Memorandum

Date: December 15, 2014

To: Forrest Westall, UNRBA

From: Alix Matos, Cardno ENTRIX and Neely Law, Center for Watershed Protection, Inc.

RE: UNRBA Nutrient Credits Project, Task 1.1, Watershed Trapping Analysis

1 Introduction

A supporting activity identified under Task 1.1 in the Nutrient Credits Project Scope of Work includes the development of trapping factors associated with major impoundments and streams in order to estimate the amount of nutrient loading that reaches Falls Lake from various points in the watershed. Nutrients are affected by various physical, chemical, and biological processes in streams, rivers, and impoundments that effectively reduce nutrient concentrations such that a pound of nutrient released far upstream in the watershed may be significantly reduced by the time it reaches the lake. While both nitrogen and phosphorus are taken up and cycled by plants or algae, “permanent” losses for these nutrients are likely due to sedimentation, storage in large, woody plant material or on floodplains, and denitrification. The methods outlined in this memorandum are based on regional models developed by USGS, which are calibrated to flow and nutrient concentrations observed in waterbodies. Thus, the data that these methods are based on represents the net effects of these processes as they move through streams and impoundments.

As outlined in the scope of work, this trapping analysis will rely on pre-developed empirical methods to estimate trapping that occurs in the streams, rivers, and impoundments in the Falls Lake Watershed. In July 2014, Cardno and the Center submitted a technical memorandum describing the data and methods that would be used to estimate trapping factors in the watershed. More recent publications by USGS indicate that the SPARROW model for the Southeast has been revised with more refined hydrography and an accounting of the impacts of riparian wetlands on in stream concentrations. We have modified our approach to incorporate these revisions.

The City of Durham is in the process of refining the WARMF modeling for the subwatersheds that include their jurisdictional area. Once this modeling is completed, we will compare those results to the SPARROW-based estimates. The City of Durham and the other jurisdictions located in subwatersheds that are covered by the City of Durham’s revised modeling will decide at that time which trapping factors to adopt.

The following steps were conducted for this analysis:

- Delineated subwatersheds
- Estimated nutrient losses in streams
    - Estimated average annual flow in each subwatershed
    - Calculated stream residence time in days
    - Estimated average ratio of width of adjacent wetlands
    - Applied SPARROW coefficients to estimate losses in streams
- Estimated trapping factors for impoundments
    - Calculated hydraulic load
    - Applied SPARROW coefficients to estimate trapping in impoundments

During the PFC meeting on August 6th, the PFC members, in particular representatives from the City of Durham, expressed interest in using a simplified method that was fair and equitable for all jurisdictions and agreed that the approach proposed in the technical memorandum submitted on July 17th, 2014 met these requirements.

The remainder of this memorandum describes these steps and results for review by the Path Forward Committee. We would like to thank Michelle Moorman, Anne Hoos, and Richard Smith at USGS for their technical input and assistance with the revised SPARROW modeling for the Southeast.

2 Subwatershed Delineations

To estimate loss rates and trapping factors for the Falls Lake Watershed, the first step is to delineate the subwatersheds that will be assigned unique trapping factors. The base layer for this analysis is the 12-digit hydrologic unit code (HUC) developed by the US Geologic Survey. Slight modifications to this coverage were made to isolate areas upstream of major impoundments and separate individual tributaries to the lake. Figure 2-1 shows the subwatershed delineations for this analysis. Table 2-1 provides a summary of the watershed characteristics used for the analysis. The datasets and assumptions used to derive these characteristics are based on the following:

> The drainage areas and longest flow path of perennial stream in each basin which is based on the USGS National Hydrography Dataset (NHD) 1:24,000 data.

> Drainage areas contributing directly to an arm of Falls Lake are assumed to have a delivery factor of 1.0 and are shaded orange in Figure 2-1.

> Mean annual velocities based on values reported in the USGS NHDPlus dataset. While the spatial resolution of this dataset is less refined than the NHD 1:24,000 data used to estimate stream lengths, for the streams analyzed the differences in length and pattern are minor. Staff at USGS recommended using the NHDPlus coverage to obtain mean annual velocities to estimate residence time in streams to be consistent with the methods applied in the revised SPARROW model (personal communication, Anne Hoos, 9/10/2014).

> The USGS Gap Analysis Program Land Cover data set and the NHDPlus dataset were used to calculate the subwatershed wetland to flow length ratio which is estimated by dividing the area of Southern Piedmont Small Floodplain and Riparian Forest (Figure 2-2) by the total length of flow path in the subwatershed.

> Percent impervious cover, which is used to designate subwatersheds as rural or urban, is based on the 2011 NLCD Impervious Cover dataset.

