# Falls Lake WARMF Model Update

## Presentation to the Upper Neuse River Basin Association (UNRBA)

July 23, 2015

**Laura Weintraub**
**Derek Schlea**
**Scott Bell**

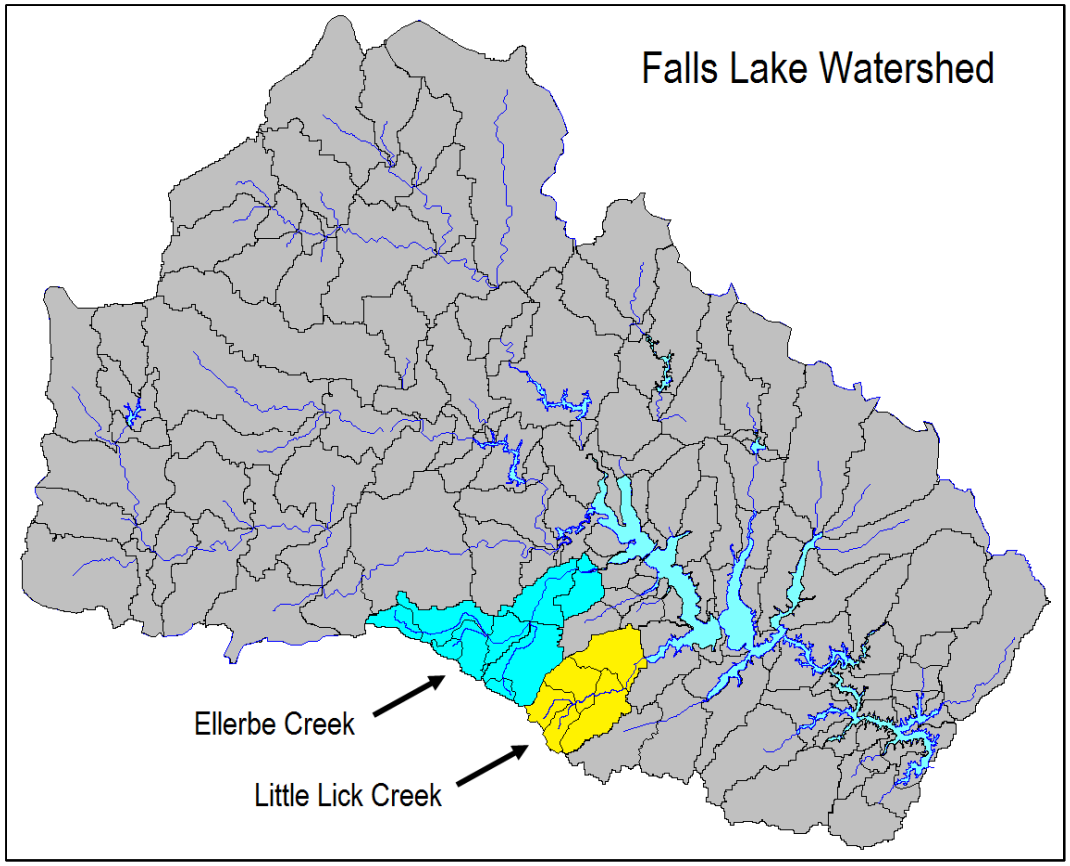
# Overview

- Objectives of model update, scope of work
- Spatial changes to model
- Updated calibration
- Uncovered observations with septic systems and sand filters
- Status of scenario analysis
- Considerations for future use of model

# WARMF Modeling Tasks

- Transitioned model to the latest version of WARMF
- Redelineated Ellerbe and Little Lick Watersheds
- Extended simulation period through December 2013
  - Updated land cover and septic systems inputs with more recent data
  - Calibrated Little Lick Creek and recalibrated Ellerbe Creek watersheds
- Documented all work in a technical memo

