WARMF Watershed Modeling Status

Modeling Status and Recent Changes

- The modeling team presented preliminary draft water quality modeling results for the WARMF watershed model at the August PFC meeting
- Based on input received during the meeting, the following changes have been made
  - Soil phosphorus concentrations based on USGS published data have been applied and result in improved calibration statistics for phosphorus
  - Nutrient processes in Little River Reservoir have been revised following review of USGS quarterly water quality data collected in the reservoir; results in improved statistics here
  - Code generating comparative statistics has been reviewed and revised for the loading calculations (annual and daily)
  - Annual loading calculations include all loads simulated under all flows for LOADEST and WARMF
  - Modeling performance terminology has been revised (see next topic)

Model Performance Targets

Model Performance Terminology

- During the August PFC meeting, there was a lot of discussion about the proper term for the performance criteria listed in the UNRBA Modeling Quality Assurance Project Plan (QAPP) that includes the quality rankings
- The UNRBA Modeling QAPP says “The percent difference (also known as **percent bias**) is a measure of model error relative to the observed mean and is calculated as follows:

$$\frac{\sum P - O}{\sum O} \times 100$$

- The DWR (2009) modeling report also refers to this equation as percent difference. Without the “x 100”, the DWR report refers to this as relative error.
- The references cited in the UNRBA Modeling QAPP refer to both percent difference and percent mean error in relation to the performance criteria ranked as good, fair, etc.
- Moving forward, we propose to refer to this calculation as **percent bias** because this is the more precise term; discussed with Dan Obenour and he agreed this is appropriate

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
- Loading comparisons to other estimates are included in this presentation for context
  - Are not required by the QAPP
  - Are useful for ensuring loads from big five are reasonably represented as well as other tributaries (when comparing total load to Falls Lake)

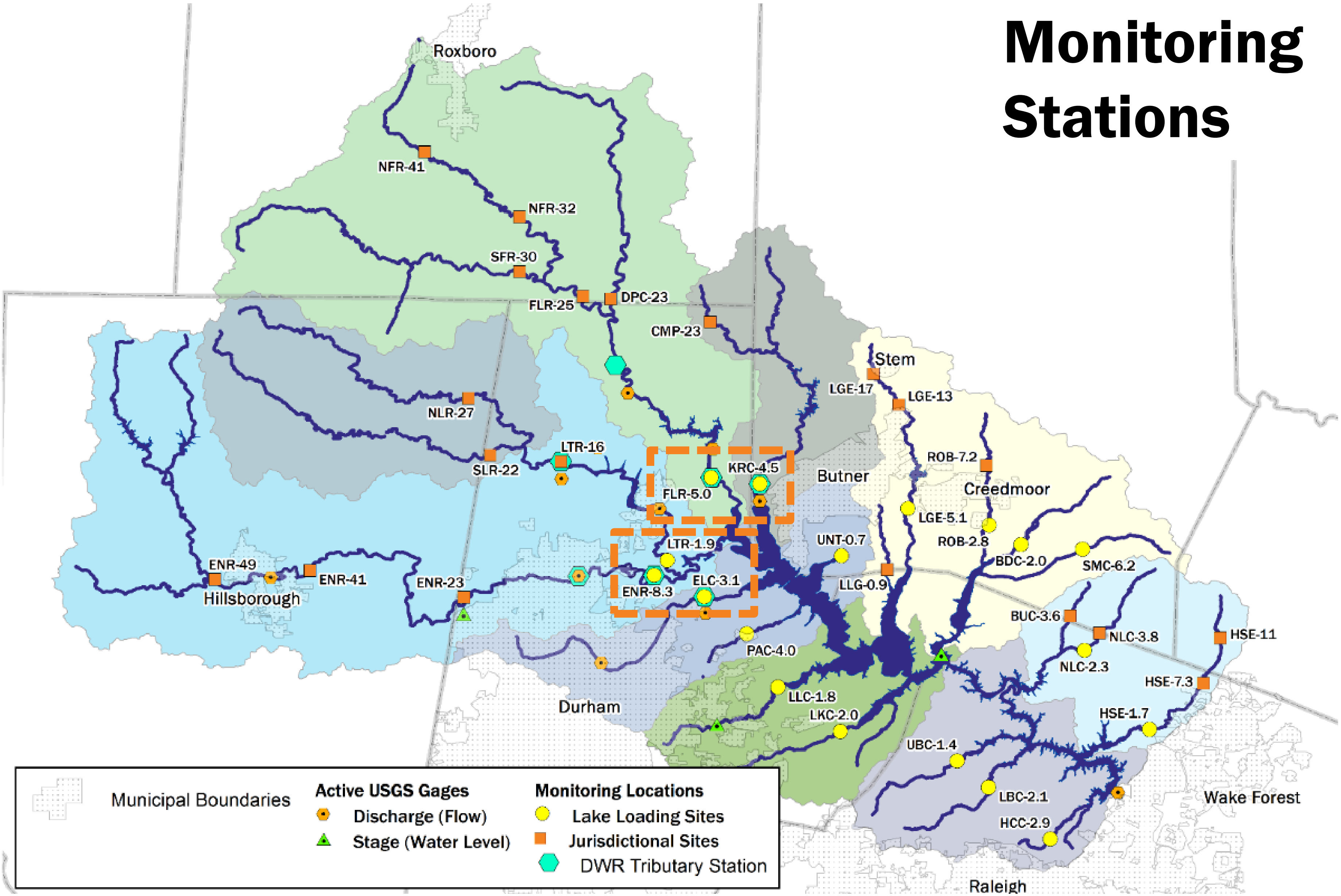
Table A.7-2 General Watershed Model Calibration Guidance

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%

WARMF Watershed Modeling Comparisons

- As described in the QAPP, calibration and performance criteria focus on the upper five tributaries that deliver more than 70 percent of the flow to the lake
- Draft model results were compared to:
  - UNRBA water quality observations (**concentrations**) as well as DWR ambient monitoring data where co-located with a UNRBA Station
  - **Annual loads** estimated using LOADEST (all flows included; all tributaries included)
  - **Daily loads** estimated using water quality observations and daily average flow estimates based on USGS gaged flows
- This presentation includes performance results for the full modeling period (2015-2018) as well as results broken down for
  - Calibration (2015-2016)
  - Validation (2017-2018)

Monitoring Stations



Model Performance Challenges

Calibration Challenges

- We have relatively good model performance statistics for the big five tributaries for most of the parameters
- Models can always be further improved with infinite time and resources
- Performance statistics are important but are challenges and limitations to consider
    - Many water quality parameters are linked, so when the model is adjusted to try to improve one parameter, another or multiple parameters will get worse.
    - Laboratory measurements also have uncertainty and are not “exact” measurements (see UNRBA 2019 Monitoring Report)

Calibration Challenges

- Sampling most often occurred when flows were low to moderate

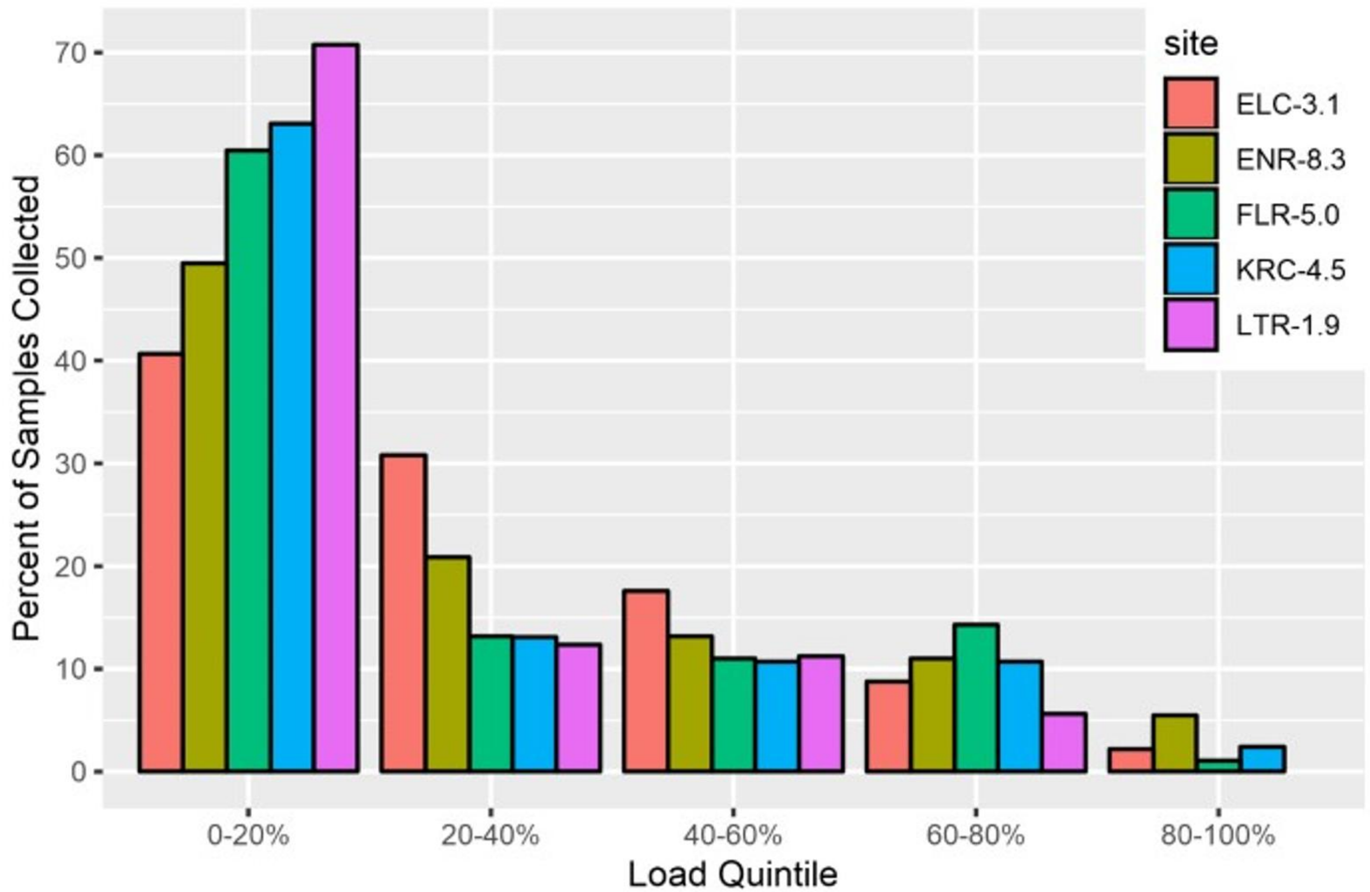


Table 6-3. Field blank concentrations greater than the reporting limit

Parameter	N (Blanks)	N > RL	% > RL	95th Percentile Blank Concentration	Nominal Reporting Limit
Dissolved Organic Carbon, mg/L	46	-	0	< 1.0	1.0
Soluble Ortho-Phosphate as P, mg/L	350	-	0	< 0.01	0.01
Total Organic Carbon, mg/L	169	-	0	< 1.0	1.0
Total Ortho-Phosphate as P, mg/L	102	-	0	< 0.01	0.01
Volatile Suspended Residue, mg/L	79	-	0	< 2.5	2.5
Total Suspended Residue, mg/L	205	2	1	< 2.5	2.5
Chlorophyll-A, µg/L	99	1	1	< 1.0	1.0
Nitrate-Nitrite as N, mg/L	258	4	2	< 0.01	0.01
Total Kjeldahl Nitrogen as N, mg/L	258	4	2	< 0.2	0.2
Total Phosphorus as P, mg/L	253	30	12	0.03	0.02
Ammonia Nitrogen as N, mg/L	254	85	33	0.04	0.01

Field blanks, filling bottles in the field with deionized water, were also evaluated by the laboratory. Table 6-3 lists the number of field blanks exceeding the reporting limit (RL). For ammonia and total phosphorus, the 95%tile blank concentration was > RL.

Table 6-5. The uncertainty and expanded uncertainty (95% confidence interval) associated with the collection of field duplicate samples			
Parameter	Measurement Range	Standard Uncertainty, u	Expanded Uncertainty, U (95% confidence level)
Chlorophyll-a, µg/l	1 - 20	10%	± 19%
	20 - 200	5%	± 9%
Total Organic Carbon, mg/L	1.6 - 21	2%	± 4%
Ammonia Nitrogen as N, mg/L	0.01 - 0.06	35%	± 69%
	0.06 - 0.33	27%	± 54%
Nitrate-Nitrite as N, mg/L	0.01 - 0.2	9%	± 18%
	0.2 - 3.3	4%	± 8%
Total Kjeldahl Nitrogen as N, mg/L	0.2 - 0.8	13%	± 27%
	0.8 - 2.8	12%	± 23%
Total Ortho-Phosphate as P, mg/L	0.01 - 0.25	7%	± 15%
Total Phosphorus as P, mg/L	0.02 - 0.31	22%	± 44%
Total Suspended Solids, mg/L	2.5 - 190	17%	± 33%

For some parameters like ammonia and total phosphorus, the uncertainty in the laboratory measurements is relatively high based on the field duplicates. This uncertainty may affect model performance, particularly at low concentrations.

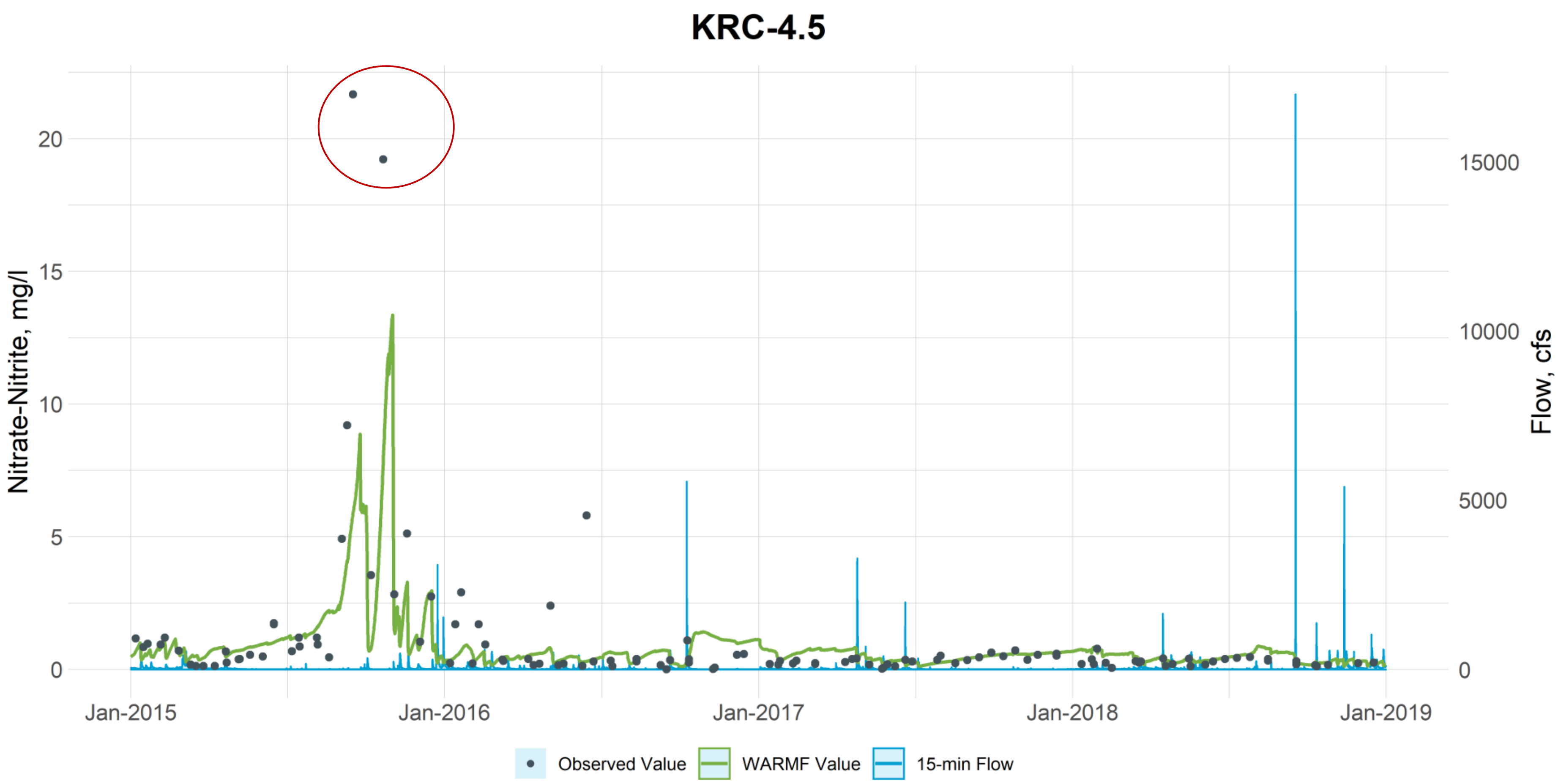
Challenges with Low Concentrations

- When observed concentrations are very low on average, it can be difficult to meet the performance criteria (percentages).
  - **Low concentrations out to hundredths of a mg do not greatly affect loading to the lake especially if they occur during low flows.**
    - E.g., if the average ammonia concentration is 0.1 mg/L, a 50% difference is 0.15 mg/L or 0.05 mg/L.
    - 0.05 mg-N/L in 100 L of water = +- 5 mg-N
  - Alternatively, if the average nitrate concentration is 1 mg/L, a 50% difference could be 0.5 mg/L or 1.5 mg/L. These higher concentrations have a greater potential to impact loading to the lake.
    - 0.5 mg-N/L in 100 L of water = +- 50 mg-N

Challenges with Model Input Data

- The model can only be as good as its inputs
- We have more input data and information than most
- But some events may not have been captured by the input data, for example, Knap of Reeds Creek in late 2015
  - Variation at the WWTP ?
  - Sanitary sewer overflow that wasn't captured?
  - Other illicit discharge?
- The UNRBA monitoring captured an increase in stream concentrations for a specific period (whatever the issue it was resolved)
- The model cannot represent this situation well because we don't have the information needed to specify an input
- This negatively impacts the performance criteria at Knap of Reeds Creek for the calibration period in terms of concentrations, but because flows were relatively low during this period, comparisons of loading are less affected

Challenges with Model Input Data

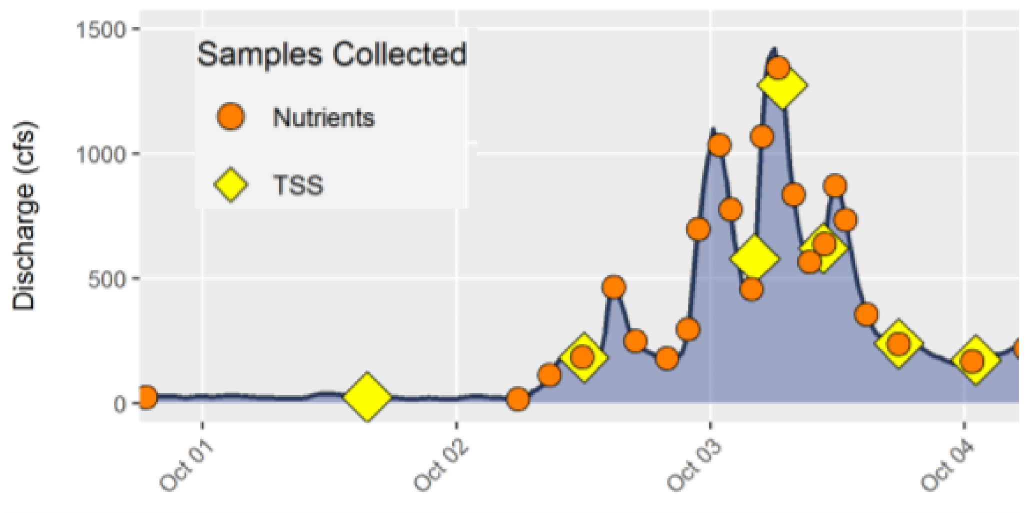


Challenges with Upstream Impoundments

- The presence of upstream impoundments like Lake Michie and Little River Reservoir complicates the calibration.
- Frequent water quality measurements in the lake are not available, so it is difficult to know how well the model is simulating lake processes.
  - Modeling team has reviewed quarterly USGS measurements and modified LRR in response
  - Nitrogen simulations downstream of LRR have improved
- Further improving simulation of these impoundments could take a significant amount of effort given lack of information.
- Without extensive data, there is no reasonable way to develop appropriate lake behavior.
- This could be a critical factor in terms of project schedule

Challenges Associated with Time

- Water quality observations are collected at specific points in time and represent instantaneous conditions
- The WARMF model time step is 6-hours, so each model output represents a 6-hour average, not a specific instant
- Water quality concentrations can change quickly, especially in response to storm events (example of storm event sampling collected on Ellerbe Creek
- This complicates comparisons to daily load estimates which are also based on point-in-time grab samples



Structural Model Changes

Structural Model Changes Required

- WARMF is a “lumped parameter” model, so the land uses, soils, etc. for each catchment are simulated in one “bucket”
- In its default mode, WARMF keeps track of the nutrient balances associated with land uses in a catchment, but the soils are not kept separate (e.g., the soil conditions under the ag land are the same as under forest)
- The local soils bind nutrients for many years, and this contributes to the loading by land use
- Preliminary source load allocation did not generate different results among the land uses because the soils were the same

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

Structural Model Changes Required

- 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	15 to 20 years of simulation

- Given the soil chemistry in the watershed[1], a four-year model period 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 3 to 4 times to reach equilibrium and each iteration takes one day

Model Performance

Gaged Stream Flow Comparisons (Total Volume)

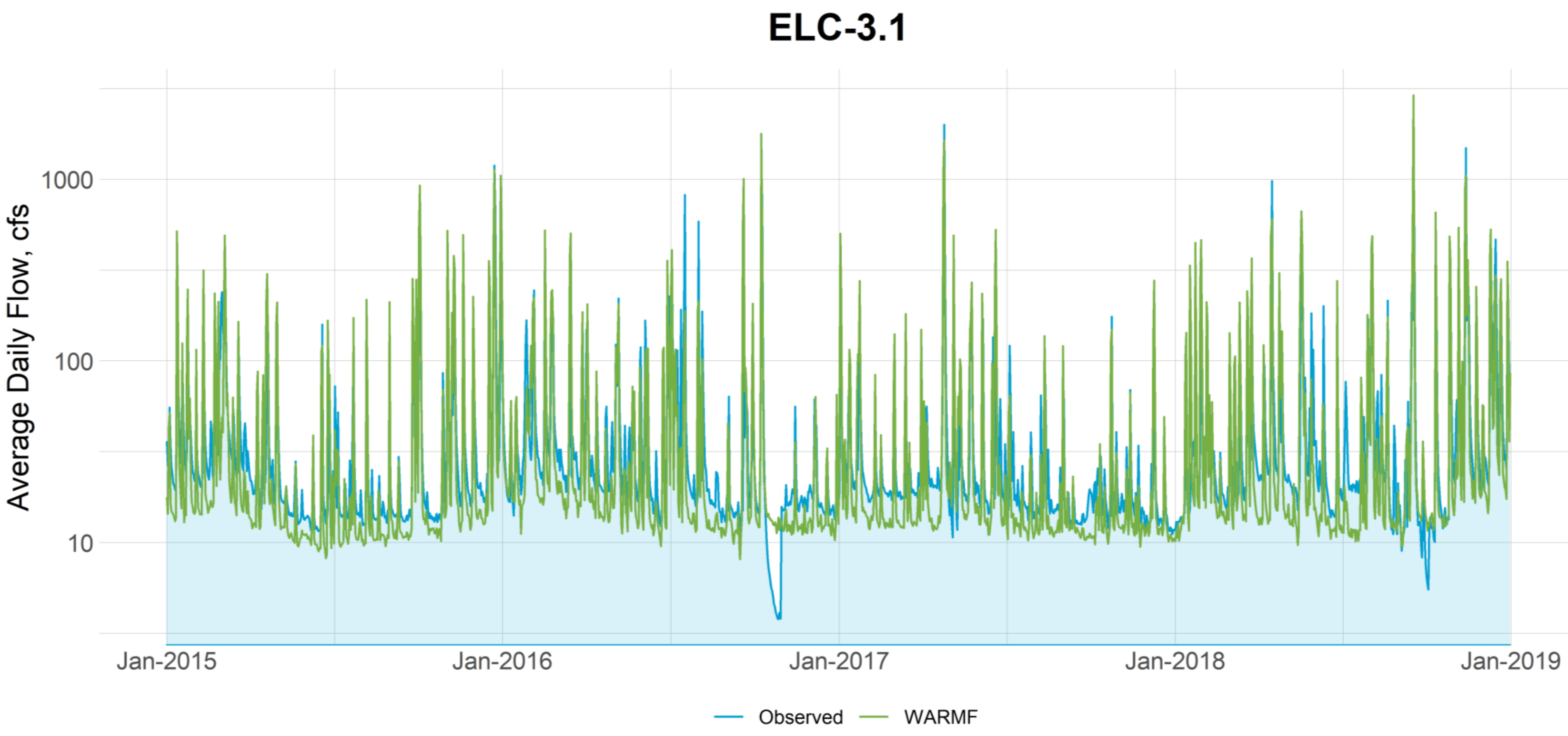
- Model performance is very good to good at each gage
- There is some uncertainty with the gaged flows particularly during low flows (previous rating curve discussions)
- The NEXRAD precipitation data provides a good coverage of rainfall patterns, but some storms are missed or over-predicted
- Simulated flows from upstream impoundments with little flow release data introduce challenges for calibration

Model Performance for Gaged Tributaries Near Falls Lake (2015 to 2018)

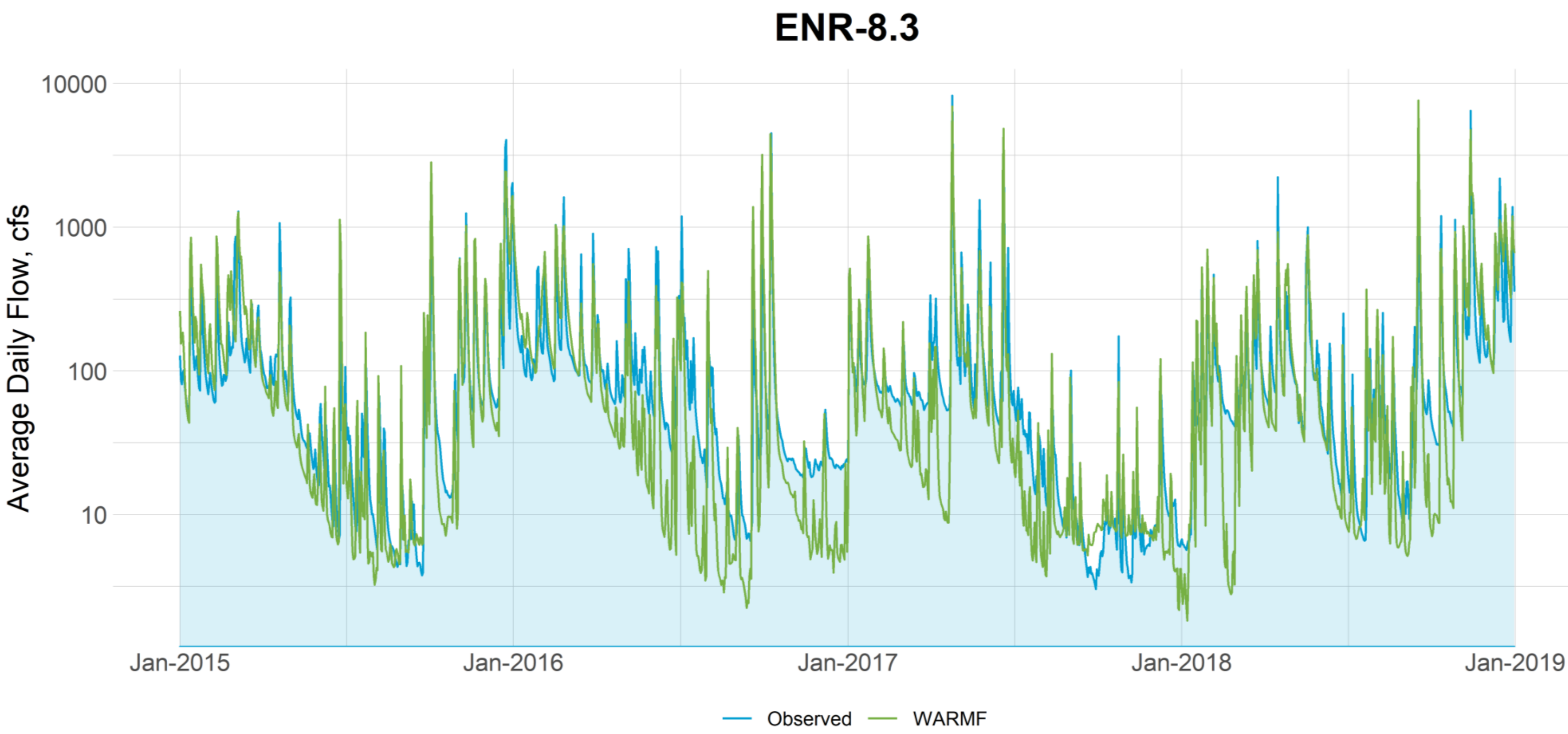
ELLERBE CREEK AT CLUB BOULEVARD (USGS 0208675010)	ELLERBE CREEK NEAR GORMAN, NC (USGS 02086849)	ENO RIVER AT HILLSBOROUGH, NC (USGS 02085000)	ENO RIVER NEAR DURHAM, NC (USGS 02085070)	FLAT RIVER AT BAHAMA,NC (USGS 02085500)	FLAT RIVER AT DAM NEAR BAHAMA, NC (USGS 02086500)	KNAP OF REEDS CREEK NEAR BUTNER, NC (USGS 02086624)	LITTLE RIVER AT SR1461 NEAR ORANGE FACTORY, NC (USGS 0208521324)
1%	3%	-3%	5%	-9%	-9%	-3%	-4%