Table 2-1 Subwatershed Drainage Areas and Perennial Stream Length

Subwatershed	Drainage Area (mi^2)	Percent Impervious	Longest Flow Path (miles)	Mean Annual Velocity (ft/s)	Travel Time Over ½ Longest Flow Path (d)	Subwatershed Wetland to Flow Length Ratio (ft)
BDC	14.00	0.6%	7.15	0.80	0.27	211
ELC	23.60	20.6%	10.56	0.87	0.37	150
ENR1	37.29	7.3%	17.52	1.26	0.42	56
ENR2	52.10	3.1%	14.79	1.11	0.41	52
ENR3	16.32	1.2%	6.59	1.01	0.20	66
ENR3b	18.54	2.7%	7.39	0.88	0.26	62
ENR4	7.90	0.3%	2.11	0.95	0.07	76
ENR5a	9.36	0.9%	4.97	0.83	0.18	73
ENR5b	8.86	1.0%	4.47	0.79	0.17	46
FLR1	33.31	0.7%	9.13	1.28	0.22	61
FLR2a	56.52	0.8%	18.39	0.93	0.61	57
FLR2b	40.26	3.1%	17.21	0.92	0.57	63
FLR2c	36.93	0.5%	16.59	0.93	0.55	85
HCC	5.04	5.3%	3.36	0.82	0.13	38
HSE	14.49	3.4%	8.20	0.88	0.29	75
KRC1	15.92	5.6%	4.97	1.09	0.14	190
KRC2	28.13	0.2%	5.97	0.84	0.22	54
LAU	3.47	1.1%	2.86	0.80	0.11	39
LBC	9.28	5.7%	3.67	0.83	0.13	80
LGE1	8.05	5.6%	3.23	0.88	0.11	177
LGE2	17.39	2.2%	6.84	0.83	0.25	128
LKC	13.25	3.2%	6.03	0.80	0.23	180
LLC	15.01	10.2%	7.15	0.79	0.28	101
LTR1	7.94	3.4%	6.09	1.07	0.17	574
LTR2	24.69	1.2%	4.16	1.21	0.11	33
LTR3a	32.98	0.6%	20.01	0.92	0.66	94
LTR3b	39.02	0.5%	18.14	0.96	0.58	82
NLC	17.04	1.1%	5.72	0.88	0.20	81
ROB	14.84	2.2%	6.96	0.82	0.26	127
SMC	10.93	0.6%	7.64	0.88	0.27	204
UBC	6.56	3.1%	4.66	0.94	0.15	178
UNT1	2.12	6.9%	1.93	0.81	0.07	39

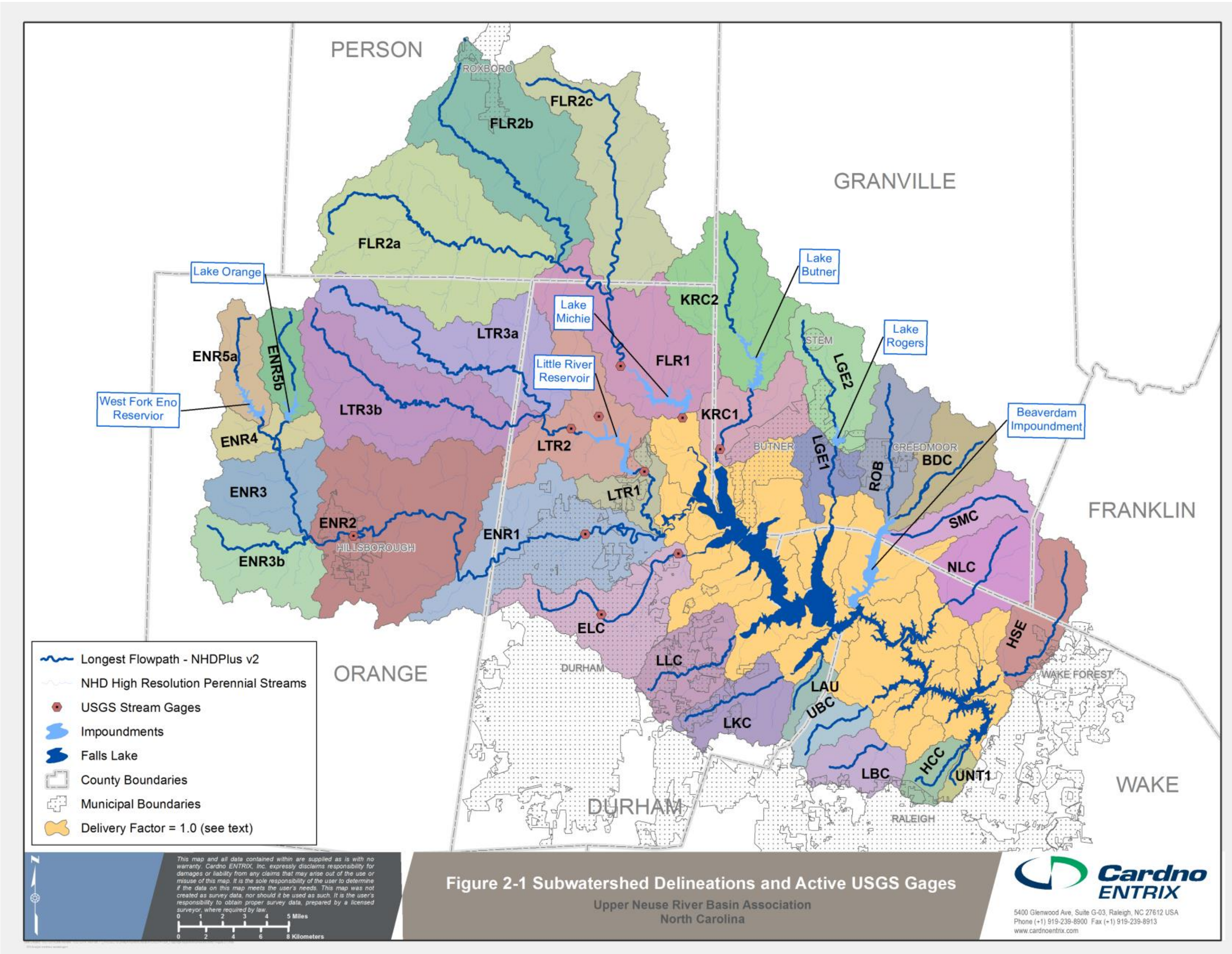
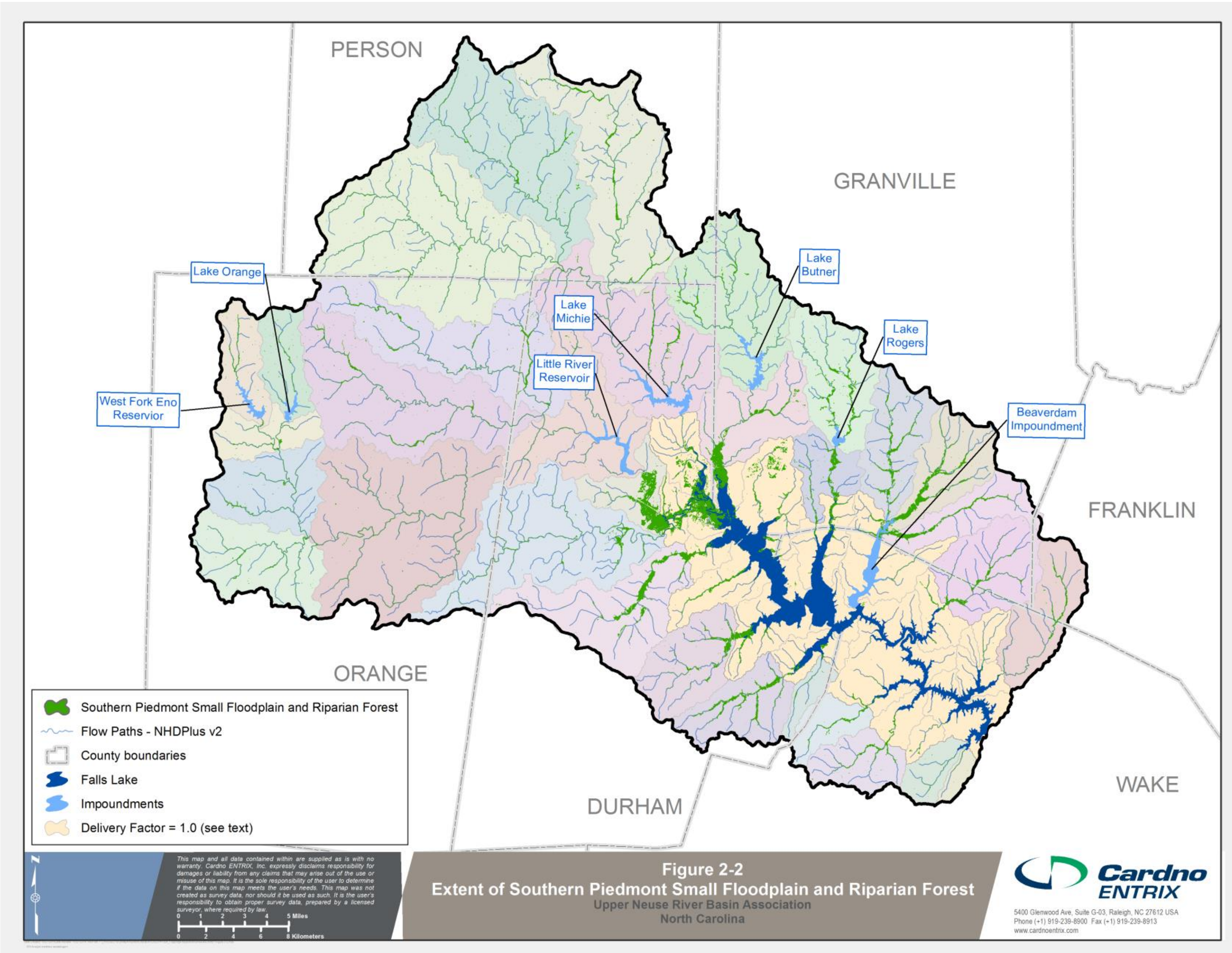


