TECHNICAL MEMORANDUM

SUMMARY OF MODELING TOOLS USED IN ASSESSING MANAGEMENT MEASURES IN THE UPPER NEUSE WATERSHED

Prepared for the Upper Neuse River Basin Association

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1. Table of Contents

1. Background and Model Selection

The Upper Neuse Watershed (Figure 1-1) includes nine public water supply reservoirs, which currently provide high-quality drinking water for an estimated 500,000 people. In addition, lakes and streams in the watershed provide important recreational opportunities and abundant fish and wildlife habitat. With some water resources currently stressed and with the watershed's population projected to increase by 100,000 in the next 25 years, protecting water quality and stream habitat will be increasingly important.

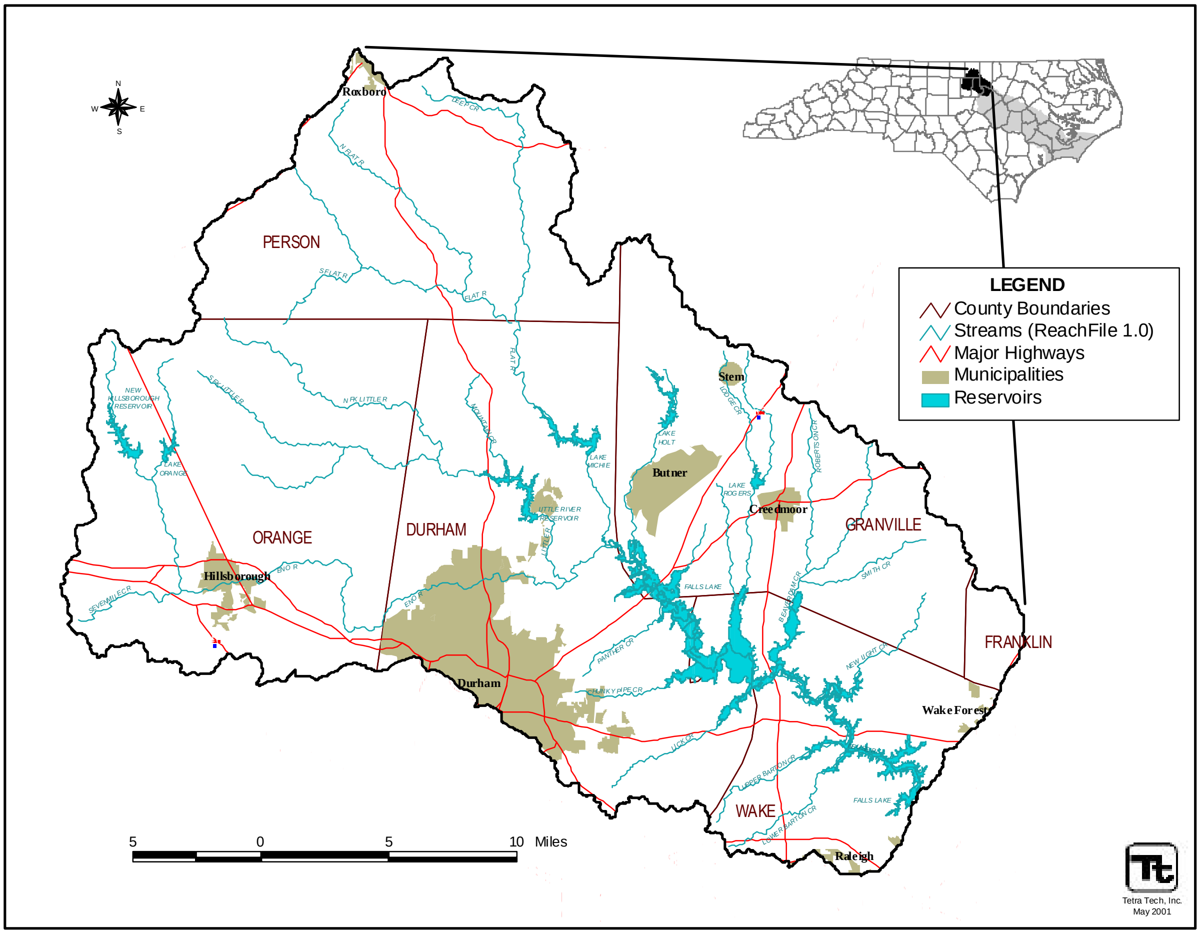

Figure 1-1. Location Map of the Upper Neuse River Basin

The Upper Neuse River Basin Association (UNRBA) was voluntarily formed by the 14 local governments with land use planning and zoning jurisdiction in the 770-square mile Upper Neuse River Basin watershed. With the assistance of the Soil and Water Conservation Districts and policy leaders from the North Carolina Department of the Environment and Natural Resources (NCDENR), the North Carolina Environmental Management Commission, and the North Carolina Department of Transportation, the UNRBA developed the Draft Upper Neuse Watershed Management Approach to help guide future management decisions in order to protect and improve water quantity and quality. The approach set in place the mechanisms by which UNRBA members, state/federal agencies, and other stakeholders will coordinate to manage water quality in the basin. Among the components are two key forums that support policy and executive decision-making (the Policy Coordinating Council or PCC) and technical analysis and decision-making (the Technical Advisory Committee or TAC). Based on the advice of these two forums, the UNRBA Board decided to move forward by developing an initial watershed management plan for the Upper Neuse. Although the approach outlines a five-year planning cycle that is synchronized with the North Carolina Division of Water Quality's basin planning cycle, the Board believed that existing information was sufficient to forego additional monitoring and assessment in the first round of planning. It was deemed more important to develop an initial plan within a two-year time horizon.

The UNRBA received a grant of $300,000 from the General Assembly to develop a watershed management plan for the Upper Neuse. A portion of those funds ($230,000) was used to contract with a project consulting team to support plan development. The amount of funds available limited the level of technical analysis that could be performed. Therefore, the challenge to the UNRBA and project consulting team was to determine the best techniques to support management planning cost-effectively. This increased the importance of identifying priorities so that use of funds could be focused on addressing management gaps for the most important issues.

Based on the recommendations of the TAC and PCC, the UNRBA Board of Directors adopted five primary priorities that were ranked by three levels of importance (Table 1). The project consulting team and TAC then identified the primary threats (stressors) in the watershed that could affect the priority concerns, along with decision criteria for determining which threats were greatest for each priority (Figure 1-2).

Table 1-1. Management Priorities Adopted by the UNRBA

Level 1 – Most Important	• Drinking Water Safety
Level 2 – Very Important	• Limits on Recreational Use • Threat to Aquatic and Riparian Habitat
Level 3 – Important	• Inadequate Water Supply • Threat to Aesthetics

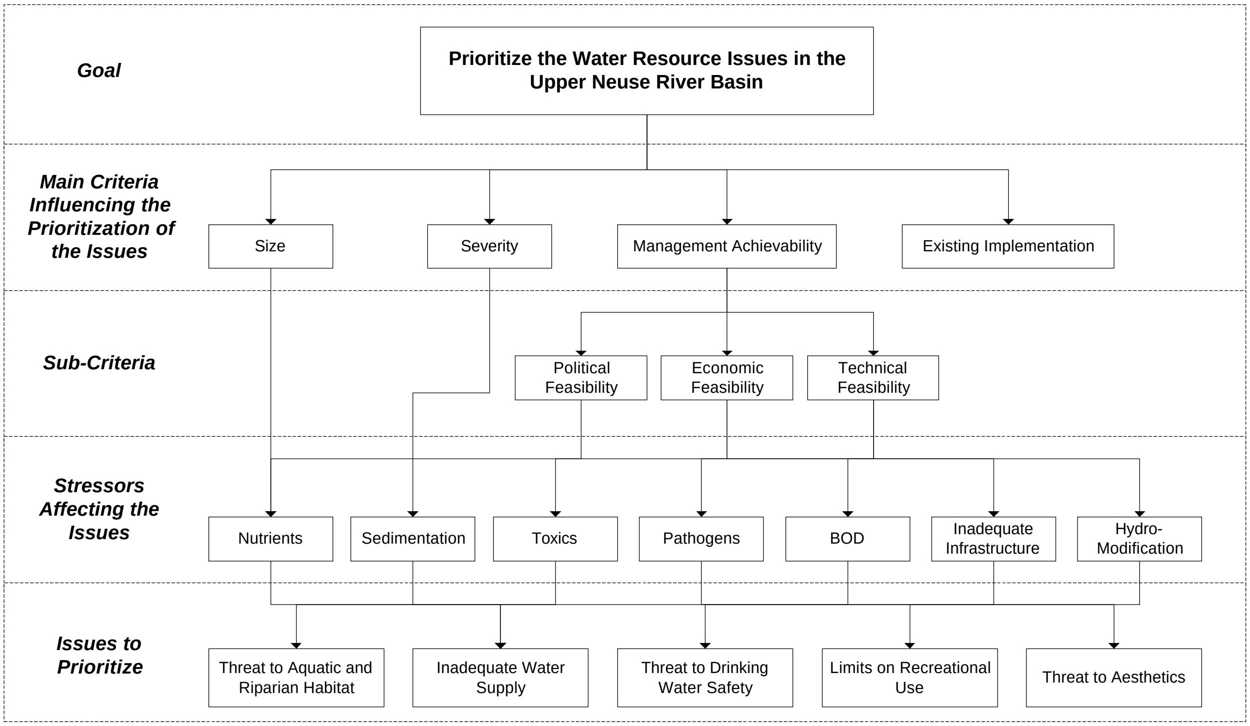

Figure 1-2. Primary Stressors Affecting Management Objectives and Criteria for Prioritizing

Next, the project consulting team and TAC collectively determined whether there were adequate existing local or state programs in place to address each of the primary threats. Based on consensus recommendations from the TAC, the UNRBA Board determined that more emphasis should be placed on addressing eutrophication stressors (nutrients/algae/TOC) and erosion and sedimentation stressors. Although other stressors, including toxics, pathogens, and BOD, were considered important, the TAC believed that existing programs were very effective in addressing these stressors. Gaps in management programs to address eutrophication and erosion/sedimentation problems, however, led to the UNRBA Board targeting these stressors for a greater level of effort in developing new management strategies. A full description of the stressor selection process is found in the memo *Proposed Methods of Evaluation for Targeted Stressors in the Upper Neuse Watershed* included in Appendix A. Table 1-2 summarizes the UNRBA's adopted priorities and level of effort to devote to addressing the key stressors in the management planning process.

Table 1-2. Priorities and Level of Effort for Key Stressors

Type of Stressor	Level of Effort	Priorities				
		Drinking Water Safety	Recreational Use	Aquatic & Riparian Habitat	Inadequate Water Supply	Aesthetics
Nutrients/ Algae/ TOC	Largest	✓	✓	✓		✓
Sedimentation and Erosion	Largest	✓	✓	✓		✓
Hydro-modification	Moderate		✓	✓		✓
Inadequate Infrastructure	Moderate	✓		✓	✓	
Toxics	Some	✓		✓		
Pathogens	Some	✓	✓			
BOD	Some			✓		

In November 1999, the project consulting team proposed methods of evaluation for the targeted stressors in the Upper Neuse watershed. The assessment methods were based on identification of indicators that linked stressors to management objectives, the availability of existing predictive tools for evaluation of the indicators, and time and funding constraints. A summary of the thought process behind method selection was documented in a memo that is provided in Appendix A of this report. Based on the evaluation, the project consulting team recommended use of the following:

- Generalized Watershed Loading Function (GWLF) model (Haith et al, 1992) to address annual average upland sediment and nutrient loading, and impact on long-term streamflow volume at the subwatershed scale.
- GIS analysis of impervious cover to relate to risk to biological condition.
- The BATHTUB model (Walker, 1987) previously calibrated for Falls Lake to address eutrophication impacts in Falls Lake (Butcher et al, 1995).
- Empirical equations drawn from BATHTUB (referred to as Walker equations) for prediction of eutrophication response in the other eight water supplies in the watershed in addition to Falls Lake.

1.1 OVERVIEW OF GWLF

GWLF provides monthly and annual estimates of flow volume, dissolved and total nitrogen and phosphorus, as well as sediment mass. The complexity of the GWLF 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. Solids load, runoff, and ground water processes are used to estimate particulate and dissolved-phase pollutant delivery to a stream, based on pollutant concentrations in soil, runoff, and ground water.

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 landuse 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 ground water pathways. The amount of water available to the shallow ground water 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 with a modified rainfall erosivity coefficient that accounts for the precipitation energy available to detach soil particles. 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.

GWLF simulates nutrient loads based on the movement of sediment (sorbed phase) and water (dissolved phase). The dissolved component is further subdivided into surface and subsurface or ground water fractions. Nutrient loadings from wastewater treatment plants (WWTPs) and onsite wastewater disposal via septic systems are also simulated by the model.

Particulate nutrient concentrations are taken as a general characteristic of area soils, determined by bulk soil concentration and an enrichment ratio indicating preferential association of nutrients with the more erodible soil fraction, and not varied by landuse. Nutrients generated from urban landuses are described by a buildup/washoff formulation. Pollutant accumulation is summarized by an exponential buildup rate, and GWLF assumes that 95% of the limiting pollutant storage is reached in a 20-day period without washoff. WWTP loadings were developed based on measured and predicted discharge characteristics. Parameters affecting nutrient loading from septic systems were based on delivery assumptions, per capita load generation, and plant uptake.

The GWLF model was run using the inputs specified in this document to develop loadings by subwatershed. The results of the model required further processing to account for the effects of riparian buffers, nutrient reductions, and stormwater controls specified in the water supply ordinances and the Neuse River Basin - Nutrient Sensitive Waters Management Strategy (15A NCAC 02B.0232). The final loadings were aggregated to produce estimates of the loadings to each drinking water supply (Figure 2-2).

