Key Findings from the UNRBA Watershed Model

The UNRBA developed a watershed model for Falls Lake. The computer software program is called the Watershed Analysis Risk Management Program (WARMF). The model simulates stream flows and pollutant loading to Falls Lake. The input data, model development, calibration, and application are described in the UNRBA Watershed Modeling Report available in the UNRBA resource library.

Key findings of the watershed modeling and data evaluation are included here.

- Unmanaged or naturals areas with little human impact comprise 75% of the 770 square-mile basin. These areas include forest, wetlands, non-pasture grassland, and shrubland. These lands contribute approximately half of the total nitrogen and total phosphorus load delivered to Falls Lake. Reducing nutrients loads from these areas is very difficult.
- 2006 is the tracking year for the 2011 Falls Lake Rules. The area of land in active agricultural production has declined by nearly one-half since 2006. Lands out of production maybe have been developed, are no longer in production, or are transitioning to grassland or forests. The acreage of agriculture has declined 44% due to economic and other pressures.
- Urban development in the watershed has increased and comprises approximately 12% of the watershed area. Most of the urban land is low intensity development, local road rights of way, and developed open space. Just over 1% of the urban areas are medium or high intensity development.
- Regulated entities have significantly reduced nutrient loading to Falls Lake. From 2006 to 2018, the following reductions had occurred:
    - Major wastewater treatment plants reduced total nitrogen loads by 38%. These facilities reduced total phosphorus loads by 81%.
    - Over 350 stormwater treatment practices have been implemented to mitigate loading from development that occurred before 2012.
    - Requirements to limit nutrient export from development occurring since 2012 have been implemented by every local government in the watershed.
    - Atmospheric deposition of total nitrogen has decreased by 20% to 25%.
    - Best management practices have been broadly implemented on agriculture land. Practices include nutrient management plans, livestock exclusion, and stream buffer restorations.
- Opportunities for further nutrient reductions are limited.
- Forested areas are critical to the ecological health of the watershed and should be protected. Natural areas cycle and provide nutrients to waters that sustain aquatic life.
- Precipitation increases nutrient loading to Falls Lake.
- The watershed soils and lake sediments adsorb nutrients. These nutrients can be released slowly over decades. Continued releases will extend the time that changes in the watershed will result in water quality changes in the lake.
- Reductions to the nutrients applied or deposited in the watershed do not have an equivalent reduction in delivered loading to Falls Lake. Crop harvesting and watershed processes remove nutrients from the system.

Additional information follows.

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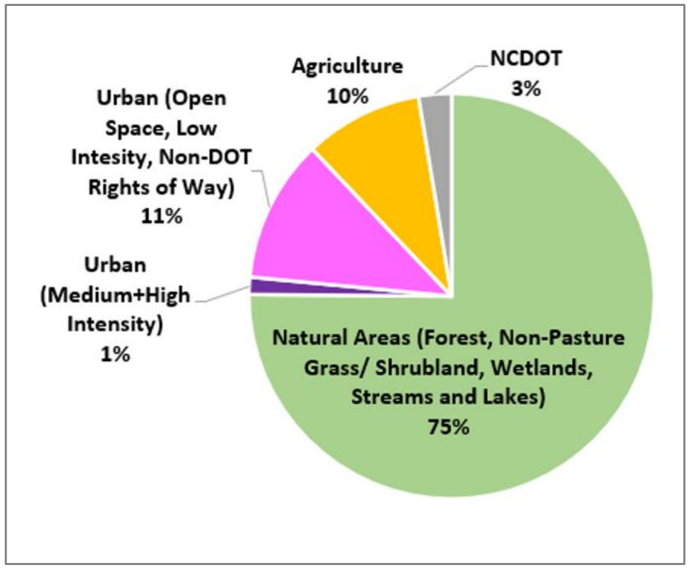
Historic Trends in Nutrient Loading to Falls Lake

Nutrient loading to Falls Lake comes from the watershed, atmosphere, and lake sediments. Loading from the watershed can be estimated from stream flow and water quality data collected since the 1980s. This component of the load comprises most of the load to the lake. Most of the watershed load enters the system at the upstream end of the lake. This part of the load includes atmospheric deposition to the watershed, including natural areas.

