WARMF Watershed Modeling Status

WARMF Watershed Modeling

- Model has been calibrated for stream flow and water quality across the watershed
- 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 with:
  - UNRBA water quality observations (concentrations) as well as DWR ambient monitoring data where co-located with a UNRBA Station
  - Annual loads estimated using LOADEST (excluding top 1% of flows)
  - Daily loads estimated using water quality observations and USGS gaged flows
- Checks for “reasonableness” were conducted for the other tributaries using the UNRBA monitoring data despite lack of gaged stream flows
- This presentation only includes performance results for the full (2015-2018) modeling period
  - Results for the calibration (2015-2016) and validation (2017-2018) periods will be included in the report

Water Quality Model Performance Criteria

The UNRBA Modeling Quality Assurance Project Plan includes the following guidance for water quality calibration:

"*For water quality variables, a similar 3-tiered system of categorizing statistical performance developed by Donigian (2002) will be used for calibration guidance at the locations where statistical water quality calibration will be performed. The system is based on the percent difference measure with the categorized values shown in Table A.7-2…These statistical measures will be used to supplement graphical evaluation of the model results and aid in determining the endpoints of model calibration.*"

Table A.7-2 General Watershed Model Calibration Guidance

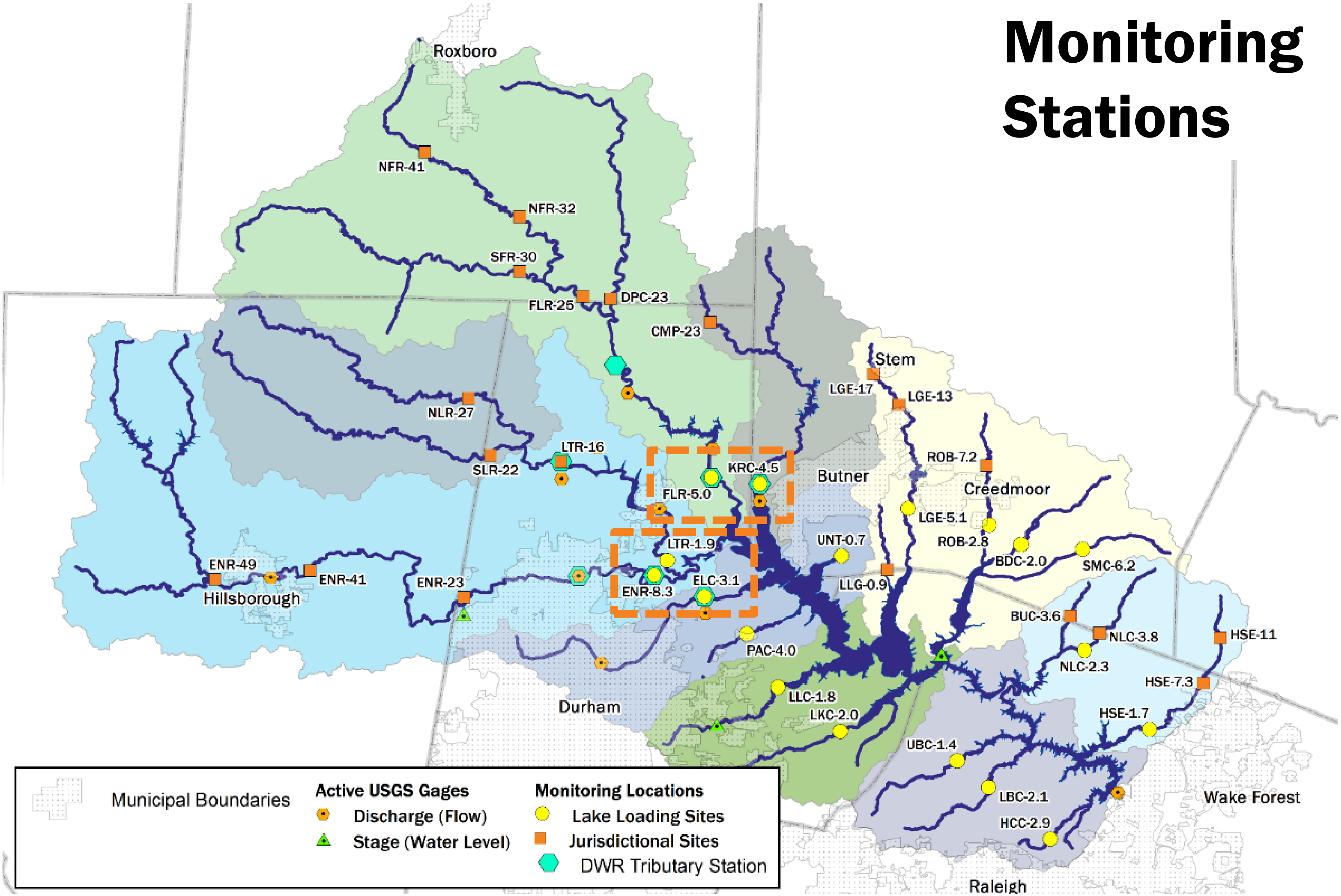
Parameter	% Relative Error (RE) Criteria		
	Very Good	Good	Fair
Sediment	< ± 20	± 20-30	± 30-45
Water Temperature	< ± 7	± 8-12	± 13-18
Water Quality/Nutrients	< ± 15	± 15-25	± 25-35
Flow (Total Volume)	≤ 5%	5-10%	10-15%

Locations for Water Quality Model Evaluation

The UNRBA Modeling Quality Assurance Project Plan includes the following guidance:

"*A complete water quality calibration (for each parameter) including evaluation of performance criteria and generation of documentation will be performed for a minimum of 7 locations. These locations include the lake loading stations of the five largest tributaries (ELC-3.1, ENR-8.3, LTR-1.9, FLR-5.0, and KRC-4.5)…Data collected at all watershed stations will be used to support calibration. Specific stations and parameters will be utilized to improve model calibration at locations where full calibration will be conducted*."

Monitoring Stations



Gaged Stream Flow Comparisons (Total Volume)

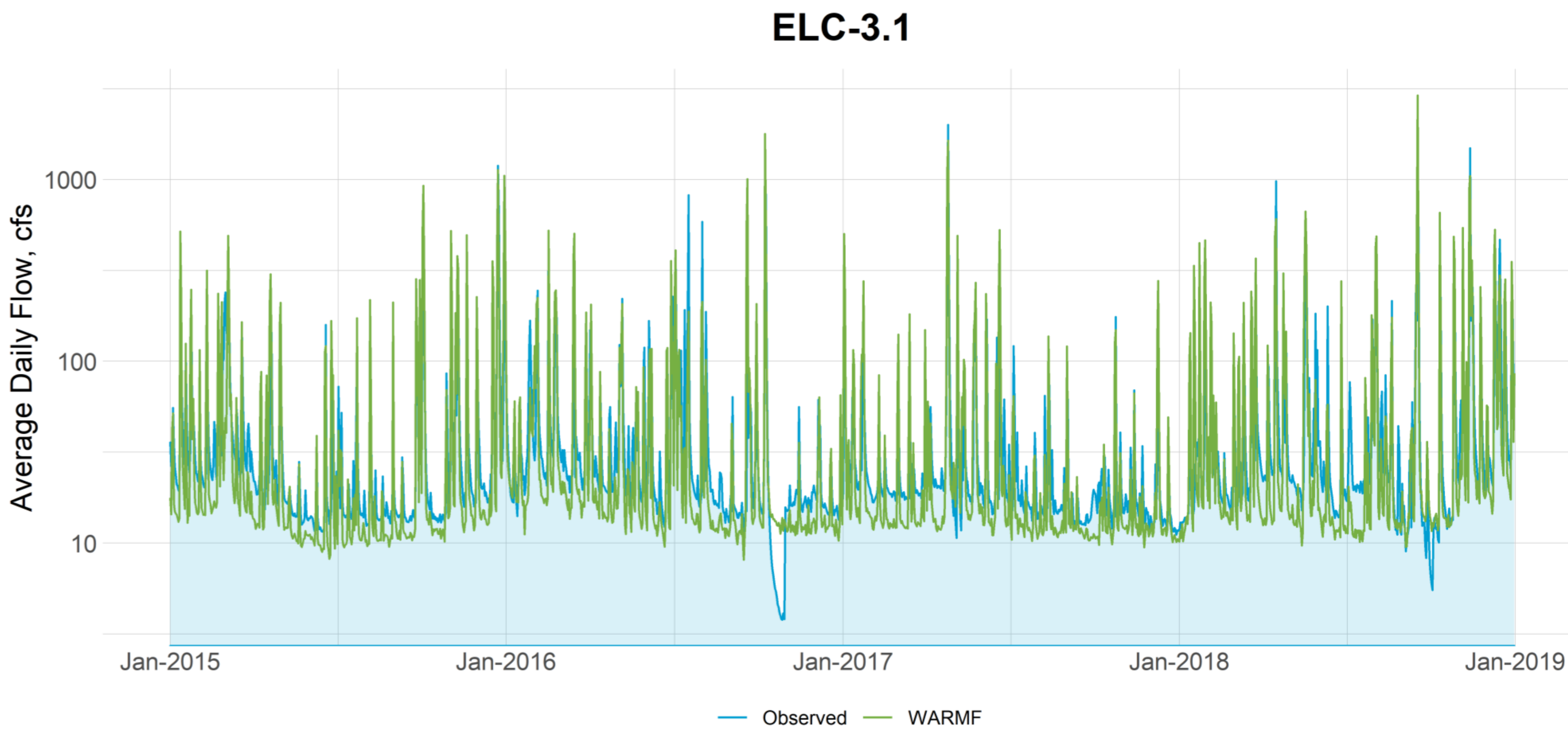
- Model performs well in predicting stream flows
- There is some uncertainty with the gaged flows particularly during low flows (previous rating curve discussions)
- The NEXRAD precipitation data provides a good coverage of rainfall patterns, but some storms are either missed or over-predicted in some areas
- 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)

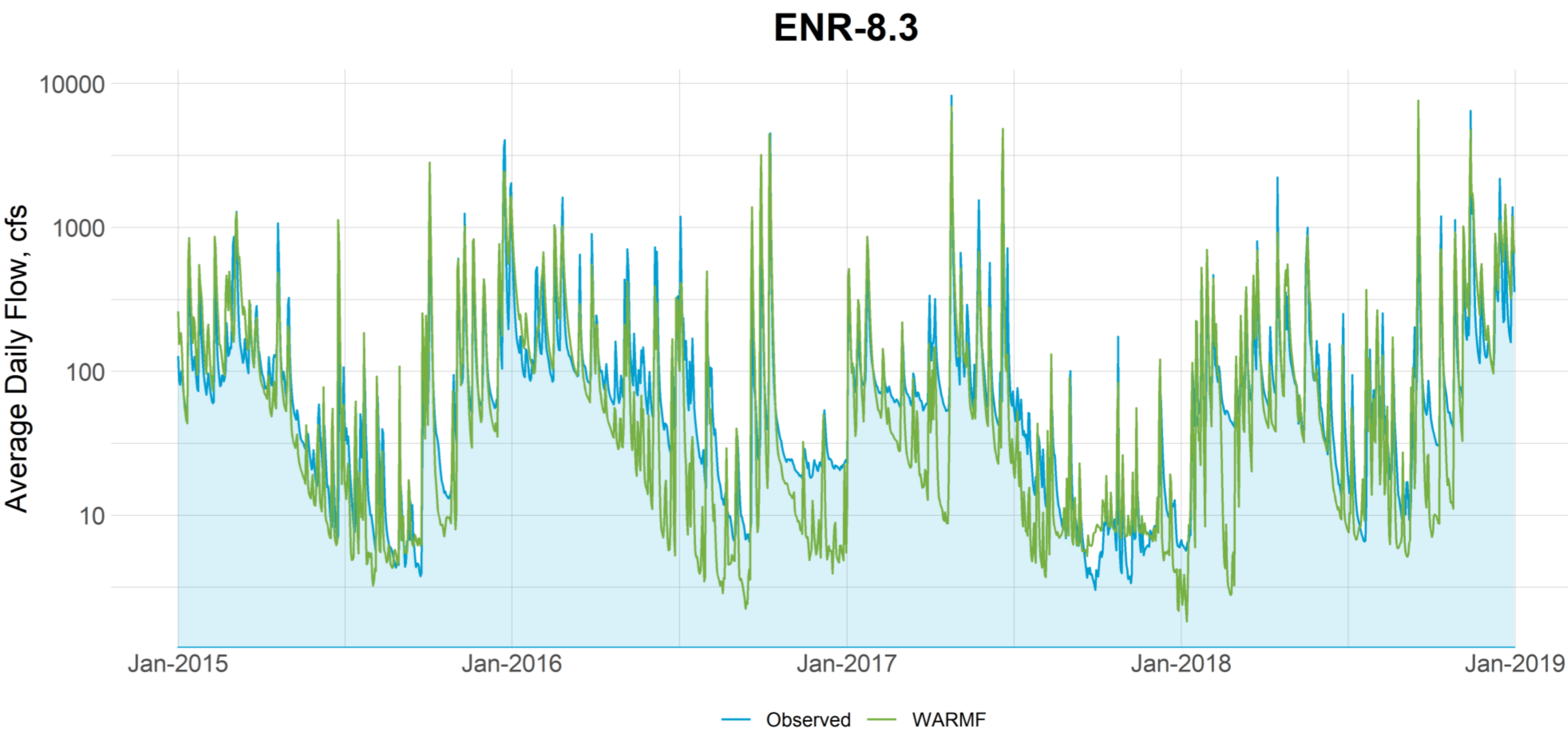
ELLERBE CREEK AT CLUB BOULEVARD (USGS 0208675010)	ELLERBE CREEK NEAR GORMAN, NC (USGS 02086849)	ENO RIVER AT HILLSBOROU GH, NC (USGS 02085000)	ENO RIVER NEAR DURHAM, NC (USGS 02085070)	FLAT RIVER AT BAHAMA,NC (USGS 02085500)	FLAT RIVER AT DAM NEAR BAHAMA, NC (USGS 02086500)	KNAP OF REEDS CREEK NEAR BUTNER, 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)

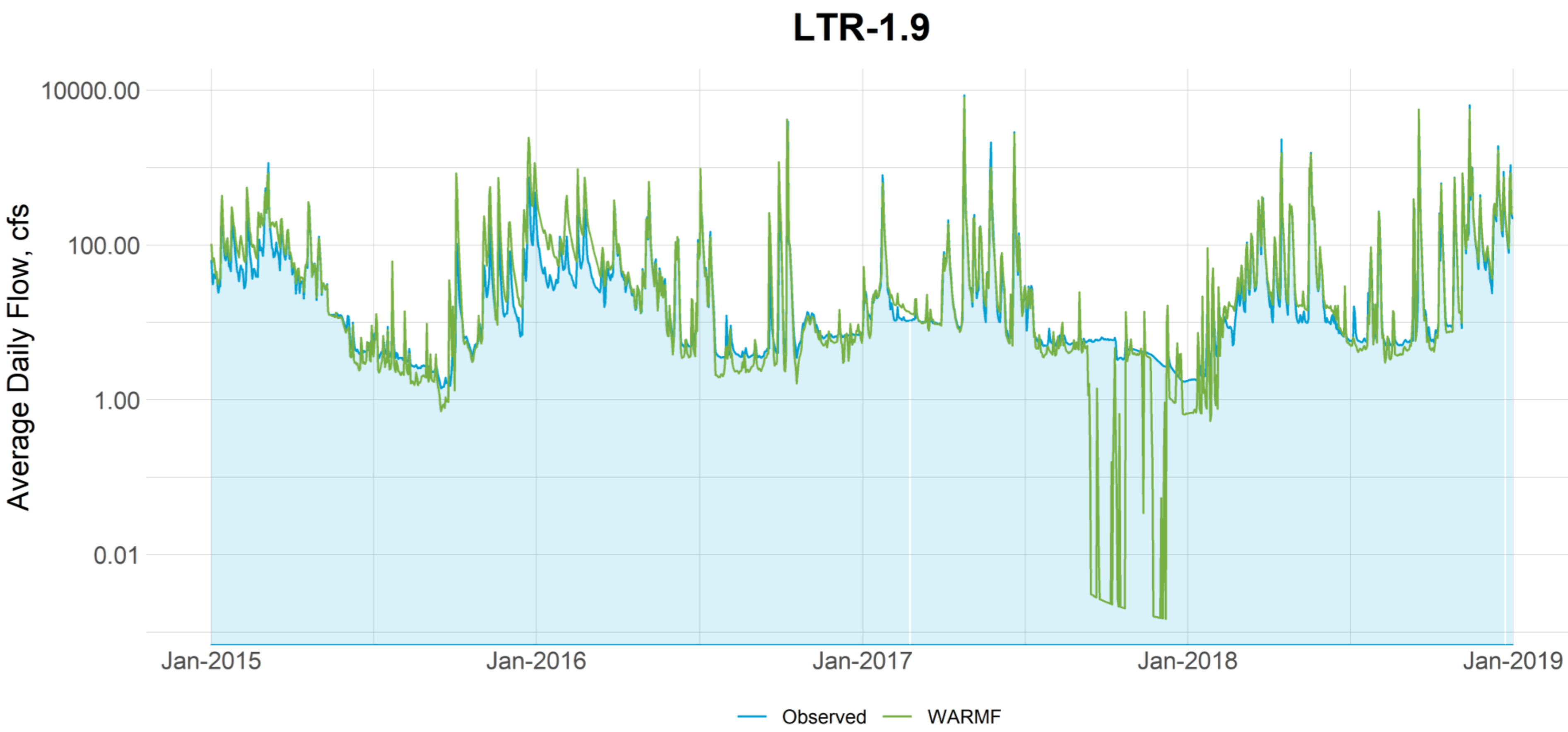
Stream Flows – Ellerbe Creek (USGS 02086849)



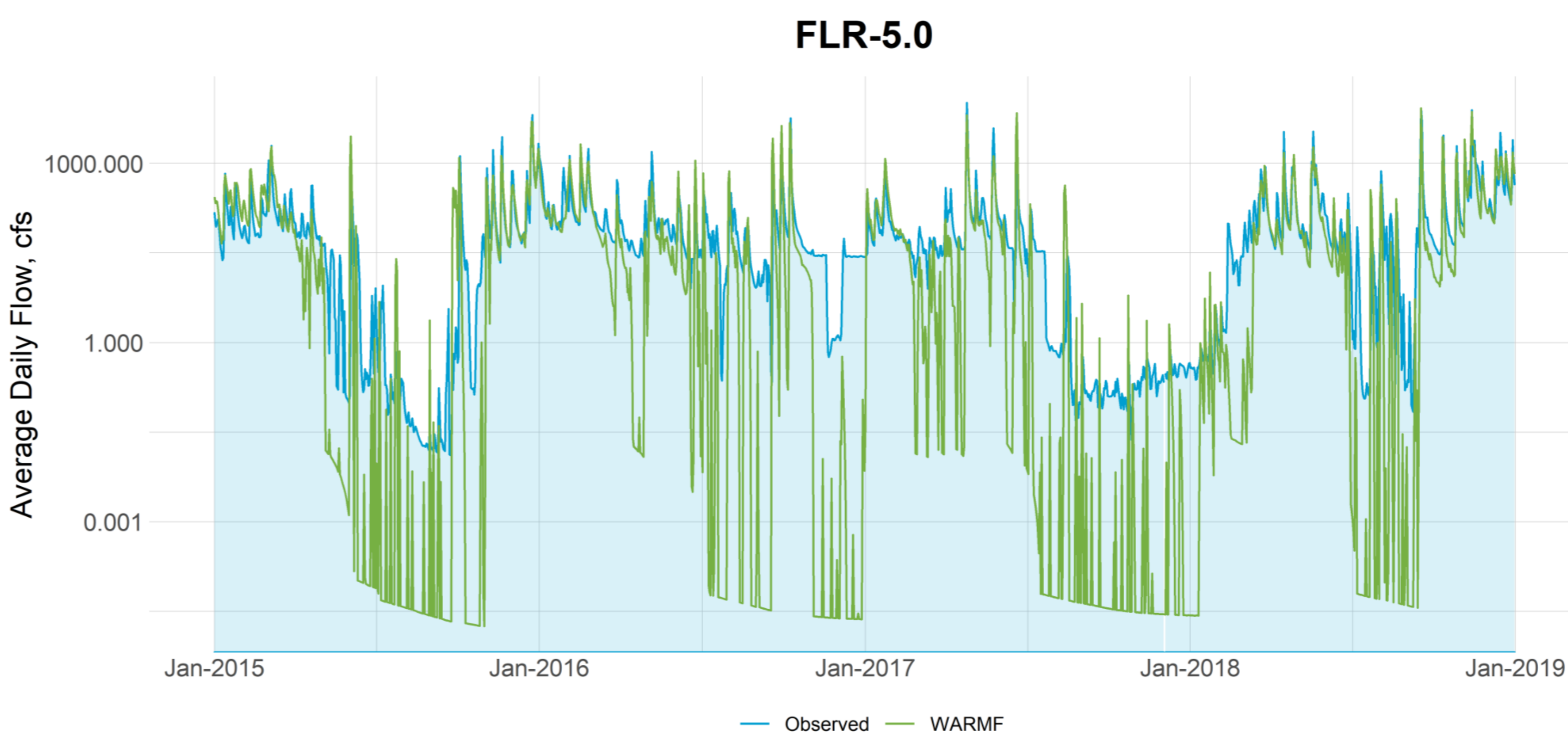
Stream Flows – Eno River



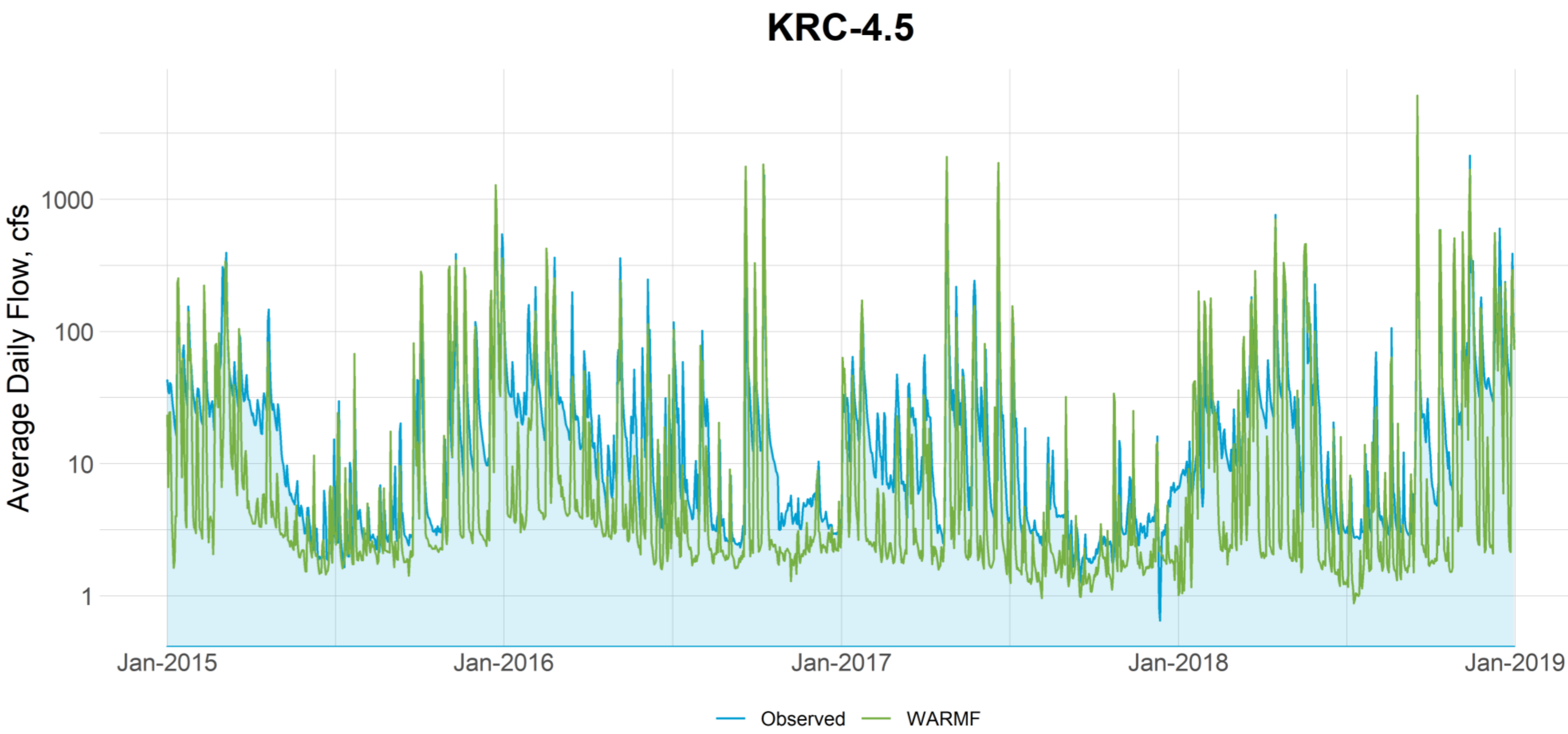
Stream Flows – Little River



Stream Flows – Flat River



Stream Flows – Knap of Reeds (USGS 02086624)



Water Quality Comparisons at Big Five Lake Tributaries

Calibration Challenges

- When observed concentrations are very low on average, it can be difficult to meet the performance criteria.
  - **These very 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 concentration is 0.1 mg/L, a 50% difference is 0.15 mg/L or 0.05 mg/L.
  - Alternatively, if the average 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.

