Key Findings of the Falls Lake Watershed Monitoring Data

Water quality and stream flow data have been collected in the Falls Lake Watershed for several decades. This data was critical to the development of the UNRBA models. Additional summaries and analyses of water quality data are provided in the following documents. These and other files are available in the UNRBA resource library:

- 2019 UNRBA Annual Monitoring Report (comprehensive report)
- UNRBA Watershed Modeling Report
- Key findings of the lake monitoring data

Watershed monitoring data were critical to the development of the UNRBA recommendations for a revised nutrient management strategy. Land use data provides critical understanding about watershed constraints. The recommendations and a focused set of consensus principles will guide the update of the Falls Lake Rules.

- Most of the watershed (75%) is made up of unmanaged or natural areas like forests and wetlands (Figure 1). These areas store nutrients during dry periods and export them during wet periods. Reducing nutrients from natural areas is very difficult.
- Nutrient loads are calculated from stream flows and water quality concentration data. All land uses and areas in the basin contribute nutrients to Falls Lake.

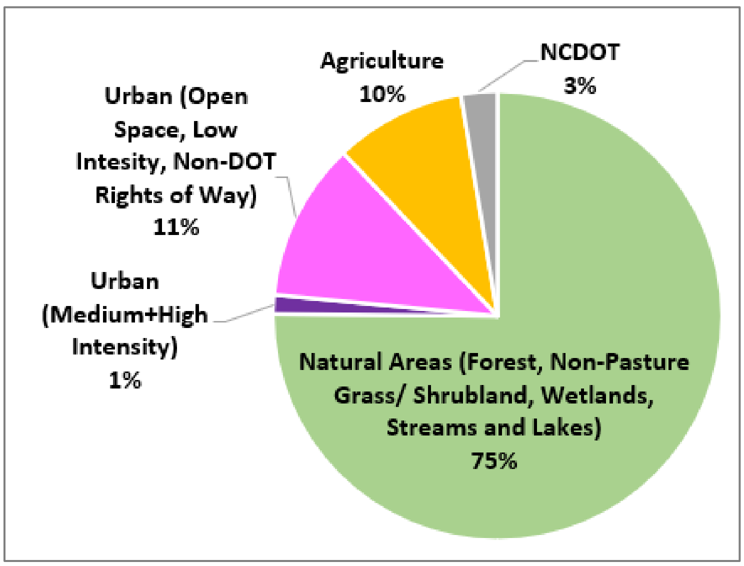

Figure 1. Land Use Composition of the Falls Lake Watershed

- Nutrient loading to Falls Lake has decreased significantly since the 1980s. Most of the variability in loading in the recent years is due to rainfall. For example, rainfall in 2017 was average (45 inches). Rainfall in 2018 was 30% higher than average (60 inches). As a result, nutrient loading in 2018 was significantly higher than 2017. For comparison, 2007 had only 38 inches of rain and occurred during a historic drought for the area. Even though 2017 had higher rainfall than 2007, the total nitrogen loads to Falls Lake were similar. The total phosphorus loads to Falls Lake in 2017 were much lower than 2007. Reductions in nutrient loading due to improvements in the watershed kept nutrient loads in 2017 lower than they would have otherwise been. Summary figures are provided below.

Total nitrogen loads to Falls Lake have declined since the 1980s.

The 2011 Falls Lake Rules track reductions relative to year 2006. Between 2006 and 2018, the following total nitrogen reductions have been achieved:

- Atmospheric deposition to land and water surfaces (~25 percent)
- Wastewater treatment plant improvements (~40 percent)
- Nutrient application on farmland (~40 percent)
- Nearly 400 stormwater retrofits have been constructed

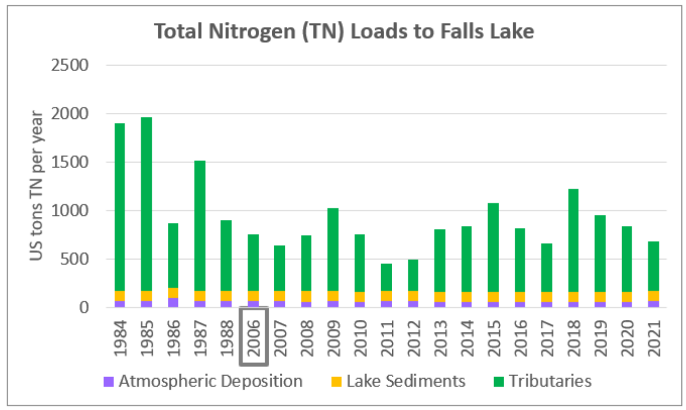

Figure notes: Load is a function of stream flow and concentration.
Atmospheric deposition directly to the lake surface is a minor contributor of the total nitrogen load to Falls Lake. Atmospheric deposition to the watershed is included in the tributary loading.
Total nitrogen loads released from lake sediments are based on modeled years (2014 to 2018).
Missing years indicate a lack of tributary monitoring data.

