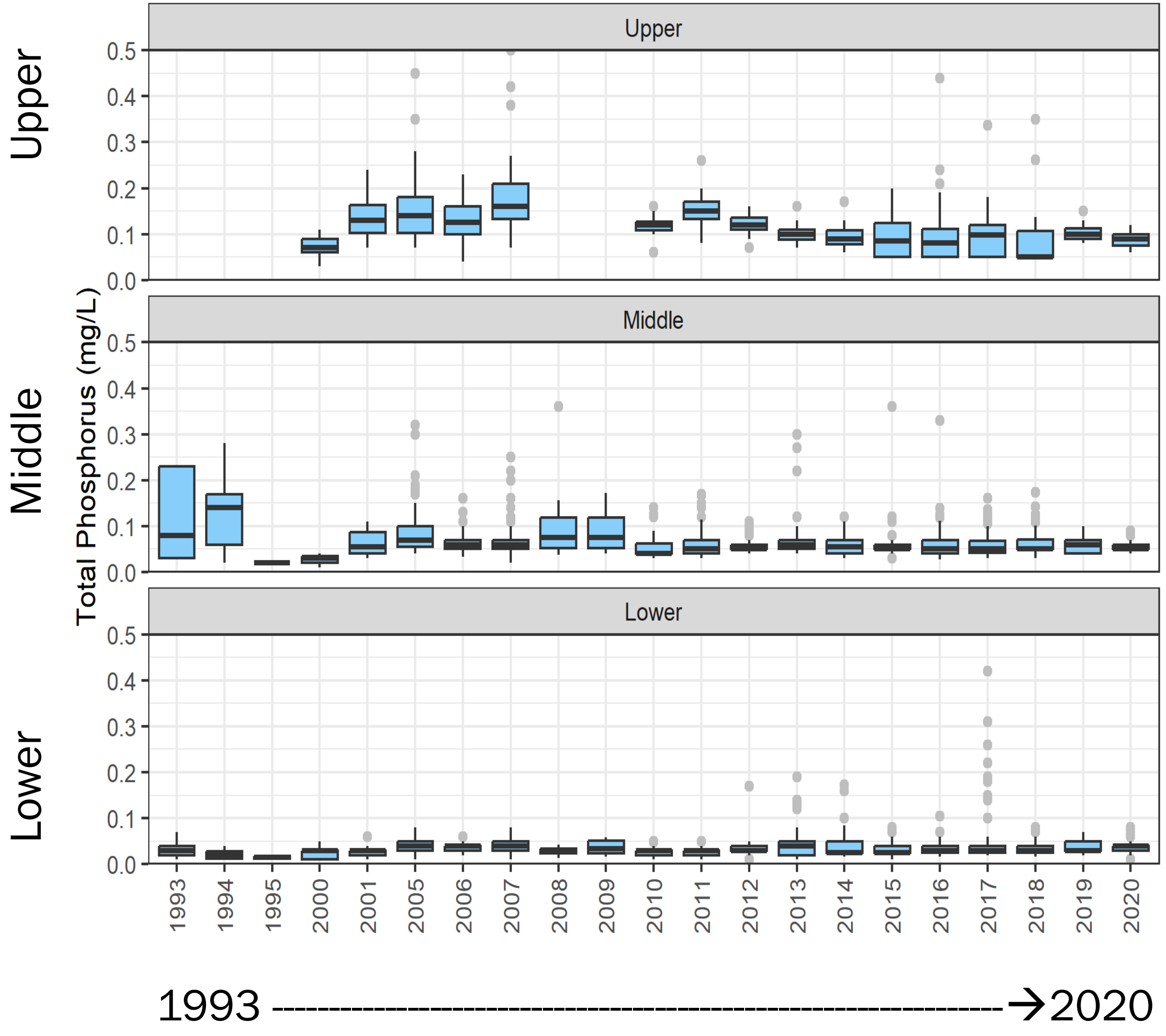
Total Nitrogen (mg-N/L)

- Concentrations decrease from upstream to downstream
  - Upper is above I-85
  - Middle between I-85 and Hwy. 50
  - Lower between Hwy. 50 and the dam
- Concentrations have decreased over time in the upper segment and slightly increased over time in the lower segments (also affected by sampling regime with more frequent data collection in recent years)
- **Since 2010, concentrations in the middle and lower segments have been relatively stable**



Total Phosphorus (mg-P/L)

- Less data available in early years
- Concentrations decrease from upstream to downstream
- Concentrations have decreased over time in upper and middle segments
- Concentrations are generally stable in the lower segment, but more outliers occurred in 2017
- **Since 2010, concentrations in middle and lower segments have been relatively stable**



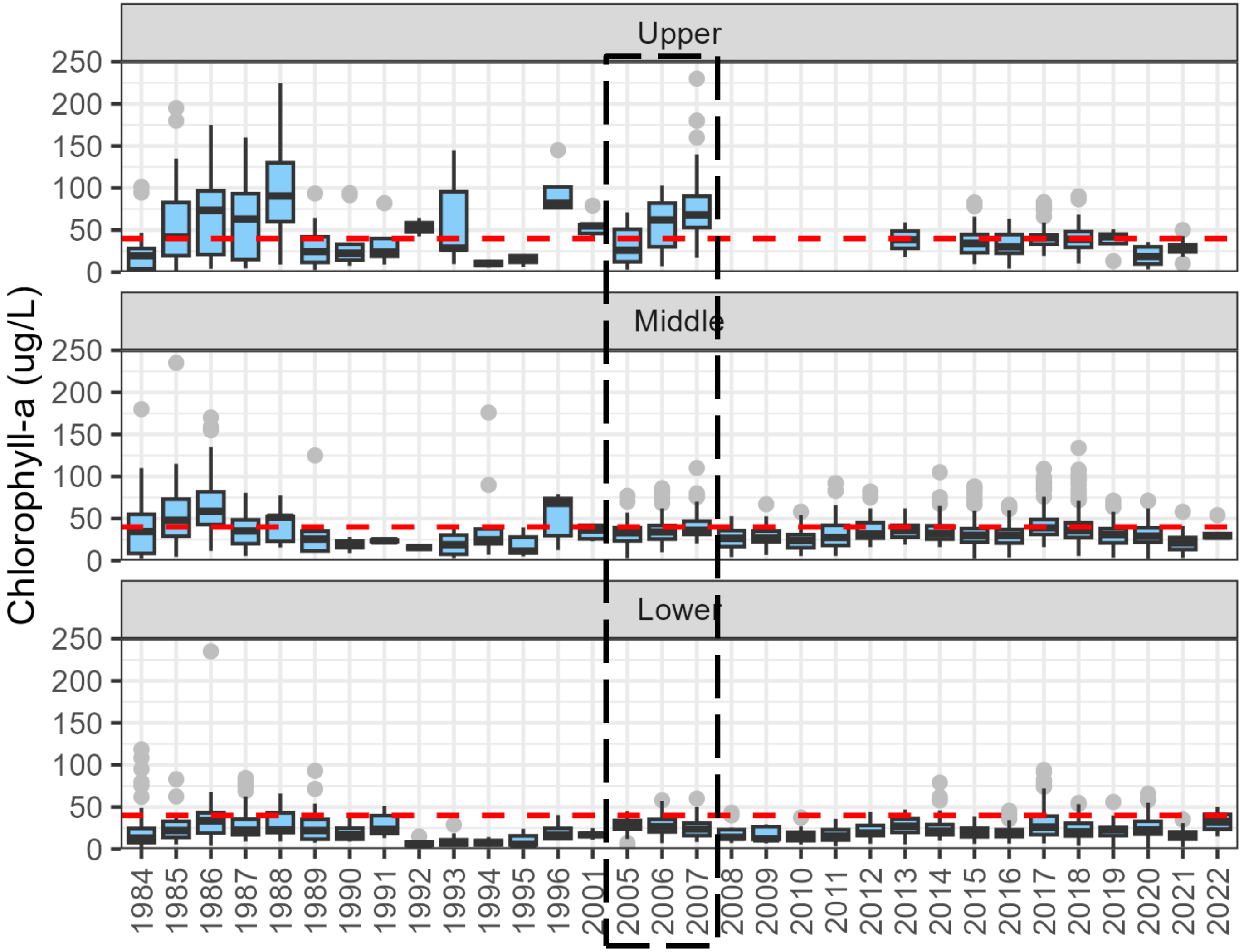
Chlorophyll-a Water Quality Standard

- Photosynthetic pigment used as an indicator for phytoplankton algae
- **NC is the only state with an instantaneous chlorophyll-a standard (40 µg/L) that applies everywhere in the lake**
- Falls Lake listed on NC's 303(d) list for chlorophyll-a in 2008
- Falls Lake Rules adopted in 2010 following monitoring and modeling conducted during a historic drought (2005 to 2007)

Falls Lake at I-85 in November 2007
Source: Southeast Regional Climate Center

Chlorophyll-a (µg/L)

- Historic levels (1980s) well above 40 µg/L, especially in upper and middle sections
- Shallow areas have more exceedances than deeper areas
- Chlorophyll-a decreases and stabilizes from upstream to downstream direction
- Lower segment has always seen fewest excursions above 40 µg/L
- Reservoir improves water quality, as intended
- **Concentrations are relatively stable in each segment**



Dotted box is the historic drought that occurred in 2005 to 2007.

Chlorophyll-a Insights

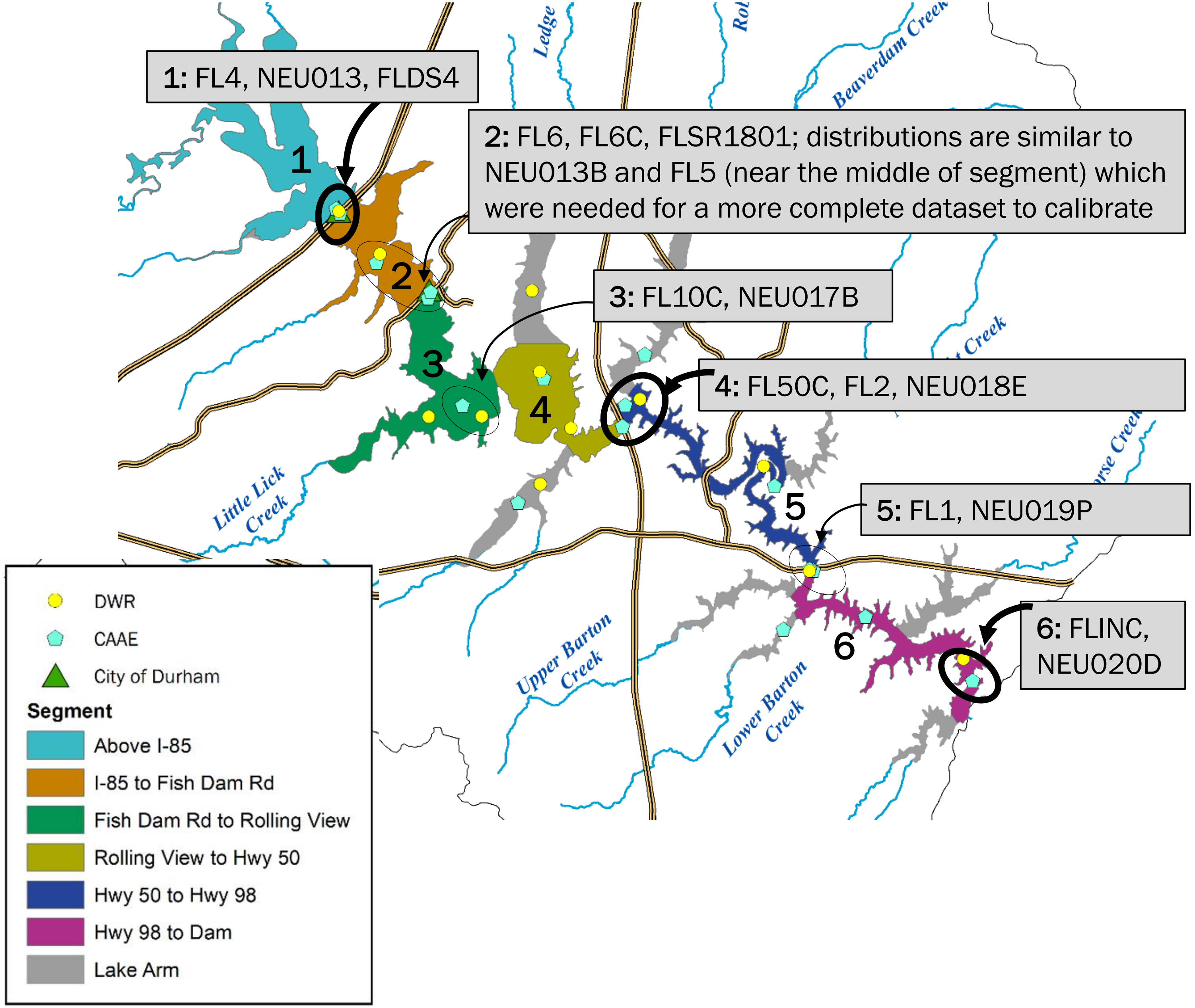
- Water quality is better than predicted and has improved since reservoir construction
- Eutrophication is not occurring (trophic condition is not changing)
- UNRBA's watershed and lake models indicate that the shallow upper part of the lake cannot meet the criterion even under a hypothetical "all forest/no humans" scenario
- Long-term nutrient management is needed to sustain designated uses and protect the lake
- Application of chlorophyll-a criterion of 40 µg/L at every location and at all times is not indicative of attainment of designated uses
- A site-specific criterion that considers designated uses is needed

WARMF Lake Model Development and Calibration

12:00 PM

WARMF Lake

- Six main lake segments
- Calibrated to downstream water quality stations in each segment
- Uses inputs from WARMF watershed model
- 6-hr time steps
- 2015-2018
- Figures today focus on Segments 1, 4, and 6 to represent upper, middle, and lower lake



Evaluation of Model Performance

- WARMF Lake uses the same performance targets (percent bias) as the watershed model for water quality evaluations in the six main stem segments
- Measurements in Falls Lake are compared to the segment output for the 6-hour time step that contains the observation
- WARMF Lake layers are ~ 0.75 meters deep
- Observed values are compared to the average of simulated layers comprising the photic zone (twice the Secchi depth)

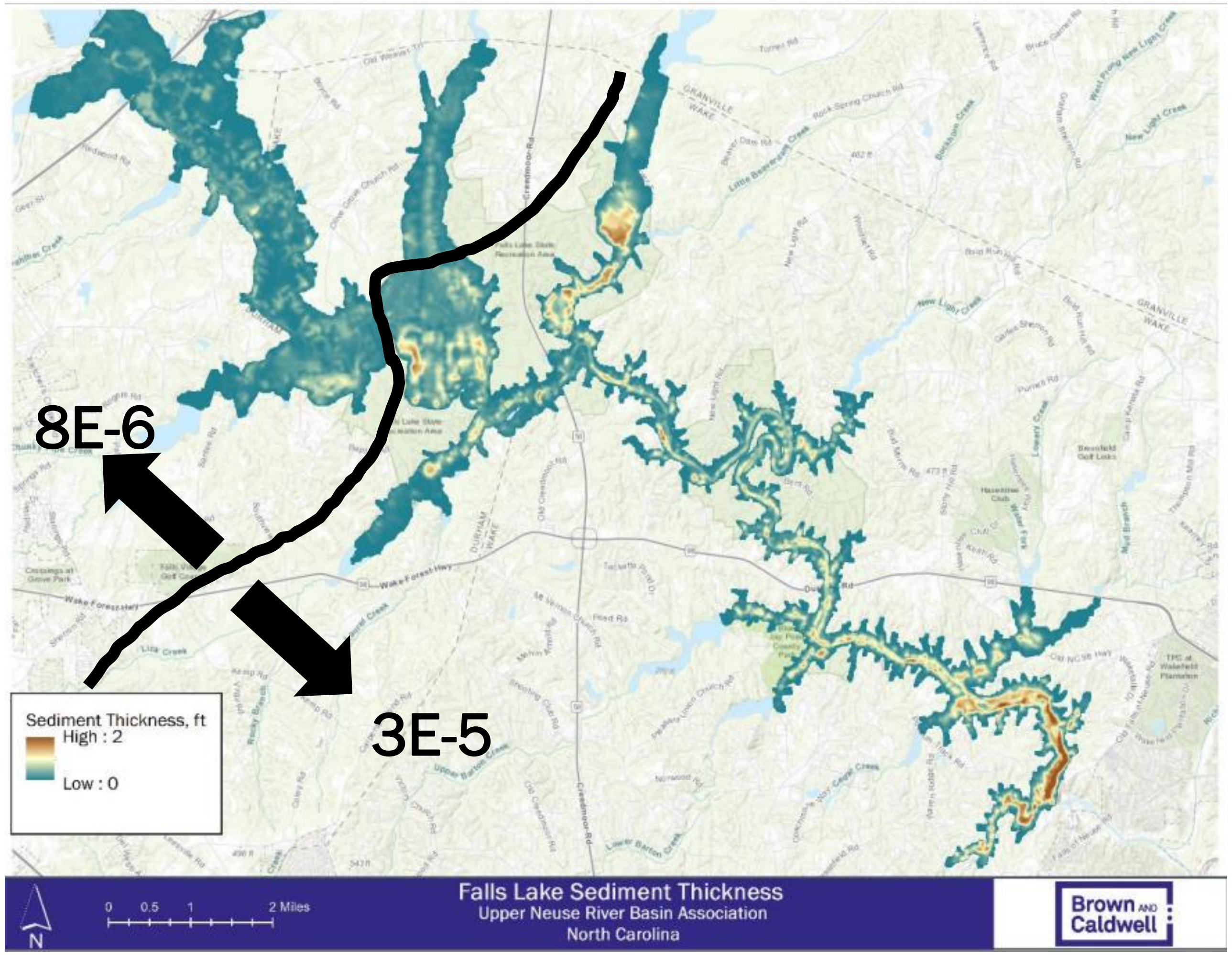
Segment	Typical Secchi Depth (m)	Typical Photic Zone (m)	Top Layers to Average
1	0.4	0.8	1
2	0.6	1.2	1, 2
3	0.75	1.5	1, 2
4	1	2	1, 2, 3
5	1.1	2.2	1, 2, 3
6	1.25	2.5	1, 2, 3

Data to Support WARMF Lake Model Development

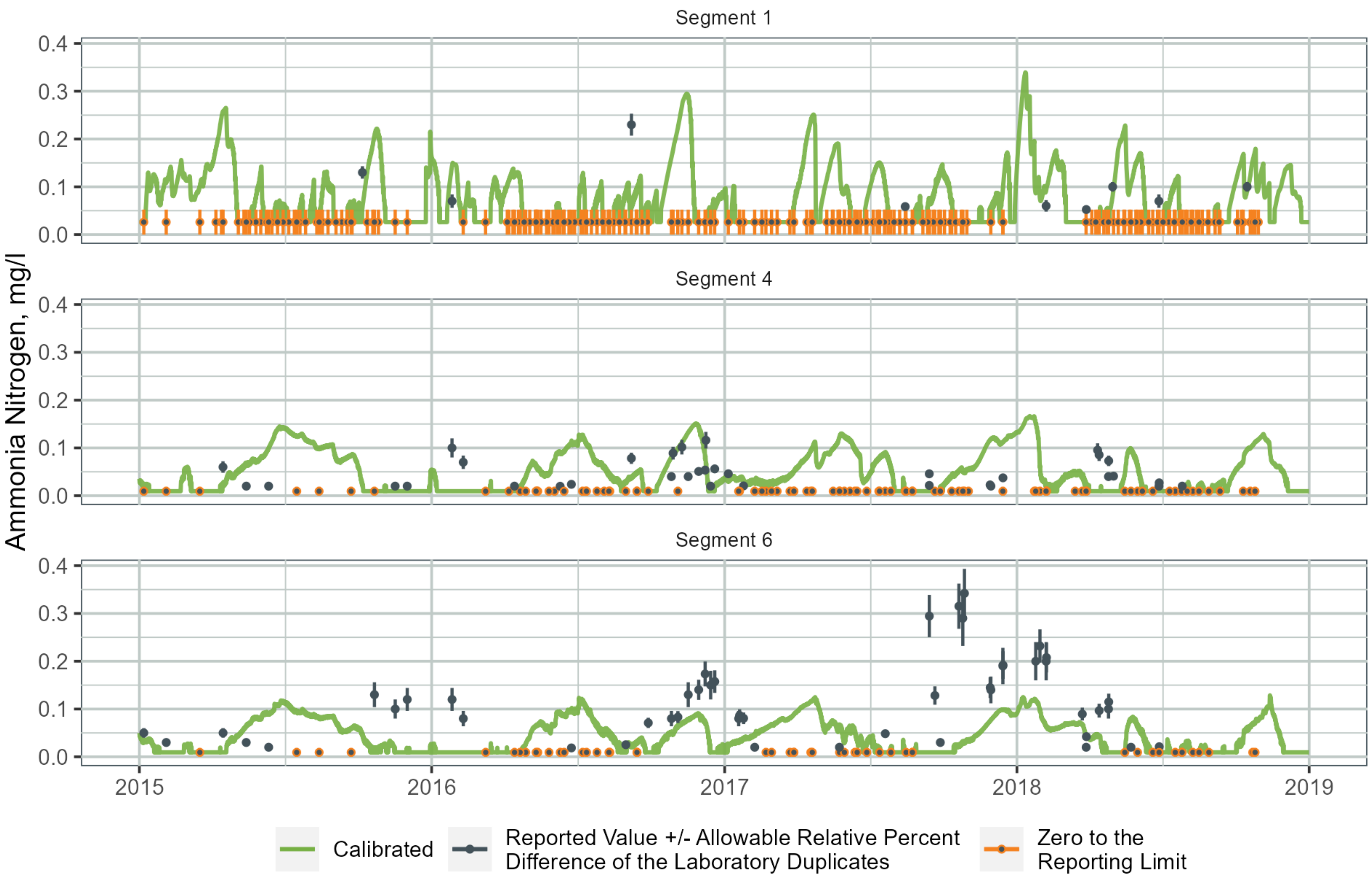
Initial conditions for lake sediment quality and sediment depth	• UNRBA sediment quality and sediment depth special studies (Alperin 2016)
Nutrient releases from lake sediments for comparison to simulated values	• DWR 2006, Alperin 2016, EPA 2018, Piehler 2023, Hall 2023
Lake water quality data for initial conditions and calibration	• DWR, City of Durham and City of Raleigh, Center for Applied Aquatic Ecology
Development of lake model segments	• UNRBA bathymetric survey of Falls Lake
Precipitation and atmospheric deposition	• From watershed modeling
Tributary flow and constituent loading from the WARMF	• From watershed modeling