# Spatial Scope of Model

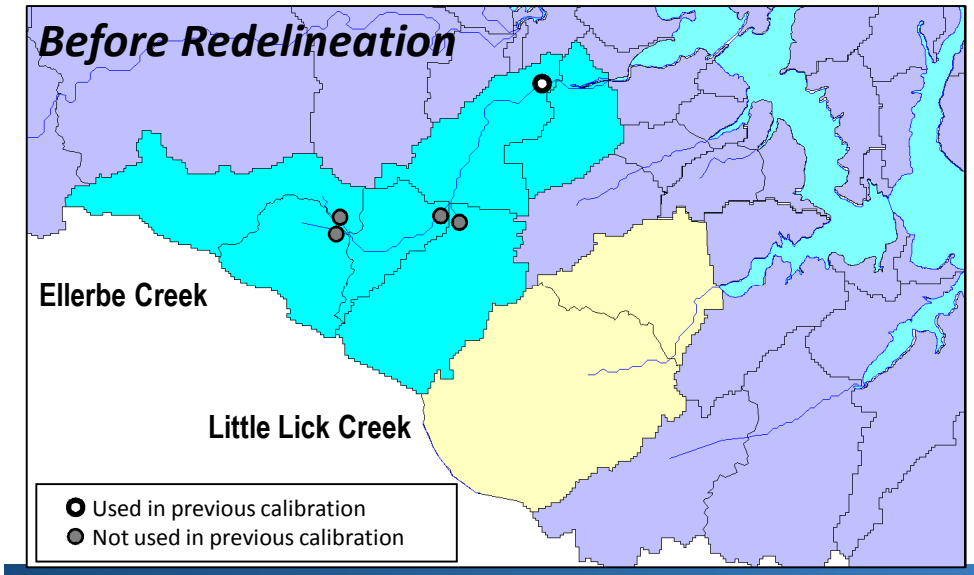


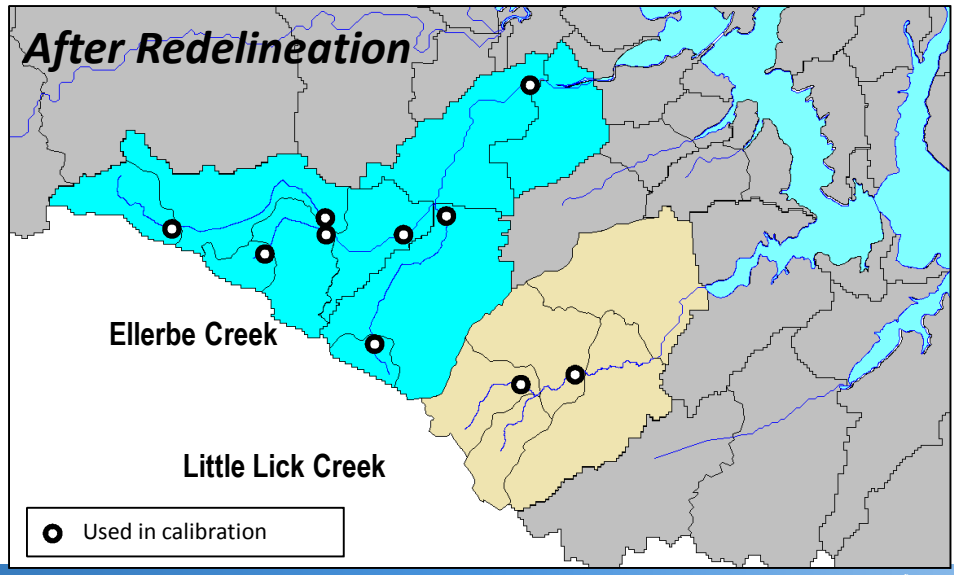
# WARMF Version Transition

- Version 6.3 (used by NCDENR and Durham) to Version 6.5
  - Improved algorithm for calculation of evapotranspiration from catchments resulted in higher evapotranspiration and lower streamflows
    - Adjusted model input parameters during calibration to decrease evapotranspiration
  - Differences in loading output attributed to septic systems
    - Version 6.5 addressed an error in load source tracking
- Version 6.5 to Version 6.7c
  - Done to accommodate resegmentation changes
  - Differences relate to graphical user interface, no changes algorithms
  - Confirmed model output generated between versions was essentially identical for all hydrology and water quality constituents

# Model Redelineation

- Catchments and rivers refined to higher spatial resolution and better alignment with water quality sampling stations
- External subwatershed boundaries modified to correspond with delineation used for the Watershed Improvement Plan



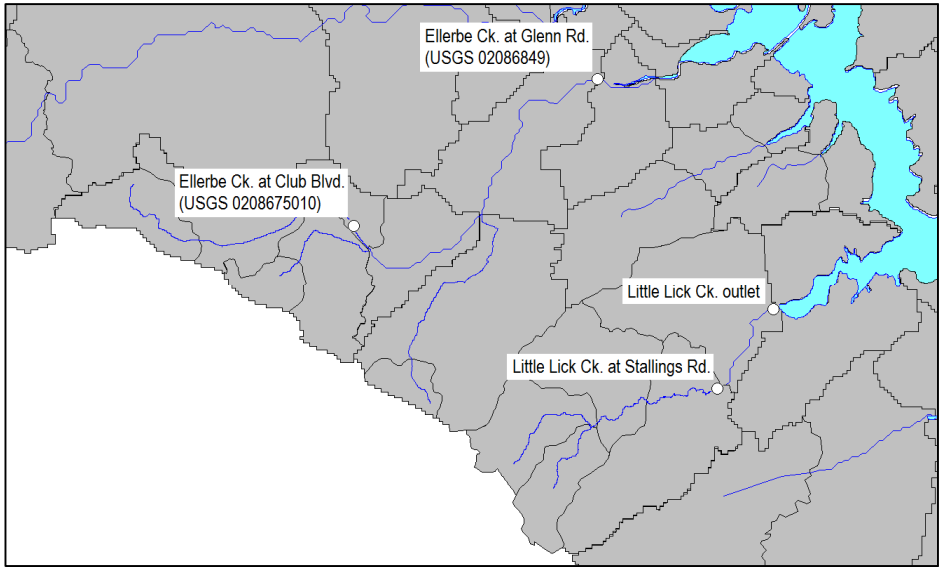



# Model Database Update: Extended Input Data for 2008-2013

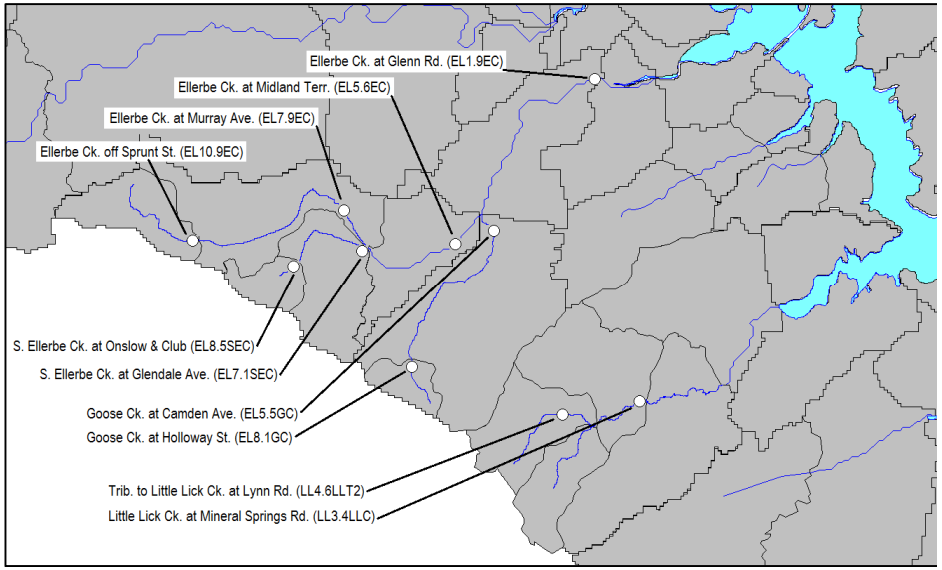
- Land Cover
  - Combination of 2011 NLCD layer and 2014 NCDOT road layer
- Meteorology
  - Extended 1 existing NCDC station
  - 5 new stations: 4 USGS stations and 1 N. Durham WRF station (NC Climate Center)
- Atmospheric deposition
  - Extended data files for stations used in original model application
- Point source inputs
  - Durham WRF
  - Septic systems, sand filters, and SSOs – 2013 inventory