Daily Stream Flow Comparisons at Upper Five Lake Tributaries (Log-Scale)

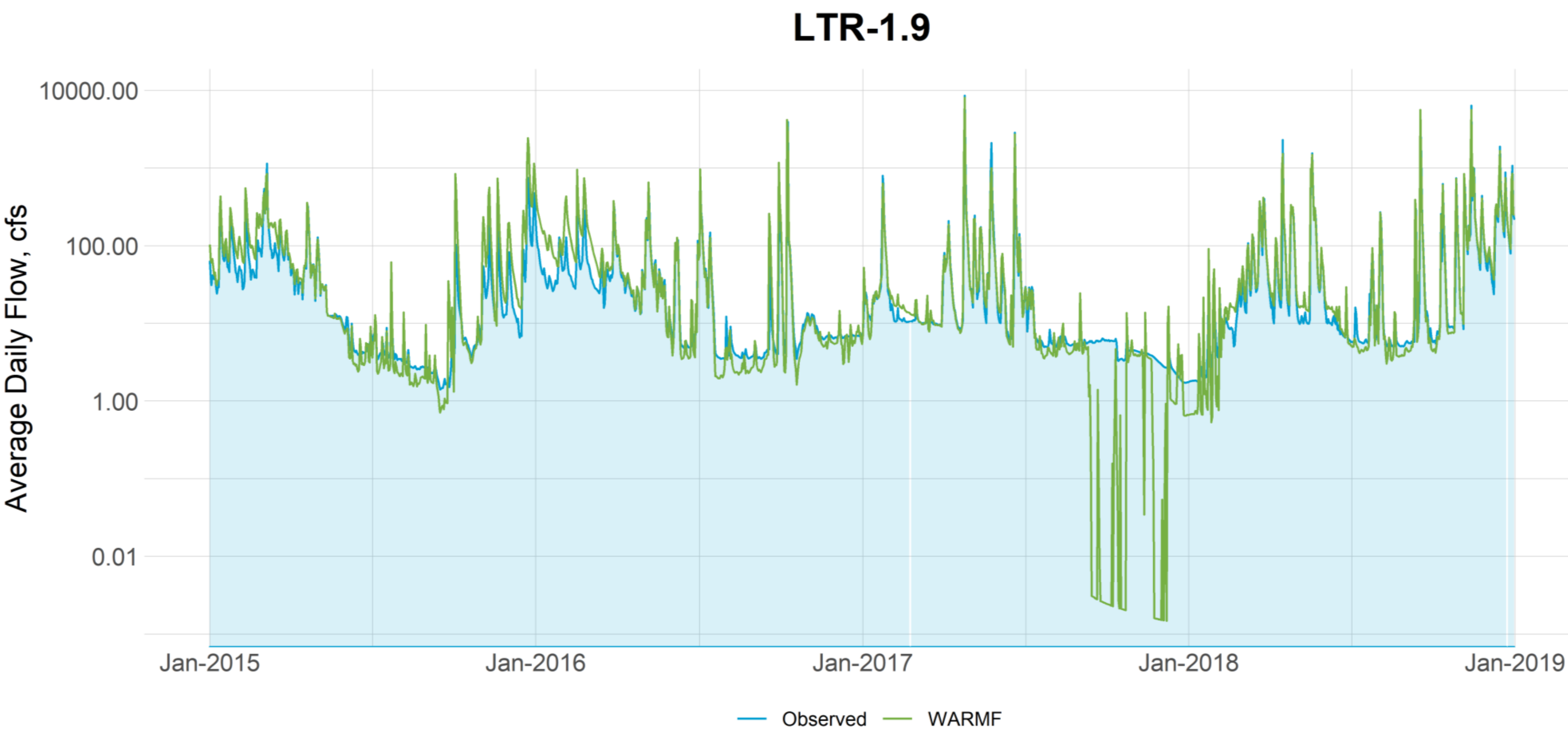
Stream Flows – Ellerbe Creek (USGS 02086849)



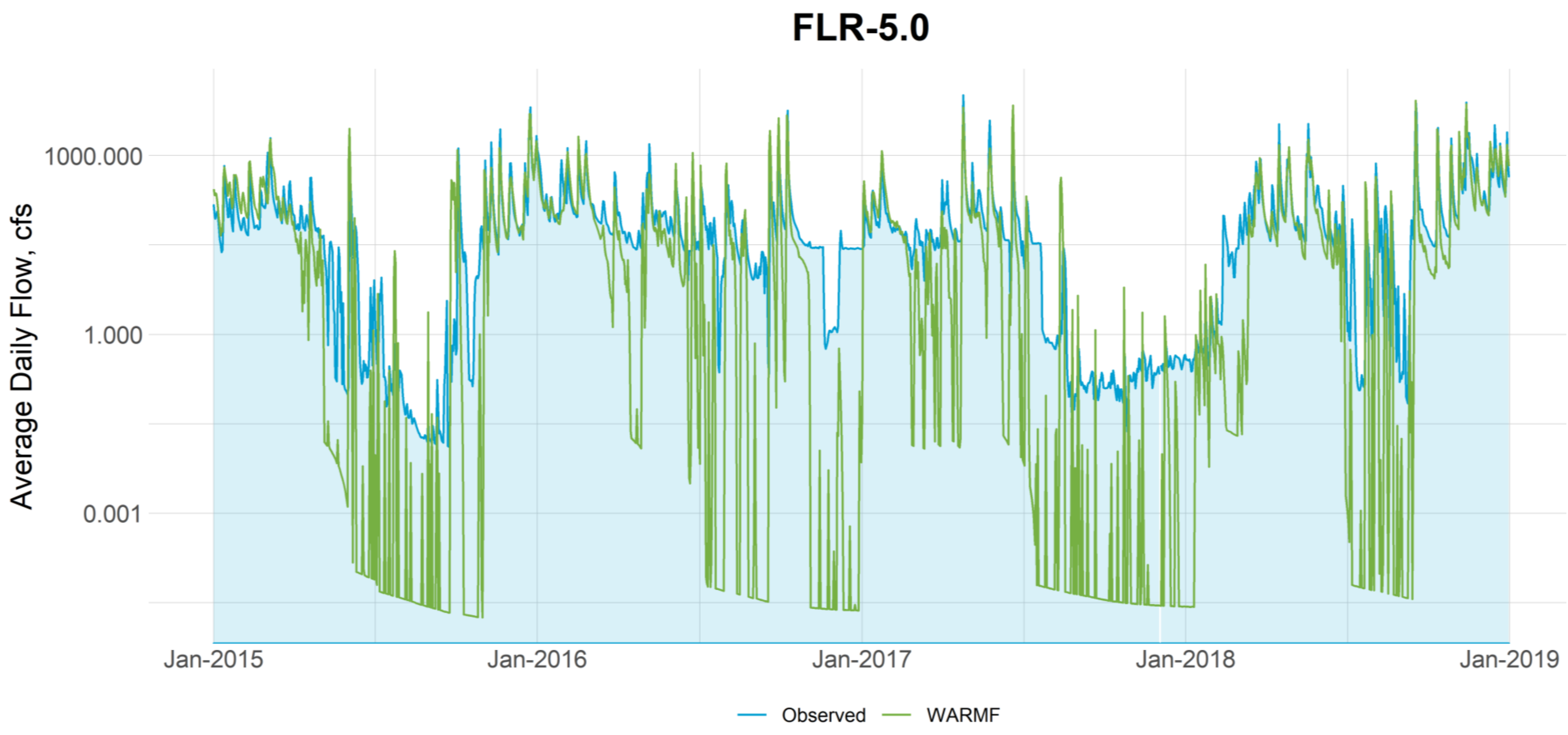
Stream Flows – Eno River



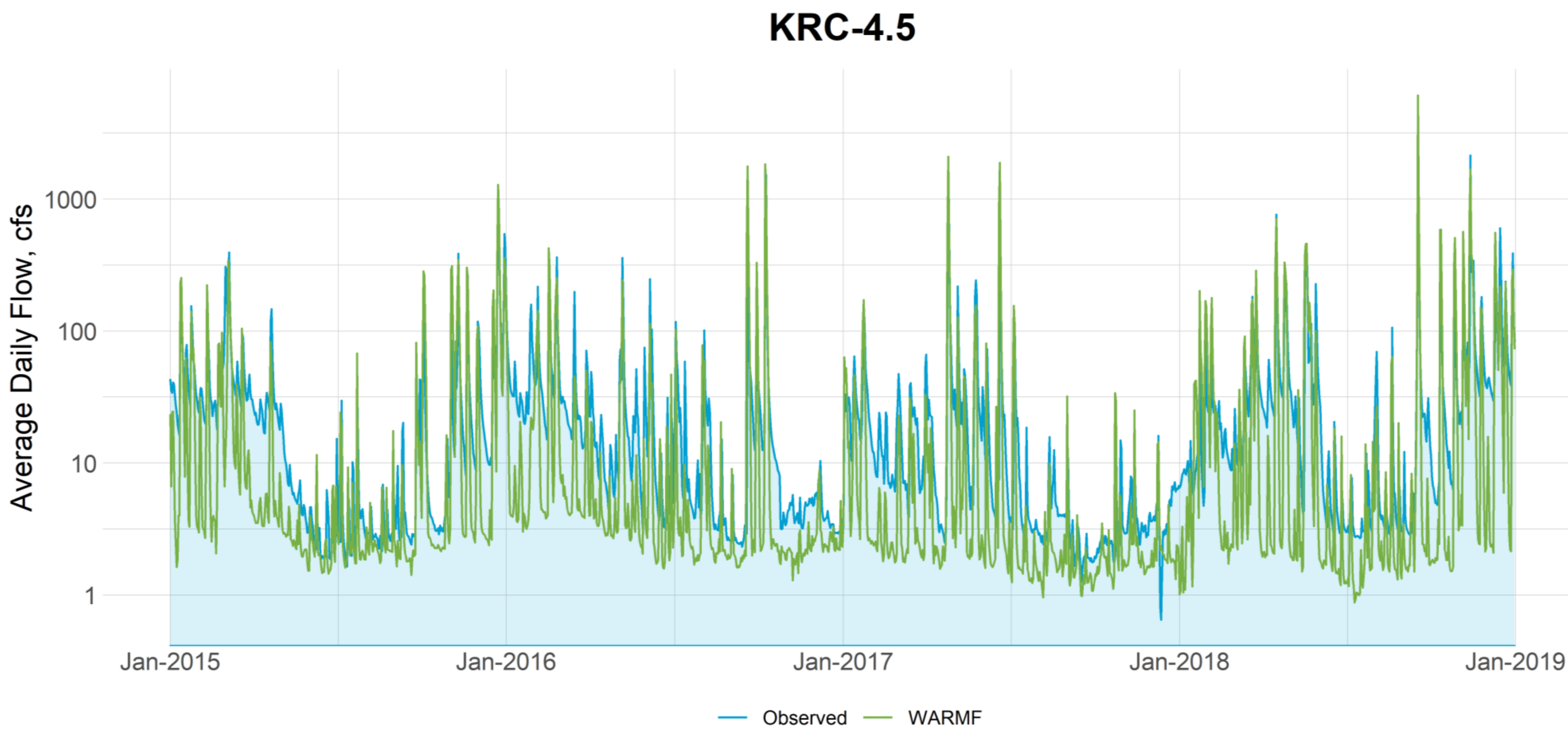
Stream Flows – Little River



Stream Flows – Flat River



Stream Flows – Knap of Reeds (USGS 02086624)



Water Quality Comparisons at Big Five Lake Tributaries

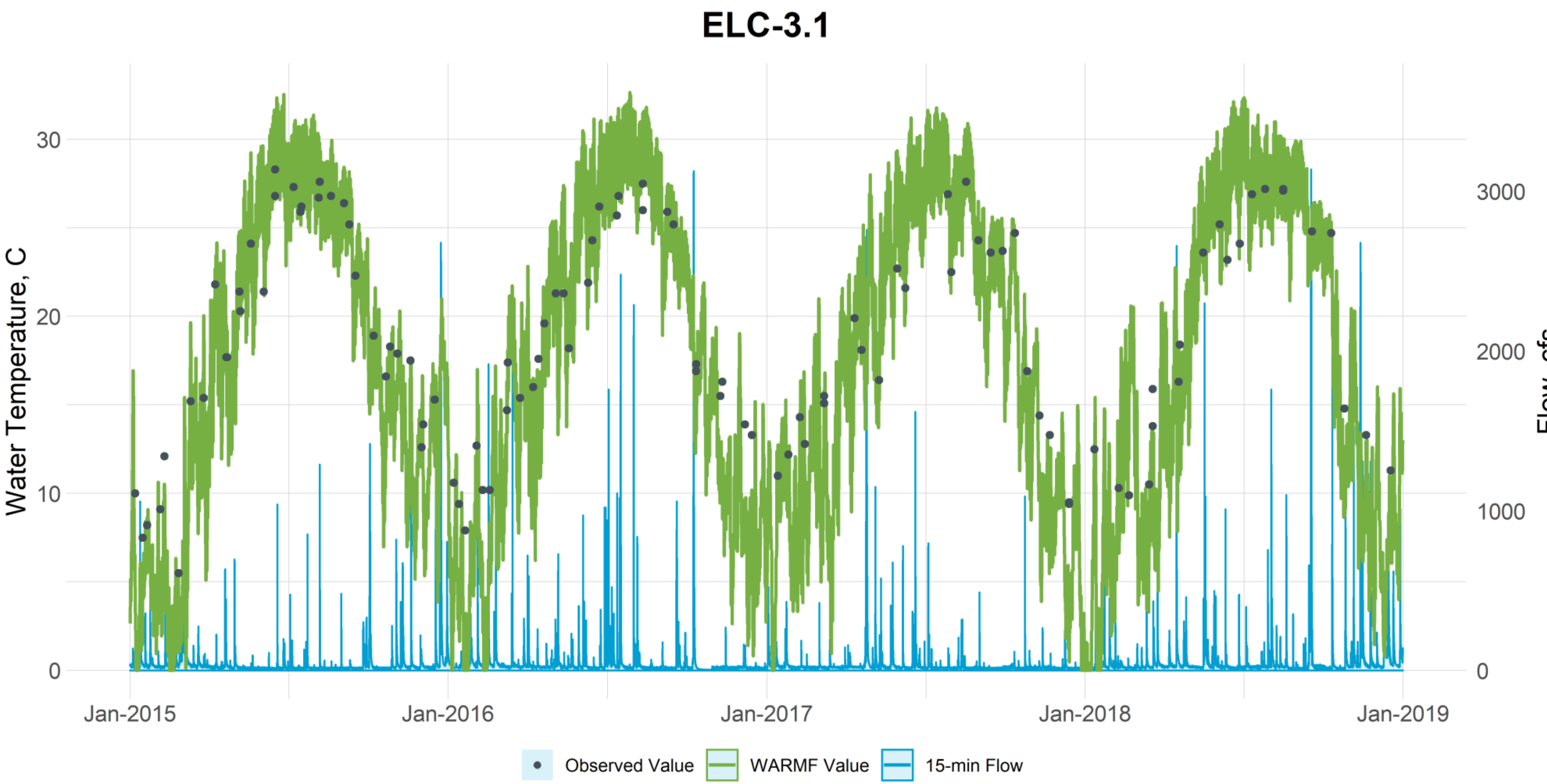
Draft Temperature

- Model performance is very good to good at each of the "big five" lake loading stations

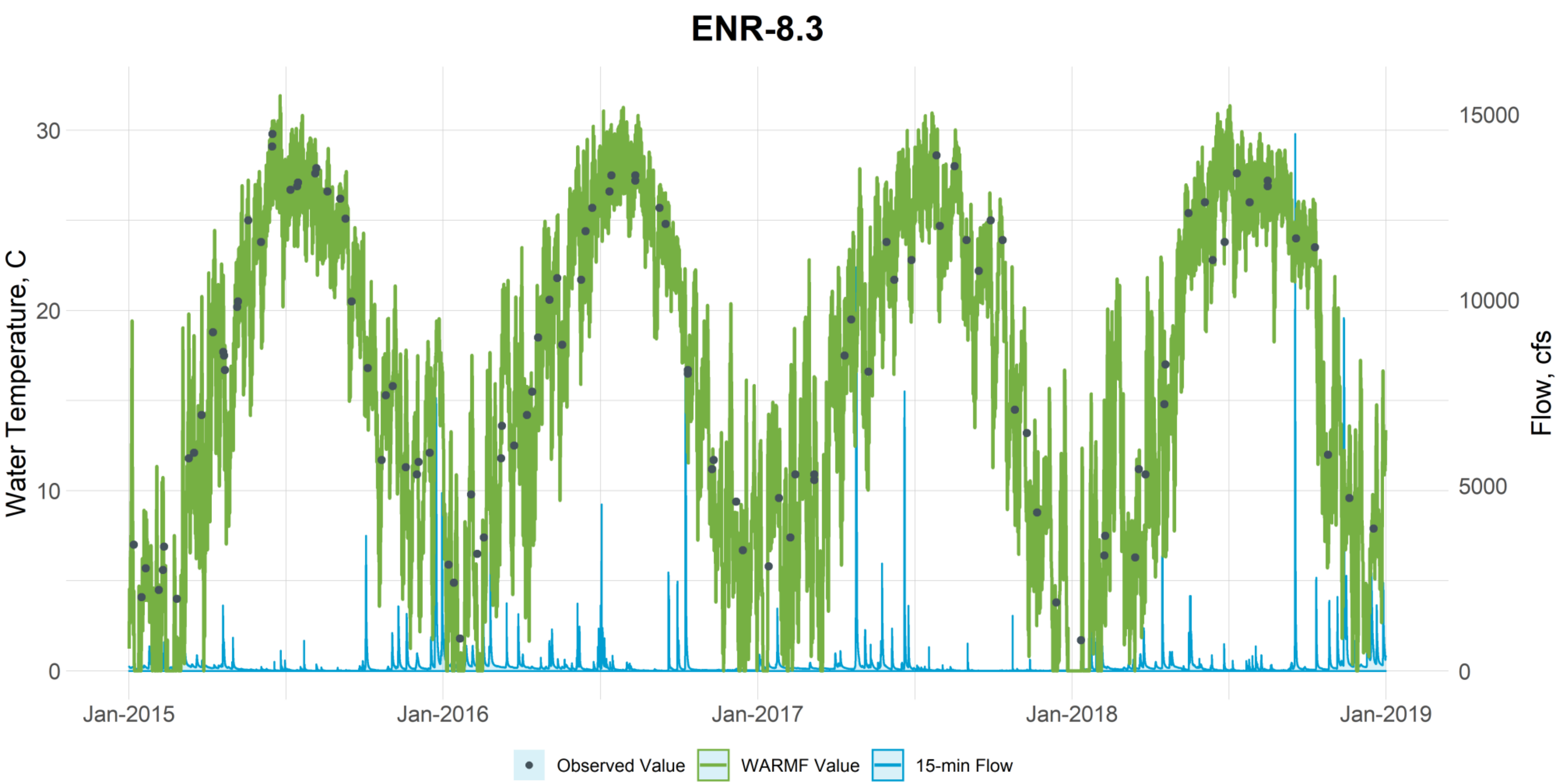
Drainage Characteristics and Percent Bias for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Flat	Knap	Little
Drainage Area (sq.mi.)	21.9	149	169	41.9	104
Percent of Flow to Falls Lake	9	24	28	5	11
Water Temperature, C;					
Observed Mean Full Period:	18.6	16.8	15.1	17.8	16.8
Calibration Period	4.4	7.9	9.2	9.1	-7.8
Full	4.4	7.2	8.9	7.8	-9.0
Validation Period	4.3	6.1	8.5	6.0	-11.3