WARMF Lake Calibration Parameters

- Ammonia and phosphate sediment adsorption isotherms using Alperin (2016) sediment core and pore water concentration data
- Reaction rates and growth parameters applied uniformly across model segments:
  - Algal growth, respiration, settling, and decay rates
  - Sediment bed and water column reaction rates
- Two sediment bed diffusion rates were set based on the average sediment depth for the segments



WARMF Model Results – Ammonia



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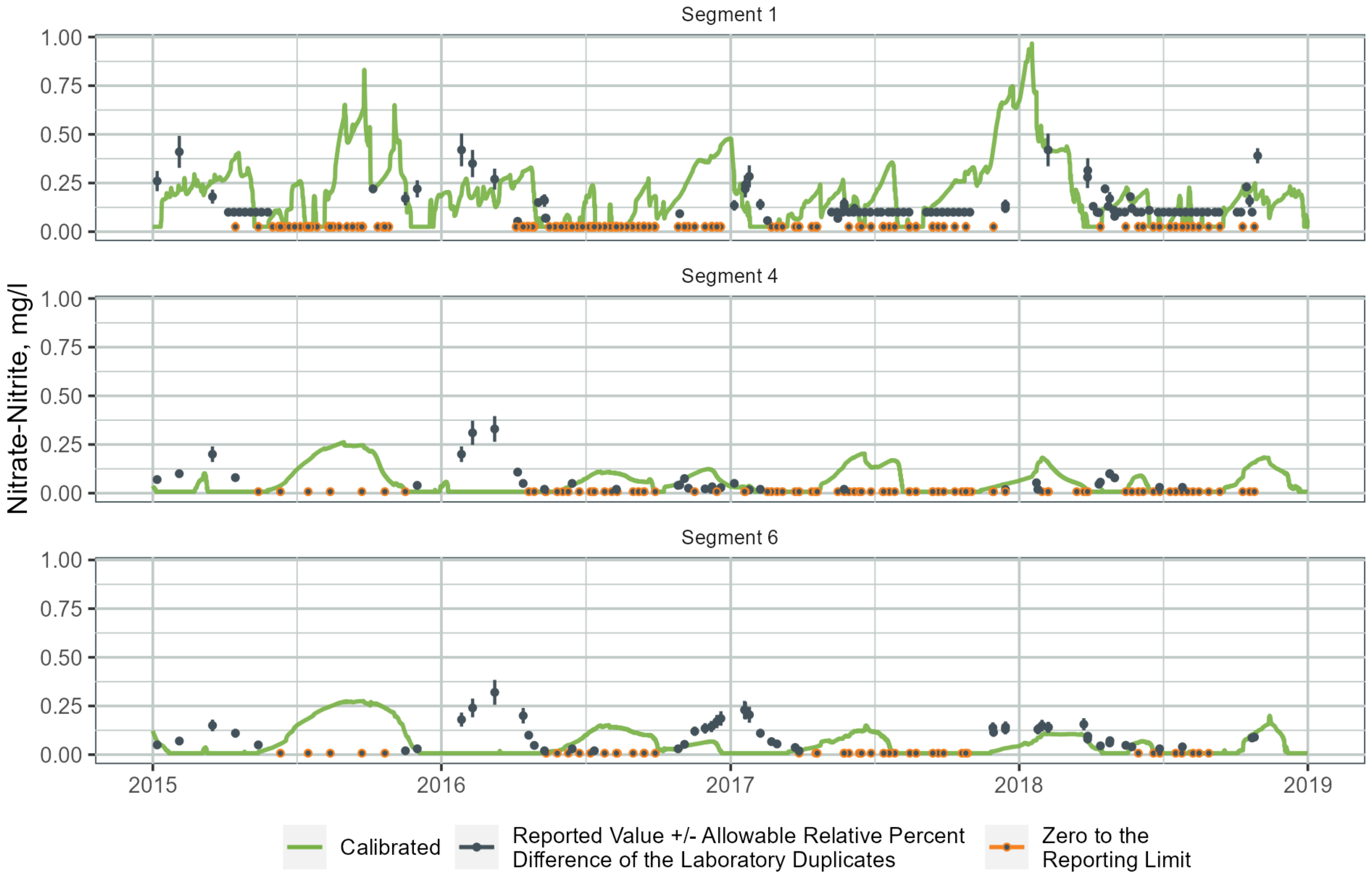
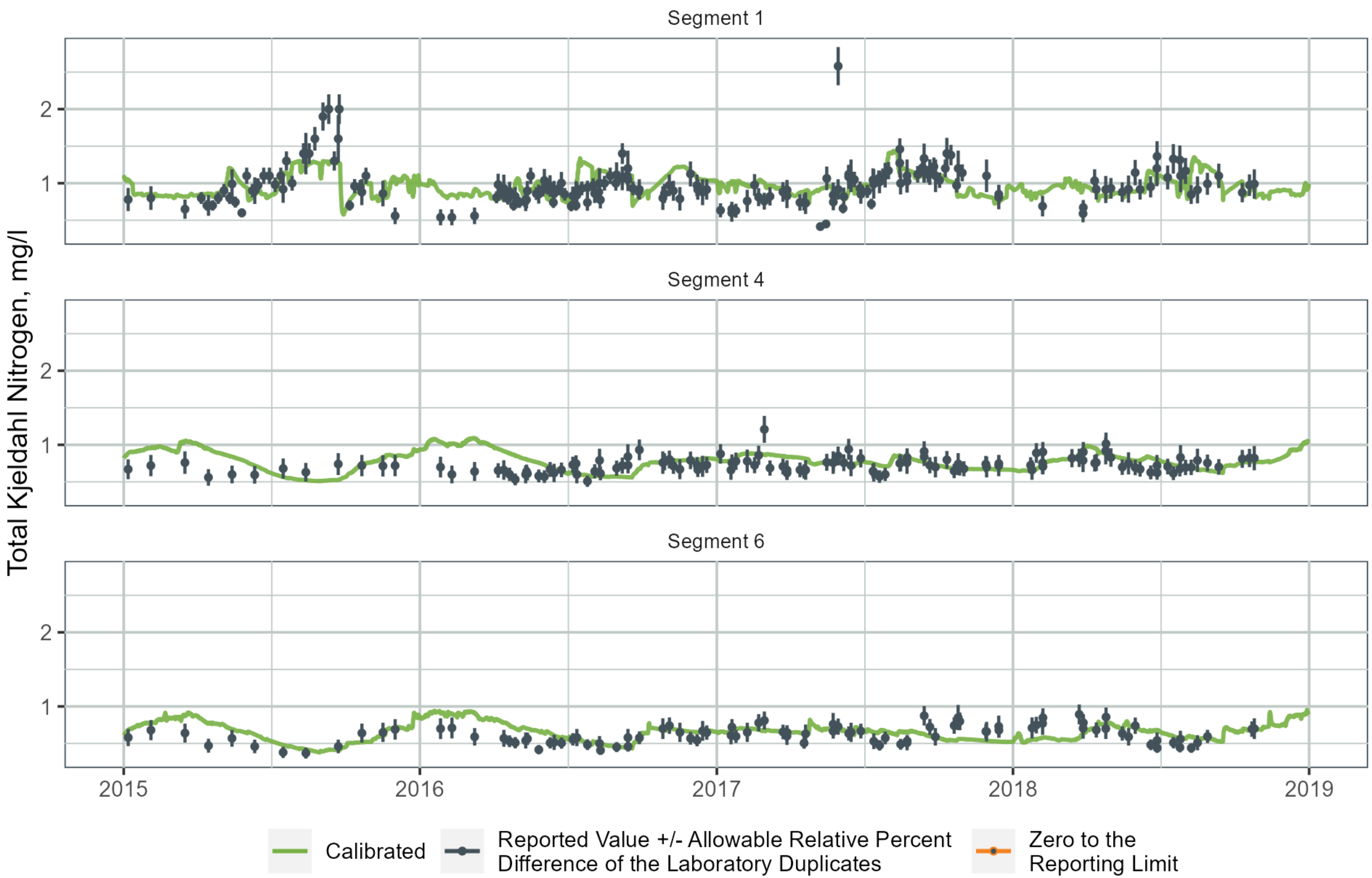
WARMF Model Results – Nitrate/Nitrite



WARMF Model Results – TKN



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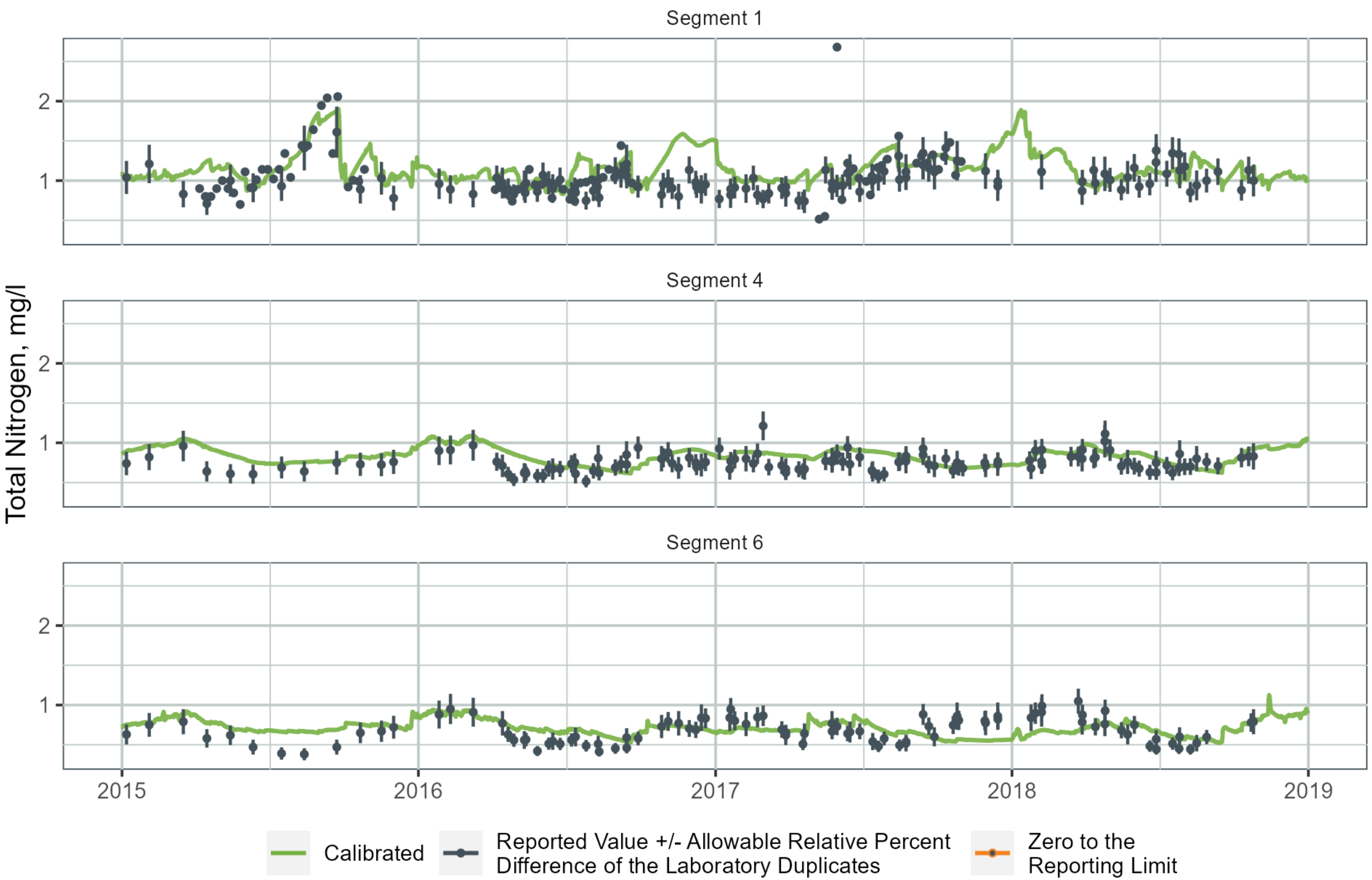
WARMF Model Results – Total Nitrogen



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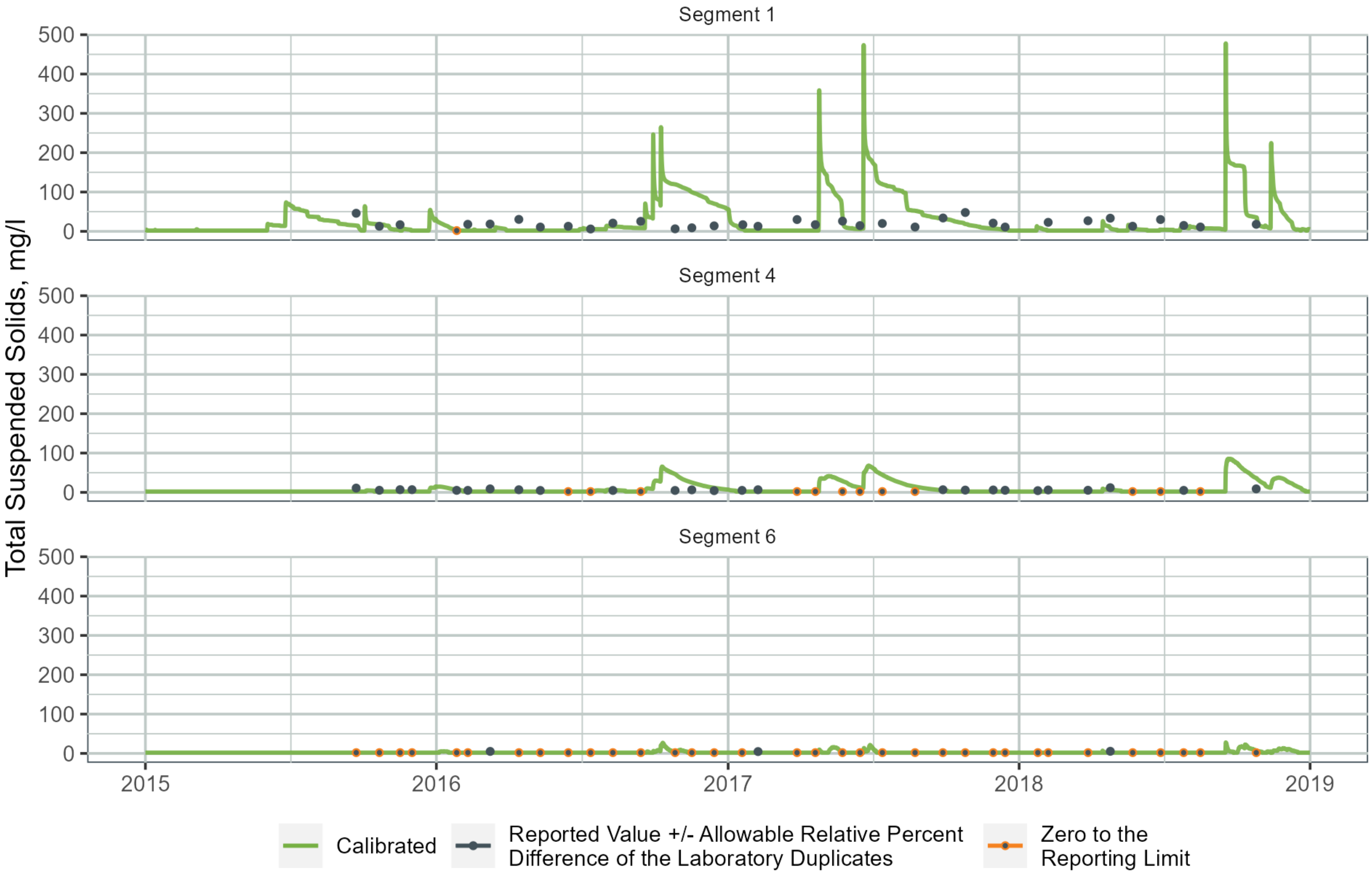
WARMF Model Results – Total Suspended Solids (TSS)



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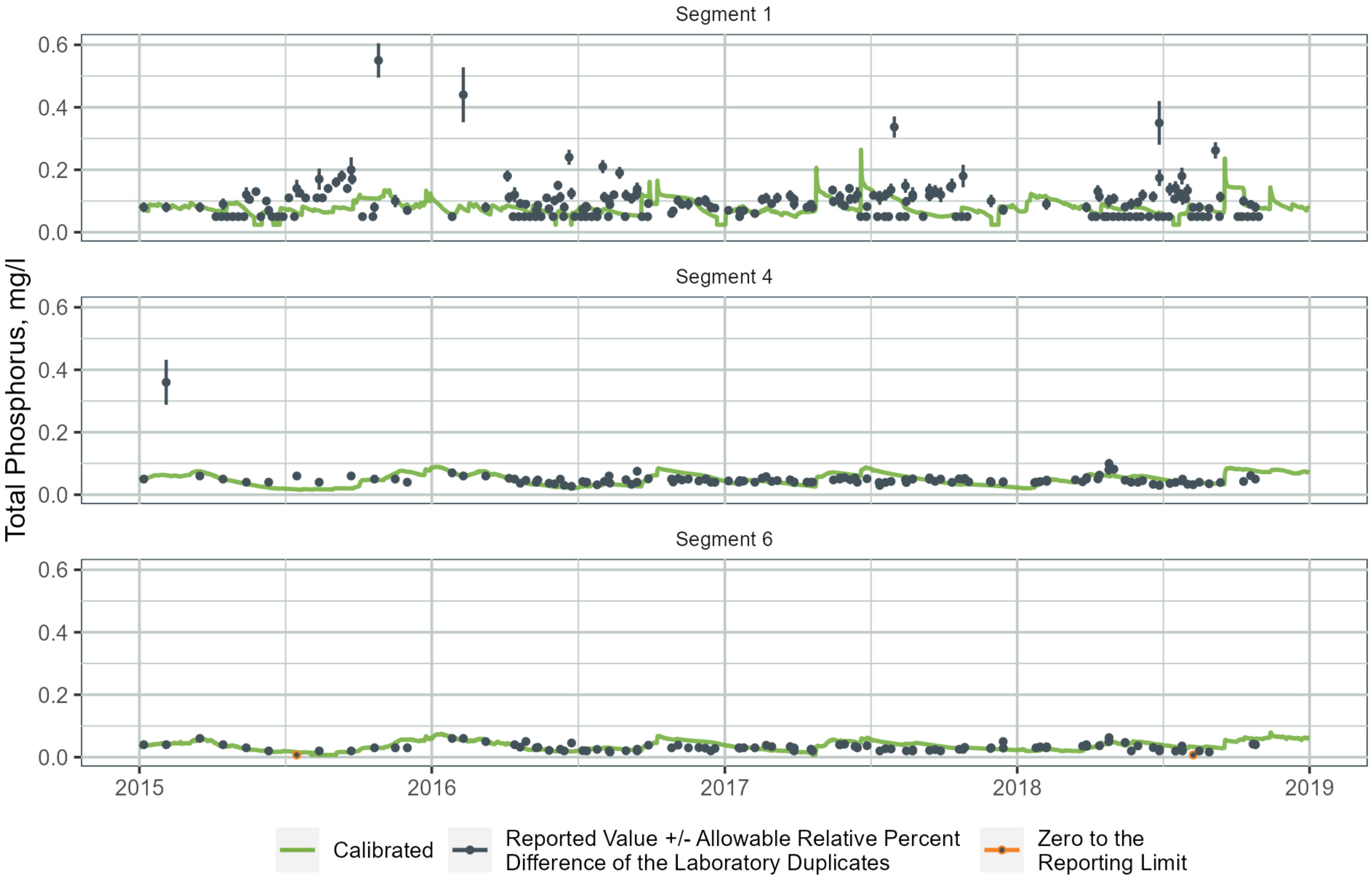
WARMF Model Results – Total Phosphorus



