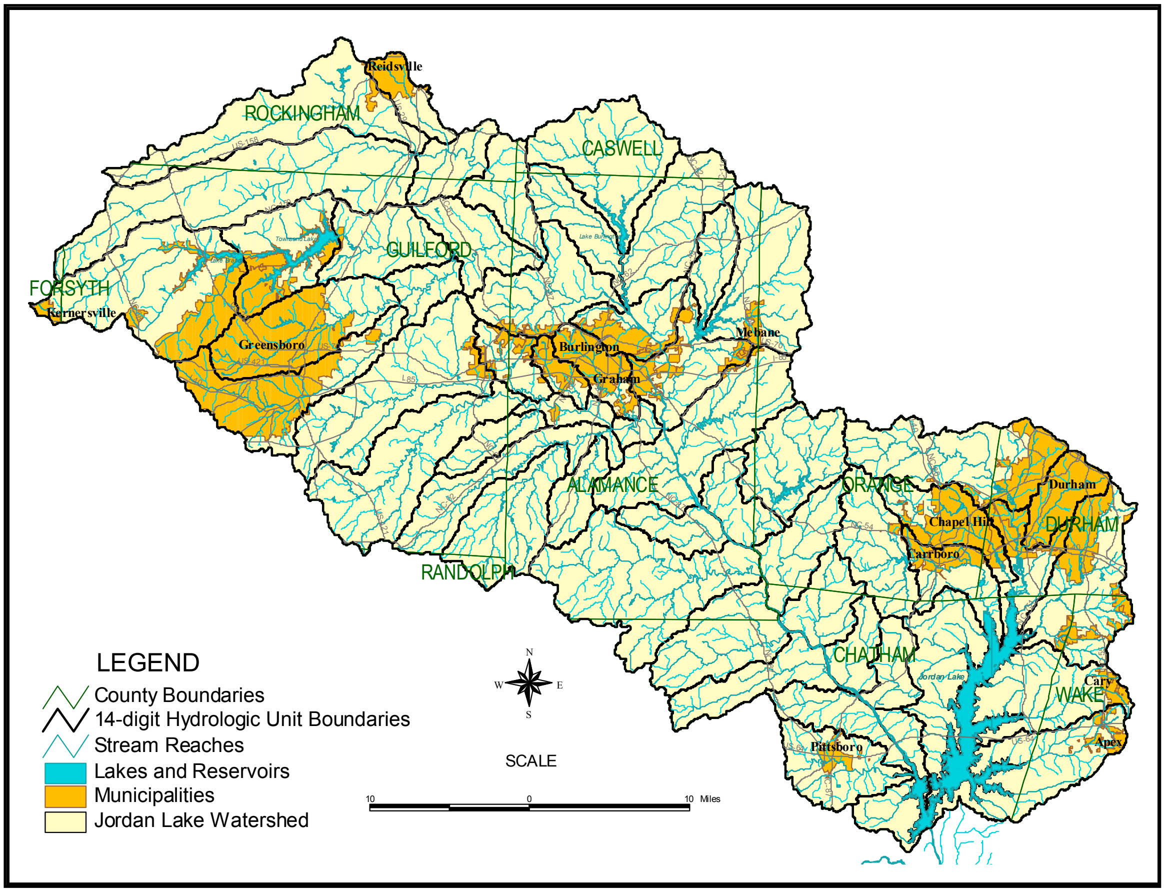
B. Everett Jordan Lake TMDL Watershed Model Development

NC DWQ Contract Number EW030318, Project Number 1-2



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1 Introduction

B. Everett Jordan Lake, within the Cape Fear River basin, has been declared a Nutrient Sensitive Water (NSW) and is subject to potential management of nutrient loads to control eutrophication. The upper New Hope portion of Jordan Lake has been placed on the North Carolina list of impaired waters (the 303(d) list) and now requires estimation of a Total Maximum Daily Load (TMDL) for nutrients in order to meet the water quality criterion for chlorophyll *a*. The complex flow and mixing patterns of the lake result in a situation in which loads to any part of the lake may affect the listed segments, and loading from all tributaries to the lake must be evaluated for NSW management.

Tetra Tech (2002) developed a nutrient response model for Jordan Lake under contract to the Jordan Lake Project Partners. The modeling system consists of linked Environmental Fluid Dynamics Code (EFDC) and Water Analysis Simulation Program (WASP) simulations for 1997-2000 and was presented to the Environmental Management Commission in July 2002. The lake model is driven by observations of flow and nutrient loads in tributaries to the lake, calculated using the FLUX model. This reliance on observations meant that it was not necessary to develop a full watershed model to implement the lake model. However, as part of the analyses performed for that work, RTI (2002) developed a point source nutrient delivery tool to estimate the fractions of discharged point source nutrient loads that are delivered to the lake. This work was based on national parameters for an instream loss model, and not calibrated to site-specific observations. In addition, the existing suite of tools did not explicitly represent the sources of nonpoint nutrient loads within the Jordan Lake watershed. The Jordan Lake nutrient response model provides an ideal platform with which to evaluate the impacts of a range of nutrient reduction scenarios. However, additional watershed nutrient loading analysis tools are needed to provide a foundation for attributing and evaluating nutrient load sources, delivery, and management opportunities within the watershed. North Carolina Division of Water Quality (DWQ) issued a work order to Tetra Tech in April 2003 to develop the necessary enhancements to meet these needs.

The Jordan Lake watershed covers an area of 1686 square miles (excluding the lake itself). It includes parts of 10 counties, and includes some or all of the urban areas of Durham, Chapel Hill, Cary, Burlington, Greensboro, and several other small municipalities (Figure 1).

There are a variety of approaches for developing watershed-based nutrient loading models, ranging from simple export coefficient models to complex hydrodynamic models. For this work assignment, DWQ requested a basis for seasonal and annual loads over a variety of hydrologic conditions (wet and dry years). Use of simple export coefficient models can therefore be eliminated from consideration because they cannot meet DWQ's objectives of evaluating seasonal/annual nonpoint load delivery under varying hydrologic conditions. However, data and resource (time and funding) constraints prevent selection of the more complex process-based watershed simulation models such as SWAT or HSPF for application to the entire watershed. Further, DWQ's request explicitly stated that a watershed model capable of reproducing the daily or sub-daily loading time series needed to drive the lake response model was not required at this time. Tetra Tech therefore proposed use of a simplified watershed model that falls between the simple and complex level and is capable of predicting both annual and seasonal loads for varying hydrology years.

The nonpoint component of the analysis is based in the Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992). The GWLF model provides an appropriate, well-accepted tool for generating seasonal loads at the small watershed scale. However, GWLF is limited in its ability to simulate large watersheds (such as the Haw River drainage) as it does not explicitly represent nutrient transformations and losses during transport through the stream network and upstream impoundments. To meet DWQ's objectives, Tetra Tech developed a spreadsheet-based model that combines GWLF simulation of seasonal loads at the 14-digit HUC scale coupled with a stream transport/delivery model that can estimate both the point and nonpoint source component nutrient delivery to the lake. Such a tool

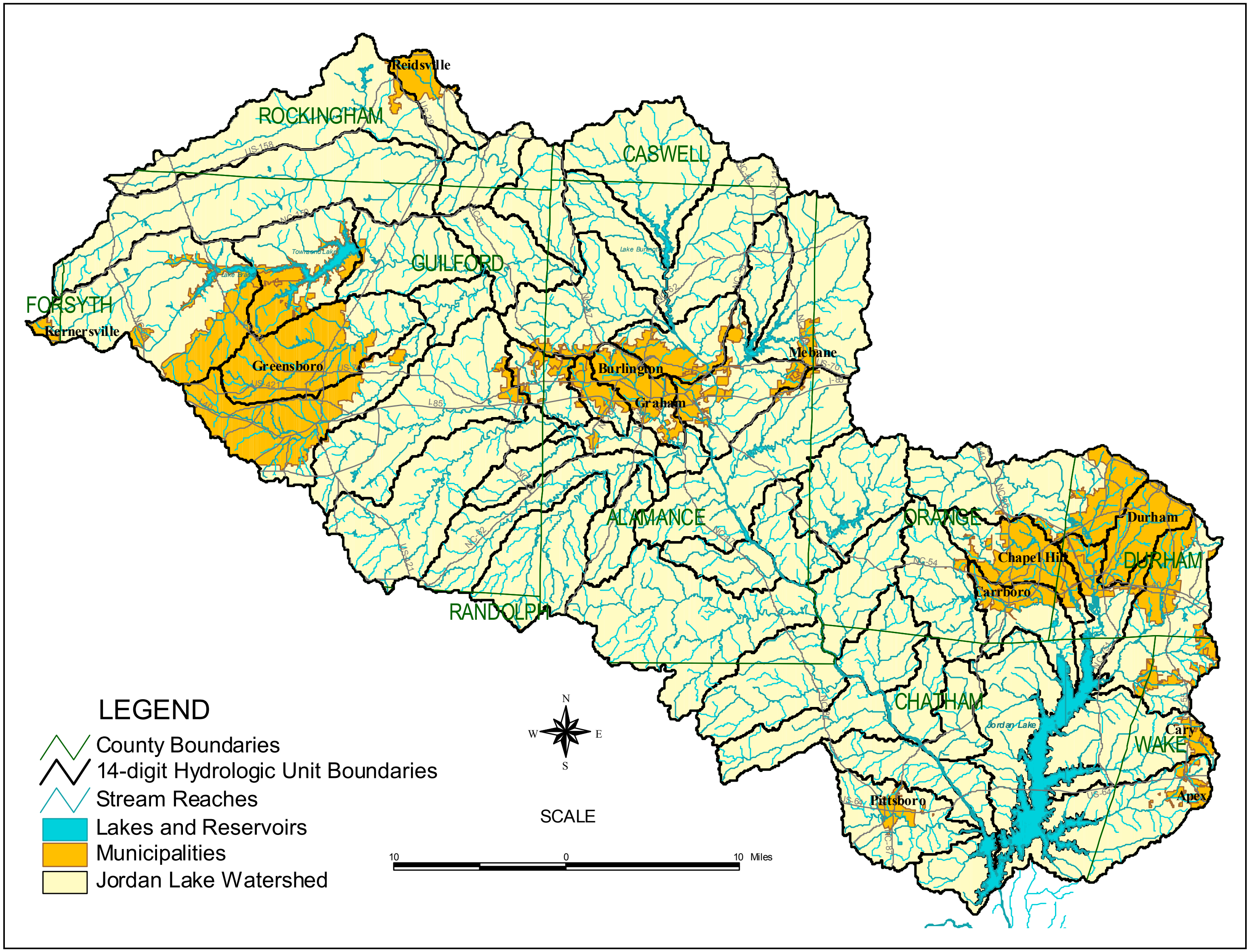

Figure 1. Jordan Lake Watershed

provides a basis to estimate nutrient load allocations by addressing over-land runoff, septic system input, groundwater discharge into streams, and nutrient delivery to Jordan Lake. The spreadsheet model incorporates a nonpoint loading series that ties nutrient load generation to land use and meteorology. The loading series are developed for the major land use, geology and soil areas in the watershed, drawing to a large extent upon existing GWLF calibrations local to the area, including the Cane Creek Reservoir watershed (located within the Jordan Lake watershed) and the adjacent Falls Lake watershed. Quarterly and annual loads are generated based on variations in hydrology using the example GWLF models to calibrate the loading factors for the entire watershed. Point source loads are input to the spreadsheet according to outfall location in the stream network. The stream network and delivery component of the spreadsheet are based on an enhanced and refined version of the RTI Jordan Lake Nutrient Delivery Model (JLNDM).

The combined load generation and delivery models provide a comprehensive analysis of nutrient load delivery to Jordan Lake on a seasonal basis. Performance of the model was calibrated against detailed information on point source discharges and FLUX analyses of delivered loads for 1996-1998, using hydrology derived from the Cape Fear Hydrologic Model (DHI and Moffett and Nichols, 2000). All modeling components have been incorporated into a deliverable spreadsheet, which can be readily modified to evaluate impacts of land use changes, alteration of unit loading rate by Best Management Practices (BMPs), or changes in point source wasteload allocations.

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2 Watershed Land Use Database

The first requirement for a watershed model is an accurate description of land use, land cover, and flow paths within the watershed. This is not a trivial task, as no current database of land use within the watershed is available. This section describes the creation of a watershed land use database for the watershed, combining information from a variety of sources.

2.1 Watershed Boundaries and Hydrologic Response Units

The Jordan Lake watershed encompasses 1,686 square miles and includes parts of Alamance, Caswell, Chatham, Durham, Forsyth, Guilford, Orange, Randolph, Rockingham, and Wake counties, NC. The majority of the watershed (1,293 square miles) drains to the lake via the Haw River. The TMDL segments in the Upper New Hope Arm of the lake have a watershed drainage area of 209 square miles in Chatham, Orange, Durham, and Wake counties.

The U.S Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS) delineated the Jordan Lake watershed into 58 hydrologic units (HUCs), averaging 29 square miles (Figure 2). For analytical and planning purposes, Tetra Tech categorized these units into one of 14 nutrient response zones based on soil erodibility, geographic region, and rainfall-runoff response.

For model development, unit (per-acre) watershed loads are combined with estimates of delivery to the lake. Different unit loads are appropriate for different areas of the watershed, due to differences in precipitation patterns and soil characteristics. Those areas with similar characteristics can be combined for the analysis of unit loads. Such areas of similar characteristics are termed hydrologic response units or HRUs.

Figure 3 shows the primary geologic regions of North Carolina (NC Geologic Survey). The Jordan Lake watershed lies within the Carolina Slate Belt and Triassic Basins. Figure 4 shows the unit runoff zones used to estimate stream flow in the Cape Fear River Basin Model (DHI and Moffett and Nichols, 2000). Each runoff zone has a unique response to rainfall events based on climate, topography, and soil characteristics. Figure 5 displays the soil erodibility (K factor) reported by the NRCS in the STATSGO soils database. An area weighted K factor was then calculated for each of the 58 hydrologic units.

HRUs for the Jordan watershed are based on geologic region, runoff zone, and soil erodibility. The aggregation to 14 HRUs was achieved through a series of ArcView queries that grouped hydrologic units in the same geographic region and unit runoff zone by soil erodibility (Figure 6).

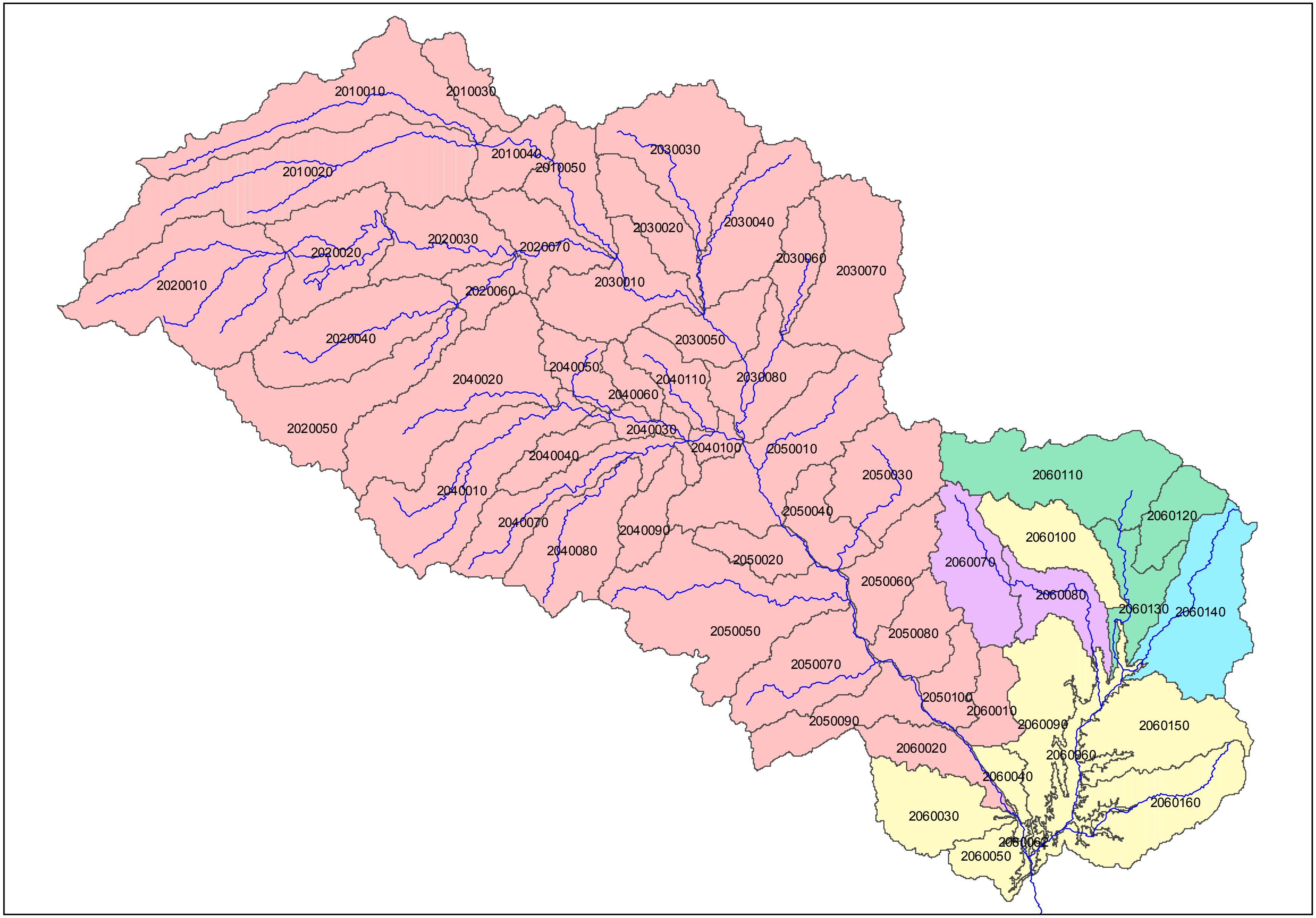

Figure 2. Jordan Lake Watershed 14-Digit HUCs

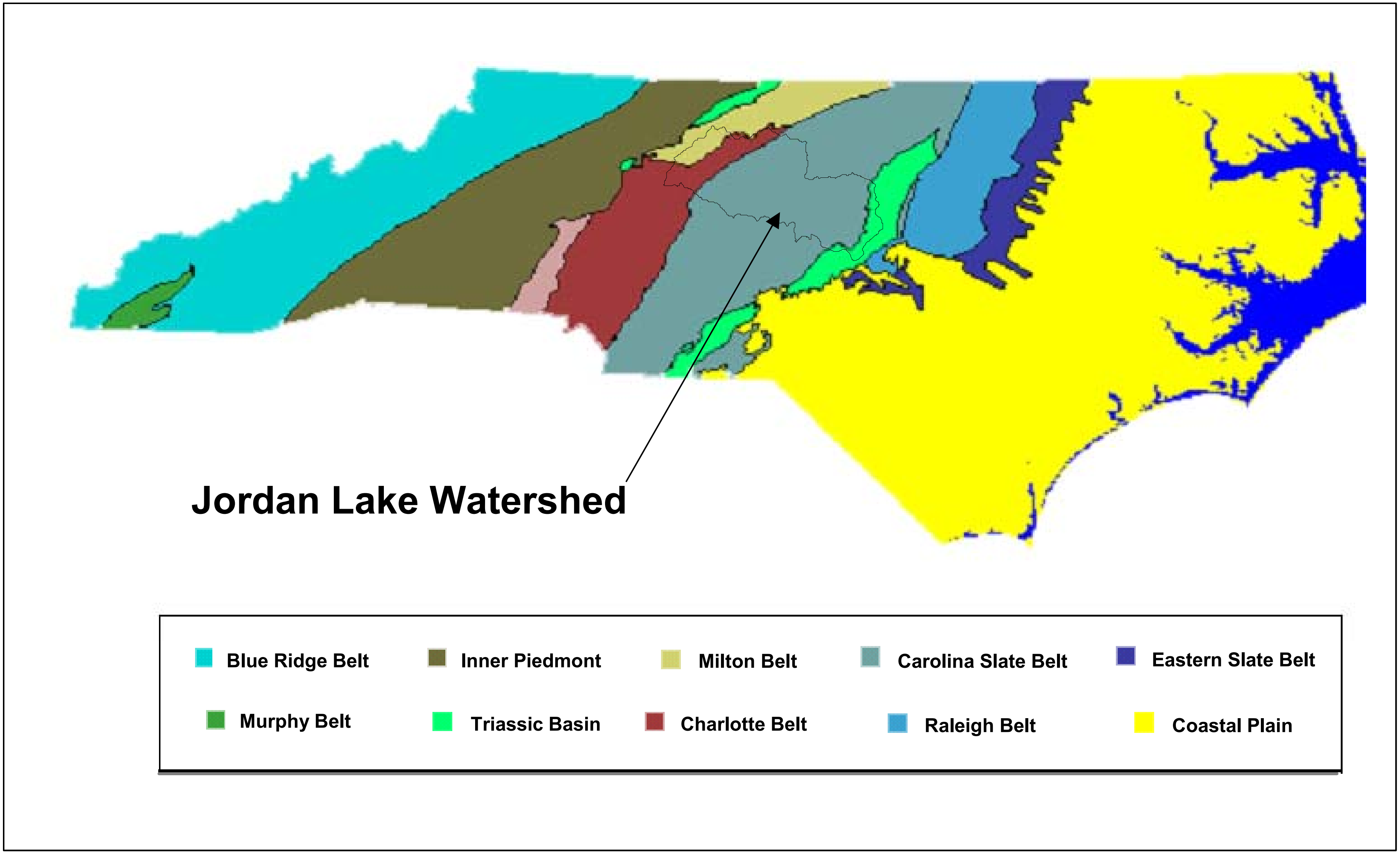

Figure 3. Geologic Regions of North Carolina

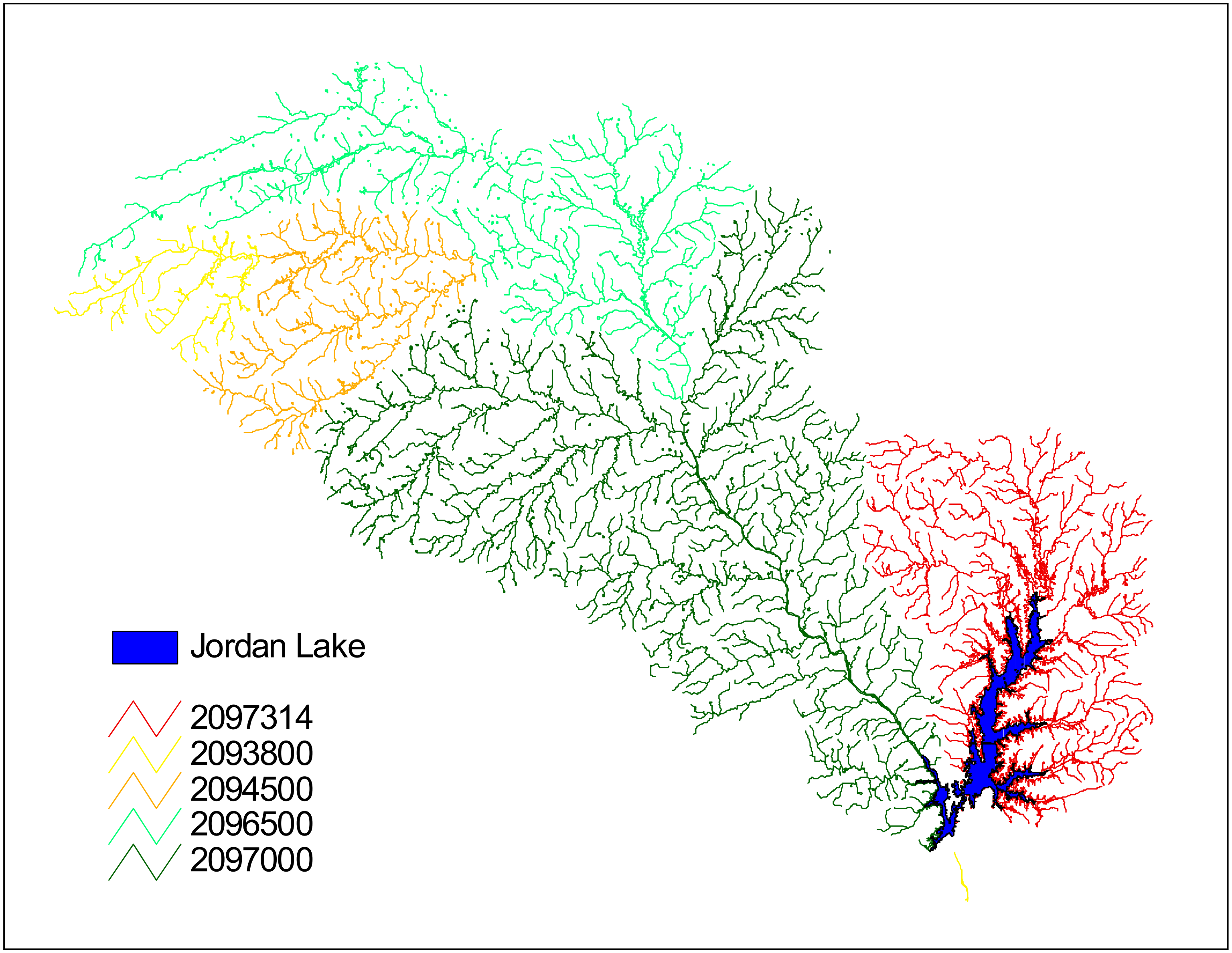

Figure 4. Unit Runoff Response Zones from the Cape Fear River Basin Model (DHI and Moffett and Nichols, 2000)

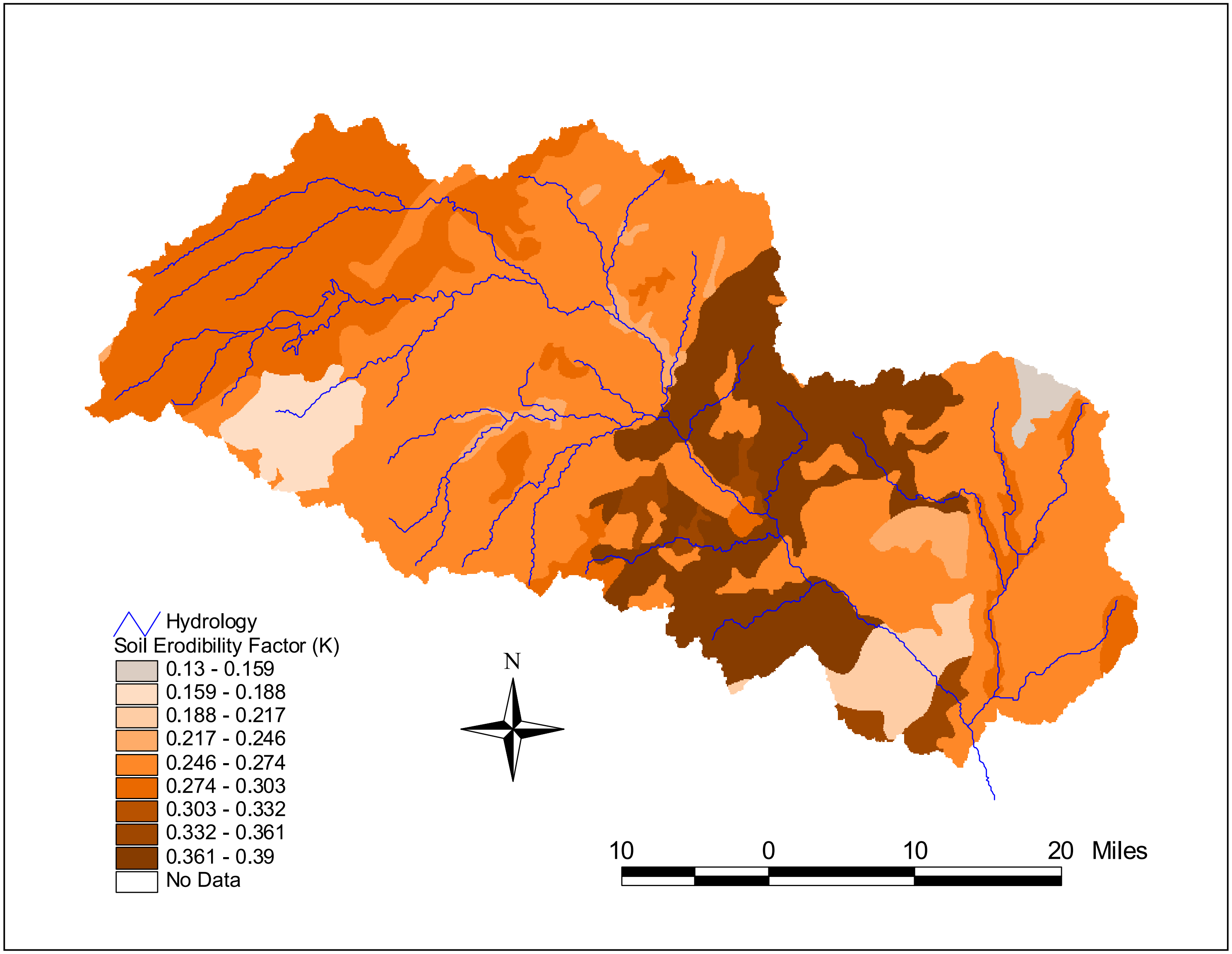

Figure 5. Soil Erodibility Factors in the Jordan Lake Watershed

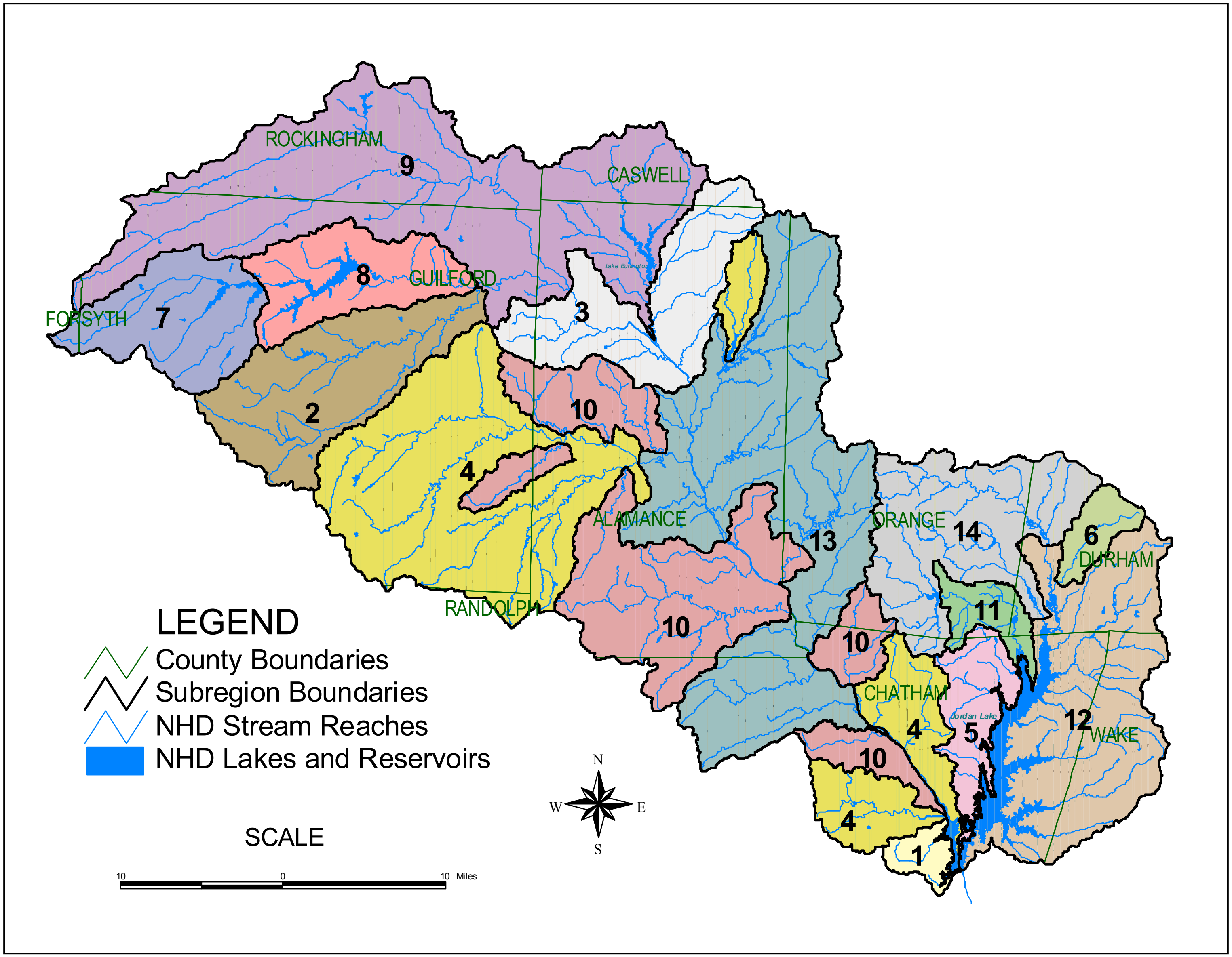

Figure 6. Jordan Lake Watershed HRUs

2.2 NLCD LAND USE

The most recent, comprehensive landcover database available for the entire Jordan Lake watershed is contained in the National Land Cover Database (NLCD) from the Multi-Resolution Land Characterization (MRLC) Consortium (USGS, 2000). The NLCD is based on interpretation of Landsat satellite thematic mapper imagery. The images were recorded between 1992 and 1994 for North Carolina.