Figure 2-1 Subwatershed Delineations and Active USGS Gages


PERSON
GRANVILLE
FRANKLIN
ORANGE
DURHAM
WAKE
Lake Orange
West Fork Eno Reservior
Lake Michie
Little River Reservoir
Lake Butner
Lake Rogers
Beaverdam Impoundment
Southern Piedmont Small Floodplain and Riparian Forest
Flow Paths - NHDPlus v2
County boundaries
Falls Lake
Impoundments
Delivery Factor = 1.0 (see text)
This map and all data contained within are supplied as is with no warranty. Cardno ENTRIX, Inc. expressly disclaims responsibility for damages or liability from any claims that may arise out of the use or misuse of this map. It is the sole responsibility of the user to determine if the data on this map meets the user's needs. This map was not created as survey data, nor should it be used as such. It is the user's responsibility to obtain proper survey data, prepared by a licensed surveyor, where required by law.
0 1 2 3 4 5 Miles
0 2 4 6 8 Kilometers
Figure 2-2
Extent of Southern Piedmont Small Floodplain and Riparian Forest
Upper Neuse River Basin Association
North Carolina
Cardno ENTRIX
5400 Glenwood Ave, Suite G-03, Raleigh, NC 27612 USA
Phone (+1) 919-239-8900 Fax (+1) 919-239-8913
www.cardnoentrix.com

3 Estimation of Nutrient Loss in Streams

In 2013 and 2014, the USGS revised and reported on an updated SPARROW model for the Southeast. This revised model uses a more refined hydrologic dataset (1:100,000) than the previous model published in 2002 (1:500,000), includes more impoundments (23,748 compared to 173), and also accounts for losses that occur in the channel due to adjacent wetlands and riparian forests. This revised SPARROW model estimates loss rates for streams in the Southeast as a function of stream flow, travel time, and ratio of riparian wetland to total flow length (Hoos et al. 2013 and Moorman et al. 2014). This section describes the data, assumptions, and methods for calculating nutrient loss in streams in the Falls Lake Watershed using the revised SPARROW modeling approach.