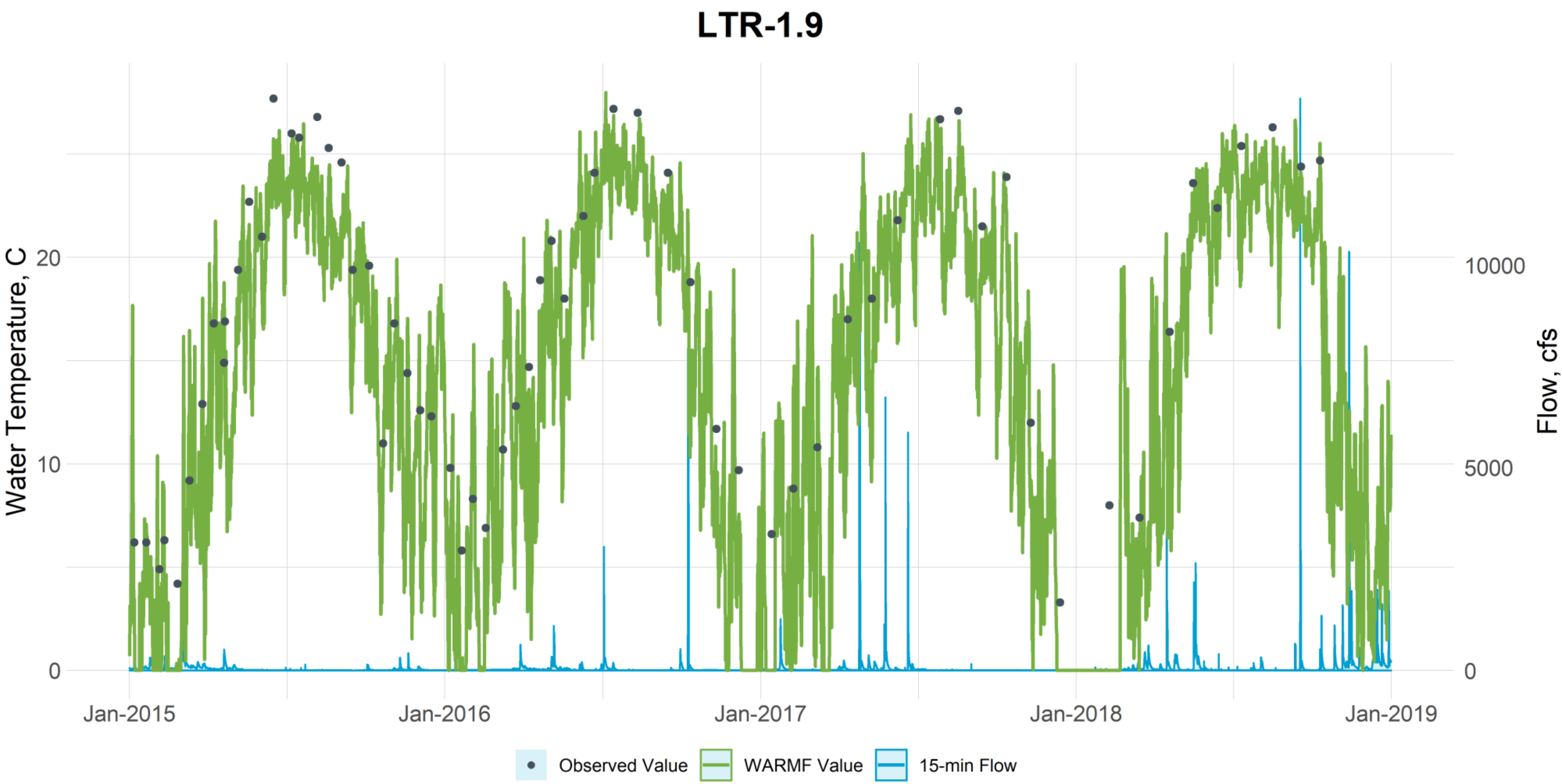
Temperature, C – Ellerbe Creek



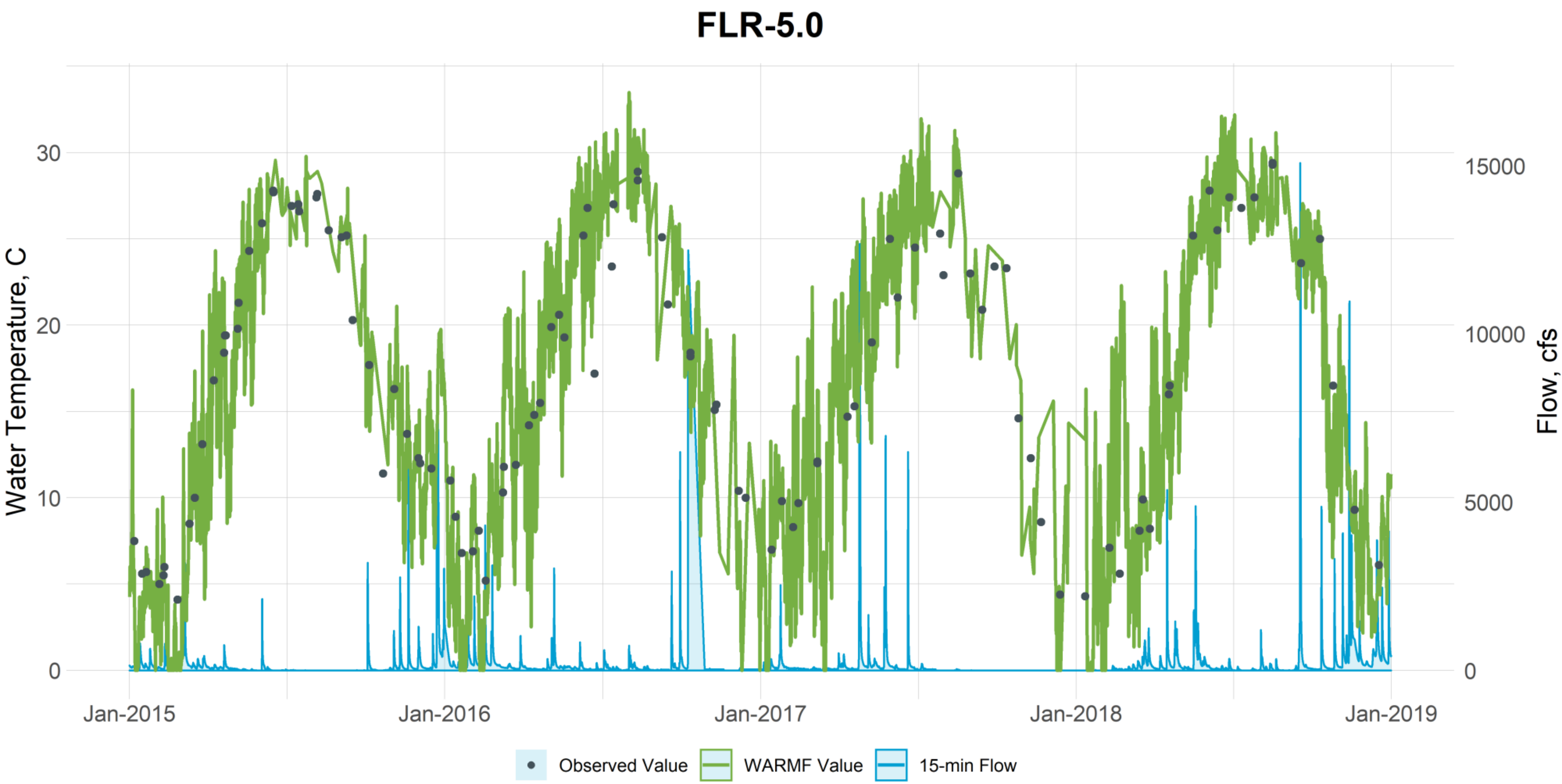
Temperature, C – Eno River



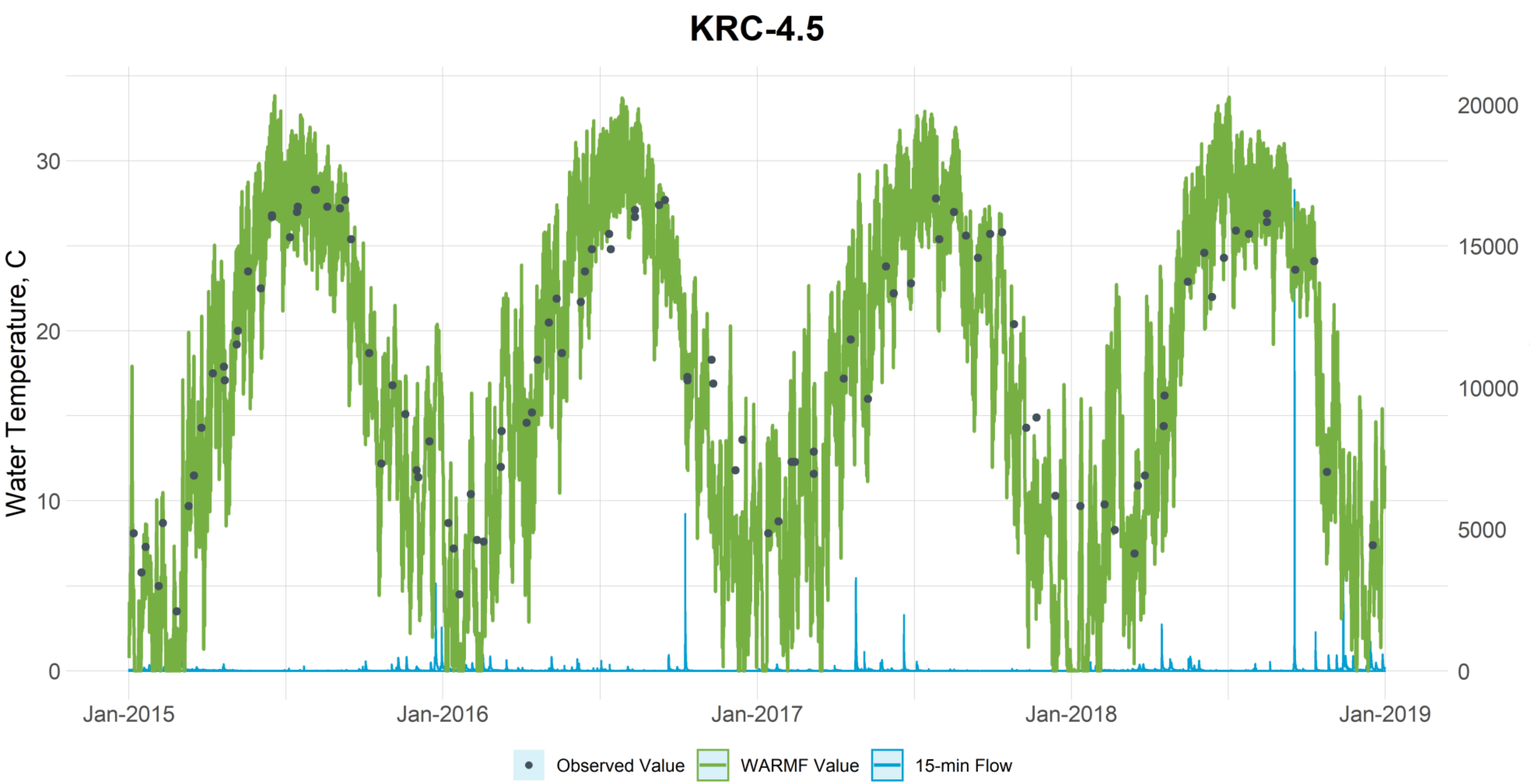
Temperature, C – Little River



Temperature, C – Flat River



Temperature, C – Knap of Reeds



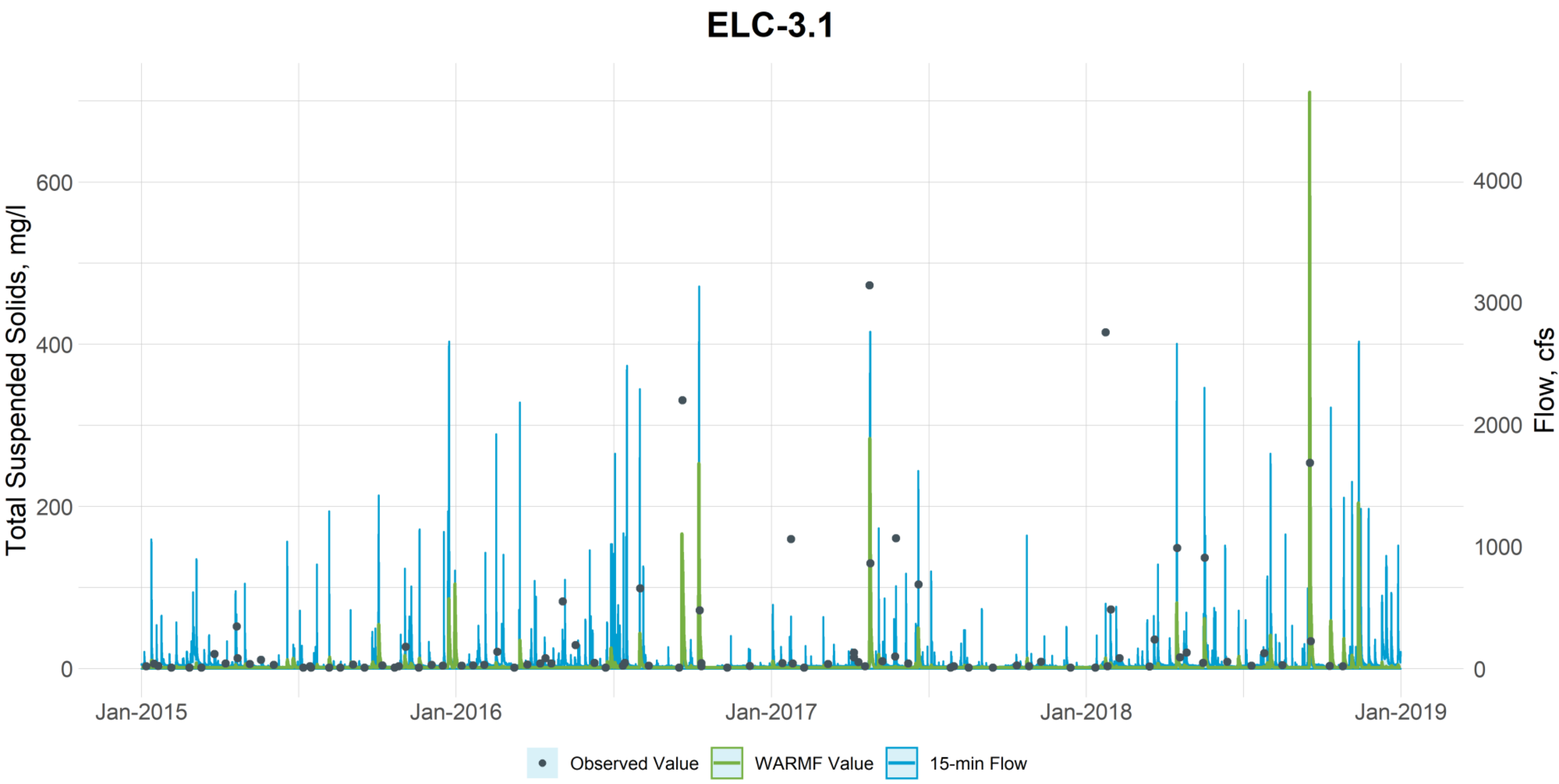
Preliminary Draft Total Suspended Sediment (TSS)

- WARMF simulates three classes of sediment accounted for in TSS: sand, silt, clay
- Laboratory measurements would include all suspended solids, not just sediments
- As expected, simulation of TSS is less than laboratory measurements

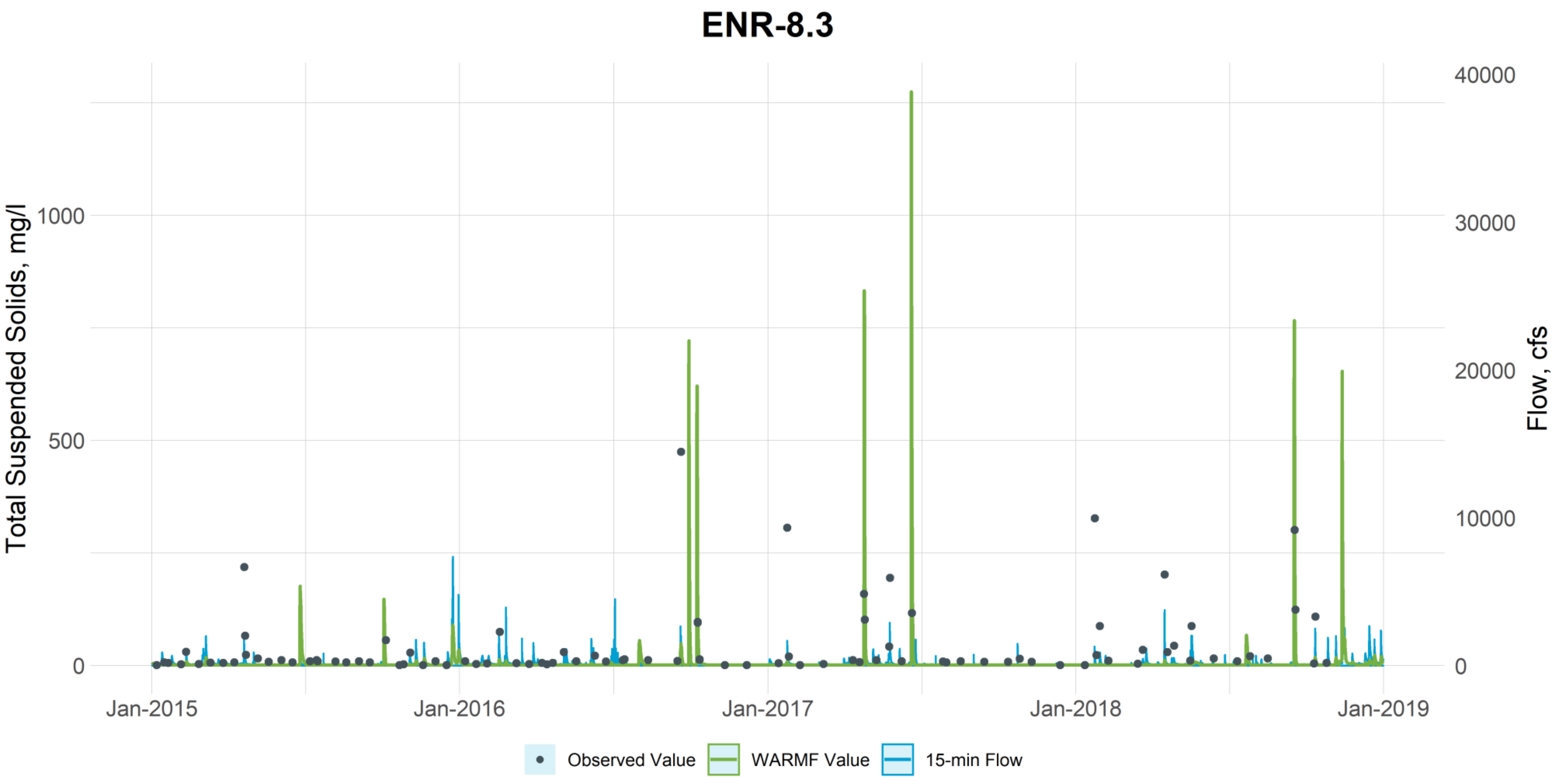
Drainage Characteristics and Percent Bias for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Flat	Knap	Little
Drainage Area (sq.mi.)	21.9	149	169	41.9	104
Percent of Flow to Falls Lake	9	24	28	5	11
Total Suspended Solids, mg/l;					
Observed Mean Full Period:	34.3	41.8	13.6	21.6	21.7
Calibration Period	-60.3	-69.5	-62.7	-46.5	-61.6
Full	-63.9	-47.6	-57.9	-43.6	-36.8
Validation Period	-65.3	-34.5	-53.4	-42.4	-20.7

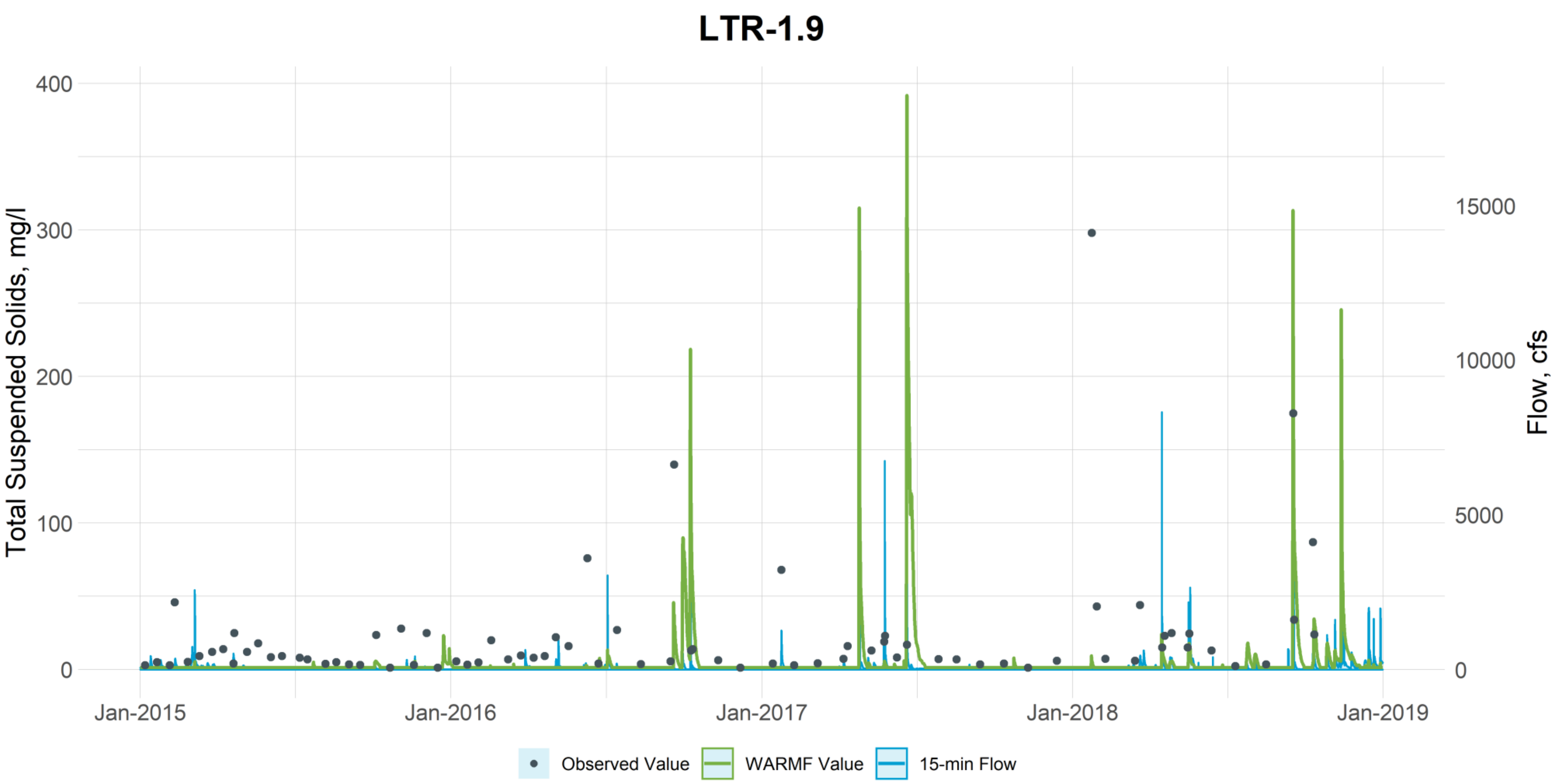
Total Suspended Sediment, mg/L – Ellerbe Creek



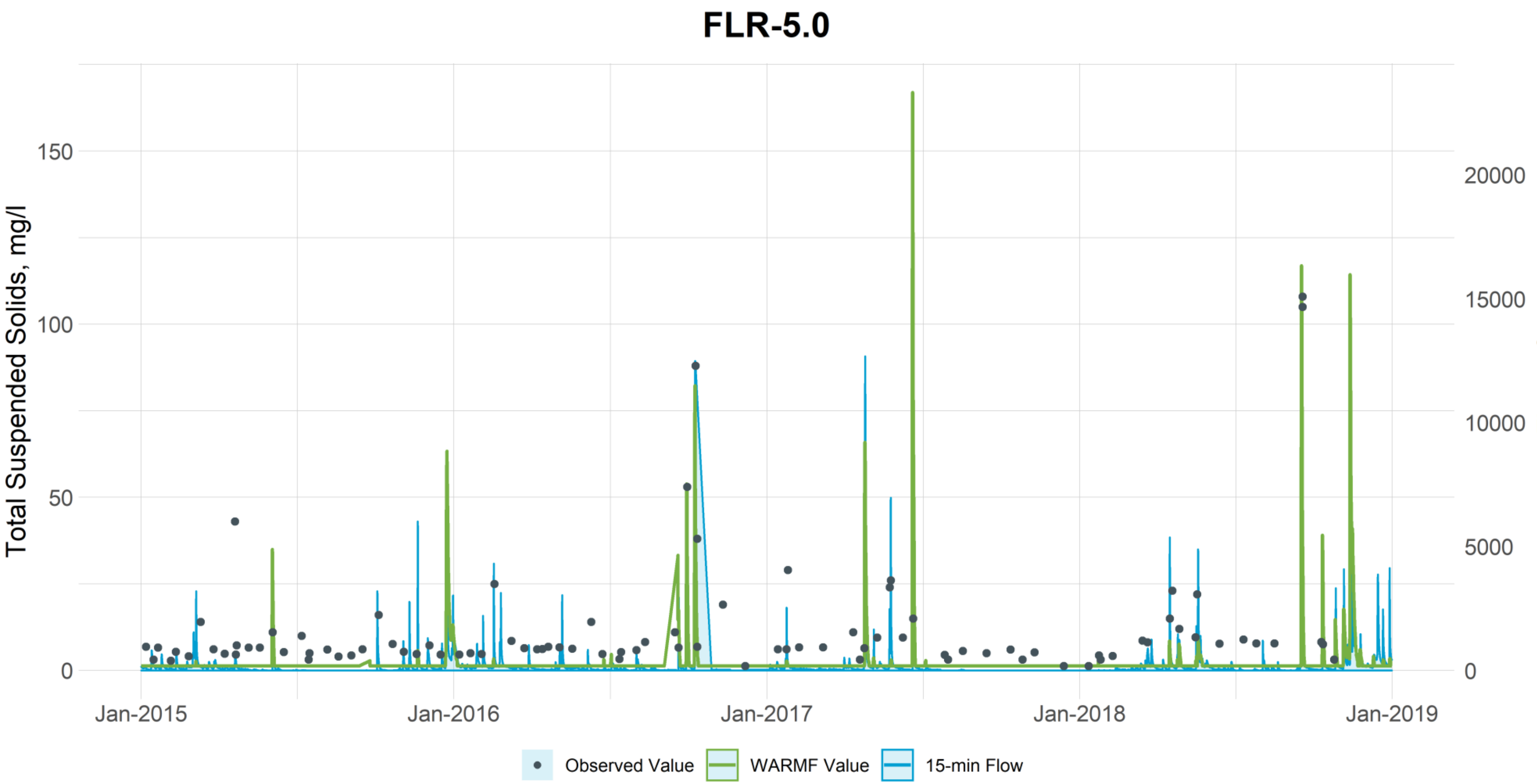
Total Suspended Sediment, mg/L – Eno River



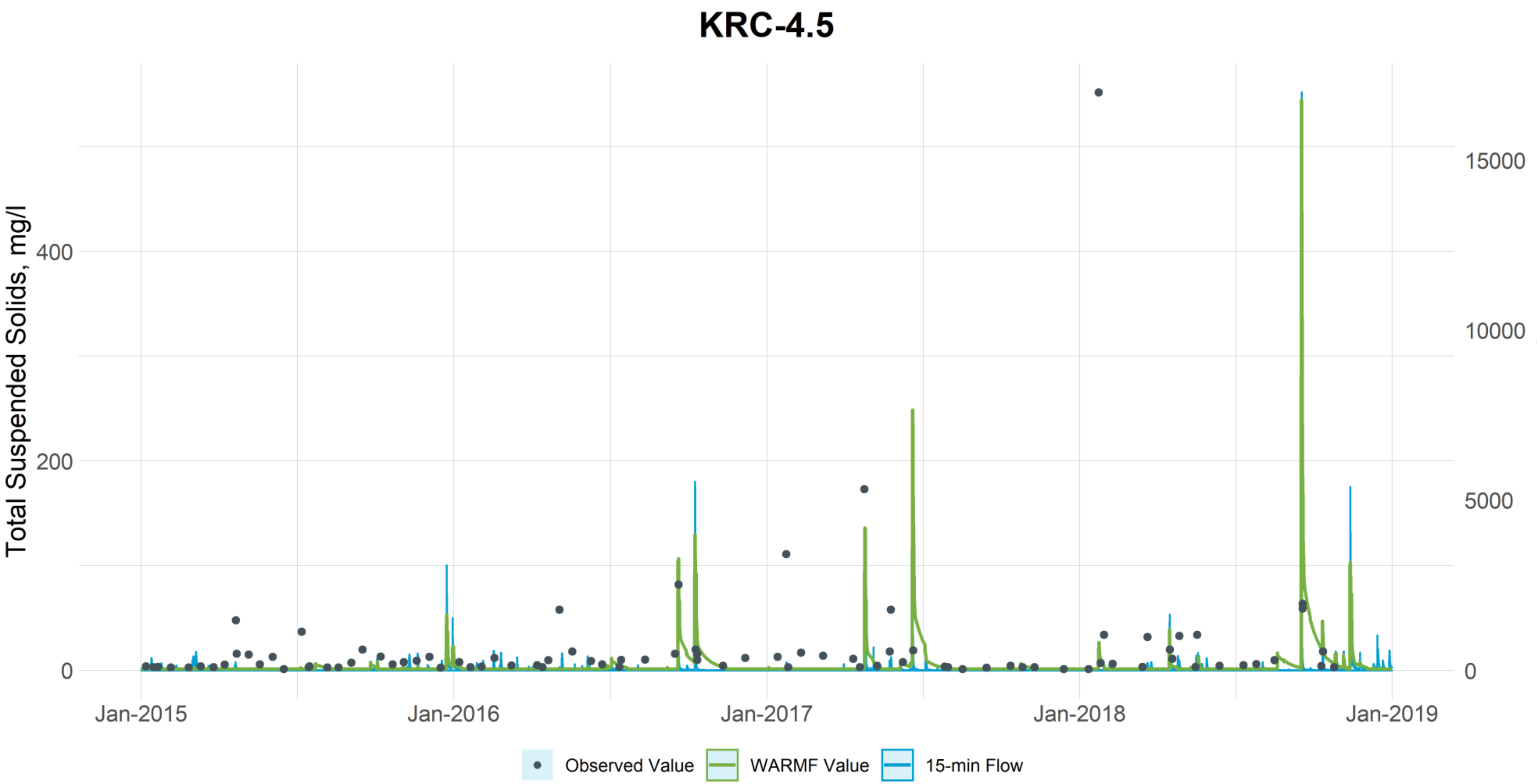
Total Suspended Sediment, mg/L – Little River



Total Suspended Sediment, mg/L – Flat River



Total Suspended Sediment, mg/L – Knap of Reeds



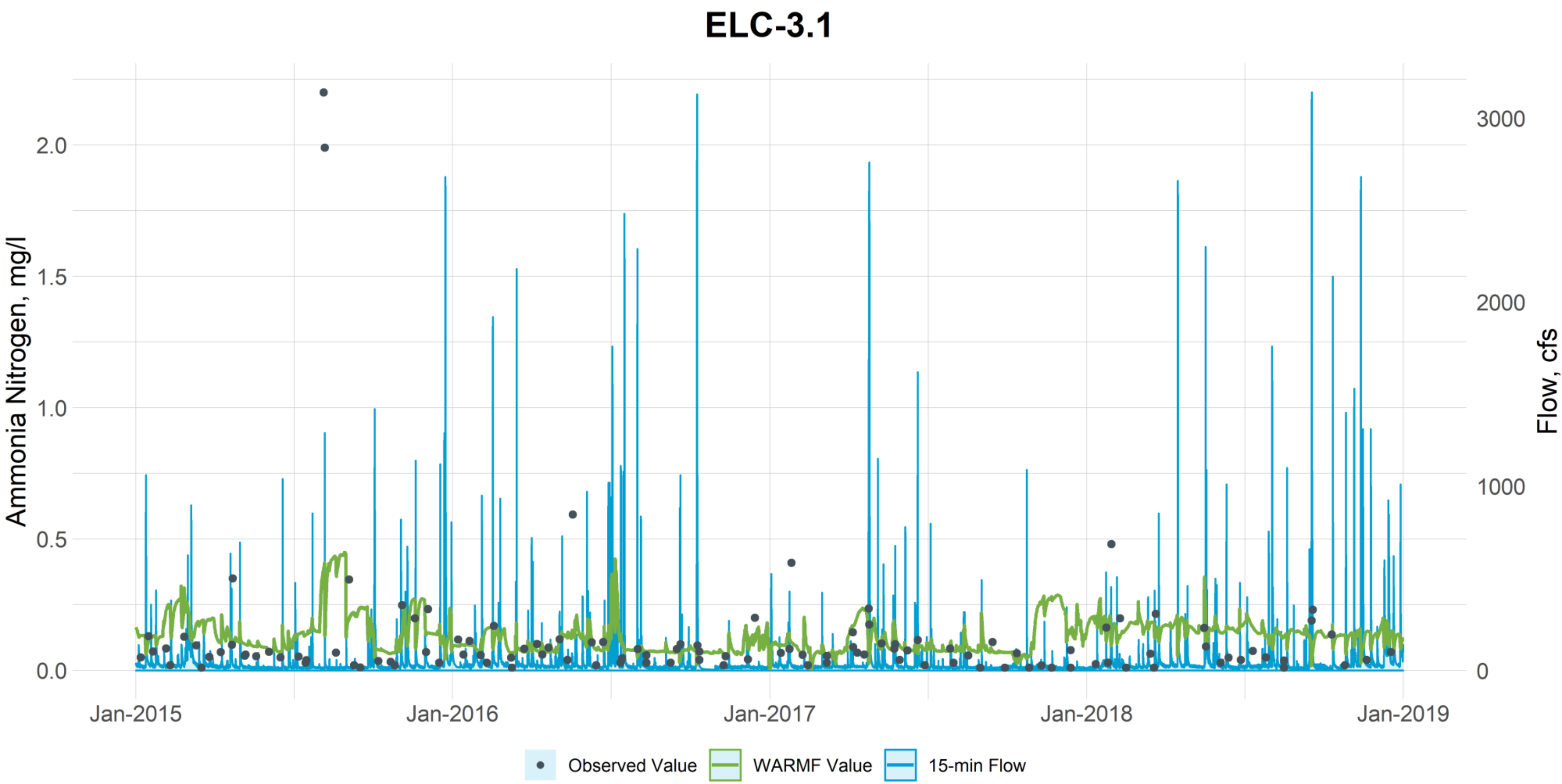
Draft Ammonia

- Model is "very good" to "fair" at Flat River and Knap of Reeds with mixed results at Ellerbe and Little (over)
- Model over predicts ammonia concentrations at Eno River, but the observed mean concentrations are the lowest here
- Very low ammonia concentrations do not greatly affect total nitrogen loading