Seventy-five percent of the watershed is in an unmanaged or natural state (like forests and wetlands). Land use changes have occurred over the past several decades. The area of land in agricultural production (10%) has declined by nearly one-half since 2006 (the tracking year for the 2011 Falls Lake Rules). These lands have either been developed or are no longer in production and transitioning to grassland or forests. Urban development in the watershed has increased and comprises approximately 12% of the watershed area. Most of the urban land is low intensity development, local road rights of way, and developed open space. Just over 1% of the urban areas are medium or high intensity development.



Nutrients are also deposited from the atmosphere. Deposition falls with precipitation or settles like dust. This source of loading affects all land and water surfaces. Air quality improvements have reduced total nitrogen deposition significantly. Reductions of 20% to 25% have occurred since 2006. Air quality and rainfall chemistry data are available to estimate these loads.

Nutrients can also be recycled from the lake sediments. This load is often called “internal.” The UNRBA, US Environmental Protection Agency, and NC Collaboratory have conducted sediment studies in Falls Lake to estimate the amount of loading from the sediments to the lake water. Sufficient data is not available to estimate how this source of loading has changed with time. Because it is a relatively small source compared to the watershed load, seasonal loads predicted by UNRBA lake models provide these estimates. The UNRBA lake models were developed using the data collected in Falls Lake and are a reasonable approximation of internal loading.

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 60 inches (30 percent higher than average). 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 2017, 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. The summary figures show how nutrient loading to Falls Lake has changed since the 1980s.

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

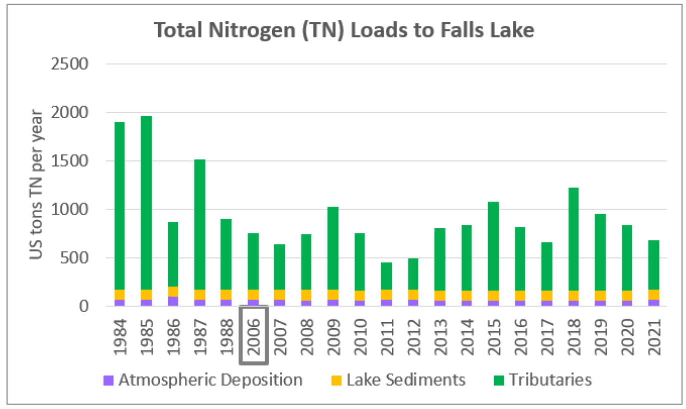


Figure notes: Load is a function of stream flow and concentration.
Atmospheric deposition directly to the lake surface is a minor contributor of the total nitrogen load to Falls Lake. Atmospheric deposition to the watershed is included in the tributary loading.
Total nitrogen loads released from lake 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

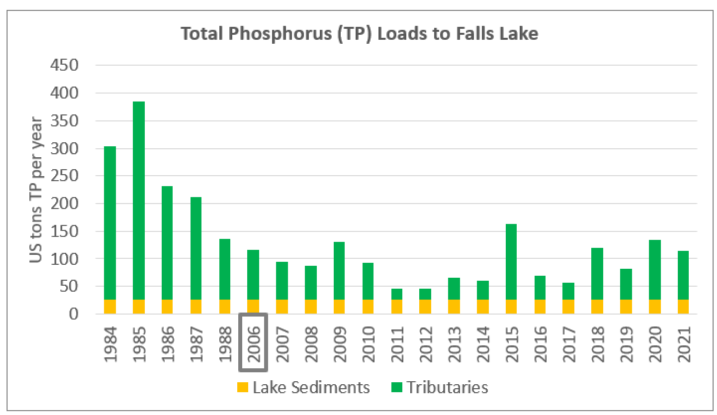


Figure notes: Load is a function of stream flow and concentration.
Atmospheric deposition directly to the lake surface is a minor contributor of the total phosphorus load to Falls Lake. Atmospheric deposition to the watershed is included in the tributary loading.
Total phosphorus loads released from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

Annual loads can also be "weighted" by annual rainfall. This approach better illustrates changes over time by ignoring variations in rainfall. Compliance with air and water quality requirements have achieved significant reductions in loading in Falls Lake since the 1980's.