Calibration Challenges Continued

- When there is significant variation at a WWTP and the sampling at the plant did not capture this but the UNRBA monitoring program may have captured the increase in stream concentrations, the model will not reflect this situation.
  - This negatively impacts the performance criteria at Knap of Reeds Creek for the full model period
- The presence of upstream impoundments like Lake Michie and Little River Reservoir complicates the calibration. Water quality measurements in the lake are not available, so it is difficult to know how well the model is simulating lake processes. Improving simulation of these impoundments would take a significant amount of effort. Without extensive data, there is no reasonable way to develop appropriate lake behavior. This is also a critical time factor.

Calibration Challenges Continued

Many water quality parameters are linked so if the model is adjusted to try to improve one parameter another or multiple parameters will get worse.

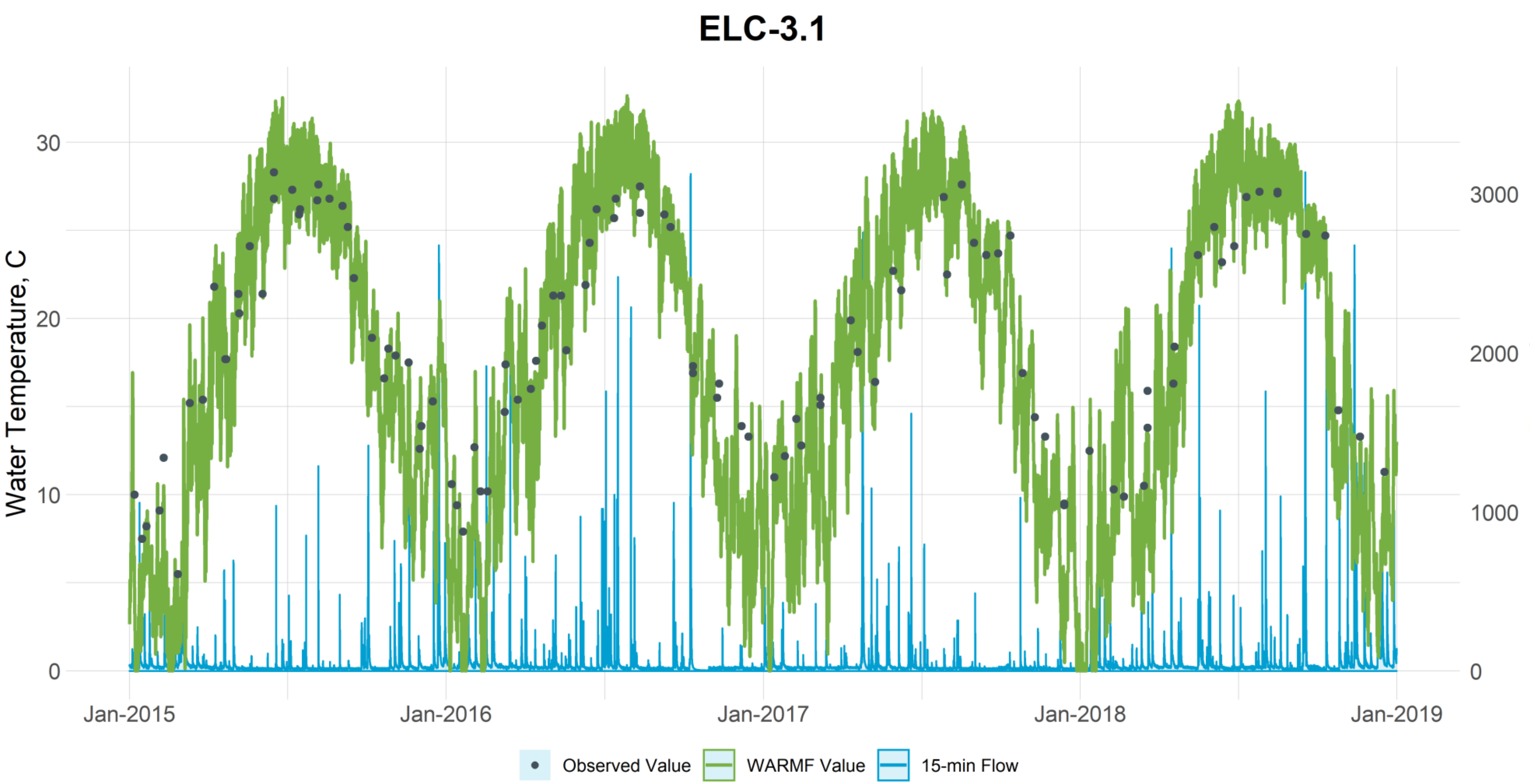
Draft Temperature

- The model performs well for predicting temperature

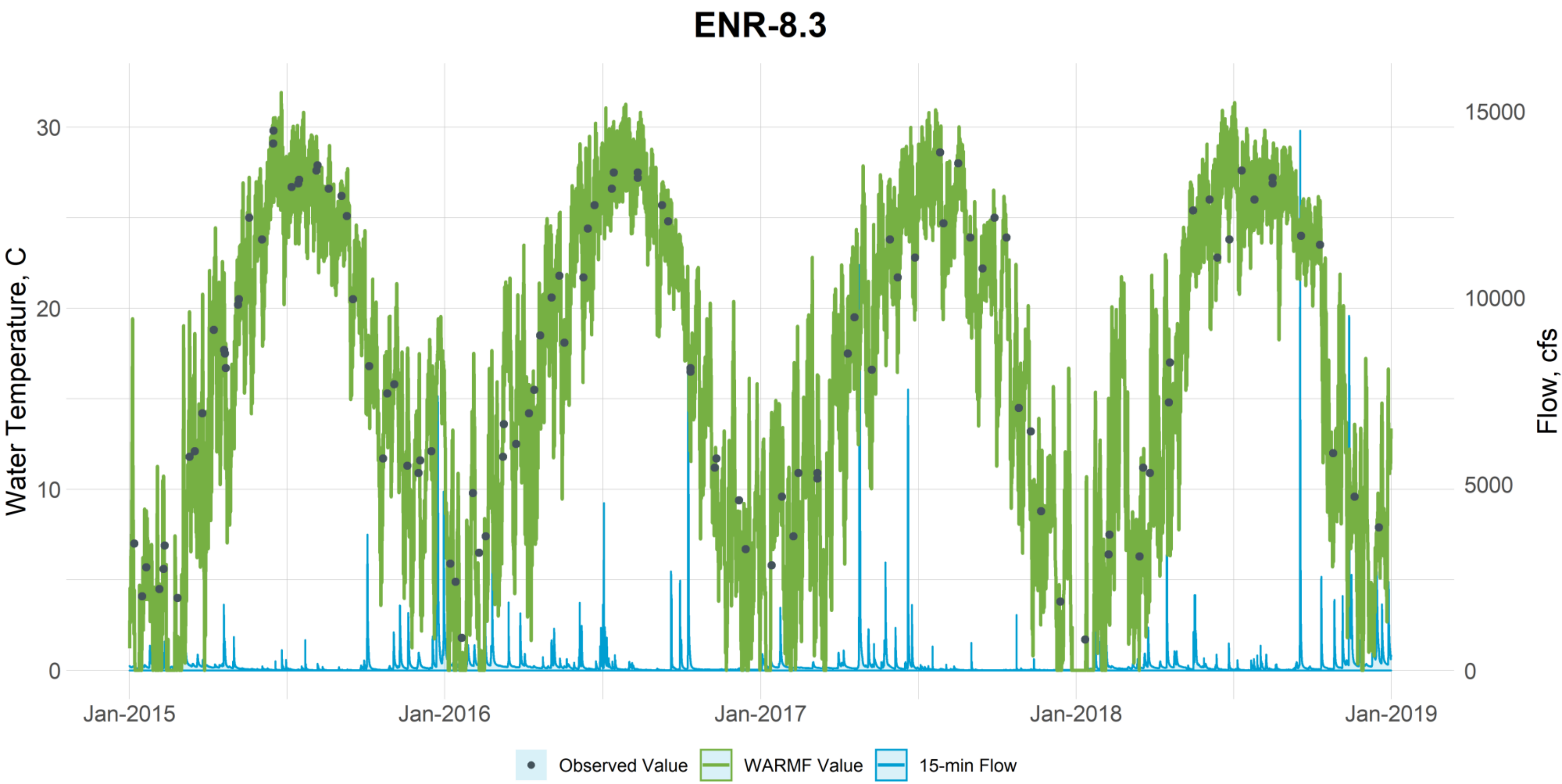
Model Performance for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Little	Flat	Knap of Reeds
RE (%)	4%	7%	-9%	-9%	8%
Observed Mean (°C)	**19**	**18**	**16**	**19**	**15**

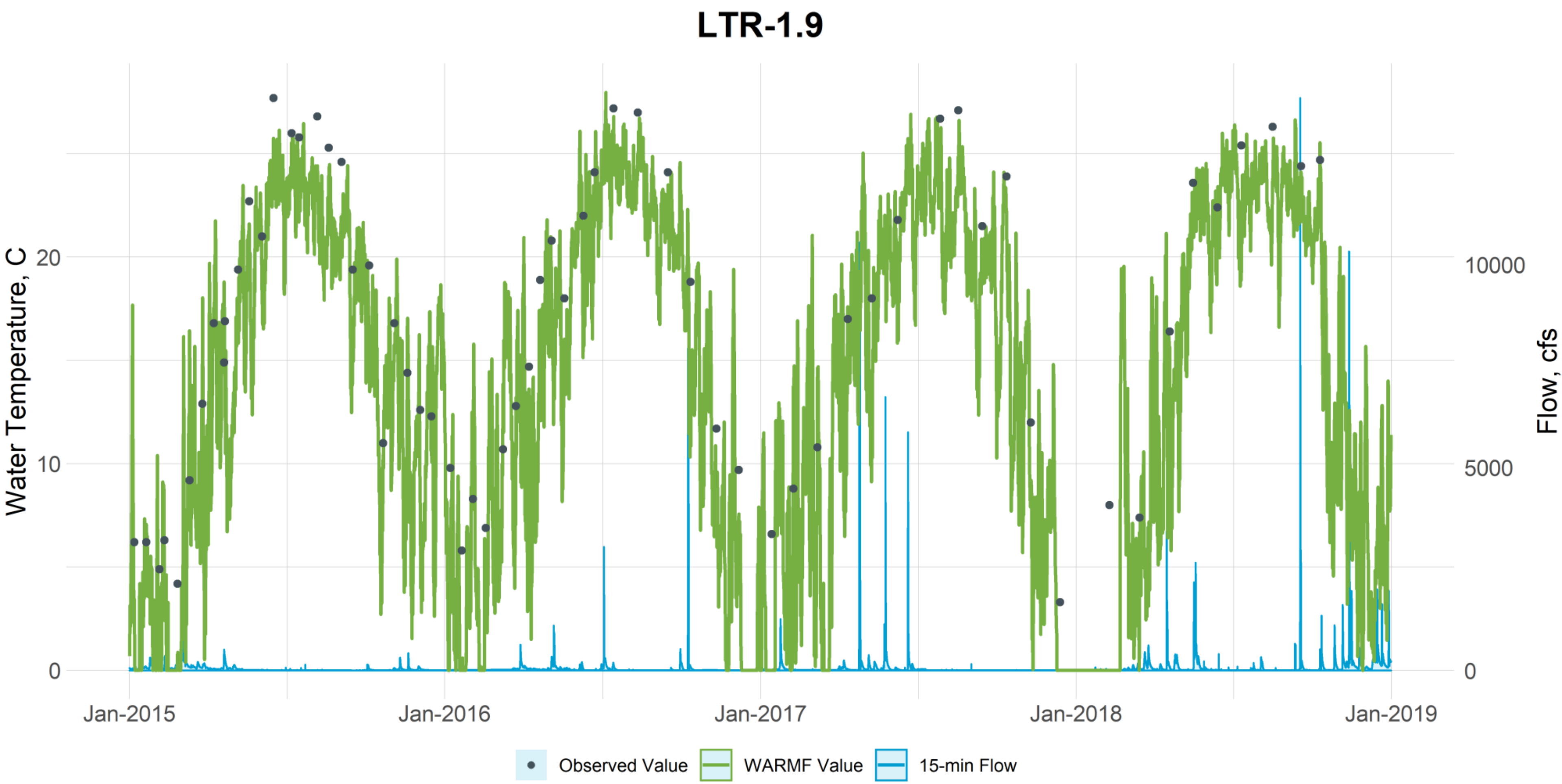
Temperature, C – Ellerbe Creek



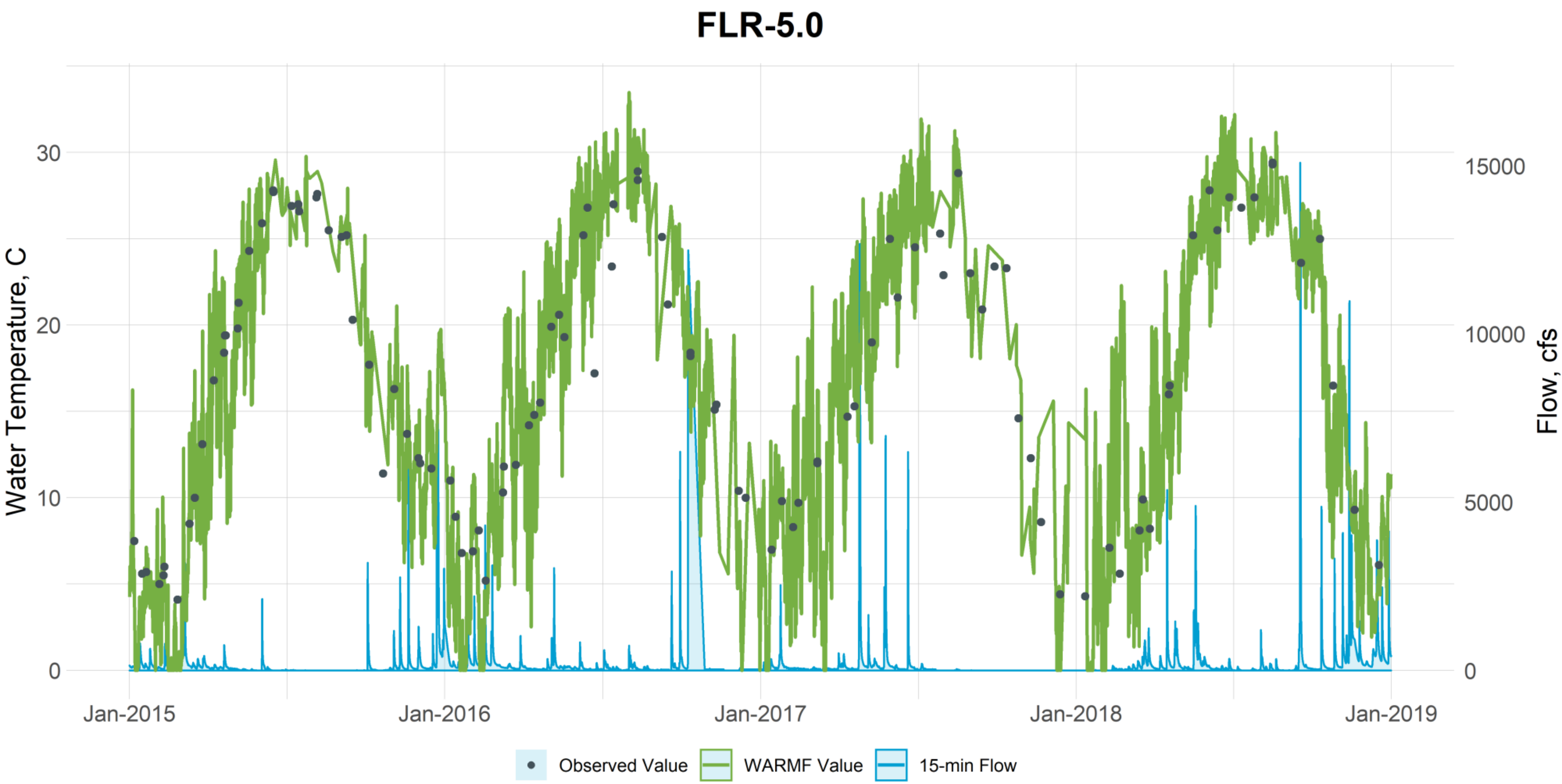
Temperature, C – Eno River



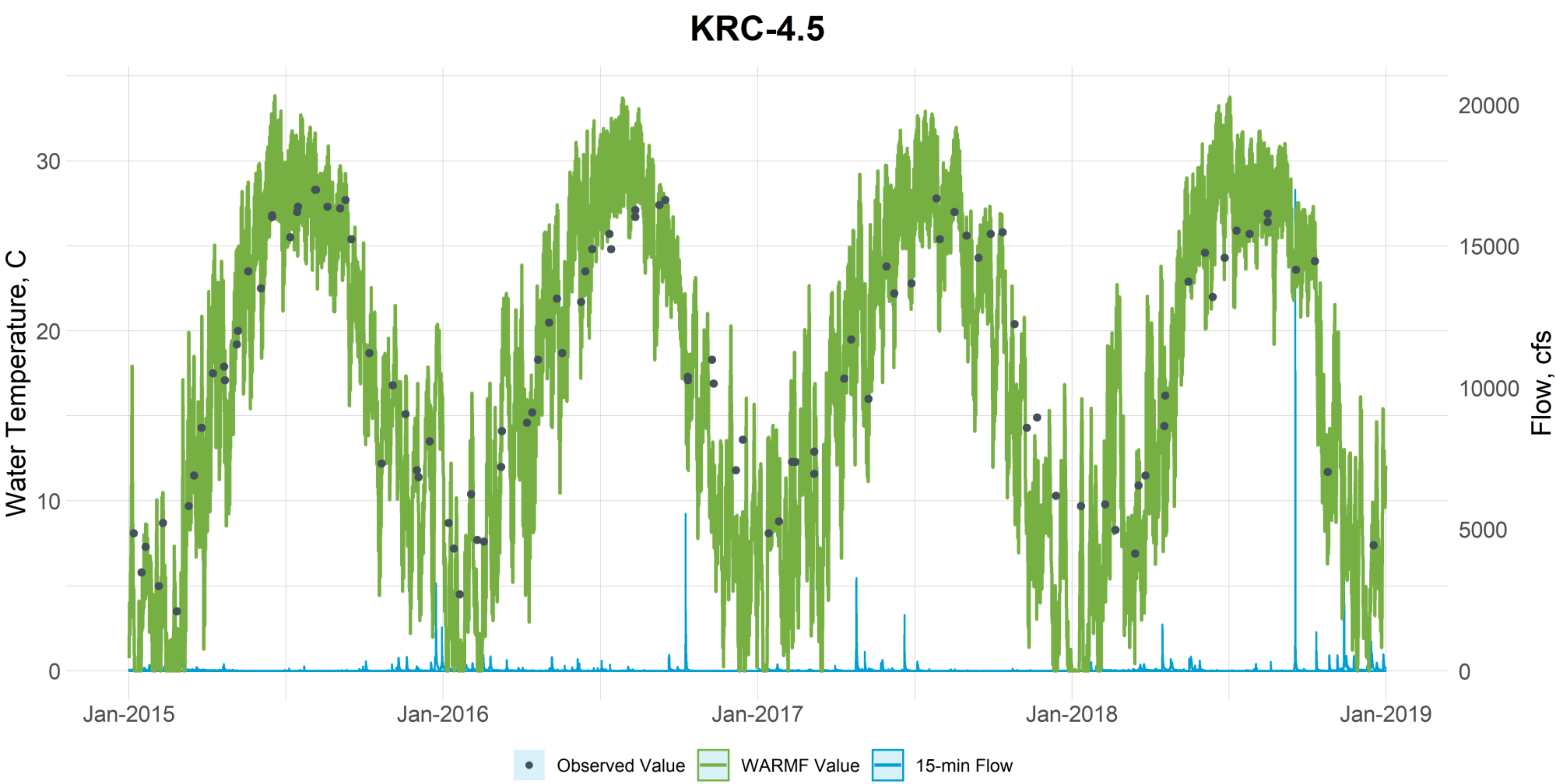
Temperature, C – Little River



Temperature, C – Flat River



Temperature, C – Knap of Reeds



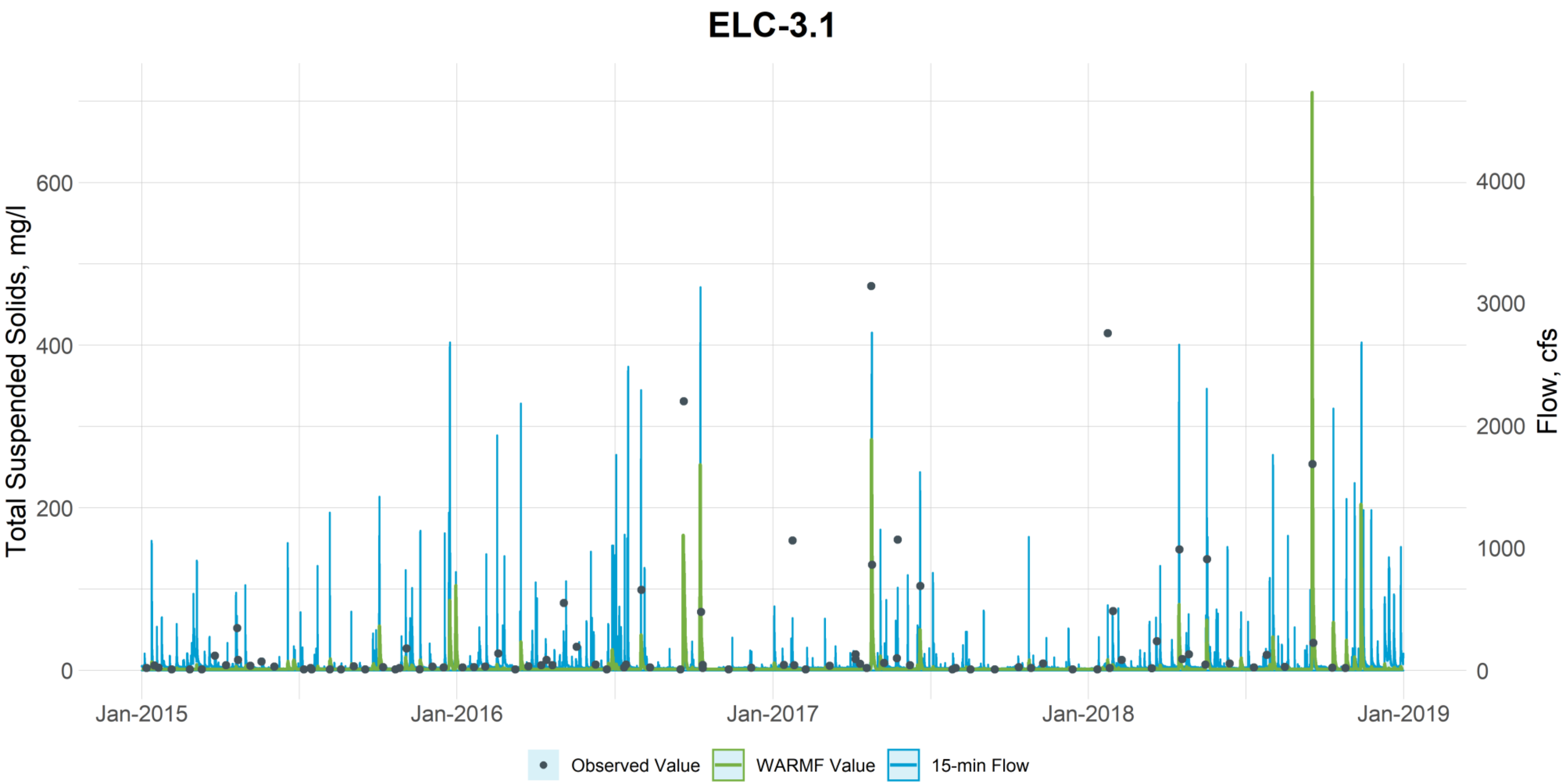
Preliminary Draft Total Suspended Sediment (TSS)

- Model performs well during baseflows, but over/under predicts concentrations during periods of high flows
- Accurate TSS simulation requires very accurate precipitation intensity information which is difficult when using a 6-hour timestep
  - E.g. brief storms are not captured
  - Work is in progress to model TSS values associated with high flows