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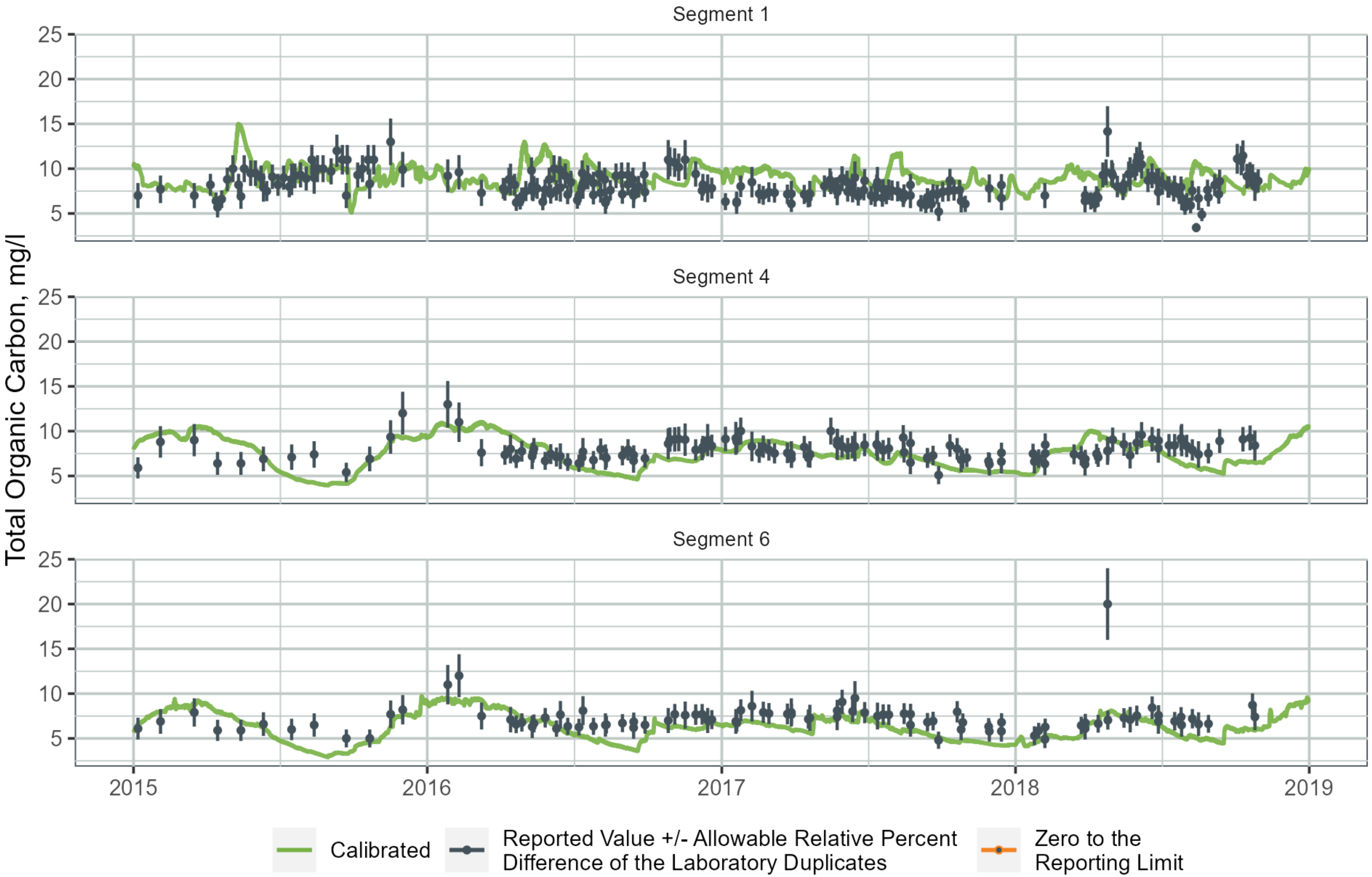
Falls Lake Water Quality – Total Organic Carbon (TOC)



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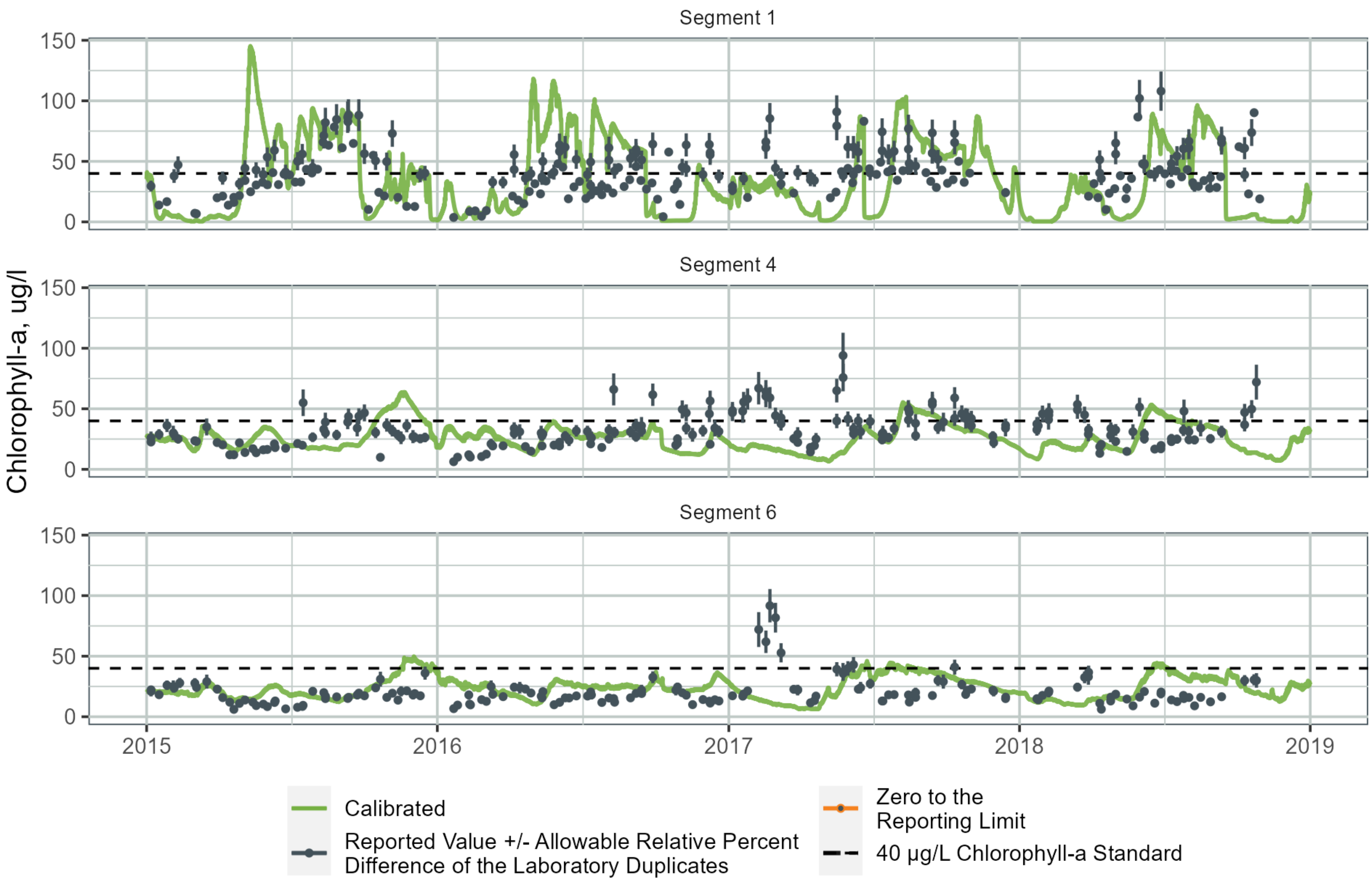
WARMF Model Results– Chlorophyll-a



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Performance Criteria, Final WARMF Lake Calibration

	Average of pBias:						Average of Observations by period (n), % below reporting limit (full period)					
Lake Segment:	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
Chlorophyll-a, ug/l							0%	0%	0%	0%	0%	0%
Full Period, n=2	3	-2	-6	-16	-2	13	42.2 (284)	36.5 (277)	35.3 (111)	32.3 (243)	27 (57)	20.6 (57)
Calibration, n=1	18	20	10	-3	23	19	39.6 (169)	31.2 (147)	31.4 (69)	28.6 (146)	21.3 (35)	18.2 (36)
Validation, n=1	-16	-21	-25	-31	-20	3	45.8 (115)	42.4 (130)	41.1 (42)	37.6 (97)	33.4 (22)	24.5 (21)
Total Organic Carbon, mg/l							0%	0%	0%	0%	0%	0%
Full Period	13	1	6	-6	-9	-15	8.1 (235)	8.1 (219)	7.6 (54)	7.8 (139)	7.5 (57)	7.2 (57)
Calibration	13	-1	5	-3	-6	-11	8.5 (116)	8.3 (109)	7.8 (33)	7.6 (61)	7.5 (35)	7 (36)
Validation	13	4	6	-8	-12	-18	7.8 (119)	7.8 (110)	7.3 (21)	7.9 (78)	7.6 (22)	7.3 (21)
Total Phosphorus as P, mg/l							30%	47%	0%	0%	0%	0%
Full Period	-22	-7	-7	-3	-2	11	0.097 (225)	0.053 (212)	0.06 (54)	0.048 (139)	0.04 (56)	0.031 (57)
Calibration	-25	-15	-13	-11	1	8	0.1 (114)	0.05 (106)	0.064 (33)	0.052 (61)	0.039 (34)	0.033 (36)
Validation	-18	0	3	5	-4	15	0.093 (111)	0.057 (106)	0.054 (21)	0.045 (78)	0.042 (22)	0.03 (21)
Total Suspended Solids, mg/l					Calculated (TSS minus VSS)							
Full Period	7	-33	4	61	0	-2	19.5 (35)	13.9 (36)	6.2 (37)	5 (37)	3.1 (36)	2.2 (36)
Calibration	45	-27	1	36	-17	-9	16.7 (15)	12.6 (16)	6.2 (16)	5.5 (16)	3.2 (14)	2.2 (15)
Validation	-15	-36	7	84	14	3	21.6 (20)	14.9 (20)	6.2 (21)	4.6 (21)	3.1 (22)	2.2 (21)
Water Temperature, C							0%	0%	0%	0%	0%	0%
Full Period	3	6	7	9	12	10	22 (60)	22.4 (54)	17.8 (53)	17.8 (57)	17.7 (57)	17.5 (56)
Calibration	4	5	5	9	13	11	21.5 (37)	22 (34)	17.4 (32)	17.4 (36)	16.9 (35)	17 (35)
Validation	2	7	9	8	10	9	22.6 (23)	22.8 (20)	18.5 (21)	18.6 (21)	19.2 (22)	18.3 (21)

- Chlorophyll-a model performance is good to very good during calibration and validation at segments 1, 2, 5, and 6. It is very good at segments 3 and 4 during the calibration period and fair at both in the validation period.
- Total organic carbon model performance is very good in all segments/periods except one (good)
- Total phosphorus model performance is good to very good for each segment and period except one that is 0.2 over threshold
- There are fewer TSS observations due to lack of VSS measurements for comparison to WARMF output [WARMF TSS (silt plus clay) corresponds to observed TSS minus observed VSS]. TSS model performance is fair to very good except in segment 4.
- Water temperature model performance is usually good to very good with one segment/period that is fair.

Performance Criteria, Final WARMF Lake Calibration

	Average of pBias:						Average of Observations by period (n), % below reporting limit (full period					
Lake Segment:	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
Ammonia Nitrogen as N, mg/l							64%	65%	11%	47%	23%	27%
Full Period	151	40	58	168	5	-29	0.029 (232)	0.031 (215)	0.019 (54)	0.019 (139)	0.045 (56)	0.06 (57
Calibration	146	26	11	131	2	-12	0.029 (113)	0.03 (107)	0.022 (33)	0.022 (61)	0.046 (34)	0.051 (36
Validation	155	52	185	212	9	-39	0.029 (119)	0.033 (108)	0.013 (21)	0.015 (78)	0.043 (22)	0.069 (21
Nitrate-Nitrite as N, mg/l							35%	37%	7%	46%	17%	28%
Full Period	117	5	-9	96	6	-8	0.077 (234)	0.08 (218)	0.06 (54)	0.031 (139)	0.053 (56)	0.06 (57
Calibration	200	27	-47	32	0	12	0.064 (115)	0.06 (109)	0.081 (33)	0.049 (61)	0.069 (34)	0.067 (36
Validation	58	-8	166	264	19	-29	0.091 (119)	0.101 (109)	0.027 (21)	0.014 (78)	0.034 (22)	0.053 (21
Total Kjeldahl Nitrogen as N, mg/l							0%	0%	0%	0%	0%	0%
Full Period	3	0	9	7	8	3	0.96 (204)	0.83 (190)	0.76 (54)	0.72 (139)	0.67 (56)	0.62 (57
Calibration	7	-2	13	13	11	11	0.94 (115)	0.81 (109)	0.73 (33)	0.68 (61)	0.65 (34)	0.58 (36
Validation	-1	2	2	3	5	-3	0.98 (89)	0.85 (81)	0.8 (21)	0.76 (78)	0.68 (22)	0.65 (21
Total N - calculated, mg/l						Calculated parameter						
Full Period	13	0	7	10	8	2	1.03 (204)	0.9 (190)	0.82 (54)	0.75 (139)	0.72 (56)	0.68 (57
Calibration	18	-1	7	14	10	11	1.01 (115)	0.87 (109)	0.81 (33)	0.73 (61)	0.72 (34)	0.65 (36
Validation	6	2	7	7	5	-5	1.06 (89)	0.94 (81)	0.83 (21)	0.77 (78)	0.71 (22)	0.71 (21

- Values on right side of table in **black font**: average of the observations (number of samples)
- Values in blue font: percent of samples less than reporting limit for the full period
- Different organizations sample different segments; segments 1 and 2 have the most data
- Meeting the performance criteria (left side) is more difficult when concentrations are very low
- Ammonia and nitrate are generally overpredicted upstream of Highway 50
- Most of the total nitrogen is in the organic nitrogen form (TKN minus ammonia)
- TKN and TN are very good in all segments/periods except one (good)

Highway 50 is downstream of Segment 4

WARMF Lake Scenarios

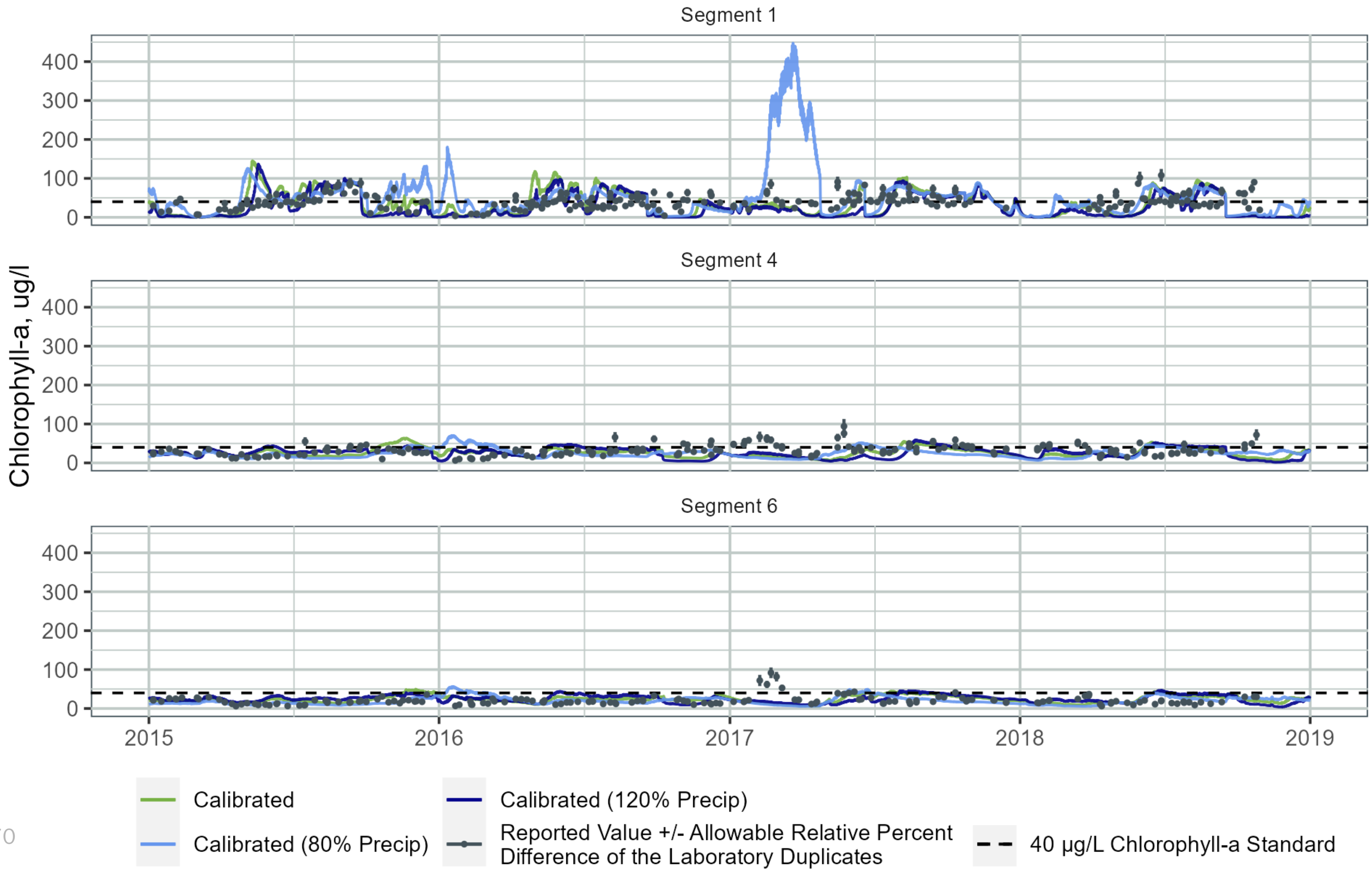
12:10 PM

WARMF Lake Scenarios

- All watershed scenarios were also evaluated with the lake model
  - 20 percent more or less rainfall
  - 25 percent more or less atmospheric deposition
  - Hypothetical land conversion to forests and removal of human inputs
- An additional scenario to test modification of the dam release was also evaluated
  - Assumes spillway is at normal pool elevation (251.5 ft above mean sea level)
  - Changes from operating the lake as a flood control reservoir
- None of the scenarios have dramatic effects on chlorophyll-a concentrations

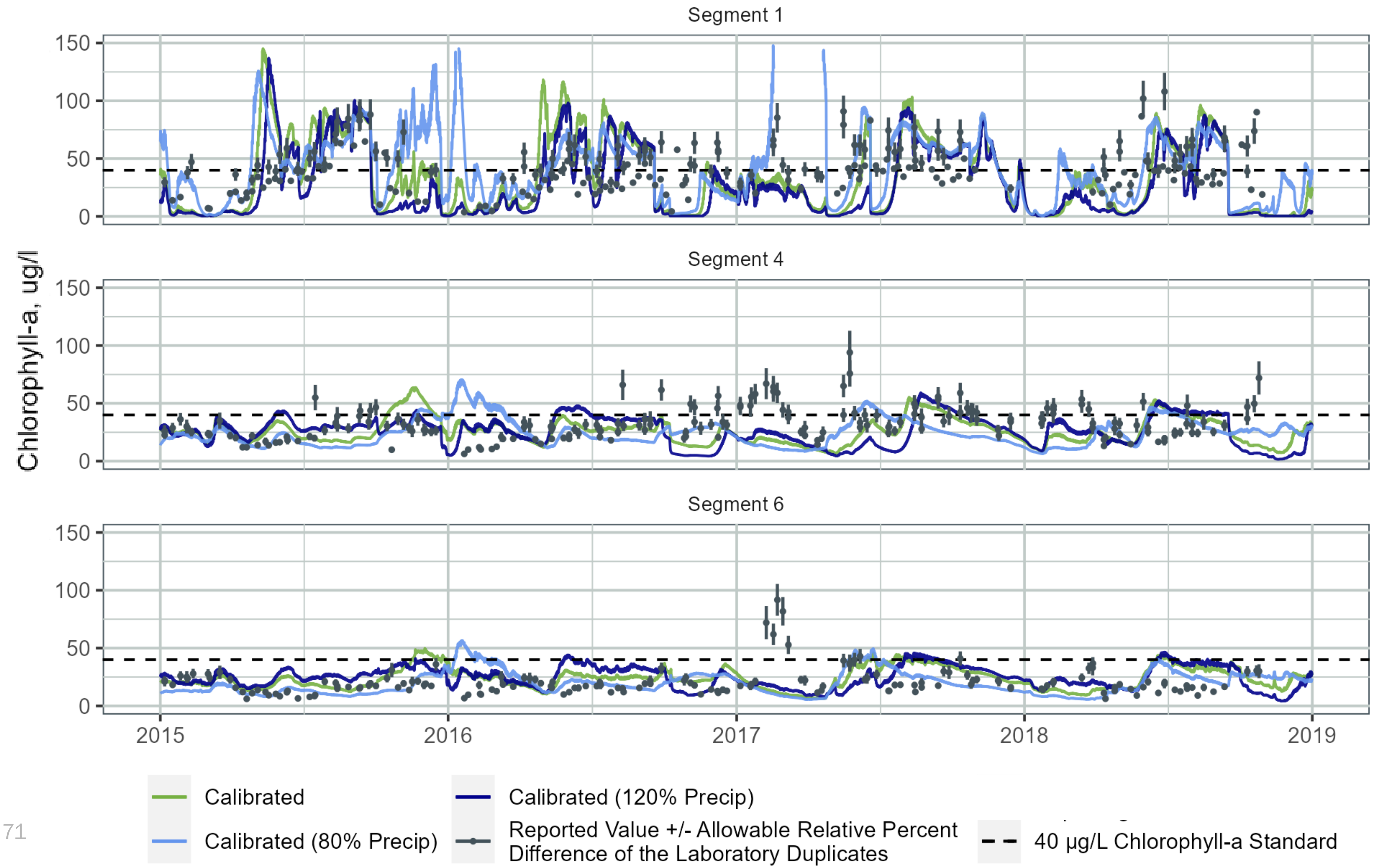
None of the scenarios would achieve the chlorophyll-a standard everywhere in the lake, not even a hypothetical conversion of all land to forest with removal of human inputs.