When the hydrography coverage and the NLCD grid data were displayed together, it became apparent that the two coverages were not aligning properly. The source of the error is unknown but is likely due to the original projection used by the NLCD, which is optimized for the entire lower 48 states and is not specific to North Carolina. The NLCD data was spatially shifted about 12 meters south and 75 meters west to achieve an optimal visual alignment between the hydrography coverage and the NLCD grid.

The NLCD coverage has a nominal 30-meter resolution. In essence, it is an identification of the predominant land cover (rather than land use) within each 30-m pixel. Data are classified into 21 types of land cover, including numerous forest and agricultural classes. In contrast, the information on developed land is somewhat limited. For residential land, the NLCD identifies two classes: “Low”-Intensity Residential is defined as areas with a mixture of constructed materials or other cover in which constructed materials account for 30-80 percent of the total area, while “High”-Intensity Residential is defined as areas in which constructed materials account for 80-100 percent of the total area. These attributions are made at the 30-m resolution, and so may not accurately reflect the characteristics of actual residential parcels. In addition, suburban residential development with significant tree cover may be missed entirely by the Landsat interpretation and be classified as forest.

Land uses described in the NLCD coverage for the study area were reclassified into 15 aggregate land uses with varying physical and chemical properties. Since NLCD does not differentiate between non-residential urban land uses, but reports them in one lumped class, Tetra Tech assumed this NLCD class was equally divided between office/light industrial and commercial/heavy industrial land uses. These land uses make up about 2 percent of the Jordan Lake watershed, so a more in-depth analysis was not deemed necessary.

Given the rapid growth in several locations of the Jordan Lake watershed (southern Durham, Chapel Hill-Carrboro, Greensboro, Cary, etc.), many areas have undergone land use conversion in the decade since the NLCD was compiled. In addition, the NLCD has limitations as a basis for modeling urban/suburban areas because it yields land cover (rather than land use) and does not always accurately reflect the extent of single-family residential development, particularly where tree canopy is present. Tetra Tech has checked with the Triangle J Council of Governments (TJCOG), Piedmont-Triad Council of Governments (PTCOG), and U.S. Environmental Protection Agency (US EPA), and there are no newer comprehensive land use/land cover (LULC) data currently compiled for the watershed.

2.3 PARCEL-BASED LAND USE ANALYSIS

The NLCD is from the early 1990s, is known to underestimate lower-density residential land, and provides a poor resolution of residential land use types. In contrast, current parcel-based land use coverage is available in GIS format for the land areas that drain to the upper, listed segments of Jordan Lake from Orange, Durham, Chatham, and Wake counties. This provides direct and current information on land use, as opposed to land cover. However, the type of information available differs significantly from county to county, resulting in cumbersome processing. Further, in some counties it is also difficult to separate single family and multi-family lots in the tax parcel data.

Given limitations on availability and the time required for processing, Tetra Tech performed parcel-based analysis for only a limited subset of HUCs. Tetra Tech had already processed the parcel-based land use data for the Morgan/Little/Bolin/Booker Creek drainages in support of NCWRP Local Watershed Planning. Additional analyses were undertaken for other HUCs surrounding the listed segments of Jordan Lake whose watersheds are contained within Orange, Chatham, Durham, and Wake counties. For these HUCs, parcel-based results for developed residential and commercial land uses were substituted directly for NLCD results. An exception was made for larger lots, which are capped at 3 acres on the assumption that the balance of the lot is likely to remain largely rural in nature. Analysis of land cover for undeveloped lots retained the NLCD interpretation, after correction to preserve correct area totals.

2.4 Census Update to NLCD Land Use

A parcel-based analysis was possible for only a subset of the many HUCs in the Jordan watershed. To improve the technical defensibility for the TMDL that will be generated using the watershed and lake models, Tetra Tech updated the NLCD coverage by comparison to the 2000 census data, which provides an actual count of residences with a more current date.

While the Census gives actual density of housing units, there are several difficulties in applying the correction. First, the 2000 Census does not clearly distinguish single family from multi-family residential units (in 2000 this question was asked only on the long form, sent to a statistical subset of the total population). Further, the Census block information cannot reliably be used to infer lot size. Census blocks were often drawn to contain densely developed areas, plus adjacent “empty” land, leading to an overestimation of the number of acres per dwelling unit. On the other hand, some rural areas appear to have a significant number of lots containing multiple single family housing units. Finally, some proportioning of households is necessary in areas where census block boundaries and HUC boundaries do not coincide.

The Census provides at best an uncertain estimate of the density of residential land uses, and use of the Census data thus requires use of a translation method to account for these uncertainties. The translation method was developed using county tax parcel data for the subset of watersheds analyzed in Section 2.3. In developing the translation, it should be noted that the type of information contained in the tax parcel data differs significantly from county to county, and in some counties it is also difficult to separate single family and multi-family lots in the tax parcel data. The tax parcel data are also newer than the Census data (near current versus 2000), which can lead to discrepancies in rapidly developing areas.

Nonetheless, a reasonable, empirical translation can be developed for residential land areas. The first step was to analyze the residential information from Census blocks, calculate an “apparent” lot size (area of the Census block divided by number of households, which is generally biased high), and sort the parcel counts into bins by this apparent Census lot size, as follows:

CRVH	< 0.25 acres per dwelling unit
CRHH	0.25 – 0.5 acres per dwelling unit
CRMH	0.5 – 1 acres per dwelling unit
CRML	1 – 1.5 acres per dwelling unit
CRLL	1.5 – 2 acres per dwelling unit
CRVL	2-3 acres per dwelling unit
CRR	> 3 acres per dwelling unit

In comparison to areas with parcel data, a reasonable approximation is obtained from the Census counts by minimizing the sum of the squared error in parcel counts, using the empirical relationships shown in Table 1.

Table 1. Interpretation of Residential Land Use from Census Housing Units

Land Use Name	Code	Nominal Size (ac per du)	Number of Units
Residential – Very High Density (<0.25 acres per du)	RVH	0.077	CRVH + CRHH
Residential – High Density (0.25 – 0.5 acres per du)	RHH	Not interpreted from Census	
Residential – Medium High Density (0.5-1 acres per du)	RMH	0.5	CRMH + CRML + CRLL + 0.79·CRVL + 0.181·CRR
Residential – Medium Low Density (1-1.5 acres per du)	RML	1.5	0.21·CRVL + 0.261·CRR
Residential – Low Density (1.5-2 acres per du)	RLL	Not interpreted from Census	
Residential, Very Low Density (>2 acres per du)	RVL	2.5	0.479·CRR

The attribution assigns 100 percent of the Census households in all classes except CRR, where 92.1 percent of the Census count is assigned. The remaining portion of CRR presumably represents multiple housing units on large rural lots.

Two residential classes that are available from the parcel analysis (RHH and RLL) are not interpreted from the Census. Single family RHH is essentially mixed into the RVH and RMH classes due to the failure of the Census to distinguish multi-family and single-family units. RMH is set at the lower bound acreage to compensate. RML and RLL are essentially predicted as a unit, with area set at the intervening breakpoint. Finally, RVL is predicted as the number of households times 2.5 acres. While many rural lots are larger, the balance of the tract can generally be considered as rural forest or pasture rather than developed land. In any case, the success of the simulation is more dependent on a reasonable estimate of the number of residential units, and thus their imperviousness, than on the total acreage in residential lots.

Tests on 15 HUCs for which parcel analysis was conducted show a reasonable agreement between the number of lots predicted by this method from the Census information and the actual count of improved parcels. A comparison of the parcel counts is shown in Figure 7.

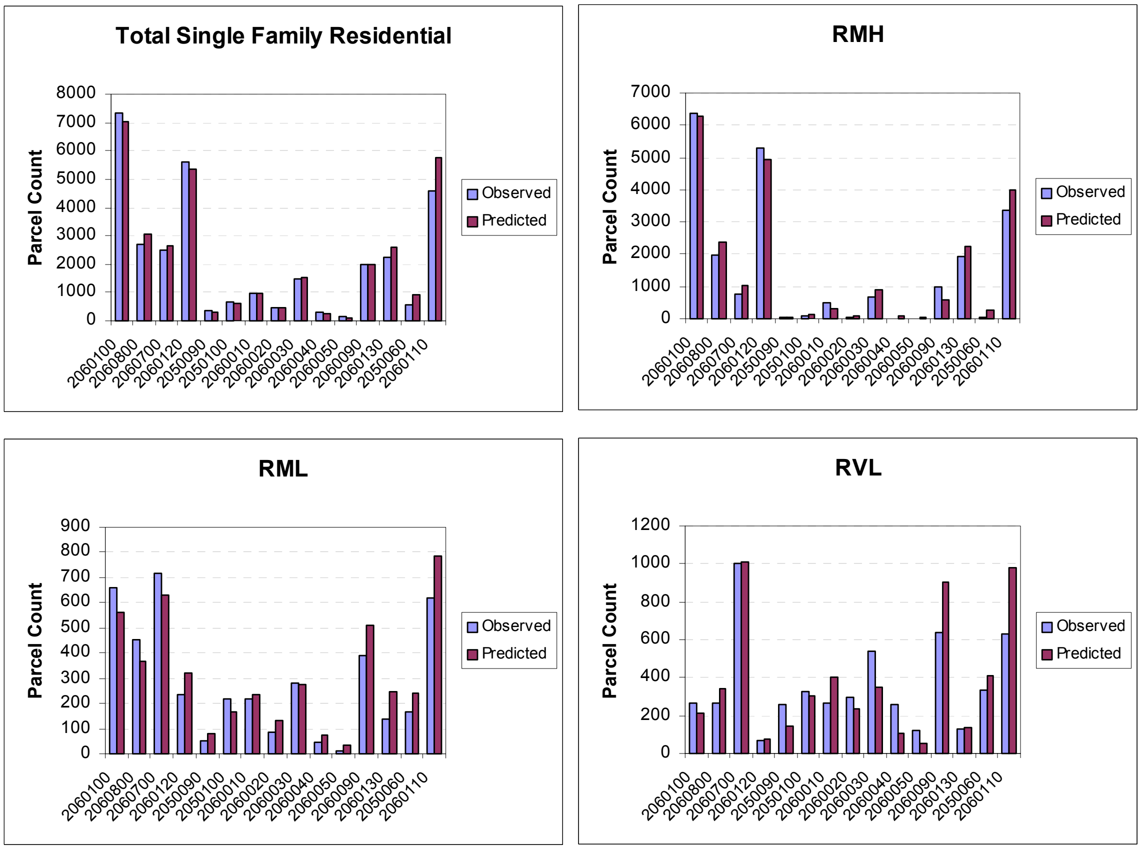

Figure 7. Comparison of Housing Units by Size Predicted from Census to Tax Parcel Counts

2.5 Final Land Use Database

2.5.1 Land Use Distribution by HUC

The final land use database consists of the 1992 NLCD, updated in Orange, Durham, Chatham, and Wake counties using current tax parcel information, and updated in all other areas for residential density using the 2000 Census. This yields a near-current estimate of land use in the basin, with the primary exception that commercial/industrial development in the Haw River basin after the date of the NLCD has not been captured. The distribution of land use acreage by HUC is provided in Table 2; a visual summary is provided in Figure 8. (Note: the acronyms for land use categories are defined in Table 3.)

Table 2. Final Land Use Distribution by HUC (acres)

HUC	RVL	RLL	RML	RMH	RHH	RVH	OFF	CIT	UGR	PAS	ROW	FOR	WET	BAR	WAT
2010010	3089.5	0.0	1102.9	447.6	0.0	2.7	193.9	193.9	226.4	2677.3	8586.5	17071.4	1114.4	68.7	1135.3
2010020	4609.0	0.0	1680.0	691.7	0.0	15.5	213.8	213.8	310.7	3647.1	11228.6	27373.3	2688.3	50.7	422.3
2010030	777.3	0.0	396.8	884.3	0.0	95.6	335.5	335.5	153.0	462.9	1032.8	3469.8	98.7	15.1	40.7
2010040	768.5	0.0	260.7	94.6	0.0	2.5	31.0	31.0	50.0	1044.9	2877.1	4969.2	310.0	28.2	126.5
2010050	861.1	0.0	292.3	100.3	0.0	0.7	38.1	38.1	38.3	938.4	3727.2	6814.3	57.6	18.0	104.3
2020010	3672.3	0.0	2179.1	4536.1	0.0	726.5	693.6	693.6	1419.5	1520.2	7496.5	19387.1	1047.7	125.2	1308.6
2020020	1663.0	0.0	821.5	1548.3	0.0	385.2	127.5	127.5	288.9	592.1	2904.6	11642.4	345.8	14.0	1819.0

HUC	RVL	RLL	RML	RMH	RHH	RVH	OFF	CIT	UGR	PAS	ROW	FOR	WET	BAR	WAT
2020030	1344.7	0.0	545.0	575.2	0.0	15.2	159.9	159.9	145.9	1127.2	3580.6	9407.7	185.9	82.5	166.1
2020040	1289.4	0.0	1062.7	5039.9	0.0	2120.5	2209.6	2209.6	340.3	520.8	1777.9	10993.2	75.8	173.0	185.3
2020050	1404.7	0.0	1065.8	4065.8	0.0	2147.4	2282.4	2282.4	281.1	900.1	2599.8	11189.5	271.5	346.9	106.3
2020060	772.0	0.0	271.9	102.2	0.0	0.0	21.8	21.8	40.0	784.5	1748.7	3656.8	38.9	12.5	72.1
2020070	928.6	0.0	312.5	151.4	0.0	4.4	24.6	24.6	13.1	1766.4	4141.9	6869.7	58.0	34.7	119.4
2030010	2196.2	0.0	921.7	904.3	0.0	51.8	275.3	275.3	204.6	1899.0	4213.8	10936.9	142.6	39.8	183.7
2030020	965.8	0.0	326.6	92.6	0.0	0.0	29.1	29.1	26.7	1122.8	3296.0	7039.0	81.0	48.7	142.1
2030030	1345.9	0.0	445.6	112.4	0.0	0.0	50.4	50.4	31.8	1964.4	5901.7	18808.8	173.2	129.9	900.0
2030040	1173.7	0.0	393.3	102.2	0.0	0.0	27.0	27.0	38.3	1953.9	5752.8	13603.7	280.0	73.2	230.2
2030050	1110.6	0.0	678.0	1496.9	0.0	431.4	652.1	652.1	174.4	340.9	1370.5	5686.3	51.4	247.7	119.0
2030060	649.5	0.0	215.4	53.1	0.0	0.0	20.5	20.5	40.9	818.4	2086.8	5005.0	74.7	18.2	221.1
2030070	2453.4	0.0	936.2	677.2	0.0	40.6	142.7	142.7	55.6	2867.3	5430.9	17648.0	227.5	37.8	599.4
2030080	1183.5	0.0	1006.0	2166.6	0.0	173.7	535.0	535.0	295.8	1247.3	2364.7	7876.7	135.0	181.7	193.7
2040010	3287.1	0.0	1220.9	499.1	0.0	3.1	100.1	100.1	53.6	3174.2	6463.4	19401.8	107.9	18.9	197.7
2040020	4219.8	0.0	1944.4	1514.1	0.0	19.5	426.8	426.8	434.6	3133.4	6510.7	20086.4	242.2	188.6	415.4
2040030	634.6	0.0	258.9	137.7	0.0	0.0	60.3	60.3	108.8	281.1	569.5	3001.4	16.7	8.0	49.4
2040040	647.6	0.0	224.0	72.5	0.0	0.0	1.9	1.9	0.2	877.6	2093.3	3955.8	19.1	6.7	26.5
2040050	616.1	0.0	326.1	812.5	0.0	82.7	115.4	115.4	45.8	513.4	1315.4	4565.5	28.7	126.8	60.3
2040060	369.6	0.0	254.3	862.4	0.0	90.1	271.7	271.7	290.4	65.5	699.2	1746.6	15.6	31.4	15.6
2040070	1474.5	0.0	498.8	144.6	0.0	0.0	27.2	27.2	43.4	2558.0	4475.8	11062.9	223.5	14.0	91.6
2040080	1372.2	0.0	455.6	116.6	0.0	0.6	13.7	13.7	21.1	2227.0	5165.9	13134.5	248.0	31.4	181.5
2040090	823.3	0.0	274.9	76.7	0.0	0.8	10.2	10.2	8.7	714.9	1518.9	5627.2	32.5	51.2	24.5
2040100	647.0	0.0	265.4	163.5	0.0	0.0	38.6	38.6	39.8	223.5	482.6	1580.9	17.6	9.6	17.1
2040110	341.0	0.0	482.0	2368.1	0.0	547.6	690.2	690.2	181.7	194.0	668.9	3916.4	24.7	10.7	36.0
2050010	3966.5	0.0	1462.1	727.5	0.0	26.6	165.6	165.6	169.5	2867.6	5220.3	20121.0	151.0	177.7	354.9
2050020	762.3	0.0	249.4	58.0	0.0	0.0	13.0	13.0	0.9	1057.5	1667.8	5111.7	39.1	5.6	23.4
2050030	1075.0	0.0	361.8	96.7	0.0	0.0	1.7	1.7	2.0	2653.3	2749.2	13939.0	98.1	15.8	493.0
2050040	673.1	0.0	255.9	110.2	0.0	2.0	26.9	26.9	8.0	998.7	1928.3	6462.6	51.6	6.9	68.9
2050050	2028.9	0.0	671.3	174.5	0.0	0.2	11.3	11.3	114.8	7232.2	9333.1	25008.5	200.4	55.2	147.4
2050060	951.9	136.4	112.0	40.4	0.6	0.2	3.6	3.6	1.1	1340.1	1283.5	11066.3	71.8	12.9	97.9
2050070	655.0	0.0	214.2	50.5	0.0	0.0	1.6	1.6	0.0	2890.1	3677.1	14740.1	87.0	120.3	64.0
2050080	1144.9	58.9	41.2	15.3	4.5	0.0	1.1	1.1	13.1	492.9	513.4	9363.3	208.4	227.7	110.5
2050090	757.4	53.1	28.9	20.6	0.4	0.0	1.1	1.1	0.0	1228.4	1026.9	11421.6	103.0	719.9	51.2
2050100	921.8	150.4	161.1	75.7	5.0	0.8	1.7	1.7	0.4	108.3	118.0	6776.0	111.6	4.9	141.0
2060010	751.7	144.7	162.4	218.2	75.8	5.1	6.7	6.7	0.0	378.9	290.7	6295.3	123.4	6.9	63.8
2060020	855.2	69.3	56.5	43.4	3.0	0.9	9.5	9.5	0.4	269.5	399.0	9500.0	31.6	226.8	42.9
2060030	1539.4	157.0	236.3	214.9	135.6	33.5	104.0	104.0	14.0	603.0	742.3	14096.4	46.7	151.2	81.4
2060040	770.2	50.1	22.6	11.3	1.1	0.4	0.3	0.3	0.0	7.7	8.6	3408.4	108.3	125.0	289.8
2060050	367.0	11.8	8.1	4.1	0.5	0.4	0.4	0.4	0.0	33.2	86.2	6549.9	166.4	4.2	96.1
2060060	39.5	0.0	12.9	3.0	0.0	0.0	1.6	1.6	0.0	3.1	31.5	600.7	203.5	1.3	11270.7
2060062	0.8	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7	75.1	37.8	0.0	1219.8
2060070	2766.9	438.3	433.2	387.6	118.4	13.7	8.8	24.8	2.2	1020.8	844.3	12731.9	69.2	110.8	231.7
2060080	736.5	217.1	383.5	620.8	413.5	517.0	336.1	241.4	3031	153.2	267.4	7408.7	1018.1	27.6	93.4
2060090	1848.6	221.2	308.0	397.6	164.2	89.7	14.9	14.9	283.6	232.8	355.4	17205.1	672.5	388.3	739.0
2060100	737.3	236.9	608.8	1619.9	1503.7	1121.5	234.9	433.4	186.5	176.7	330.6	7689.4	733.7	31.6	99.6

HUC	RVL	RLL	RML	RMH	RHH	RVH	OFF	CIT	UGR	PAS	ROW	FOR	WET	BAR	WAT
2060110	1741.8	269.0	544.0	1057.5	695.5	1062.2	652.0	652.0	87.6	848.5	1540.4	22667.6	1197.6	93.0	66.1
2060120	173.2	88.4	214.5	787.3	1401.3	1559.7	525.0	525.0	92.1	9.1	85.5	4509.8	532.9	20.7	24.5
2060130	372.0	47.4	132.9	432.5	484.4	508.8	266.5	266.5	6.7	109.2	319.7	6636.8	2248.4	62.9	177.2
2060140	1064.9	124.9	204.3	565.8	1002.0	639.9	1270.7	1270.7	920.7	289.8	577.4	19577.7	2110.5	366.5	175.5
2060150	2755.8	217.3	160.5	151.9	523.1	333.6	55.6	55.6	0.0	750.0	1154.2	15896.3	1538.1	80.7	419.2
2060160	2073.6	229.3	129.0	154.4	689.9	637.6	106.7	106.7	0.4	806.4	1352.8	17635.1	1885.9	38.0	899.8
Sum (ac)	78222	2922	28295	38650	7222	13512	14152	14152	7421	68695	147956	603365	22281	5326	26853

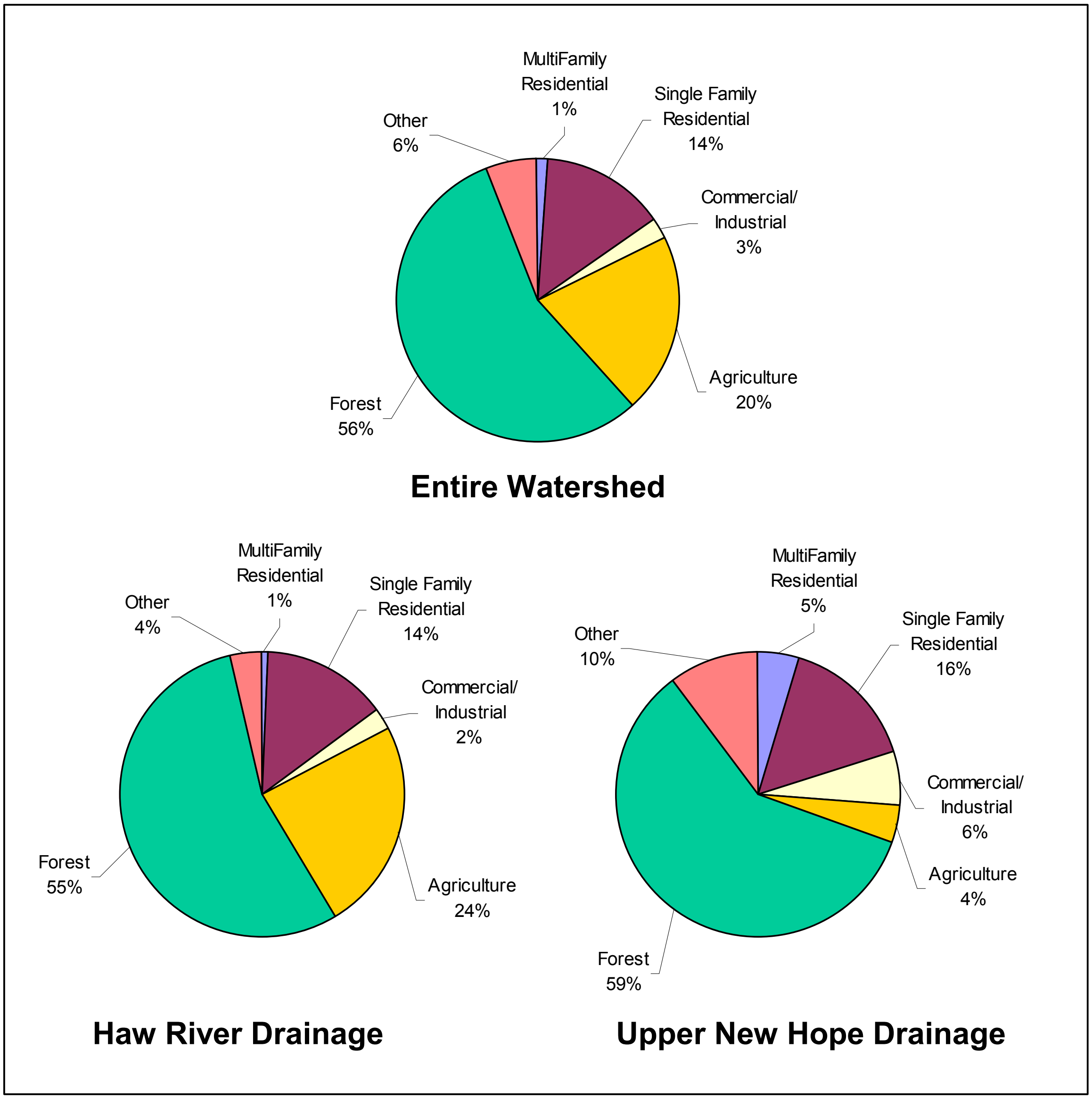

Figure 8. Distribution of Land Uses across the Jordan Lake Watershed

2.5.2 Impervious Area Coverage

For modeling, an important characteristic of a land use is the extent of impervious area coverage. Impervious areas represent the amount of the land surface that rainfall does not penetrate and include roads, parking lots, and sidewalks. Imperviousness increases with the amount and density of development and affects the quantity and velocity of runoff and the quantity of contaminant washoff. Imperviousness estimates for the model are based on interpolation of percentages by lot size given in SCS (1986) to the NLCD land use classes. Table 3 summarizes the assumptions used for each of the urban land uses included in the model. Rural land uses such as forest and pasture are assumed to be 100 percent pervious.

Table 3. Land Uses and Estimated Impervious Percentages

Land Use Name	GWLF Code	Percent Impervious
Residential – Very Low Density (2+ acres per d.u.)	RVL	8
Residential – Low Density (1.5-2 acre s per d.u.)	RLL	14
Residential – Medium Low Density (1-1.5 acre s per d.u.)	RML	18
Residential – Medium High Density (0.5-1 acres per d.u.)	RMH	23
Residential – High Density (0.25-0.5 acres per d.u.)	RHH	29
Residential – Multifamily/Very High Density (< 0.25 acres per d.u.)	RVH	50
Office/Light Industrial	OFF	70
Commercial/Heavy Industrial	CIT	85
Urban Greenspace	UGR	0
Pasture	PAS	0
Row Crop	ROW	0
Forest	FOR	0
Wetlands	WET	0
Barren	BAR	0
Water	WAT	NA

2.5.3 Sewer Service Areas

The watershed modeling distinguishes between residential land uses served by sewer and those with onsite wastewater disposal systems (e.g., septic systems). For areas on sewer service, nutrient loading via wastewater is accounted for in wastewater discharge monitoring. Residences with onsite wastewater disposal also generate significant nutrient loads, but these must be accounted for in the watershed nonpoint source model. Thus, each of the residential land uses must be subdivided into sewered and unsewered fractions.