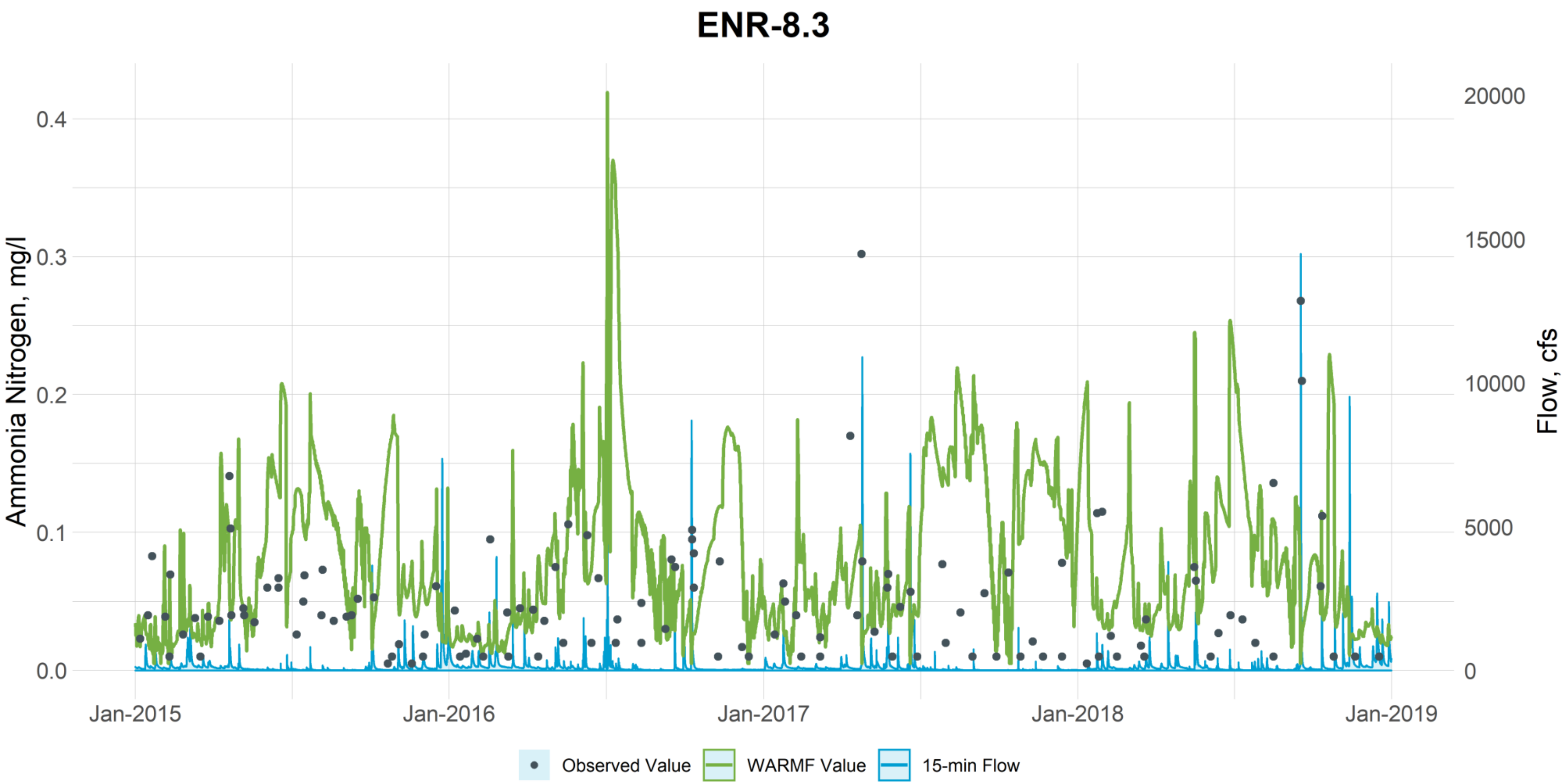
Drainage Characteristics and Percent Bias for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Flat	Knap	Little
Drainage Area (sq.mi.)	21.9	149	169	41.9	104
Percent of Flow to Falls Lake	9	24	28	5	11
Ammonia Nitrogen, mg/l; Observed Mean Full Period:	0.12	0.05	0.08	0.19	0.08
Calibration Period	-16.8	53.0	28.1	-20.7	74.7
Full	2.3	49.5	8.6	-4.9	40.2
Validation Period	40.6	45.6	-14.6	11.6	-0.3

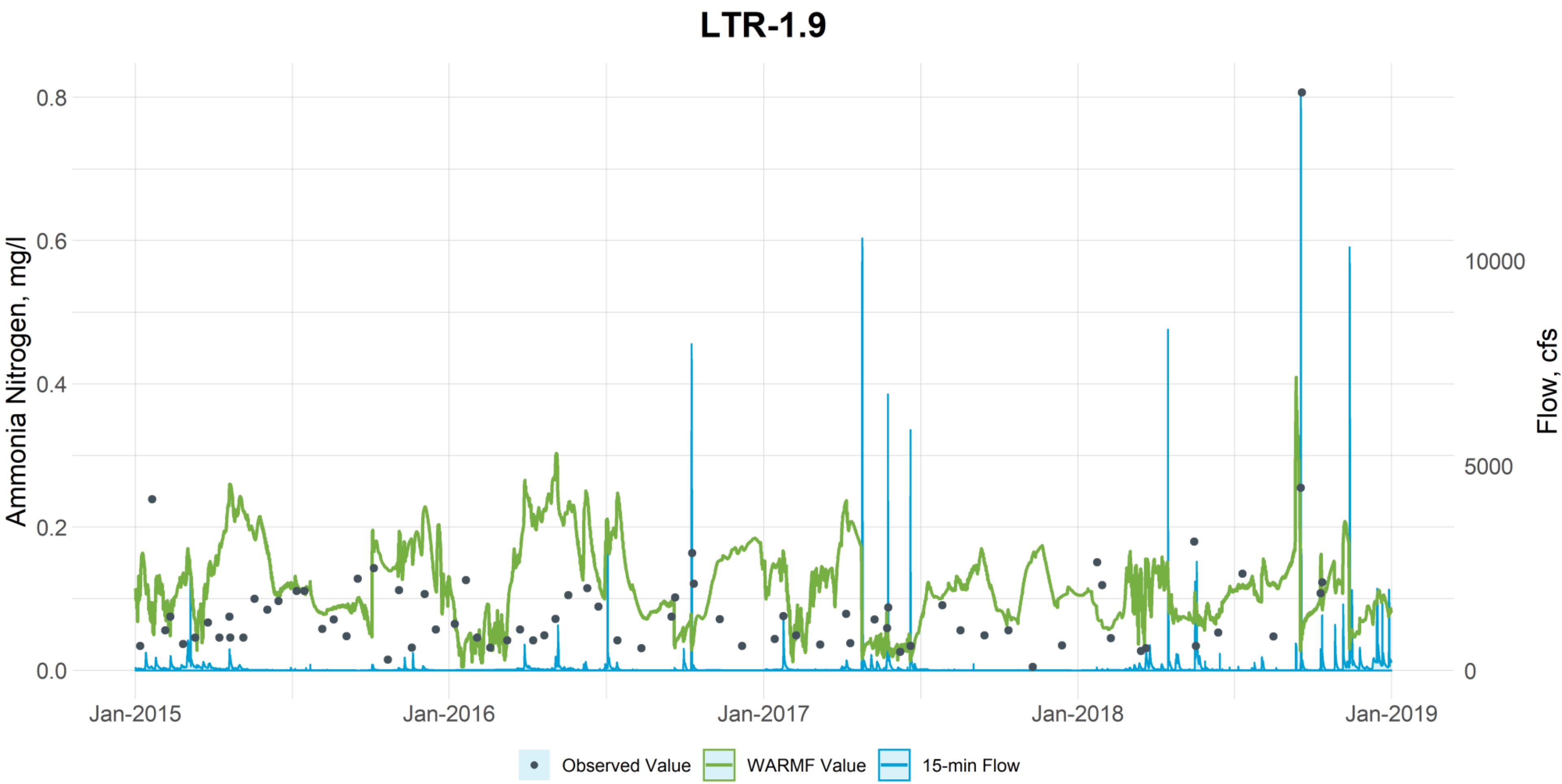
Ammonia, mg/L – Ellerbe Creek



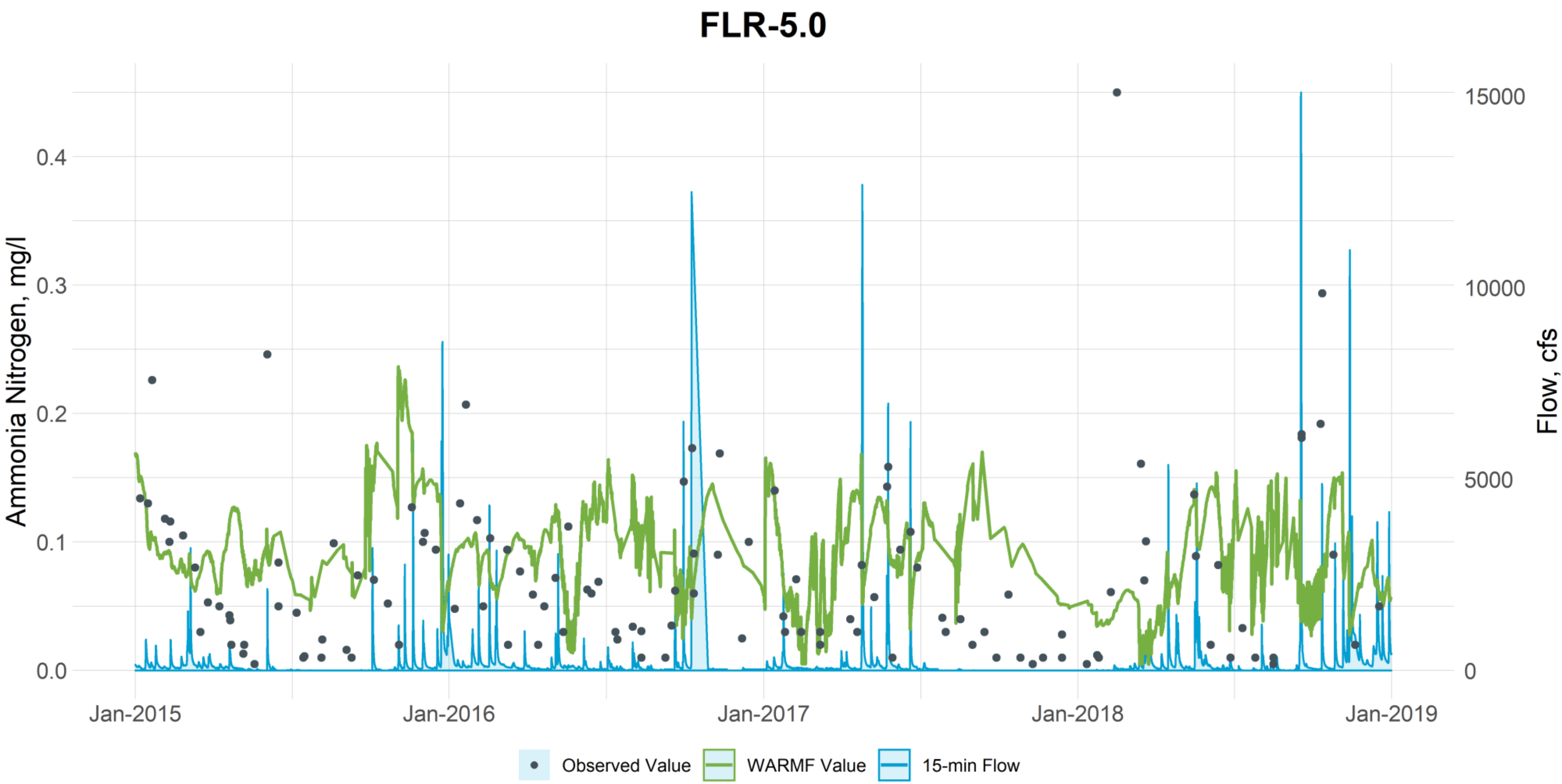
Ammonia, mg/L – Eno River



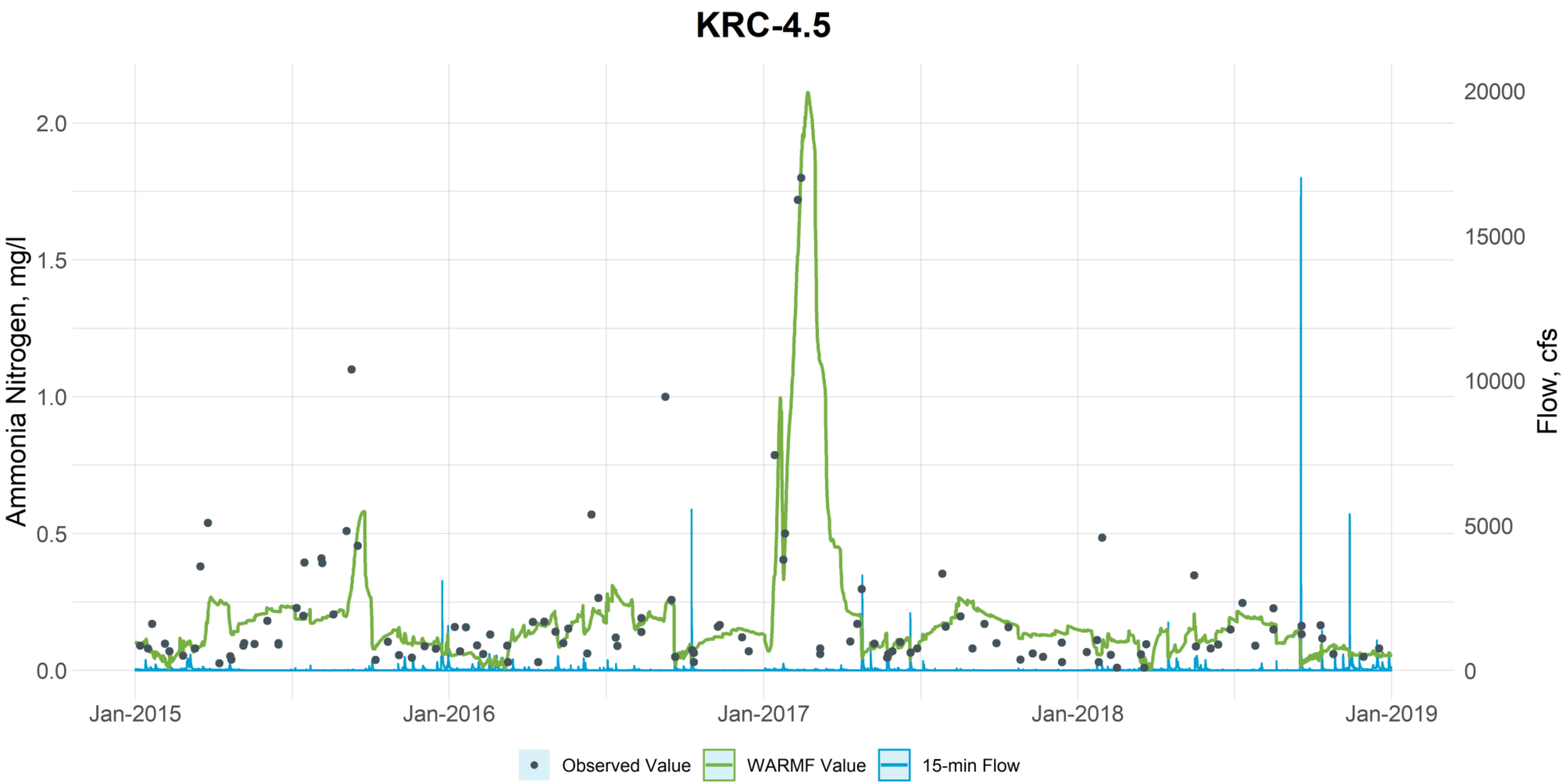
Ammonia, mg/L – Little River



Ammonia, mg/L – Flat River



Ammonia, mg/L – Knap of Reeds Creek



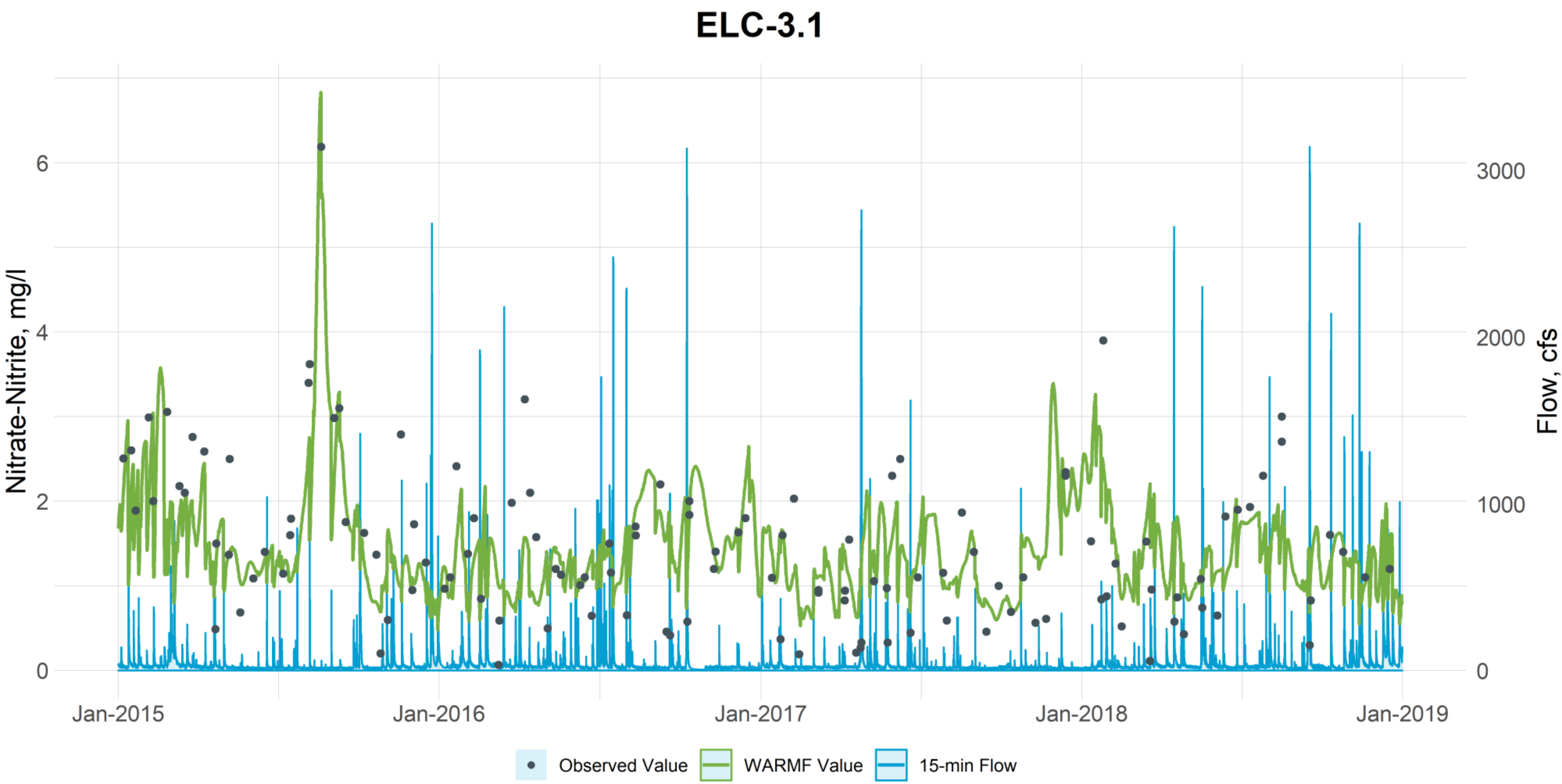
Draft Nitrate

- Model performance is "very good" at Ellerbe and Little
- Model performance is "fair" at Eno and Flat (just outside fair)
- Model is under-predicting nitrate in calibration period and over predicting in validation period at Knap of Reeds, but is "fair" when both periods are considered together

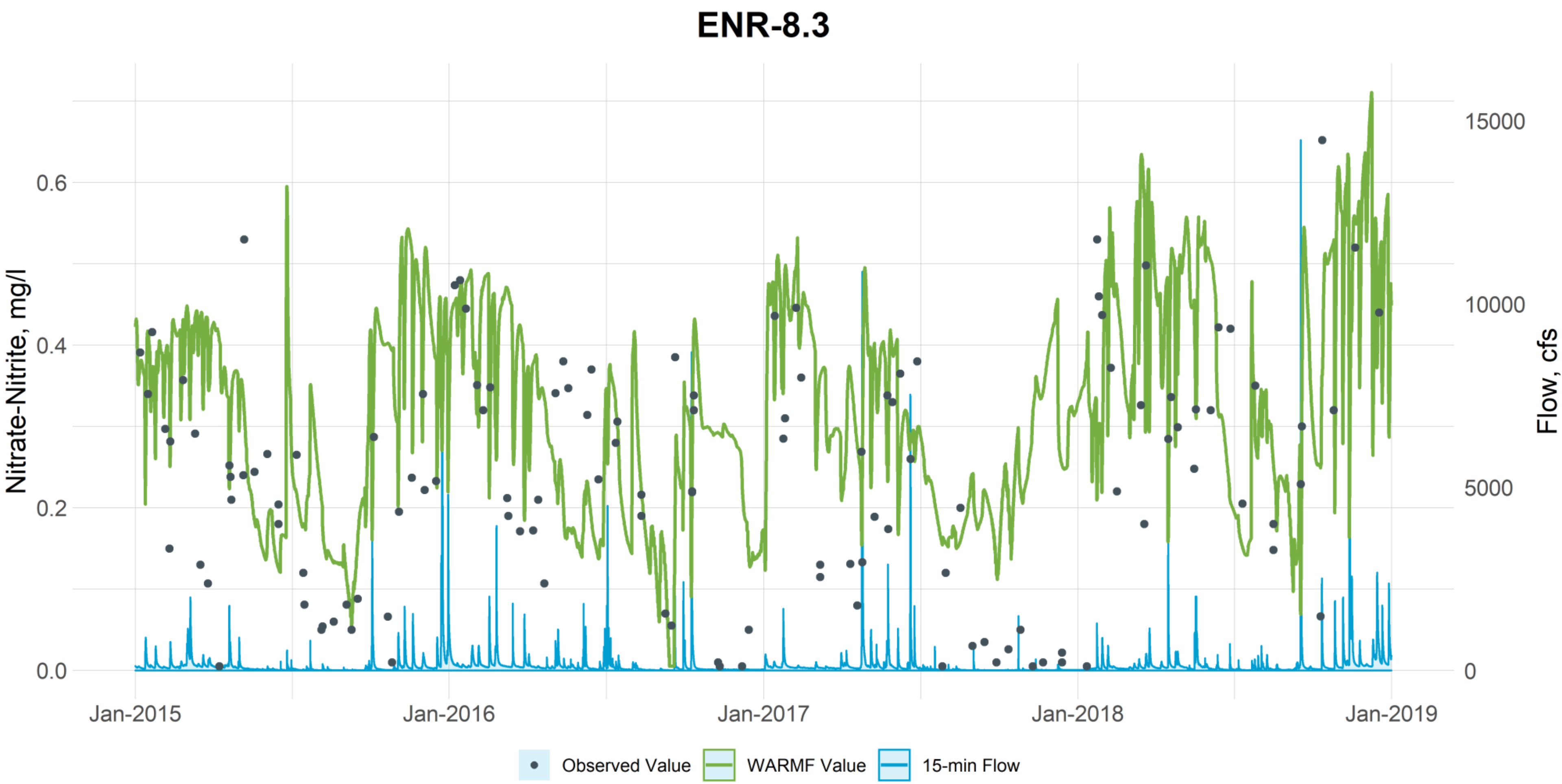
Drainage Characteristics and Percent Bias for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Flat	Knap	Little
Drainage Area (sq.mi.)	21.9	149	169	41.9	104
Percent of Flow to Falls Lake	9	24	28	5	11
Nitrate-Nitrite, mg/l;					
ObsMeanFull:	1.46	0.23	0.19	1.07	0.19
Calibration Period	-9.5	31.8	-31.2	-38.4	-3.6
Full	-0.5	30.8	-33.2	-27.2	0.1
Validation Period	14.1	29.7	-35.9	42.6	5.8