20% More or Less Rainfall Scenario - Chlorophyll-a



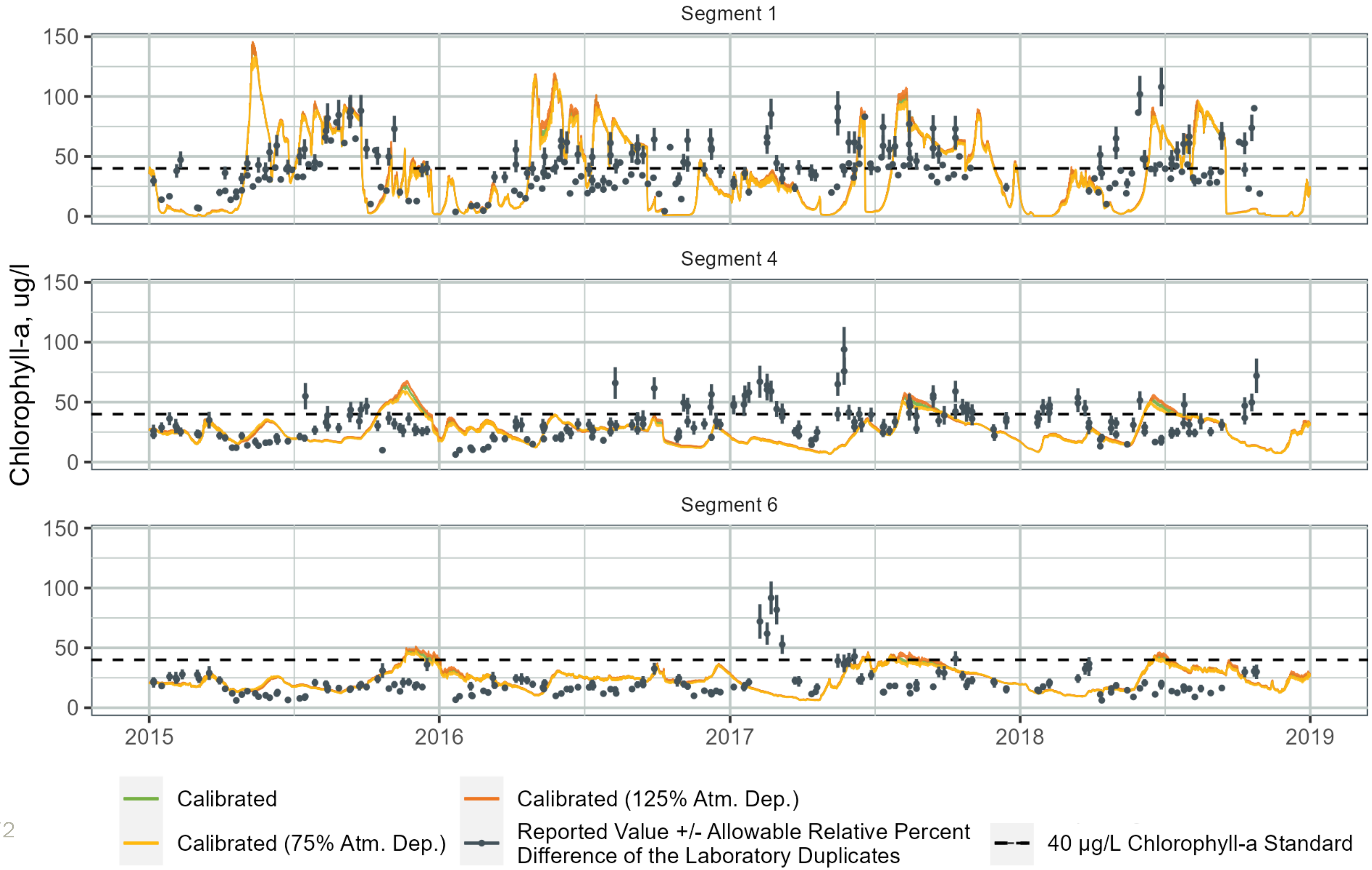
Next slide has the y-axes capped at 150 µg/L.

20% More or Less Rainfall Scenario - Chlorophyll-a (capped)



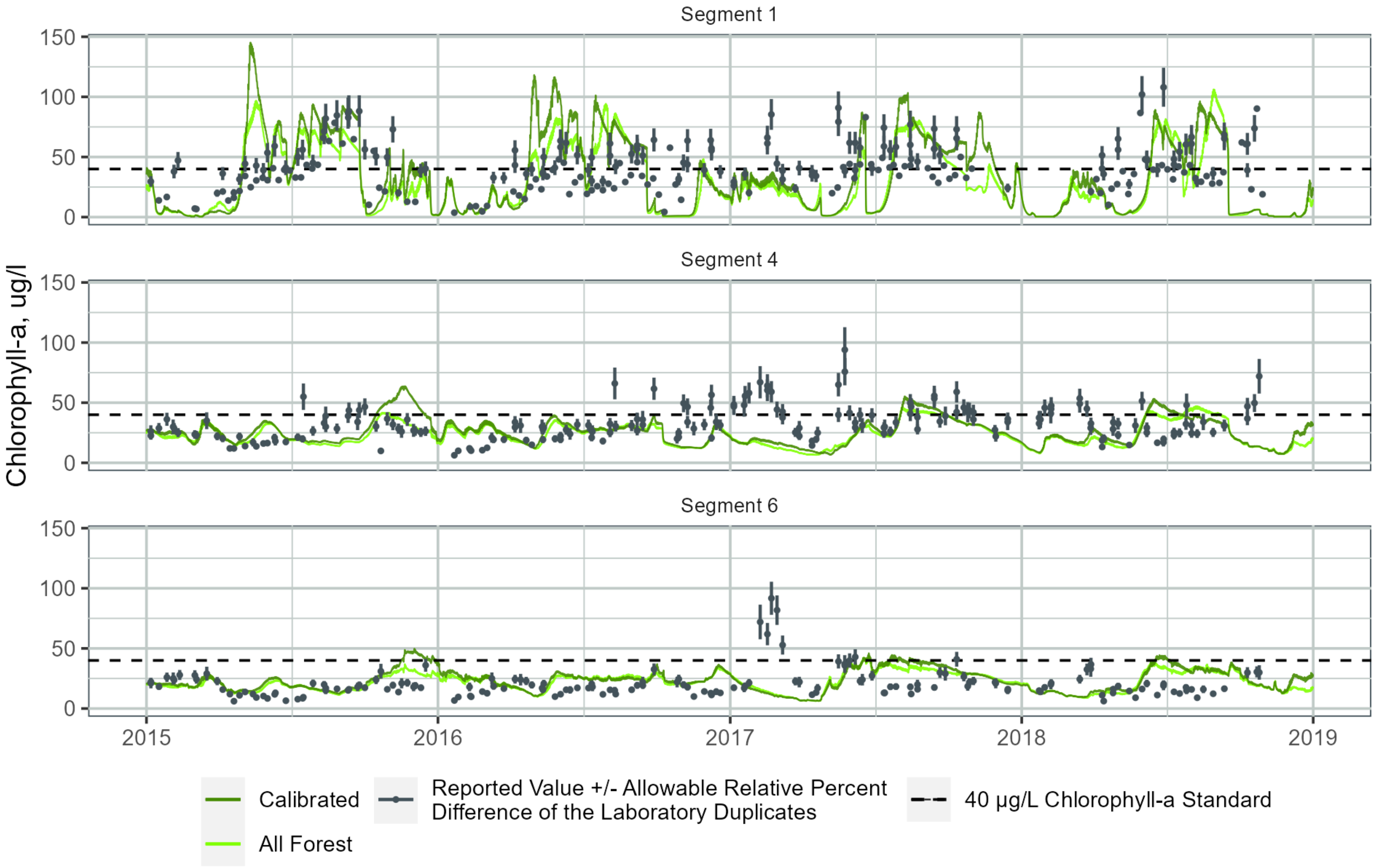
Sometimes 20% less rainfall has higher chlorophyll-a values and sometimes lower.

25% More or Less Atmospheric Deposition - Chlorophyll-a

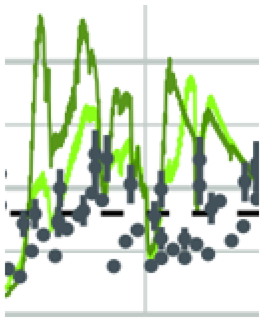


The calibrated model and sensitivity time series for atmospheric deposition are very similar. The lines are not discernable unless the peaks are zoomed in on:

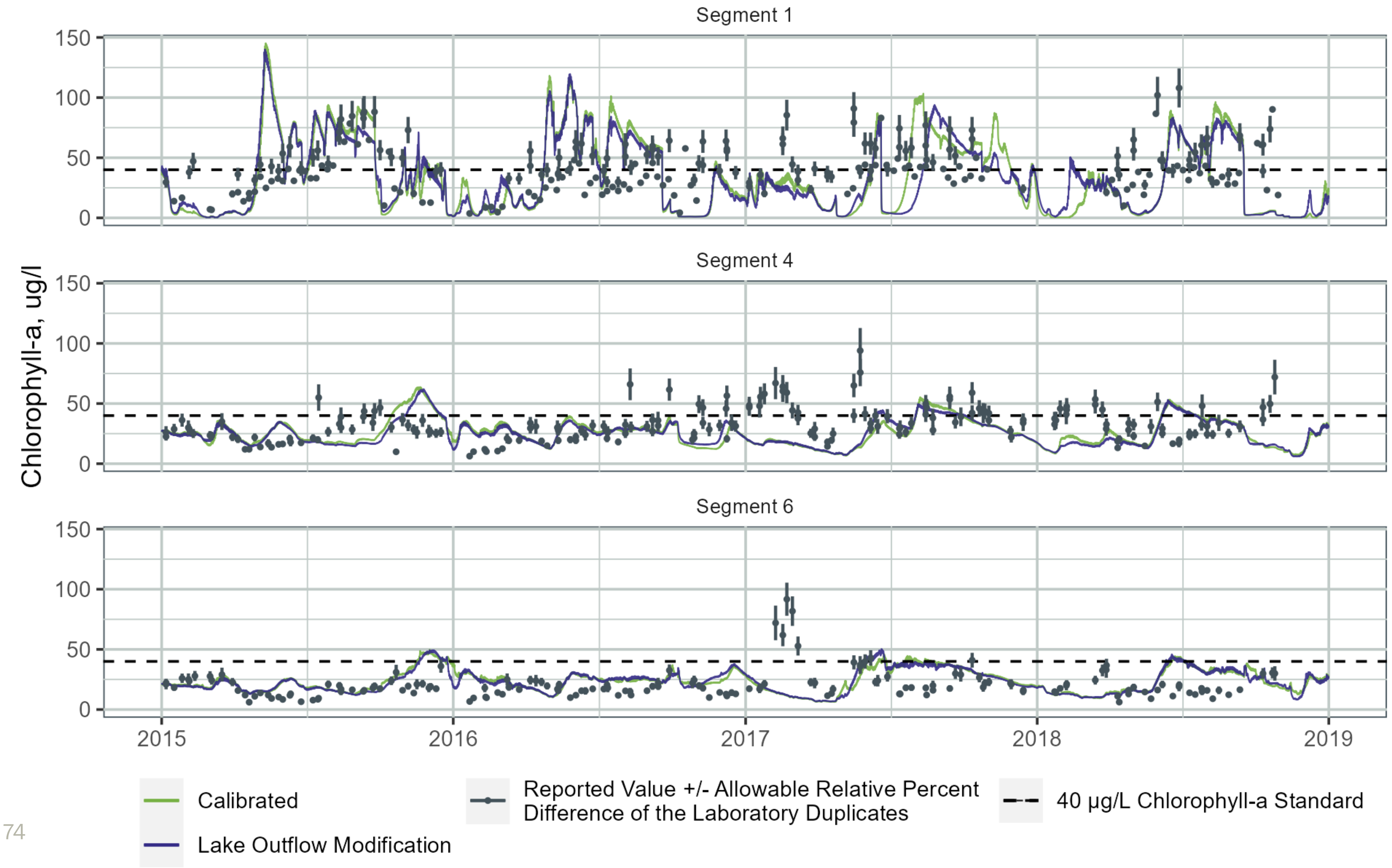
Land Conversion to All Forest Scenario - Chlorophyll-a



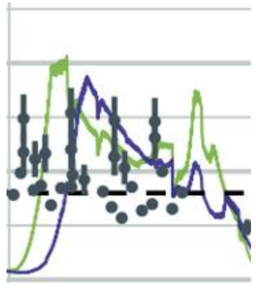
The All Forest/ No Human Impacts scenario often has lower peaks but still above the standard of 40 µg/L.



Dam Release Scenario - Chlorophyll-a



Changing the assumptions about how the USACE operates Falls Lake does not change whether or not chlorophyll-a will be in compliance with the standard. It does sometimes shift the timing and magnitude of the peaks:



Questions/Discussion Regarding Lake Data and WARMF Lake Modeling

12:20 PM

Lunch Break /
Meeting Room Phone Reset
12:30 PM to 1:00 PM

Those with dietary restrictions and next-session speakers please go first

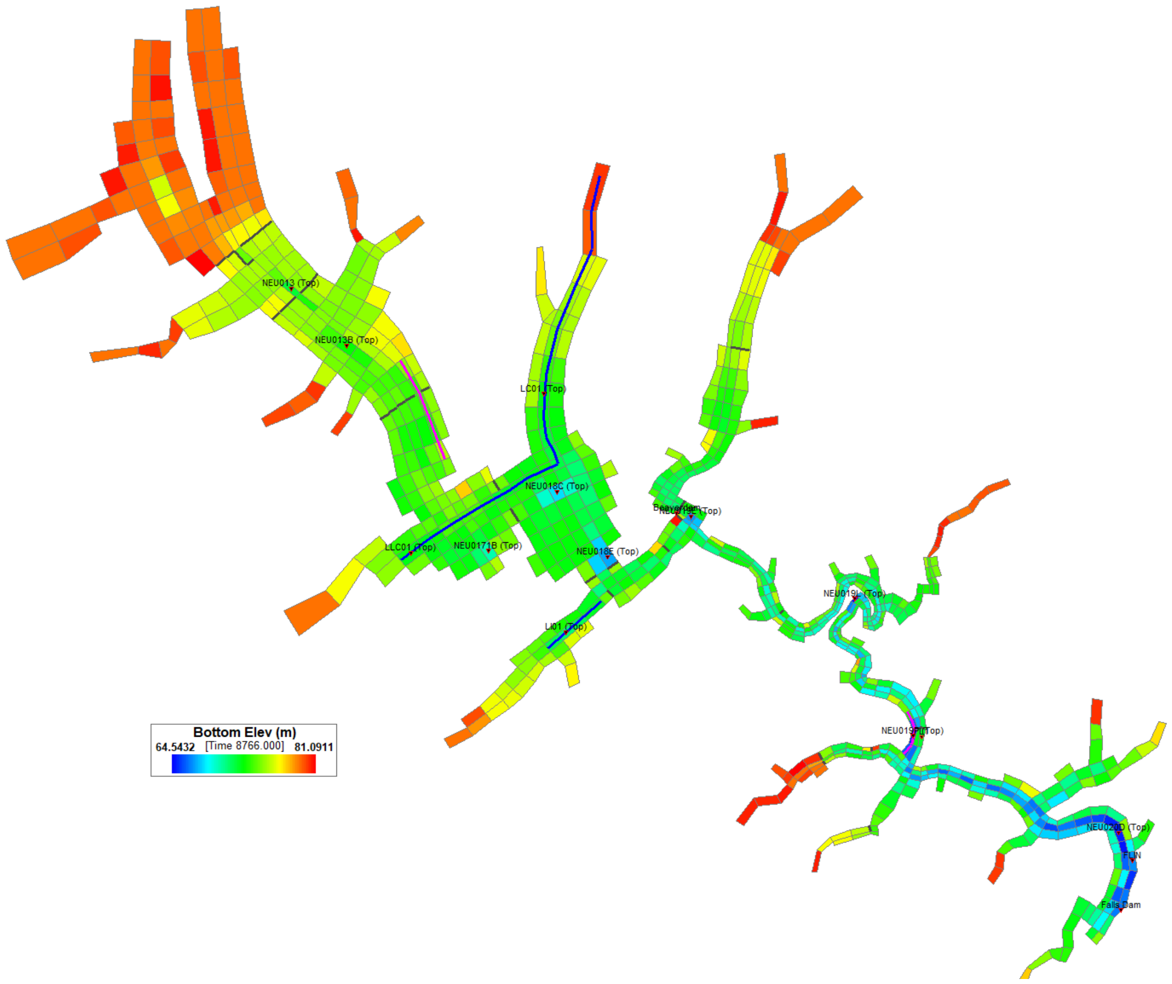
EFDC Lake Modeling

EFDC Model Development and Calibration

1:00 PM

EFDC Lake Model Grid

- 862 horizontal grid cells
- Up to 10 Sigma-Zed vertical layers.
  - Allows the number of layers to vary over model domain.
  - Each cell can use a different number of layers, though the number of layers for each cell is constant in time.
  - The thickness of each layer varies in time to accommodate the time varying depths.