No up-to-date, comprehensive coverage of sewer service areas was available for the whole watershed. In previous decades, type of wastewater disposal was identified for each household on the Census; however, for the 2000 Census this question was included only on the detailed questionnaire sent to a statistical subset of households. To obtain a reasonable approximation of the extent of sewer service in the watershed as a whole, it was assumed that single-family households within municipal boundaries were on sewer service, while those outside municipal boundaries were not. All single family lots on less than ½ acre and multifamily parcels (RHH and RVH) were assumed to be sewered even if outside municipal boundaries (the vast majority of these land uses are within municipal boundaries). For the Morgan and Little/Bolin Creek drainages (HUCs 2060070, 2060080, and 2060100) a more detailed analysis was undertaken matching parcel data to actual sewer service coverages as part of the project undertaken by Tetra Tech for the NC Wetlands Restoration Program. Results of the analysis are shown in Table 4.

Table 4. Fraction of Residential Land Uses with Onsite Wastewater Disposal by HUC

HUC	RVL	RLL	RML	RMH
2010010	58.1%	90.6%	66.7%	32.2%
2010020	33.7%	38.8%	44.5%	94.2%
2010030	41.4%	0.0%	0.1%	0.2%
2010040	100.0%	100.0%	100.0%	100.0%
2010050	100.0%	100.0%	100.0%	100.0%
2020010	16.4%	55.5%	27.7%	22.1%
2020020	39.6%	66.9%	22.5%	12.3%
2020030	97.9%	98.6%	100.0%	99.3%
2020040	55.9%	1.7%	32.9%	1.5%
2020050	22.2%	14.4%	13.4%	0.9%
2020060	100.0%	100.0%	100.0%	100.0%
2020070	100.0%	100.0%	100.0%	100.0%
2030010	95.7%	59.6%	63.2%	54.7%
2030020	100.0%	100.0%	100.0%	100.0%
2030030	100.0%	100.0%	100.0%	100.0%
2030040	100.0%	100.0%	100.0%	100.0%
2030050	27.8%	47.4%	18.9%	2.5%
2030060	100.0%	100.0%	100.0%	100.0%
2030070	85.7%	42.9%	69.0%	23.2%
2030080	84.0%	61.8%	27.7%	12.2%
2040010	24.2%	100.0%	72.6%	78.6%
2040020	96.3%	96.0%	95.9%	93.3%
2040030	48.3%	33.8%	55.9%	90.8%
2040040	100.0%	0.0%	100.0%	100.0%
2040050	50.8%	12.0%	46.8%	11.7%
2040060	1.1%	7.3%	4.2%	2.1%
2040070	100.0%	99.3%	100.0%	100.0%
2040080	67.7%	100.0%	100.0%	100.0%
2040090	100.0%	100.0%	100.0%	100.0%
2040100	94.7%	92.0%	100.0%	95.7%
2040110	2.4%	34.3%	5.6%	6.9%
2050010	93.3%	68.1%	69.1%	18.4%
2050020	100.0%	100.0%	100.0%	100.0%

HUC	RVL	RLL	RML	RMH
2050030	100.0%	100.0%	100.0%	100.0%
2050040	100.0%	100.0%	100.0%	100.0%
2050050	100.0%	100.0%	100.0%	100.0%
2050060	100.0%	100.0%	100.0%	100.0%
2050070	100.0%	100.0%	100.0%	100.0%
2050080	100.0%	100.0%	100.0%	100.0%
2050090	100.0%	100.0%	100.0%	100.0%
2050100	100.0%	100.0%	100.0%	100.0%
2060010	100.0%	100.0%	100.0%	100.0%
2060020	55.8%	100.0%	100.0%	100.0%
2060030	30.8%	43.9%	25.9%	5.6%
2060040	100.0%	100.0%	100.0%	100.0%
2060050	100.0%	100.0%	100.0%	100.0%
2060060	100.0%	100.0%	100.0%	100.0%
2060062	100.0%	100.0%	100.0%	100.0%
2060070	99.8%	99.8%	99.2%	92.0%
2060080	77.4%	56.4%	49.5%	35.7%
2060090	100.0%	100.0%	100.0%	100.0%
2060100	60.5%	36.5%	22.8%	10.2%
2060110	35.9%	13.4%	29.9%	8.1%
2060120	0.0%	0.0%	0.0%	0.0%
2060130	41.9%	5.8%	12.2%	8.5%
2060140	50.3%	42.1%	15.0%	9.5%
2060150	62.8%	5.5%	7.2%	7.1%
2060160	49.5%	46.7%	9.2%	10.9%

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3 GWLF Watershed Model Development

Nonpoint loading of water and nutrients is simulated using the Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992). The complexity of this loading function model falls between that of detailed simulation models, which attempt a mechanistic, time-dependent representation of pollutant load generation and transport, and simple export coefficient models, which do not represent temporal variability. GWLF provides a mechanistic, simplified simulation of precipitation-driven runoff and sediment delivery, yet is intended to be applicable as an assessment tool with or without formal calibration. Solids load, runoff, and groundwater seepage can then be used to estimate particulate and dissolved-phase nutrient delivery to a stream, based on concentrations in soil, runoff, and groundwater. The GWLF model has a long history of successful application in watershed studies throughout the eastern U.S. (e.g., Howarth et al., 1991; Dodd and Tippett, 1994; Cadmus, 1995; Swaney et al., 1996; Schneiderman et al., 2002; Lee et al., 2001; Evans et al., 2002).

3.1 The GWLF Model

GWLF simulates runoff and streamflow by a water-balance method, based on measurements of daily precipitation and average temperature. Precipitation is partitioned into direct runoff and infiltration using a form of the Natural Resources Conservation Service's (NRCS) Curve Number method. The Curve Number determines the amount of precipitation that runs off directly, adjusted for antecedent soil moisture based on total precipitation in the preceding five days. A separate Curve Number is specified for each land use by hydrologic soil grouping. Infiltrated water is first assigned to unsaturated zone storage, where it may be lost through evapotranspiration. When storage in the unsaturated zone exceeds soil water capacity, the excess percolates to the shallow saturated zone. This zone is treated as a linear reservoir that discharges to the stream or loses moisture to deep seepage, at a rate described by the product of the zone's moisture storage and a constant rate coefficient.

Flow in rural streams may derive from surface runoff during precipitation events or from groundwater pathways. The amount of water available to the shallow groundwater zone is strongly affected by evapotranspiration, which GWLF estimates from available moisture in the unsaturated zone, potential evapotranspiration, and a cover coefficient. Potential evapotranspiration is estimated from a relationship to mean daily temperature and the number of daylight hours.

Monthly sediment delivery from each land use is computed from erosion and the transport capacity of runoff, whereas total erosion is based on the universal soil loss equation (Wischmeier and Smith, 1978), with a modified rainfall erosivity coefficient that accounts for the precipitation energy available to detach soil particles (Haith and Merrill, 1987). Thus, erosion can occur when there is precipitation, but no surface runoff to the stream; delivery of sediment, however, depends on surface runoff volume. Sediment available for delivery is accumulated over a year, although excess sediment supply is not assumed to carry over from one year to the next. It should be noted that the current versions of GWLF do not make use of the improvements to USLE developed by USDA-Agricultural Research Service for prediction of annual erosion known as RUSLE (Renard et al., 1997). RUSLE provides corrections for the interaction of USLE parameters on a spatial and temporal scale that can improve sediment yield prediction; however, the USLE-based approach in GWLF has been found to perform well in a variety of watershed studies.

The basic processes addressed in the GWLF simulation are shown schematically in Figure 9. Actual implementation of the model made use of the Windows-based version known as BasinSim (Dai and Wetzel, 1999).

The GWLF application requires information on land use distribution, meteorology, and parameters that govern runoff, erosion, and nutrient load generation. In addition to the land use database, four primary data input classes are used to develop the model parameters for the watershed simulations: 1) soil and hydrologic properties, 2) nutrient concentration, buildup, and runoff assumptions, 3) onsite wastewater disposal information, and 4) meteorological data. The land use, watershed delineations, population, septic numbers, and meteorology data were collected and processed to generate a 10-year time series (April 1991 – March 2001 meteorology), which was used to derive seasonal and annual loading rates by land use type for each model HRU.

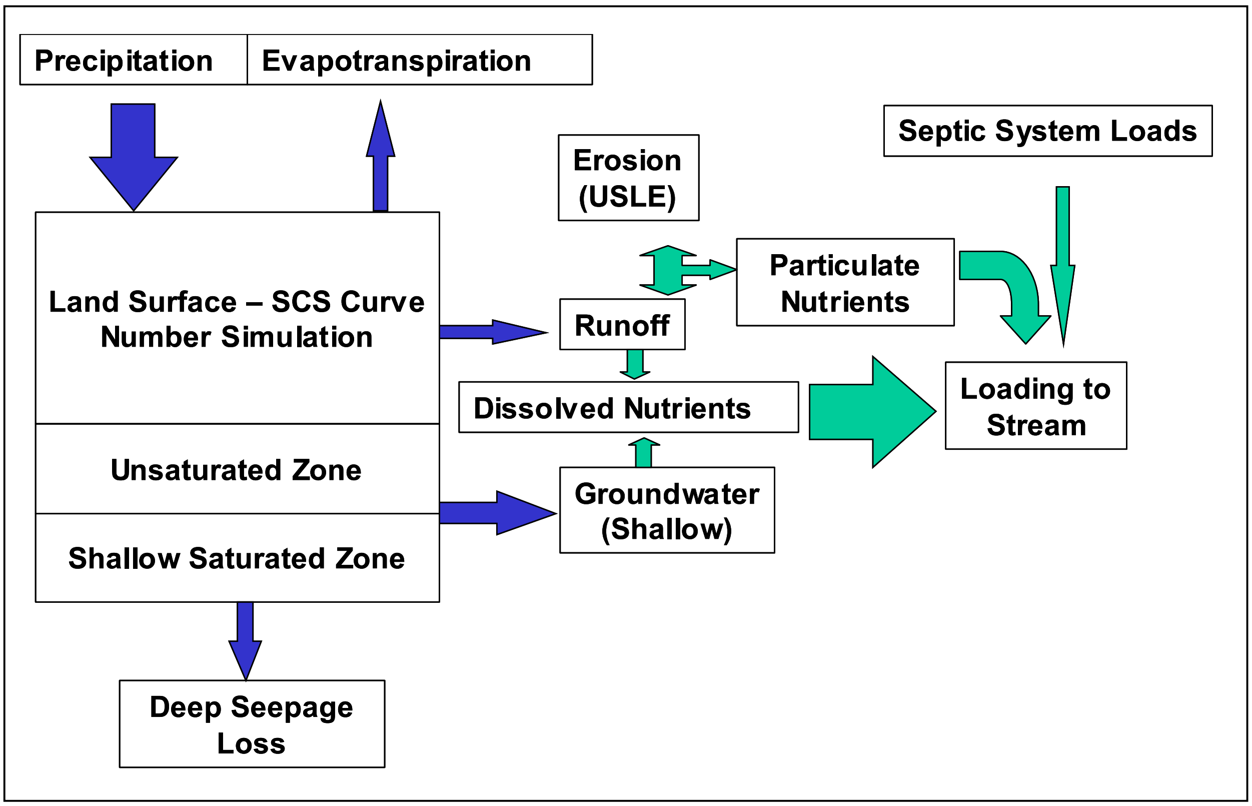


Figure 9. Schematic Representation of the GWLF Model

3.2 SOIL AND HYDROLOGIC PROPERTIES

GWLF simulates rural soil erosion using the universal soil loss equation (USLE). This method has been applied extensively in North Carolina, so parameter values are well established. The physical variables used for the current study were adapted in large part from the calibrated GWLF model previously developed for the Falls Lake and Cane Creek watersheds (Cadmus, 1996).

Runoff Curve Numbers: The direct runoff fraction of precipitation in GWLF is calculated using the curve number method from the NRCS TR55 method, based on imperviousness and soil hydrologic group. The hydrologic soil group was determined for subwatersheds using the STATSGO database. Weighted curve numbers were calculated for each land use category based on soil distribution among groups A, B, C, and D (Table 5). Forest CNs are assigned between the NRCS "Good" and "Fair" values, based on experience with the model in the Cane Creek and Falls Lake watersheds (Cadmus, 1995, 1996), while pasture was simulated as in "Fair" condition.

Table 5. Curve Numbers for Antecedent Soil Moisture Condition II by Land Use and Soil Hydrologic Group

Land Use	Hydrologic Group A	Hydrologic Group B	Hydrologic Group C	Hydrologic Group D
Residential – Very Low Density	44	64	76	82
Residential – Low Density	47	66	77	83
Residential – Medium Low Density	50	67	78	84
Residential – Medium High Density	53	69	80	84
Residential – High Density	56	72	81	85
Residential – Very High Density	68	79	86	89
Office/Light Industrial	80	87	91	93
Commercial/Heavy Industrial	89	92	94	95
Urban Greenspace	49	69	79	84
Pasture	49	69	79	84
Row Crop	67	78	85	89
Forest	33	57	71	78
Wetlands	45	66	77	83
Barren	77	86	91	94
Water	98	98	98	98

Evapotranspiration Cover Coefficients: The portion of rainfall returned to the atmosphere is determined by temperature and the amount of vegetative cover, which differs for each land use and varies by season (growing and dormant). For rural land uses, ET rates were based on seasonal values reported in the GWLF manual; for urban land uses, ET was calculated as 1 minus the impervious fraction.

ET growing and ET dormant are the same for urban land uses whose pervious area is mostly lawn and landscaped plants. Barren land is assumed to have no significant plant cover, but water is still lost through evaporation.

Soil Water Capacity: Water stored in soil may evaporate, be transpired by plants, or percolate to groundwater below the rooting zone. The amount of water that can be stored in soil and is available to evapotranspiration—the soil water capacity—varies by soil type and rooting depth. Average soil water capacity was estimated from STATSGO information on available water capacity in the soil column, assuming a rooted depth of 100 cm, yielding a value of 16.5 cm.

Recession Coefficients: The rate of groundwater discharge to streams is governed by the recession coefficient. In theory, this coefficient can be determined by examining the flow hydrograph when gaging data are available. For use in the Jordan Lake watershed, a typical recession coefficient of 0.03 was used, based on previous GWLF applications to the Cane Creek and University Lake watersheds.

Deep Seepage Coefficient: The GWLF model has three subsurface zones: a shallow unsaturated zone, a shallow saturated zone (aquifer), and a deep aquifer zone. The deep seepage coefficient is the portion of the moisture content in the shallow saturated zone that seeps to the deep aquifer zone and does not reappear as surface flow, effectively removing it from the watershed system. To model this process, the saturated zone is treated as a linear reservoir in which the moisture lost equals the moisture content multiplied by the saturation coefficient. Deep seepage is expected to be a small fraction in the watershed, as the Haw River (and Jordan Lake) represent regional groundwater discharge axes, so that precipitation on the land surface eventually either returns to the atmosphere or flows to Jordan Lake. However, some losses do occur due to withdrawal and consumptive use. A deep seepage coefficient of 1 percent appears to provide reasonable flow estimates on a watershed basis.

Soil Erodibility (K Factor): Erosion in the GWLF model is simulated with the Universal Soil Loss Equation (USLE), for which four input factors are required (K, LS, C, and P). The first of these is the soil erodibility factor, K, which indicates the propensity of a given soil type to erode. Soil erodibility factors from the STATSGO database were analyzed by subwatershed. Weighted-average values by subwatershed vary from 0.23 to 0.33.

Length-Slope (LS) Factor: Erosion potential varies by slope as well as soil type. The LS factor is the length (L) that runoff travels from the highest point in the watershed to the point of concentrated flow, multiplied by the slope (S) which represents the effect of slope steepness on erodibility for each soil type. LS factors for the Jordan Lake watershed were calculated using the Watershed Characterization System (Tetra Tech, 2000) which relies on topography and soils data (STATSGO) to calculate LS. LS factors in the Jordan Lake watershed range from 0.73 to 1.47 for the 14 HRUs.

Cover and Management (C) and Practice (P) Factors: The mechanism by which soil is eroded from a land area and the amount of soil eroded depends on soil treatment resulting from a combination of land uses (e.g., forestry versus row-cropped agriculture) and the specific manner in which land uses are carried out (e.g., no-till agriculture versus non-contoured row cropping). Land use and management variations are represented by cover and management factors in the universal soil loss equation and in the erosion model of GWLF. Cover and management factors for non-agricultural land uses were drawn from several sources (Wischmeier and Smith, 1978; Haith et al., 1992; Novotny and Olem, 1994). Factors for agricultural land uses follow recommendations of the Orange County NRCS. The resulting factors are summarized in Table 6. C and P factors are not required for the “urban” land uses, which are modeled in GWLF via a buildup-washoff formulation rather than the USLE (Section 3.3.3).

Table 6. Cover and Management (C) and Practice (P) Factors for Land Uses in the Jordan Lake Watershed

Land Use	C	P
Residential – Very Low Density	0.0065	1.0000
Barren Land	0.5000	1.0000
Wetlands	0.0030	1.0000
Forest	0.0030	1.0000
Pasture	0.0110	1.0000
Row Crop	0.1600	0.5000
Urban Grass	0.0130	1.0000

Sediment Delivery. Application of GWLF typically includes use of sediment delivery ratio that accounts for trapping of sediment and sediment-sorbed pollutants between the edge of field and the basin scale employed in the modeling. This empirical approach is a major source of uncertainty in GWLF modeling. For the JLNDM, a sediment delivery ratio is *not* used. Instead, GWLF is used to generate edge-of-field loading factors. Reduction of nutrient loads during transport is then addressed through the stream network delivery model (Section 4), which includes a component for local-scale trapping within the 14-digit HUC subbasins (Section 4.4).

3.3 Nutrient Modeling Assumptions

3.3.1 Soil Nutrient Concentrations

Soil nutrient concentrations were assigned based on their location within the Triassic Basin or the Carolina Slate Belt. In the Triassic Basin, the soil concentrations were initially set to 1,000 mg/kg for nitrogen and 616 mg/kg for phosphorus, based on results of calibrated GWLF model development for the Falls Lake study (Cadmus, 1995). In the Carolina Slate Belt, the soil concentrations were initially set to 600 mg/kg nitrogen and 260 mg/kg phosphorus, based on results of GWLF calibration for Cane Creek Reservoir (Cadmus, 1996).

These previously determined numbers appear to provide reasonable results for nitrogen. However, the phosphorus concentration assumptions appear to result in an underestimate of loading in the Slate Belt soils while overestimating the loading in the Triassic Basin soils. In addition, the phosphorus concentration used in the Cane Creek study is at the low end of the expected range for this part of the country and, while appropriate for Cane Creek, may not be a good average for the entire area. Therefore, the Slate Belt phosphorus concentration was re-estimated based on an assumption of a median P_2O_5 concentration of 0.07 percent (Mills et al., 1985) and an enrichment ratio of 1.5 for soils in the area, based on clay fraction, yielding a concentration of 475 mg/kg. This value was also determined to be reasonable in a finer-scale modeling study of the University Lake watershed, within the Jordan watershed, for Orange Water and Sewer Authority by Tetra Tech (2003c).

The phosphorus concentration used in the Falls Lake study appears high relative to the concentration expected for depleted Triassic basin soils. This may be due to the inclusion of other soil types in the Falls Lake study, plus use of an approach in which the pervious portion of residential lots (where phosphorus concentrations are likely to be enhanced by fertilization) was treated as a rural land use, with erosion simulated by USLE. Mills et al. (1985) suggest that the phosphorus concentration should decrease with transition from soils derived from metamorphic rock in the Piedmont to sedimentary soils of the Coastal Plain. The Triassic Basin is essentially a sedimentary inclusion within the Piedmont, and assumption of a P_2O_5 concentration of 0.04 percent (264 mg/kg P) appears to provide a better fit to observed nutrient loads in New Hope Creek and Northeast Creek, which predominantly drain Triassic Basin soils.

3.3.2 Groundwater Nutrient Concentrations

The GWLF model applies average groundwater nitrogen and phosphorus concentrations to flow from the saturated zone to the stream channel. For rural agricultural watersheds, concentrations are based on the Cane Creek model (Cadmus, 1996) and assigned at 0.76 mg/L N and 0.07 mg/L P. Estimates for rural non-agricultural watersheds were adopted from Falls Lake model results (Cadmus, 1995), and set at 0.25 mg/L N and 0.06 mg/L P. Falls Lake model estimates of 0.60 mg/L N and 0.10 mg/L P were also used for urban/developed areas. These values were initially developed from base flow nutrient concentrations observed in USGS studies of low-order streams. The groundwater component in GWLF, however, does not represent true groundwater flux alone. Because groundwater discharge varies slowly in comparison to overland runoff, the "groundwater" coefficient in a best-fit GWLF model includes true groundwater pathways and all components of nutrient load whose arrival at the watershed mouth is significantly delayed compared to the flow of water. Therefore, the calibrated groundwater concentrations are somewhat greater than would be expected in true baseflow discharge. Resulting estimates are shown in Table 7.

Table 7. Groundwater Nutrient Concentrations by Land Use

Parameter	Nitrogen (mg/L)	Phosphorus (mg/L)
Rural Groundwater (agricultural areas)	0.76	0.07
Rural Groundwater (non-agricultural areas)	0.5	0.06
Urban Groundwater	0.60	0.10
Septic Effluent	12.00	1.50
Uptake Rate (g/day)	1.60	0.40

3.3.3 Buildup Rates and Runoff Concentrations

In GWLF, nutrient loading from different land uses is based on the volume of flow and its pathways (overland or seepage), the amount of soil eroded, and coefficients that express the amount of nutrient load per unit volume of flow or erosion from a given land use. The GWLF model uses buildup/washoff relationships and runoff concentrations to predict nutrient loadings. These processes vary based on soil types and land use and are defined by a number of parameter values. Table 8 presents values used in the Jordan Lake GWLF model. Runoff concentrations are based on those used in the Cane Creek and Falls Lake models, and are generally well established. Buildup and washoff rates from urban areas were set at values sufficient to reproduce annual stormwater unit loading rates developed for the Town of Cary (Tetra Tech, 2003a) when applied to Cary soil and hydrologic conditions. These loading rates were calculated from a modeling analysis of Event Mean Concentration (EMC) values (including Line et al., 2002; CH2M HILL, 2000; Greensboro, 2003; and U.S. EPA, 1983), and are in general agreement with export coefficients reported in the literature (CDM, 1989; Hartigan et al., 1983; U.S. EPA, 1983; Beaulac and Reckhow, 1982; Frink, 1991). Results of the fit are shown in Figure 10 and Figure 11.

Table 8. Nutrient Runoff and Buildup Rates

Runoff and Buildup Rates		
Rural Land Uses	**Dissolved N (mg/L)**	**Dissolved P (mg/L)**
Pasture	2.770	0.250
Row Crop	2.770	0.250
Forest	0.190	0.006
Wetlands	0.190	0.006
Barren	0.190	0.006
Residential – Very Low Density	0.230	0.007
Urban Land Uses	**N Buildup (kg/ha-day)**	**P Buildup (kg/ha-day)**
Residential – Low Density	0.214	0.040
Residential – Medium Low Density	0.242	0.040
Residential – Medium High Density	0.242	0.040
Residential – High Density	0.219	0.037
Residential – Very High Density	0.201	0.033
Office/Light Industrial	0.158	0.025
Commercial/Heavy Industrial	0.191	0.029
Urban Greenspace	0.045	0.008

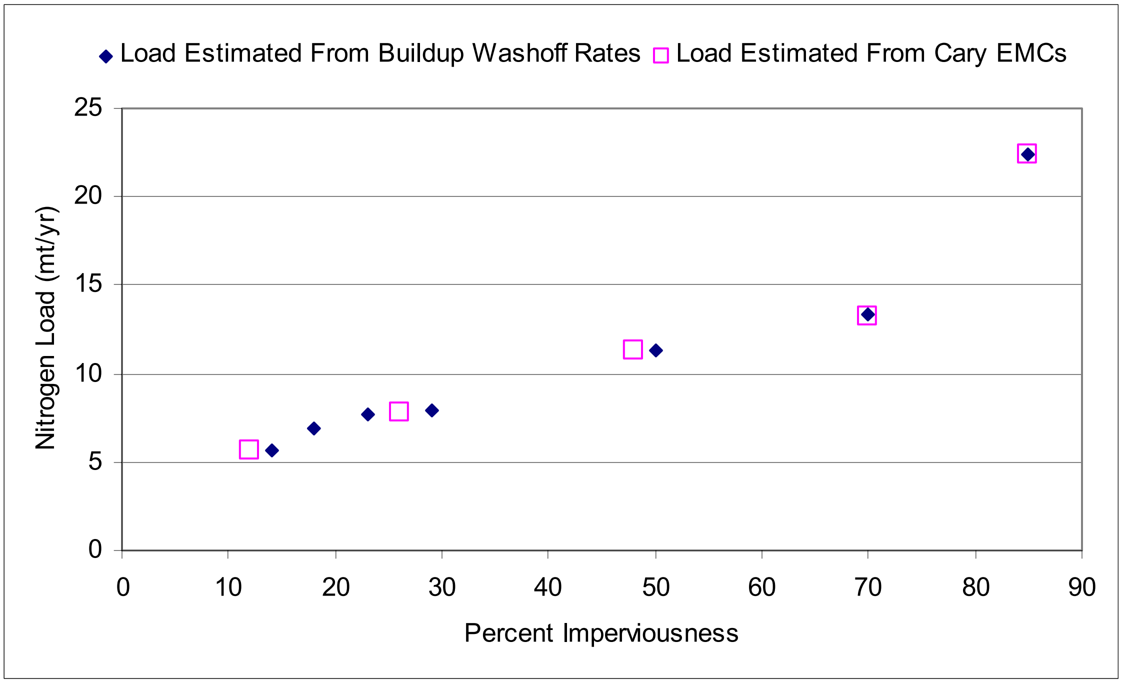


Figure 10. Comparison of Annual Nitrogen Loads Resulting from 1,000 Hectares of Urban Land with Varying Percent Imperviousness

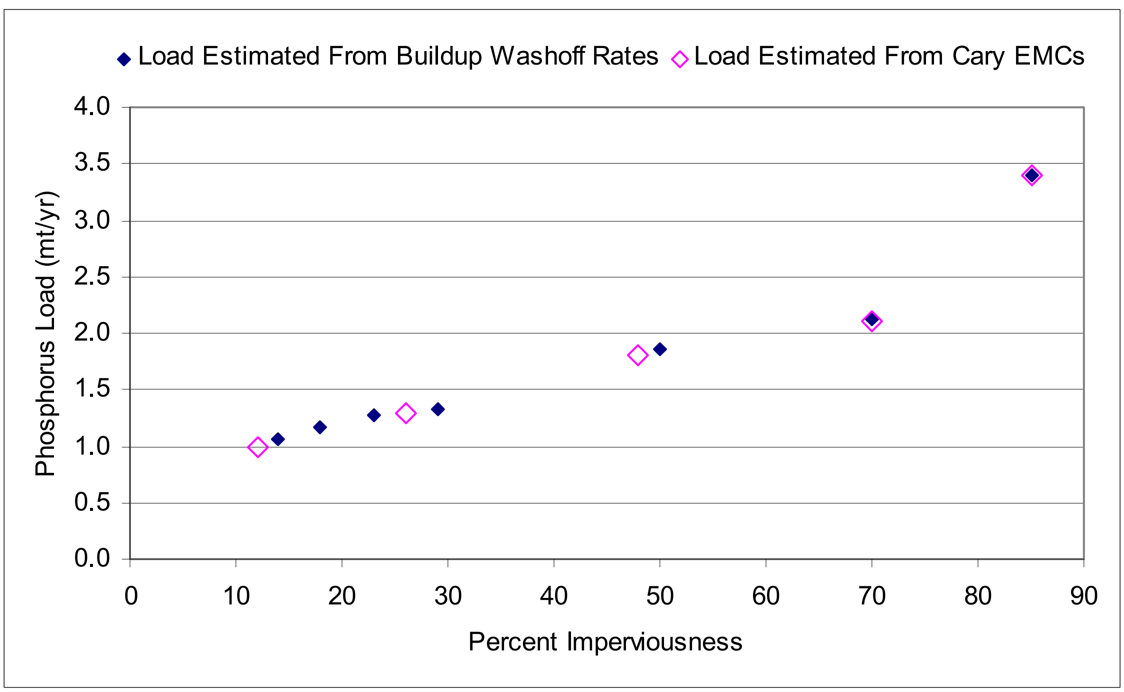


Figure 11. Comparison of Annual Phosphorus Loads Resulting from 1,000 Hectares of Urban Land with Varying Percent Imperviousness

3.4 ONSITE WASTEWATER DISPOSAL

The GWLF model simulates septic system nutrient contributions using nitrogen and phosphorus input values per capita and subtracting growing season plant uptake. Monthly nitrogen load contributed by normal septic tanks is assumed to mix with a larger reservoir of groundwater and enter the stream in proportion to local groundwater flow. For properly functioning systems, all phosphorus is assumed adsorbed by soils and retained. Septic systems that are either ponded or short-circuited are assumed to transfer phosphorus to the surface water with no losses to plant uptake and no adsorption attenuating the load.

For this study, GWLF default values (Haith et al., 1992) are assigned for septic system nutrient contribution of 12 grams/capita/day of nitrogen and 1.5 grams/capita/day of phosphorus. The average rates of nutrient attenuation by plant uptake during the growing season were also set to default values of 1.6 g/day and 0.4 g/day for nitrogen and phosphorus, respectively.

A steady-state failure rate of 2.5 percent was used to estimate the quantity of failed septic systems, based on the CDM (1989) study for Little River Reservoir and Lake Michie subwatersheds, which assumes a 10–15 percent steady-state rate of septic system failure, 20 percent of which is sufficiently close to waterbodies to cause direct loading.

Loading rates for each low to medium-density residential land use (GWLF classes RVL, RLL, RML, and RMH) were estimated with and without onsite wastewater disposal for use in the nutrient loading model. Average lot size was used to determine the average number of houses per acre, and a population density of 2.5 people/household was assumed. The calculated loading rates were used in the subsequent watershed scale analysis that took into account areas assumed to be sewered versus areas assumed to use onsite treatment.