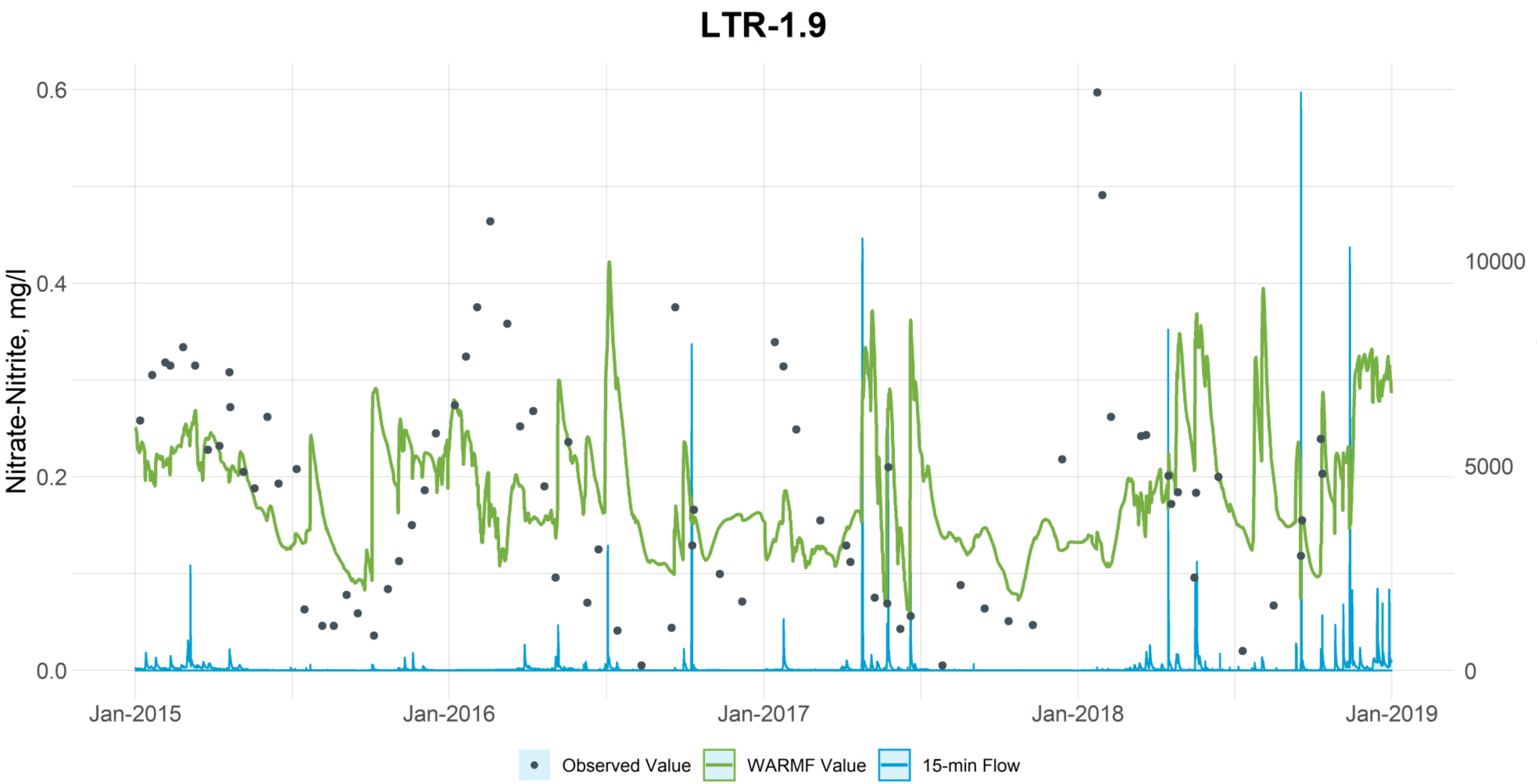
Nitrate, mg/L – Ellerbe Creek



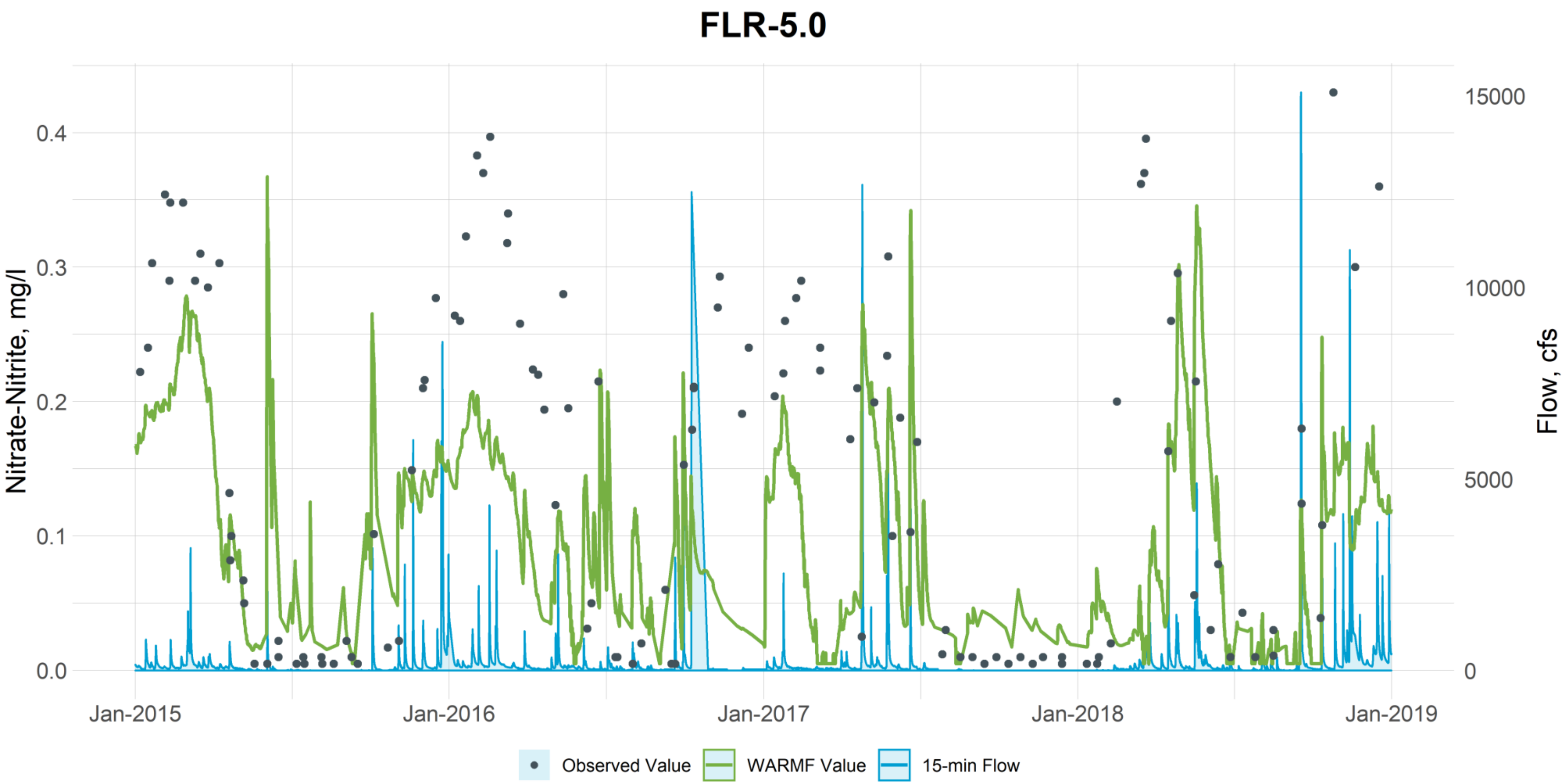
Nitrate, mg/L – Eno River



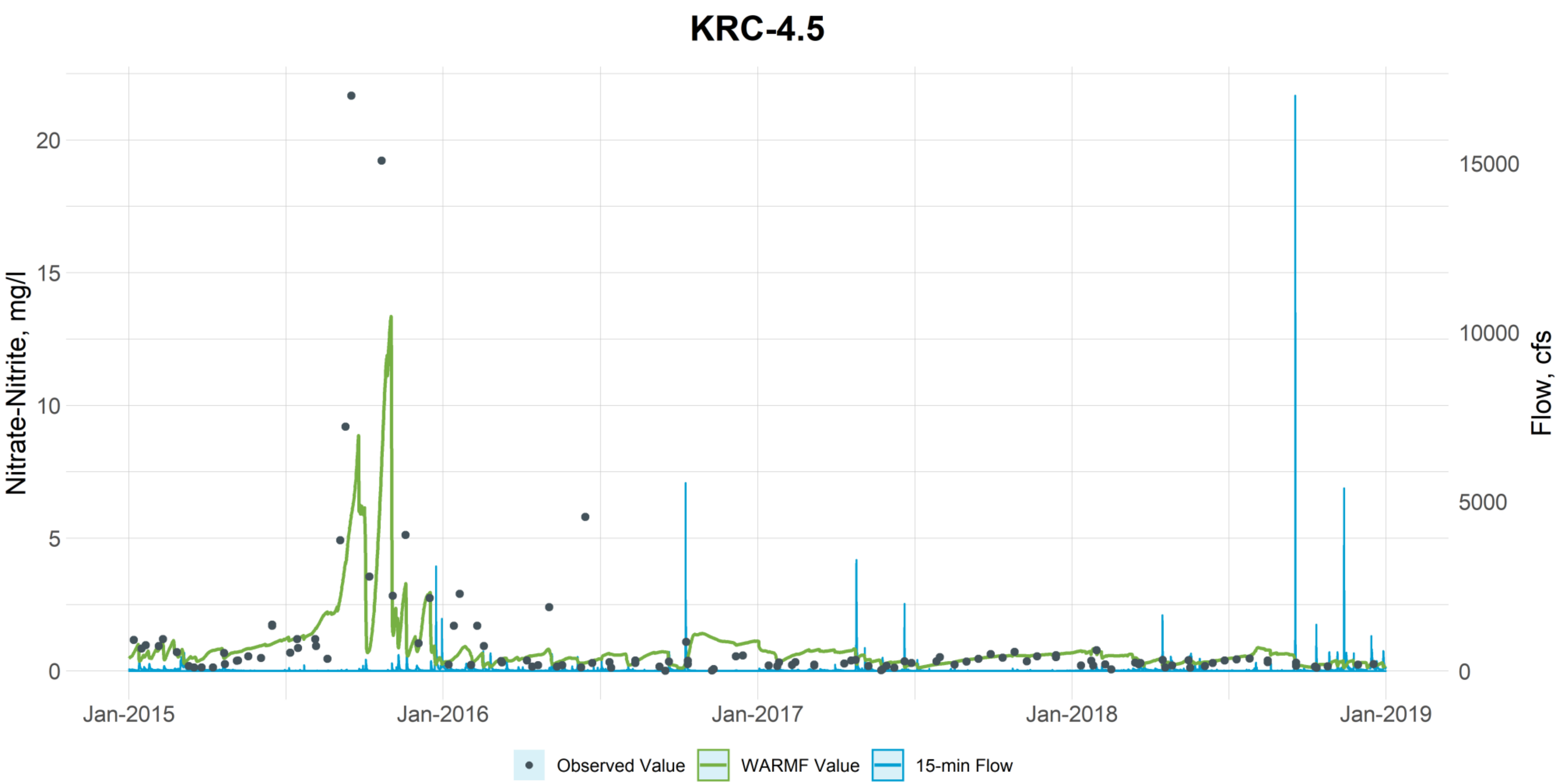
Nitrate, mg/L – Little River



Nitrate, mg/L – Flat River



Nitrate, mg/L – Knap of Reeds Creek



Draft Total Kjeldahl Nitrogen (TKN)

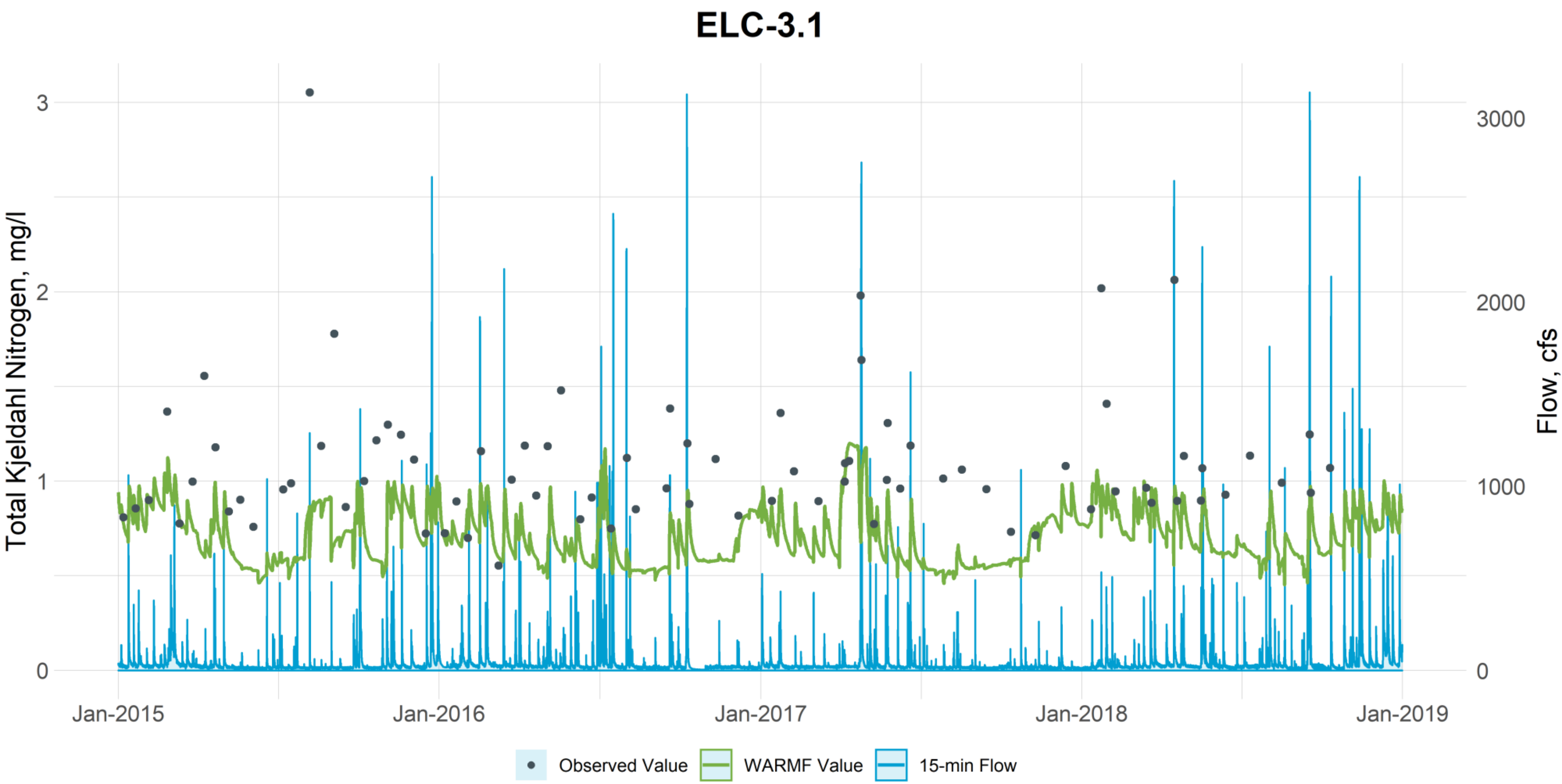
Ammonia plus Organic N

- Model performance is "very good" to "fair" at 5 stations
- Organic fraction is under-simulated in some areas like Ellerbe Creek and over-estimated in other areas like Little River and Flat River
- Improved nitrogen simulation within Little River Reservoir

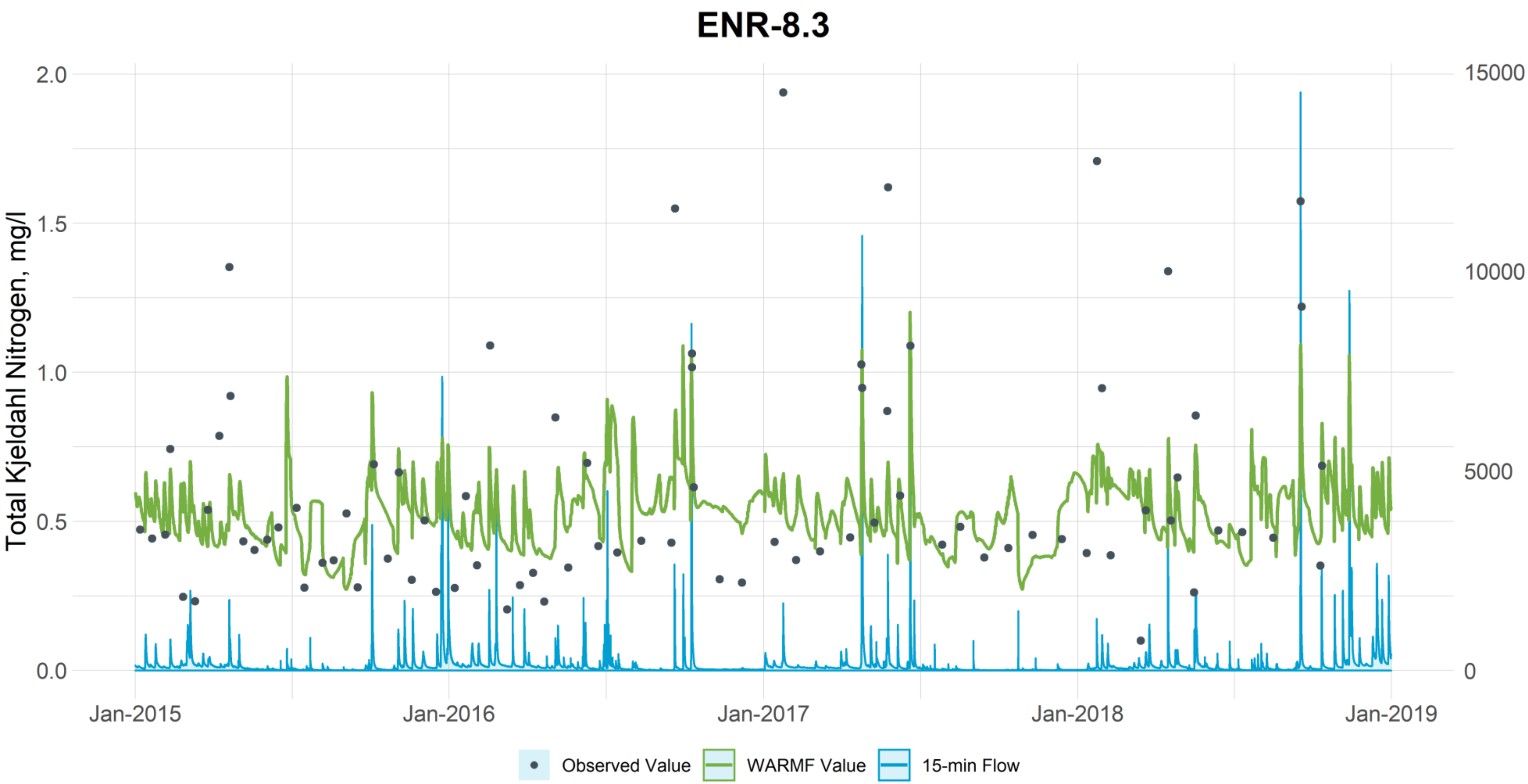
Drainage Characteristics and Percent Bias for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Flat	Knap	Little
Drainage Area (sq.mi.)	21.9	149	169	41.9	104
Percent of Flow to Falls Lake	9	24	28	5	11
Total Kjeldahl Nitrogen, mg/l;					
Observed Mean Full Period:	1.09	0.61	0.70	1.02	0.61
Calibration Period	-33.6	1.8	15.9	-20.0	28.9
Full	-31.4	-5.7	19.1	-9.6	28.8
Validation Period	-28.9	-13.0	23.8	3.9	28.6

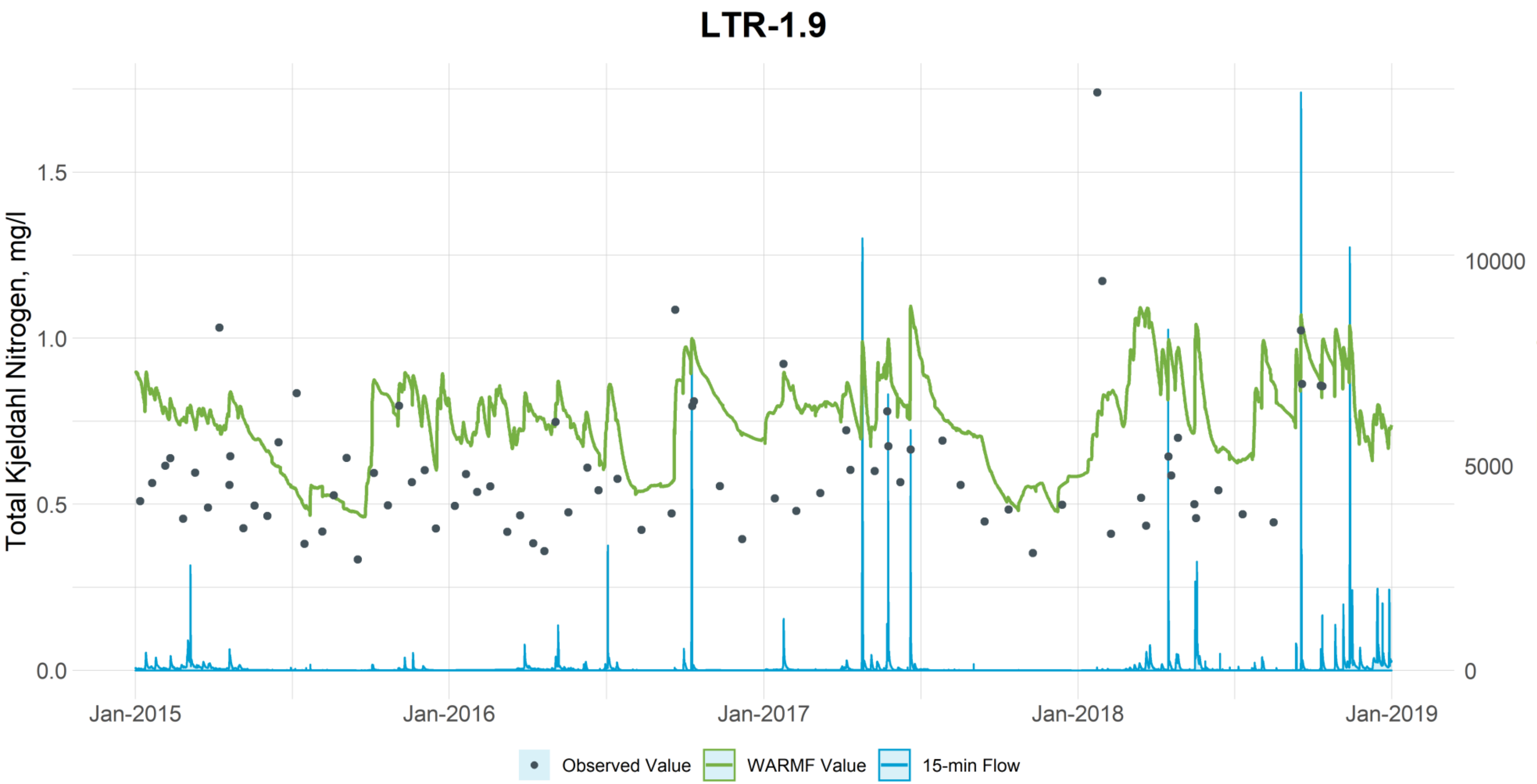
Total Kjeldahl Nitrogen, mg/L– Ellerbe Creek



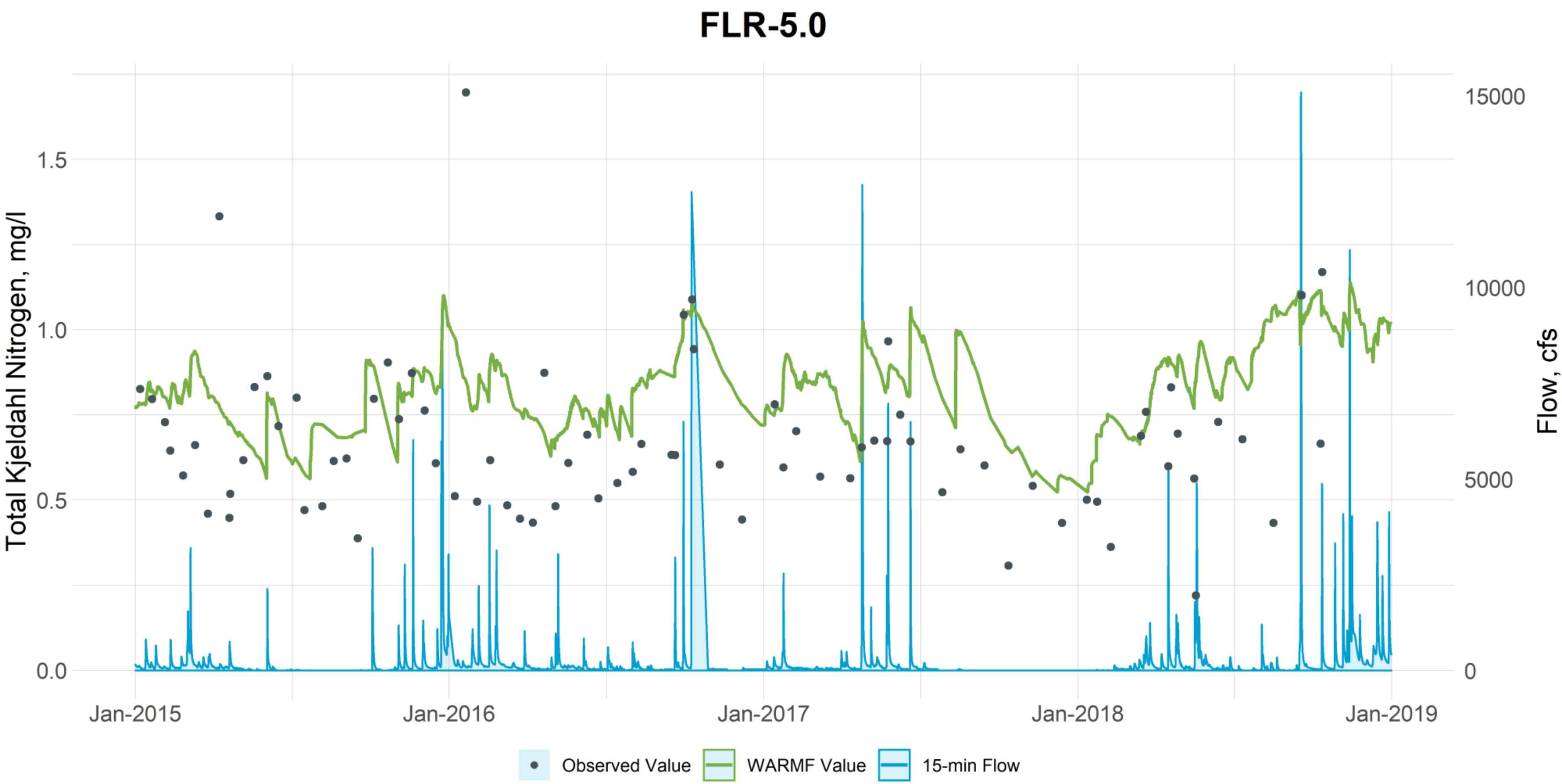
Total Kjeldahl Nitrogen, mg/L– Eno River



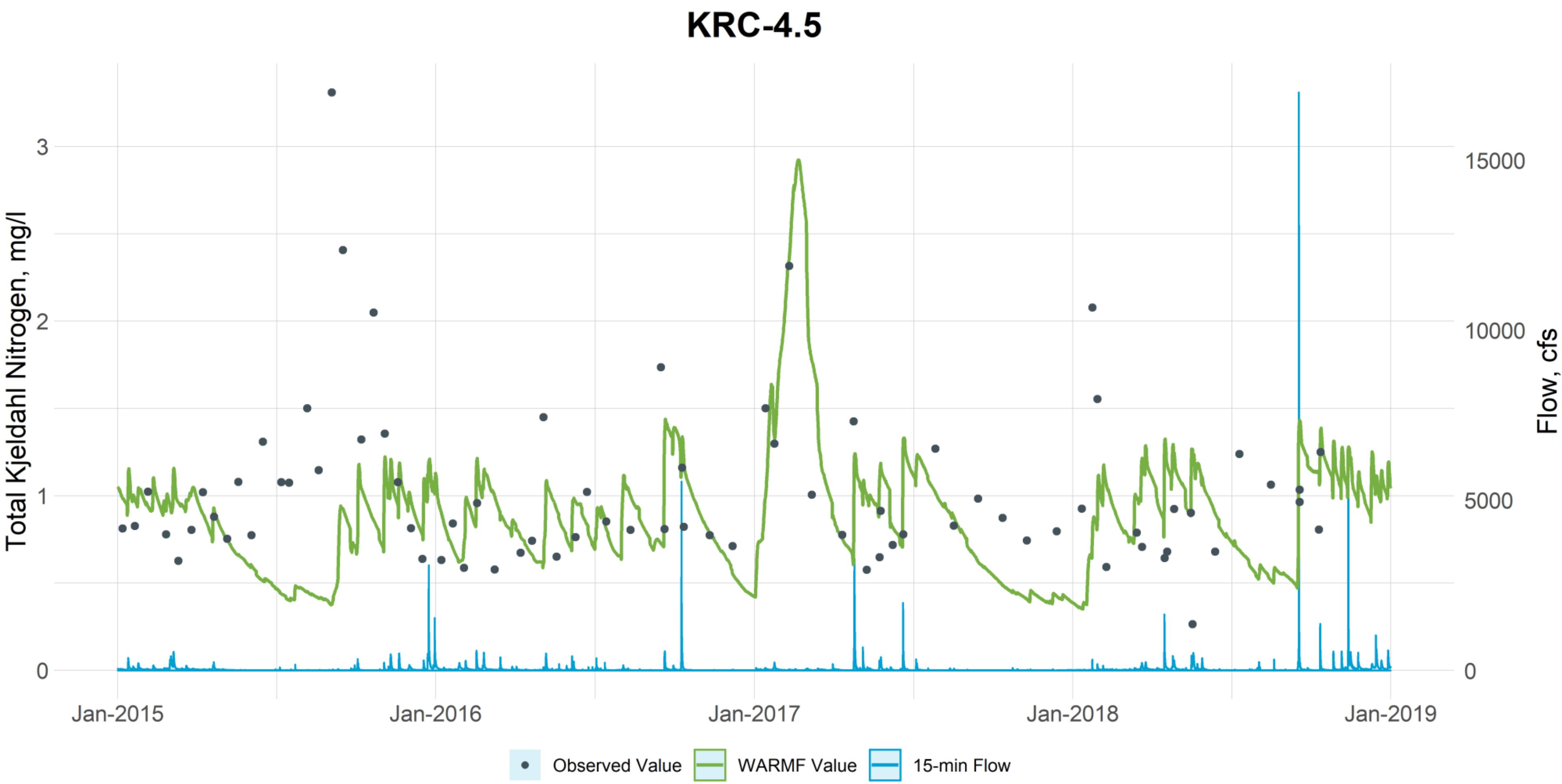
Total Kjeldahl Nitrogen, mg/L – Little River



Total Kjeldahl Nitrogen, mg/L– Flat River



Total Kjeldahl Nitrogen, mg/L – Knap of Reeds



Draft Total Nitrogen (TN) - Concentrations

- Model performance is generally "very good" to "good" at 5 stations except for the calibration period for Knap or Reeds which is "fair"
- Improved nitrogen simulation within Little River Reservoir

Drainage Characteristics and Percent Bias for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Flat	Knap	Little
Drainage Area (sq.mi.)	21.9	149	169	41.9	104
Percent of Flow to Falls Lake	9	24	28	5	11
Total Nitrogen, mg/l;					
Observed Mean Full Period:	2.50	0.85	0.88	2.22	0.79
Calibration Period	-19.6	10.1	6.6	-32.8	20.6
Full	-13.1	2.8	10.1	-20.9	22.0
Validation Period	-3.5	-4.6	15.1	13.2	23.9

Comparison to Load Estimates

- Load is a function of concentration and flow
- Comparison of loads generated by WARMF to other load estimates provides context for the model performance and helps assure reasonable results
  - All three methods provide estimates (WARMF, LOADEST, and daily load calculations)
  - Load comparisons are not included in the QAPP
- Annual load comparison to LOADEST models developed for the UNRBA 2019 Monitoring Report (using full flow regime)
- Daily load comparison using UNRBA sampling data (concentrations) and daily average estimated flows using basin proration with USGS gaged flows
  - Based on a small number of samples (~12 per year)
  - Samples usually collected in low to moderate flow periods

Draft Total Nitrogen (TN) - Loads

- At Ellerbe and Flat, load comparisons generate similar results (green)
- At Eno, annual load comparisons are similar; WARMF generates lower daily loads than daily load estimates
- At Knap, WARMF predicts higher daily and annual loads except for annual loads during the calibration period
- For Little, WARMF generally predicts higher loads, except for the daily estimates for the validation period
- Color coding is included for reference; these are not required statistics

