Lake B. Everett Jordan Watershed Model Report

Prepared for

North Carolina Nutrient Science Advisory Board

North Carolina Division of Water Resources

Triangle J Council of Governments

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Contents

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List of Tables

List of Figures

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Executive Summary

Project Background

This project was completed for the Triangle J Council of Governments (TJCOG) under the direction of the North Carolina Division of Water Resources (DWR, previously known as the Division of Water Quality (DWQ)) and the North Carolina Nutrient Scientific Advisory Board (NSAB). The overarching goal of the project is to develop a dynamic flow and water quality watershed model using the Loading Simulation Program in C++ (LSPC) model, to accurately estimate baseline (1997 to 2001) nutrient loads by each regulated entity (e.g., jurisdiction) for the purpose of establishing load allocations under the Jordan Lake Rules. Additional details regarding the regulatory background and context for the modeling work are provided in Section 1 of this report.

In August 2012 the Tetra Tech modeling team began coordinating with a model subcommittee comprised of select DWR staff and several members of the NSAB Board. Collectively, these parties and TJCOG contract managers clarified modeling objectives and constraints, selected the LSPC model for the project, and negotiated a project scope and schedule for completion of a draft version of the model and associated documentation summarizing model development and application to generate draft baseline jurisdictional load estimates of total phosphorus and total nitrogen. Work under the model development scope officially began in October 2012.

Model Development

The first step in the modeling process was to develop a Quality Assurance Project Plan (QAPP) which comprised a model development plan detailing the project goals and data quality objectives, project team and key partner roles, project scope, methods for conducting the work, quality assurance and quality control (QA/QC) procedures, model performance acceptance criteria, and supplementary information related to model development. A draft QAPP was completed in October 2012, reviewed with the NSAB model subcommittee, and revised in November 2012 (Tetra Tech, 2012a). The QAPP is reproduced as Appendix B to this report.

Data compilation and screening, database development, QA/QC and metadata documentation proceeded in accordance with the QAPP. Information needs beyond readily available data were conveyed by the modeling team through TJCOG to stakeholders in the process. A data inventory was maintained electronically and is being delivered with the project modeling files. A full description of data obtained and processed for the model development is provided in Section 2 of this report.

Interim progress was communicated by the modeling team approximately monthly to the TJCOG contract manager, and at select times with either the NSAB model subcommittee or full NSAB per the project scope and schedule. In addition to oral and PowerPoint presentations at these meetings, interim Technical Memorandums were provided to provide detailed information on data used in the project, key assumptions, technical methods, and interim results.

An important decision was made following the data compilation phase of the project that impacted the original model development plan. Detailed information on already installed structural stormwater control measures (sometimes referred to as structural best management practices or BMPs) was not available for the vast majority of jurisdictions in the watershed at the time of model configuration. Since most BMPs that were designed to improve water quality were not installed until after the baseline period (1997 to 2001) specified by the Jordan Rules, it was determined in consultation with the NSAB model subcommittee that model development without incorporation of BMPs was preferable to a model with only partial data and considerable uncertainty regarding accuracy of BMP representation. Model water quality calibration was therefore focused on the baseline period such that lack of BMP representation was believed to be of little consequence to model accuracy for that period. DWR determined that it would work with regulated parties to provide proof of BMP installation in the watershed post baseline period and provide regulatory credit through a process separate from this model development project. Accurate data collected through that process can then be used to incorporate structural water quality BMPs into a future enhanced version of the model should DWR or other parties determine that to be necessary.

Three technical memorandums were submitted to TJCOG in accordance with the scope. The first technical memorandum (Tetra Tech, 2013a) provided a summary of the data compiled to support model setup and calibration. The second technical memorandum (Tetra Tech, 2013b) described how the compiled data were used to configure LSPC for the Jordan Lake watershed. The third technical memorandum summarized the model performance achieved through calibration and additional information to help reviewers understand model limitations and preliminarily identified opportunities for future model enhancement.

Although some comments were provided by NSAB model subcommittee members on the interim technical memoranda, no revised interim documents were generated. Rather, to use project resources efficiently, comments were taken into consideration and addressed in the model development and incorporated with this model report as the final deliverable under the first phase of work.

Model calibration and corroboration methods are described in detail in Section 3 of the report, and calibration results and interpretation are summarized in Section 4. Hydrologic calibration was successful and provides a reasonable basis for the water quality model, despite some localized discrepancies. Hydrology is well represented at key points for dominant inflows into Jordan Lake: Haw River, New Hope Creek, Morgan Creek, and Northeast Creek.

The LSPC water quality model was built with a unified set of parameters that vary according to land use, soils, and geology. The model was calibrated simultaneously to 35 different stations, ensuring a broad and representative sample of watershed conditions. Available monitoring data provide an imprecise target, as laboratory analytical results have associated uncertainty, especially when concentrations are near practical quantification limits. In addition, most sample data are point-in-time grab samples, which are expected to be imprecise estimates of the daily average concentration predictions produced by the model. Calibration thus consists of comparing two uncertain numbers. The calibration strategy avoided arbitrary adjustments to upland parameter values to obtain better fit statistics in individual catchments as good practice to avoid over-fitting to data that are limited in coverage, particularly for high-flow events.

As a result of these considerations, relatively large apparent percentage differences between observations and predictions are acceptable at some stations as long as the unified parameter set provides reasonable results across stations in aggregate. Analysis of the absolute magnitude of errors shows that these are generally small, and that higher percentage errors generally reflect low baseline concentrations.

The water quality calibration included assuring reasonable simulation of water temperature, DO, sediment, and nutrients, examining both concentrations and loads; however, the evaluation relative to the intended uses of the model should focus primarily on ability to predict nutrient loads. Evaluation of the accuracy of load predictions is difficult because load is not directly measured, but inferred from infrequent concentration monitoring that is combined with continuous flow data. Statistical comparison of paired daily estimated and simulated loads show that a majority of stations rank as “good” or “very good” in either the calibration or corroboration period or both, suggesting that model predictions of load at most stations do not have any consistent bias. Comparison to interpolated estimates of mass flux calculated with the USGS LOADEST software showed a good or very good fit for total phosphorus, except for Haw River and North Buffalo Creek, and a good or very good fit for total nitrogen, except for Northeast Creek and Morgan Creek.

Discrepancies relative to LOADEST for total phosphorus, in which load appears under-predicted at high flows, are seen in the Haw River at Bynum and Haw River at Haw River. Data at the Bynum station suggest that the "missing" phosphorus load is primarily in organic form. Because loading rates by land use appear reasonable and there is not a consistent under-prediction of phosphorus load in small headwater streams it is likely that the un-simulated excess load is derived from instream sources. Specifically, it appears likely that high flow events may mobilize organic detritus stored behind the several run-of-river dams present in the Haw, including the dam at Bynum, resulting in increased total P concentrations at high flows. Solids in these areas are likely to be highly enriched in organic matter due to historical WWTP and textile mill discharges. LSPC (as does the parent HSPF model) includes an algorithm to associated orthophosphate with eroded inorganic sediment; however, the model does not include any mechanism to represent the mobilization of organic muck and associated organic nutrients from behind low head dams during high flow events. Thus, the additional loading from these areas may need to be estimated external to the watershed model.

In New Hope Creek, Northeast Creek, and Morgan Creek below the OWASA discharge, the LOADEST analysis suggests relative over-estimation of total nitrogen load by the model. For New Hope Creek, LOADEST continuous time series of loads of N appear to be generally over-predicted by the model from 2005 to present, despite the fact that the paired comparison of loads on days with water quality samples yielded good fit ratings. For Northeast Creek, downstream of the Durham Triangle WWTP, apparent over-prediction of TN load occurs for the 2001 – 2006 period, while for Morgan Creek there is some over-prediction of TN load throughout the model period. For all three locations, the discrepancies seem likely to be associated with estimates of point source loading resulting from interpolation of approximately weekly measurements of effluent concentrations of total N to continuous time series.

For nonpoint source loads the model appears to be approximately unbiased, although imprecise in simulating responses to individual events. Given that the purpose of the model is to evaluate the relative magnitude of annual loads the model is adequate to task, although further improvement could be pursued.

Model Acceptance and Application for Load Estimates

The Jordan watershed model generally meets the criteria for model acceptability specified in the QAPP for addressing the decision purposes of estimating baseline nutrient loads for establishing regulated entity load allocations under the Jordan Lake Rules. The model in its current configuration was reviewed by multiple entities between November 2013 and April 2014. Teresa Culver, PhD, from the University of Virginia was contracted by TJCOG to conduct a defined peer review on behalf of DWR in consultation with the NSAB Model Subcommittee. Additional reviews of the model were conducted by Glen Fernandez, PhD, USEPA Region 4 at the request of DWR and by LimnoTech under funding from NCDOT and the City of Durham. The peer review by Dr. Culver found that sound state-of-practice methods were used in the development of the Jordan Lake Model which was well documented, that the model results could be replicated, and that the model appears appropriate for its intended application. Based on this peer review, no modifications were made to the model.

Comments by all reviewers, however, led to additional refinement of the model documentation to clarify or correct specific text, tables and figures. Of particular note, lack of comprehensive planimetric data for accurately representing baseline impervious surface estimates meant that canopy coverage interfered with aerial interpretation for urban developed areas with significant tree cover resulting in some underestimation of imperviousness for the baseline period. Tetra Tech conducted follow up analysis and determined that the model calibration was sufficiently robust to this underestimation at the subwatershed and watershed scales. Because of this discrepancy, however, Tetra Tech does not recommend using the difference between model baseline and 2010 impervious surface areas to estimate interim developed area for regulatory purposes where better information is available. Where jurisdictions can provide DWR with quality assured documentation of actual development area following the baseline (1997-2001) period, it is recommended that regulatory calculations for the reductions beyond the baseline requirements be based on the more accurate developed area information.

Overall, Tetra Tech concludes that the calibrated model performance is sufficiently well demonstrated to be applied for its intended purposes, including evaluation of both current nutrient loads and changes in nutrient loads since the 1997 – 2001 baseline established in the Rules. The application of the model to calculate loads for each entity in the watershed was carried out by developing separate versions of the model for both baseline and 2010 time periods. These versions of the model employ the same upland modeling units used for calibration that reflect land use/land cover, soils, and geology, but add regulated entity to the spatial representation of land area. This enables summation of at-source loads by both land use and entity. The model was also used to estimate long-term rates of throughput of nutrient loads through the stream network, accounting for losses and attenuation during transport. This analysis is combined with the source load analysis to provide a full accounting of nutrient loads from developed land delivered to Lake Jordan from each regulated entity.

The results of the loading analysis are presented in Section 5.1 and summarized below.

Application of the calibrated LSPC model for Jordan watershed was performed to answer three primary study questions:

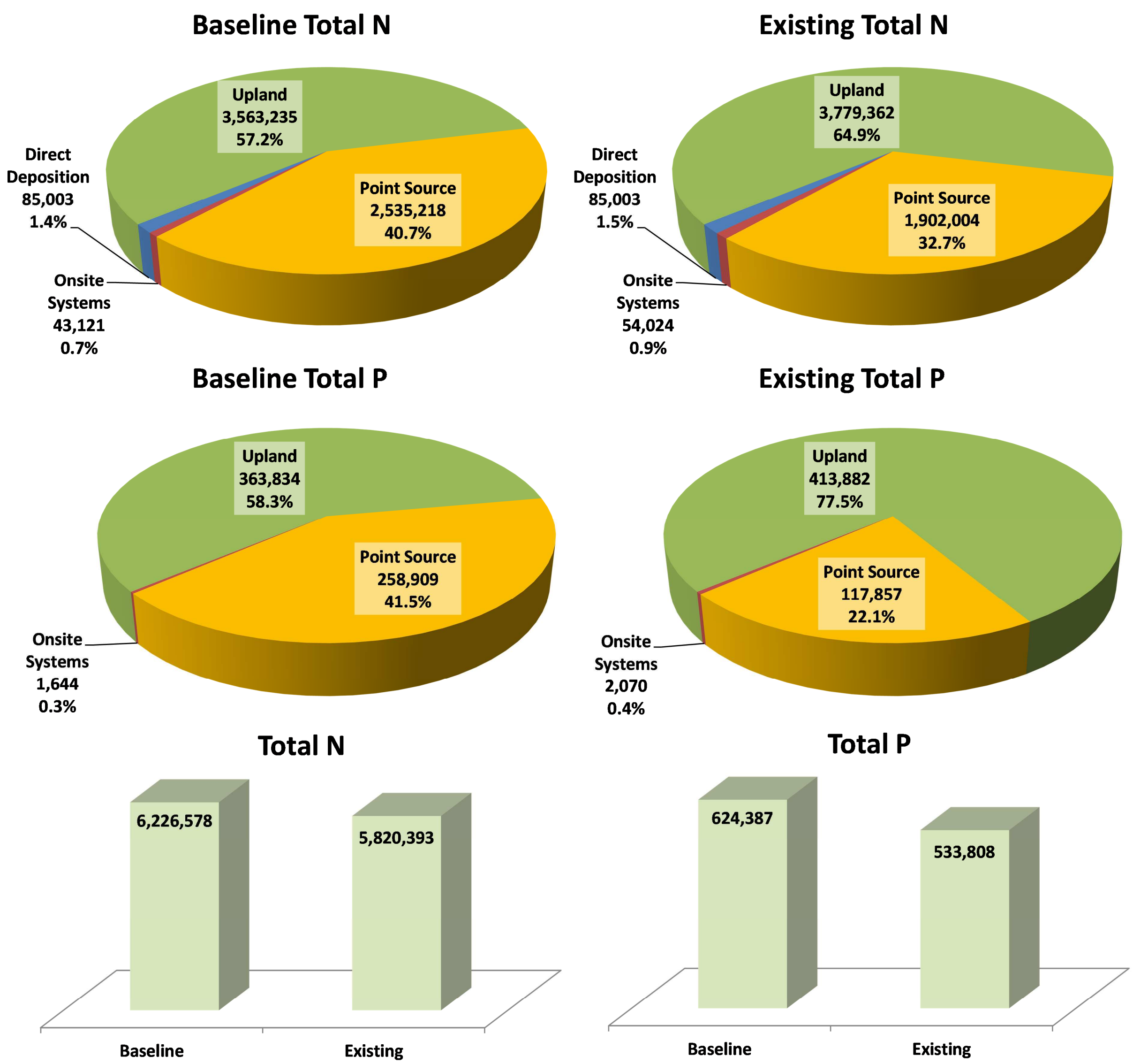
1. What are the baseline (1997 – 2001) loads of nutrients associated with each jurisdiction in the watershed?
2. How much of the load generated in specific source areas is ultimately transported to Lake Jordan?
3. How have those loads changed in the period from baseline to current conditions?

The calibrated model provides estimates of load for the baseline period (1997 – 2001). To evaluate the change in loads under current conditions, the model was re-run with current land use combined with 1997 – 2001 meteorology. This approach ensures that the estimated changes in current condition load estimates for nonpoint sources reflect changes in land use, not variability in weather.

A comparison of runs for the baseline period and 2010 land use conditions shows that overall loads of both nitrogen and phosphorus decreased (with meteorology held constant). Specifically, point source loads of both nitrogen and phosphorus have decreased, while loads due to upland sources and onsite wastewater systems have increased, although by a lesser amount than the point source decrease, resulting in a net decrease in loads from all sources. The increased upland loads are mostly derived from increased impervious surface area, while loads from row crop agriculture and other rural land uses have decreased.

Recommendations for Potential Future Model Enhancements

The model is judged to be useful for the intended purposes, but, like all simulation models, is not a perfect representation of reality. In part, this is because the true state of reality is not known due to data that are imprecise or incomplete; however, it is also likely that the accuracy of the model could be improved through additional efforts that were outside the scope of the current effort, including both additional data collection and refinements to model calibration. A discussion of potential improvements in the model is provided in Section 5.2.1 and summarized below. It is important to note that, while these additional efforts have the potential to increase the accuracy of the model and reduce uncertainty in individual entity allocations, they are not a necessary pre-requisite to use of the model to establish allocations.



Areas in which model accuracy and performance could likely be improved with additional effort include hydrology and water quality simulation as well as source load representation. For hydrology, key potential enhancements include use of additional precipitation data (including spatially interpolated products such as radar-based measurements) and a more detailed representation of reservoir operations, withdrawals, and releases. For the water quality simulation, the representation of nutrient loads delivered to waterbodies from onsite wastewater disposal systems remains a key source of uncertainty and could likely be improved through additional data collection efforts that better characterize subsurface attenuation rates and provide additional information on rates and types of system failures. It is also clear that the available information on point source discharges, generally based on bi-weekly nutrient monitoring for major dischargers, is a source of uncertainty in the model. This representation could potentially be enhanced through the development of empirical models that relate effluent nutrient concentrations and loads to system flow rates, weather, and other factors. Finally, despite the extensive water quality monitoring that has been conducted, there are significant areas of the Jordan Lake watershed for which relatively little monitoring data are available, including southeastern Guilford Co., southern Alamance Co., and much of the Chatham Co. portion of the watershed.

Relationship of Model to Load Reduction Accounting Methods

Final determination on how the model will be used for load reduction accounting will be the responsibility of DWR. Two issues must be addressed: interpretation of model results for the baseline period relative to the Jordan Purpose and Scope Rule and evaluation of the changes in regulated loads during the interim period prior to implementation of the new development rules. (The interim period begins in 2002 following the baseline period, and will continue until adoption of new development programs between 2017 through 2020.) Further information about the regulatory context is provided in Section 1.2.

The Jordan Purpose and Scope Rule (15A NCAC 02b.0262) explicitly incorporates estimates of the baseline loading to the three assessment units of Jordan Lake. These estimates ultimately derive from the Jordan Lake nutrient response model, completed in 2003. Load estimates for the baseline period from the refined model described in this report will not exactly match the loads set forth in the Rule. It is anticipated that the estimates of percentages of baseline loading attributable to each entity as calculated by the new allocation model described in this report (provided in Section 5.1.3) will be applied to the loads identified in the Rule to establish the regulatory baseline estimates by entity.

It will also be necessary to calculate changes in loading, by entity, between the baseline period and conditions at the end of the interim period. "Current" conditions in the model for this report reflect 2010 land use, and it is anticipated that future updates will be needed to represent additional changes in land use through the end of the interim period.

The rules specify allowable loading rates for new development during the interim period. New loads in excess of these rates become an additional responsibility for load reduction by each entity. These rates reflect loads at the source level, rather than loads delivered to the lake.

Estimates of loading with land use changes after 2010 could be derived by rerunning the model with altered land use (combined with 1997-2001 baseline meteorology). Alternatively, and more simply, the effect of changes since 2010 could be estimated by applying the average loading rate (for developed land classes within an entity) to the change in developed land use area. However, as discussed above, the change in developed area for development occurring after 2001 should be based upon quality assured records of development within each jurisdiction, where possible, given underestimation of impervious surfaces for the baseline period which could result in overestimation of interim development when comparing baseline to current levels.

It is also anticipated that entities will, at their discretion, calculate and claim credit for BMPs installed between the end of the baseline period and the end of the interim period. The method for calculating credit for BMPs will be determined by DWR. It is likely, however, that the method will use the Jordan/Falls Lake Stormwater Nutrient Load Accounting Tool (JF SW Tool) or a similar spreadsheet-based tool designed for calculating nutrient loads and assessing the impacts of BMPs at the scale of a development or individual sites. Such a tool could be used to determine the number of pounds of average annual nutrient load avoided by the installation of specific sets of BMPs.

Regulated entities may also wish to claim credit for reductions associated with management measures not represented in JF SW Tool – for example, the reduction in nutrient loads achieved by providing sewer service to a neighborhood with poorly performing onsite wastewater disposal systems. Analyses of this sort should generally be made relative to the representation of the source in the watershed model.

1 Introduction

1.1 PROJECT OVERVIEW

This project was completed for the Triangle J Council of Governments (TJCOG) under the direction of the North Carolina Division of Water Resources (DWR, previously known as the Division of Water Quality (DWQ)) and the North Carolina Nutrient Scientific Advisory Board (NSAB). The overarching goal of the project is to develop a dynamic flow and water quality watershed model using the Loading Simulation Program in C++ (LSPC) model, to accurately estimate baseline nutrient loads by each regulated entity (e.g., jurisdiction) for the purpose of establishing load allocations under the Jordan Lake Rules. In August 2012 the Tetra Tech modeling team began coordinating with a model subcommittee comprised of select DWR staff and several members of the NSAB Board. Collectively, these parties and TJCOG contract managers clarified modeling objectives and constraints, selected the LSPC model for the project, and negotiated a project scope and schedule for completion of a draft version of the model and associated documentation summarizing model development and application to generate draft baseline jurisdictional load estimates of total phosphorus and total nitrogen. Work under the model development scope officially began in October 2012.

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Although some comments were provided by NSAB model subcommittee members on the interim technical memoranda, no revised interim documents were generated. Rather, to use project resources efficiently, comments were taken into consideration and addressed in the model development and incorporated within this overall draft documentation as the final deliverable under this first phase of work. The next phase of work will involve peer review of the draft model and documentation, and draft baseline jurisdictional load estimates. The modeling team will work with TJCOG and the NSAB model subcommittee to address questions and concerns raised through the peer review, determining collectively what can be accomplished in the near term given project resource constraints and what is recommended for future model enhancement.

An important decision was made following the data compilation phase of the project that impacted the original model development plan. Detailed information on already installed structural stormwater control measures (sometimes referred to as structural best management practices or BMPs) was not available for the vast majority of jurisdictions in the watershed at the time of model configuration. Since most BMPs that were designed to improve water quality were not installed until after the baseline period (1997 to 2001) specified by the Jordan Rules, it was determined in consultation with the NSAB model subcommittee that model development without incorporation of BMPs was preferable to a model with only partial data and considerable uncertainty regarding accuracy of BMP representation. Model water quality calibration was therefore focused on the baseline period such that lack of BMP representation was believed to be of little consequence to model accuracy for that period. DWR determined that it would work with regulated parties to provide proof of BMP installation in the watershed post baseline period and provide regulatory credit through a process separate from this model development project. Accurate data collected through that process can then be used to incorporate structural water quality BMPs into a future enhanced version of the model should DWR or other parties determine that to be necessary. This decision was documented in a supplemental memorandum by the project modeling team (Clements and Butcher, 2013).

Further details on the purpose of the modeling in the context of the regulatory process are provided in Section 1.2.

1.2 Regulatory Background and Modeling Purposes

Based on its assessment of water quality in B. Everett Jordan Reservoir (Jordan Lake), the North Carolina Division of Water Quality (DWQ[1]) identified the lake as impaired by eutrophication (excess growth of algae and associated changes in water quality) caused by excess nutrient loads (nitrogen and phosphorus) derived from both point and nonpoint sources in the watershed. To address this impairment, DWQ developed and the U.S. Environmental Protection Agency approved a Total Maximum Daily Load (TMDL; NC DENR, 2007).

The TMDL requirement is established in Section 303(d) of the 1972 Clean Water Act. The TMDL is intended to identify the amount by which both point and nonpoint sources of pollutants would need to be reduced in order for the waterbody to meet ambient water quality standards and support its designated uses. This requires identifying the sources of excess pollutant loads and assigning allocations to sources such that the loading capacity – the maximum amount of pollutant load that is consistent with meeting ambient water quality standards – is achieved.

The Jordan nutrient strategy is a set of state regulations designed to reduce nutrient loading to B. Everett Jordan Reservoir to meet the requirements of the TMDL and restore full designated uses to its waters. The overall strategy consists of a Point Source Strategy (addressing wasteload allocations for permitted wastewater discharges) and a Nonpoint Source Strategy (addressing other sources of nutrient loads to the lake). The Phase I TMDL determined that traditional point source discharges, such as effluent discharged from wastewater treatment plants, constituted well less than half of the total nitrogen and phosphorus loading to the lake and that loads derived from runoff and groundwater discharge from urban development are a major component of the total load. The loads derived from development may be characterized as point source loads (if they fall within the purview of discharge permit requirements placed on Municipal Separate Storm Sewer, or MS4, stormwater discharges) or as nonpoint source loads

[1] The former DWQ is now the Water Planning Section within the North Carolina Division of Water Resources.

not subject to permits. Regardless of the regulatory characterization, these are diffuse loads from the land surface, as distinguished from more traditional point source discharges from municipal and industrial wastewater treatment plants.

The strategy to address diffuse sources of nutrient loads consists of Rules 15A NCAC 2B .0262 - .0272 as augmented or replaced by subsequent Session Laws 2009-216 and 2009-484. The session laws set requirements regarding existing developed lands, including a requirement for the Department of Environment and Natural Resources to assign nutrient load allocations for existing development to municipalities, counties, and state and federal entities that have jurisdiction in the Jordan Lake watershed. Allocations are to reflect application of strategy percentage reduction goals to loads representative of the baseline period, 1997 through 2001, adjusted to account for loading increases post-baseline and prior to implementation of programs to address new development. (The dates for adoption of new development programs under the Jordan Lake Rules were recently delayed by the Legislature to dates between 2017 through 2020). Allocations are to be established in terms of annual mass loads delivered from these entities' lands to each of three assessment units of Jordan Lake (Upper New Hope Arm, Lower New Hope Arm, and Haw River Arm).

Allocations thus assigned to the parties subject to this regulation will effectively serve as benchmarks that they will use, in combination with recognized load-reducing practices and associated load reduction estimation methods, to design load reduction programs. The subject parties will use these programs, following approval by the NC Environmental Management Commission, to guide their implementation of nutrient load-reducing activities on a continuous basis toward the objective of meeting the allocations or until the lake's water quality is recovered, whichever comes first.

The watershed model addresses the watershed draining to B. Everett Jordan Reservoir. This is part of the Cape Fear Basin and includes the Haw River, New Hope Creek, Morgan Creek, and various other tributary drainages, with a land area (excluding the lake surface) of 1,686 square miles (Figure 1-1). The watershed includes parts of ten North Carolina counties and some or all of the urban areas of Durham, Chapel Hill, Cary, Burlington, Greensboro, and several other smaller municipalities.

A simplified nutrient loading model for Jordan Lake watershed was developed by Tetra Tech in 2003 to support the Jordan Phase I nutrient TMDL. The Nutrient Science Advisory Board (NSAB) reviewed that modeling approach and concluded that it was not compatible with the current regulatory purpose because the model did not retain the ability to associate specific land use / land cover data or related loading outputs with local or other government jurisdictional boundaries. In addition they recognized certain features of the model that they felt would be important to improve. Key features noted as in need of improvement were: representation of onsite wastewater processes, which appear to overestimate this source; limited number of instream calibration points, believed to bias load estimates upward due to their proximal location downstream of wastewater discharges; and now-outdated delivery component coefficients.

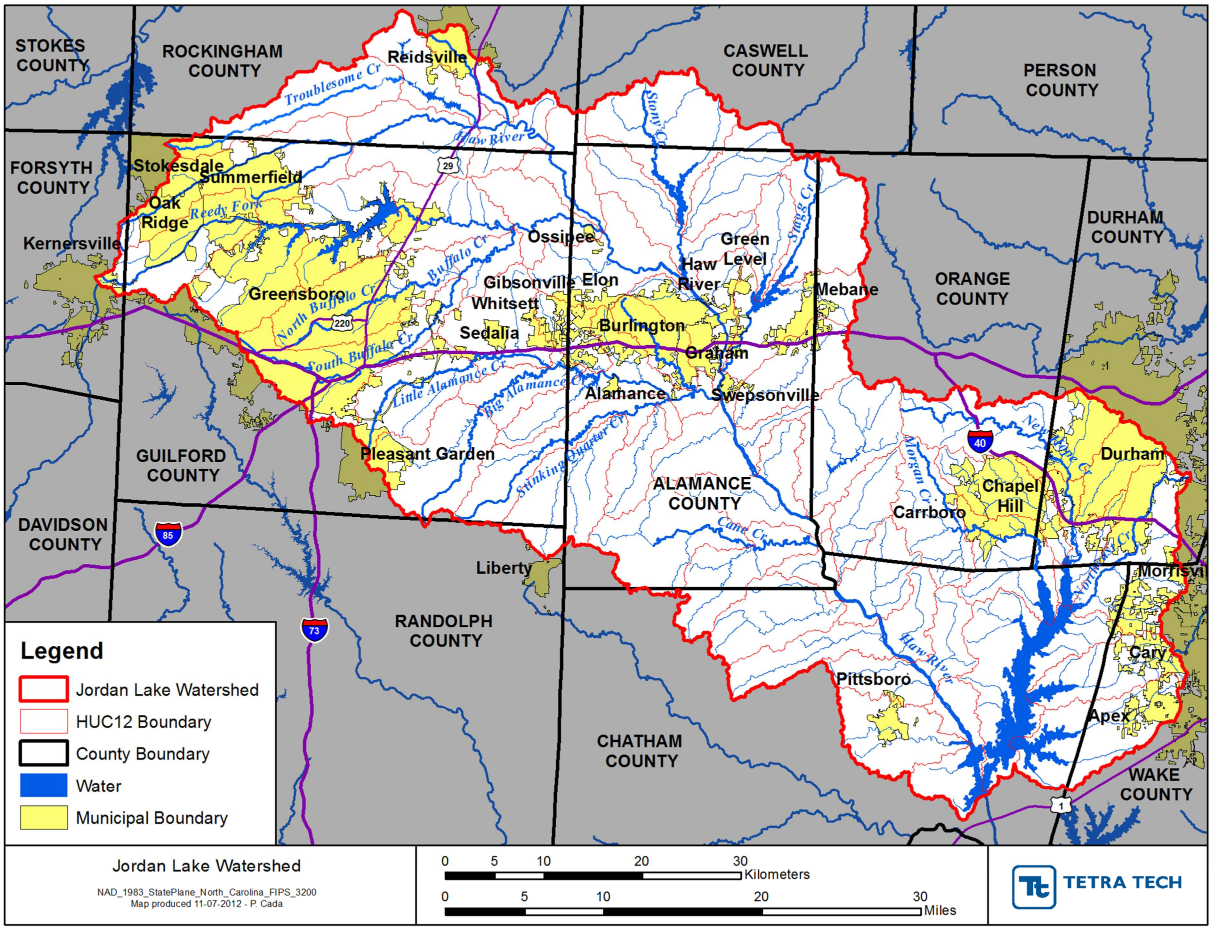

Figure 1-1. The Jordan Lake Watershed

The revised Jordan Watershed Model, described in this report, is intended to provide a refined basis with which to support the nutrient strategy. The principal study questions to be addressed with the model and described in this report are as follows:

1. What are the baseline (1997 – 2001) loads of nutrients associated with each regulated entity in the watershed?
2. How much of the load generated in specific source areas is ultimately transported to Lake Jordan?
3. How have those loads changed in the period from baseline to current conditions?

The 1997 – 2001 time period was selected to represent baseline loads specifically for regulatory purposes as required by the Jordan Lake Rules. Model output was used to determine the amount of source loads delivered to Jordan Lake for each subbasin in the watershed. To assess changes in upland loading between the baseline period and current conditions, a supplemental model run was performed using existing land use in place of the baseline 1997 – 2001 land use. Changes in other sources (e.g., permitted point sources) were estimated using independent data sources, such as facility discharge records.

Sections 2 through 4 of this document describe the model development, calibration, and corroboration. Calibration tunes the models to represent conditions appropriate to the waterbody and watershed under study. To help determine the adequacy of the calibration and to evaluate the uncertainty associated with the calibration, the model is subjected to a corroboration test. Corroboration is often referred to as model validation, although the term corroboration is now preferred (CREM, 2009). In the corroboration step, the performance of the model is evaluated through application to a set of data different from that used in calibration. Application of the model is described in Section 5, and directly answers study questions 1 and 2. Finally, Section 5 discusses ways in which the watershed model, combined with other tools, can be used by jurisdictions and other regulated entities to address study question 3.

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2 Model Development

Development of the Jordan Watershed Model was undertaken under a Quality Assurance Project Plan (QAPP). Preparation of the QAPP (Tetra Tech, 2012a; see Appendix B to this document) was the first step in this project. The QAPP lays out the decision needs to be addressed by the model and performance criteria to determine the extent to which the model meets those needs. It was important to document these requirements and expectations prior to model development to ensure a transparent and defensible process. The first step in the model development process is the selection of an appropriate modeling framework (Section 2.1). This is followed by documentation of the model simulation period (Section 2.2) and the model representation of the watershed as a series of connected stream reaches, waterbody segments, and upland land units (Sections 2.3 and 2.4). The remaining portions of Section 2 describe the availability, assembly, and processing of model input data.

2.1 Model Selection

2.1.1 Selection of LSPC Model

Based on a survey of candidate models, Tetra Tech recommended that either the Hydrologic Simulation Program (HSPF; Bicknell et al., 2005) or Loading Simulation Program in C++ (LSPC; Tetra Tech, 2003a, 2009) be applied to estimate nutrient loads from existing development in the Jordan Lake watershed in accordance with State rules. These models are similar, as LSPC is based on the US Environmental Protection Agency (EPA)-supported HSPF analytical code. HSPF and LSPC were chosen from a subset of six models that met basic criteria as outlined in Table 2-1.

The preliminary screening examined six models that are widely used for nutrient load estimation (Table 2-1). The following types of models were eliminated from consideration: proprietary models that are not open source, models that are considered experimental or academic tools, and models that do not have a track record of successful performance on similar projects.

The SWMM model (Rossman, 2010), which is often used in urban areas for stormwater drainage system representation was eliminated from consideration because of the very large level of effort and cost that would be incurred applying it at the large scale associated with the Jordan watershed. SWMM can be applied more simply if stormwater infrastructure is not explicitly represented, but this would negate most of the advantages of using this model. SWMM also is not designed to represent agricultural features well, can experience difficulty representing baseflow processes in Piedmont streams, and its instream sediment transport and nutrient kinetics capabilities are relatively poor.

The WARMF model (EPRI, 2000, 2001) was not recommended due to the lack of full code availability and primary use under a daily time step. There is also not a strong record of successful calibration to address many of the questions of interest to the NSAB.

A GWLF-based model of the watershed was previously developed (Tetra Tech, 2003b) and could be improved to address identified shortcomings. Although it can be used cost-effectively to estimate nutrient loads, GWLF (Haith et al., 1992) was not the first choice for application in the Jordan Watershed application. GWLF severely limits the representation of multiple small hydrologic response units (HRUs) needed to capture entity loads more accurately, provides only a rudimentary representation of BMP performance, and its reliance on the daily curve number approach and Universal Soil Loss Equation (USLE) restricts load estimation to seasonal and annual levels. Furthermore, GWLF's lack of instream sediment transport dynamics and nutrient species kinetics means that it must be paired with another model to provide an accurate representation of nutrient delivery cumulatively through the watershed.

The SWAT model (Neitsch et al., 2005) was of interest because it is currently being set up by NCSU for application in the watershed to inform agricultural management decision-making. The model is an excellent tool to simulate agricultural land uses and management practices for sediment and nutrient source loading estimates. However, it is not the first choice among options for estimating loads delivered to Jordan Lake because its daily time step and approach to estimating solids delivery limits accurate representation of urban land use hydrology and pollutant transport, it has lesser capability to represent urban stormwater BMPs, and its relatively weak instream water quality kinetics capabilities limit trust in ultimate fate and transport predictions.

The HSPF and LSPC models were found to have the best overall combination of features related to the Jordan watershed modeling needs: strong spatial and temporal scale representation, strong representation of urban and other land uses, flexibility to represent multiple source and loading features, and a strong history of application to TMDL and water supply protection studies. Both models are capable of producing accurate sub-daily concentration predictions (unlike SWAT, WARMF, and GWLF), allowing more detailed calibration to instream water quality observations. In addition, both models possess the flexibility to allow for efficient enhancement in areas where improved capabilities may be needed (e.g., simulation of onsite wastewater disposal). In summary, the key benefits of these models are:

1. HSPF and LSPC provide dynamic simulation of water, nutrients, and sediment; including both upland and instream sediment processes at a user-specified level of detail and complexity, and is thus suitable for addressing the principle study questions.
2. HSPF is supported by EPA with open source code and has a long history of well-documented applications for addressing hydrology and sediment management applications. It also provides a platform for full simulation of nutrients, bacteria, and other endpoints of potential interest.
3. LSPC implements the HSPF code with an improved user interface and database structure, which will be particularly useful for tracking regulated entity loads in the model.

HSPF/LSPC’s sophisticated instream kinetics simulation provides a firm basis for assessing basin-scale impacts; however, the model is weaker at process-based representation of the details of agricultural management at the field scale. This disadvantage can be overcome through use of smaller-scale agronomic models to constrain the basin-scale simulations. The aggregate behavior of the large-scale model is adjusted to replicate the findings of the field-scale models – which increases both the accuracy and the credibility of the watershed model.

Ultimately, LSPC was selected for use in the project due to its improved interface and database structure, which is well suited for the task of tabulating loads by land use and entity.

Table 2-1. Comparison of capability of candidate models to satisfy project objectives

Capability key: ● High ◒ Medium • Low

Criteria	Technical approach options						
	Relative Importance	**GWLF**	**WARMF**	**HSPF**	**LSPC**	**SWAT**	**SWMM**
Technical							
Spatial Scale and Representation							
• Ability to customize segmentation	●	◒	●	●	●	●	●
• Predict loads for multiple spatial scales	●	◒	●	●	●	●	●
• Ability to predict HRU-based loading	●	--	●	●	●	●	◒
Temporal Scale and Representation							
• Long-term trends and averages	●	●	●	●	●	●	◒
• Continuous –predict shorter time period variability	●	◒	◒	●	●	●	●
• Loads by flow regime	●	--	◒	●	●	◒	●
• Simulation time step	◒	Daily	Daily	Sub-daily	Sub-daily	Daily	Sub-daily
Sources							
• Land uses represented (urban and non-urban)	●	●	●	●	●	●	◒
• Explicit simulation of urban land uses	●	◒	◒	●	●	◒	●
• WWTPs	●	◒	●	●	●	●	●
• Atmospheric Deposition	◒	--	●	●	●	◒	◒
• Sanitary sewer discharges	◒	--	•	◒	◒	•	●
• Septic systems	●	•	◒	•	•	•	•
Land and Water Features							
• Agricultural, urban, forest land use/ land cover	●	◒	●	●	●	●	◒
• Tillage and fertilization practices	•	•	◒	◒	◒	●	--
• Land use change	●	●	◒	●	●	◒	•
• Stream network/routing	●	•	●	●	●	●	●
• Impoundments (flow and water quality)	◒	--	●	◒	◒	◒	◒

Capability key: ● High ◒ Medium • Low							
Criteria	**Technical approach options**						
	Relative Importance	**GWLF**	**WARMF**	**HSPF**	**LSPC**	**SWAT**	**SWMM**
Pollutants							
• Total nutrient concentrations	●	●	●	●	●	●	●
• Dissolved/particulate partitioning	◒	●	●	●	●	●	•
• Nutrient species/kinetics	◒	•	●	●	●	●	--
• Sediment loading	◒	◒	●	●	●	●	●
• Instream sediment transport	•	--	●	●	●	◒	•
• Instream nutrient species/kinetics	◒	--	●	●	●	◒	•
Physical Processes/Critical Basin Factors							
• Nutrient load sensitivity to soils and geology	◒	•	◒	●	●	●	◒
• Integrated groundwater modeling	•	--	●	◒	◒	◒	◒
User Requirements							
• Assign WLAs by jurisdiction	●	◒	●	●	●	●	◒
• Technically defensible (previous use/validation, thoroughly tested, results in peer-reviewed literature, previous TMDL studies)	●	●	◒	●	●	●	●
• Fully publicly available domain code	●	◒	--	●	◒	◒	●
• Code modifiable to address specific needs	◒	◒	--	●	●	●	◒
• Level of effort required for Jordan watershed application	●	Low	Medium	High	High	Medium	Very High
Management Scenarios							
• Represent impact of existing SW controls	●	--	◒	●	●	◒	●
• Urban BMP representation	●	--	◒	◒	●	•	●
• Agricultural BMP representation	•	•[a]	◒	◒	◒	●	--
• Shared vision scenario generation	●	--	●	◒	●	◒	•

Notes: a. GWLF-E version

● = High: detailed simulation of processes associated with land feature

◒ = Medium: moderate level of analysis; some limitations

• = Low: simplified representation of features, significant limitations

-- = Not supported

2.1.2 Characteristics of the LSPC Model

LSPC uses HSPF's algorithms for simulating watershed hydrology, erosion, and water quality processes, as well as instream transport processes (http://www.epa.gov/athens/wwqtsc/html/lspc.html). LSPC integrates a geographical information system (GIS), comprehensive data storage and management capabilities, and a data analysis/post-processing system into a convenient, PC-based, Windows interface. LSPC's algorithms are identical to a subset of those in the HSPF model. LSPC is freely distributed by EPA's Office of Research and Development in Athens, Georgia, and is a component of EPA's National TMDL Toolbox (http://www.epa.gov/athens/wwqtsc/index.html). The model executable used for this project is version 3.2, compiled on August 20, 2013.

A key advantage of LSPC over HSPF and other watershed models is a data management feature that uses a Microsoft Access database to manage model data and weather files for driving the simulation. This provides great flexibility for data transfer and manipulation, which is critical for complex watershed studies. LSPC was designed specifically to handle very large-scale watershed and receiving water modeling applications at a high resolution. The model has been successfully used to model watershed systems composed of well over 1,000 sub-watersheds and at least as many individual stream elements. The highly adaptable design and programming architecture allows for future modular additions based on specific project needs. Furthermore, the entire system is designed to simplify model sharing.

2.1.2.1 LSPC Hydrology Representation

Watershed hydrology plays an important role in the determination of nonpoint source flow and ultimately nonpoint source loadings to a waterbody. The watershed model must appropriately represent the spatial and temporal variability of hydrological characteristics within a watershed. Key hydrological characteristics include interception storage capacities, infiltration properties, evaporation and transpiration rates, and watershed slope and roughness. LSPC's algorithms are identical to those in the Hydrologic Simulation Program FORTRAN (HSPF). The LSPC/HSPF modules used to represent watershed hydrology include PWATER (water budget simulation for pervious land units) and IWATER (water budget simulation for impervious land units). A detailed description of relevant hydrological algorithms is presented in the HSPF (v12) User's Manual (Bicknell et al., 2005).

A schematic of the LSPC hydrology model is provided in Figure 2-1. Rain falling toward the land first experiences interception storage (CEPSC). If there is space available in interception storage, it is filled up and all remaining precipitation volume proceeds to the land surface. Once on the land surface, water is divided into subsurface flow and surface flow by infiltration (INFILT). Any water not being infiltrated is divided between upper zone storage (UZSN), interflow (INTFW), and overland flow (SURO). If space exists in upper zone storage, it is filled first before becoming interflow or overland flow. Overland flow travels directly to the stream, and timing is based on the slope, length, and Manning's *n* value of the overland flow plane. Interflow travels to the stream under the surface of the land, and the timing of interflow outflow is dependent on the interflow recession constant (IRC). Water in the upper zone storage is either evaporated or moves deeper into the soil profile through percolation. Infiltrated water first fills the capacity of lower zone storage (LZSN) and water is lost from lower zone storage through evapotranspiration (LZETP). Any remaining water then enters one of two groundwater storage components. Inactive groundwater (water not having the ability to become stream flow) is supplied by a value for DEEPFR. Active ground water storage is released to the stream through a groundwater recession constant (AGWRC). Water can be lost from both active groundwater storage and groundwater outflow by values supplied for AGWETP and BASETP respectively. The model simulates total actual ET by trying to fulfill PET by first removing water from baseflow outflow, then interception storage, then upper zone storage, then groundwater storage and finally lower zone storage.

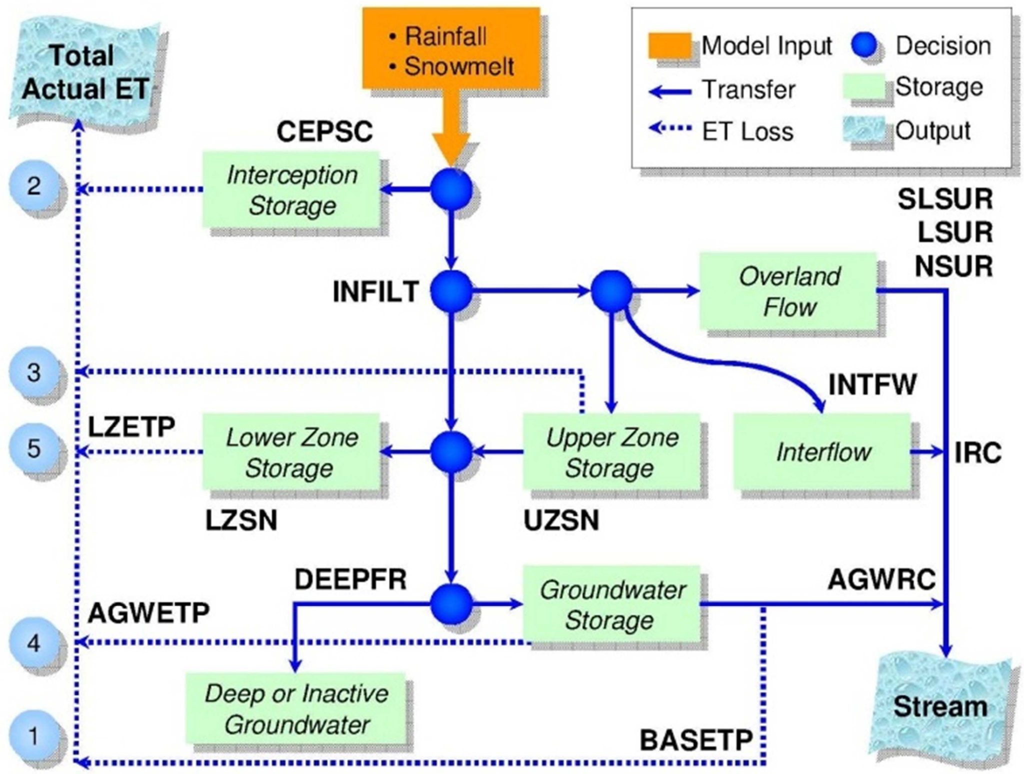


Figure 2-1. Schematic of LSPC Hydrology Components and Pathways

2.1.2.2 LSPC Water Quality Representation

The LSPC platform provides comprehensive water quality simulation on the land surface and within waterbodies. Upland sediment production is based on detachment and scour from the soil matrix or buildup processes on impervious surfaces with transport by flow energy. Transport of nutrients and other pollutants from the land surface may be simulated using a buildup/washoff approach and as associated with the movement of sediment. Pollutant loads may also be associated with interflow and groundwater discharge. The stream reach simulation includes modules addressing sediment scour, deposition, and transport; dissolved oxygen simulation; complete nutrient and eutrophication kinetics; and a variety of other options. A general schematic of the nutrient simulation processes represented in LSPC is provided in Figure 2-2.