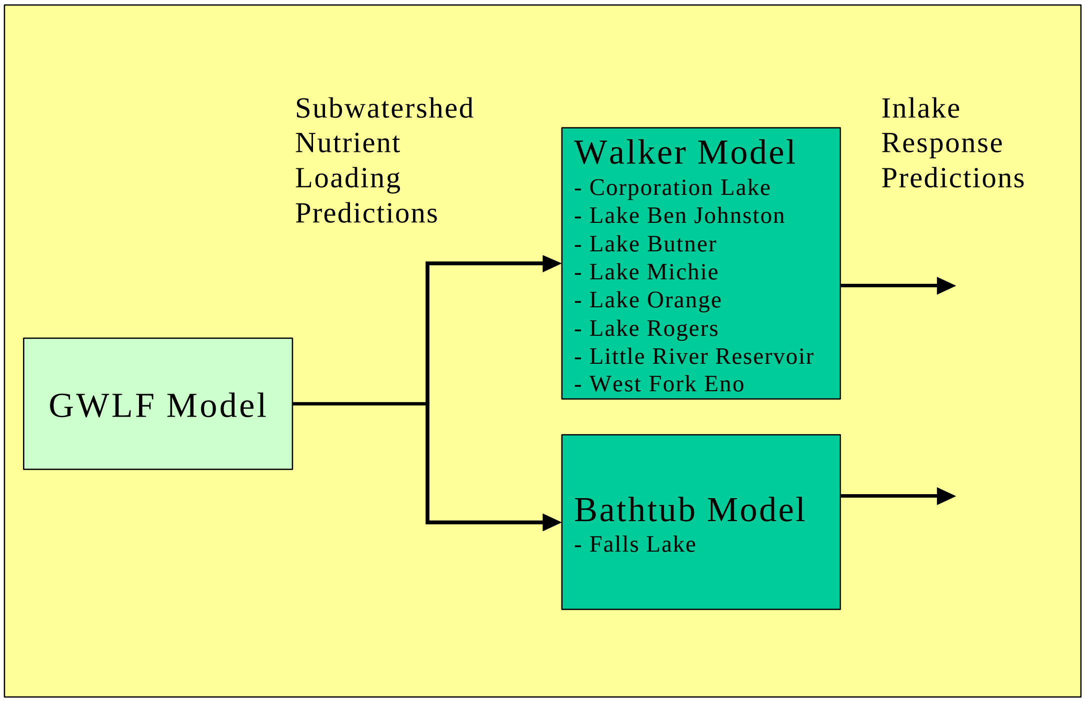

Figure 2-2. Watershed and Lake Model Linkage

1.2 OVERVIEW OF BATHTUB AND WALKER EQUATIONS

Lake eutrophication is a primary concern for the drinking water supplies in the Neuse River Basin. The algal growth which can produce this condition is strongly dependent on the amount of available nutrients. The GWLF model results were used as inputs to semi-empirical relationships developed and tested on reservoirs for the BATHTUB model (Walker 1987). This model utilizes total nitrogen, total phosphorus, and orthophosphate loads to estimate chlorophyll *a* concentrations.

Chlorophyll *a* is the primary photosynthetic pigment in algae, and is thus used as an indicator of algal biomass. It is an inexact indicator of algal biomass, but has regulatory status in North Carolina, where the water quality standards specify a chlorophyll *a* concentration of less than 40 μg/L. Notably, chlorophyll *a* is a weak producer of the biomass of blue-green algae, which are of primary concern for aesthetic and treatability considerations in North Carolina waters. Predicted chlorophyll *a* is, however, a useful indicator of general lake conditions. Average growing season loads of nutrients from each of the drinking water supply drainage areas were input to the Walker relationships. These results were used to predict the relative change in chlorophyll *a* and therefore eutrophication conditions.

A BATHTUB model for Falls Lake including lake morphometry and nutrient cycle parameterization was developed for the original eutrophication study (Butcher et al, 1995). This extensively calibrated model was used as the basis for the Falls Lake nutrient and chlorophyll *a* simulations. No similar models had been developed for the other eight existing and proposed drinking water supplies. The semi-empirical relationships used in the BATHTUB model (referred to as the Walker equations) were re-created in a Quattro Pro spreadsheet to develop the eight remaining drinking water supply reservoir models. The simulated flow and loading estimates from the GWLF simulations were used to provide the existing and future inputs to the BATHTUB and Walker equations to predict the inlake chlorophyll *a* response for the future and existing scenarios.

The set-up and refinement of these tools, including key assumptions, are documented in the remainder of this report.

2. Description of Scenarios for Model Setup

A number of scenarios were specified by the TAC to analyze the parameters of concern under existing (Year 2000), Year 2025, Low Buildout, and High Buildout conditions. Each scenario is described briefly below. Collectively, the scenarios drive the model setup process. The primary assumptions and specific data processing used to develop the model inputs for each scenario will be described in greater detail in following sections.

2.1 EXISTING CONDITIONS (YEAR 2000)

The existing scenario represents current conditions (Year 2000) within the Upper Neuse Basin. Satellite imagery developed by the US EPA was used to estimate the current landuse distribution within the watershed. This coverage classifies 1993-1996 SPOT and 1999-2000 LANDSAT imagery into 49 distinct landuses (EPA 2000). Population estimates from TJCOG (2000) household sewage disposal methods from the US Department of Census (US Census, 1991) and historical point source withdrawals and discharges (TJCOG 2000) were used to develop the model inputs.

2.2 YEAR 2025

The 2025 scenario uses estimates of changes in population and dwellings from TJCOG to develop changes in landuse. The TJCOG study compiled information for the Triangle area including existing and future dwellings and population (TJCOG 1997). This information and urban service boundaries were used to estimate the number of sewered dwellings and septic systems. All areas zoned as non-residential are assumed to be developed by this time. Estimates provided by TJCOG were used to characterize point source withdrawals and discharges.

2.3 LOW RANGE BUILDOUT

The Low Range Buildout scenario represents a moderate estimate of the potential future development within the watershed. All forest and agricultural land not protected from development is assumed to be converted to residential or non-residential lands based upon zoned use. Landuse changes used for this scenario are based on realized residential densities and zoning (i.e., the actual density that is observed on development in a given zoning designation). Where available, realized densities provided by municipal and county governments were used to determine the total area lost to development in non-sewered areas. If realized densities were not available, zoning restrictions were used to estimate rural land lost to development. All urban development was regulated according to the *low option* for jurisdictions which specified density limits in the watershed regulations. The *low option* typically placed limits on maximum imperviousness of 12 to 24 percent for areas without stormwater controls. All areas zoned as non-residential are assumed to be completely developed under this scenario. Estimates provided by TJCOG were used to characterize point source withdrawals and discharges.

2.4 HIGH RANGE BUILDOUT

The High Range Buildout scenario represents a worst-case estimate of the potential future development within the watershed. All forest and agricultural land not protected from development is assumed to be converted to residential or non-residential lands based upon zoned use. Development was based upon zoning restrictions to determine the maximum allowable urban and rural density. All landuses were assumed to be developed to the maximum allowed imperviousness. All urban development followed the *high option* specified in the watershed regulations. This option allows higher development densities and imperviousness limits (from 50 to 70 percent) and typically requires storm water controls. All areas zoned as non-residential are assumed to be developed by this time. Estimates provided by TJCOG were used to characterize point source withdrawals and discharges.

3. GWLF Model Input

The GWLF application requires information on land use distribution, meteorology, and parameters that govern runoff, erosion, and nutrient load generation. Eight primary data inputs are used to develop the model parameters used for the watershed simulations: 1) Watershed Boundaries, 2) Landuse, 3) Nutrient Buildup and Runoff Assumptions, 4) Population and Onsite Wastewater Disposal Data, 5) Impervious Area Estimates, 6) Soil Parameters, 7) Surface Water Withdrawals and Point source Discharges, and 8) Meteorological Monitoring Data. This application of the GWLF model was derived from a calibrated GWLF model developed for the North Carolina Department of Environment, Health, and Natural Resources (Butcher et al., 1995). The soil and erosion characteristics as well as the nutrient loading and buildup rates were considered to be applicable for the current study. However, revised data had become available for meteorology, landuse, watershed delineations, population, and septic numbers. This new information was processed to generate the set of GWLF input files used to represent the four scenarios. The GWLF nutrient and transport input files can be found in Appendix B.

3.1 WATERSHED BOUNDARIES

The 770 square mile Upper Neuse Basin was delineated into 32 subwatersheds based on the 14-digit hydrological units, locations of drinking water intakes, and drainage areas for drinking water supplies. As shown in Figure 3-1, these 32 subwatersheds collectively form the headwaters of the large Neuse River Basin. The original subwatershed boundaries were developed by the NRCS and refined by TJCOG to isolate the drainage areas for major tributaries to Falls Lake and the other drinking water supplies. For analytical and planning purposes, the sub-watersheds (averaging 24 sq. mi.) were combined to form nine drinking water supply watersheds, with the smallest being Lake Orange and the largest being Falls Lake (Table 3-1).

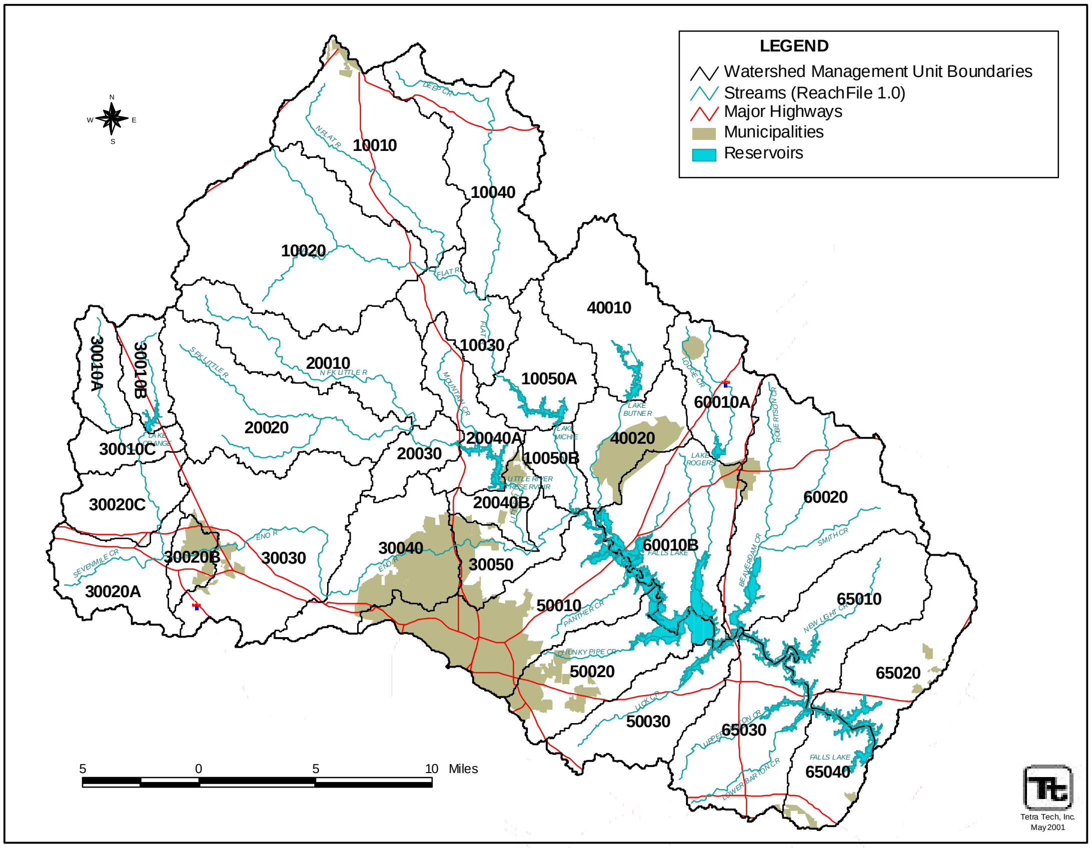

Figure 3-1. Upper Neuse River Basin Model Subwatersheds

Table 3-1. Model Subwatersheds and Drainage Area

Project ID	NRCS/TJCOG ID (within basin 30202010)	Upper Neuse Subwatersheds	Drainage Area (mi^{2})
1	10010	Flat River above Lake Michie	40.3
2	10020	Flat River above Lake Michie	56.5
3	10030	Flat River above Lake Michie	15.1
4	10040	Flat River above Lake Michie	37.0
5A	10050A	Flat River	19.0
5B	10050B	Flat River	7.4
6	20010	Little River above Little River Reservoir	33.0
7	20020	Little River above Little River Reservoir	39.1

Project ID	NRCS/TJCOG ID (within basin 30202010)	Upper Neuse Subwatersheds	Drainage Area (mi^{2})
8	20030	Little River above Little River Reservoir	8.3
9A	20040A	Little River Reservoir	16.5
9B	20040B	Little River below Little River Reservoir	8.0
10A1	30010	New Hillsborough Reservoir	9.5
10A2	30010	Lake Orange	9.1
10B	30010	Eno River above Lake Ben Johnston	8.2
11A1	30020A	Lake Ben Johnston	14.7
11A2	30020A	Corporation Lake	18.8
11B	30020B	Eno River below Corporation Lake	5.9
12	30030	Eno River	47.9
13	30040	Eno River	28.2
14	30050	Eno River	13.0
15	40010	Knap of Reeds above Lake Butner	28.6
16	40020	Knap of Reeds Creek	18.0
17	50010	Ellerbe Creek	38.2
18	50020	Little Lick Creek	25.2
19	50030	Lick Creek	22.9
21A	60010A	Ledge Creek above Lake Rogers	17.6
21B	60010B	Ledge Creek	34.3
22	60020	Beaverdam Creek	53.3
24	65010	Newlight Creek	28.1
25	65020	Horse Creek	24.7
26	65030	Barton Creek	31.0
27	65040	Cedar Creek	14.3
Total			771.4

3.2 LANDUSE

The original application of the GWLF model to the Upper Neuse was developed using 1987-88 Landsat Thematic Imagery data developed as part of the Albemarle-Pamlico Estuarine Study. The Landsat coverage and ground-truthing analyses were used to determine the landuse distribution by subwatershed. Landuses were classified into 18 separate classes including agriculture, four types of wetlands, and ten urban landuses including two separate impervious groups.

3.2.1 Existing

More recent landuse information was provided by TJCOG for use in setting up the Year 2000 GWLF simulation. This landuse data was obtained from the US EPA, Landscape Characterization Branch and is a highly detailed geo-dataset of the Neuse River derived from SPOT and Landsat 7 ETM+ imagery. This data was developed by the US EPA Landscape Characterization Branch, Research Triangle Park, to support studies requiring high-resolution (15 meter) land use/land cover data. Source time period dates range from Oct. 1998 to March 1999 (EPA, 2000). The data is classified into seven major classes: Urban/Built-up, Agricultural, Woody Vegetation, Herbaceous Vegetation, Water, Wetland, and Barren, which are further separated into 49 distinct subclasses.