Comparison of Daily and Annual Loading Estimates

Statistic	Ellerbe	Eno	Flat	Knap	Little
Drainage Area (sq.mi.)	21.9	149	169	41.9	104
Percent of Flow to Falls Lake	9	24	28	5	11
Total Nitrogen, lb/day for UNRBA sampling days					
Calibration Period	18.3	-12.7	23.3	32.0	80.4
Full	-2.3	-36.9	-7.4	49.1	-9.6
Validation Period	-7.9	-42.3	-24.2	63.8	-24.3
Total Nitrogen, lb/year (365 days/year)					
Calibration Period	-8.2	-4.5	13.4	-23.8	58.6
Full	2.6	-1.0	13.7	4.6	40.6
Validation Period	15.7	2.5	14.0	47.4	31.5

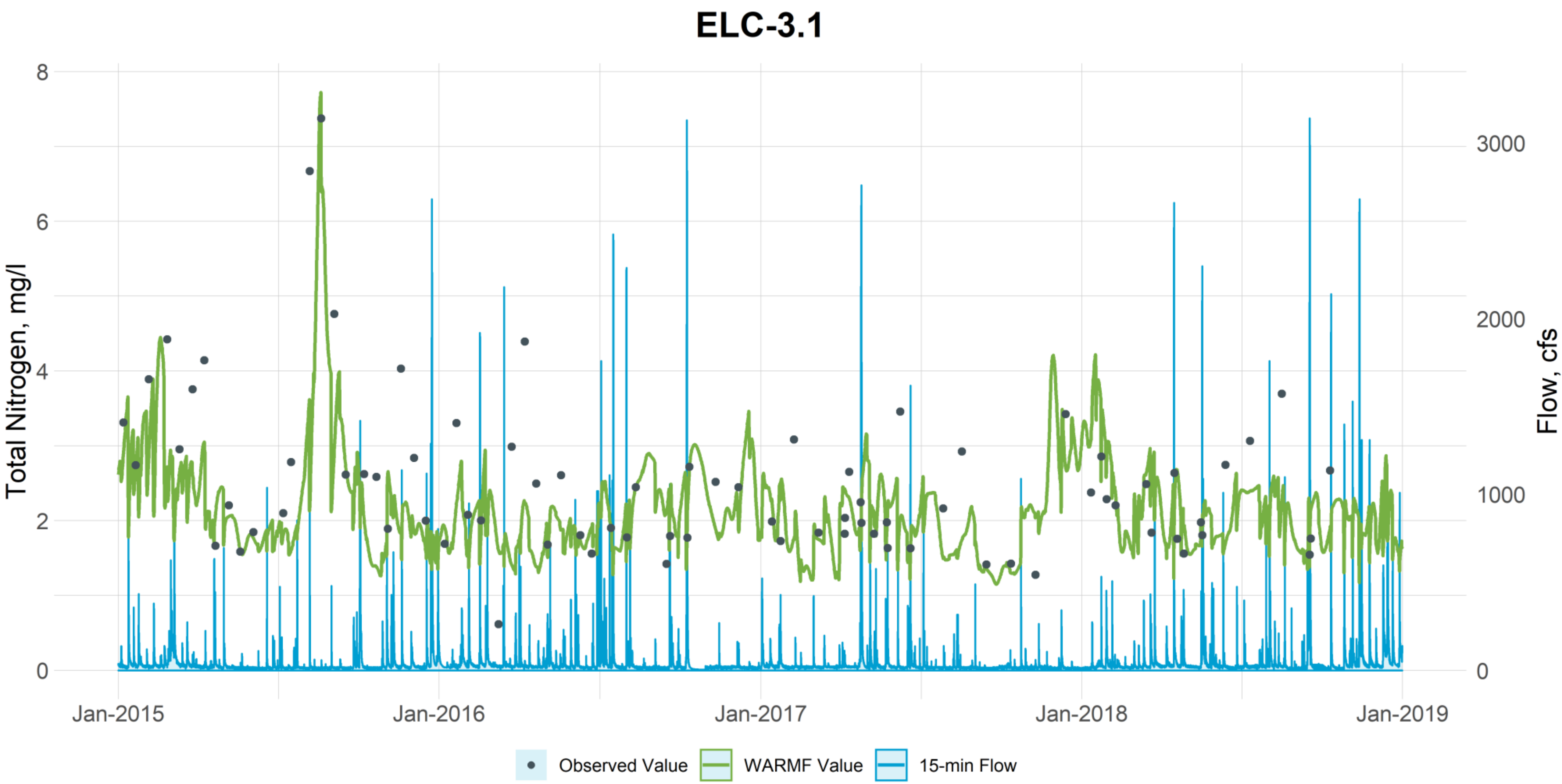
TN Loads Compared to LOADEST for All Tributaries

- All tributaries are accounted for in these comparisons
- All flows are included in the LOADEST and WARMF numbers
- Total loading estimates are similar for total nitrogen with WARMF predicting higher loads than LOADEST each year
- These are included for reference and not required by QAPP

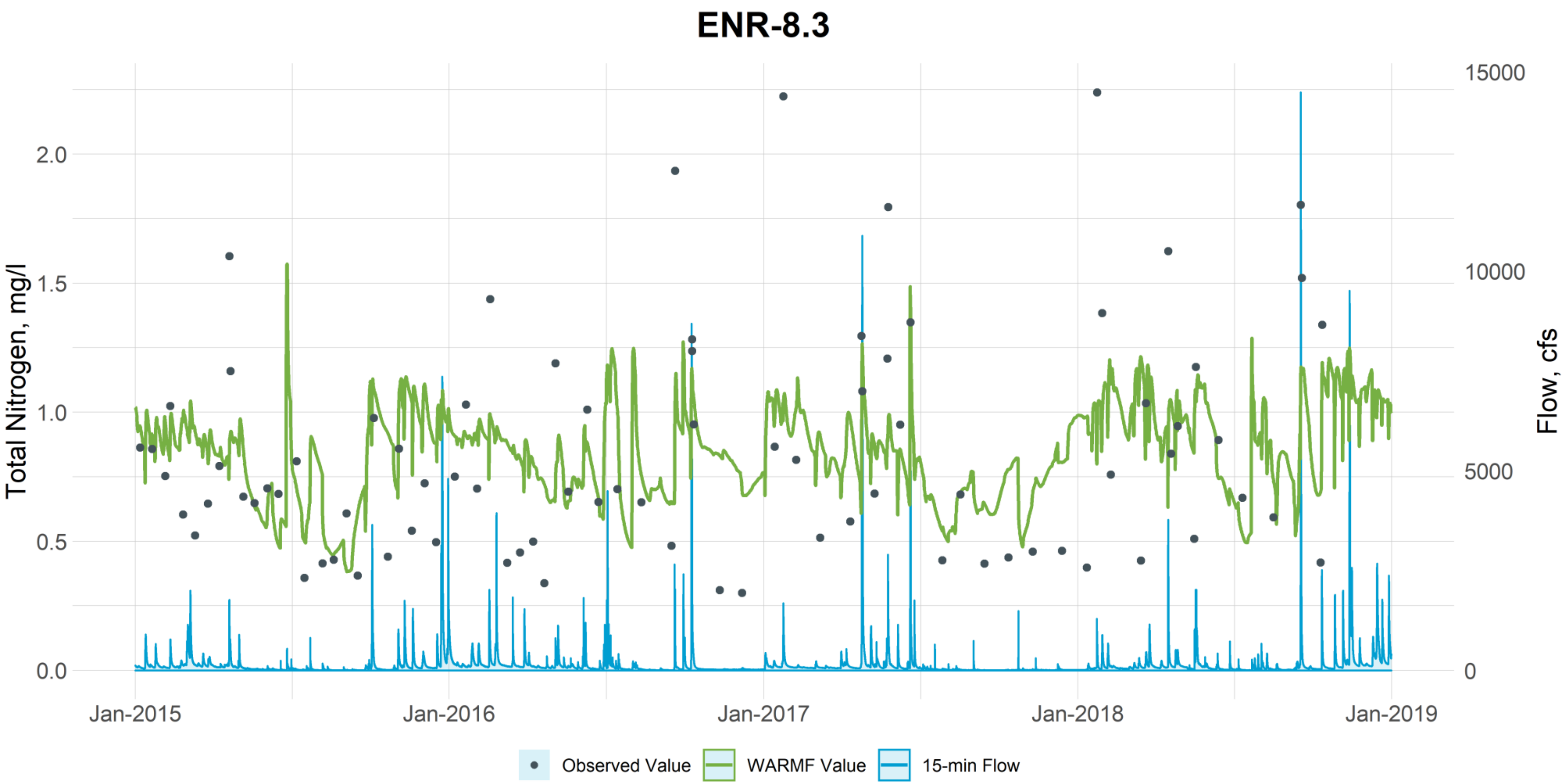
Comparison of Daily and Annual Loading Estimates – All Tributaries

All Tribs	LOADEST LL	WARMF LL	%Bias
Total Nitrogen, lb/year			
2015	1,354,401	1,562,983	15.40
2016	1,168,702	1,274,658	9.07
2017	831,362	1,065,950	28.22
2018	1,853,888	2,351,606	26.85

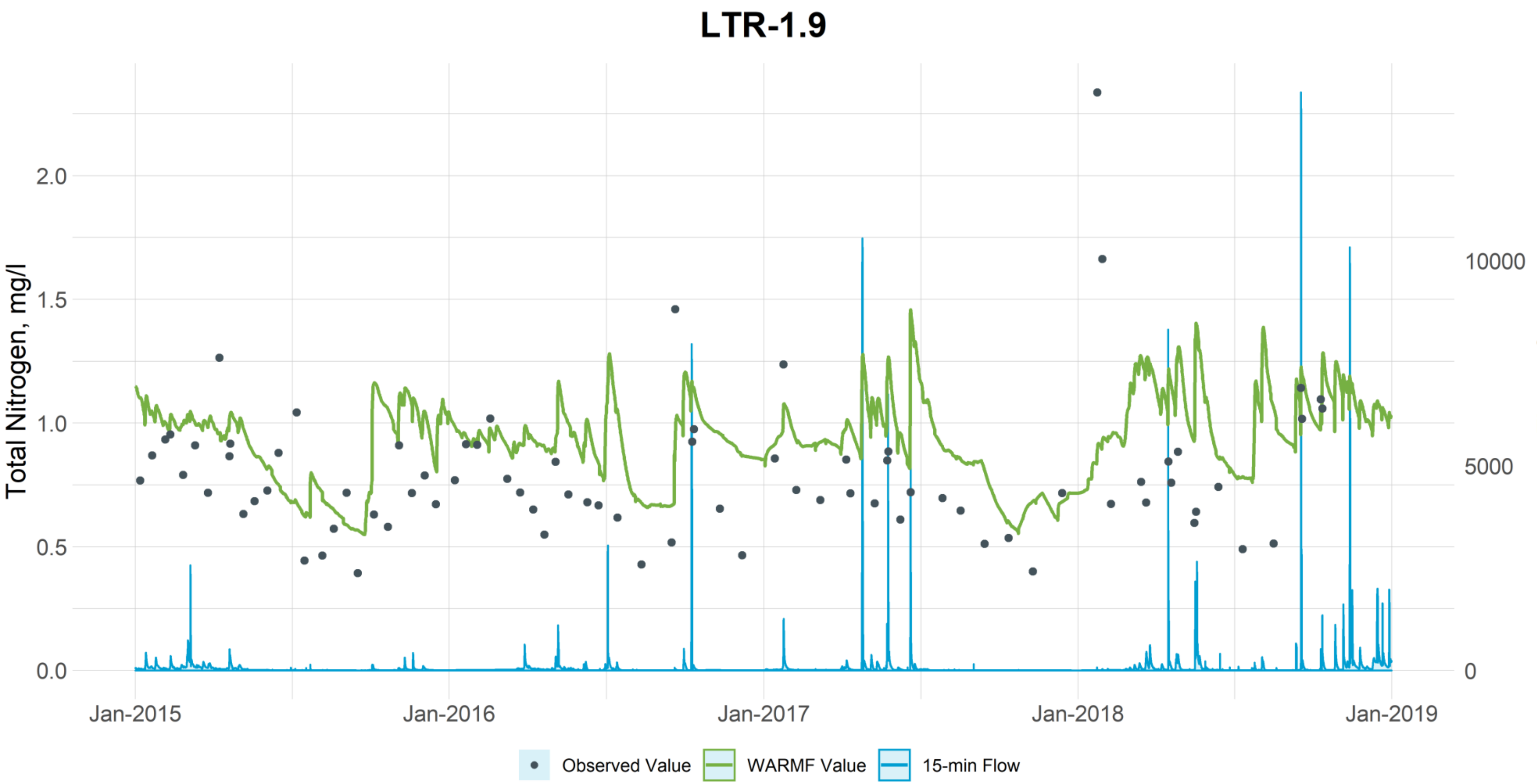
Total Nitrogen, mg/L – Ellerbe Creek



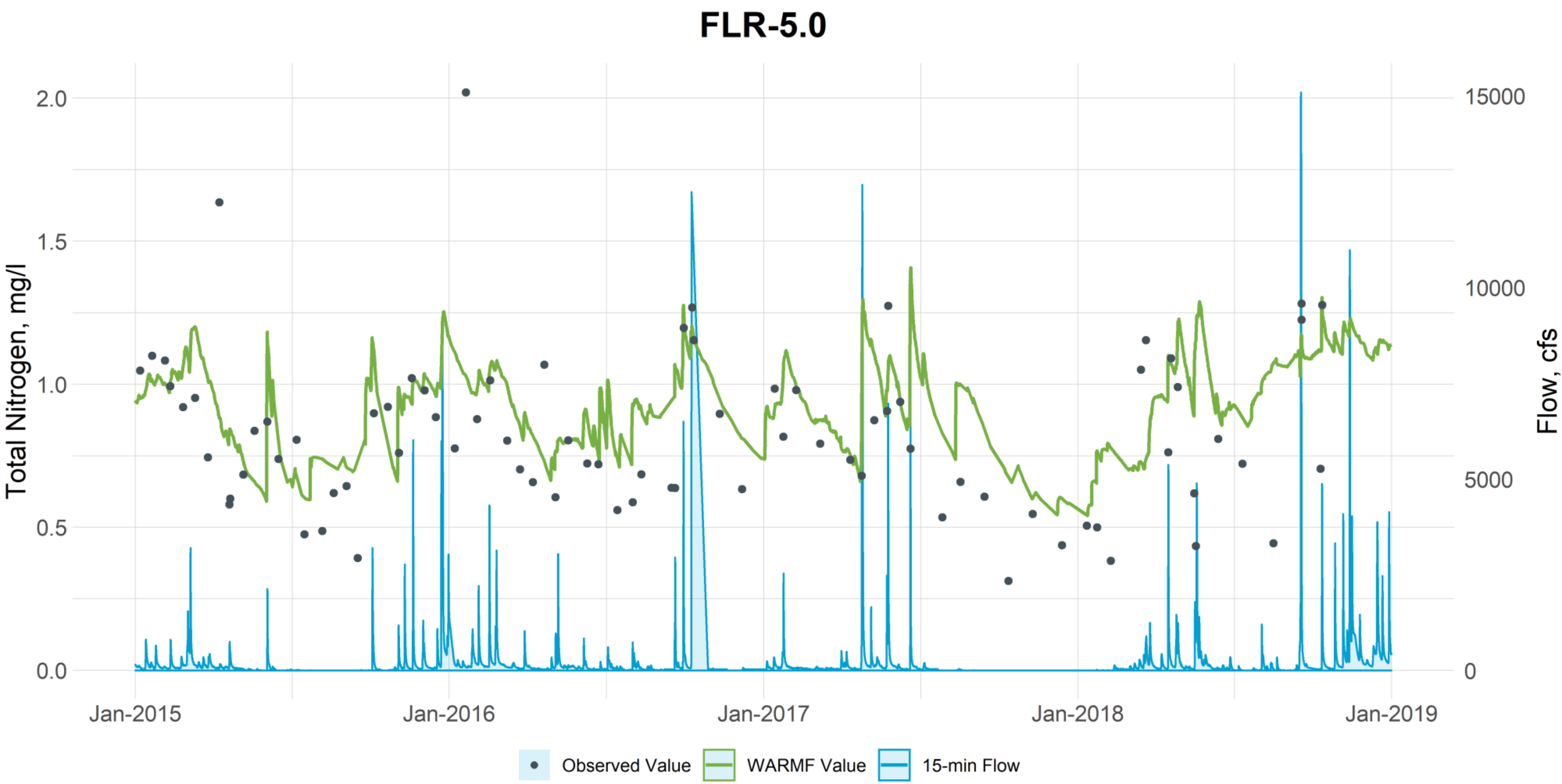
Total Nitrogen, mg/L – Eno River



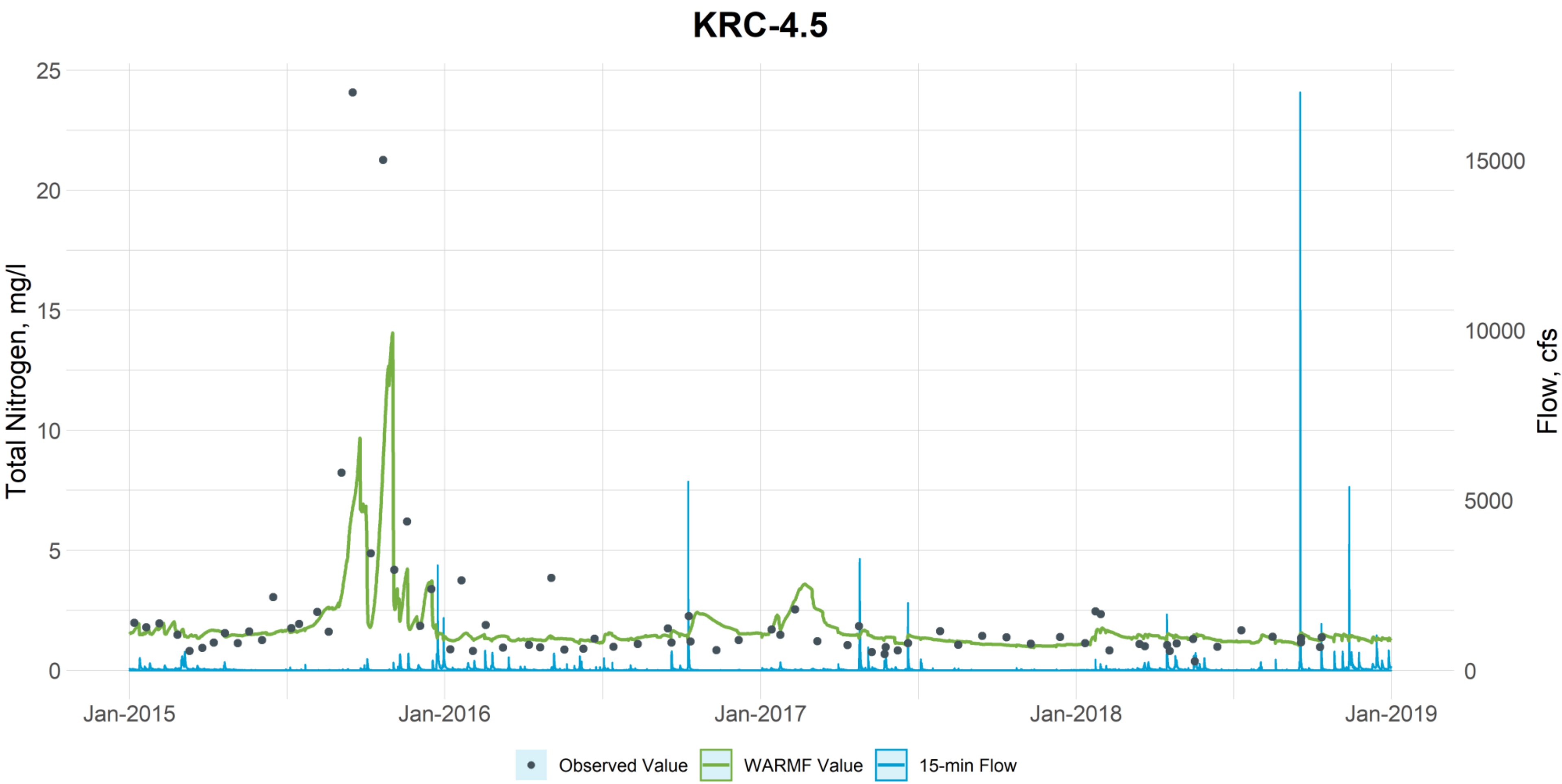
Total Nitrogen, mg/L – Little River



Total Nitrogen, mg/L – Flat River



Total Nitrogen, mg/L – Knap of Reeds



Draft Total Phosphorus (TP) - Concentrations

- Revised soil P concentrations improve simulations for high flows
- At Ellerbe and Eno: "very good" to "good"
- At Little and Flat, nearly "very good" to "fair"
- Knap of Reeds is generally low with data limitations affecting calibration period and validation period "good"

Drainage Characteristics and Percent Bias for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	**Ellerbe**	**Eno**	**Flat**	**Knap**	**Little**
Drainage Area (sq.mi.)	21.9	149	169	41.9	104
Percent of Flow to Falls Lake	9	24	28	5	11
Total Phosphorus, mg/l;					
Observed Mean Full Period:	0.13	0.08	0.06	0.44	0.07
Calibration Period	24.9	9.2	36.6	-63.4	28.5
Full	7.6	-9.1	21.1	-57.1	5.6
Validation Period	-5.2	-23.3	4.1	-22.7	-13.5

Draft TP - Loads

- At Ellerbe, Eno, and Knap, daily & annual load comparisons are similar between WARMF and the other methods
  - For Knap, we underestimated concentrations but when flow is considered, we overestimate loads
- At Flat, annual load comparisons are similar; daily WARMF loads are lower than those estimated from concentrations and flows
- At Little, WARMF daily loads are higher for the calibration period and lower for validation period; annual loads are higher in the calibration period, but similar for validation or full period
- Color coding is included for reference; these are not required statistics

Comparison of Daily and Annual Loading Estimates

Statistic	Ellerbe	Eno	Flat	Knap	Little
Total Phosphorus, lb/day for UNRBA sampling days					
Calibration Period	10.7	-22.1	-20.6	28.4	50.9
Full	-29.9	-23.4	-37.8	30.0	-35.8
Validation Period	-35.1	-23.5	-48.3	31.2	-45.9
Total Phosphorus, lb/year (365 days/year)					
Calibration Period	-28.1	-35.8	33.6	10.6	76.3
Full	-22.0	-22.4	0.1	29.8	25.9
Validation Period	-16.2	-9.8	-18.4	48.1	7.6

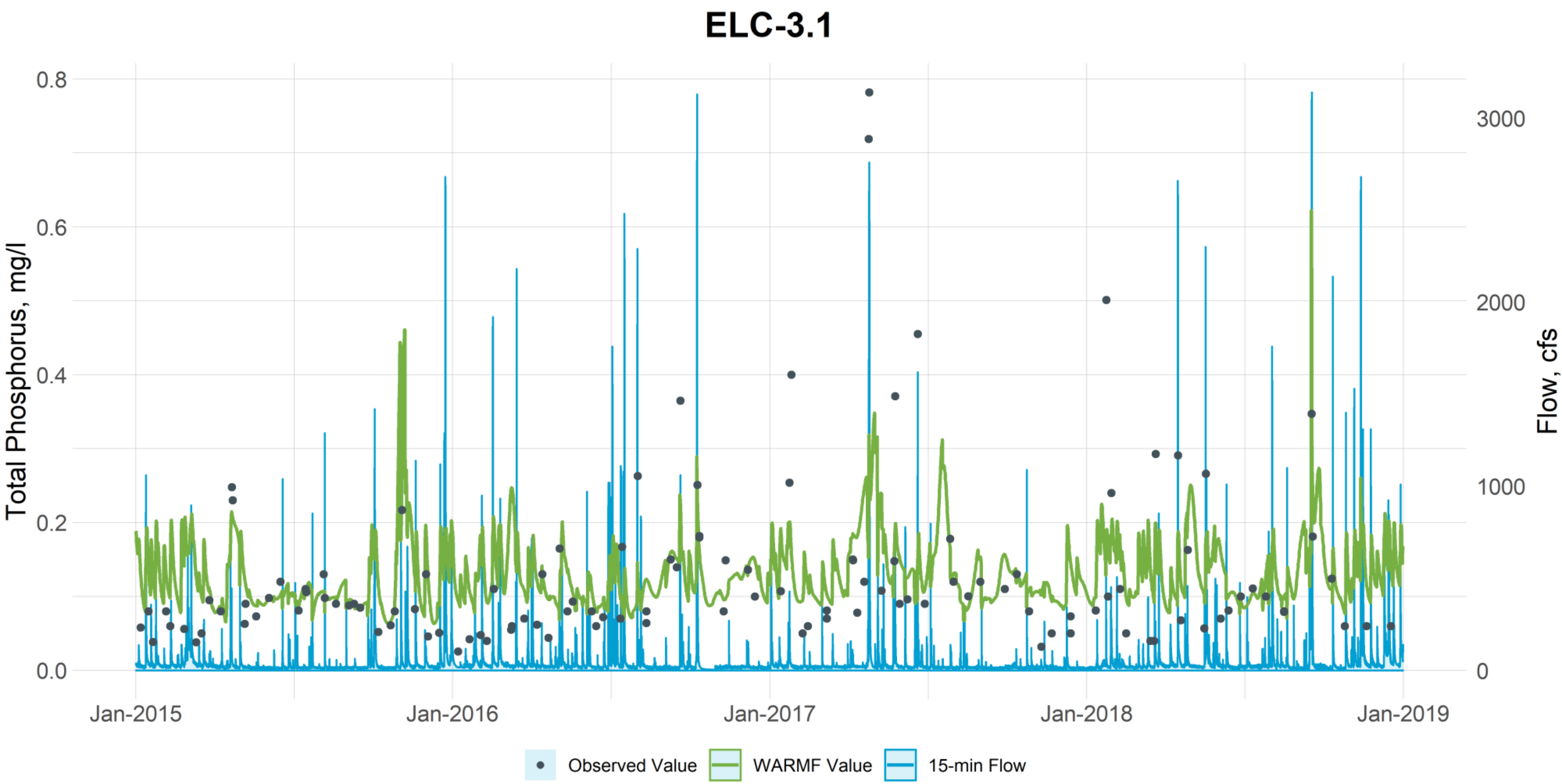
TP Loads Compared to LOADEST for All Tributaries

- All tributaries are included
- All flows are included in the LOADEST and WARMF numbers
- These are included for reference and not required by QAPP
- Total loading estimates are similar for total phosphorus
- WARMF sometime predicts higher and sometimes lower loads