# Flow and Water Quality Sampling Stations

Flow Stations




Water Quality Sampling Stations

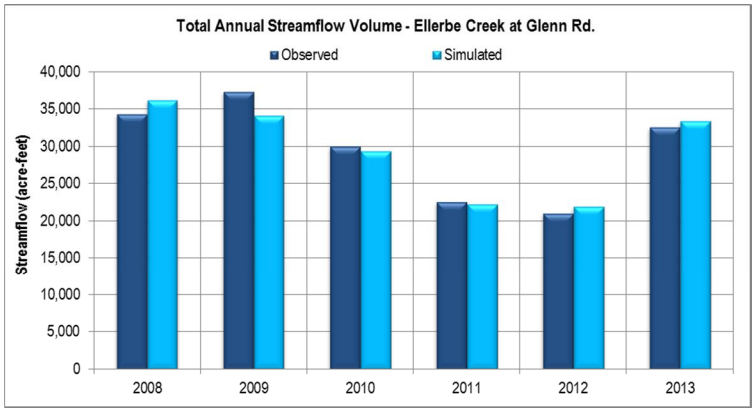


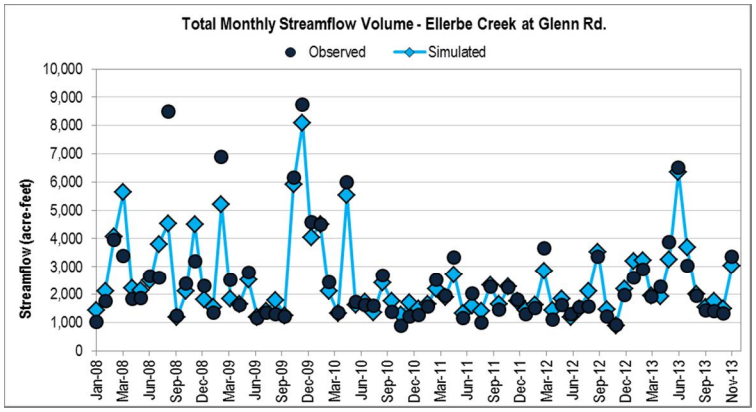

- Observed flow stations on Little Lick Creek developed from drainage area relationship (DAR)
- Observed water quality
  - 8 stations in Ellerbe Creek
  - 2 stations in Little Lick Creek

# Hydrology Calibration: Parameters

- Primary parameters adjusted
  - Evaporation magnitude and skewness
  - Fraction impervious and detention storage
  - Soil horizontal and vertical conductivities
  - Soil porosity and field capacity
  - Initial soil moisture content
- Consistent with key parameters adjusted during calibration (*Herr and Chen 2012*)
- Visual Comparisons
  - Daily time series and scatter plots
  - Monthly time series plots and annual bar charts
- Statistical Comparisons
  - Calibration targets based on Donigian 2000, Moriasi et al. 2007, Parajuli et al. 2009

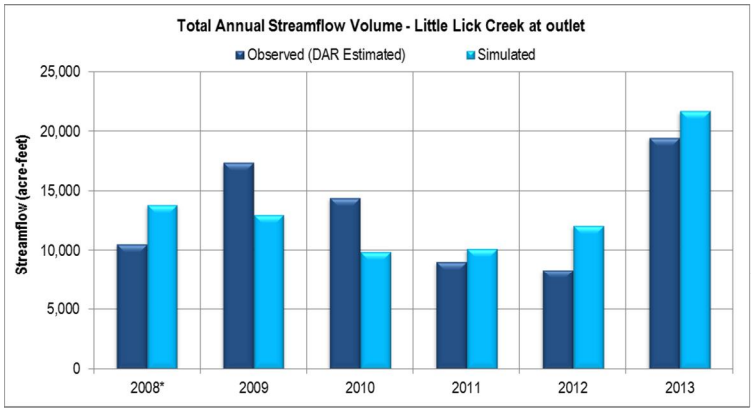
# Hydrology Calibration: Ellerbe Creek

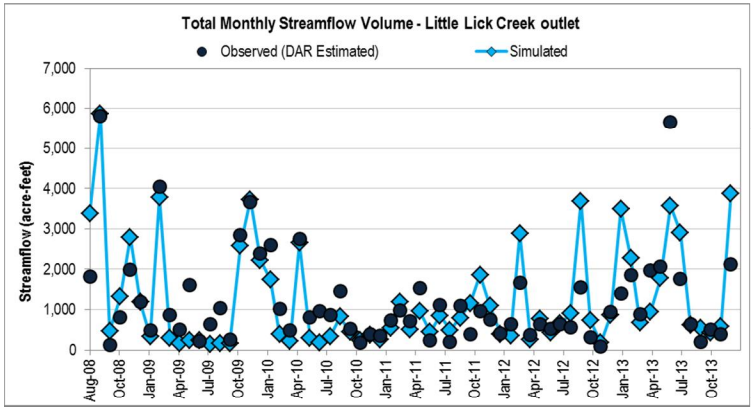



| | Statistic | Ellerbe Creek at Glenn Rd. | Ellerbe Creek at Club Blvd. |
|---|---|---|---|
| Annual | *Count* | 6 | 6 |
| | *R-Squared* | 0.93 | 0.88 |
| | *Nash-Sutcliffe Efficiency* | 0.93 | 0.83 |
| | *P-Bias* | 0.25 | -6.15 |
| | *Relative Percent Difference* | -0.01 | 6.10 |
| Monthly | *Count* | 72 | 65 |
| | *R-Squared* | 0.83 | 0.75 |
| | *Nash-Sutcliffe Efficiency* | 0.83 | 0.72 |
| | *P-Bias* | 0.25 | -6.15 |
| | *Relative Percent Difference* | 3.64 | 10.52 |
| Daily | *Count* | 2192 | 1979 |
| | *R-Sq* | 0.63 | 0.65 |
| | *Nash-Sutcliffe Efficiency* | 0.63 | 0.65 |
| | *P-Bias* | 0.25 | -6.15 |
| | *Relative Percent Difference* | 9.43 | 3.24 |

# Hydrology Calibration: Little Lick Creek



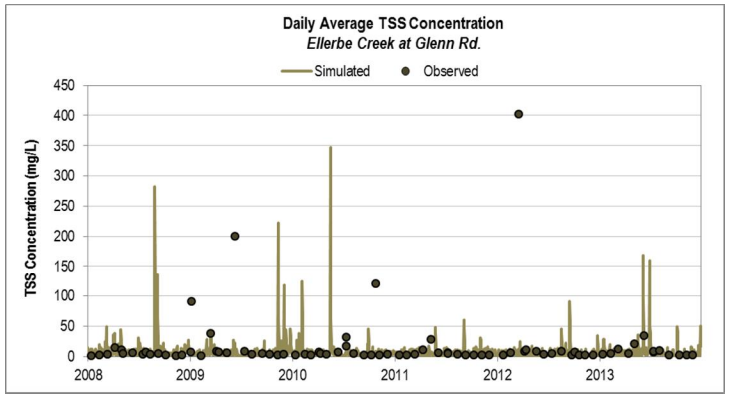




| | Statistic | Little Lick Creek outlet | Little Lick Creek at Stallings Rd. |
|---|---|---|---|
| Annual | *Count* | 6 | 6 |
| | *R-Squared* | 0.42 | 0.43 |
| | *Nash-Sutcliffe Efficiency* | 0.34 | 0.35 |
| | *P-Bias* | -1.82 | -1.33 |
| | *Relative Percent Difference* | 3.29 | 2.82 |
| Monthly | *Count* | 65 | 65 |
| | *R-Squared* | 0.69 | 0.70 |
| | *Nash-Sutcliffe Efficiency* | 0.62 | 0.63 |
| | *P-Bias* | -1.82 | -1.33 |
| | *Relative Percent Difference* | -7.46 | -11.03 |
| Daily | *Count* | 1979 | 1979 |
| | *R-Sq* | 0.56 | 0.61 |
| | *Nash-Sutcliffe Efficiency* | 0.56 | 0.61 |
| | *P-Bias* | -1.82 | -1.33 |
| | *Relative Percent Difference* | 27.31 | -24.40 |