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 smaller storms throughout the year. Back-to-back large storms saturate soils and result in higher stream flows. In their [2021 status report for Falls Lake,] the North Carolina Division of Water Resources (DWR) developed flow-weighted estimates of loading back to 2006. These values divide the delivered load by the stream flow volume. DWR reports that total nitrogen loads from 2006 to 2019 **decreased by 20 percent**, and the total phosphorus loads **decreased by 50 percent**.

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

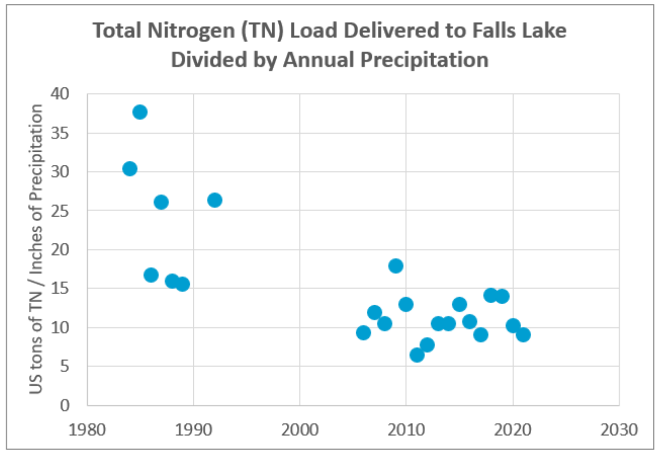


Figure notes: Load is a function of stream flow and concentration.
Missing years indicate a lack of tributary monitoring data.

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

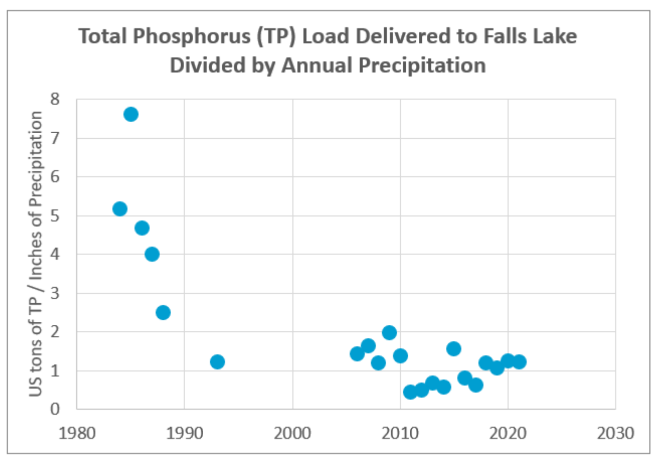


Figure notes: Load is a function of stream flow and concentration.
Missing years indicate a lack of tributary monitoring data.

Importance of Precipitation on Nutrient Loading to Falls Lake

Delivered nutrient loading to Falls Lake depends on rainfall, stream flows, and water quality concentrations. In watersheds like Falls Lake where most land is unmanaged, rainfall patterns are the primary drivers of variation in nutrient loading from one year to the next.

Nutrients are deposited from the atmosphere to all areas of the watershed. Nutrients may also be applied to urban and agricultural areas. Pervious areas like forests and agricultural fields can store nutrients during dry periods and export them during wet periods.

Loading from unmanaged and natural lands is not constant. Loads fluctuate based on the amount and timing of rainfall. Very large storms can increase delivered loads to Falls Lake by hundreds of times compared to days with little rainfall. Large storms exceeding 1 inch of rain occur infrequently (approximately 4 percent of days during the UNRBA study period which had above average rainfall).

Percent land use composition of Falls Lake Watershed

Natural areas (forests, wetlands, non-pasture grassland)

- **Difficult to reduce nutrient loading**

Managed lands (urban, agriculture)

- **Agricultural acreage has decreased nearly 50% with BMPs widely implemented on remaining areas**
- **Hundreds of stormwater control measures have been implemented on urban lands**

The NC Division of Water Resources (DWR) developed estimates of nutrient loading to Falls Lake. Annual loads from 2006 to 2019 are provided here. The loads reported for years 2015 to 2019 demonstrate the importance of rainfall on stream flow and delivered loading. Other than a 30 percent increase in annual rainfall, little changed in the watershed to cause an increase in nutrient loading from 2017 to 2018. Similarly, the reduction in delivered loading from 2018 to 2019 was due primarily to reduced rainfall. The next page shows tables from DWR's status report that show this increase and following decrease in nutrient loading to Falls Lake.