The subclasses found in the study area were reclassified into the pervious landuses represented in the original application (Butcher et al., 1995); Water, Agriculture, Low Density Vegetation, Pine Forest, Bottom Forest, Mixed Forest, Dist. Non-Ag, Shadow, Low Density Residential, Medium Density Residential, High Density Residential, Medium Density Residential (1-2 houses/ac), Low Density Residential (2-4 houses/ac), and Urban Greenspace. Impervious landuse classes are also included in the model based on the estimated fraction of the rural and urban imperviousness from review of Durham landuse information and discussion with the developers of the EPA landuse coverage (Lunetta, personal communication, December 2000). Each 15-meter cell within the EPA coverage is classified according to the landuse which comprises the majority of the area. For example, EPA landuse 123 is classified as MD-Woody (36-50%). This classification is interpreted as Medium Density Urban Area, secondary majority of landuse is Woody Herbaceous Vegetation, with an overall impervious of 36-50 percent. Review of the EPA imperviousness ranges and comparison with maps and zoning were used to estimate a typical imperviousness percentage for each landuse class. This imperviousness includes roads, parking lots, and sidewalks, as well as barren areas and dirt roads, which are essentially impervious. The EPA landuse distribution, model landuse class, and associated imperviousness are summarized in Table 3-2. The complete reclassified landuse distribution by subwatershed is found in Appendix B.

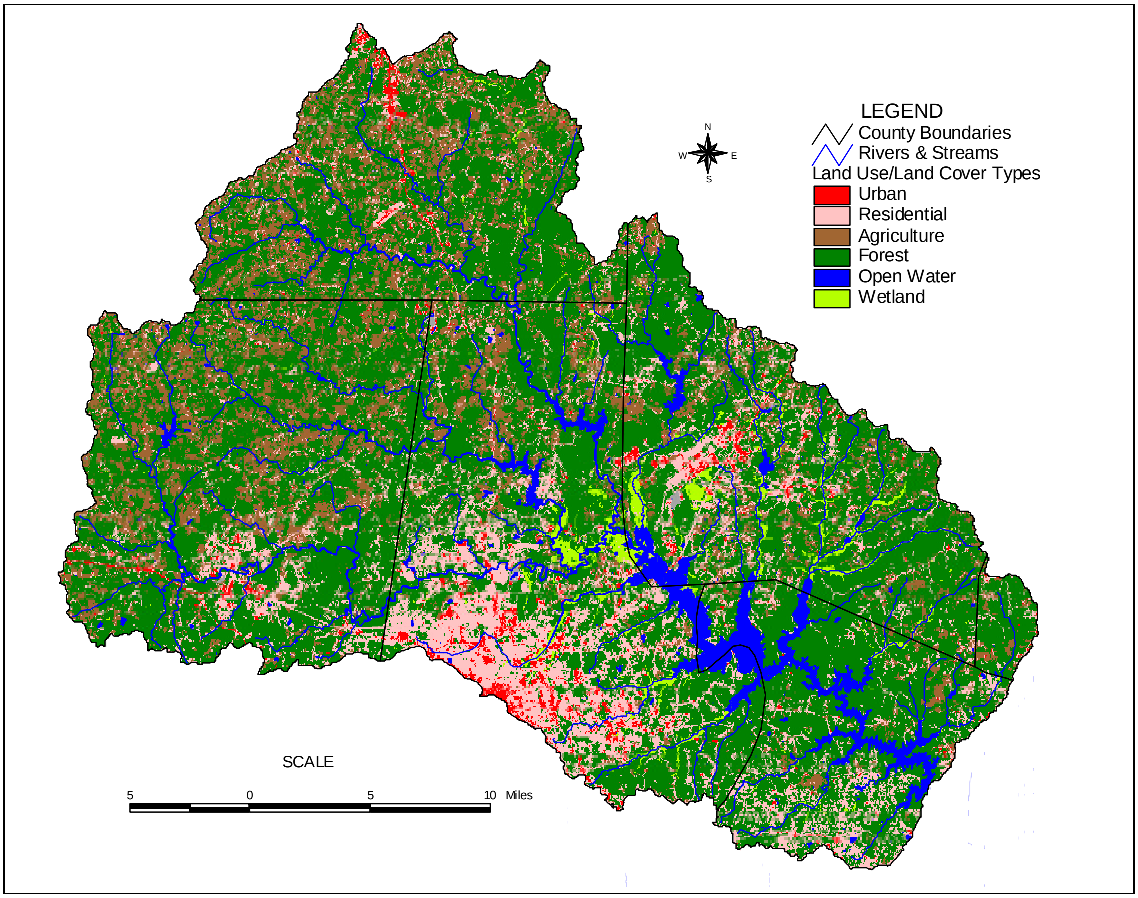

Figure 3-2. Upper Neuse River Landuse Coverage (EPA 2000)

Table 3-2. Landuse Distribution and Estimated Impervious Percentages

EPA Landuse Code	EPA Landuse Name	EPA Landuse Area (ha)	GWLF Landuse	Percent Impervious
110	Urban - High Density (71-100%)	4,282.4	Commercial	90
120	Urban - Medium Density (50-70%)	1,598.2	Light Industrial	60
122	MD - Agriculture	38.5	Urban Greenspace	17
123	MD - Woody (36-50%)	91.7	High Density Residential	40
124	MD - Herbaceous (36-50%)	38.2		
125	MD - Water (36-50%)	3.3		
126	MD - Wetlands (36-50%)	3.2		
127	MD - Barren (36-50%)	4.6		

EPA Landuse Code	EPA Landuse Name	EPA Landuse Area (ha)	GWLF Landuse	Percent Impervious
130	Urban - Low Density (10 - 30%)	7,695.6	Medium Density Residential	30
132	LD - Agriculture	6,150.6	Urban Greenspace	17
133	LD - Woody	12,381.2	Low Density Residential	17
134	LD - Herbaceous	2,526.0		
135	LD - Water	494.3		
136	LD - Wetlands	190.3		
137	LD - Barren	75.4		
212	Agriculture - Corn	3,215.9	Agriculture	4
213	Agriculture - Soybean	1,658.9		
214	Agriculture - Tobacco	1,254.0		
220	Pasture	24,832.6		
230	Fallow	1,339.3		
310	Woody - Deciduous	80,667.3	Deciduous Forest	4
320	Woody - Evergreen	34,048.5	Pine Forest	4
330	Woody - Mixed	7,001.7	Mixed Forest	4
410	Grasslands	200.2	Low Density Veg	4
500	Water	365.1	Water	0
510	Streams and Rivers	77.8		
530	Reservoirs	3,646.5		
550	Ponds	604.0		
610	Herbaceous Wetlands	1,062.1	Wetlands	4
620	Woody Wetlands	4,001.3		
710	Barren	171.8	Dist. Non-Ag	10
Total		**199,780.6**		

* Assume 4% imperviousness for undeveloped rural areas based on Durham County data and conversation with EPA.

Future landuse cover was estimated using a variety of information including zoning regulations, urban service areas, open space estimates, predicted housing increases, and assumed lot sizes. This information was processed to predict future landuse in the year 2025 and under buildout scenarios.

3.2.2 Year 2025

The 2025 scenario uses estimates of changes in population and dwellings from the Triangle Area Zoning (TAZ) coverage to develop changes in landuse (TJCOG, 1997). The TAZ coverage includes for the period from 1995 to 2025 for the spatial distribution of dwellings in urban and rural areas in Franklin, Wake, Durham, and Orange Counties. The difference between these counts was assumed to be the number of new dwellings built in this 25-year period. Information for Granville and Person Counties was not covered in detail by the TAZ data. Data from the North Carolina Census Bureau and county estimates of growth were used to complete the dwelling information from these counties. The number of new dwellings and an area per dwelling ratio was used to determine the landuse change due to residential development. Where available, realized densities provided by municipal and county governments were used to determine the total area lost to development in non-sewered areas (Table 3-3). These realized densities reflect the lot sizes which are typically being built within a watershed. These lot sizes vary depending on zoning limits, homeowner preferences, and septic system requirements. If realized densities were not available, zoning restrictions were used to estimate urban and rural land lost to development. All areas zoned as non-residential (commercial, industrial, etc.) are assumed to be built out by 2025 at the zoned density. Where applicable, non-residential growth with a maximum impervious area of 70% will be allowed up to a limit of 5% of the total watershed area.

3.2.3 Low Range Buildout

The Low Range Buildout scenario represents a moderate estimate of the potential future development within the watershed. Buildout is intended to represent the future condition where all available undeveloped lands have been converted to urban and suburban areas. The time period at which this will occur is unspecified. Areas in urban centers such as Durham are likely to reach buildout by 2025, whereas more rural areas may not reach buildout for many decades. Under this scenario, all forest and agricultural land not protected from development was assumed to be converted to residential or non-residential lands based upon zoned use. The landuse conversion assumptions used for this scenario were based on realized residential densities and zoning (Table 3-3). Fifteen percent of the available land was assumed to remain as undeveloped land (e.g., unbuildable, community open space). This estimate was based on discussion with TJCOG staff (personal communication, Ben Hitchings, December 2000). Where available, realized densities provided by municipal and county governments were used to determine the total area lost to development in non-sewered areas. If realized densities were not available, zoning restrictions were used to estimate rural land lost to development. The lesser of the realized lot size or density limit was used to estimate the final number of dwellings. The maximum density for rural dwellings was assumed to not exceed one unit/ac. All non-residential development was developed as regulated by the *low option* specified in the watershed regulations.

3.2.4 High Range Buildout

The High Range Buildout scenario represents a worst-case estimate of the potential future development within the watershed. The assumptions used for this scenario were based on maximum development as allowed by zoning. All forest and agricultural land not protected from development was assumed to be converted to residential or non-residential lands based upon zoned use. Fifteen percent of the available land was assumed to remain as undeveloped land. Estimated development was based upon zoning restrictions to determine the maximum allowable urban and rural density (Table 3-3). All landuses was assumed to develop to the maximum allowed imperviousness specified by the current watershed regulations. All non-residential was developed as regulated by the *high option*. This option allows higher development densities and imperviousness limits and may require storm water controls.

Table 3-3. Upper Neuse River Basin Summary of Residential Density Assumptions

Jurisdiction	Watersheds	Urban Zoned (Units/ac)	Rural Zoned (Units/ac)	Rural Realized (Units/ac)
Butner	5A, 5B, 15,16, 21A	1.0[3]	0.5[3]	-
Creedmoor	21A, 21B, 22	2.0[3]	1	-
Durham	3,4,5A, 5B, 6, 7, 8, 9A, 9B, 13, 14, 15, 16, 17, 18, 19, 20, 21A, 21B, 23, 24, 25, 26	2.0[3]	0.5[3]	0.5[3]
Franklin	24, 25	2.0[2]	1.45[2]	-
Granville	5A, 5B, 11B, 12, 15, 16, 17, 20, 21A, 21B, 22, 23, 24, 25	1.74[2]	1.09[3]	0.2[4]
Hillsborough	11B, 12	9.0[3]	0.5 – 1[3]	0.34[3]
Orange	2, 3, 6, 7, 8, 10, 11A, 11B, 12, 13	-	0.2 – 1[4]	0.34[1]
Person	1, 2, 3, 4, 5A, 6, 15	2.0[2]	1[2]	-
Raleigh	25, 26, 27	1.0[3]	1[3]	0.5[4]
Roxboro	1	2.0[2]	1[2]	-
Stem	21A	1.74[2]	1.09[2]	-
Wake County	18, 19, 20, 21B, 22, 23, 24, 25, 26, 27, 28	0.5 – 1.0[3]	0.5 – 1[3]	0.5[3]
Wake Forest	25	0.5 – 1.0[3]	0.5 - 1[3]	-

Sources:
[1] TJ COG, 2000
[2] Kerr-Tar Council of Governments, 2000
[3] UNRBA Regulatory Review and Assessment, 1999
[4] Best Professional Judgment
[5] TAZ Density Estimates

3.3 NUTRIENT BUILDUP AND RUNOFF ASSUMPTIONS

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 application of the GWLF model separated impervious land area from each residential land-use category and assigned a build-up function of 0.0112 kilogram/hectare/day (kg/ha/day) for phosphorus and 0.0900 kg/ha/day for nitrogen. This constant phosphorus buildup rate for the impervious portion of residential land uses is consistent with the previous studies for Little River Reservoir and Lake Michie, in which total load generated by residential land uses is approximately constant when normalized to impervious area.

Because phosphorus loading from fertilizers and plant material is a function of pervious area for residential lot sizes, a constant loading factor is used. The following build-up factors were applied to the pervious portion of the residential landuse categories modeled in GWLF.

- Nitrogen: 0.0220 kg/ha/day
- Phosphorus: 0.0039 kg/ha/day

The pervious portion of lots larger than 1 acre was categorized as rural land use. In GWLF, a runoff nutrient concentration rather than a buildup/washoff loading rate is assigned to rural land uses, because the high proportion of pervious surface results in long overland flow over vegetated surface, which traps solid material and causes the dissolved pollutant fraction to dominate.

The GWLF model uses buildup/washoff relationships and runoff concentrations to predict nutrient loadings. These processes vary based on soil types and landuse and are defined by a number of parameter values. Table 3-4 presents the ranges of the primary parameter values used in the Upper Neuse models. Appendix B contains the complete set of input files should the reader desire more specific information on a given subwatershed.

Table 3-4. Nutrient Runoff and Buildup Rates

Runoff and Buildup Rates		
Rural Landuses	**Dissolved N (mg/L)**	**Dissolved P (mg/L)**
Agriculture	2.62 - 2.81	0.1750 - 0.230
Pine Forest	0.19	0.006
Bottom Forest	0.19	0.006
Mixed Forest	0.19	0.006
Wetlands	0.19	0.006
VLDR	0.34	0.013
Urban Landuses*	**N Buildup (kg/ha-day)**	**P Buildup (kg/ha-day)**
Rural Impervious	0.045	0.0045
VLDR Impervious	0.045	0.0045
Other Impervious	0.045	0.0045
Commercial Industrial	0.045	0.0045
Light Industrial	0.022	0.0039

Urban Landuses*	N Buildup (kg/ha-day)	P Buildup (kg/ha-day)
HDR	0.022	0.0039
MDR	0.022	0.0039
LDR	0.022	0.0039
Urban Green	0.022	0.0039
Barren	0.022	0.0039
Commercial Impervious	0.09	0.0112
Industrial Impervious	0.09	0.0112
HDR Impervious	0.09	0.0112
MDR Impervious	0.09	0.0112
LDR Impervious	0.09	0.0112

Note: Many of the urban landuse appear to have the same buildup rates. However, the urban landuses within each subwatershed are split into pervious and impervious areas. As imperviousness increases, a greater area is assigned the high impervious buildup rate and the landuse will have a comparably higher net loading rate as a result.

3.4 POPULATION AND ONSITE WASTEWATER DISPOSAL DATA

The Upper Neuse watershed includes parts of Durham, Franklin, Granville, Orange, Person, and Wake Counties and eight municipalities. The largest urban areas are Durham, Hillsborough, and Camp Butner. The population of the watershed grew by 21% over the last decade (from 157,000 in 1990 to 190,000 in 2000). Approximately 40% of the households are in the City of Durham and 22% in Durham County (outside of the City's jurisdiction).

