Modeling and Regulatory Support Workgroup Meeting

Remote Access, January 4, 2022

Remote Access Options

Equipment Type	Access Information	Notes
Computers with microphones and speakers	Join Microsoft Teams Meeting **Please mute your microphone** unless you want to provide input.	Press control and click on this link to bring up Microsoft Teams through the internet. You can view the screen share and communicate through your computer's speakers and microphone
Computers without audio capabilities, or audio that is not working	Join Microsoft Teams Meeting (888) 404-2493 Passcode: 371 817 961# **Please mute your phone** unless you want to provide input.	Follow instructions above **Turn down your computer speakers, mute your computer microphone,** and dial the toll-free number through your phone and enter the passcode
Phone only	(888) 404-2493 Passcode: 371 817 961# **Please mute your phone** unless you want to provide input.	Dial the toll-free number and enter the passcode

Remote Access Guidelines

- This meeting will open 30 minutes prior to the official meeting start time to allow users to test equipment and ensure communication methods are working
- If you dial in through your phone, mute your microphone and turn down your speakers to avoid feedback
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Agenda

- Opening Comments, Agenda Review/Revisions
- Modeling and Regulatory Support Status
- MRSW Workgroup Reports
- Plan for Statistical Model Development and Regulatory Options for the Chlorophyll-a Water Quality Standard

Modeling and Regulatory Support Status

Third Party Review of WARMF Watershed Model

Third-party review of the WARMF Watershed Model

- Important to receive input and feedback throughout model development and before the lake models are calibrated
- Third-party reviewers and subject matter experts reviewing the calibrated watershed model and the load allocations
  - Daniel Obenour, NCSU
  - Nathan Hall, UNC
  - Deanna Osmond, NCSU
  - Johnny Boggs, Forest Service
  - Michael O’Driscoll, Guy Iverson, Charles Humphrey, ECU

Review Components

- Discussion of simulated processes in WARMF and the change made to isolate the soils beneath each land use
- Running the model more than three times to get further separation of the soils beneath the land uses and more variation in the areal loading rates
- Comparisons to other modeling studies and literature reviews of published areal loading rates
- Comparison to areal loading rates from forested areas in the Falls Lake watershed monitored by the Forest Service

Areal loading rates are mass per area per time, e.g.,

- *Pounds per acre per year (lb/ac/yr)*
- *Kilograms per hectare per year (kg/ha/yr)*
- *1 lb/ac/yr = 1.12 kg/ha/yr*
- *Both are used in these slides as most publications report kg/ha/yr*

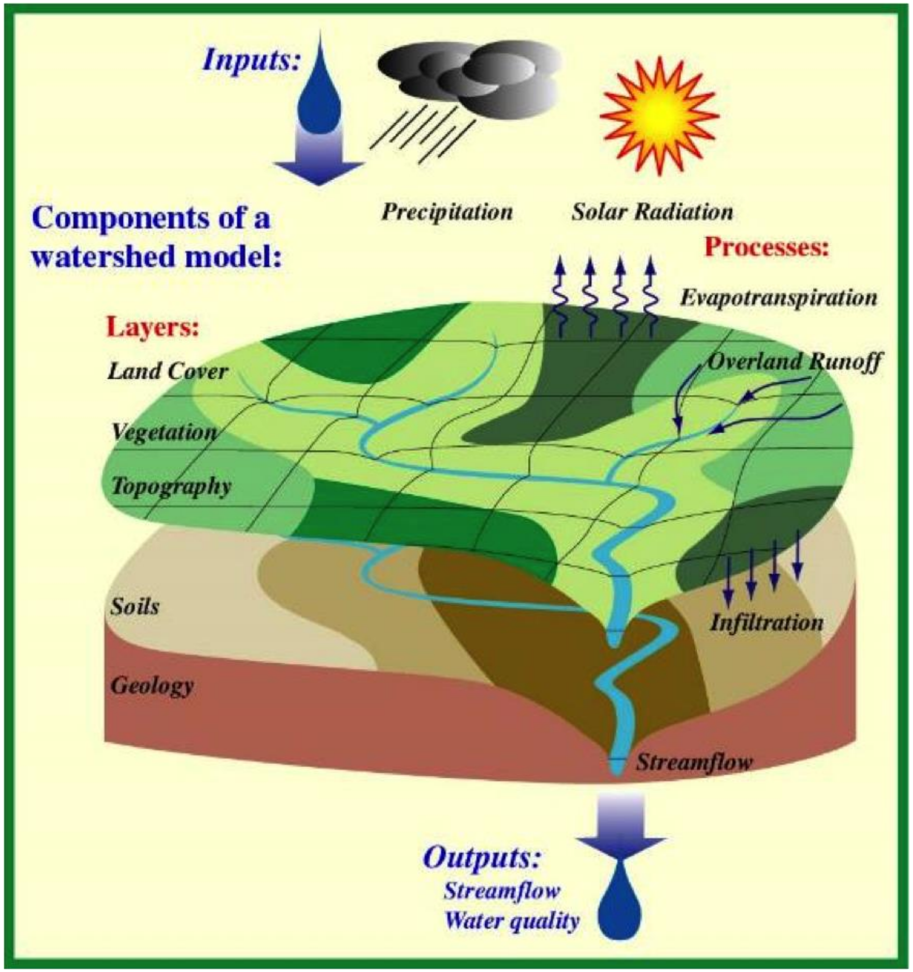
Evaluations Conducted

- Testing the model under varying precipitation conditions for comparison to other studies that were conducted during drier periods
- Testing the model without accounting for stormwater control measures, stream buffers, and natural routing of runoff from impervious surfaces onto pervious areas
- Summary of findings follow; additional details will be provided as an appendix to the watershed modeling report

Question: How does the WARMF Watershed Model simulate the processes occurring in the watershed?

Watershed Modeling Approach

- Inputs
  - Meteorology
  - Land Use
  - Soils
  - Nutrient application
  - Topography
  - Hydrologic network
- Processes
  - Catchments
  - Streams
  - Impoundments
- Outputs: flow and water quality



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

Watershed Processes

- The Watershed Analysis Risk Management Framework (WARMF) is a watershed model and decision support system which simulates the processes in a watershed and provides scientific information to stakeholders
  - Physical, chemical, and biological processes
  - Catchments, stream reaches, impoundments
  - Stream flow and water quality concentrations
  - Pollutant loads by source
  - Areal loading rates are calculated from simulated loads and drainage areas for each land use
- WARMF does not “prescribe” any results (e.g., runoff nutrient concentrations are calculated at each timestep, not assigned in a model input file like many other models)

Separate Soil Simulations

- There is an option in WARMF to separate the soils under each land use, but the 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

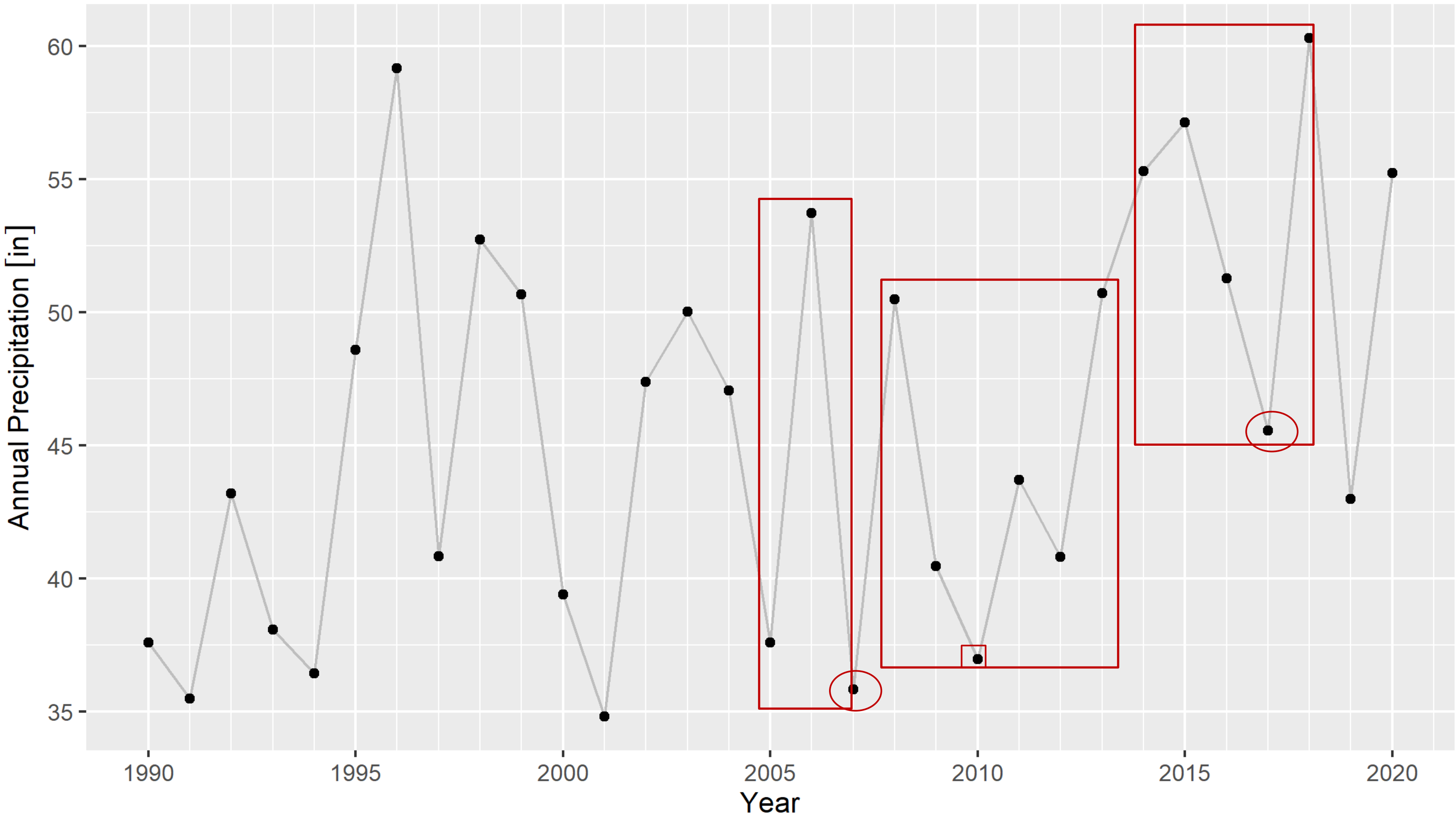
Forest	Development	Crops	Pasture	Wetlands	
Soils	Soils	Soils	Soils	Soils	Multiple iterations

- Given the soil chemistry in the watershed, a five-year model period (one model iteration) is not long enough for the initial soil conditions to separate by land use and output distinguishable loads by land use
- The WARMF model has to be run several times to see this separation
- Previously, we ran the model three times to simulate water quality concentrations and evaluate model performance; this output was reviewed by the MRSW and PFC

Variability of Precipitation

- In this watershed, precipitation is simulated for 78 stations based on NEXRAD data provided by the State Climate Office
- For a given year, annual precipitation can vary by up to 20 inches per year across the precipitation stations
- Loading rates simulated for one catchment can vary greatly from another based on this and other factors (slope, etc.)
- The following slides use precipitation at RDU as an example of the annual variability when testing conditions

Annual Precipitation at RDU



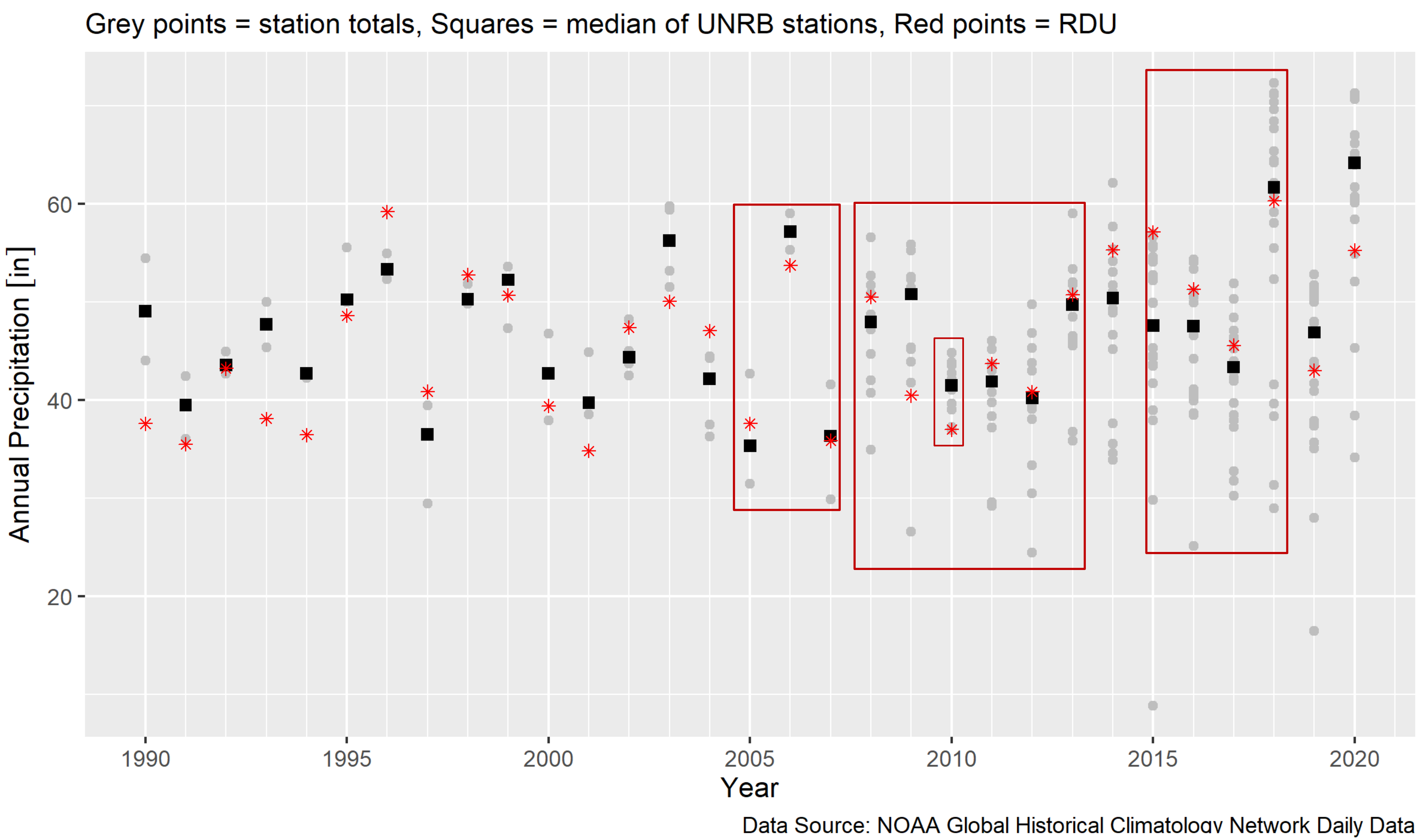
Data Source: NOAA Global Historical Climatology Network Daily Data

Baseline (2005-07)

Forest Service Monitoring (2008-2013)

UNRBA Modeling (2014-18)

Annual Precipitation Across Watershed



Baseline (2005-07)

Forest Service Monitoring (2008-2013)