3.5 WEATHER DATA

The GWLF model hydrologic simulation is driven by daily precipitation totals and maximum and minimum daily temperature. Potential evapotranspiration is calculated from temperature. The meteorological data required by GWLF was collected and processed for the meteorological stations at Greensboro, NC (Station 313630), Burlington, NC (Station 311241), and Durham, NC (Station 312515) to represent the range of conditions across the watershed. The raw data were obtained from the Southeast Regional Climate Center and the National Climatic Data Center for 1990 through 2001. Meteorological data was assigned to subwatersheds as presented in Table 9.

Table 9. Meteorology Station Assignment

Subregion (HRU)	Meteorology Station
1	Durham
2	Greensboro
3	Burlington
4	Burlington
5	Durham
6	Durham
7	Greensboro
8	Greensboro
9	Greensboro
10	Burlington
11	Durham
12	Durham
13	Burlington
14	Durham

3.6 UNIT AREA NONPOINT LOADS

As discussed in the previous section, GWLF is used to generate unit loading rates for Jordan Lake watershed land uses within 14 nutrient response zones that encompass each of the 58 hydrologic units within the basin. Four of the residential land uses have two possible loading rates – areas that are sewered versus areas that use onsite wastewater treatment. Complete results (seasonal and annual) are provided in Appendix A. Average loading rates by land use are summarized in Table 10. The range across Jordan watershed HRUs of average annual loading rates for selected land uses is shown in Figure 12 and Figure 13.

Table 10. Summary of Average Annual Field-Scale Loading Rates by Land Use Across all HRUs (lb/ac/yr)

Code	Land Use Description[JBB1]	TN	TP
BAR	Barren	45.96	29.92
CIT	Commercial/Heavy Industrial	24.05	3.70
FOR	Forest	1.59	0.33
OFF	Office/Light Industrial	16.47	2.63
PAS	Pasture	5.69	1.08
RVH	Residential <0.25 ac per du (sewered)	15.03	2.47
RHH	Residential - 0.25-0.5 ac per du (sewered)	11.86	2.00
RMH	Residential - 0.5-1.0 ac per du (sewered)	11.72	1.94
S-RMH	Residential - 0.5-1.0 ac per du (unsewered)	41.42	2.03
RML	Residential - 1.0-1.5 ac per du (sewered)	10.89	1.81
S-RML	Residential - 1.0-1.5 ac per du (unsewered)	28.71	1.86
RLL	Residential - 1.5-2 ac per du (sewered)	9.37	1.71
S-RLL	Residential - 1.5-2 ac per du (unsewered)	22.09	1.74
RVL	Residential - 2+ ac per du (sewered)	2.49	0.60
S-RVL	Residential - 2+ ac per du (unsewered)	11.40	0.63
ROW	Row Crop	13.37	5.32
UGR	Urban Green Space	3.57	0.61
WAT	Water	0.00	0.00
WET	Wetland	2.20	0.40

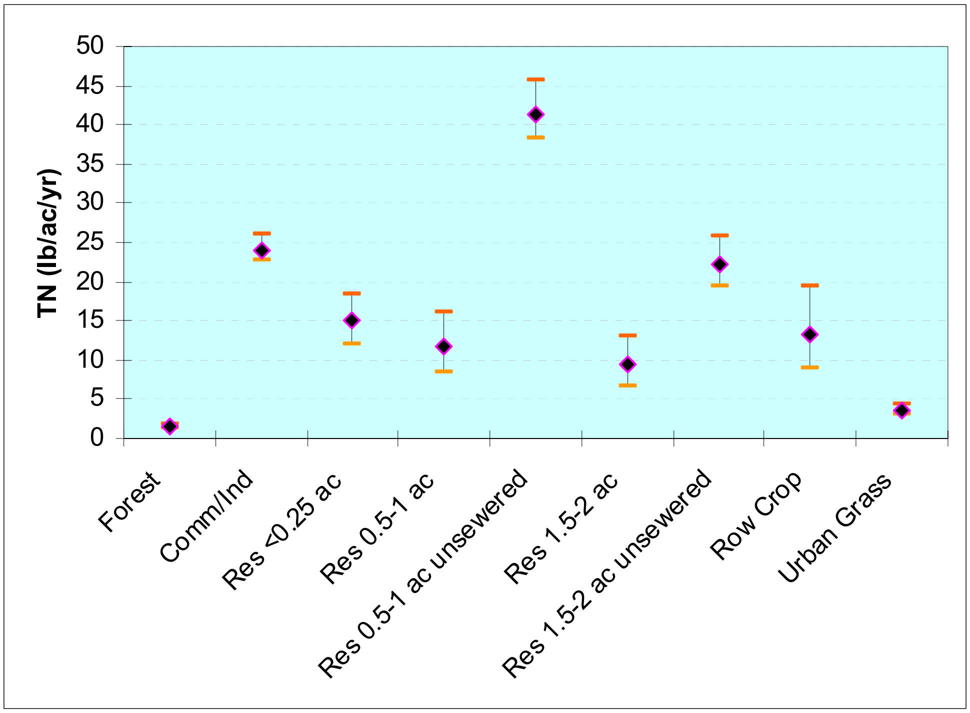


Figure 12. Average Annual Total Nitrogen Field-Scale Loading Rates for Selected Land Uses (Range across 14 HRUs)

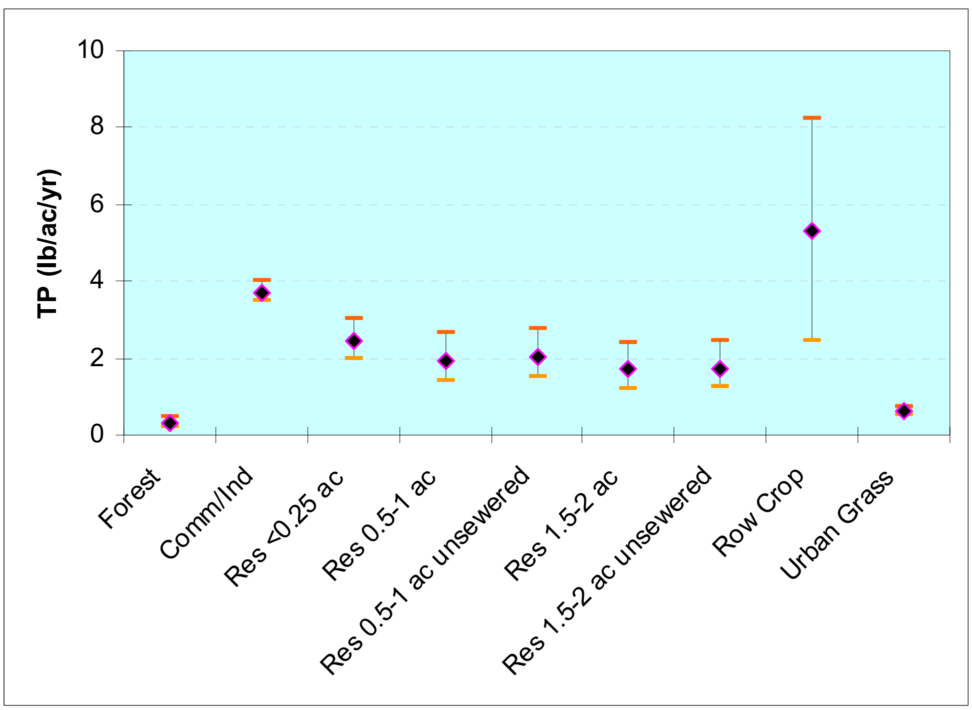


Figure 13. Average Annual Total Phosphorus Field-Scale Loading Rates for Selected Land Uses (Range across 14 HRUs)

The field-scale loading rates generated by the GWLF application tend to be somewhat higher than those reported in the literature for similar land uses based on monitoring of homogenous small watersheds (Table 11). However, these studies have typically been conducted at the scale of tens to hundreds of acres, and thus represent results after some trapping has occurred in first-order streams. As discussed in Section 4, the smallest streams appear to be the locus of the greatest rate of trapping. In addition, studied areas often include some amount of vacant land, which reduces the apparent loading rate. Finally, many of the literature studies have focused on storm-event monitoring and may not fully account for groundwater export of nutrients. For all these reasons, the field-scale estimates are reasonably expected to be higher than the literature values.

Table 11. Comparison of GWLF Field-Scale Loading Rates to Literature Export Coefficients

GWLF Land Use	GWLF Field-Scale Total P Loading (lb/ac/yr)	Literature Total P Export Coefficients (lb/ac/yr)	GWLF Field-Scale Total N Loading (lb/ac/yr)	Literature Total N Export Coefficients (lb/ac/yr)
RVL, RLL	0.6 – 1.7	0.25 – 0.9[1]	2.5 – 9.4	3.0 – 6.5[1]
RMH, RHH	1.9 – 2.0	0.86 – 1.1[1,2]	11.7 – 11.9	6.0 – 8.8[1,2]
RVH	2.5	1.6 – 1.8[1]	15.0	11.7 – 13.3[1]
CIT	3.7	1.6 – 3.4[1,2,3]	24.0	10.7 – 25.0[1,2,3]
FOR	0.33	0.01 – 0.99[1,2,4,5]	1.6	0.6 – 2.8[1,2,4,5]

Notes:
1. CDM (1989)
2. Hartigan et al. (1983) (surface only)
3. US EPA (1983)
4. Beaulac and Reckhow (1982)
5. Frink (1991)

The GWLF estimates of nitrogen loading from unsewered (septic system) residential lots, based on GWLF defaults, appear relatively high, and reflect incorporation of a significant number of failed/ponding systems. To our knowledge, no comprehensive study of septic system failure rates and resulting nitrogen loading is available for the watershed, and this component is a source of uncertainty in the model.

While the estimated loading rates do appear to be relatively high compared to literature values, use of these values, combined with point source loads, does lead to a reasonably accurate replication of observed nutrient loading estimated by the FLUX model, as described in Section 6. It remains possible that the estimated field-scale loads are high, but are compensated by elevated estimates of downstream trapping, resulting in a good fit to exerted loads at the lake. However, because trapping affects both point and nonpoint loads, and the exerted loads are the prediction of interest, this would not result in a significant bias in the determination of the relative importance of different sources of loading.

4 Stream Network Delivery Model

The stream network delivery model relates the field scale loading estimates by land use and measured point source loads to the delivered or exerted load at Jordan Lake. Three types of factors are assessed: major stream delivery rates, representing the fraction delivered from point source discharges or the pour points of 14-digit HUCs during stream/river transport, trapping within impoundments, and local-scale trapping within 14-digit HUCs. All three factors serve to reduce the delivered nutrient load.

4.1 MAJOR STREAM DELIVERY RATES

Delivery through the major stream network is represented using a methodology similar to the transport component of the USGS SPARROW approach (Smith et al., 1997). SPARROW refers to spatially referenced regressions of contaminant transport on watershed attributes, and was developed based on nationwide USGS NASQAN monitoring of 414 stations. The model empirically estimates the origin and fate of contaminants in streams, and quantifies uncertainties in these estimates based on model coefficient error and unexplained variability in the observed data.

The SPARROW tool actually contains two portions, one to generate loads and one to account for mass transport through stream reaches. Our approach is to use GWLF to generate the loads at the 14-digit HUC scale and then apply the portion of SPARROW that estimates instream transport losses.

In SPARROW, nutrient mass reduction during transport is calculated using first order decay equations that are a function of time-of-travel:

$$C_t = C_o \cdot e^{-\delta t}$$

where:

- C_o = pollutant mass present at the upstream end of a reach
- C_t = pollutant mass present at the downstream end of a reach following travel time *t*
- δ = decay rate (1/day)
- t = time of travel (days)

Initial estimates of rates of nutrient transmission within the stream network were developed by RTI (Section 4.1.1). Comparison to FLUX load estimates during model calibration (Section 6) revealed that the reduction rates assumed for the Haw River mainstem based on the national SPARROW model were too high, consistent with the more recent North Carolina SPARROW model developed by McMahon et al. (2003). Therefore, a method was developed to modify the major stream delivery rates in the spreadsheet model, as described in Section 4.1.2. The adjustment factor on the loss rate parameter was then modified during calibration (Section 6) to achieve qualitative agreement with loads calculated by FLUX.

4.1.1 RTI Stream Delivery Model

In a previous project completed in 2002, the Project Partners contracted for the development of a nutrient loading and delivery model (JLNDM) to assess point source nutrient loads transported by the major tributaries within the lake's watershed (RTI, 2002). The foundation of the methodology used for the analysis presented herein, which relied on the SPARROW methodology for stream transport, was developed as part of the original work by RTI. Key steps in developing the model included: setting up the stream network and routing system below each municipal point source outfall; predicting daily stream flow and channel hydraulics for each stream reach; creating input files of historical and projected wastewater treatment plant (WWTP) effluent characteristics; and modeling the instream attenuation of nitrogen and phosphorus (Table 12). The delivery model development process involved deriving daily wastewater and instream flow and nutrient concentration and time-of-travel estimates based on effluent data, runoff records, and estimates of travel distances and stream channel characteristics. The principal technical challenge was to create an integrated data management and modeling application that managed the large and previously unrelated data; defined mathematical relationships describing the delivery of nutrients; and managed model output.

Table 12. Primary Model Specifications for RTI Stream Delivery Model

Model Component	Approach
Spatial domain	1-dimensional advective stream model Downstream boundary at stream/lake interface
Temporal domain	Daily time step Steady state for each day
State variables	Stream flow Total phosphorus (TP) and total nitrogen (TN) upstream of lake
Stream flow	Calculated daily for each reach based on analysis completed as part of the Cape Fear River Basin Model, gaged data, and drainage area calculated for each stream reach
Hydraulics	Assume stable channel, channelized flow Include stream width, depth, sinuosity, slope, velocity, time-of-travel
Instream kinetics	First order decay, variable by stream flow, based on analyses by USGS
Sources	Daily waste flow, total nitrogen, total phosphorus based on discharger monitoring data for Project Partners and several other facilities
Computational element	Stream reach as defined by US EPA Reach File Version 3

For this project, the previously developed application was modified and used to calculate nitrogen and phosphorus delivery from the outlet of small watersheds (14-digit hydrologic units, or HUs) within the basin discharging upstream of the lake. The steps performed to modify the application from the original study (RTI, 2002) to achieve this objective are listed below:

1) All point source discharger inputs were removed from the model.
2) Reaches associated with the downstream extent of each HU were identified as "outlet reaches" (Table 13). These reaches were used as the points of reference for routing nutrients through the stream network. No attempt was made by RTI to model delivery from headwater and tributary reaches within each HU. (Note: this is accounted for by the modifications in Section 4.3.)
3) Unit loadings were input to these outlet reaches. Unit loadings were defined based on daily streamflows derived from the Cape Fear Hydrology Model and the median instream total nitrogen (mg/l) and total phosphorus (mg/l) concentration obtained from instream monitoring. These concentration values were multiplied by streamflows to calculate daily loading values for each reach in the network. Daily values were averaged annually and by season (spring: March 1- May 31; summer: June 1-August 31; fall: September 1 – November 30; winter: December 1- February 28).
4) Node-to-node sequencing was determined for the HUs to allow for tracking the delivery from the source reach to the lake, through each node. Where more than one HU was tributary to a

downstream HU, it was assumed that the instream loss from the upstream nodes to the downstream node was proportionally allocated to each upstream node. This introduces a small bias into situations where upstream tributary HUs have very different flow lengths to the downstream node. Visual inspection indicates that this bias is likely very minimal.

5) The model code and input and output data structure were modified to perform the necessary calculations.

As with the original study, the model was applied using streamflow inputs from 1996-1998, the period available from the Cape Fear Hydrology Model. Additionally, the same assumptions for instream hydraulics and decay processes were employed. Percent delivery was calculated as the difference between the input load for each HU and the downstream reach located at the lake interface, as defined in the original application. Delivery from HU outlet to Jordan Lake was calculated for 44 of the 56 HUs in the entire watershed. All but two of these HUs discharge into the Haw River, with one HU representing the University Lake watershed on Morgan Creek, and one HU located on upper New Hope Creek. The remaining 12 HUs discharge directly into Jordan Lake (or define the lake proper), and were therefore not included in the analysis of instream transport.

Table 13. Hydrologic Unit Attributes for Stream Delivery Model

HU Code	Level	Downstream HU	RF3 Outlet Reach	Arm
03030002010010	8	03030002010040	3030002 24 0.00	Haw
03030002010020	8	03030002010040	3030002 25 0.00	Haw
03030002010030	8	03030002010040	3030002 73 0.00	Haw
03030002010040	7	03030002010050	3030002 23 7.68	Haw
03030002010050	6	03030002030010	3030002 23 0.00	Haw
03030002020010	9	03030002020020	3030002 33 0.11	Haw
03030002020020	8	03030002020030	3030002 29 9.65	Haw
03030002020030	7	03030002020070	3030002 29 0.00	Haw
03030002020040	8	03030002020060	3030002 38 0.00	Haw
03030002020050	8	03030002020060	3030002 39 0.00	Haw
03030002020060	7	03030002020070	3030002 37 0.00	Haw
03030002020070	6	03030002030010	3030002 28 0.00	Haw
03030002030010	5	03030002030050	3030002 22 0.00	Haw
03030002030020	5	03030002030050	3030002 19 0.00	Haw
03030002030030	6	03030002030040	3030002 21 0.34	Haw
03030002030040	6	03030002030050	3030002 20 0.00	Haw
03030002030050	4	03030002030080	3030002 18 2.70	Haw
03030002030060	4	03030002030080	3030002 83 0.00	Haw
03030002030070	4	03030002030080	3030002 17 5.42	Haw
03030002030080	3	03030002050010	3030002 16 0.00	Haw
03030002040010	5	03030002040030	3030002 45 0.80	Haw
03030002040020	6	03030002040010	3030002 46 0.00	Haw
03030002040030	4	03030002040100	3030002 43 0.00	Haw
03030002040040	5	03030002040030	3030002 893 0.00	Haw
03030002040050	5	03030002040030	3030002 44 0.00	Haw
03030002040060	5	03030002040030	3030002 68 0.00	Haw
03030002040070	4	03030002040100	3030002 50 0.00	Haw
03030002040080	5	03030002040070	3030002 52 0.00	Haw
03030002040090	5	03030002040070	3030002 86 0.00	Haw
03030002040100	3	03030002050010	3030002 40 0.00	Haw
03030002040110	4	03030002040100	3030002 41 0.00	Haw

HU Code	Level	Downstream HU	RF3 Outlet Reach	Arm
03030002050010	2	03030002050020	3030002 13 4.92	Haw
03030002050020	2	03030002050050	3030002 74 0.00	Haw
03030002050030	2	03030002050040	3030002 12 3.31	Haw
03030002050040	1	03030002050050	3030002 11 1.21	Haw
03030002050050	1	03030002050070	3030002 53 0.00	Haw
03030002050060	1	03030002050080	3030002 62 0.00	Haw
03030002050070	1	03030002050090	3030002 54 0.00	Haw
03030002050080	1	03030002050100	3030002 90 0.00	Haw
03030002050090	1	03030002060010	3030002 66 0.00	Haw
03030002050100	1	03030002060010	3030002 97 0.00	Haw
03030002060010	1	03030002060020	3030002 81 0.00	Haw
03030002060020	0	03030002060060	3030002 9 4.07	Haw
03030002060030	0	03030002060060	3030002 85 0.00	Haw
03030002060040	0	03030002060060	3030002 9 4.77	Haw
03030002060050	0	03030002060060	3030002 89 0.00	Haw
03030002060070	1	03030002060080	3030002 812.01	Morgan
03030002060080	0	03030002060060	3030002 8 2.55	Morgan
03030002060090	0	03030002060060	Multiple	Multiple
03030002060100	0	03030002060060	30300021446 0.00	Little Creek
03030002060110	1	03030002060130	3030002 7 7.72	New Hope Creek
03030002060120	0	03030002060060	3030002 91 0.00	Third Fork
03030002060130	0	03030002060060	3030002 7 4.36	New Hope Creek
03030002060140	0	03030002060060	30300021617 1.21	Northeast
03030002060150	0	03030002060060	30300021674 0.00	White Oak
03030002060160	0	03030002060060	3030002 3 2.34	Beaver

The RTI model, using national SPARROW loss rates, indicates that, on average 67 percent of the nitrogen and 78 percent of the phosphorus discharged from HUC outlets in the watershed is predicted to reach the lake. Annual delivery rates from HU outlets to the lake ranged from 27 percent to 91 percent, with lower delivery rates generally observed during the summer and fall lower flow seasons and from HUs located upstream in the Haw River watershed. These estimates do not, however, account for the effects of impoundments, nor do they include potential modifications to the SPARROW loss rate coefficients that may be appropriate for this basin.

4.1.2 Modification of the Stream Delivery Model

Estimates of instream losses during transport were calculated by RTI using a modification of the USGS SPARROW methodology (see previous section). In this approach, loss rate is given by an exponential decay on travel time: $e^{-\delta T}$, where δ is a loss rate and T is estimated travel time. Specification of δ was based on SPARROW national numbers (Smith et al., 1997) with a modification to address the observed phenomenon of greater losses in smaller streams, as shown in Table 14. RTI's modified approach retains the central tendency of the loss rate for flows below 1000 cfs reported by Smith et al.

Table 14. Default SPARROW and RTI Loss Rates (δ, per day)

Flow Regime	SPARROW (Smith et al., 1997)		RTI	
	Total N	Total P	Total N	Total P
< 1000 cfs	0.3842 (bootstrap) 0.3758 (parametric)	0.2680 (bootstrap) 0.2584 (parametric)	=-0.082·LN(flow) + 0.843	=-.058·LN(flow) + 0.607
1000 – 10000 cfs	0.1227	0.0956	0.1227	0.0956
> 10000 cfs	0.0408	0.0	0.0408	0.0

4.1.2.1 SPARROW Loss Rates for North Carolina

It is important to note that the loss rates used by RTI were not calibrated to observations in the Jordan Lake watershed. Indeed, they could not be calibrated because no estimates were available of the nonpoint source contribution to nutrient load. The results did, however, appear reasonable for smaller, effluent-dominated streams in which the known point source loading was the major portion of total transported load.

Subsequent research suggests that the nitrogen loss rates reported by Smith et al. (1997) may not be appropriate for North Carolina Piedmont rivers. Alexander et al. (2000) provided a reanalysis of SPARROW results for the Mississippi River basin, and estimated a slight reduction in the nitrogen loss rate for the 1,000 to 10,000 cfs category (0.118), which they subsequently applied on a national scale (Smith et al., 2003). Preston and Brakebill (1999) investigated nitrogen losses in the Chesapeake Bay watersheds and fit rates of 0.7595 (per day) for streams less than 200 cfs, 0.3021 for streams from 200 to 1000 cfs, and 0.0609 for streams greater than 1000 cfs. This fit shifts losses toward smaller streams, and provides a much lower loss rate in streams from 200 to 1000 cfs than the national SPARROW model. McMahon et al. (2003) attempted a similar application for nitrogen delivery in the Cape Fear, Neuse, and Tar-Pamlico basins in North Carolina, including several stations on the Haw River. Their loss rates are reported primarily on a per kilometer basis, but are also interpreted to a time basis, yielding 0.99 per day for small streams and 0.06 for large streams. The cutoff between small and large streams is defined by McMahon et al. at 37 cfs, rather than 1000 cfs. The result is once again a much lower rate of removal in streams with mean flow between 37 and 1000 cfs than would be estimated by the national SPARROW model.

The behavior of phosphorus in SPARROW models has been less well studied in the United States. However, work in New Zealand (Alexander et al., 2002) shows that phosphorus retention also dominantly occurs in smaller streams without impoundments. Alexander et al. found a high loss rate in streams with less than 35 cfs, and no significant losses in larger streams. While the results from New Zealand are not directly transferable to North Carolina, this study suggests that the national SPARROW model is likely to over-estimate phosphorus retention in rivers approaching the 1,000 cfs cutoff. However, run-of-river impoundments, such as are present in the Haw, could increase loss rates due to sediment settling.

4.1.2.2 Procedures for Modifying SPARROW Transmission Estimates

RTI calculated only delivery from point sources and 14-digit HUC pour points to Jordan Lake. These numbers can be modified to evaluate different SPARROW loss coefficients without re-running the RTI model.

Basic Correction

SPARROW transmission (delivery fraction) estimated with one loss coefficient (δ) can be converted to estimates with another loss coefficient (δ*) as follows:

The desired correction factor on the reported transmission is $e^{-\delta^* T} / e^{-\delta T}$. Let $k = \delta^*/\delta$, the ratio of the new to the original loss factor, and $R = e^{-\delta T}$, the reported transmission rate. Algebraic manipulation then yields an expression for the correction factor that eliminates T:

$$correction = e^{-LN(R)\cdot(1-k)}$$

Thus, the reported transmissions can be corrected without re-running the delivery model.

Composite Correction

It may be desirable to correct the transmission estimate only for larger, higher-order streams, as the work cited in the previous section suggests that it is primarily in the flow range from 200 to 1000 cfs that the national SPARROW estimates may introduce error into the calculation. Given two estimates of transmission to the terminus for two points along a flow path, R_1 (from an upstream, low-order position) and R_2 (from a downstream, higher-order position), it is desirable to correct only the portion of R_1 that is due to transmission from point 2 downstream to the lake. R_1 may be decomposed as $R_1 = R_{12} \cdot R_2$, where R_{12} is the (unreported) transmission rate from point 1 to point 2. Thus, $R_{12} = R_1/R_2$. If R_2 is corrected to a new value, R_2^* (using the methods in the previous section, for instance), R_1 may be re-estimated as $R_1^* = R_{12} \cdot R_2^*$.

4.2 TRAPPING IN IMPOUNDMENTS

There are a number of impoundments in the watersheds upstream of Jordan Lake. These impoundments can serve as effective traps of sediment and sediment-associated pollutants, such as phosphorus. Nitrogen can also be removed by impoundments, although removal rates are typically much lower than for phosphorus.

The effect of impoundments is not included in the RTI stream delivery model, but must be considered to obtain an accurate accounting of nonpoint nutrient delivery from the watershed. The major impoundments explicitly considered in the analysis are shown in Table 15. These lakes are generally located near the outlet of HUCs. Several smaller lakes (including Hunt, Higgins, and Richland) are located in upstream positions within HUCs and are not included in the model. Information on storage volumes differs widely for some of these lakes, and some appear to be reported incorrectly in the Cape Fear Basinwide Assessment Report. The volume of Reidsville Lake was corrected based on information supplied by the town, while the volume of Lake Brandt was corrected based on Greensboro information. Normal pool volumes of Cane Creek Reservoir and University Lake were obtained from OWASA reports.

Table 15. Larger Impoundments in the Jordan Lake Watershed

Impoundment	HU	Normal Pool Volume (m^3)
Reidsville Lake	03030002010010	$9.45 \cdot 10^6$
Lake Brandt	03030002020010	$7.96 \cdot 10^6$
Lake Townsend	03030002020020	$2.50 \cdot 10^7$
Lake Burlington	03030002030040	$1.50 \cdot 10^6$
Burlington Reservoir	03030002030030	$1.22 \cdot 10^7$
Graham-Mebane Reservoir	03030002030070	$8.70 \cdot 10^6$
Lake Macintosh	03030002040040	$2.90 \cdot 10^7$
Cane Creek Reservoir	03030002050030	$1.14 \cdot 10^7$
University Lake	03030002060070	$2.16 \cdot 10^6$

Nutrient removal in these lakes was approximated using the same second order sedimentation rate equations employed in the BATHTUB model (Walker, 1987). BATHTUB calculates average annual concentrations, and the trapping efficiency can be assumed equal to the reduction in concentration between inflow and in-lake concentrations. The average fraction transmitted through a lake depends on the inflow concentrations, the residence time, and the average depth. Equations for N and P, derived from Walker (1987), are:

$$P\ transmission = \frac{\sqrt{1 + 4 \cdot A \cdot P_i \cdot T} - 1}{2 \cdot A \cdot T \cdot P_i}$$

$$N\ transmission = \frac{\sqrt{1 + 4 \cdot B \cdot N_i \cdot T} - 1}{2 \cdot B \cdot T \cdot N_i}$$

where P_i and N_i are the inflow concentrations (µg/L), T is the residence time (volume divided by inflow, years), and A and B are empirical coefficients specified as $A = (0.17\ Q_s)/(Q_s + 13.3)$ and $B = (0.0045\ Q_s)/(Q_s + 7.2)$, in which Q_s is the overflow rate (m/yr), obtained by dividing the mean depth by the residence time.

Trapping by smaller impoundments (those not listed in Table 15) is not explicitly addressed in the model due to its large spatial scale. The effects of low head dams in the Haw River on nutrient transmission are also not explicitly modeled, and are not well understood at this time. However, the impact of these dams on travel time is incorporated into the SPARROW analysis, and thus increases estimated nutrient removal. Final calibration adjustments to the model (Section 6.2) implicitly account for the net effects of all such unmodeled components.

4.3 WITHIN-HUC NUTRIENT LOSSES

Trapping also occurs within the boundaries of each 14-digit HUC. As with stream delivery, this is not estimated using the GWLF delivery ratio approach. Instead, a SPARROW-type estimate of delivery to the pour point is made, on a seasonal basis.

SPARROW losses depend on time of travel, which can be calculated from distance and velocity. Assuming an average 2:1 aspect ratio for the shape of a HUC, the average travel distance for sources originating within a HUC, X (m), is $(A/2)^{0.5}$, where A is the area of the HUC in meters.

A variety of parametric and empirical methods are also available for velocity. For instance, the Manning equation is often used to estimate velocity based on channel cross section, slope and channel roughness. This type of approach provides a point estimate, and can be reliably extended to average velocity across a reach only if information is available on the changing channel geometry across the reach. More importantly, a point estimate of velocity may not be a relevant measure of the rate of pollutant transport, because it fails to take into account the effect of pools, riffles, dead zones, and so on (Burke, 1983). For analysis of time of travel observations across a stream reach and extrapolation to other flows, the empirical method of Leopold and Maddock (1953) is often used. This represents velocity as a power function of flow, $U = a\ Q^n$, where a is a function of site-specific characteristics and n is an exponent in the range 0.4 to 0.6, typically found to be around 0.43 (Barnwell et al., 1989).