Total phosphorus loads to Falls Lake have declined since the 1980s.

The 2011 Falls Lake Rules track reductions relative to year 2006. Between 2006 and 2018, the following total phosphorus reductions have been achieved:

- Wastewater treatment plant improvements (~80 percent)
- Nutrient application on farmland (~40 percent)
- Nearly 400 stormwater retrofits or streambank erosion projects have been constructed

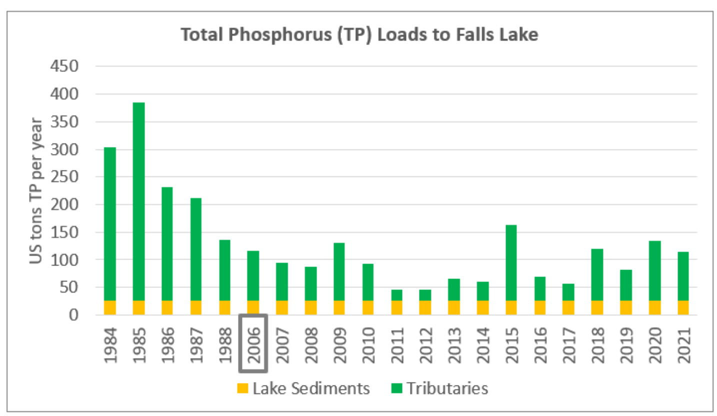

Figure notes: Load is a function of stream flow and concentration.
Atmospheric deposition directly to the lake surface is a minor contributor of the total phosphorus load to Falls Lake. Atmospheric deposition to the watershed is included in the tributary loading.
Total phosphorus loads released from lake sediments are based on modeled years (2014 to 2018).
Missing years indicate a lack of tributary monitoring data.

When total nitrogen loads to Falls Lake are divided by the annual precipitation at Raleigh-Durham International Airport, significant reductions in loading from the 1980s are evident.

Regulated entities complying with clean air and water quality regulations have achieved significant reductions in loading:

- 1999 Neuse River Rules
- 2002 Clean Smokestacks Act
- 2011 Falls Lake Rules

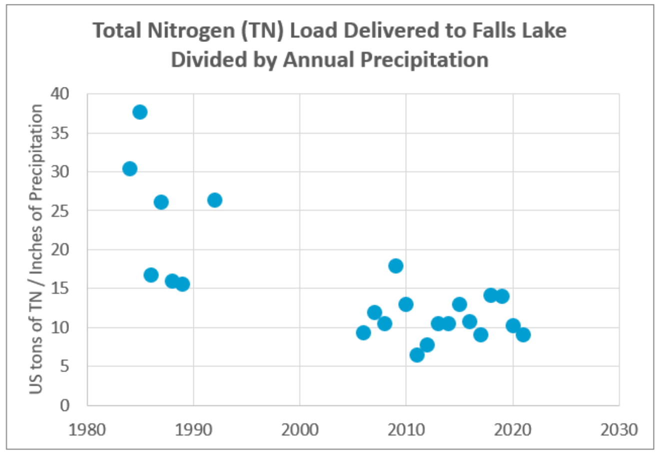

Figure notes: Load is a function of stream flow and concentration.
Missing years indicate a lack of tributary monitoring data.

When total phosphorus loads to Falls Lake are divided by the annual precipitation at Raleigh-Durham International Airport, significant reductions in loading from the 1980s are evident.

Regulated entities complying with clean air and water quality regulations have achieved significant reductions in loading:

- 1988 NC Phosphate Detergent Ban
- 2011 Falls Lake Rules

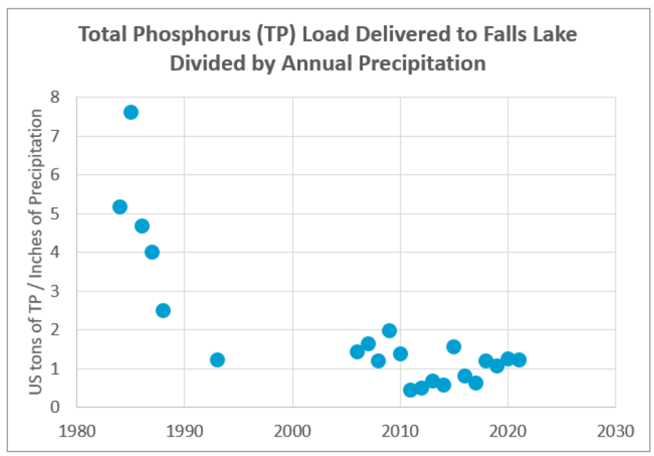

Figure notes: Load is a function of stream flow and concentration.
Missing years indicate a lack of tributary monitoring data.