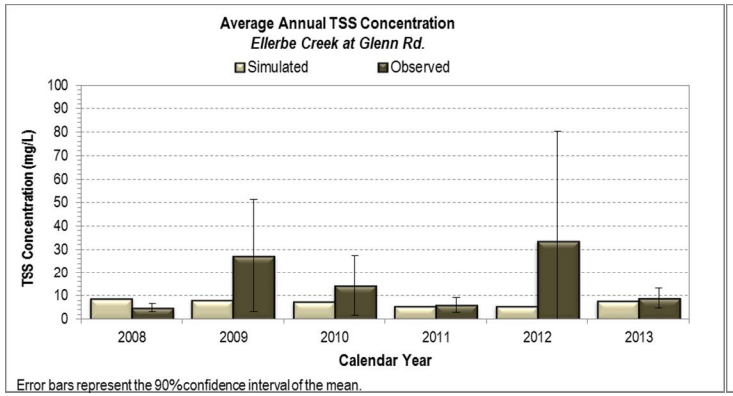
# Water Quality Calibration

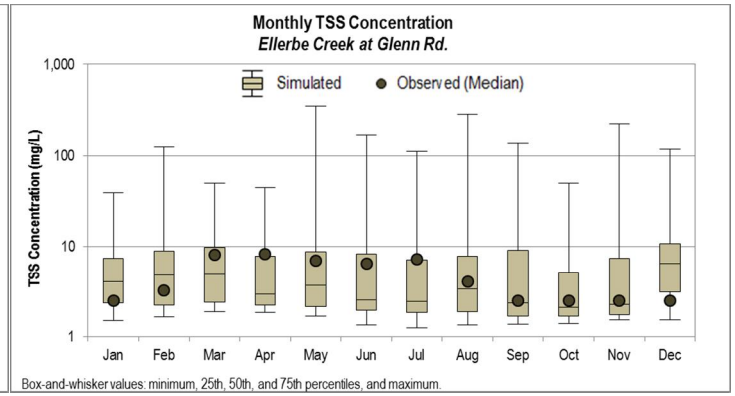
- Split developed land cover into separate pervious and impervious categories
  - Applied higher application rates to pervious and lower to impervious
  - Resolved issues with unrealistic nutrient spikes in upper, highly impervious catchments
- Primary parameters adjusted
  - Sediment detachment velocity coefficients and initial bed sediment depth
  - Nutrient application rates on developed land uses
  - Initial soil concentrations
  - Soil adsorption coefficients
- Constituents calibrated: TSS, TN ($NO_3$, $NH_3$, TKN), TP
- Visual Comparisons
  - Daily time series
  - Monthly box-and-whisker plots
  - Annual bar charts
- Statistical Comparisons
  - Calibration targets based on Donigian 2000

# Water Quality Calibration: Ellerbe Creek - TSS

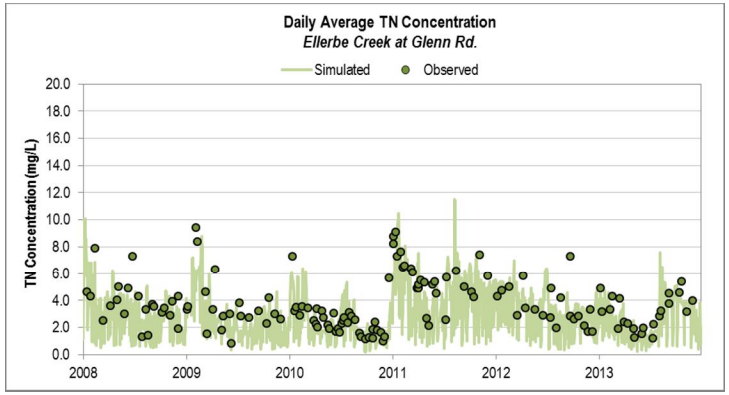



| Station | Count | Avg. TSS, mg/L (data) | Avg. TSS, mg/L (model-paired) | Avg. TSS, mg/L (model-all) | RPD |
|---|---|---|---|---|---|
| EL1.9EC | 83 | 16.0 | 5.5 | 7.1 | -30% |
| EL10.7EC | 59 | 7.2 | 17.0 | 9.0 | -2% |
| EL5.5GC | 36 | 7.7 | 7.2 | 9.4 | -20% |
| EL5.6EC | 60 | 12.4 | 9.3 | 10.2 | 8% |
| EL7.1SEC | 48 | 14.8 | 15.1 | 20.6 | 43% |
| EL7.9EC | 76 | 8.0 | 9.5 | 10.1 | 36% |
| EL8.1GC | 64 | 22.8 | 7.4 | 12.7 | -29% |
| EL8.5SEC | 55 | 104.7 | 17.3 | 20.8 | -18% |