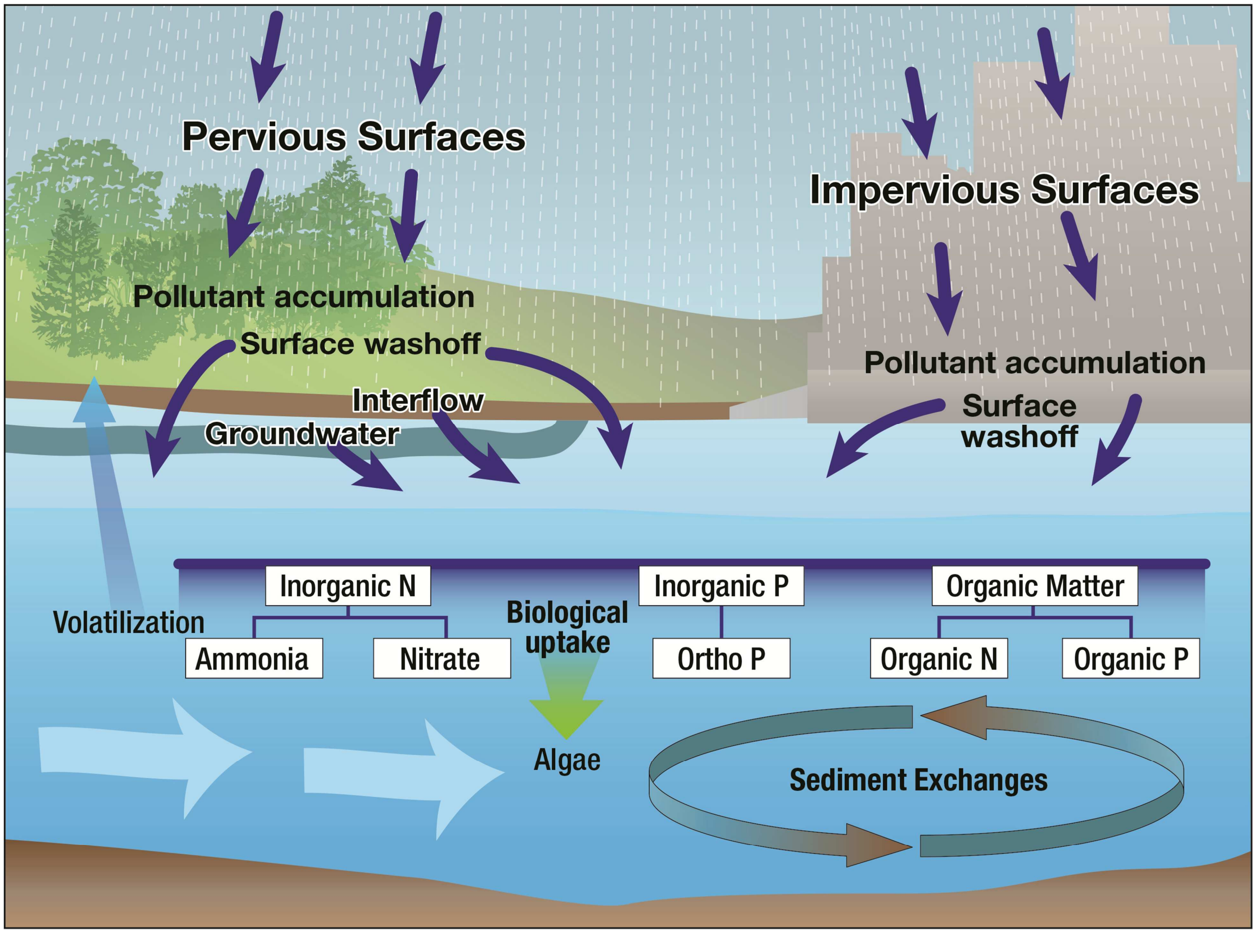


Figure 2-2. Schematic Representation of Key Nutrient Simulation Processes

2.2 Simulation Period

The model simulation period was selected based on the purposes of the project and the availability of data. A key output required of the modeling is a comparison of watershed loading from the legislatively defined baseline period of 1997-2001 and current conditions. Therefore, the model must commence in 1997 or earlier and proceed as close to present as possible. Data available for calibration (see Section 3) are more numerous after 1997, while land use information is available for 2001 and 2010 conditions (see Section 2.4.2). Rapid urban development in parts of the watershed during the 1990s renders data from prior to 1997 less useful for model calibration and less well matched to the 2001 land use information. However, it is also necessary to provide a year of model spin up to allow the simulation of soil and shallow groundwater stores to equilibrate prior to the period from which calibrated model output is required. Therefore, the starting point for the simulation was set to January 1, 1996.

While it is desired to run the model to as close to the current date as possible, the ending point for the simulation is constrained by the availability of time series data for meteorology (Section 2.5) and point source discharges (Section 2.6). Based on data availability at the time of model development, the endpoint for the model simulation is September 30, 2012, for a total simulation length of 15.75 years. The length of the simulation period is consistent with the recommendations made in the QAPP to allow at least 15 years for hydrologic calibration and corroboration.

2.3 Model Segmentation

2.3.1 Subwatershed Delineation

To evaluate the sources contributing to an impaired waterbody and to represent the spatial variability of those sources within the LSPC watershed model, the drainage area contributing to the waterbodies is represented by a series of hydrologically connected subwatersheds. Each subwatershed (or SWS) has a representative reach to receive runoff from the local subwatershed as well as receive the instream flow from any subwatersheds located upstream.

NHDPlus Version 2 catchments (McKay et al., 2012) provided the foundation for delineating the SWSs. The NHDPlus catchments are much smaller than the targeted size for the ultimate model SWSs; however, it is more efficient to aggregate polygons than to split them along fine-scale drainage divides or at points of interest (e.g., confluences of interest, monitoring locations). In a few cases, manual editing to split NHDPlus catchments was needed to meet the goals of subsequent modeling efforts. To facilitate subsequent model calibration and corroboration, a process of aggregating the NHDPlus catchments was used to create model SWSs with the goal of having outlets at:

- Major water quality and/or stream flow monitoring stations
- Major regulatory boundaries
- Major waterbody outlets
- Major confluences

Secondary objectives to be met through the catchment aggregation process were to minimize variability in SWS size while specifying catchments with relatively consistent land use and cover. The aggregation process resulted in 152 model SWSs in total (compared to 56 HUC-12 watersheds that drain to Jordan Lake). The resultant model SWSs compared to the HUC-12 watersheds along with descriptive statistics can be found in Figure 2-3. The subwatershed numbering scheme is shown in Figure 2-4

In four cases, monitoring sites are located directly downstream of the confluence of two model subwatersheds. For those locations, short routing reaches with no additional upland drainage area were created. These routing reaches are used solely to aggregate model output to compare the simulated results to the observed field data at those four locations and do not otherwise affect the simulation.

The subwatershed delineation is consistent with the topography of the watershed and final modifications were made in reference to a digital elevation model (DEM). The 30-meter resolution DEM provided as part of NHDPlus Version 2 is the most recently updated National Elevation Dataset (NED) release from the U. S. Geological Survey (USGS). Additionally, NHDPlus Version 2 also provides a conditioned DEM (HydroDEM) used to produce the NHDPlus Version 2 stream polyline and catchment polygon shapefiles (http://www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php). These two DEMs are ideal for this project because there is complete alignment of NHDPlus catchments (and by extension model subwatersheds), DEM values, and NHDPlus Version 2 stream polylines maximizing the accuracy of model inputs with minimal processing effort.

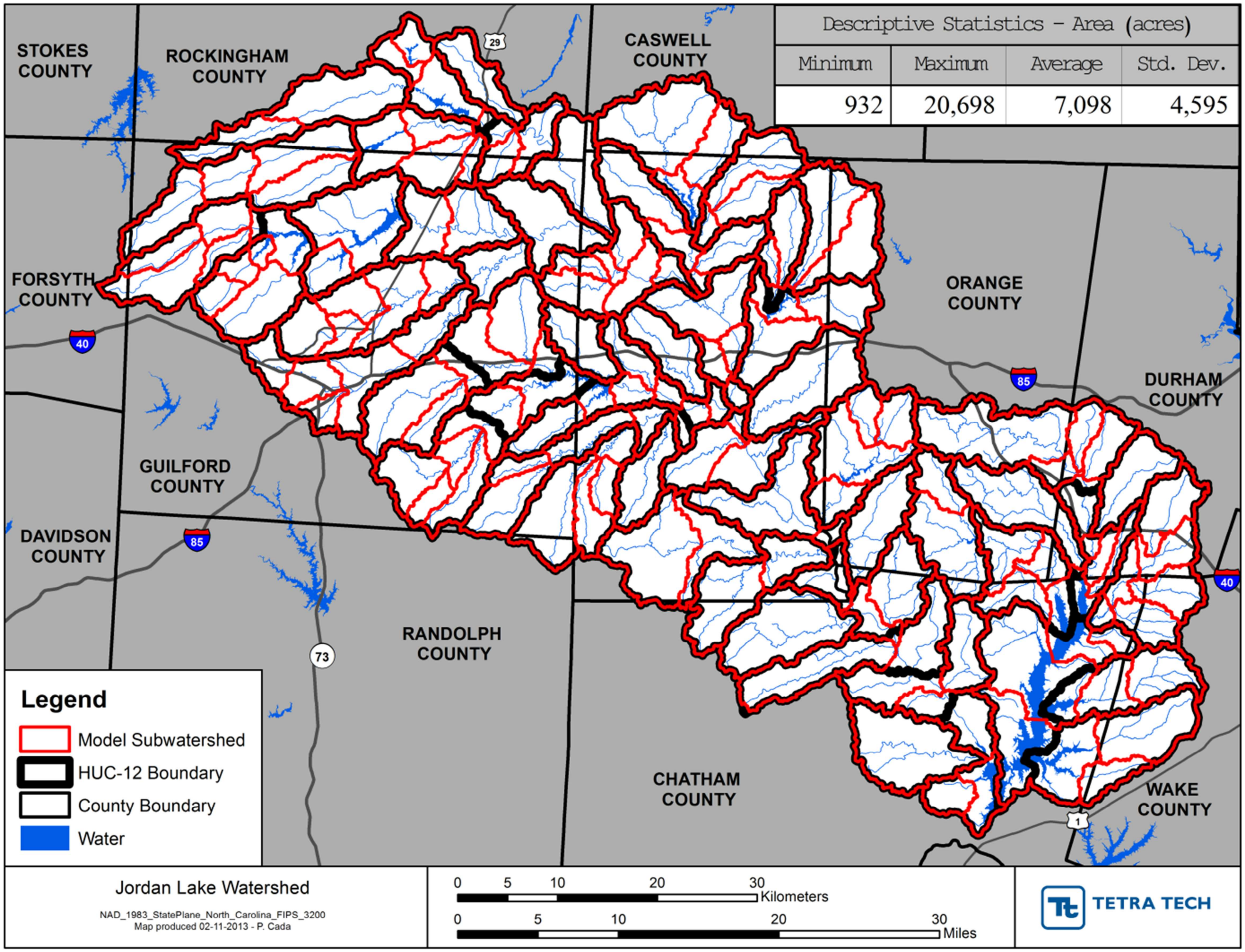


Figure 2-3. Model Subwatersheds (SWSs) and HUC-12 Boundary Comparisons

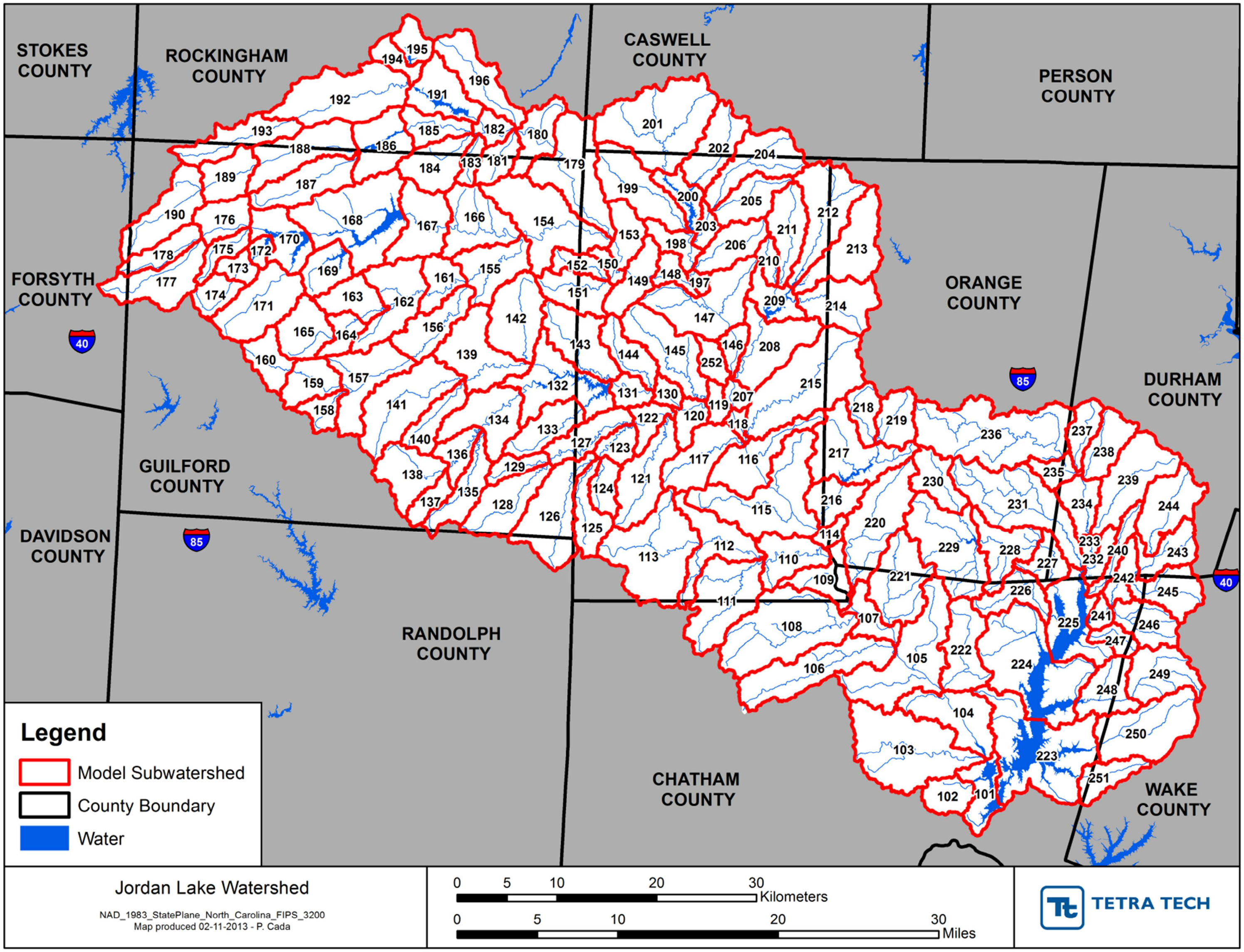


Figure 2-4. Model Subwatershed Numbering

2.3.2 Waterbody Representation

2.3.2.1 Stream and River Segments

2.3.2.1.1 Delineation of Stream and River Segments

Stream and river segments are represented in the model as water reaches. These reaches were created from the HydroDEM using ArcSWAT's automatic watershed delineation toolset (built upon ArcHydro tools). Because the NHDPlus Version 2 stream polylines and the HydroDEM are completely aligned, model reaches produced by ArcSWAT also match up perfectly with their NHDPlus Version 2 stream polyline counterparts. ArcSWAT allows the production of a significantly pared down reach coverage allowing for quick creation of model reaches by leaving out ancillary tributaries within each model subwatershed.

2.3.2.1.2 Reach Characteristics

LSPC itself is not a hydraulic model. Instead, the stage-storage-discharge relationships for each stream reach are represented through a Functional Table (FTable). The FTable describes the hydraulic behavior of a waterbody segment by defining the functional relationship between water depth, surface area, water volume, and outflow in the segment. The assumption of a fixed depth-area-volume-outflow relationship rules out cases where flow reverses direction or where one reach influences another upstream of it in a time-dependent way. The routing technique falls in the class known as "storage routing" or "kinematic wave" methods. In these methods, momentum is not considered (USEPA, 2007). FTables can be specified in the model using two methods – externally supplied, or internally calculated. Table 2-2 provides an example of an externally supplied FTable.

Table 2-2. Example of an FTable used by LSPC

RCHID	DEPTH_FT	AREA_AC	VOL_AC-FT	DISCH1_CFS
101	0	0	0	0
101	0.465528	19.23142	8.72895	184.5238
101	8.379509	35.57813	225.6098	27506.71
101	8.845037	91.34924	242.3962	30449.98
101	44.22519	119.8671	3978.829	1441000
101	185.7458	233.9387	29014.23	24600000
101	362.6465	376.5281	83010.25	1.02E+08

Externally supplied FTables can be generated from the output of a hydraulic model such as HEC-RAS; however, such models are not available for the majority of stream reaches in the Jordan watershed (with some exceptions, such as the Haw mainstem). Therefore, internal calculations were used to generate FTables for most reaches that were sufficient for evaluation of flow and pollutant concentrations and loads. The characteristics needed for each reach to estimate an FTable include reach length (LENGTH), reach slope (SLOPE), reach bankfull depth (DEP), reach bankfull width (WID), Manning's *n*, a reach bottom width factor (R1), slope of the sides of the overland flow channel (R2) and a floodplain width factor (W1). A schematic of the channel geometry in LSPC is provided in Figure 2-5. Reach length, upstream elevation and downstream elevation (to calculate reach slope) were obtained when creating the representative reach file during the watershed delineation process. Values for R1, R2, and W2 were left at default values of 0.2, 0.5, and 1.5 respectively. The assumed Manning's *n* value for all reaches in the model was 0.04. Bankfull width and depth were estimated by using a hydraulic geometry equation that estimates bankfull depth and width as a function of upstream drainage area (Leopold and Maddock, 1953). The LSPC default equations are as follows:

$$\text{Bankfull Width} = 1.4995 \cdot DA^{14.49}, \text{ and}$$

$$\text{Bankfull Depth} = 0.2838 \cdot DA^{0.4},$$

where DA is the drainage area in square miles and width and depth are in units of feet.

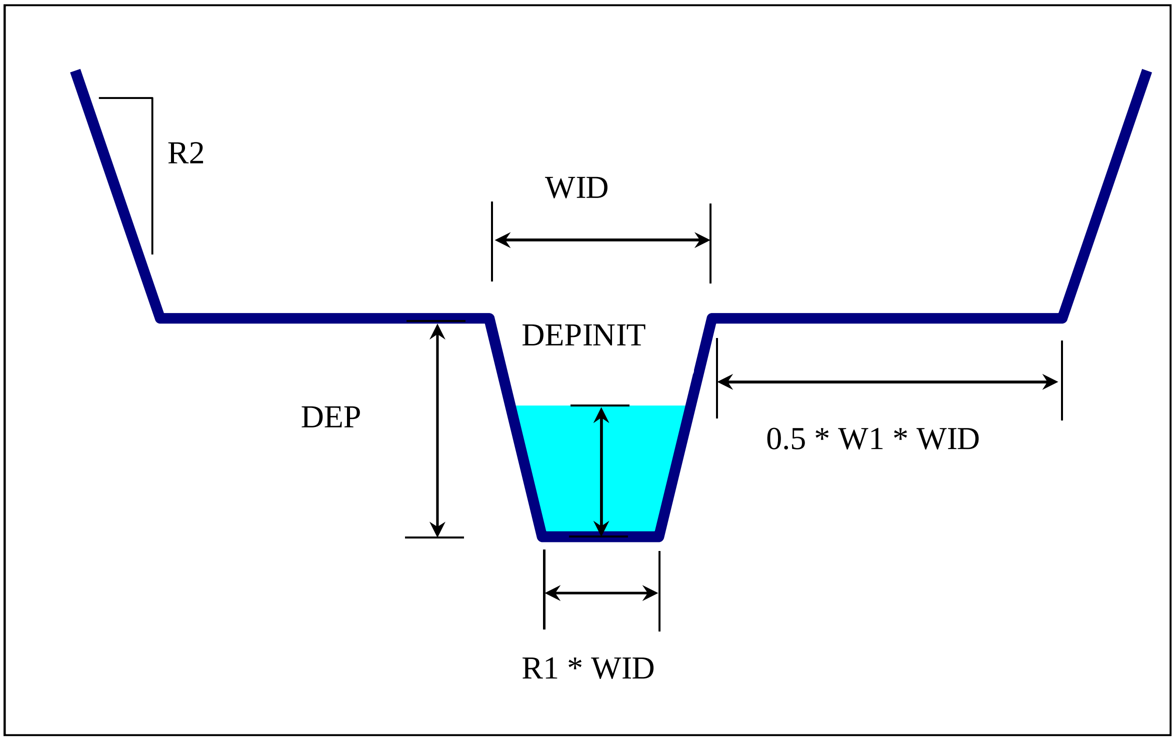


Figure 2-5. Channel Geometry Representation in the LSPC Model

Detailed stream cross section information provided by the North Carolina Flood Mapping Program (NCFMP) for Alamance County was used to investigate if the default values provided reasonable estimates as compared to the field observations. The stream geometry of Haw River was checked at seven locations and Reedy Fork Creek, Jordan Creek, Big Alamance Creek, Cane Creek, and Haw Creek were each checked at one location (Table 2-3). The default values for bankfull width provided reasonable estimates when compared to field observations but bankfull depth was too shallow. The exponent in the equation for bankfull depth was modified until an acceptable agreement was achieved between calculated and observed bankfull depth. The final exponent value used was 0.3338 for all stream reaches with internal calculated FTables.

Table 2-3. Comparison of Observed and Calculated Bankfull Widths and Depths

LSPC Subwatershed (SWS)	Stream Name	Observed Cross Section Measurements			Calculated Cross Section Measurements			
					Initial		Final	
		NCFMP Reference	Bankfull Width (m)	Bankfull Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)
109	Haw River	A_HR_15X	83.07	4.04	74.19	3.38	74.19	4.81
115	Haw River	A_HR_17X	61.92	3.56	71.07	3.28	71.07	4.64
116	Haw River	A_HR_21X	92.73	2.82	70.34	3.26	70.34	4.60
207	Haw River	A_HR_26X	64.48	2.97	60.50	2.93	60.50	4.06
147	Haw River	A_HR_33X	67.86	3.80	57.18	2.81	57.18	3.87
149	Haw River	A_HR_40X	38.9	4.55	51.97	2.63	51.97	3.58
179	Haw River	A_HR_46X	26.82	3.41	35.92	2.02	35.92	2.63
154	Reedy Fork	A_RF_04X	32.25	3.02	40.54	2.20	40.54	2.91
198	Jordan Creek	A_SYC_04DSX	65.35	2.53	27.18	1.66	27.18	2.08
144	Big Alamance	A_GC_01X	11.19	3.11	10.09	0.82	10.09	0.91
112	Cane Creek	A_CC_10X	12.82	2.54	19.16	1.29	19.16	1.56
215	Haw Creek	A_HC_02X	14.11	3.12	16.85	1.18	16.85	1.40

2.3.2.2 Lakes and Reservoirs

The Jordan watershed contains a variety of impoundments, ranging from small farm ponds to large reservoirs. The larger impoundments are explicitly represented using externally supplied FTables, as are numerous run-of-river low head dams. The effects of small ponds are represented implicitly as a water land use.

2.3.2.2.1 Reservoirs Explicitly Simulated

There are 12 lakes or reservoirs within the Jordan Lake watershed that are explicitly simulated in the LSPC model. These are listed in Table 2-4 and shown spatially in Figure 2-6. (Jordan Lake itself is not simulated in this model.) Like the stream and river segments, lake hydraulic behavior is also represented through FTables. Two sources provided the majority of information used to estimate the lake FTables – information from the OASIS water supply model (Hydrologics, 2009), and NC Department of Environment and Natural Resources (NC DENR) lake assessment reports.

Table 2-4. Reservoirs Included in the LSPC Watershed Model

Name	Normal Pool Volume (ac-ft)	Model Reach	Data Source
Reidsville Lake	8,593	191	OASIS
Lake Brandt	10,131	170	OASIS
Lake Townsend	19,426	168	OASIS
Stony Creek Reservoir (Lake Burlington)	2,800	197	OASIS
Lake Cammack (Burlington Reservoir)	9,891	200	Lake Assessment Reports
Quaker Creek Reservoir (Graham-Mebane Reservoir)	7,052	209	OASIS
Lake Mackintosh	21,530	132	OASIS
Cane Creek Reservoir	9,232	217	OASIS
University Lake	1,378	229	OASIS
Lake Hunt	2,270	195	Lake Assessment Reports
Lake Higgins	2,432	172	Lake Assessment Reports
Lake Jeanette (Richland Lake)	3,405	169	Lake Assessment Reports

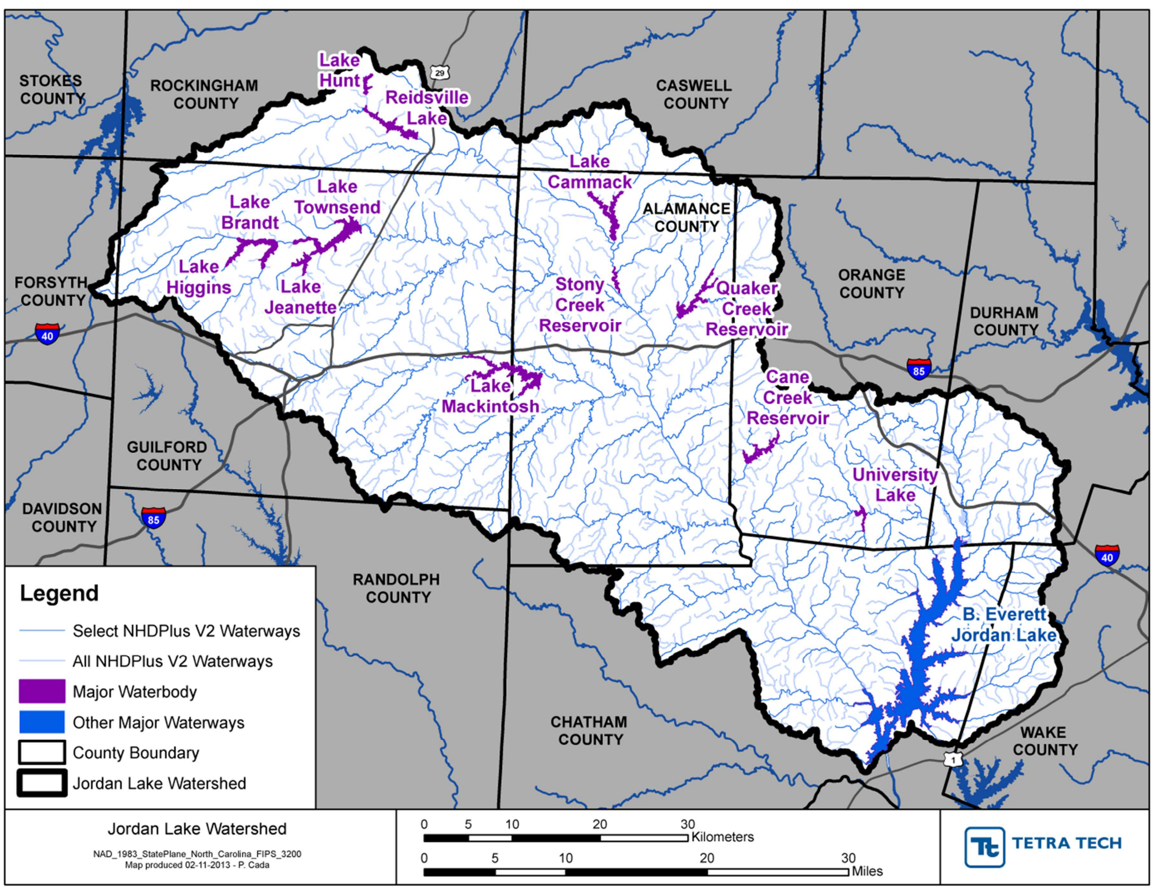


Figure 2-6. Lakes and Reservoirs in the Jordan Lake Watershed Model

DWR provided Tetra Tech access to the OASIS water supply model of the Cape Fear River basin, which includes information on the stage-storage-area relationships of the reservoirs and also their normal operational range. For each lake with the data source listed as "OASIS" in Table 2-4, the OASIS stage-storage-area relationships were directly used to construct the FTables. In some cases, the OASIS data was incomplete or lacked sufficient detail for representing outflow at stages close to normal pool. The OASIS information was updated and corrected for the normal pool area of Quaker Creek Reservoir and for various characteristics of Lake Townsend, Lake Brandt, and Reidsville Lake. OASIS information on discharge rates was insufficient to estimate outflow hydrographs, so downstream gaging was used, when available, to adjust stage-outflow relationships until an agreement was reached between simulated and observed normal pool elevations and downstream flows. In some cases, the FTables were refined with a weir equation using weir dimensions estimated from aerial photography (Google Earth).

Four lakes included in this watershed model are not explicitly represented in OASIS. Each lake with the data source listed as "Lake Assessment Reports" in Table 2-4 used normal pool volumes and surface areas published in NC DENR (1992) and NC DENR (2009) along with weir width measurements made in Google Earth to help estimate the FTable. Normal pool surface area for Lake Higgins was updated using recent information from the City of Greensboro Parks and Recreation website (http://www.greensboro-nc.gov/). The FTables were then calculated by using the Gray Infrastructure Tool, part of the HSPF BMP web Toolkit (USEPA, 2013). Each lake was considered to be a trapezoidal channel and inputs to the tool included maximum channel depth, top channel width, channel side slope, channel length, channel Manning's *n* value, and slope. The outlet was represented as a broad crested weir. The values of the parameters used to generate the FTables for each of these four lakes are provided in Table 2-5.

Table 2-5. Parameters for Calculating Lake FTables with the EPA Tool

Name	Depth (ft)	Width (ft)	Side Slope	Length (ft)	Manning's *n*	Slope	Weir Width(ft)	Weir Invert (ft)
Lake Cammack (Burlington Reservoir)	13.17	1636	1	20,000	0.04	0.00127	343	12
Lake Hunt	12.58	1429	1	5,500	0.04	0.00966	62	11
Lake Higgins	14.0	1093	1	9,000	0.04	0.00095	100	11
Lake Jeanette (Richland Lake)	13.12	2018	1	5,600	0.04	0.00193	60	12

2.3.2.2.2 Low Head Dams

A dataset identifying the locations of dams was downloaded from the National Atlas Spatial Dataset (http://nationalatlas.gov/atlasftp.html). Additional smaller low head (run-of-river) dam locations were identified from materials provided by Kurt Golembesky with the NCFMP. Specific materials provided included limited-detail HEC-RAS models for the main-stem Haw River for Chatham and Rockingham counties and detailed survey information collected in 2010-2011, repeating a study conducted in the 1980's, for Guilford and Alamance counties.

The NCFMP data were used to determine the height for each dam. It was found that dam height was generally the same as calculated bankfull height of the stream reach. As a result, the FTables internally calculated by the mode were considered sufficient for representing stage-storage-volume relationships, and only outflow values needed to be updated. The FTable for each watershed with a low head dam was modified to account for the effect of the dam on outflows as a function of stage. Outflows below the dam height were set to zero, while outflows above the weir were set to the range of outflows in the original

FTable starting with zero stage (i.e., the outflow at stage *x* in the original FTable was substituted for the outflow at stage *x* plus the weir height in the revised FTable). It was assumed that this approach would cause a reasonable expansion of volume in the watersheds with low head dams. Table 2-6 provides an inventory of the low head dams input into the Jordan Lake watershed model, and Figure 2-7 shows their spatial location. Some model subwatersheds (SWS) contain more than one low head dam. In such cases, only the most downstream dam, which controls outflow from the reach, is represented in the model. For the low head dams an FTable is supplied in the model database.

Table 2-6. Low Head Dams in the Jordan Lake Watershed

Figure ID	LSPC SWS	Name	NCFMP Reference	Weir Height
1	105	Bynum Dam	Chatham County HECRAS	16
2	110	unknown	A_CC_05	N/A
3	110	Unknown	A_CC_03	6
4	112	Unknown	A_CC_09	5
5	115	Saxapahaw Dam	A_HR_20	15
6	118	Puryer Dam	A_HR_23	15
7	207	Unknown	A_HR_24	13
8	131	Unknown	A_BAC_02	8
9	145	Unknown	A_BB_02	4
10	145	Unknown	A_LAC_11	N/A
11	143	Unknown	A_WBCT1-0	4
12	143	Unknown	A_MB_01	N/A
13	143	Unknown	A_MB_04	N/A
14	208	Unknown	A_EBC_09	7
15	197	Old Stony	A_SYC_02	N/A*
16	197	Unknown	A_SYC_03	N/A
17	148	Irelands Dam	A_HR_38	N/A
18	148	Glencoe Mills Dam	A_HR_37	12
19	154	Unknown	A_RF_02	10
20	179	Altamahaw Mill Dam	A_HR_45	9
21	179	Unknown	GU_HAW_03	N/A
22	184	Unknown	GU_BEN_05	N/A
23	184	unknown	GU_BEN_04	4

Note: N/A* means already represented by a reservoir; N/A means not represented due to being upstream of another dam in the same model segment

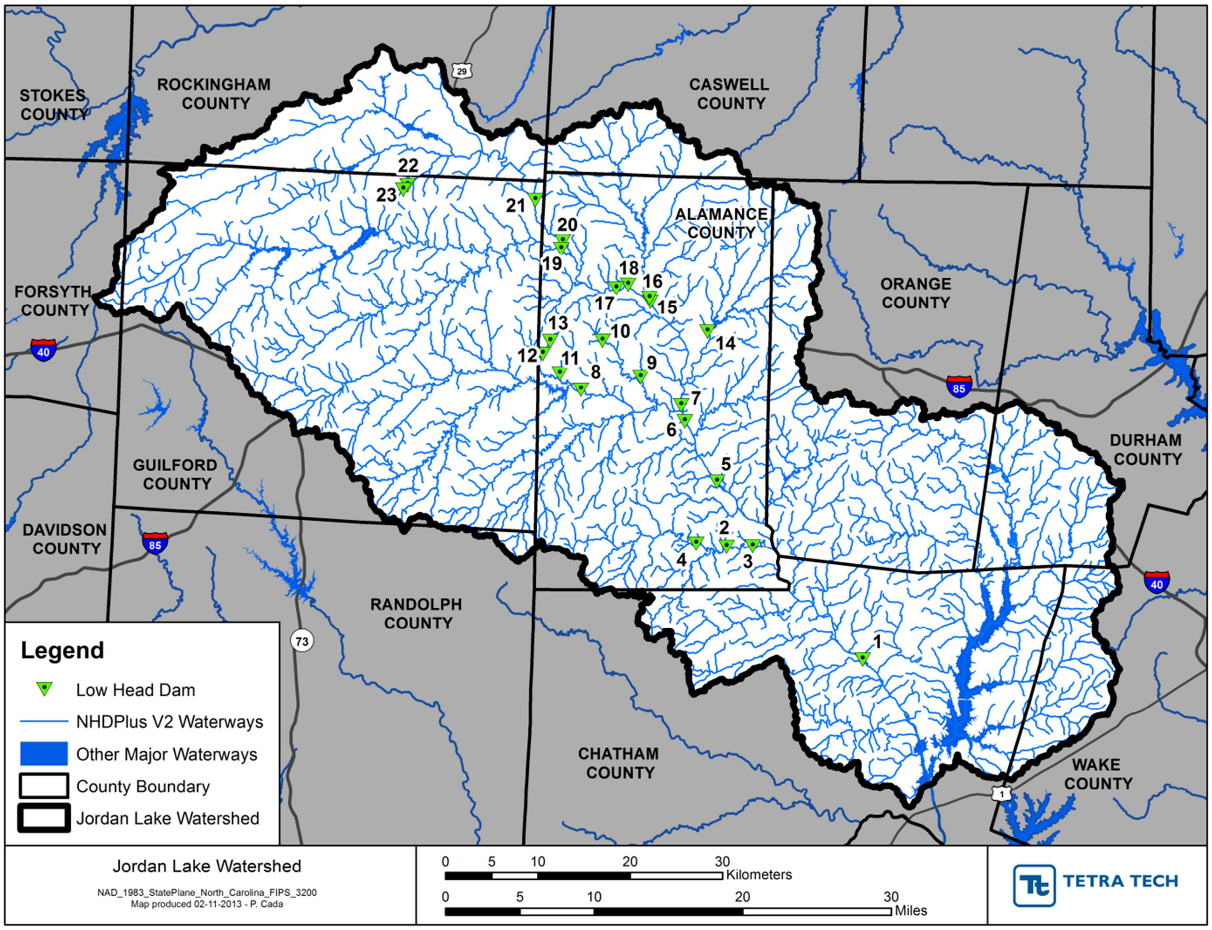


Figure 2-7. Location of Low Head Dams in the Jordan Lake Watershed

2.3.2.2.3 Minor Ponds

Smaller ponds are not explicitly simulated in the model; however, their impacts are approximated through a water land use. This is designed to reflect the balance of precipitation, evaporation, and runoff experienced in ponds.

Simulating water as an upland land use requires unique parameterization in the LSPC model. For hydrology, the infiltration rate is set to a small value, the slope of the overland flow plane is also set to an extremely small value (range in the hundred thousandths ft/ft) and the length of the overland flow plane is set to an extremely large value (range in the millions of feet). LZSN is set to zero, which causes the LSPC code to default to passing all infiltrated water through to active groundwater storage. This causes the model to simulate precipitation as ponded in surface and upper soil zone storage, with slow infiltration into the subsurface. With this configuration, most of the incoming precipitation is eventually returned to the atmosphere as evaporation. The remainder is routed to surface spillage during large rainfall events. This approach is intended to mimic the hydrologic behavior of small, shallow ponds scattered throughout the landscape. However, because the water land use is not simulated as a waterbody reach, the role of ponds in damping flow peaks from their contributing area cannot be represented.

Because these small ponds are not simulated as reaches, their role in trapping nutrients from adjacent land is also not explicitly represented. Instead, losses in small ponds are implicitly included in the loading rates from other upland land uses. The water land use itself is assumed to provide a net zero contribution of nutrients to downstream reaches.

2.4 UPLAND REPRESENTATION

2.4.1 Hydrologic Response Unit Approach

A key goal of the watershed model is to provide a tool that can provide accurate estimates of nutrient loads (both at source and delivered) for individual land uses and areas. This provides the basis for allocations to individual entities and is accomplished by constructing the model land use representation using a hydrologic response unit (HRU) basis. The hydrologic response unit (HRU) concept provides a way to capture landscape variability into discrete units. In general, the HRU approach holds that landscapes possess an identifiable spatial structure, and that the corresponding patterns of runoff and stream chemistry are strongly influenced by climate, geology, and land use. An HRU is defined as a unit of land with relatively homogenous hydrologic properties, taking into account the combination of land use/land cover, soil properties, and geology. The HRUs can thus be simulated on a unit-area basis and multiplied by the relevant area to estimate the flow and pollutant input to a given stream reach.

2.4.2 Land Cover and Imperviousness

Land use and land cover (LULC) datasets with coverage of the entire watershed are available; however, the most recent watershed-wide data for developed areas are derived from the Landsat Enhanced Thematic Mapper satellite platform circa 2006 (Fry, et al., 2011) and only available as 30-meter resolution grid-based data. This project requires model LULC inputs for both the baseline scenario (1997-2001) and existing scenario (2010). Additionally, both scenario outputs will be used to determine load allocations for entities having boundaries that require finer scale resolution than the available 30-meter resolution grid-based data. To increase the precision of LULC inputs and therefore the accuracy of subsequent load allocations, creation of higher-resolution LULC datasets for both scenarios was proposed. Tetra Tech enlisted their Geomatics Technologies team to create high-resolution LULC datasets for the baseline and existing scenarios.

The Tetra Tech Geomatics Technologies team provided land use and land cover classification data for the Jordan Watershed area for two distinct temporal imagery datasets. The 2010 imagery classification effort used NAIP (National Agricultural Imagery Program) 1-meter resolution, 4-band imagery (red, green, blue, and near-infrared bands). The 1999 imagery classification used USDA (United States Department of Agriculture) ½-meter resolution, 3-band color-infrared (CIR) imagery (red, green, and near-infrared bands). The team also collected numerous other GIS datasets for the watershed, such as impervious surface data, building footprints, hydrology data, and general land cover datasets. Most of the GIS datasets were obtained from individual municipalities within the Jordan Watershed boundaries.

2.4.2.1 2010 Imagery Data Processing

Satellite imaging sensors often collect multiple spectral bands (i.e., red, green, blue, near infrared). Multispectral classification techniques are used to analyze the data and classify ground features based on their spectral characteristics (colors, reflectance, etc.). These techniques are generally categorized as supervised and unsupervised classification. In a supervised classification known ground features are used as training samples to guide the classification. Known ground features can belong to classes such as water, asphalt, vegetation. The spectral image characteristics of these training samples are used to classify the imagery data. On the other hand, for an unsupervised classification no training samples are required. The image is classified without prior knowledge of the ground. In most cases, a combination of both methods is used. First, an unsupervised classification is performed, followed by a supervised classification to refine unsupervised classification outputs.

Both spectral unsupervised (fully automated) and supervised classification of the NAIP 2010, 1-meter resolution imagery was performed on a test tile. The test tile was chosen because it contained a good representation of most land cover types within the watershed. The unsupervised and supervised classification was necessary to create a training set to classify all tiles within the watershed in bulk. The process to create the training set was iterative to improve accuracy of the final land cover/land use classification. Once the training set was complete, a spectral supervised classification of the NAIP 2010, 1 meter resolution was applied to all 45 tiles covering the Jordan Lake watershed. The process was batched and run within the Erdas Imagine software.

GIS datasets provided by stakeholders were subjected to a QA/QC process to determine if the layers were complete and accurate enough to use as training samples for imagery classification. Layers included planimetrics, land use, building footprints, and various planning boundary datasets. Those categorized as not sufficiently accurate had issues such as numerous random inaccurate polygons that appeared to have come from a spectral classification process, or in other cases, polygons that were not classified in such a way that proved useful to the imagery classification efforts.

Some of the USGS NHD (US Geological Survey, National Hydrography Dataset) GIS data used for the classifications were edited to enhance accuracy of the dataset for training purposes. Because the NHD water layer (04/27/10) differed substantially from the NAIP 2010 imagery, a partially automated process was created to classify vegetation via an unsupervised classification, convert to shapefile, and identify NHD polygons that contained overlapping vegetation. These overlapping polygon areas were visually assessed to determine if they could be eliminated from the NHD-based training dataset.

During this first QA/QC step, it was determined that not only were there overlapping polygons of individual lakes in the NHD dataset, but that a large number of lakes were missing from the shapefile, and the shape, or outlines, of lakes within the dataset were inaccurate. The team created a ‘major lakes’ shapefile of water bodies compiled from NHDPlus High Resolution and Hydro 24k datasets, and improved accuracy of the dataset by adding and editing lakes (to match aerial imagery) that met a specific size threshold (> 200 square meters).

Impervious surface layers were also edited to improve accuracy of training datasets. Buildings and all other impervious surfaces (e.g., roads, driveways, sidewalks, parking lots) were often lumped into one shapefile, as provided by stakeholders. Shapefile attribute data were used to separate the buildings from the other impervious surface types.

The GIS layers discussed above were “burned” into the 2010 land cover classification output. These layers included the NHD, major lakes, impervious surface, and buildings datasets. In Erdas Imagine software, the datasets were converted to masks, and the pixels within the masks were then reclassified into the appropriate land cover types. For the NAIP 2010 imagery, in isolated areas, the supervised classification was manually improved by converting areas misclassified as water to impervious and areas misclassified as impervious to lakes and rivers.

2.4.2.2 1999 Imagery Data Processing

Color infrared imagery (CIR) from the USDA NAPP (National Aerial Photography Program) was purchased to help develop LULC inputs for the model baseline period (1997 – 2001). The imagery was delivered as 151 individual scans of film that required orthorectification and creation of mosaics. The imagery was acquired from 11 different rolls of film, representing four different cameras and four acquisition firms, and was flown during a period of February through April 1998 and throughout 1999. The imagery received had 30 percent sidelap and 10 percent forward overlap (meaning that there was not full stereo coverage and that only every other image was provided). The team downloaded approximate photocenter coordinates from the USDA web site and collected ground control data from NAIP 2010 (XY coordinates) and from NED elevation data set (Z coordinates). The image was oriented by performing aerotriangulation and orthorectified in Inpho Orthovista software using NED (National Elevation Data) elevation models. The imagery was orthorectified to 1 meter resolution to match the NAIP 2010 imagery dataset.

Due to the different acquisition dates, the imagery had four large, distinct areas of different colors. These distinct areas were treated separately for imagery classification. The project area were divided into several blocks, according to these acquisition dates/colors and images were mosaicked for each individual, distinct block. A spectral supervised classification of the USDA 1999, 1 meter resolution imagery was then performed. Due to the fact that the USDA 1999 imagery had four distinct areas, it was not possible to use one training set on all of the tiles covering the watershed. In addition, the quality of the imagery color and contrast was poor. The imagery was retiled according to spectral signature resulting in six different sets of imagery tiles. Training sets were made individually for each of the six. Due to the lack of contrast in some of the imagery, two training sets were necessary for some of the six subsets of tiles. A total of nine training sets were used in the imagery classification process. Once training set creation was complete, supervised classification was batched in Erdas Imagine software with the separate classification results merged to create one seamless dataset for the watershed.

Just as with the 2010 imagery classification process, impervious surface layers were also edited to improve accuracy of classification outputs. As previously mentioned, buildings and all other impervious surfaces (e.g., roads, driveways, sidewalks, parking lots) were often lumped into one shapefile, as provided by stakeholders. Shapefile attribute data were used to separate the buildings from the other impervious surface types. The impervious surface datasets for the 1999 imagery classification were created by querying provided GIS layer attribute tables for dates 2005 or earlier. Also, in many cases, the building footprint datasets did not match the 1999 imagery and were often not used in the process; however, it was possible to manually correct some datasets in a bulk “select and drag” process to ensure accurate geo-location of building footprints.

The impervious surface datasets provided by stakeholders deemed sufficiently accurate, along with the same NHD and major lakes datasets used in the 2010 imagery classification process, were “burned” into the 1999 imagery classification output. The majority filter tool was used to smooth the final classification output.

2.4.2.3 Supplemental Land Use/Land Cover Data Processing

An important objective of identifying land use/land cover for 1999 and 2010 was to perform a change analysis identifying areas that transitioned from one land use/land cover to another, particularly areas that were converted from more pervious land use types (i.e., forest, pasture, grassland, row crop agriculture) to types of land uses with more impervious surfaces (i.e., suburban/urban developed areas). Because of three factors—1) the different acquisition dates of the 1999 imagery, 2) errors observed throughout areas of more pervious land use types in both the 1999 and 2010 imagery classification processes (often misclassified as impervious, such as very sandy, barren fields that have a highly reflective signature), and 3) the inability to decipher different pervious land uses (row crops vs. forest vs. pasture vs. developed, open space)—additional post-imagery classification steps were needed for areas not classified as forest, impervious, or water at this stage of image processing. To address these issues the 2002 and 2010 Cropland Data Layer (CDL) products were downloaded from the following website: http://www.nass.usda.gov/research/Cropland/metadata/metadata_nc10.htm. Since Tetra Tech’s imagery classification efforts identified areas of forest and impervious surfaces for 2010 with relative accuracy, it was only necessary to use the 2010 CDL product to clarify and aggregate land uses and land covers in the rural and vegetated areas (other than forest) identified by Tetra Tech’s 2010 imagery classification efforts.