- Nutrient loading to Falls Lake depends on rainfall. Low rainfall years deliver approximately half the load compared to high rainfall years. Annual loading estimates were developed by the North Carolina Division of Water Resources (DWR) for 2006 to 2019 (click here for the report). Tables showing values for 2015 to 2019 are provided on the next page. Other than a 30 percent increase in annual rainfall, little changed in the watershed between 2017 to 2018, but nutrient loads nearly doubled. Similarly, the reduction in delivered loading from 2018 to 2019 was due primarily to lower rainfall.

- The timing of rainfall events also affects delivered load. The same amount of annual rainfall occurring over several large storm events will deliver more load than if the rain occurs as several smaller storms. Back-to-back, large storms saturate soils and generate higher stream flows. The DWR 2021 status report for Falls Lake includes flow-weighted estimates of loading back to 2006. These values divide the delivered load by the stream flow volume. DWR reports that flow-weighted total nitrogen loads from 2006 compared to 2019 decreased by 20 percent. The flow-weighted total phosphorus loads decreased by 50 percent. Click here for more information about the importance of precipitation on delivered nutrient loading to Falls Lake.

Delivered Nutrient Loading to Falls Lake Due to Rainfall and Resulting Stream Flows

- Load is a function of stream flow and concentration
- Nutrient loads are highly variable from year to year based on precipitation
- The DWR 2021 status report for Falls Lake shows that nutrient loads can double from one year to the next based on precipitation and stream flow.
- Annual rainfall at RDU airport:
  - 2015: ~57 inches
  - 2016: ~51 inches
  - 2017: ~45 inches (average)
  - 2018: ~60 inches
  - 2019: ~43 inches

DWR Estimates of Delivered Total Nitrogen Load and Stream Flow to Falls Lake

YEAR	Combined Tributary Total Nitrogen Annual Load Estimate (lbs.)	Total Annual Tributary Flow (Cubic Feet Per Year)
2015	1,171,854	15,121,981,066
2016	1,139,275	14,654,135,866
2017	1,060,060	11,671,222,151
2018	1,806,557	23,243,318,582
2019	1,311,452	18,099,995,832

DWR Estimates of Delivered Total Phosphorus Load and Stream Flow to Falls Lake

YEAR	Combined Tributary Total Phosphorus Annual Load Estimate (lbs.)	Total Annual Tributary Flow (Cubic Feet Per Year)
2015	120,502	15,121,981,066
2016	129,568	14,654,135,866
2017	150,788	11,671,222,151
2018	243,621	23,243,318,582
2019	143,732	18,099,995,832

Data for 2015 to 2019 copied from the NC Division of Water Resources (DWR) 2021 Status Report for Falls Lake. The next report is anticipated in 2026.

Several organizations have collected or studied data in the Falls Lake watershed (Table 1). Figure 2 shows the location of stations monitored by the UNRBA, DWR, and US Geological Survey (USGS). Monitoring locations for other organizations are provided in the linked reports listed in Table 1. UNRBA reports are available in the UNRBA resource library.