Over the next 25 years, the watershed is projected to grow by 53% (from 190,000 to approximately 280,000 people). In the longer term, the population could ultimately triple or quadruple if land is built upon as allowed in existing local zoning and development regulations. Population data plays two roles in the modeling process when more specific data are not available: 1) it provides an estimate of the number of new households in the watershed; 2) it provides an estimate of the number of septic systems. The number of new households is used to model the shift in landuse from agricultural and forest lands to urban or suburban landuses. The model represents these landuses differently with each having individual runoff and nutrient loading characteristics. Onsite wastewater disposal systems provide indirect loading on nutrients to the system.

A number of sources were used to estimate the population by subwatershed for the year 2000, the year 2025, and final buildout. The primary source of population data used for the analysis of Upper Neuse Basin was the TAZ coverage. This coverage includes population and dwelling estimates for the period from 1995 – 2025 for the majority of the Upper Neuse watershed and is organized by TAZ blocks. The 1990 US Bureau of Census data was used to complete population data for areas not covered by the TAZ coverage.

3.4.1 Existing Conditions (2000)

The population by watershed and number using wastewater disposal practices were calculated using the ArcView GIS. A GIS theme defining the subwatershed boundaries was provided by the Triangle J Council of Governments. This GIS coverage defined the boundaries as well as providing population and growth estimates for the years 1995, 2005, 2015, and 2025. Data for the Year 2000 scenario were interpolated between the 1995 and 2005 TAZ estimates. An ArcView script was run to allocate the estimates by subwatershed based on area-weighting. The Triangle J COG population estimates were used to determine the annual growth rate by subwatershed.

A significant portion of the population in subwatersheds 1, 2, 3, 4, and 15 were underestimated. These subwatersheds are located in the Northwest section of the Upper Neuse and are not fully covered by the TAZ boundaries used by the TJ COG. Where data from the TAZ estimates was missing or incomplete, the 1990 census estimates and county estimated annual growth rate were used to fill in the gaps. The 1990 Census gathered information on population and the number of households using septic, sewer, or other disposal methods. This information is available by census tract/block groups. Block numbering areas are small statistical subdivisions of a county for grouping and numbering blocks in non-metropolitan counties where local census statistical area committees have not established census tracts. The census tract/block group coverage was overlayed with the subwatershed boundary theme to estimate the population and disposal practice. The population estimates and percent of the population in each subwatershed using sewer, septic, or other disposal means was calculated using the 1990 census data.. This ratio was multiplied by the county growth estimates to predict the population on septic systems (Table 3-5). This number was input to the GWLF model to estimate subsurface nutrient loadings based on typical concentrations (Table 3-6).

3.4.2 Future Conditions (2025 and Buildout Scenarios)

The landuse and population estimates for the year 2025 were developed using the TJCOG estimates for each TAZ. The TAZ database contains estimates of the number of dwellings in the year 2025. By overlaying the TAZ coverage with the subwatershed boundaries, the predicted change in the number of dwellings was calculated. The TAZ coverage was overlayed with the urban boundary coverage, to estimate the distribution between septic and sewered dwelling. The distribution between houses on sewer and septic systems was estimated using the distribution calculated using the 1990 census data review.

The TAZ, municipal boundaries, and urban development zone coverages were used to determine the number of the new dwellings that would be provided with sewer and water in the future. Wastewater treatment would be allowed to expand as projected Based on available data provided by local planners, expansion of water and sewer services (areas within urban development zones) were projected to occur for Durham and Hillsborough (but not for other jurisdictions in the watershed) (refer to Section 3.7). It was assumed that no additional community wastewater systems would be allowed within the Upper Neuse watershed. All new dwellings built within municipal and urban development zones were assumed to be sewered by 2025.

Buildout populations were developed using existing populations and predicted development as described in Section 3.2. The number of new dwellings estimated in the low and high buildout scenarios was multiplied by a population density factor of 2.1 persons/dwelling. These new populations were added to the year 2025 predictions to develop the final buildout populations. The results of the TAZ processing and application of the future assumptions were summarized for each subwatershed in the study area under the four scenarios (Table 3-5).

Table 3-5. Estimated Population on Septic Systems

Subwatershed	Existing	2025	Low Buildout	High Buildout
1	2,740	2,791	39,039	68,983
2	2,385	3,398	58,227	104,419
3	928	1,259	7,963	19,697
4	1,697	2,258	42,157	75,234
5A	1,250	1,517	8,043	19,761
5B	902	902	1,990	4,680
6	2,241	3,143	17,056	34,733
7	3,325	4,375	19,360	43,960
8	1,678	2,626	5,941	8,747
9A	2,810	3,409	9,656	26,222
9B	2,909	3,033	3,789	5,793
10A1	540	702	5,038	10,078
10A2	524	682	3,283	8,816
10B	471	664	3,185	8,553
11A1	1,313	3,030	7,975	16,309
11A2	1,541	1,541	6,322	14,380
11B	875	1,355	1,923	2,880
12	7,495	10,129	21,638	41,035
13	9,738	10,460	13,376	22,213
14	2,210	2,212	2,212	2,212
15	1,071	1,272	19,942	34,658
16	531	1,031	1,031	1,031
17	5,646	5,921	5,921	5,921

Subwatershed	Existing	2025	Low Buildout	High Buildout
18	5,888	7,153	7,153	7,153
19	3,674	4,356	10,091	25,301
21B	2,600	1,146	16,939	27,604
22	2,719	4,476	4,476	4,476
24	1,999	5,105	47,276	61,809
25	2,277	5,263	20,177	22,654
26	11,857	7,044	16,510	19,061
27	6,584	22,328	22,328	22,328
Total	92,517	124,582	450,016	770,700

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

In this modeling study, a septic system nutrient contribution of 4 grams/capita/day of nitrogen, and 1.5 grams/capita/day of phosphorus were used. The nitrogen contribution is an attenuated rate (33 percent of total) to account for uptake between drain field and stream. 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.

The GWLF model applies average groundwater nitrogen and phosphorus concentrations to flow from the saturated zone to the stream channel. These values were initially set to 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.

Table 3-6. Sediment and Subsurface Nutrient Parameters

Sediment and Subsurface Nutrient Data	
Sediment N (mg/kg)	1000
Sediment P (mg/kg)	616
Groundwater N (mg/L)	0.6
Groundwater P (mg/L)	0.04
Manure Application	No
Septic Effluent N (g/day)	4
Septic Effluent P (g/day)	1.5
N uptake (g/day)	0 (attenuation accounted for in effluent concentration)
P uptake (g/day)	0.4

3.5 IMPERVIOUSNESS AREA ESTIMATES

Imperviousness represents the amount of the land surface that rainfall does not penetrate. This parameter affects the quantity and velocity of runoff and the quantity of contaminant washoff. Imperviousness increases with the amount and density of development. Imperviousness estimates for the model are based upon the landuse/landcover and watershed imperviousness restrictions. The model setup for the existing conditions utilized the imperviousness estimates provided by the EPA landuse analysis discussed in Section 3.2.1. Impervious fractions for the future landuse inputs were developed based on the landuse change and applicable imperviousness limits specified in the water supply protection ordinances. These ordinances were interpreted using the assumptions specified below.

Key Future Impervious Area Assumptions

- Imperviousness of all new development will not exceed the limit specified in the watershed regulations.
- Areas that are allowed to reach 36% imperviousness without curbs and gutters were considered to be equivalent to 24% imperviousness.
- Where no density limits apply, the maximum imperviousness for residential areas will not exceed 50%.
- Future zoning regulations would remain the same as existing regulations (i.e., no shift in the total allowable non-residential area)

Table 3-7 summarizes the water supply ordinances used to develop the imperviousness used for future landuse estimates.

Table 3-7. Upper Neuse River Basin Summary of Maximum Imperviousness Assumptions

Jurisdiction	Area Designation	Watershed	Zoning Class	% Imp (Low)	% Imp (High)	Comments
Butner	Critical	WS-II (Ledge Creek)	Resid.	6%	24%	
		WS-III (Flat River)		12%	30%	
		WS-IV (Falls Lake)		24%	50%	
			Non-Resid.	70%	70%	Limit of 5% of watershed
	Protected	WS-II (Ledge Creek)	Resid.	12%	30%	
		WS-III (Flat River)		24%	50%	
		WS-IV (Falls Lake)		36%	70%	
			Non-Resid.	70%	70%	Limit of 5% of watershed
Creedmoor	Critical		Resid.	6%	6%	
			Non-Resid.	6%	6%	
	Protected		Resid.	12% - 24%	12% - 24%	Zoning dependent
			Non-Resid.	70%	70%	Limit of 5% of watershed
Durham	Critical	WS-II (Little River Reservoir)	Resid.	6%	6%	Not Permitted
		WS-III (Flat River)		6-9%	6-9%	
		WS-IV (Eno River)		24%	24%	
			Non-Resid.	Special	Special	Requires special use permit
	Protected	WS-II (Little River Reservoir)	Resid.	6%	6%	
		WS-III (Flat River)		6-9%	6-9%	
		WS-IV (Eno River)		12%[a]-24%[b]	70%[b]	
		WS-II (Little River Reservoir)	Non-Resid.	6%[a]		Not permitted without utilities in the Little River Reservoir watershed
				6-9%[a]	70%[b]	
		WS-III (Flat River)		12%[a] - 24%[b]	70%[b]	
		WS-IV (Eno River)				

Jurisdiction	Area Designation	Watershed	Zoning Class	% Imp (Low)	% Imp (High)	Comments
Franklin	Critical	WS-IV (Falls Lake)	Resid.	24%	24%	Assumed to be same as Granville County
		WS-IV (Falls Lake)	Non-Resid.	70%	70%	Assumed to be same as Granville; limit of 5% of watershed
	Protected	WS-IV (Falls Lake)	Resid.	24%	24%	Assumed to be same as Granville
		WS-IV (Falls Lake)	Non-Resid.	70%	70%	Assumed to be same as Granville; limit of 5% of watershed
Granville	Critical	WS-II (Ledge Creek) WS-III (Flat River) WS-IV (Falls Lake)	Resid.	6% 24% 24%	6% 24% 24%	Stormwater management required for subdivisions
			Non-Resid.	70%	70%	Limit of 5% of watershed
	Protected	WS-II (Ledge Creek) WS-III (Flat River) WS-IV (Falls Lake)	Resid.	12% 24% 24%	12% 24% 24%	Stormwater management required for subdivisions
			Non-Resid.	70%	70%	Limit of 5% of watershed
Hillsborough	Critical		Resid.	6%	6%	Stormwater management required to meet watershed district guidelines
			Non-Resid.	6%[c], 24%[d]	6%[c], 24%[d]	Watershed stormwater management guidelines required to meet targets
	Protected		Resid.	12%, 30%[c]	12%, 30%[c]	Watershed stormwater management guidelines required to meet targets
			Non-Resid.	70%	70%	

Jurisdiction	Area Designation	Watershed	Zoning Class	% Imp (Low)	% Imp (High)	Comments
Orange	Critical	WS-IV (Eno River)	Resid.	6%	6%	
		WS-IV (Eno River)	Non-Resid.	6%	6%	
	Protected	WS-II (Little River Reservoir)	Resid.	6%	6%	
		WS-III (Flat River)		12%	12%	
		WS-IV (Eno River)		24%	24%	
		WS-II (Little River Reservoir)	Non-Resid.	12%	12%	
		WS-III (Flat River)		70%	70%	
		WS-IV (Eno River)		70%	70%	
Person	Critical		Resid.	6%	6%	
			Non-Resid.	6%	6%	
	Protected	WS-II (Little River Reservoir)	Resid.	12%	12%	
		WS-III (Flat River)		24%	24%	
			Non-Resid.	70%	70%	Limit 5% of watershed
Raleigh	Secondary		Resid.	12%[a], 24%[b], 30%[b.d]	12%[a], 24%[b], 30%[b.d]	
			Non-Resid.	12%[a], 24%[b], 30%[b,d]	12%[a], 24%[b], 30%[b,d]	
Roxboro	Critical		Resid.	6%	6%	
			Non-Resid.	6%	6%	
	Protected	WS-II (Little River Reservoir)	Resid.	12%	12%	
		WS-III (Flat River)		24%	24%	
			Non-Resid.	70%	70%	Limit 5% of watershed

Jurisdiction	Area Designation	Watershed	Zoning Class	% Imp (Low)	% Imp (High)	Comments
Stem	Critical	WS-II (Ledge Creek)	Resid.	6%	6%	
		WS-III (Flat River)				
		WS-IV (Falls Lake)		24%	24%	
				24%	24%	
			Non-Resid.	70%	70%	Limit 5% of watershed
	Protected	WS-II (Ledge Creek)	Resid.	12%	12%	
		WS-III (Flat River)				
		WS-IV (Falls Lake)		24%	24%	
				24%	24%	
			Non-Resid.	70%	70%	
Wake County		All	Resid.	6 – 24%	6 – 24%	Imperv. restriction by zone: R-80W (6%), R-40W (24%)
			Non-Resid.	6 – 24%	6 – 24%	Requires special permit.
Wake Forest		All	Resid.	6%, 12%[a], 24%[b]	6%, 12%[a], 24%[b]	
			Non-Resid.	6%, 12%[a], 24%[b]	6%, 12%[a], 24%[b]	

[a] Without utilities

[b] With utilities

[c] Without stormwater controls

[d] With stormwater controls

3.6 SOIL PARAMETERS

GWLF simulates rural soil erosion using the universal soil loss equation. This method has been applied extensively in North Carolina, so parameter values are well established. As specified earlier, the physical variables used for the current study were adopted from the calibrated GWLF model developed for the North Carolina Department of Environment, Health, and Natural Resources (Butcher et al., 1995).

Runoff Curve Numbers: The direct runoff fraction of precipitation in GWLF is calculated using the curve number method from the SCS TR55 method literature based on landuse and soil hydrologic group. The hydrologic soil group was determined for subwatersheds using the STATSGO database. Weighted curve numbers were calculated for each landuse category based on soil distribution among groups A, B, C, and D. Although the model is driven by the SCS curve number method, it is relatively insensitive to small variations in the curve numbers.

Erosion at the field scale is not, however, equivalent to sediment yield, as substantial trapping may occur, particularly during overland flow or in first-order tributaries or impoundments. Sediment trapping in overland flow and small streams was simulated using a drainage ratio factor. Trapping in major downstream impoundments was simulated based on separate model applications above and below the impoundment and on empirical evidence.

Soil Erodibility (K Factor): The soil erodibility factor 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. Length-slope factors were calculated by measuring representative slopes from topographic maps for upland and bottomland landuse categories.