There are significant differences in the source imagery and classification methods between the 2002 and 2010 CDL products, and it was identified that the 2002 CDL product’s accuracy compared to ground-truthing data was relatively poor. To ensure a more accurate change analysis between Tetra Tech’s 1999 and 2010 imagery classifications, the 2010 CDL product was used to define the 1999 land use and land cover classifications in the more rural and vegetated areas (other than forest) as identified by Tetra Tech’s 1999 imagery classifications. Consequently, several classes from the output of the 1999 and 2010 imagery classification process were replaced with an aggregated version of the CDL 2010 dataset. As mentioned in the 3rd factor above, aerial imagery classification efforts were unable to decipher areas of developed open space from areas under pasture/grassland or row crop land covers, resulting in what is often called "errors of commission". Through spot checks performed over the entire watershed it was deemed more accurate to consider these areas of classified aerial imagery only as developed, open space within municipal boundaries. Therefore, to further refine the model LULC inputs areas classified as Pasture/Grassland or Row Crops within municipal boundaries (using both existing and circa 1999 boundaries) were converted to Developed, Open Space.

2.4.2.4 Supplemental Impervious Surface Data Incorporation

To increase accuracy of the model LULC inputs and subsequent load allocation assignments, the North Carolina Department of Transportation (NCDOT) provided a geodatabase (via a consultant) that contained polygon shapefiles representing four major LULC classes for both the 2001 and 2012 time periods for DOT-maintained roads:

- Impervious Road Surfaces
- Road Right-of-Way Areas (Pervious)
- Non-road Impervious Surfaces
- Non-road Pervious Surfaces

Street centerlines were also provided by the City of Burlington which covered all of Alamance County. Road centerlines and right-of-ways (polygons) were also provided by the City of Durham, covering all of Durham County.

Aside from the aforementioned transportation-specific impervious surfaces, data were obtained from multiple sources (municipalities, counties, universities) for Guilford, Alamance, Orange, Durham, Chatham, and Wake counties, and in Forsyth County from the City of Kernersville. Only NCDOT impervious data was provided for those areas of the watershed within Randolph, Caswell, and Rockingham counties (Figure 2-8). For all other areas, non-DOT impervious surfaces are identified as part of the aforementioned imagery classification.

Because various areas of 1999 imagery were misclassified as impervious or water, some areas of the 1999 land cover classification were reclassified based using the smoothed 2010 imagery classification outputs. First, if land cover was impervious in 1999, but not impervious in 2010, the 1999 land cover was converted to the 2010 land cover type. Similarly, if land cover was water in 1999, but not in 2010, then the 1999 land cover value was converted to the 2010 land cover type.

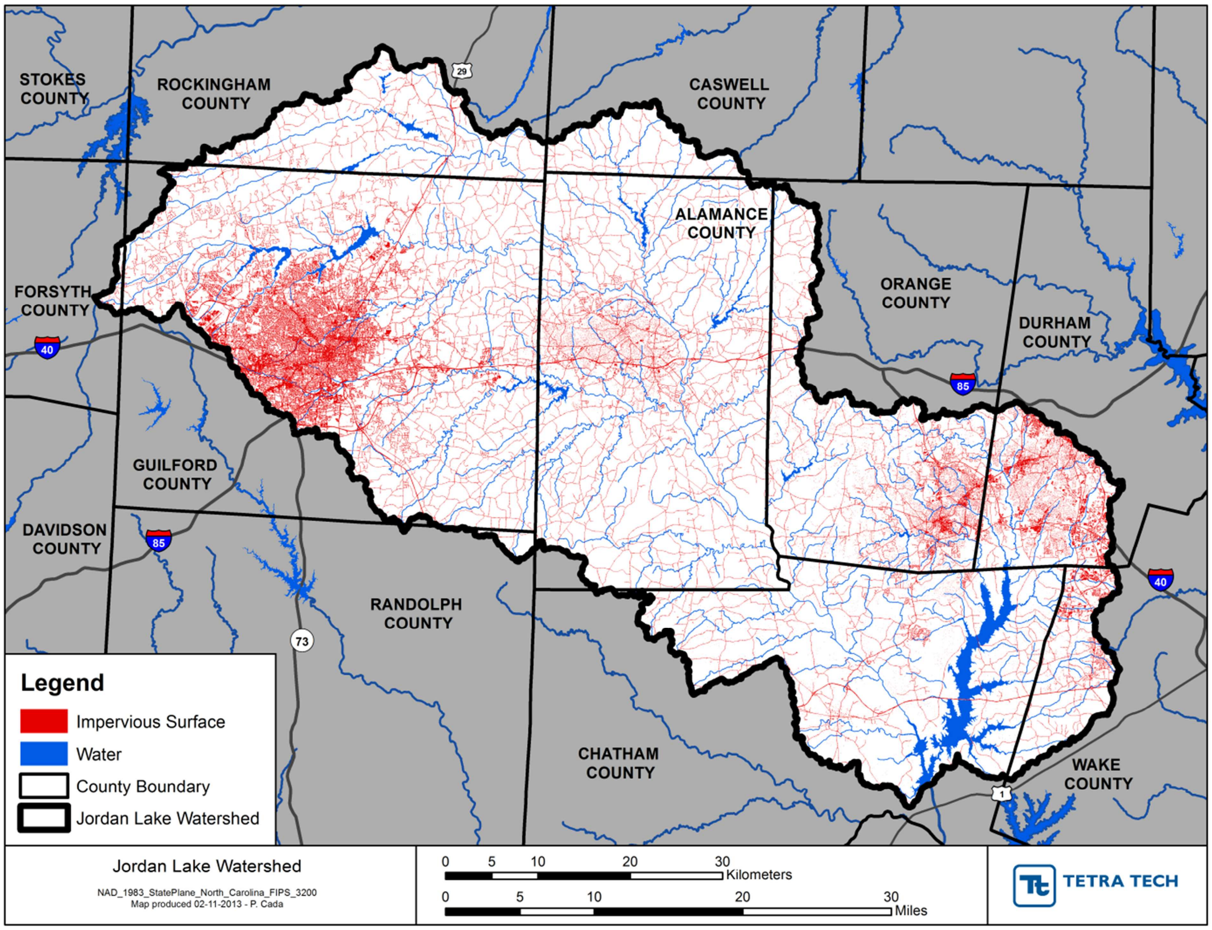


Figure 2-8. Impervious Surface Data Obtained for the Existing Scenario and Imagery Classification

To further improve model accuracy and subsequent load allocations two steps were taken to better represent impervious surfaces throughout the watershed. First, NCDOT roadways were delineated into three categories; primary road-impervious, secondary road-impervious, and right-of-way pervious. Primary road-impervious included all roadways except for State Routes, which were considered secondary road-impervious land cover.

Second, impervious surfaces other than NCDOT primary and secondary roads were classified into one of two land cover types: high intensity impervious surface or low intensity impervious surface. Demarcations into one of these two land cover types was based on a Neighborhood Statistics approach where all impervious grid cells (as determined by previous GIS steps) with more than 20% of its "Surrounding Area" also classified as impervious surface were re-classified as High-Intensity Impervious ("Surrounding Area" is defined as a square extent with dimensions 100m x 100m that is centered on the impervious cell currently being analyzed). All other impervious surfaces in the watershed (i.e., with less than <20% impervious surfaces in its "Surrounding Area") were classified as Low Intensity Impervious.

Direct interpretation of aerial imagery has the tendency to under-estimate impervious surfaces where such surfaces are hidden by over-hanging tree canopy. Subsequent to completion of the model, the City of Durham provided new information on impervious surface area generated from 1999 planimetric data suggesting that there could be a significant under-estimation of imperviousness in the interpretation of the 1999 imagery. The implications of this issue are evaluated in detail in Appendix C. Because hydrology was calibrated to the later time period and the Durham impervious cover for 2010 was burned in, any revisions to the 1999 imperviousness have no effect on model calibration in this area. Further, model predictions of flow and load for the baseline period would change by at most a few percentage points with the revised impervious coverage. Planimetric impervious coverage for 1999 similar to that provided by Durham is not available for most other jurisdictions in the watershed, and results for Durham may not be applicable elsewhere (due, for instance, to Durham's tree protection ordinance). It also proved to be infeasible to identify the extent to which runoff from existing developed areas is routed to stormwater BMPs and thus disconnected from direct runoff to the stream network (see discussion in Section 2.4.6).

Given the many uncertainties associated with impervious surface area determination, the watershed model was constructed without any correction for connected or "effective" impervious area. Converting total impervious area to effective impervious area is a recommended practice for evaluation of storm events and storm event loads in hydraulic modeling; however, the ideal approach is less clear for continuous simulation and estimation of total pollutant loads. If impervious areas are removed due to disconnection then they must be replaced by an equivalent area of pervious surfaces to maintain mass balance. This improves estimation of storm event quickflow response; however, it is physically incorrect to attribute the infiltration and evapotranspiration capacity of pervious land to these disconnected impervious surfaces which, when they drain to pervious land, can overload the available infiltration capacity. Further, pervious and impervious surfaces have different pollutant load generation characteristics. While correcting for connected impervious area is the optimal approach for storm event hydrograph prediction it is not the best approach for long-term load estimation. Given time and funding constraints it was decided to calibrate the model without an effective impervious area adjustment. This potentially allows jurisdictions to take credit for existing or future impervious disconnection where it can be documented, using methods discussed in Section 5.3.

2.4.2.5 Land Use and Land Cover Dataset Summaries

The final model land use products can be viewed in tabular format in Table 2-7, and spatially in Figure 2-9 and Figure 2-10.

Table 2-7. Model Land Use and Land Cover (LULC) Input Comparisons

Model LULC Code	Model LULC Description	Area (square miles)		Change in Area 1999 to 2010 (square miles)	Percent Change
		1999	2010		
11	Water	48	53	5	10%
12	Impervious	65	135	70	107%
13	Developed, Open Space	148	184	36	24%
14	Row Crops	159	141	-18	-11%
15	Pasture/Grassland	199	172	-27	-14%
16	Scrub/Shrub	5.7	6.7	1.0	17%
17	Forest	1,057	991	-66	-6%
18	Wetland	3.6	2.9	-0.7	-20%

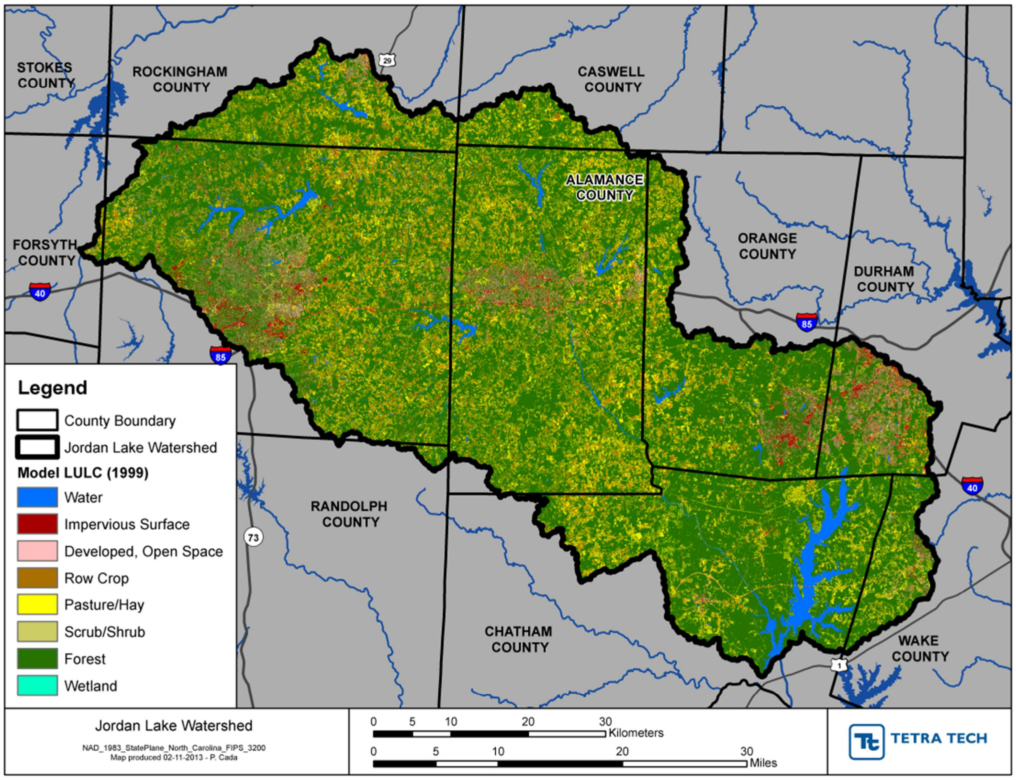


Figure 2-9. Model Land Use and Land Cover (LULC) Inputs for 1999 (Baseline Model Scenario)

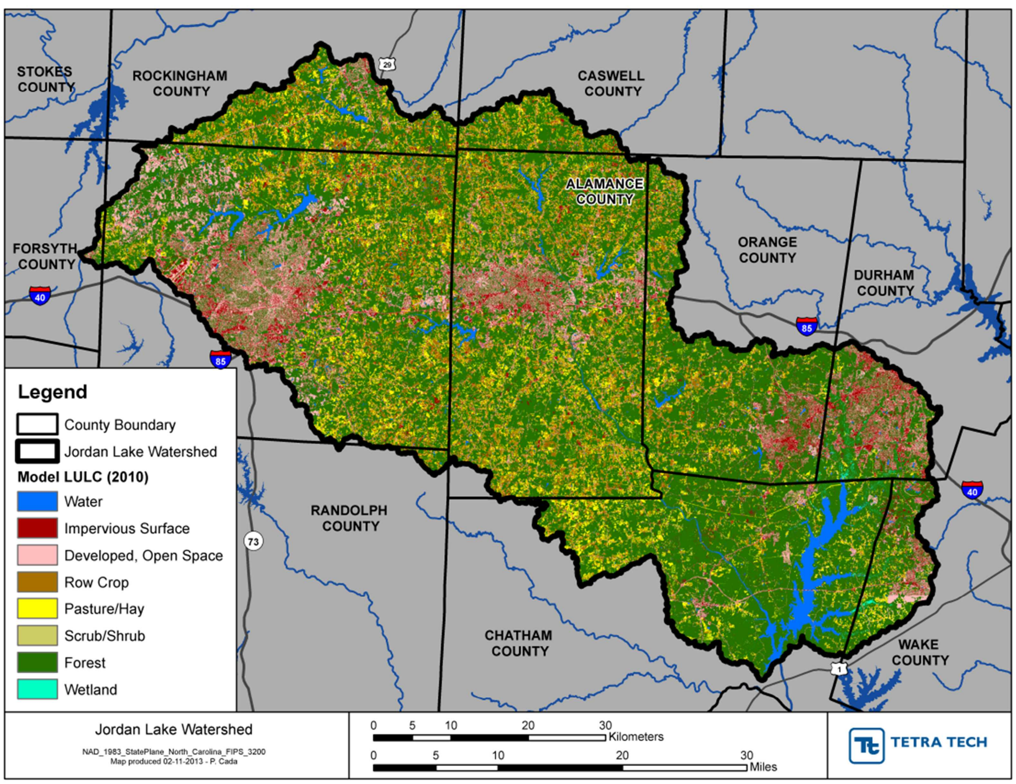


Figure 2-10. Model Land Use and Land Cover (LULC) Inputs for 2010 (Existing Model Scenario)

The distribution of land uses by watershed assessment unit and for the entire watershed in 1999 is shown in Table 2-8 and Figure 2-11. The distribution for 2010 is shown in Table 2-9 and Figure 2-12.

Table 2-8. 1999 Land Use Distribution (acres) by Watershed Assessment Unit

Land Cover Class	Haw River	Lower New Hope	Upper New Hope	Entire Watershed
Impervious	29,213	1,612	10,840	41,665
Developed, Open Space	72,193	3,976	18,527	94,696
Row Crops	97,381	1,294	2,908	101,583
Pasture/Grassland	113,760	5,973	7,577	127,311
Scrub/Shrub	3,159	168	327	3,653
Forest	526,600	48,851	100,962	676,413
Wetland	197	497	1,596	2,289
Water	16,668	9,486	4,739	30,893
Total	859,169	71,857	147,476	1,078,503

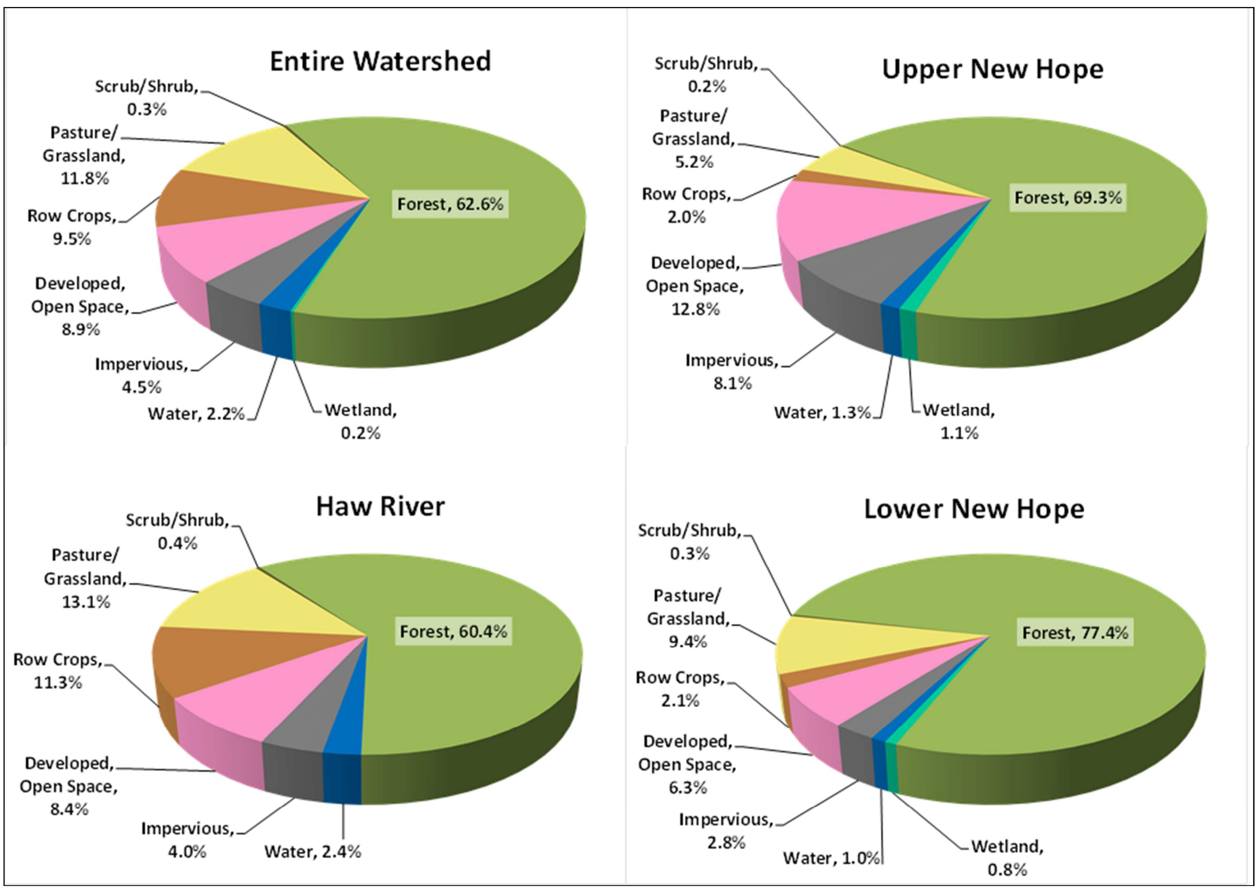


Figure 2-11. Summary of 1999 Land Use Distribution by Watershed Assessment Unit

Table 2-9. 2010 Land Use Distribution (acres) by Watershed Assessment Unit

Land Cover Class	Haw River	Lower New Hope	Upper New Hope	Entire Watershed
Impervious	62,424	3,716	20,291	86,431
Developed, Open Space	93,049	5,161	19,650	117,859
Row Crops	86,175	1,164	2,681	90,019
Pasture/Grassland	98,756	4,929	6,402	110,087
Scrub/Shrub	3,681	195	409	4,285
Forest	495,906	46,406	91,794	634,106
Wetland	207	581	1,052	1,840
Water	18,989	9,710	5,206	33,905
Total	859,185	71,861	147,485	1,078,531

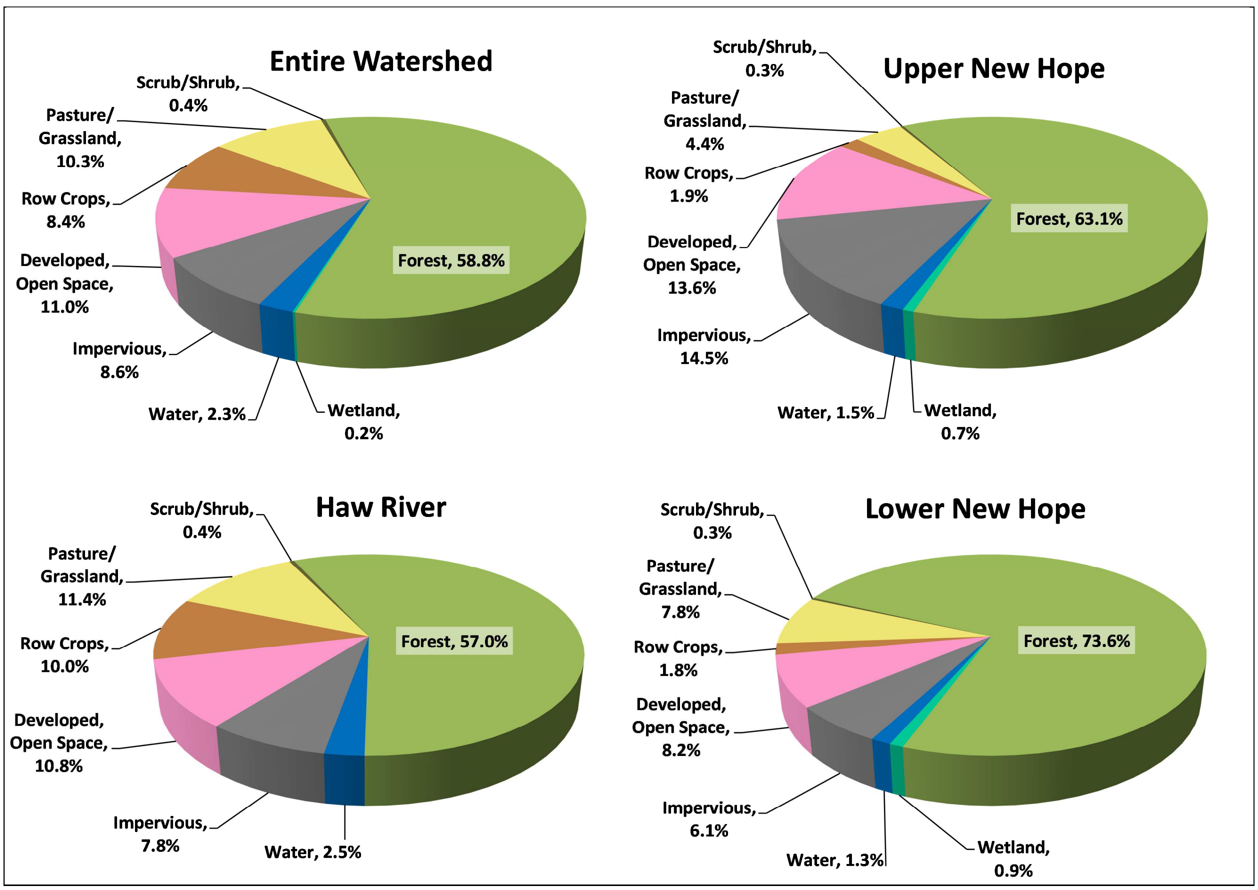


Figure 2-12. Summary of 2010 Land Use Distribution by Watershed Assessment Unit

2.4.3 Soils and Geology

2.4.3.1 Soils

The county-level Soil Survey Geographic (SSURGO) databases were downloaded and used to determine soil types and conditions for the model. SSURGO data has not yet been digitized for Caswell County. For this county the State Soil Geographic (STATSGO) data were used to supplement SSURGO and ensure full model coverage. Both SSURGO and STATSGO are available for download directly from the USDA at http://datagateway.nrcs.usda.gov/.

Two attributes from the SSURGO and STATSGO datasets are used directly to build model inputs: the Hydrologic Soil Group (HSG), which provides an index for infiltration rate, and the USLE "K factor" which is a relative index of soil erodibility that is used in the development of upland sediment parameters (Section 3.4.2.1). These two attributes were extracted using the Soil Data Viewer tool for GIS available from http://soils.usda.gov/sdv/. Distribution of HSGs in the watershed is shown in Figure 2-13.

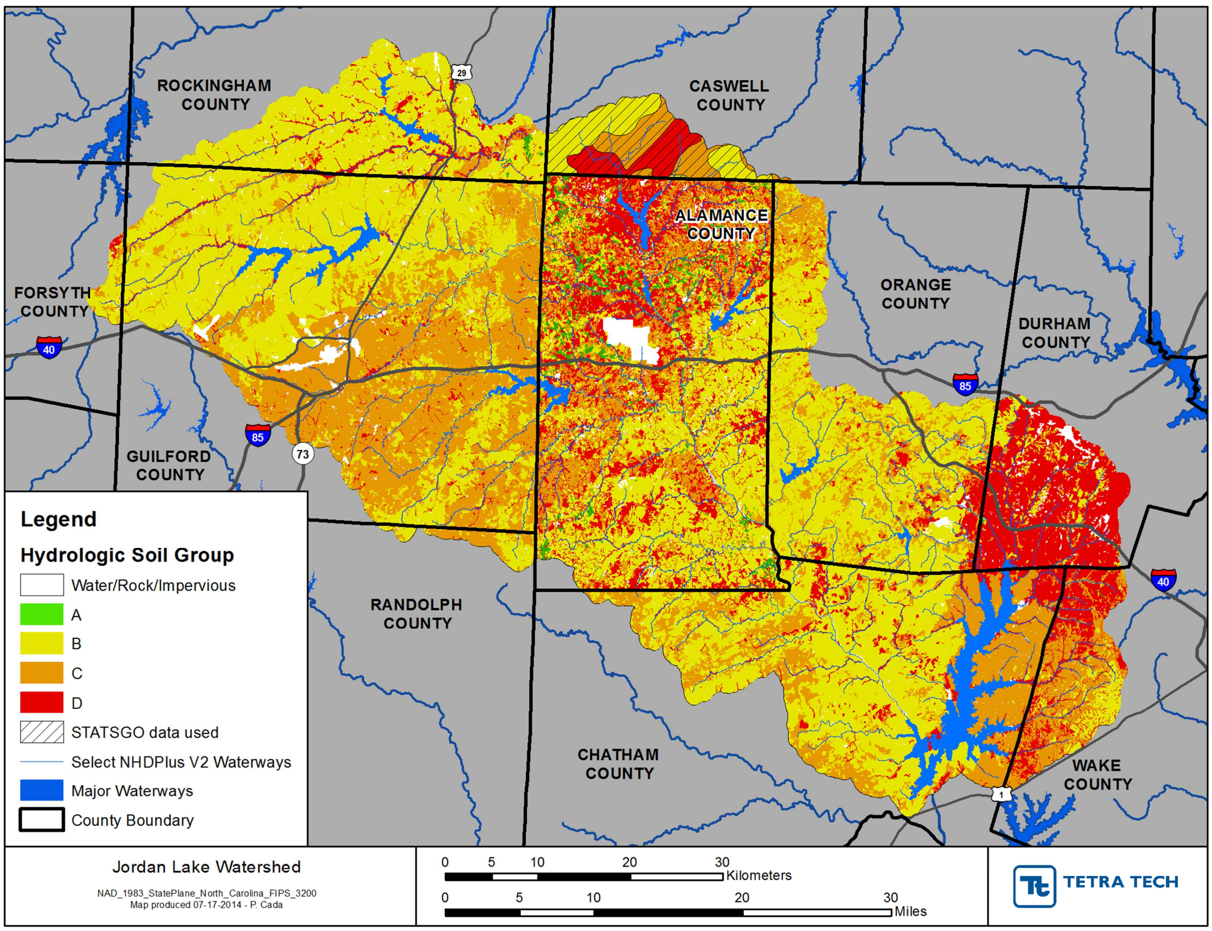


Figure 2-13. Hydrologic Soil Groups in the Jordan Lake Watershed

Based on local knowledge of the region and geology, and the discrepancies between county-scale datasets (especially between Chatham and adjoining counties around Jordan Lake), the HSGs were combined into classes based on geology for modeling purposes: 1) HSG classes A + B and C + D in the non-Triassic Basin area, and 2) HSG classes A + B + C and D in the Triassic Basin. The purpose of the aggregation was to simplify the model by reducing the number of discrete combinations of land cover and HSG to be simulated. In the non-Triassic Basin area, soils are primarily B or C with some D in localized areas; as a result, A was grouped with B and D was grouped with C. In the Triassic Basin, the soils are primarily C or D, so A and B were grouped with C, and D was designated as its own class.

In certain areas the soils databases show the HSG as null. These areas generally represent water, rock, or imperviousness within urban areas where the soil and land use coverages do not match exactly. Reclassification of land areas with null HSG used the following assumptions: In both the Triassic Basin and non-Triassic Basin, areas with null HSGs overlying undeveloped land uses (row crop, pasture/grassland, scrub/shrub, forest, and wetland) were split equally into water and low intensity impervious land. Developed open space with a null HSG assignment in the non-Triassic Basin area was split into high intensity impervious cover (3 percent), low intensity impervious cover (7 percent), developed open space on A + B soils (30 percent) and developed open space on C + D soils (60 percent). Developed open space with a null HSG assignment in the Triassic Basin area was split into high intensity impervious cover (3 percent), low intensity impervious cover (7 percent), developed open space on A + B + C soils (45 percent) and developed open space on D soils (45 percent). These assumptions were determined through visual GIS investigation and best professional judgment.

2.4.3.2 Geology

For the Jordan Lake watershed, model geology also plays an important role. It was assumed that the portion of the watershed located in the Triassic Basins might need different parameterization and assumptions to properly represent the hydrology and nutrient loading in that area. The Triassic Basin is formed in an ancient lake bed and has fine-grained soils, often with shrink-swell clays, underlain by deep layers of siltstone and mudstone atop coarser fluvial sandstone. This differs from the remainder of the watershed where depth to bedrock is generally small and lacustrine clays largely absent, resulting in different chemical and groundwater transport properties. The unique soils of the Triassic Basin result in different infiltration, runoff, and soil erosion characteristics for this region. In general, reduced infiltration rates, very low baseflow, and elevated erosion potential is expected in this area compared to the remainder of the watershed. The Carolina Slate Belt consists mostly of rocks originally deposited on or near the earth’s surface by volcanic eruption and sedimentation, and is referred to as the Slate Belt because low-grade metamorphism has given many of the rocks a slaty cleavage. In contrast, the Charlotte Belt is of igneous origin.

In the final model setup, parameters (for a given land use and HSG) can be specified separately on a geographic and geologic basis for four geographic areas (see Figure 2-14): Charlotte Belt, Upper Slate Belt, Lower Slate Belt, and Triassic Basin. The primary differences are expected to occur between the Triassic Basin and the remaining three areas. While the majority of parameters are varied by HSG and not further divided by geology, the potential to specify variations among all four zones was retained and used if different responses were revealed during the model calibration process.

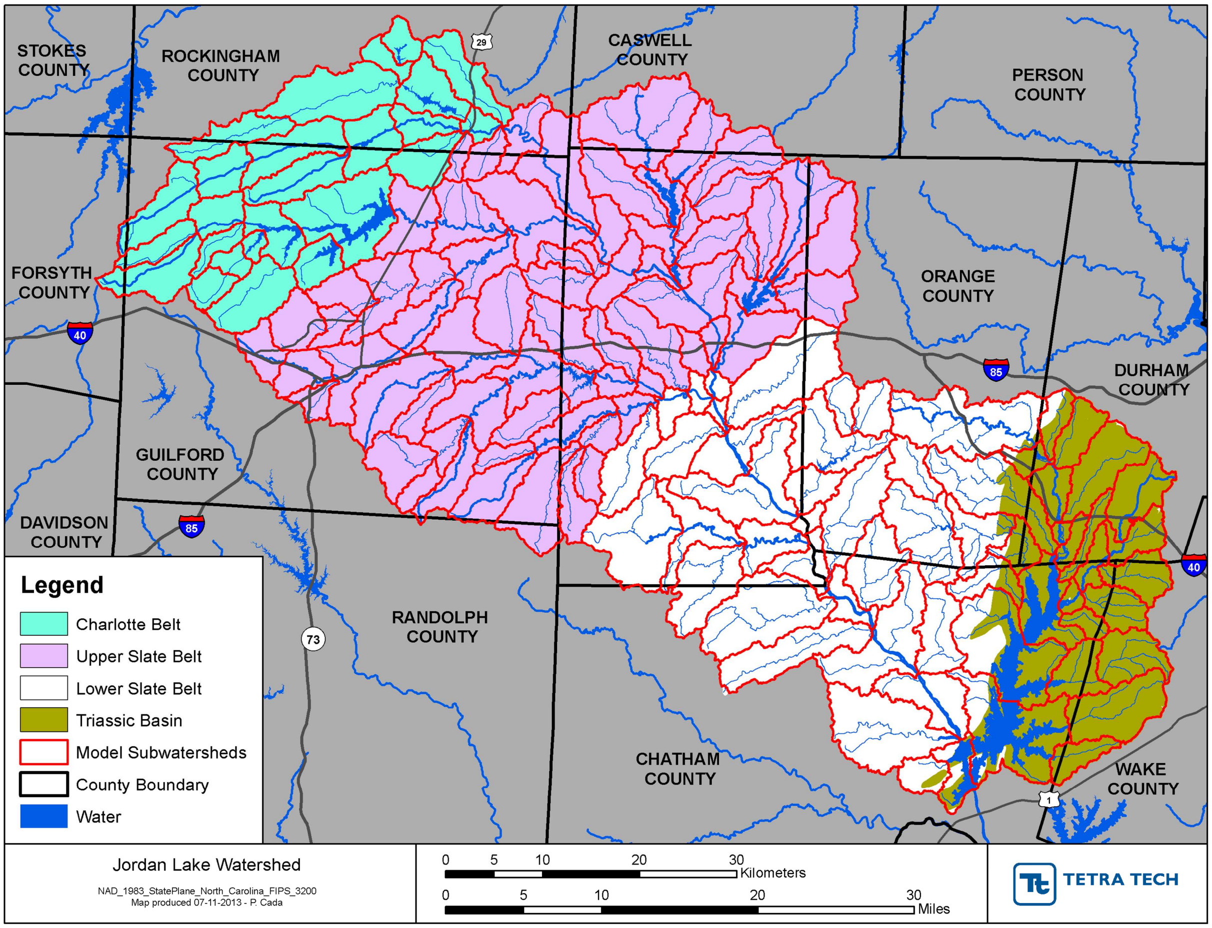


Figure 2-14. Geology Zone Assignment

Subbasins in the Charlotte Belt, Upper Slate Belt, and Lower Slate Belt are distinguished by separate group identifiers in the model (using DEFID in the model input file). HRU numbers can repeat between these groups (but can have different parameter values assigned at the group level); however, all area within a subwatershed is assigned to a single geology – with the exception of areas in the Triassic Basin. To represent the complex boundary between the Triassic Basin and Lower Slate Belt, Triassic Basin soils/geology is indicated by assigning a separate value for the HSG code. The codes and description used to represent both HSGs and geology in the HRU definitions are provided in Table 2-10. Geology is further differentiated using separate DEFID groups.

Table 2-10. HSG and Geology Classification Schema

HSG Code	Description
0	Water/Rock/Impervious (non-Triassic)
1	A + B soils (non-Triassic)
2	C + D soils (non-Triassic)
3	Water/Rock/Impervious (Triassic Basin)
4	A + B + C soils in Triassic Basin
5	D soils in Triassic Basin

2.4.4 Upland Specification

2.4.4.1 Creation of HRUs

Raster files of the soils/geology combination, land use and the watershed delineation were combined using the raster calculator in ArcGIS. This allowed for the tabulation of each soil/geology/land use intersection with each subwatershed in the delineation. The rasters were developed with a cell size of one m^2. The resultant table of data was exported to Excel and processed to provide a table of HRU area by subwatershed. This process was completed for each of the land uses (1999 and 2010) that are being used for the Jordan Lake watershed model. HRU's were organized by a 2-digit code for land use (Table 2-7) plus a 1-digit code for HSG/Geology (Table 2-10).

2.4.4.2 Model Representation: Reduced Modeling Units (RMUs)

Reduced modeling units (RMUs) were created from the list of developed HRUs to allow some simplification of the upland model. RMUs condense like land uses into a modeling group which eliminates the need to repeat a set of parameters multiple times. All combinations of the water land use and HSG were reduced into a single Water category; all other pervious land uses retained the HSG classifications shown in Table 2-10. Table 2-11 provides the final list of RMUs for the Jordan Lake watershed model, which are equivalent to the DELUIDs used in the model input file. The RMUs combined with DEFID groups provide for efficient parameter specification in the calibration model. The final allocation model further subdivides the RMUs by assigning a jurisdictional membership tag. Thus, output from the final model can be directly summarized by both land use and entity.

Table 2-11. Jordan Lake Watershed Model Reduced Modeling Units (RMUs)

RMU	Description	RMU	Description
1	Water	16	ScrubShrubHSG4
2	DevOpenSpaceHSG1	17	ScrubShrubHSG5
3	DevOpenSpaceHSG2	18	ForestHSG1
4	DevOpenSpaceHSG4	19	ForestHSG2
5	DevOpenSpaceHSG5	20	ForestHSG4
6	RowCropHSG1	21	ForestHSG5
7	RowCropHSG2	22	WetlandHSG1
8	RowCropHSG4	23	WetlandHSG2
9	RowCropHSG5	24	WetlandHSG4
10	PastGrassHSG1	25	WetlandHSG5
11	PastGrassHSG2	26	NCDOT Primary Road Impervious
12	PastGrassHSG4	27	NCDOT Secondary Road Impervious
13	PastGrassHSG5	28	High Intensity Impervious
14	ScrubShrubHSG1	29	Low Intensity Impervious
15	ScrubShrubHSG2		

Along with the land use composition, the slope length (LSUR) and slope (SLSUR) of the overland flow plane need to be supplied for each RMU, by subwatershed, in the model. For the Jordan Lake watershed, which has only moderate topographic relief, single representative values were assigned for each land use category using best professional judgment (Table 2-12). This approach was used to maintain consistency between the set of calibration RMUs (HSG/geology/land use) and the set of allocation/tabulation RMUs (HSG/geology/land use/entity).

The mean land elevation (MELEV) and mean reach elevation (RMELEV) also need to be supplied for the temperature lapse rate adjustments. MELEV can be supplied for each RMU by subwatershed. Due to having the two sets of HRU's for calibration and tabulation, the MELEV value was supplied by determining the average elevation of each subwatershed. RMELEV is specified by reach segment and was determined by averaging the upstream and downstream elevations.

Table 2-12. Length and Slope of the Overland Flow Plane for Each RMU

RMU (DELUID)	Description	Slope (SLSUR)	Slope Length (LSUR; (ft)
1	Water	0.000001	1,000,000
2	DevOpenSpaceHSG1	0.05	75
3	DevOpenSpaceHSG2	0.05	75
4	DevOpenSpaceHSG4	0.05	75
5	DevOpenSpaceHSG5	0.05	75
6	RowCropHSG1	0.05	150
7	RowCropHSG2	0.05	150
8	RowCropHSG4	0.05	150
9	RowCropHSG5	0.05	150
10	PastGrassHSG1	0.05	150
11	PastGrassHSG2	0.05	150
12	PastGrassHSG4	0.05	150
13	PastGrassHSG5	0.05	150
14	ScrubShrubHSG1	0.05	150
15	ScrubShrubHSG2	0.05	150
16	ScrubShrubHSG4	0.05	150
17	ScrubShrubHSG5	0.05	150
18	ForestHSG1	0.05	150
19	ForestHSG2	0.05	150
20	ForestHSG4	0.05	150
21	ForestHSG5	0.05	150
22	WetlandHSG1	0.05	150
23	WetlandHSG2	0.05	150
24	WetlandHSG4	0.05	150
25	WetlandHSG5	0.05	150
26	NCDOT Primary Road Impervious	0.05	50
27	NCDOT Secondary Road Impervious	0.05	50
28	High Intensity Impervious	0.05	50
29	Low Intensity Impervious	0.05	50

2.4.5 Representation of Land Use Change over Time

To efficiently simulate two time periods of land use in the LSPC watershed model, a component called time-variable land use is utilized. Time-variable land use allows the LSPC model to switch from one land use snapshot (i.e. the baseline 1999 snapshot) to another (i.e. the current 2010 snapshot) based on a user defined time interval. The time interval of the switch can be sharp or gradual over a prolonged period of time and land use at any given point during the change is dependent on the time and a linear regression between the two land use snapshots. The representation in the Jordan Lake watershed model uses a sharp change from the 1999 land use to the 2010 land use on January 1, 2002. This date was selected because it is immediately after the baseline modeling period (2001) and provides a long length of time for the model to come back into equilibrium before the current period for which loads will be estimated to compare against the baseline period.

After time-varying land use was configured in the model, a basic test of functionality was conducted. First, the model with the time-varying land use was parameterized with a basic set of default parameters and setup to run from January 1, 1996 through December 31, 2012. Then this model was used to create two additional models. Each of these models used either the 1999 land use or the 2010 land use for the entire simulation period. The simulated outputs from the three models were compared to verify that the time-variable land use representation was functioning properly.

2.4.6 Representation of BMPs

Stormwater BMPs installed after the baseline period from 2001 to present have mitigated some of the increased load associated with new development. There is a strong interest in providing credit for the impacts of such BMPs; however, Tetra Tech's scope did not include development of an inventory of individual BMPs, which are typically installed at the parcel or individual development scale. In the original scope, it was assumed that the model would incorporate existing stormwater BMPs to the extent that information is provided by jurisdictions. All jurisdictions in the watershed were queried as to the availability of data to characterize BMPs, but only a small amount of usable information was obtained.

Tetra Tech met with the NSAB Model Subcommittee on January 16, 2013 to review progress on the Jordan watershed model development. A large part of the meeting discussion centered on how to handle representation of stormwater best management practices (BMPs) in the LSPC model. A significant challenge for the team was that very little information has been provided to date regarding existing BMPs and obtaining that needed information would require a significant effort outside of the project's contracted scope and budget.

Discussion with the NSAB Model Subcommittee led to the following general points (Clements and Butcher, 2013):

1) Given that prior to the baseline period the only strong driver for water quality BMPs was the Water Supply Watershed Protection regulations, and that these applied to only a portion of the watershed and most ordinances impacting BMP installation were not effective until the mid-1990s, the group surmised that relatively few BMPs were influencing water quality in 2001.

2) Even with sufficient effort to work with local governments to obtain best available information, details needed for accurate representation (e.g., BMP drainage area) will often not be available. Therefore, it is expected that such a process would not capture all BMPs, and that the overall level of accuracy in BMP performance representation would be in question.

3) From a post-modeling regulatory program standpoint, including partial and inaccurate BMP representation could make it more difficult in managing credits down the road: (a) having to track which BMPs are in the model and which are not, (b) handling situations where model assumptions end up being significantly inaccurate when compared to actual BMP data.

Thus, there appeared to be multiple benefits from not trying to include the BMPs in the LSPC model. However, after the discussion, the question remained whether there would be significant influence of BMPs on water quality conditions such that it would impact model calibration negatively by not including them.

Tetra Tech conducted additional analysis to address this question. The first step was to examine the extent of water supply watershed (WSW) protection area in the overall Jordan lake watershed, along with assumption that significant WSW protection area is above water supply reservoirs other than Jordan Lake. Figure 2-15 displays the water supply critical (magenta) and protected (green) areas. Where the colors are hatched, the areas are above other reservoirs besides Jordan. GIS analysis revealed that 60 percent of the WSW protection area and 45 percent of the WSW critical area in the entire Jordan watershed is above reservoirs other than Jordan Lake. Combined these account for approximately 58 percent of all designated protected or critical area in the watershed.

Next, to examine the potential impact of excluding stormwater BMPs in the model configuration, Tetra Tech examined BMPs constructed in the Greensboro jurisdiction. The City staff provided information on BMP location, type, and year built. Figure 2-16 displays the findings, showing a total of 878 constructed BMPs (688 within WSW protection areas, 190 outside of the WSW areas). The BMPs with the red circle surrounding them have been confirmed as being in place prior to 2001 (there are likely more in the WSW areas, but that could not be confirmed without considerably more effort by the City). Note that there is only 1 BMP outside of the water supply watersheds that was built before 2001. For those BMPs confirmed as built in the water supply watersheds before 2001, the majority are located above Lake Higgins, which then drains into Lake Brandt, which then drains into Lake Townsend.

The Greensboro BMP analysis lent confidence that the model would not be negatively impacted by not including the BMPs in the model. With only one BMP out of 190 outside of the WSW protection areas having been in place before 2001, model calibration below the water supply reservoirs for the baseline period would not be significantly impacted by our decision. Additionally, the sheer size and complexity of the Greensboro BMP database demonstrates how important it will be to accurately assign credits to BMPs. In general, the details for the BMP crediting approach as well as a much more complete BMP data set are needed before BMPs can be accurately addressed in the model.

It was concluded that the State and stakeholders would be best served by applying and calibrating the LSPC watershed model to baseline conditions without including BMPs explicitly. Interested entities could then use approved accounting methods (see discussion in Section 5.3) to estimate total reductions for installed BMPs (or other forms of imperviousness disconnection) and subtract that from the model predictions to compare with observed loads where data are available.