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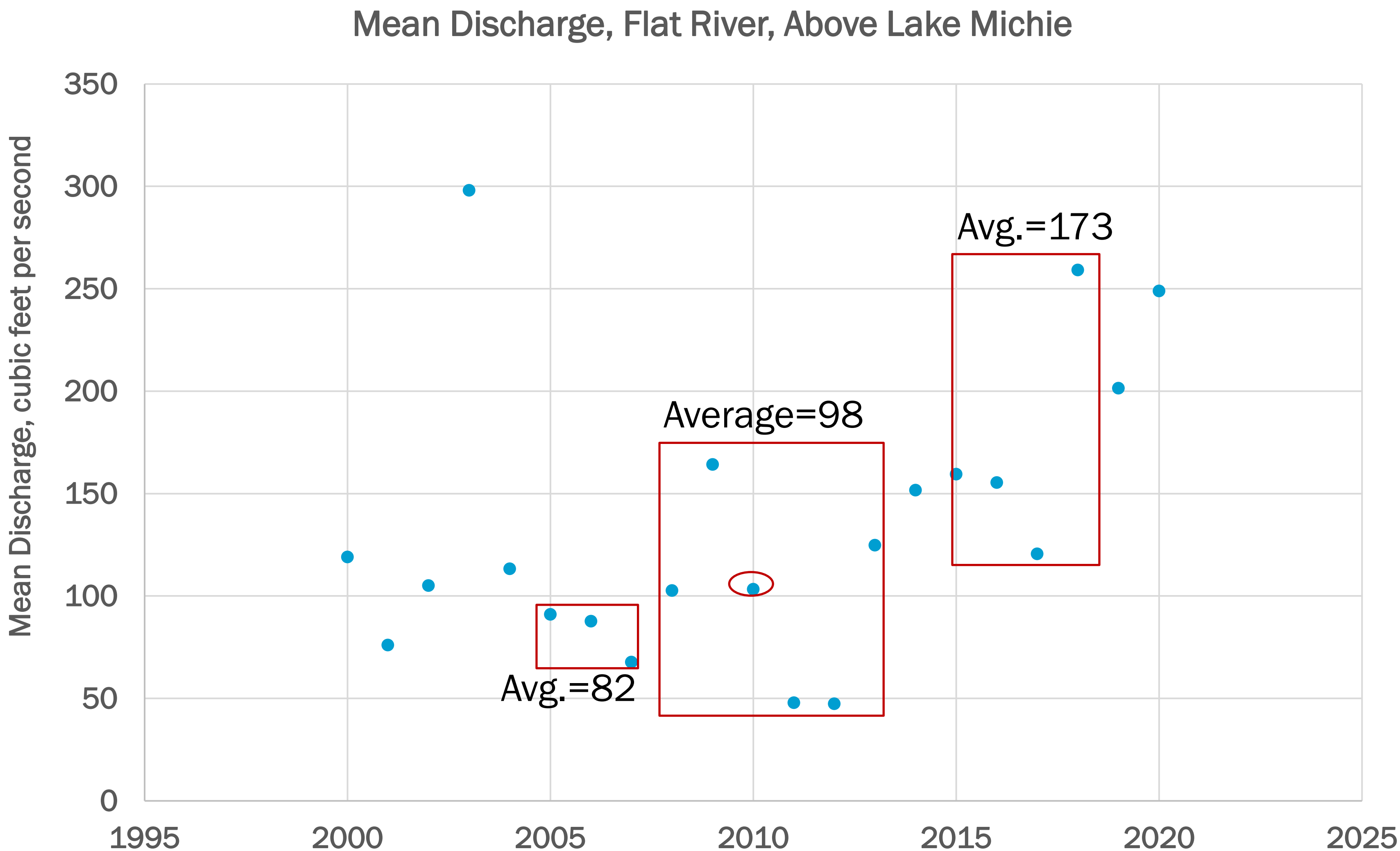
Mean Annual Discharge, Example Gage



Baseline (2005-07)

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UNRBA Modeling (2014-18)

Importance of Precipitation for Loading

- Load is a function of concentration and flow
- Nutrient loads are highly variable from year to year based on precipitation because flow is a key driver of loading
- Precipitation in 2018 was ~ 15 inches higher than 2017
- TN, TP, TOC loads in 2018 were 2-2.5 times higher than 2017

Year	Annual Precipitation at RDU (in) [ratio to 2017]	TN (lb/yr) [ratio to 2017]	TP (lb/yr) [ratio to 2017]	TOC (lb/yr) [ratio to 2017]
2015	57.1 [1.25]	1,306,800 [1.6]	128,000 [1.2]	10,031,000 [1.5]
2016	51.3 [1.13]	1,053,800 [1.3]	123,000 [1.1]	8,344,000 [1.3]
2017	**45.6 [1.00]**	**826,800 [1.0]**	**108,800 [1.0]**	**6,671,000 [1.0]**
2018	60.3 [1.32]	1,859,400 [2.2]	224,200 [2.1]	15,738,000 [2.4]

Question: What happens if you run the model more than three times?

Would you get further separation of the soil quality beneath the land uses and more variation in the areal loading rates?

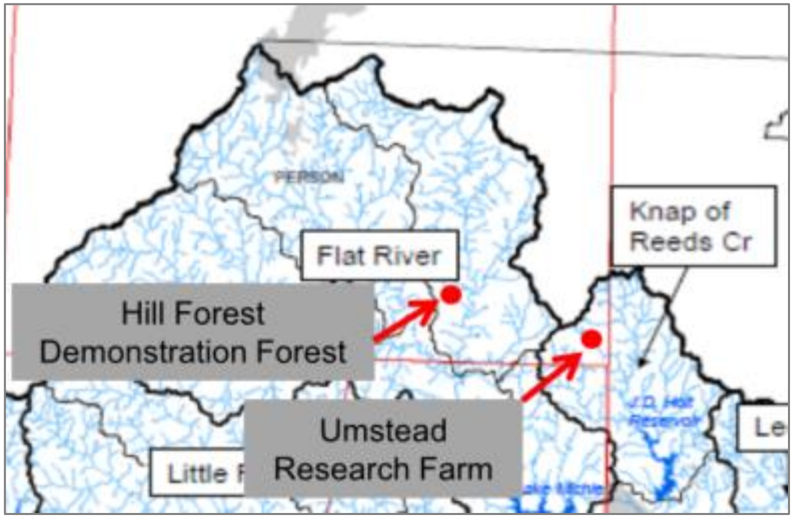
Increased Model Iterations/N Refinements

- The modelers ran the model ten times (50 years) rather than three times (15 years) to see if additional separation in areal loading rates occurred
  - Areal loading rates from forested areas decreased a little
  - Areal loading rates from agriculture increased too much for nitrogen because the nutrient content of the harvested vegetation was set too low and nitrogen was building up with ten model iterations (not an issue with three iterations)
- Replaced the model defaults for vegetation with crop-specific nitrogen contents based on the Soil and Water Assessment Tool crop database
- Refined the nitrogen calibration to achieve performance rankings similar to previous model
- Running the model 5 times (25 years) results in loads not changing by more than 3 percent from any area (most areas have less change)
- Results that follow incorporate these revisions after running the model 5 times

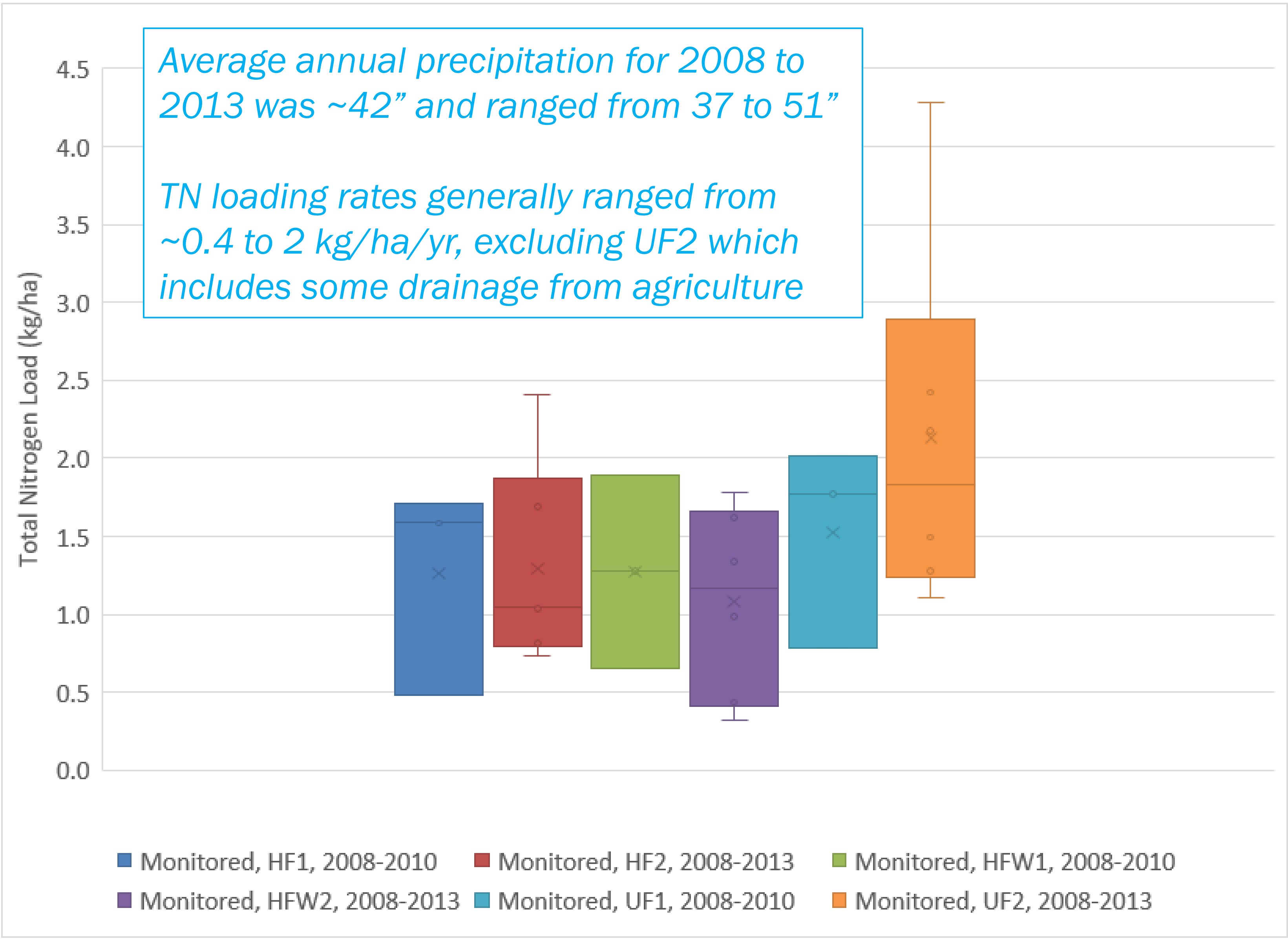
Question: Why are forest loading rates simulated by the UNRBA model for 2014 to 2018 higher than those measured by the Forest Service?

Forest Service Monitoring Studies

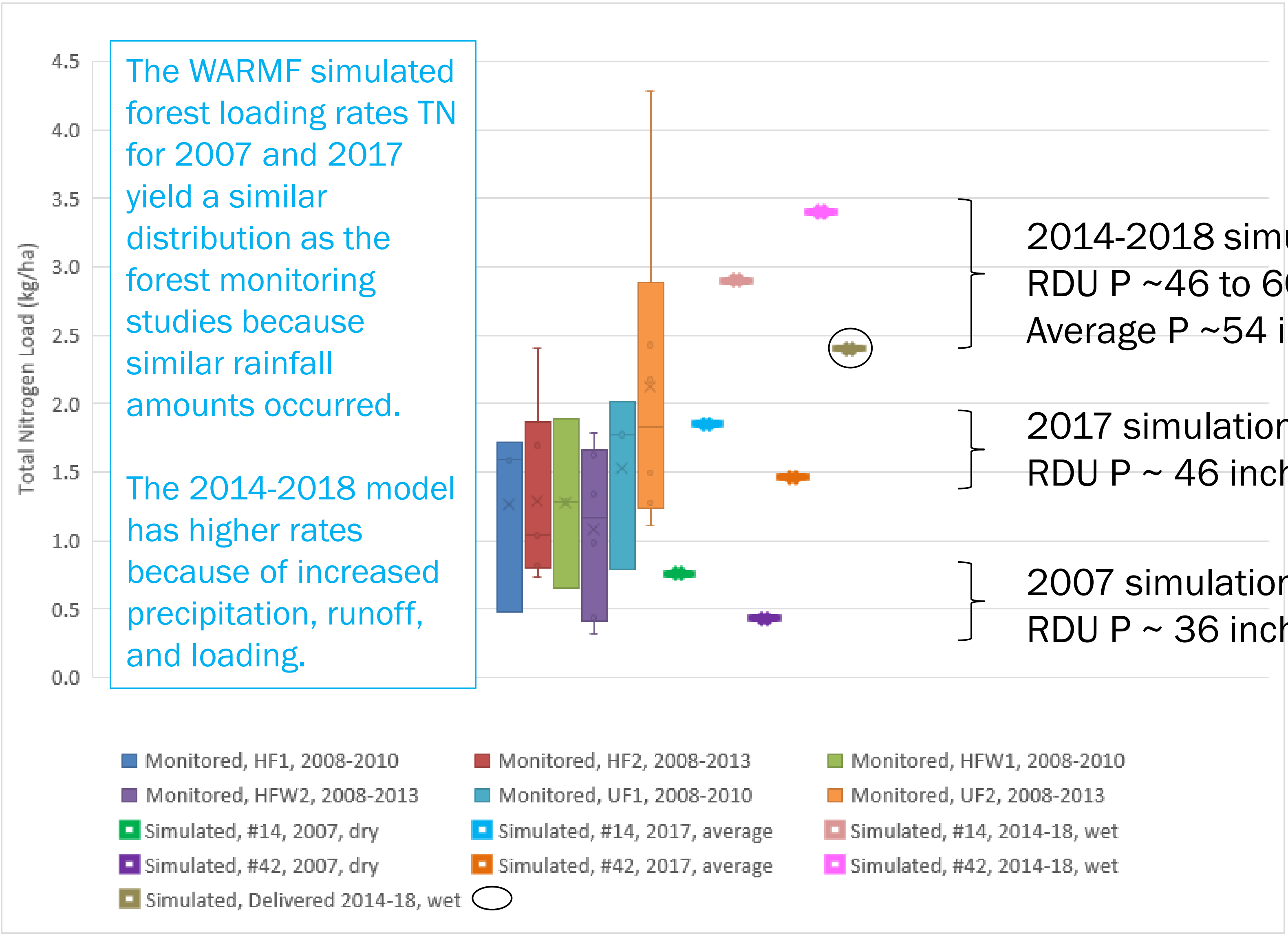
- The Forest Service conducted monitoring studies from 2008 to 2013 on forested headwater catchments in the Falls Lake watershed
  - Average annual precipitation is 42 inches at RDU
- Areal loading rates of total nitrogen, phosphorus, and carbon were calculated based on storm flow and baseflow sampling
  - The Forest Service provided box plots summarizing the relevant data (excluding post-harvest data in treatment watersheds)
- Hill Forest is in WARMF Catchment #14 (60 percent forest) which includes a UNRBA monitoring station on Deep Creek
- Umstead Research Farm is in Catchment #19 which does not include a UNRBA monitoring station