LS values for land uses in the Falls Lake Watershed vary from 0.76 to 1.84. The LS factor has a proportional effect on the predicted rate of soil erosion (i.e., an LS factor of 1.1 will result in a predicted soil erosion rate 10 percent higher than would a factor of 1.0). For a 100 ft. slope, increasing the slope from 1 to 5 percent increases the LS factor from 0.13 to 0.54, roughly a fourfold increase. In comparison, the management factor, which reflects land-use practices, varies from 0.003 for idle forest to roughly 0.3 for a variety of conventional corn production practices, a 100-fold increase. Land use is potentially a much greater determinant of erosion than is the LS factor.

Evapotranspiration Cover Coefficients: The portion of rainfall returned to the atmosphere is determined by temperature and the amount of vegetative cover. Cover coefficients were set to 1.0 for the growing season and 0.4 for the nongrowing season.

Soil Water Capacity: Water stored in soil may evaporate, be transpired by plants, or percolate to ground water below the rooting zone. The amount of water that can be stored in soil—the soil water capacity—varies by soil type and rooting depth. Average soil water capacity was calculated for each subwatershed by converting STATSGO values to a depth in centimeters (cm), assuming a rooted depth of 100 cm. Typical values were 12–15 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; however, interpretation may be difficult for larger watersheds in which flows arrive at different times from different parts of the watershed and precipitation varies over the watershed area. Recession coefficients, R, for each subwatershed were initially estimated from the recession portion of flood hydrographs using the equation:

$$R = \frac{Ln\frac{Q_s}{Q_t}}{t \cdot s}$$

where

Q_s = flow on day *s*, where *s* is greater than *t* and both observations are on the receding limb of a flood hydrograph, and

Q_t = flow on day *t*.

Minor adjustments in recession coefficients were made to better fit simulated data to actual streamflow data. Values ranged from 0.04 to 0.14 per day.

Seepage Coefficients: The GWLF model has three subsurface zones: a shallow unsaturated zone, a shallow saturated zone, and a deep aquifer zone. The deep seepage coefficient, s, is the portion of the moisture content in the shallow saturated zone that seeps to the deep aquifer zone, 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 coefficients were initially set to zero, with no loss from the modeled system, as a calibration coefficient to reduce the simulated streamflow to better fit measured data. The model, which is fairly sensitive to this parameter, was calibrated for 1984–1988 using values from 0 to 0.05 per day, then validated for the period 1988–1992.

Table 3-8. Curve Number and USLE Parameter Estimates

Landuse	CN*	KLSCP Factor*
Agriculture	70 – 78	0.0040 – 0.0517
Pine Forest	57 - 72	0.0003 - 0.0006
Bottom Forest	57 - 72	0.0003 - 0.0006
Mixed Forest	57 - 72	0.0003 - 0.0006
Wetlands	66 - 80	0.0003 - 0.0006
VLDR	62 - 75	0.0017 – 0.0140
Rural Impervious	98	Non Erodible
VLDR Impervious	98	Non Erodible
Other Impervious	98	Non Erodible
Commercial Industrial	66 - 75	0.0017 – 0.0140
Light Industrial	66 - 75	0.0017 – 0.0140
HDR	66 - 75	0.0017 – 0.0140
MDR	66 - 75	0.0017 – 0.0140
LDR	62 - 75	0.0017 – 0.0140
Urban Green	66 - 75	0.0017 – 0.0140
Barren	66 - 75	0.0017 – 0.0140
Commercial Impervious	98	Non Erodible

Landuse	CN*	KLSCP Factor*
Industrial Impervious	98	Non Erodible
HDR Impervious	98	Non Erodible
MDR Impervious	98	Non Erodible
LDR Impervious	98	Non Erodible

3.7 SURFACE WATER WITHDRAWALS AND POINT SOURCE DISCHARGES

The withdrawals and point source discharges within the basin are also modeled to maintain the hydrological balance and account for nutrient loadings from direct discharges. These estimates were developed from information provided by TJCOG (2000) and are based on historical monitoring and proposed changes. Tables 3-9 through 3-14 present the assumed withdrawals and discharge characteristics within the watershed.

Key Assumptions

- The 1998 – 2000 Discharge Monitoring Records were assumed to be representative of typical point source discharges and were used to represent existing conditions.
- Year 2025 withdrawals and discharges were based on proposed facility changes.
- The High Range Buildout discharges were based upon the Low Range projections and were assumed to have a linear relationship to population.

Table 3-9. 1998 – 2000 Point Source Discharge Characteristics

Point Source	Flow (MGD)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Total Nitrogen (kg)	Total Phosphorus (kg)
Durham NS	9.27	4.29	0.17	55,008.2	2,115.7
Hillsborough	0.98	11.10	0.82	15,009.5	1,112.9
Butner	2.11	14.71	1.79	42,852.9	5,223.3

Source: 1998 – 2000 NPDES Discharge Monitoring Records

Table 3-10. Current Surface Water Withdrawals

Withdrawal	Flow (MGD)	Flow (hm^3/yr)
Lake Johnston/Corporation Lake (Hillsborough/OAWS)	2.6	3.6
Lake Michie (Durham)	15.0	20.7
Little River Reservoir (Durham)	15.0	20.7
Lake Holt (Butner)	2.6	3.6
Lake Rogers (Creedmoor)	0.25	0.35

Source: TJ COG, 2000

Table 3-11. 2025 Projected Point Source Discharge Characteristics

Point Source	Flow (MGD)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Total Nitrogen (kg)	Total Phosphorus (kg)
Durham NS	15.05	3.5	0.17	72,829.6	3,433.4
Hillsborough	3.00	3.5	0.82	14,517.5	3,413.7
Butner	6.50	3.5	1.79	31,454.6	16,113.8

Source: TJ COG, 2000

Table 3-12. 2025 Projected Surface Water Withdrawals

Withdrawal	Flow (MGD)	Flow (hm^3/yr)
Lake Johnston/Corporation Lake (Hillsborough/OAWS)	4.2	5.8
Lake Michie (Durham)	17.0	23.5
Little River Reservoir (Durham)	20.0	27.7
Lake Holt (Butner)	3.1	4.3
Lake Rogers (Creedmoor)	0.32	0.44

Source: TJ COG, 2000

Table 3-13. Buildout Point Source Discharge Characteristics

Point Source	Flow (MGD)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Total Nitrogen (kg)	Total Phosphorus (kg)
Durham NS	20.00	3.5	0.17	96,783.5	4,562.7
Hillsborough	9.08	3.5	0.82	43,915.5	10,326.4
Butner	10.00	3.5	1.79	48,391.7	24,790.4

Source: TJ COG, 2000

Table 3-14. Surface Water Withdrawals at Buildout

Withdrawal	Flow (MGD)	Flow (hm^3/yr)
Lake Johnston/Corporation Lake (Hillsborough/OAWS)	5.5	7.6
Lake Michie (Durham)	20.0	27.7
Little River Reservoir (Durham)	20.0	27.7
Lake Holt (Butner)	12.0	16.6
Lake Rogers (Creedmoor)	0.80	1.11

Source: TJ COG, 2000

3.8 WEATHER DATA

The GWLF model is precipitation driven and is designed to utilize daily monitoring information. The meteorological data required for the GWLF model was collected and processed for the period from January 1984 – April 2000 for the meteorological stations at Rougemont (Station 7499), Durham (Station 2515), and Neuse, NC (Station 6091). This represents an update of the data used in the earlier model. Raw data were obtained from the Southeast Regional Climate Center and consisted of daily mean temperature and precipitation at Durham and precipitation data only for Rougemont and Neuse. The Durham temperature timeseries was used to characterize the mean daily temperature for all the watersheds.

The raw data were processed in Excel and formatted to meet the GWLF input requirements. Meteorological data was assigned to subwatersheds according to the following: Station 2515 for Ellerbe Creek, Eno River, Little Lick Creek, and Lick Creek; Station 7499 for Flat River, Little River, Beaverdam Creek, Knap of Reeds Creek, and Ledge Creek; and Station 6091 for Barton Creek, Cedar Creek, Horse Creek, and Newlight Creek.

4. Lake Model Setup

As described in earlier sections, the models used for this analysis are based on models developed for the North Carolina Department of Environment, Health, and Natural Resources. As part of this effort, a BATHTUB model was setup using bathymetry data and estimates of nutrient cycling rates. Detailed information regarding the original model development can be found in *Falls Lake Watershed Study – Final Report* (Butcher et al., 1995). No similar models had been developed for the other eight existing and proposed drinking water supplies. The semi-empirical relationships used in the BATHTUB model (referred to as the Walker equations) were re-created in a Quattro Pro spreadsheet to develop the eight remaining drinking water supply reservoir models.

The Walker Model utilizes lake volume, residence time, flow volume, and nutrient loadings to estimate growing season averages of chlorophyll *a*. The GWLF model described in the previous section was used to generate flow, sediment, and nutrient loadings by subwatersheds for the existing, 2025, low buildout, and high buildout scenarios. The subwatershed loadings were summed by drainage area to represent the total contributions to each drinking water supply.

To account for settling and uptake of nutrients in these reservoirs, a trapping efficiency was applied to the loadings leaving the drinking water supplies. GWLF does not directly calculate trapping in impoundments; therefore, for Little River (Little River Reservoir), Flat River (Lake Michie), Knap of Reeds (Lake Butner), and Ledge Creek (Lake Rodgers), GWLF was applied both above and below the impoundment dam. Delivery ratio adjustments were made for the below-dam land area to reflect closer proximity to the lake. Empirical estimates of impoundment trap efficiency were used to adjust total load delivery to Falls Lake from the portions of area upstream of the impoundments. The drainage area loadings were also adjusted to account for water quality protection measures such as buffers and stormwater BMPs as specified in the water supply ordinances. The resulting flow and nutrient loading estimates contributing to each drinking water supply were summed and input to the Walker equations.

5. Summary of Modeling Results

5.1 GWLF MODEL RESULTS

The GWLF model was run using the inputs specified in this document. The results of the model required further processing to account for the effects of riparian buffers, nutrient reductions, and stormwater controls specified in the water supply ordinances and the Neuse River Basin - Nutrient Sensitive Waters Management Strategy (15A NCAC 02B.0232).

Riparian buffers have been shown to reduce the impact of stormwater runoff due to reduction of runoff velocities, trapping of sediment, and uptake of nutrients. According to the Center for Watershed Protection (1995), a maximum of 150 feet of adjacent land draining to these buffers is effectively treated. GIS was used to create stream buffers ranging from 50 to 150 feet according to each jurisdiction's existing or proposed regulations. The total area by subwatershed which would receive water quality benefits was estimated using GIS to calculate the area within 150 feet of the buffered area. A reduction efficiency of 60% for TP and 65% for TN was applied to the loading from these buffered areas.

The drinking water ordinances governing the jurisdictions in the Upper Neuse study area often require stormwater controls when imperviousness exceeds a given percentage. Where applicable, the sediment and nutrient loads from urban areas which are currently, or will be in the future, regulated by stormwater controls were reduced by 22.5 percent for total nitrogen load and 47.8 percent for total phosphorus. These reductions were based on typical observed Best Management Practice removal efficiencies (Winer 2000).

Year 2025 and buildout scenario results were also adjusted to meet the agricultural reductions specified in Neuse River Basin - Nutrient Sensitive Waters Management Strategy – Agricultural Loading Reduction (15A NCAC 02B.0236) and Agricultural Loading Reduction Strategy (15A NCAC 02B.0238). This strategy directs agricultural operators to achieve and maintain a 30 percent net reduction in total nitrogen loading rates. The GWLF annual loadings from agricultural areas were correspondingly reduced by 30%. This reduction included both nitrogen and phosphorus with the assumption that control measures would be, at minimum, as effective on phosphorus as they are on nitrogen.

Outputs were summarized as annual average flow, sediment, and nutrient loadings by subwatershed (Appendix C) These results were then aggregated to represent the total contributions to each drinking water reservoir and input into the lakes as described in Section 2.

5.2 LAKE MODEL RESULTS

5.2.1 Lake Management Targets

During the model selection process, chlorophyll was chosen as the key indicator for interpreting impacts of alternative management strategies. The Project Consulting Team evaluated observed lake data and proposed initial chlorophyll *a* targets for consideration by the TAC (see Appendix A). Based on discussions with the TAC, chlorophyll *a* targets were specified to reflect management objectives (Table 5-1). In general, the TAC recommended no significant increase in nutrient loading/chlorophyll *a* levels from existing conditions. Minor exceptions were made for lakes below the EPA recommended criteria of 15 *µ*g/L chlorophyll *a*.

Analysis of the available data indicated that the lakes could be readily broken into distinct groups. Lake Butner and the Little River Reservoir both have watersheds with relatively limited amounts of development and chlorophyll *a* levels that average safely below the USEPA recommended threshold of 15 µg/L in the vicinity of their water supply intakes. The lake models for these two reservoirs predicts slightly below 15 *µ*g/L and the targets were set at 15 *µ*g/L to reflect the EPA recommended criteria.

Lake Orange already exhibits average conditions slightly higher than Lake Butner and Little River Reservoir. The prediction model also estimated a growing season mean above 15 *µ*g/L. Thus, the target was set at the model prediction level for 2000 as a means for comparing future scenarios to the "no significant increase" criterion.

No data are yet available for the new Hillsborough Lake, but given its configuration and the relatively undeveloped nature of its watershed, it is expected to behave in a similar fashion to Lake Orange. The Hillsborough lake target is slightly lower based on the model prediction for 2000.

Corporation Lake and Lake Ben Johnston are smaller than the above group of impoundments with much shorter residence times. As such, they behave much more like wide, slow spots within a river in terms of eutrophication dynamics. The short residence times and steady input of available nitrogen from upstream result in environments conducive to the growth of green algal communities, rather than the blue-green algal communities that thrive in the reservoir group above. These lakes often have concentrations of chlorophyll *a* in excess of the USEPA recommendations for drinking water supplies, but appear to be less likely to experience blooms of nuisance algae than some of the other lakes.

Lake Michie and Lake Rogers are each characterized by unique management issues. Lake Michie may already be experiencing median chlorophyll *a* levels at or near the 15 µg/L threshold in the intake vicinity, but current indications are that these levels are not posing significant difficulties for water treatment or drinking water quality. Phosphorus is considered to be the limiting nutrient controlling algal growth in Lake Michie. As a result, maintaining a level of phosphorus loading equal to or less than the current load may be the optimum management target for this impoundment. If the lake is expanded in the future, the phosphorus load that could be absorbed without resulting in elevated chlorophyll *a* levels would increase, and chlorophyll *a* might become the optimum indicator of eutrophic conditions.