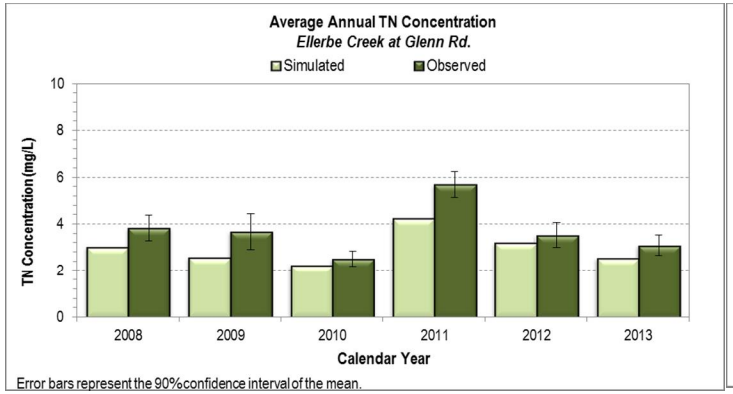


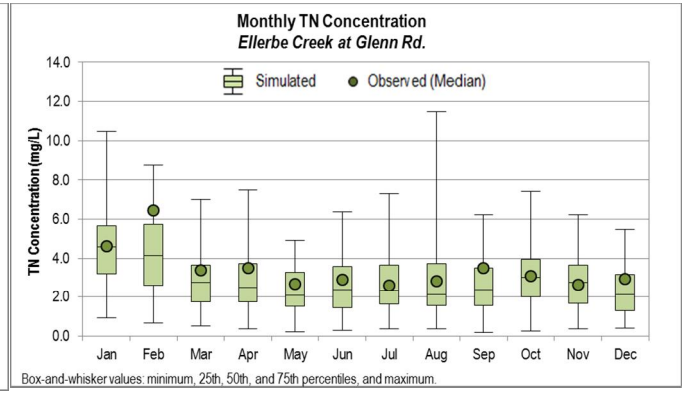



# Water Quality Calibration: Ellerbe Creek - Nitrogen

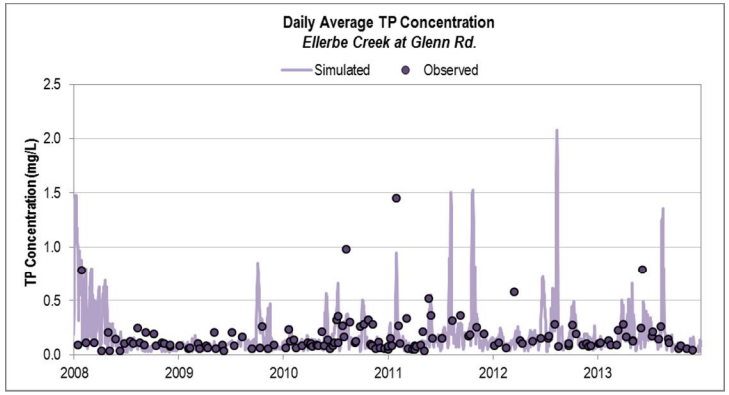



| Station | Count | Avg. TN, mg/L (data) | Avg. TN, mg/L (model-paired) | Avg. TN, mg/L (model-all) | RPD |
|---|---|---|---|---|---|
| EL1.9EC | 148 | 3.66 | 2.87 | 2.95 | -25% |
| EL10.7EC | 59 | 0.70 | 0.95 | 0.83 | 23% |
| EL5.5GC | 36 | 0.77 | 0.80 | 0.79 | -3% |
| EL5.6EC | 60 | 0.82 | 0.87 | 0.74 | 0% |
| EL7.1SEC | 48 | 1.05 | 1.25 | 0.87 | -7% |
| EL7.9EC | 71 | 0.67 | 0.81 | 0.78 | 11% |
| EL8.1GC | 60 | 0.88 | 0.82 | 0.82 | -10% |
| EL8.5SEC | 52 | 1.56 | 0.69 | 0.90 | -56% |

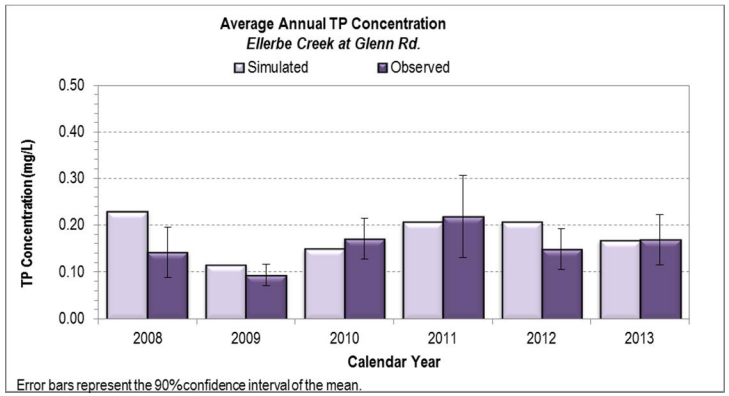


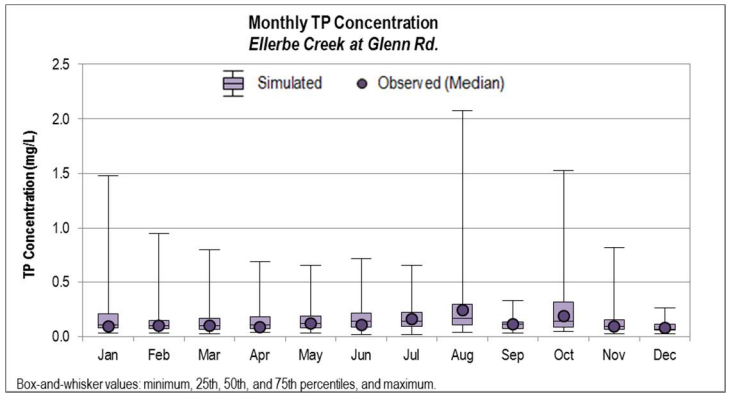



# Water Quality Calibration: Ellerbe Creek - Phosphorus




| Station | Count | Avg. TP, mg/L (data) | Avg. TP, mg/L (model-paired) | Avg. TP, mg/L (model-all) | RPD |
|---|---|---|---|---|---|
| EL1.9EC | 149 | 0.16 | 0.15 | 0.18 | 2% |
| EL10.7EC | 59 | 0.12 | 0.13 | 0.09 | 13% |
| EL5.5GC | 36 | 0.11 | 0.09 | 0.10 | -9% |
| EL5.6EC | 60 | 0.09 | 0.08 | 0.08 | -8% |
| EL7.1SEC | 48 | 0.12 | 0.15 | 0.12 | 14% |
| EL7.9EC | 72 | 0.09 | 0.08 | 0.09 | 0% |
| EL8.1GC | 60 | 0.11 | 0.08 | 0.11 | -30% |
| EL8.5SEC | 51 | 0.31 | 0.09 | 0.12 | -59% |