Distribution of TN Loading Rates from the Forest Service Monitoring Study

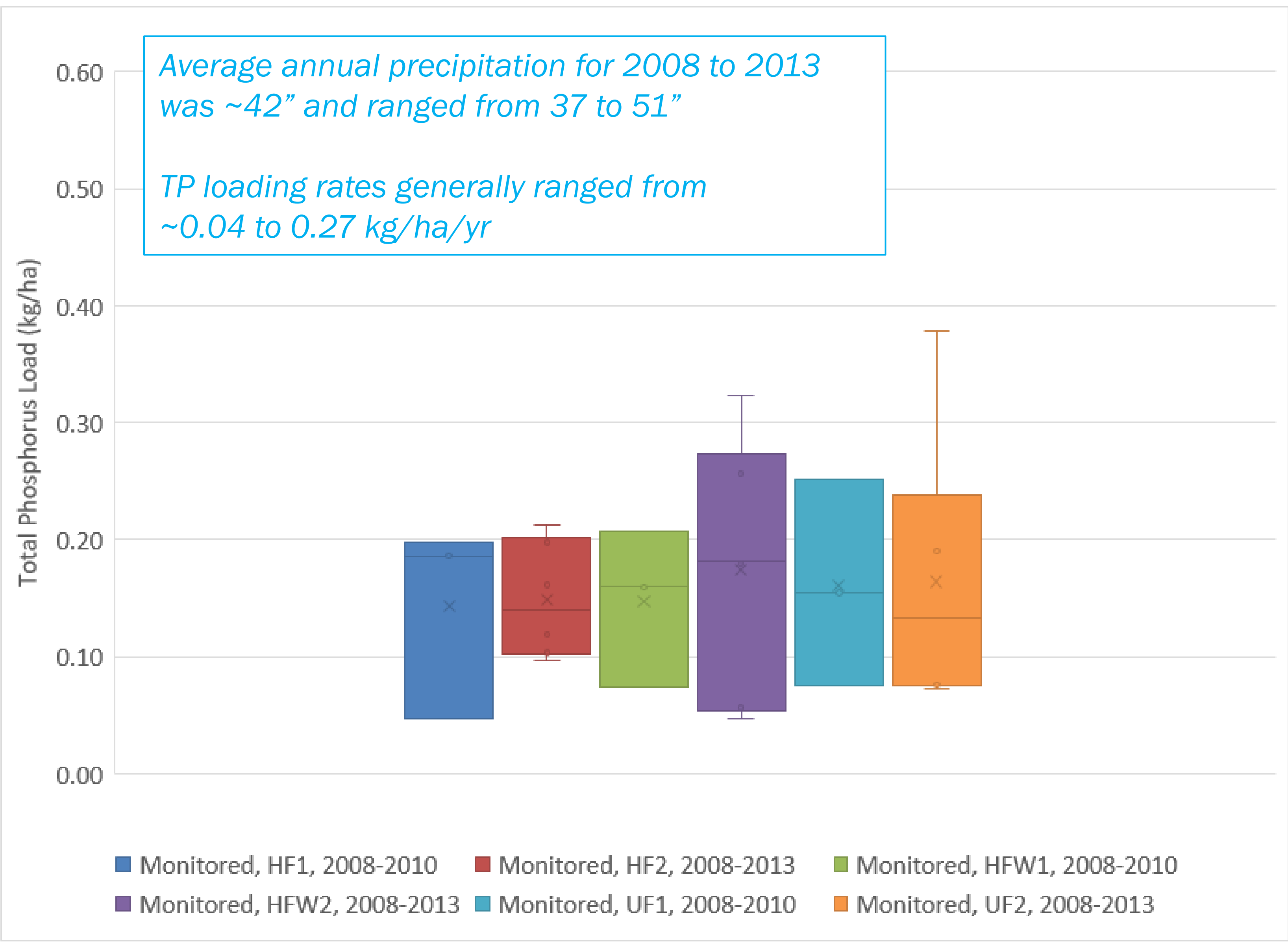


Distribution of TN Loading Rates from the Forest Service Monitoring Study Compared to Simulated Forest Lands for Three Precipitation Conditions



The catchment results do not represent transformations in downstream river segments or impoundments. The "delivered to Falls Lake" result does include these transformations.

Distribution of TP Loading Rates from the Forest Service Monitoring Study



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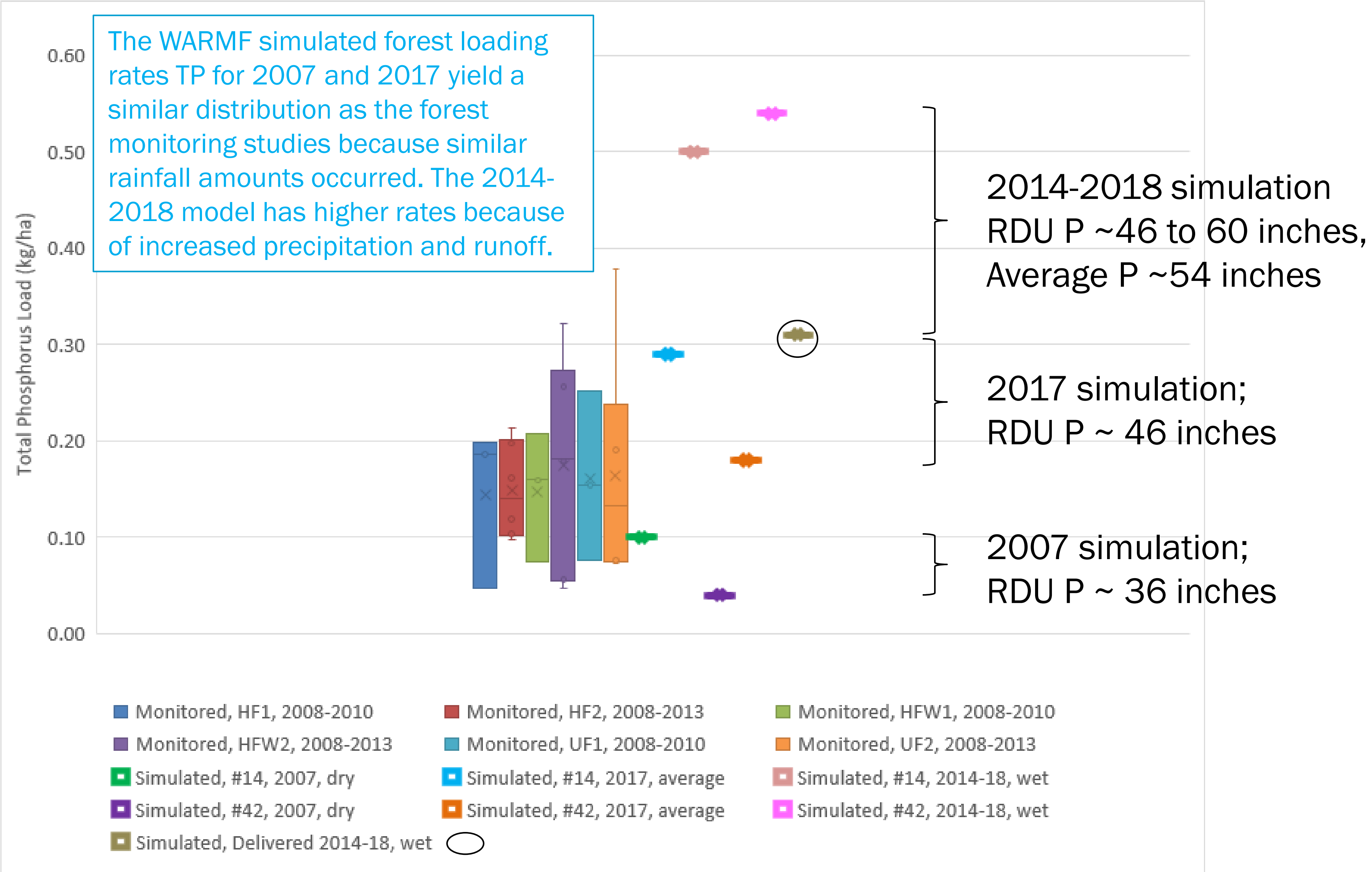
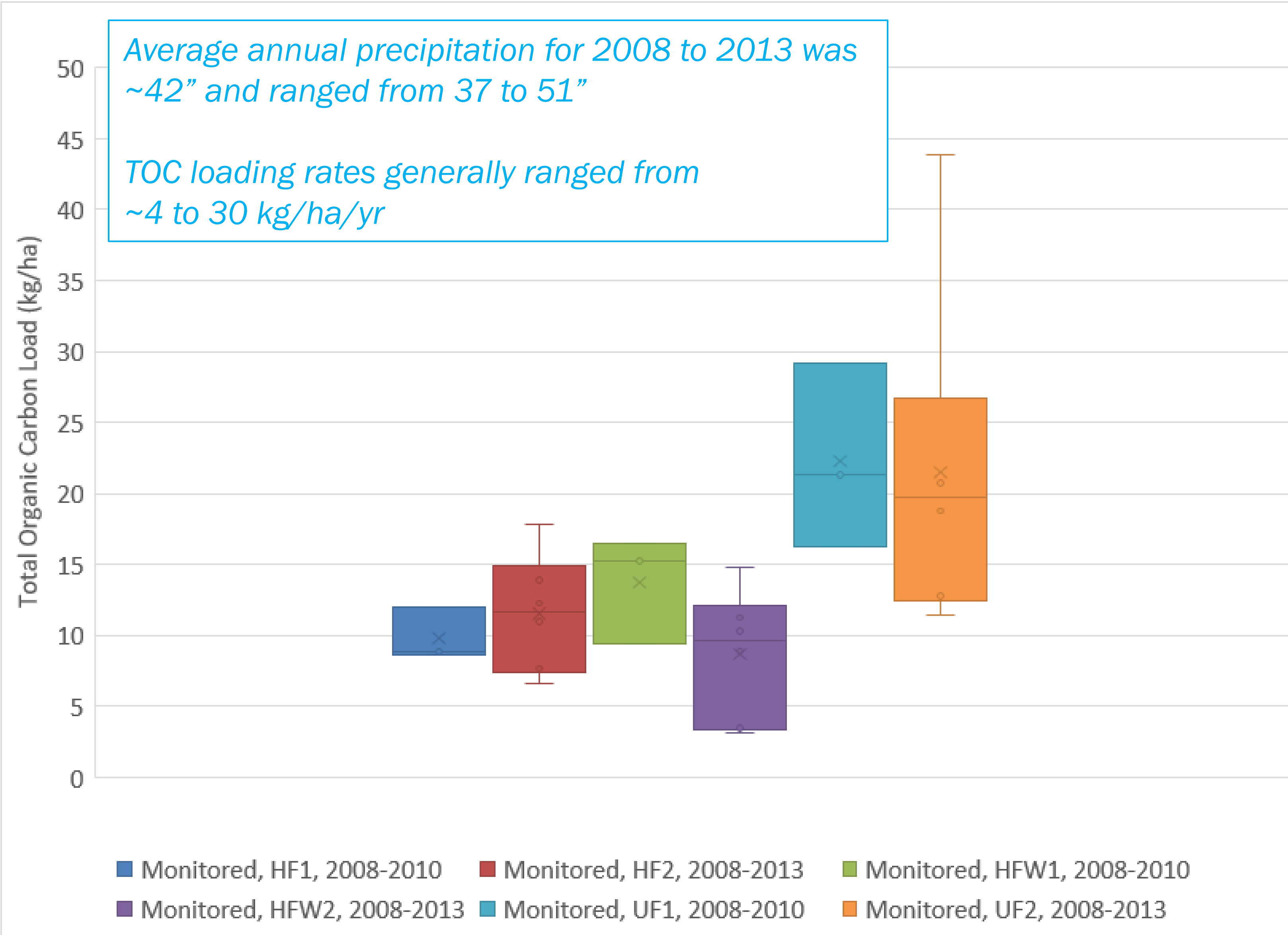
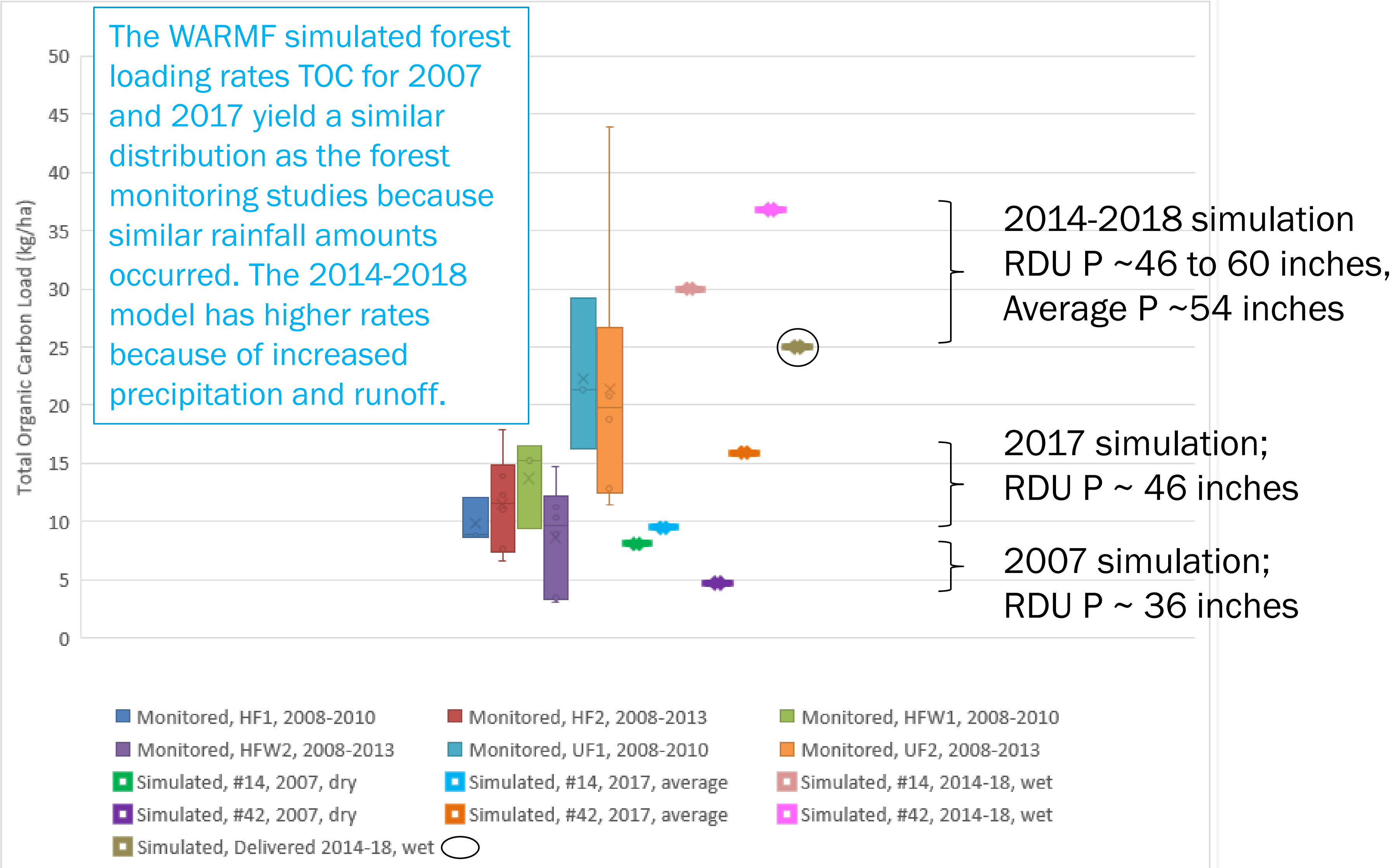


The catchment results do not represent transformations in downstream river segments or impoundments.
The “delivered to Falls Lake” result does include these transformations.

Distribution of TOC Loading Rates from the Forest Service Monitoring Study



Distribution of TOC Loading Rates from the Forest Service Monitoring Study Compared to Simulated Forest Lands for Three Precipitation Conditions



The catchment results do not represent transformations in downstream river segments or impoundments. The "delivered to Falls Lake" result does include these transformations.

Question: why aren’t the WARMF simulated forest loading rates for the Falls Lake watershed much lower than rates simulated for urban areas?