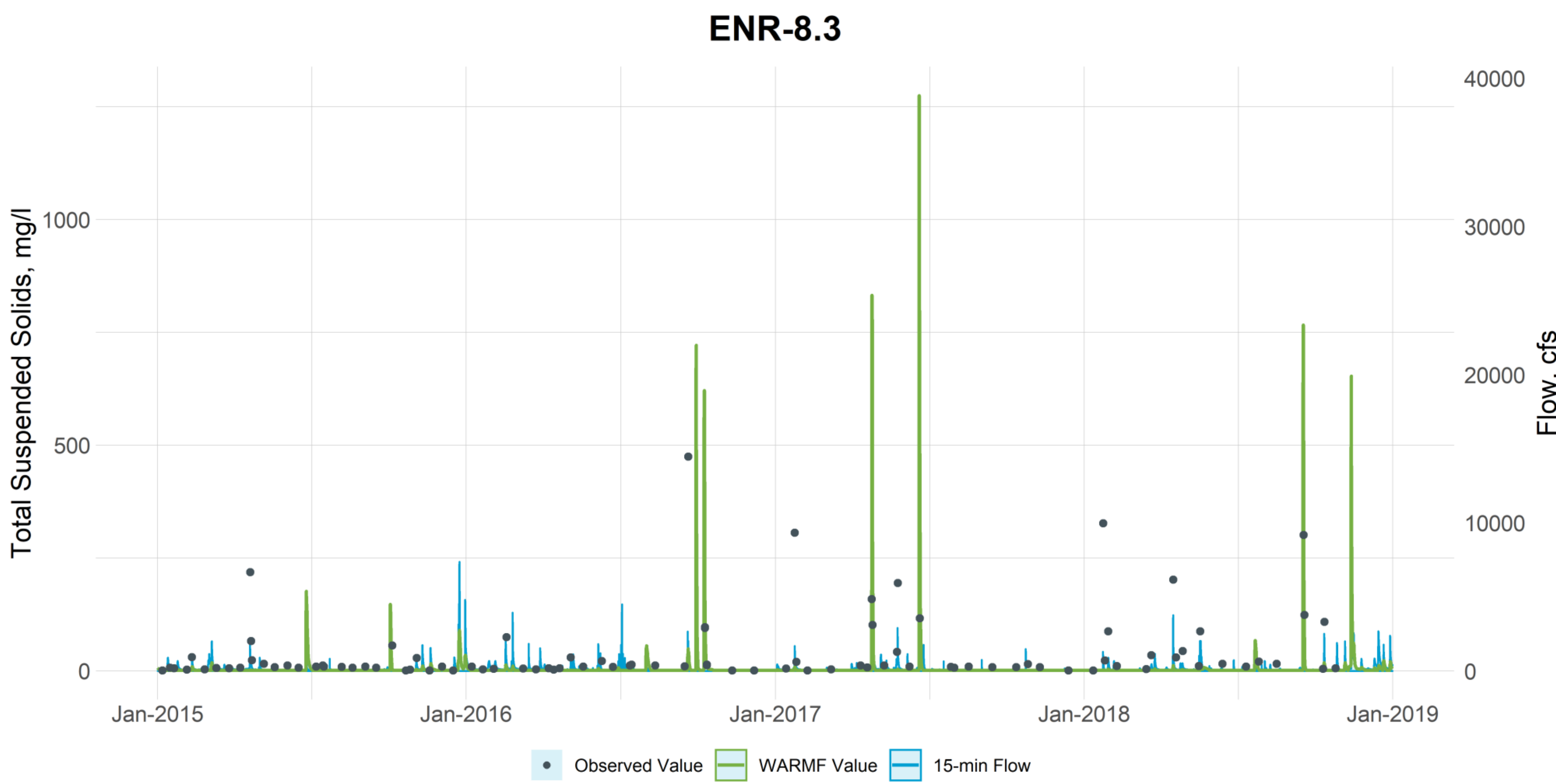
Model Performance for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Little	Flat	Knap of Reeds
RE (%)	**-64**	**-48**	**-37**	**-58**	**-44**
Observed Mean (mg/L)	**34**	**42**	**22**	**14**	**22**

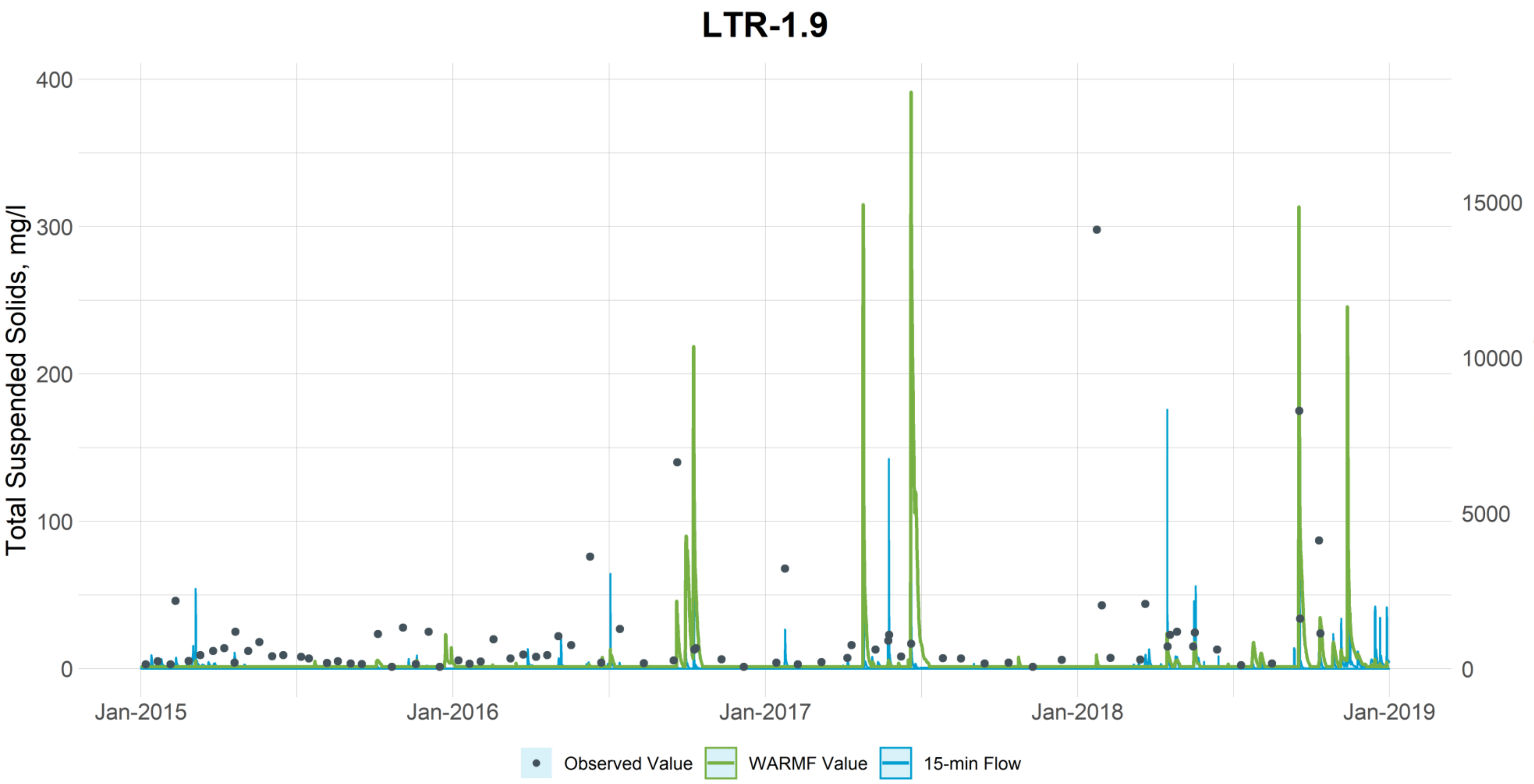
Total Suspended Sediment, mg/L – Ellerbe Creek



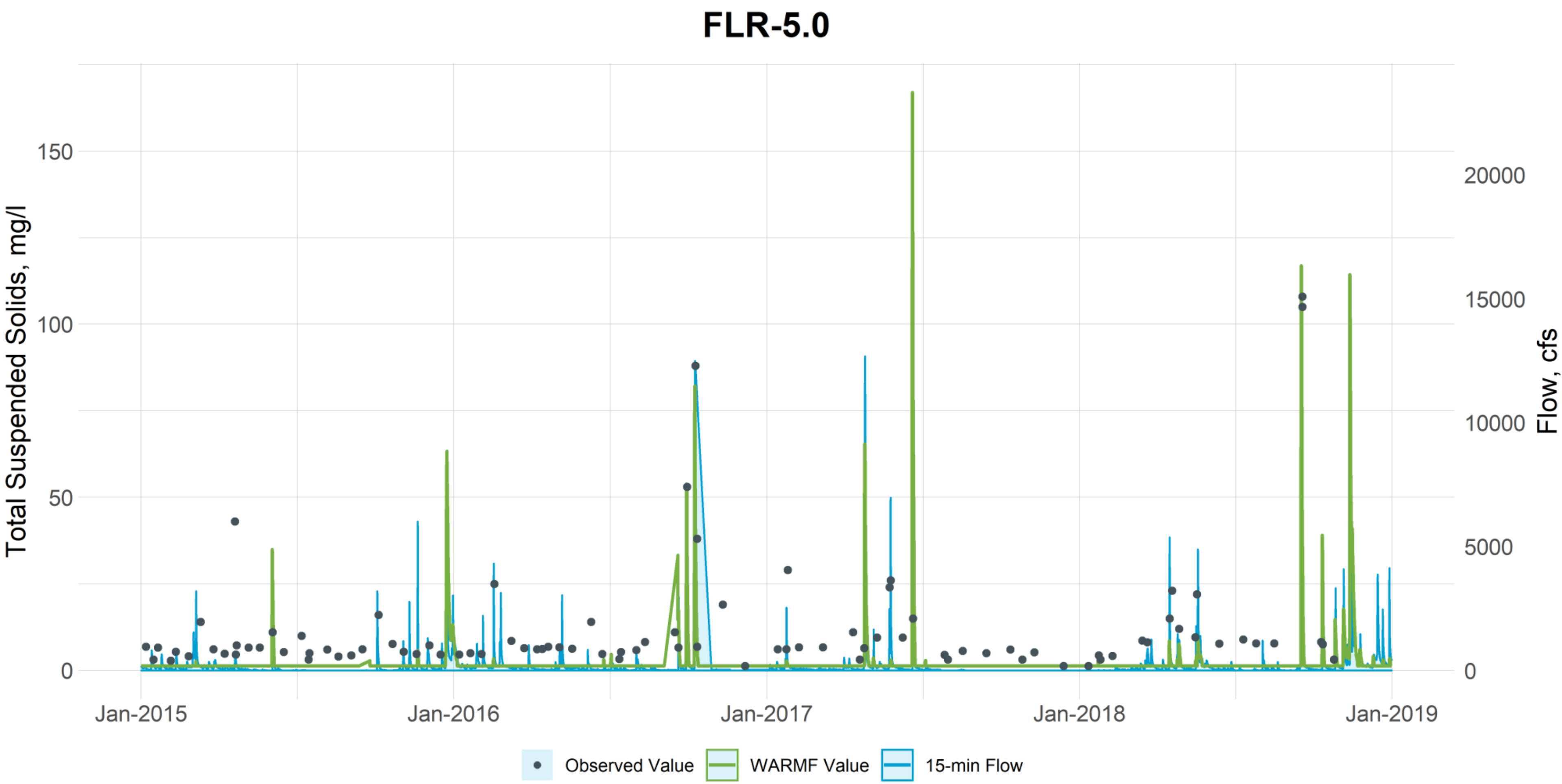
Total Suspended Sediment, mg/L – Eno River



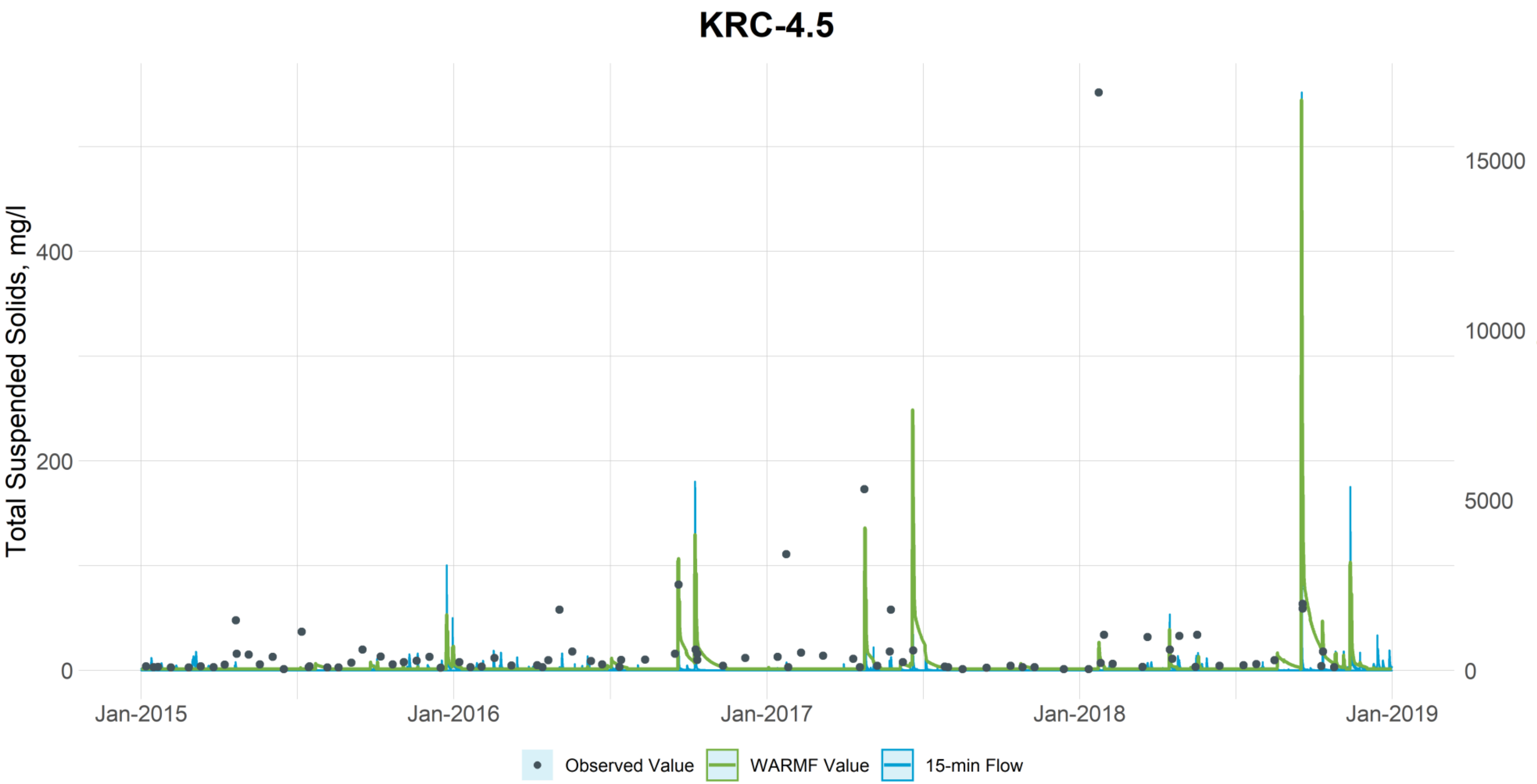
Total Suspended Sediment, mg/L – Little River



Total Suspended Sediment, mg/L – Flat River



Total Suspended Sediment, mg/L – Knap of Reeds



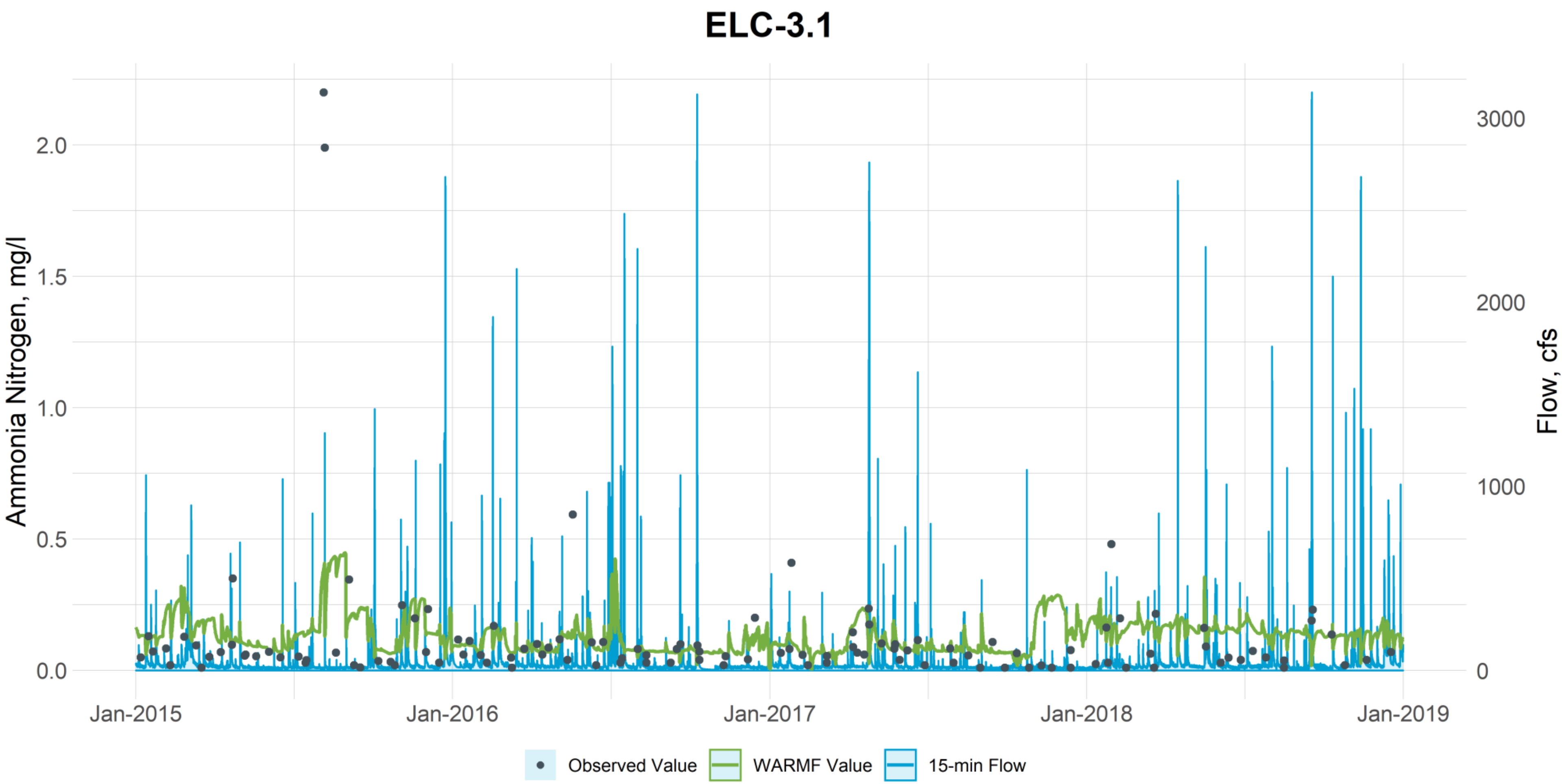
Draft Ammonia

- Model performs well when streams are flowing, but underpredicts concentrations during stagnant periods
  - Does not significantly affect loading to the lake
- Simulated and observed concentrations are often very low, so large relative errors are sometimes due to very small concentrations which don't greatly affect loading

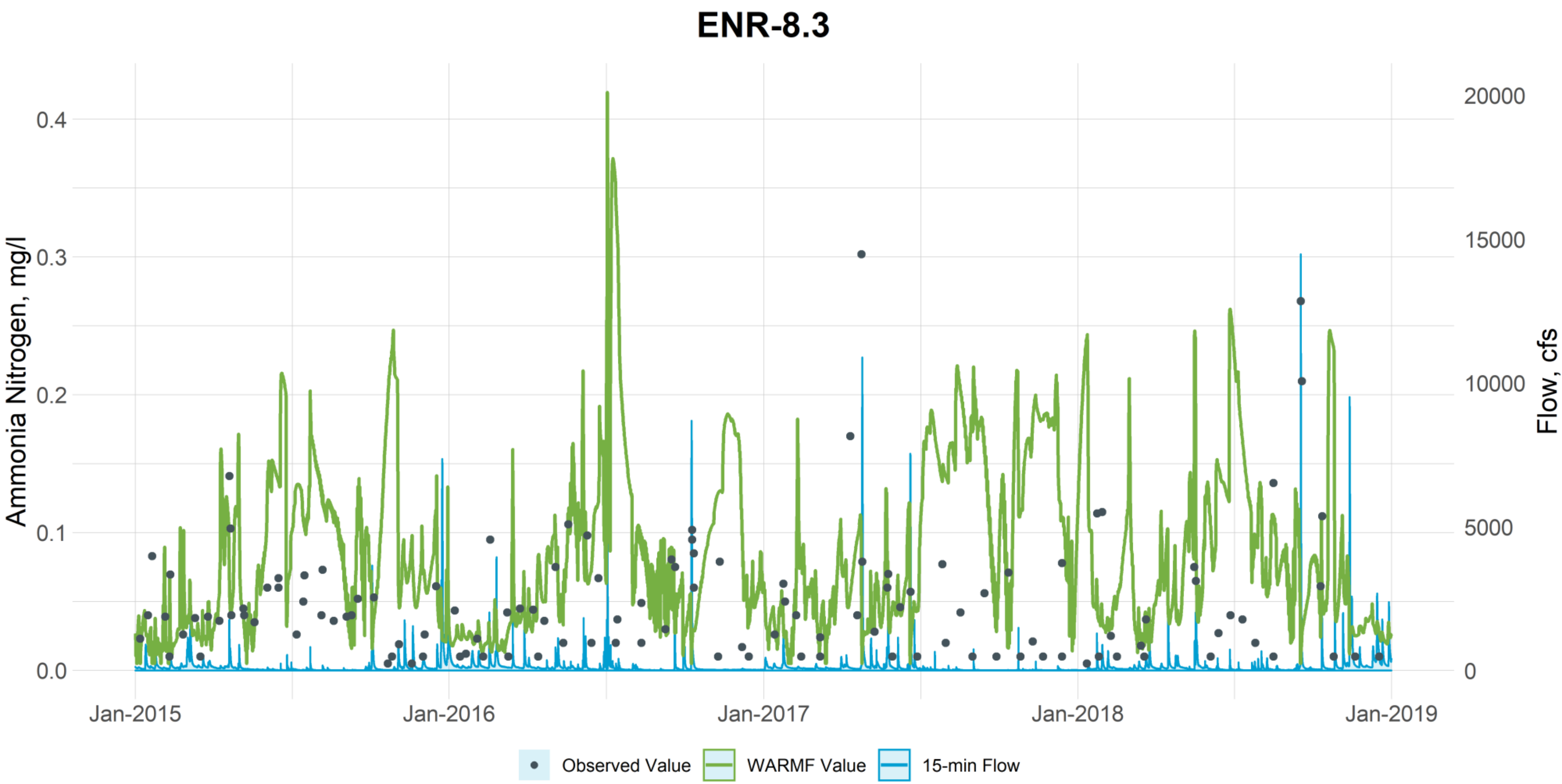
Model Performance for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Little	Flat	Knap of Reeds
RE (%)	**2**	**56**	**30**	**-13**	**-5**
Observed Mean (mg/L)	**0.12**	**0.05**	**0.08**	**0.07**	**0.18**