Where segment-specific data are not available, various methods have been proposed to constrain the relationship based on other factors. For instance, Burke (1983) estimated reach velocities in Georgia as U = "$Q^a S_0^b (DA)^c L^d$, where U is flow-through velocity in ft/s, Q is flow in cfs, S_0 is slope in ft/mi, DA is drainage area in mi², and L is reach length in miles. The empirical coefficients ", *a, b, c* and *d* vary according to soil type and are summarized by Burke for four different geographic regions of Georgia. The coefficients vary significantly by region, and do not appear to be transferable to North Carolina.

Further, the explanatory variables are obviously correlated with one another; however, the general approach is applicable. NCDEM (1984) conducted a study on the development of a similar velocity equation for North Carolina streams, based on 125 velocity studies, and found that DA and L were not statistically significant explanatory variables. Their "Level B" velocity equation takes the following form:

$$U\ (f/s) = 0.124\ \frac{{Q_{act}}^{0.75}}{{Q_{avg}}^{0.35}}\ {S_0}^{0.29}$$

where Q_{act} is the "actual" flow of interest (cfs) and Q_{avg} is the average flow of the segment (cfs) and S_0 is slope in ft/mi. Note that for evaluation at average flow (with change of units to m/s) this reduces to

$$U\ (m/s) = 0.0378\ {Q_{avg}}^{0.4}\ {S_0}^{0.29}$$

in which the exponent on Q is in the range recommended by Barnwell et al.

Given the average travel distance and length, average travel time can be calculated. The fraction of N and P transmitted is then estimated using the standard SPARROW equations for small streams.

4.4 Wetland and Riparian Area Attenuation in the Upper New Hope Creek Arm of Jordan Lake

Most tributaries to the Upper New Hope Arm of Jordan Lake do not enter as unobstructed streams. Due to the flat topography, most influent streams have extensive meanders with riparian wetlands and multiple channels. The points of entry to Jordan Lake typically have excessive macrophyte cover in shallow water. In addition, flow from Little Creek and New Hope Creek is affected by seasonally-operated greentree impoundments. All of these factors may reduce delivered loads, requiring site-specific calibration.

4.4.1 Approach for Morgan Creek Total Nitrogen Analysis

Applying the SPARROW methods to lower Morgan Creek presents special challenges. It is clear that OWASA's discharge at present constitutes the majority of nitrogen load in Morgan Creek under low flow conditions. The RTI delivery model analysis, however, predicts a cumulative exerted point source load of TN from the OWASA plant that is slightly greater than the delivered TN load estimated by FLUX (Figure 14), even without accounting for nonpoint sources.

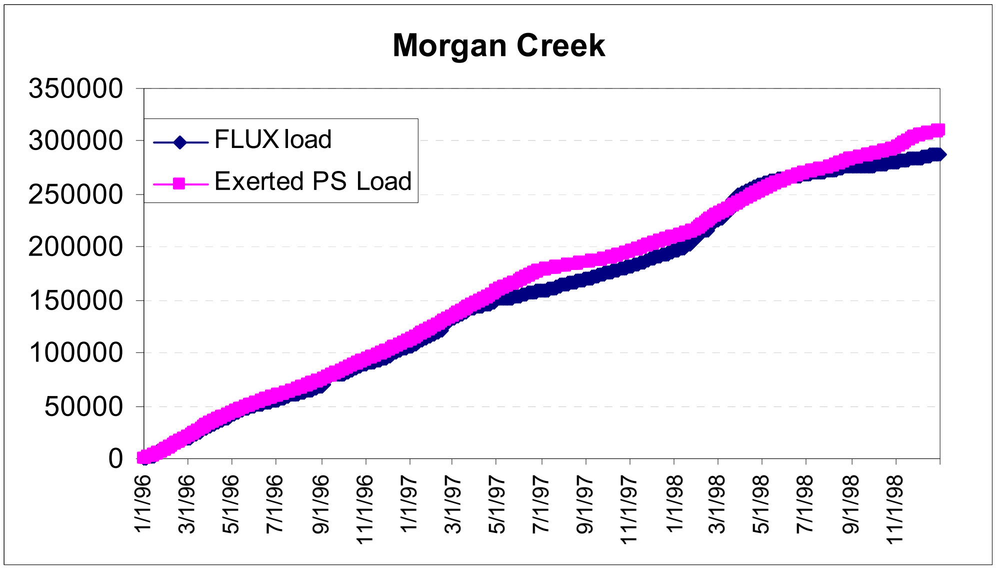


Figure 14. Comparison of Cumulative Total Nitrogen Load at Mouth of Morgan Creek Estimated by FLUX and Exerted Point Source Load Estimated by the RTI Delivery Model

There are a number of potential reasons for this discrepancy, including the following:

- Total nitrogen in OWASA effluent is measured only once per month; thus the interpolated estimates for intervening days are highly uncertain.
- First order decay estimates of nutrient instream loss are based on the national work of Smith et al. (1997). These estimates are likely to differ from actual site-specific conditions, which may include significant retention in the wooded meandering backwater of lower Morgan Creek.
- The RTI delivery model calculates travel time, and thus reduction in exerted load, based on output from the Cape Fear Hydrology Model. Where these estimates differ from actual flows, the estimated reduction may not be correct.
- There are potentially small biases in measurements of flow. In particular, the Morgan Creek stream gage was damaged by Hurricane Fran and flow estimates for the succeeding period are estimated values obtained from stage readings downstream.
- A small (but unquantified) reduction in total loads below the OWASA plant occurs as a result of diversions for irrigation at Finley Golf Course.

The exact cause of the discrepancy has not been determined, although it is suspected that it is due to a combination of several of the factors cited above.

A revised estimate of delivery in lower Morgan Creek can be obtained by comparing load upstream of OWASA with that at the FLUX station near the mouth of Morgan Creek. OWASA has periodically measured concentrations upstream of the Mason Farm plant as part of their discharge self monitoring. Examination of these data suggests that upstream concentration varies significantly at low flows, but is relatively constant at higher flows, which provide the majority of mass loading (Figure 15). This is the typical pattern for nitrogen, where subsurface pathways rather than surface washoff typically dominate loads. The presence of University Lake upstream also serves to dampen variability in high flow concentrations.

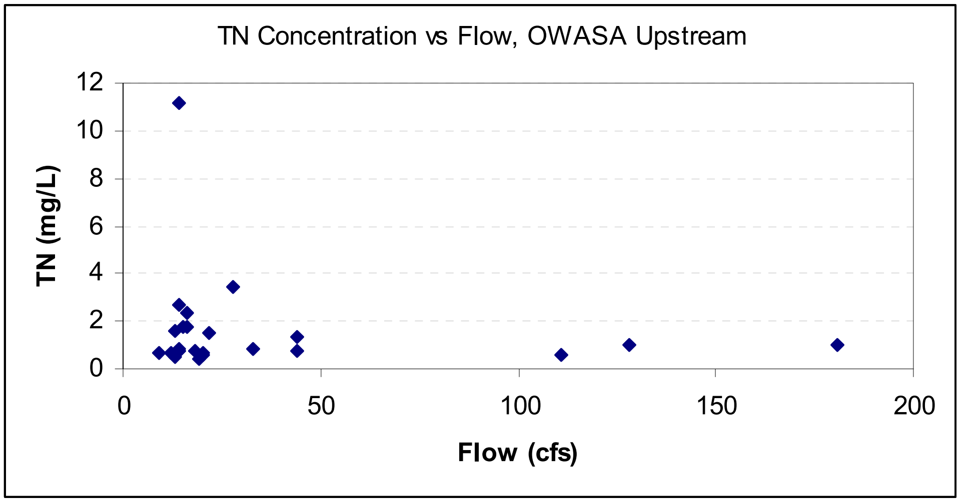


Figure 15. Total Nitrogen Concentrations Reported by OWASA Upstream of Mason Farm WWTP, Plotted against Flow

Based on these observations, it is appropriate to represent the upstream concentration as an approximately constant value, which was set to the median of the OWASA upstream observations, or 0.825 mg/L TN. The delivery ratio is also assumed to be approximately constant over time, based on the RTI analysis. The RTI analysis does calculate higher values of the delivery ratio for higher flows; however, the loading seen at these higher flows consists in part of wash-through of constituents stored during low flows. It is therefore most appropriate to use an estimate of delivery based on the comparison of discharged plus upstream loads and delivered loads over time. This yields an approximate delivery fraction of 69 percent for lower Morgan Creek, rather than the 92 percent predicted by RTI.

4.4.2 Morgan Creek Phosphorus

Comparison of the FLUX model to the RTI analysis for total phosphorus in Morgan Creek suggests that the delivered fraction of phosphorus is also likely overestimated. It stands to reason that, if nitrogen removal rates in this stream are significantly higher than the SPARROW estimates, phosphorus removal rates should also be higher. However, the concentrations of phosphorus upstream of the OWASA discharge are much more variable in time than nitrogen concentrations, so a direct analysis is more difficult. Accordingly, the delivery rate for phosphorus in lower Morgan Creek was taken as a calibration parameter, with the intent of obtaining an approximate match between model predictions and FLUX analysis of loads.

4.4.3 New Hope and Little Creek Nutrient Delivery

New Hope and Little Creek also have shallow, low gradient, meandering systems at their entrance to Jordan Lake. In addition, these two streams have greentree impoundments that are flooded during the winter to provide habitat for waterfowl and likely provide additional trapping. Thus, these creeks are also expected to exhibit elevated nutrient loss rates.

For New Hope Creek, a FLUX analysis supported by frequent observations is available just above the point of entry into Jordan Lake. Therefore, N and P loss rates for New Hope Creek can also be adjusted during calibration to provide an approximation of observed nutrient delivery from FLUX. Monitoring is not available for Little Creek. As the characteristics of the lower portions of this stream are similar to New Hope Creek the loss rates are assumed to be the same.

4.4.4 Northeast Creek

In Northeast Creek, the monitoring point is upstream, just below the wastewater treatment plant. Thus, there is not an available basis to calibrate delivery in this creek. In addition, Northeast Creek does not have significant restrictions to flow (no impoundments), a well-defined channel is present all the way to the lake, and the stream is subject to periodic flushing from the large amounts of impervious surface upstream. Therefore, no adjustments were made to loss rates in Northeast Creek.

4.5 Delivery Model Summary

Final calibration of the delivery model and resulting loss rates are discussed in Section 6. This section summarizes the performance of the delivery model (using those calibrated values) to provide a visual example of the behavior of the model.

Figure 16 shows the reduction in nonpoint nitrogen load that occurs during transport from Troublesome Creek (HUC 2010010 near Reidsville, in the upper part of the Haw watershed) to Lake Jordan for April-June 1996. The initial estimated nitrogen load generated from land surfaces in the HUC is over 11,000 kg. This is first reduced by local-scale trapping within the HUC and significant further reduction occurs by trapping in Reidsville Lake near the mouth of the HUC. Additional trapping occurs during transport through the Haw River, with results shown at Saxapahaw (32.5 miles below Reidsville Lake) and at Bynum (another 23 miles below Saxapahaw), just upstream of Jordan Lake. Of the initial load generated in this subwatershed, only 23 percent reaches Jordan Lake.

Figure 17 compares the delivery of nonpoint and point source nitrogen from the entire Haw River for 1996. Figure 18 provides a similar comparison for nitrogen loading to the listed segments of the Upper New Hope Arm of Jordan Lake. The nonpoint load is subject to three types of removal: retention in the local HUC, removal by lakes, and removal during instream transport. In contrast, the point source loads are subject only to removal during instream transport (none of the point sources are upstream of major impoundments). As a result, the delivered fraction for point sources is on average much higher than the delivered fraction for nonpoint sources, even though point and nonpoint sources are subject to the same instream removal processes.

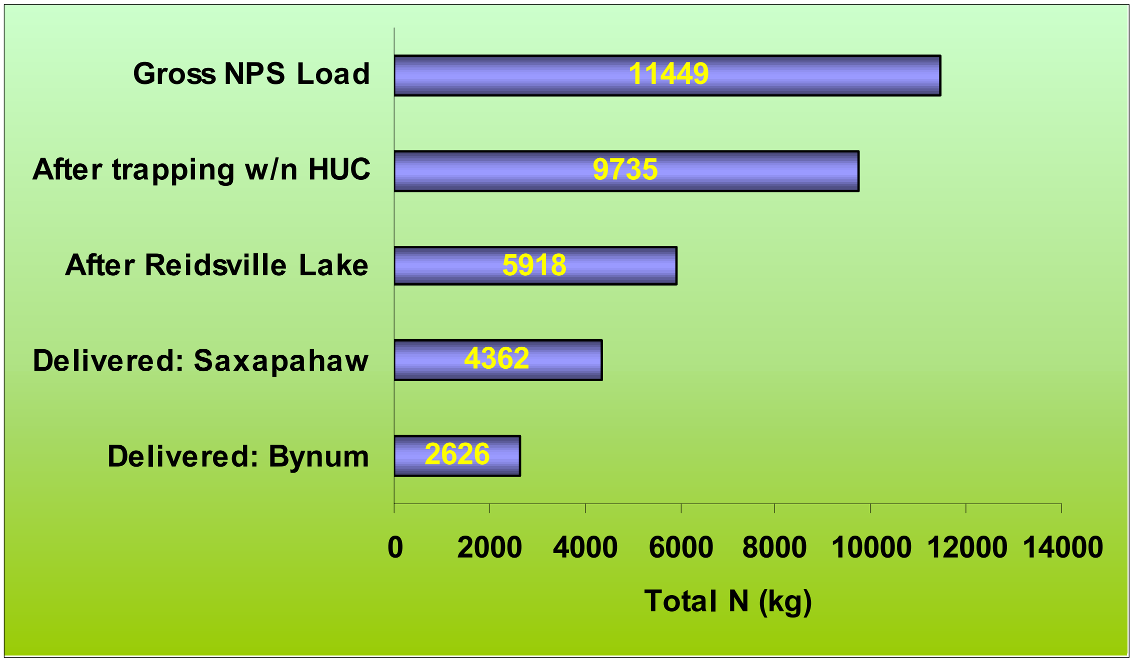


Figure 16. Example Reduction of Total Nitrogen Nonpoint Load from Troublesome Creek (HUC 2010010), April-June 1996

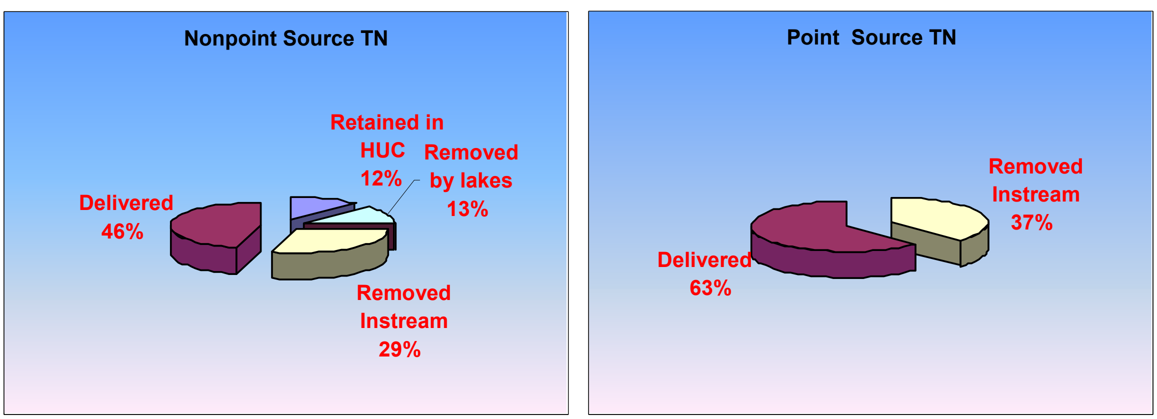
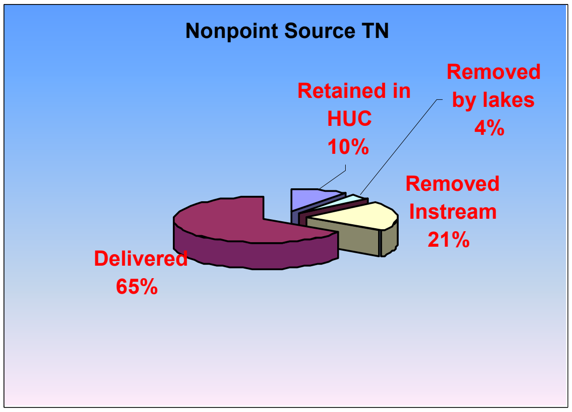


Figure 17. Example Comparison of Point and Nonpoint Total Nitrogen Delivery from the Haw River, 1996



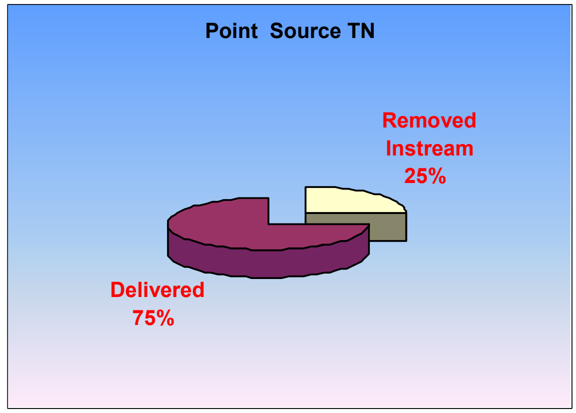


Figure 18. Example Comparison of Point and Nonpoint Total Nitrogen Delivery to the Listed Segments of the Upper New Hope Arm of Jordan Lake

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5 Jordan Lake Watershed Spreadsheet Tool

5.1 CREATION OF THE SPREADSHEET TOOL

As discussed in Section 3, GWLF was used to generate unit loading rates for Jordan Lake watershed land uses within 14 nutrient response zones. Loading rates for each land use were tabulated for each of the 58 hydrologic units within the basin based on their nutrient response zone. The loading rates were then multiplied by the corresponding land use areas within each hydrologic unit, and the loads were summed to provide the total nonpoint load for each hydrologic unit. Since GWLF produces output on a monthly basis, it was possible to calculate loads for any time period during the 10-year model run.

Four of the residential land uses had two possible loading rates – for areas that are sewered versus areas that use onsite wastewater treatment. Since no basin-scale data were available showing the distribution of sewer lines or septic systems, Tetra Tech assumed that sewer use would occur primarily inside municipal boundaries. Therefore, these land uses were assigned the lower sewered loading rate when they fell within municipal boundaries (as of year 2000), or were assigned the higher onsite treatment rate when they fell outside of municipal boundaries. The two remaining residential land uses (with housing densities of two or more units per acre) were assumed to be entirely sewered. A small portion (less than five percent) of the two high density land uses fell outside of municipal boundaries, but tended to be close to municipalities.

Monthly unit loads and flows were summed from GWLF output on a seasonal and annual basis and were entered into the spreadsheet tool for each hydrologic unit. Land use within each hydrologic unit was also entered into the tool, thus providing an environment that facilitates the development of scenarios with differing land use and loading rates. Total nitrogen and total phosphorus loads were then calculated for each hydrologic unit on a seasonal and annual basis.

The nonpoint source components of the Stream Network Delivery Model were implemented in an iterative fashion since the mainstem delivery is influenced by the other nonpoint reductions. First, the delivery ratio within each hydrologic unit was applied to the load, resulting in a reduced load at the mouth of each hydrologic unit.

Next, the delivery ratio for trapping within impoundments was applied to the nonpoint load entering each impoundment. The delivered load entering each lake and average GWLF model flow were used to calculate the average TN and TP concentration within the lake. The impoundment trapping factor was calculated as discussed in Section 4.2, and applied to the nonpoint load entering the lake. There were no point source loads entering any of the lakes. Two lakes are influenced by upstream

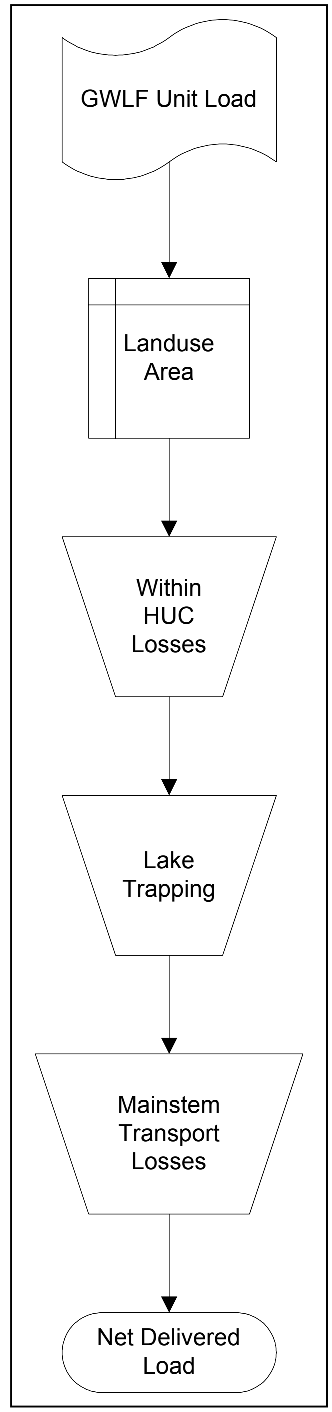

Figure 19. Sequencing to Calculate Delivered Nonpoint Source Load

impoundments (Lake Brandt is upstream of Lake Townsend and Burlington Reservoir is upstream of Lake Burlington), so the load exiting the two upstream lakes was used as the upstream nonpoint load entering the downstream lakes.

Finally, the nonpoint load leaving each hydrologic unit (or each lake, for hydrologic units that drain to a lake) was further reduced using the mainstem delivery ratio. The final load calculated for each hydrologic unit represented the net load reaching each of the representative outfall locations. Total loads reaching each outfall location were summed for the hydrologic units upstream of the location.

Point source loads were reduced by mainstem delivery ratios as well. During calibration, monthly loads were calculated from available Discharge Monitoring Report (DMR) data from the major WWTPs (Table 16). Minor point sources, such as package WWTPs, are not included in the model as their load contribution is insignificant at the basin scale. In most cases, communities served by such minor WWTPs have been simulated as unsewered (because they are outside municipal boundaries), so a load component for these communities is implicitly approximated as a septic tank load.

The monthly load from major WWTPs was assumed to be the product of total monthly flow and the concentration of total nitrogen or total phosphorus measured during the same month. For many dischargers there was one measurement per month for these parameters, but the average concentration was used in cases where more than one measurement was made. Monthly reduction ratios were calculated using the stream delivery model, and total loads reaching the representative outfall locations were summed on a seasonal and annual basis.

Table 16. Major WWTPs Included in the Model

NPDES #	Plant Name	Municipality	Receiving Tributary
NC0023868	East Burlington WWTP	Burlington	Haw River
NC0023876	South Burlington WWTP	Burlington	Haw River
NC0047597	South Durham WRF	Durham	New Hope Creek
NC0026051	Durham County Triangle WWTP	Durham County	Northeast Creek
NC0021211	Graham WWTP	Graham	Haw River
NC0024325	North Buffalo Creek WWTP	Greensboro	Haw River
NC0047384	T.Z. Osborne WWTP	Greensboro	Haw River
NC0047384	Mebane WWTP	Mebane	Haw River
NC0025241	Mason Farm WWTP	OWASA	Morgan Creek

5.2 Deliverable Spreadsheet Tool

Tetra Tech produced a deliverable version of the spreadsheet model suitable for testing and analysis of loading scenarios. The tool is a self-contained Excel spreadsheet with all the pertinent data and calculations needed for determining seasonal and annual nonpoint loads. Point source loading is not included in the deliverable spreadsheet tool as this may be calculated separately using the results provided by RTI (2002). Inputs to the spreadsheet tool include the following:

- Land use by hydrologic unit (includes residential land use calculated directly from parcel data where available)
- TN and TP loading rates by season, land use, and subregion
- Proportions of less dense residential classes served by septic by hydrologic unit
- Reach travel distance and mean stream velocity by hydrologic unit (used for within-hydrologic unit delivery)
- Impoundment properties (average inflow, mean depth, lake volume)

Seasonal TN and TP loading rates are calculated for each land use in each hydrologic unit. Septic and sewered rates are area-averaged to produce an aggregate rate for less dense residential land use classes. Within-hydrologic unit delivery and impoundment delivery are calculated within the model, and the adjusted seasonal mainstem delivery rates by hydrologic unit are included. Seasonal and total TN and TP loads are calculated before and after delivery reductions for each hydrologic unit. Hydrologic unit areal loading rates and overall delivery are also shown, as well as final delivered loads by land use and hydrologic unit. Seasonal loads, overall annual loads, and annual loads by land use are summarized by tributary arm.

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6 Calibration and Uncertainty Analysis

Model calibration was performed for the 1996-1998 time period, which corresponded to the availability of the detailed time series of point source reduction ratios calculated by RTI using the CFHM hydrology ratios. Model results were compared to FLUX analysis estimates of actual load in each of the tributary arms (Haw River, Morgan Creek, New Hope Creek, and Northeast Creek). The FLUX analyses were performed previously for the Jordan Lake nutrient response model (Tetra Tech, 2002). An additional FLUX analysis was performed at an intermediate location on the Haw River mainstem using data from the DWQ monitoring station at Saxapahaw, NC (station B2000000). Since FLUX estimates loads from actual monitoring data, both delivered point source and nonpoint source loads were included in the calibration.

6.1 FLUX ANALYSES

While the calibration is performed on 1996-1998 results, the FLUX models used in the calibration are based on longer periods of data, running through 2001, and are the same analyses used to drive the revised lake model (Tetra Tech, 2003b). The FLUX analyses are themselves subject to considerable uncertainty. These are best estimates of load based on continuous monitoring of flow and intermittent, point-in-time measurements of concentration. The resulting load estimates depend on the correlation that is inferred between flow and load. This is particularly important for high flows, which can transport much of the load, as the amount of high flow sampling is limited and loads during these conditions are extrapolated from observations at lower flows.

The FLUX model provides a coefficient of variation (CV – standard deviation divided by the mean) that summarizes the quality of fit between predicted and observed loads (where the observed loads are constructed from instantaneous concentration times flow). Phosphorus is predicted directly as total phosphorus, whereas total nitrogen is estimated as the sum of nitrate nitrogen and total Kjeldahl nitrogen. The final FLUX models and their CVs are summarized in Table 17.

Table 17. Final FLUX Models for Jordan Lake Tributaries

Tributary	Model Type	Stratification	Period	CV
Nitrate Nitrogen				
Haw River	Regression #3	Seasonal	1/1/83 – 12/31/01	0.038
Morgan Creek	Regression #3	Flow	1/1/84 – 12/31/01	0.044
New Hope Creek	Regression #1	Flow + Seasonal	1/1/95 – 12/31/01	0.042
Northeast Creek	Regression #3	None	10/1/95 – 12/31/01	0.088
Total Kjeldahl Nitrogen				
Haw River	Regression #1	Flow	1/1/86 – 12/31/01	0.054
Morgan Creek	Regression #1	None	1/1/84 – 12/31/01	0.061
New Hope Creek	Regression #1	Seasonal	1/1/87 – 12/31/01	0.043
Northeast Creek	Regression #3	Flow	10/1/95 – 12/31/01	0.078
Total Phosphorus				
Haw River	Regression #1	Flow	1/1/89 – 12/31/01	0.087
Morgan Creek	Regression #1	Flow + Date	1/1/88 – 12/31/01	0.051
New Hope Creek	Regression #1	Flow	1/1/89 – 12/31/01	0.049
Northeast Creek	Regression #3	Flow	10/1/95 – 12/31/01	0.078

A span about the mean of plus or minus one standard deviation is approximately equivalent to 67 percent of the probability density, while plus or minus two standard deviations should encompass about 95 percent of the probability. A range up to two times the CV can thus be taken as a measure of the expected percentage variability about the FLUX estimate. The magnitude of the CVs reported in Table 17 indicates that there is little to be gained by requiring the fit between the watershed model and FLUX results to be closer than about 10 percent.

Accordingly, the default delivery model assumptions were adjusted when a consistent bias appeared to be present (greater than 10 percent error).

6.2 Delivery Model Calibration

The model output was compared with the FLUX analysis estimates of load in Morgan, New Hope, and Northeast Creek to perform a calibration consistency check on watershed loading predictions. Stream delivery ratios were adjusted to address any consistent bias between the two estimates.

6.2.1 Haw River

As described in Section 4.1, there is evidence to suggest that the loss rates in the national SPARROW model likely over-estimate nitrogen loss in larger rivers, such as the Haw. Comparison of the watershed model results using the RTI delivery model, without modification, to FLUX observations at Bynum indeed shows a significant downward bias, suggesting that loss rates are too high. Accordingly, the nitrogen loss rate was reduced for the larger mainstem portion of the Haw, assumed to be the reaches from the confluence of the Haw River and Reedy Fork at Altamahaw, NC to Jordan Lake. No changes were made in loss rates for smaller streams.

A much improved fit to FLUX estimates of total nitrogen is obtained if the loss rate in the Haw mainstem is reduced to 65 percent of the national SPARROW estimate. This changes the average loss rate for nitrogen from 0.384 to 0.25 per day.

In contrast to nitrogen, the national SPARROW loss rates appear to over-estimate phosphorus delivery to Bynum. This is likely due to the presence of a number of run-of-river hydropower impoundments on the Haw mainstem. These impoundments trap sediment, which in turn will reduce the throughput of phosphorus, which is particle-reactive. In contrast, nitrogen species are primarily present in dissolved form and much less sensitive to reduction by sedimentation.

As with nitrogen, no change was made to the RTI estimates of phosphorus loss in smaller streams. However, an adjustment was made to the mainstem Haw reduction rates to achieve an approximate match with FLUX results. Setting a factor of 1.3 on the RTI estimates of phosphorus loss rates in the mainstem provides a good match. This is equivalent to a loss rate of $\delta = 0.3454$ for streams with flow less than 1000 cfs.