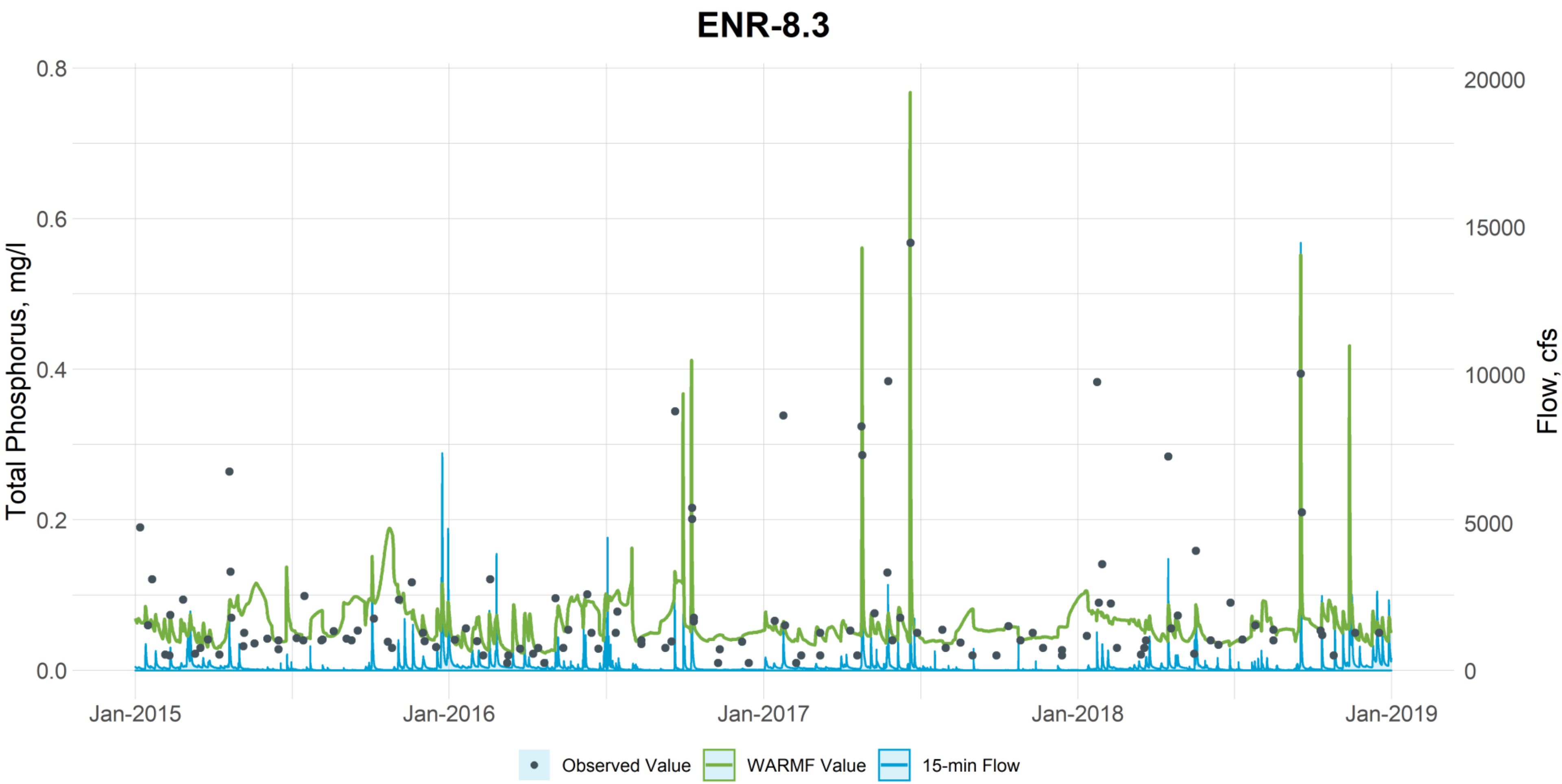
Comparison of Daily and Annual Loading Estimates – All Tributaries

All Tribs	LOADEST LL	WARMF LL	%Bias
Total Phosphorus, lb/year			
2015	122,621	125,054	1.98
2016	131,439	123,048	-6.38
2017	85,744	108,657	26.72
2018	256,916	222,616	-13.35

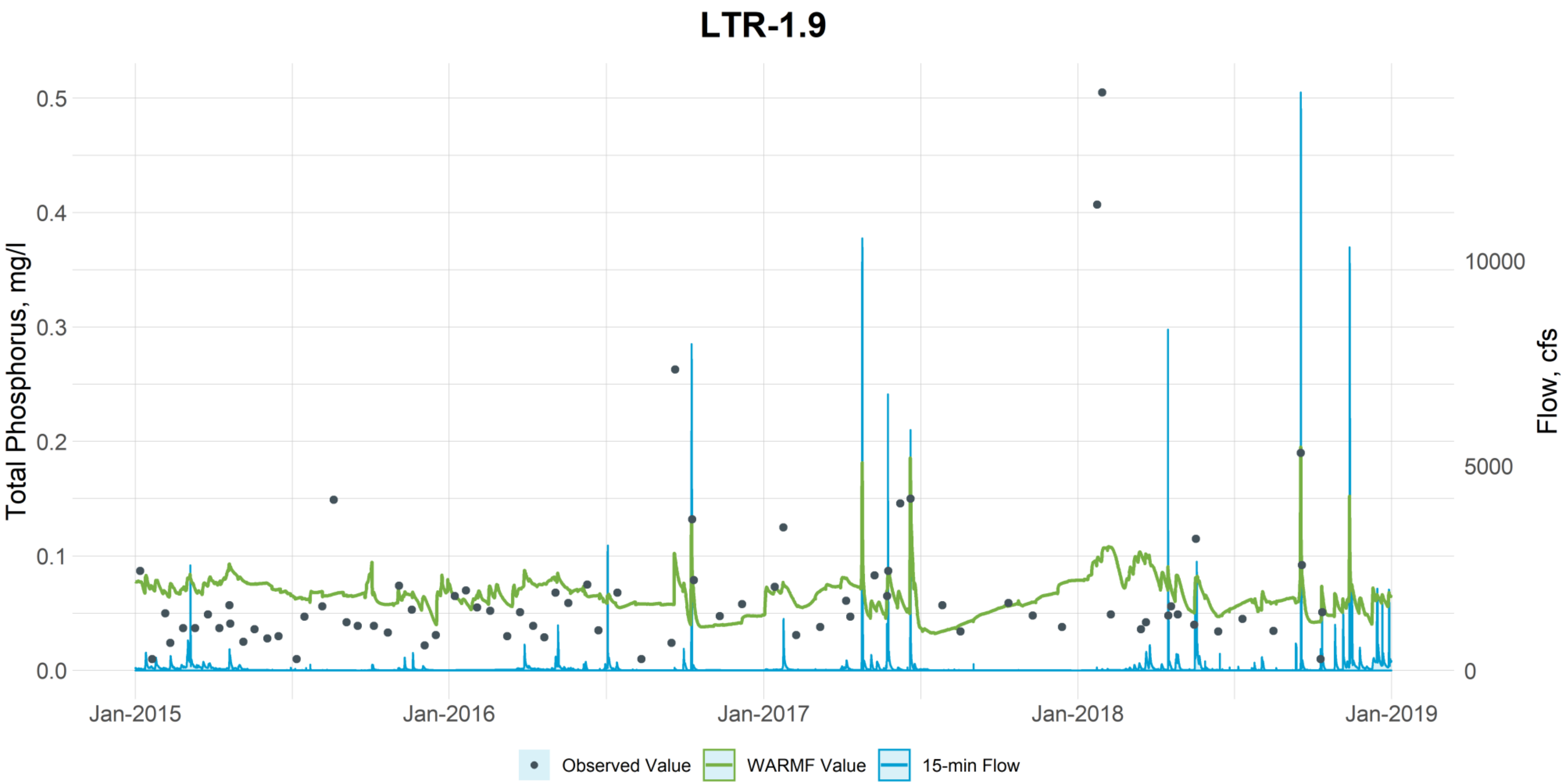
Total Phosphorus, mg/L – Ellerbe Creek



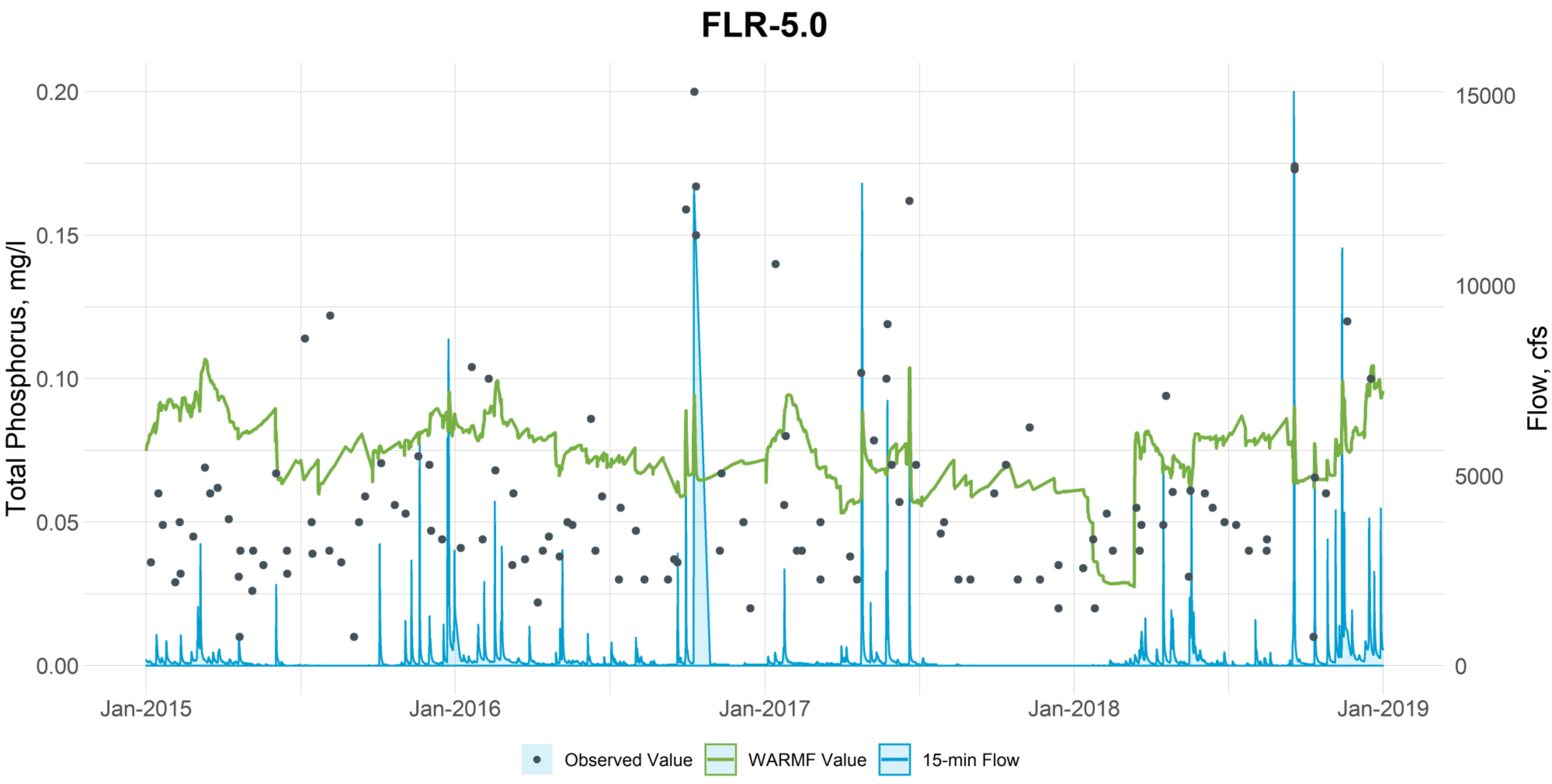
Total Phosphorus, mg/L – Eno River



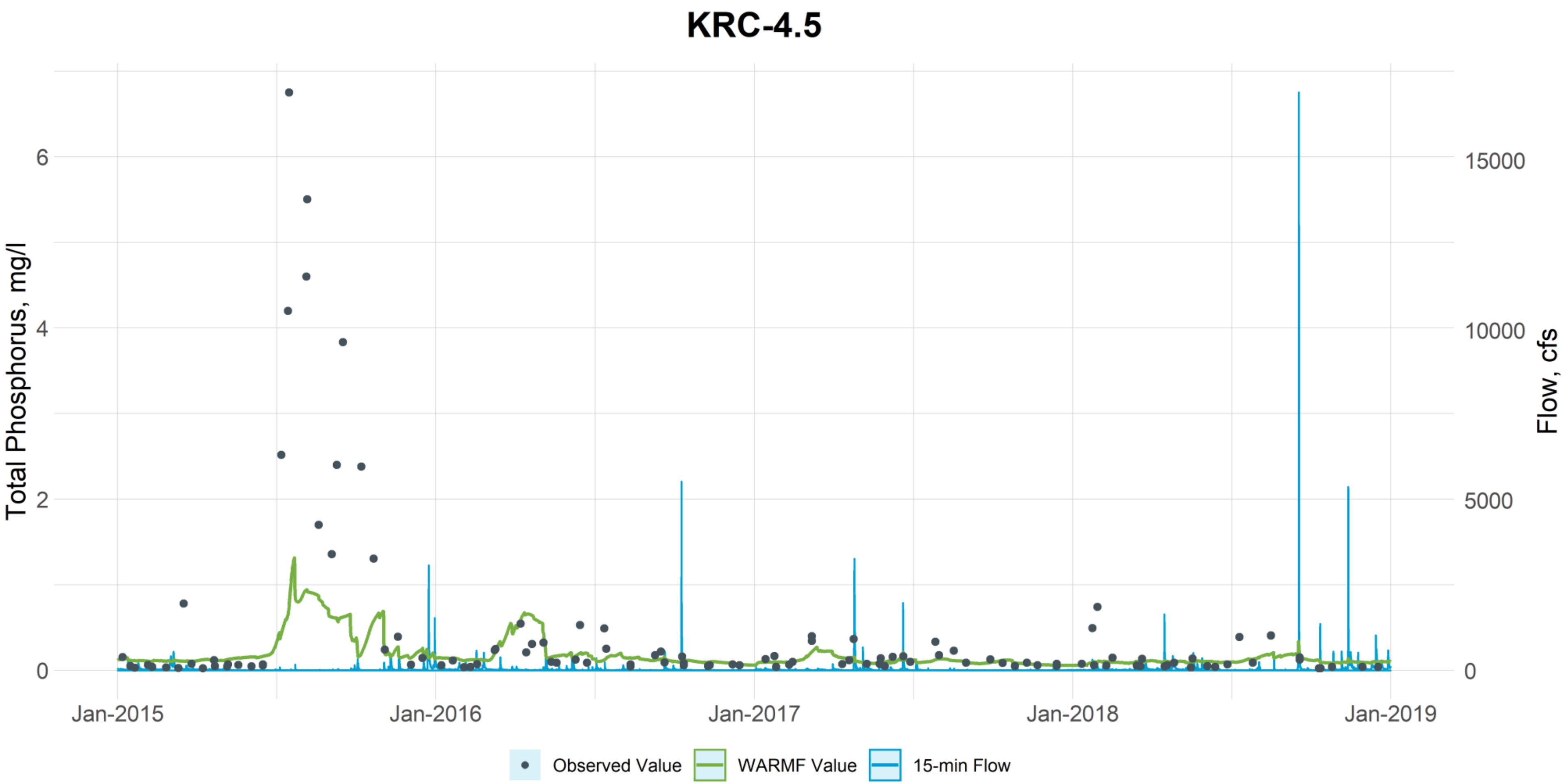
Total Phosphorus, mg/L – Little River



Total Phosphorus, mg/L – Flat River



Total Phosphorus, mg/L – Knap of Reeds



Draft Total Organic Carbon (TOC) - Concentrations

- Model performance is "very good" at all 5 stations

Model Performance for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Flat	Knap	Little
Drainage Area (sq.mi.)	21.9	149	169	41.9	104
Percent of Flow to Falls Lake	9	24	28	5	11
Total Organic Carbon, mg/l; Observed Mean Full Period:	7.6	5.8	7.8	8.3	7.0
Calibration Period	-12.2	-3.1	-2.1	-6.9	-3.6
Full	-9.2	-5.3	1.8	0.2	2.9
Validation Period	-5.9	-7.7	7.5	8.8	11.2

Draft Total Organic Carbon (TOC) - Loads

- WARMF generates similar daily and annual loads as the other methods at Ellerbe, Eno, and Flat
- At Knap, annual loads are similar and daily loads are higher
- At Little, WARMF generates similar annual loads and daily loads are higher or lower depending on the period

Comparison of Daily and Annual Loading Estimates

Statistic	Ellerbe	Eno	Flat	Knap	Little
Total Organic Carbon, lb/day for UNRBA sampling days					
Calibration Period	-9.0	-9.6	2.3	88.4	55.6
Full	-24.7	-22.4	-15.2	67.9	-14.4
Validation Period	-28.6	-25.5	-26.5	57.2	-26.5
Total Organic Carbon, lb/year (365 days/year)					
Calibration Period	-10.7	1.5	13.9	4.6	40.3
Full	-7.0	-1.5	4.1	23.7	21.4
Validation Period	-3.2	-4.2	-2.5	38.5	13.0

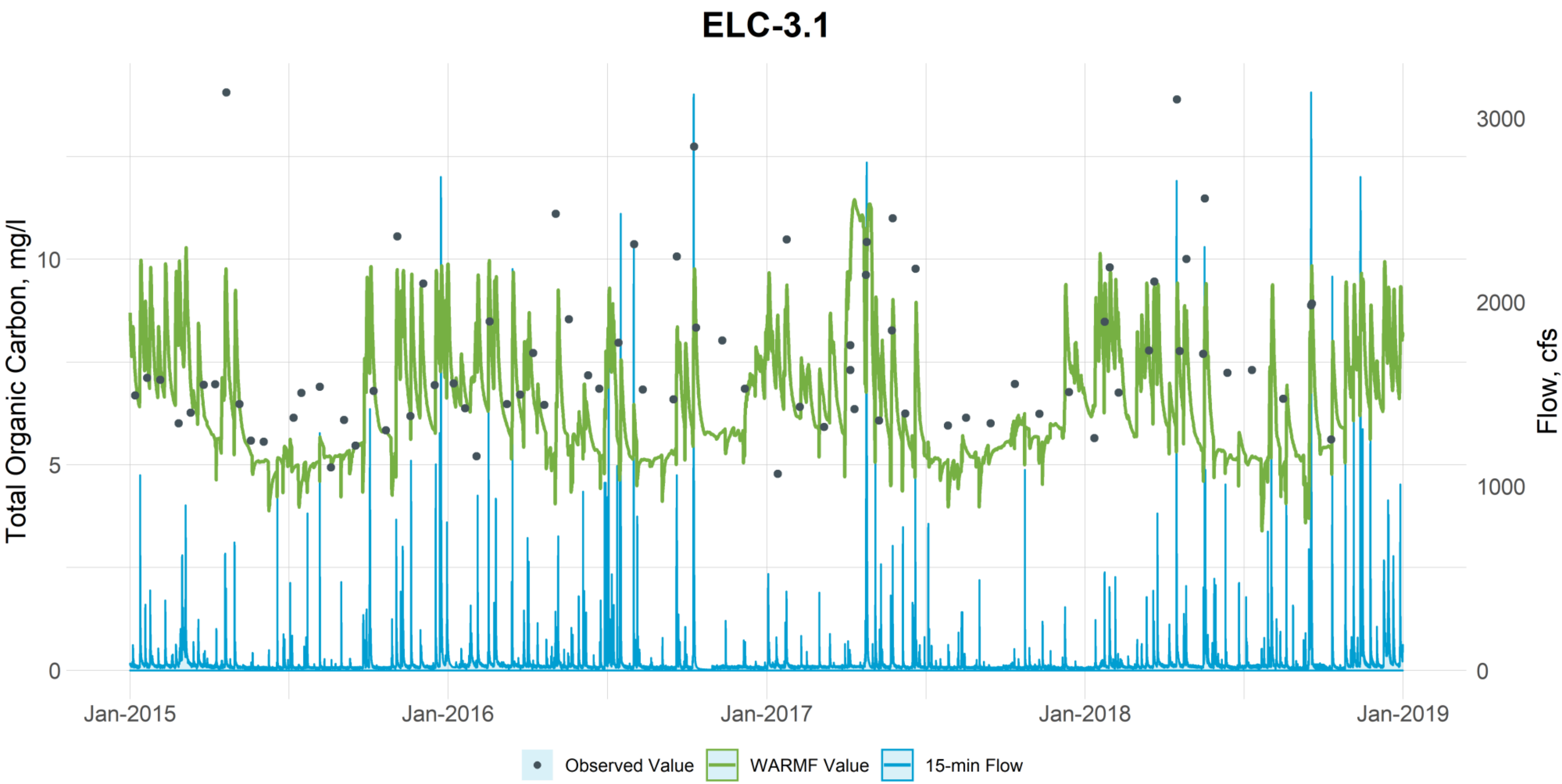
TOC Loads Compared to LOADEST for All Tributaries

- All tributaries are included
- All flows are included in the LOADEST and WARMF numbers
- These are included for reference and not required by QAPP
- Total loading estimates are similar for total organic carbon with WARMF estimates higher than LOADEST each year

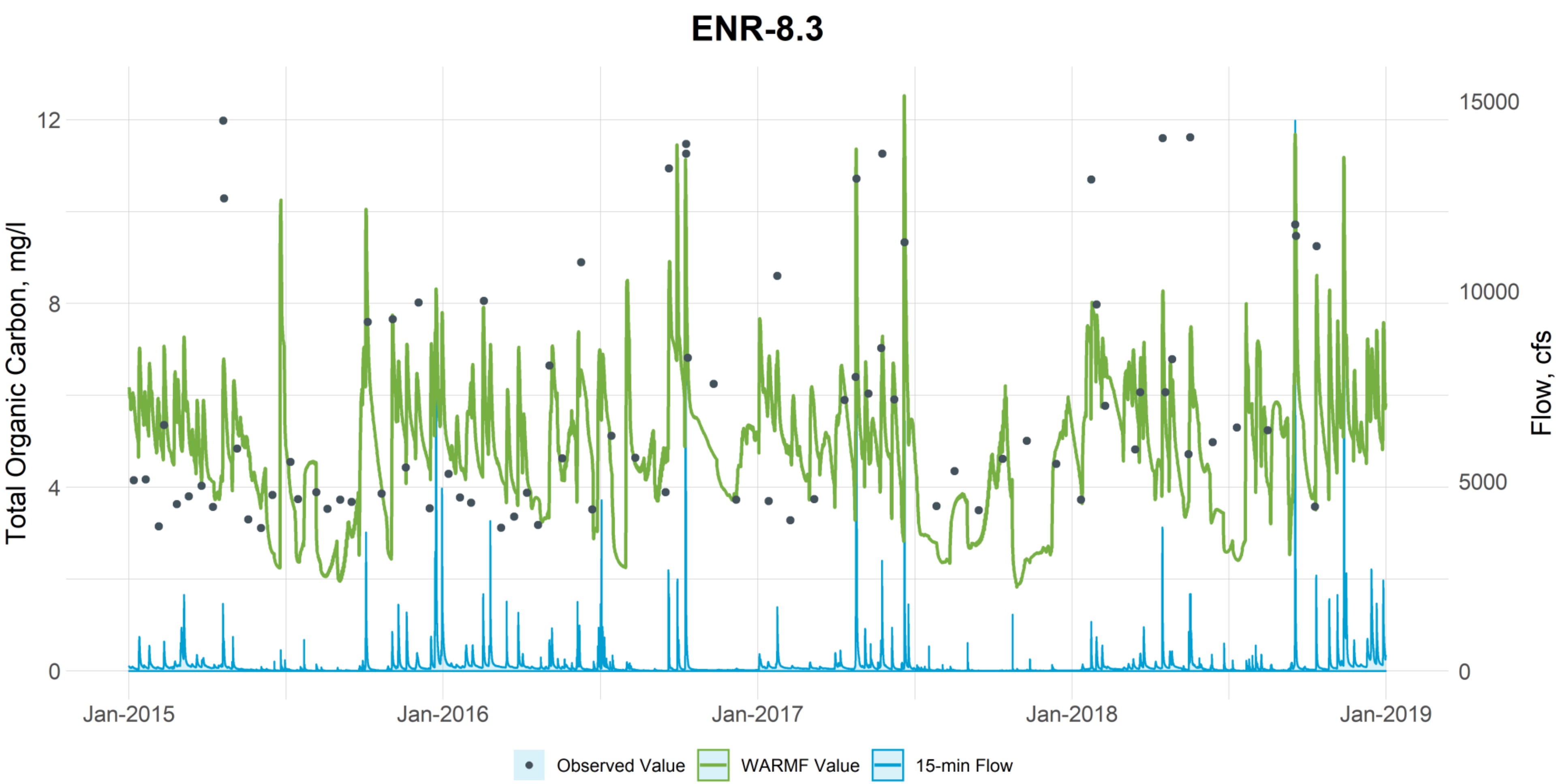
Comparison of Daily and Annual Loading Estimates – All Tributaries

All Tribs	LOADEST LL	WARMF LL	%Bias
Total Organic Carbon, lb/year			
2015	9,029,855	10,469,464	15.94
2016	8,467,061	9,235,364	9.07
2017	6,343,279	7,601,607	19.84
2018	16,527,640	17,724,986	7.24

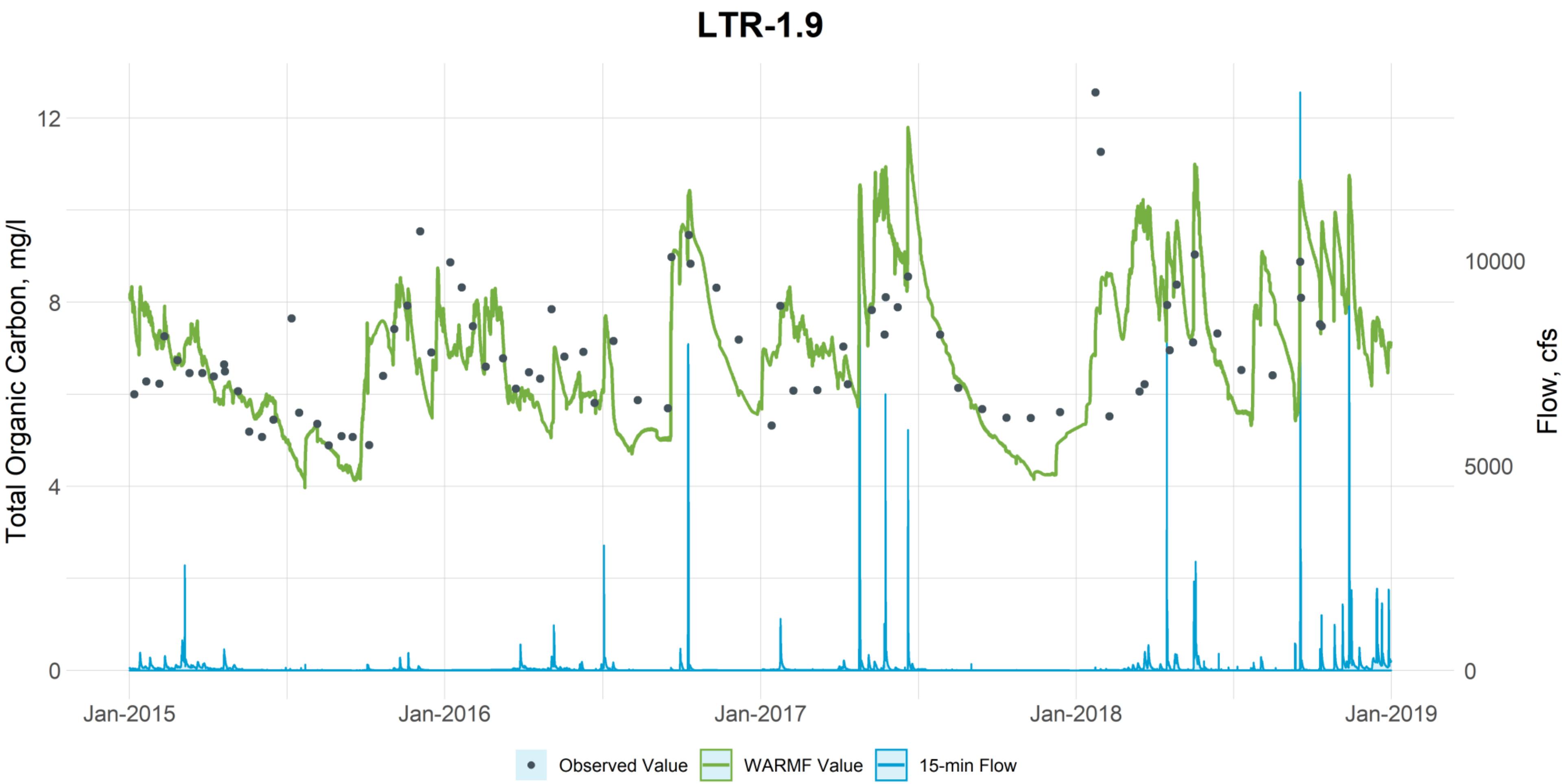
Total Organic Carbon, mg/L – Ellerbe Creek