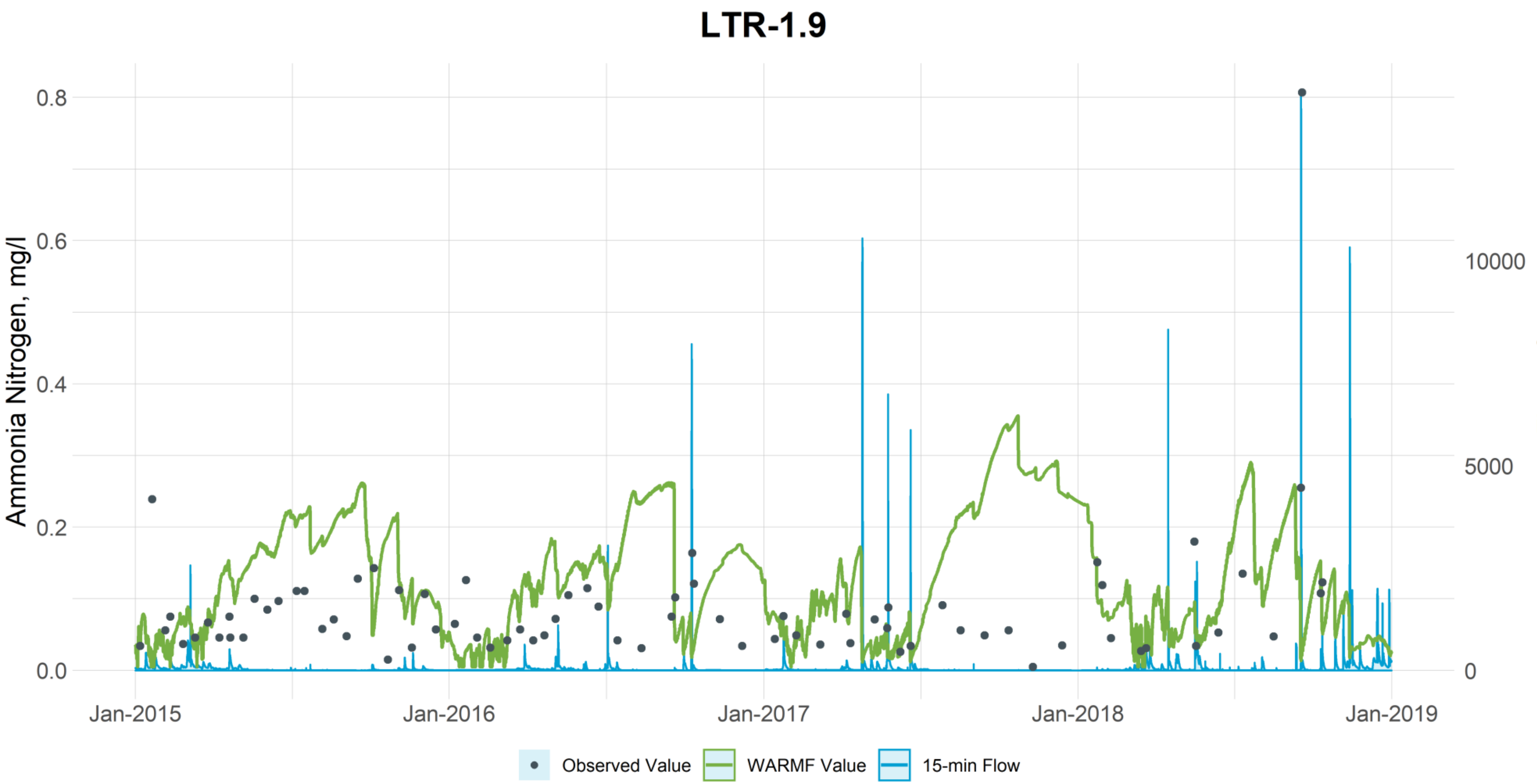
Ammonia, mg/L – Ellerbe Creek



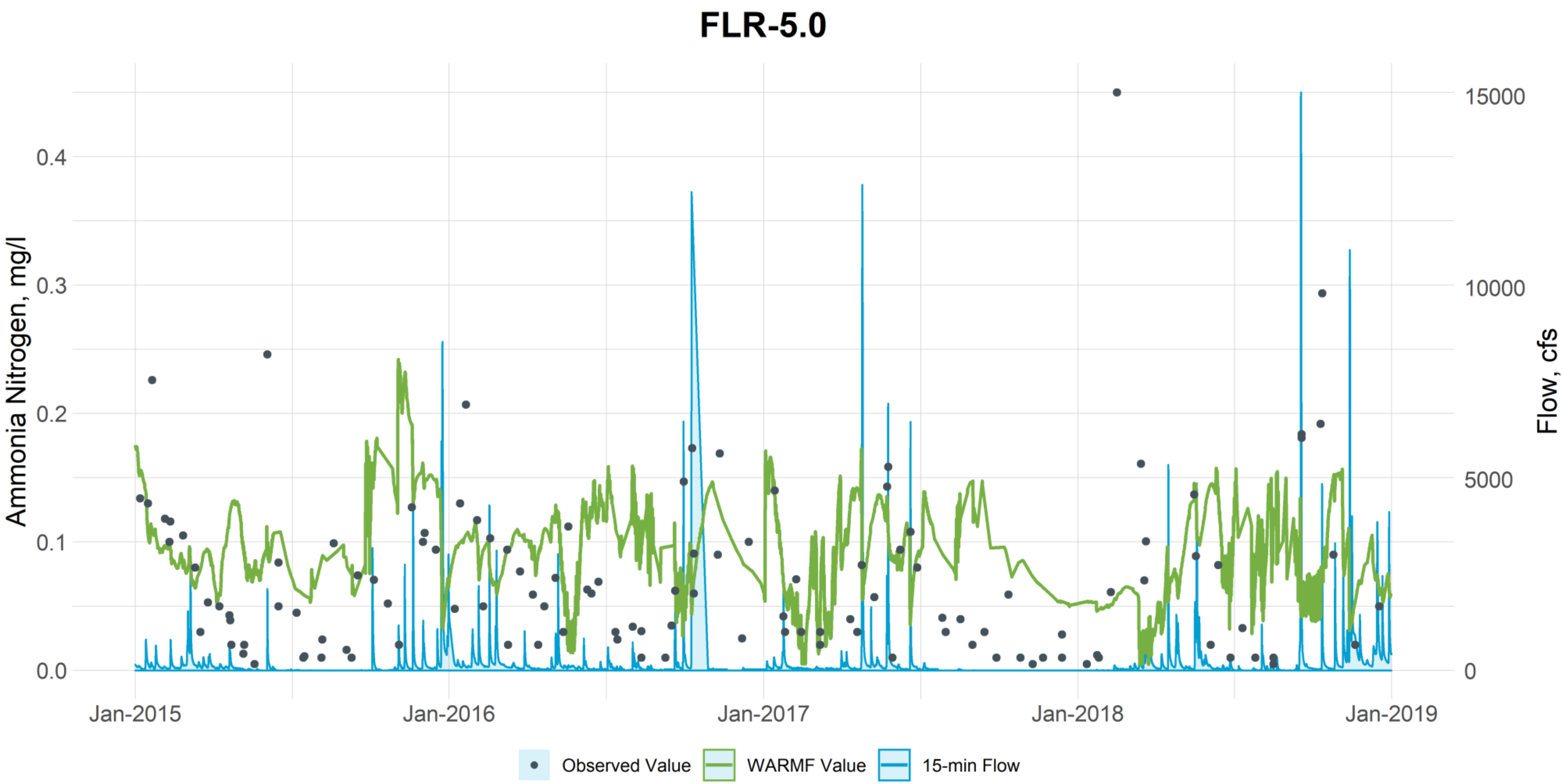
Ammonia, mg/L – Eno River



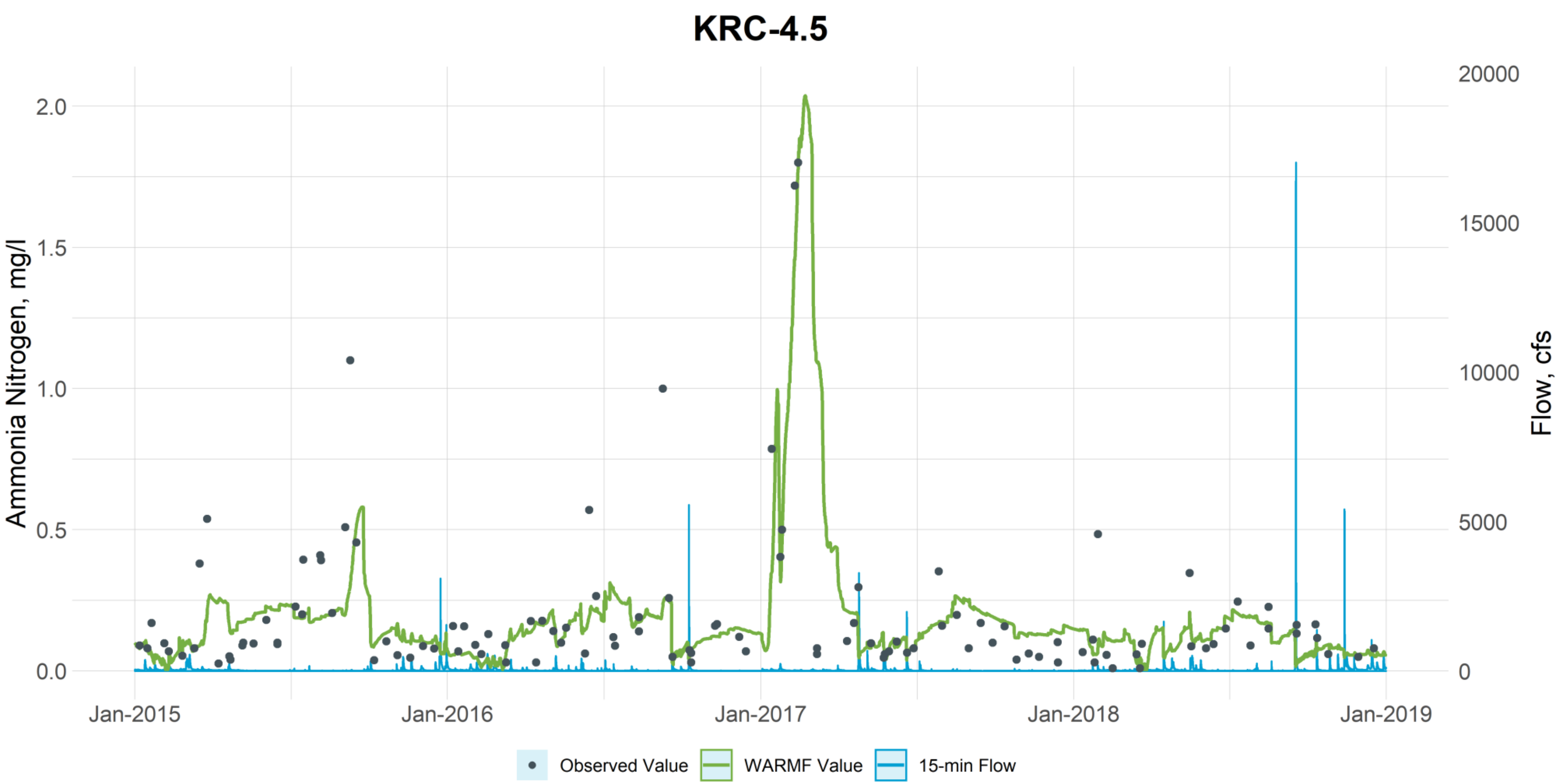
Ammonia, mg/L – Little River



Ammonia, mg/L – Flat River



Ammonia, mg/L – Knap of Reeds Creek



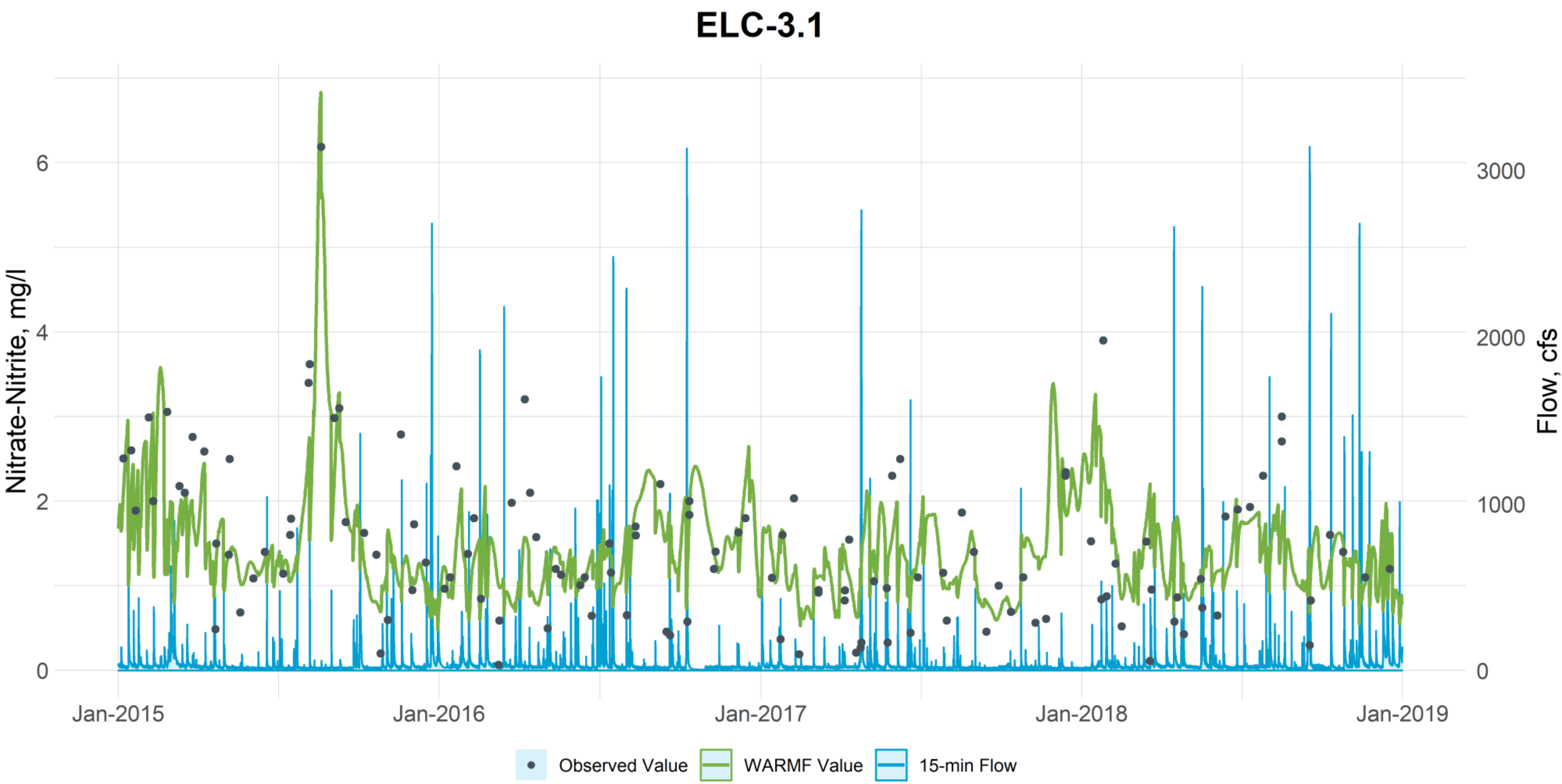
Draft Nitrate

- Model performs well in most locations
- Nutrient application and wastewater discharges contribute to loading
- Atmospheric deposition is a key driver for the magnitude and timing of observed nitrate concentrations in streams
  - Model relies on CASTNET data for air concentrations and NADP data for precipitation concentrations
  - Used the NCDEQ to verify the variability in deposition rates and to better understand seasonal trends
- Denitrification in wetland-dominated areas and upstream impoundments is needed to match lower nitrate concentrations in those streams

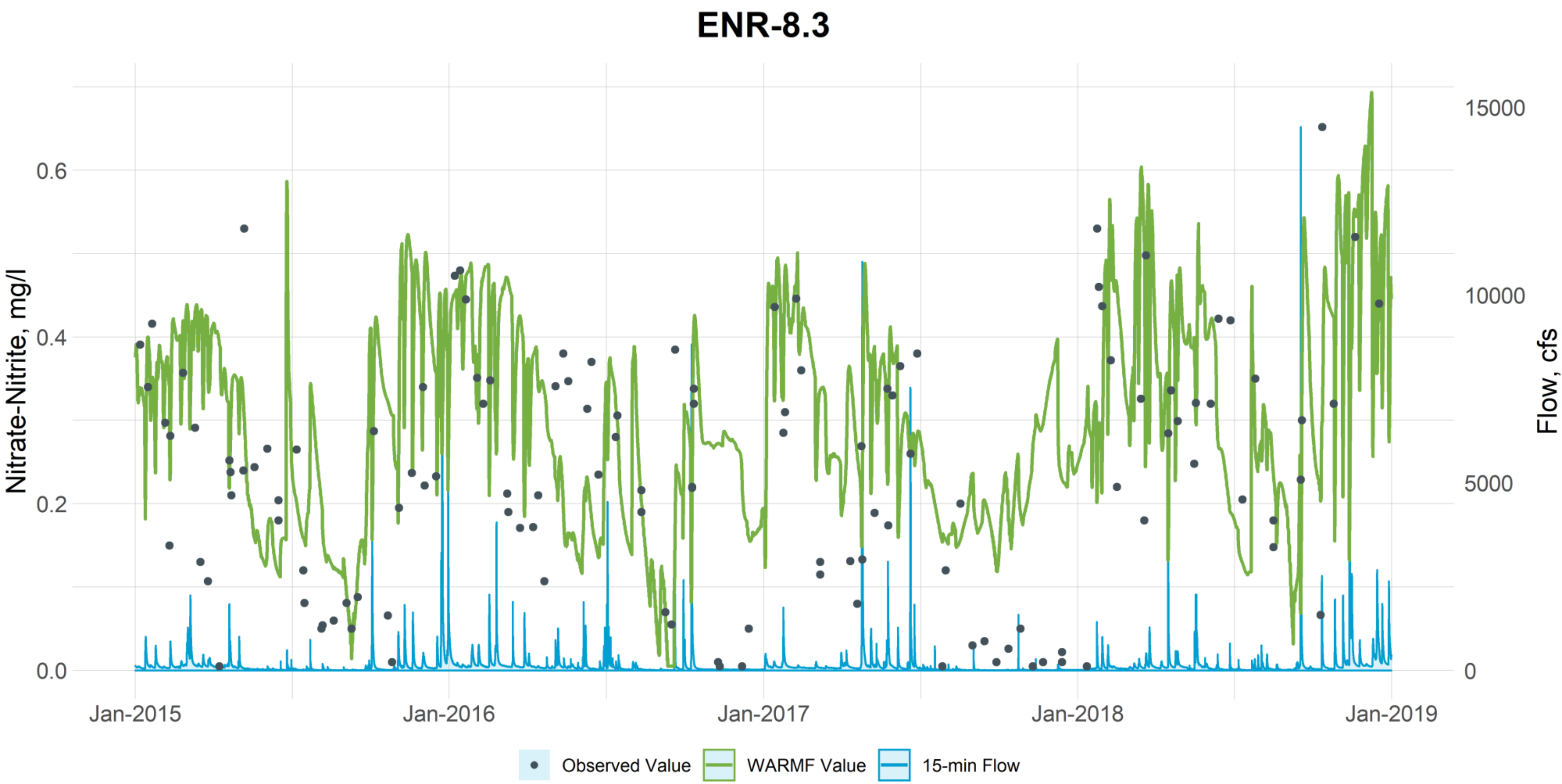
Model Performance for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Little	Flat	Knap of Reeds
RE (%)	-1	23	15	-32	-27
Observed Mean (mg/L)	**1.5**	**0.2**	**0.2**	**0.2**	**1.1**