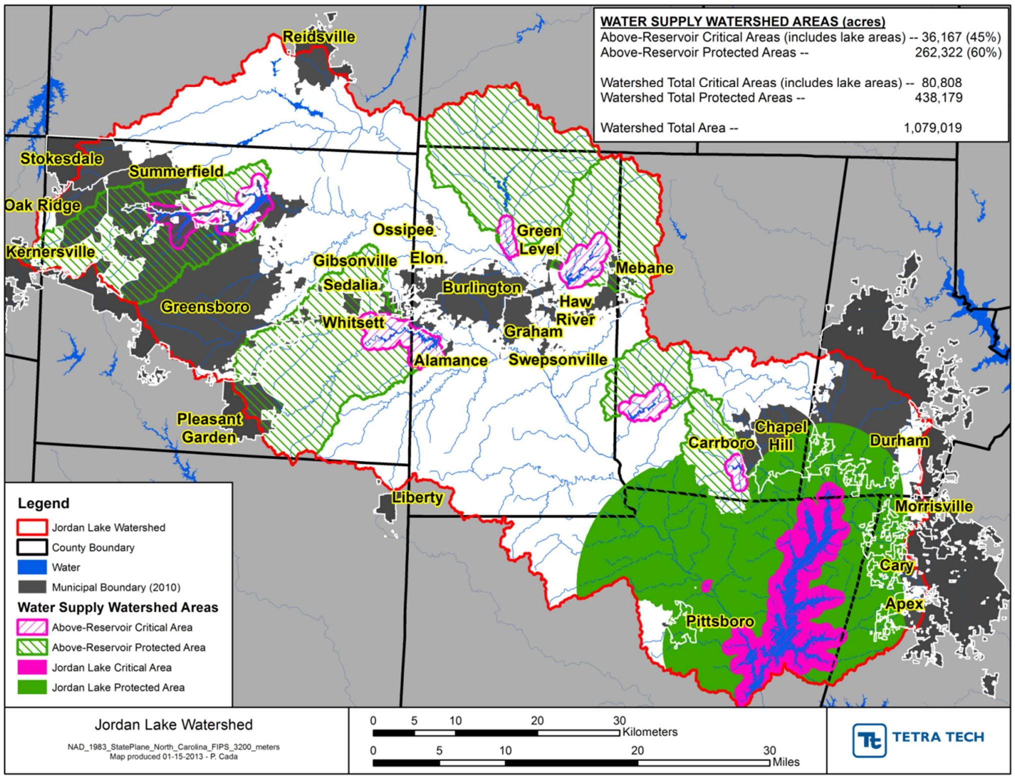


Figure 2-15. Water Supply Critical and Protected Areas within the Jordan Lake Watershed

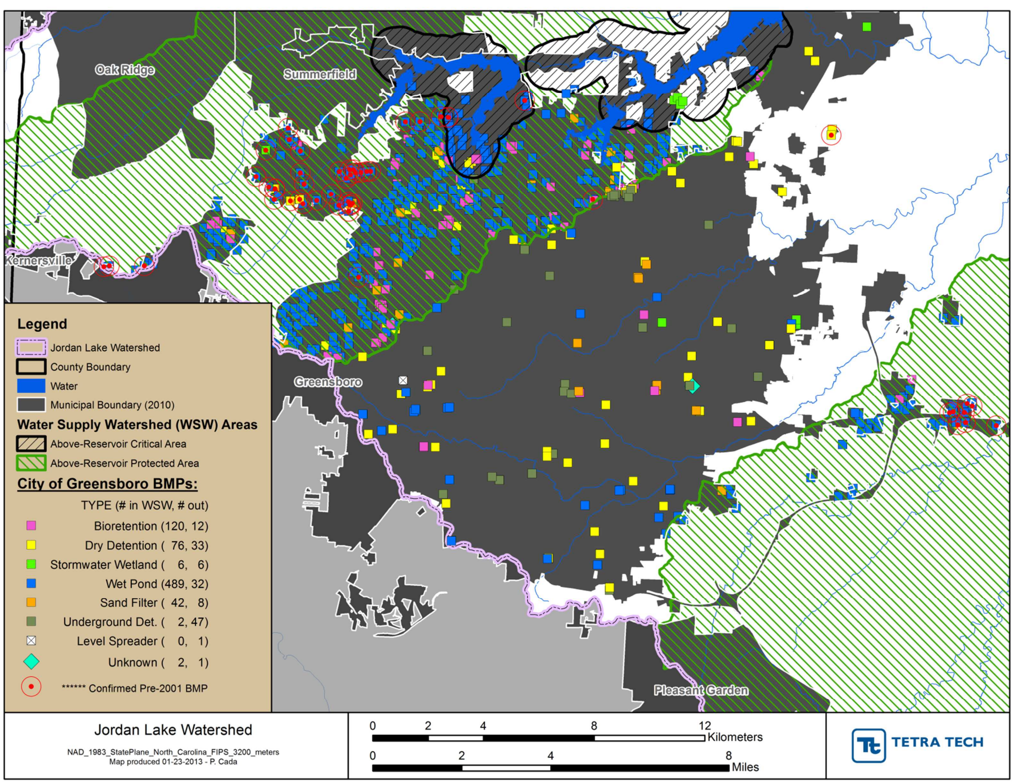


Figure 2-16. Stormwater BMPs Constructed within Greensboro Jurisdictional Limits

2.5 METEOROLOGICAL DATA

2.5.1 Weather Data

Meteorological (weather) time series data are used by the LSPC model to drive the simulation of hydrology and the water balance. This section describes the selection and processing of meteorological data for the model.

2.5.1.1 Data Sources

Primary data sources included National Climatic Data Center (NCDC) Summary of the Day (SOD) stations, Hourly Precipitation Dataset (HPD) stations, and Surface Airways (SA) stations. NC ECONet data were also reviewed, but the monitored period of record began in 2005 and did not cover the needed period of model simulation. GIS spatial coverage's of all NCDC station types were reviewed and all stations within and in close proximity to the Jordan Lake watershed were considered for utilization in developing the atmospheric forcing files.

Weather time series almost always have gaps and aggregated observations. In addition, the model requires hourly data, but only a limited number of hourly stations are available, so daily data are typically disaggregated to an hourly scale to provide better spatial coverage. A weather processing tool developed by Tetra Tech called MetADAPT was used to carry out pre- and post-processing of the obtained data, create model input files, and provide statistical summaries for QA/QC purposes.

Raw SOD station data were obtained using a Tetra Tech internal utility tool called GHCN-D. This tool obtains and pre-preprocesses data from the NCDC FTP site into a format ready for MetADAPT. The data associated with SOD stations are typically daily rainfall, daily minimum air temperature, and daily maximum air temperature. Initially, a total of 43 SOD stations were considered for use in the weather file development. Twenty of those stations were excluded based on the percentage of impaired records and time period of the observed data. The remaining 23 SOD stations were used for the weather processing for the Jordan Lake watershed (Table 2-13 and Figure 2-17). Ten of the SOD station data sets were chosen for development into model input files (*.air) and considered core stations. The selection of the ten core stations was based on spatial coverage, period of observed records, and stations having the lowest level of impairment in the observed records. The remaining 13 SOD stations were used as index stations to patch the impaired records of the core stations. Table 2-13 identifies weather station type as a core or an index station.

Table 2-13. SOD Stations used for Precipitation Time Series in the Jordan Watershed

Sta. No.	Station ID	Station Name	County	Elevation (ft)	Latitude	Longitude	Type	Period of Record
1	310212	APEX	WAKE	450	35.7436	-78.8372	Core	7/1/1993-1/1/2013
2	310286	ASHEBORO 2 W	RANDOLPH	870	35.7044	-79.8378	Index	2/1/1926-12/26/2012
3	311285	BUTNER FILTER PLANT	GRANVILLE	355	36.1414	-78.7736	Index	2/1/1956-10/31/2012
4	311515	CARTHAGE WATER TR PLT	MOORE	440	35.3314	-79.4078	Index	8/1/1948-11/30/2012
5	311535	CARY	WAKE	390	35.7192	-78.7878	Index	7/1/2000-1/1/2013
6	311677	CHAPEL HILL 2 W	ORANGE	500	35.9086	-79.0794	Core	1/1/1900-12/31/2012
7	312238	DANBURY 5 SE	STOKES	760	36.3950	-80.1422	Index	10/21/1946-12/31/2012
8	312500	DUNN 4 NW	HARNETT	200	35.3247	-78.6881	Index	9/1/1962-12/26/2012
9	312515	DURHAM	DURHAM	400	36.0425	-78.9625	Core	3/1/1900-12/31/2012
10	312631	EDEN	ROCKINGHAM	678	36.4742	-79.7433	Index	10/1/1969-1/1/2013
11	313168	FORT BRAGG WATER PLANT	CUMBERLAND	160	35.1778	-79.0239	Index	5/1/1964-3/31/2010
12	313555	GRAHAM 2 ENE	ALAMANCE	660	36.0503	-79.3728	Core	7/1/1902-1/1/2013
13	313630	GREENSBORO WSO AIRPORT	GUILFORD	897	36.0975	-79.9436	Core	11/1/1928-12/31/2012
14	313919	HAW RIVER 1 E	ALAMANCE	656	36.0972	-79.3972	Core	11/1/2001-1/1/2013
15	314063	HIGH POINT	GUILFORD	900	35.9672	-79.9722	Index	7/1/1921-11/30/2012
16	317069	RALEIGH DURHAM WSFO AP	WAKE	416	35.8706	-78.7864	Core	5/18/1944-12/31/2012
17	317074	RALEIGH 4 SW	WAKE	420	35.7283	-78.6844	Index	1/1/1921-6/1/2010
18	317079	RALEIGH STATE UNIV	WAKE	400	35.7944	-78.6989	Index	1/15/1900-11/30/2012
19	317097	RANDLEMAN	RANDOLPH	810	35.8222	-79.7917	Index	1/4/1905-12/30/2012
20	317202	REIDSVILLE 2 NW	ROCKINGHAM	890	36.3825	-79.6947	Core	2/1/1962-12/21/2012
21	317656	SANFORD 8 NE	LEE	262	35.5347	-79.0464	Core	11/1/1972-11/30/2012
22	317924	SILER CITY 2 N	CHATHAM	610	35.7606	-79.4622	Core	7/1/1916-1/1/2013
23	319704	YANCEYVILLE 4 SE	CASWELL	655	36.3783	-79.2544	Index	12/1/1996-1/1/2013

A National Climate Data Center Web subscription was used to obtain SA data for four airport stations in the watershed. SA stations typically have hourly values of precipitation, air temperature, wind speed, dew point, cloud cover, and relative humidity. The SA stations used for the Jordan Lake watershed are provided in Table 2-14 and Figure 2-17. To enhance the coverage of hourly precipitation data, HPD data were obtained from EarthInfo CD sets, which provide weather data from the NCDC. The HPD stations used for the Jordan Lake watershed are provided in Table 2-15 and Figure 2-17. Data in the CD sets was only available through 2010 for three stations and through 2006 for one station.

It is Tetra Tech's experience that the SOD station daily precipitation totals provide more reliable estimates of *total* rainfall than do automated hourly or sub-hourly methods, which tend to underestimate low-intensity precipitation; therefore data from SA and HPD stations were used only for disaggregating daily totals. The process of disaggregation distributes the daily total to the hourly increments needed for model input based on the observed hourly pattern. Refer to Table 2-16 for a reference as to which HPD station was used to disaggregate which SOD station.

Table 2-14. List of Surface Airways Stations

Sta. No.	Station ID	Station Name	County	Elevation (ft)	Latitude	Longitude	Period of Record
1	13722	Raleigh Durham International AP	Wake	426	35.8710	-78.7860	01/01/1997 - 12/31/2012
2	13723	Greensboro Piedmont Triad International Airport	Guilford	980	36.0980	-79.9440	01/01/1997 - 12/31/2012
3	93783	Burlington Alamance Rgl AP	Alamance	646	36.0470	-79.4770	07/01/1998 - 12/31/2012
4	93785	Horace Williams Airport	Orange	538	35.9330	-79.0640	07/14/1999 - 12/31/2012

Table 2-15. List of Hourly Precipitation Stations

Sta. No.	Station ID	Station Name	County	Elevation (ft)	Latitude	Longitude	Period of Record
1	NC1241	Burlington 3 NNE	Alamance	640	36.1278	-79.4069	6/1/1948 - 12/27/2010
2	NC3232	Franklinton	Franklin	375	36.1050	-78.4592	6/1/1948 - 2/28/2006
3	NC3630	Greensboro WSO Airport	Guilford	897	36.0975	-79.9436	6/4/1948 - 12/26/2010
4	NC7069	Raleigh Durham WSFO AP	Wake	416	35.8706	-78.7864	6/1/1948 - 12/26/2010

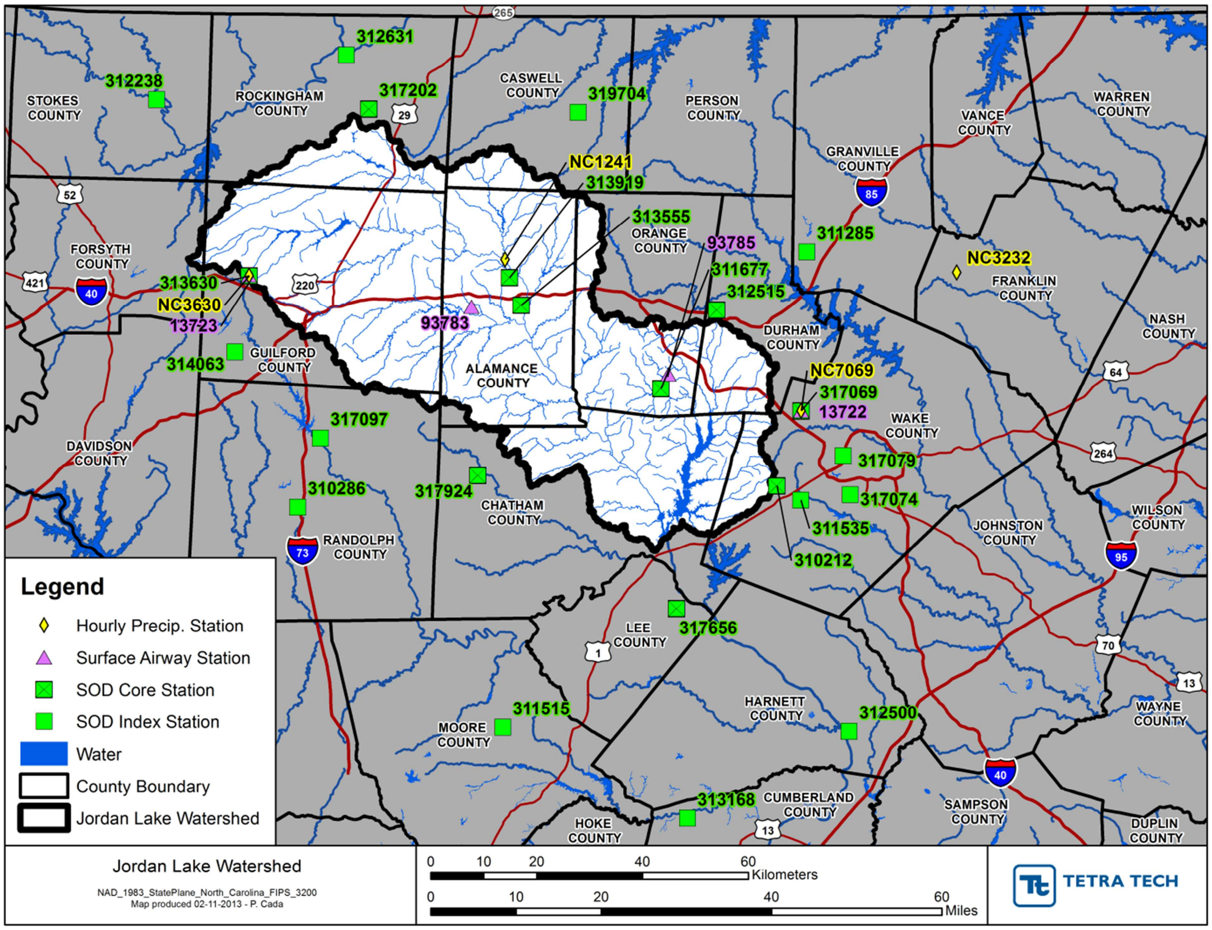


Figure 2-17. Atmospheric Monitoring Stations Selected for Model Development

2.5.1.2 Weather Data Processing

Impaired (missing or aggregated) precipitation records of the core SOD stations were filled using neighboring index stations (Table 2-16) using the normal ratio method (Dunne and Leopold, 1978). Data patching and disaggregation for each core SOD station were performed using data from the station listed in the Station 1 column; if that station had a gap in temporal coverage for some time period, then Station 2 was used, then Station 3. SA and HPD stations were used only for disaggregation of daily totals at the core SOD stations. QA/QC on patched precipitation data was carried out by comparing monthly totals, annual totals, and seasonal variation. The process of patching, disaggregation and QA/QC was carried out iteratively by revising the flagging (periods of impairment) and re-patching the data.

Monthly precipitation totals were reviewed to identify periods of low rainfall and high rainfall amounts in a side-by-side comparison of station precipitation totals. Annual totals were evaluated as another QC tool to assess annual magnitudes before and after patching of the core SOD stations.

Table 2-16. Precipitation patching assignments for daily totals and disaggregation

Core SOD Station	Index SOD Station 1	Index SOD Station 2	Index SOD Station 3	Disagg. HPD/SA Station 1	Disagg. HPD/SA Station 2	Disagg. HPD/SA Station 3
310212	311535	317074	317069	NC7069	13722_uo	
311677	317079	317069	311285	NC7069	93785_uo	
312515	317079	317069	311285	NC3232	NC7069	93785_uo
313555	313919	319704	311677	NC1241	93783_uo	93785_uo
313630	314063	317097	317202	NC3630	13723_uo	
313919	313555	319704	311677	NC1241	93783_uo	93785_uo
317069	311285	317079	317074	NC7069	NC3232	13722_uo
317202	312631	312238	319704	NC3630	13723_uo	93783_uo
317656	313168	312500	311515	NC7069	13722_uo	
317924	317097	313555	310286	NC1241	93783_uo	

Note: *_uo* means unedited observation and is used directly from the quality assured data source

SA stations 13722 (Raleigh-Durham Airport) and 13723 (Greensboro Airport) were used for calculating potential evapotranspiration and solar radiation and for assigning hourly temperature, dew point, wind speed and cloud cover. SOD stations generally have daily minimum and maximum temperatures and therefore need to be disaggregated to an hourly time-step. As temperature variability across the watershed is low, actual hourly observations from SA stations were used to assign the hourly temperature for model input. Evapotranspiration was estimated using the Hamon (1961) method. The Hamon method was selected because, in the humid southeast, this method of calculating evapotranspiration performs well compared to energy balance methods, such as the Penman-Monteith method, that depend on multiple uncertain datasets (Lu et al., 2005). Solar radiation was calculated using the CE-QUAL-W2 method.

SA stations 93783 (Burlington) and 93785 (Chapel Hill) were not used for temperature or PET calculation because quality review identified anomalous outliers in the air temperature and dew point temperature time series when compared to the Raleigh and Greensboro airport data. Weather stations in the northeast part of the watershed were assigned observed and calculated weather constituents (other than for precipitation) from Greensboro Airport (13723) and stations in the southwest were assigned observed and calculated weather constituents from Raleigh-Durham’s (13722). Table 2-17 summarizes the assignments of the processed data for the meteorological input files developed for Jordan watershed.

Table 2-17. LSPC *.air file Constituent Assignments

Precipitation	Potential Evapotran-spiration	Air Temperature	Wind	Solar Radiation	Dew Point	Cloud Cover
310212	13722_uoh	13722_uo	13722_uo	13722_uo	13722_uo	13722_uo
311677	13722_uoh	13722_uo	13722_uo	13722_uo	13722_uo	13722_uo
312515	13722_uoh	13722_uo	13722_uo	13722_uo	13722_uo	13722_uo
313555	13723_uoh	13723_uo	13723_uo	13723_uo	13723_uo	13723_uo
313630	13723_uoh	13723_uo	13723_uo	13723_uo	13723_uo	13723_uo
313919	13723_uoh	13723_uo	13723_uo	13723_uo	13723_uo	13723_uo
317069	13722_uoh	13722_uo	13722_uo	13722_uo	13722_uo	13722_uo
317202	13723_uoh	13723_uo	13723_uo	13723_uo	13723_uo	13723_uo
317656	13722_uoh	13722_uo	13722_uo	13722_uo	13722_uo	13722_uo
317924	13723_uoh	13723_uo	13723_uo	13723_uo	13723_uo	13723_uo

Note: _uo means unedited observation and is used directly from the quality assured data source; _uoh means unedited observation with Hamon calculation

Ten weather (AIR) files were developed for the Jordan Lake watershed for the entire calibration and corroboration period (Table 2-18). Each file provides hourly values of precipitation, air temperature, dew point temperature, wind speed, cloud cover, evaporation, and solar radiation. Air files were assigned to subwatersheds based on a Thiessen polygon and each subwatershed was assigned only one AIR file. Figure 2-18 shows the AIR file locations, the Thiessen polygon and the subwatershed AIR file assignments.

Table 2-18. Weather Files used for the Jordan Watershed Model

Sta. No.	Station ID	Station Name	County	Latitude	Longitude	Simulation Elevation (ft)
1	313630	GREENSBORO WSO AIRPORT	GUILFORD	36.0975	-79.9436	897
2	317202	REIDSVILLE 2 NW	ROCKINGHAM	36.3825	-79.6947	897
3	313919	HAW RIVER 1 E	ALAMANCE	36.0972	-79.3972	897
4	313555	GRAHAM 2 ENE	ALAMANCE	36.0503	-79.3728	897
5	317924	SILER CITY 2 N	CHATHAM	35.7606	-79.4622	897
6	311677	CHAPEL HILL 2 W	ORANGE	35.9086	-79.0794	416
7	312515	DURHAM	DURHAM	36.0425	-78.9625	416
8	317069	RALEIGH DURHAM WSFO AP	WAKE	35.8706	-78.7864	416
9	310212	APEX	WAKE	35.7436	-78.8372	416
10	317656	SANFORD 8 NE	LEE	35.5347	-79.0464	416

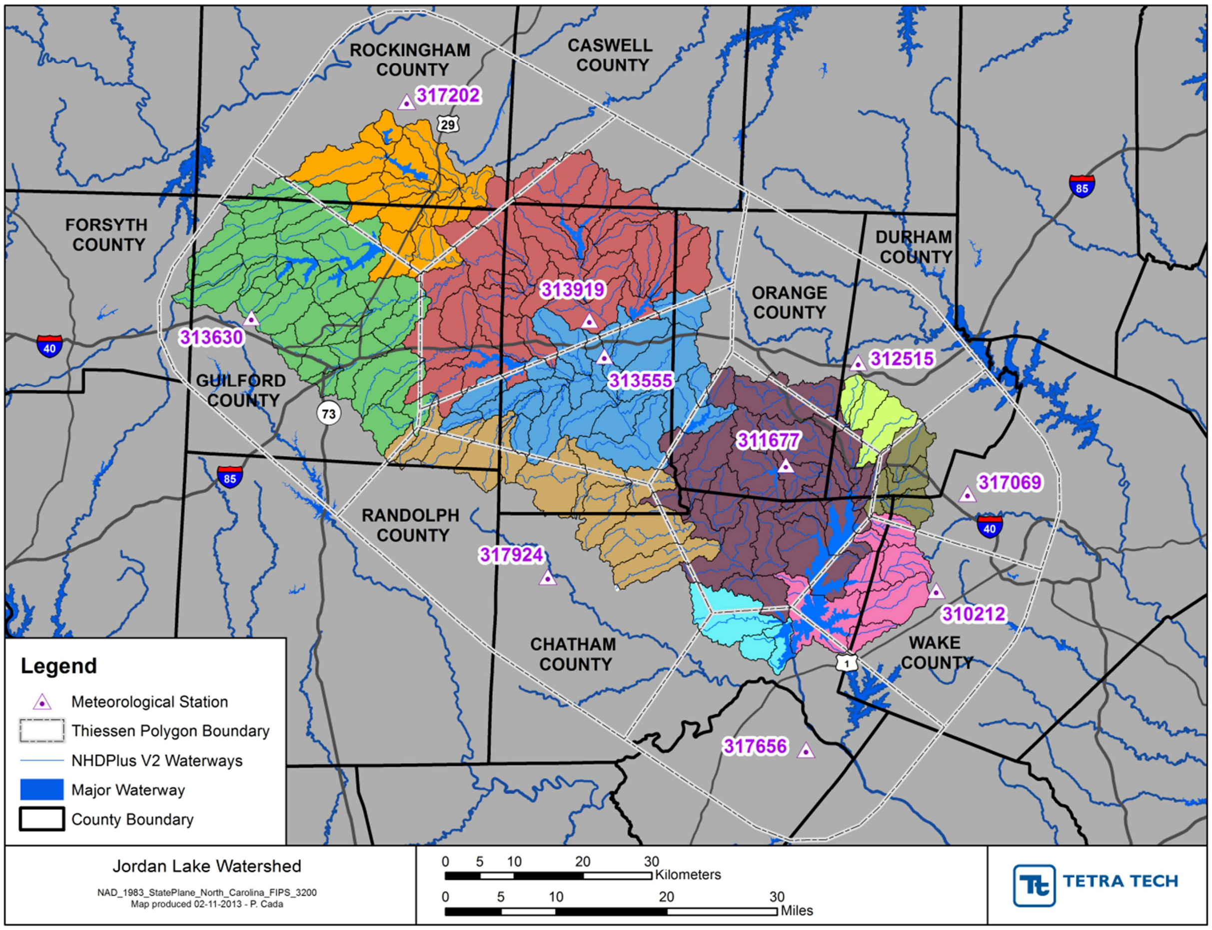


Figure 2-18. Meteorological Station Assignments

2.5.2 Atmospheric Deposition

Atmospheric deposition is an important source of loading of nitrogen to waterbodies and watersheds. LSPC specifies wet deposition of pollutants as concentrations, which are applied to precipitation falling on the land and streams/water bodies. Individual monthly values are used to represent seasonal variability. Dry deposition is also incorporated in LSPC, and is represented as a mass flux to both land surfaces and directly to streams/water bodies. Individual monthly values are also used for dry deposition rates. The LSPC model does not have the ability to simulate year-to-year variation in atmospheric deposition except insofar as this depends on changes in precipitation volume.

2.5.2.1 Nitrogen Wet Deposition

Wet deposition occurs primarily as ammonium (NH_4^+) and nitrate (NO_3^-/ HNO_3) ions and has been monitored throughout the country by the National Trends Network (NTN) of the National Acid Deposition Program (NADP). The active NTN sites closest to the Jordan Lake Watershed are NC41 (located at Finley Farms on the North Carolina State University campus) and NC34 (located at the Piedmont Research Station in Rowan County). EPA's Clean Air Status and Trends (CASTNET) provides interpolated estimates of average annual wet deposition concentration and load based on NTN results at their dry deposition monitoring locations. The closest active CASTNET sites to the Jordan Lake Watershed are Prince Edward in Virginia (PED108) and Candor in Montgomery County, NC (CND125). The station locations are shown in Figure 2-19.

In monitoring since 1979 at the NTN stations (NADP, 2013) and as interpolated at the CASTNET stations beginning in 1989 (CASTNET, 2013), wet atmospheric deposition concentration of NH_4^+ as N typically varies between 0.15 – 0.35 mg/L, with no clear trend over time (Figure 2-20). On the other hand, NO_3-N concentrations appear to be decreasing beginning in about 2000 (Figure 2-21) from about 0.25 mg/L to 0.15 mg/L, consistent with national efforts to control oxidized nitrogen emissions from coal-fired power plants. However, total inorganic nitrogen wet deposition loads have been relatively stable (Figure 2-22), and range from 2.6 to 8.1 kg/ha/yr.

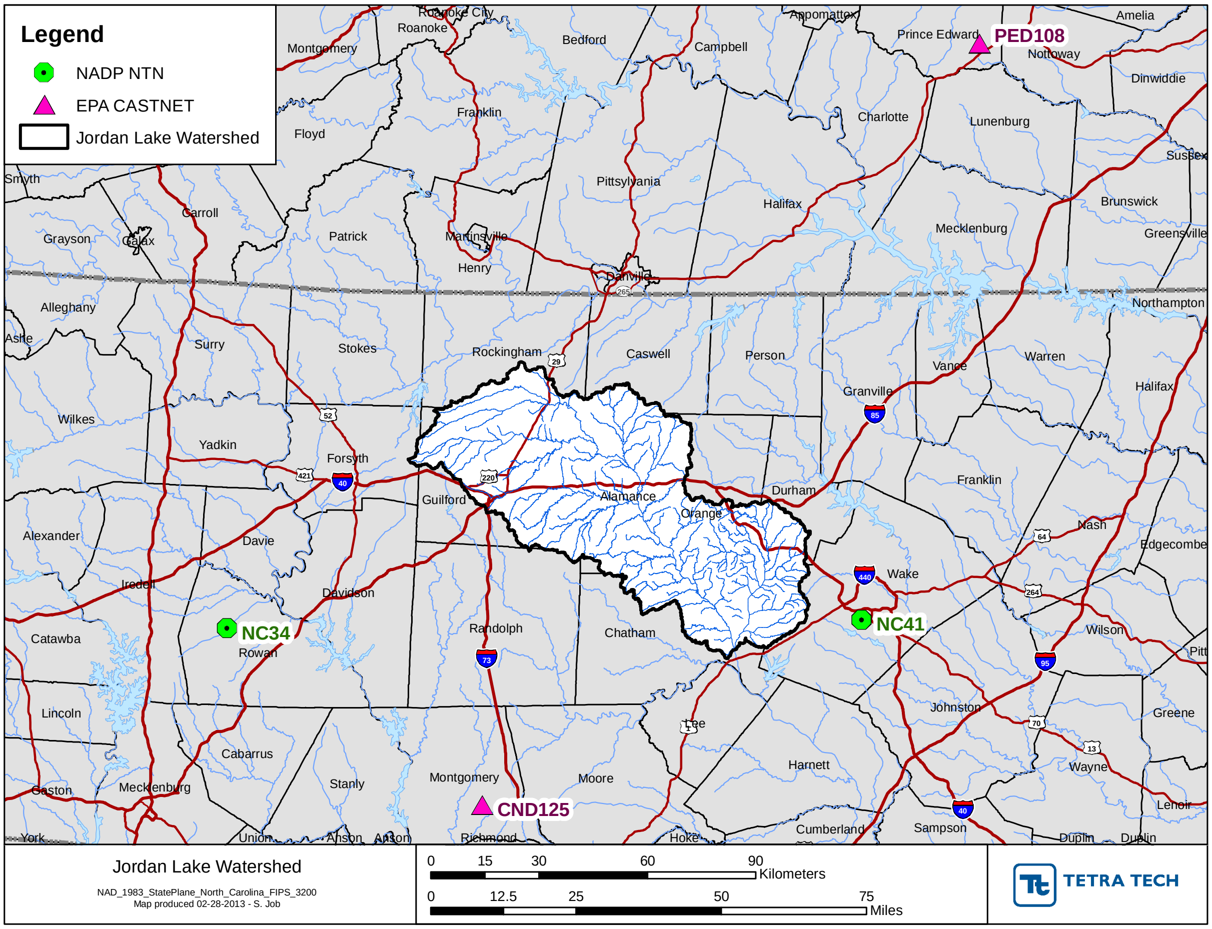


Figure 2-19. NADP NTN and EPA CASTNET Monitoring Stations near Jordan Lake Watershed

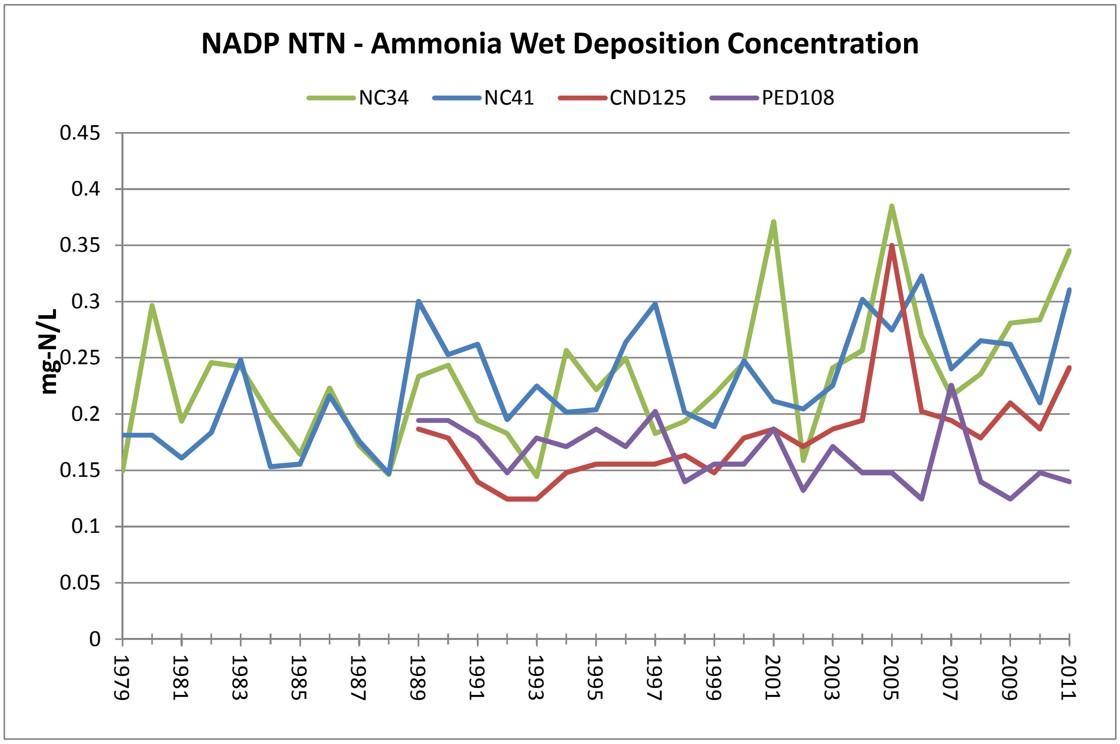


Figure 2-20. NADP NTN Precipitation-Weighted Annual Average Concentration of Ammonia as N

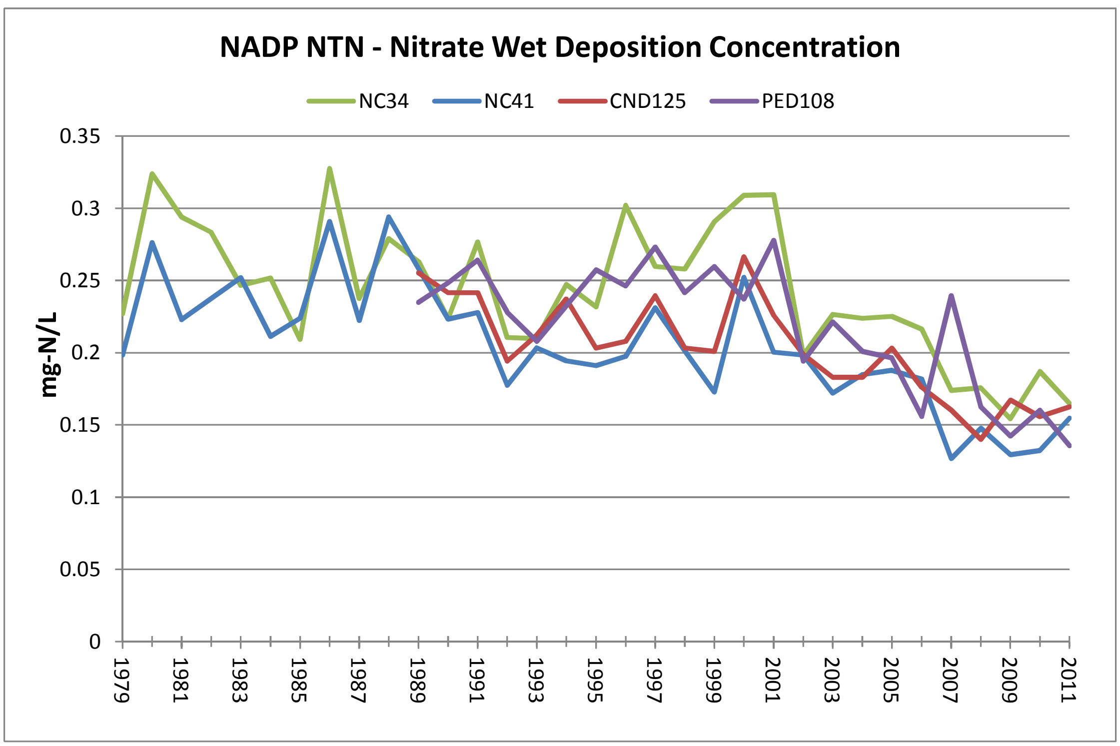


Figure 2-21. NADP NTN Precipitation-Weighted Annual Average Concentration of Nitrate as N

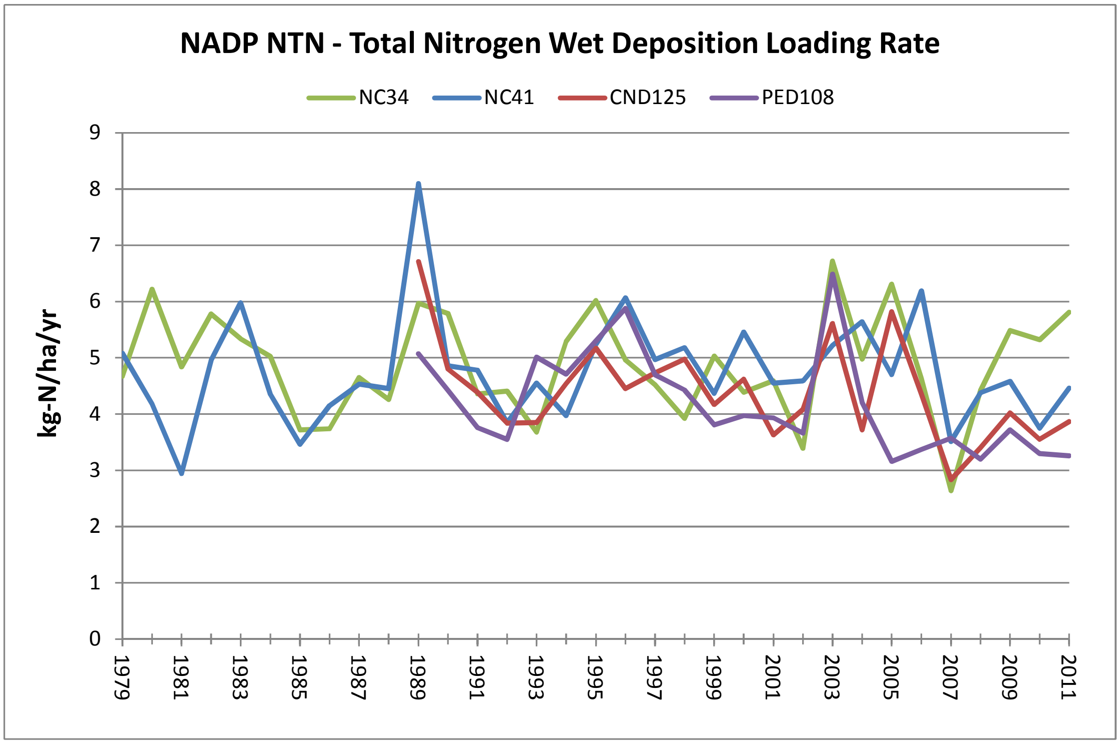


Figure 2-22. NADP NTN Precipitation-Weighted Annual Average Total Inorganic N Loading Rate

NTN results do suggest significant spatial variability in N wet deposition across the watershed (Figure 2-23), so inference from a single monitoring station may not accurately reflect wet deposition concentrations across the entire watershed. To provide spatial interpolation of the data Tetra Tech relied on EPA's Atmospheric Deposition Tool (http://www.epa.gov/AMD/Tools/wdt.html; Schwede et al., 2009), which summarizes the Community Multi-Scale Air Quality (CMAQ) Model v. 4.7 (Appel et al., 2007) output of inorganic nitrogen deposition. The tool provides area-weighted summaries of CMAQ output across a user-defined watershed, while the underlying CMAQ model is calibrated to the NTN observations. The Atmospheric Deposition Tool contains CMAQ output for 2002-2008. Summarization over this period is appropriate as it represents the central tendency of NO_3-N wet deposition concentrations over the period of model application.

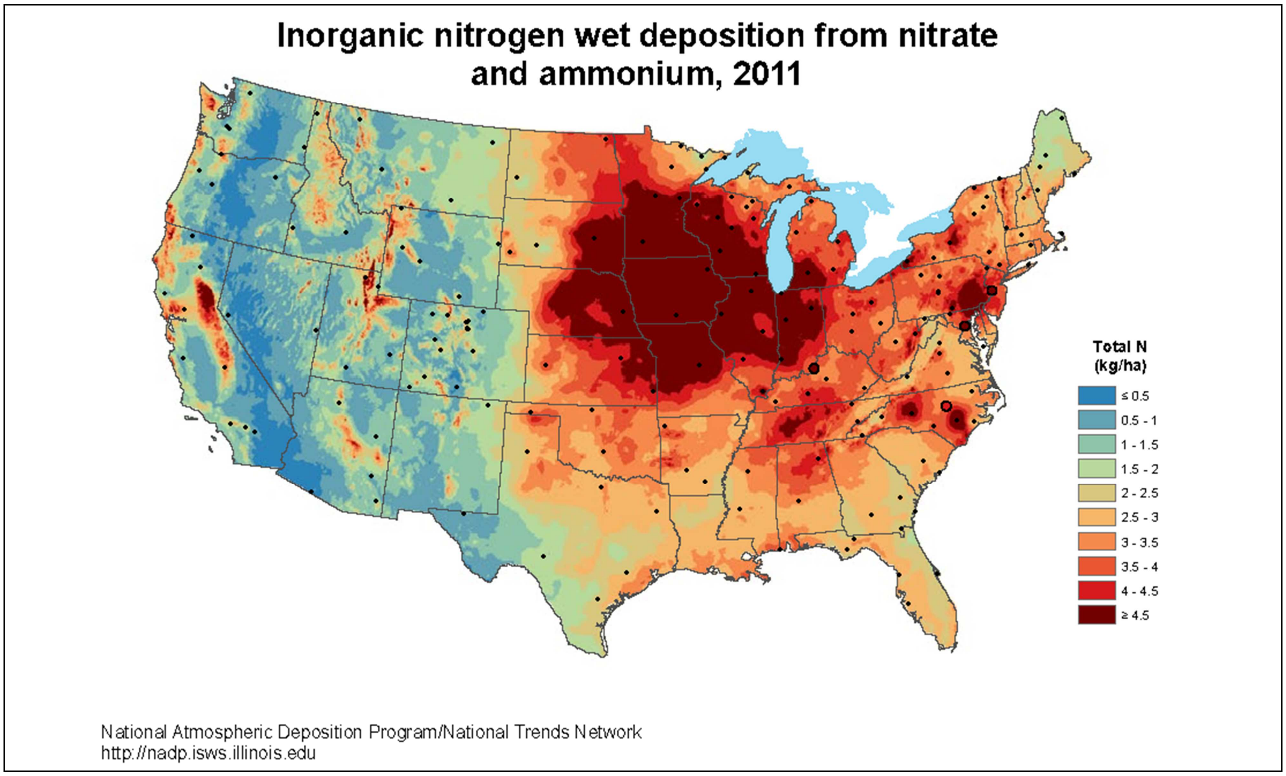


Figure 2-23. 2011 NTN Isopleths of Total Wet Deposition of N

Averages by month were calculated for NH_4-N and NO_3-N using the Atmospheric Deposition Tool. Table 2-19 and Figure 2-24 provide the atmospheric wet deposition values being utilized.

Table 2-19. Atmospheric Wet Deposition by Constituent and Month for Model Input

Constituent	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
NH_4-N (mg/L)	0.142	0.186	0.271	0.357	0.455	0.336	0.401	0.315	0.192	0.287	0.103	0.062
NO_3-N (mg/L)	0.309	0.312	0.335	0.304	0.373	0.208	0.237	0.205	0.132	0.357	0.159	0.188

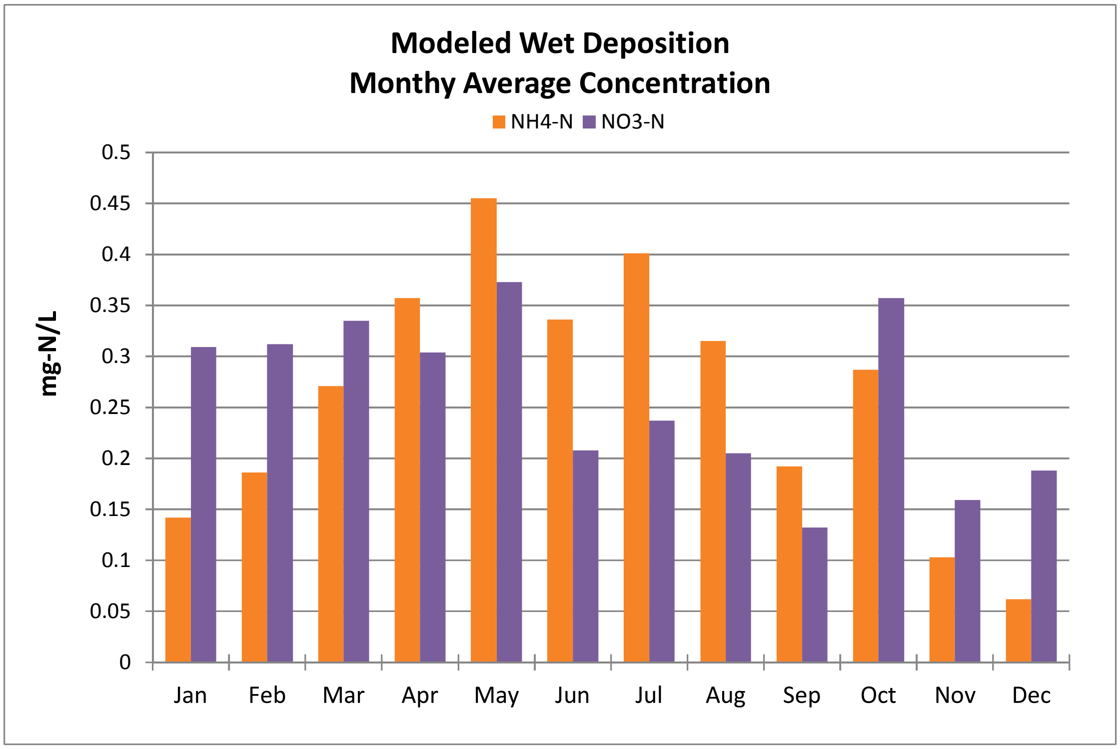


Figure 2-24. Modeled Wet Deposition Monthly Average Concentrations

2.5.2.2 Nitrogen Dry Deposition

Dry deposition of nitrogen is subject to much greater uncertainty than wet deposition because it is extremely difficult to directly measure net dry deposition, which reflects trapping on leaves, ground, and other surfaces balanced by re-emission. EPA's CASTNET system monitors air *concentrations* of NH_4^{+}, HNO_3^{-}, and NO_3, and *calculates* net dry deposition fluxes using the Multi-Layer Model (MLM).

Dry deposition seasonal and annual loads of N species beginning in 1989 were obtained from the CASTNET website (CASTNET, 2013). MLM output for the nearest active CASTNET stations (Figure 2-19), summed to total inorganic nitrogen deposition (as N), is shown in Figure 2-25. In contrast to overall wet deposition, there appears to be a downward trend over time in dry deposition at both stations. For the most recent years of monitoring where annual values were available (2005-2011) the total dry atmospheric deposition averaged 1.55 and 1.07 kg-N/ha/yr (1.38 and 0.95 lb/ac/yr) at CND125 and PED108, respectively, suggesting that dry deposition likely accounts for around one-quarter of the total atmospheric deposition load to the watershed.