The 2021 status report for Falls Lake also includes flow-weighted estimates of nutrient loading back to 2006. These values divide the delivered load by the stream flow volume. DWR reports that flow-weighted total nitrogen loads **decreased by 20 percent** from 2006 to 2019. Flow-weighted total phosphorus loads **decreased by 50 percent**.

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

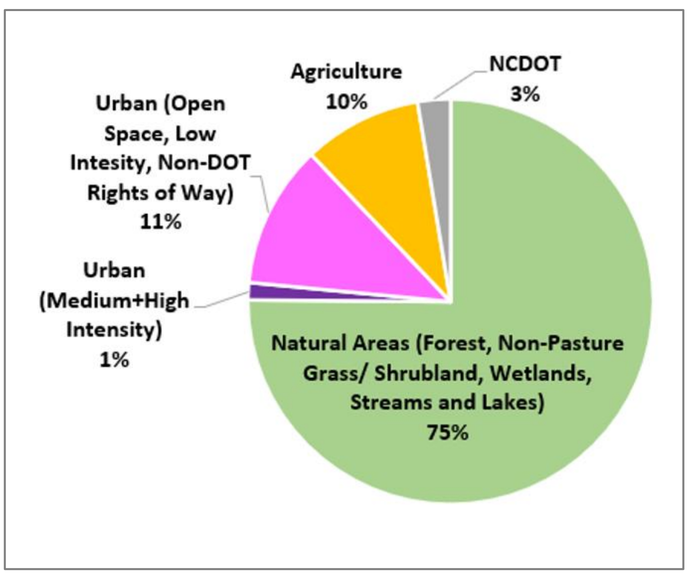
YEAR	Combined Tributary Total Phosphorus Annual Load Estimate (lbs.)	Total Annual Tributary Flow (Cubic Feet Per Year)
2015	120,502	15,121,981,066
2016	129,568	14,654,135,866
2017	150,788	11,671,222,151
2018	243,621	23,243,318,582
2019	143,732	18,099,995,832

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.

Sources of Nutrient Loading to Falls Lake from 2014 to 2018

The UNRBA developed a watershed model using a computer software program called the Watershed Analysis Risk Management Program (WARMF). This model simulates stream flows and pollutant loading from the tributaries to Falls Lake. The UNRBA Watershed Modeling Report is available in the UNRBA resource library.

The WARMF watershed model was developed to represent the UNRBA study period (2014 to 2018). Land use data is a critical input to the model. Many organizations provided local data. The land use composition of the watershed during the study period is summarized below:



- 75% unmanaged or natural areas with little human impact
    - Important for protection of water quality
    - Difficult to reduce nutrient loading
- 10% is agriculture
    - Half crop, half pastureland
    - Mostly small family farms
    - Best management practices (BMPs) widely implemented

    - Acreage of agriculture has declined by almost one-half since 2006, the tracking year for the 2011 Falls Lake Rules
- 3% is NC Department of Transportation road rights of way
- 11% "less impervious" urban land
    - Developed open space
    - Non-DOT rights of way
    - Low intensity existing development
- 1% "more impervious" urban land
    - Medium intensity development
    - High intensity development

Other data sets are also important to accurately simulate stream flows and nutrient loading to Falls Lake. These data are summarized in the UNRBA Watershed Modeling Report available in the UNRBA resource library.