Table 1. Summary of Falls Lake Watershed Data and Tributary Loading Evaluations

Study	Date Range and Location	Organization	Summary of Results or Link to Data	Applicability
Compilation of watershed and lake data to support planning for the reexamination	1999 to 2012 Watershed and Falls Lake	DWR, USGS, Local Governments,	UNRBA review of water quality data for Falls Lake and the Watershed by organization, sampling depth, month, year, etc. (Task 2 Report)	While this evaluation period does not overlap with the UNRBA Study Period, previous DWR sampling included water quality sampling at deeper depths in the water column. Distributions of past water quality summarized by depth provide a reasonableness check on EFDC and WARMF Lake simulations relative to predicted water quality in the bottom layers.
Measurement of nutrient, TSS, and total organic carbon from forested areas	2008 to 2013, forested headwater catchments in the Falls Lake watershed	US Forest Service	Measured loading rates from forested areas and comparison to simulated loading rates under varying rainfall conditions is provided in the UNRBA WARMF Watershed Modeling Report. Published data are available in Boggs et al. (2012).	While this evaluation period does not overlap with the UNRBA Study Period, these studies were used to provide a reasonableness check on WARMF-simulated loading rates for forested areas. When WARMF was evaluated for similar rainfall conditions to the Forest Service monitoring studies conducted in the Falls Lake watershed, simulated rates were similar to measured rates (baseflow and storm event runoff).
Tributary water quality monitoring to support UNRBA watershed model development	Aug. 2014 to Oct. 2018, Watershed and Falls Lake	UNRBA Routine Monitoring	Data summarized in the UNRBA 2019 Annual Report Raw data are available on the UNRBA data portal available in the UNRBA Resource Library.	Watershed data was used to calibrate the WARMF watershed model which provides stream flow and water quality concentrations delivered to Falls Lake for both WARMF Lake and EFDC.
Tributary high flow sampling to support UNRBA watershed model development	Grab sampling targeting precipitation events on largest 5 tributaries or corresponding with routine monitoring events, Aug 2014 to Dec. 2018	UNRBA Special Study	Distribution of concentrations by flow percentile in the 2019 Annual Report in Section 3.4.1; and partial results summarized in a different format in Results summarized in the 2016 Annual Report, Section 4.2	Watershed data was used to calibrate the WARMF watershed model which provides stream flow and water quality concentrations delivered to Falls Lake for both WARMF Lake and EFDC.

Study	Date Range and Location	Organization	Summary of Results or Link to Data	Applicability
Tributary storm event sampling to support UNRBA watershed model development	Automated samplers deployed April, September, and October 2015 on Ellerbe Creek and Eno River capturing four or more distinct storm peaks for each tributary.	UNRBA Special Study	Results summarized in the 2016 Annual Report, Section 4.1	Watershed data was used to calibrate the WARMF watershed model which provides stream flow and water quality concentrations delivered to Falls Lake for both WARMF Lake and EFDC.
Sediment and carbon inputs to Falls Lake	Flat River, Eno River, Little River and Ellerbe Creek August 2019 to March 2020	NC Collaboratory	Results summarized in McKee et al. (2023)	This study concludes that most of the particulate organic matter entering Falls Lake originates from soil organic matter, freshwater algae (likely from upstream impoundments) and fertilizer. The cores from Falls Lake only indicate soil organic matter in the carbon signature. Average sedimentation rates in Falls Lake from 0.7 cm/yr to 1 cm/yr. The study concludes that ". If other reservoirs are similar in nature to Falls Lake, then the organic carbon accumulating in reservoirs (to offset growing CO_2 concentrations in the atmosphere) is primarily from the carbon from reservoir watersheds which are better preserved and stored in reservoir bottom sediments. This conclusion is contrary to the idea that the source of the sedimentary carbon in bottom sediments results from the input of excess nutrients to reservoirs that results in large seasonal algae blooms and low oxygen waters." **For Falls Lake, the dominant source of carbon is from the watershed, and that is comprised mostly of soil organic matter.**
Empirical estimates of loading to Falls Lake	1980's to present at four tributaries with historic data (Flat River, Eno River, Knap of Reeds, and Ellerbe Creek	DWR data evaluated by UNRBA	See UNRBA Lake Modeling Report	Provides historic loading (total nitrogen and total phosphorus) to the UNRBA Statistical/Bayesian model

Study	Date Range and Location	Organization	Summary of Results or Link to Data	Applicability
Historic water quality measurements.	Several locations in Falls Lake and the watershed	DWR and USGS data	EPA Water Quality Portal	Historic lake data used to evaluate long-term trends in Falls Lake. Historic water quality data from the watershed used to develop annual average ratios of total organic carbon to total nitrogen to develop historic loading estimates of total organic carbon from the GAM models for total nitrogen described in the previous row.
WARMF simulated loading to Falls Lake	2014 to 2018 for seventeen tributary inputs	UNRBA Watershed Model	Summarized in the UNRBA Watershed Modeling Report	Simulated stream flows and water quality concentrations provide input to EFDC, WARMF Lake, and the UNRBA Statistical/Bayesian model
CBOD5 in lake loading in lake samples	August 2014 to December 2015 for seventeen tributary inputs	UNRBA Routine Monitoring	Data summary provided in the UNRBA 2016 Annual Report, Section 3.2 (parameter discontinued the following year) Data portal available in the UNRBA Resource Library	Approximately 95 percent of the organic material entering Falls Lake is in the dissolved form; see description of development of labile and refractory constituents for EFDC model in Appendix A
Atmospheric deposition	Estimated for historic record	CASTNET, NADP, and NC State Climate Office	Summarized in the UNRBA Watershed Modeling Report and the UNRBA Lake Modeling Report	Provides estimates of wet and dry deposition for WARMF Lake and EFDC models for 2014 to 2018 and long-term estimates used for the UNRBA statistical/Bayesian model.