3.1 Trapping Coefficients to Estimate Nutrient Loss

The revised SPARROW model estimates losses in streams as a first order loss. The terms in the equation for in-channel processes and out-of-bank processes are represented by regionally specific coefficients, travel time in the stream, and the subwatershed wetland area to flow length ratio:

Fraction of Load Lost = 1 – exp(-$C_{in\text{-}channel}$*travel time-$C_{out\text{-}of\text{-}bank}$* wetland area to flow length ratio/3.208*travel time)

> Where $C_{in\text{-}channel}$ is the loss coefficient for in-channel processes, travel time is in days, $C_{out\text{-}of\text{-}bank}$ is the out-of-bank loss coefficient, and the wetland area to flow length ratio is in feet.
>
> For nitrogen, $C_{in\text{-}channel}$ and $C_{out\text{-}of\text{-}bank}$ are 0.27 and 0.0011, respectively. In the revised SPARROW model, the in-channel nitrogen losses are only significant when the mean annual flow rate is less than 1.98 m^3/s (approximately 70 ft^3/s) and the influence of denitrification is more significant. Subwatersheds ENR1 and FLR1 have mean annual flowrates greater than 1.98 m^3/s, so $C_{in\text{-}channel}$ for nitrogen was set to zero for these watersheds.
>
> For phosphorus, $C_{out\text{-}of\text{-}bank}$ is 0.0012 and $C_{in\text{-}channel}$ is essentially zero: in the revised SPARROW model, there was no net loss of phosphorus associated with in-channel processes likely because settling and transport of phosphorus bound to sediments tends to balance out on an annual basis at the regional scale (personal communication, Anne Hoos, 9/10/2014).

3.2 Calculate Stream Travel Time (Residence Time)

Stream residence time represents the amount of time a molecule of water would travel in a given stream segment. Similar to flow, only water entering the system at the upper end of the stream would travel the entire length of perennial channel. To represent the average travel distance for the subwatershed in which a molecule of water originates (the subwatershed of origination), we divide the longest perennial stream length based on the NHD 1:24,000 dataset by two. The travel time is calculated by dividing one-half the longest flow path by the mean annual velocity for the reach reported in the NHDPlus dataset.

> Travel Time = 1 / [86400 * (Length / 2 * 5280) / Mean Annual Velocity],
>
> Where travel time is expressed in days, mean annual velocity is ft/s, the longest perennial stream length is in miles, 86400 converts seconds to days, 2 converts the full flow path to one-half the flow path, and 5280 converts miles to feet.

Because of the connectedness of some of the subwatersheds, two calculations were performed for each subwatershed that receives flow from an upstream subwatershed. The first calculation is for the watershed of origination as described above which assumes that water originating in a particular subwatershed travels, on average, half of the longest flow path length. The second calculation is for receiving subwatersheds where the flow path of water is always the full flow path length. All calculations for these average conditions are based on the longest 1st order stream for a given subwatershed, and trapping in 2nd or 3rd order streams is not included in this assessment. Because trapping in higher order streams is not accounted for in these calculations, the estimate is less than what actually might occur depending on where in the subwatershed the water originates.

3.3 Estimation of Annual Flows

Nutrient trapping factors will be calculated for the subwatersheds in the Falls Lake basin, some of which are gaged, but most of which are not.

3.3.1 Flows from Unregulated Watersheds

Cardno ENTRIX has previously investigated several techniques for estimating flow in ungaged watersheds and has presented the results in a Technical Memo (Cardno ENTRIX 2014) to the UNRBA. Of the methods explored in that memo, basin proration is the most straightforward method and performs as well as the other, more complex, flow estimation methods. The mean annual flow for unregulated portions of each watershed (not affected by impoundments) can be estimated by scaling the average, area-normalized unregulated flow for the Falls Lake watershed.

For this analysis, the watershed drainage area can be multiplied by the area-normalized flow calculated for the Falls Lake watershed. To calculate a regional average flow that is somewhat robust against particularly wet or dry years, the average was calculated using data from the previous 10 years, specifically January 1, 2004 through December 31, 2013. Because USGS flow gages may be missing data due to equipment error, termination of the gage, or other factors, we limited the gages included in this analysis to only those gages in the Falls Lake basin with data for at least 85% of the 10 year period. Because we are interested primarily in unregulated flow at ungaged locations, we also excluded gages directly downstream from reservoirs or wastewater treatment plant outfalls. Six gages in the Falls Lake basin met these criteria (Table 3-1); for each of these gages, the average daily flow was calculated from the USGS data and drainage area obtained from USGS records. Area-normalized flow was calculated simply as the mean daily flow (in cubic feet per second, cfs) divided by the drainage area (in square miles, mi^2). The average area-normalized flow for unregulated sites within the Falls Lake catchment is 0.60 cfs/mi^2 (± 0.043 Standard Deviation (SD)) for the 10 year period between the years 2004 and 2013. Even if the two Eno River gages are excluded from the analysis (this watershed is partially regulated in the headwaters) the ratio is still 0.60 cfs/mi^2.

Table 3-1 Unregulated USGS Gages in the Falls Lake Watershed for Rural Subwatersheds

USGS Gage No.	Description	Mean Daily Flow (cfs)	Drainage Area (mi2)	Area-normalized flow (cfs/mi2)
02085000	Eno River at Hillsborough, NC	36.2	66.0	0.548
02085070	Eno River near Durham, NC	87.7	141	0.622
0208521324	Little River at SR1461 near Orange Factory, NC	50.4	78.2	0.645
0208524090	Mountain Creek at SR1617 near Bahama, NC	4.60	7.97	0.578
02085500	Flat River at Bahama,NC	95.0	149	0.638
0208650112	Flat River tributary near Willardville, NC	0.629	1.14	0.551
Mean				0.597
SD (Standard Deviation)				0.043
CV (Coefficient of variation)				7.3%

Land use and land cover at the gaged sites are not largely different from the rest of the Falls Lake basin, except for the Ellerbe Creek watershed which is mostly urban. The average unregulated flow on Ellerbe (at Club Boulevard, Durham, NC) is 1.13 cfs/mi^2 over the previous 5 years (USGS Gage 0208675010, installed July 24, 2008). Flow in the Ellerbe watershed, therefore, was not included in the estimate of area-normalized, mean annual flow for the other subwatersheds in the basin. This estimate of flow will be used for Ellerbe Creek, which is the only subwatershed with greater than 20 percent imperviousness.