- Soils data (chemical and hydrologic properties)
- Stream and impoundment data
- Rainfall and weather data
- Discharges from wastewater treatment plants
- Locations, types, and failure rates for onsite wastewater treatment systems
- Rates and timing of nutrient application by land use
- Crop planting and harvest dates
- Precipitation chemistry and air concentrations of pollutants

Securing the data needed to provide the best configuration of the model was a large and important task. The effort would not have been possible without the cooperation of others. Many stakeholders provided data, information, insights, and feedback to support this modeling effort and ensure that all available information was incorporated accurately into the model:

- Local governments and utilities that comprise the UNRBA (click here for a list of jurisdictions)
- State agencies like the NC Division of Water Resources, NC Department of Agriculture and Consumer Services, NC Department of Transportation, NC Wildlife Resources Commission, and the NC State Climate Office
- Federal agencies like the US Forest Service and US Geologic Survey
- Researchers funded through the NC Collaboratory
- Representatives from the Farm Bureau and American Rivers

Information obtained through this process has been reviewed and quality assured prior to use in the model. The NC Collaboratory provided funding for a "third-party" review of the model. This extensive review resulted in improvements to the model. Source load allocation and simulated loading rates from specific land uses were a significant part of the review. The UNRBA applied consistent assumptions and underlying data sets to characterize the watershed.

WARMF tracks delivered loads from sources in the watershed. Calculated loads are based on the nutrient inputs, processes that affect each source, and transformations that occur on and below land surfaces, in streams, and in impoundments. Agricultural and urban lands receive nutrient application in the model, but unmanaged and natural lands do not. The loads delivered to Falls Lake are a function of tributary stream flow and water quality concentrations. Delivered loads are strongly dependent on rainfall amounts and prior rainfall conditions. The following sources are tracked in the model:

- Individual land uses (e.g., deciduous forest, full-season soybeans, developed open space) including
    - Atmospheric deposition
    - Nutrient application
    - Litter fall
- Individual types of onsite wastewater treatment systems (e.g., conventional functioning systems, conventional malfunctioning systems)
- Point sources (includes major and minor dischargers, discharging sand filter systems, and sanitary sewer overflows)
- Initial mass of chemical constituents in the watershed soils, streams, and impoundments
- Stream bank erosion
- Direct wet and dry deposition to Falls Lake

The next page shows the percent contribution and the source of the delivered loads to Falls Lake. Pie charts are provided for total nitrogen, total phosphorus, and total organic carbon. These delivered loads account for nutrient removal due to crop harvesting and processes that reduce loading before delivery to the lake (e.g., setting). The surface of Falls Lake receives direct inputs from the atmosphere as rain or particulate settling.

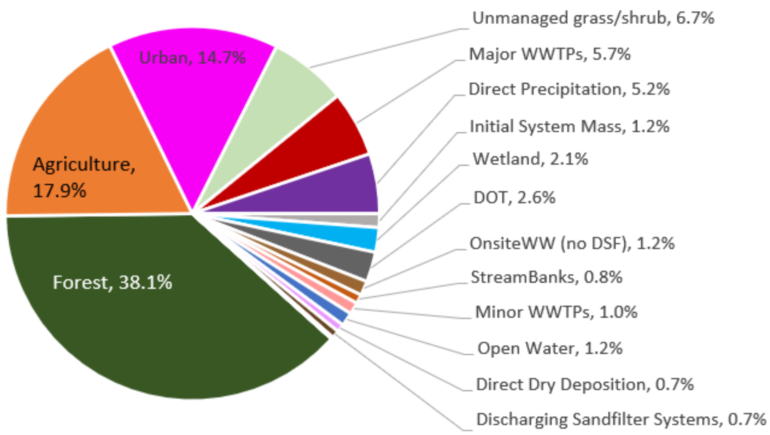
Three-quarters of the watershed is unmanaged land. These areas include forests, wetlands, unmanaged grassland and shrubland, land in forest succession, and open water. Over one-half of the total nitrogen, total phosphorus, and total organic carbon loads delivered to Falls Lake originates from these areas. Loading from these areas is higher during wet conditions when soils are saturated. Unmanaged lands are important to the health of the watershed. These areas store and cycle nutrients and carbon, infiltrate and store rainwater, buffer temperatures, and provide habitat. Increased loading from forested areas following large rainfall events has been reported by many researchers. The UNRBA Watershed Modeling Report provides a summary of this research.

Models are representations of systems. No model is exact. In order the calibrate the model to observed stream flows and water quality, the simulation must be reasonably accurate. Large storm events result in increased loading from all land uses in the watershed. Rainfall is the single most important factor in watershed loading to Falls Lake. This model was developed specifically for the Falls Lake watershed. Local land use intensity, soil characteristics, and nutrient reduction achievements must be considered when evaluating model results.