As a check on model performance for nitrogen delivery, a FLUX analysis was also developed for the Haw River at Saxapahaw. Monitoring data here are available through 1999 only, and flow is not gaged at Saxapahaw, but instead must be prorated from Bynum. These factors make FLUX estimates at Saxapahaw much less reliable than those at Bynum; still, the comparison provides a useful qualitative indication of model performance. Over the 1996-1998 period, the total nitrogen load at Saxapahaw estimated by the spreadsheet tool is 4,135 metric tones, while the FLUX estimate is 4,090 tons. This difference amounts to only 1.1 percent. In 1997, the spreadsheet estimate of load is less than the FLUX estimate at both Saxapahaw and Bynum; however, in 1996 and 1998 the spreadsheet estimate was about 7 percent greater than FLUX at Saxapahaw, but was 6 percent lower at Bynum for 1996, and essentially equal to FLUX at Bynum for 1998. The analysis at Saxapahaw thus indicates general agreement further up the Haw, without consistent sign to the error, and provides additional confirmation of the spreadsheet results.

6.2.2 Morgan Creek

RTI did not develop an estimate of nutrient reduction in transit through lower Morgan Creek (downstream of University Lake), as this HUC empties directly to the lake. However, RTI did develop estimates of transport from OWASA to the lake. For Morgan Creek, nitrogen transmission was adjusted to the value obtained from the upstream-downstream analysis of loading from the OWASA plant, as described in Section 4.4.1 (factor of 0.688). A comparable or greater adjustment is expected for phosphorus, and factor of 0.5 provides good agreement with the FLUX results.

6.2.3 New Hope Creek

As described in Section 4.1.2, increased trapping (and decreased transmission) of both nitrogen and phosphorus is expected for New Hope Creek. As with Morgan Creek, RTI estimates are for delivery from the WWTP. In the case of lower New Hope, this WWTP is located well down in the watershed, and loss rates for the general load originating in the HUC are likely to be higher for this reason as well. Approximate calibration to FLUX results is achieved by applying factors of 0.8 and 0.7 for nitrogen and phosphorus transmission, respectively, to RTI estimates of delivery from Durham Southside WWTP. The same assumptions are applied to Little Creek, which is not monitored but has a similar physical configuration near the lake.

6.2.4 Northeast Creek

Water quality monitoring in Northeast Creek takes place at SR 1100, less than a mile below the Durham Triangle WWTP and about 3 miles upstream of Jordan Lake. Monitoring and FLUX estimates for Northeast Creek thus do not provide a basis for calibration adjustment of loss rates. As discussed in Section 4.4.4, it is likely that loss rates in Northeast Creek may be lower than those in New Hope Creek. Therefore, no modifications were made to the delivery rates calculated by RTI.

For comparison to FLUX, separate load estimates can be calculated for the 44 percent of the Northeast Creek HUC that is upstream of the monitoring point. This comparison tends to show an underestimate of nitrogen load and an overestimate of phosphorus load by the model relative to FLUX, but does not provide a firm basis for revision. Much of the load in Northeast Creek derives from the Durham Co. Triangle WWTP, so the discrepancy, if real, could be due to any or all of a number of factors, including nonpoint unit loading rates, uncertainty in the estimate of WWTP loads, or stream delivery to SR 1100.

6.2.5 Comparison of Watershed Model and FLUX Loads, 1996-1998

After the adjustments to instream loss rates described in Sections 6.2.1 through 6.2.4, the model provides a good approximation of the FLUX estimates of loads for the calibration period. Apparent percent differences between the model and FLUX estimates are less than or equal to 10 percent, except for phosphorus in Northeast Creek. The difference in phosphorus for Northeast Creek is primarily due to an over-estimation in 1998, and could reflect an inaccurate estimate of the point source loading component, estimated at 43 percent of the total phosphorus load for 1998. Table 18 provides a comparison of FLUX and model loads by year, while Figure 20 and Figure 21 compare the three year sums.

Table 18. Watershed Model Comparison to FLUX Estimated Loads, 1996-1998 (metric tonnes)

Stream	Model				FLUX				Percent Difference
	1996	1997	1998	Total	1996	1997	1998	Total	
Total Nitrogen									
Haw	2,006	1,251	1,858	5,115	2,142	1,460	1,859	5,461	-6.3%
Morgan	127	91	122	340	104	102	118	324	4.9%
New Hope	205	154	165	523	184	171	189	544	-3.7%
Northeast	116	76	124	316	134	102	114	351	-10.0%
Total Phosphorus									
Haw	417.0	159.4	361.2	938	328.0	214.4	358.6	901	4.1%
Morgan	8.6	3.8	8.2	21	6.0	5.6	9.3	21	-1.4%
New Hope	27.7	13.3	22.8	64	23.5	21.4	24.8	70	-8.4%
Northeast	14.6	8.5	14.8	38	13.5	8.6	10.2	32	18.0%

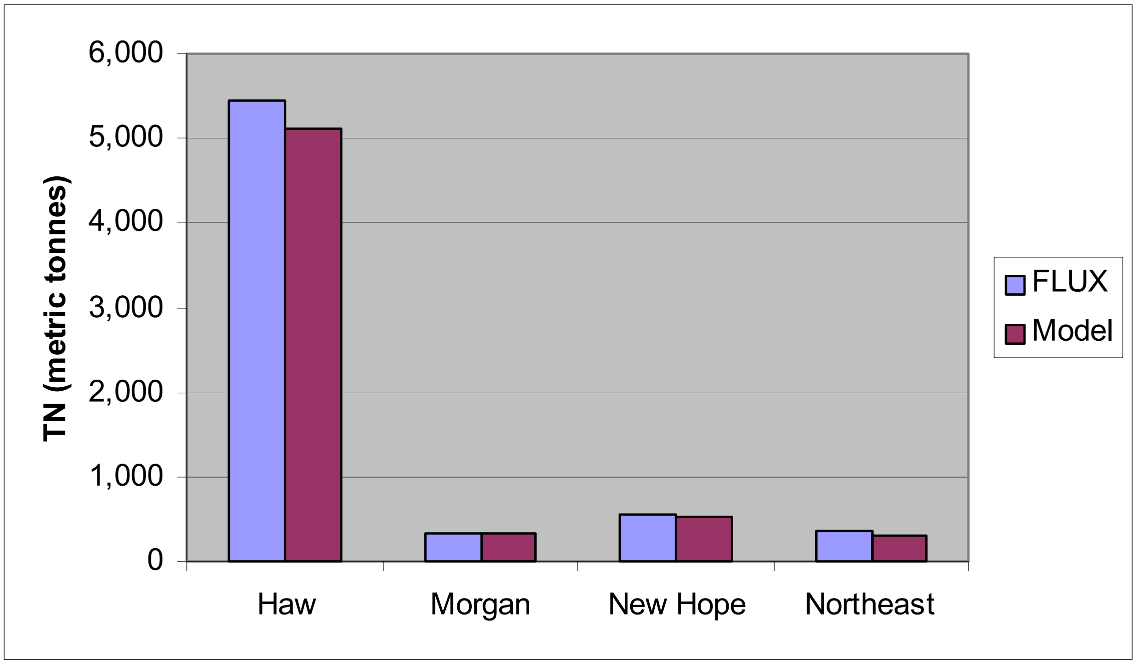

Figure 20. FLUX and Modeled Total Nitrogen Load, 1996-1998 Sum

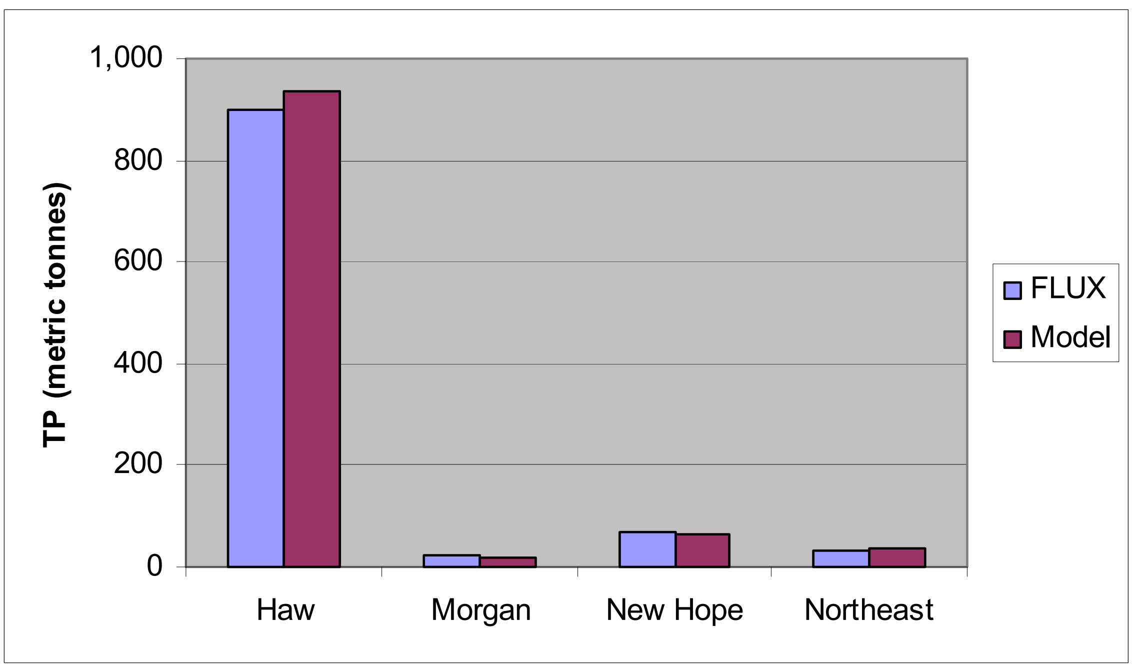

Figure 21. FLUX and Modeled Total Phosphorus Load, 1996-1998 Sum

6.3 Uncertainty Analysis

Watershed models of nutrient loading are inherently subject to high levels of variability, consisting of both uncertainty and natural variability. The natural variability arises because of year to year changes in meteorology, plant/growth cover, and land management. Uncertainty reflects the facts that simulation models are, at best, an approximation of reality, and the parameters of simulation models are not known with a high level of precision. Natural variability, or at least that part of it due to meteorology, is best addressed by simulation over a number of years that provide a selection of different weather patterns. This section focuses on the portion of variability that is due to prediction uncertainty.

The Jordan Lake watershed nonpoint simulation model consists of two basic components: the GWLF model of load generation and the SPARROW model of nutrient delivery. Uncertainty in these two components is multiplicative for nonpoint loads. The SPARROW component also affects the estimation of point source load delivery. Both components are addressed below; however, SPARROW is addressed first, because it affects both point and nonpoint load estimation.

For SPARROW, Smith et al. (2002), in presenting the revised national SPARROW model, provide 90 percent confidence limits on the delivery coefficients, based on bootstrap analysis in which the model is repeatedly fit with random sites deleted from the analysis. For total nitrogen, the 90 percent confidence limits on the delivery parameter is plus or minus 27 percent of the best fit value (for flows less than 1000 cfs). For total phosphorus, the 90 percent confidence limits are plus or minus about 31 percent. The bootstrap confidence limits are actually slightly asymmetric, but the symmetric approximation is close. These estimates can be used to assess the effects of uncertainty in loss rates on model predictions. However, the effect on estimated loads is nonlinear, as the parameter enters into an exponential formulation on travel time.

Application of the bootstrap confidence limits to stream delivery in the Jordan watershed changes estimates of annual average delivered load by approximately ± 3 percent during the calibration period. Thus, the uncertainty associated with loss rate estimates appears small. Significantly greater uncertainty is likely due to errors in estimation of travel time and unmodeled seasonal variation in removal during transport. These sources of uncertainty apply to both point and nonpoint load estimation, as noted above.

For nonpoint load generation, the GWLF model provides a highly simplified representation of actual load generation processes. While GWLF has been widely used, no comprehensive analyses of uncertainty in model predictions are available in the literature. Some information is, however, available from applications to specific sites. Work of Schneiderman et al. (2002) in rural New York state suggests that uncertainty in GWLF predictions of cumulative nutrient load, without modifications to the model, is on the order of 20 percent. However, this uncertainty includes uncertainty in both load generation and transport in a relatively large watershed.

Information on uncertainty in GWLF predictions of nutrient loading for smaller watersheds in North Carolina is available from local model applications (Cadmus, 1995 and 1996). The Falls Lake study (Cadmus, 1995) documents errors in the prediction of four-year cumulative phosphorus loads relative to FLUX analyses of 4.4 percent for Little River and 2.2 percent for Flat River. While these are post-calibration results, the calibration used the same parameters for both watersheds and is thus robust. A good fit was also obtained for total nitrogen in these watersheds, although results for individual months show considerably more variability. In the Cane Creek study (Cadmus, 1996), the error in cumulative loads relative to FLUX estimates over four years was similarly low (9.6 percent for total nitrogen and 0.4 percent for total phosphorus). However, reanalysis of the results shows that the average absolute error of seasonal (3-month) predictions was much larger, amounting to 36 percent of the mean for total nitrogen and 53 percent of the mean for total phosphorus.

These results indicate that GWLF is much better at predicting long-term loads than individual seasonal loads. This arises in large part because of the simplified approach taken in GWLF to sediment, and sediment-associated pollutant, washoff, which is not able to capture the timing of load delivery to streams.

GWLF application for the majority of the Jordan watershed is not calibrated to site-specific observations (although it uses calibrations from watersheds in the area), which will increase uncertainty. It appears reasonable, based on the Cadmus studies, to assume that uncertainty in the estimation of cumulative loads is on the order of 10 percent. The load generation and transport uncertainties are multiplicative. If the transport uncertainty is taken as ± 5 percent, this leads to a range from –14 to +16 percent about the central estimate.

Some further evidence on uncertainty is provided by the comparison of 1996-1998 total loads (point and nonpoint) from the model and FLUX. As noted in Section 6.2.5, error relative to FLUX on annual loads appears to be on the order of ± 10 percent. This results, however, from adjustment of loss rates to achieve a better fit.

Bringing together all these lines of evidence suggests that the total uncertainty on cumulative nutrient loads is likely to be on the order of 20 percent, consistent with Schneiderman et al. (2002). Uncertainty in the estimates of loads for individual seasons is undoubtedly much greater, on the order of about 50 percent. Uncertainty in model estimates of loads for individual years should fall between these ranges.

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7 Watershed Model Results

7.1 Long-term Analysis of Nonpoint Loading Sources

The long-term seasonal analysis of nonpoint loads is based on average loading rates and stream delivery by season. Average rates were calculated based on 10 years of GWLF simulation, from April 1991 to March of 2000. Source unit loading rates by land use (per acre) are shown in Appendix A. The average total nonpoint nitrogen and phosphorus loads delivered to the lake (exerted load), by tributary watershed and season, are summarized in Table 19 and Table 20.

Table 19. Average Nonpoint Total Nitrogen Loads (lbs) Delivered to Jordan Lake by Season and Tributary

	Jan-Feb-Mar	Apr-May-Jun	Jul-Aug-Sep	Oct-Nov-Dec	Annual
Haw River	1,110,429	521,678	465,069	328,336	2,425,512
Morgan Creek	45,879	20,563	15,401	15,949	97,792
New Hope Creek	96,905	42,493	45,859	40,946	226,203
Northeast Creek	68,580	28,790	36,390	29,010	162,770
Other Watersheds	224,231	94,092	88,273	75,295	481,891
Total	1,546,024	707,616	650,992	489,536	3,394,168

Table 20. Average Nonpoint Total Phosphorus Loads (lbs) Delivered to Jordan Lake by Season and Tributary

	Jan-Feb-Mar	Apr-May-Jun	Jul-Aug-Sep	Oct-Nov-Dec	Annual
Haw River	265,386	60,261	160,325	60,808	546,780
Morgan Creek	5,135	1,228	2,910	1,513	10,785
New Hope Creek	18,860	5,779	11,010	6,822	42,472
Northeast Creek	12,084	4,257	7,289	4,925	28,554
Other Watersheds	41,930	10,656	24,939	12,105	89,630
Total	343,395	82,181	206,473	86,173	718,221

Considerable differences exist in the source strength of exerted load at the lake, as shown in Figure 22 and Figure 23. Exerted loading rates per acre are higher for those HUCs that have a greater proportion of land uses, such as agriculture, residential, and commercial uses, that produce a higher rate of edge-of-field loading. However, exerted loading rates are reduced for HUCs that have a long travel path to the lake.

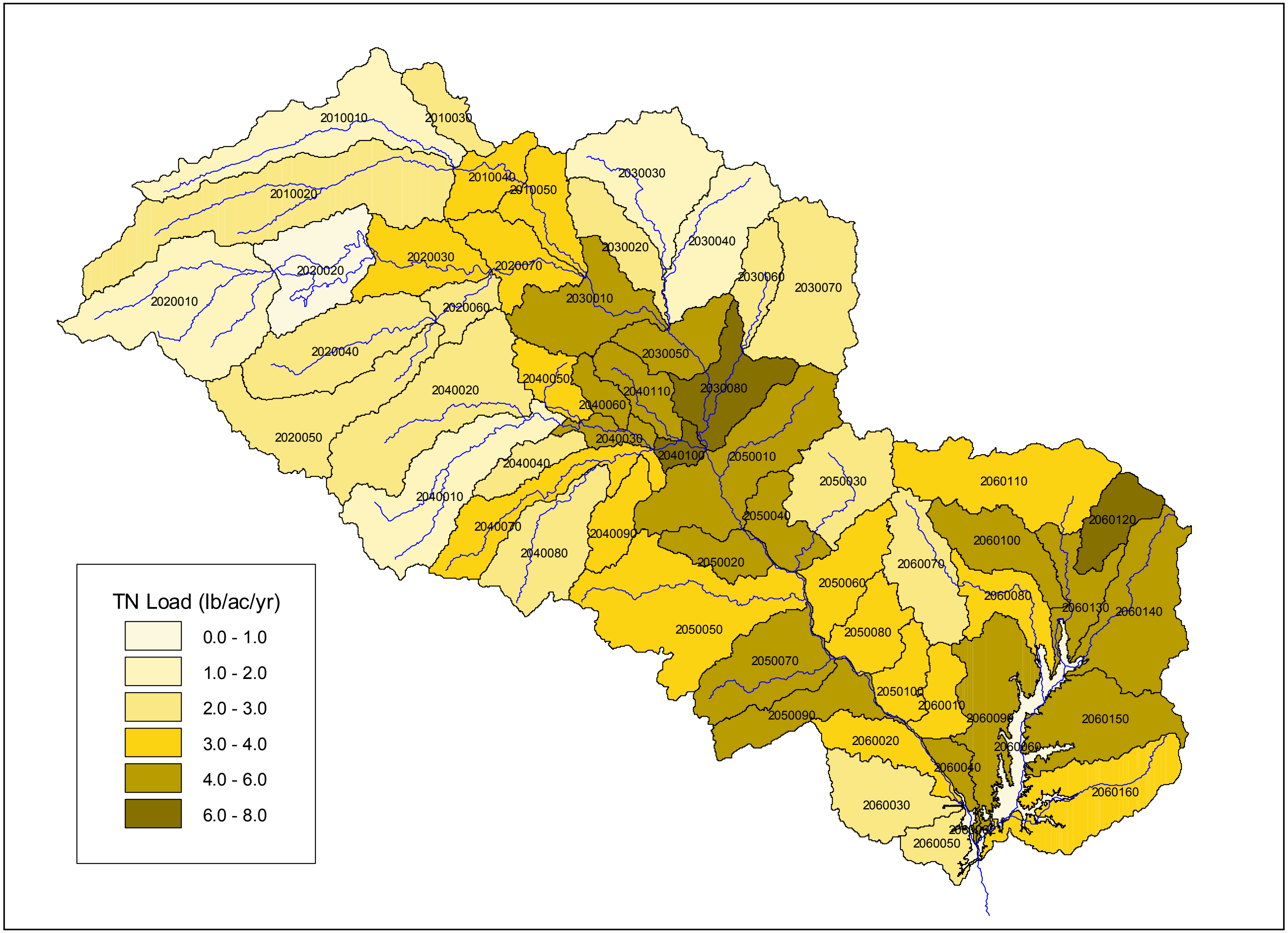

Figure 22. Total Nitrogen Nonpoint Loading Rates Exerted at Jordan Lake, by HUC

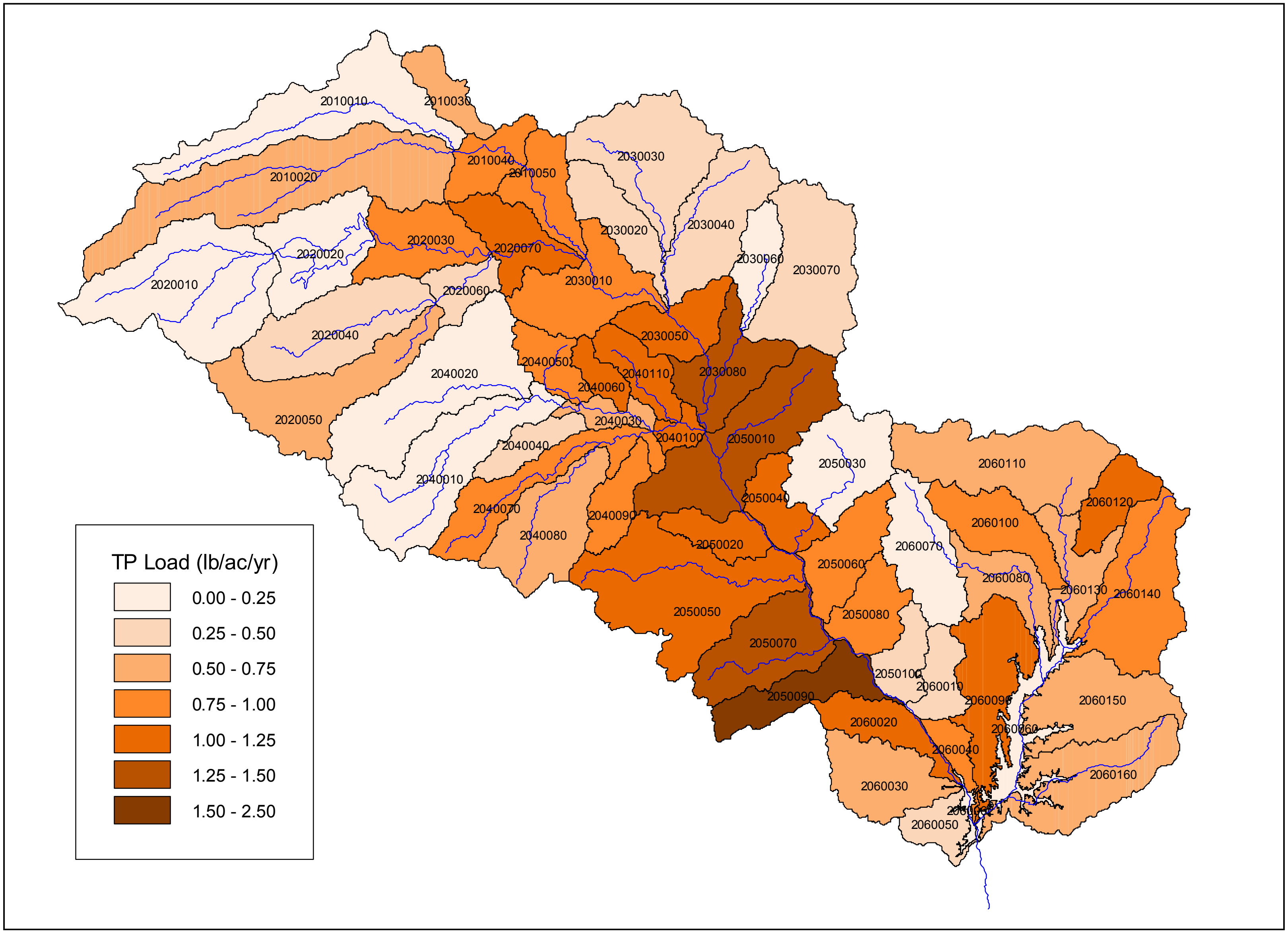

Figure 23. Total Phosphorus Nonpoint Loading Rates Exerted at Jordan Lake, by HUC

7.2 Relative Importance of Point and Nonpoint Source Loading

7.2.1 Total Loading to Jordan Lake

Figure 24 shows the percentage breakdown between point and nonpoint load sources delivered to Jordan Lake as a whole, while Figure 25 shows load sources to the Haw River and Upper New Hope arms of the lake. In these figures, the nonpoint loads represent the long-term average derived from a 10-year simulation with the watershed model, while the point source loads represent the average delivered load for 1996-1998, the period for which RTI conducted a detailed analysis. The percentage contribution of point sources to nitrogen loads is similar to previous estimates (e.g., Tetra Tech, 2002) made without a calibrated watershed model. However, the point source contribution of phosphorus is less than was previously estimated, due to changes in the rates of instream trapping made during calibration of the delivery model.

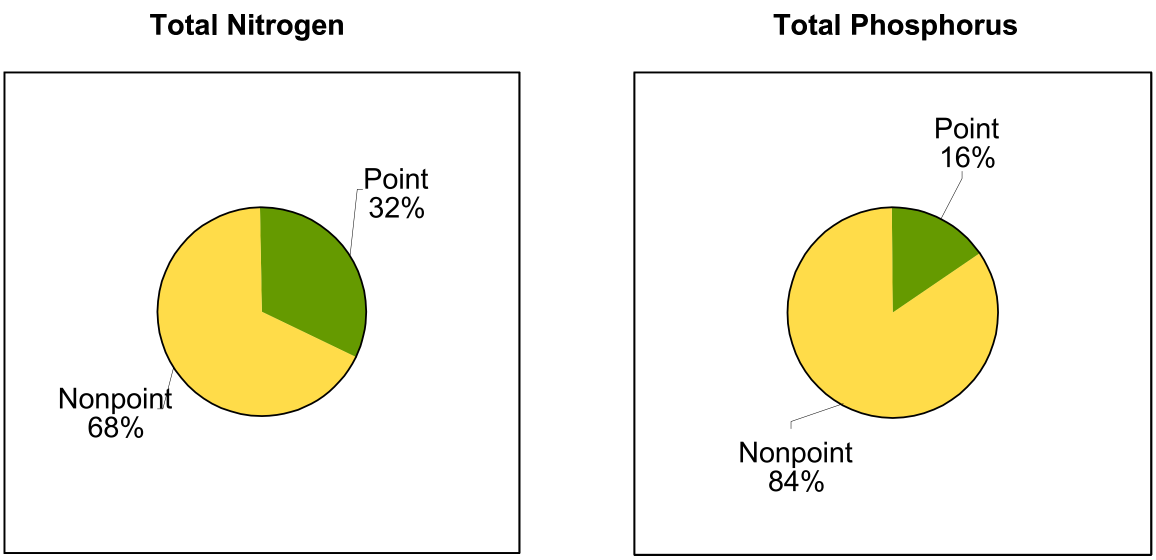

Figure 24. Relative Importance of Point and Nonpoint Source Loads Delivered to Jordan Lake

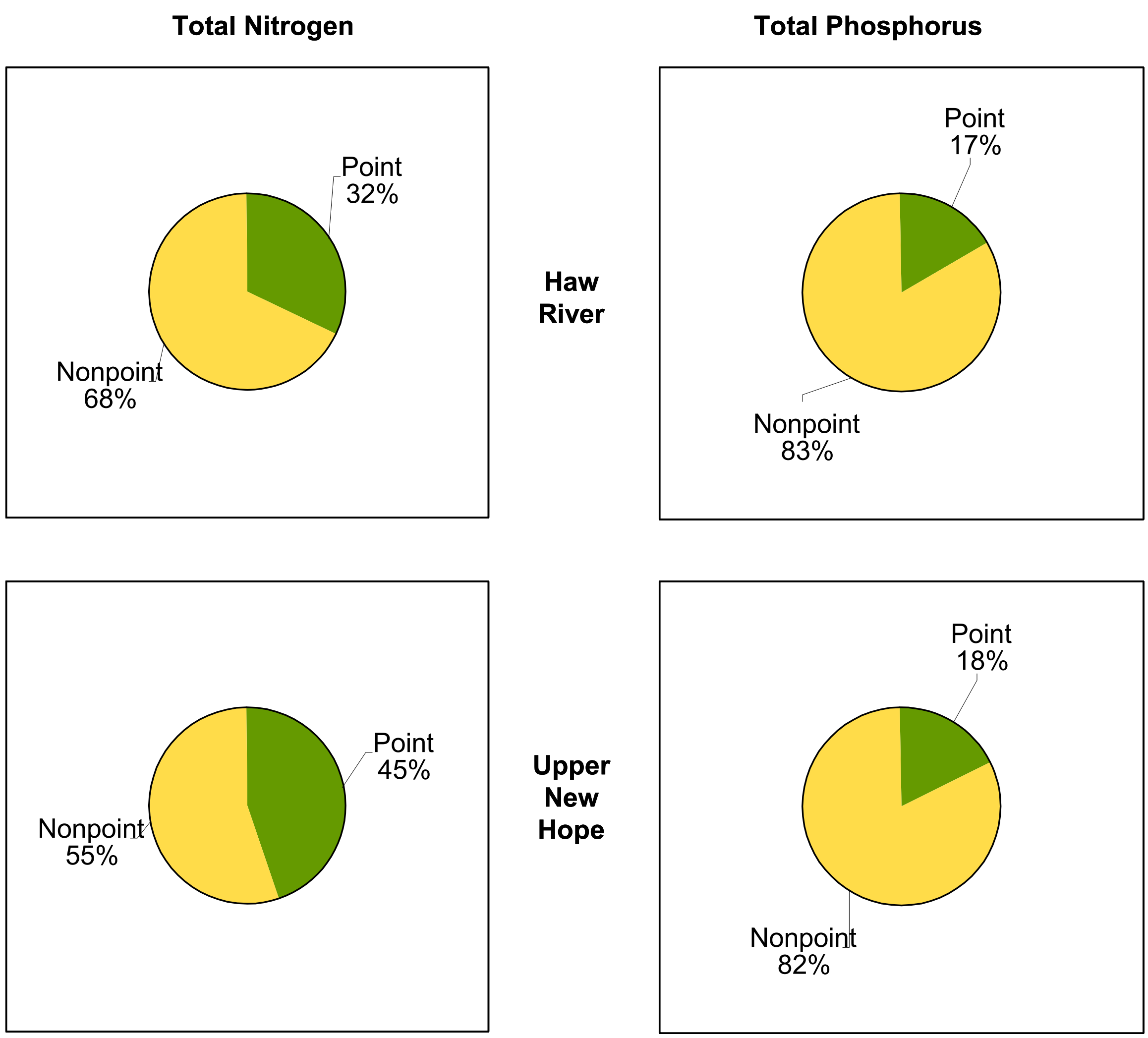

Figure 25. Relative Importance of Delivered Point and Nonpoint Source Loads by Lake Segment

The model allows attribution of the nonpoint loading to individual land use types. Sources of the nonpoint nitrogen load are summarized in Figure 26 and Figure 27, which also shows the land use distribution for comparison.