WARMF Simulation of Developed Areas

- WARMF designates the percentages of pervious and impervious areas for each developed land use class
  - Fertilizer can only be applied to pervious areas
  - Atmospheric deposition affects pervious and impervious areas
- WARMF assumes that runoff from impervious surfaces immediately reaches the stream reach in the catchment, unless it is detained
  - If the precipitation/runoff has a lower concentration of a parameter than the stream, rapid dilutions are simulated
  - Natural topography results in some runoff from impervious surfaces flowing over pervious areas. This water volume can either run off or infiltrate and interact with soil particles as it travels to the stream
  - Features in the watershed also retain water, release it more slowly, allow for evaporation, and allow for chemical reaction (increase or decrease concentrations)
- Some BMPs like street sweeping remove pollutants from impervious areas
- The WARMF model allows the user to account for these processes by:
  - Assigning some of the runoff from impervious surfaces to go to “detention”
  - Turning on BMPs like street sweeping or stream buffers

WARMF Accounting for Stream Bank Erosion

- Stream bank erosion is simulated by WARMF separately from the individual land uses
- Stream bank erosion is an average condition for the reach that accounts for soil erosivity, simulated shear stress, bank and vegetation characteristics, etc.
- The hydrologic impacts of impervious surfaces are not reflected in the nutrient loading rates reported by land use - these are the loading rates from the land surface that account for nutrient application/deposition, soil interactions, etc.
- This approach is very different than empirical models that relate land use characteristics in a watershed to water quality observations in streams or assign export coefficients to land uses (Dodd, 1992; Harden et al. 2013, Lin 2004, Tetra Tech 2014, Miller et al. (2019 and 2021))
    - In these studies, the hydrologic impacts on stream bank erosion and resulting nutrient loading rates are associated with the land uses in the drainage area
- Care will need to be taken when messaging nutrient loading results from WARMF that show higher intensity development having lower nutrient loading rates and do not account for hydrologic impacts

Test Conditions for Developed Areas

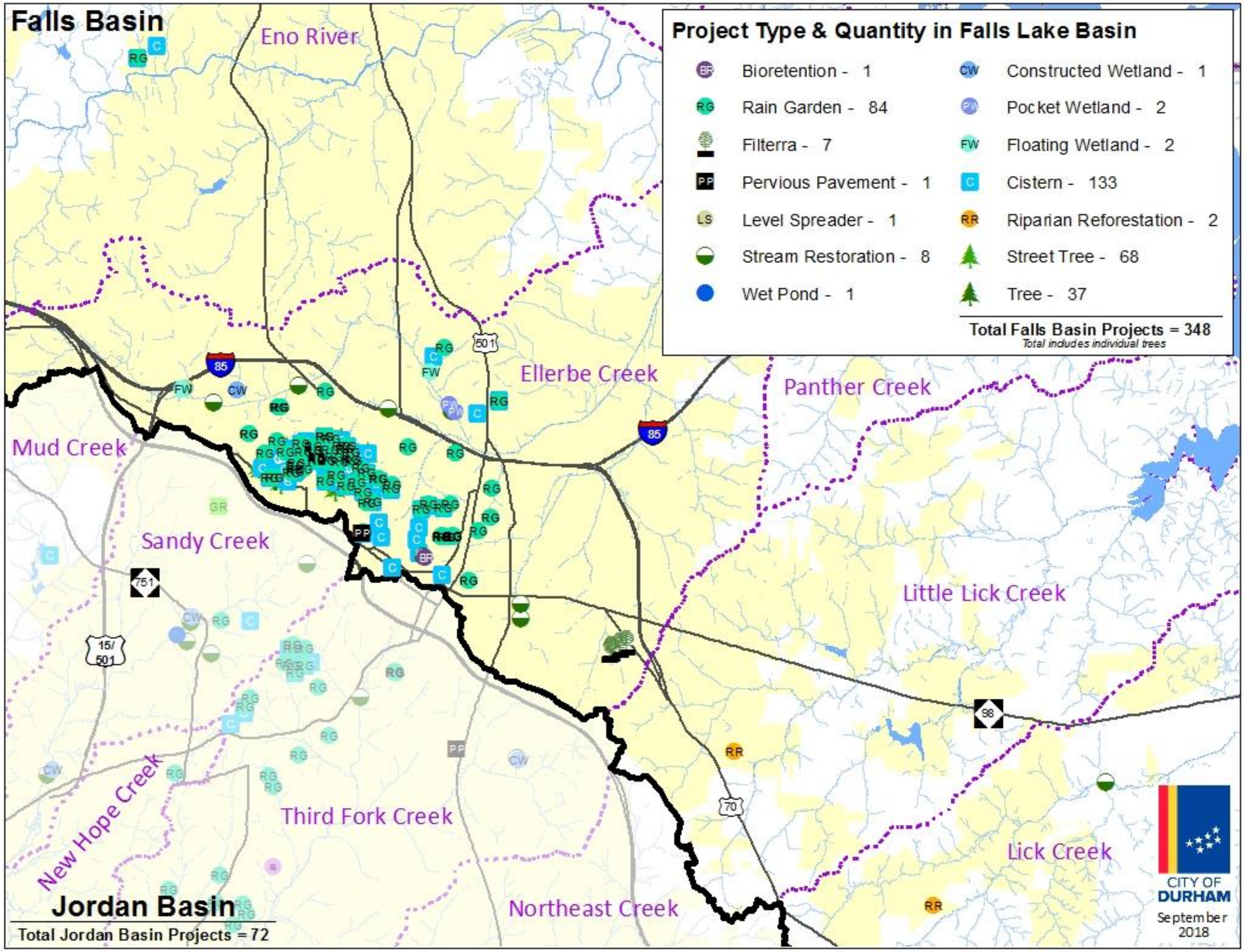
- The Falls Lake Nutrient Management Strategy went into affect in 2011
- The local governments have been implementing best management practices and stormwater control measures to address nutrient loading from development in the watershed (City of Durham example on next slide)
- For the Falls Lake WARMF model, small amounts of detention were assumed in the catchments to calibrate the hydrology and water quality responses in the watershed
- Street sweeping and stream buffers are also present in varying amounts
- We tested the models simulation of urban areas in Ellerbe Creek without BMPs to see what loading rates would be predicted from developed areas
- This test negates implemented practices and topographic routing of impervious surface runoff to pervious areas

City of Durham Existing Development Retrofits as of December 2015

<u>Falls Basin</u>:
348 projects
83% of projects

<u>Jordan Basin</u>:
72 projects
17% of projects

Nearly five times the number of projects have been implemented in the Falls Basin than the Jordan Basin.



Simulated Catchment-Scale Nitrogen Loading Rates for Existing Development and Developed Open Space in Ellerbe Creek, 2014 to 2018

- Land use loading rates to streams, with and without BMPs/stream buffers
- Do not account for downstream stream or impoundment attenuation

Catchment Scale TN Loading Rates (kg/ha/yr) Prior to Instream Processing		
Land Use	With BMPs 2014-18	No BMPs 2014-18
Existing development, high intensity	10.3	11.8
Existing development, medium intensity	12.7	13.8
Existing development, low intensity	12.3	13.2
Developed open space	8.5	8.9
Forest	4.0	4.0

- The urban nitrogen loading rates are slightly higher when the BMPs are removed.
- Nitrogen in dissolved form, associated with fertilizer leaching and atmospheric deposition, is less affected by these BMPs than particulate bound nutrients
- Simulated loads to the stream from urban areas in Ellerbe Creek watershed are 2 to 3 times higher than from forests

Simulated Catchment-Scale Phosphorus Loading Rates for Existing Development and Developed Open Space in Ellerbe Creek, 2014 to 2018

- Land use loading rates to streams, with and without BMPs/stream buffers
- Do not account for downstream stream or impoundment attenuation

Catchment Scale TP Loading Rates (kg/ha/yr) Prior to Instream Processing		
Land Use	With BMPs 2014-18	No BMPs 2014-18
Existing development, high intensity	0.37	0.39
Existing development, medium intensity	0.90	2.0
Existing development, low intensity	1.8	5.2
Developed open space	1.4	2.7
Forest	1.4	2.3

- The urban loading rates for phosphorus are more significantly affected when the BMPs are removed, especially when the percent of pervious area is higher
  - Only pervious areas receive fertilizer in the model
  - Soil-bound P can be eroded and transported
  - Particulate P is treated more effectively due to trapping and settling
  - Dissolved P dominates impervious surface runoff and is quickly transported
- Catchment scale loading rates for urban areas in Ellerbe Creek watershed are 2 to 4 times higher than catchment scale P loading rates for forests (no BMPs/stream buffers affects P load delivered to streams from forests)

Question: does the simulated nutrient load from stream bank erosion differ when the catchment is urban versus forested?

Stream Bank Loading Comparison

- WARMF accounts for loading associated with stream bank erosion as an individual source (it is not lumped into the land uses)
- We compared phosphorus loading from streambank erosion on a per foot basis (load divided by length of stream in the catchment, grams per meter per year (g/m/yr)
- Three catchments with 75 percent or more forest and unmanaged grass/shrubland
- Three urban catchments from the Ellerbe Creek watershed
- Cumulative drainage area is an important consideration because more area for a given land use generally yields more flow that can erode banks
- Percent clay, silt, and sand is important because sand tends to settle out quickly
- Soil erodibility factor is an important distinction when land use is similar

Simulated Phosphorus Loads Associated with Stream Bank Erosion for Forested and Developed Catchments, 2014 to 2018

No downstream stream or impoundment attenuation

Catch-ment	Dominant Land Uses	Cumulative Drainage Area (ac)	Soil erodibility factor	Percent clay, silt, sand	Streambank P load for this reach (g-P/m/yr)	Percent of Catchment P load from reach
42	79 % forest, unmanaged grass	1,133	0.297	15,32,53	0.01	0.01%
14	77% forest, unmanaged grass	20,284	0.150	16,47,37	0.03	0.02%
4	76% forest, unmanaged grass	14,421	0.414	16,48,46	10.2	8.2%
55	50% developed open, 33% existing dev. 5% DOT right of way (ROW)	3,696	0.211	15,23,62	10.7	5.4%
56	33% developed open, 40% existing dev. 6% DOT ROW	4,122	0.222	14,22,64	20.0	3.9%
249	39% developed open, 28% existing dev. 6% DOT ROW	6,804	0.241	13,27,60	150.7	36.2%

- P loading rates from streambanks associated with two forested catchments are three to four orders of magnitude lower than the urban catchments
- The forested catchment streambank P loads at the low end of the urban range has a low percentage of sand (which settles out quickly) and the highest erodibility factor of the catchments evaluated
- Even though the developed catchments have higher percentages of sand than the forested catchments, the impervious surfaces result in hydrologic changes that increase peak flows and stresses on stream banks. As cumulative drainage area increases, so does stream flow and stress on the streambanks in the catchment.

Question: how do urban loading rates change under different hydrologic conditions?

Evaluation

- The Ellerbe Creek watershed was run under three different hydrologic conditions
  - 2014 to 2018 (calibrated model, average to wet years)
  - 2007 (dry year)
  - 2017 (average precipitation year)
- The following slides show <u>delivered loads</u> to Falls Lake; these do account for instream processing

Simulated Delivered Nitrogen Loading Rates for Existing Development and Developed Open Space from Ellerbe Creek to Falls Lake

- Delivered rates account for instream processing
- Evaluated for three hydrologic conditions

Land Use	2007 Hydrology P~36 inches	2017 Hydrology P~46 inches	Calibrated 2014-18 Average P~54 inches
Existing development, high intensity	6.7	7.9	10.3
Existing development, medium intensity	8.5	9.4	12.7
Existing development, low intensity	8.5	9.8	12.3
Developed open space	4.7	5.2	8.5

- The urban nitrogen loading rates increase by 1.5 to 1.8 times when the hydrologic condition goes from dry (2007) to wet (2014 to 2018)

Simulated Delivered Phosphorus Loading Rates for Existing Development and Developed Open Space from Ellerbe Creek to Falls Lake

- Delivered rates account for instream processing
- Evaluated for three hydrologic conditions

Land Use	2007 Hydrology P~36 inches	2017 Hydrology P~46 inches	Calibrated 2014-18 Average P~54 inches
Existing development, high intensity	0.13	0.11	0.37
Existing development, medium intensity	0.27	0.28	0.90
Existing development, low intensity	0.48	0.57	1.78
Developed open space	0.43	0.49	1.39

- The urban phosphorus loading rates increase by 2.9 to 3.7 times when the hydrologic condition goes from dry (2007) to wet (2014 to 2018)

Part 4: how do urban loading rates compare to other modeling studies?

Urban/Developed TN Loading Rates from the Literature (Modeling Studies)

Study	TN Loading Rate kg/ha/yr
Miller et al. (2019) low end of range, post 80s	0.7
Hoos and Roland (2019), low end of range, with delivery accounted for	1.3
Lin (2004) low end of range	1.5
Tetra Tech (2014) low end of the literature range for high density dev.	1.8
Tetra Tech (2014) low end of the simulated range, low-medium density dev.	2.4
Hoos and Roland (2019), high end of range, with delivery accounted for	2.5
Tetra Tech (2014) low end of the literature range, low-medium density dev.	2.9
Harden et al (2013) low intensity urban	3.0
Harden et al (2013) high intensity urban	4.1
Dodd (1992) low end of range	5
Tetra Tech (2014) low end of the simulated range for high density dev.	5.7
Tetra Tech (2014) high end of the sim. range, low-medium density dev.	6.5
Miller et al. (2019) high end of range, post 80s	7.3
Miller et al. (2019) low end of range, pre80s	7.4
Tetra Tech (2014) high end of the lit. range, low-medium density dev.	9.0
Tetra Tech (2014) high end of the simulated range for high density dev.	9.2
Dodd (1992) high end of range	9.72
Miller et al. (2019) high end of range, pre 80s	11.4
Tetra Tech (2014) high end of the literatur range, high density dev.	12.3
Chesapeake Bay CASTNET Phase 6 for developed	18.9
Lin (2004) high end of range	38.5

Simulated TN from Existing Development in Ellerbe Creek Compared to Other Models

WARMF Simulated Land Use	2007 Hydrology	2017 Hydrology	Calibrated 2014-18
Existing development, high intensity	6.7	7.9	10.3
Existing development, medium intensity	8.5	9.4	12.7
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WARMF simulated urban loading rates for N in Ellerbe Creek with BMPs range from 4.7 to 12.7 kg-N/ha/yr depending on the development type and hydrologic condition.

They are within the ranges reported by other modeling studies 0.7 to 38.5 kg-N/ha/yr.

WARMF rates do not account for stream bank erosion (calculated separately).

Urban/Developed TP Loading Rates from the Literature (Modeling Studies)

Study	TP Loading Rate kg/ha/yr
Miller et al. (2019) low, post 80s	0.03
Tetra Tech (2014) low end of the literature range for high density development	0.11
Lin (2004) low end of range	0.19
Hoos and Roland (2019), low, with delivery accounted for	0.21
Tetra Tech (2014) low end of the sim. range, low-medium density dev.	0.26
Hoos and Roland (2019), high, with delivery accounted for	0.34
Harden et al (2013) low intensity urban	0.35
Tetra Tech (2014) low end of the lit. range for low-medium density dev.	0.38
Dodd (1992)	0.45
Harden et al (2013) high intensity urban	0.70
Tetra Tech (2014) high end of the sim. range for low-medium density dev.	0.88
Tetra Tech (2014) low end of the simulated range for high density dev.	0.88
Miller et al. (2019) low, pre80s	1.1
Miller et al. (2019) high, post 80s	1.4
Chesapeake Bay CASTNET Phase 6 for developed	1.4
Dodd (1992)	1.5
Tetra Tech (2014) high end of the simulated range for high density dev.	1.5
Tetra Tech (2014) high end of the lit. range for low-medium density dev.	1.6
Miller et al. (2019) high, pre 80s	1.8
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Simulated TP from Existing Development in Ellerbe Creek Compared to Other Models

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Miller et al. (2019) high, post 80s	1.4
Chesapeake Bay CASTNET Phase 6 for developed	1.4
Dodd (1992)	1.5
Tetra Tech (2014) high end of the simulated range for high density dev.	1.5
Tetra Tech (2014) high end of the lit. range for low-medium density dev.	1.6
Miller et al. (2019) high, pre 80s	1.8
Tetra Tech (2014) high end of the literature range for high density dev.	3.4
Lin (2004) high end of range	6.2

WARMF simulated urban loading rates for P in Ellerbe Creek with BMPs range from 0.13 to 1.78 kg-P/ha/yr depending on the development type and hydrologic condition.

They are within the ranges reported by other modeling studies 0.03 to 6.2 kg-P/ha/yr.

WARMF rates do not account for stream bank erosion (calculated separately).

Question: why are simulated loading rates from agriculture for 2014 to 2018 higher than those typically measured at edge of field?