Lake Rogers is already experiencing considerable water quality degradation with highly elevated algal concentrations. Due to extensive macrophyte growth and internal cycling of nutrients, watershed management alone may not achieve significant water quality improvements in Lake Rogers. A detailed Clean Lakes Assessment and an interim goal of no increase in phosphorus loading are recommended for this waterbody. However, it would be imprudent to allow increased nutrient loads in the interim.

Due to its larger size and the broader range of nutrient management issues associated with it, Falls Lake is considered separately from these impoundments and varying management targets are recommended for different areas of the lake.

Table 5-1. Proposed Lake Management Targets

Waterbody	Indicator(s)	Management Target[1]
Lake Butner	Chlorophyll *a*	15 µg/L[2] (2000 model average = 14.7µg/L)
Little River Reservoir	Chlorophyll *a*	15 µg/L[2] (2000 model average = 14.8 µg/L)
Lake Orange	Chlorophyll *a*	No significant increase (2000 model average = 23.0 µg/L)
New Hillsborough Lake	Chlorophyll *a*	No significant increase (2000 model average = 19.9 µg/L)
Corporation Lake	Chlorophyll *a*	No significant increase (2000 model average = 24.2 µg/L)
Lake Ben Johnston	Chlorophyll *a*	No significant increase (2000 model average = 18.8 µg/L)
Lake Michie	Nutrient Load [3]	No significant increase in existing annual load (P average = 46,790 lbs/yr; N average = 271,550 lbs/yr)
	or	
	Chlorophyll *a*	No significant increase in existing levels at intake (2000 model average = 25.2 µg/L)
Lake Rogers	Nutrient Load	Interim[4] - No significant increase in existing annual load (P average = 3,460 lbs/yr; N average = 35,480 lbs/yr)
Falls Lake		
Raleigh Intake (Segment 6)	Chlorophyll *a*	15 µg/L[2] (2000 model average = 9 µg/L)
Upper Segments	Chlorophyll *a*	No significant increase in existing levels Segment #1 2000 model average = 49 µg/L Segment #2 2000 model average = 16 µg/L Segment #3 2000 model average = 16 µg/L

[1]. Targets for Chlorophyll *a* represent growing season averages (May - Sept.) as predicted by the applicable lake model. The phosphorus load targets are based on estimated watershed conditions for the year 2000 using GWLF models.

[2] The U.S.EPA Office of Research and Development Athens GA Laboratory recommends 15 µg/L for chlorophyll *a* as a target for water supply intake areas in Southeastern Lakes, and a growing season average of 25 µg/L for lakewide protection of other uses. (Raschke 1993)

[3]. Phosphorus load is recommended as the indicator under existing lake and watershed conditions. If Lake Michie is expanded in the future, or if another reservoir is constructed upstream, the assimilative capacity for phosphorus loading within the watershed would increase and chlorophyll *a* levels at the intake would become the optimum indicator.

[4] Existing water quality in Lake Rogers is highly degraded. Watershed management alone will not achieve substantial water quality improvements. A Clean Lakes Assessment is highly recommended.

5.2.2 Chlorophyll *a* Predictions

The results of the modeling efforts generally indicate that all the drinking water supplies are likely to continue to meet the specified targets through the next 25 years (Table 15). The relatively small predicted increases in seasonal average chlorophyll *a* are within the margin of error for the models. These results are based on 100% compliance of existing regulations and compliance with the Neuse River Basin - Nutrient Sensitive Waters Management Strategy

(15A NCAC 02B.0232). Review of the GWLF model results (Appendix C) shows a significant increase in nonpoint source loading from urban areas which is largely offset by losses of agricultural lands with their associated higher nutrient loading rates. As the watersheds near buildout, the conversion of agricultural lands have less significance and the lake targets are exceeded (Figure 4).

Table 5-2. Predicted Seasonal Average chlorophyll *a* Concentrations

Scenario	Michie	Little River	Butner	Rogers	B Johnston	Corporation	Orange	W ForkEno	Falls Lake
Existing	25.2	14.8	14.7	29.1	18.8	24.2	23.0	23.2	20.6
2025	26.8	16.3	15.4	31.0	21.1	26.2	23.9	23.8	21.1
Buildout-Low	33.4	19.7	20.2	48.9	21.5	25.5	20.0	21.0	22.4
Buildout-High	39.8	21.2	24.9	63.9	34.9	40.6	28.4	26.6	23.2

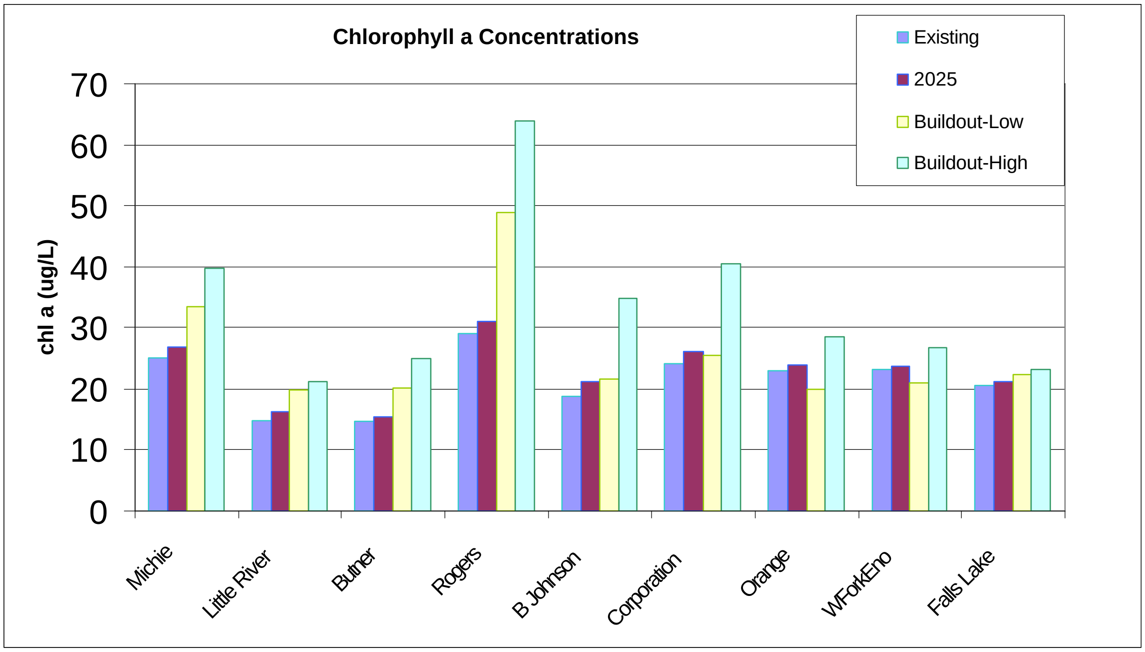

Figure 5-1. Predicted Seasonal Average chlorophyll *a* Concentrations in Water Supply Reservoir

A number of scenarios were tested to determine what steps would be necessary to continue to meet the water quality targets. The primary focus was on rural and suburban development, as this comprised the largest loading increases from the 2025 and buildout scenarios. Holding the nonresidential areas at 2025 conditions, it was determined that restricting housing densities would allow the targets to be met under the low buildout scenario. Density restrictions alone were determined to be insufficient for achievement of the water quality targets under the high buildout conditions. The density limits that would meet the water quality objectives were determined by calculating the maximum allowable loading predicted to meet the objectives. The range of lot sizes from 1 to 10 acres was tested to determine the minimum lot size for which the combination of septic and runoff loadings did not exceed the maximum load. The results vary by subwatershed depending on soil and slope and fall in the range of 3 to 5 acres. Specific recommendations proposed by the TAC regarding these minimum lot sizes were tested to ensure the targets were met for each jurisdiction. The results of these analyses may be found in the Upper Neuse Watershed Management Plan (TetraTech 2002).

5.3 PERFORMANCE STANDARDS

The Watershed Management Plan outlines steps that will aid in achieving the overall management goals. As part of the plan, specific urban and rural guidelines are described based on the modeling analysis. Two options were identified to meet the lake management targets; specific lot size restrictions or performance standards. As specified in Section 5.2, rural development restricted to 3 to 5 acre lots, depending on soil and slope, would meet the lake targets. An alternative approach to density restrictions is the designation of performance standards. These standards specify the amount of nutrient loading allowed fro a developed property. By using model assumptions for runoff volume and nutrient concentrations for different landuses, loading estimates can be generated for any combination of landuses on a given property. Allowable loads (i.e., the performance standards) can be set based on the average areal loading rates that must be achieved for that land to be developed. In this case, the TAC chose to establish two sets of standards to reflect the differences in what can be achieved in urban versus rural settings.

GWLF predicts nutrient load *yield* from a drainage area based on buildup rates, meteorology, soils, etc. Note, however, that load factors obtained in this way are at the *subwatershed* scale. For distributed rural sources, GWLF results may be used to back-calculate average load factors at the *field* scale by dividing the total nutrient load from each source by the associated area. However, phosphorus loading must first be adjusted to account for the particulate fraction by dividing the sediment associated fraction that was settled out at the watershed scale but would be washed off add the field scale. This is accomplished by the sediment delivery ratio for each landuse:

$$TP_l = DP_l + \frac{SAP_w}{SDR_w}$$

where TP_l = phosphorus load for landuse l (lbs/year),

DP_l = dissolved phosphorus for landuse l (lbs),

SAP_w = sediment associated phosphorus for subwatershed w (lbs), and

SDR_w = sediment delivery ratio for subwatershed w.

The GWLF model was run for the low buildout scenario to determine the total loading from the each subwatershed and landuse type. The total load for nitrogen and the adjusted load for phosphorus were then divided by the landuse area to determine areal loading rate:

$$AR_l = \frac{Load_{l,w}}{Area_l}$$

where AR_l = Areal loading rate for nitrogen or phosphorus for landuse *l* (lbs/ac/year)

$Load_{l,w}$ = nitrogen or phosphorus load for landuse *l* in subwatershed *w* (lbs/year)

$Area_w$ = landuse area in subwatershed *w* (acres)

The areal loading rates for nitrogen and phosphorus vary between subwatersheds being highly dependent on slope and soil types found within a watershed. The ranges of areal loading rates for the urban and rural residential landuses across watersheds are shown in Table 5-3.

Two sets of performance standards were developed to allow for urban/suburban and rural residential development. Urban/suburban areas are typically required to implement stormwater controls and are also restricted by the Neuse Nutrient Sensitive Waters Management Strategy. This strategy limits nitrogen runoff in urban areas to 3.6 lbs/ac/yr. Review of the performance standards calculations indicate the associated phosphorus load would be approximately 0.6 lbs/ac/yr. Modeling analysis determined that with this level of loading from urban areas, rural residential lot sizes from 3 to 5 acres would meet the lake water quality targets for each drinking water supply. This housing density falls between the low density residential (LDR) and the very low density residential (VLDR) classes modeled. The TAC reviewed these estimates and selected rural residential performance standards of 1.7 lbs/ac/yr and 0.3 lbs/ac/yr for nitrogen and phosphorus, respectively. These numbers are conservative estimates designed to account for variations in performance standard implementation. It should be noted that these numbers represent the surface loading of nutrients and do not include subsurface loadings from septic systems.

Table 5-3. Upper Neuse TP and TN Areal Loading Rates by Landuse Category

Landuse	Description	TP Area Loading		TN Area Loading	
		Low (lb/ac/yr)	High (lb/ac/yr)	Low (lb/ac/yr)	High (lb/ac/yr)
Agriculture		0.41	1.70	2.90	5.73
Forest		0.02	0.06	0.17	0.37
Commercial		0.69	1.70	5.68	12.90
Industrial		0.53	1.09	4.11	8.60
HDR	> 2 dwell/ac	0.49	0.88	3.71	7.26
MDR	2 dwell/ac	0.33	0.62	2.50	4.77
LDR	1 dwell/ac	0.29	0.42	2.21	3.33
VLDR	0.25 dwell/ac	0.09	0.19	0.45	0.86
Urban Green		0.06	0.15	0.37	0.83

Note: Area loading rates for each land use represent delivered load for a subwatershed, not edge of field values (rates are influenced by sediment delivery ratio). Therefore, they are not directly comparable to literature export coefficients. The range of values (low, high) reflects the difference in curve numbers and runoff concentrations across the 32 subwatersheds modeled.

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APPENDIX A

PROPOSED METHODS OF EVALUATION FOR TARGETED STRESSORS IN THE UPPER NEUSE

Proposed Methods of Evaluation for Targeted Stressors in the Upper Neuse Watershed

Draft 11/22/99

This document provides a characterization of the stressors targeted in the Upper Neuse and their relationship to management priorities. For each link between a stressor and a management priority, a risk hypothesis is provided to describe the likely causes of a problem condition(s). Next, a status statement summarizes what is readily available regarding knowledge and methods for assessing these causal relationships. Indicators and thresholds are identified where known. Proposed methods for evaluating baseline conditions and predicting response to future management options are divided into two sections, those that are recommended for use in preparing this first watershed management plan and those that might be considered in the future if additional resources are made available. The document begins with the stressors that have been targeted by the Technical Advisory Committee for a large level-of-effort, proceeds to stressors recommended for moderate level-of-effort, and ends with those targeted for some level-of-effort

Large Level-of-Effort Linkages

Link 1: Nutrients/Algae –> Drinking Water Safety

Risk Hypothesis 1.1 (Blue-Green Algae):
Increased nutrient loads to water supply reservoirs set off blue-green algal blooms, which result in taste & odor problems, increased treatment costs, and potential problems with algal toxins.

Status: Ability to predict blue-green blooms is an emerging area of the science. Generalized algal growth potential is not sufficient to predict blooms. Additional research in the recent literature is needed.

Tracking Indicators: Frequency of blooms, concentrations of particular problem species (e.g., *Anabaena spp*.) in reservoirs, concentrations of algal toxins (e.g., microcystins) in finished water.

Predictive Indicators: Uncertain at this time. Predicted chlorophyll *a* concentration is not sufficient, nor are nutrient concentrations alone. Temperature, turbidity, and flow are important co-factors.

Thresholds: Not determined.

Potential Modeling Tools: Models of nutrient loading and summer average chlorophyll *a* response are of limited utility here, but may provide a rough indicator of the *potential* for bloom conditions. New modeling approaches are appearing in the literature.

Risk Hypothesis 1.2 (TOC):

Increased nutrient loads cause increased biomass of algae and macrophytes within water supply reservoirs and upstream waters, which increase TOC loads, causing increased treatment costs and risk of formation of harmful disinfection byproducts (DBPs).
Status: Considerable research is now available on DPB precursors, allowing evaluation of acceptable thresholds in the raw water. Key uncertainties are further back in the causal linkage: What is the relative importance of internal production by algae versus external load? A study in Cane Creek Reservoir suggested about 3/4 of the TOC inlake was delivered from the watershed and thus would not be responsive to nutrient management in the lake. TAWSMP data may help evaluated significance of external load to Neuse-basin reservoirs, but the analysis has not yet been done.