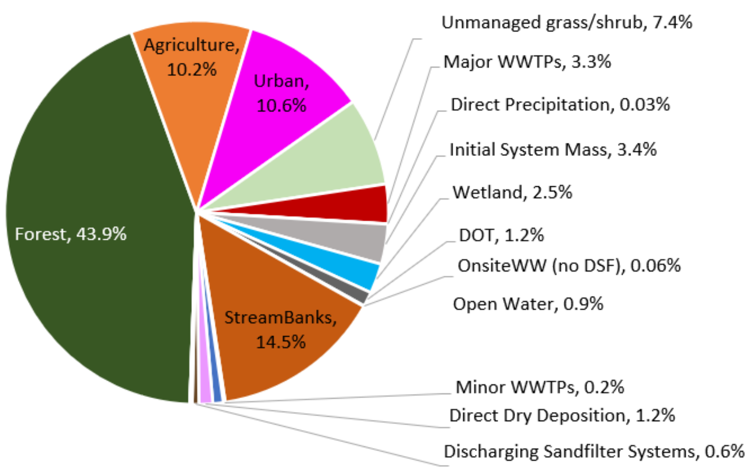
Delivered loads are what reach Falls Lake after the nutrient inputs and watershed processes have been accounted for. Delivered loads represent only 20 percent of "applied' nutrients in the watershed.

Forests, non-pasture grassland, wetlands, and other natural lands contribute approximately half of the nutrient load to Falls Lake because they are the majority of the drainage area. These areas are important to the health of the watershed and provide many benefits.

Total Nitrogen (1.65 million pounds per year)



Total Phosphorus (183,000 pounds per year)



Total Organic Carbon (13.2 million pounds per year)

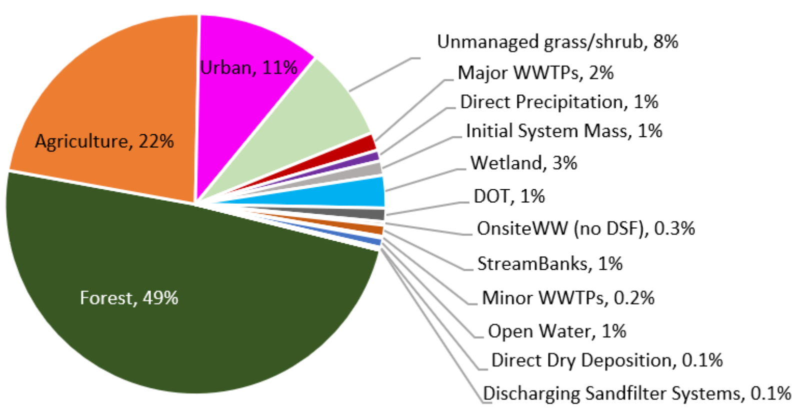


FIGURE NOTES:

Loads from unmanaged areas, including forests, contribute the largest fraction of the load because 75 percent of the watershed is comprised of these areas (Figure ES-1). These areas are important to the health of the watershed.

Loads from wastewater treatment plants (WWTPs) include major and minor discharges as well as sanitary sewer overflows. Loads from WWTPs have been significantly reduced since the baseline year (2006).

Loads from onsite wastewater treatment systems (Onsite WW) are listed separately for discharging sandfilter systems (DSF) and other systems (no DSF).

13% of the watershed is “urban.” 68% of "urban" area is developed open space (mostly non-DOT road right of way) and 20% is existing development, low intensity. Less than 1.5% of the watershed is medium or high intensity development. Thus, most of the “urban” land in the watershed is low intensity.

Loads from streambank erosion are listed separately from urban loads.

Only 9 % of the watershed remains in agriculture. 57% of agriculture is pasture, 12% is full season soybeans, 10% is hay, 7% is double-cropped soybeans, 6% is flue-cured tobacco, 6% is no-till grain corn, and 2% is wheat or other crops. These are mostly small family farms.

Atmospheric deposition affects the entire watershed. Direct deposition and direct precipitation are the amounts falling on lake surfaces.

Initial system mass is the amount of pollutant in the streams and impoundments at the start of the model simulation.