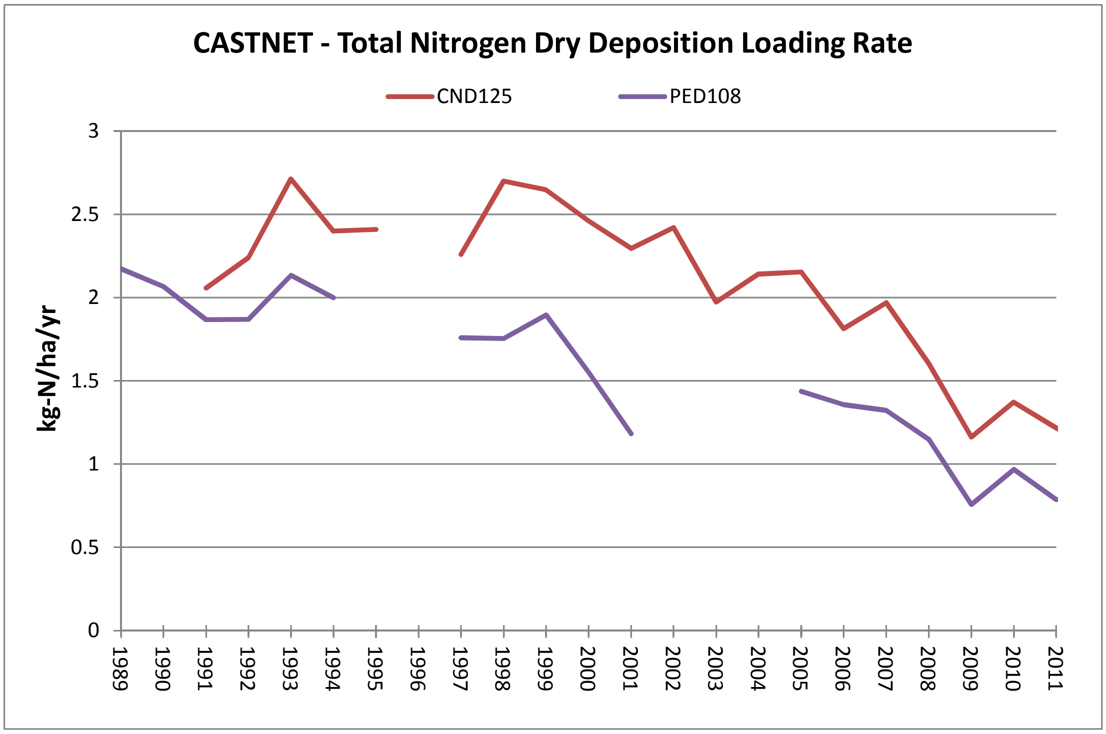


Figure 2-25. CASTNET Annual Average Inorganic N Loading Rate

The CMAQ model also simulates dry deposition fluxes, and we evaluated both use of CMAQ output and CASTNET estimates in the Jordan model. This results in significantly higher N dry deposition rates (about 5.9 lb/ac/yr from CMAQ versus around 1 lb/ac/yr from CASTNET).

The two methods differ due to difficulties in the estimation of dry deposition of N, which is subject to high uncertainty. It is important to remember that the CMAQ and CASTNET estimates are both derived from models and not directly observed: CASTNET combines observed air concentrations with simulated deposition velocities generated by the MLM model, while CMAQ models both N transport and deposition. Studies conducted in Durham by AMEC (2012) show dry deposition of N at about 0.9 lb/ac/yr, consistent with CASTNET; however, this is also a modeled estimate using the MLM model, not an independent observation.

There is recognition in the literature that CMAQ-modeled dry deposition rates of N are generally higher than CASTNET estimates. CASTNET omits some N species (un-ionized ammonia, organic N, un-ionized nitrogen oxides); however, the big differences are in the simulation of the deposition velocity of the ionized nitrate and ammonium components. All available model-based estimates are rated as uncertain and Koo et al. (2012) document average bias of over 200 percent between different methods of estimation.

Direct measurement data to resolve this discrepancy are rare. Zhang et al. (2012) used the Geos_CHEM model to estimate N deposition over the U.S. and compared the result to a few available direct eddy covariance measurements of N deposition. They cite measurements at Harvard Forest for 1999-2002 of 5.4 kg/ha/yr oxidized N and 2003 measurements at Duke Forest, near the Jordan watershed, of 4.3 kg/ha/yr oxidized N (the citation is missing in Zhang et al., but the Duke Forest work is in Sparks et al., 2008). In comparison, the CMAQ estimate of oxidized N deposition in this area for 2002 is about 7.3kg/ha/yr, while that from CASTNET is around 2.4 kg/ha/yr. However, net deposition is likely to be higher on forests than on many other surfaces due to leaf uptake. At this point the true spatially averaged N dry deposition rates on the watershed are considered uncertain, but likely lie between the CMAQ and CASTNET estimated rates.

Sensitivity analyses were undertaken relative to the different N deposition methods (see Section 4.3.3). During this process it was determined that use of the CMAQ-based estimates of dry deposition led to an over-estimate of observed inorganic N concentrations during baseflow conditions. Therefore, the CASTNET-based estimates are used in the final model.

As with wet deposition, the LSPC model does not have the ability to simulate year-to-year variability in dry deposition rates. Monthly average dry deposition rates were calculated for NH_4-N and NO_3-N using seasonal estimated deposition fluxes from WY1997-2011 at stations CND125 and PED108 (Table 2-20 and Figure 2-26). Similar to the monthly pattern seen for wet deposition, seasonal deposition rates of inorganic nitrogen are highest in the spring and summer, and lowest in the fall and winter.

Table 2-20. Atmospheric Dry Rates Deposition by Constituent and Season

Constituent	Dec – Feb	Mar – May	Jun – Aug	Sep – Nov
NH_4-N (lb/acre/day)	7.40E-04	1.24E-03	1.56E-03	8.78E-04
NO_3-N (lb/acre/day)	2.61E-03	5.05E-03	4.51E-03	3.13E-03

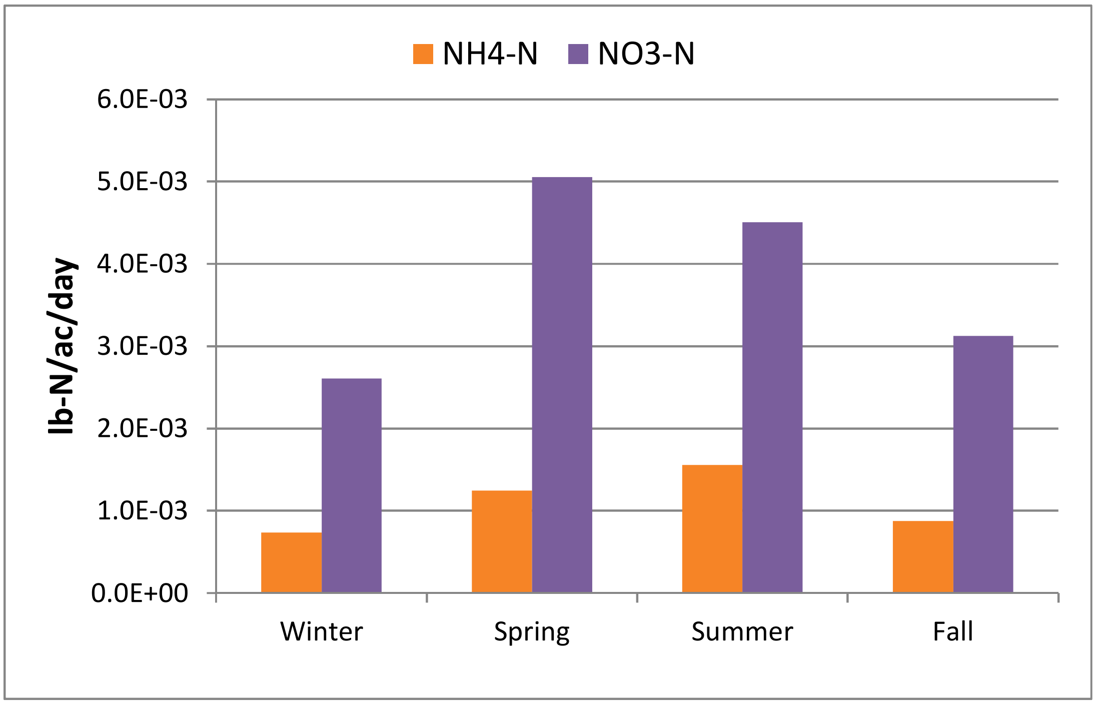


Figure 2-26. CASTNET Seasonal Average Inorganic N Loading Rate

2.6 Point Source Discharges

Discharges of waste to surface waters from wastewater treatment plants, industrial facilities, and other point sources are regulated under the National Pollutant Discharge Elimination System (NPDES). DWQ provided to Tetra Tech a provisional list of existing and discontinued NPDES permits located in the Jordan Lake watershed. The provisional list included 427 records with each record containing the Permit Number, Permit Status, Permit Type, Permitted Flow, Basin Name, Facility Name, and Latitude/ Longitude coordinates. Duplicate permit entries were removed, resulting in 321 unique permits to evaluate for inclusion in the model. Tetra Tech further reduced the list by removing permits associated with Single Family Domestic Wastewater Discharge Certificate of Coverage (COC), Non-contact Cooling, Boiler Blowdown Wastewater Discharge COC, Groundwater Remediation Wastewater Discharge COC, and Fish Farms Packing and Rinsing Wastewater Discharge COC as it was assumed that these types of permits would have little to no available data, generally would not contribute significant nutrient loads, or in the case of the Single Family Domestic Wastewater Discharge COC would be covered by the implicit on-site discharge representation.

2.6.1 Dischargers Included in the Model

This selection process produced a list of permits for which discharge monitoring report (DMR) data were requested and included 52 permits considered actively discharging and 41 permits that were potentially active during the baseline period. A memo detailing the decision process and the resulting targeted list of facilities was sent to DWQ, and DMR data were retrieved and sent to Tetra Tech. Before the DMR data was retrieved, Mike Templeton from the point sources branch reviewed the provided lists of facilities and concurred that Tetra Tech selected the proper permits to include in the Jordan Lake watershed modeling effort. Table 2-21 provides the currently active NPDES permits that are not included in the watershed model and the reason why each is not included.

Table 2-21. List of Facilities Actively Discharging Not Used as Model Inputs

Permit Number	Permitted Flow (MGD)	Facility Name	Reason for Exclusion
NC0003671	0.0000	Greensboro Terminal II	Small flows; flow & sediment only
NC0045292	0.0000	Graham / Mebane Water Treatment Plant (WTP)	Not a significant source of nutrients
NC0046345	0.0000	Reidsville WTP	Not a significant source of nutrients
NC0080896	0.0000	Pittsboro WTP	Not a significant source of nutrients
NC0081426	0.0000	N.L. Mitchell WTP	Not a significant source of nutrients
NC0081591	0.0000	Cary & Apex WTP	Not a significant source of nutrients
NC0081671	0.0000	Lake Townsend WTP	Not a significant source of Nutrients
NC0082210	0.0000	Jones Ferry Road WTP	Not a significant source of nutrients
NC0083828	0.0000	J.D. Mackintosh, Jr. WTP	Not a significant source of nutrients
NC0084093	0.0000	Jordan Lake WTP	Not a significant source of nutrients
NC0088986	0.0010	SFR - White Cross Volunteer Fire Dept.	No data and probably not nutrient bearing
NC0088994	0.0000	SFR - 9 S. Circle Drive	No data and probably not a significant nutrient source

Table 2-22 lists the list of facilities that are considered to be actively discharging and are included in the model. Table 2-23 lists the facilities that were historically discharging during the baseline period of the model but have subsequently discontinued discharging. The current and historic discharger’s spatial locations are provided in Figure 2-27.

Table 2-22. List of Actively Discharging NPDES Facilities used as Model Inputs

Map ID	Permit Number	Permitted Flow (MGD)	Facility Name	Period for Model	Model Segment
C1	NC0047384	40.0000	Greensboro - T.Z. Osborne WWTP	1/1/1996 - 12/31/2012	156
C2	NC0047597	20.0000	South Durham WRF	1/1/1996 - 12/31/2012	234
C3	NC0024325	16.0000	North Buffalo Creek WWTP	1/1/1996 - 12/31/2012	162
C4	NC0025241	14.5000	OWASA - Mason Farm WWTP	1/1/1996 - 12/31/2012	227
C5	NC0026051	12.0000	Durham County Triangle WWTP	1/1/1996 - 12/31/2012	243
C6	NC0023876	12.0000	Burlington - Southside WWTP	1/1/1996 - 12/31/2012	119
C7	NC0023868	12.0000	Burlington - Eastside WWTP	1/1/1996 - 12/31/2012	147
C8	NC0024881	7.5000	Reidsville WWTP	1/1/1996 - 12/31/2012	196
C9	NC0021211	3.5000	Graham WWTP	1/1/1996 - 12/31/2012	146
C10	NC0020354	3.2200	Pittsboro WWTP	1/1/1996 - 12/31/2012	103
C11	NC0021474	2.5000	Mebane WWTP	1/1/1996 - 12/31/2012	208
C12	NC0043559	0.5000	Fearrington Village WWTP	1/1/1996 - 12/31/2012	224
C13	NC0056413	0.3500	Chatham Water Reclamation Facility	1/1/1996 - 12/31/2012	227
C14	NC0066966	0.2000	Quarterstone Farm WWTP	1/1/1996 - 12/31/2012	155
C15	NC0025305	0.0922	UNC Cogeneration Facility	1/1/1996 - 12/31/2012	228
C16	NC0022691	0.0820	Autumn Forest MHC WWTP	1/1/1996 - 12/31/2012	167
C17	NC0043257	0.0600	Nature Trails Mobile Home Park WWTP	1/1/1996 - 12/31/2012	226
C18	NC0042528	0.0500	Saxapahaw Plant WWTP	1/1/1996 - 12/31/2012	115
C19	NC0051314	0.0500	Cole Park Plaza Shopping Center WWTP	1/1/1996 - 12/31/2012	226
C20	NC0042285	0.0400	Trails WWTP	1/1/1996 - 12/31/2012	220
C21	NC0077968	0.0400	Horners Mobile Home Park	1/1/1996 - 12/31/2012	154
C22	NC0046043	0.0400	Oak Ridge Military Academy WWTP	1/1/1996 - 12/31/2012	190
C23	NC0073571	0.0300	Countryside Manor WWTP	1/1/1996 - 12/31/2012	193
C24	NC0035866	0.0250	Bynum WWTP	1/1/1996 - 12/31/2012	105
C25	NC0001384	0.0250	Williamsburg Plant	1/1/1996 - 12/31/2012	199
C26	NC0065412	0.0235	Pleasant Ridge WWTP	1/1/1996 - 12/31/2012	180
C27	NC0046809	0.0200	Cornerstone Conf. & Resource Center WWTP	1/1/1996 - 12/31/2012	184
C28	NC0042803	0.0180	Birchwood Mobile Home Park	1/1/1996 - 12/31/2012	236
C29	NC0060259	0.0175	Willow Oak Mobile Home Park	1/1/1996 - 12/31/2012	196
C30	NC0031607	0.0150	Western Alamance Middle School	1/1/1996 - 12/31/2012	153
C31	NC0046019	0.0150	The Summit at Haw River State Park WWTP	1/1/1996 - 12/31/2012	186
C32	NC0074446	0.0120	Hilltop Mobile Home Park WWTP	1/1/1996 - 12/31/2012	236
C33	NC0045161	0.0120	Altamahaw/Ossipee Elementary School	1/1/1996 - 12/31/2012	179
C34	NC0045144	0.0115	Western Alamance High School	1/1/1996 - 12/31/2012	153
C35	NC0022098	0.0100	Cranbrook Village WWTP	1/1/1996 - 12/31/2012	141
C36	NC0045152	0.0075	Jordan Elementary School	1/1/1996 - 12/31/2012	115
C37	NC0055271	0.0060	Shields Mobile Home Park	1/1/1996 - 12/31/2012	150
C38	NC0038164	0.0045	Nathanael Greene Elementary School WWTP	1/1/1996 - 12/31/2012	128
C39	NC0045128	0.0030	Sylvan Elementary School	1/1/1996 - 12/31/2012	113
C40	NC0071463	0.0000	Apex Oil Company	1/1/1996 - 12/31/2012	171

Table 2-23. List of Historically Discharging NPDES Facilities used as Model Inputs

Map ID	Permit Number	Permitted Flow (MGD)	Facility Name	Period for Model	Model Segment
H1	NC0000876	1.250000	White Oak Plant (Cone Mills)	1/1/1996 - 8/30/2001	163
H2	NC0001210	0.050000	Monarch Hosiery Mills Incorporated	1/1/1996 - 7/31/2002	154
H3	NC0003913	0.150000	Glen Touch Yarn Company	1/1/1996 - 6/28/2005	179
H4	NC0022446	0.050000	Aquasource, Inc.-Quarry Hill	1/1/1996 - 7/31/2000	207
H5	NC0022675	0.043000	Birmingham Place WWTP	1/1/1996 - 5/31/2007	141
H6	NC0029351	0.007000	Arrowhead Motor Lodge	1/1/1996 - 7/31/1999	215
H7	NC0029726	0.025000	Guilford Correctional Center WWTP	1/1/1996 - 6/30/2011	161
H8	NC0036994	0.004200	Monroeton Elementary School	1/1/1996 - 2/28/2004	192
H9	NC0038105	0.015000	Guilford Co Sch-E Guilford	1/1/1996 - 11/30/1999	142
H10	NC0038130	0.031000	Guilford Co Sch-Northwest J	1/1/1996 - 9/30/2000	175
H11	NC0038156	0.032000	Northeast Middle & Senior High WWTP	1/1/1996 - 9/30/2005	166
H12	NC0038172	0.011300	McLeansville Middle School WWTP	1/1/1996 - 9/30/2007	156
H13	NC0043362	0.005000	Guilford Co Sch-Ple'snt Gar	1/1/1996 - 8/31/1997	138
H14	NC0048429	0.005000	Cedar Village Apartments	1/1/1996 - 7/31/2011	226
H15	NC0050024	0.010000	Forest Oaks Country Club	1/1/1996 - 1/31/1999	140
H16	NC0051331	0.001600	Chapel Hill West/ Tower Ap	1/1/1996 - 8/31/2001	221
H17	NC0066010	0.004000	Williamsburg Elementary School	1/1/1996 - 9/30/2005	182

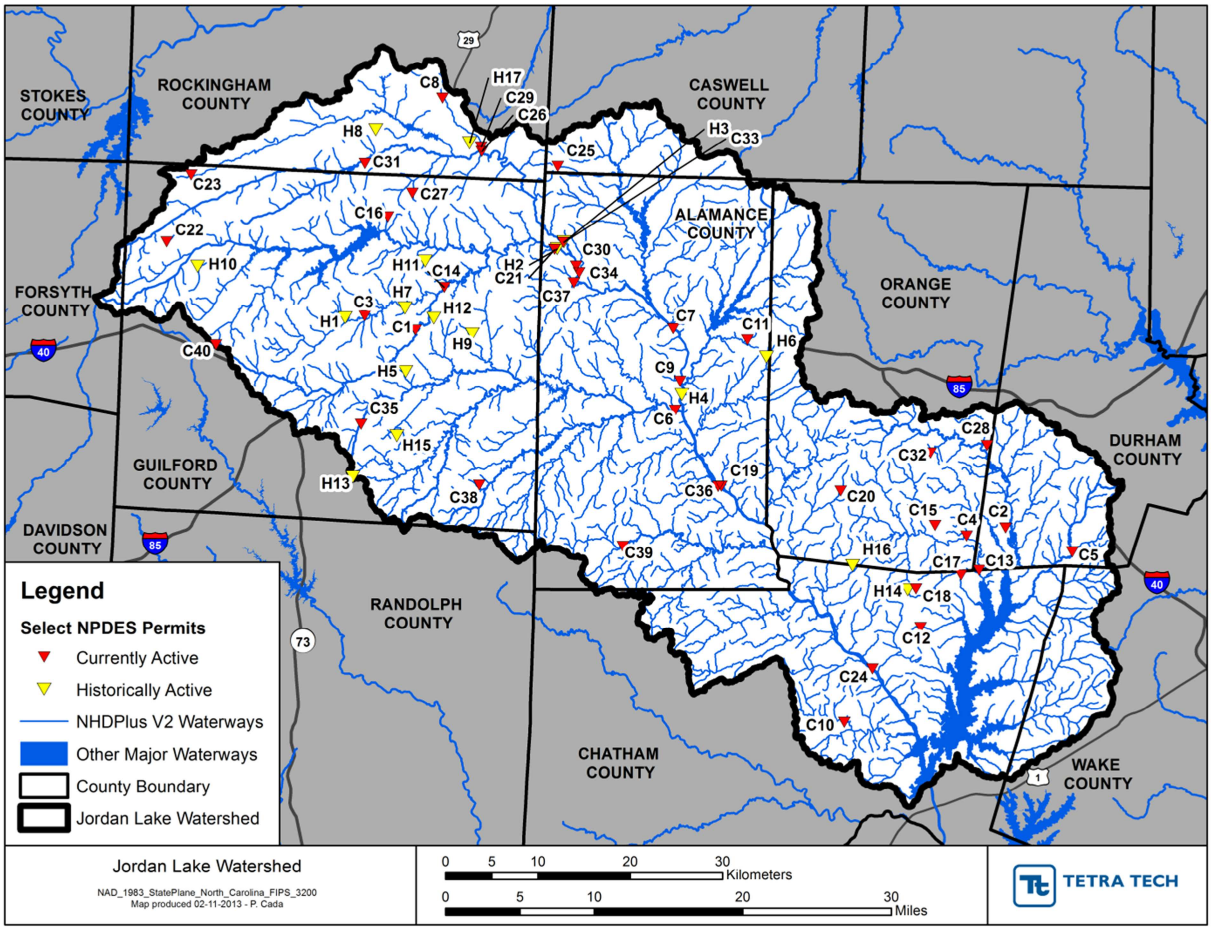


Figure 2-27. Currently Active and Historically Active NPDES Permits in the Watershed Model

Note: See Table 2-22 and Table 2-23 for key to facilities.

2.6.2 Processing of Discharge Data

DWQ provided discharge monitoring data for inclusion in the model. The DMR data were checked for quality control problems, revealing outliers in the data for some of the facilities. Some of the outliers were easily explained, such as flow in gallons per day instead of million gallons per day or a decimal point in the wrong spot for dissolved oxygen concentration. Known and easily identifiable outliers were fixed but some smaller outliers may still exist in the model time series. The input time series specified to the model for each facility are CBOD, DO, Ammonia (as N), Nitrate+Nitrite (as N), Refractory Organic Nitrogen (as N), Total Nitrogen, Ortho-phosphate (as P), Refractory Organic Phosphorus (as P), Total Phosphorus, Total Suspended Sediment, and Water Temperature.

All of the permitted major discharges (>1 MGD) had DMR data at a daily frequency and are represented by daily time series in the model. Gaps in the observed data were filled by holding constant the last available measurement until a new measurement became available. Starting in 2007 the DMR data contained measurements for all nitrogen species. These values were used to calculate average nitrogen speciation ratios for each facility, which were applied to data prior to 2007 when only total nitrogen and ammonia were reported. Additionally, the DMR data contained only total phosphorus data. A default assumption was applied that 30 percent was total organic phosphorus and 70 percent was inorganic orthophosphate P. These default speciation assumptions to fractionate total phosphorus were also used by

Tetra Tech in previous watershed modeling conducted for the Georgia State-wide Watershed Management Plan and are reproduced below in Table 2-24.

The DMR data for the minor discharges (<1 MGD) were reported at monthly or sub-monthly frequencies and are represented by a monthly average time series in the model. To develop the time series, any sub-monthly data was assembled to a monthly average value. Then, data gaps of three month or less data were filled with the average of the values of the months preceding and following the gap. The long term monthly average was used to fill any gaps larger than three months. For facilities that had observed nitrogen speciation data in recent years, this information was used to estimate nitrate+nitrite-N and total organic nitrogen concentrations previous to 2007, similar to the approach used for major facilities. For facilities without such data a default speciation was used as follows: If total nitrogen (TN) and ammonia-N were both reported, the difference between TN and ammonia-N was multiplied by 83 percent to estimate the nitrate+nitrite-N fraction and by 17 percent to estimate total organic nitrogen fraction. If only TN was monitored then the nitrogen speciation defaulted to 59 percent ammonia-N, 34 percent nitrate+nitrite-N, and 7 percent total organic nitrogen. Only total phosphorus was reported so a default assumption was made that 10 percent was total organic phosphorus and 90 percent was orthophosphate-P. Additionally, some facilities had not reported values for all of the constituents needed for model input. When no data were available on a constituent the following default assumptions were applied: CBOD: 30 mg/L, DO: 5 mg/L and temperature of 15 °C in October, November, December, January, February and March and 25 °C in the other months. The assumption used to create the time-series inputs for the minor point sources are shown in Table 2-24.

LSPC represents organic nutrients in two forms: refractory organic nutrients (not subject to decay) and labile organic nutrients (which are subject to decay). The refractory organic nutrients are state variables in the model. The labile organic nutrients are not state variables; instead LSPC represents them implicitly through the CBOD (and plankton) state variables. When CBOD decays inorganic nutrients are released according to user-specified stoichiometric relationships that relate the carbon content of organic matter to the phosphorus and nitrogen content. Thus, the specification of the CBOD load for NPDES facilities also implies a certain level of organic phosphorus and organic nitrogen load. To prevent double-counting of organic nutrients, the “hidden” labile fractions were calculated based on the stoichiometric ratios used by the model and the CBOD input. Refractory organic nitrogen and refractory organic phosphorus model inputs were calculated as the difference between total organics and the calculated labile organics. When this difference calculation resulted in a negative number the refractory portion was zeroed and it was assumed that all organic nutrients were labile.

Table 2-24. Default Water Quality Concentrations of Constituents without Data for Major and Minor Municipal Facilities

Constituent	Parameter Id	Minor (<1.0 MGD)	Major (>1.0 MGD)
Discharge Flow	FLOW	Maximum found from 1997 through 2009 or Permitted Flow	Maximum found from 1997 through 2009 or Permitted Flow
Total Phosphorus	TP	5.0 mg/l	1.0 mg/l
Orthophosphate	PO4	4.5 mg/l (90% of TP)	0.7 mg/l (70% of TP)
Organic Phosphorus	OrgP	0.5 mg/l (10% TP)	0.3 mg/l (30% of TP)
Total Nitrogen	TN	29.4 mg/l (sum of species)	17.0 mg/l (sum of species)
Ammonia	NH3	17.4 mg/l	5.0 mg/l
Nitrate+Nitrite	NOx	10.0 mg/l	10.0 mg/l
Organic Nitrogen	OrgN	2.0 mg/l	2.0 mg/l
5-day BOD	BOD5	30.0 mg/l	10.0 mg/l
Dissolved Oxygen	DO	5.0 mg/l	5 mg/L
Total Suspended Solids	TSS	30 mg/l	30 mg/L
Water Temperature	WTEM	15.0 ℃ October through March 25.0 ℃ April through September	15.0 ℃ October through March 25.0 ℃ April through September

2.7 ONSITE WASTEWATER DISPOSAL SYSTEMS

Potentially significant sources of nutrient loads in the Jordan Lake watershed include onsite and other decentralized wastewater disposal systems. For this analysis, *decentralized systems* are defined as any wastewater management system not represented as NPDES Discharges (described in Section 2.6). This includes individual single family residential (SFR) surface and subsurface effluent dispersal systems, large/non-residential surface and subsurface effluent dispersal systems, and SFR NPDES systems.

For the purposes of model setup, decentralized wastewater systems are lumped together by subwatershed, with their load to stream being represented as an aggregate artificial point source input to the receiving reach. This section focuses on the data processing steps used to estimate the collective pollutant loads attributed to decentralized systems in each subwatershed. This was accomplished by first developing an overall baseline source load for each subwatershed using per capita flow and pollutant generation rates multiplied by the unsewered population (as derived using census block data and parsing out population in sewer service areas) and then applying pollutant reduction factors based on the distribution of various types of systems (weighted by their design flow rates) in those subwatersheds followed by reductions due to attenuation during transport.

This protocol was selected in part to ensure that future modifications could readily be made to the analysis. For example, if it were decided to later account for a selected subwatershed having certain soil characteristics expected to yield different pollutant reduction efficiencies, an additional modifier could be applied. Likewise, future refinement and annual updating of system inventory data can easily be incorporated by adjusting the numbers of different types of systems in each subwatershed (along with the served population using future census or other population data).

The protocol was developed to be consistent with the most recent Chesapeake Bay Program Office (CBPO) findings, previously developed methodologies for other watershed models in North Carolina (e.g., High Rock Lake) and the most recent and robust scientific research (with priority given to North Carolina specific studies) informed by input from local health departments (LHDs) and staff of the Onsite Water Protection Branch of the North Carolina Department of Health and Human Services.

The protocol includes the following steps (each described in more detail in subsections below):

1. The number of people served by decentralized systems within each subwatershed was estimated using census block data, excluding population served by existing municipal wastewater collection systems (Population Estimate)
2. Flow and total pollutant (TN and TP) input loads generated by the population served by decentralized systems was estimated for each subwatershed using standard per capita loadings, based on updated CBPO criteria and standard wastewater engineering references (Baseline Load Estimate)
3. *Edge of system* pollutant loads were estimated by reducing the total pollutant loads (from #2 above) based on the distribution of system types within each subwatershed using system inventory data and estimated treatment reductions based on the CBPO literature review and preliminary findings (Edge of System Load Estimate)
4. *Delivered loads* were estimated by applying an attenuation rate to the *edge of system* loads (from #3 above) for each type of system except SFR NPDES systems based on published septic load delivery studies in North Carolina (Attenuated Load Estimate)
5. A fraction of the total pollutant reduction (sum of system reduction and attenuation reduction) for each subwatershed was added back to the delivered load to account for malfunctioning systems during the winter season (Malfunction Load Estimate)
6. Loads for each speciated pollutant of interest were estimated for years 2000 and 2010 (Time Series Pollutant Load Estimate)

2.7.1 Sewer Service Boundaries

The extent of sewer service areas was used to ascertain the density of onsite wastewater treatment systems. Sanitary sewer service area coverages were obtained from several sources. In some cases, service areas were not available. In place of a sewer service area polygon, available sanitary sewer lines and/or points (for manholes) were used to estimate sewer service areas wherever available. All areas with centralized sewer service were obtained in GIS for use in model development (Figure 2-28).

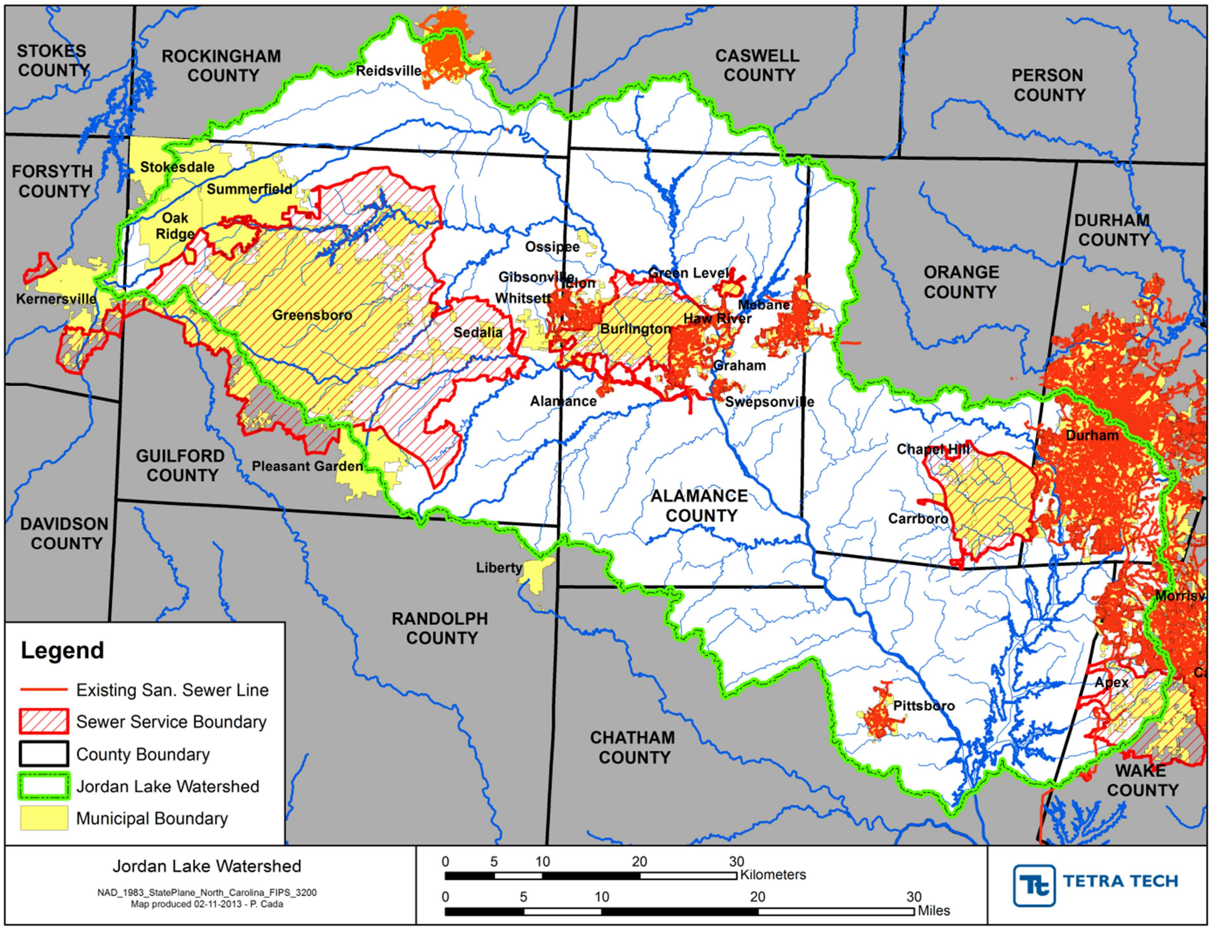


Figure 2-28. Sanitary Sewer Service Area Boundaries and Infrastructure (Lines and/or Manholes)

2.7.2 Population Estimate

Processed US census block data for 2000 and 2010 were downloaded from the NC Center for Geographic Information and Analysis (NCCGIA). These datasets contain a multitude of demographic data analyzed at the block scale, which is the smallest geographic unit utilized by the US Census Bureau. The census blocks provided total population and the number of households (both vacant and occupied) for each block unit.

A series of GIS processes were used to extract the total number of onsite wastewater systems within each model subwatershed. First, the two census block datasets were intersected with the model subwatersheds. Areas were recalculated to determine the area of each census block located in each subwatershed. These values were used to calculate area-weighted population and household quantities for each subwatershed in Microsoft Excel.

The next step involved identifying which intersected census blocks were served by existing sewer systems. All of the municipalities within the watershed provided sewer coverages as either a polygon (sewer service area), a polyline (force main or gravity main locations), or as a point file (manhole locations). For the polygons, a “select by location” process was used to determine if the centroid of each intersected census block was located in a sewer service polygon. A centroid analysis was used in lieu of a discrete intersection method to account for geospatial deviations that might overestimate the sewer area coverage, such as a small piece of a sewer service area located in a larger census block that otherwise does not receive sewer service. This analysis may slightly overestimate the number of onsite wastewater systems in the subwatershed but is likely balanced by other assumptions that tend to underestimate the number of systems.

A discrete intersection method was used to identify sewered census blocks using the sewer line and manhole point datasets. In other words, if the edge of a census block intersected either a sewer line or manhole location, it was assumed that the entire block was served by a sewer system. With this approach, the number of onsite wastewater systems might be slightly underestimated at the subwatershed scale.

A relatively small number of septic systems are still in operation within municipal wastewater service areas at properties whose owners have not voluntarily connected and have not been required to do so. Tetra Tech was able to obtain specific septic system inventory information from several counties which could potentially be used to identify those systems within municipal service areas. However, to be consistent from county to county across the watershed, system inventory information was only used to provide a more refined estimate of distribution of various system *types* within counties and, but not to estimate loadings within subwatersheds as this would have required a number of additional assumptions believed to be less accurate than the population-based load estimation method described above. The simplifying assumption that all properties within sewer service areas are indeed served by municipal systems will introduce a slight underestimate of septic system loads associated with areas served by public sewer.

After identifying which census blocks were likely to be served by sewer systems, the processed shapefiles were imported to a spreadsheet to calculate total population and household values for each subwatershed. To determine the area-weighted population and household numbers for the non-sewered census blocks, the intersected block area was divided by the original block area to determine the percentage of the block contained in each subwatershed. This ratio was subsequently multiplied by the “population” and “household” attribute values to determine the numbers of each in each subwatershed. This approach assumes that population and households are equally distributed throughout a census block. Finally, the area-weighted population and household values were summed by subwatershed as a basis for estimating the load managed using decentralized wastewater systems.

2.7.3 Baseline Load Estimate

Baseline input loads for each subwatershed were calculated by multiplying the number of people using decentralized wastewater systems in the subwatershed by the per-capita loading factors listed in Table 2-25.

Table 2-25. Per Capita Loading Factors for Decentralized Wastewater Systems

Characteristic	Per capita value	Units	Source
Flow	60	gallons per day (gpd)	CBPO (2013)/Metcalf and Eddy (2003)
Total Nitrogen	13.7	grams per day (g/d)	Metcalf and Eddy (2003)
Total Phosphorus	3.3	grams per day (g/d)	Metcalf and Eddy (2003)

2.7.4 Edge of System Load Estimate

The input loads were first reduced by accounting for treatment within footprint of the decentralized wastewater system. The distribution of system types was estimated for each subwatershed using inventory information provided by county local health departments (LHDs). Relatively accurate subwatershed-specific system counts were determined for those counties whose LHDs provided geospatial inventories of systems. For those counties where fairly complete geospatial inventories were not available, the distribution of most system types (most notably, the SFR subsurface systems) was assumed constant across all relevant subwatersheds in the county. A summary of the data sources used for estimating the distribution of system types is provided in Table 2-26.

Table 2-26. Summary of Data Sources used to Estimate System Type Distribution

Facility Type	System Type	Data Source
SFR	Subsurface/Conventional	LHD geospatial data, County activity reports, estimates from adjacent subwatersheds and counties
SFR	Subsurface/Pressure Dosed	LHD geospatial data, County activity reports, estimates from adjacent subwatersheds and counties
SFR	Subsurface/Pretreatment	LHD geospatial data, County activity reports, estimates from adjacent subwatersheds and counties
SFR	Non Discharge (surface irrigation)	DWQ-LAU geospatial database, LHD geospatial data
Non-SFR	Subsurface/Conventional	DHHS-OSWPB database, County activity reports, LHD geospatial data, estimates from adjacent subwatersheds and counties
Non-SFR	Subsurface/Pressure Dosed	DHHS-OSWPB database, County activity reports, LHD geospatial data, estimates from adjacent subwatersheds and counties
Non-SFR	Subsurface/Pretreatment	DHHS-OSWPB database, County activity reports, LHD geospatial data, estimates from adjacent subwatersheds and counties
Non-SFR	Non Discharge (surface irrigation)	DWQ-LAU geospatial database, LHD geospatial data
SFR	NPDES	LHD geospatial data, County estimates, NPDES database

Using the counts of the various system types indicated in Table 2-26, weighting factors were calculated based on design flow rates. Design flow rates were used to provide a common basis for apportioning loads. Although actual average flow rates are typically considerably lower than design flow rates, it was assumed that the ratio of average-to-design flow would be similar regardless of the system type. For example, the ratio of average-to-design flow for an SFR is assumed to be the same as the ratio for an office building. This assumption may not be as justifiable for systems designed for short term peak flows, like churches whose systems are typically sized to accommodate Sunday flows while flows on other days are much lower, resulting in a relatively low average-to-design flow ratio. Because the total loads for each subwatershed are based on population, however, these minor discrepancies in the system distribution calculations are unlikely to have a significant effect on final delivered loads.

On a subwatershed basis, the total design flow rate for each type of system was calculated. The design flow rate for each system type was then divided by the total design flow rate for the subwatershed to determine the weighting factor for that system type. Then the baseline pollutant load associated with each system was calculated by multiplying the weighting factor by the total pollutant loading (calculated based on Table 2-25). Next, the baseline pollutant load associated with each system was reduced by the treatment efficiencies listed in Table 2-27 to determine *edge-of-system* loads.

Table 2-27. Design Flows and Reduction Efficiencies for Properly Functioning System Types

Facility Type	System Type	Flow	TN	TP
SFR	Subsurface/Conventional	360 gpd	50%	100%
SFR	Subsurface/Pressure Dosed	360 gpd	70%	100%
SFR	Subsurface/Pretreatment	360 gpd	65%	100%
SFR	Non Discharge (surface irrigation)	360 gpd	80%	100%
Non-SFR	Subsurface/Conventional	Design[1]	50%	100%
Non-SFR	Subsurface/Pressure Dosed	Design[1]	70%	100%
Non-SFR	Subsurface/Pretreatment	Design[1]	65%	100%
Non-SFR	Non Discharge (surface irrigation)	Design[1]	80%	100%
SFR	NPDES	360 gpd	35%	50%

[1] Based on actual design flow as provided in geospatial or other databases. Where not available, an average non-SFR design flow rate of 1,000 gpd was assumed.

Table 2-27 includes essentially five different types of systems:

1. Conventional subsurface – these systems have only a septic tank for treatment prior to soil dispersal using conventional gravity distribution. When properly functioning in fine textured soils, TP will be sequestered in the soil matrix. Although phosphorus sequestration capacity is a function of unsaturated soil depth, the availability of iron and other metal cations and other variables which may change over time, the CPBO and other water quality studies recognize that the TP sorption capacity for most finely textured soils is high and assume complete removal of TP for properly functioning soil treatment systems. Biological nitrogen removal (sequential nitrification and denitrification) is the predominant TN reduction mechanism. TN removal in conventional systems is partially a function of soil texture, with finer textured soils supporting proper development of a biomat which facilitates an alternating aerobic/anoxic environment and other conditions that promote TN reduction. A 50 percent TN reduction was assumed, based on US EPA (2002) guidance for soil treatment at a depth of 0.6 meter (2 feet). 50 percent represents a relatively conservative estimate of TN reduction in conventional systems within the Jordan Lake Watershed based on conclusions presented by Long (1995) in a literature review on predicting nitrogen loading for onsite wastewater treatment systems

2. Pressure-dosed subsurface – these systems have only a septic tank for treatment prior to soil dispersal, but dose effluent into the soil treatment unit periodically under pressure which improves overall treatment performance by avoiding localized overloading and further promoting sequential aerobic/unsaturated and anoxic/saturated conditions. An increase in TN reduction efficiency to 70 percent was assumed for pressure-dosed subsurface dispersal systems. 70 percent represents the efficiency suggested by Long (1995) for conventional systems in silty or clayey soils which predominate in the Jordan Lake Watershed.

3. Pretreatment system to subsurface dispersal – these systems primarily use aerobic biological treatment prior to soil dispersal. Typically, the primary objective of pretreatment is reduction of CBOD which can grow biofilms which can clog the trench-soil interface in marginal soils and for nitrification of ammonia. Although some systems are designed for a substantial amount of total nitrogen removal (i.e., denitrification), most are not. Inventory information collected for this project does not allow for denitrification systems to be distinguished from other types of

advanced treatment systems. With pretreatment, lower TN reduction efficiencies in the soil treatment unit are expected since labile carbon availability is decreased and biomat formation reduced. However, microbial assimilation of nitrogen, simultaneous nitrification/denitrification, and abiotic removal processes within the pretreatment unit along with lower efficiency TN reduction processes within the soil absorption system will result in higher overall TN reduction efficiencies than for conventional septic tank-gravity flow drainfield systems. Accordingly, a 65 percent efficiency was used.

4. Surface irrigation – these systems generally have a septic tank and some form of pretreatment prior to soil dispersal on the land surface (via spray or drip irrigation). Irrigation into surficial soil layers enhances TN reduction since these soils typically contain higher amounts of labile carbon needed to drive denitrification. Vegetative nitrogen uptake can also be a significant TN reduction mechanism in surface irrigation systems. Accordingly, an 80 percent reduction efficiency was used for surface irrigation systems.
5. SFR discharge – these systems typically consist of a septic tank followed by a single pass biological filter with an underdrain system that collects effluent for discharge (typically to a ditch or surface water). There is a large amount of variability in the design of these systems. Older units often consisted of buried sand filters with no liners. Consequently, many older systems function as (relatively deep) subsurface dispersal systems and do not discharge through their underdrains during dry weather. Between 31 and 32 percent of the discharging sand filters in Durham County inspected by DWQ showed evidence of a discharge (Brown and Caldwell, 2013). Newer systems may use pressure distribution to disperse septic tank effluent on filters that can be accessed at-grade. TN reduction efficiencies are based on performance data for intermittent sand filters (Crites and Tchobanoglous, 1998) and TP reduction efficiencies are based on typical septic tank removal efficiencies (Lombardo, 2006) with additional allowances to account for systems that discharge to the soil during dry weather, as well as the effect of attenuation in lower-order stream reaches for those systems that do discharge. TN reduction efficiencies are consistent with concentrations measured by the City of Durham (City of Durham Stormwater Services, 2008), again with some allowance for those systems whose effluent is dispersed into soil beneath the system instead of discharging.

2.7.5 Attenuated Load Estimate

Attenuated or delivered pollutant load for properly functioning systems was calculated by reducing the *edge of system* loadings by attenuation factors for TN. (Attenuation factors are not needed for TP because 100 percent reduction is assumed to occur within the system for properly functioning systems.) An average TN attenuation rate of 80 percent was initially applied for all functioning soil treatment (surface, subsurface) systems. Although this attenuation rate is higher than the attenuation rate currently used by the CBPO, the CBPO's constant 60 percent rate is scheduled to be revisited by an Expert Panel later in 2013. An existing Expert Panel studying onsite system performance has found no clear justification for the 60 percent factor used in the current version of the CBPO watershed model and believes that the 60 percent factor generally underestimates attenuation averaged across the watershed. Furthermore, North Carolina studies suggest that overall (i.e., after soil treatment and attenuation reductions) TN delivery of 10 percent or less of the base load can be expected. Most notably, NC DENR (2010) in collaboration with the United States Geological Survey (USGS) report TN deliveries of 0.5 to 8.0 percent in Triassic Basin Falls Lake subwatersheds served by decentralized systems. By contrast, the soil treatment and attenuation calculations described above result in a 10 percent TN delivery for conventional subsurface wastewater systems (other system types have lower delivered TN loads, although the numbers of these other systems are much smaller than those for conventional systems).

During model calibration, the original attenuation rate of 80% was found to result in over-simulation of nitrogen concentrations at low flows in streams without significant point source discharges. The attenuation rate for TN was revised during calibration to be 95%, which is in line with the NC DENR studies.

Although first-order decay functions are sometimes used to characterize attenuation between edge of system and modeled stream reach, decay rate constants assume consistent soil and landscape scale TN reduction characteristics over the area being modeled. Additionally, travel time (a function of distance, slope, and saturated hydraulic conductivity) must be known to accurately estimate resulting TN delivery. Using a constant percent attenuation rate, as done for this exercise, implicitly assumes a constant first-order decay function and average travel time across the watershed. Review of the watershed and subwatershed characteristics (e.g., soil characteristics, locations of receiving waters) suggests that use of a constant attenuation rate is reasonable, as well as consistent with the data currently available to represent pollutant delivery.

Watershed characteristics also suggest that system density at various distances from surface waters is similar (i.e., as a general rule, development is not concentrated adjacent to streams). Accordingly, no spatial analysis was conducted to attempt to allocate different load deliveries based on proximity to surface waters, as has been done in other water quality modeling exercises (e.g., High Rock Lake). The attenuation rates used therefore represent watershed-wide averages.