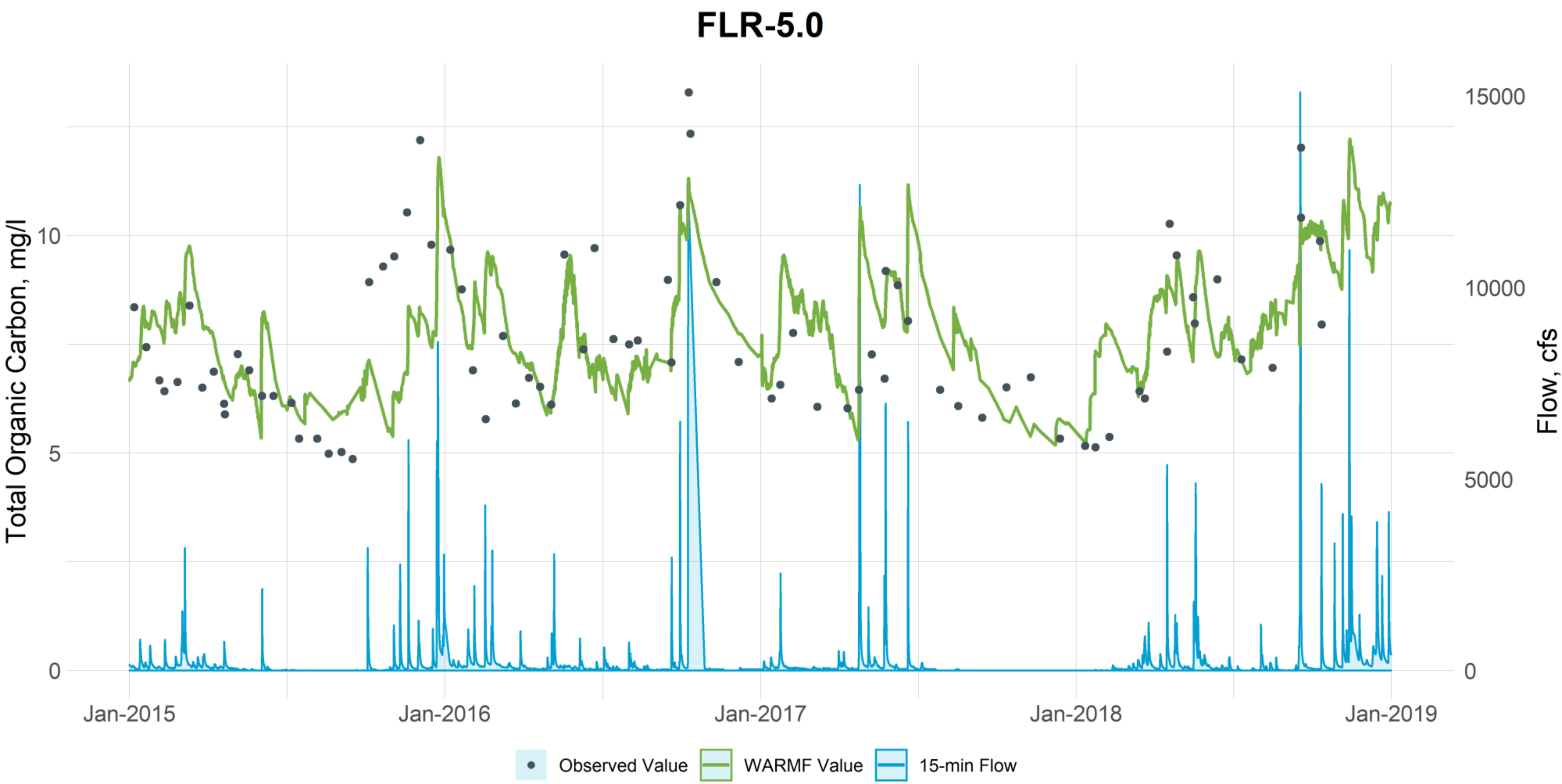
Total Organic Carbon, mg/L – Eno River



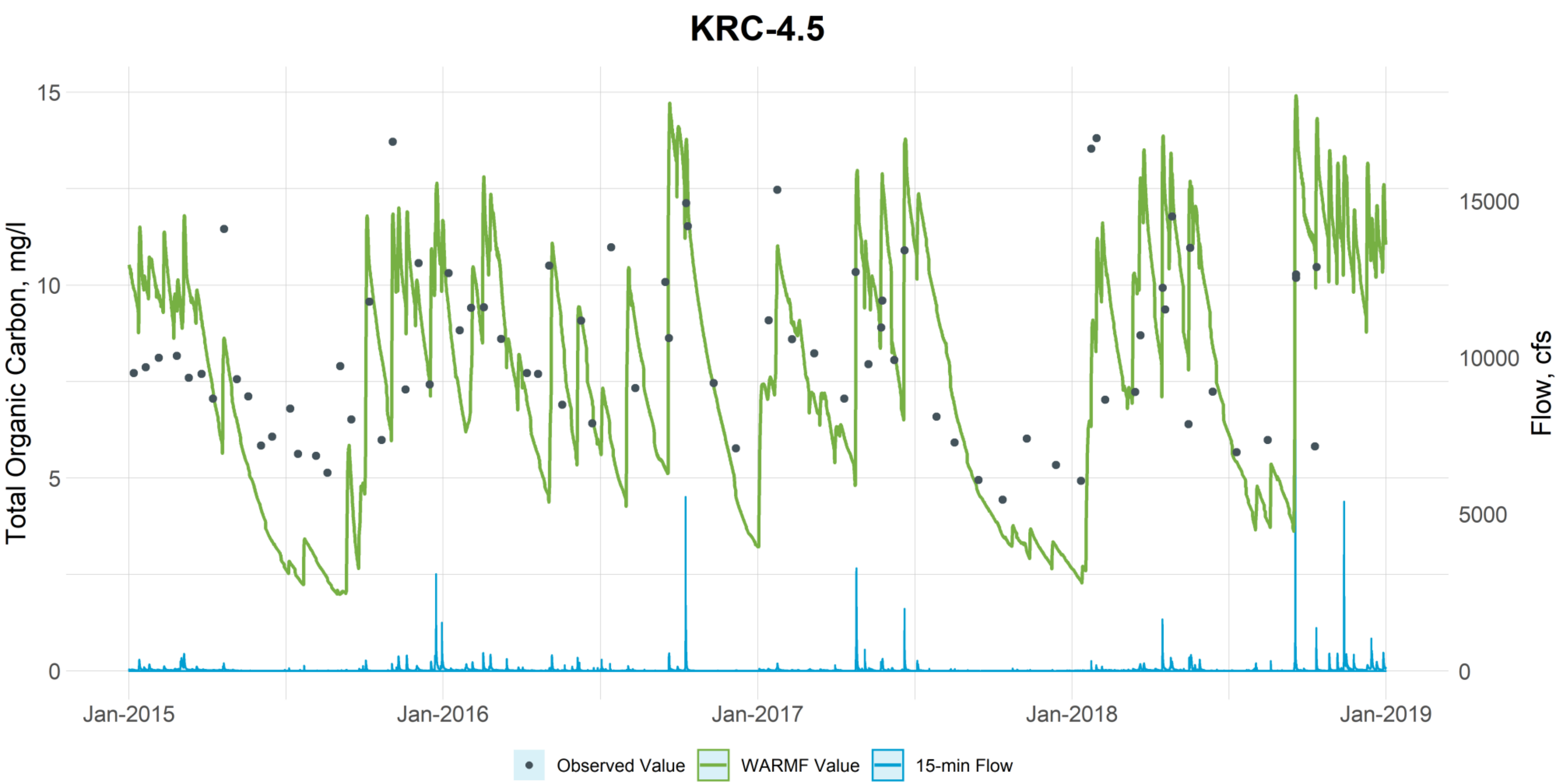
Total Organic Carbon, mg/L – Little River



Total Organic Carbon, mg/L – Flat River



Total Organic Carbon, mg/L – Knap of Reeds



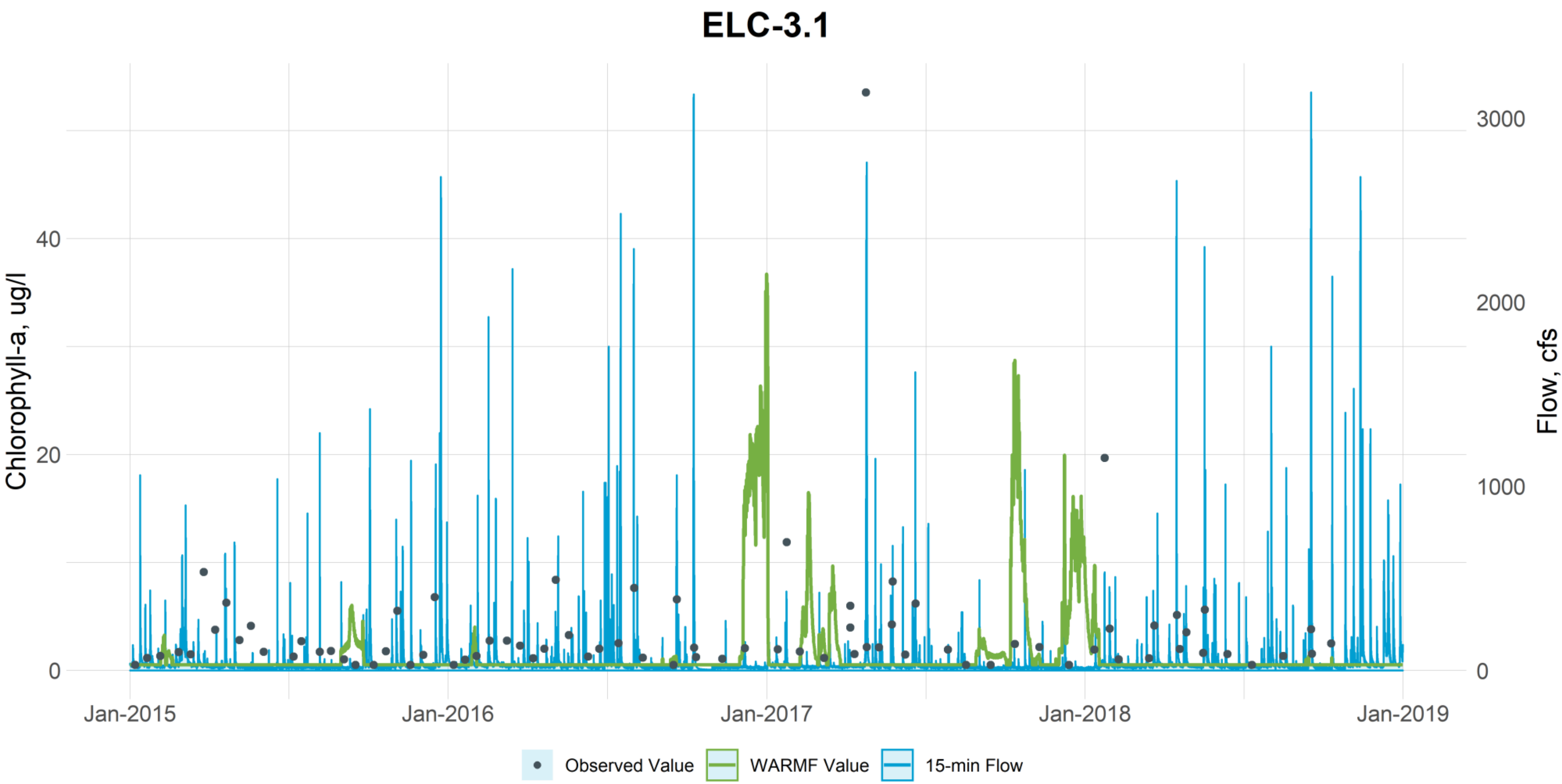
Draft Chlorophyll-a (Chl-a)

- Model performance is "very good" at Flat and Knap and almost "fair" at Eno
- Model underestimates at Ellerbe, but concentrations are generally low based on observations
- Particularly in streams, measured chlorophyll-a is likely due to sloughing of periphyton, not floating algae
- Concentrations in streams are low relative to in-lake concentrations, and the model is doing well representing potential inputs to the lake

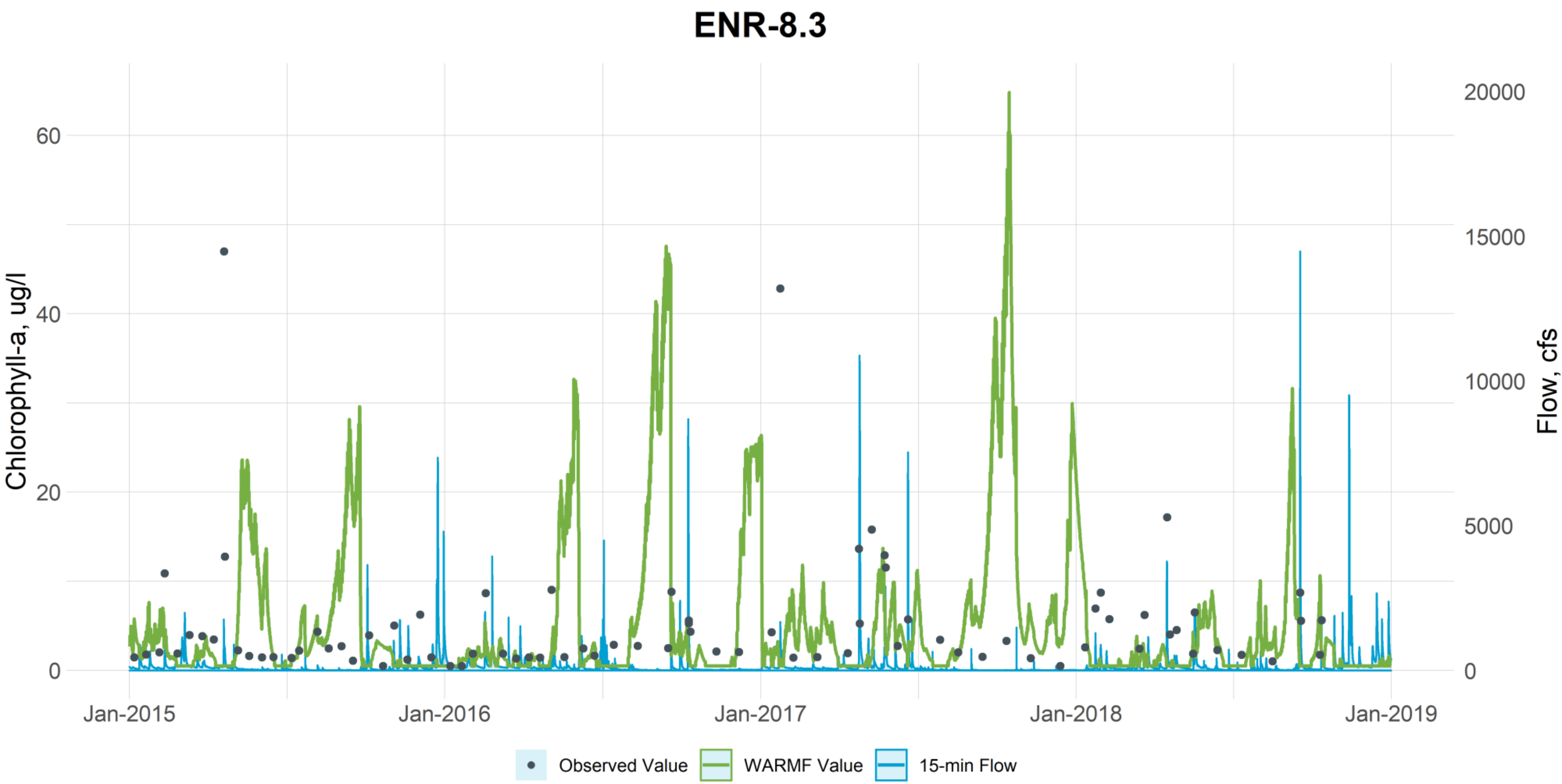
Drainage Characteristics and Percent Bias for Upper Five Lake

Statistic	Ellerbe	Eno	Flat	Knap	Little
Drainage Area (sq.mi.)	21.9	149	169	41.9	104
Percent of Flow to Falls Lake	9	24	28	5	11
Chlorophyll-a, ug/l;					
Observed Mean Full Period:	3.6	5.1	12.6	3.7	9.9
Calibration Period	-61.2	6.2	-2.7	-3.3	51.1
Full	-63.1	-16.4	-6.6	5.8	9.7
Validation Period	-64.3	-36.2	-10.3	12.6	-15.4

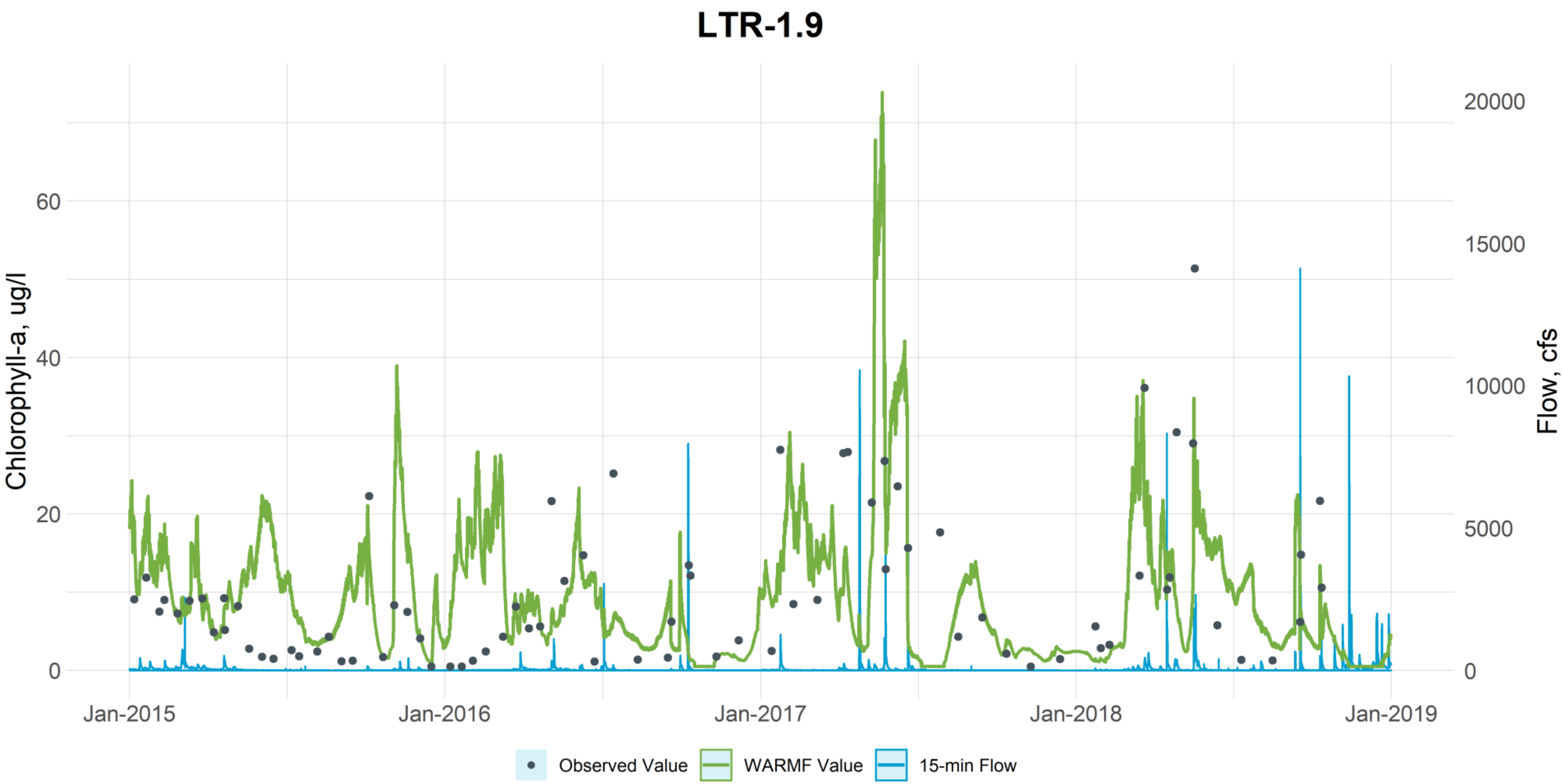
Chlorophyll-*a*, ug/L – Ellerbe Creek



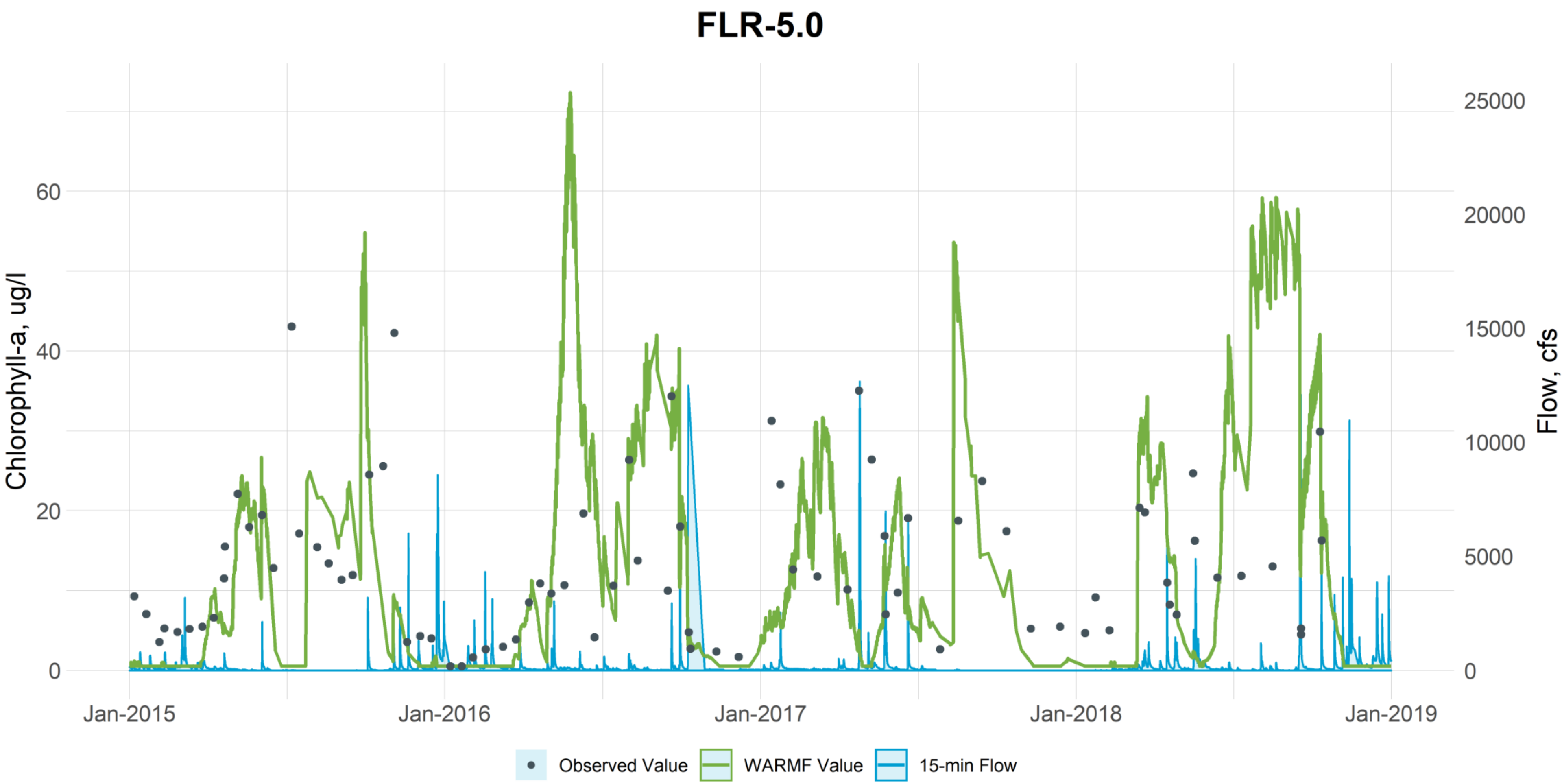
Chlorophyll-*a*, ug/L – Eno River



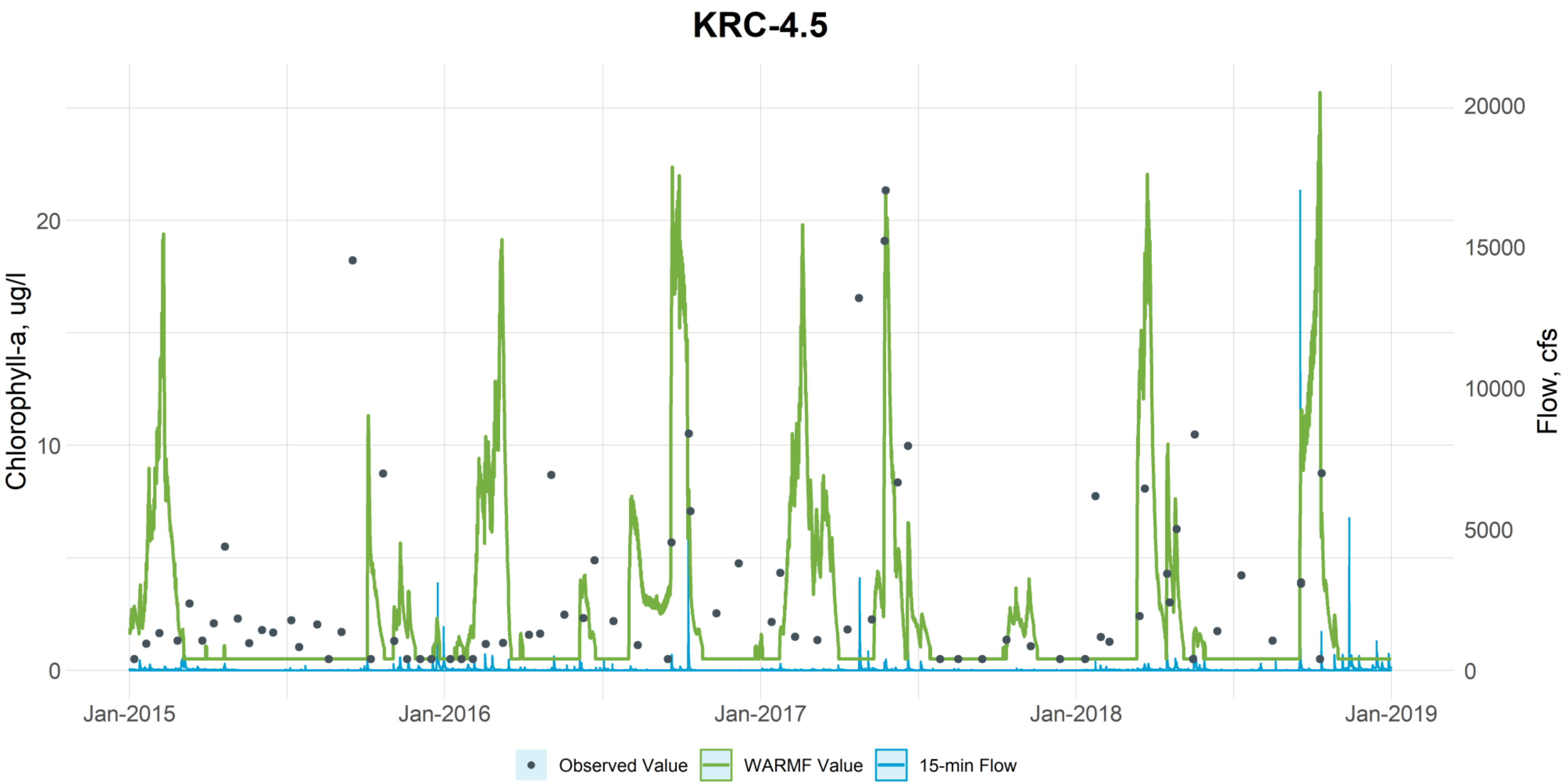
Chlorophyll-*a*, ug/L – Little River



Chlorophyll-*a*, ug/L – Flat River



Chlorophyll-*a*, ug/L – Knap of Reeds



LOADEST and WARMF – All Tributaries

- These are included for reference and not required by QAPP
- Total loading estimates are similar for all three parameters (+-30%)
- All flows are included in the LOADEST and WARMF numbers

All Tribs	LOADEST LL	WARMF LL	%Bias
Total Nitrogen, lb/year			
2015	1,354,401	1,562,983	15.40
2016	1,168,702	1,274,658	9.07
2017	831,362	1,065,950	28.22
2018	1,853,888	2,351,606	26.85
Total Organic Carbon, lb/year			
2015	9,029,855	10,469,464	15.94
2016	8,467,061	9,235,364	9.07
2017	6,343,279	7,601,607	19.84
2018	16,527,640	17,724,986	7.24
Total Phosphorus, lb/year			
2015	122,621	125,054	1.98
2016	131,439	123,048	-6.38
2017	85,744	108,657	26.72
2018	256,916	222,616	-13.35

Discussion

- Overall, the model is performing well in terms of simulated concentrations and total loading to Falls Lake
- We can continue to make small improvements on the model, but each change requires at least a full week to evaluate
- Additional changes will likely not improve overall loading to the lake or simulated lake response
  - WARMF predicts higher TN and TOC loads than LOADEST
  - WARMF predicts TP loads within -13 to +27 percent
- We need to get started on the lake modeling (WARMF Lake and EFDC) to meet our goal of developing recommendations by mid 2023
- MRSW discussion