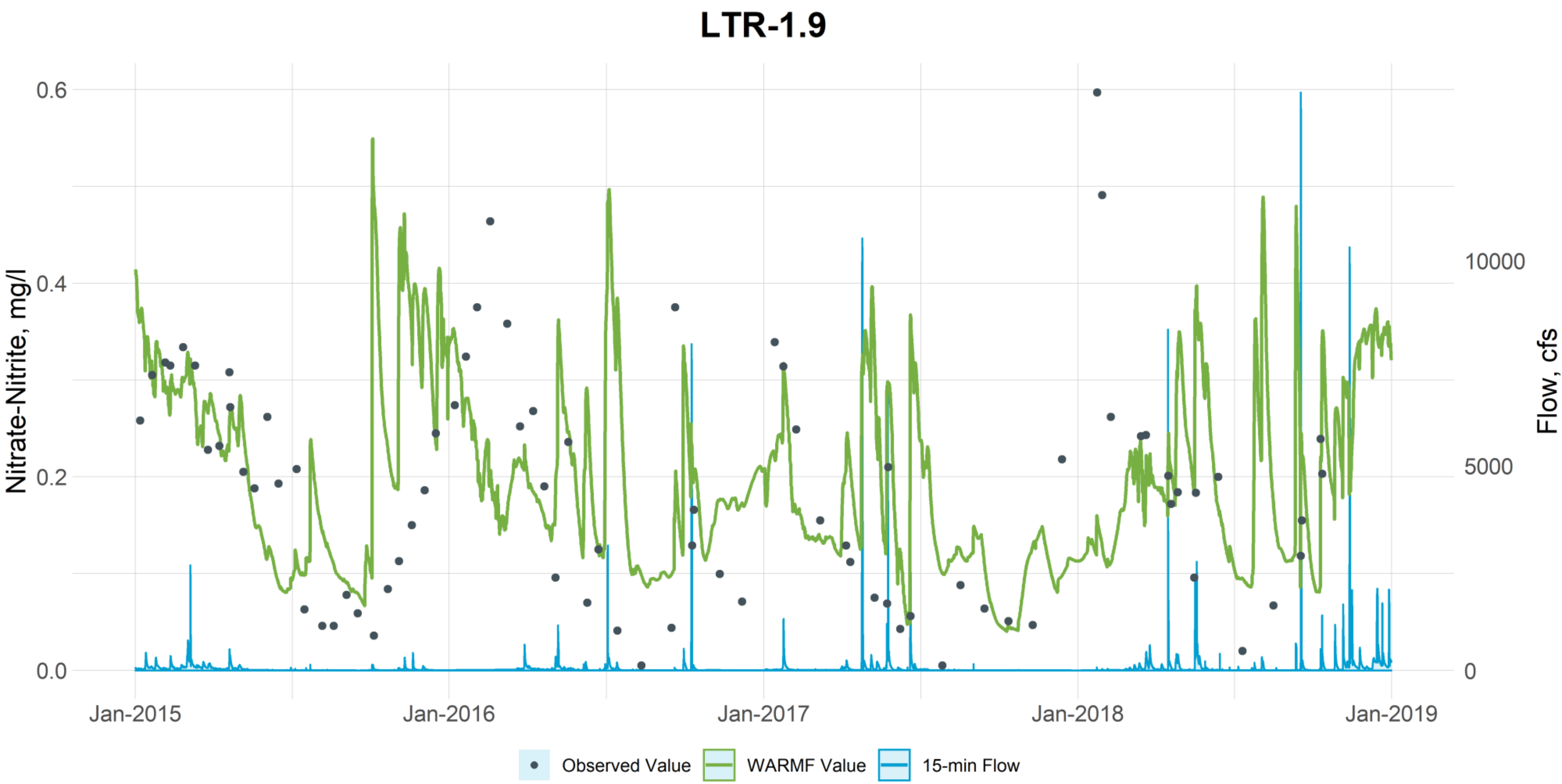
Nitrate, mg/L – Ellerbe Creek



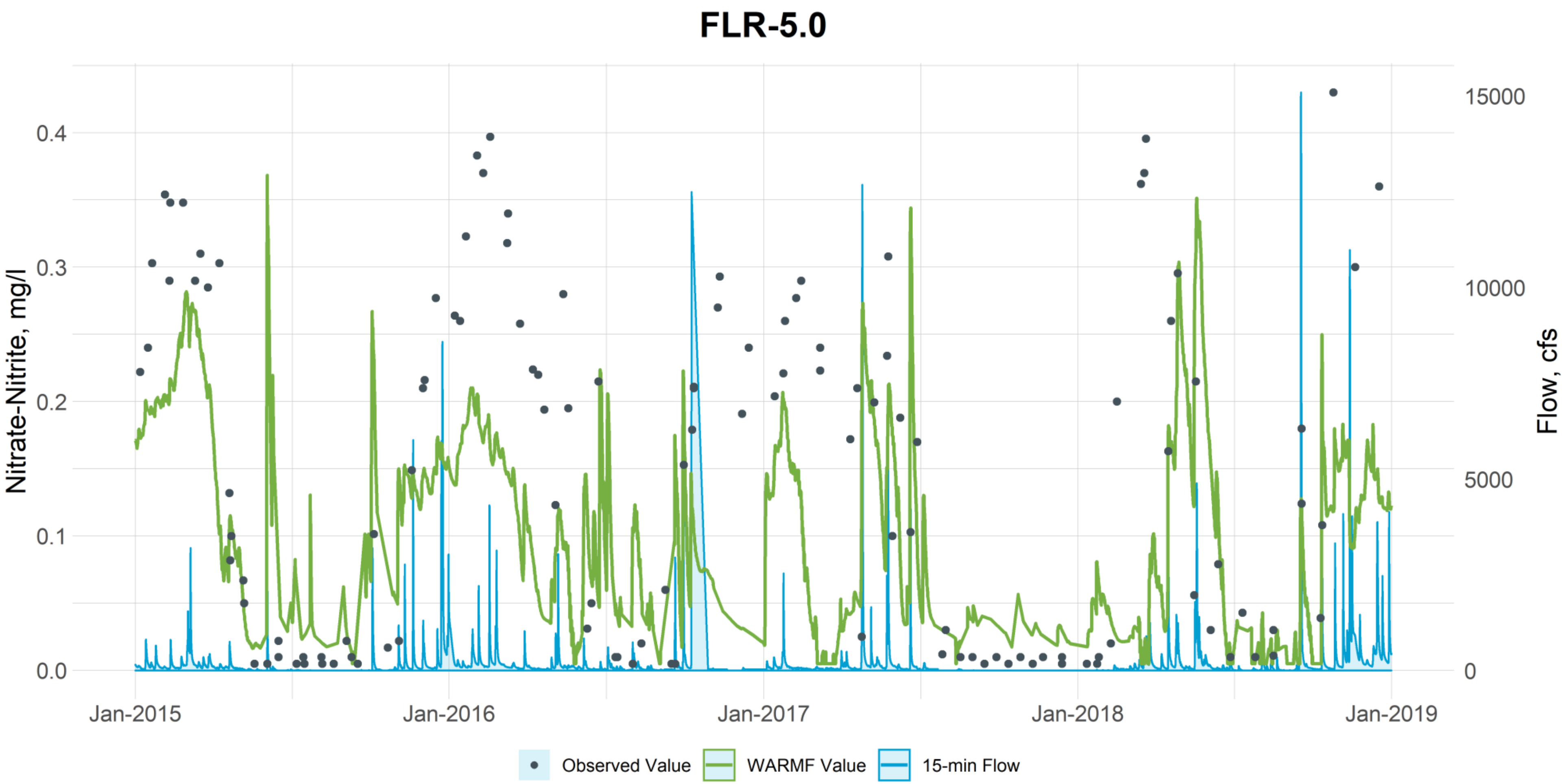
Nitrate, mg/L – Eno River



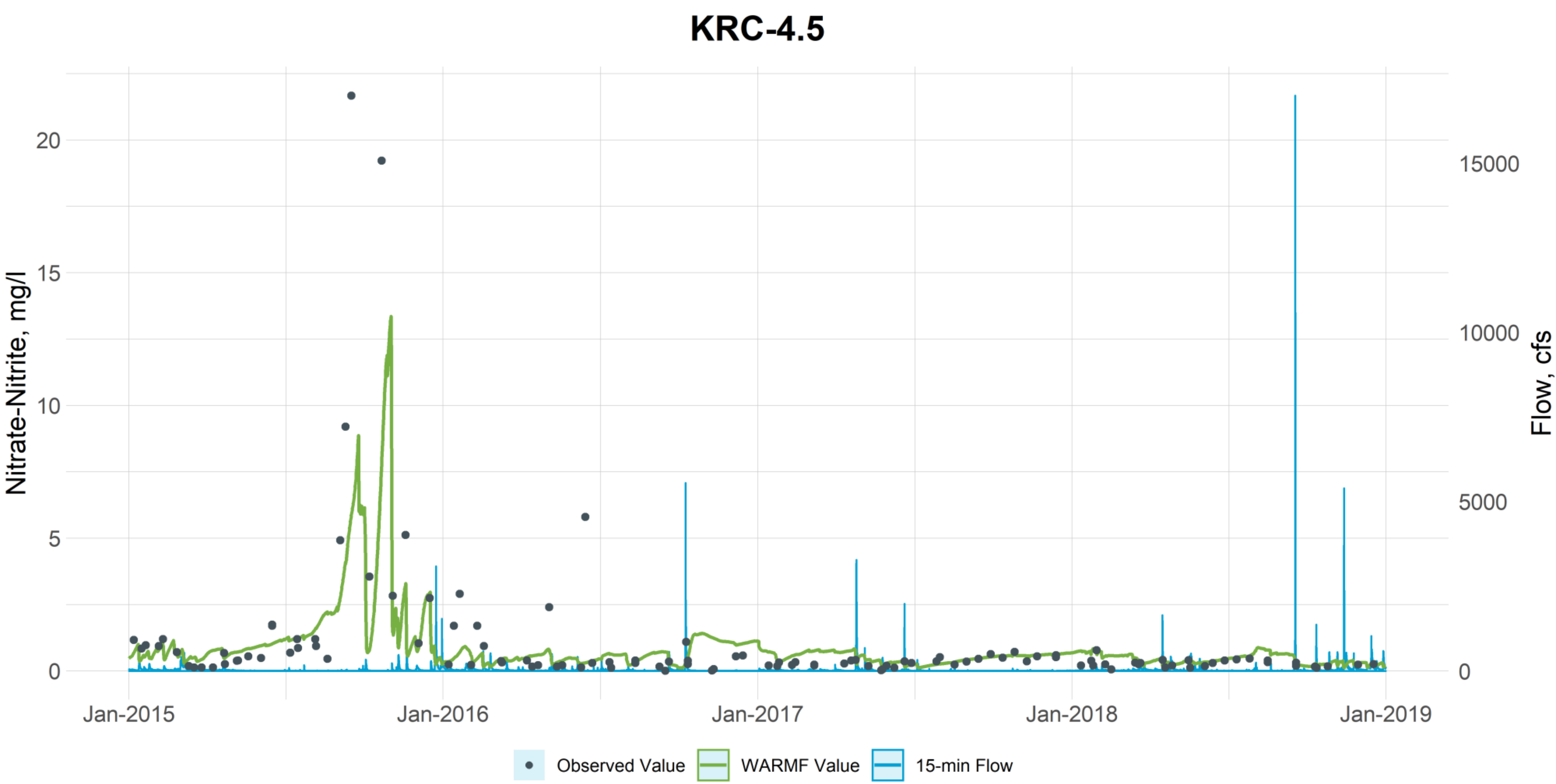
Nitrate, mg/L – Little River



Nitrate, mg/L – Flat River



Nitrate, mg/L – Knap of Reeds Creek



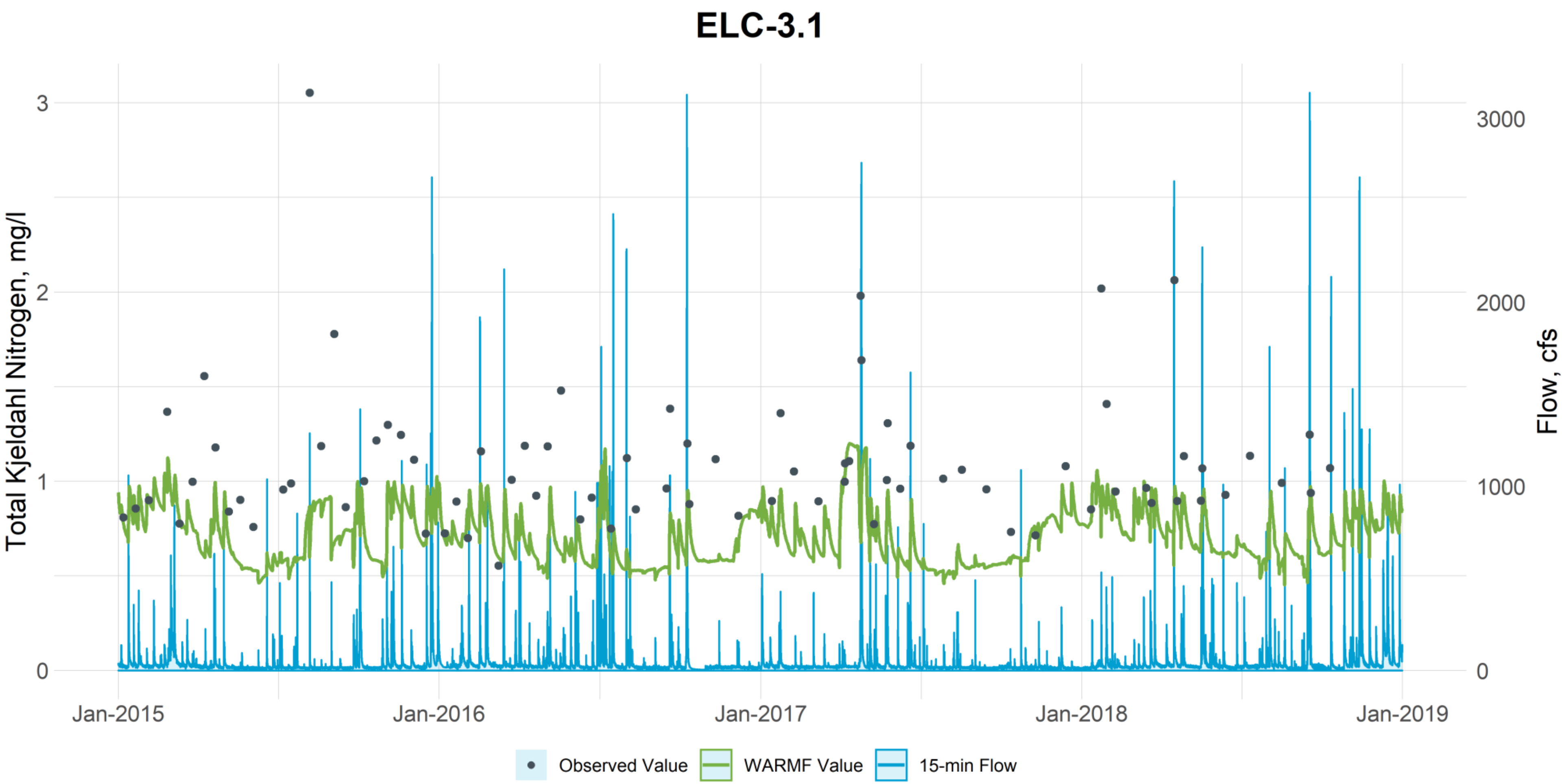
Draft Total Kjeldahl Nitrogen (TKN) Ammonia plus Organic N

- Model performs well on average;
  - Organic fraction is low in some areas like Ellerbe Creek
  - Model over-estimated in other areas like Little River that have large upstream impoundments

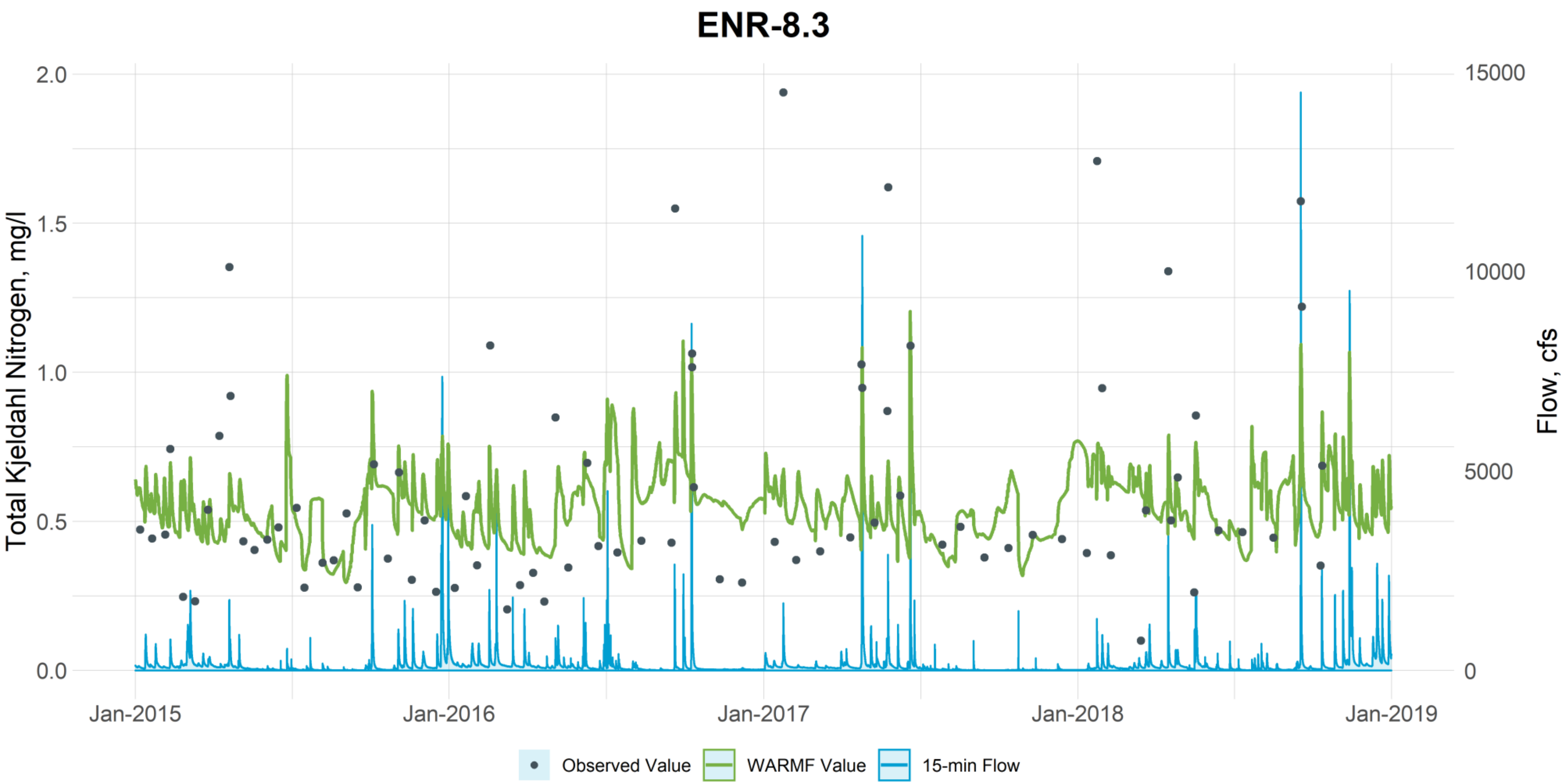
Model Performance for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Little	Flat	Knap of Reeds
RE (%)	-31	-3	47	20	-9
Observed Mean (mg/L)	**1.1**	**0.6**	**0.6**	**0.7**	**1.0**

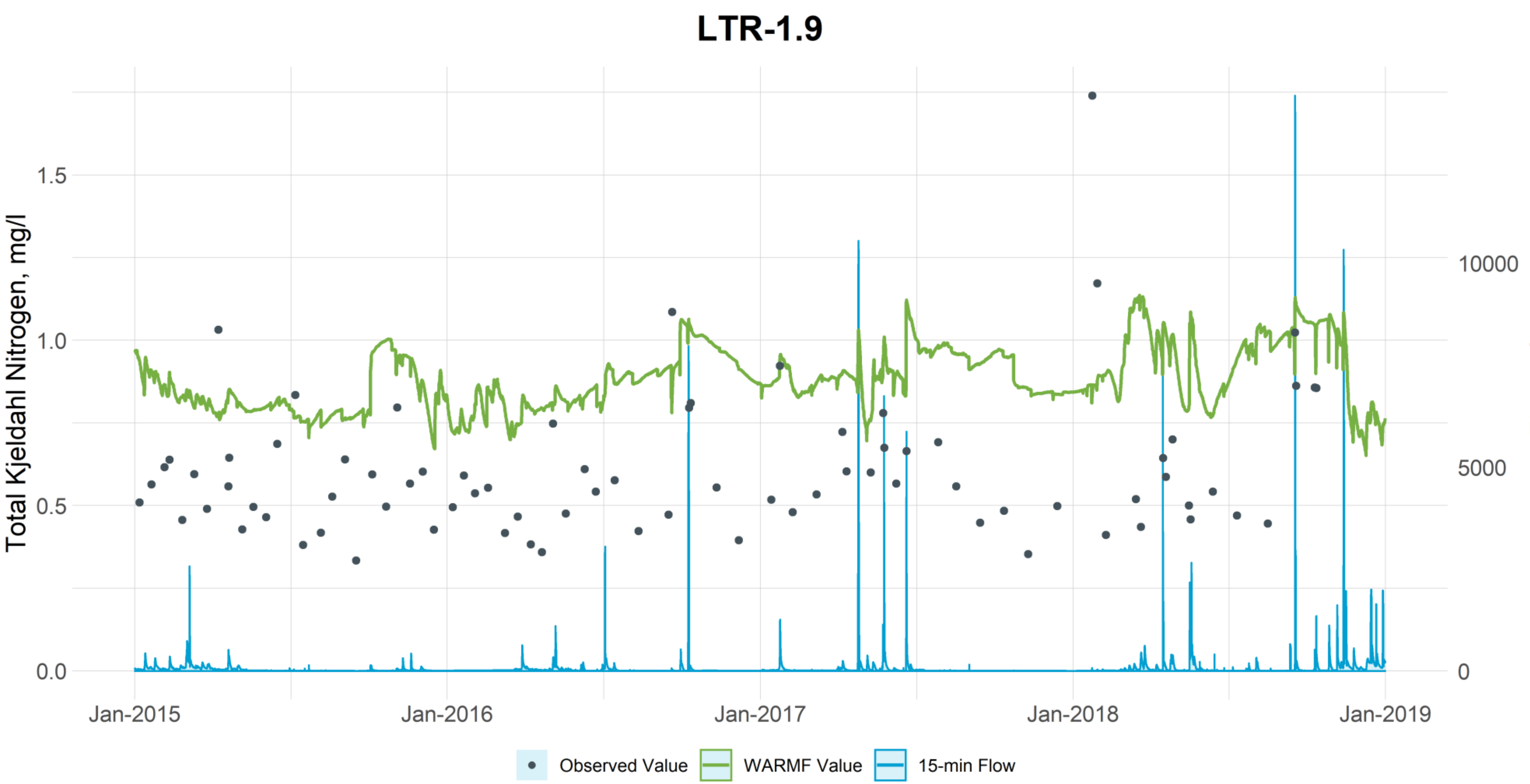
Total Kjeldahl Nitrogen, mg/L– Ellerbe Creek



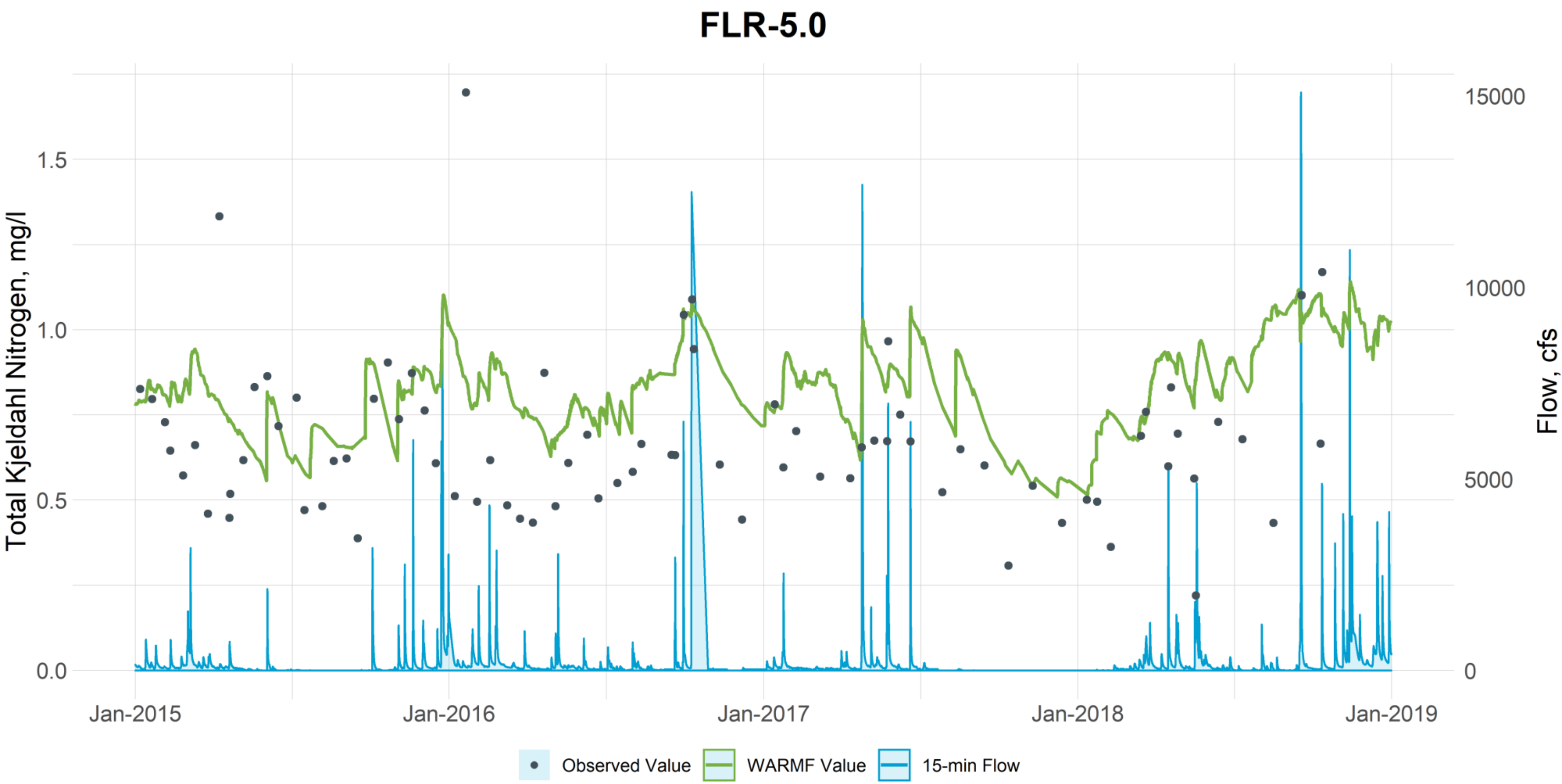
Total Kjeldahl Nitrogen, mg/L– Eno River



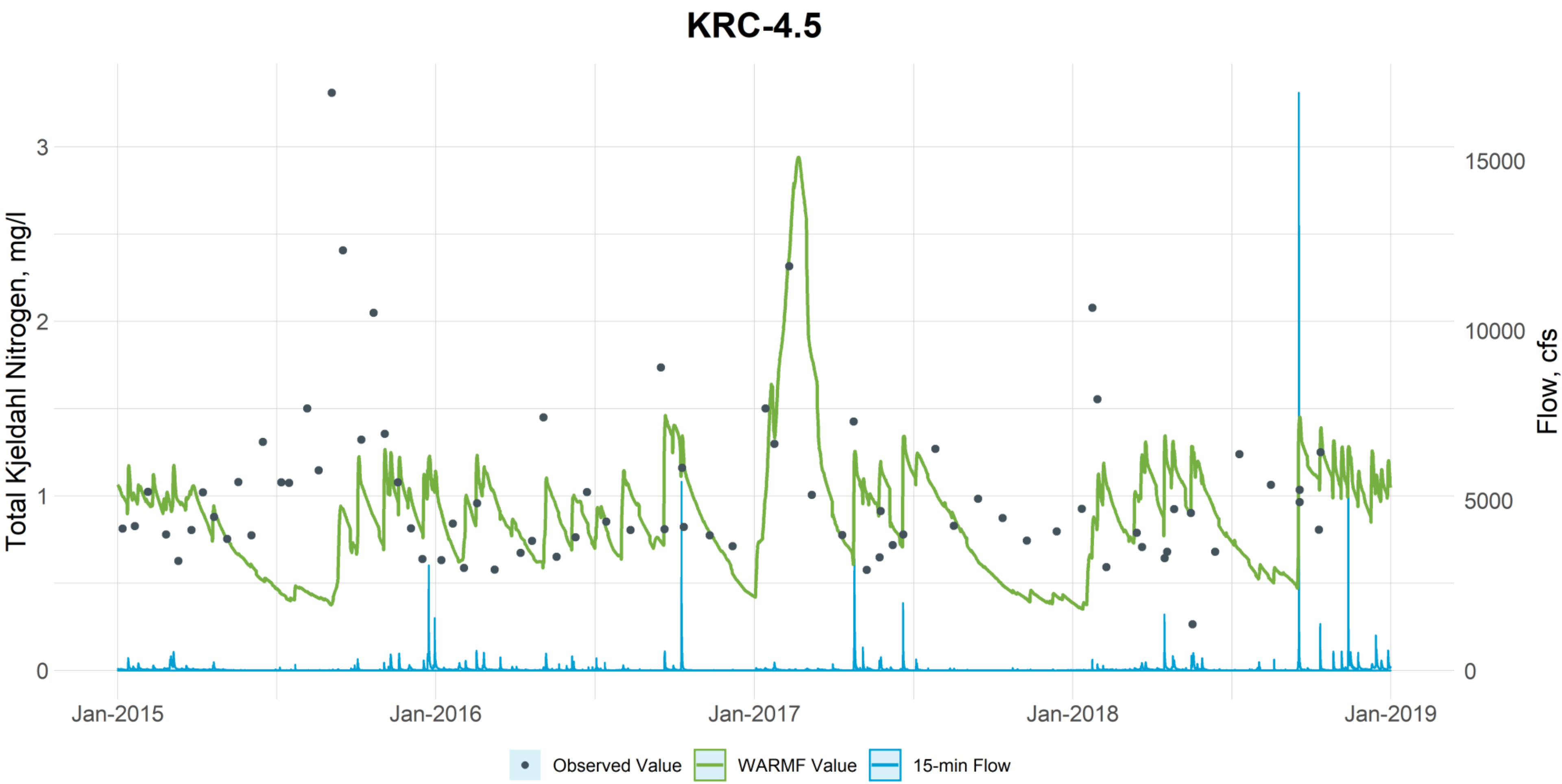
Total Kjeldahl Nitrogen, mg/L – Little River



Total Kjeldahl Nitrogen, mg/L– Flat River



Total Kjeldahl Nitrogen, mg/L – Knap of Reeds



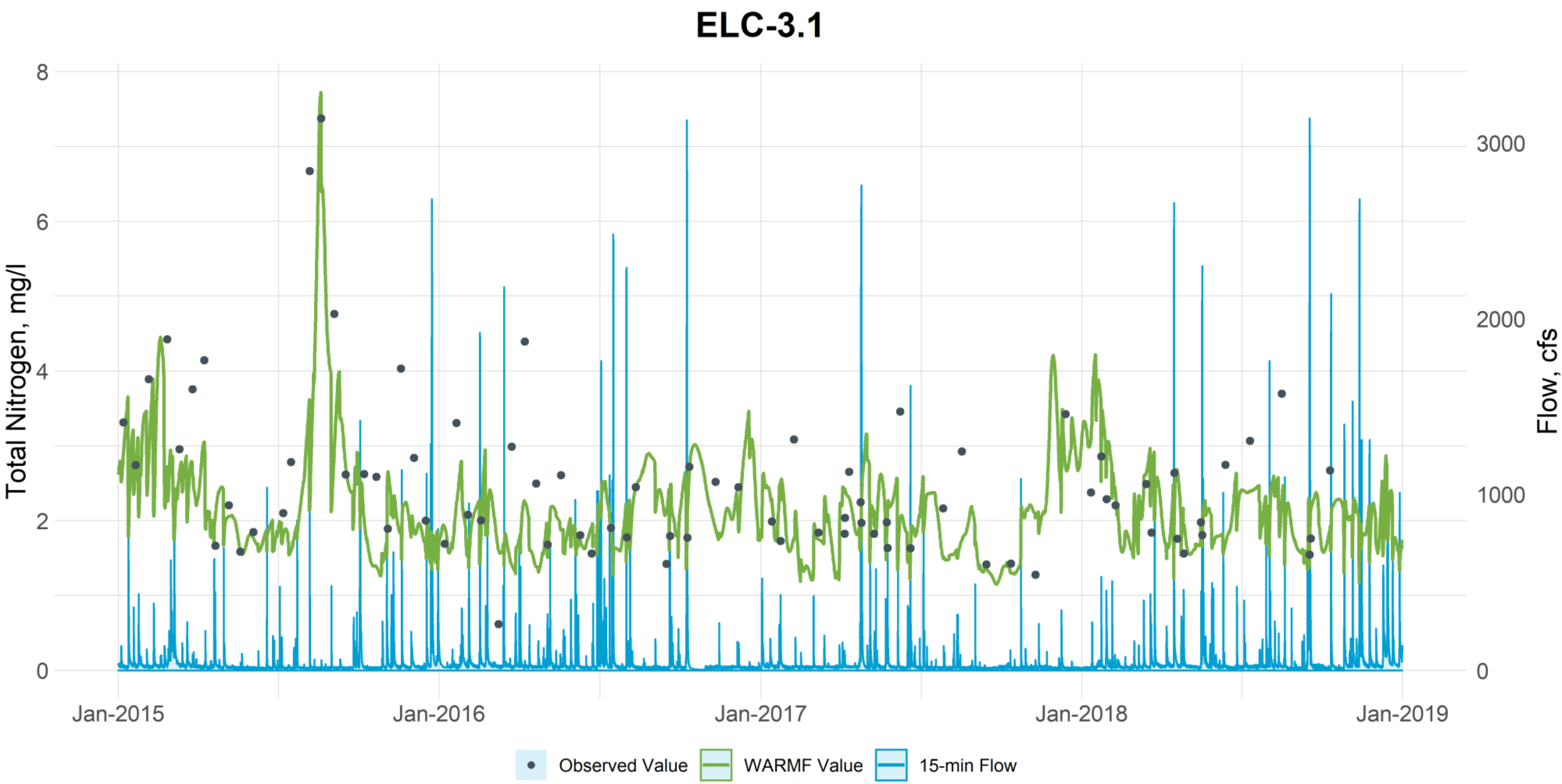
Draft Total Nitrogen (TN)