Data to Support EFDC Model Development

Initial conditions for lake sediment quality and sediment depth	• UNRBA sediment quality and sediment depth special studies
Nutrient releases from lake sediments	• DWR 2006, Alperin 2016, EPA 2018, Piehler 2023, Hall 2023 – **compared to sediment diagenesis model**
Lake water quality data for initial conditions and calibration	• DWR, City of Durham and City of Raleigh, Center for Applied Aquatic Ecology

Evaluation of Model Performance

- Primary performance criteria is the RSR:
  - Normalized root mean square error (RMSE/Standard Deviation, RSR)
  - Target is 100 percent
- Other statistics are also evaluated for context (e.g., percent bias)
- Reviewing calibration figures today
- Performance statistics are available in the January 2023 MRSW materials and will be provided in the lake model report
- Simulated values for photic zone compared to photic zone composite samples:

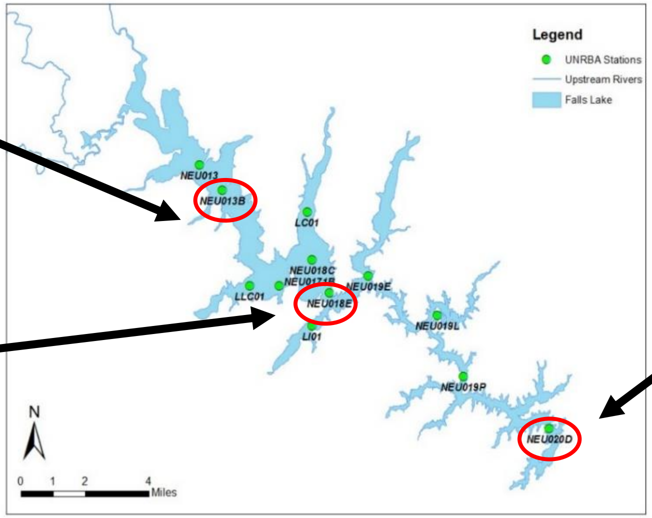
Stations	When water level is below normal pool	When water level is above normal pool
NEU013,13B	Top layer	Top layer
LLC01; LC01; LI01; NEU017B,18C,18E,19E,19L,19P	Top 2 layers	Top layer
NEU020D	Top 3 layers	Top 2 layers

Water Quality Stations

- Model was calibrated to the 12 DWR lake monitoring stations as described in the [UNRBA Modeling QAPP]
- Data from other organizations used to inform model development
- Results shown for three stations (upper, middle, and lower lake) for example water quality parameters

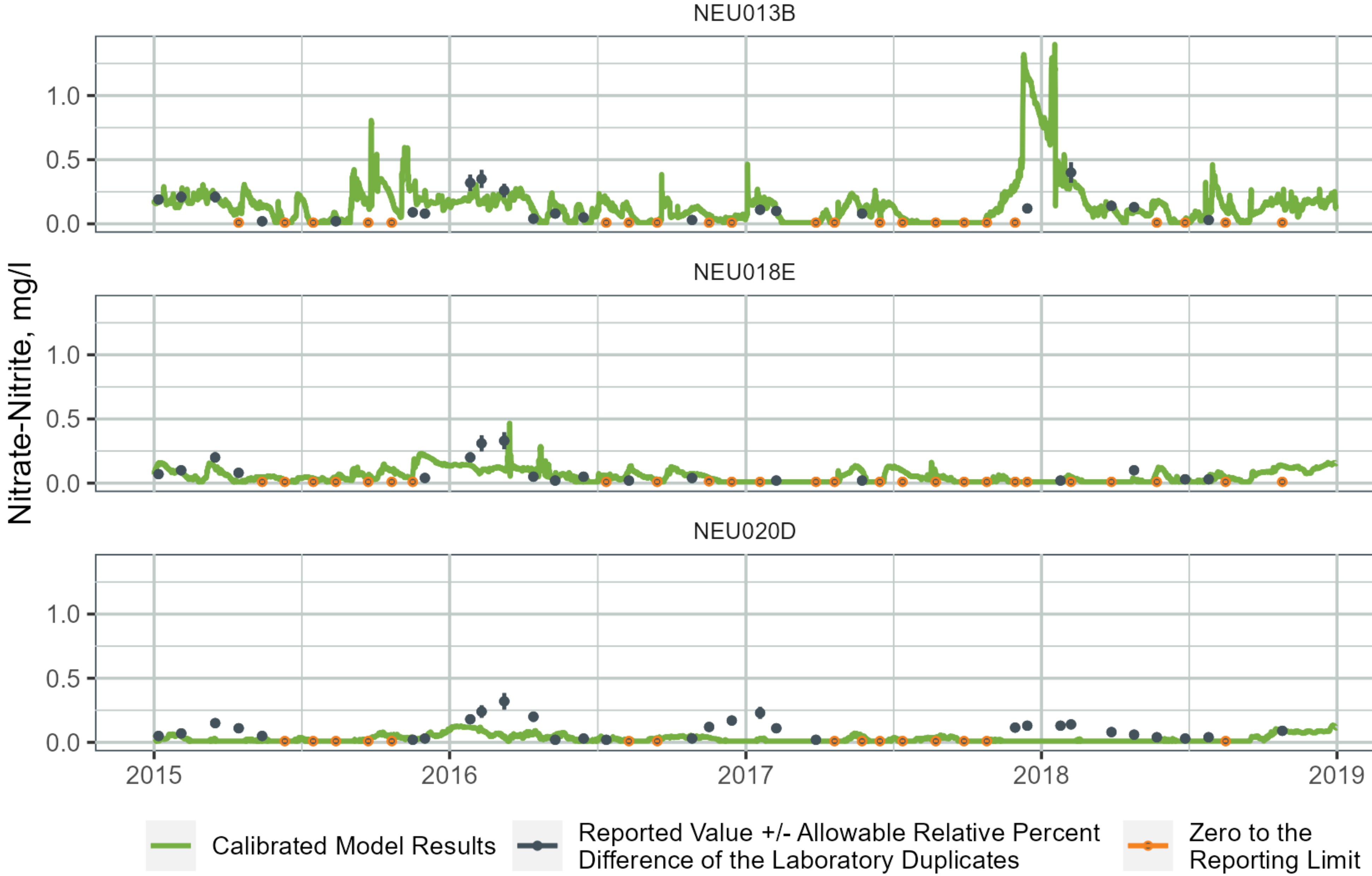
NEU013B in the upper lake (photic layer is the top layer [10])

NEU018E in the middle lake (photic layer is the top layer [10])

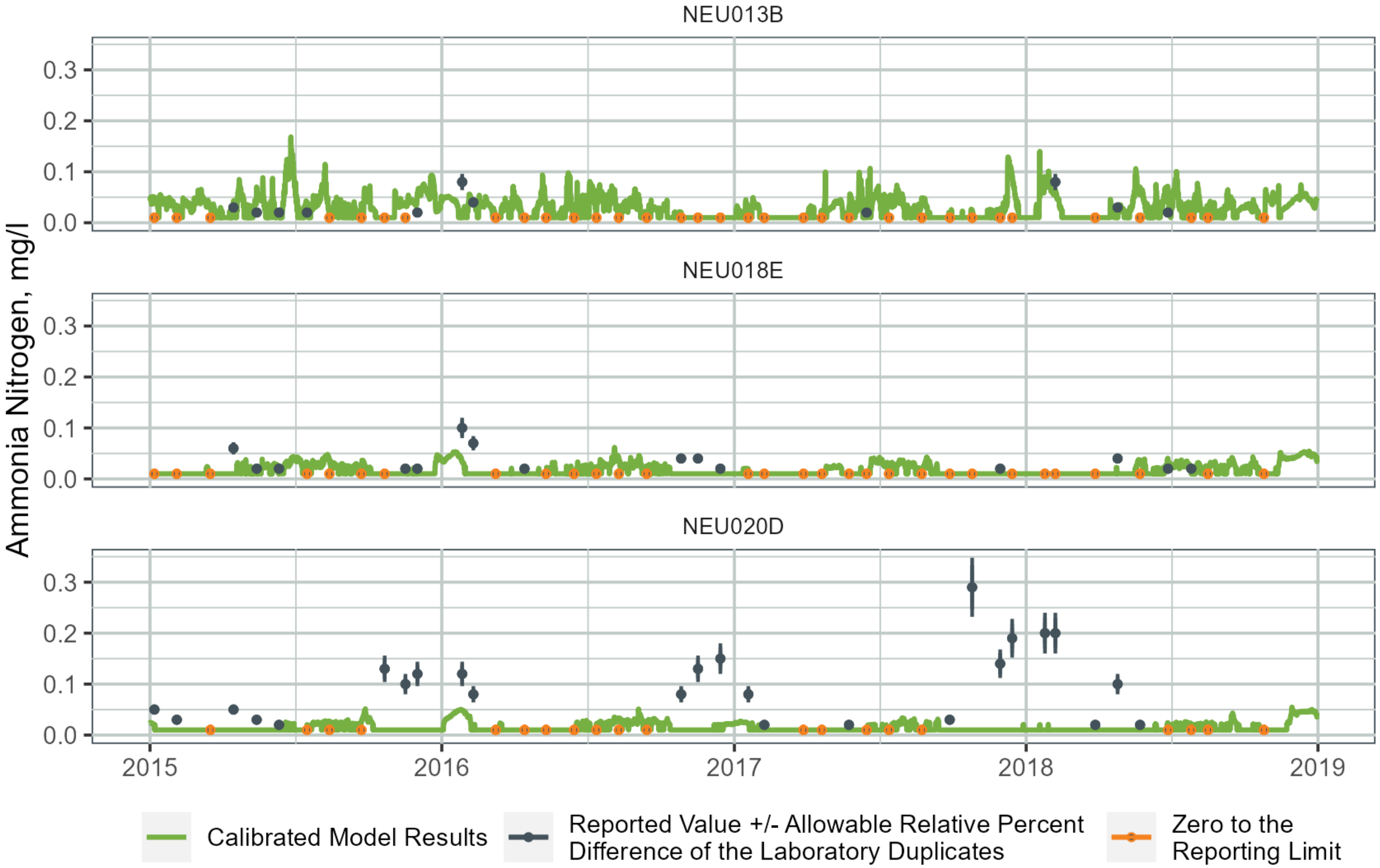


NEU020D in the lower lake photic layers include 10, 9, and 8 depending on the water level.