For nitrogen, residential, commercial/industrial, and agricultural land uses contribute a share of the load disproportionate to their land area, with agricultural and residential land uses contributing 36 and 29 percent of the nonpoint load, respectively. A significant portion of the residential nitrogen load is due to onsite wastewater disposal. While 56 percent of the watershed land area is in forest, this land contributes only 19 percent of the nitrogen load. Thus continued conversion of forest to developed land uses will tend to increase loads.

For phosphorus, the dominant source of nonpoint load is estimated to be agriculture (51 percent). A major portion of this load is due to erosion from croplands and is amenable to reduction through additional adoption of agricultural BMPs.

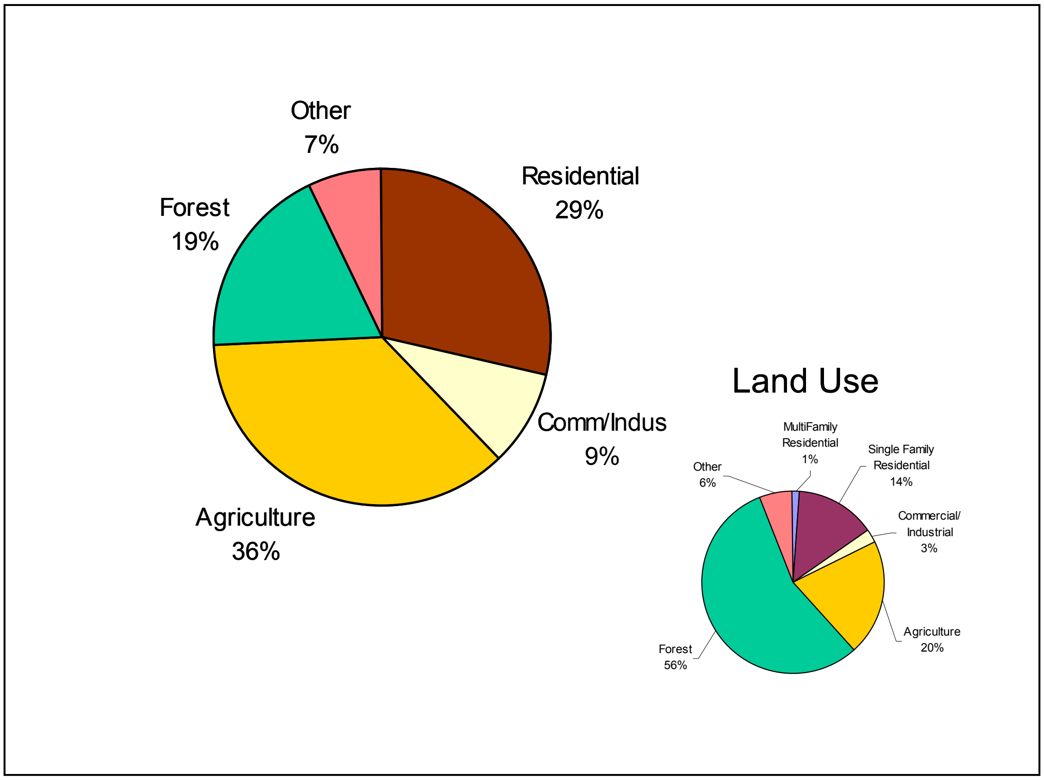

Figure 26. Source Attribution of the Nonpoint Nitrogen Load Delivered to Jordan Lake

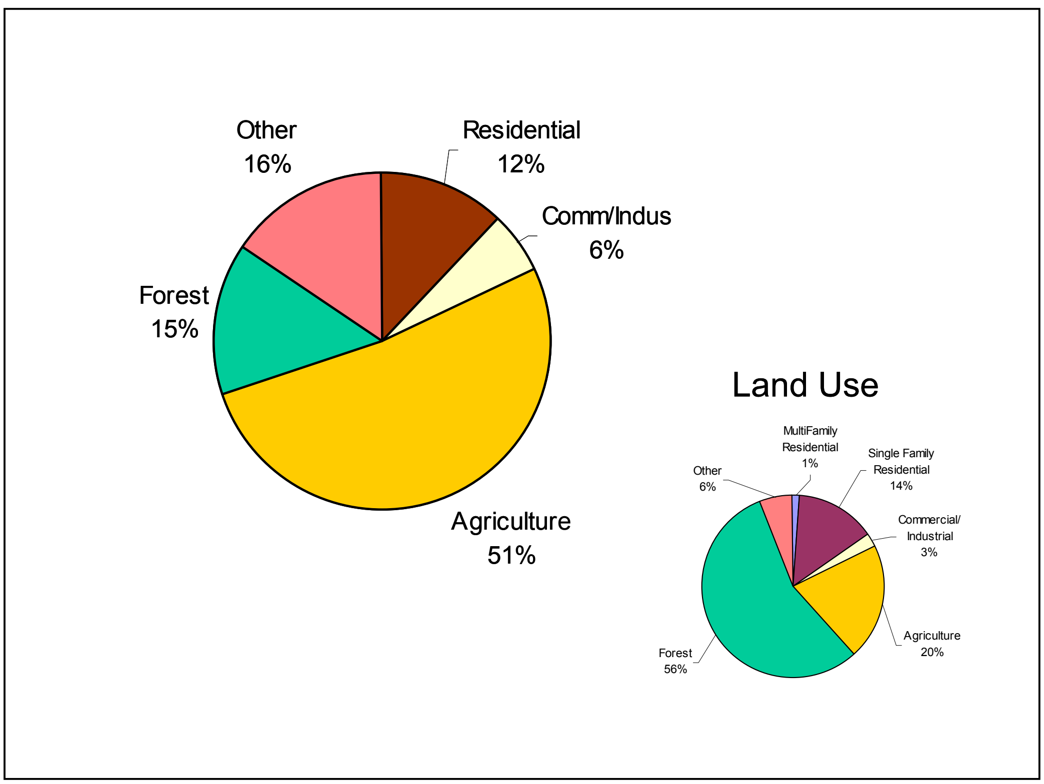

Figure 27. Source Attribution of the Nonpoint Phosphorus Load Delivered to Jordan Lake

7.2.2 Haw River Arm of Jordan Lake

Figure 28 and Figure 29 show the seasonal distribution of point and nonpoint loads of nitrogen and phosphorus to the Haw River arm of Jordan Lake. Nonpoint load results represent the average of the 10-year simulation (April 1991-March 2001 meteorology), while point source results are based on the average delivered load for 1996-1998 estimated by RTI (2002). Supporting data are provided in Appendix B. During all seasons, the nonpoint load exceeds the point source load on a 3-month basis. However, the importance of point source loads increases relative to nonpoint loads during the low flow period of fall. In addition, much of the nonpoint loading will be intermittent, associated with rainfall events. During long dry periods point source loading is expected to dominate the influent loads.

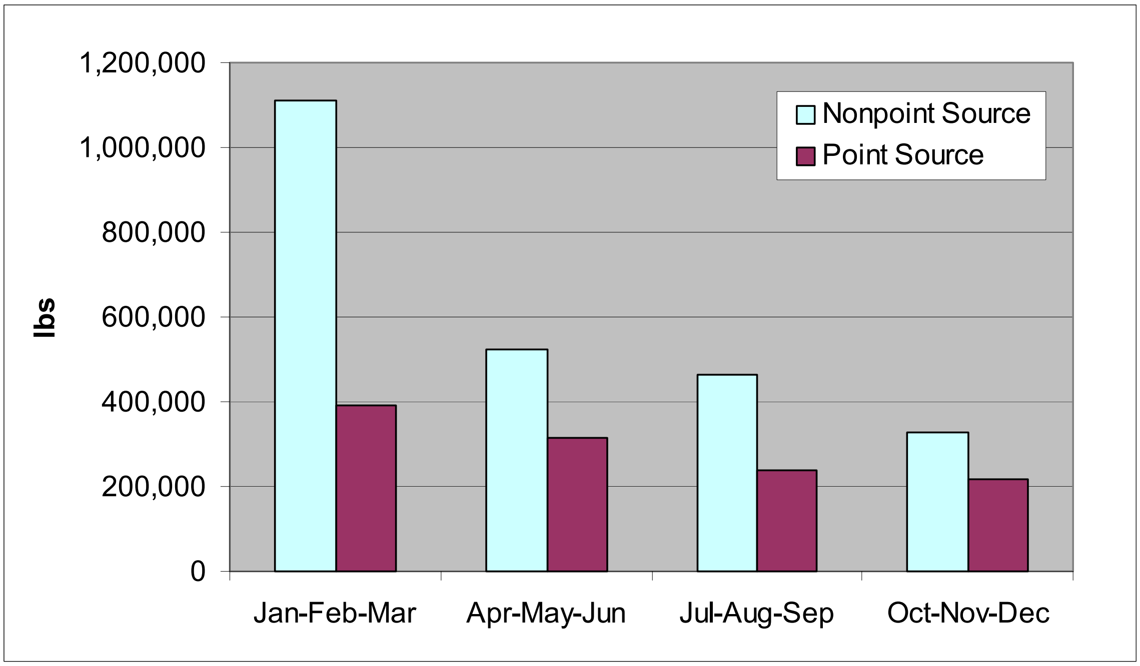

Figure 28. Seasonal Distribution of Delivered Nitrogen Loads, Haw River

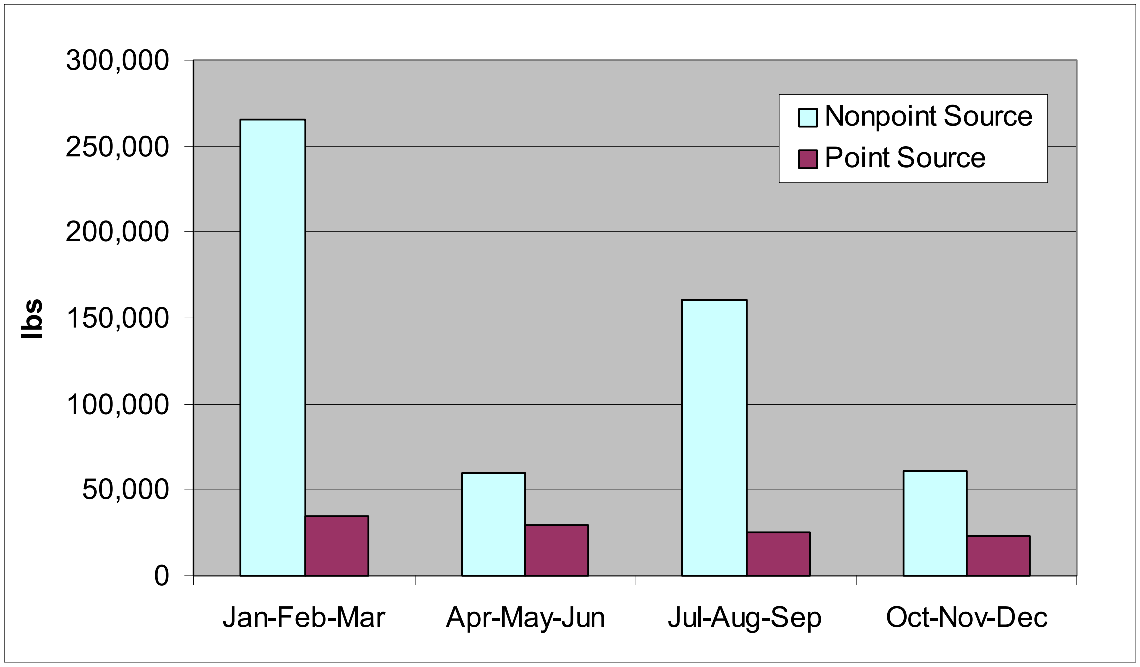

Figure 29. Seasonal Distribution of Delivered Phosphorus Loads, Haw River

Sources of the nonpoint nitrogen and phosphorus loading to the Haw River watershed are summarized in Figure 30 and Figure 31. Agricultural land use is concentrated in the Haw portion of the Jordan watershed, and is a significant contributor to both nitrogen and phosphorus load.

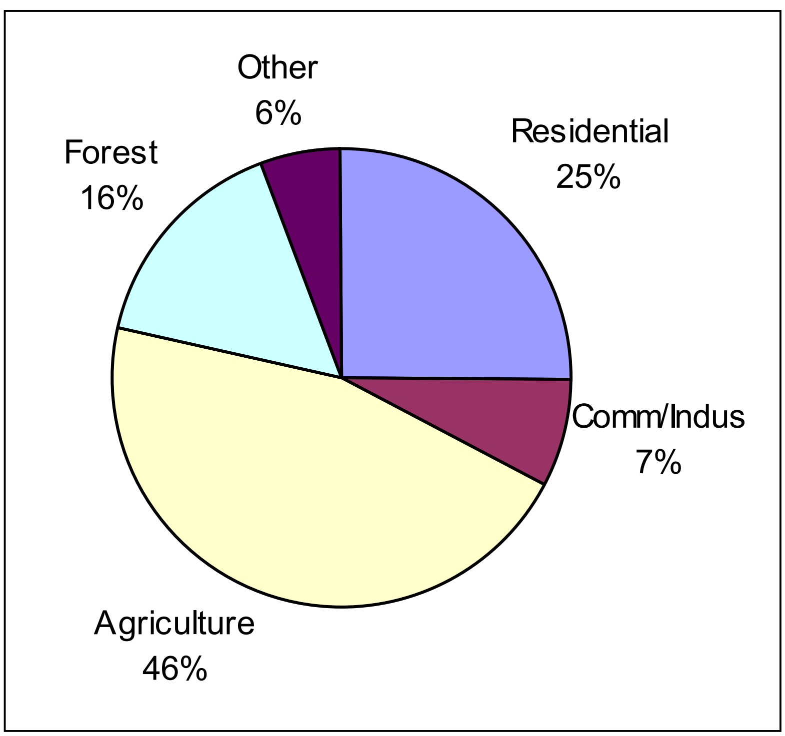

Figure 30. Sources of Nonpoint Nitrogen Loading to the Haw River

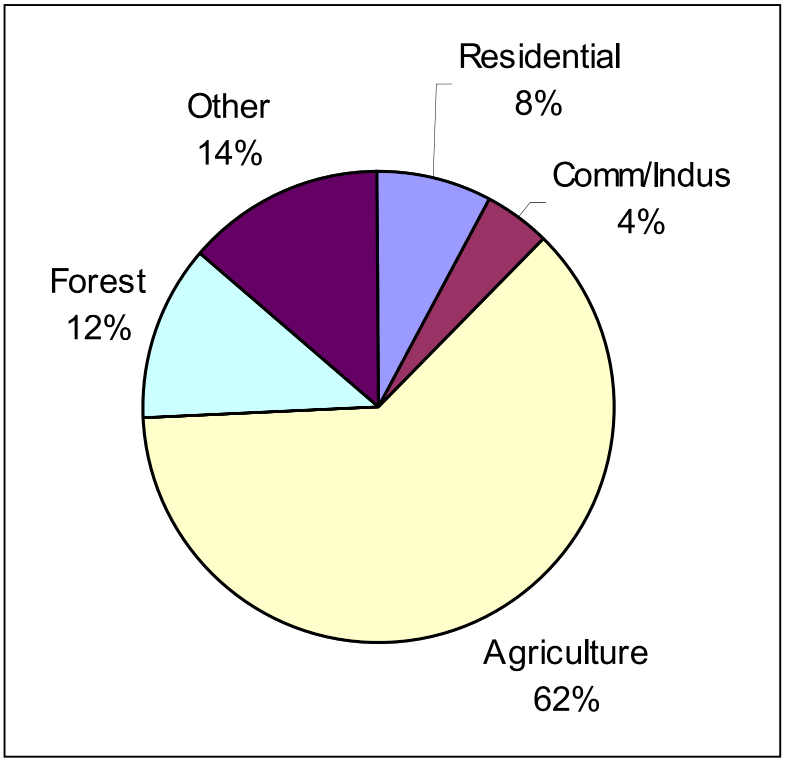

Figure 31. Sources of Nonpoint Phosphorus Loading to the Haw River

7.2.3 Upper New Hope Arm of Jordan Lake

The distribution of point and nonpoint loads to the Upper New Hope Arm above SR 1008 (the listed sections of the lake) is shown by season and major tributary in Figure 32 and Figure 33, while supporting data are provided in Appendix B. New Hope Creek contributes the greatest percentage of the nonpoint load. For phosphorus, the total nonpoint loads always exceed the point source loads on a seasonal basis, reflecting relatively high degrees of phosphorus removal in the three WWTPs. For nitrogen loads to the Upper New Hope Arm, the point source component is of similar magnitude to or greater than the total nonpoint load for April through December, with nonpoint load exceeding the point source load by a significant amount only in the January-March high flow period.

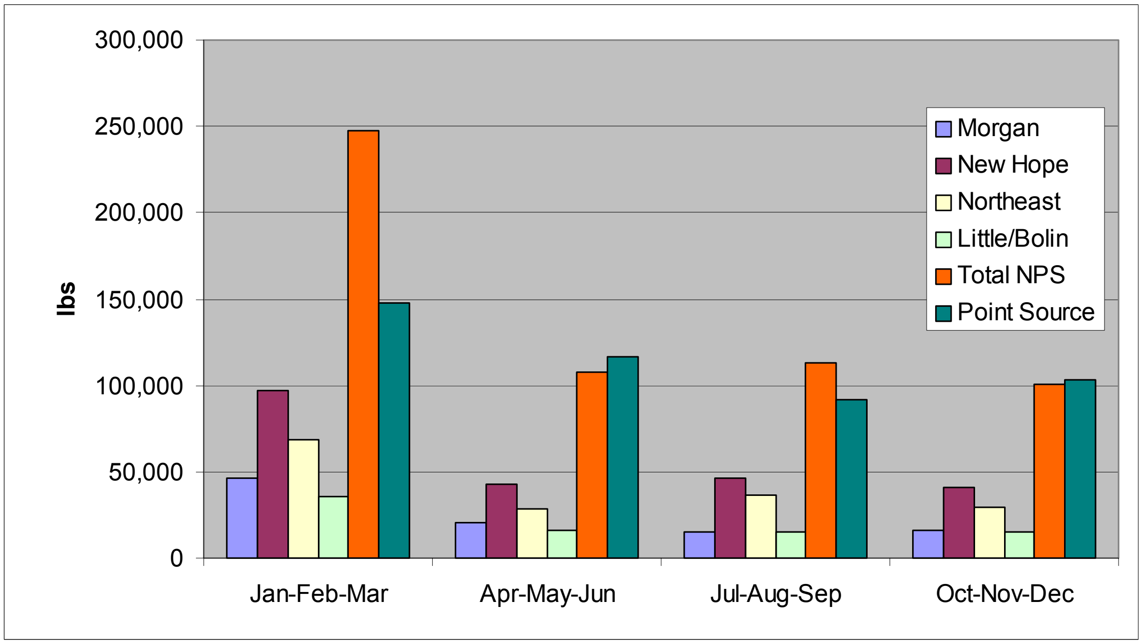

Figure 32. Seasonal Distribution of Delivered Nitrogen Loads, Upper New Hope Arm of Jordan Lake

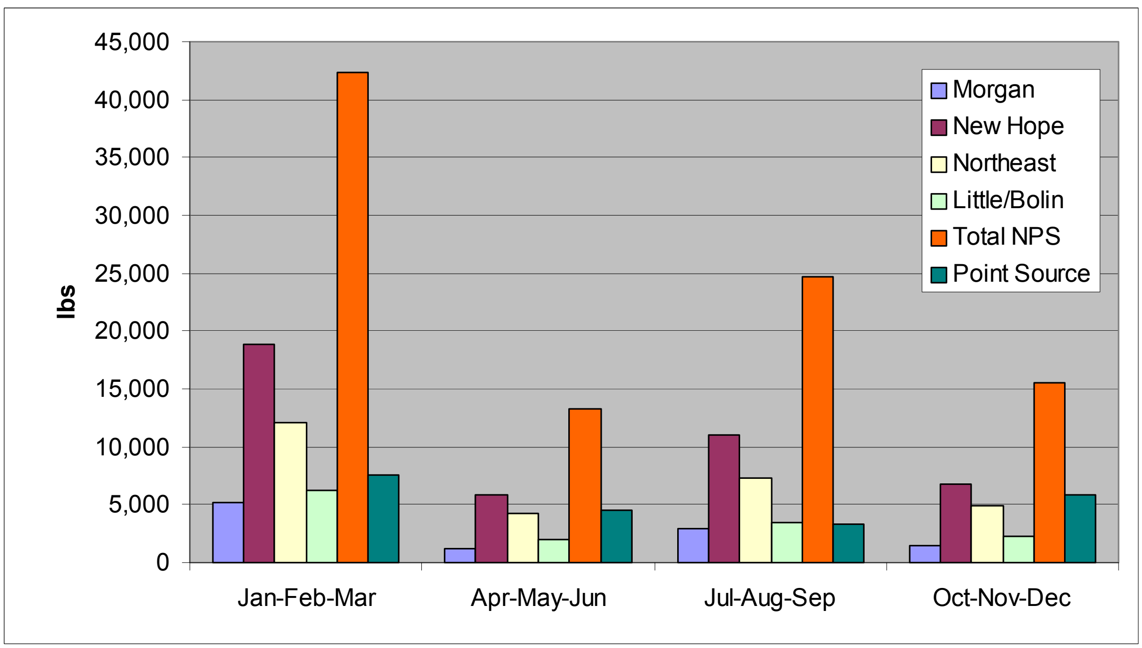

Figure 33. Seasonal Distribution of Delivered Phosphorus Loads, Upper New Hope Arm of Jordan Lake

Sources of the nonpoint nitrogen and phosphorus loading to the TMDL-listed segments are summarized in Figure 34 and Figure 35. Relative to the lake as a whole, loading from residential and commercial/industrial uses is of much greater importance in this more developed area.

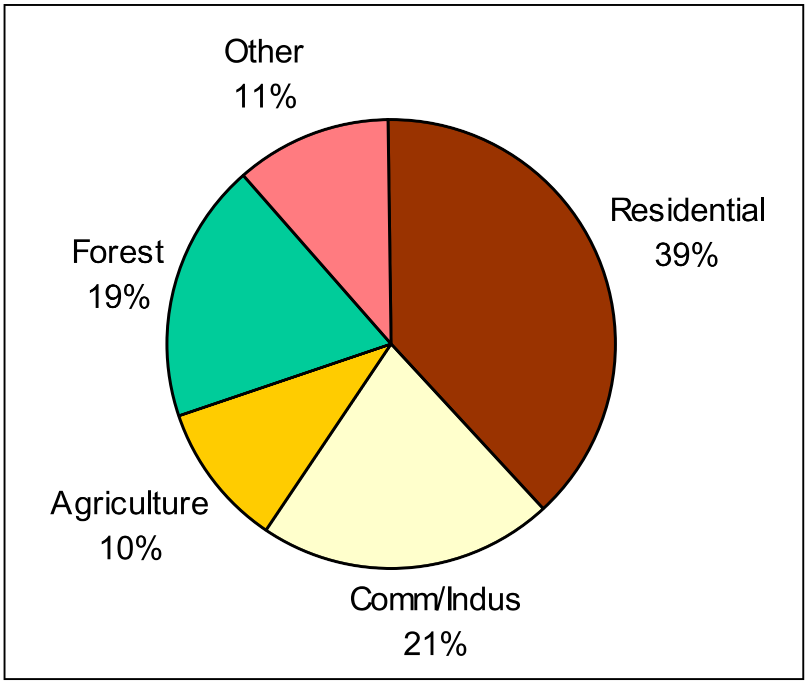

Figure 34. Sources of Nonpoint Nitrogen Loading to the TMDL Segments of Jordan Lake

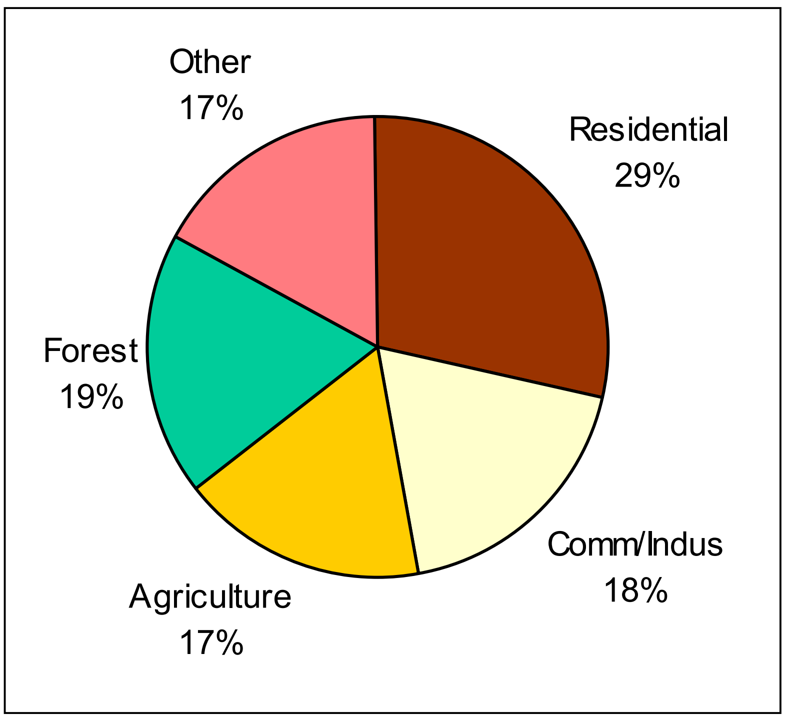

Figure 35. Sources of Nonpoint Phosphorus Loading to the TMDL Segments of Jordan Lake

7.3 Distribution of Loading by Jurisdiction

The Jordan Lake watershed contains a complex overlay of municipal and county jurisdictions with responsibility for the management of point and nonpoint sources. These jurisdictional boundaries typically do not correspond with subwatershed boundaries, which complicates any analysis of loads from individual jurisdictions to specific segments of the lake. A useful summary is provided by analyzing exerted loads (loads delivered to the lake) by county. This is obtained by overlaying county and HUC boundaries, and weighting the exerted load from each HUC by area in a given county. Results are shown in Table 21. For the lake as a whole, the largest contributors of total nitrogen are Alamance and Guilford counties, together accounting for 57 percent of the total. For the TMDL segments, Orange and Durham counties are the major contributors, with approximately equal total loads.

Table 21. Distribution of Point and Nonpoint Source Nutrient Load Delivered to Jordan Lake by County

County	Nonpoint Load	Point Source Load	Total Delivered	Percent of Total
Total Nitrogen				
Alamance	1,057,181	551,935	1,609,117	32.1%
Caswell	39,540	0	39,540	0.8%
Chatham	648,685	13,902	662,586	13.2%
Durham	251,321	298,027	549,348	11.0%
Forsyth	3,089	0	3,089	0.1%
Guilford	698,739	556,505	1,255,244	25.0%
Orange	395,160	156,728	551,888	11.0%
Randolph	8,686	0	8,686	0.2%
Rockingham	140,240	41,799	182,039	3.6%
Wake	151,527	0	151,527	3.0%
Total	**3,394,168**	**1,618,896**	**5,013,064**	
Total Phosphorus				
Alamance	244,814	45,679	290,493	34.1%
Caswell	5,505	0	5,505	0.6%
Chatham	160,706	2,383	163,089	19.2%
Durham	42,691	15,445	58,136	6.8%
Forsyth	566	0	566	0.1%
Guilford	132,043	60,986	193,029	22.7%
Orange	72,930	4,702	77,631	9.1%
Randolph	2,062	0	2,062	0.2%
Rockingham	32,384	3,987	36,371	4.3%
Wake	24,520	0	24,520	2.9%
Total	**718,221**	**133,182**	**851,403**	

7.4 Potential Uses for TMDL Allocations and Lakewide Management

The Jordan Lake Watershed Model provides a simplified representation of nonpoint load generation and delivery to the lake. Despite its simplified nature, the model appears to provide estimates of cumulative (multi-year) nutrient loads that are accurate within about 20 percent. Considerably greater uncertainty may apply to estimates of loads for individual years or seasons. The model should, however, provide a reliable estimate of relative changes in loads that would occur from changes in land use or alterations in average loading rates from individual land use types (calculated externally), such as would occur through adoption of management measures.

The Jordan Lake Nutrient Response Model (Tetra Tech, 2003b) is driven by FLUX analyses of actual loading series in each of the major tributaries specified at a daily time step. The lake model thus will not be linked directly to the watershed model described in this document. Rather, the watershed model (coupled with the analysis of point source delivery) can be used to derive relative changes in loading resulting from a management scenario that can be applied as adjustment factors to the tributary input time series used by the lake model.

The Jordan Lake TMDL will result in the specification of point source wasteload allocations and nonpoint source load allocations of nutrients delivered to the lake. The watershed model described in this report provides a sound technical basis for apportioning the gross allotment of a total nonpoint source load allocation back to individual source areas and land use types. Using the spreadsheet tool, scenarios involving different management measures can readily be examined to determine if they achieve the needed load reductions to meet water quality standards.

The watershed model can be used in a similar manner as a tool for evaluating management strategies for the whole lake. For development of a Nutrient Sensitive Water management plan for the lake, a key feature provided by the watershed model is the capability to evaluate changes in nutrient loading expected from future modifications in watershed land use.