Tracking Indicators: TOC concentrations in raw water and in-plant following coagulation/precipitation; chlorine demand.

Predictive Indicators: TOC concentration in raw water.

Thresholds: Terry Rolan suggests 2 mg/L after precipitation as the key level. Brad Boris suggests 10–15 mg/L in raw water as an appropriate threshold.

Potential Modeling Tools: Could construct a simple mass balance model of watershed TOC load coupled to an empirical relationship between nutrient load and algal biomass production. GWLF flow components coupled with observed tributary TOC data could be used.

Risk Hypothesis 1.3 (Metals):

Increased nutrient loading causes increased biomass production in reservoirs. This biomass contributes organic material to the lower levels and sediments of lakes, resulting in anoxic conditions and the release of metals (e.g., manganese) that present problems for treatment and result in low quality finished water.

Status: During summer stratification, hypoxia in bottom waters appears to be a natural feature of most Piedmont reservoirs (depending on morphometry), resulting in mobilization of manganese into the hypolimnion. Whether or not this presents a problem for the drinking water supply depends on the occurrence of vertical mixing events and the physical configuration of the raw water intake. It seems unlikely that watershed management can have a significant effect on manganese cycling in reservoirs; however, in-lake management is potentially useful.

Tracking Indicators: Manganese concentration in raw water supply.

Predictive Indicators: Manganese concentration, hypolimnetic oxygen demand.

Thresholds: {no responses received}

Potential Modeling Tools: BATHTUB can be used to estimate seasonal-average hypolimnetic oxygen demand, but a calibrated model is only available for Falls Lake. More sophisticated analysis suitable for operational management would require simulation of thermal stratification and metals speciation.

Link 2: Nutrients/Algae –> Recreational Use, Aesthetics

Risk Hypothesis 2.1:

Increased nutrient loads to lakes and rivers increases the frequency of algal blooms which result in unaesthetic conditions and limit recreational opportunities.

Status: There are well-established methods for prediction of algal bloom frequency on a seasonal basis. These are suitable for evaluating relative risk among candidate management approaches. Predicting the occurrence of individual blooms is much more difficult.

Tracking Indicators: Algal biomass; occurrence of nuisance blooms; chlorophyll *a* concentration.

Predictive Indicators: Summer average chlorophyll *a* concentration and associated probability of blooms greater than a specified threshold; NC Trophic State Index.

Thresholds: NC DWQ has defined thresholds for nuisance conditions in terms of algal biomass and cell concentration. NC also has a chlorophyll *a* standard (40 g/L), while EPA Region IV has recommended maximum chlorophyll *a* concentrations for impoundments.

Potential Modeling Tools: BATHTUB can provide estimates of bloom frequency, but a BATHTUB model is currently available only for Falls Lake. Simpler empirical relationships are available to relate phosphorus load to chlorophyll *a* concentration

Link 3: Nutrients/Algae –> Aquatic & Riparian Habitat

Risk Hypothesis 3.1 (Lakes):

Increased nutrient load causes increased algal biomass production in impoundments. This increased biomass results in oxygen depletion in bottom waters during stratification, which, curing mixing events, can result in episodic depletion of dissolved oxygen in surface water and impairment of aquatic life support.

Status: The relationship between nutrient loads and lake eutrophication response is well-established. Effects on dissolved oxygen are more problematic. Models are in place only for Falls Lake. Suggest this Risk Hypothesis needs investigation only in water bodies where a demonstrated problem (e.g., fish kills) has been demonstrated.

Tracking Indicators: Surface dissolved oxygen, fish kills.

Predictive Indicators: Hypolimnetic DO at fall overturn and predicted mixed water column concentration; resistance to (or probability of) vertical mixing during summer.

Thresholds: The State water quality standard for DO is the most directly applicable threshold; however, defining a threshold in terms of summer average chlorophyll *a* concentration would considerably simplify the analysis.

Potential Modeling Tools: GWLF is adequate for assessing nutrient loads throughout the watershed. The calibrated BATHTUB model provides a basis for analysis of Falls Lake. Similar models are not available for other reservoirs in the UNRB.

Risk Hypothesis 3.2 (Streams):

Increased nutrient concentration in streams causes excess growth of periphytic algae which can smother and alter the benthic community.

Status: Growth potential for periphytic algae is usually assumed to depend most strongly on soluble reactive phosphorus concentrations, and empirical relationships are available. Light availability (riparian shading) and frequency of scour events are important cofactors which are more difficult to evaluate.

Tracking Indicators: Percent area of substrate covered by algal mats; citizen complaints; benthic RBP results.

Predictive Indicators: Predicted areal bioumass of periphytic algae.

Thresholds: Need to define an acceptable threshold in terms of biomass of algae per square meter of stream substrate.

Potential Modeling Tools: GWLF is adequate to estimate SRP concentrations. Empirical relationships could be used to estimate algal response. Much more sophisticated modeling approaches are available, but have not been implemented.

Link 4: Sedimentation and Erosion –> Drinking Water Safety

Risk Hypothesis 4.1 (Water Treatment)

Sedimentation and erosion results in increased turbidity in water supply reservoirs, which decreases the efficiency and increases the cost of water treatment.

Status: Elevated turbidity makes it harder to remove all particulate matter from the finished water, increasing the risk of transmission of particle-reactive pathogens and toxics. I believe this is primarily an operational and cost issue?

{See Risk Hypothesis 5.1}

Link 5: Sedimentation and Erosion –> Recreational Use, Aesthetics

Risk Hypothesis 5.1 (Turbidity):

Increased stormflow from unstabilized areas (e.g., construction, road margins, unpaved roads) results in higher loads of fine sediment and causes scour of instream sediments which result in increased levels of turbidity instream following rain events and in reservoirs for long periods following events. Removal of natural filtering capacity in wetlands and riparian areas (either through vegetation removal or channel incision) increases delivery of fine suspended particulate matter.

Status: Turbidity is a measure of optical scattering or clarity and results from a combination of suspended particles (primarily clay), dissolved “color” in the water, and colloidal organic material. While increasing sediment load correlates with increasing turbidity, the relationship is inexact and nonlinear. It is thus very difficult to predict turbidity from sediment models.

Tracking Indicators: Measured turbidity.

Thresholds: NC turbidity standards provide a starting point.

Predictive Indicators: Uncertain. Fine sediment load *combined* with site-specific information on the relationship of such sediment to measured turbidity would probably work, but there is no exact general method readily available.

Potential Modeling Tools: Could use a combination of GWLF-predicted sediment load together with a site-specific regression analysis. This is not an existing tool and would require significant additional work.

Risk Hypothesis 5.2 (Bank Instability):

Increased imperviousness leads to increased peak flows which cause undercutting and failure of stream banks and loss of riparian trees, degrading aesthetics of stream corridors.

{See Risk Hypothesis 6.2}

Link 6: Sedimentation and Erosion –> Aquatic & Riparian Habitat

Risk Hypothesis 6.1 (Stream Substrate):

Excess watershed fine sediment loads and channel erosion result in smothering of the stream substrate that reduces habitat suitability for benthic organisms and fish spawning.

Status: Sedimentation and erosion is likely a major cause of impaired biota in area streams; however, the excess sediment loads observed in streams are not solely a result of erosion on the land surface. Studies in various urbanized areas show that a greater portion of sediment in streams is due to bank erosion that is due to sediment generated from the land surface. Impacts on substrate thus ought to be analyzed in conjunction with geomorphological changes, which result from the combined effects of external sediment loads and hydromodification. See Risk Hypothesis 6.2 for further detail. In some streams, however, impacts may arise primarily due to increased fine sediment loads (e.g., below construction sites).

Tracking Indicators: Benthic RBP results; pebble counts/measures of embeddedness.

Predictive Indicators: Yield of fine sediment from land-disturbing activities.

Thresholds: Could define a percent similarity to reference site approach, or select fixed targets from RBP habitat assessment.

Potential Modeling Tools: GWLF models provide rough estimates of sediment yield at the sub-basin scale; they do not simulate sediment dynamics within stream reaches. With some modifications, GWLF should provide adequate scoping of relative risk where the threat is primarily from increased sediment load. Quantitative prediction of absolute risk would require hydrodynamic modeling. (Q: What is available from Flood Insurance Mapping Studies?)

Risk Hypothesis 6.2 (Geomorphological Impact):

Increased development leads to changes in sediment load and increased peak flows as imperviousness increases. The combined effects of altered sediment loads *and* hydromodification result in geomorphological changes to streams such as widening or incision; bank instability; loss of cover; and filling of pools that raise water temperatures while reducing cool refugia, resulting in decreased DO and increased bionergetic stress, which impair aquatic life.

Status: Geomorphological impact is a combined result of changes in erosion & sedimentation and hydromodification. It is not clear that there is an adequate database to evaluate morphological condition of most streams in the UNRB. Quantitative methods to predict responses from first principles are limited, although good predictions of impacts on individual streams can often be made from observation by trained fluvial geomorphologists.

Tracking Indicators: To track impacts instream, we would likely need to define a variety of tracking indicators related to the various potential types of adverse morphological response. These could include: miles of degraded stream banks; riffle-pool structure; percent filling of pools; and other morphological measures (e.g., width to depth ratio). A key upland indicator is the percent of directly-connected impervious cover in the watershed. Research cited by the Center for Watershed Protection suggests that adverse geomorphological impacts and impaired biota typically occur when basin imperviousness exceeds 10 percent.

Predictive Indicators: Ability to quantitatively predict geomorphological impacts is limited at present. Predicted changes in peak flow velocity and sediment supply should be relevant.

Thresholds: Need to define in terms of stream morphological descriptors for tracking; in terms of response to peak flow and sediment supply for prediction.

Potential Modeling Tools: Stream morphological responses to changes in flow and sediment load are complex and not incorporated within existing simulation models, although various qualitative guidelines are available. A useful approach (probably outside the scope of this project) would be regional correlation among multiple sites, including unimpacted reference sites. It is suspected that hydromodification is likely to be more important than watershed sediment load in geomorphological impact in most streams in the UNRB. A scoping-level analysis of the relative risks to channel stability from hydromodification can be constructed by estimating peak flows in response to a design storm, using the NRCS TR-55 methodology, which largely depends on data already developed for the GWLF models.

Moderate Level-of-Effort Linkages

Note: Inadequate Infrastructure is primarily a programmatic/funding issue and is not addressed within these risk hypotheses.

Link 7: Hydromodification –> Aquatic & Riparian Habitat

Risk Hypothesis 7.1 (Geomorphological Impact):

{While this is a "moderate" level-of-effort issue, geomorphological impact of hydromodification is intimately connected with the impacts of erosion and sedimentation, and the two issues cannot properly be analyzed in isolation. See Risk Hypothesis 6.2 for a discussion of the joint impacts of erosion & sedimentation and hydromodification.}

Risk Hypothesis 7.2 (Base Flows):

Increased impervious areas due to development tend to increase the fraction of percipitation percolating to ground water, which in turn decreases base flows in streams.

Reduced base flows result in increased temperature, lower DO, and reduced pool refuge areas that limit ability of streams to fully support aquatic life.

Status: The relationship between imperviousness, stormflow management, and reduced baseflow is well understood and can be described by water balance models. A potential secondary effect of reduced baseflow is increased minimum flow releases from reservoirs, which result in less water supply storage. Shifting of flow delivery from base to peak periods also results in greater spillage losses from reservoirs.
Tracking Indicators: Observed flow minima, summer average dry weather flows.

Predictive Indicators: Predicted baseflow response to summer dry weather.

Potential Modeling Tools: Existing GWLF tools are adequate to address changes in base flow. They could also be connected to a reservoir storage:yield balance to assess impacts on reservoir operations.

Link 8: Hydromodification –> Aesthetics

Risk Hypothesis 8.1 (Turbidity):

{See Risk Hypothesis 5.1}

Risk Hypothesis 8.2 (Bank Instability):

Increased imperviousness leads to increased peak flows which cause undercutting and failure of stream banks and loss of riparian trees, degrading aesthetics of stream corridors.

(See Risk Hypothesis 6.2)

Link 9: Hydromodification –> Limits on Recreation

Risk Hypothesis 9.1 (Recreation Limits due to Inadequate Flow)

Increased impervious area in the watershed results in increased storm flow and reduced base flow which reduces the opportunity for recreational uses such as canoeing and fishing.

{See Risk Hypothesis 7.2}

“Some” Level-of-Effort Linkages

Link 10: Toxics –> Drinking Water Safety

Risk Hypothesis 10.1 (Toxics and Drinking Water)

Watershed loading and point-source contributions of toxic organic chemicals can result in potential threats to human health in the water supply, or increased costs in water treatment.

Status: Due to permitting requirements on point sources and spill containment requirements for hazardous material users, the biggest potential threats are from transportation spills and low-level loading of chemicals used on a widespread basis throughout the watershed. Most organic chemicals are removed from the water column by a variety of processes (volatilization, sedimentation, degradation), so actual risk depends on the proximity of the source to the water supply intake, magnitude of the source, and the properties of the chemical. TAWSMP monitoring has not indicated any consistent major problems in the UNRB, so spills are the major concern. A general modeling approach for evaluation of risk for toxic chemical spills was developed as part of the Falls Lake study.

Tracking Indicators: Priority pollutant scans of raw water quality (TAWSMP). Performance-based assessment of the adequacy of hazardous waste management and spill response capabilities may be more important.

Predictive Indicators: Predicted intake concentrations in response to chronic low-level watershed loads and hypothetical spill events.

Thresholds: Drinking water MCLs and MCLGs.

Potential Modeling Tools: Toxics scoping model developed for the Falls Lake study.

Link 11: Toxics –> Aquarian & Riparian Habitat

Risk Hypothesis 11.1 (Toxics and Aquatic Life)

Watershed loading and point-source contributions of toxic organic chemicals and metals result in acute and/or chronic toxic impacts on aquatic life, leading to direct mortality, disruptions of the aquatic food chain, and changes in community species composition.

Status: Water quality standards exist for many toxic chemicals; however, monitoring is expensive and there are likely many chemicals which have adverse effects but for which water quality standards have not been developed. There is also a risk of additive or synergistic impacts from exposure to low levels of many different chemicals. Measures of biotic integrity are the best indicator of the existence of a problem, but present problems for distinguishing between toxic chemical and habitat impacts. USGS NAWQA studies demonstrate that the relative level of contamination by herbicides and pesticides is generally higher in urban areas than agricultural areas.