Loading Rates for Agriculture

- To address this question, we have evaluated three precipitation conditions using the calibrated model for Catchment 42, which has a high percentage of ag land (24%)
- The model was run 5 times under each precipitation condition
- As with the forested areas, loads increase with precipitation

Simulated Nitrogen Loading Rates for Catchment 42 under Varying Precipitation Conditions *(no Stream or Impoundment Attenuation)*

Land use	2007	2017	2014-2018
Conventional Grain Corn	0.24	1.64	3.35
Double-cropped Soybeans	0.42	1.54	3.45
Fescue (Pasture)	0.64	3.84	15.00
Fescue (Hay)	0.40	1.68	3.31
Flue-Cured Tobacco	1.43	2.89	6.44
Full Season Soybeans	0.43	1.55	3.46
No-Till Grain Corn	0.40	1.91	3.48
Wheat	0.10	0.99	4.05

- The N loading rates vary by approximately an order of magnitude based on the amount of precipitation simulated depending on the crop type

Simulated TN from Agriculture Compared to Other Modeling Studies

Study	TN Loading Rate kg/ha/yr
Tetra Tech (2014) low end of the literature range for cropland	0.4
Lin (2004) low end of range for pasture	1.5
Tetra Tech (2014) low end of the modeled range for pasture/grassland	2.0
Lin (2004) low end of range for cropland	2.1
Miller et al. (2019) low end of range for pasture and cropland	2.3
Harden et al (2013) low intensity agriculture	2.4
Tetra Tech (2014) low end of the modeled range for cropland	2.5
Tetra Tech (2014) low end of the literature range for pasture/grassland	3.2
Harden et al (2013) high intensity agriculture	3.8
Dodd (1992) low end of range for pasture and cropland	5
Miller et al. (2019) high end of range for pasture and cropland	5.7
Tetra Tech (2014) high end of the modeled range for pasture/grassland	5.7
Tetra Tech (2014) high end of the modeled range for cropland	11.5
Tetra Tech (2014) high end of the literature range for pasture/grassland	14.0
Dodd (1992) high end of range for pasture and cropland	14.3
Chesapeake Bay CASTNET Phase 6 for pasture/hay	16.7
Lin (2004) high end of range for pasture	30.8
Tetra Tech (2014) high end of the literature range for cropland	49.3
Chesapeake Bay CASTNET Phase 6 for cropland	53.4
Lin (2004) high end of range for cropland	79.6

WARMF simulated crop and pasture loading rates for N in Catchment #42 range from 0.1 to 15 kg-N/ha/y r depending on the precipitation condition.

These are within the ranges reported by other modeling studies (0.4 to 79.6 kg-N/ha/yr).

Simulated Phosphorus Loading Rates for Catchment 42 under Varying Precipitation Conditions ***(no Stream or Impoundment Attenuation)***

Land use	2007	2017	2014-2018
Conventional Grain Corn	0.03	0.25	0.79
Double-cropped Soybeans	0.04	0.23	0.60
Fescue (Pasture)	0.04	0.29	0.72
Fescue (Hay)	0.04	0.25	0.59
Flue-Cured Tobacco	0.04	0.29	0.95
Full Season Soybeans	0.04	0.23	0.61
No-Till Grain Corn	0.04	0.24	0.75
Wheat	0.01	0.15	0.50

- The P loading rates vary by more than an order of magnitude based on the amount of precipitation simulated and the crop type

Simulated TP from Agriculture Compared to Other Modeling Studies

Study	TP Loading Rate kg/ha/yr
Tetra Tech (2014) low end of the literature range for cropland	0.10
Tetra Tech (2014) low end of the simulated range for pasture/grassland	0.10
Lin (2004) low end of range for pasture	0.14
Tetra Tech (2014) low end of the simulated range for cropland	0.18
Harden et al (2013) low intensity agriculture	0.24
Lin (2004) low end of range for cropland	0.26
Tetra Tech (2014) high end of the simulated range for pasture/grassland	0.29
Harden et al (2013) high intensity agriculture	0.35
Miller et al. (2019) low end of range for pasture and cropland	0.40
Tetra Tech (2014) low end of the literature range for pasture/grassland	0.50
Dodd 1992 low end of range for pasture and cropland	0.55
Miller et al. (2019) high end of range for pasture and cropland	0.80
Dodd (1992) high end of range for pasture and cropland	0.99
Tetra Tech (2014) high end of the simulated range for cropland	1.4
Chesapeake Bay CASTNET Phase 6 for pasture/hay	1.7
Chesapeake Bay CASTNET Phase 6 for cropland	2.5
Lin (2004) high end of range for pasture	4.9
Tetra Tech (2014) high end of the literature range for pasture/grassland	5.3
Tetra Tech (2014) high end of the literature range for cropland	6.5
Lin (2004) high end of range for cropland	18.6

WARMF simulated crop and pasture loading rates for P in Catchment #42 range from 0.01 to 0.95 kg-P/ha/y r depending on the precipitation.

These are lower than (2007) or within the ranges reported by other modeling studies (0.1 to 18.6 kg-P/ha/yr).

Outstanding SME question:

- **How do the loading rates vary across catchments for the agricultural land uses?**
  - The original request was for loading rates to be extracted for all 264 catchments
  - After discussion with SMEs, the request has been revised to extract land use data from several catchments ~ 7 with high percentages of agricultural land use for comparison
  - This revised approach will not be resource intensive, and the additional information can be incorporated into the appendix being drafted to describe the SME review process and additional evaluations

Executive Director Input

Outstanding SME question:

- **How does the source load allocation to Falls Lake vary with precipitation condition?**
  - The original request was to run the entire watershed model for 2007 precipitation conditions which would have required modification ~70 meteorology files
  - After discussion with SMEs, the request has been revised to evaluate the distribution of loading for Ellerbe Creek, which has already been run for 2007
  - This revised approach will not be resource intensive, and the additional information can be incorporated into the appendix being drafted to describe the SME review process and additional evaluations

Executive Director Input

Re-Evaluation of Performance Rankings

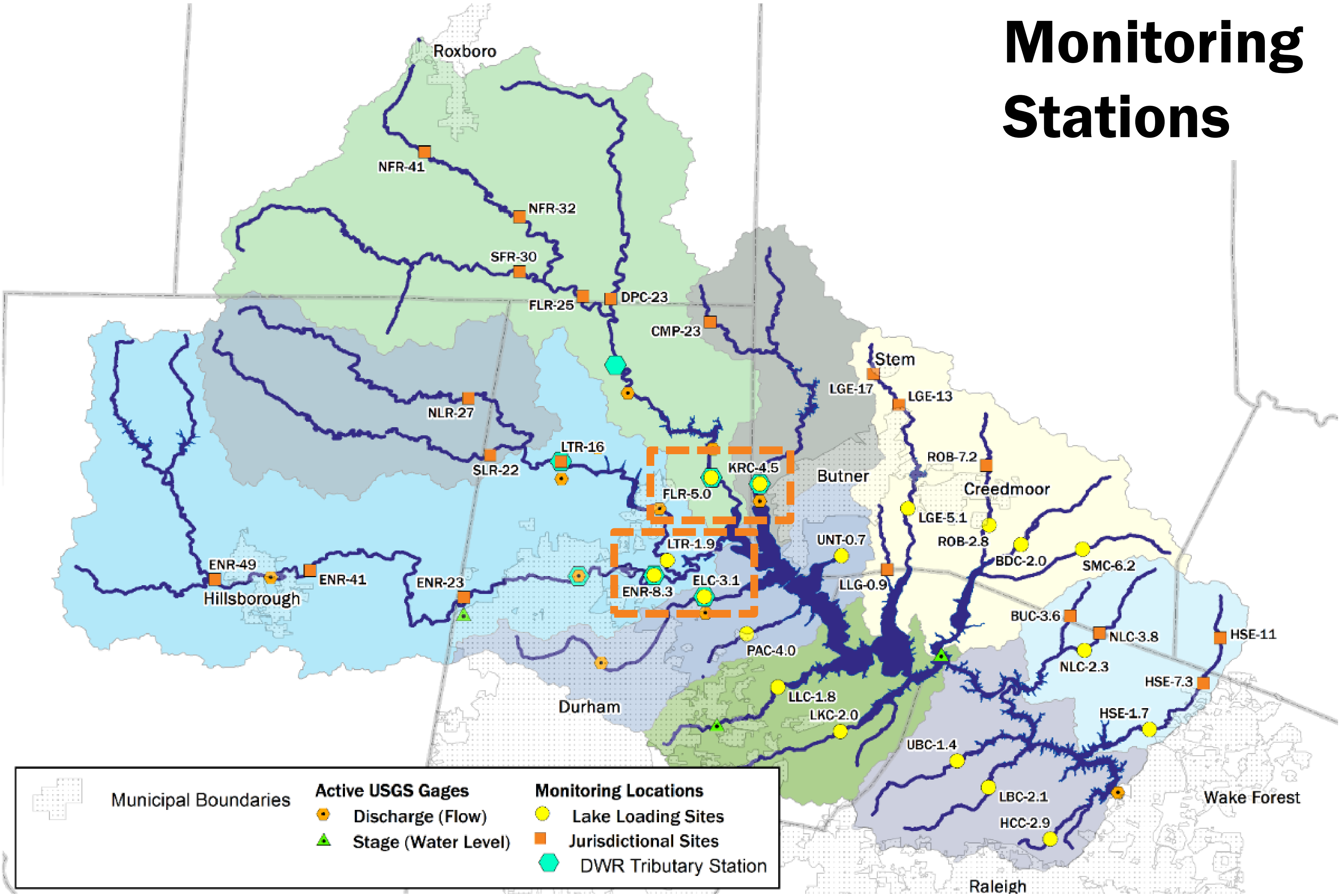
Water Quality Model Performance Criteria

- The UNRBA Modeling QAPP includes the following guidance for water quality calibration (Table A.7-2 from QAPP) for concentrations
- The DWR (2009) watershed modeling report only provided performance criteria for flow, not water quality

Table A.7-2 General Watershed Model Calibration Guidance

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
Flow (Total Volume)	≤ 5%	5-10%	10-15%

Monitoring Stations



Revised Performance Summary for Ellerbe Lake Loading Station (2015-18)

Parameter	Ellerbe – September version before SME Review	Ellerbe- December version after revisions
Temperature	Very good	Very good
TSS	Low	Low
Ammonia	Very good	Very good
Nitrate	Very good	Very good
TKN	Fair	Fair
TN	Very good	Good
TP	Very good	Very good
TOC	Very good	Very good
Chlorophyll-a	Low	Low

- The only change in ranking for Ellerbe Creek was for TN. The percent bias was -12 percent and is now -20 percent. This is due to an under-estimation of TKN.

Revised Performance Summary for Eno River Lake Loading Station (2015-18)

Parameter	Eno - September version before SME Review	Eno- December version after revisions
Temperature	Good	Good
TSS	Fair	Low
Ammonia	High	Fair
Nitrate	Fair	Good
TKN	Very good	Very good
TN	Very good	Very good
TP	Very good	Very good
TOC	Very good	Very good
Chlorophyll-a	Good	Very good

- TSS declined from fair to low.
- Ammonia improved to fair.
- Nitrate improved to good.
- Chlorophyll-a improved to very good.

Revised Performance Summary for Flat River Lake Loading Station (2015-18)

Parameter	Flat - September version before SME Review	Flat- December version after revisions
Temperature	Good	Good
TSS	Low	Low
Ammonia	Very good	Good
Nitrate	Fair	Low
TKN	Good	Very good
TN	Very good	Very good
TP	Good	Good
TOC	Very good	Very good
Chlorophyll-a	Very good	Very good

- Ammonia changed to good. The mean observed concentration is 0.08 mg-N/L.
- Nitrate declined to low; the mean observed concentration of 0.18 mg-N/L.
- TKN improved to very good. The mean TKN concentration is 0.7 mg/L; organic N comprises most of the TN.
- The effect on TN is a simulated mean 10 percent lower (very good) than the average of 0.88 mg-N/L.

Revised Performance Summary for Little River Lake Loading Station (2015-18)

Parameter	Little - September version before SME Review	Little - December version after revisions
Temperature	Good	Good
TSS	Good	Good
Ammonia	High	Low
Nitrate	Very good	Low
TKN	Fair	Very good
TN	Good	Very good
TP	Very good	Very good
TOC	Very good	Very good
Chlorophyll-a	Very good	Very good

- The mean simulated concentration for ammonia is approximately half the mean observed (0.08 mg-N/L).
- Nitrate declined to low; the simulated concentration is 62% lower than the mean observed (0.19 mg-N/L).
- TKN improved to very good; the mean observed concentration is 0.60 mg-N/L.
- The effect on TN is a simulated mean 10 percent lower (very good) than the average of 0.80 mg-N/L.

Revised Performance Summary for Knap of Reeds Creek Lake Loading Station (2015-18)

Parameter	Knap - September version before SME Review	Knap - December version after revisions (full period)	Knap - December version after revisions (validation period)
Temperature	Good	Good	Very good
TSS	Fair	Fair	Fair
Ammonia	Very good	Good	Very good
Nitrate	Fair	Low	Very good
TKN	Very good	Good	Very good
TN	Good	Fair	Very good
TP	Low	Low	Very good
TOC	Very good	Very good	Very good
Chlorophyll-a	Very good	Low	Low

For Knap of Reeds Creek during the calibration period, there is a source of nitrogen and phosphorus that is not represented by the model input files due to missing information. The rankings for the full model period are negatively affected. Once this source is resolved, the rankings are good to very good for all parameters except TSS.

Comparison of Annual Estimated Loads

Parameter, Period	LOADEST	WARMF	% Bias
Total Nitrogen, lb/year			
Full	1,304,526	1,261,700	-3
Calibration Period	1,263,994	1,180,294	-7
Validation Period	1,345,059	1,343,107	0
Total Organic Carbon, lb/year			
Full	10,116,418	10,196,076	1
Calibration Period	8,775,259	9,187,578	5
Validation Period	11,457,576	11,204,573	-2
Total Phosphorus, lb/year			
Full	149,471	146,007	-2
Calibration Period	127,298	125,505	-1
Validation Period	171,644	166,509	-3

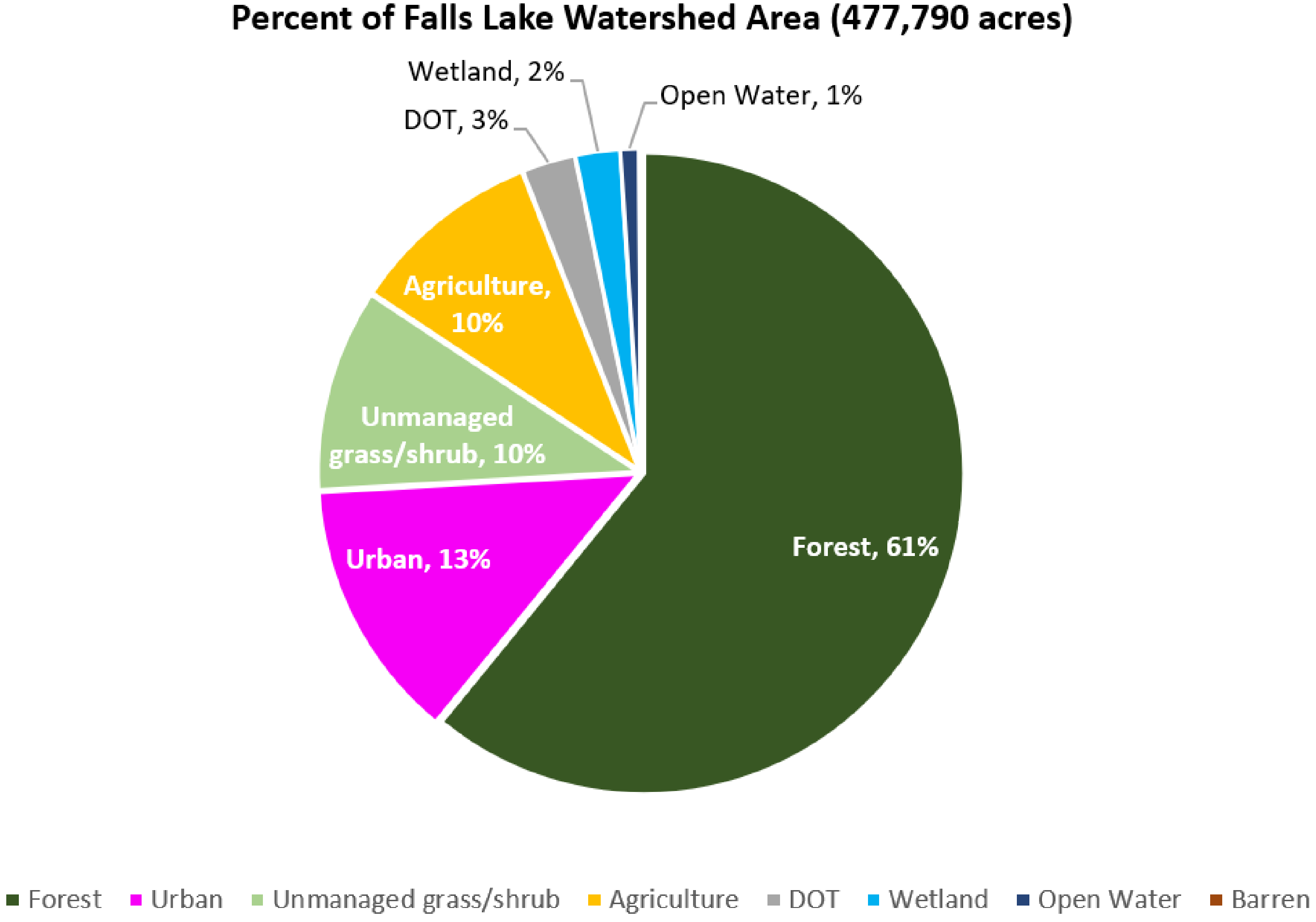
- The annual average loading estimates for both models are within -7 to 5 percent.