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Appendix A. Estimated Unit Load Rates[JBB3]

Table A-1. Seasonal and Annual Total Nitrogen Unit Load Rates

Jan-Feb-Mar		lb/ac/mo																	
HRU	BAR	CIT	FOR	OFF	PAS	RHH	RLL	RMH	RML	ROW	RVH	RVL	S-RLL	S-RMH	S-RML	S-RVL	UGR	WET	
1	5.61	2.51	0.30	1.91	0.98	1.89	1.65	1.95	1.87	2.02	2.03	0.41	3.62	6.32	4.58	1.83	0.62	0.38	
2	2.93	2.43	0.20	1.77	0.58	1.43	1.15	1.42	1.33	1.17	1.73	0.28	2.95	5.41	3.80	1.55	0.45	0.28	
3	4.87	2.42	0.23	1.81	0.73	1.63	1.34	1.65	1.55	1.61	1.87	0.33	3.20	5.79	4.11	1.65	0.51	0.31	
4	4.37	2.43	0.23	1.82	0.72	1.66	1.37	1.67	1.58	1.54	1.89	0.32	3.22	5.82	4.14	1.64	0.52	0.31	
5	6.57	2.49	0.31	1.89	0.98	1.83	1.59	1.88	1.80	2.15	1.99	0.42	3.55	6.23	4.49	1.84	0.61	0.39	
6	6.60	2.57	0.30	1.98	1.11	2.07	1.85	2.17	2.10	2.31	2.17	0.41	3.86	6.63	4.85	1.86	0.64	0.37	
7	6.15	2.35	0.23	1.66	0.61	1.18	0.91	1.15	1.06	1.63	1.53	0.33	2.69	5.09	3.50	1.59	0.42	0.31	
8	6.30	2.35	0.23	1.66	0.61	1.17	0.91	1.14	1.05	1.65	1.52	0.33	2.68	5.08	3.49	1.59	0.42	0.31	
9	6.00	2.36	0.22	1.67	0.61	1.21	0.94	1.18	1.09	1.61	1.55	0.33	2.72	5.13	3.53	1.59	0.42	0.30	
10	6.30	2.41	0.24	1.79	0.74	1.58	1.28	1.58	1.48	1.83	1.84	0.35	3.13	5.71	4.04	1.67	0.50	0.32	
11	7.99	2.50	0.32	1.89	1.02	1.84	1.60	1.89	1.81	2.39	2.00	0.44	3.56	6.25	4.50	1.86	0.61	0.40	
12	11.66	2.55	0.33	1.96	1.19	2.00	1.78	2.08	2.01	3.10	2.12	0.49	3.77	6.51	4.75	1.92	0.63	0.41	
13	8.18	2.41	0.25	1.79	0.78	1.56	1.26	1.56	1.46	2.13	1.82	0.37	3.11	5.68	4.01	1.70	0.50	0.33	
14	9.92	2.49	0.33	1.88	1.05	1.80	1.56	1.85	1.77	2.69	1.98	0.47	3.52	6.20	4.46	1.88	0.61	0.41	
Apr-May-Jun		lb/ac/mo																	
HRU	BAR	CIT	FOR	OFF	PAS	RHH	RLL	RMH	RML	ROW	RVH	RVL	S-RLL	S-RMH	S-RML	S-RVL	UGR	WET	
1	0.66	1.82	0.12	1.20	0.32	0.80	0.61	0.77	0.71	0.50	1.06	0.18	1.84	3.66	2.44	1.03	0.28	0.18	
2	0.80	1.78	0.15	1.15	0.40	0.84	0.69	0.84	0.78	0.60	1.03	0.21	2.18	4.23	2.86	1.26	0.31	0.21	
3	0.82	1.67	0.13	1.09	0.37	0.63	0.47	0.60	0.54	0.55	0.90	0.19	1.86	3.78	2.48	1.17	0.25	0.19	
4	0.76	1.67	0.13	1.10	0.37	0.65	0.48	0.61	0.55	0.54	0.91	0.19	1.87	3.80	2.50	1.17	0.25	0.19	
5	0.73	1.79	0.13	1.18	0.32	0.75	0.57	0.72	0.66	0.49	1.02	0.18	1.79	3.59	2.38	1.03	0.27	0.18	
6	0.76	1.92	0.12	1.31	0.36	0.98	0.78	0.97	0.90	0.57	1.21	0.17	2.03	3.92	2.67	1.04	0.30	0.17	
7	1.42	1.68	0.15	1.06	0.38	0.72	0.58	0.71	0.66	0.64	0.92	0.21	2.05	4.06	2.70	1.26	0.30	0.21	
8	1.44	1.67	0.15	1.05	0.38	0.72	0.58	0.70	0.65	0.64	0.92	0.21	2.05	4.05	2.70	1.26	0.30	0.21	
9	1.39	1.69	0.15	1.07	0.38	0.74	0.59	0.72	0.67	0.64	0.94	0.21	2.07	4.08	2.72	1.26	0.30	0.21	
10	1.00	1.64	0.14	1.06	0.37	0.60	0.44	0.56	0.51	0.58	0.87	0.20	1.82	3.72	2.44	1.17	0.25	0.19	
11	0.83	1.79	0.13	1.18	0.32	0.76	0.57	0.73	0.66	0.51	1.02	0.18	1.80	3.60	2.38	1.03	0.27	0.18	
12	1.14	1.88	0.12	1.27	0.35	0.91	0.71	0.89	0.82	0.60	1.15	0.18	1.95	3.81	2.57	1.04	0.29	0.18	
13	1.23	1.64	0.14	1.05	0.37	0.59	0.43	0.55	0.49	0.61	0.85	0.20	1.81	3.70	2.42	1.17	0.25	0.19	

14	0.97	1.78	0.13	1.16	0.32	0.73	0.55	0.70	0.64	0.52	1.00	0.18	1.77	3.57	2.35	1.03	0.27	0.18
Jul-Aug-Sep		**lb/ac/mo**																
HRU	**BAR**	**CIT**	**FOR**	**OFF**	**PAS**	**RHH**	**RLL**	**RMH**	**RML**	**ROW**	**RVH**	**RVL**	**S-RLL**	**S-RMH**	**S-RML**	**S-RVL**	**UGR**	**WET**
1	4.31	2.05	0.06	1.37	0.44	0.87	0.65	0.85	0.78	1.16	1.19	0.12	0.96	1.66	1.24	0.31	0.18	0.08
2	2.46	2.00	0.03	1.30	0.29	0.75	0.54	0.72	0.65	0.73	1.07	0.08	0.87	1.65	1.15	0.30	0.15	0.06
3	4.56	2.05	0.06	1.37	0.43	0.96	0.75	0.96	0.89	1.20	1.23	0.12	1.11	1.95	1.43	0.36	0.20	0.08
4	4.09	2.06	0.06	1.38	0.42	0.98	0.77	0.98	0.91	1.13	1.24	0.12	1.13	1.96	1.45	0.35	0.20	0.08
5	5.04	2.03	0.06	1.34	0.44	0.81	0.60	0.79	0.72	1.25	1.14	0.13	0.91	1.61	1.18	0.33	0.17	0.08
6	5.14	2.14	0.07	1.48	0.54	1.09	0.86	1.10	1.02	1.41	1.37	0.13	1.15	1.86	1.45	0.32	0.22	0.08
7	5.10	1.91	0.05	1.18	0.30	0.58	0.40	0.54	0.48	1.07	0.90	0.12	0.76	1.55	1.02	0.35	0.13	0.08
8	5.23	1.91	0.05	1.18	0.30	0.58	0.39	0.54	0.48	1.08	0.90	0.12	0.76	1.55	1.02	0.36	0.13	0.08
9	4.98	1.93	0.05	1.20	0.30	0.60	0.41	0.56	0.50	1.06	0.92	0.11	0.77	1.56	1.04	0.35	0.13	0.08
10	5.91	2.04	0.07	1.35	0.44	0.92	0.70	0.91	0.84	1.39	1.19	0.14	1.07	1.92	1.39	0.38	0.19	0.09
11	6.14	2.03	0.07	1.34	0.47	0.82	0.61	0.79	0.73	1.43	1.14	0.14	0.92	1.62	1.19	0.34	0.17	0.09
12	9.07	2.11	0.09	1.44	0.60	1.01	0.77	1.00	0.92	1.99	1.30	0.18	1.07	1.78	1.36	0.37	0.20	0.11
13	7.70	2.03	0.08	1.34	0.48	0.91	0.69	0.90	0.82	1.68	1.18	0.17	1.06	1.91	1.37	0.41	0.19	0.10
14	7.61	2.02	0.08	1.33	0.49	0.78	0.58	0.76	0.69	1.65	1.11	0.16	0.89	1.59	1.16	0.36	0.16	0.10
Oct-Nov-Dec		**lb/ac/mo**																
HRU	**BAR**	**CIT**	**FOR**	**OFF**	**PAS**	**RHH**	**RLL**	**RMH**	**RML**	**ROW**	**RVH**	**RVL**	**S-RLL**	**S-RMH**	**S-RML**	**S-RVL**	**UGR**	**WET**
1	1.59	2.00	0.07	1.38	0.28	0.88	0.64	0.85	0.76	0.54	1.23	0.14	1.37	2.67	1.82	0.63	0.24	0.12
2	1.48	1.70	0.06	1.09	0.27	0.56	0.42	0.54	0.50	0.51	0.84	0.11	1.05	2.12	1.39	0.53	0.15	0.09
3	1.28	1.67	0.06	1.13	0.23	0.77	0.58	0.75	0.68	0.43	1.01	0.11	1.21	2.34	1.58	0.55	0.21	0.10
4	1.17	1.68	0.06	1.14	0.23	0.79	0.59	0.76	0.70	0.42	1.03	0.11	1.22	2.35	1.59	0.54	0.21	0.10
5	1.80	1.97	0.07	1.35	0.28	0.82	0.58	0.77	0.70	0.56	1.17	0.14	1.32	2.62	1.76	0.65	0.23	0.13
6	1.97	2.08	0.07	1.48	0.33	1.11	0.86	1.10	1.01	0.66	1.40	0.13	1.54	2.82	2.00	0.60	0.27	0.12
7	2.97	1.62	0.07	0.97	0.29	0.47	0.37	0.46	0.42	0.73	0.70	0.13	1.00	2.06	1.34	0.56	0.14	0.11
8	3.04	1.61	0.07	0.97	0.29	0.47	0.36	0.45	0.42	0.74	0.69	0.14	1.00	2.05	1.34	0.56	0.14	0.11
9	2.90	1.63	0.07	0.99	0.29	0.48	0.37	0.46	0.43	0.72	0.72	0.13	1.01	2.06	1.35	0.56	0.15	0.11
10	1.57	1.65	0.06	1.11	0.23	0.74	0.54	0.71	0.64	0.46	0.99	0.11	1.18	2.32	1.55	0.55	0.20	0.10
11	2.15	1.98	0.07	1.35	0.29	0.83	0.59	0.79	0.71	0.61	1.18	0.14	1.33	2.63	1.77	0.65	0.23	0.13
12	3.26	2.05	0.08	1.44	0.33	1.02	0.77	1.00	0.91	0.81	1.33	0.15	1.47	2.76	1.93	0.63	0.26	0.13
13	1.98	1.65	0.07	1.11	0.23	0.73	0.53	0.69	0.63	0.50	0.98	0.12	1.17	2.31	1.54	0.55	0.20	0.11
14	2.60	1.96	0.08	1.34	0.29	0.79	0.56	0.75	0.67	0.66	1.15	0.15	1.30	2.60	1.74	0.66	0.22	0.13

Year	lb/ac/yr																	
HRU	BAR	CIT	FOR	OFF	PAS	RHH	RLL	RMH	RML	ROW	RVH	RVL	S-RLL	S-RMH	S-RML	S-RVL	UGR	WET
1	36.50	25.12	1.66	17.59	6.10	13.31	10.66	13.25	12.38	12.65	16.53	2.51	23.39	42.95	30.20	11.42	3.93	2.28
2	23.01	23.72	1.33	15.91	4.65	10.73	8.41	10.55	9.78	9.02	14.03	2.03	21.14	40.25	27.60	10.94	3.23	1.91
3	34.61	23.44	1.46	16.22	5.27	12.01	9.41	11.86	10.98	11.37	15.03	2.26	22.14	41.56	28.80	11.17	3.52	2.06
4	31.17	23.51	1.44	16.31	5.25	12.20	9.61	12.07	11.21	10.89	15.19	2.21	22.33	41.77	29.03	11.12	3.55	2.03
5	42.42	24.87	1.70	17.25	6.04	12.61	10.00	12.47	11.61	13.35	15.96	2.60	22.72	42.17	29.43	11.51	3.83	2.34
6	43.38	26.15	1.66	18.76	7.03	15.74	13.04	15.98	15.11	14.83	18.45	2.52	25.77	45.69	32.93	11.43	4.27	2.23
7	46.92	22.67	1.49	14.62	4.74	8.86	6.77	8.56	7.86	12.21	12.15	2.38	19.50	38.26	25.69	11.29	2.98	2.11
8	48.03	22.64	1.50	14.58	4.75	8.80	6.73	8.50	7.81	12.37	12.09	2.40	19.46	38.20	25.63	11.31	2.97	2.12
9	45.82	22.82	1.48	14.78	4.77	9.08	6.96	8.79	8.09	12.11	12.38	2.36	19.69	38.49	25.91	11.27	3.00	2.10
10	44.34	23.23	1.53	15.96	5.36	11.51	8.90	11.29	10.41	12.75	14.64	2.40	21.62	40.99	28.23	11.31	3.44	2.13
11	51.35	24.90	1.76	17.30	6.27	12.71	10.09	12.58	11.72	14.82	16.05	2.72	22.82	42.29	29.54	11.63	3.85	2.39
12	75.39	25.76	1.87	18.31	7.41	14.80	12.08	14.90	14.02	19.51	17.70	2.97	24.81	44.61	31.84	11.88	4.14	2.46
13	57.26	23.17	1.61	15.87	5.60	11.34	8.72	11.09	10.21	14.76	14.50	2.57	21.45	40.79	28.03	11.48	3.42	2.21
14	63.28	24.73	1.83	17.10	6.43	12.33	9.74	12.16	11.31	16.57	15.72	2.88	22.47	41.87	29.13	11.79	3.79	2.47

Table A-2. Seasonal and Annual Total Phosphorus Unit Load Rates

Jan-Feb-Mar		lb/ac/mo																
HRU	BAR	CIT	FOR	OFF	PAS	RHH	RLL	RMH	RML	ROW	RVH	RVL	S-RLL	S-RMH	S-RML	S-RVL	UGR	WET
1	4.20	0.39	0.06	0.30	0.18	0.32	0.30	0.32	0.31	0.80	0.33	0.10	0.30	0.33	0.32	0.10	0.11	0.07
2	2.12	0.37	0.03	0.28	0.10	0.24	0.21	0.24	0.22	0.41	0.29	0.06	0.21	0.24	0.23	0.06	0.08	0.04
3	3.64	0.37	0.05	0.29	0.14	0.27	0.24	0.27	0.26	0.67	0.31	0.08	0.25	0.28	0.26	0.08	0.09	0.05
4	3.25	0.37	0.04	0.29	0.13	0.28	0.25	0.28	0.26	0.61	0.31	0.07	0.25	0.29	0.27	0.08	0.09	0.05
5	4.96	0.38	0.06	0.30	0.19	0.31	0.29	0.31	0.30	0.92	0.33	0.11	0.29	0.32	0.30	0.11	0.10	0.07
6	1.69	0.39	0.04	0.32	0.13	0.35	0.34	0.36	0.35	0.39	0.36	0.06	0.34	0.37	0.35	0.06	0.11	0.05
7	4.67	0.36	0.05	0.27	0.15	0.20	0.16	0.19	0.18	0.82	0.25	0.09	0.17	0.20	0.18	0.09	0.07	0.06
8	4.79	0.36	0.05	0.26	0.15	0.20	0.16	0.19	0.17	0.84	0.25	0.09	0.17	0.20	0.18	0.10	0.07	0.06
9	4.55	0.36	0.05	0.27	0.15	0.20	0.17	0.20	0.18	0.80	0.26	0.09	0.17	0.20	0.19	0.09	0.07	0.06
10	4.77	0.37	0.05	0.29	0.16	0.27	0.23	0.26	0.25	0.85	0.30	0.09	0.24	0.27	0.25	0.10	0.09	0.06
11	6.08	0.38	0.07	0.30	0.22	0.31	0.29	0.31	0.30	1.11	0.33	0.12	0.29	0.32	0.31	0.12	0.10	0.08
12	3.02	0.39	0.05	0.31	0.15	0.34	0.33	0.35	0.33	0.61	0.35	0.08	0.33	0.35	0.34	0.08	0.11	0.06
13	6.26	0.37	0.06	0.29	0.20	0.26	0.23	0.26	0.24	1.10	0.30	0.11	0.23	0.27	0.25	0.12	0.08	0.07

14	7.61	0.38	0.08	0.30	0.25	0.30	0.28	0.31	0.29	1.36	0.33	0.14	0.29	0.32	0.30	0.15	0.10	0.09
Apr-May-Jun		**lb/ac/mo**																
HRU	**BAR**	**CIT**	**FOR**	**OFF**	**PAS**	**RHH**	**RLL**	**RMH**	**RML**	**ROW**	**RVH**	**RVL**	**S-RLL**	**S-RMH**	**S-RML**	**S-RVL**	**UGR**	**WET**
1	0.34	0.28	0.02	0.19	0.03	0.13	0.11	0.13	0.12	0.08	0.17	0.02	0.11	0.13	0.12	0.03	0.05	0.02
2	0.44	0.27	0.02	0.18	0.04	0.14	0.12	0.14	0.13	0.11	0.17	0.03	0.13	0.14	0.13	0.03	0.05	0.03
3	0.46	0.26	0.02	0.17	0.04	0.11	0.08	0.10	0.09	0.12	0.15	0.03	0.09	0.11	0.09	0.03	0.04	0.02
4	0.41	0.26	0.02	0.18	0.04	0.11	0.08	0.10	0.09	0.11	0.15	0.03	0.09	0.11	0.10	0.03	0.04	0.02
5	0.39	0.28	0.02	0.19	0.03	0.13	0.10	0.12	0.11	0.09	0.17	0.02	0.10	0.13	0.11	0.03	0.05	0.02
6	0.16	0.30	0.01	0.21	0.03	0.16	0.14	0.16	0.15	0.06	0.20	0.02	0.14	0.17	0.15	0.02	0.05	0.02
7	0.92	0.26	0.02	0.17	0.05	0.12	0.10	0.12	0.11	0.17	0.15	0.03	0.11	0.12	0.11	0.03	0.05	0.03
8	0.94	0.26	0.02	0.17	0.05	0.12	0.10	0.12	0.11	0.17	0.15	0.03	0.11	0.12	0.11	0.03	0.05	0.03
9	0.90	0.26	0.02	0.17	0.05	0.12	0.11	0.12	0.11	0.17	0.15	0.03	0.11	0.13	0.12	0.03	0.05	0.03
10	0.60	0.25	0.02	0.17	0.05	0.10	0.08	0.09	0.08	0.14	0.14	0.03	0.08	0.10	0.09	0.03	0.04	0.03
11	0.47	0.28	0.02	0.19	0.04	0.13	0.10	0.12	0.11	0.10	0.17	0.02	0.11	0.13	0.11	0.03	0.05	0.02
12	0.26	0.29	0.02	0.20	0.03	0.15	0.13	0.15	0.14	0.08	0.19	0.02	0.13	0.15	0.14	0.02	0.05	0.02
13	0.78	0.25	0.02	0.17	0.05	0.10	0.08	0.09	0.08	0.17	0.14	0.03	0.08	0.10	0.09	0.04	0.04	0.03
14	0.57	0.27	0.02	0.19	0.04	0.12	0.10	0.12	0.11	0.11	0.16	0.03	0.10	0.12	0.11	0.03	0.04	0.02
Jul-Aug-Sep		**lb/ac/mo**																
HRU	**BAR**	**CIT**	**FOR**	**OFF**	**PAS**	**RHH**	**RLL**	**RMH**	**RML**	**ROW**	**RVH**	**RVL**	**S-RLL**	**S-RMH**	**S-RML**	**S-RVL**	**UGR**	**WET**
1	3.25	0.32	0.02	0.22	0.10	0.15	0.12	0.14	0.13	0.56	0.20	0.05	0.12	0.15	0.13	0.05	0.03	0.02
2	1.78	0.31	0.01	0.21	0.06	0.13	0.10	0.12	0.11	0.31	0.18	0.03	0.10	0.13	0.11	0.03	0.03	0.01
3	3.44	0.32	0.02	0.22	0.11	0.16	0.14	0.16	0.15	0.60	0.20	0.05	0.14	0.17	0.15	0.05	0.03	0.03
4	3.07	0.32	0.02	0.22	0.10	0.16	0.14	0.16	0.15	0.54	0.20	0.05	0.14	0.17	0.15	0.05	0.04	0.02
5	3.82	0.31	0.03	0.21	0.11	0.14	0.11	0.13	0.12	0.65	0.19	0.06	0.11	0.14	0.12	0.06	0.03	0.03
6	1.32	0.33	0.01	0.24	0.07	0.18	0.16	0.18	0.17	0.26	0.23	0.02	0.16	0.19	0.17	0.02	0.04	0.01
7	3.87	0.29	0.02	0.19	0.10	0.10	0.07	0.09	0.08	0.63	0.15	0.05	0.08	0.10	0.08	0.06	0.02	0.03
8	3.97	0.29	0.03	0.19	0.10	0.10	0.07	0.09	0.08	0.65	0.15	0.06	0.08	0.10	0.08	0.06	0.02	0.03
9	3.78	0.30	0.02	0.19	0.10	0.10	0.08	0.09	0.08	0.62	0.15	0.05	0.08	0.10	0.09	0.06	0.02	0.03
10	4.51	0.31	0.03	0.22	0.13	0.16	0.13	0.15	0.14	0.77	0.20	0.07	0.13	0.16	0.14	0.07	0.03	0.03
11	4.69	0.31	0.03	0.21	0.13	0.14	0.11	0.13	0.12	0.79	0.19	0.07	0.11	0.14	0.12	0.07	0.03	0.03
12	2.36	0.32	0.02	0.23	0.09	0.17	0.14	0.17	0.15	0.43	0.21	0.04	0.15	0.17	0.16	0.04	0.03	0.02
13	5.92	0.31	0.04	0.21	0.16	0.15	0.13	0.15	0.14	1.00	0.19	0.09	0.13	0.16	0.14	0.09	0.03	0.04
14	5.86	0.31	0.04	0.21	0.16	0.13	0.11	0.13	0.11	0.98	0.18	0.08	0.11	0.13	0.12	0.08	0.03	0.04

Oct-Nov-Dec		**lb/ac/mo**																
HRU	BAR	CIT	FOR	OFF	PAS	RHH	RLL	RMH	RML	ROW	RVH	RVL	S-RLL	S-RMH	S-RML	S-RVL	UGR	WET
1	1.08	0.31	0.01	0.22	0.04	0.15	0.12	0.14	0.13	0.18	0.20	0.02	0.12	0.15	0.13	0.03	0.04	0.02
2	1.02	0.26	0.01	0.17	0.04	0.09	0.08	0.09	0.08	0.19	0.14	0.02	0.08	0.10	0.09	0.03	0.03	0.02
3	0.86	0.26	0.01	0.18	0.03	0.13	0.11	0.12	0.11	0.13	0.17	0.02	0.11	0.13	0.12	0.02	0.04	0.01
4	0.77	0.26	0.01	0.18	0.03	0.13	0.11	0.13	0.12	0.12	0.17	0.02	0.11	0.13	0.12	0.02	0.04	0.01
5	1.24	0.30	0.01	0.22	0.04	0.14	0.11	0.13	0.12	0.20	0.19	0.03	0.11	0.14	0.12	0.03	0.04	0.02
6	0.48	0.32	0.01	0.24	0.03	0.19	0.16	0.18	0.17	0.10	0.23	0.02	0.16	0.19	0.17	0.02	0.05	0.01
7	2.18	0.25	0.02	0.16	0.07	0.08	0.07	0.08	0.07	0.38	0.12	0.04	0.07	0.08	0.07	0.04	0.02	0.02
8	2.24	0.25	0.02	0.16	0.07	0.08	0.07	0.08	0.07	0.39	0.11	0.04	0.07	0.08	0.07	0.04	0.02	0.02
9	2.13	0.25	0.02	0.16	0.07	0.08	0.07	0.08	0.07	0.37	0.12	0.04	0.07	0.08	0.08	0.04	0.02	0.02
10	1.09	0.25	0.01	0.18	0.03	0.12	0.10	0.12	0.11	0.15	0.16	0.02	0.10	0.13	0.11	0.02	0.03	0.02
11	1.52	0.30	0.01	0.22	0.05	0.14	0.11	0.13	0.12	0.24	0.19	0.03	0.11	0.14	0.12	0.03	0.04	0.02
12	0.82	0.32	0.01	0.23	0.04	0.17	0.14	0.17	0.15	0.15	0.22	0.02	0.14	0.17	0.16	0.02	0.04	0.02
13	1.41	0.25	0.01	0.18	0.04	0.12	0.10	0.12	0.10	0.19	0.16	0.02	0.10	0.12	0.11	0.02	0.03	0.02
14	1.87	0.30	0.02	0.21	0.05	0.13	0.10	0.12	0.11	0.29	0.19	0.03	0.10	0.13	0.12	0.04	0.04	0.02

Year	**lb/ac/yr**																	
HRU	**BAR**	**CIT**	**FOR**	**OFF**	**PAS**	**RHH**	**RLL**	**RMH**	**RML**	**ROW**	**RVH**	**RVL**	**S-RLL**	**S-RMH**	**S-RML**	**S-RVL**	**UGR**	**WET**
1	26.58	3.86	0.32	2.81	1.07	2.24	1.94	2.20	2.05	4.86	2.72	0.57	1.98	2.28	2.10	0.60	0.67	0.39
2	16.09	3.65	0.23	2.54	0.73	1.81	1.53	1.75	1.62	3.05	2.31	0.40	1.57	1.83	1.67	0.43	0.55	0.30
3	25.22	3.61	0.29	2.59	0.96	2.02	1.72	1.97	1.82	4.56	2.47	0.53	1.75	2.05	1.87	0.56	0.60	0.36
4	22.50	3.62	0.28	2.61	0.91	2.05	1.75	2.00	1.86	4.13	2.50	0.50	1.79	2.09	1.91	0.52	0.60	0.34
5	31.24	3.83	0.35	2.76	1.15	2.12	1.82	2.07	1.93	5.58	2.63	0.64	1.86	2.15	1.98	0.66	0.65	0.42
6	10.94	4.02	0.22	3.00	0.79	2.65	2.39	2.65	2.50	2.46	3.03	0.35	2.43	2.73	2.56	0.38	0.73	0.28
7	34.93	3.49	0.35	2.34	1.10	1.49	1.22	1.42	1.30	6.00	2.00	0.66	1.26	1.50	1.36	0.68	0.50	0.42
8	35.81	3.49	0.35	2.34	1.12	1.48	1.21	1.41	1.30	6.14	1.99	0.67	1.25	1.49	1.35	0.69	0.50	0.43
9	34.07	3.52	0.34	2.37	1.09	1.53	1.26	1.46	1.34	5.87	2.04	0.64	1.29	1.54	1.39	0.67	0.51	0.41
10	32.90	3.58	0.34	2.55	1.12	1.94	1.62	1.87	1.73	5.77	2.41	0.63	1.66	1.96	1.78	0.66	0.58	0.41
11	38.31	3.83	0.39	2.77	1.31	2.14	1.84	2.09	1.94	6.72	2.64	0.73	1.87	2.17	2.00	0.75	0.65	0.47
12	19.38	3.96	0.27	2.92	0.95	2.49	2.21	2.47	2.32	3.77	2.91	0.47	2.25	2.56	2.38	0.50	0.70	0.34
13	43.13	3.57	0.40	2.54	1.34	1.91	1.59	1.84	1.69	7.40	2.39	0.77	1.62	1.92	1.74	0.79	0.58	0.47
14	47.74	3.81	0.45	2.74	1.51	2.07	1.77	2.02	1.88	8.21	2.59	0.85	1.81	2.10	1.93	0.88	0.64	0.52

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Appendix B. Seasonal Distribution of Delivered Nutrient Loads by Source Area

Seasonal and Annual TN Loads by Tributary (lbs)					
	Jan-Feb-Mar	**Apr-May-Jun**	**Jul-Aug-Sep**	**Oct-Nov-Dec**	**Annual**
Haw River NPS	1,110,429	521,678	465,069	328,336	2,425,511
Haw River PS	391,561	313,790	238,006	216,232	1,159,589
Upper New Hope NPS	247,355	107,794	112,939	100,911	568,998
Morgan	45,879	20,563	15,401	15,949	97,792
New Hope	96,905	42,493	45,859	40,946	226,204
Northeast	68,581	28,791	36,390	29,010	162,771
Little/Bolin	35,990	15,947	15,289	15,006	82,232
Upper New Hope PS	147,725	116,226	92,022	103,337	459310
Lower New Hope NPS	188,241	78,145	72,984	60,289	399,659
Seasonal and Annual TP Loads by Tributary (lbs)					
	Jan-Feb-Mar	**Apr-May-Jun**	**Jul-Aug-Sep**	**Oct-Nov-Dec**	**Annual**
Haw River NPS	265,386	60,261	160,325	60,808	546,780
Haw River PS	34,773	29,316	25,017	22,970	112,076
Upper New Hope NPS	42,370	13,252	24,641	15,555	95,818
Morgan	5,135	1,228	2,910	1,513	10,785
New Hope	18,860	5,779	11,010	6,822	42,472
Northeast	12,084	4,257	7,289	4,925	28,554
Little/Bolin	6,291	1,988	3,433	2,296	14,007
Upper New Hope PS	7,564	4,453	3,257	5,832	21,106
Lower New Hope NPS	35,639	8,668	21,506	9,809	75,623

Note: This table provides results corresponding to Figure 28 through Figure 33. Nonpoint loads are based on the average of the 10-year model simulation run (April 1991-March 2001 meteorology), while point source loads are based on the average of the 1996-1998 analysis of delivered loads provided by RTI (2002).