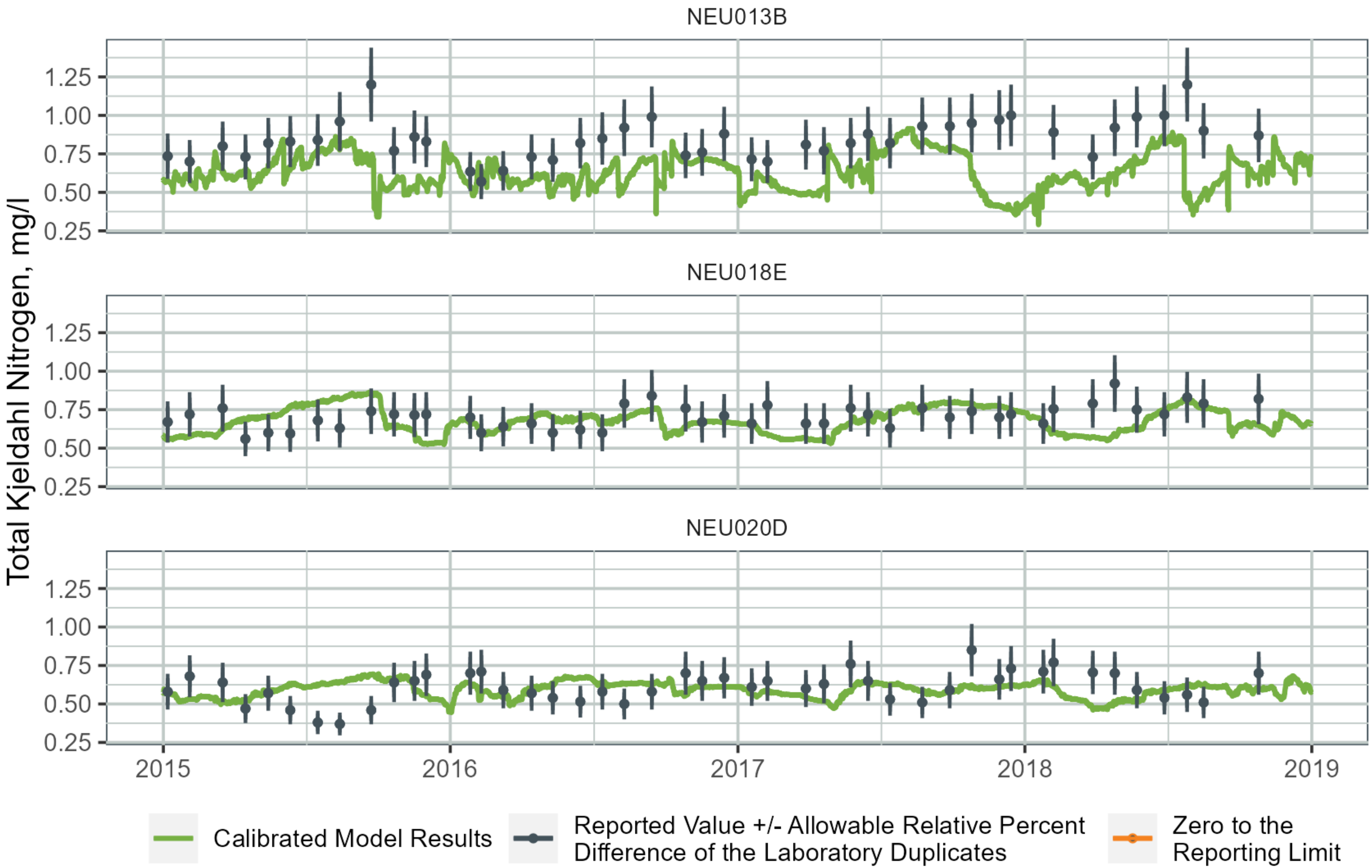
EFDC Model Results – Nitrate/Nitrite



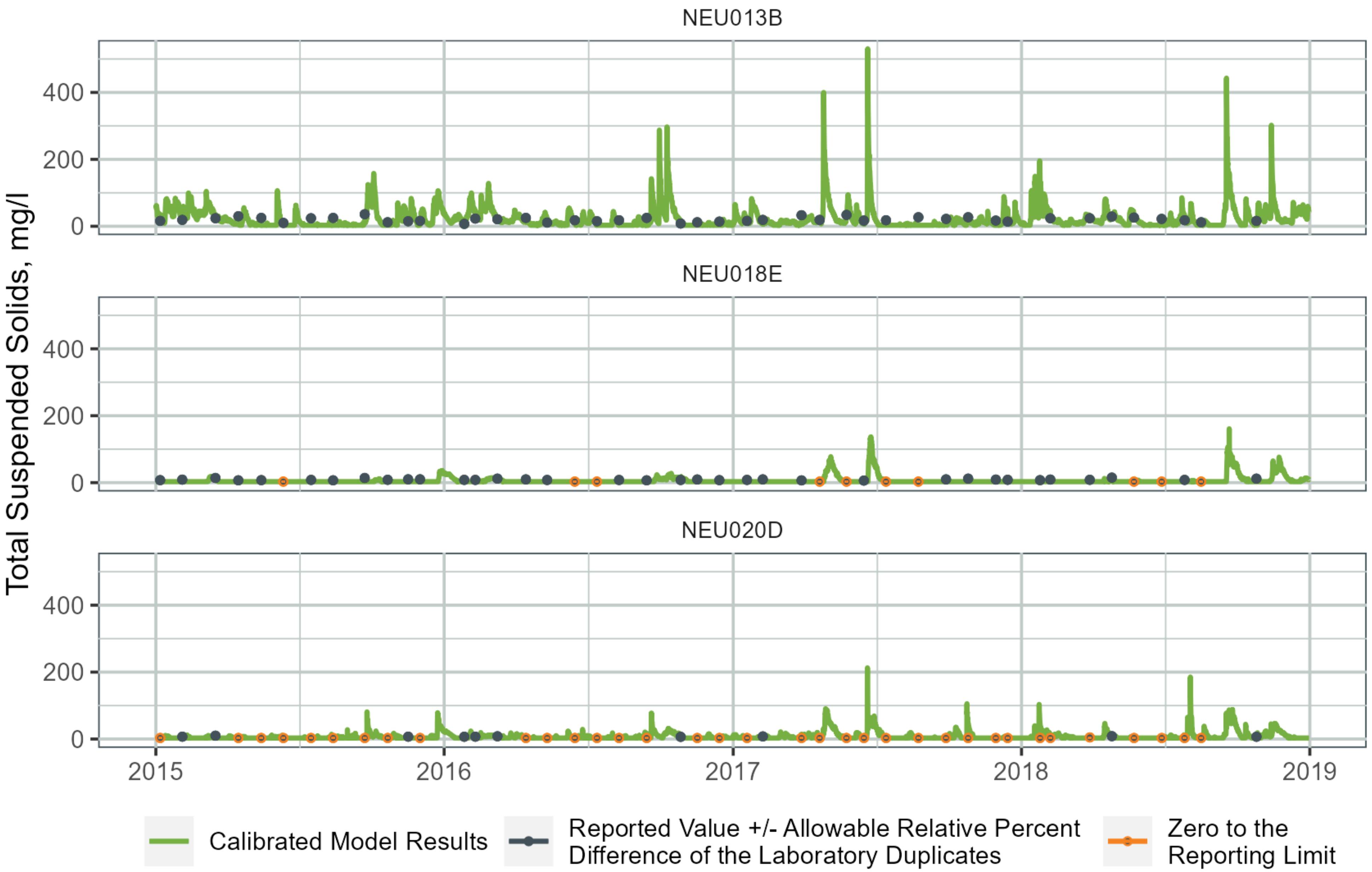
EFDC Model Results – Ammonia



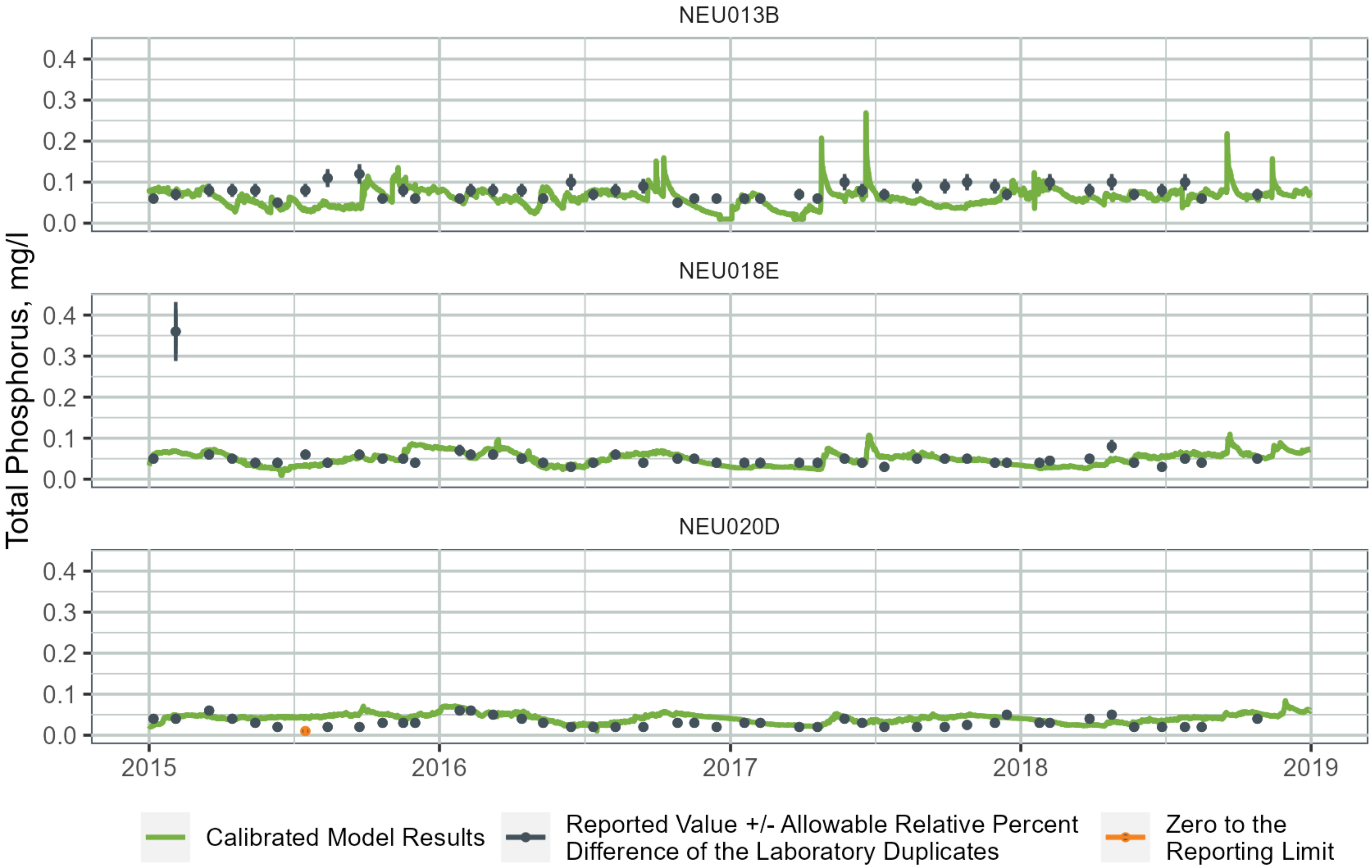
EFDC Model Results – TKN



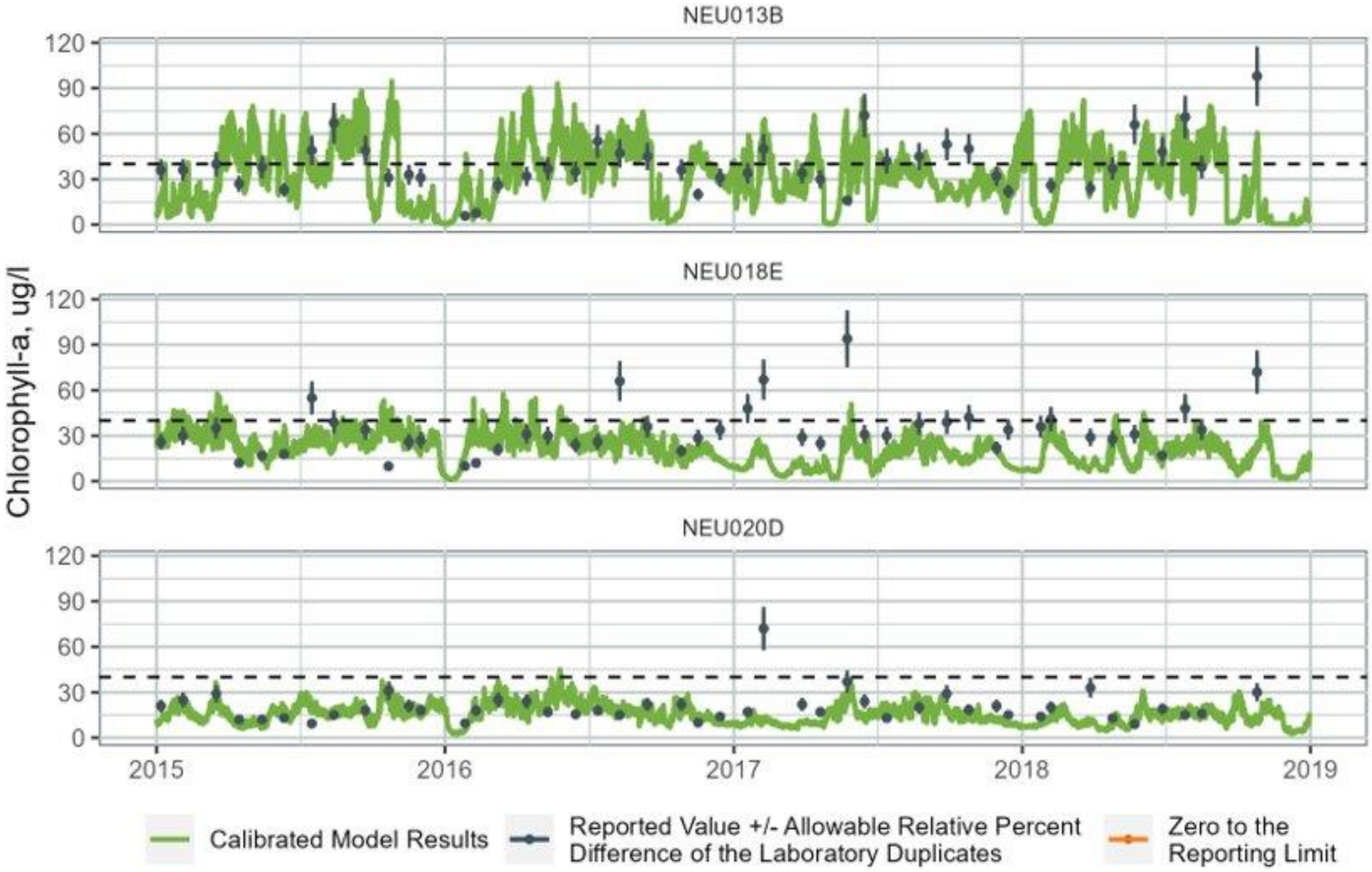
EFDC Model Results – TSS



EFDC Model Results – Total Phosphorus

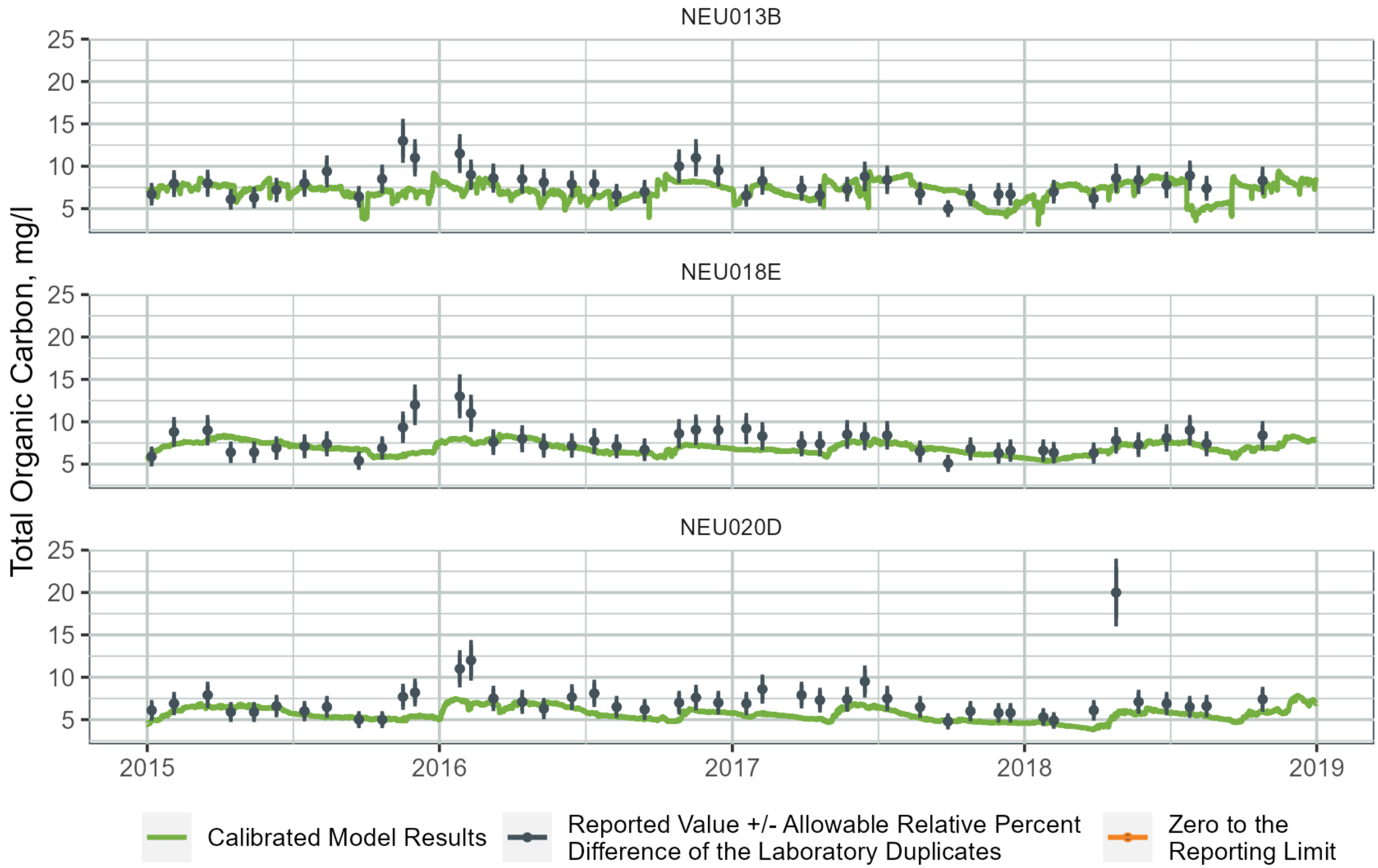


EFDC Model Results – Chl-a



- - - 40 µg/L Chlorophyll-a Standard

EFDC Model Results – TOC



EFDC Lake Model Scenarios

1:20 PM

EFDC Lake Model Scenarios

- What happens if you run the lake model for 25 years or 50 years with current levels of flow and loading from the watershed?
  - How do simulated nutrient releases from lake sediments change?
  - How do simulated chlorophyll-a concentrations change?
- What additional level of load reduction would be required from 2015/2016 levels to achieve the chlorophyll-a standard everywhere in the lake at least 90% of the time?
  - Note: meeting chlorophyll-a at least 90% of the time is still not compliant with the current 303(d) methodology and would not result in delisting Falls Lake for chlorophyll-a
- What happens to simulated chlorophyll-a concentrations if total nitrogen and total phosphorus loads to Falls Lake increase by 20%?

Key Findings from EFDC Lake Model Scenarios

- Current levels of watershed nutrient inputs are sufficient to
  - Sustain algal growth and chlorophyll-a concentrations at the stable levels observed over the past decade
  - Maintain nutrient release rates from sediments
- To achieve 10% exceedance for 2015/2016 in the upper lake
  - ~50% reduction in total nitrogen relative to 2015/16 levels
  - Phosphorus reductions from three major WWTPs have been reduced by 81% since 2006 which shifts the relative amount of sediment-bound P which is less available
  - Achieving this reduction in chlorophyll-a in the upper lake would not affect percent of time chlorophyll-a is exceeded in the lower lake
- Lower lake chlorophyll-a has been and will likely continue to be stable in time, even with a 20% increase in total nitrogen and total phosphorus

Questions/Discussion Regarding EFDC Lake Modeling

1:30 PM

Lake Data Associated with Designated Uses

1:40 PM

Algal Toxin Data

- Falls Lake data collected by DWR, City of Raleigh, and NCSU (Astrid Schnetzer‘s lab, funded by the NC Collaboratory)
- National data provided by Center for Disease Control (CDC)
- Algal toxins can cause human health and animal health adverse events
- EPA has proposed guidelines for recreation and drinking water
- Three toxins are monitored in Falls Lake

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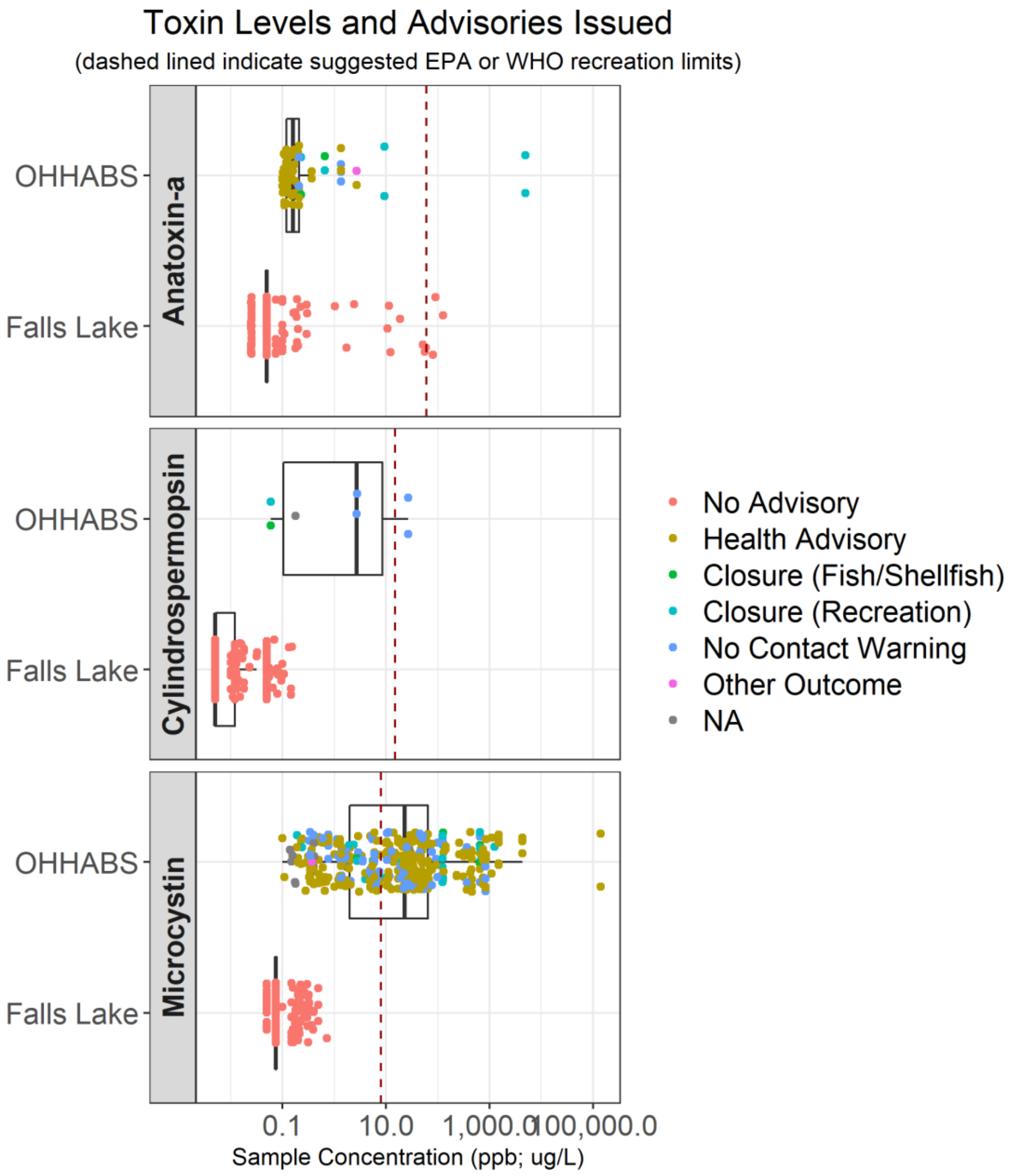
Algal Toxin Data

CDC OHHABS (national):

- Voluntary, presence only
- Majority reports associated with:
  - human or animal health event
  - high toxin levels detected during monitoring
- Microcystin most frequently exceeds guidelines

Falls Lake:

- No health advisories or closures have ever been issued due to toxins
- Anatoxin-a is the only toxin to exceed recreational guidelines (**January only**)
- Falls lake levels generally well below OHHABS reported levels



OHHABS and Raleigh data

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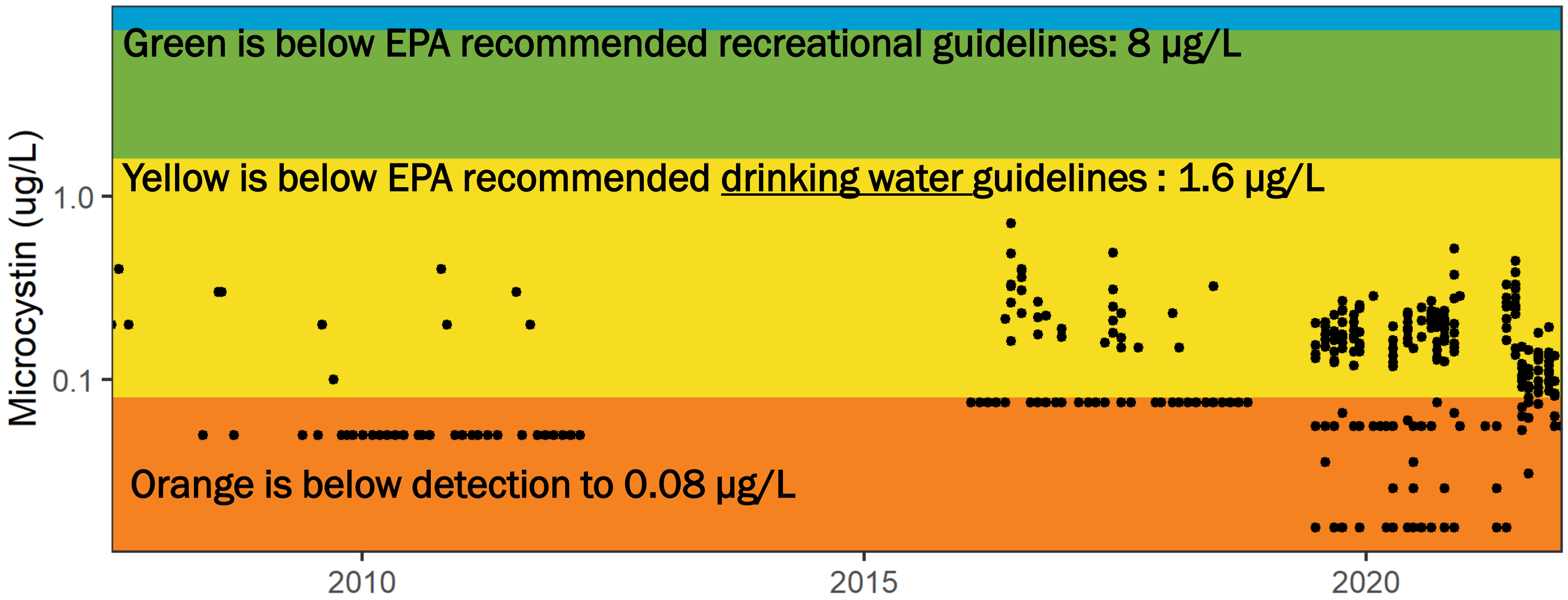
Falls Lake Algal Toxins: Microcystin (μg/L) Example



Microcystin (μg/L)[1]

Very low	ND to 0.08	
Low	0.08 to 1.6:	Below recommendations for drinking water and recreation
Moderate	1.6 to 8:	Below recommendations for recreation, but not drinking water
High	> 8:	Higher than both recommendations

- Collected by City of Raleigh and Dr. Astrid Schnetzer, NCSU
- **Microcystin concentrations are consistently below EPA drinking water and recreational guidelines**
- Same for cylindrospermopsin
- EPA does not have anatoxin guidelines; the World Health Organization (WHO) does
    - January 2016 had exceedances of WHO recommendations for anatoxin

Feedback from Users on Falls Lake Algal Toxins

- Triangle Fly Fishers does not track algal toxin data in Falls Lake because toxins are consistently low;
  - If a swimming beach closure occurred due to high toxin levels, the group would be alerted which may affect their decision on where to fish.
  - The group is not concerned about exposure to algal toxins on Falls Lake (either environmental or consumptive)
- Wake County has a response plan that includes coordination with DEQ, signage, etc. if DEQ confirms toxin exposure led to an adverse event
- City of Raleigh drinking water staff track toxin levels; not a concern in Falls Lake due to consistently low levels.
  - If toxin levels were found to be high in their terminal ponds, granulated active carbon could be used to remove these.
  - No concern that toxin levels could not be addressed at the water treatment plant.
- Food web accumulation is a potential exposure pathway but there is no data from Falls Lake to include in the model (potential future study)

Falls Lake Algal Biovolume Data

- DWR collects data at three stations monthly (upper, middle, and lower lake)
- City of Durham collects data in the upper lake when DO or pH values indicate an algal bloom
- Biovolume is an estimate of how much space the algal cells take up in a water sample
  - Based on cell counts of different algal groups
  - Volumes are estimated from cell counts and group-specific equations
- DWR uses 5,000 mm^3/m^3 (millimeters cubed of algae per meters cubed of water) as their threshold for bloom

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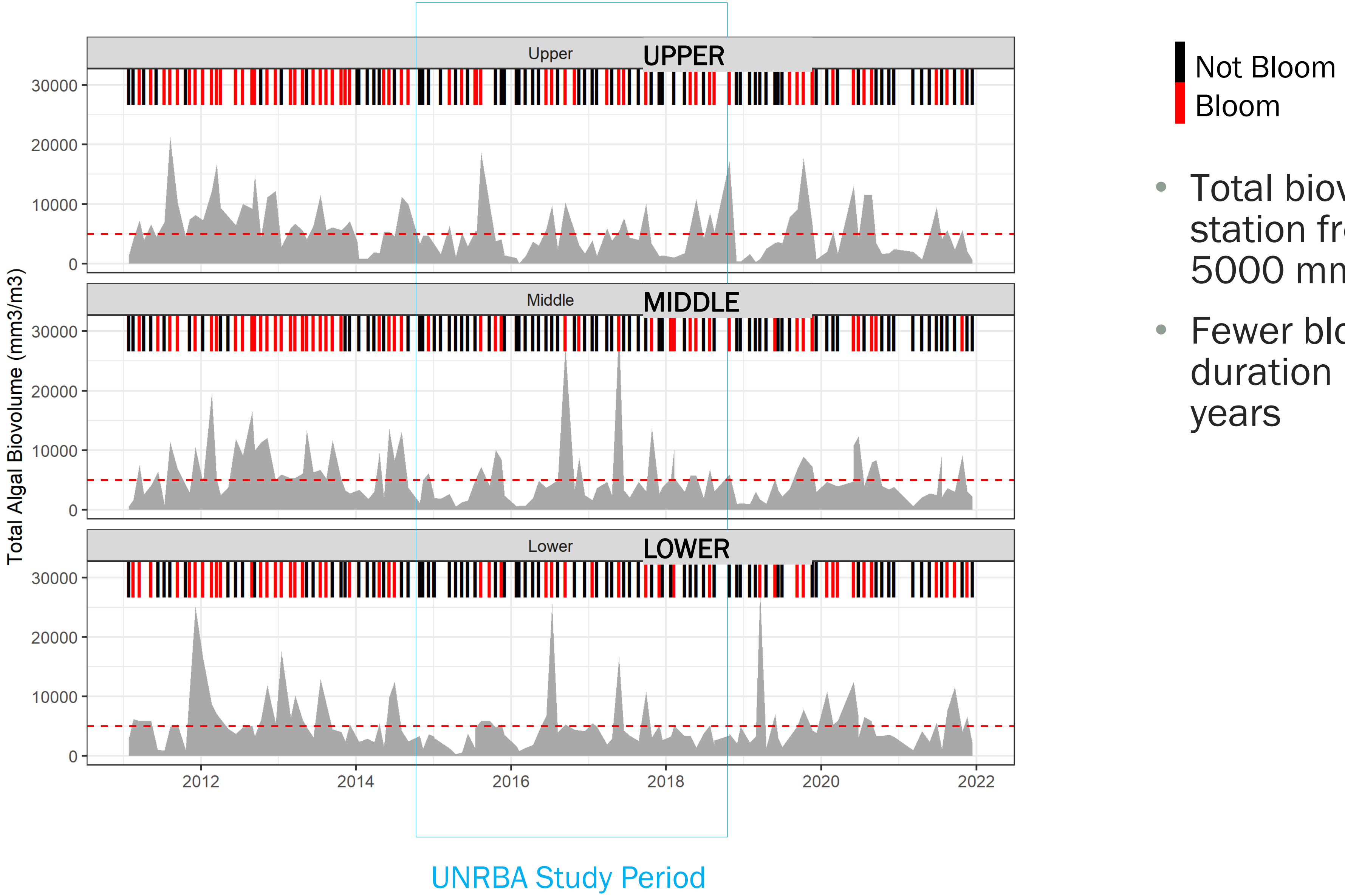
Total Algal Biovolume