The USGS gages in the Falls Lake basin are also concentrated in the upper watershed in areas of mostly Carolina Slate Belt geology. The lower watershed is in the Triassic Basin and Raleigh Belt geologic formations and there is some evidence suggesting flow in these areas may be different from those seen in the upper watershed (Boggs et al. 2013). However, there are no gages installed in this region, and the evidence for a significant difference is mixed. According to Boggs et al. (2013), the difference in discharge to precipitation ratios was not significantly different between Triassic Basin and Carolina Slate Belt regions over the entire monitoring period (November 2007 to June 2010), but when specific time periods were examined, there were some periods with different discharge to precipitation ratios between the two regions. However, the direction of the difference was not always the same. Until gages are installed on tributaries in this area, the gages in the upper watershed provide the best available estimates of flow for this region.

3.3.2 Withdrawals from and Discharges to River Segments

Flows from major point sources in the watershed also contribute flows that will affect mean annual flow and residence time in the streams. Discharge data and withdrawal data from year 2012 were used to approximate impacts to flows from these facilities.

Annual average discharge data for the Town of Hillsborough and the City of Durham were provided by the UNRBA for year 2012 (Table 3-2). Because the wastewater discharge from SGWASA occurs near the outlet of Knap of Reeds Creek, these flows do not affect flows or transport times in the majority of the creek, so they were not included in the trapping analysis.

In addition, three entities withdraw water from the Eno River according to the Eno River Management data available through DWR (http://www.ncwater.org/Permits_and_Registration/Capacity_Use/Eno_River_Management/). Withdrawals are indicated by negative values in Table 3-2. In 2012, the Town of Hillsborough withdrew an average of 1.7 cfs from the Eno River (ENR2). The Orange-Alamance Water System withdrew 0.13 cfs. Piedmont Minerals also withdraws water from the Eno on a limited basis: in 2012, the average daily withdrawal rate was 0.0002 cfs. Withdrawals from impoundments are discussed in Section 4.1.

Table 3-2 Withdrawals and Discharges Affecting Streams in the Watershed

NPDES Permit Number	Facility Name	Mean Actual Discharge or Withdrawals (cfs)	Subwatershed
NC0023841	North Durham WRF	12.5	Ellerbe Creek (ELC)
NC0026433	Hillsborough WWTP	1.3	Eno River (ENR2)
No permitted discharge	Hillsborough WTP	-1.7	Eno River (ENR2)
No permitted discharge	Orange-Alamance	-0.13	Eno River (ENR3)
No permitted discharge	Piedmont Minerals	-0.0002	Eno River (ENR2)

Note: Because the wastewater discharge from SGWASA occurs near the outlet of Knap of Reeds Creek, these flows do not affect flows or transport times in the majority of the creek, so they were not included in the analysis.

3.4 Calculate Trapping in Streams

The mass of nutrients trapped in each stream reach was calculated for two conditions: 1) assuming the water originates in the subwatershed or 2) assuming the water originates in an upstream subwatershed, where applicable. Table 3-3 presents the percentage of nutrients trapped in each stream reach if the water travels over one-half of the flow length or over the full flow length.

Table 3-3 Percentage of Nutrients Trapped in Stream Reaches by Individual Subwatershed

Subwatershed	Nitrogen Trapped Over ½ Flow Length	Nitrogen Trapped Over Total Flow Length	Phosphorus Trapped Over ½ Flow Length	Phosphorus Trapped Over Total Flow Length
BDC	8.9%	None upstream	2.1%	None upstream
ELC	11.2%	None upstream	2.1%	None upstream
ENR1	0.8%	1.6%	0.9%	1.8%
ENR2	11.1%	21.0%	0.8%	1.6%
ENR3	5.6%	11.0%	0.5%	1.0%
ENR3b	7.2%	13.9%	0.6%	1.2%
ENR4	2.0%	4.0%	0.2%	0.4%
ENR5a	5.3%	None upstream	0.5%	None upstream
ENR5b	4.8%	None upstream	0.3%	None upstream
FLR1	0.5%	0.9%	0.5%	1.0%
FLR2a	16.1%	None upstream	1.3%	None upstream
FLR2b	15.3%	None upstream	1.3%	None upstream
FLR2c	15.1%	None upstream	1.7%	None upstream
HCC	3.5%	None upstream	0.2%	None upstream
HSE	8.1%	None upstream	0.8%	None upstream
KRC1	4.6%	8.9%	1.0%	2.0%
KRC2	6.1%	None upstream	0.4%	None upstream
LAU	3.0%	None upstream	0.2%	None upstream
LBC	3.9%	None upstream	0.4%	None upstream
LGE1	3.6%	7.2%	0.7%	1.5%
LGE2	7.6%	None upstream	1.2%	None upstream
LKC	7.3%	None upstream	1.5%	None upstream
LLC	8.0%	None upstream	1.0%	None upstream
LTR1	7.8%	15.0%	3.7%	7.2%
LTR2	2.9%	5.8%	0.1%	0.3%
LTR3a	18.1%	None upstream	2.3%	None upstream
LTR3b	15.8%	None upstream	1.8%	None upstream
NLC	5.8%	None upstream	0.6%	None upstream
ROB	7.8%	None upstream	1.2%	None upstream
SMC	8.6%	None upstream	2.0%	None upstream
UBC	4.9%	None upstream	1.0%	None upstream
UNT1	2.0%	None upstream	0.1%	None upstream

4 Estimation of Trapping Factors and Hydrologic Alterations in Impoundments

The USGS SPARROW model estimates trapping factors for impoundments in the Southeast as a function of the hydraulic load for each impoundment (Hoos et al. 2013 and Moorman et al. 2014). In addition, impoundments may affect the hydrology of downstream waters. This section describes the data, assumptions, and methods for calculating nutrient trapping losses in impoundments and accounting for hydrologic changes.