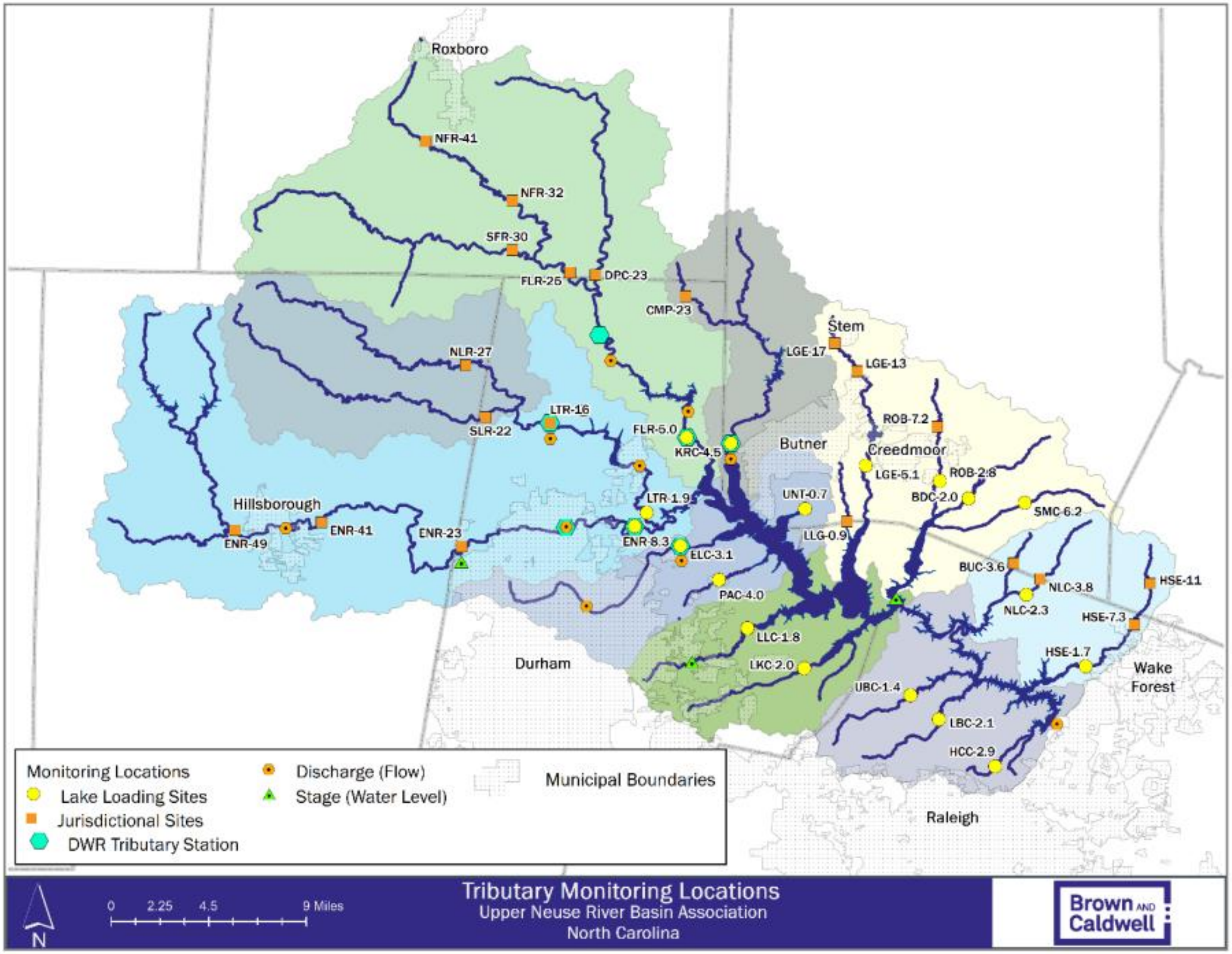

Figure 2. Location of UNRBA, DWR, and USGS (Discharge and Stage) Monitoring Stations in the Falls Lake Watershed