- Total biovolume at any given station frequently exceeds 5000 mm^3/m^3 (red bar at top)
- Fewer blooms with shorter duration in the more recent years

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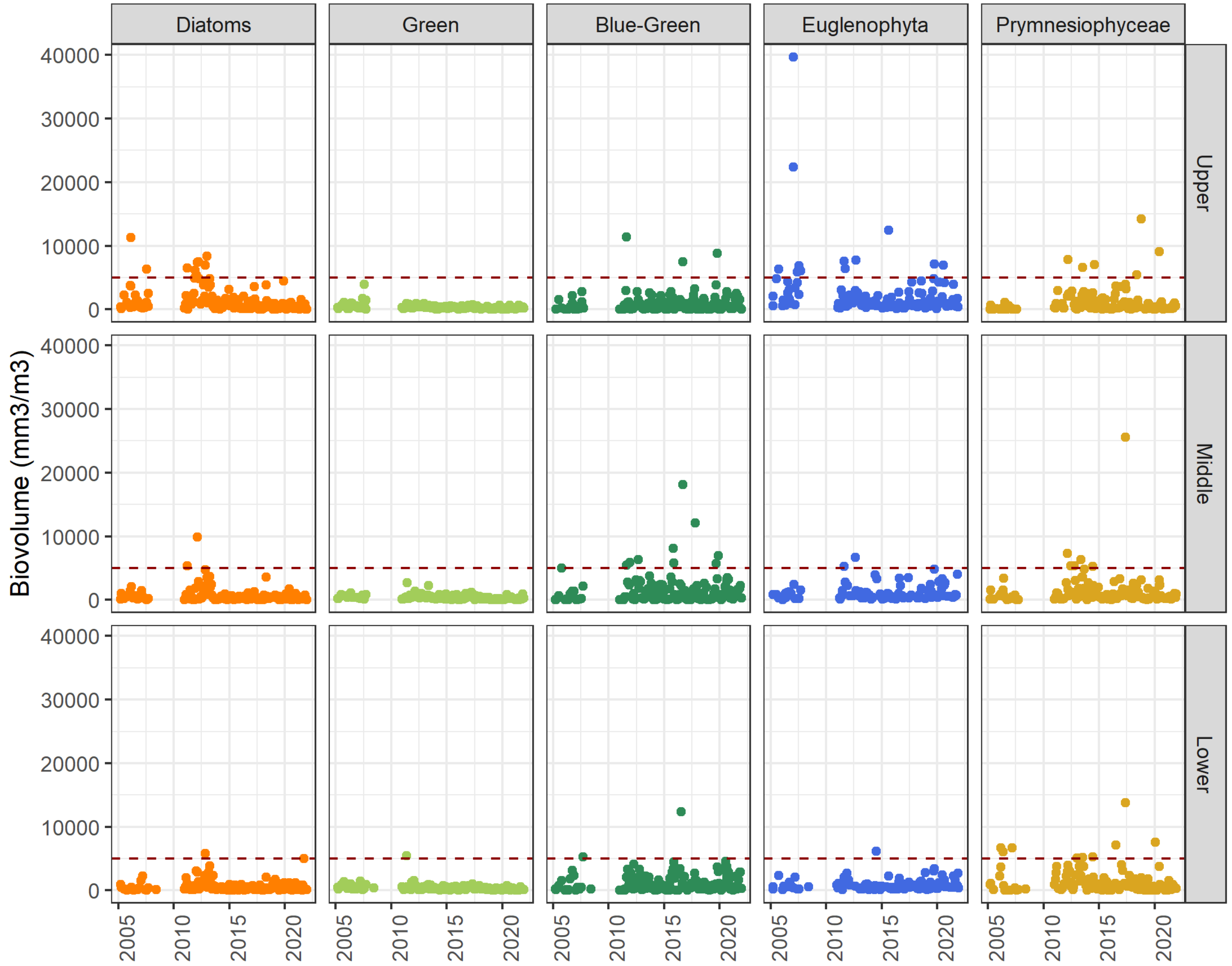
Algal Composition: Biovolume by Algal Type



- Different groups of algae can impact designated uses
  - Diatoms can clog water treatment filters
  - Blue-greens can produce algal toxins
- All except Green periodically exceed 5000 mm^3/m^3 level
- Euglenophyta have largest documented events based on biovolume
- Prymnesiophytes are associated with more recent blooms
- Fewer blooms documented as move downstream

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Feedback from Users on Algal Communities

- The City of Raleigh has two terminal reservoirs that are used for treatment of diatoms when needed
  - City’s biological laboratory handles evaluations once a month with the Falls Lake intake sample
  - One issue occurred about seven years ago that required treatment
- Neither Triangle Fly Fishers nor Wake County track algal community data in Falls Lake

Falls Lake Total Organic Carbon (TOC) Data and User Feedback

- Data collected by DWR, City of Raleigh, Center for Applied Aquatic Ecology, City of Durham, and USGS
- High concentrations of TOC can affect the drinking water supply designated use
  - Can generate disinfection by-products if not removed from raw water
  - Increased treatment costs when concentrations are 9 to 10 mg/L
- Raleigh withdraws water near the dam in the lower lake segment for water supply

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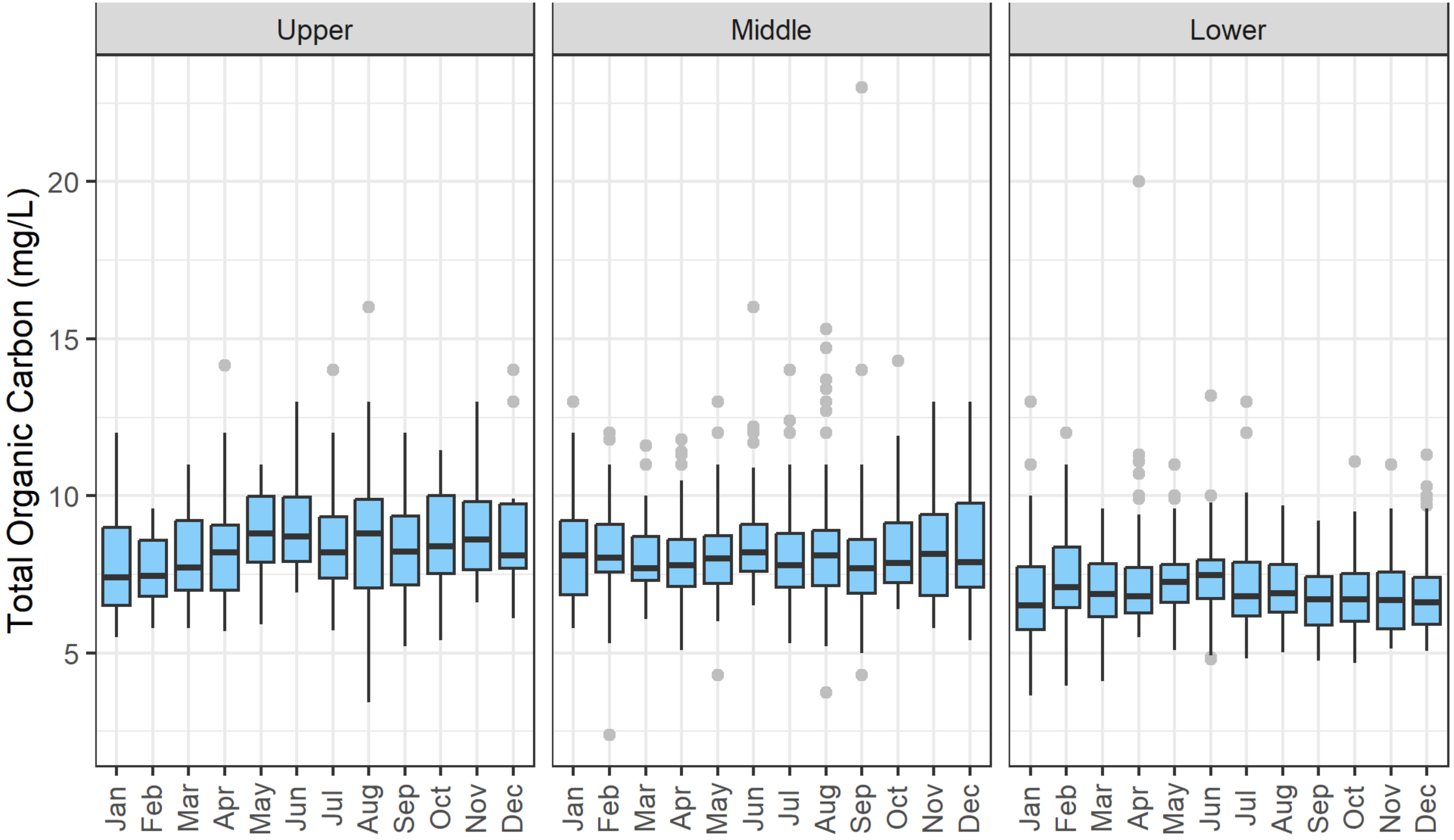
Photic Zone TOC by Month



- TOC values in Falls Lake decrease from upper to lower lake
- No strong seasonal trend
- 95% of data is below 10 mg/L in the lower lake where Raleigh withdraws water

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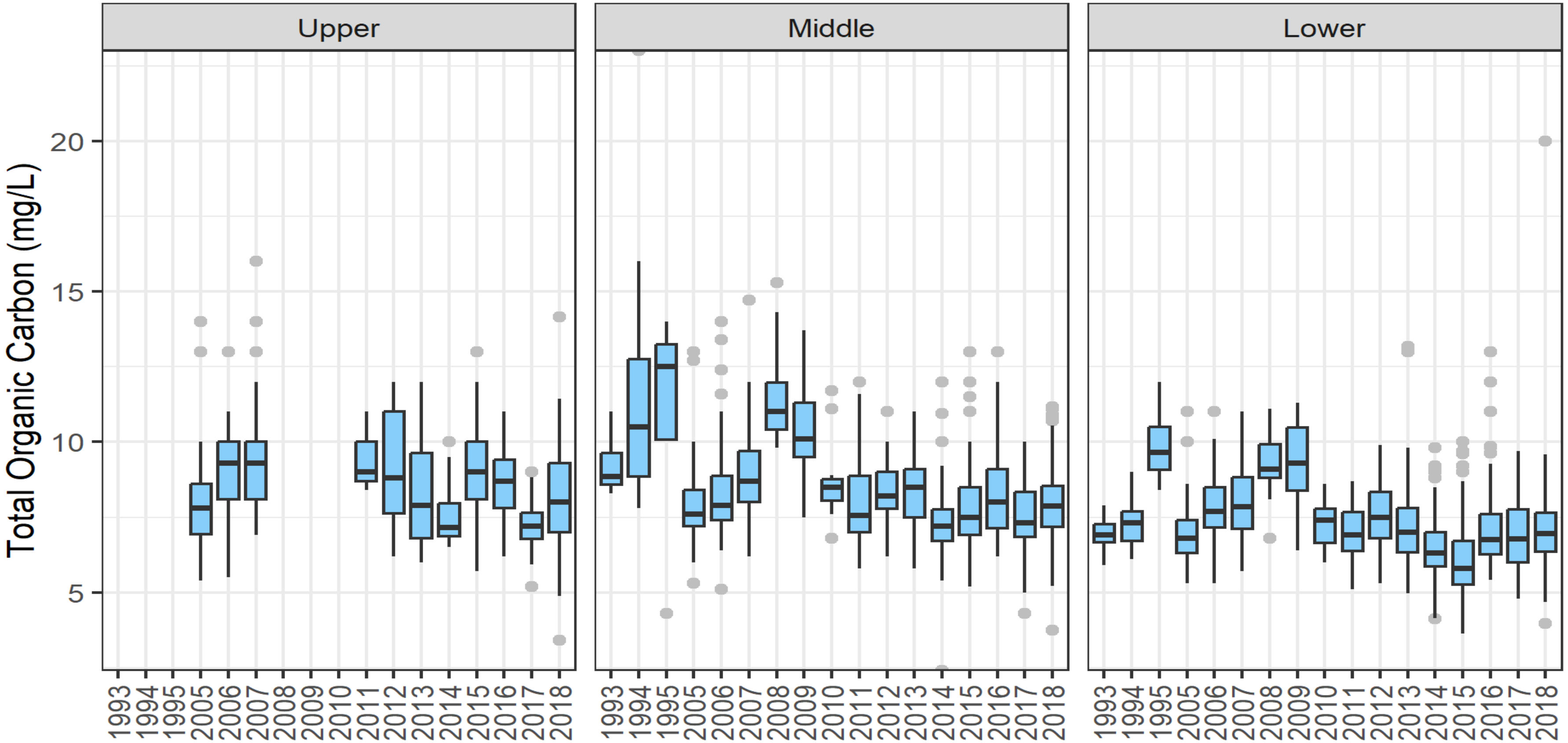
Photic Zone TOC by Year



- Data gaps in upper lake (*x-axis is not continuous*)
- Shorter time series comparison to other parameters
- TOC has shown cyclical patterns in earlier years
- Generally lower concentrations and more stable since 2010
- More than 95% of data is below 10 mg/L in the lower lake since 2010

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Falls Lake Manganese (Mn) Data and User Feedback

- Data collected by DWR, City of Raleigh, and USGS
- High concentrations of manganese can affect drinking water supply designated use
  - Short filter runs require frequent washing
  - Requires additional chlorine that can generate trihalomethanes (THMs)
- Raleigh withdraws water near the dam in the lower lake segment for water supply

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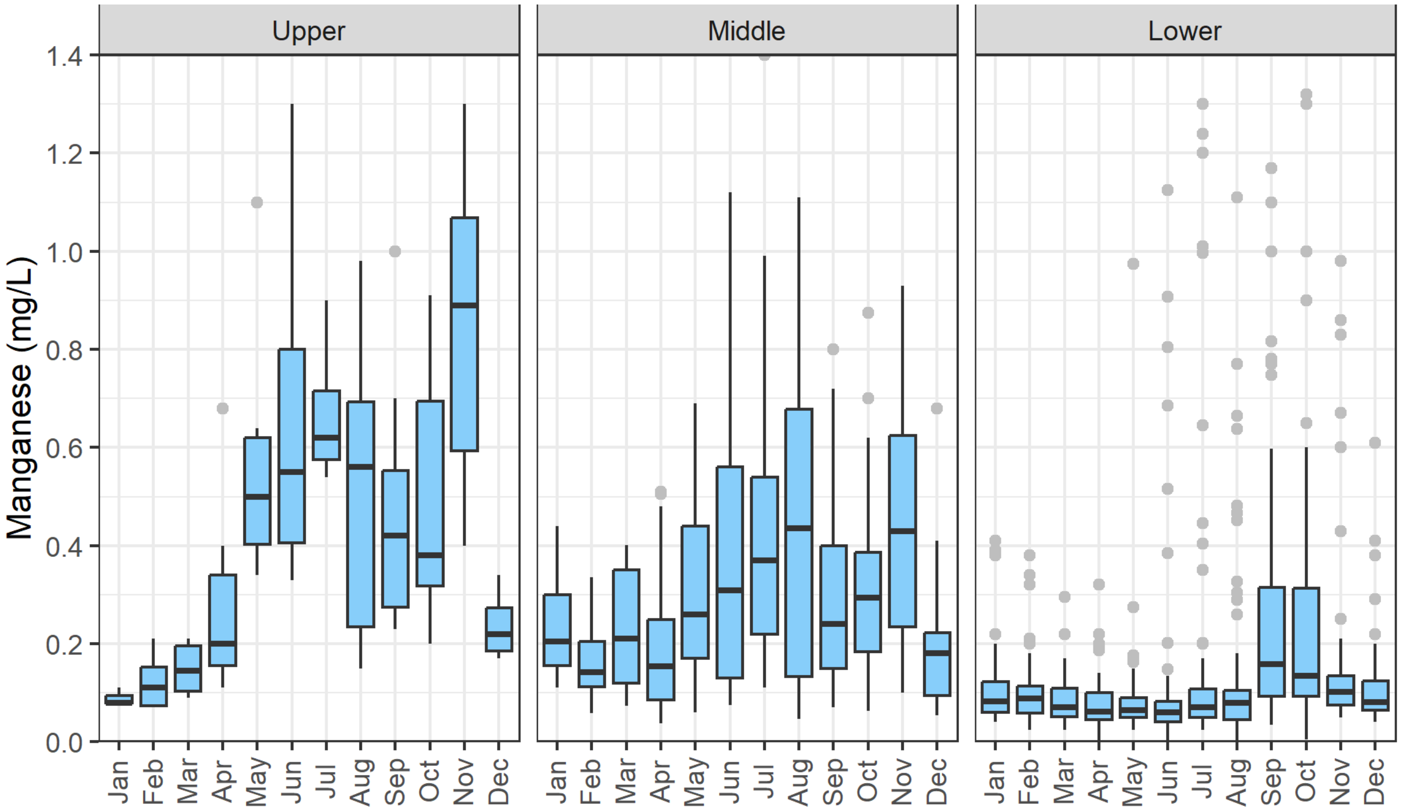
Photic Zone Mn by Month (cropped at 1.4 mg/L)



LAKEUNIT	DATE	VALUE
Lower	2013-08-26	2.073
Lower	2014-08-25	2.078
Lower	2014-09-30	2.020
Lower	2015-08-25	2.390
Lower	2015-09-29	5.160
Lower	2016-08-30	2.675
Lower	2017-08-23	2.370

7 values above 1.4 mg/L;
all in lower lake

- Seasonal peak values occur later in each downstream lake segment
- Wider variance in upper and middle lake, but many extremely high outliers in lower lake

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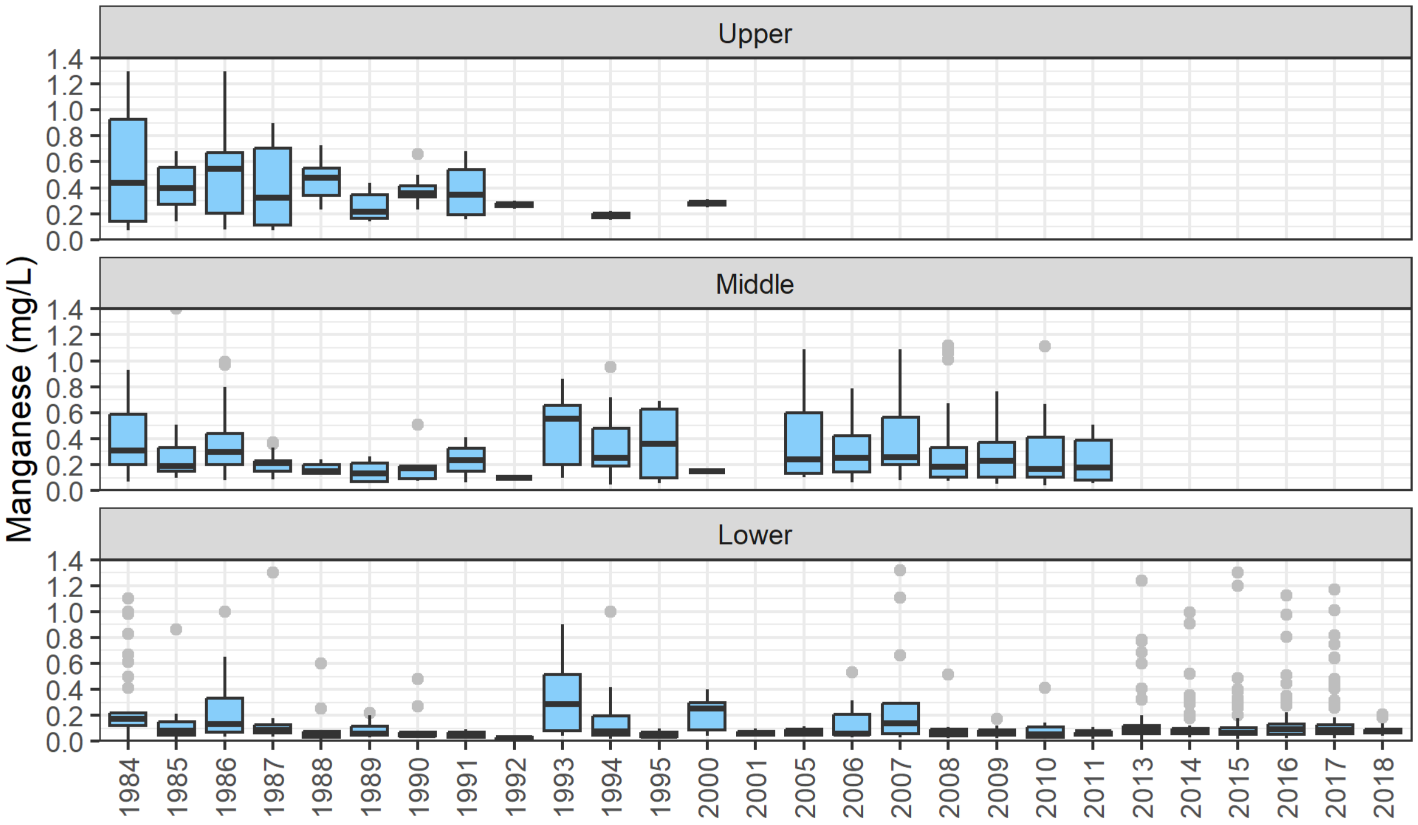
Photic Zone Mn by Year (cropped to 1.4 mg/L)