4.1 Estimation of Flows Downstream of Impoundments

For each of the subwatersheds of origination, flows are estimated using the method described in Section 3.3 for unregulated drainages. At the downstream end of several of the subwatersheds are impoundments that alter the hydrology of the impounded segment as well as reaches downstream. On an average annual basis, however, mean annual flow is likely not significantly impacted by these impoundments other than through evaporative losses, direct precipitation, and mean annual water withdrawals. To estimate regulated flows downstream of impoundments, the following approach is used:

1) Estimate mean annual flow using gaged flows if an active gage is located immediately downstream of the impoundment. These gaged flows would already account for the net effects of precipitation, evaporation, and water supply withdrawals. Mean annual flows downstream of Lake Michie and Little River Reservoir are 96.5 cfs (USGS gage 02086500) and 40.2 cfs (USGS gage 0208524975), respectively. If a gage is not located immediately downstream, the analysis established the mean annual, area-normalized flow rate for the watershed draining to the impoundment as described in Section 3.3.1.

2) For those impoundments where the mean annual, area-normalized flow rate was used rather than gaged flows, we accounted for the net effects of direct precipitation and evaporative losses from each lake surface using pan evaporation data reported for the Raleigh Durham International Airport by NOAA and the Southeast Climate Consortium (54.3 inches; NOAA 1982) and the ratio of lake evaporation to pan evaporation reported by USGS for Lake Michie (0.72; Yonts et al. 1973). This resulted in an evaporative loss of 39.1 inches per year. Direct precipitation to the lake surfaces is estimated to be 42.3 inches based on data provided by the USACE (mean annual precipitation for 1999 to 2011).

3) For Lake Butner where the mean annual, area-normalized flow rate was used rather than gaged flows, we accounted for mean annual withdrawals for water supply using withdrawal values as provided to the UNRBA for use with its membership dues formula for 2014 which is based on year 2013 water usage (4.6 cfs).

The results of this analysis are presented in Table 4-1. Where USGS flow gages are used, the flow estimates are based on annual averages over a ten year period (January 1, 2004 to December 31, 2013) so extreme hydrologic years are not reflected in the trapping factor analysis.

Table 4-1 Changes in Flow Due to Evaporation, Precipitation, and Withdrawals from the Lake Surface for Impoundments that Do Not Have a USGS Gage Immediately Downstream

Impoundment	Drainage Area (mi^2)	Average Annual Inflow (cfs)	Surface Area (acres)	Average Annual Precipitation (cfs)	Average Annual Evaporation (cfs)	Average Annual Withdrawal (cfs)	Net Outflow (cfs)
Beaverdam Lake	51.0	30.6	863	4.2	3.9	0	30.9
Lake Butner	28.1	16.9	373	1.8	1.7	4.6	12.4
Lake Orange	8.9	5.3	156	0.8	0.7	0	5.4
Lake Rogers	17.4	10.4	141	0.7	0.6	0	10.5
West Fork Eno River Reservoir	9.4	5.6	204	1.0	0.9	0	5.7

Note: USGS gaged flows are used to estimate mean annual flow downstream of Lake Michie and Little River Reservoir.

4.2 Estimation of Hydraulic Load for the Seven Impoundments

Hoos et al. (2013) and Moorman et al. (2014) quantify annual nutrient removal in impoundments based on the mean annual hydraulic load, which is the mean annual outflow divided by the surface area of the impoundment. This parameter has the units of length per time and is correlated to the depth of the water column in the impoundment over which nutrient trapping processes, such as sedimentation, occur. This parameter is calculated as follows:

Hydraulic Load (m/year) = Net Mean Annual Outflow / Surface Area * 86400 * 365 / 3.2808

Where hydraulic load is in meters per year, surface area at normal pool is in ft^2 and mean annual outflow is in ft^3/s as reported in Table 4-1. The conversion factors convert seconds to days, days to years, and feet to meters, respectively.

Table 4-2 lists the hydraulic load for each major impoundment in the watershed.

Table 4-2 Surface Areas and Withdrawals from Major Impoundments in the Falls Lake Watershed

Impoundment	Surface Area (acres)	Net Outflow (cfs)	Hydraulic Load (m/y)
Beaverdam Lake	863	30.9	7.9
Lake Butner	373	12.4	7.3
Lake Michie	541	96.5	39.4
Lake Orange	156	5.4	7.6
Lake Rogers	141	10.5	16.4
Little River Reservoir	529	40.2	16.8
West Fork Eno River Reservoir	204	5.7	6.2

4.3 Calculate Trapping in Impoundments

For impoundments in the Southeast, Hoos et al. (2013) assign a nitrogen loss coefficient of 5.82 m/year and a phosphorus loss coefficient of 29.6 m/year. The equation presented by Moorman et al. (2014) can be used to estimate the fraction of load trapped in impoundments:

Fraction of Load Trapped $= 1 – 1 / (1 + C_{reservoir} / HL)$

Where $C_{reservoir}$ is 5.82 m/year for nitrogen and 29.6 m/yr for phosphorus, and HL is the hydraulic load in m/yr described in Section 4.2.

Losses in each impoundment are summarized in Table 4-3.