Simulated Nutrient Inputs to the Watershed

Simulated Nutrient Inputs and Source Tracking of Delivered Loads

- Most sources of nutrient loading to Falls Lake are represented in the model using model input files; these sources are not tracked separately as delivered loads to Falls Lake except onsite wastewater treatment systems
  - Atmospheric deposition
  - Nutrient application to agriculture or urban land
  - Wastewater treatment facilities
  - Sanitary sewer overflows
  - Onsite wastewater treatment systems
- Some loads are internally calculated by the model like streambank erosion and loading associated with soils, dissolution of nutrients, and erosion (the model tracks these as sources of loading delivered to Falls Lake, but these are not prescribed with model input files)

Land Use Composition for the Falls Lake Watershed



Agriculture:

- *57% pasture*
- *12% full season soybeans*
- *10% hay*
- *7% double-cropped soybeans*
- *6% flue-cured tobacco*
- *6% no-till grain corn*
- *2% wheat or other crops*

Urban:

- *68% developed open space (mostly non-DOT road right of way)*
- *20% existing development, low intensity.*

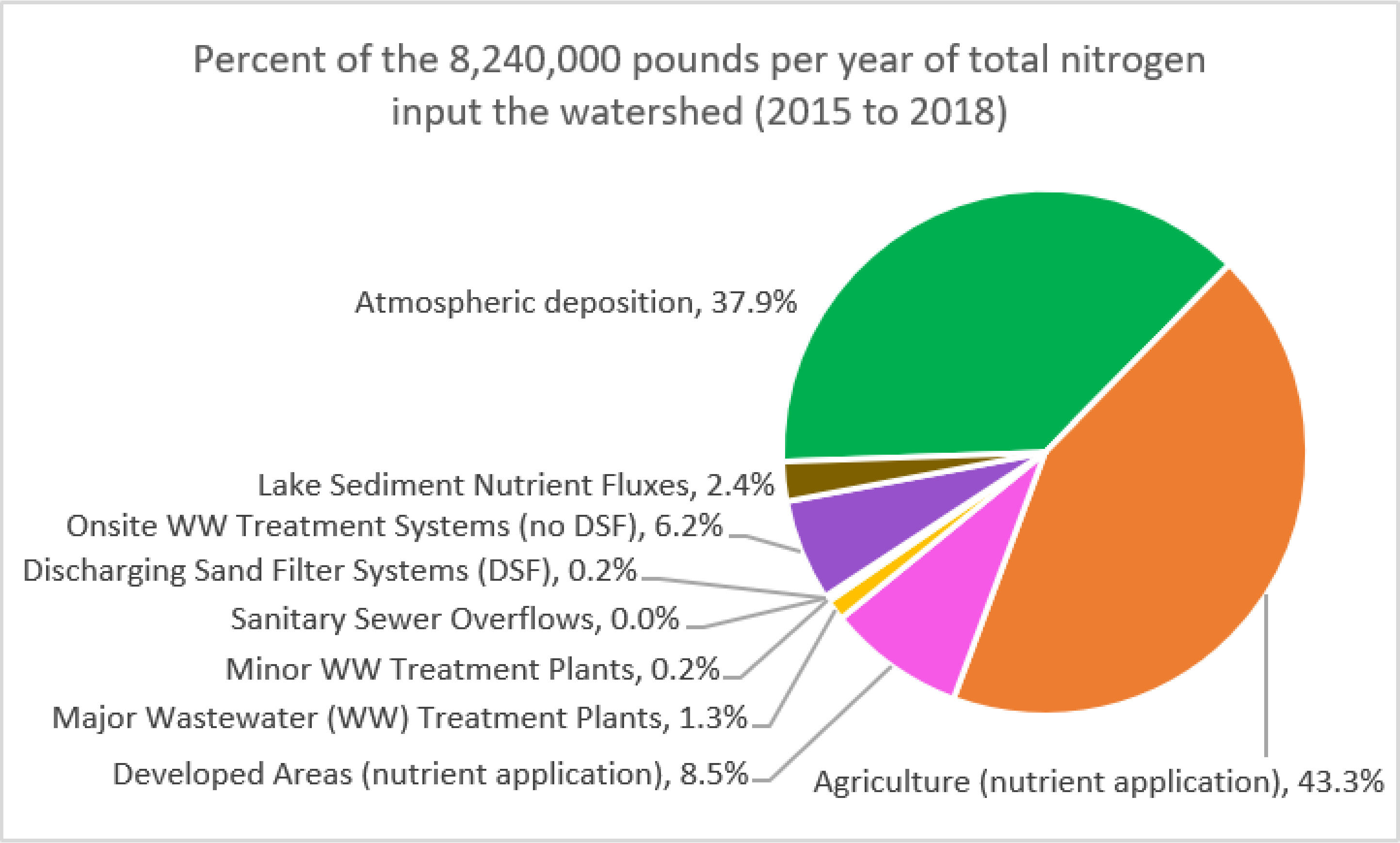
Simulated Nutrient Inputs and Source Tracking of Delivered Loads

- The following pie charts show the percentage of the gross inputs to the watershed from sources that were defined using model inputs
- Internal loading from lake sediments will be simulated soon; for now the pie charts include this using the estimates from the UNRBA 2019 Monitoring Report
- These gross inputs are significantly reduced prior to delivery to Falls Lake

Gross Inputs Versus Delivered Loads

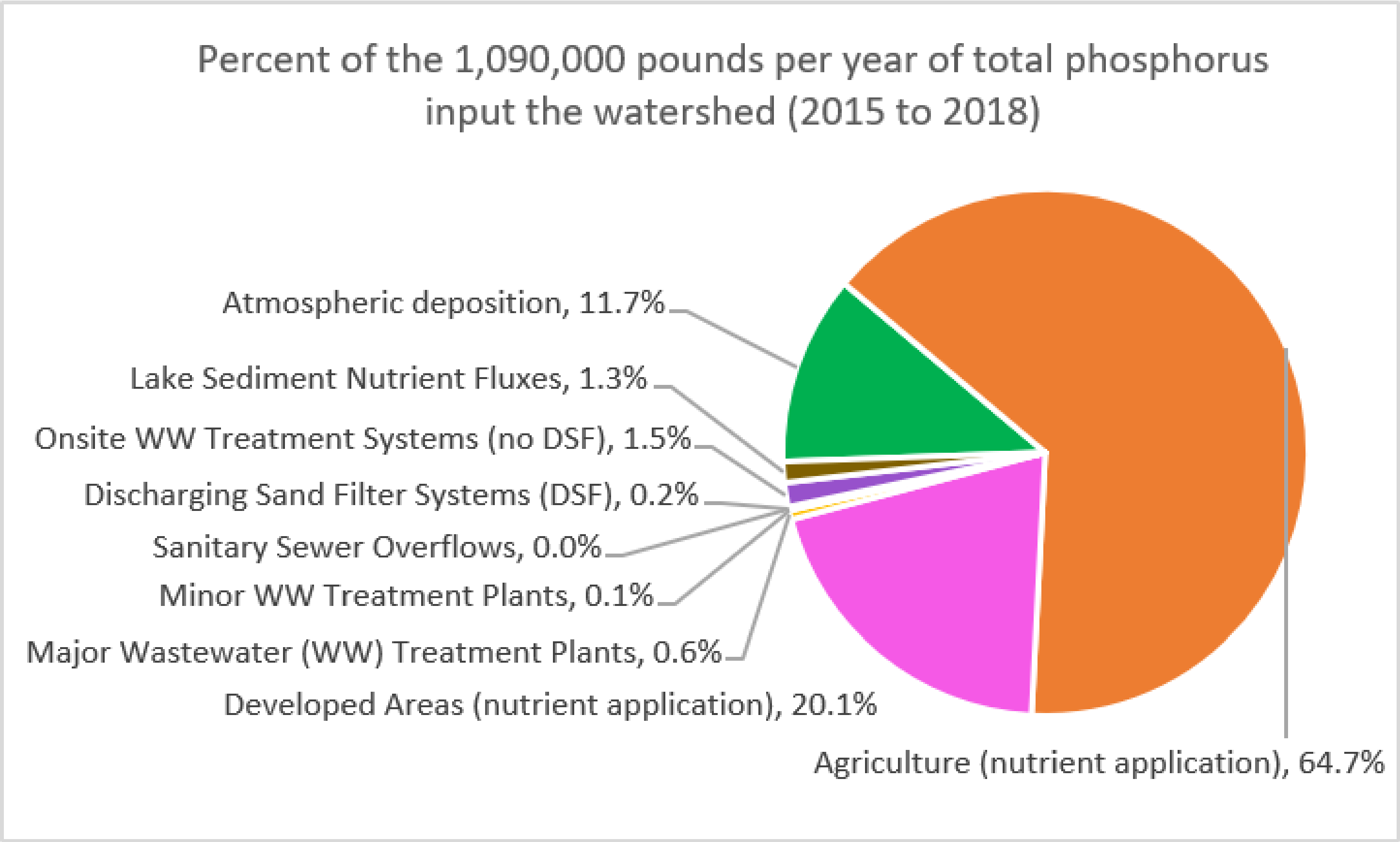
- Gross inputs from nutrient application to agriculture are high relative to other sources
  - Much of these nutrients are stored in crops, harvested, and ultimately removed from the system
  - The % contribution to delivered load is smaller than the % contribution of inputs
- Atmospheric deposition is also a major input which affects all land use types
  - A portion of this load is also removed with crops
  - % contribution to delivered load is smaller than % contribution of inputs
- The percent contribution from wastewater (WW) treatment plants is relatively small in terms of inputs to the system
  - These are directly discharged to streams
  - % contribution to delivered load is larger than % contribution of inputs
- Streambank erosion is a significant source of delivered loading of phosphorus (~15 %) but is not reflected in these pie charts because it is calculated internally by the model

Gross Total Nitrogen Inputs to the Watershed



Watershed processes including vegetation uptake, crop harvesting, overland and aquatic transformations in streams and impoundments reduce the total nitrogen load by approximately 79 percent prior to delivery to Falls Lake.

Gross Total Phosphorus Inputs to the Watershed



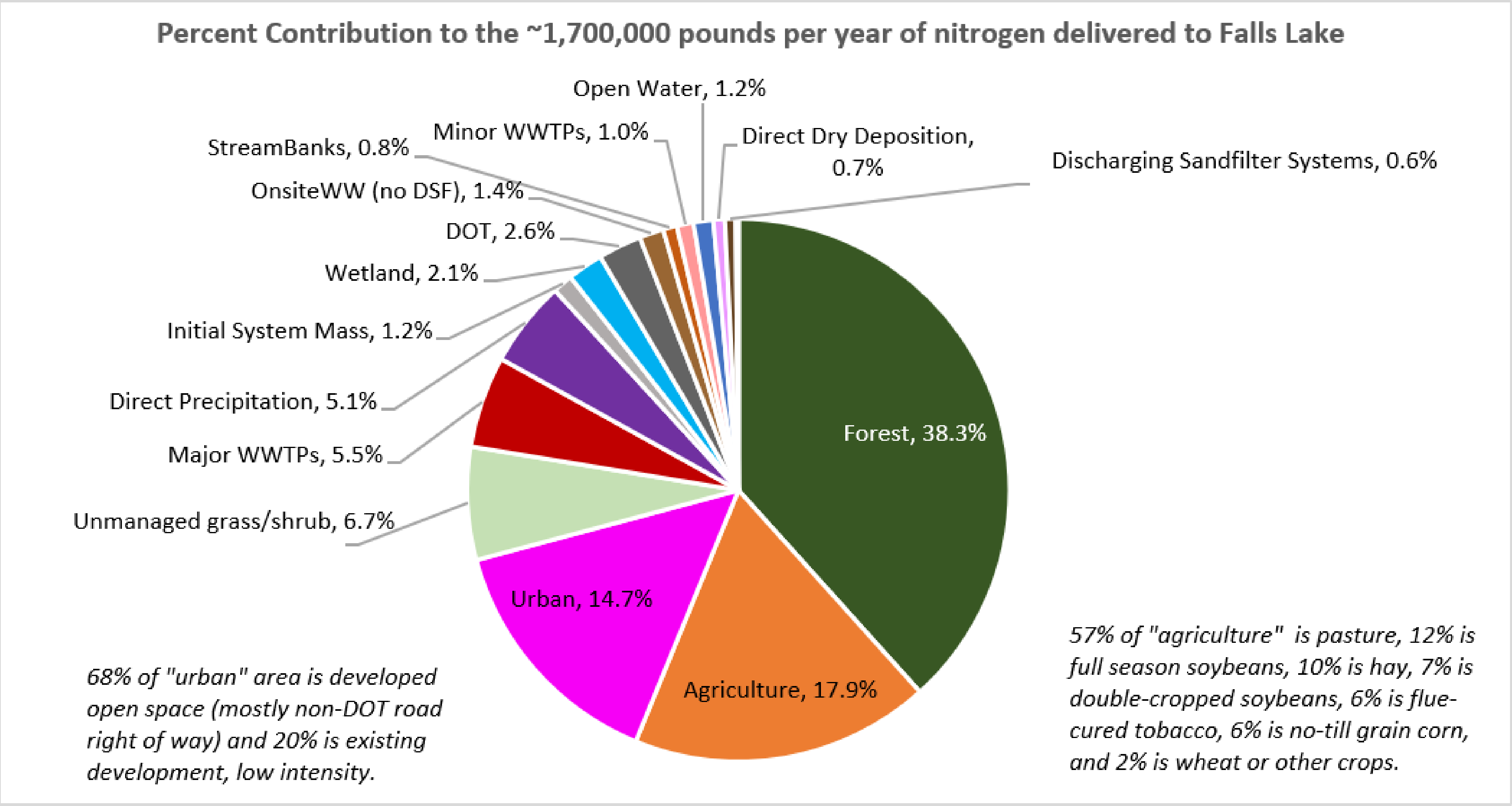
Watershed processes including vegetation uptake, crop harvesting, overland and aquatic transformations in streams and impoundments reduce the total phosphorus load by approximately 84 percent prior to delivery to Falls Lake.