The literature regarding the importance of horizontal separation distance on TN delivery from decentralized systems is not conclusive. Although it appears that an extremely low first order denitrification rate applied over the travel distance between the system and receiving surface water is applicable, the potential TN reduction associated with this "background" denitrification is small, being limited by prevailing conditions that are inhospitable for denitrification. More important than travel distance/time *per se* are landscape-scale characteristics and land uses between systems and receiving surface waters. Intact riparian areas (particularly forested riparian areas), for example, have demonstrated a high capacity for denitrification of nitrate plumes associated with septic systems and other sources. As indicated previously, the watershed-wide attenuation rate applied implicitly includes the mechanisms described and is sufficient for the purposes of this study. However, it would be appropriate to consider landscape characteristics, surface water proximity, and a host of other nitrogen loading "risk" factors when considering how to prioritize systems for remediation or retrofit. Such analyses will be more feasible and meaningful when approached at the subwatershed or smaller scale.

2.7.6 Malfunction Load Estimate

Additional load delivery associated with seasonally malfunctioning soil treatment systems was estimated by applying a malfunction loading factor to the total load reduction estimates (i.e., baseline load minus the delivered load). The malfunction loading factor was calculated by applying county-wide malfunction rate estimates (typically provided by LHDs) over an assumed *average* system malfunction profile. The malfunction profile assumes that, on average, a "malfunctioning" system results in surfacing effluent for a total of four weeks (two weeks to identify the malfunction and two weeks to mitigate it). It was additionally assumed that malfunctioning systems deliver 50 percent of their TN and TP load when surfacing. Finally, it was assumed that all malfunctioning systems malfunction only during the 13 week winter season when evapotranspiration is lowest.

So, for an example county with a 10 percent reported malfunction rate, the loading factor would be (0.1 x 4 x 0.5) / 13 = 0.0154. This loading factor was then multiplied by the load reduction estimates for all system types except SFR NPDES to determine the added load resulting from malfunctioning systems. This load is only applied during the winter season (December 21 – March 22).

In contrast to other areas in North Carolina, per discussion with the On-Site Water Protection Branch staff at the NC Department of Public Health, illicit discharges (e.g., graywater or blackwater straightpipes) are not believed to be significant in the Jordan Lake watershed and therefore have not been separately considered in the decentralized system representation.

2.7.7 Time Series Pollutant Load Estimate

Model inputs for decentralized wastewater systems were estimated for two time series: year 2000 and year 2010 (based on census population data availability). Logic for determining the distribution of the (speciated) pollutants of interest is summarized in Table 2-28. The year 2000 load estimates will be used in the model from January 1, 1997 through December 31, 2001 (baseline period) and the year 2010 load estimates are used in the model from January 1, 2002 through September 30, 2012.

Table 2-28. Pollutant Speciation Assumptions

Pollutant Species	Applicable Systems
Ammonia-N	Predominant form of nitrogen from malfunctioning soil treatment systems and SFR NPDES systems
NOx-N	Predominant form of nitrogen from functioning systems
Organic N	No contribution (converted to ammonia in septic tank)
Orthophosphate	No contribution from functioning soil treatment systems; predominant form of phosphorus load from malfunctioning soil treatment systems and SFR NPDES systems
Organic phosphorus	No contribution
CBOD	No contribution (not a pollutant of concern)
TSS	No contribution
DO	Low/zero DO in groundwater
Temperature	Same as the constant groundwater temperature

An example calculation worksheet for a hypothetical subwatershed containing 2,926 people served by decentralized systems is summarized in Table 2-29 (only TN calculations are shown) and Table 2-30 shows the model input parameters for the same hypothetical subwatershed.

Table 2-29. Example TN Load Worksheet for Single Subwatershed

Facility	System	Number	Design Flow (gpd)	Load Factor	TN Loads (grams per day)				
					Influent	System Eff.	Delivered	Malfunction	Total Winter
SFR	SS-Conventional	1,200	432,000	0.8441	33,833	16916	3383	468.9	3,852.2
SFR	SS-LPP	100	36,000	0.0703	2,819	846	169	40.8	210.0
SFR	SS-Pretreatment	8	2,880	0.0056	226	79	16	3.2	19.0
SFR	Non Discharge	10	3,600	0.0070	282	56	11	4.2	15.4
Non-SFR	SS-Conventional	4	12,000	0.0234	940	470	94	13.0	107.0
Non-SFR	SS-LPP	2	6,000	0.0117	470	141	28	6.8	35.0
Non-SFR	SS-Pretreatment	1	3,000	0.0059	235	82	16	3.4	19.8
Non-SFR	Non Discharge	2	12,000	0.0234	940	188	38	13.9	51.5
SFR	NPDES	12	4,320	0.0084	338	220	220	1.8	221.7
Total for Subwatershed			511,800		40082	18998	3976	556	4532

Table 2-30. Example Decentralized Wastewater Input Data for Single Subwatershed

Model Input	March 21-December 20		December 21-March 20	
Flow	175,560 gpd	0.27 cfs	175,560 gpd	0.27 cfs
Ammonia-N	220 gm/d	0.33 mg/l	776 gm/d	1.17 mg/l
NOx-N	3756 gm/d	5.65 mg/l	3756 gm/d	5.65 mg/l
Orthophosphate	41 gm/d	0.06 mg/l	188 gm/d	0.28 mg/l

2.8 Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) can provide intermittent loads of nutrients into the system. In some cases, SSOs have been large; however, large overflows occur only very infrequently, so they are not believed to constitute a significant part of the nutrient mass balance.

DWQ provided Tetra Tech with a list of SSO events, from 1995 through 2012, from the BasinWide Information Management System (BIMS) database they maintain. Included in the list are date, estimated volume, an indication of whether or not the spill reached a waterbody, and general, non-specific location information (e.g. a pump station name or a street name).

The City of Durham provided Tetra Tech with a list of sewer spill reports for their jurisdiction in the Jordan Lake watershed from 1997 through 2012. Included in the list are date, volume, non-specific location information, and the waterbody that the spill would have impacted.

Orange Water and Sewer Authority provided Tetra Tech with a list of reportable sewer overflows in their service area from 2001 through 2012. Included in the list are date, volume, volume reaching surface waters, general location information, and latitude/longitude.

SSOs are not explicitly included in the model; however, water quality observations were checked against the record of major spills without clear result. Most spills in the watershed are reported as 400,000 gallons or less, which equates to only 0.62 cfs on a daily basis – too little to show a clear signal in most monitored streams. In many cases, monitoring data are lacking immediately following spills. Some of the largest spills to monitored watersheds occurred near the Triangle WWTP on Northeast Creek, with a spill of 6 million gallons on 3/18/1998 and another of 1.6 million gallons on 7/1/1997. There is no downstream monitoring at B3660000 corresponding to the 1998 event. On 7/2/1997 this station reported 0.21 mg/L ammonia N, 2.6 mg/L total N, and 0.41 mg/L total P – all of which are within the normal range for this station. Based on these observations, omission of direct representation of SSOs in the model appears appropriate.

In sum, insufficient data are available to characterize SSOs on a watershed-wide basis, and inclusion of SSOs does not appear to be needed to improve model calibration. A jurisdiction that had detailed information on SSO volumes over time might be able to request a nutrient reduction credit for eliminating such events.

2.9 Water Withdrawals

Information on water withdrawals is more difficult to obtain than information on discharges. However, the OASIS water supply model of the Cape Fear River Basin (Hydrologics, 2009) contains information for nine water withdrawals upstream of B. Everett Jordan Reservoir.

Water withdrawals are input into the LSPC model in the same manner as point sources but with a negative flow and a zero load. The water withdrawals that are included in the LSPC model based on data from the OASIS model are identified in Table 2-31 and Figure 2-29. All facilities have provided average daily water withdrawal by month and year for the period of record January 2004 through December 2011. Most have also provided permitted capacity and the year in which operations started. Data gaps less than three months had the before and after gap values averaged and supplied in place of the missing data. The long-term monthly average was used to extend the period of record to January 1, 1994 through December 31, 2012 for model simulation.

Table 2-31. Water Withdrawal Information Obtained from the OASIS Model

Water System Name	PWSID	Permitted Capacity (MGD)	Source Water	LSPC SWS ID
Reidsville Water Supply via the Reidsville WTP	02-79-020	9	Lake Reidsville	191
Burlington Water Supply via the Ed Thomas WTP	02-01-010	16	Stony Creek Reservoir	197
Burlington Water Supply via the J.D. Mackintosh WTP	02-01-010	18	Mackintosh Reservoir	132
Greensboro Water Supply via the N.L. Mitchell WTP	02-41-010	30	Brandt Reservoir	170
Greensboro Water Supply via the Lake Townsend WTP	02-41-010	35	Lake Townsend	168
Graham Water Supply via the Graham/Mebane WTP	02-01-015	12	Graham Mebane Reservoir	209
OWASA Cane Creek Water Supply	03-68-010	N/A	Cane Creek Reservoir	217
OWASA University Lake Water Supply	03-68-010	N/A	University Lake	229
Pittsboro Water Supply via the Town of Pittsboro WTP	03-19-015	2	Haw River	105

N/A means the information was not available in the OASIS data

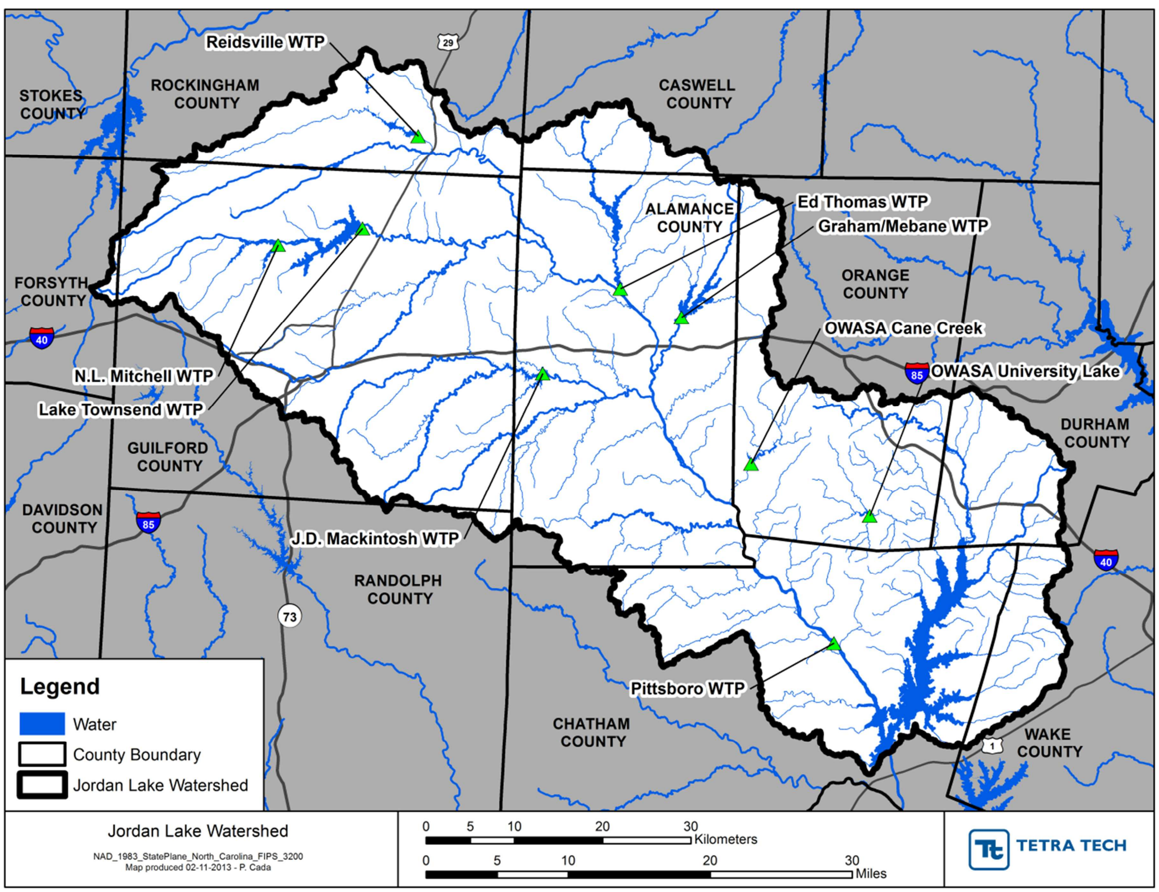


Figure 2-29. Water Withdrawal Locations

3 Calibration and Corroboration Process

3.1 Model Quality Objectives

Given the inherent errors in input and observed data and the approximate nature of model formulations, absolute criteria for watershed model acceptance or rejection are not generally considered appropriate by most modeling professionals. And yet, most decision makers want definitive answers to the questions—"How accurate is the model?" and "Is the model good enough for this evaluation?" Consequently, the current state of the art for model evaluation is to express model results in terms of ranges that correspond to "very good", "good", "fair", or "poor" quality of simulation fit to observed behavior, as summarized in Tetra Tech (2012a). These characterizations inform appropriate uses of the model: for example, where a model achieves a good to very good fit, decision-makers often have greater confidence in having the model assume a strong role in evaluating management options. Conversely, where a model achieves only a fair or poor fit, decision makers may assume a much less prominent role for the model results in the overall weight-of-evidence evaluation of management options.

The intended uses of this LSPC model application focus on accurately estimating baseline nutrient loads by regulated entity or jurisdiction for the purpose of establishing load allocations under the Jordan Lake Rules. As such, the ability of the models to represent the relative contributions of different source areas is of greatest importance, while obtaining a precise estimate of loading time series is of less direct interest. Ideally, the models should attain tight calibration to observed data; however, a less precise calibration can still provide useful information. The general acceptance criterion for models to be applied in this project is to achieve a quality of fit of "good" or better. In the event that this level of quality is not achieved on some or all measures the model may still be useful; however, a detailed description of its potential range of applicability will be provided.

3.1.1 Hydrology Performance Targets

As provided in the Quality Assurance Project Plan (Tetra Tech, 2012a), a variety of watershed model performance targets have been documented in the literature, including Donigian et al. (1984), Lumb et al. (1994), and Donigian (2000). Based on these references and past experience, the HSPF/LSPC performance targets for simulation of the water balance components are summarized in Table 3-1. Statistics are calculated using average daily flows (both observed and simulated) unless otherwise indicated by the statistic name (e.g., winter volume error is calculated using summed flow from January through March). Monthly Nash-Sutcliffe coefficient of model fit efficiency was added as an overall indicator of seasonal hydrology performance. Three measures were selected as being the most critical for evaluating performance at each gage – error in total volume (ETV), error in the 10% highest flow volumes (E10%), and the monthly Nash-Sutcliffe coefficient (NSE). (Error in the 10% highest flow volumes was selected as preferable to storm volume error, since storm volume estimation is influenced by hydrograph separation method and much of the storm hydrograph information is lost when daily observed flow is used.) In the performance summary tables that follow, the error statistics for the critical components are color-coded as follows:

- Blue indicates the value lies within the "very good" range
- Green indicates the value lies within the "good" range
- Yellow indicates the value lies within the "fair" range
- Orange indicates the value lies within the "poor" range.

It is important to clarify that the tolerance ranges are intended to be applied to mean values, and that individual events or observations may show larger differences and still be acceptable.

Table 3-1. Performance Targets for LSPC Hydrologic Simulation (Magnitude of Annual and Seasonal Relative Mean Error (*RE)*; Daily and Monthly R^2)

Model Component	Code	Very Good	Good	Fair	Poor
1. Error in total volume	ETV	≤ 5%	5 - 10%	10 - 15%	> 15%
2. Error in 50% lowest flow volumes	E50%	≤ 10%	10 - 15%	15 - 25%	> 25%
3. Error in 10% highest flow volumes	E10%	≤ 10%	10 - 15%	15 - 25%	> 25%
4. Error in storm volume	EST	≤ 10%	10 - 15%	15 - 25%	> 25%
5. Winter volume error	EW	≤ 15%	15 - 30%	30 - 50%	> 50%
6. Spring volume error	ES	≤ 15%	15 - 30%	30 - 50%	> 50%
7. Summer volume error	ESU	≤ 15%	15 - 30%	30 - 50%	> 50%
8. Fall volume error	EF	≤ 15%	15 - 30%	30 - 50%	> 50%
9. Monthly NSE*	NSE	> 0.85	> 0.75	> 0.65	≤ 0.65
10. R^2 monthly values	R2M	> 0.85	> 0.75	> 0.65	≤ 0.65
11. R^2 daily values	R2D	> 0.80	> 0.70	> 0.60	≤ 0.60

* Nash-Sutcliffe Coefficient of Efficiency

3.1.2 Water Quality Performance Targets

As provided in the QAPP (Tetra Tech, 2012a), relative error performance targets for water quality simulation with HSPF/LSPC are also provided by Donigian (2000) and are shown in Table 3-2. The measures were calculated from observed and simulated daily values (paired on the same date), and were applied only in cases where there were a minimum of 20 observations. Measures were calculated for mean and median relative errors for both concentrations and loads. For the paired loads, the values were calculated from the product of average daily concentration and average daily flow. The QAPP provides greater detail regarding the calculation of relative errors.

Similar to hydrology, a table cell color code scheme has been utilized to aid in the presentation of the model performance results. The color blue indicates the value lies within the “very good” range; green indicates the value lies within the “good” range; yellow indicates the value lies within the “fair” range; and finally orange indicates the value lies within the “poor” range. The colors shown in Table 3-2 are used below in the Water Quality Calibration and Corroboration Performance Evaluations sections.

Table 3-2. Performance Targets for LSPC Water Quality Simulation (Magnitude of Annual and Seasonal Relative Average Error (*RE*) on Daily Values)

Model Component	Very Good	Good	Fair	Poor
1. Suspended Sediment	≤ 20%	20 - 30%	30 - 45%	> 45%
2. Nutrients	≤ 15%	15 - 25%	25 - 35%	> 35%

3.2 LSPC Model Setup

The LSPC water quality model is setup to model Temperature, Dissolved Oxygen, Carbonaceous Biochemical Oxygen Demand (CBOD), Ammonia (NH3), Nitrate+Nitrite (NOx), Organic Nitrogen (Org-N), Orthophosphate (PO4), Organic Phosphorus (Org-P), Total Suspended Solids (TSS), Phytoplankton, Chlorophyll *a*, and Benthic Algae. From the species of nitrogen and phosphorus both Total Nitrogen (TN) and Total Phosphorus (TP) can be calculated for comparison against observed water quality data.

3.2.1 Reach Group

For the instream water quality simulation, LSPC provides the ability to parameterize instream biochemical processes, for the modeled reaches, by assigning them to reach groups. Assigning reaches into groups allows for the assignment of unique values, for each reach group, for certain LSPC parameters. The parameters that can be assigned differently by reach group include: sediment bed storage parameters, cohesive and non-cohesive suspended sediment variables for instream transport, temperature for stream groups, bed heat conduction parameters, land to stream mapping (non-point nutrient loading speciation), variables associated with BOD sinking, decay, and benthic release, variables for dissolved oxygen reaeration, benthic oxygen demand, oxygen scour, all biochemical nutrient transformation parameters, and all plankton growth, death and transport parameters. In LSPC, reach group is analogous to the RCHRES block in HSPF. A detailed description of relevant instream and transport algorithms is presented in the HSPF (v12) User's Manual (Bicknell et al., 2005).

3.2.2 Water Temperature

Instream temperature is an important parameter for simulating biochemical transformations. The LSPC/HSPF modules used to represent water temperature include PSTEMP (soil temperature) and HTRCH (heat exchange and water temperature).).

Simulation of soil temperature is accomplished by using three layers: surface, upper subsurface, and groundwater subsurface. The surface layer is the portion of the land segment that determines the overland flow water temperature. The upper subsurface layer determines interflow temperature while the groundwater subsurface layer determines groundwater temperature. Surface and upper subsurface layer temperatures are estimated by applying a regression equation relative to measured air temperature. The groundwater subsurface temperatures are supplied a temperature which reflects the mean average earth temperature for north central North Carolina.

Coefficients for the surface and upper sub-surface temperature regression equations were obtained from a detailed calibration exercise previously conducted for the Georgia Automated Environmental Monitoring Network stations at Ellijay, Georgia as part of the Carters Lake TMDL for the Georgia Environmental Protection Division. Data used included the measured daily average surface layer soil temperature and measured air temperature.

Soil temperature is only used to determine the water temperature of the three different flow paths (surface outflow, upper subsurface/interflow outflow, lower subsurface/groundwater outflow) as the water is contributing to stream flow. Once the water is in the stream, the temperature is impacted by mechanisms that can increase or decrease the heat content of the water and these mechanisms are dependent on the weather forcing file (*.air). Mechanisms which can increase the heat content of the water are absorption of solar radiation, absorption of long-wave radiation, and conduction-convection. Mechanisms which decrease the heat content are emission of long-wave radiation, conduction-convection, and evaporation (Bicknell et al. 2005).

3.2.3 Dissolved Oxygen

LSPC simulates dissolved oxygen by using algorithms identical to those in the Hydrologic Simulation Program FORTRAN (HSPF). The LSPC/HSPF modules used to represent dissolved oxygen include PWTGAS (pervious water temperature and dissolved gas concentrations), IWTGAS (impervious water temperature and dissolved gas concentrations), and OXRX (primary instream DO and CBOD balances). A detailed description of relevant temperature algorithms is presented in the HSPF (v12) User's Manual (Bicknell et al. 2005).

In addition to instream transformations, which either consume or produce dissolved oxygen, the dissolved oxygen simulation is sensitive to stream temperature, which controls the saturation concentration of dissolved gases, and atmospheric reaeration. Atmospheric reaeration rates depend on water temperature, water depth, water velocity, and surface area.

3.2.4 Sediment

LSPC models sediment using algorithms identical to those in the Hydrologic Simulation Program FORTRAN (HSPF). The LSPC/HSPF modules used to represent sediment include SEDMNT (pervious production and removal of sediment), SOLIDS (accumulation and removal of solids on impervious land), and SEDTRN (transport and behavior of inorganic sediment in streams). A detailed description of relevant sediment algorithms is presented in the HSPF (v12) User's Manual (Bicknell et al., 2005). In brief, SEDMNT simulates detachment of sediment from the soil matrix by rain drop impact, reattachment into the matrix, and transport of detached sediment by overland flow energy. Overland flow can also cause gully scouring in which the material available for transport is not limited by raindrop detachment. SOLIDS simulates sediment availability and washoff from impervious surfaces using a buildup/washoff formulation in which solids accumulate at a specified buildup rate towards an asymptotic limit and are washed off and removed as a function of flow energy. The upland components consider only a single sediment size class, but this is partitioned at the stream edge into sand, silt, and clay fractions. SEDTRN simulates these size classes within the stream, including deposition and scour. The sand fraction is simulated as non-cohesive, with the rate of transport expressed as a power function of flow. Silt and clay are simulated as cohesive sediments, for each of which there is a critical shear stress for deposition and a critical shear stress for scour.

3.2.5 Nutrients and Plankton

LSPC models nutrients and plankton by using algorithms identical to those in the Hydrologic Simulation Program FORTRAN (HSPF). The LSPC/HSPF modules used to represent nutrients and plankton include PQUAL (quality constituent loading from pervious land), IQUAL (quality constituent loading from impervious land), NUTRX (primary inorganic nitrogen and phosphorus balances instream), and PLANK (plankton populations, organic nutrients, and associated reactions instream). A detailed description of relevant sediment algorithms is presented in the HSPF (v12) User's Manual (Bicknell et al., 2005).

PQUAL can simulate loading from the land surface via a buildup/washoff process or as a function of the movement of sediment. PQUAL also simulates subsurface loading as a function of monthly concentration specifications. IQUAL simulations for impervious surfaces also use either a buildup/washoff formulation or a sediment potency approach.

Four nutrient constituents (Organic Matter, Ammonia-N, Nitrate+Nitrite-N and orthophosphate-P) are represented in the Jordan watershed model. Organic matter and orthophosphate P are simulated using a sediment potency approach for pervious lands and a buildup/washoff approach for impervious lands. In contrast to these constituents, inorganic nitrogen is highly soluble and loading in surface runoff may occur independently of sediment movement (particularly where fertilizer is applied). Further, much of the nitrate load in surface runoff represents input from atmospheric deposition. Therefore, inorganic nitrogen loading from pervious surfaces is represented via a buildup-washoff approach.

Total organic matter load – generally representing humus, leaf litter, other detritus, and particulate and dissolved organic compounds - is partitioned at the edge of the stream reach into labile and refractory organic phosphorus, organic nitrogen, and organic carbon using stoichiometric ratios based on the chemical composition of forest soils (as forest is the largest land use in the basin). Within the stream reaches, LSPC uses carbonaceous biochemical oxygen demand (CBOD) as the primary state variable for labile organic matter. Totals for refractory organic carbon, organic phosphorus, and organic nitrogen are tracked and updated.

The stoichiometry of organic matter is specified by flow path. The fractions used in the model are shown in Table 3-3. As an example, a pound of organic matter running off impervious surface would produce 0.2 pounds (20%) of BOD into the receiving reach.

Table 3-3. Organic Matter Fractionation parameter values by Flow Path and Constituent

Flow Path	BOD Fraction	Organic Nitrogen Fraction	Organic Phosphorus Fraction	Organic Carbon Fraction
Impervious surface flow	20.0%	1.8%	0.8%	55.0%
Pervious surface flow	10.0%	3.0%	0.8%	60.0%
Pervious land interflow	15.0%	3.0%	0.5%	60.0%
Pervious land groundwater flow	15.0%	3.0%	0.5%	60.0%

Within lakes, rivers, and streams, the model undertakes a full simulation of nutrients and eutrophication kinetics, including dissolved oxygen and biochemical oxygen demand balances, organic and inorganic nutrient cycling, and both planktonic and benthic algal populations. Key processes for nutrients include: nitrification, denitrification, adsorption/desorption of ammonia and ortho-phosphorus, assimilation of nutrients by algae, and mineralization of organic materials to produce inorganic nitrogen and phosphorus.

3.3 Hydrologic Calibration Process

3.3.1 Flow Gaging

Stream flow gaging data were obtained from the United States Geological Survey (USGS) National Water Information System (NWIS) and were assumed to be quality assured. Daily average flow data were downloaded for each station selected for model calibration and corroboration. QA/QC was performed by spot checking a handful of the data points downloaded for each station. For each station, the data were then transferred from the download spreadsheet to an internal Tetra Tech tool called HydroCal, which is used for comparing simulated and observed flows. QA/QC included checking first and last values plus a subset of values in between to ensure that data were transferred accurately to HydroCal workbooks. Flow data were downloaded in January 2013, at which time the October, November and December data in the year of 2012 for all flow gages was indicated to be provisional data and subject to revision. Additionally, gages 02097517 and 0209782609 had provisional data starting on 10/1/2011 that continued on as provisional data through 12/31/2012.

A total of 22 stations were selected for use in calibrating and corroborating the Jordan Lake watershed model. The stations were categorized as either *core* or *non-core* according to their relative importance to the calibration process; core stations were given priority, while non-core stations had lower priority to achieve specified hydrology calibration targets. First, stations were identified representing drainages not influenced by major NPDES point sources or upstream impoundments. A cross section of these stations across geologic zones was selected to become core stations. In addition, three stations with significant upstream drainage area were chosen as core stations (one on Reedy Fork and two on the Haw River), since proper simulation of flow in the Haw River is needed to estimate nutrients loads entering Jordan Lake. The gage on Northeast Creek in Durham County was also considered a core station; while it is influenced by a major WWTP, it drains an urbanized area and has an important role for delivering flow and nutrient loads to the upper portion of Jordan Lake. The remaining stations were categorized as non-core stations; some drain headwaters areas but were duplicative of other nearby core stations. Table 3-4 provides the list of stations used and core/non-core assignment. Figure 2-1 shows the location of the core and non-core stations.

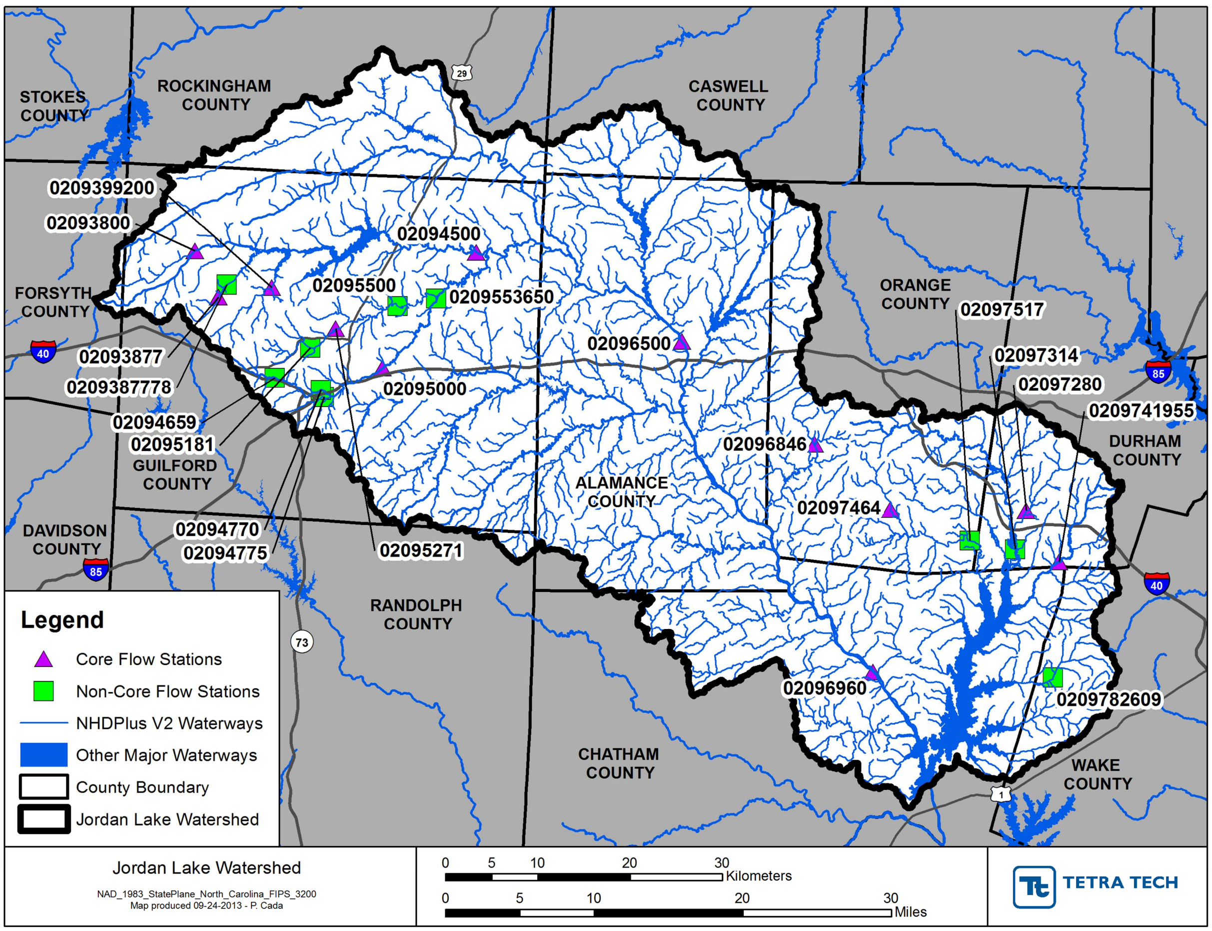


Figure 3-1. Location of Hydrology Calibration Gages in the Jordan Lake Watershed

Table 3-4. USGS Flow Gaging Stations used for the Jordan Lake Watershed Model

Site Number	Site Name	Core
02093800	REEDY FORK NEAR OAK RIDGE, NC	Yes
02093877	BRUSH CREEK AT MUIRFIELD RD AT GREENSBORO, NC	Yes
0209387778	BRUSH CREEK AT FLEMING ROAD AT GREENSBORO, NC	No
0209399200	HORSEPEN CREEK AT US 220 NR GREENSBORO, NC	Yes
02094500	REEDY FORK NEAR GIBSONVILLE, NC	Yes
02094659	SOUTH BUFFALO CREEK NR POMONA, NC	No
02094770	SOUTH BUFFALO CREEK AT US 220 AT GREENSBORO, NC	No
02094775	RYAN CREEK BELOW US 220 AT GREENSBORO, NC	No
02095000	SOUTH BUFFALO CR NEAR GREENSBORO, NC	Yes
02095181	N BUFFALO CR AT WESTOVER TERRACE AT GREENSBORO, NC	No
02095271	NORTH BUFFALO CREEK AT CHURCH ST AT GREENSBORO, NC	Yes
02095500	NORTH BUFFALO CREEK NEAR GREENSBORO, NC	No
0209553650	BUFFALO CREEK AT SR2819 NR MCLEANSVILLE, NC	No
02096500	HAW RIVER AT HAW RIVER, NC	Yes
02096846	CANE CREEK NEAR ORANGE GROVE, NC	Yes
02096960	HAW RIVER NEAR BYNUM, NC	Yes
02097280	THIRD FORK CR AT WOODCROFT PARKWAY NR BLANDS, NC	Yes
02097314	NEW HOPE CREEK NEAR BLANDS, NC	No
0209741955	NORTHEAST CREEK AT SR1100 NR GENLEE, NC	Yes
02097464	MORGAN CREEK NEAR WHITE CROSS, NC	Yes
02097517	MORGAN CREEK NEAR CHAPEL HILL, NC	No
0209782609	WHITE OAK CR AT MOUTH NEAR GREEN LEVEL, NC	No

The available gages have an uneven spatial coverage. As a result of funding and requirements relative to major reservoirs and point source discharges, the majority of the gages are clustered around the upper arm of Jordan Lake or in the Greensboro area, with relatively few gages in the center of the watershed.

Many factors were considered during the calibration process. Gage period of record is important, since not all of the gages were active during the entire calibration and corroboration time periods. Figure 3-2 provides a comparison of flow monitoring available for the corroboration and calibration time periods for each station. Other factors influence flow records; point sources can be problematic since effluent volume monitoring data may have gaps, may be aggregated to monthly averages, and/or may not have been measured accurately. Upstream impoundments with active management of water levels introduce uncertainty since detailed time series for water management were not used in the model. Upstream drainage area, land use characteristics, and soil properties also play a significant role in defining hydrologic response to meteorology. Table 3-5 provides contributing area, average point source contribution, and whether the gage is influenced by a major reservoir, while Table 3-6 shows percent impervious area and relative proportion of the two HSG classes respectively for the 2001 and 2010 time periods.

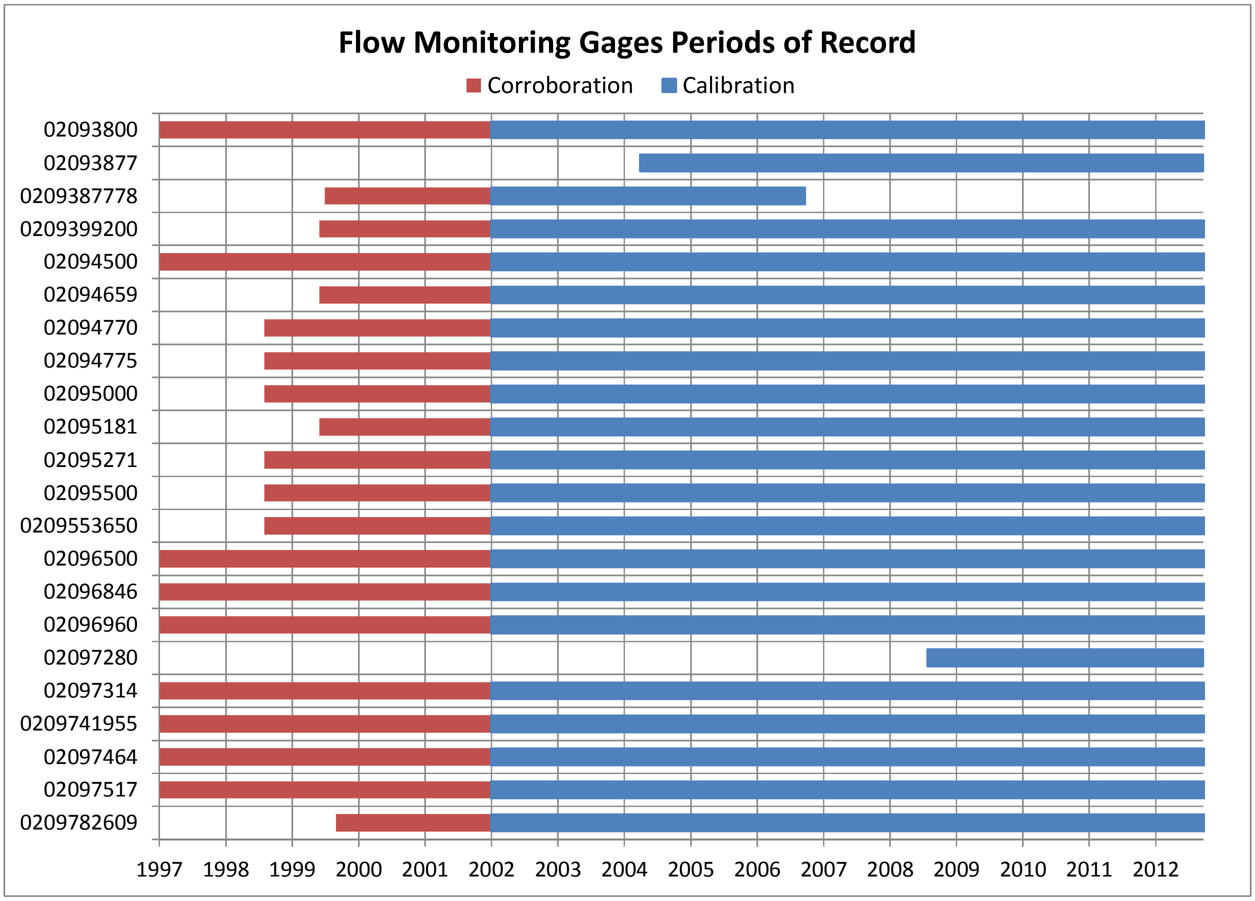


Figure 3-2. Availability of Flow Monitoring Data Used for Calibration and Corroboration

Table 3-5. Drainage Area, Point Source Volume, and Reservoir Influence Upstream of Flow Monitoring Stations

Site Number	Upstream Contributing Area (mi^2)	Point Source Contribution (MGD)	Significant Upstream Impoundment
02093800	20.2		
02093877	5.5		
0209387778	9.2		
0209399200	16.1		
02094500	132	0.1	Yes
02094659	7.3		
02094770	15.3		
02094775	4.3		
02095000	34.4		
02095181	9.8		
02095271	14.6		
02095500	37.1	17.3	
0209553650	88.8	57.3	
02096500	603	77.6	Yes
02096846	7.6		
02096960	1,273	95.9	Yes
02097280	16.6		
02097314	75.9	20.0	
0209741955	21.1	12.0	
02097464	8.3		
02097517	40.6	7.5	Yes
0209782609	12.2		

Table 3-6. Percent Imperviousness and Proportion of HSG Class Upstream of Flow Monitoring Stations

Site Number	2001 Land Use/Land Cover			2010 Land Use/Land Cover		
	Percent Impervious	HSG Class 1[a]	HSG Class 2[b]	Percent Impervious	HSG Class 1[a]	HSG Class 2[b]
02093800	4.0%	84%	12%	8.2%	80%	11%
02093877	9.8%	78%	12%	21.9%	67%	11%
0209387778	8.6%	81%	11%	19.1%	71%	10%
0209399200	12.3%	54%	34%	24.3%	47%	29%
02094500	5.1%	80%	15%	10.7%	75%	14%
02094659	19.5%	44%	36%	33.4%	36%	31%
02094770	19.6%	22%	58%	30.2%	18%	52%
02094775	15.1%	1%	84%	27.0%	1%	72%
02095000	18.1%	12%	70%	28.0%	10%	62%
02095181	11.1%	62%	26%	19.3%	56%	24%
02095271	12.2%	47%	41%	20.0%	42%	37%
02095500	12.2%	39%	49%	18.8%	35%	46%
0209553650	13.2%	25%	62%	20.7%	23%	57%
02096500	5.0%	56%	39%	9.6%	53%	37%
02096846	0.9%	74%	25%	3.7%	72%	24%
02096960	4.0%	54%	42%	8.0%	52%	40%
02097280	19.6%	27%	53%	31.4%	24%	44%
02097314	10.4%	49%	41%	17.0%	47%	36%
0209741955	13.3%	32%	54%	19.9%	30%	50%
02097464	1.2%	71%	27%	4.4%	69%	27%
02097517	5.7%	71%	24%	10.8%	67%	22%
0209782609	5.6%	70%	25%	13.6%	63%	23%

a. HSG A+B in non-Triassic Basin areas, and HSG A+B+C in Triassic Basin areas
b. HSG C+D in non-Triassic Basin areas, and HSG D in Triassic Basin areas

3.3.2 Hydrologic Calibration Approach

Calibration of the HSPF model is a sequential process, beginning with hydrology, followed by the movement of sediment, and chemical water quality.

Hydrologic calibration for the Jordan Lake watershed used the standard operating procedures for the model described in Donigian et al. (1984), Lumb et al. (1994), and USEPA (2000). The general approach began with replicating the total water balance, followed by adjustments to represent the division between high flows (due mostly to surface runoff) and low flows (due mostly to subsurface flow). Fine tuning was then used to adjust the seasonal balance. Calibration performance was tracked using Tetra Tech's HydroCal spreadsheet tool, which automatically retrieves model output and generates relevant statistics and graphical comparisons.

Initial values for the hydrologic parameters were obtained from the successfully calibrated and validated High Rock Lake HSPF model created by Tetra Tech (2012b), with additional reference to Tetra Tech's LSPC model of the Goose and Crooked Creek watersheds in Mecklenburg and Union counties (Tetra Tech, 2012c). These starting values were checked for consistency with the ranges recommended in USEPA (2000), and were then varied during calibration to obtain improved fit across the entire suite of gaging stations.

Key hydrologic parameters adjusted during calibration included the following:

LZSN: The LZSN parameter in HSPF is an index of the lower zone nominal soil moisture storage (inches), where the lower zone is operationally defined as the depth of the soil profile subject to evapotranspiration losses. LZSN is related, but not equivalent to the available water capacity (AWC) of a soil. It also reflects precipitation characteristics. USEPA (2000) recommends setting initial values at one-eighth of annual mean rainfall plus 4 inches in coastal, humid, and sub-humid regions, but also notes that this formula tends to yield "values somewhat higher than we typically see as final calibrated values." The LZSN parameter plays an important role in the total water balance and in the low flow simulation. High values increase the amount of water stored in the lower zone which is subject to evapotranspiration and therefore reduces baseflow while low values decrease the amount of stored water subject to evapotranspiration and therefore increases baseflow. Values used by land use, geologic zone and hydrologic soil group are provided in Table 3-7.

Table 3-7. LZSN Values by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	*HSG A+B*	*HSG C+D*	*HSG A+B*	*HSG C+D*	*HSG A+B*	*HSG C+D*	*HSG A+B+C*	*HSG D*
Water	0	0	0	0	0	0	0	0
Developed Open Space	9	9	9	9	9.5	9.5	7.5	7.5
Row Crops	9	9	9	9	9.5	9.5	7.5	7.5
Pasture/Grassland	9	9	9	9	9.5	9.5	7.5	7.5
Scrub/Shrub	9	9	9	9	9.5	9.5	7.5	7.5
Forest	9.5	9.5	9.5	9.5	10	10	8	8
Wetland	5	5	5	5	5	5	5	5

INFILT. The INFILT parameter is an index to mean soil infiltration rate (in/hr), which controls the overall division of the available moisture from precipitation (after interception) into surface and subsurface flows. INFILT is not a maximum infiltration rate, nor an infiltration capacity term. As a result, values of INFILT used in the model are expected to be much less than published infiltration rates or permeability rates shown in the soil survey (often on the order of 1 to 10 percent of soil survey values). USEPA (2000) shows acceptable ranges of INFILT for soil hydrologic groups, ranging from a minimum of 0.01 in/hr in group D soils to a maximum of 1.0 in/hr in group A soils. Values used by land use, geologic zone, and hydrologic soil group are provided in Table 3-8.

Table 3-8. INFILT Values by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007
Developed Open Space	0.08	0.02	0.1	0.015	0.12	0.007	0.07	0.0055
Row Crops	0.165	0.045	0.1	0.015	0.12	0.007	0.06	0.0035
Pasture/Grassland	0.16	0.040	0.1	0.015	0.12	0.007	0.06	0.0035
Scrub/Shrub	0.17	0.041	0.1	0.015	0.12	0.007	0.06	0.0035
Forest	0.18	0.045	0.1	0.015	0.12	0.007	0.09	0.0055
Wetland	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007	0.00007

AGWRC and KVARY: The AGWRC parameter is the groundwater recession rate (/day) and is specified as the ratio of current groundwater discharge to that from 24 hours earlier. The overall watershed recession rate is a complex function of watershed conditions, including climate, topography, soils and land use (USEPA, 2000). The KVARY parameter modifies the groundwater recession equation to describe a non-linear recession rate and is used when the observed groundwater recession shows a seasonal variability with a faster recession during wet periods and a slower recession during dry periods (USEPA, 2000). The groundwater recession coefficients were initially set based on baseflow separation and graphical analysis of simulated and observed recession rates and modified throughout the course of calibration to keep simulated baseflow recession in line with observed baseflow recession (Table 3-9 and Table 3-10).

Table 3-9. AGWRC Values by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
Developed Open Space	0.96	0.96	0.95	0.95	0.91	0.91	0.93	0.93
Row Crops	0.97	0.97	0.95	0.95	0.91	0.91	0.93	0.93
Pasture/Grassland	0.97	0.97	0.95	0.95	0.91	0.91	0.93	0.93
Scrub/Shrub	0.98	0.98	0.95	0.95	0.91	0.91	0.93	0.93
Forest	0.985	0.985	0.96	0.96	0.92	0.92	0.94	0.94
Wetland	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999

Table 3-10. KVARY Values by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0	0	0	0	0	0	0	0
Developed Open Space	0	0	0	0	3	3	1	1
Row Crops	0	0	0	0	3	3	1	1
Pasture/Grassland	0	0	0	0	3	3	1	1
Scrub/Shrub	0	0	0	0	3	3	1	1
Forest	0	0	0	0	4	4	1	1
Wetland	0	0	0	0	0	0	0	0

LZETP: The LZETP parameter is a coefficient to define the evapotranspiration opportunity from the soil lower zone and is a function of cover type. It is essentially a crop coefficient that modifies the available potential evapotranspiration to reflect vegetative development stage. The parameter controls the evaporation from the lower (root) zone of the surface soil profile, which represents the primary soil moisture storage. Monthly coefficients (MON-LZETP) were specified for all land uses with the lowest values used in the winter months and the highest values used in the summer months (Table 3-11). The same values were used for each of the geologic zones and HSGs.