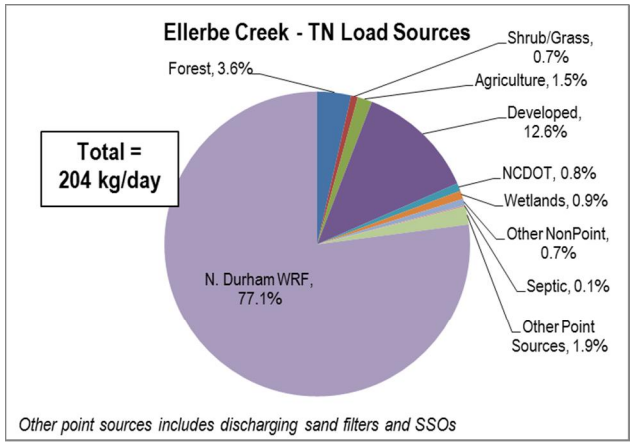



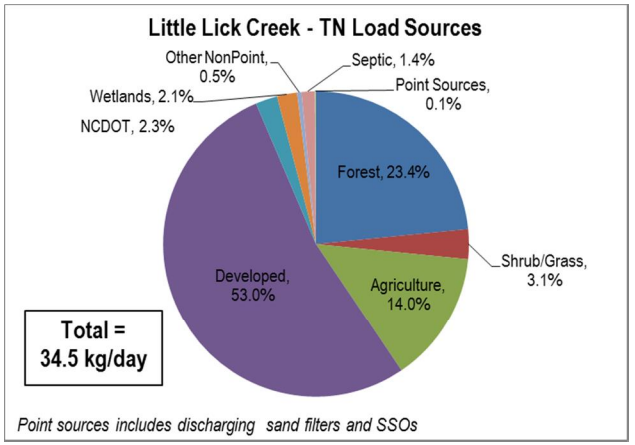
# Summary of WARMF Calibration Update

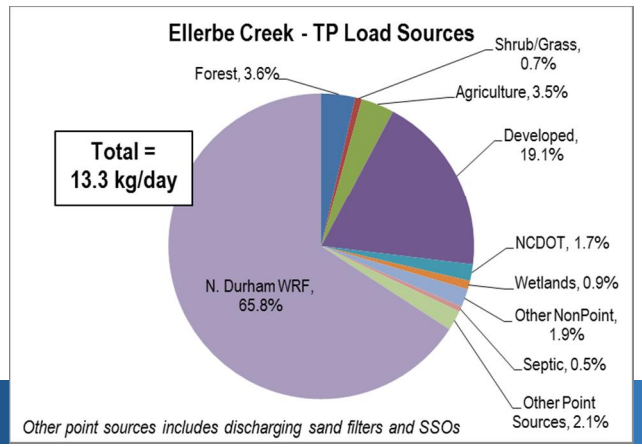
- Re-calibrated Ellerbe Creek
  - Hydrology – "good" to "very good" both stations
  - TSS – "fair" to "very good"
  - Nutrients – "good" to "very good" most stations
- Calibrated Little Lick Creek
  - Hydrology – "fair" to "good" both stations
  - Water Quality – "good" to "very good" for both stations, all constituents

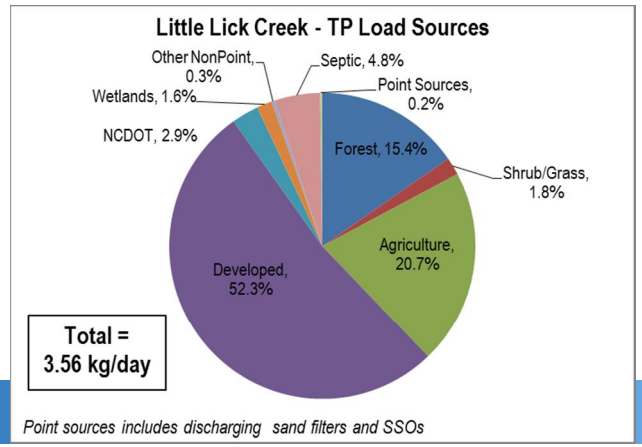
# Loading Summary from Updated WARMF

*10/1/2007-12/31/2013 simulation period*



# Findings Related to Septic Systems

- Simulations of WARMF V6.3 and V6.5 revealed differences in loading output attributed to septic systems
  - Systech verified mass balance code related to septic systems between versions is consistent
  - Source tracking code in V6.3 had errors, over-estimated the load attributed to septic systems
  - V6.5 correctly accounts for septic system loading
- Loads attributed to septic systems reported in 2009 NCDENR report are higher than actually computed by the model
  - Could be misleading if used for basis of management decisions

| Watershed | TN Load from Septic Systems | TP Load from Septic Systems |
|---|---|---|
| Ellerbe Creek | 4% | 17% |
| Eno River | 28% | 12% |

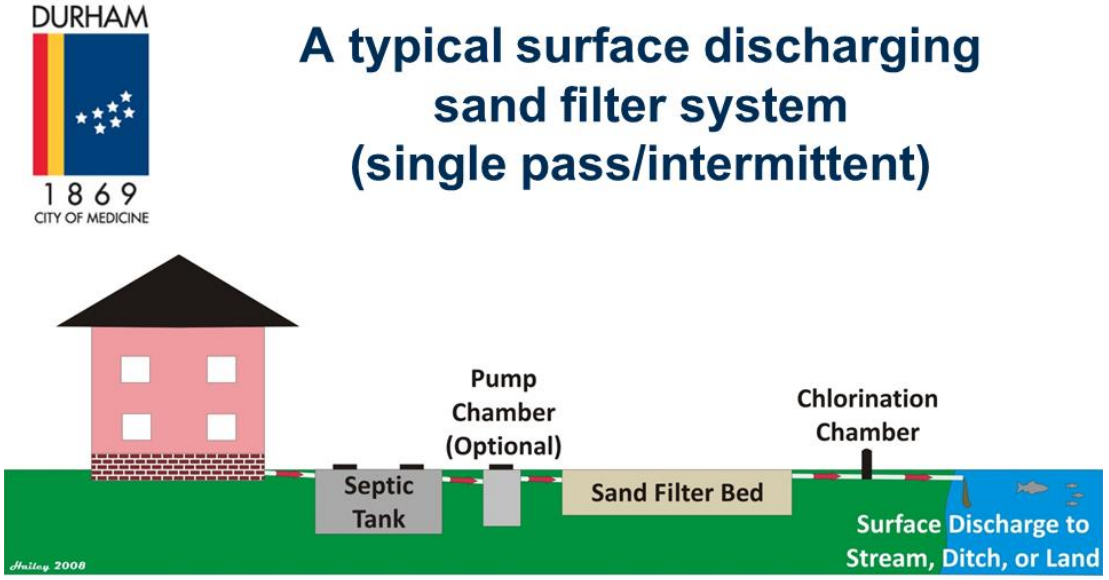
*Source: NCDENR, 2009*

# Findings Related to Septic Systems (continued)

- WARMF septic loading output is correct, but only reflects loading introduced during the simulation period
  - WARMF does not attribute a portion of legacy nutrients in soil to be from septics
- Does not simulate "short-circuiting" loads from failing septic systems to streams
- Septic system loads of TN and TP account for ~10% of the total inflow loads to catchments in Little Lick Creek and majority of load is attenuated
  - ~98% attenuation of TN, ~95% attenuation of TP
  - Septic system is ~1.4% of total TN load to lake and ~4.8% of total TP load to lake
- WARMF suggests that removal of functioning septic systems is not a priority strategy for reducing loads from the Little Lick Creek watershed to Falls Lake