Source Load Allocations for Delivered Loads to Falls Lake

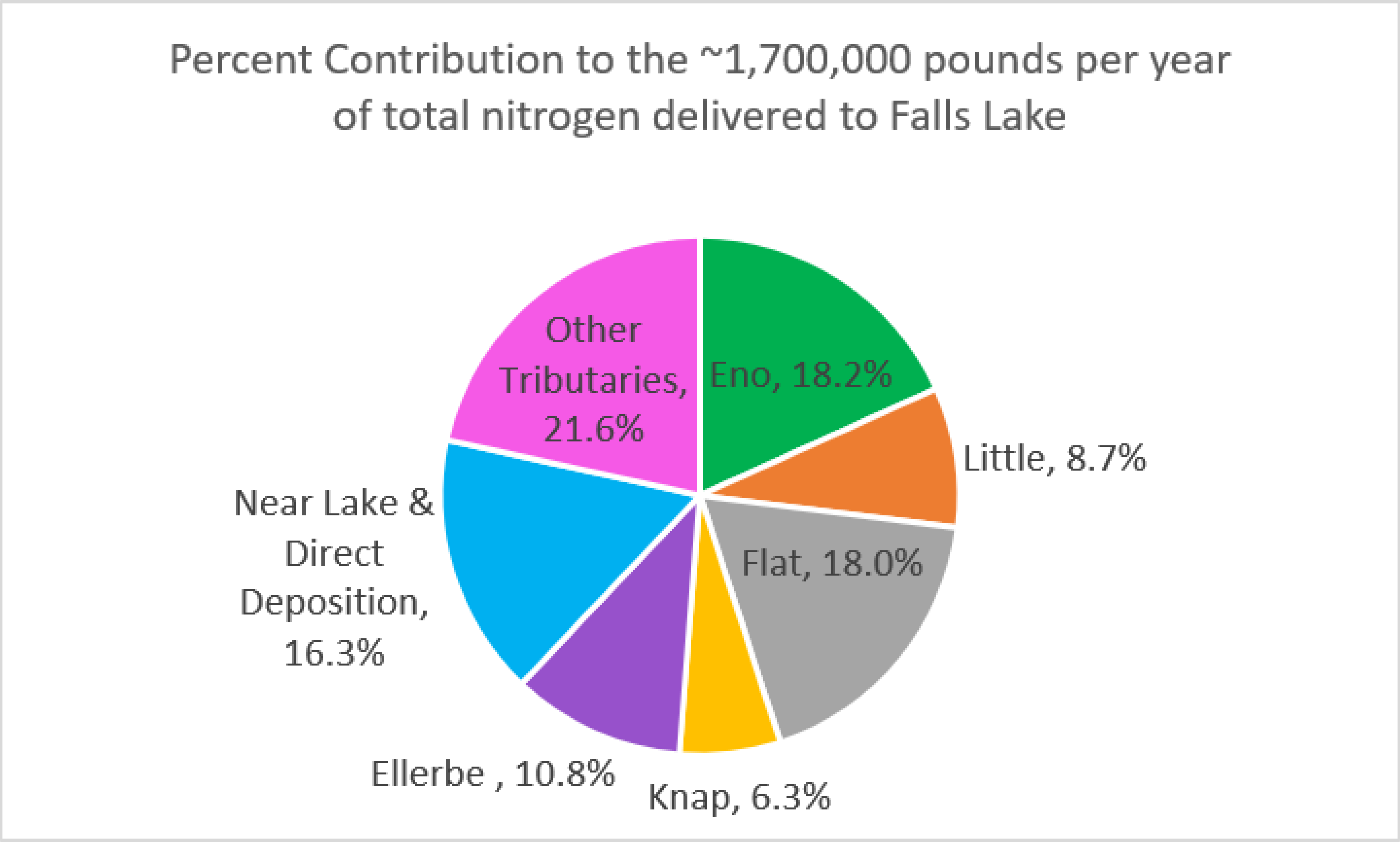
Source Load Allocations

- WARMF tracks loads from each source in the watershed
  - Individual land uses
  - Individual types of onsite wastewater treatment systems
  - "General point sources" (includes major and minor dischargers, discharging sand filter systems, and sanitary sewer overflows)
  - "General nonpoint sources" (accounts for the initial mass in the streams and impoundments)
  - Stream bank erosion
  - Direct wet and dry deposition to lake surfaces
- The following pie charts show the percent contribution of the delivered load to Falls Lake which accounts for instream and impoundment processes that reduce loading before it is delivered to the lake

Total Nitrogen Delivered to Falls Lake

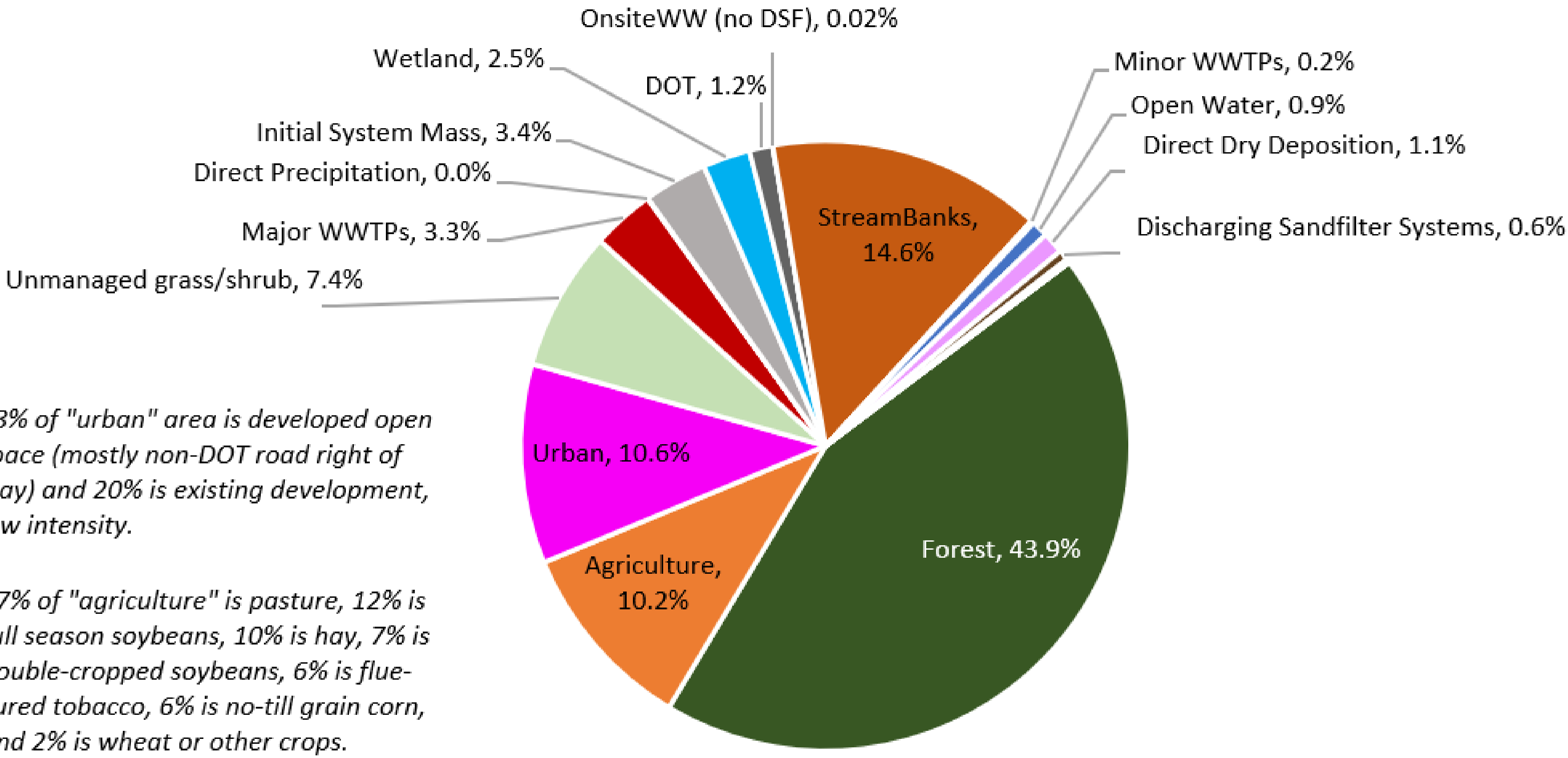


Total Nitrogen Delivered to Falls Lake



Total Phosphorus Delivered to Falls Lake

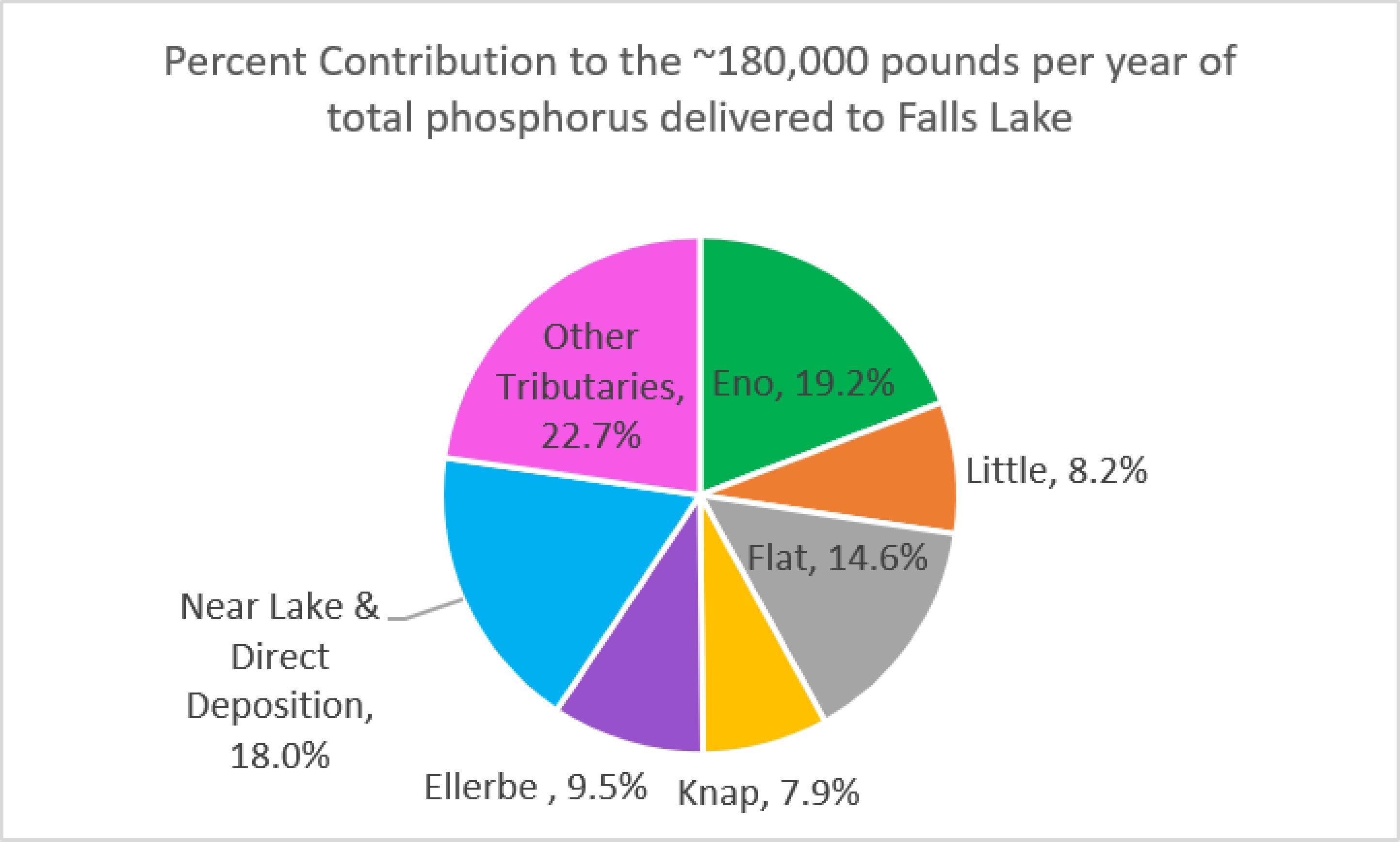
Percent Contribution to the ~180,000 pounds per year of phosphorus delivered to Falls Lake



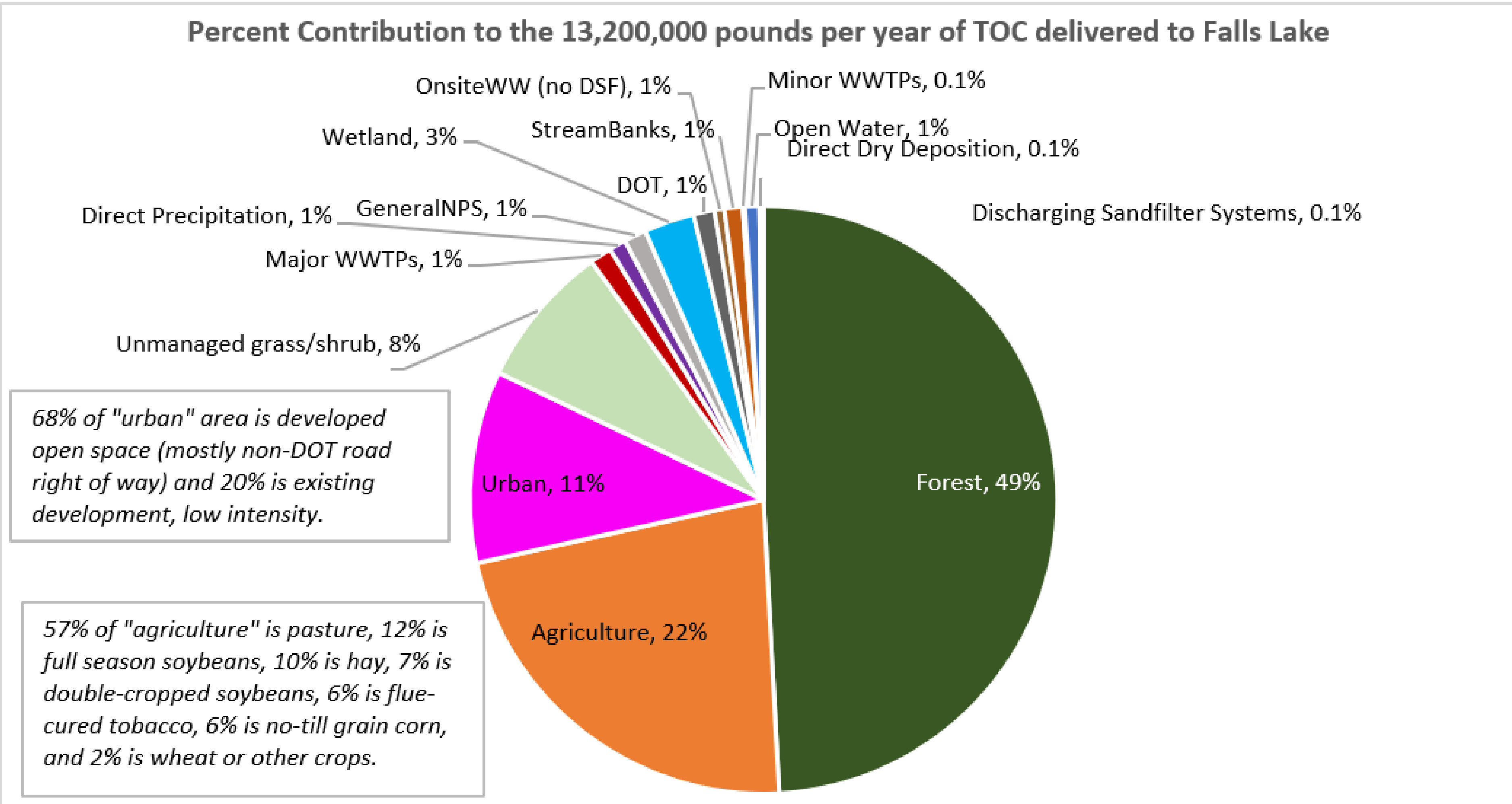
68% of "urban" area is developed open space (mostly non-DOT road right of way) and 20% is existing development, low intensity.

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.