Table 3-11. LZETP parameter values by Land Use

Land Use	***LZETP***
Water	0.43-0.6
Developed Open Space	0.129-0.894
Row Crops	0.15-0.989
Pasture/Grassland	0.129-0.894
Scrub/Shrub	0.171-0.989
Forest	0.171-0.989
Wetland	0.171-0.989

BASETP, CEPSC, UZSN, and AGWETP – Remaining soil moisture controls. The simulated actual evapotranspiration is calculated by trying to meet the demand (PET) from five sources in the following order: 1) BASETP – Active groundwater outflow or baseflow, 2) CEPSC – Interception Storage, 3) UZSN – Upper Zone Storage, 4) AGWETP – Active Groundwater Storage, and 5) LZSN – Lower Zone Storage. The values used for BASETP are set constant at 0.03. Interception storage reflects leaf area development, and the values used for CEPSC vary monthly and are supplied in Table 3-12. The upper soil zone nominal storage UZSN is set at a constant value of 1.2 in, except in the Triassic Basin, where it is set at 1.5 in the summer and 1.0 in the winter to account for the presence of shrink-swell clays. AGWETP is set to zero except for wetland land uses, consistent with the guidance in USEPA (2000).

Table 3-12. CEPSC parameter values by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0-0		0-0		0-0		0-0	
Developed Open Space	0.05-0.15	0.05-0.15	0.05-0.15	0.05-0.15	0.05-0.15	0.05-0.15	0.05-0.15	0.05-0.15
Row Crops	0.017-0.25	0.017-0.25	0.017-0.25	0.017-0.25	0.017-0.25	0.017-0.25	0.012-0.2	0.012-0.2
Pasture/Grassland	0.01-0.098	0.01-0.098	0.01-0.098	0.01-0.098	0.01-0.098	0.01-0.098	0.01-0.078	0.01-0.078
Scrub/Shrub	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2
Forest	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2
Wetland	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2	0.013-0.2
Impervious (all)	0.05-0.2		0.05-0.2		0.05-0.2		0.05-0.2	

Initial parameterization (obtained from the High Rock Lake HSPF simulation) resulted in over-prediction at all gages during low flows and under-prediction high flows. This required reductions to INFILT and increases to LZSN in order to balance these flows. After bringing the high and low flow simulation more in-line the model was generally overestimating total volume. This required increasing the amount of simulated ET, primarily by introducing a multiplier on the specified PET to account for uncertainties in the Hamon method estimates (Table 3-13). This brought simulated total volume more in line with observed total volume and a reasonable water balance. Once these changes were made, INFILT and LZSN in concert with AGWRC and KVARY were once again optimized to improve fit. Lastly, small monthly changes in LZETP and CEPSC were employed to fine tune the calibration to better match seasonal trends.

Table 3-13. Atmospheric Forcing Files PET Multipliers

Weather File Name	Station Name	PET Multiplier
313630.air	GREENSBORO WSO AIRPORT	1
317202.air	REIDSVILLE 2 NW	1.25
313919.air	HAW RIVER 1 E	1.25
313555.air	GRAHAM 2 ENE	1.25
317924.air	SILER CITY 2 N	1.25
311677.air	CHAPEL HILL 2 W	1.5
317069.air	RALEIGH DURHAM WSFO AP	1.5
310212.air	APEX	1.25
317656.air	SANFORD 8 NE	1.5

3.4 Water Quality Calibration Process

3.4.1 Monitoring Data

Both DWQ through their Ambient Monitoring System (NCAMBNT) and the Upper Cape Fear River Basin Association (UCFRBA) have monitoring stations in the Lake Jordan watershed. Additional monitoring has been conducted by USGS and some local jurisdictions. All of the NCAMBNT and UCFRBA water quality data is stored in EPA STORET.

Water quality data were obtained from the USGS National Water Information System (NWIS) and provided by DWQ from EPA STORET, all of which sources are deemed quality assured per the QAPP. Similar to the hydrology data, USGS NWIS water quality data and associated remark codes were downloaded into an Excel spreadsheet. QA/QC was performed by spot checking a fraction of the data points downloaded for each station. Constituent data for temperature, dissolved oxygen, sediment, nutrients, and chlorophyll *a* were retrieved for each station selected to be included for calibration and corroboration. The resultant EPA STORET export was processed with Excel and put into a format that is easily transferrable to pre-established water quality calibration tools. Data codes from both the collection agency and the analyzing agency were preserved for each date and constituent. QA/QC was performed by spot checking the formatted data with the original data obtained from STORET.

There were 35 unique station locations selected for use in calibrating and validating the Jordan Lake watershed model. To aid in the presentation of the results the stations have been separated into three groups. Stations associated with USGS flow gages were of primary interest to the water quality calibration due to co-location of flow and water quality samples which provided the best opportunity for proper calculation of pollutant load, therefore have been placed in the 1st/Primary group. Stations with limited or no influence by upstream point sources were also deemed important for estimation of nonpoint pollutant contributions, and were placed in the 2^{md}/Secondary group. Finally, all station locations not in the primary or secondary groups were placed into the 3rd/Tertiary group. (Note that station B3670000 was moved from the tertiary to the secondary group to allow the results for the tertiary group to be displayed in a single page format.)

Table 3-14 provides the list of station locations used, the group that it was placed in, the general period of data located at each location and the calibration and corroboration periods used for each location. As stated in the QAPP (Tetra Tech, 2012a), for the intended applications of the model it is important to demonstrate that adequate performance is achieved for both the baseline condition (1997-2001) and current conditions through 2012. Calibration and corroboration time periods for water quality are selected as 1997-2004 or 2005-2012, or the available periods within that range. To help ensure that both time periods are fit well, some stations use 1997-2004 as the calibration period and other stations (not located downstream of the first group) use 2005-2012 as the calibration period. Figure 3-3 provides the spatial location of the primary, secondary, and tertiary station locations for water quality calibration.

Table 3-14. Water Quality Stations used for Calibration and Corroboration

Map Key	Agency	Station ID	Location	Group	Calibration Period	Corroboration Period
1	NCAMBNT	B0040000	HAW RIV AT SR 2109 NR OAK RIDGE	2nd	1997 - 2004	2005 - 2012
2	UCFRBA	B0050000	HAW RIV AT US 29 BUS NR BENAJA	2nd	1997 - 2004	2005 - 2012
3	UCFRBA	B0070010	TROUBLESOME CRK AT US 29 BUS NR REIDSVILLE	2nd	2005 - 2012	2000 - 2004
4	NCAMBNT	B0160000	LITTLE TROUBLESOME CRK AT SR 2600 NR REIDSVILLE	3rd	2005 - 2012	1997 - 2004
5	UCFRBA	B0170000	HAW RIV AT SR 2620 HIGH ROCK RD NR WILLIAMSBURG	3rd	2000 - 2004	2005 - 2012
6	NCAMBNT	B0210000	HAW RIV AT SR 1561 NR ALTAMAHAW	2nd	1997 - 2004	2005 - 2012
7	UCFRBA	B0400000	REEDY FORK AT SR 2719 HIGH ROCK RD NR MONTICELLO	1st	2005 - 2011	2002 - 2004
8	UCFRBA	B0480050	N BUFFALO CRK AT N BUFFALO CRK WWTP INFLUENT CONDUIT PIER AT GREENSBORO	2nd	2002 - 2004	2005 - 2011
9	NCAMBNT	B0540000	N BUFFALO CRK AT SR 2832 NR GREENSBORO	1st	1997 - 2004	2005 - 2012
10	UCFRBA	B0540050	N BUFFALO CRK AT SR 2770 HUFFINE MILL RD NR MCLEANSVILLE	3rd	2000 - 2004	2005 - 2012
11	UCFRBA	B0670000	S BUFFALO CRK AT SR 3000 MCCONNELL RD NR GREENSBORO	1st	2005 - 2011	2000 - 2004
12	NCAMBNT/ UCFRBA	B0750000	S BUFFALO CRK AT SR 2821 AT MCLEANSVILLE	3rd	2005 - 2012	1997 - 2004
13	NCAMBNT	B0840000	REEDY FORK AT NC 87 AT OSSIPEE	3rd	1997 - 2004	2005 - 2012
14	UCFRBA	B0850000	HAW RIV AT SR 1530 GERRINGER MILL RD NR OSSIPEE	3rd	2000 - 2004	2005 - 2010
15	NCAMBNT	B1095000	JORDAN CRK AT SR 1754 NR UNION RIDGE	2nd	1997 - 2004	2005 - 2012
16	NCAMBNT	B1140000	HAW RIV AT NC 49N AT HAW RIVER	1st	1997 - 2004	2005 - 2012
17	UCFRBA	B1200000	HAW RIV AT NC 54 NR GRAHAM	3rd	1997 - 2004	2005 - 2012
18	NCAMBNT	B1260000	TOWN BRANCH AT SR 2109 NR GRAHAM	2nd	2005 - 2012	1997 - 2004
19	UCFRBA	B1440000	HAW RIV AT SR 2158 SWEPSONVILLE RD NR SWEPSONVILLE	3rd	1997 - 2004	2005 - 2011
20	UCFRBA	B1940000	BIG ALAMANCE CRK AT NC 87 NR SWEPSONVILLE	2nd	2000 - 2004	2005 - 2011

Map Key	Agency	Station ID	Location	Group	Calibration Period	Corroboration Period
21	NCAMBNT/ UCFRBA	B1960000	ALAMANCE CRK AT SR 2116 AT SWEPSONSVILLE	2nd	1997 - 2004	2005 - 2012
22	NCAMBNT	B1980000	HAW RIV AT SR 2171 AT SAXAPAHAW	3rd	2000 - 2004	2005 - 2012
23	UCFRBA	B2000000	HAW RIV AT SR 1005 NR SAXAPAHAW	3rd	1997 - 2004	2005 - 2011
24	NCAMBNT/ UCFRBA/ USGS	B2100000 + 02096960	HAW RIV AT SR 1713 NR BYNUM	1st	1997 - 2004	2005 - 2012
25	UCFRBA	B3020000	NEW HOPE CRK AT NC 54 NR DURHAM	2nd	2000 - 2004	2005 - 2011
26	UCFRBA	B3025000	THIRD FORK CRK AT NC 54 NR DURHAM	1st	2005 - 2012	1997 - 2004
27	NCAMBNT/ UCFRBA/ USGS	B3040000 + 02097314	NEW HOPE CRK AT SR 1107 NR BLANDS	1st	1997 - 2004	2005 - 2012
28	UCFRBA	B3300000	NORTHEAST CRK AT SR 1102 SEDWICK RD NR RTP	2nd	2000 - 2004	2005 - 2011
29	NCAMBNT/ USGS	B3660000 + 0209741955	NORTHEAST CRK AT SR 1100 NR NELSON	1st	1997 - 2004	2005 - 2012
30	UCFRBA	B3670000	NORTHEAST CRK AT SR 1731 O KELLY CHURCH RD NR DURHAM	2nd	1997 - 2004	2005 - 2011
31	UCFRBA	B3899180	MORGAN CRK AT MASON FARM WWTP ENTRANCE AT CHAPEL HILL	1st	2000 - 2004	2005 - 2011
32	NCAMBNT/ UCFRBA	B3900000	MORGAN CRK AT SR 1726 NR FARRINGTON	3rd	1997 - 2004	2005 - 2012
33	USGS	02096846	CANE CREEK NEAR ORANGE GROVE, NC	1st	1997 - 2004	2005 - 2012
34	USGS	02097464	MORGAN CREEK NEAR WHITE CROSS, NC	1st	1997 - 2004	2005 - 2012
35	USGS	0209782609	WHITE OAK CR AT MOUTH NEAR GREEN LEVEL, NC	1st	2005 - 2012	1999 - 2004

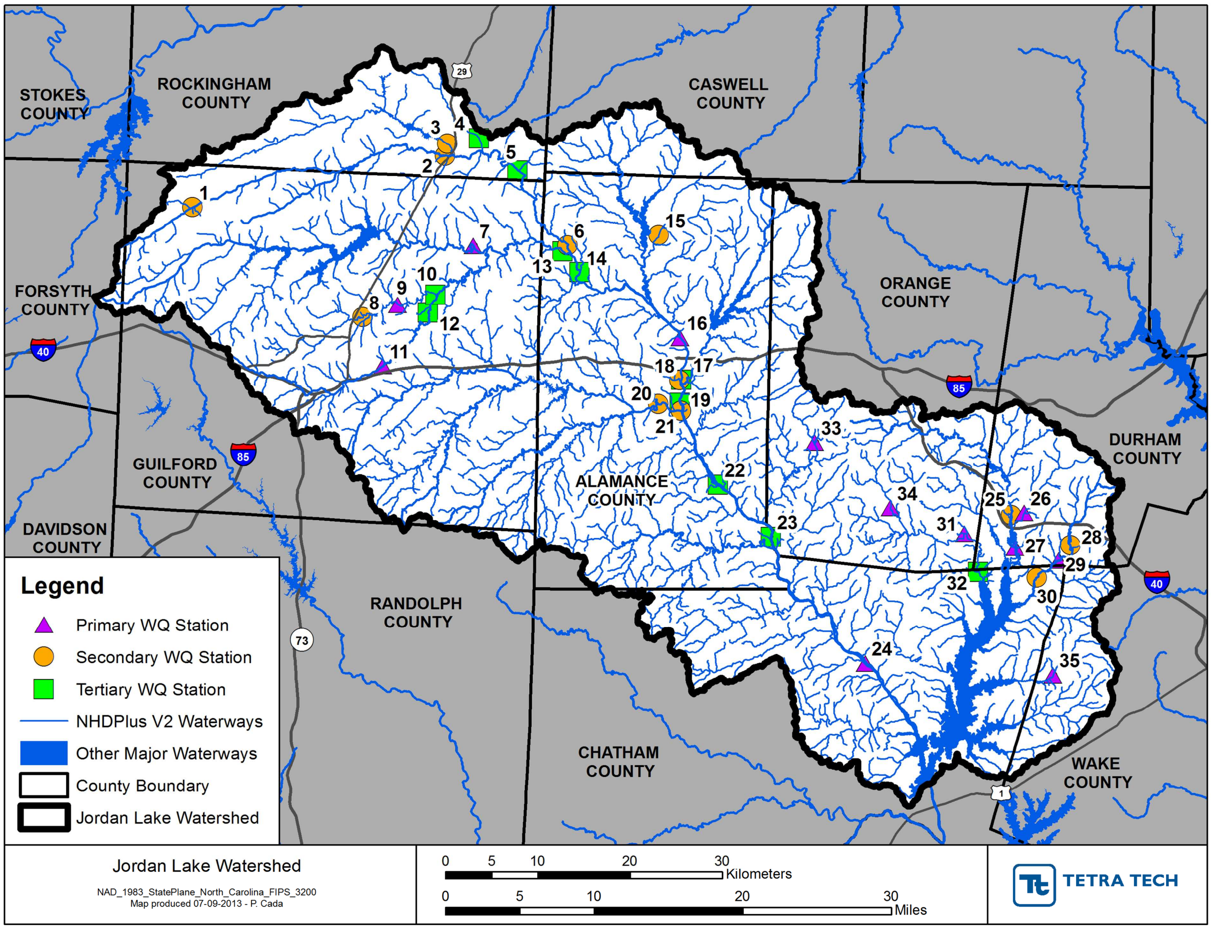


Figure 3-3. Spatial Location of Water Quality Primary, Secondary, and Tertiary Stations

Note: See Table 3-14 for key to stations.

3.4.2 Water Quality Calibration Approach

Model calibration for water quality depends on hydrology, and any uncertainties in the hydrologic calibration can be expected to propagate into the water quality simulation. Water quality calibration is also inherently more difficult than hydrology calibration. Water quality simulation must represent a complex set of multiple interacting processes. Further, the data available for water quality simulation are generally less precise and less numerous than those available for hydrologic calibration. Unlike flow, continuous measurement of water quality is not available at any monitoring station in the Jordan watershed. While significant effort and expense has been invested in water quality monitoring, results are available only for limited snapshots in time. The most intensively monitored stations have, at best, biweekly sampling. A challenge is thus to fit a continuous model to a limited number of discrete points, recognizing that differences between model predictions and observations could reflect either a substantive difference or merely a small shift in the timing of loads. A further challenge is that nutrient *load*, which is the ultimate objective of the modeling, is not directly observed, but must be inferred from limited concentration data and flow, which can introduce considerable uncertainty into the calibration target. For these reasons a perfect fit is not expected and model calibration must be evaluated using a statistical approach, as described in the QAPP (Tetra Tech, 2012a). Further, past experience with the application of similar models and best professional judgment as to reasonable ranges of model parameters must be applied.

As described above in Section 2.4.4, water quality parameters (for a given land use and HSG) can be specified separately on a geographic and geologic basis through use of group DEFIDs and the HSG numbers as follows (refer back to Figure 2-14):

- Charlotte Belt (DEFID 1)
- Upper Slate Belt (DEFID 2)
- Lower Slate Belt (DEFID 3 with HSG = 1 or 2)
- Triassic Basin (DEFID 3 with HSG= 4 or 5).

This approach provides flexibility to the model and was particularly important for the hydrologic calibration; however, it also introduces a risk of spurious over-fitting to limited data. Therefore, the majority of water quality parameters for nutrients were kept constant by land use (specifically, sediment potency, nutrient buildup, and nutrient washoff parameters were set constant by land use). Parameters controlling sediment erosion were based on average soil characteristics by HSG, based on the analysis described below, but not otherwise varied by geographic location. However, the impacts of all water quality parameters do vary with the geologic distinctions in hydrology parameters described above.

One area in which there was an evident need for geographic distinction was the background groundwater concentration pattern for nitrate-plus-nitrite N. Specifically, it was evident during the calibration that concentrations were generally lower in the Triassic Basin than in the remainder of the watershed. This likely reflects longer residence time and greater denitrification capacity in the slowly permeable soils of the Triassic Basin, and differences in concentrations were introduced accordingly.

3.4.2.1 Sediment Calibration Approach

Sediment is one of the most difficult water quality parameters to accurately simulate with watershed models because observed instream concentrations depend on the net effects of a variety of upland and stream reach processes. During calibration sediment parameters were adjusted in accordance with guidelines established in EPA BASINS Technical Note 8: *Sediment Parameters and Calibration guidance to HSP*F (USEPA, 2006) and *Sediment Calibration Procedures and Guidelines for Watershed Modeling* (Donigian and Love, 2003). Sediment calibration used a weight of evidence approach. The first step in calibration involved setting channel erosion to values that achieve a reasonable fit to observations when upland erosion is held to reasonable values consistent with the literature and soil survey data. Second, the long-term behavior of sediment in channels was constrained to a reasonable representation in which degradation or aggradation amounts are physically realistic and consistent with available local information. Finally, results from detailed local stream studies (e.g., Third Fork Creek) were used to further ensure that the model provides a reasonable representation in specific areas.

The upland parameters for sediment were related to soil and topographic properties. The LSPC model does not use the USLE for sediment simulation; however, some of the parameters used in LSPC are similar to those in the USLE. LSPC erosion parameters for pervious land covers were estimated based on a theoretical relationship between LSPC algorithms and documented soil parameters, ensuring consistency in relative estimates of erosion based on soil type and cover. LSPC calculates the detachment rate of sediment by rainfall (in tons/acre) as

$$DET = (1 - COVER) \cdot SMPF \cdot KRER \cdot P^{JRER}$$

where *DET* is the detachment rate (tons/acre), *COVER* is the dimensionless factor accounting for the effects of cover on the detachment of soil particles, *SMPF* is the dimensionless management practice factor, *KRER* is the coefficient in the soil detachment equation, *JRER* is the exponent in the soil detachment equation, which is recommended to be set to 1.81, and *P* is precipitation depth in inches over the simulation time interval. Actual detached sediment storage available for transport (*DETS*) is a function of accumulation over time and the reincorporation rate, *AFFIX*. The equation for *DET* is formally similar to the USLE equation (Wischmeier and Smith, 1978) where *RE* is the rainfall erosivity, *K* is the soil erodibility factor, *LS* is the length-slope factor, *C* is the cover factor, and *P* is the practice factor,

$$RE \cdot K \cdot LS \cdot C \cdot P.$$

USLE predicts sediment loss from one or a series of events at the field scale, and thus incorporates local transport as well as sediment detachment. For a large event with a significant antecedent dry period, it is reasonable to assume that $DET \approx DETS$ if *AFFIX* is greater than zero. Further, during a large event, sediment yield at the field scale is assumed to be limited by supply, rather than transport capacity. Under those conditions, the USLE yield from an event should approximate *DET* in HSPF.

With these assumptions, the HSPF variable *SMPF* may be taken as fully analogous to the USLE *P* factor. The complement of *COVER* is equivalent to the USLE *C* factor (i.e., (1 - *COVER*) = *C*). This leaves the following equivalence (given *JRER* = 1.81):

$$KRER \cdot P^{JRER} = RE \cdot K \cdot LS \text{, or}$$

$$KRER = RE \cdot K \cdot LS \big/ P^{1.81}$$

The empirical equation of Richardson et al. (1983) as further tested by Haith and Merrill (1987) gives an expression for *RE* (in units of MJ-mm/ha-h) in terms of precipitation:

$$RE = 64.6 \cdot a_t \cdot R^{1.81},$$

where *R* is precipitation in cm and a_t is an empirical factor that varies by location and season. As shown in Haith et al. (1992), the expression for *RE* can be re-expressed in units of metric tons/ha as:

$$RE = 0.132 \cdot 64.6 \cdot a_t \cdot R^{1.81}.$$

This relationship suggests that the HSPF exponent on precipitation, *JRER*, should be set to 1.81.

The remainder of the terms in the calculation of *RE* must be subsumed into the *KRER* term of HSPF, with a units conversion. Writing *RE* in terms of tons/acre and using precipitation in inches:

$$RE\,(tons/ac) = [0.132 \cdot 64.6 \cdot a_t] \cdot P\,(in)^{1.81} \cdot (2.54\ cm/in)^{1.81} \cdot (1\ ton/ac)/(2.24\ tonnes/ha)$$

The average value for a_t for this part of North Carolina (USLE Region 28) is 0.225 (Selker et al., 1990), yielding

$$RE = 4.629 \cdot P^{1.81}$$

The power term for precipitation can then be eliminated from the equation for *KRER*, leaving the following expression (English units) in terms of the USLE K factor:

$$KRER = 4.629 \cdot K \cdot LS$$

The *K* factor is available directly from soil surveys, while the *LS* factor can be estimated from slope, using the expression of Wischmeier and Smith (1978):

$$LS = (0.045\,L)^b \cdot (65.41 \sin^2 \theta_k + 4.56 \sin \theta_k + 0.065) \text{, where}$$

$\theta = \tan^{-1}(S/100)$, *S* is the slope in percent, *L* is the slope length (in meters), and *b* takes the following values: 0.5 for $S \geq 5$, 0.4 for $3.5 \leq S < 5$, 0.3 for $1 \leq S < 3$, and 0.2 for $S < 1$.

This approach establishes values for *KRER* that are consistent with USLE information. Sediment calibration is then pursued primarily by modifying the transport coefficient, *KSER.* It should be noted that Donigian and Love (2003) recommend setting *KRER* directly equal to the USLE *K* factor. As was seen from the discussion above, this is theoretically incorrect, although *KRER* will be proportional to *K*, depending on slope. Because a different approach is used here, the "typical" ranges for *KRER* and *KSER* cited by Donigian and Love are not applicable.

Once *KRER* is established, the primary upland calibration parameter for sediment is *KSER*, which determines the ability of overland flow to transport detached sediment. Sediment yield varies as a function of erodibility, slope, and hydrology.

Key parameters controlling sediment transport within streams and rivers are as follows (Donigian and Love (2003) :

KSAND: Sand transport is represented with a power function based on velocity. KSAND, the coefficient in the sand load power function, was set to 0.1 to start calibration and adjusted to improve the comparison between simulated and observed sand concentrations.

TAUCD: LSPC calculates bed shear stress (TAU) during each model time step for each individual reach. The critical bed shear stress for deposition (lb/ft^2) represents the energy level below which cohesive sediment (silt and clay) begins to deposit to the bed. Values of TAUCD for silt and clay were estimated on a reach-group basis by examining the cumulative distribution function of simulated shear stress and setting the parameter to a lower percentile of the distribution in each reach segment, as recommended by Donigian and Love. The 5th percentile was used for clay and the 10th percentile for silt.

TAUCS: The critical bed shear stress for scour (lb/ft^2) represents the energy level above which scour of cohesive sediment begins. Initial values of TAUCS were set, as recommended, at upper percentiles of the distribution of simulated shear stress in each reach (the 85th percentile for clay and the 90th percentile for silt). Values for some individual reaches were subsequently modified during calibration.

M: The erodibility coefficient of the sediment (lb/ft^2-d) determines the maximum rate at which scour of cohesive sediment occurs when shear stress exceeds TAUCS. This coefficient is a calibration parameter. It was initially set to 0.01 and adjusted during calibration to be 0.001 in most reaches and 0.005 behind run-of-river dams where additional fine sediment resuspension loads appear to be generated during high flow events.

In LSPC reaches are assigned to groups (RGID) and the sand, silt, and clay parameter values are supplied for each of those groups. Reaches were assigned to groups based on Strahler (1957) stream order. Additionally, low head dams within the Strahler stream group were grouped together and put into a group separate from the original Strahler grouping. Lastly, each lake was given its own unique reach group. The final 22 reach groups are provided in Table 3-15.

Table 3-15. Reach Group Assignments based on Strahler Stream Order.

RGID	Description	RGID	Description
1	Strahler 1	12	Lake Brandt
2	Strahler 2	13	Lake Jeannette
3	Strahler 3	14	Lake Townsend
4	Lowhead3	15	Lake Hunt
5	Strahler4	16	Lake Reidsville
6	Lowhead4	17	Lake Mackintosh
7	Strahler5	18	Lake Cammack
8	Lowhead5	19	Old Stony Creek Reservoir
9	Strahler6	20	Quaker Creek Reservoir
10	Lowhead6	21	Cane Creek Reservoir
11	Lake Higgins	22	University Lake

A representative reach was selected to calibrate the instream sediment simulation for each group by visual inspection of the simulated output for suspended concentrations, bed storage, and scour and deposition for each sediment class. The goal of parameterizing the coefficient and exponent for the sand simulation was to try to maintain 0.5 to 1 mg/L suspended sand in the stream during baseflow conditions. Therefore, calibration focused on calibrating the coefficient and exponent to provide transport capacity sufficient enough to maintain small sand concentrations during low velocity situations. The goals of parameterizing the threshold values for silt and clay deposit and scour were to have scour during high flow events and deposition during low flow events. Simulated bed shear stress TAU values were summarized for each reach group by 1) finding the maximum, average, minimum and percentiles by increments of 5 for each individual reach and 2) averaging the maximums, averages, minimums, and percentiles for the reaches contained within each group. Values in the 75^{th} to 90^{th} percentile range became TAUCS and values in the 25^{th} to 10^{th} percentile range became TAUCD. Using these ranges of values ensured the most of the time the reaches were simply transporting silt and clay but during the extremely high flow events they were scouring material from the bed and during times of extremely low flow they were depositing material to the bed.

3.4.2.2 Nutrients Calibration Approach

Nutrient calibration relies on matching both simulated instream concentration and nutrient load to observed instream concentrations and estimated load. Unlike sediment, instream nutrient concentrations are generally more dependent on upland loading than on instream processes, except in lakes and reservoirs with long residence times.

Initial values for nutrient parameters were obtained from the High Rock Lake HSPF model. Initial model runs revealed that Ammonia-N and Nitrate+Nitrite-N from upland sources were over-estimated in the Jordan watershed as compared to the observed data. First, interflow and groundwater concentrations of Ammonia-N and Nitrate+Nitrite-N were reduced while preserving the seasonal trends and magnitude differences between land uses as determined in the High Rock Lake calibration. Initial model runs also revealed Ortho Phosphate concentrations were under estimated from upland sources; therefore interflow and ground water concentrations were increased to better match the observed data. After bringing Ammonia-N, Nitrate+Nitrite-N, and Ortho Phosphate concentrations more in line, the calibration turned to the instream organic nutrient simulations. The model run with initial parameters revealed relatively acceptable organic nutrient results but some adjustments were made. Concentrations of organic nutrients are largely driven by the fractionation of upland organic matter into organic constituents as it enters the reach, and the fractions are specified as model parameters. The organic nitrogen fraction was reduced slightly and organic phosphorus fraction was slightly increased.

The next step was to verify that unit area loading rates were reasonable compared to literature values. After ensuring reasonable upland loading rates, calibration to instream observations was carried out to refine the simulation through further adjustment to organic matter fractionation, adjustment of organic matter settling rates and decay, bottom sediment concentrations of phosphorus and ammonium, and the growth of free floating and attached algae.

Phosphorus calibration to concentrations observed in streams was undertaken using a weight-of-evidence approach, with checks for biases relative to flow and season. As with sediment, comparison was also made to monthly load series estimated via a stratified regression approach. While nonpoint loading of phosphorus is generally associated with sediment, one major difference from the suspended sediment calibration is that the phosphorus balance in some streams in the Jordan Lake watershed is dominated by point source discharges. The accuracy with which the time series of point source loading are known imposes a fundamental limitation on the calibration in these areas.

The total nitrogen calibration uses the same general approach described above, but is much more dependent on the specification of subsurface concentrations. These were set as monthly patterns by land cover. Similar to phosphorus, the low flow nitrogen concentration in some area streams is dominated by point source discharges.

The nitrogen calibration is more complex than that for phosphorus, as three major groups (nitrate-N, ammonia-N, and organic-N) are simulated. The calibration endeavored to optimize fit to total N while also maintaining an accurate representation of the relative magnitude of these components.

The sediment potency and build-up/washoff parameters were initialized based on past experience and revised as needed during the calibration process. The first step was to verify that unit area loading rates were reasonable compared to literature values, as described in Section 4.2.1. Next, calibration to instream observations was carried out to refine the simulation through adjustment of organic matter settling rates, bottom sediment concentrations of phosphorus and ammonium, and the growth of periphyton/macrophytes. Plant growth has an important effect on nutrient balances during low flow conditions; therefore, nitrogen and phosphorus must be calibrated simultaneously.

The key parameters controlling the upland nutrient simulation are listed below:

MON-ACCUM - The monthly varying assignment of the build-up or accumulation rate of a constituent on the land surface (lb/acre/day). This parameter was used for Ammonia-N and Nitrate+Nitrite-N for all land uses and varied by month. This parameter was also used for Organic Matter and Orthophosphate-P for impervious land uses but held constant across months. The parameter value range for Ammonia-N by land use, geologic zone, and hydrologic soil group are provided in Table 3-16. The parameter value ranges for Nitrate+Nitrite-N by land use, geologic zone, and hydrologic soil group are provided in Table 3-17. For both Ammonia-N and Nitrate+Nitrite-N the monthly values are identical between geologic zones and HSG types. The parameter values for Organic Matter and Orthophosphate-P for impervious land uses, by geologic zone, are provided in Table 3-18.

MON-SQOLIM - The monthly varying upper limit value beyond which a constituent can no longer accumulate on a surface (lb/acre). This parameter was used for Ammonia-N and Nitrate+Nitrite-N for all land uses and varied by month. This parameter was also used for Organic Matter and Orthophosphate-P for impervious land uses but held constant. The parameter value ranges for Ammonia-N by land use, geologic zone, and hydrologic soil group are provided in Table 3-19. The parameter value ranges for Nitrate+Nitrite-N by land use, geologic zone, and hydrologic soil group are provided in Table 3-20. For both Ammonia-N and Nitrate+Nitrite-N the monthly values are identical between geologic zones and

HSG types. The parameter values for Organic Matter and Orthophosphate-P for impervious land uses, by geologic zone, are provided in Table 3-21.

POTFW - The specification of constituent mass per sediment mass (lb/ton). As stated above, sediment potencies were specified for Organic matter and Orthophosphate-P for pervious lands. The parameter values for Organic Matter and Orthophosphate-P for pervious land uses by land use and geologic zone are provided in Table 3-22.

Table 3-16. MON-ACCUM Values for Ammonia (as N) by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0-0		0-0		0-0		0-0	
Developed Open Space	0.0045-0.00585	0.0045-0.00585	0.0045-0.00585	0.0045-0.00585	0.0045-0.00585	0.0045-0.00585	0.0045- 0.00585	0.0045-0.00585
Row Crops	0.00945-0.011925	0.00945-0.011925	0.00945-0.011925	0.00945-0.011925	0.00945-0.011925	0.00945-0.011925	0.00945-0.011925	0.00945-0.011925
Pasture/Grassland	0.007425-0.009225	0.007425-0.009225	0.007425-0.009225	0.007425-0.009225	0.007425-0.009225	0.007425-0.009225	0.007425-0.009225	0.007425-0.009225
Scrub/Shrub	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495
Forest	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495
Wetland	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495	0.00405-0.00495
NCDOTPRIMARY Impervious	0.0054		0.0054		0.0054		0.0054	
NCDOTSECONDARY Impervious	0.002025		0.002025		0.002025		0.002025	
High Intensity Impervious	0.0027		0.0027		0.0027		0.0027	
Low Intensity Impervious	0.0027		0.0027		0.0027		0.0027	

Table 3-17. MON-ACCUM Values for Nitrate+Nitrite (as N) by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0-0		0-0		0-0		0-0	
Developed Open Space	0.0105-0.01365	0.0105-0.01365	0.0105-0.01365	0.0105-0.01365	0.0105-0.01365	0.0105-0.01365	0.0105- 0.01365	0.0105-0.01365
Row Crops	0.02205-0.027825	0.02205-0.027825	0.02205-0.027825	0.02205-0.027825	0.02205-0.027825	0.02205-0.027825	0.02205-0.027825	0.02205-0.027825
Pasture/Grassland	0.017325-0.021525	0.017325-0.021525	0.017325-0.021525	0.017325-0.021525	0.017325-0.021525	0.017325-0.021525	0.017325-0.021525	0.017325-0.021525
Scrub/Shrub	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155
Forest	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155
Wetland	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155	0.00945-0.01155
NCDOTPRIMARY Impervious	0.0126		0.0126		0.0126		0.0126	
NCDOTSECONDARY Impervious	0.004725		0.004725		0.004725		0.004725	
High Intensity Impervious	0.0063		0.0063		0.0063		0.0063	
Low Intensity Impervious	0.0063		0.0063		0.0063		0.0063	

Table 3-18. MON-ACCUM Values for Organic Matter and Orthophosphate-P by Impervious Land Use and Geologic Zone

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Constituent	***ORG MAT***	***PO4***	***ORG MAT***	***PO4***	***ORG MAT***	***PO4***	***ORG MAT***	***PO4***
NCDOTPRIMARY Impervious	0.6248	0.00495	0.6248	0.00495	0.6248	0.00495	0.6248	0.00495
NCDOTSECONDARY Impervious	0.6248	0.00605	0.6248	0.00605	0.6248	0.00605	0.6248	0.00605
High Intensity Impervious	0.6248	0.0055	0.6248	0.0055	0.6248	0.0055	0.6248	0.0055
Low Intensity Impervious	0.6248	0.0055	0.6248	0.0055	0.6248	0.0055	0.6248	0.0055

Table 3-19. MON-SQOLIM Values for Ammonia (as N) by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0- 0		0- 0		0- 0		0- 0	
Developed Open Space	0.027-0.0351	0.027-0.0351	0.027-0.0351	0.027-0.0351	0.027-0.0351	0.027-0.0351	0.027- 0.0351	0.027-0.0351
Row Crops	0.06075-1.35	0.06075-1.35	0.06075-1.35	0.06075-1.35	0.06075-1.35	0.06075-1.35	0.06075- 1.35	0.06075-1.35
Pasture/Grassland	0.04455-0.05535	0.04455-0.05535	0.04455-0.05535	0.04455-0.05535	0.04455-0.05535	0.04455-0.05535	0.04455-0.05535	0.04455-0.05535
Scrub/Shrub	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243- 0.0297	0.0243-0.0297
Forest	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243- 0.0297	0.0243-0.0297
Wetland	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243-0.0297	0.0243- 0.0297	0.0243-0.0297
NCDOTPRIMARY Impervious	0.0387		0.0387		0.0387		0.0387	
NCDOTSECONDARY Impervious	0.014512		0.014512		0.014512		0.014512	
High Intensity Impervious	0.01935		0.01935		0.01935		0.01935	
Low Intensity Impervious	0.01935		0.01935		0.01935		0.01935	

Table 3-20. MON-SQOLIM Values for Nitrate+Nitrite (as N) by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0- 0		0- 0		0- 0		0- 0	
Developed Open Space	0.063-0.0819	0.063-0.0819	0.063-0.0819	0.063-0.0819	0.063-0.0819	0.063-0.0819	0.063- 0.0819	0.063-0.0819
Row Crops	0.14175-3.15	0.14175-3.15	0.14175-3.15	0.14175-3.15	0.14175-3.15	0.14175-3.15	0.14175- 3.15	0.14175-3.15
Pasture/Grassland	0.10395-0.12915	0.10395-0.12915	0.10395-0.12915	0.10395-0.12915	0.10395-0.12915	0.10395-0.12915	0.10395-0.12915	0.10395-0.12915
Scrub/Shrub	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567- 0.0693	0.0567-0.0693
Forest	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567- 0.0693	0.0567-0.0693
Wetland	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567-0.0693	0.0567- 0.0693	0.0567-0.0693
NCDOTPRIMARY Impervious	0.0903		0.0903		0.0903		0.0903	
NCDOTSECONDARY Impervious	0.033862		0.033862		0.033862		0.033862	
High Intensity Impervious	0.04515		0.04515		0.04515		0.04515	
Low Intensity Impervious	0.04515		0.04515		0.04515		0.04515	

Table 3-21. MON-SQOLIM Values for Organic Matter and Orthophosphate-P by Impervious Land Use and Geologic Zone

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Constituent	***ORG MAT***	***PO4***	***ORG MAT***	***PO4***	***ORG MAT***	***PO4***	***ORG MAT***	*PO4*
NCDOTPRIMARY Impervious	3.135	0.029363	3.135	0.029363	3.135	0.029363	3.135	0.029363
NCDOTSECONDARY Impervious	3.135	0.035888	3.135	0.035888	3.135	0.035888	3.135	0.035888
High Intensity Impervious	3.135	0.032625	3.135	0.032625	3.135	0.032625	3.135	0.032625
Low Intensity Impervious	3.135	0.032625	3.135	0.032625	3.135	0.032625	3.135	0.032625

POTFW - The specification of constituent mass per sediment mass (lb/ton). As stated above, sediment potencies were specified for Organic Matter and Orthophosphate-P for pervious lands. The parameter values for Organic Matter and Orthophosphate-P for pervious land uses by land use and geologic zone are provided in Table 3-22.

Table 3-22. POTFW Values for Organic Matter and Orthophosphate-P by Pervious Land Use and Geologic Zone

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Constituent	***ORG MAT***	***PO4***	***ORG MAT***	***PO4***	***ORG MAT***	***PO4***	***ORG MAT***	***PO4***
Water	0	0	0	0	0	0	0	0
Developed Open Space	64	0.8	64	0.8	64	0.8	44	0.08
Row Crops	82	0.5	82	0.5	82	0.5	62	0.25
Pasture/Grassland	91	0.1	91	0.1	91	0.1	71	0.05
Scrub/Shrub	83	0.8	83	0.8	83	0.8	63	0.05
Forest	83	0.8	83	0.8	83	0.8	63	0.05
Wetland	63	0.035	63	0.035	63	0.035	63	0.035

MON-IFLW-CONC - The monthly varying interflow constituent concentrations. Parameter values were supplied for all four constituents. The parameter value range for Organic Matter by land use, geologic zone, and hydrologic soil group are provided below in Table 3-23. The parameter value ranges for Ammonia-N by land use, geologic zone, and hydrologic soil group are provided in Table 3-24. The parameter value ranges for Nitrate+Nitrite-N by land use, geologic zone, and hydrologic soil group are provided in Table 3-25. The parameter values for Orthophosphate-P by land use, geologic zone, and hydrologic soil group are provided in Table 3-26.

Table 3-23. MON- IFLW-CONC Values for Organic Matter by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0	0	0	0	0	0	0	0
Developed Open Space	3.43- 12	3.43- 12	3.43- 12	3.43- 12	3.43- 12	3.43- 12	3.43- 12	3.43- 12
Row Crops	3.14- 11	3.14- 11	3.14- 11	3.14- 11	3.14- 11	3.14- 11	3.14- 11	3.14- 11
Pasture/Grassland	5.71- 20	5.71- 20	5.71- 20	5.71- 20	5.71- 20	5.71- 20	5.71- 20	5.71- 20
Scrub/Shrub	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15
Forest	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15
Wetland	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15	4.29- 15

MON-GRND-CONC - The monthly varying groundwater flow path constituent concentrations. Parameter values were supplied for all four constituents. The parameter value ranges for Organic Matter by land use, geologic zone, and hydrologic soil group are provided in Table 3-27. The parameter value ranges for Ammonia-N by land use, geologic zone, and hydrologic soil group are provided in Table 3-28. The parameter value ranges for Nitrate+Nitrite-N by land use, geologic zone, and hydrologic soil group are provided in Table 3-29. The parameter values for Orthophosphate-P by land use, geologic zone, and hydrologic soil group are provided in Table 3-30.

Table 3-24. MON- IFLW-CONC Values for Ammonia (as N) by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0	0	0	0	0	0	0	0
Developed Open Space	0.00585-0.01305	0.00585-0.01305	0.00585-0.01305	0.00585-0.01305	0.00585-0.01305	0.00585-0.01305	0.00585-0.01305	0.00585-0.01305
Row Crops	0.0243- 0.54	0.0243- 0.54	0.0243- 0.54	0.0243- 0.54	0.0243- 0.54	0.0243- 0.54	0.0243- 0.54	0.0243- 0.54
Pasture/Grassland	0.0207-0.0381	0.0207-0.0381	0.0207-0.0381	0.0207-0.0381	0.0207-0.0381	0.0207-0.0381	0.0207- 0.0381	0.0207-0.0381
Scrub/Shrub	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012- 0.0069	0.0012-0.0069
Forest	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012- 0.0069	0.0012-0.0069
Wetland	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012-0.0069	0.0012- 0.0069	0.0012-0.0069

Table 3-25. MON- IFLW-CONC Values for Nitrate+Nitrite (as N) by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0	0	0	0	0	0	0	0
Developed Open Space	0.034125-0.076125	0.034125-0.076125	0.034125-0.076125	0.034125-0.076125	0.034125-0.076125	0.034125-0.076125	0.003413-0.007613	0.003413-0.007613
Row Crops	0.0567- 1.26	0.0567- 1.26	0.0567- 1.26	0.0567- 1.26	0.0567- 1.26	0.0567- 1.26	0.042525- 0.945	0.042525-0.945
Pasture/Grassland	0.0483-0.0889	0.0483-0.0889	0.0483-0.0889	0.0483-0.0889	0.0483-0.0889	0.0483-0.0889	0.036225-0.066675	0.036225-0.066675
Scrub/Shrub	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0021-0.012075	0.0021-0.012075
Forest	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0021-0.012075	0.0021-0.012075
Wetland	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0028-0.0161	0.0028- 0.0161	0.0028-0.0161

Table 3-26. MON- IFLW-CONC Values for Orthophosphate-P by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0	0	0	0	0	0	0	0
Developed Open Space	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Row Crops	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Pasture/Grassland	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Scrub/Shrub	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Forest	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Wetland	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075

Table 3-27. MON- IFLW-CONC Values for Organic Matter by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0	0	0	0	0	0	0	0
Developed Open Space	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10
Row Crops	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10
Pasture/Grassland	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10
Scrub/Shrub	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10
Forest	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10
Wetland	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10	2.86- 10

Table 3-28. MON- GRND-CONC Values for Ammonia (as N) by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0	0	0	0	0	0	0	0
Developed Open Space	0.00885-0.0219	0.00885-0.0219	0.00885-0.0219	0.00885-0.0219	0.00885-0.0219	0.00885-0.0219	0.00885- 0.0219	0.00885-0.0219
Row Crops	0.01185-0.0249	0.01185-0.0249	0.01185-0.0249	0.01185-0.0249	0.01185-0.0249	0.01185-0.0249	0.01185- 0.0249	0.01185-0.0249
Pasture/Grassland	0.0105- 0.03	0.0105- 0.03	0.0105- 0.03	0.0105- 0.03	0.0105- 0.03	0.0105- 0.03	0.0105- 0.03	0.0105- 0.03
Scrub/Shrub	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494
Forest	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494
Wetland	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494	0.00675-0.01494

Table 3-29. MON- GRND-CONC Values for Nitrate+Nitrite (as N) by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0	0	0	0	0	0	0	0
Developed Open Space	0.051625-0.12775	0.051625-0.12775	0.051625-0.12775	0.051625-0.12775	0.051625-0.12775	0.051625-0.12775	0.005163-0.012775	0.005163-0.012775
Row Crops	0.0553-0.1162	0.0553-0.1162	0.0553-0.1162	0.0553-0.1162	0.0553-0.1162	0.0553-0.1162	0.020737-0.043575	0.020737-0.043575
Pasture/Grassland	0.049- 0.14	0.049- 0.14	0.049- 0.14	0.049- 0.14	0.049- 0.14	0.049- 0.14	0.018375-0.0525	0.018375-0.0525
Scrub/Shrub	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.011813-0.026145	0.011813-0.026145
Forest	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.011813-0.026145	0.011813-0.026145
Wetland	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.0315-0.06972	0.011813-0.026145	0.011813-0.026145

Table 3-30. MON- GRND-CONC Values for Orthophosphate-P by Land Use, Geologic Zone, and Hydrologic Soil Group

Geologic Zone	Charlotte Belt		Upper Slate Belt		Lower Slate Belt		Triassic Basin	
Hydrologic Soil Group	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B***	***HSG C+D***	***HSG A+B+C***	***HSG D***
Water	0	0	0	0	0	0	0	0
Developed Open Space	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055
Row Crops	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055
Pasture/Grassland	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055
Scrub/Shrub	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055
Forest	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055
Wetland	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055

4 Model Calibration Results

4.1 Hydrology Calibration and Corroboration

4.1.1 Water Balance Analysis

Over the period of simulation, average annual precipitation on the watershed ranges from 42 to 46 in/yr, depending on location. Average water balance by land use is shown in Table 4-1 and summarized graphically in Figure 4-1. As in most watersheds, a majority of the incoming precipitation is returned to the atmosphere as evapotranspiration (ET), with the residual divided among direct surface runoff and subsurface (interflow and groundwater) return flow. Over the 1997-2011 model application period the simulation predicts that 75 percent of precipitation is returned as ET. This is consistent with longer term analyses of measurements of the water balance of Eno River and Flat River (in the Falls Lake watershed in Durham Co.), which showed 74 and 71 percent, respectively, of precipitation returned via actual ET (Lu et al., 2005).