- Performance variation across the watershed is affected by impoundments and wastewater treatment plants
- Load estimates are available for total nitrogen and added to the performance table
- Water quality stations are not always co-located with a USGS station so many “observed” flow values are estimates)

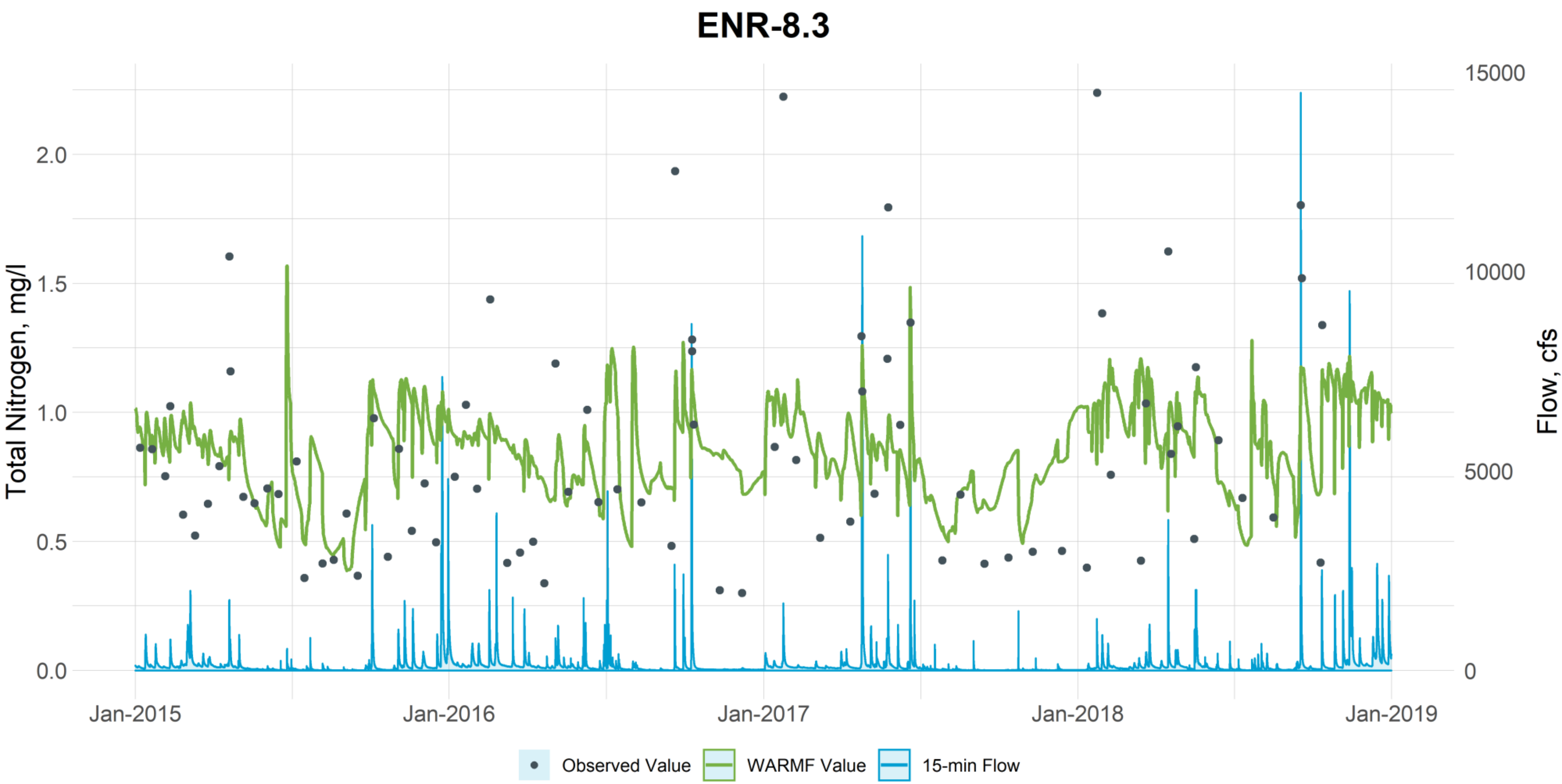
Model Performance for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Ranking	Statistic	Ellerbe	Eno	Little	Flat	Knap of Reeds
Conc.-based	**RE (%)**	**-13**	**3**	**40**	**-11**	**-21**
	Observed Mean (mg/L)	**2.5**	**0.8**	**0.8**	**0.9**	**2.2**
Load-based annual	**RE (%)**	**5**	**18**	**73**	**21**	**-8**
	LOADEST Mean (lb/year)	**169,681**	**210,475**	**71,415**	**241,787**	**88,231**
Load-based daily	**RE (%)**	**-14**	**-47**	**1**	**-22**	**30**
	Observed Mean (lb/day)	**1,799**	**5,002**	**2,064**	**4,573**	**754**

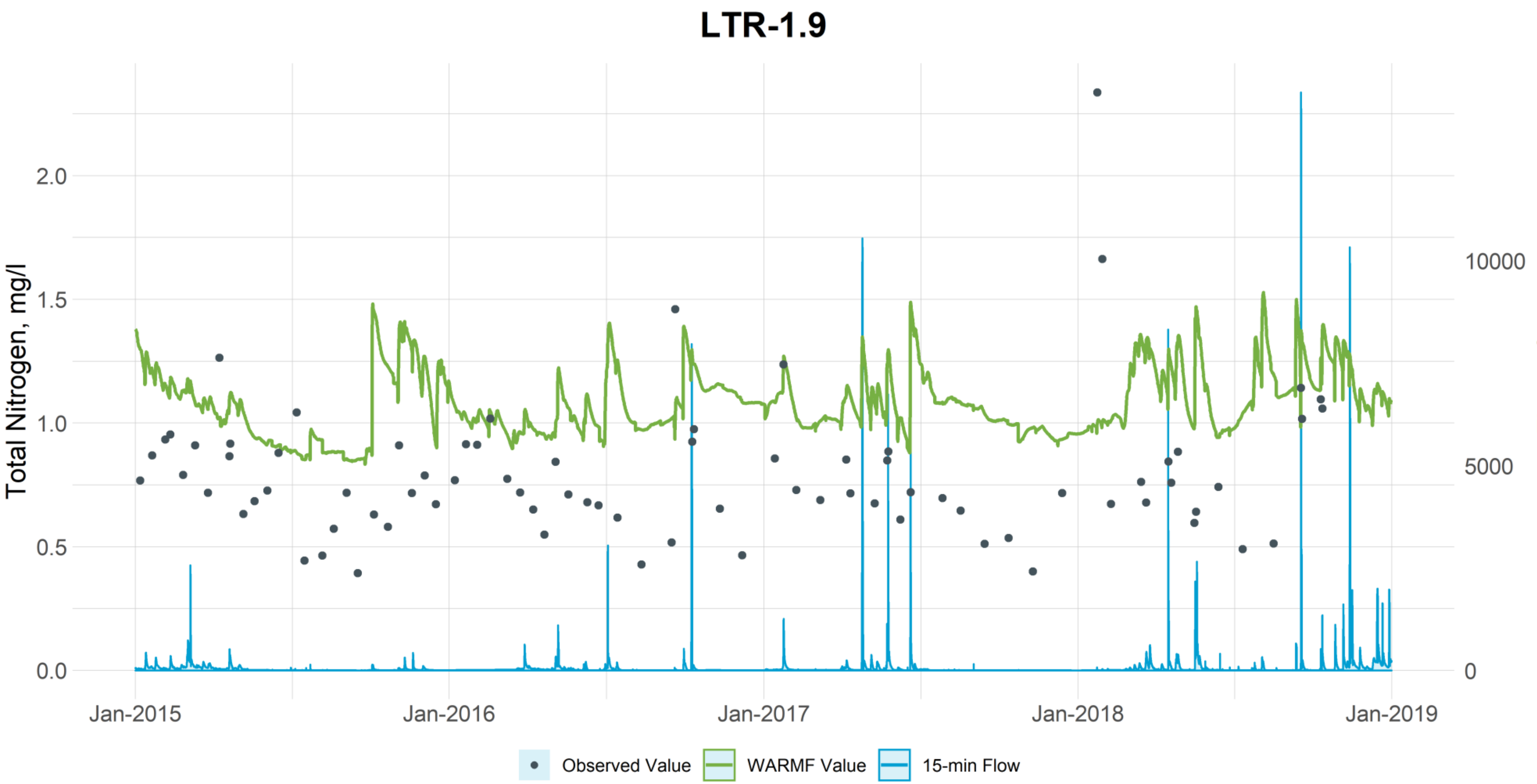
Total Nitrogen, mg/L – Ellerbe Creek



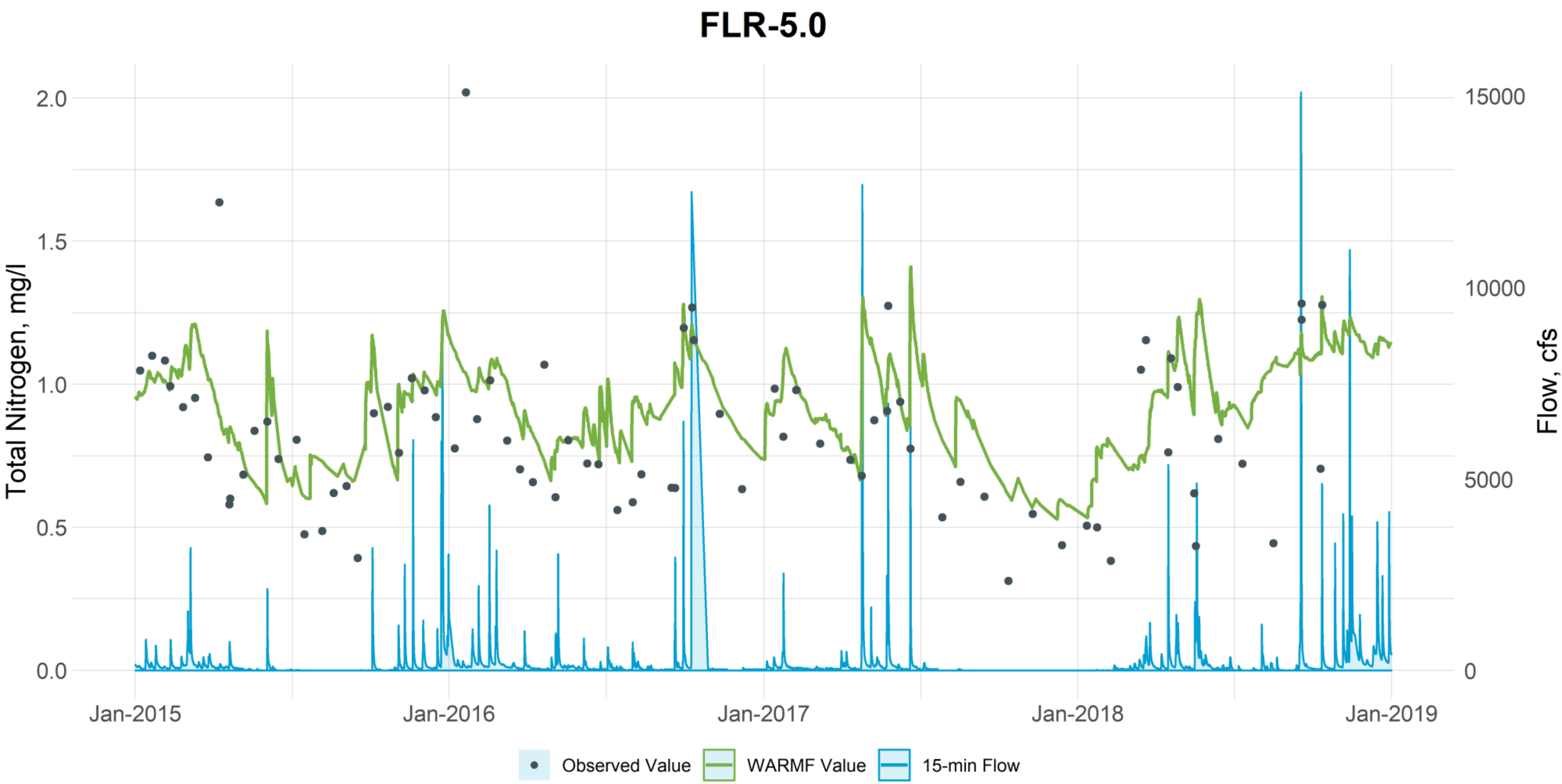
Total Nitrogen, mg/L – Eno River



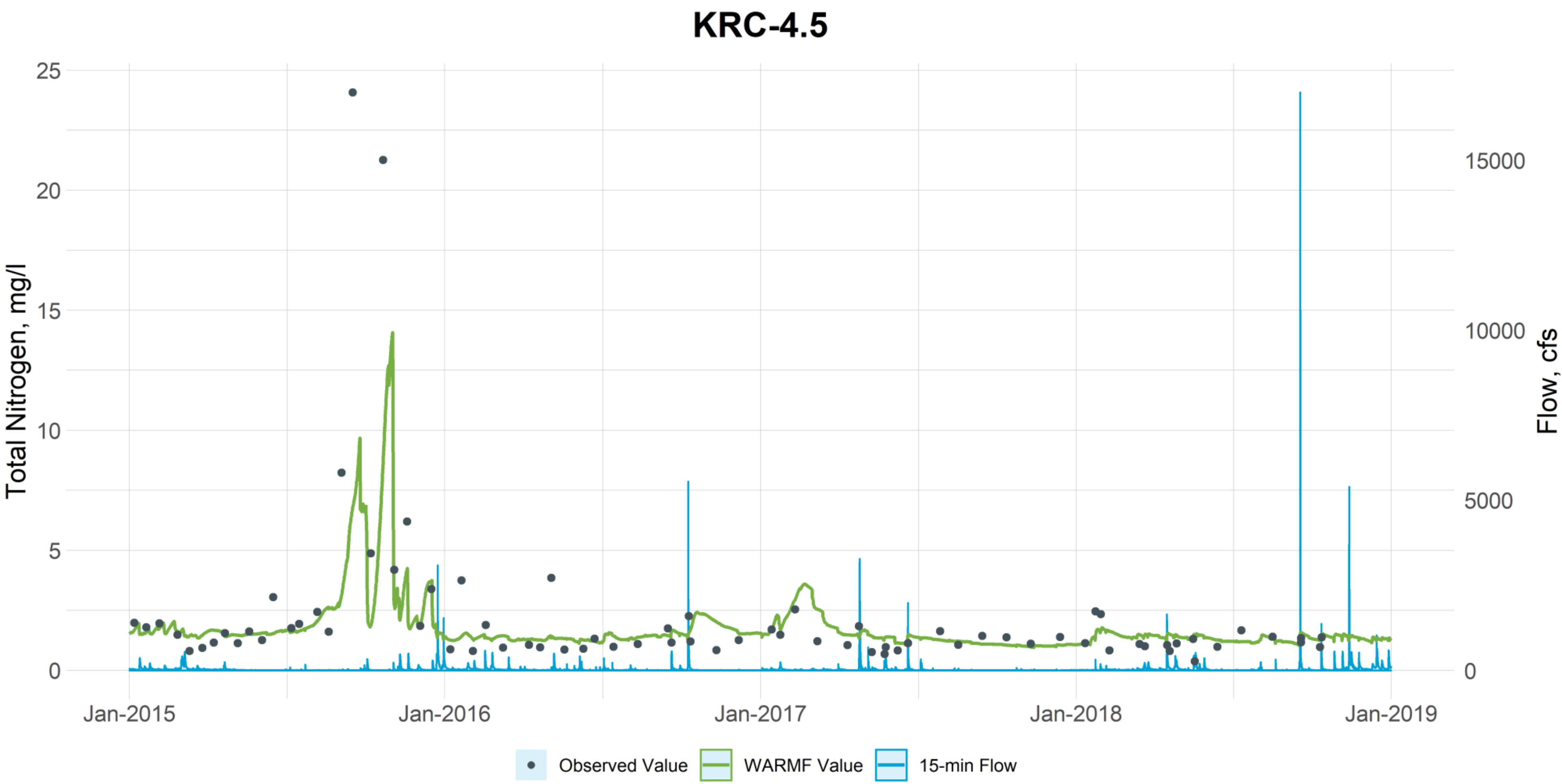
Total Nitrogen, mg/L – Little River



Total Nitrogen, mg/L – Flat River



Total Nitrogen, mg/L – Knap of Reeds



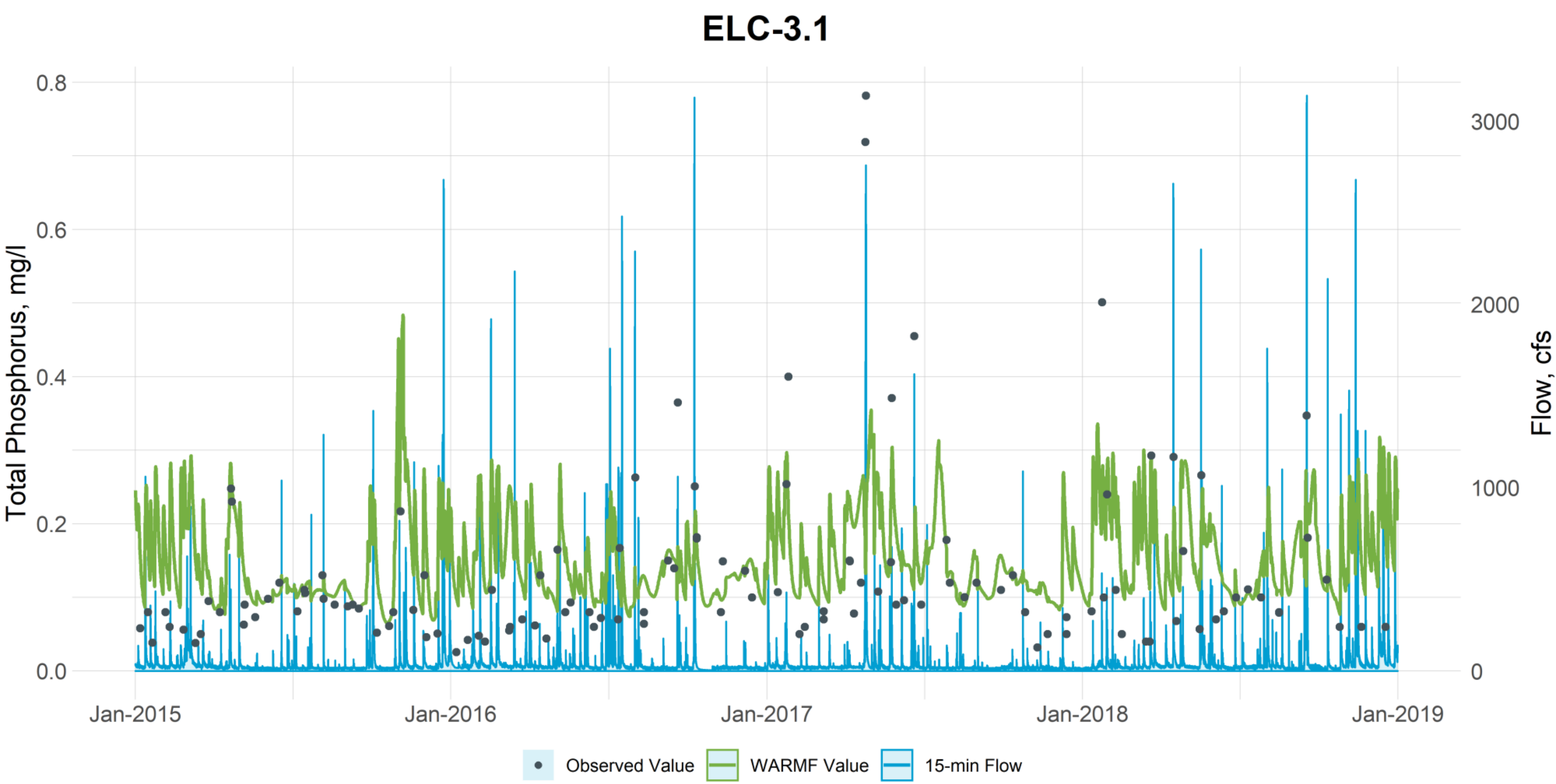
Preliminary Draft Total Phosphorus (TP)

- Model performs well, but some localized events are missed (e.g., WWTP variations at KRC)
- Also, model underpredicts concentrations during stagnant periods
- Work is in progress to model TP values associated with high flows

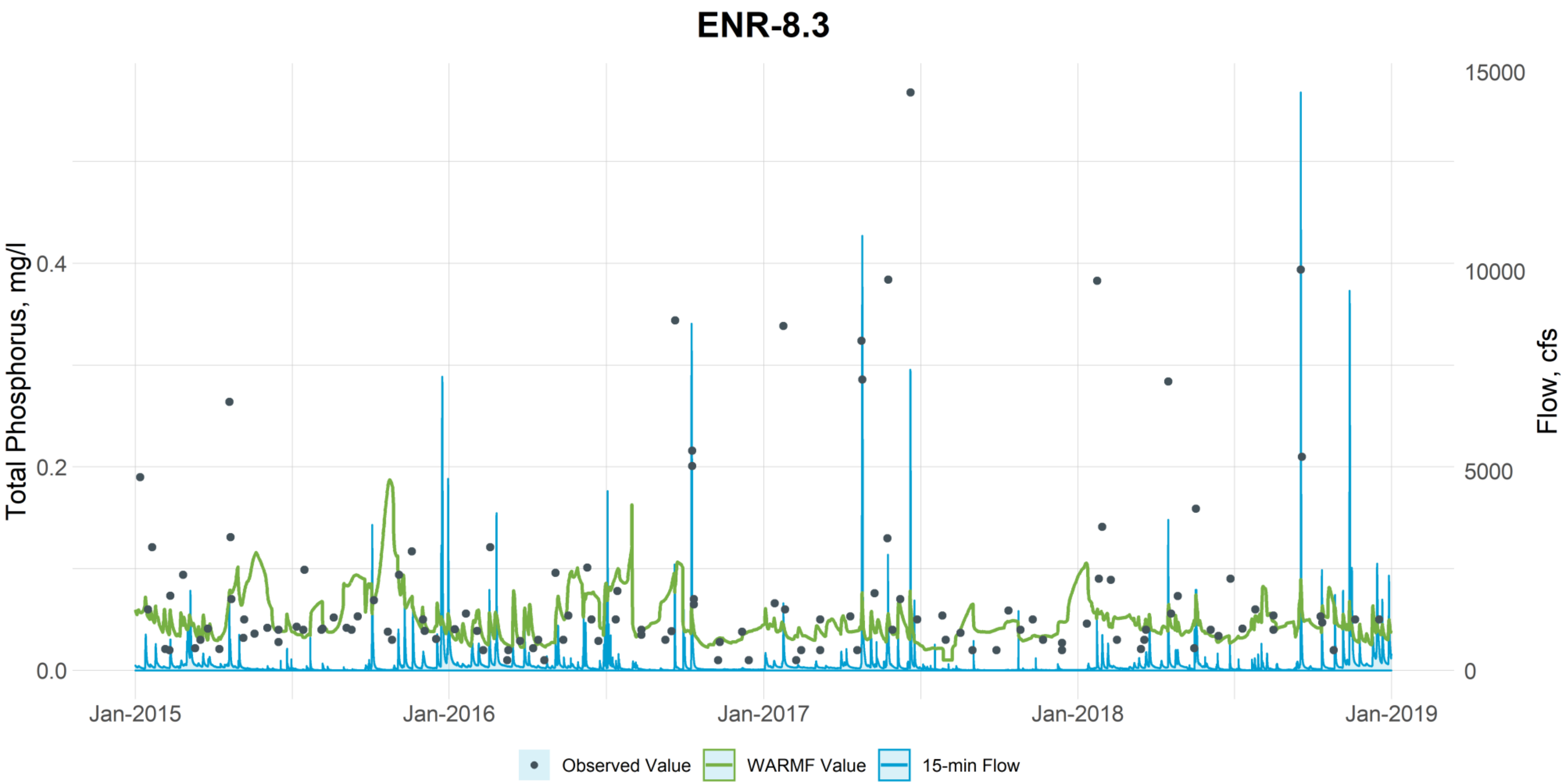
Model Performance for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Ranking	Statistic	Ellerbe	Eno	Little	Flat	Knap of Reeds
Conc.-based	**RE (%)**	22	-33	-21	14	-60
	Observed Mean (mg/L)	**0.13**	**0.08**	**0.07**	**0.06**	**0.44**
Load-based annual	**RE (%)**	24	-39	12	14	-8
	LOADEST Mean (lb/year)	13,301	20,475	5,178	18,086	6,233
Load-based daily	**RE (%)**	-58	-84	-71	-56	-31
	Observed Mean (lb/day)	**235**	**706**	**285**	**375**	**57**