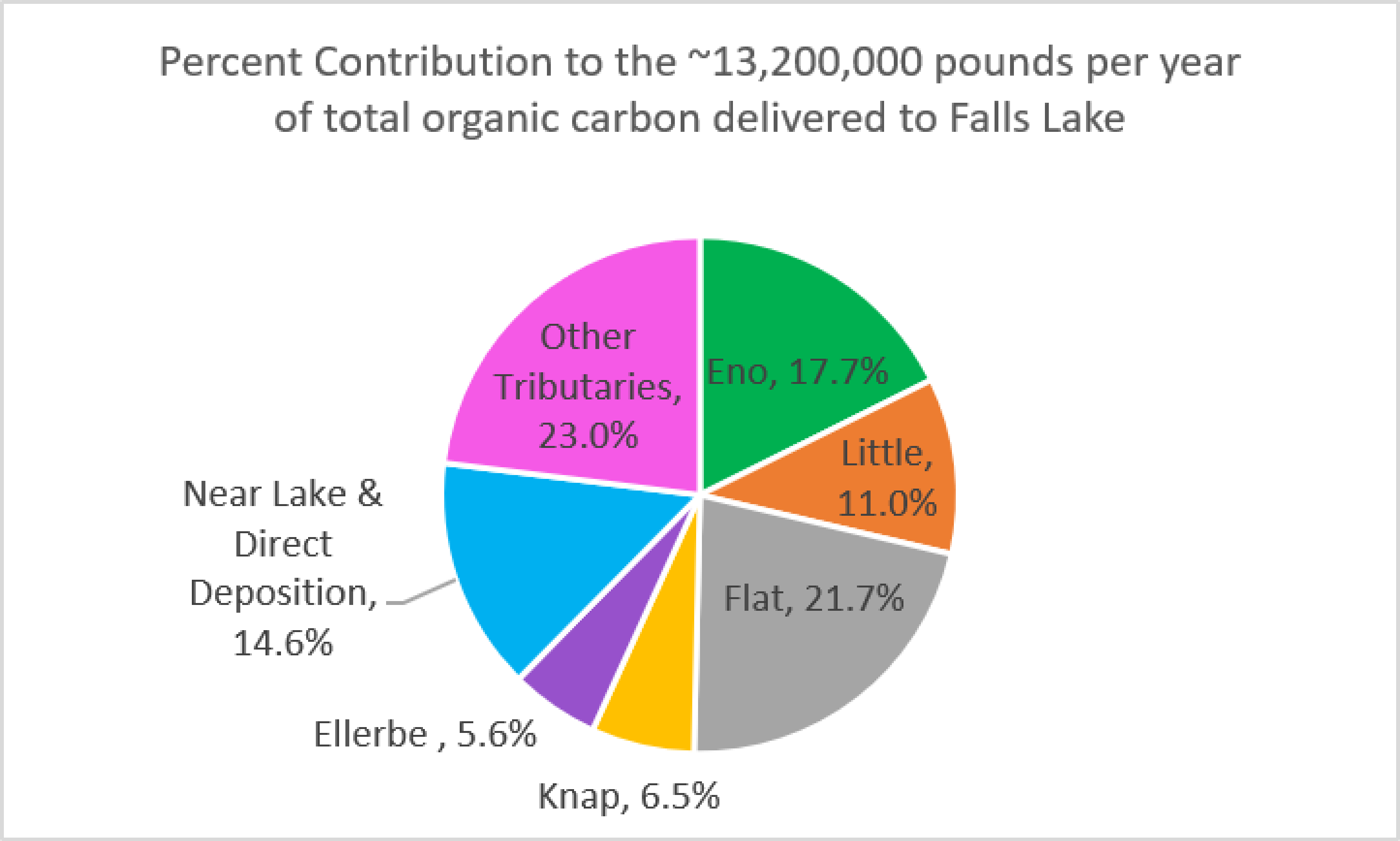
Total Phosphorus Delivered to Falls Lake



Total Organic Carbon Delivered to Falls Lake



Total Organic Carbon Delivered to Falls Lake



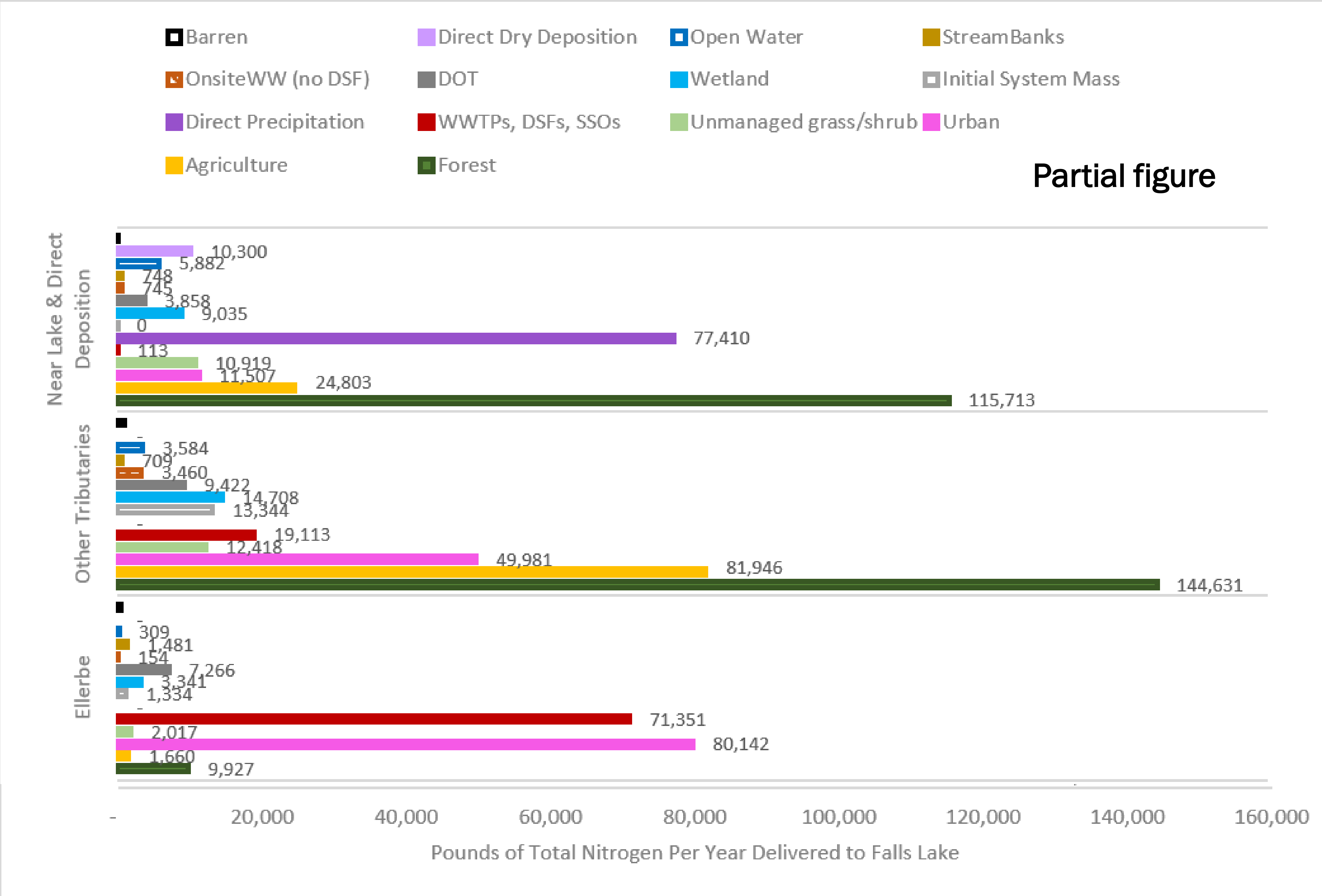
Example table - Total Nitrogen Delivered to Falls Lake

Source Group	Eno	Little	Flat	Knap	Ellerbe	Other Tributaries	Near Lake & Direct Deposi-tion to Lakes	Total
Forest	125,444	65,885	135,427	37,874	9,927	144,631	115,713	634,902
Agriculture	32,331	37,449	92,593	24,962	1,660	81,946	24,803	295,746
Urban	65,194	8,708	15,253	12,246	80,142	49,981	11,507	243,029
Unmanaged grass/shrub	25,398	16,736	39,560	4,209	2,017	12,418	10,919	111,259
WWTPs, DSFs, SSOs	7,479	1,527	237	17,712	71,351	19,113	113	117,531
Direct Precipitation	1,270	2,201	2,843	1,342	-	-	77,410	85,066
Initial System Mass	2,228	1,222	814	852	1,334	13,344	0	19,796
Wetland	1,006	2,706	1,843	2,524	3,341	14,708	9,035	35,164
DOT	15,769	1,757	3,552	1,147	7,266	9,422	3,858	42,771
OnsiteWW (noDSF)	15,560	1,857	2,142	59	154	3,460	745	23,977
Stream Banks	5,964	3,246	835	736	1,481	709	748	13,718
Open Water	4,471	1,497	3,094	617	309	3,584	5,882	19,455
Direct Dry Deposition	162	271	357	175	-	-	10,300	11,265
Barren	494	121	85	35	599	1,165	185	2,684
Total	302,770	145,184	298,634	104,489	179,583	354,483	271,218	1,656,361

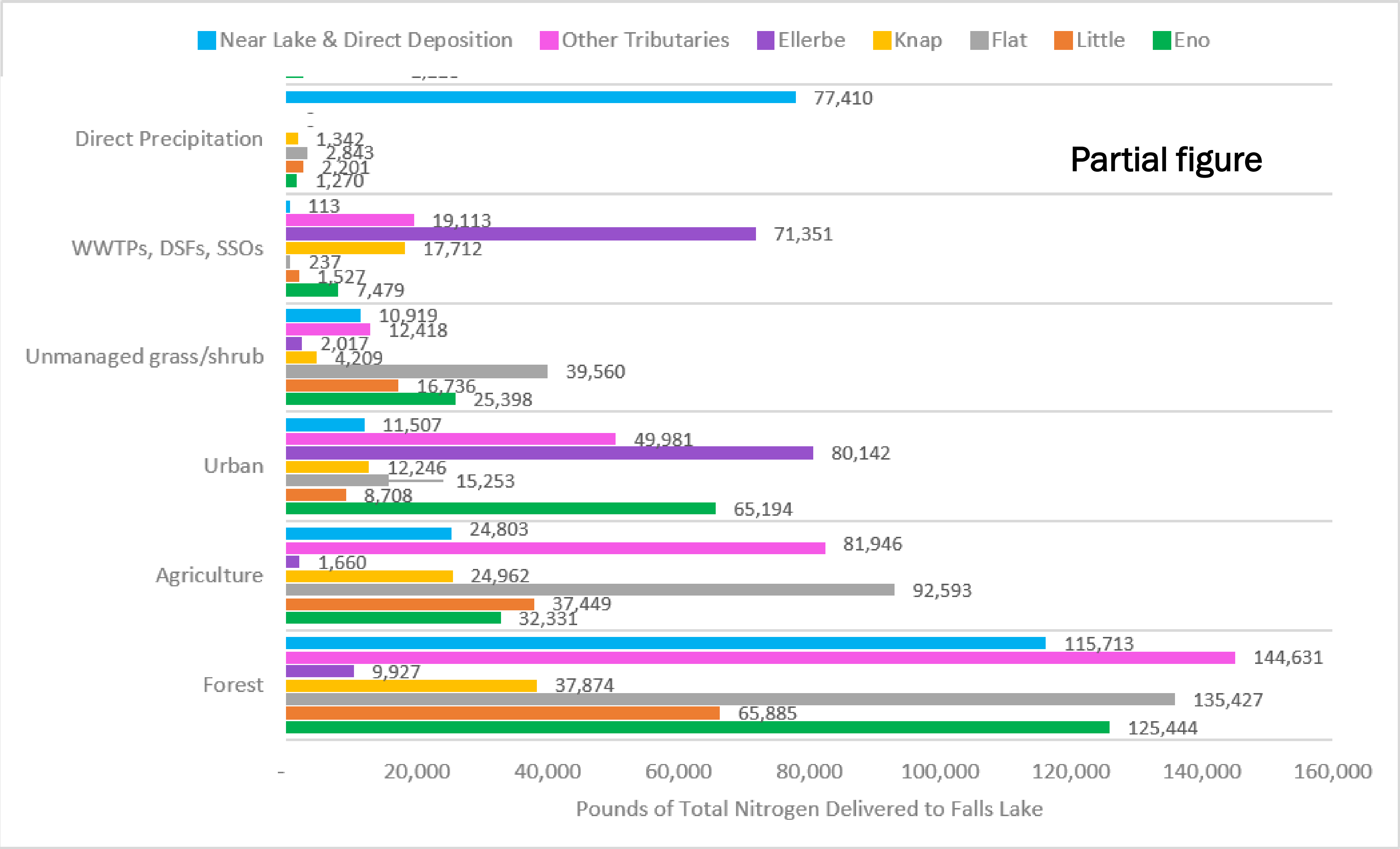
Example table - Total Nitrogen Delivered to Falls Lake

Source Group	Eno	Little	Flat	Knap	Ellerbe	Other Tributaries	Near Lake & Direct Deposition to Lakes	Total
Forest	7.6%	4.0%	8.2%	2.3%	0.6%	8.7%	7.0%	38.3%
Agriculture	2.0%	2.3%	5.6%	1.5%	0.1%	4.9%	1.5%	17.9%
Urban	3.9%	0.5%	0.9%	0.7%	4.8%	3.0%	0.7%	14.7%
Unmanaged grass/shrub	1.5%	1.0%	2.4%	0.3%	0.1%	0.7%	0.7%	6.7%
WWTPs, DSFs, SSOs	0.5%	0.1%	0.0%	1.1%	4.3%	1.2%	0.0%	7.1%
Direct Precipitation	0.1%	0.1%	0.2%	0.1%	0.0%	0.0%	4.7%	5.1%
Initial System Mass	0.1%	0.1%	0.0%	0.1%	0.1%	0.8%	0.0%	1.2%
Wetland	0.1%	0.2%	0.1%	0.2%	0.2%	0.9%	0.5%	2.1%
DOT	1.0%	0.1%	0.2%	0.1%	0.4%	0.6%	0.2%	2.6%
OnsiteWW (noDSF)	0.9%	0.1%	0.1%	0.0%	0.0%	0.2%	0.0%	1.4%
Stream Banks	0.4%	0.2%	0.1%	0.0%	0.1%	0.0%	0.0%	0.8%
Open Water	0.3%	0.1%	0.2%	0.0%	0.0%	0.2%	0.4%	1.2%
Direct Dry Deposition	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.7%
Barren	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.2%
Total	18.3%	8.8%	18.0%	6.3%	10.8%	21.4%	16.4%	100.0%

Example figure - Total Nitrogen Delivered to Falls Lake



Example figure - Total Nitrogen Delivered to Falls Lake



Revised Layering Approach for EFDC Discussed During November PFC Meeting

EFDC and WARMF Lake Modeling

- Both models are transitioning to water quality calibration where the model parameters will be adjusted to provide a good fit to observed data
- Both models separate the water column into layers
- The depths of the layers within each model are consistent; to simulate deeper water, more layers are added
- During the October 5, 2021 the MRSW approved approaches for averaging model layers for comparison to water quality observations for WARMF Lake
- DWR requested additional information regarding the layering approach for EFDC

Revised Approach for EFDC based on Simulated Water Level

- The requested additional information and a revised averaging approach was presented to the PFC at the November meeting
- MRSW members including DWR staff were able to participate in the PFC meeting
- Brief review with MRSW today to close loop

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

MRSW Workgroup Reports

Status of Scenario Screening Workgroup

- Developing a selection process for choosing scenarios and a preliminary list of scenarios to evaluate
- The 7th meeting for workgroup was held September 20, 2021
- Two subgroups of this workgroup are working on scenario forms for scenarios preliminarily assigned a high priority

Plan for Statistical Model Development and Regulatory Options for the Chlorophyll-a Water Quality Standard

Status

- The Technical Advisors Workgroup and DWR have provided contacts to the statistical modeling team to obtain data and information regarding satisfaction of designated uses in Falls Lake
- The statistical modelers continue to reach out to these contacts for data and information
- Modelers are processing and formatting the local, regional, and national datasets that have been obtained

Closing Comments

Additional

Discussion