# Findings Related to Sand Filters

- Onsite wastewater treatment systems that pass septic tank effluent through a sand filter bed for additional attenuation of solids and nutrients
- Effluent may discharge to surrounding in situ soil or directly to a ditch, creek, or stream



# Findings Related to Sand Filters

- Representation in WARMF
  - Used City of Durham GIS data to determine number sand filters per catchment
  - WARMF implementation consistent with NCDENR model (2009)
    - 50% functioning - subsurface discharge, lumped with septic in top soil layer
    - 50% poorly functioning - point source discharge to catchments (intended to be to the land surface)
- LimnoTech verified with Systech that WARMF applies catchment point sources to top soil layer as a subsurface discharge, not to land surface
  - Currently, all sand filter loads are essentially applied as a subsurface discharge (similar to septic systems)
  - Load attenuation is similar to septic systems: ~98% for N and ~95% for P
  - Under represents load from poorly functioning systems

# Findings Related to Sand Filters (continued)

- Potential to adjust the WARMF model inputs for poorly functioning sand filters to better reflect observed conditions
  - Apply a portion as point sources direct to surface water
- Would be necessary to determine appropriate assumption for % of sand filters discharging directly to surface water
  - In 2008, 50% assumption was based on little information
  - Recent efforts to target and address failing systems, actual failing likely much lower
- City of Durham recommended keep current configuration in WARMF but consider revisiting during model changes for the Eno River

# Summary of WARMF Model Improvements

- Extended database and model through 2013
- Re-calibrated Ellerbe Creek
- Calibrated Little Lick Creek
- Currently in use to support Little Lick Creek Watershed Improvement Plan

# Modeling Watershed Improvements with WARMF in Little Lick Creek

Examining stormwater control measures (SCMs), ordinance for land redevelopment, septic system removal, stream restoration

1. Baseline existing conditions for land use / land cover and SCMs
2. Future land cover
3. Future land cover with increased stormwater control: simulate in SWMM, then translated to WARMF
   - ï Additional Stormwater Performance Standards for newly developed land
   - ï Additional stormwater control measures with selected SCM retrofits
4. Stream restoration projects implemented
5. Other actions: onsite wastewater system modifications, land conservation
6. Combination scenarios

# Consideration for Future Use of Broader Falls Lake WARMF Model

- Several model inputs tailored for Durham region during calibration update
  - Global parameters for evaporation, canopy cover processes
  - Tailored developed land cover categories to separate pervious and impervious fractions
- Several inconsistencies or apparently erroneous inputs discovered in the original model
  - N. Durham WRF dissolved oxygen input time series, non-zero nitrate adsorption, inconsistent land application rates for select catchments
- LimnoTech recommends a more thorough review and evaluation of model inputs in areas outside of Ellerbe Creek and Little Lick Creek to improve the representation of real-world processes and enhance the model's predictive capabilities
- Potential need for recalibration effort in other watersheds

# Extras

# Hydrology Calibration: Targets

- Visual Comparisons
  - Daily time series and scatter plots
  - Monthly time series plots and annual bar charts
- Statistical Comparisons
- Complete results documented in technical report

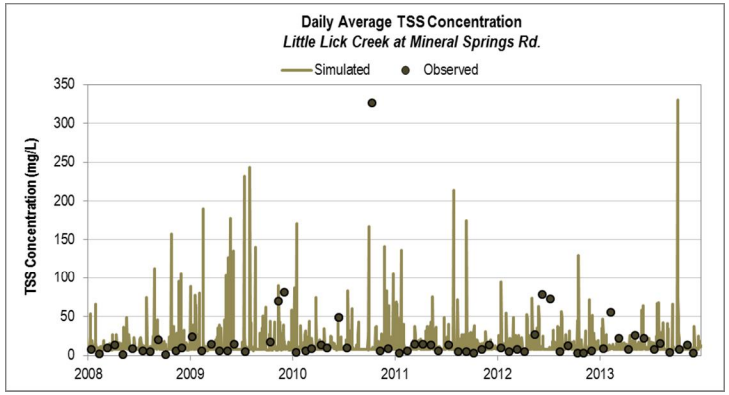
| Performance Rating | $R^2$ - Monthly Flows (Donigian 2000) | NSE for Streamflow (Parajuli et al. 2009) | PBIAS for Streamflow (Moriasi et al. 2007) | Percent Difference Between Simulated and Recorded Values (Donigian 2000) |
|---|---|---|---|---|
| Excellent | | > 0.90 | | |
| Very good | > 0.85 | 0.75 – 0.89 | PBIAS < ±10 | <10 |
| Good | 0.75-0.85 | 0.50 – 0.74 | ±10 < PBIAS < ±15 | 10-15 |
| Fair/Satisfactory | 0.65-0.75 | 0.25 – 0.49 | ±15 < PBIAS < ±25 | 15-25 |
| Poor | 0.55-0.65 | 0.00 – 0.24 | | |
| Unsatisfactory | < 0.55 | < 0.00 | PBIAS > ±25 | |

# Water Quality Calibration: Targets

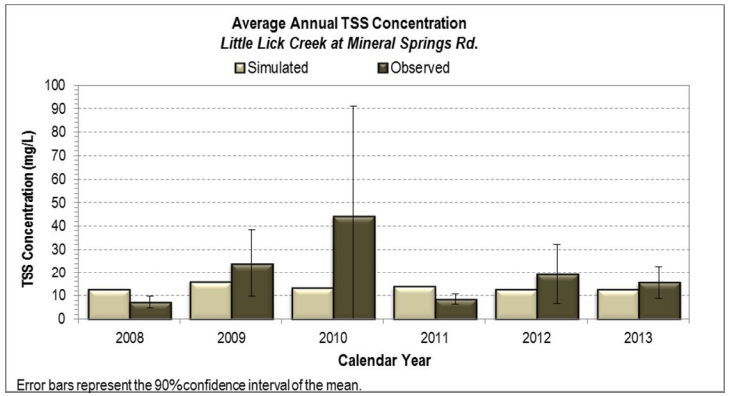
- Visual Comparisons
  - Daily time series
  - Monthly box-and-whisker plots
  - Annual bar charts
- Statistical Comparisons
- Complete results documented in technical report