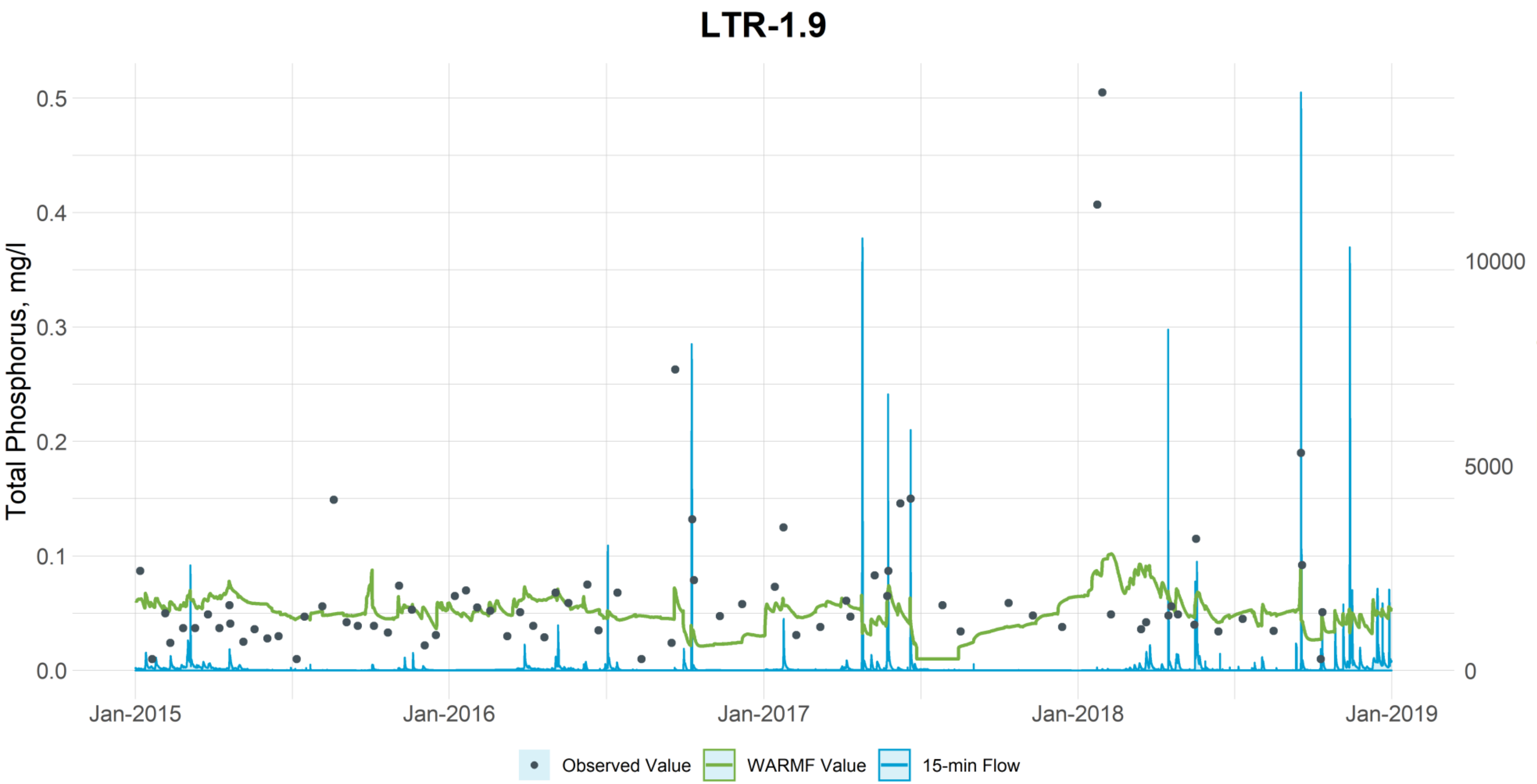
Total Phosphorus, mg/L – Ellerbe Creek



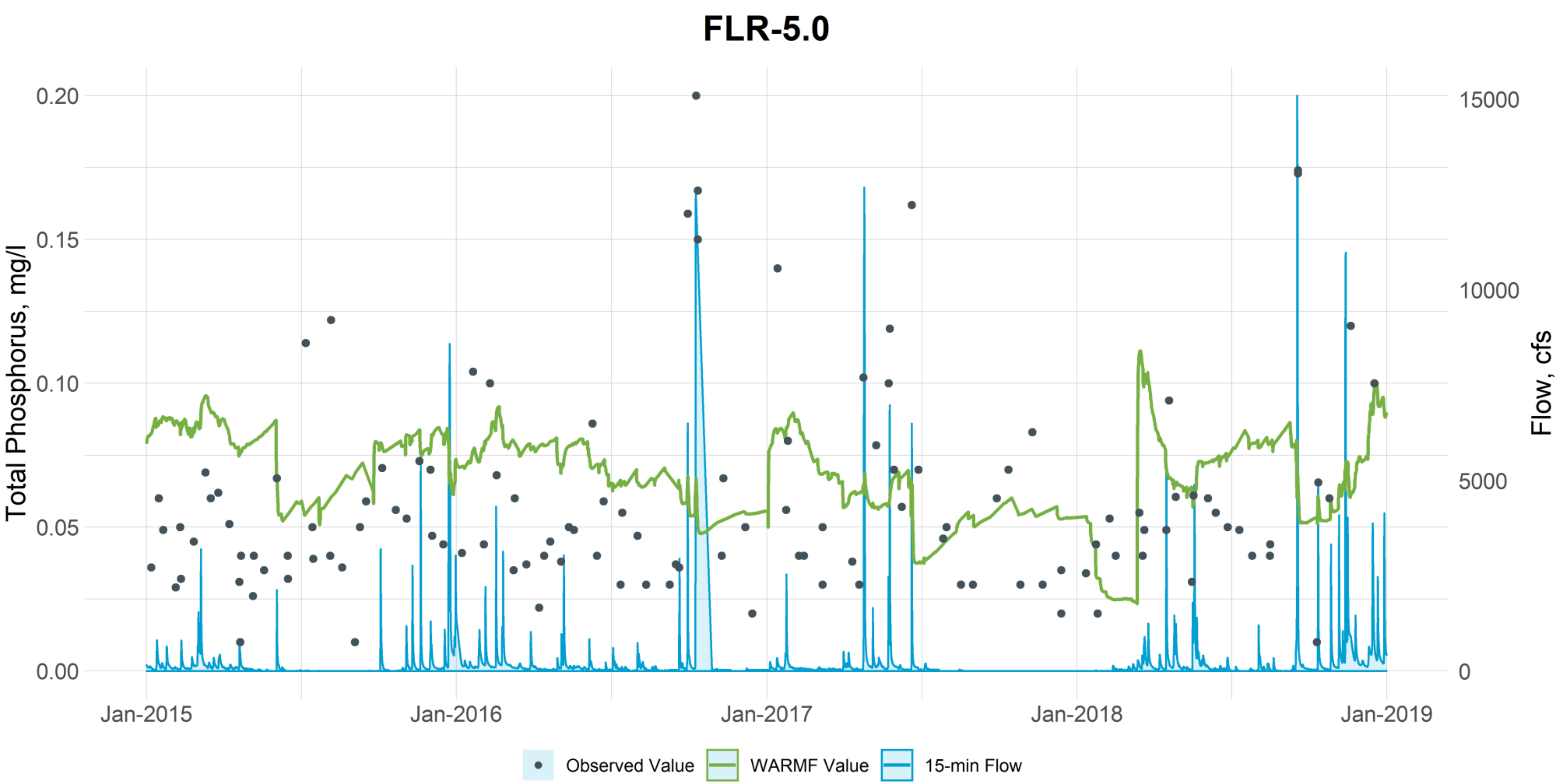
Total Phosphorus, mg/L – Eno River



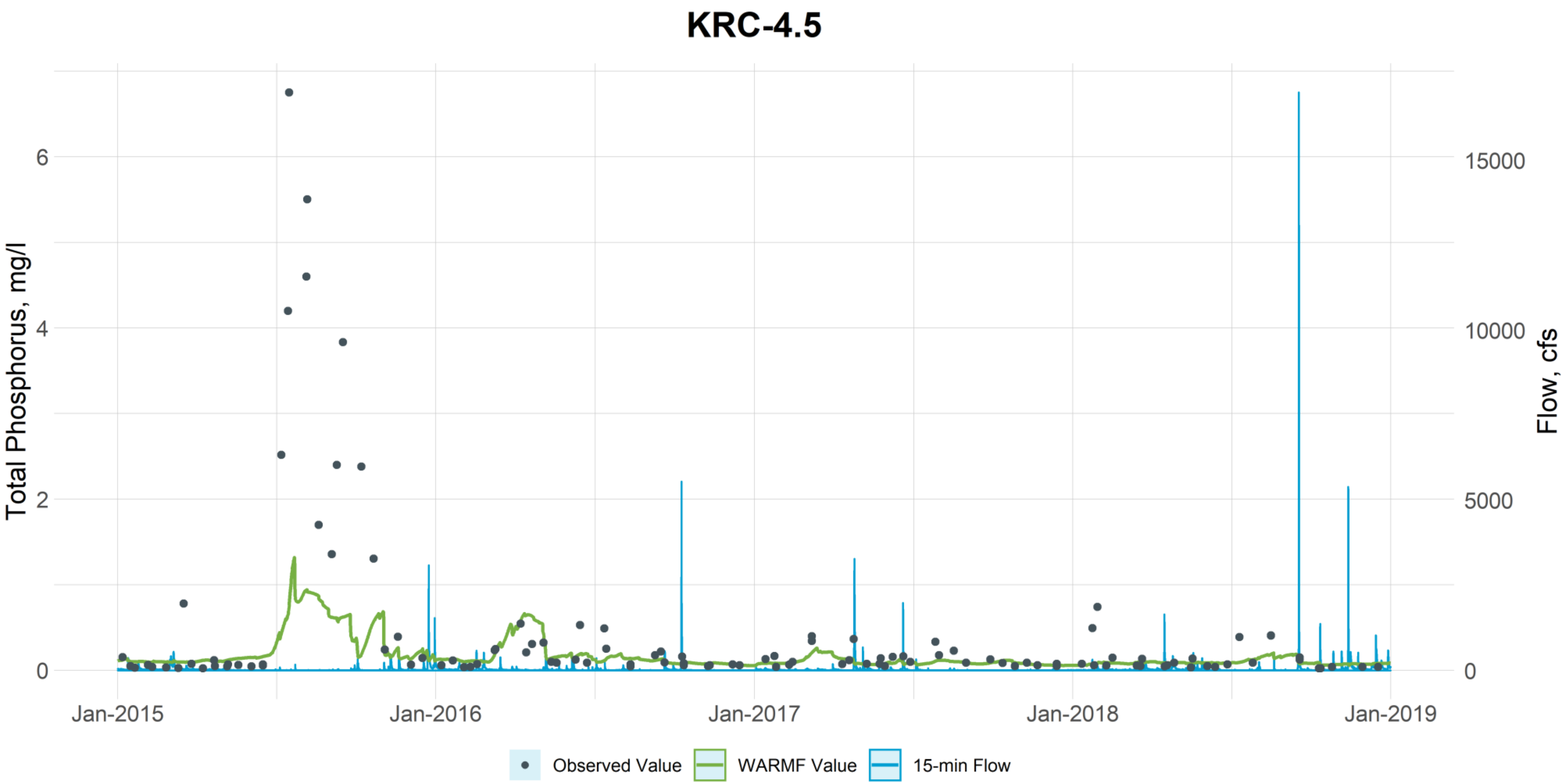
Total Phosphorus, mg/L – Little River



Total Phosphorus, mg/L – Flat River



Total Phosphorus, mg/L – Knap of Reeds



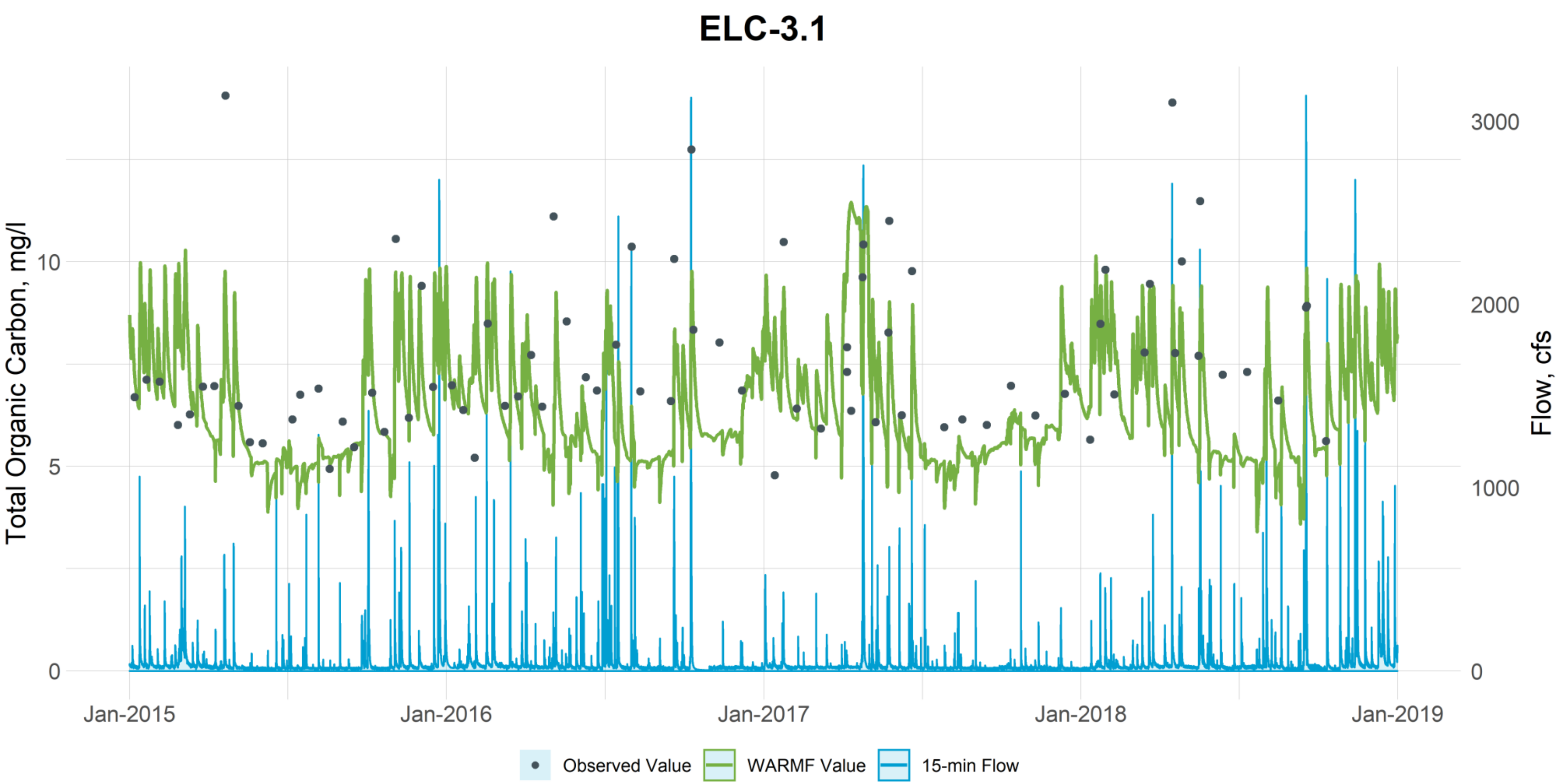
Draft Total Organic Carbon (TOC)

- Model performs well at most sites.
  - Daily loading values at Eno are low, high at Knap of Reeds and high at Little

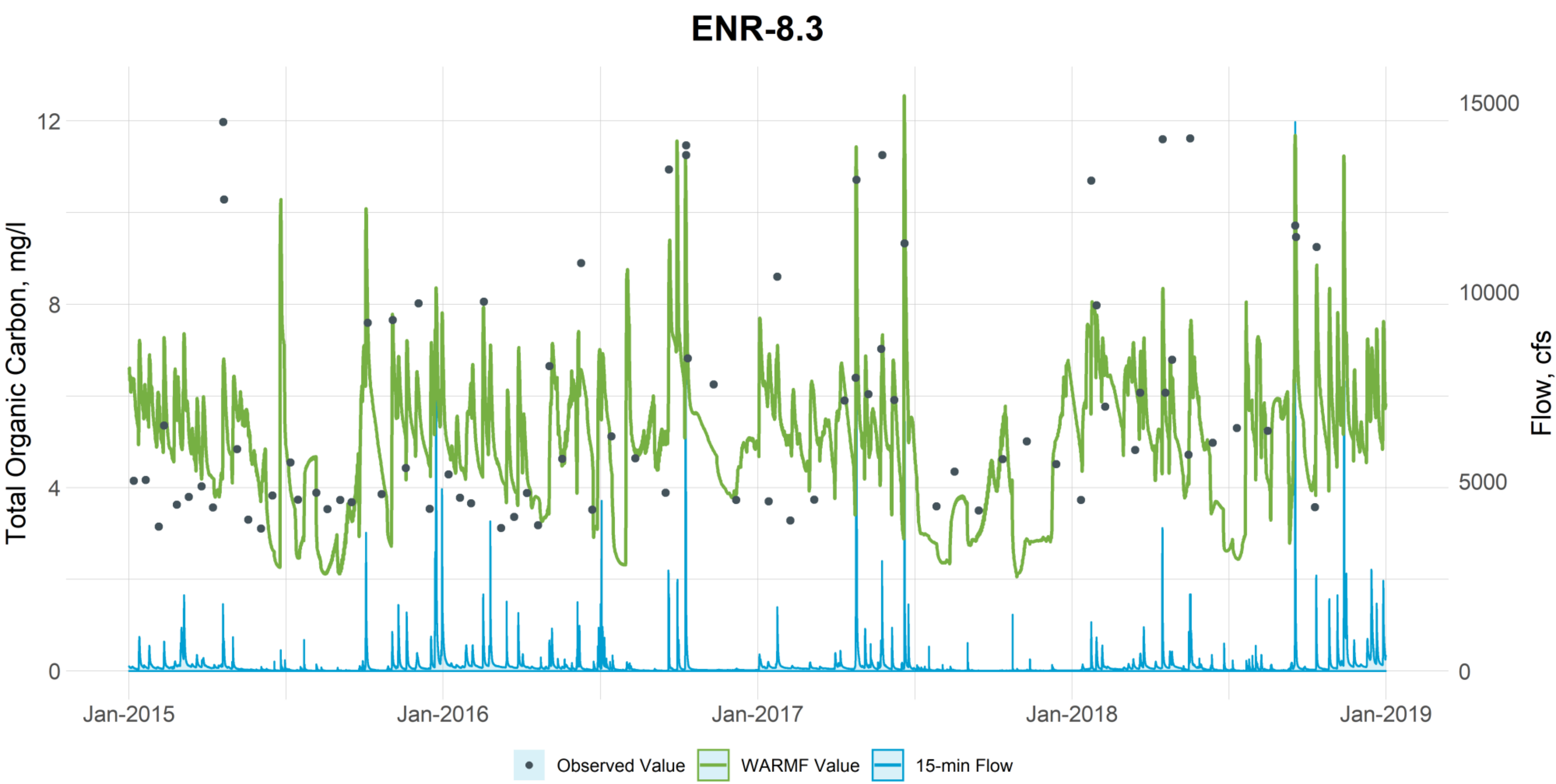
Model Performance for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Ranking	Statistic	Ellerbe	Eno	Little	Flat	Knap of Reeds
Conc.-based	**RE (%)**	-9	-3	22	-2	1
	Observed Mean (mg/L)	**7.6**	**5.8**	**7.0**	**7.8**	**8.3**
Load-based annual	**RE (%)**	-2	11	50	9	6
	LOADEST Mean (lb/year)	648,250	1,437,524	624,591	2,210,352	528,010
Load-based daily	**RE (%)**	-35	-36	-4	-30	48
	Observed Mean (lb/day)	9,319	34,382	17,713	40,166	5,430

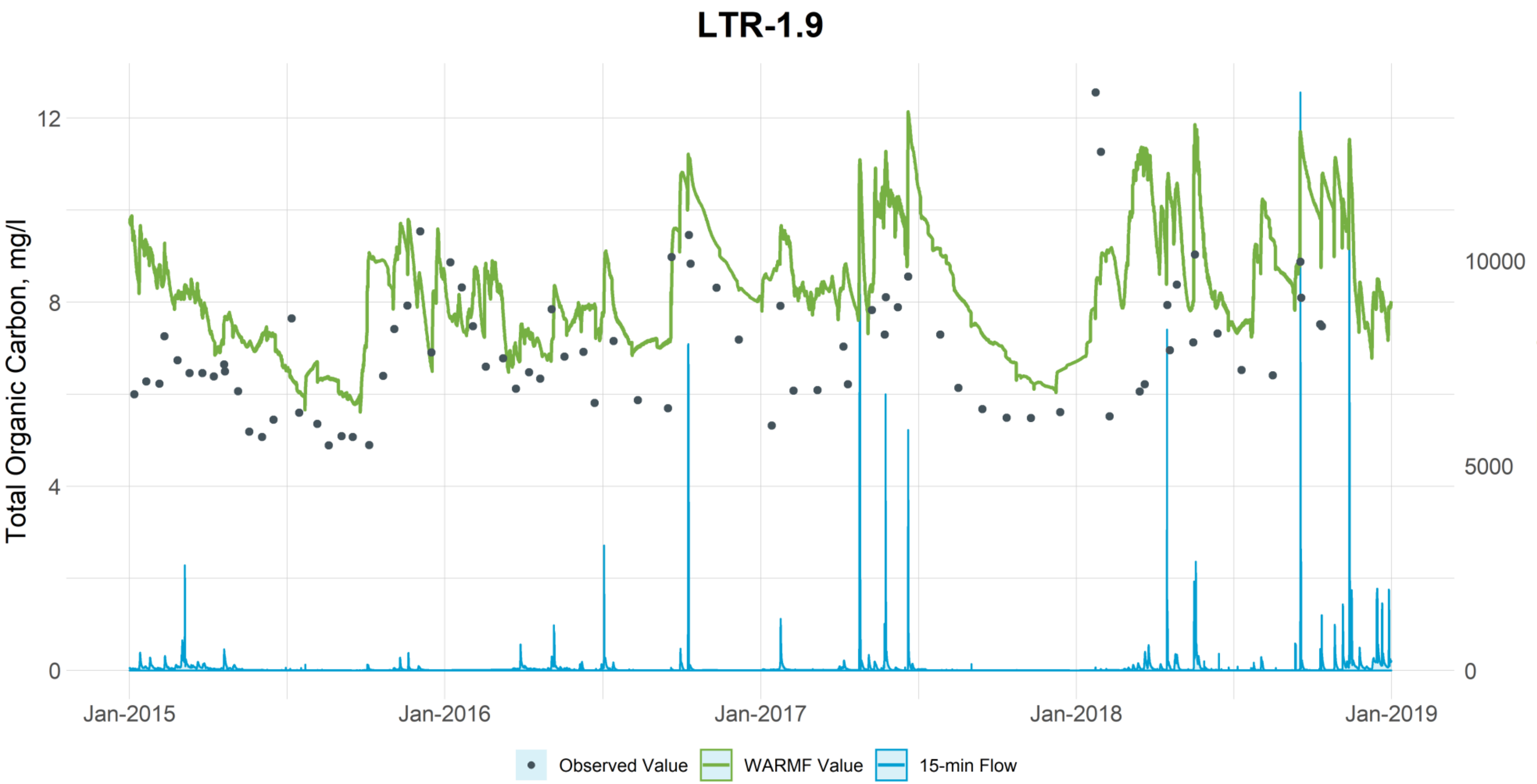
Total Organic Carbon, mg/L – Ellerbe Creek