Table 4-3 Nutrient Losses in Major Impoundments in the Falls Lake Watershed

Impoundment	Hydraulic Load (m/y)	Percent of Nitrogen Trapped	Percent of Phosphorus Trapped
Beaverdam Lake	7.9	42%	79%
Lake Butner	7.3	44%	80%
Lake Michie	39.4	13%	43%
Lake Orange	7.6	43%	80%
Lake Rogers	16.4	26%	64%
Little River Reservoir	16.8	26%	64%
West Fork Eno River Reservoir	6.2	49%	83%

5 Cumulative Trapping in the Watershed

Loss rates are estimated for each individual subwatershed using the methods described above. To estimate delivery to the lake, the loss rates are first converted to delivery factors:

Percent Delivered = 100 – Percent Trapped

As water moves from one subwatershed to the next, it is subject to additional trapping. The cumulative delivery factor for water moving through Subwatershed_A and then through Subwatershed_B is calculated as

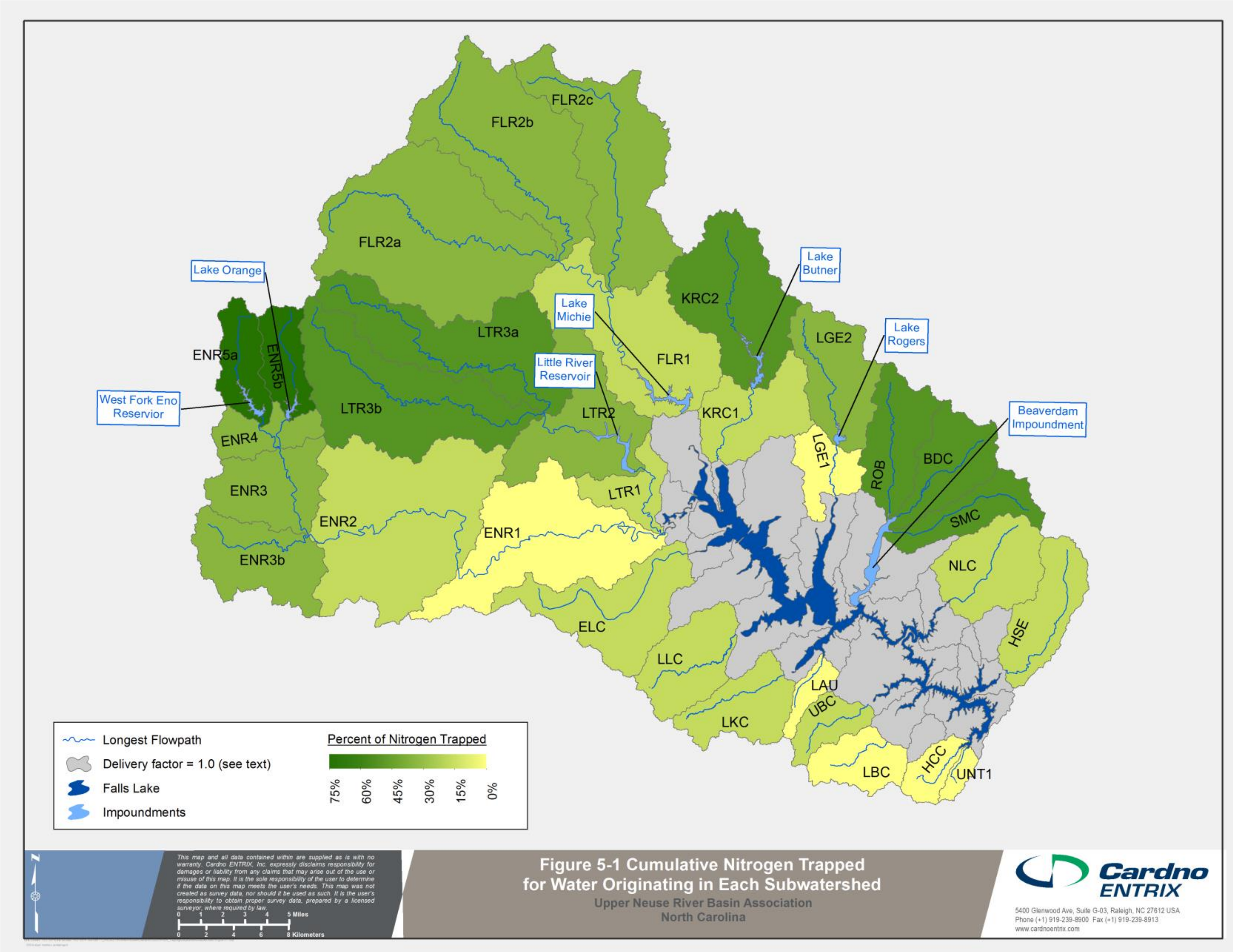
Cumulative Delivery = $(\text{Percent Delivered})_A$ * $(\text{Percent Delivered})_B$

For the purposes of calculating cumulative delivery factors, travel times for downstream reaches were used over the full reach length, rather than the half reach length applied to an individual basin.