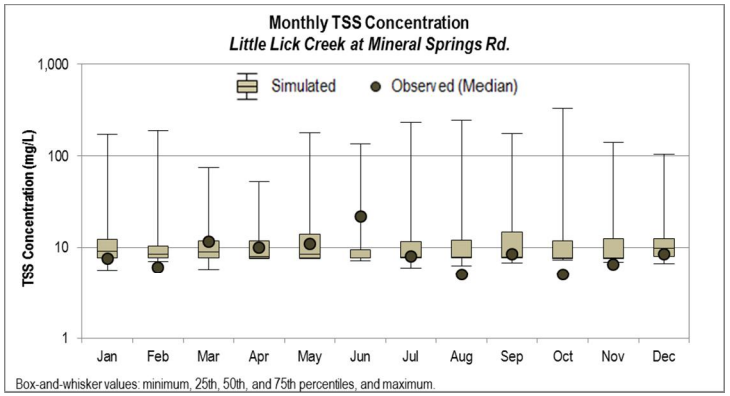
| Parameter | Percent Difference Between Simulated and Recorded Values (Donigian 2000) | | |
|---|---|---|---|
| | Very Good | Good | Fair |
| Hydrology / Flow | < 10 | 10 - 15 | 15 – 25 |
| Sediment | < 20 | 20 - 30 | 30 - 45 |
| Water Temperature | < 7 | 8 - 12 | 13 - 18 |
| Water Quality / Nutrients | < 15 | 15 - 25 | 25 - 35 |

# Water Quality Calibration: Little Lick Creek - TSS

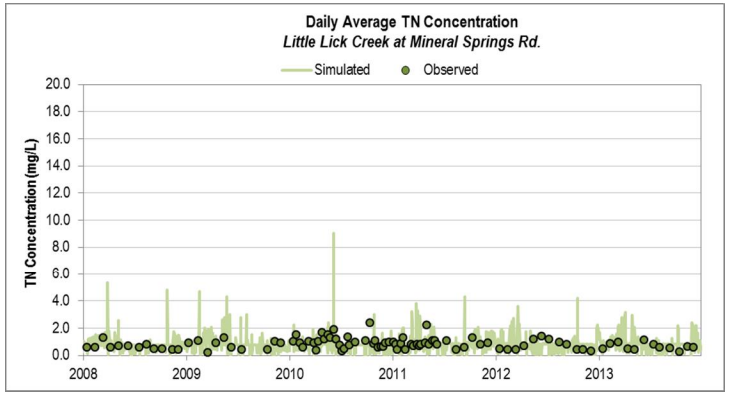



| Station | Count | Avg. TSS, mg/L (data) | Avg. TSS, mg/L (model-paired) | Avg. TSS, mg/L (model-all) | RPD |
|---|---|---|---|---|---|
| LL3.4LLC | 69 | 19.4 | 11.2 | 13.6 | 5% |
| LL4.6LLT2 | 45 | 12.3 | 9.2 | 12.2 | 15% |

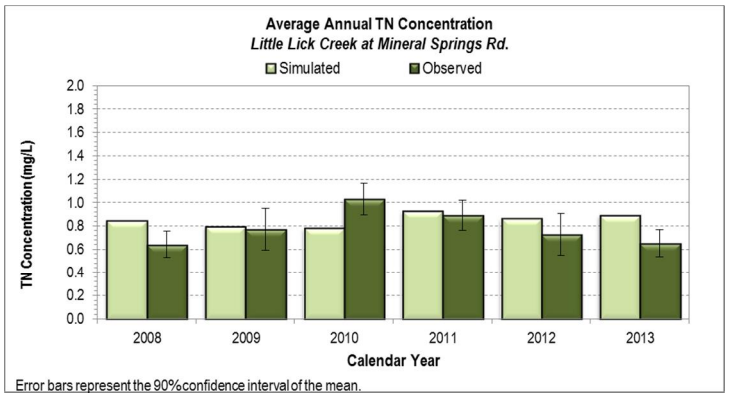


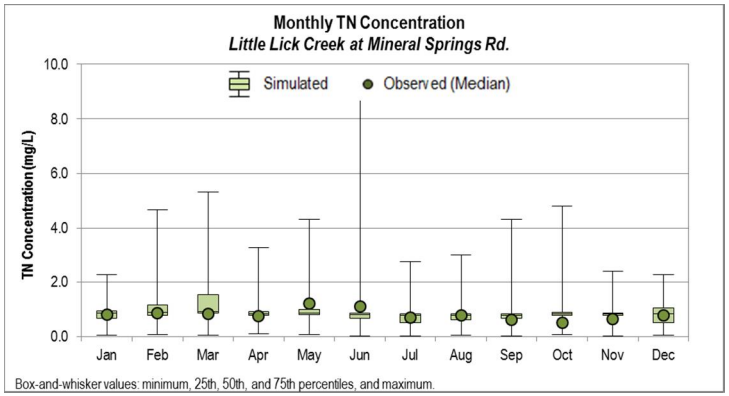



# Water Quality Calibration: Little Lick Creek - Nitrogen

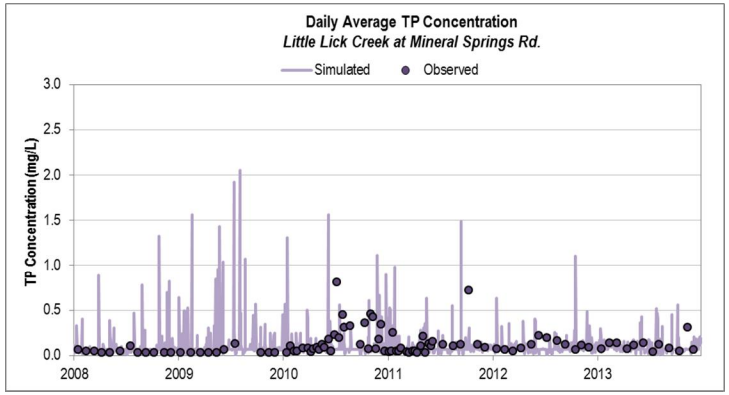



| Station | Count | Avg. TN, mg/L (data) | Avg. TN, mg/L (model-paired) | Avg. TN, mg/L (model-all) | RPD |
|---|---|---|---|---|---|
| LL3.4LLC | 99 | 0.84 | 0.78 | 0.85 | -11% |
| LL4.6LLT2 | 41 | 0.73 | 0.70 | 0.82 | 0% |



# Water Quality Calibration: Little Lick Creek - Phosphorus




| Station | Count | Avg. TP, mg/L (data) | Avg. TP, mg/L (model-paired) | Avg. TP, mg/L (model-all) | RPD |
|---|---|---|---|---|---|
| LL3.4LLC | 99 | 0.12 | 0.08 | 0.10 | -11% |
| LL4.6LLT2 | 41 | 0.06 | 0.06 | 0.09 | 10% |