Tracking Indicators: Measured concentrations of known toxics are of value where available (e.g., TAWSMP data). Such monitoring can, however, represent only a small fraction of stream segments in an area and only a small subset of the potential chemical sources of toxicity. Measures of biotic integrity provide an integrative measure, but it is often difficult to separate the impacts of toxic chemicals from the impacts of hydromodification and habitat loss.

Predictive Indicators: If an individual source of toxicity is identified, concentrations of the chemical of concern provide a predictive indicator.

Thresholds: EPA Ambient Water Quality Criteria (AWQC) for the protection of aquatic life provide regulatory thresholds for some toxics. The AWQC do not establish thresholds for synergistic effects, nor are they available for all chemicals that may cause toxicity to aquatic life.

Potential Modeling Tools: If a source of toxicity is identified various modeling tools may be applied. In many cases, however, it would first be necessary to go through a toxicity identification procedure to determine what needed to be modeled in a given waterbody segment. For some ubiquitous sources of aquatic toxicity (e.g., copper) a basin-wide approach may be useful. Basin-wide estimates of loading of metals and particle-reactive organics can be piggy-backed onto the existing GWLF models. This approach is adequate for a scoping-level analysis, but more detailed modeling may be needed for individual impaired stream segments.

Link 12: Pathogens –> Drinking Water Safety

Risk Hypothesis 12.1 (Microbial Pathogens)

Contamination of the raw water supply by human and other mammalian fecal matter can result in elevated concentrations of human pathogens. To the extent that these pathogens are resistant to treatment, or failures occur in the water treatment system, presence of pathogens in the raw water supply may present a risk to drinking water safety.

Status: Water treatment methods are capable of mitigating risk from most bacterial and viral pathogens, although it is preferable to maintain minimal levels in the raw water supply and thus establish multiple barriers. Of greater potential concern are the protozoan pathogens *Giardia* and *Cryptosporidium.* These organisms produce resting-stage cysts which are resistant to destruction by chlorination and may pass through the treatment system to threaten human health. Most all major outbreaks of protozoan disease attributed to water supply have, however, been from systems that due not use filtration or in which there were major failures in the filtration system.

Tracking Indicators: Given current treatment system capabilities and requirements, it is assumed that the only major concern in this area is for protozoan pathogens. The most reliable tracking indicators for such pathogens are immunoassay tests which directly measure the concentration of pathogen cysts. Reports of protozoan disease outbreaks are not generally reliable indicators due to the presence of other, more common means of transmission. Elevated fecal coliform bacteria provide a flag for potential high risk areas, but are not a reliable indicator

due to the fact that the protozoan cysts have much longer environmental survival times than fecal coliform bacteria. Performance-based indicators may be of more value here. There is a general consensus that adequate control of finished-water turbidity substantially reduces risk of transmission. Finished-water turbidity thus provides a simple and inexpensive tracking indicator. Status of waste management plans for any animal operations in a water supply watershed should also be tracked.

Predictive Indicators: Not needed unless high-risk circumstances are documented.

Thresholds: EPA's Enhanced Surface Water Treatment Rule establishes thresholds for protozoan cysts. A performance target for finished-water turbidity is also valuable (e.g., target established by OWASA of < 0.1 NTU for finished water).

Potential Modeling Tools: None needed.

Link 13: Pathogens –> Limits on Recreation

Risk Hypothesis 13.1 (Health Risk from Contact Recreation)

Loading of pathogens from sources including urban stormwater runoff, leaking septic tanks, animal operations, sanitary sewer overflows, and illicit connections to storm drains results in concentrations in surface water which present a health risk to people engaged in primary and secondary contact recreation in area streams.

Status: NC DWQ monitoring in 1994–1995 showed the potential for fecal coliform bacteria concentrations in excess of the water quality standard in area streams (the standard is written as a geometric mean of 200/100 ml based upon at least five consecutive samples examined during any 30 day period). Of nine stations monitored above Falls Lake, highest concentrations were observed in Knap of Reeds Creek, where 52 percent of samples exceeded 200/100 ml. Experience in other locales suggests that other small streams in urban and suburban areas are likely to exceed the standard; however, NC DWQ chose in the 1998 submission not to include any Upper Neuse streams on the 303(d) list due to fecal coliform concentrations.

Many states have expressed concern over the relevance of the fecal coliform bacteria standard. These bacteria are, by and large, not themselves pathogens of human concern, but are intended to serve as an indicator of potential risk from pathogens. The problem is that elevated levels often occur due to the presence of waterfowl, wildlife, and pets and not to human fecal contamination. As a result, standard violations are not necessarily reflective of risks to human health, and the standard may not be a realistic target for many urban streams. Except in the case of major illegal discharges, bacterial concentrations in water supply reservoirs will generally meet standards because these organisms die off over time in the environment.

Tracking Indicators: In terms of the water quality standard, concentrations of fecal coliform bacteria are the obvious tracking indicator. Better indicators exist, however, of actual risk to human health, including direct measurement of concentrations of pathogenic bacterial groups (e.g., *E. coli*, fecal streptococci).

Predictive Indicators: Same as tracking indicators.

Thresholds: Existing water quality standards for fecal coliform bacteria provide a regulatory threshold. As noted above, however, exceedance of this threshold may not reliably indicate the presence of an actual risk.

Potential Modeling Tools: Dynamic nonpoint buildup-washoff models of bacterial load can be constructed, using, for instance, HSPF or SWMM. These models generally do not give very accurate results due to the large degree of inherent natural variability in concentrations and the presence of unmodeled sources. Given this variability and the fact that the water quality standard is expressed in statistical terms, a better approach may be a statistical evaluation of exceedence frequency in low-order streams based on time between runoff events and event-mean concentrations associated with individual land uses and management practices. We are currently constructing such an approach for Rockdale County, GA, which approach could also be used for the UNRB.

Link 14: BOD –> Aquatic & Riparian Habitat

Risk Hypothesis 14.1 (Dissolved Oxygen Depletion)

Loading of biodegradable material results in an oxygen demand which depletes dissolved oxygen in streams and lakes, leading to unacceptably low dissolved oxygen concentrations and adverse effects on aquatic life.

Status: Due to the high reaeration capacity of Piedmont streams, DO depletion is primarily an issue in impoundments. It is not expected to present high risk in flowing waters, except in the immediate vicinity of high-BOD sources (e.g., runoff from an animal operation with inadequate waste management).

Tracking Indicators: DO concentration.

Predictive Indicators: DO and BOD concentrations.

Thresholds: Water quality standards for dissolved oxygen.

Potential Modeling Tools: DO/BOD modeling is well understood, but is complicated for stratified impoundments. Modeling tools are available, but have not been developed and calibrated for UNRB impoundments. Development of any such tools should be restricted to waterbodies where monitoring demonstrates that a problem occurs.

APPENDIX B

GWLF MODEL INPUTS

Table B-1. Reclassified EPA Landuse Distribution for the Upper Neuse River Basin

CLASS\SUB (ha)	1	2	3	4	5A	5B	6	7	8	9A	9B	10A1	10A2	10B	11A1	11A2	11B	12	13	14	15	16	17	18	19	21A	21B	22	24	25	26	27	Total
Water	16	34	28	11	195	14	31	34	6	178	13	11	88	2	15	18	8	43	36	42	157	3	207	714	199	77	930	381	284	283	351	290	4693
Agriculture	3188	4751	825	2197	968	201	2265	3107	247	1084	152	934	950	547	1095	762	177	1894	332	164	1078	482	306	254	203	744	678	1270	620	676	291	58	32501
Wetlands	40	27	8	100	53	139	77	56	6	14	261	20	9	11	16	15	1	2	21	340	47	368	822	248	232	159	901	753	128	28	140	20	5063
Pine Forest	504	687	848	862	1289	374	1226	1575	427	726	269	192	167	222	548	1071	221	1923	1731	635	2026	1533	1503	1141	1592	1047	2375	2725	1215	1080	1495	816	34048
Deciduous Forest	5056	6948	1785	5595	1874	993	4220	4628	1120	1548	813	1065	941	1192	1746	2424	511	6167	1841	911	3272	1026	1222	1161	2278	1405	1742	5785	3734	2947	3544	1175	80667
Mixed Forest	249	1066	38	133	31	37	158	146	31	85	24	42	36	61	61	91	9	208	127	55	39	54	201	222	396	81	203	1447	735	530	298	108	7002
VLDR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Commercial	402	125	25	38	28	12	28	19	9	37	43	17	10	1	17	114	119	175	265	212	20	271	1133	371	101	126	229	128	17	67	79	44	4282
Light Ind	82	49	22	37	40	5	24	16	28	60	18	15	3	1	33	24	57	45	56	19	52	197	78	84	18	61	28	110	47	96	114	77	1598
HDR	2	3	0	0	1	1	0	1	1	2	2	0	0	0	0	0	0	4	16	9	1	9	35	21	3	5	9	4	0	1	8	2	141
MDR	14	5	2	6	17	13	12	11	15	69	116	0	2	2	10	10	80	478	1214	480	67	191	2529	1073	267	162	621	29	14	30	93	62	7696
LDR	274	336	205	240	277	90	239	312	182	338	312	59	72	41	145	200	199	1032	1506	410	446	393	1647	1118	510	413	778	560	340	443	1509	1041	15667
Urban Green	608	596	132	342	140	26	233	222	82	123	59	98	72	37	115	133	123	432	163	58	195	122	208	127	122	261	322	585	134	218	84	15	6189
Barren	6	5	0	12	0	0	33	0	0	0	0	3	2	1	1	3	16	1	0	37	7	0	1	1	1	5	55	18	7	5	11	1	232
Preserved	0	0	753	0	1219	792	155	1	37	370	300	283	19	14	33	314	64	887	841	758	1984	2149	1645	1481	914	15	3089	1780	1589	838	1222	836	
Total	10441	14632	3918	9574	4914	1904	8547	10127	2152	4265	2083	2456	2354	2118	3803	4864	1521	12404	7309	3370	7407	4650	9892	6535	5923	4545	8871	13795	7276	6406	8017	3708	199781

GWLF Transport and Nutrient Input Files

APPENDIX C

GWLF MODEL RESULTS FOR FLOW AND NUTRIENT LOADS

Table C-1 Flow and Nutrient Results by Subwatershed and Scenario

Scenario	**Existing**			**2025**			**BL**			**BH**		
Subwatershed	Flow (hm3)	Total P (t)	Total N (t)	Flow (hm3)	Total P (t)	Total N (t)	Flow (hm3)	Total P (t)	Total N (t)	Flow (hm3)	Total P (t)	Total N (t)
1	35.3	5.8	35.3	35.9	5.1	33.5	38.2	5.2	92.0	41.5	6.6	146.7
2	46.6	7.2	41.1	47.1	6.1	39.0	50.0	6.2	125.6	55.7	8.7	212.5
3	12.4	1.9	10.4	12.5	1.6	10.3	12.9	1.6	21.1	12.5	1.9	11.3
4	29.8	4.2	23.8	30.1	3.6	23.0	32.7	4.0	87.8	36.2	5.5	147.7
5A	16.5	2.2	12.6	16.7	1.9	12.3	17.1	1.9	22.8	18.3	2.4	43.4
5B	5.9	0.9	5.3	6.1	0.9	5.8	6.2	1.0	8.0	6.4	1.0	12.4
6	32.8	3.2	20.0	32.9	2.9	19.5	33.4	3.1	39.8	33.4	3.1	65.6
7	38.8	3.9	25.4	38.9	3.4	24.2	39.2	3.6	45.0	39.4	3.6	81.3
8	8.3	0.8	6.5	8.4	0.8	7.8	8.4	0.9	12.9	8.5	0.9	17.1
9A	17.5	1.8	13.7	17.7	1.7	14.3	18.3	2.0	25.1	18.3	2.0	49.3
9B	8.2	0.8	8.9	8.6	1.0	10.5	8.9	1.2	12.9	9.3	1.3	17.3
10A1	7.4	1.0	7.9	7.5	0.8	7.4	7.5	0.7	13.1	8.0	0.9	22.5
10A2	7.6	1.0	7.4	7.6	0.8	7.0	7.7	0.6	9.8	8.2	0.9	20.2
10B	5.7	0.7	5.9	5.7	0.6	5.7	5.7	0.5	9.0	6.2	0.7	19.0
11A1	11.5	1.3	12.0	11.6	1.2	12.6	11.7	1.0	20.5	12.5	1.4	36.1
11A2	14.8	1.4	14.3	15.1	1.4	16.1	15.3	1.3	21.5	16.1	1.8	36.6
11B	5.3	0.7	6.9	5.8	0.9	8.8	5.8	0.8	9.7	5.9	0.9	11.5
12	38.2	3.5	42.6	40.0	3.9	49.7	40.3	3.8	66.2	42.3	4.9	102.7
13	24.7	2.9	39.2	26.3	3.6	45.5	26.8	3.8	51.3	28.7	4.6	69.8
14	11.5	1.3	14.6	12.9	1.9	18.7	13.1	2.0	19.4	13.3	2.1	19.9
15	26.6	1.9	19.9	26.7	1.8	19.6	28.0	2.3	51.0	29.4	3.0	77.5
16	17.4	1.8	17.0	19.2	2.4	22.4	19.2	2.4	22.6	19.2	2.4	22.6
17	56.5	10.9	64.5	57.7	11.5	70.7	57.7	11.5	70.9	57.7	11.5	70.9
18	33.8	3.6	33.8	34.7	4.0	38.5	35.4	4.4	41.4	36.1	4.6	43.0
19	22.1	1.4	19.9	22.8	1.7	23.1	24.1	2.5	36.1	26.9	3.8	65.8
21A	17.8	1.6	16.1	17.9	1.5	15.9	18.8	1.8	41.7	19.9	2.4	61.0
21B	38.8	2.4	27.0	40.2	2.8	33.9	40.2	2.9	33.6	40.2	2.9	33.6
22	52.4	3.2	37.4	52.7	3.1	40.4	55.2	4.4	111.0	56.8	5.5	138.9
24	24.7	1.6	18.1	25.3	1.5	23.3	26.2	1.9	48.6	26.6	2.2	53.7
25	22.6	1.6	18.3	23.7	2.0	28.7	24.3	2.2	44.8	24.6	2.4	49.6
26	28.5	2.0	36.6	31.0	3.1	61.6	31.0	3.2	61.7	31.0	3.2	61.7
27	14.2	1.1	19.4	15.2	1.5	29.2	15.2	1.5	29.2	15.2	1.5	29.2
Total	734.4	79.5	682.0	754.6	81.0	779.3	774.6	86.1	1305.8	804.5	100.6	1850.6