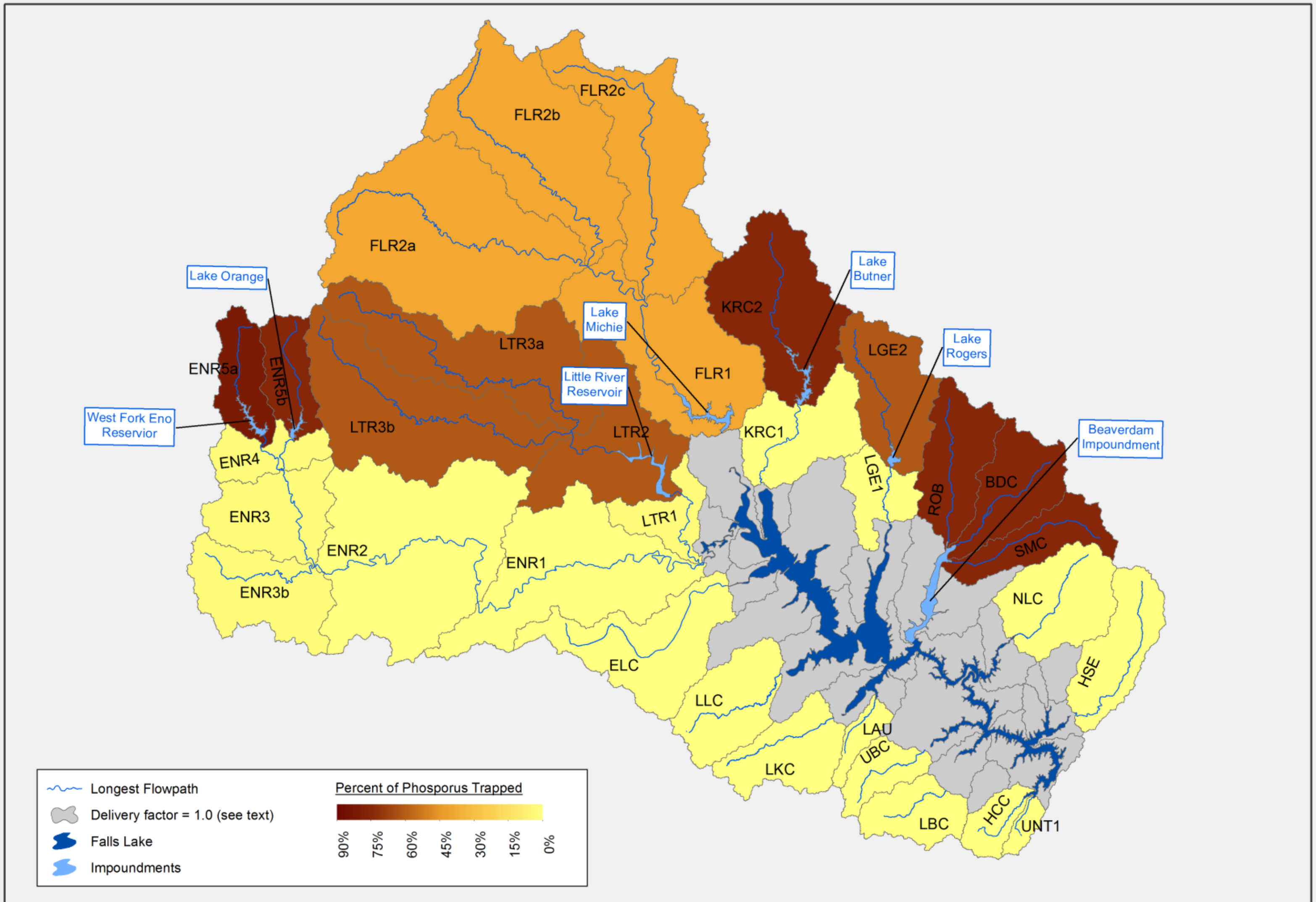
Table 5-1 presents the percentage of mass that is delivered or trapped for water originating in a given subwatershed. These values represent the cumulative effects of downstream waterbodies as well as the trapping that occurs in the subwatershed of origination. Percentages trapped are presented graphically for nitrogen and phosphorus in Figure 5-1 and Figure 5-2, respectively.

Table 5-1 Cumulative Percentage of Nutrients Delivered or Trapped in Stream Reaches and Impoundments For Water Originating in a Given Subwatershed

Subwatershed	Percent Nitrogen Delivered	Percent Nitrogen Trapped	Percent Phosphorus Delivered	Percent Phosphorus Trapped
BDC	52%	48%	21%	79%
ELC	89%	11%	98%	2%
ENR1	99%	1%	99%	1%
ENR2	87%	13%	98%	2%
ENR3	73%	27%	96%	4%
ENR3b	72%	28%	96%	4%
ENR4	68%	32%	96%	4%
ENR5a	32%	68%	16%	84%
ENR5b	36%	64%	19%	81%
FLR1	87%	13%	57%	43%
FLR2a	72%	28%	56%	44%
FLR2b	73%	27%	56%	44%
FLR2c	74%	26%	56%	44%
HCC	97%	3%	100%	0%
HSE	92%	8%	99%	1%
KRC1	95%	5%	99%	1%
KRC2	48%	52%	19%	81%
LAU	97%	3%	100%	0%
LBC	96%	4%	100%	0%
LGE1	96%	4%	99%	1%
LGE2	63%	37%	35%	65%
LKC	93%	7%	98%	2%
LLC	92%	8%	99%	1%
LTR1	92%	8%	96%	4%
LTR2	61%	39%	34%	66%
LTR3a	49%	51%	33%	67%
LTR3b	50%	50%	33%	67%
NLC	94%	6%	99%	1%
ROB	53%	47%	21%	79%
SMC	53%	47%	21%	79%
UBC	95%	5%	99%	1%
UNT1	98%	2%	100%	0%



FLR2c
FLR2b
FLR2a
Lake Orange
ENR5a
ENR5b
West Fork Eno Reservior
LTR3a
LTR3b
Lake Michie
Little River Reservoir
KRC2
Lake Butner
LGE2
Lake Rogers
FLR1
LTR2
KRC1
LGE1
ROB
BDC
Beaverdam Impoundment
ENR4
ENR3
ENR3b
ENR2
ENR1
LTR1
SMC
NLC
HSE
ELC
LLC
LAU
UBC
LKC
LBC
HCC
UNT1
Longest Flowpath
Delivery factor = 1.0 (see text)
Falls Lake
Impoundments
Percent of Nitrogen Trapped
75%
60%
45%
30%
15%
0%
Figure 5-1 Cumulative Nitrogen Trapped
for Water Originating in Each Subwatershed
Upper Neuse River Basin Association
North Carolina
Cardno ENTRIX



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0 1 2 3 4 5 Miles
0 2 4 6 8 Kilometers

Figure 5-2 Cumulative Phosphorus Trapped for Water Originating in Each Subwatershed
Upper Neuse River Basin Association
North Carolina

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