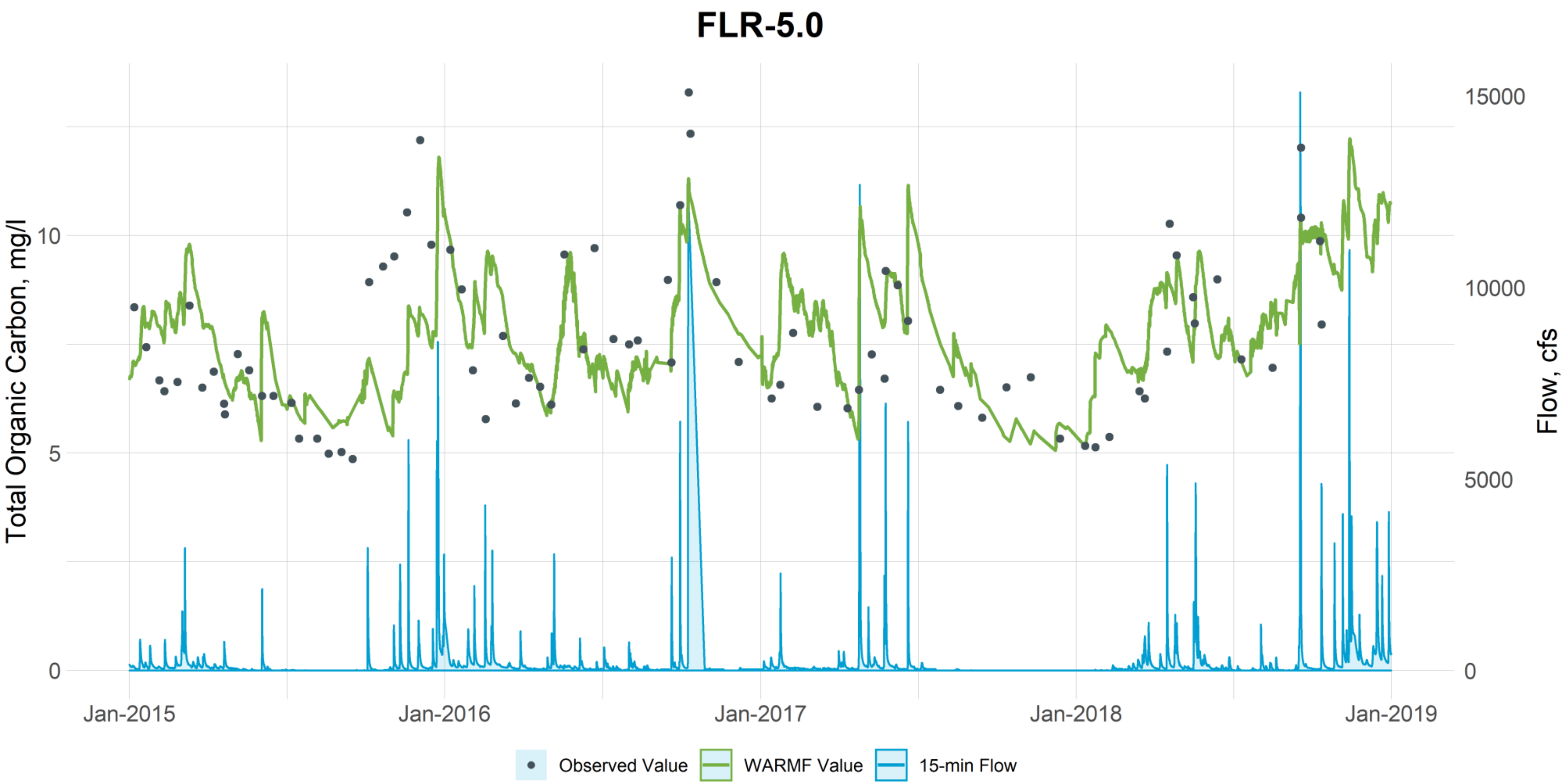
Total Organic Carbon, mg/L – Eno River



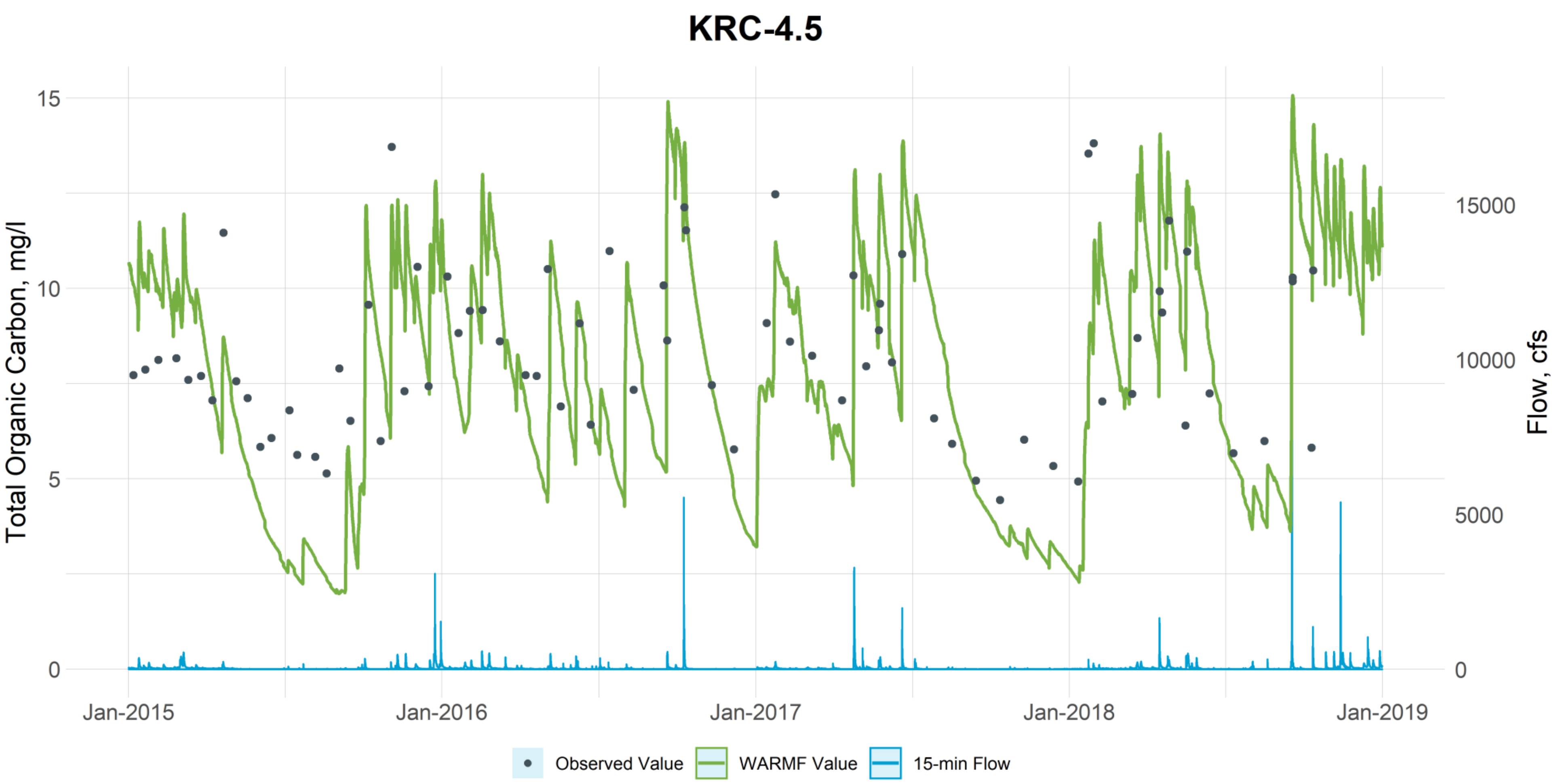
Total Organic Carbon, mg/L – Little River



Total Organic Carbon, mg/L – Flat River



Total Organic Carbon, mg/L – Knap of Reeds



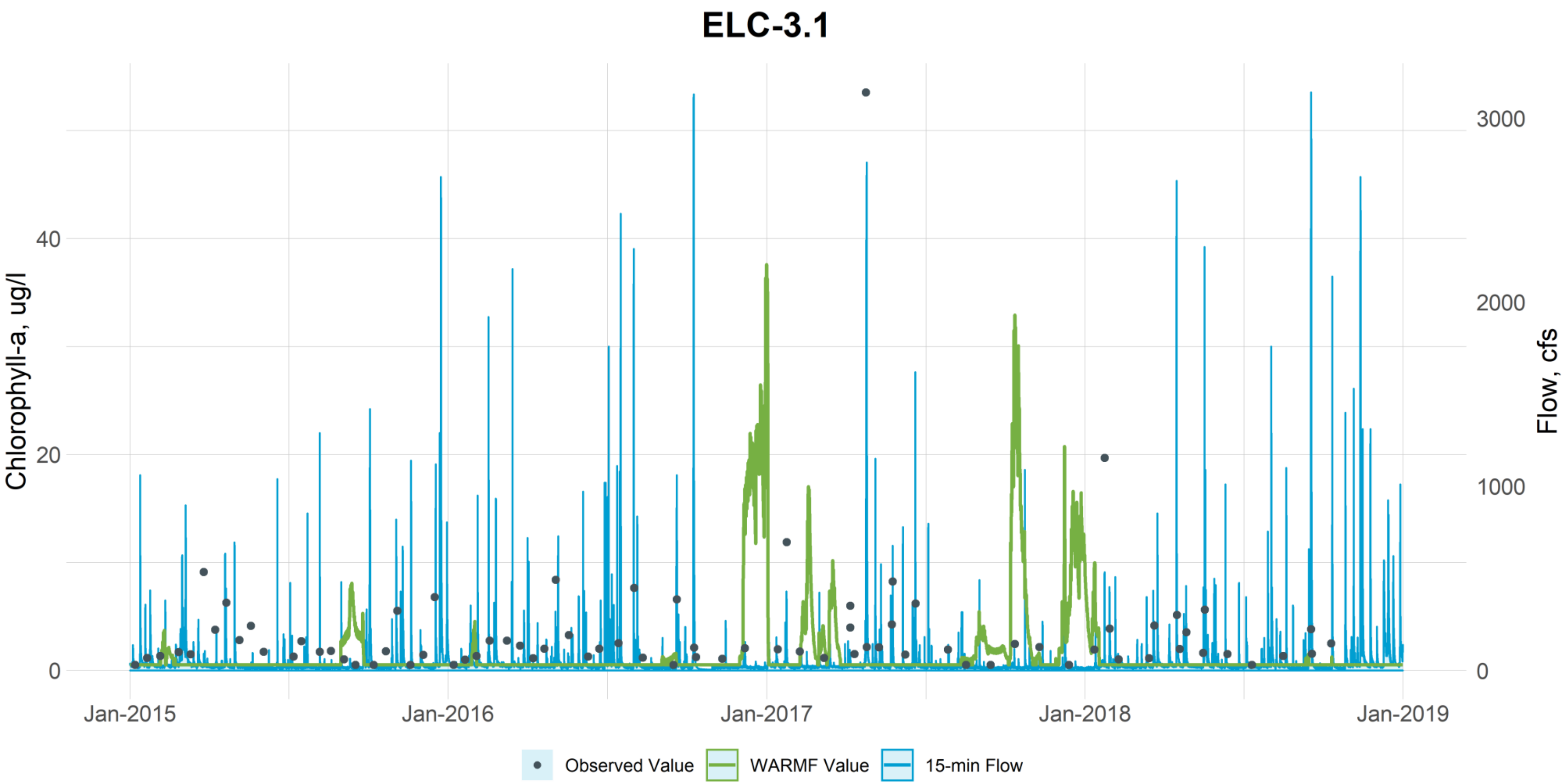
Draft Chlorophyll-a (Chl-a)

- Model performs well considering WARMF is simulating river reaches
- During baseflow conditions, WARMF does not calculate concentrations accurately
  - Algal blooms occurred in the summer

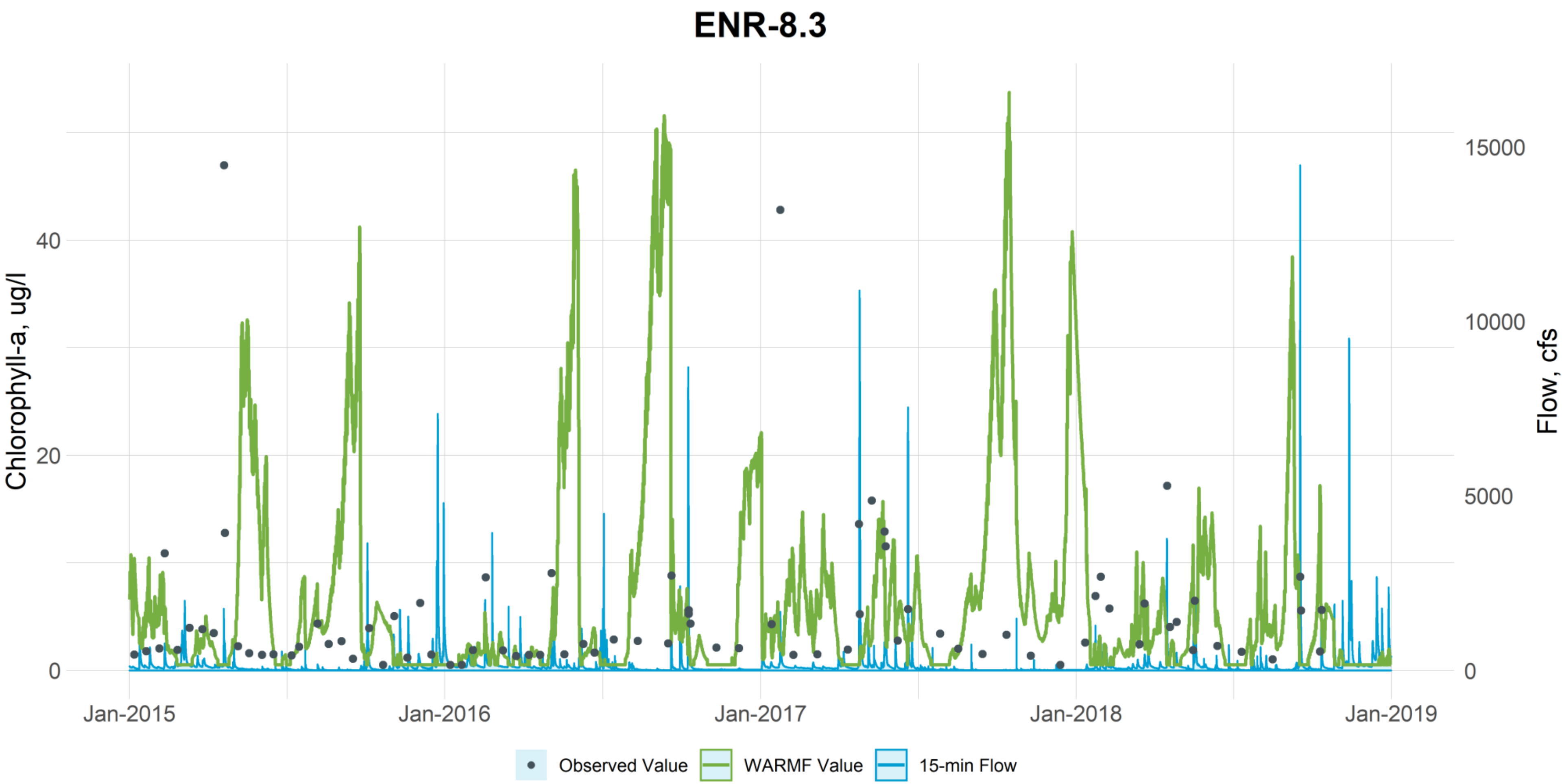
Model Performance for Upper Five Lake Tributaries Near Falls Lake (2015 to 2018)

Statistic	Ellerbe	Eno	Little	Flat	Knap of Reeds
RE (%)	-60	10	15	-6	12
Observed Mean (ug/L)	3.6	5.1	9.9	12.6	3.7

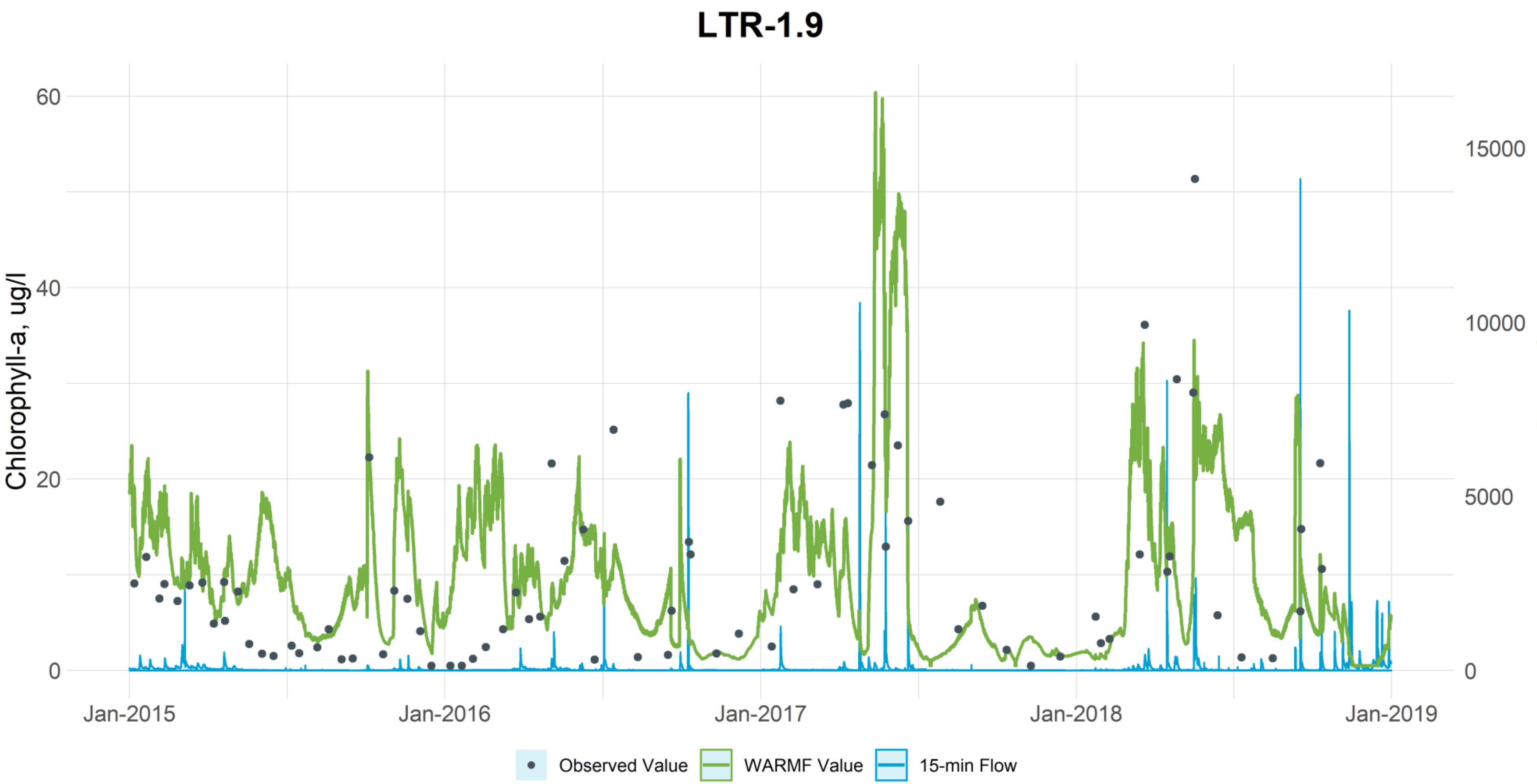
Chlorophyll-*a*, ug/L – Ellerbe Creek



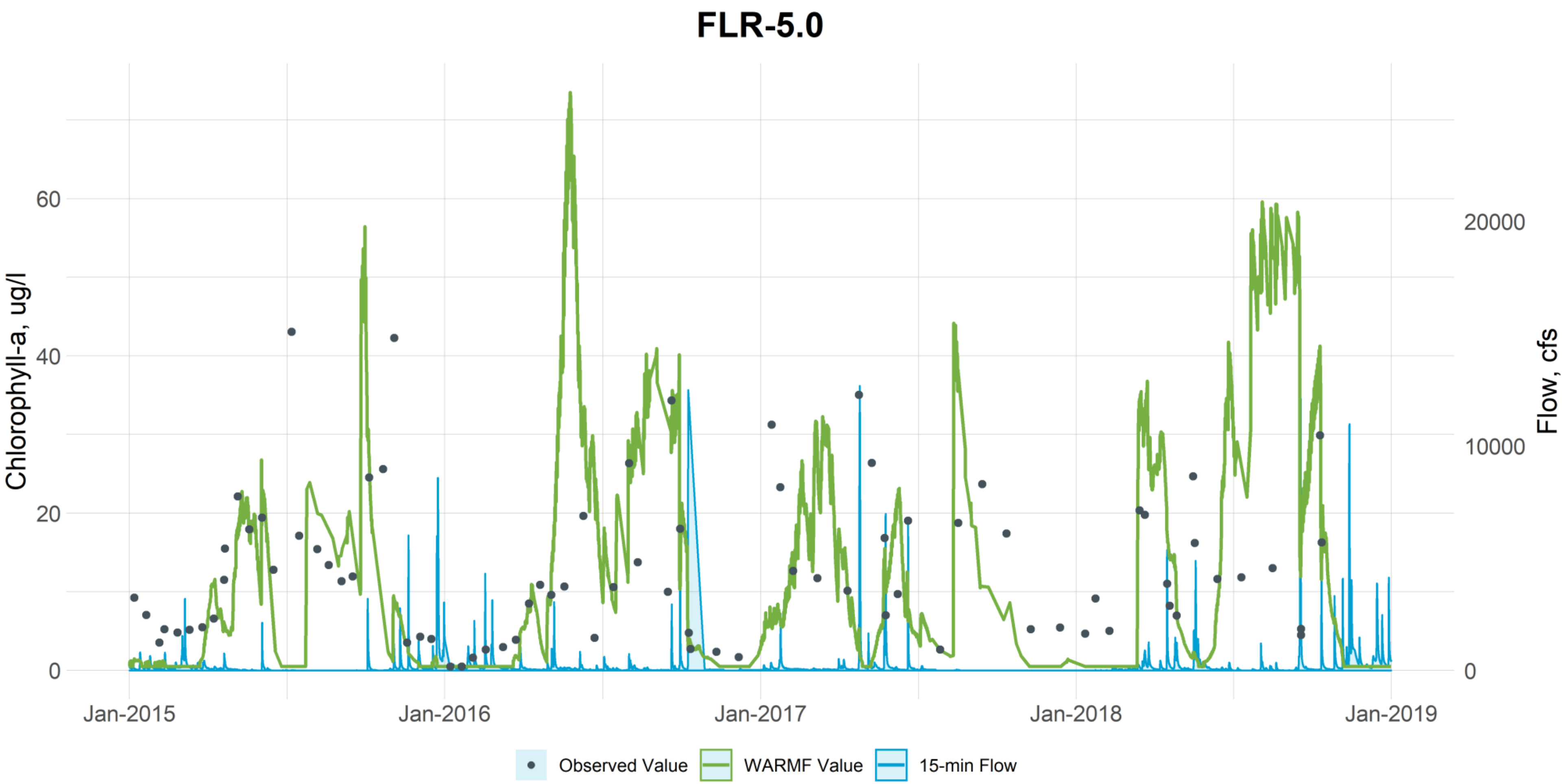
Chlorophyll-*a*, ug/L – Eno River



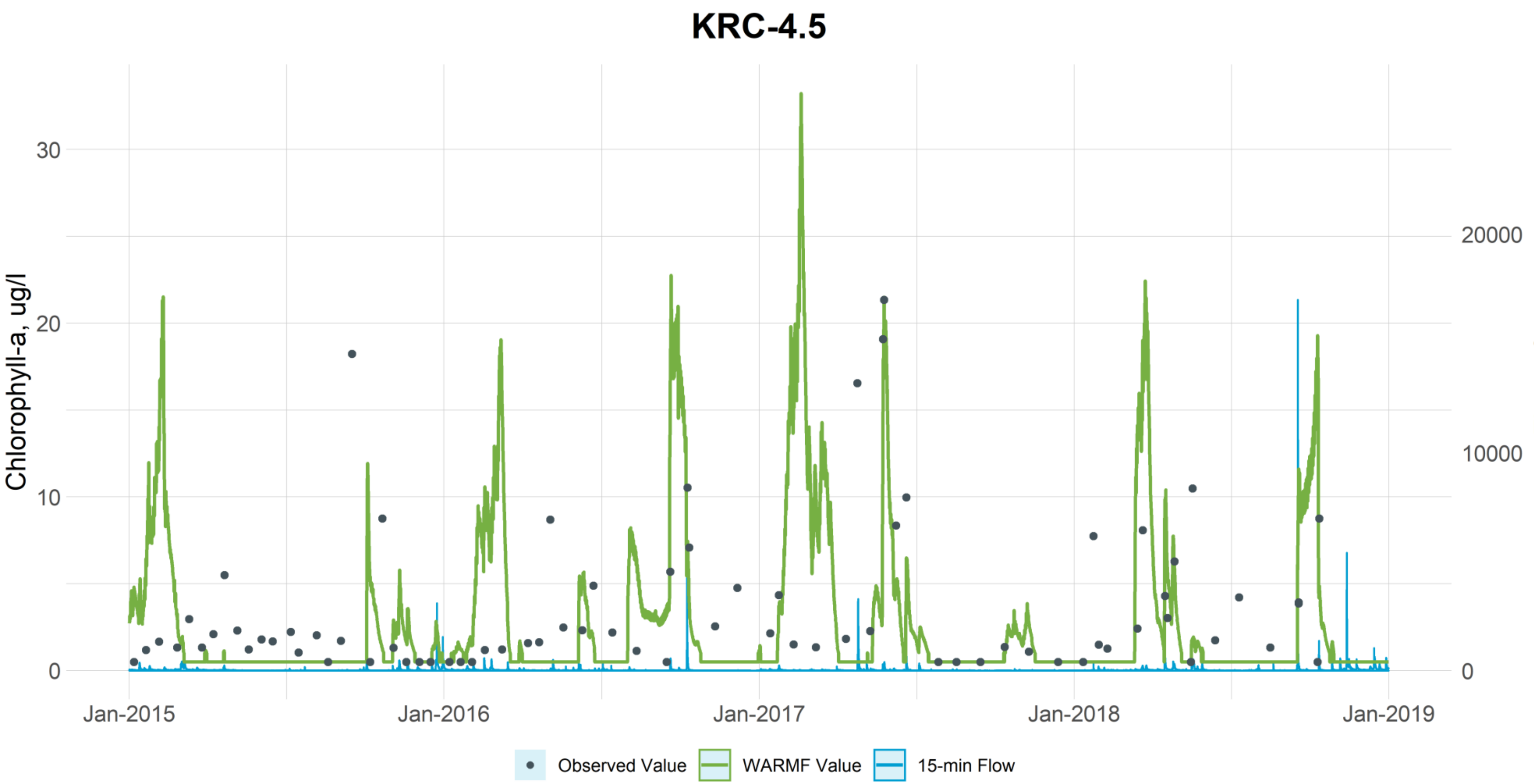
Chlorophyll-*a*, ug/L – Little River



Chlorophyll-*a*, ug/L – Flat River



Chlorophyll-*a*, ug/L – Knap of Reeds



Comparison between LOADEST and WARMF annual loading estimates (2015-2018)

- Data excludes the top 1% of flows
  - There is uncertainty that the LOADEST model can accurately estimate loading during extremely high flow events
- It is important to note that two model estimates are being compared (LOADEST vs WARMF)

	Average Annual Lake Loading (LOADEST)	Average Annual Lake Loading (WARMF)	% RE
Total Nitrogen, lb/year	949,476	1,198,409	26
Total Organic Carbon, lb/year	7,158,571	8,267,818	15
Total Phosphorus, lb/year	81,683	81,153	-1