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7 values above 1.4 mg/L;
all in lower lake

- No recent data for upper and middle lake
- Historically higher concentrations and more variable in upper lake
- Lower lake values have been relatively low and stable since 2008

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Reported Fish Kills in Falls Lake

- DWR maintains a statewide database of reported fish kills and developed a reporting application for cell phones in 2018
- Types of summary statistics for reported events vary: number of fish killed, duration of event, acreage affected
- There have been more users over time on Falls Lake, so more opportunities exist for fish kill observations, yet reports of fish kills remain very rare
  - Six kills documented in 34 years
  - Attributed to blooms/new reservoir syndrome, post-hurricane low DO, cold temperatures, and disease; algae or DO-related events were before 1997
  - Algal composition and algal toxin data are not available when these events occurred

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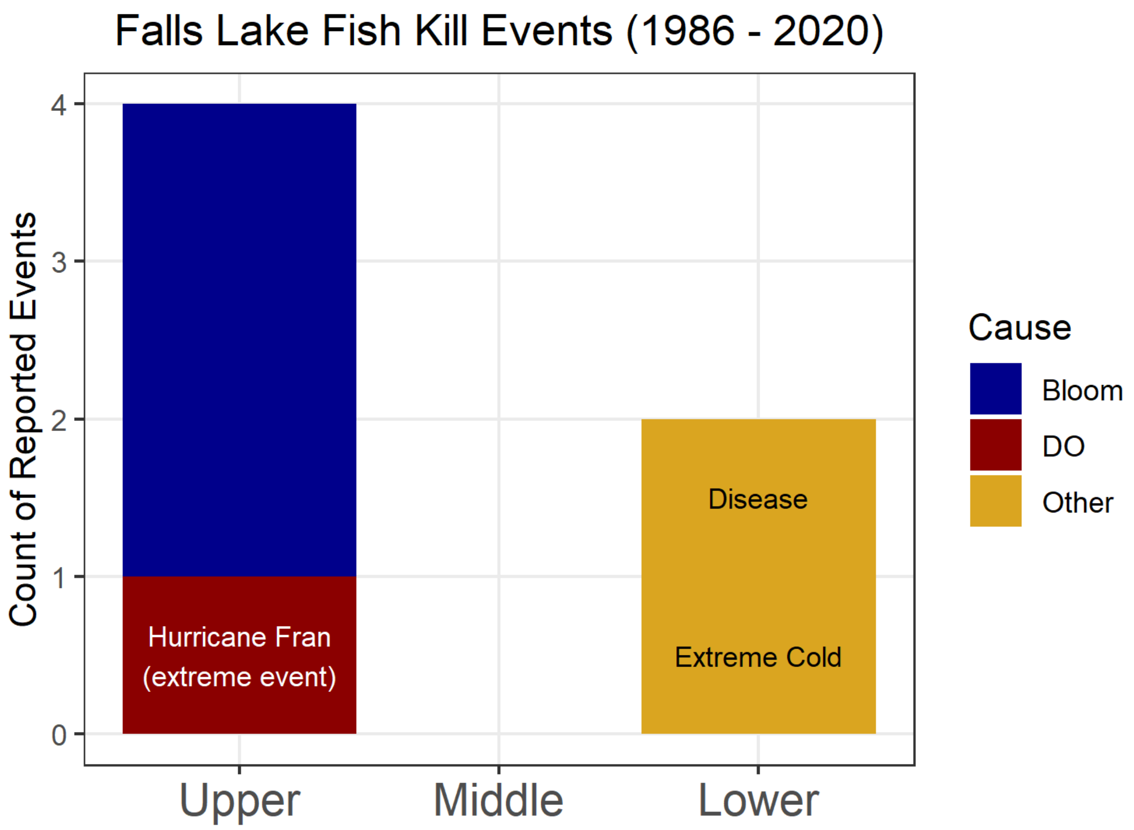
Fish Kills: Events by Lake Unit



NC DEQ data

Three kills attributed to blooms

- All in Upper lake
- No supporting sample data

One bloom attributed to low DO

- Reported as due to extreme hurricane event

"Other" are suspected disease and cold events

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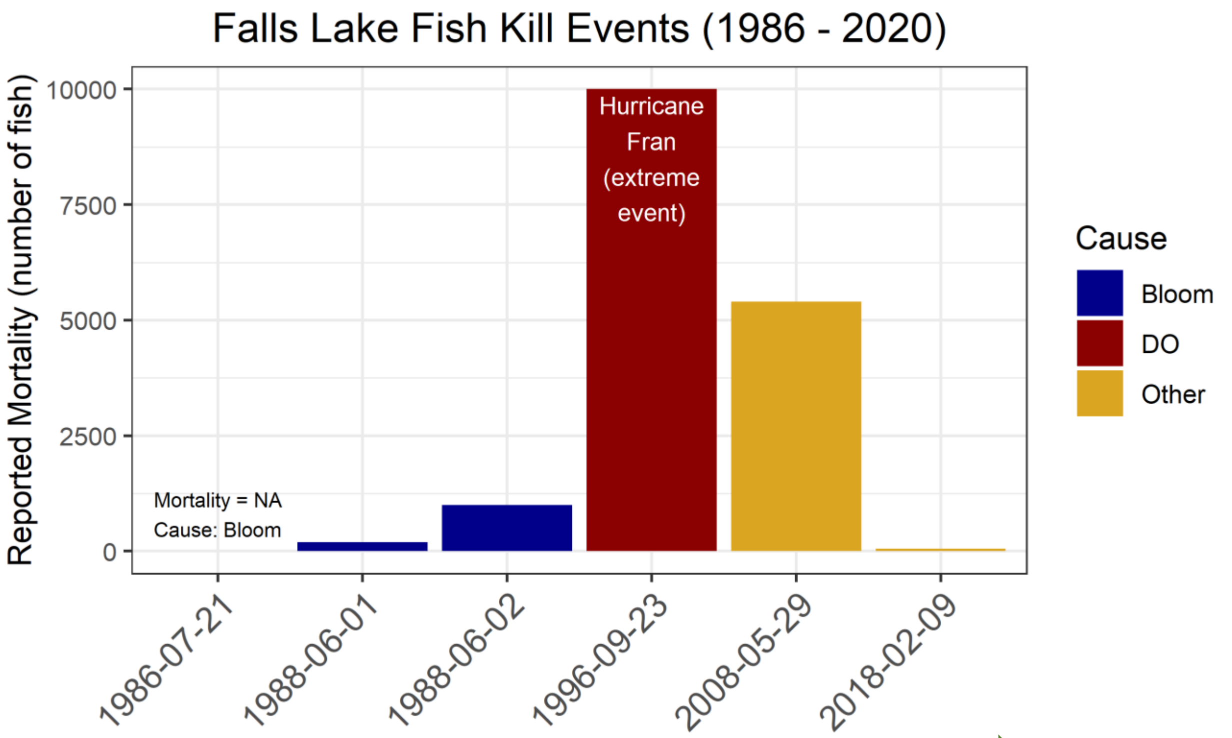
Fish Kills: Event Size and Dates



Increasing use = Increasing opportunity to detect and report fish kill if present

Bloom-attributed fish kills:

- Smaller mortality relative to DO and disease
- Reported in Summer months (June, July)
- Have not been reported since the 1980s after lake filling

Bloom events generally may be more likely to be reported when water-based recreation activity is highest

- Notable that more kills have not been documented with increased opportunity to observe and report kills.

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Feedback from Users on Reported Fish Kills

- Triangle Fly Fishers are frequently on Falls Lake
  - If a fish kill was noticed, members and DWR would be notified; the group does not see fish kills on Falls Lake
- Fish kills would affect subsistence fishers
- The species affected is important (some are more tolerant)
- Single versus multi-species is important (stressors differ)
- No bloom related fish kills has been reported on Falls Lake since the post-filling period (over 30 years ago)

UNRBA's Re-examination: What We've Learned & What It Means for Falls Lake
2:15 PM

Stage I is Being Fully Implemented

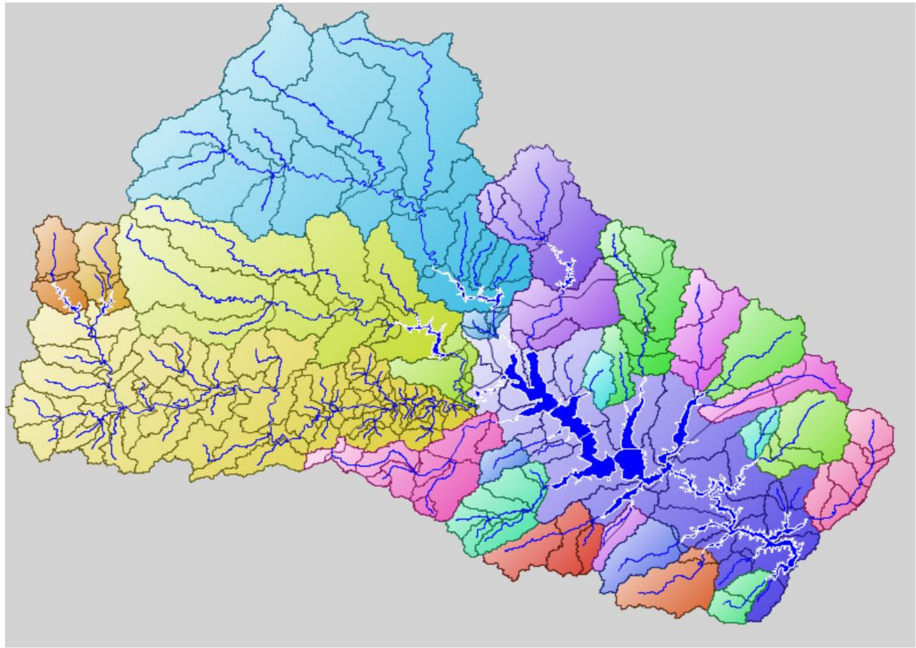
UNRBA Regulatory Support

- Support compliance efforts for Stage I of the Rules, particularly for existing development
  - Interim Alternative Implementation Approach (IAIA)
    - Investment-based approach
    - Expands eligible activities and projects
- Reexamine Stage II of the Rules
  - Conduct scientific evaluations
  - Collaborate with researchers and stakeholders
  - Propose recommendations for a revised nutrient management strategy

Land conservation site; photo courtesy of Person County

Key Findings from the Watershed Models and Data

- Watershed changes have reduced nutrient loads since 2006 (baseline year for the rules)
- Soils store and cycle nutrients for decades
- US Forest Service monitoring studies measured nutrient loads during dry to average rainfall conditions; used to compare to models
- Rainfall is key driver of nutrient loads
- Little opportunities remain to further reduce loading from the watershed by significant amounts
- Progress will be incremental



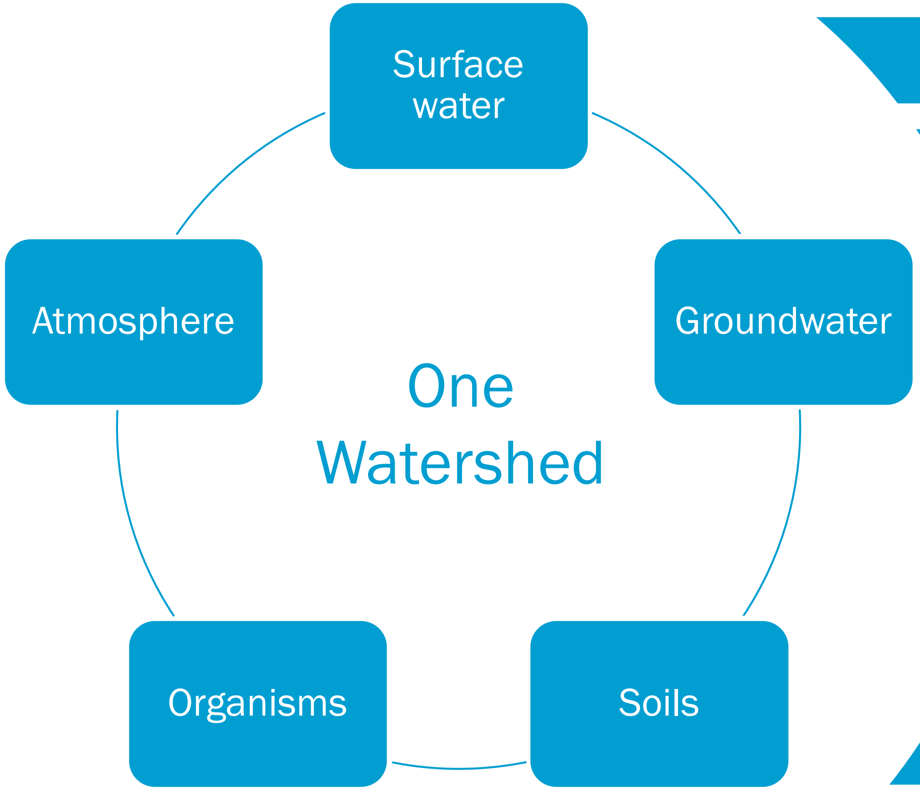
Key Findings from the Lake Models and Data

- Watershed hydrology and lake residence time are main drivers of chlorophyll-a
- Chlorophyll-a in the lower half of the lake has been stable since reservoir was constructed
- Lake sediments will continue to cycle nutrients for decades
- Changes in loading will not have immediate impacts on chlorophyll-a
- Falls Lake is meeting its designated uses
  - Algae have not been linked to a fish kill since the late 1980s (soon after filling)
  - Algal toxins are below EPA guidelines for drinking water and recreation
  - City of Raleigh provides 41 million gallons per day of safe drinking water

Implications for a Revised Nutrient Management Strategy

- Based on sources and amounts of delivered loading to Falls Lake, additional large-scale nutrient load reductions are not achievable
- Long-term nutrient management is most effective approach
- Ongoing action is needed to protect this resource and maintain uses
- A more appropriate site-specific chlorophyll-a standard would be helpful

Principles for a Revised Strategy



- Continue to improve water quality and protect uses
- Acknowledge the realities of the system
- Adaptive program with plans for re-evaluation
- Build on the cooperation and collaboration
- Build on the IAIA approach
- Encourage a fair, equitable program
- Focus on whole watershed health
- Expand types of partners and opportunities
- Consider sustainability and energy reductions

Nutrient Reduction Opportunities

Existing Lands

- Stream, wetland, buffer restoration
- Floodplain expansion
- Road and logging best practices
- Controlled burns, harvesting, forest and vegetation management
- Educate owners of stormwater control measures on proper maintenance
- Stormwater retrofits*

Wastewater related

- Track best available technologies and costs
- Encourage minor facilities to improve effluent quality*
- Identify and remedy illicit discharges*
- Track and address failing OWTS*

New development

- Continue implementing rules
- Update local ordinances to allow innovative stormwater solutions

Atmosphere

- Tree planting along busy roads
- Air pollution reduction technologies
- Public transportation
- Green energy sources

*Practices with State-approved credits

Next Steps for Developing the Recommendations

- Incorporate stakeholder feedback
  - WRRI Annual Conference (held in March)
  - Joint Symposium with Collaboratory (April)
  - Technical Stakeholder Workshop (today)
  - Expanded outreach within the watershed
- Develop draft recommendations and update Consensus Principles for consideration of UNRBA Board in September 2023
- Local government approvals in October and November 2023
- Final submittal in December 2023
- Regulatory Forum in Spring 2024 regarding the rules readoption process

Small Group Discussions and Feedback
2:35 PM

Instructions for Small Group Discussions and Feedback

- In-person groups
  - Brief introductions and identification of note keeper
  - Note keeper will document responses and “turn in” at the end of the meeting
- Online participants
  - Links will be posted in chat for Google Documents (separate link for each part)
  - Please add your name and response to each document
  - Allows editing by multiple people at once
- Discussion is broken into three parts, ten minutes each
- Report outs at the end as time allows
- After the meeting
  - You can provide additional feedback by emailing Forrest Westall by August 8th at **forrest.westall@unrba.org**

Part 1 – What did you learn today? How should that finding be factored into the management strategy?

About the watershed?

About the lake?

About the re-examination?

Virtual participants: see the link in the chat box or click here from your local copy of the presentation.

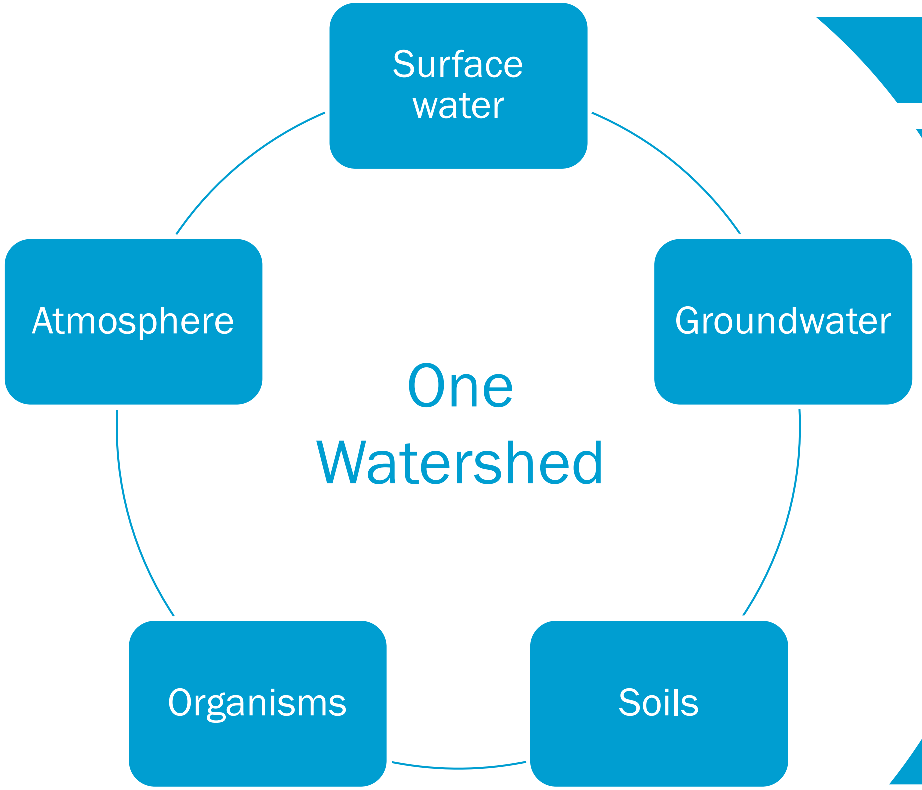
Part 2 – What are your thoughts on our conclusions and recommendations?

Long-term, incremental approach to nutrient management

Investment-based compliance

Virtual participants: see the link in the chat box or click here from your local copy of the presentation.

Part 3 – What is our proposal missing? What else do we need to consider?



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Report Outs

3:05 PM to 3:30 PM

Additional Information

- Comprehensive website
  https://www.unrba.org/
- General information website
  https://upperneuse.org/
- Reference documents
  - UNRBA Infographic
  - UNRBA Fast Facts
  - Overview of the Work of the UNRBA
  - Comprehensive UNRBA Monitoring Data Report
- NC Collaboratory Falls Lake Study website - https://nutrients.web.unc.edu/resources/
- UNRBA Draft Concepts and Principles for Reexamination

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