Table 4-1. Water Balance for the Jordan Watershed, 1997-2011 (inches/year)

Land Use Category	ET	Runoff	Interflow	Shallow Groundwater	Total Precip.
High Imperviousness	9.6	34.9	0.0	0.0	44.5
NCDOT Roads, Primary	9.6	34.8	0.0	0.0	44.4
NCDOT Roads, Secondary	9.6	34.7	0.0	0.0	44.3
Low Imperviousness	9.6	34.7	0.0	0.0	44.4
Developed Open Space	33.5	4.8	0.3	5.4	44.0
Pasture/Grass	34.2	4.3	0.2	6.1	44.7
Row Crop	35.3	3.6	0.2	5.7	44.8
Scrub Shrub	36.0	3.4	0.1	5.3	44.8
Forest	36.0	3.1	0.4	5.3	44.9
Wetland	31.5	14.3	0.0	0.0	45.9
Open Water	25.7	18.9	0.0	0.0	44.6
Watershed	33.4	6.0	0.3	5.0	44.7
Overall simulation (%)	75%	13%	1%	11%	

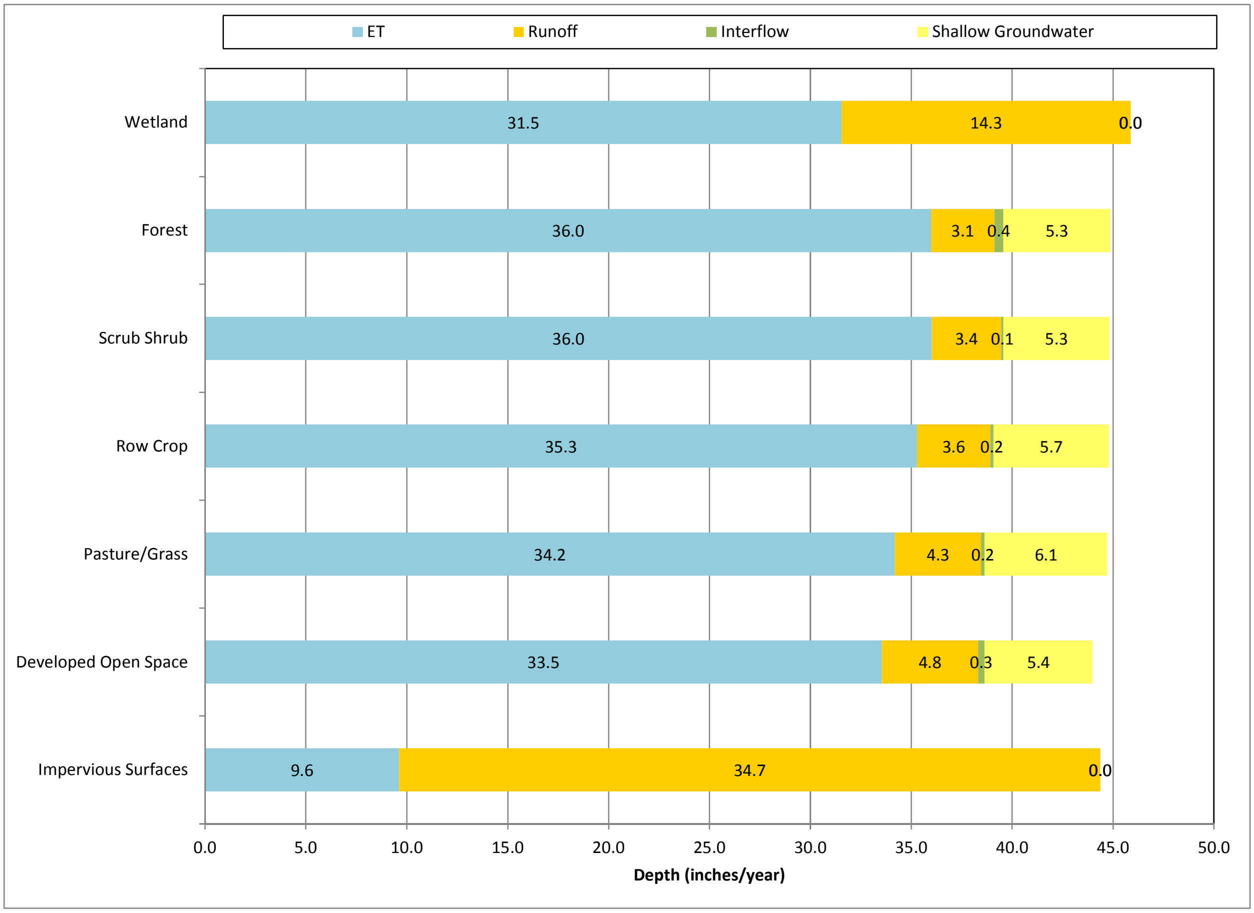


Figure 4-1. Water Balance Summary by Land Use

4.1.2 Comparison to Gage Data

4.1.2.1 Hydrology Calibration Performance Evaluation

Table 4-2 provides the performance results for the calibration period (January 1, 2002 through September 30, 2012) at the core stations. For ETV (*error in total volume* – see Table 3-1 for codes), model performance is rated as *very good* at two gages, *good* at seven gages, *fair* at one gage, and *poor* at two gages. For E10% (*error in 10% highest flow volumes*) , model performance is rated as *very good* at three gages, *good* at five gages, *fair* at three gages, and poor at one gage. Monthly NSE is rated *very good* at three gages, *good* at four gages, *fair* at three gages, and *poor* at two gages.

The station with the largest drainage area is 02096960, Haw River near Bynum, NC, for which all critical measures and nearly all non-critical measures rating *very good*. This station measures flow for the majority of the Haw River drainage, and having an accurate representation of flow is of critical importance for representing inflow hydrology to Jordan Lake. A detailed summary of representative graphical comparisons undertaken for all calibration stations is provided for Haw River near Bynum as an example.

A flow-duration plot (plot of flow versus percent-of-time exceeded, Figure 4-2) shows excellent agreement across most of the range of flows. The model over predicts flow somewhat between the 70th and 90th percentile, which may be related to uncertainty in point source discharge data and upstream reservoir operations. Monthly observed and modeled flows are plotted along with reported monthly rainfall (Figure 4-3) and show a good overall agreement.

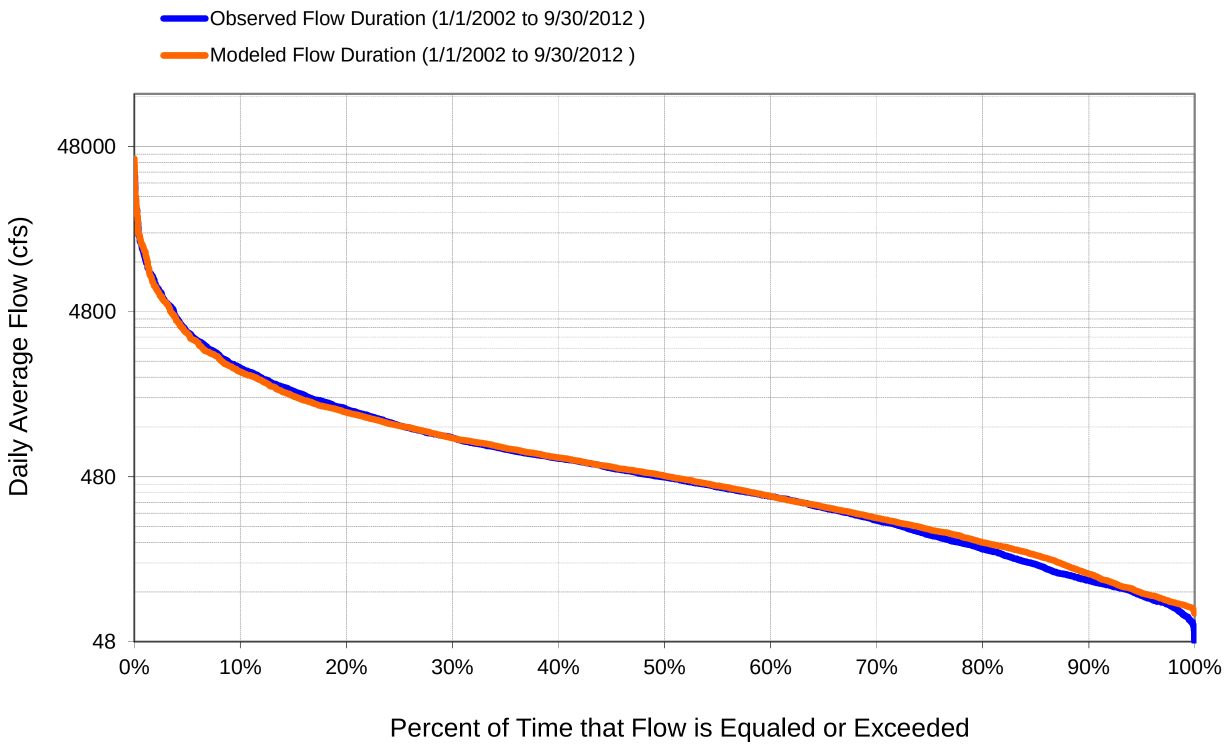


Figure 4-2. Calibration Observed and Modeled Flow-Duration, Haw River near Bynum, NC

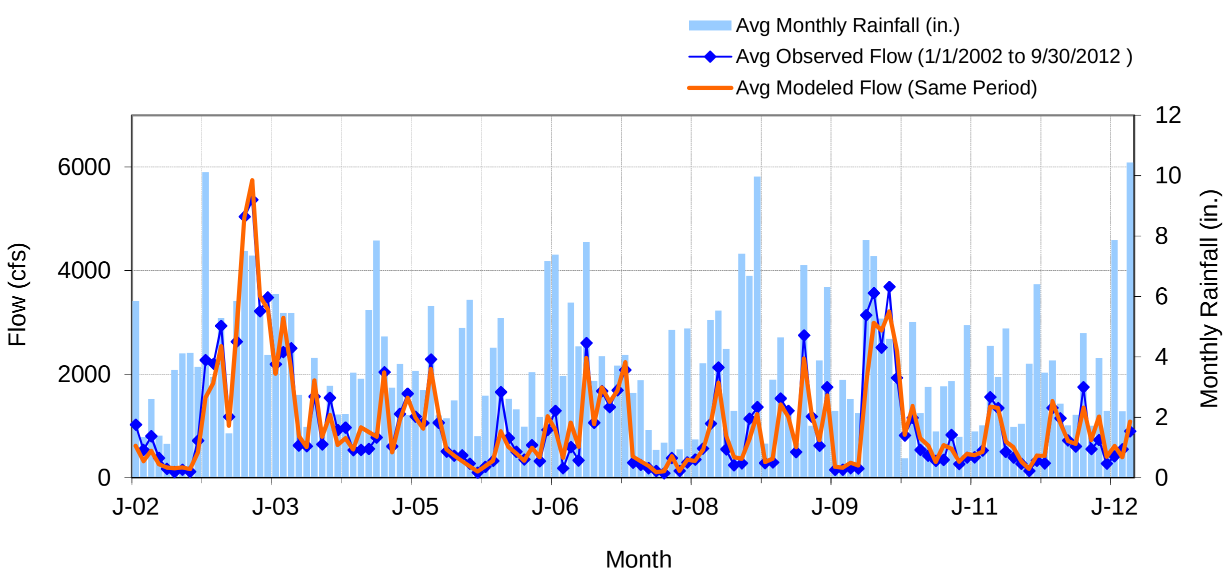


Figure 4-3. Calibration Time Series of Observed and Modeled Monthly Flows and Monthly Rainfall, Haw River near Bynum, NC

A plot of flow accumulation (Figure 4-4) shows excellent agreement between modeled and observed flow volume across a range of wet and dry years. Diagnostic plots of the distribution of observed and simulated flows by month are shown in Figure 4-5. The bar ranges indicate the range between the 25th and 75th percentile, while the center point is the median. Medians and the interquartile range are well replicated throughout the year, though 75th percentile flows tend to be a bit high during the summer. Figure 4-6 shows a comparison of average monthly flows (rather than median and interquartile flows), which can be useful if large storm events influence seasonal flow balance without affecting most of the flow distribution. Average monthly flow is well replicated during the calibration period, although there are some minor deviations for individual months.

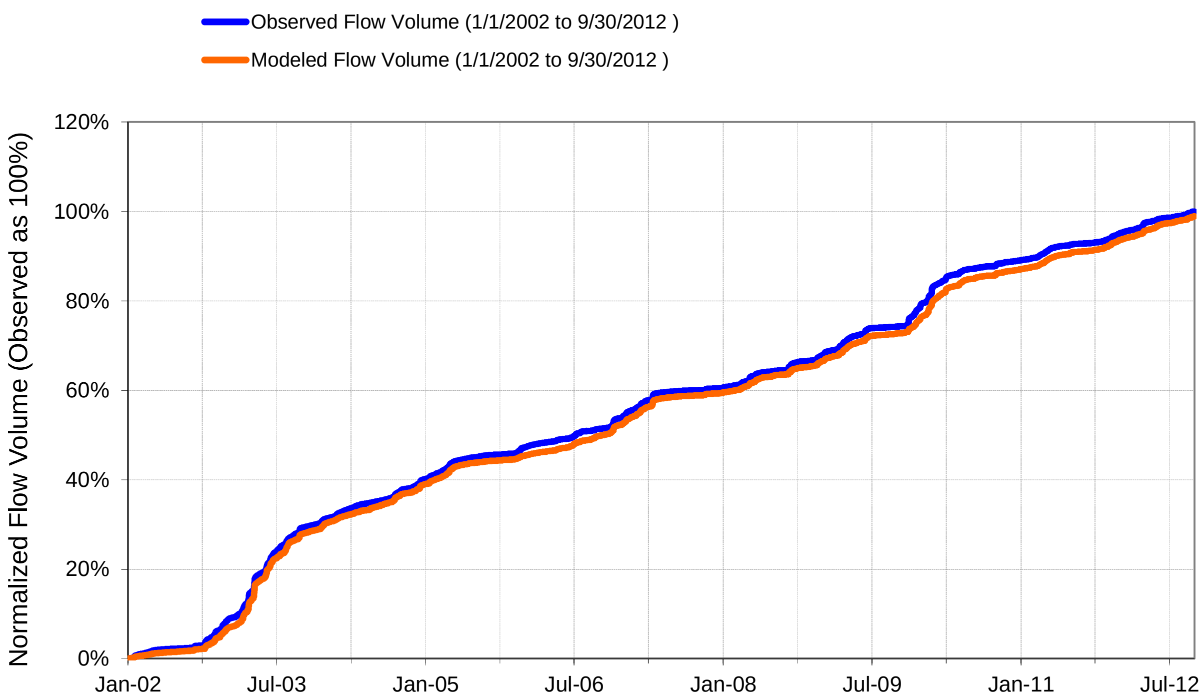


Figure 4-4. Calibration Cumulative Observed and Modeled Flow Volume, Haw River near Bynum, NC

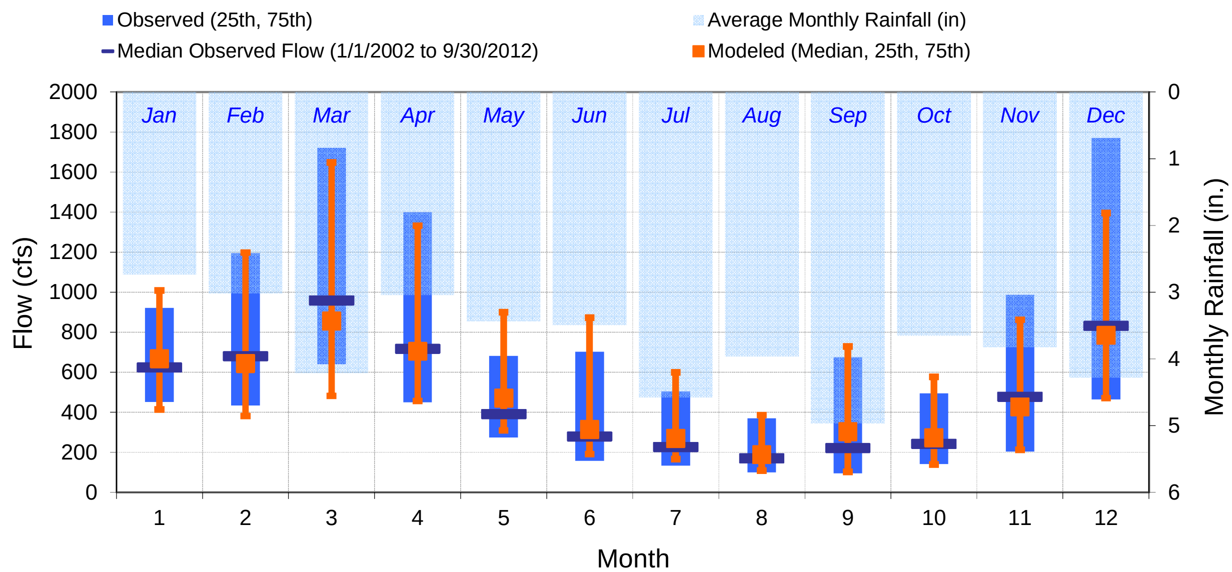


Figure 4-5. Calibration Observed and Modeled Monthly Flow Distributions with Monthly Rainfall, Haw River near Bynum, NC

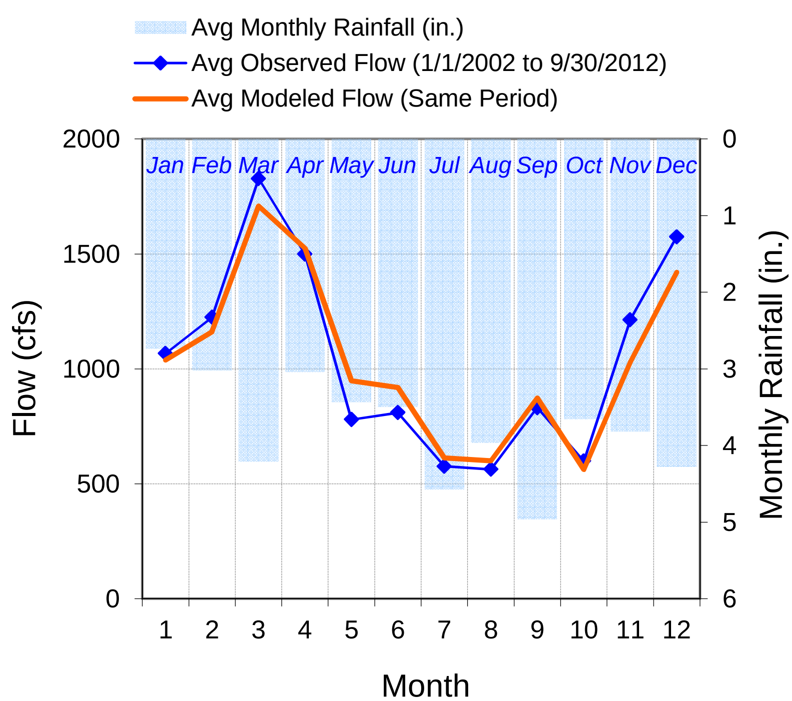


Figure 4-6. Calibration Observed and Modeled Monthly Average Flow with Monthly Rainfall, Haw River near Bynum, NC

Table 4-3 provides the performance results for the calibration period (January 1, 2002 – September 30, 2012) at the non-core stations. For ETV model performance is rated as *very good* at four gages, *good* at four gages, *fair* at one gage, and *poor* at one gage. For E10% model performance is rated as *very good* at seven gages, *good* at one gage, and *fair* at two gages. Monthly NSE is rated *good* at four gages, *fair* at three gages, and *poor* at three gages. Overall performance at the non-core stations was similar to the core stations; for the three critical components, *very good* and *good* ratings outweighed *fair* or *poor* ratings by a margin of two to one. Trends in performances are discussed below, in the context of locale and the underlying geologic zone.

Charlotte Belt Stations

USGS 02093800 – Reedy Fork near Oak Ridge NC (core station)

USGS 02093877 – Brush Creek at Muirfield road at Greensboro, NC (core station)

USGS 0209399200 – Horsepen Creek at US 220 near Greensboro, NC (core station)

USGS 02094500 – Reedy Fork near Gibsonville, NC (core station)

USGS 0209387778 – Brush Creek at Fleming Road at Greensboro, NC (non-core station)

Monitoring in the Charlotte Belt is made up of a series of four stations upstream of Lake Townsend. The Reedy Fork station near Gibsonville is technically in the Slate Belt, but the majority of its drainage comes from the Charlotte Belt. Total volume is well predicted across all of the stations. For the remaining measures, performance is mixed, but over-predictions and under-predictions tend to balance out for the 10% highest flows and for seasonal volumes. The station on Reedy Fork near Gibsonville is downstream of Lake Townsend, and it performance is likely affected by water management activities not represented in the model.

Upper Slate Belt Stations

USGS 02095000 – South Buffalo Creek near Greensboro, NC (core station)

USGS 02095271 – North Buffalo Creek at Church Street at Greensboro, NC (core station)

USGS 02094659 – South Buffalo Creek near Pomona, NC (non-core station)

USGS 02094770 – South Buffalo Creek at US 220 at Greensboro, NC (non-core station)

USGS 02094775 – Ryan Creek below US 220 at Greensboro, NC (non-core station)

USGS 02095181 – North Buffalo Creek at Westover Terrace at Greensboro, NC (non-core station)

USGS 02095500 – North Buffalo Creek near Greensboro, NC (non-core station)

USGS 0209553650 – Buffalo Creek at SR2819 near McLeansville, NC (non-core station)

The Upper Slate Belt stations are located in a cluster in Guilford County and are all associated with the Buffalo Creek system. Performance is mixed at these stations, and several of the stations rate *fair* or *poor* for the critical measures. Many of the stations are in series; one would expect errors for a given model component to carry through to the next station, but this is largely not the case. This suggests either differences in hydrology due to small scale variation in soils/geology, or perhaps uncertainty in gaging records. As seen in Table 3-6, impervious area is high and fairly consistent across the drainages, but proportions of HSG A+B versus HSG C+D are quite variable. In addition, this particular region of Guilford County may be poorly represented by the assigned model precipitation station (Greensboro WSO Airport), which is 10 to 20 miles away. It is important to note that undue weight should not be placed on these gages; while there are many of them, they have a narrow geographic focus.

Lower Slate Belt Stations

USGS 02096846 – Cane Creek near Orange Groove, NC (core station)

USGS 02097464 – Morgan Creek near White Cross, NC (core station)

USGS 02097517 – Morgan Creek near Chapel Hill, NC (non-core station)

These stations are located in southern Orange County, and primarily drain rural areas with a low intensity of development. Performance is generally good to fair at these stations. The Morgan Creek near Chapel Hill station is located downstream of University Lake, which has withdrawals for water supply and also received significant transfers from Cane Creek Reservoir during part of the simulation period. This station is also downstream of the Orange Water and Sewer Authority (OWASA) WWTP discharge.

Triassic Basin Stations

USGS 02097280 – Third Fork Creek at Woodcroft Parkway near Blands, NC (core station)

USGS 0209741955 – Northeast Creek at SR1100 near Genlee, NC (core station)

USGS 02097314 – New Hope Creek near Blands, NC (non-core station)

USGS 0209782609 – White Oak Creek at mouth near Green Level, NC (non-core station)

All of these stations rate good or very good across the majority of critical and non-critical measures. The Third Fork Creek station has a relatively low monthly NSE, but it is important to note that the period of record for this station was less than five years. Performance measures indicate that hydrology is well represented for inflows into the upper arms of Jordan Lake.

Haw River Stations

USGS 02096500 – Haw River at Haw River, NC (core station)

USGS 02096960 – Haw River near Bynum, NC (core station)

Most measures, both critical and non-critical, were assessed as *good* or *very good*. Both stations are influenced by significant point source discharges, and point source flow often dominates during drought conditions. The quality of fit at both of these stations indicates that the LSPC model adequately represents regional hydrology.

Table 4-2. Hydrology Performance for the Calibration Period at the Core Stations

Model Component	02093800	02093877	0209399200	02094500	02095000	02095271	02096500	02096846	02096960	02097280	0209741955	02097464
	Reedy Fk	Brush Crk	Horsepen	Reedy Fk	S Buffalo	N Buffalo	Haw R	Cane Cr	Haw R	Third Fk	Northeast	Morgan Cr
1. Error in total volume	-0.97%	-5.20%	5.71%	-5.75%	-17.86%	-19.90%	-7.07%	-6.08%	-1.04%	9.46%	-8.17%	12.04%
2. Error in 50% lowest flow volumes	7.41%	-8.73%	-12.16%	-9.52%	-45.73%	-33.89%	3.47%	9.45%	4.15%	-42.12%	-12.75%	5.06%
3. Error in 10% highest flow volumes	-17.26%	-9.32%	10.36%	-32.96%	-15.40%	-22.16%	-13.09%	-12.76%	-1.44%	11.56%	-7.49%	14.38%
4. Error in storm volume	-8.87%	-0.34%	21.74%	-52.67%	-15.22%	-25.49%	-15.94%	-6.25%	1.27%	31.36%	20.15%	38.61%
5. Winter volume error	-13.56%	-3.16%	-0.47%	-5.39%	-14.81%	-12.47%	-11.02%	-4.11%	-5.09%	-3.68%	-17.32%	8.69%
6. Spring volume error	16.10%	12.01%	13.09%	3.63%	-15.17%	-16.71%	7.53%	-10.10%	9.99%	16.48%	-2.17%	11.22%
7. Summer volume error	21.00%	-8.66%	22.86%	3.09%	-15.18%	-22.10%	1.02%	8.77%	5.90%	47.42%	11.39%	8.26%
8. Fall volume error	-17.25%	-18.13%	-9.38%	-21.63%	-26.01%	-27.88%	-21.11%	-10.37%	-11.03%	-12.22%	-15.89%	21.68%
9. Monthly NSE	0.625	0.788	0.831	0.691	0.711	0.604	0.833	0.866	0.934	0.716	0.750	0.903
10. R^2 monthly values	0.482	0.578	0.640	0.499	0.667	0.611	0.621	0.372	0.717	0.541	0.307	0.426
11. R^2 daily values	0.629	0.806	0.834	0.714	0.756	0.681	0.837	0.874	0.933	0.725	0.768	0.912

Note: Error statistics for hydrology are reported as simulated minus observed flows.

Table 4-3. Hydrology Performance for the Calibration Period at the Non-Core Stations

Model Component	0209387778	02094659	02094770	02094775	02095181	02095500	0209553650	02097314	02097517	0209782609
	Brush Cr	S Buffalo	S Buffalo	Ryan Cr	N Buffalo	N Buffalo	Buffalo Cr	New Hope	Morgan Cr	White Oak
1. Error in total volume	2.60%	-18.31%	-9.02%	0.85%	-8.12%	2.55%	-5.81%	-0.08%	11.42%	-8.37%
2. Error in 50% lowest flow volumes	-17.79%	-22.93%	-41.41%	-41.55%	5.85%	-3.89%	-4.80%	2.03%	23.83%	10.71%
3. Error in 10% highest flow volumes	1.91%	-21.25%	-3.11%	6.56%	-19.09%	2.71%	-7.27%	5.52%	9.12%	-11.46%
4. Error in storm volume	13.03%	-21.50%	-5.10%	8.80%	-23.10%	-1.75%	-9.24%	32.76%	22.53%	9.29%
5. Winter volume error	-12.01%	-13.70%	-3.93%	1.22%	-1.47%	3.71%	-6.47%	-6.17%	11.30%	-16.82%
6. Spring volume error	35.65%	-16.10%	-5.74%	11.59%	-6.45%	2.70%	-3.21%	-5.25%	18.29%	-4.26%
7. Summer volume error	12.93%	-21.55%	-8.28%	0.75%	-7.37%	10.43%	0.60%	22.99%	4.47%	5.82%
8. Fall volume error	-17.40%	-21.33%	-17.67%	-8.60%	-17.11%	-6.05%	-13.67%	-2.29%	10.16%	-7.17%
9. Monthly NSE	0.830	0.693	0.725	0.634	0.635	0.611	0.749	0.806	0.868	0.840
10. R^2 monthly values	0.627	0.667	0.662	0.522	0.602	0.629	0.613	0.269	0.887	0.377
11. R^2 daily values	0.845	0.754	0.748	0.659	0.681	0.690	0.751	0.860	0. 506	0.870

Note: Error statistics for hydrology are reported as simulated minus observed flows.

4.1.2.2 Hydrology Corroboration Performance Evaluation

Table 4-4 provides the performance results for the corroboration period (January 1, 1997 – December 31, 2001) at the core stations. For the ETV model performance is rated as *very good* at one gage, *good* at two gages, *fair* at three gages, and *poor* at four gages. For the E10% model performance is rated as *very good* at three gages, *fair* at five gages, and *poor* at two gages. Monthly NSE is rated *very good* at three gages, *fair* at two gages, and *poor* at five gages.

Looking at the core stations holistically, performance of the model during the corroboration period at these gages is rated as *"Fair."* Tropical storms occurring during the corroboration time period may be misrepresented in the atmospheric forcing files, and precipitation from hurricanes is manifest in strong depth gradients which are not captured using single-point precipitation gages. Figure 4-7 shows modeled flow significantly under-predicted during September 2000 at USGS 02094500 Reedy Fork near Gibsonville, NC. Average daily rainfall is shown at the top of the graph; clearly, little or no rain was represented in the forcing file, but observed flow shows a major event centered on the 16th. This corresponds to Tropical Storm Gordon, which passed through central North Carolina and dropped several inches of rain in two distinct bands on either side of the eye (Figure 4-8). This resulted in significant rainfall on the Reedy Fork watershed, but not at the relevant meteorology station. Thus, the model is unable to predict this large flow event.

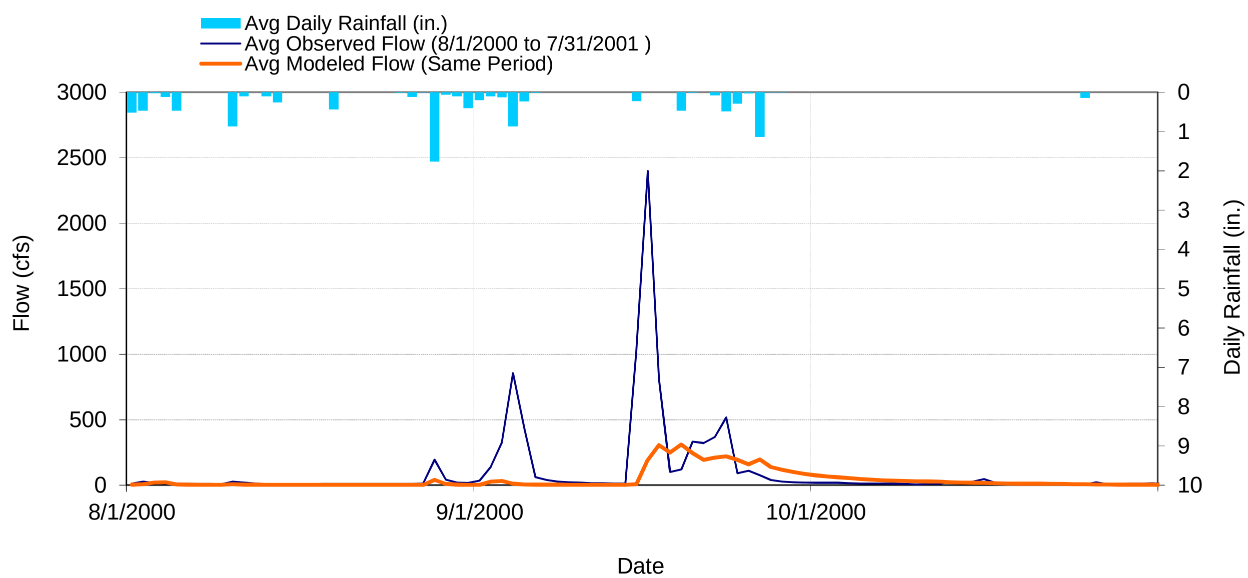
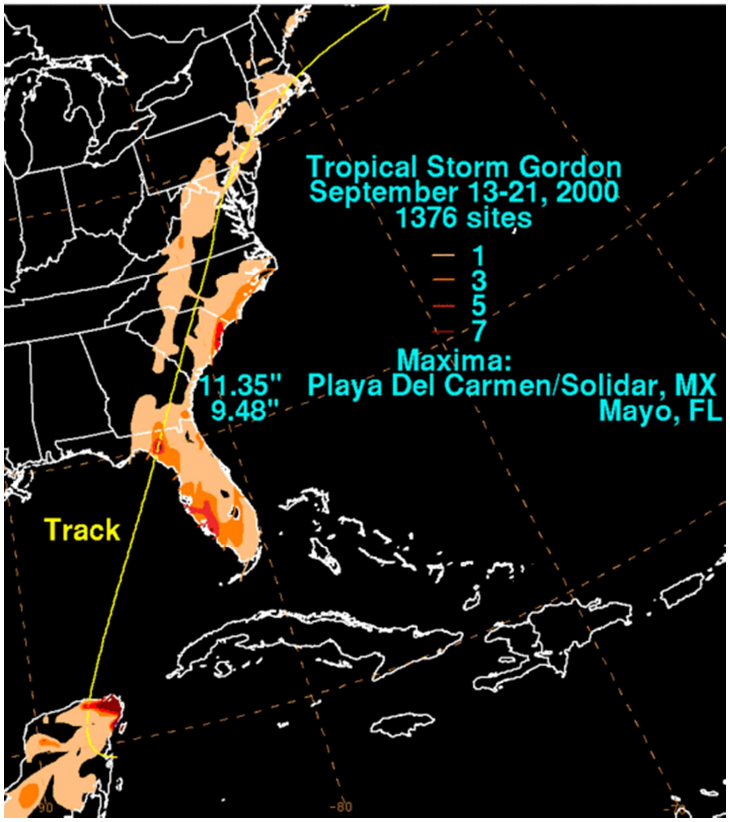


Figure 4-7. Late Summer Modeled and Observed Flow at USGS 02094500 Reedy Fork near Gibsonville, NC



(Image credit: Weather Prediction Center, Camp Springs, Maryland)

Figure 4-8. Cumulative rainfall from Tropical Storm Gordon, September 2000

Table 4-5 provides the performance results for the corroboration period (January 1, 1997 – December 31, 2001) at the non-core stations. For the ETV model performance is rated as *very good* at one gage, *good* at one gage, *fair* at three gages, and *poor* at five gages. For the E10% model performance is rated as *very good* at two gages, *good* at two gages, *fair* at one gage, and *poor* at five gages. Monthly NSE is rated *good* at one gage, *fair* at one gage, and *poor* at eight gages. Conclusions drawn when discussing the overall performance of the core stations can also be drawn about these non-core stations. In addition, flow monitoring began at most of the Charlotte Belt and Upper Slate Belt stations between 1998 and 1999, so the corroboration periods for these gages were on the order of three years or less. The worst performance is seen at the White Oak Creek gage, where less than two years of data are available for the corroboration period (9/1999 – 12/2001). This station has a negative NSE and the model also tends to over-predict low flows. Issues may in part be related to uncertainty in the rating curve in the early period of operation of this station, but the short period of record makes it difficult to draw firm conclusions. A summary of hydrology model performance within the context of overall assessment of LSPC model performance for the Jordan watershed is provided in Section 4.3.

Table 4-4. Hydrology Performance for the Corroboration Period at the Core Stations

Model Component	02093800	02093877	0209399200	02094500	02095000	02095271	02096500	02096846	02096960	02097280	0209741955	02097464
	Reedy Fk	**Brush Crk**	**Horsepen**	**Reedy Fk**	**S Buffalo**	**N Buffalo**	**Haw R**	**Cane Cr**	**Haw R**	**Third Fk**	**Northeast**	**Morgan Cr**
1. Error in total volume	-6.21%		-18.69%	-6.18%	-25.71%	-29.10%	-10.04%	-13.43%	-2.56%		-18.62%	-10.54%
2. Error in 50% lowest flow volumes	0.26%		-3.45%	-40.15%	-34.01%	-48.86%	-1.18%	-47.44%	-6.02%		-3.14%	-56.84%
3. Error in 10% highest flow volumes	-19.85%		-22.40%	-40.45%	-27.16%	-23.42%	-18.33%	-8.78%	-0.45%		-23.48%	0.07%
4. Error in storm volume	-27.19%		-18.49%	-60.64%	-27.73%	-33.66%	-26.27%	-11.04%	-3.64%		-7.44%	4.28%
5. Winter volume error	-17.00%		-34.16%	-14.89%	-23.71%	-19.29%	-17.05%	-25.24%	-7.34%		-29.62%	-18.99%
6. Spring volume error	7.88%	N/A	-2.95%	16.53%	-35.39%	-38.55%	-2.81%	-26.31%	0.08%	N/A	-6.44%	-14.73%
7. Summer volume error	-4.49%		-21.73%	-44.41%	-24.31%	-26.60%	-6.86%	72.81%	4.88%		-4.64%	28.75%
8. Fall volume error	-9.31%		-1.86%	36.83%	-17.10%	-36.00%	-3.72%	-5.85%	3.63%		-12.45%	-16.17%
9. Monthly NSE	0.743		0.603	0.681	0.572	0.057	0.878	0.358	0.936		0.879	0.729
10. R^2 monthly values	0.398		0.488	0.482	0.529	0.407	0.723	0.441	0.787		0.499	0.634
11. R^2 daily values	0.743		0.697	0.681	0.639	0.471	0.893	0.545	0.939		0.942	0.784

Note: Error statistics for hydrology are reported as simulated minus observed flows.

Table 4-5. Hydrology Performance for the Corroboration Period at the Non-Core Stations

Model Component	0209387778	02094659	02094770	02094775	02095181	02095500	0209553650	02097314	02097517	0209782609
	Brush Cr	S Buffalo	S Buffalo	Ryan Cr	N Buffalo	N Buffalo	Buffalo Cr	New Hope	Morgan Cr	White Oak
1. Error in total volume	-18.84%	-33.38%	-38.90%	-3.15%	-34.35%	-12.52%	-10.48%	-12.75%	-7.25%	28.30%
2. Error in 50% lowest flow volumes	7.23%	-6.65%	-30.12%	-29.63%	-15.82%	-11.02%	-6.83%	-0.50%	-8.89%	83.07%
3. Error in 10% highest flow volumes	-37.99%	-39.62%	-46.35%	-1.70%	-48.67%	-14.23%	-15.44%	-11.16%	-2.30%	29.00%
4. Error in storm volume	-35.45%	-41.95%	-49.19%	-3.89%	-54.15%	-21.41%	-20.69%	0.65%	1.84%	59.48%
5. Winter volume error	-13.15%	-23.14%	-31.35%	3.21%	-21.19%	-9.22%	-7.98%	-17.13%	-20.21%	-11.97%
6. Spring volume error	1.84%	-25.48%	-44.48%	3.90%	-39.53%	-23.42%	-21.19%	-37.50%	1.34%	6.36%
7. Summer volume error	-37.52%	-45.38%	-46.07%	-12.90%	-47.12%	-11.68%	-10.65%	23.50%	15.62%	79.06%
8. Fall volume error	-5.63%	-21.50%	-18.82%	4.35%	-3.03%	-4.52%	0.36%	5.91%	-10.16%	59.28%
9. Monthly NSE	0.580	0.315	0.425	0.599	0.346	0.471	0.611	0.669	0.821	-0.411
10. R^2 monthly values	0.407	0.329	0.409	0.190	0.278	0.460	0.520	0.442	0.867	0.279
11. R^2 daily values	0.688	0.538	0.631	0.594	0.558	0.565	0.645	0.699	0.705	0.589

Note: Error statistics for hydrology are reported as simulated minus observed flows.

4.2 Water Quality Calibration and Corroboration

As discussed in 3.4.2, parameters for nutrient calibration were initialized using values from the High Rock Lake HSPF model and the Goose and Crooked Creeks LSPC model. The first step in the calibration process was to compare unit area loading rates from each modeled land use to literature values, providing confirmation that the model adequately represents upland pollutant load generation. The results of the analysis and review are provided in Section 4.2.1 . Model parameters were then iteratively adjusted to support a weight-of-evidence comparison to monitoring data from the watershed. The analyses were conducted at a total of 35 monitoring stations, providing robust spatial coverage of the watershed. Simulated water quality was compared to monitoring data using both graphical and statistical methods. The model performance analysis begins with a presentation of the graphical and statistical methods using New Hope Creek as an example (Section 4.2.2). Model performance at all of the monitoring stations is then presented for the calibration and corroboration periods (Section 4.2.3 and Section 4.2.4, respectively). Due to the large number of stations, it was not practical to present detailed graphical analyses of results at each station in this memorandum. Rather, the statistical performance of the model across all stations is summarized in a series of tables. The section concludes with an evaluation of loads delivered to various points in the watershed, with a comparison of model loads to estimates of loads derived from monitoring data with the LOADEST tool (Section 4.2.6).

4.2.1 Analysis of Nutrient Loading Rates

The first step in the analysis of model calibration is a test that unit area loading rates produced by the model are reasonable compared to literature values. Unfortunately, few long-term studies are available for the Piedmont of North Carolina, and large year-to-year variability allows only a qualitative comparison. Table 4-6 compares the model range (showing the range of average annual loads over the 1997-2010 simulation period for each land use/HSG combination) to values available in the literature. Model ranges were tabulated from unique values calculated for each model subwatershed across the entire calibration/corroboration time period. Land use loading rates within each subwatershed represent area-weighted values across HSG types (see table footnotes for impervious area assumptions). For the developed uses (Low-Medium Density Residential and High Density Residential-Commercial), the loading rates were calculated by combining loads from the “Developed, Open Space” RMU with loads from the impervious RMUs using the range of impervious percentages reported in the table footnotes.

Table 4-6. Comparison of Nutrient Unit Area Loading Rates

Land Use	Model Range (lb/ac/yr)	Literature Range (lb/ac/yr)	Source
Total Nitrogen Load			
Low-Medium Density Residential [1]	2.1 – 5.8	4 - 8 2.6 – 6.2	*General*: Novotny & Olem, 1994, tables 8-2, 8-3; Hartigan et al., 1983 *NC Piedmont*: Line, 2013; Bales et al., 1999
High Density Residential, Commercial [2]	5.1 – 8.2	1.6 – 11.0	*General*: Novotny & Olem, 1994, tables 8-2, 8-3, Lin, 2004
Forest	1.0 – 3.4	1 – 6 1.1 – 3.6	*General*: Lin, 2004; Chapra, 1997, Table 28.2 *NC Piedmont*: Swartley et al., 2010; Harned, 1995; Line, 2013.
Row Crops	2.2 – 10.3	0.4 – 44 11 - 14	*General*: Chapra, 1997, Table 28.2 *NC Piedmont*: Harned, 1995
Pasture/Grassland	1.8 – 5.1	2.9 – 12.5 5.2 – 7.5	*General*: Lin, 2004 *NC Piedmont*: Line and Osmond, 2010
Total Phosphorus Load			
Low-Medium Density Residential [1]	0.23 – 0.79	0.4 – 1.4 0.34 – 0.81	*General*: Novotny & Olem, 1994, tables 8-2, 8-3; Hartigan et al., 1983 *NC Piedmont*: Line, 2013; Bales et al., 1999.
High Density Residential, Commercial [2]	0.79 – 1.38	0.1 - 3	*General*: Novotny & Olem, 1994, tables 8-2, 8-3, Lin, 2004
Forest	0.05 – 0.20	0.01 – 0.8 0.14 – 0.32	*General*: Lin, 2004; Chapra, 1997, Table 28.2 *NC Piedmont:* Swartley et al., 2010
Row Crops	0.16 – 1.22	0.09 - 4 3.5 – 5.8	*General*: Chapra, 1997, Table 28.2 *NC Piedmont*: Harned, 1995; Line and Osmond, 2010
Pasture/Grassland	0.09 – 0.26	0.45 – 0.54 2.5 – 4.7	*General*: Lin, 2004 *NC Piedmont*: Line and Osmond, 2010

1. Low-Medium Density assumed impervious area ranging from 10 percent to 30 percent
2. High Density-Commercial assumed impervious area ranging from 50 percent to 80 percent

Estimates of agricultural loading rates in the watershed were also provided to DWQ by Osmond and Neas (2007). They applied the PLAT tool to estimate phosphorus losses from a statistical sample of agricultural fields by county. The PLAT tool takes into account soil test P, fertilizer and manure application, erosion, and other factors and reports results on a pound per acre basis. However, the results are averaged, by county, over all agricultural land uses, including row crops, pasture, and hay. In contrast, the watershed model specifies row crops separately from pasture/hay, and different erosion and pollutant loading rates are expected for these land uses. The resulting estimates provided by Osmond and Neas are primarily driven by hay and pasture, which make up 68 percent of the sampled fields in the watershed, and in several counties only hay and pasture fields were analyzed. In general, Osmond and Neas report moderate to high soil test P levels, but low total P loss, mostly due to very low erosion rates. The results from the sampled fields look to be consistent with average P loss rates from hay/pasture of about 0.08 lb/acre/yr and about 0.4 lb/acre/yr from row crops. However, firm estimates of load rates from row crop versus pasture/hay are not possible from the report.

Osmond and Neas (2007) also produced estimates of total N loss from agricultural land by county. These results combine row crop and hay, but omit pasture land. The sample fields were generally under-fertilized relative to estimated N needs. More importantly, the NLEW tool used to estimate N loss is intended to evaluate relative changes in the disposition of fertilizer-derived N. Specifically, "NLEW is an 'edge-of-management unit' accounting tool; it estimates changes in nitrogen loss from croplands, but does not estimate changes in nitrogen loading to surface waters" (NBOC, 2012). Notably, the tool does not account for atmospheric N inputs. The loss rates are reported as a total amount over sampled fields, not as yield per acre, and dividing by the reported area analyzed yields widely varying results (0.14 – 15 lb/acre/yr). As with phosphorus, the information reported does not allow analysis of loss rates for row crops versus hay; however, the aggregate loss rate appear to have a mean and median across all counties in the neighborhood of 6 lb/ac/yr, consistent with the row crop and pasture/hay results in Table 4-6.

4.2.2 Graphical and Statistical Analysis Example: New Hope Creek

The details of the calibration process are presented by example for station B3040000+02097314, New Hope Creek at SR 1107 near Blands, located in Durham. This is one of the primary calibration stations. Monitoring has been conducted by three different organizations (DWQ, USGS, and the Upper Cape Fear River Basin Association). There is a co-located flow gage, and the model fits the hydrology well. This station is downstream of a major point source (South Durham WRF); however, an upstream station (B3020000) is available to check the nonpoint source simulation. Examination of the calibration at this station reveals both strengths and weaknesses of the modeling approach. Calibration and corroboration statistics are shown in Table 4-7 for TSS, TN, and TP, with color coding to indicate where each statistic falls within its performance range (discussed previously in Section 3.1.2).

Table 4-7. Statistical Performance Measures for New Hope Creek near Blands

Period		Calibration 1997 - 2004	Corroboration 2005 - 2112
Total Suspended Sediment	Sample Count	120	247
	Concentration Average Error	-53.8%	-9.1%
	Concentration Median Error	-40.2%	-47.9%
	Load Ave Error	54.3%	138.4%
	Load Median Error	-6.6%	-9.9%
Total Nitrogen	Sample Count	151	252
	Concentration Average Error	9.6%	10.5%
	Concentration Median Error	15.0%	8.9%
	Load Ave Error	8.0%	-9.1%
	Load Median Error	10.6%	5.9%
Total Phosphorus	Sample Count	157	246
	Concentration Average Error	3.6%	0.5%
	Concentration Median Error	-0.3%	-0.3%
	Load Ave Error	-19.3%	-26.5%
	Load Median Error	-0.1%	-0.1%

Note: Error statistics are based on simulated minus observed values.

As noted above, temperature and DO are not primary objectives of the model; however, reasonable simulations are required. The temperature simulation (Figure 4-9) is reasonable, although peak summer temperatures in the hottest years appear to be under-estimated. For DO (Figure 4-10), the model over-estimates the summer minimum, likely due to sediment oxygen demand (i.e., actual rates may be higher than simulated rates). However, neither the model nor the data indicate oxygen conditions sufficiently low to strongly influence nutrient kinetics. Therefore, this portion of the model is acceptable for the intended applications.

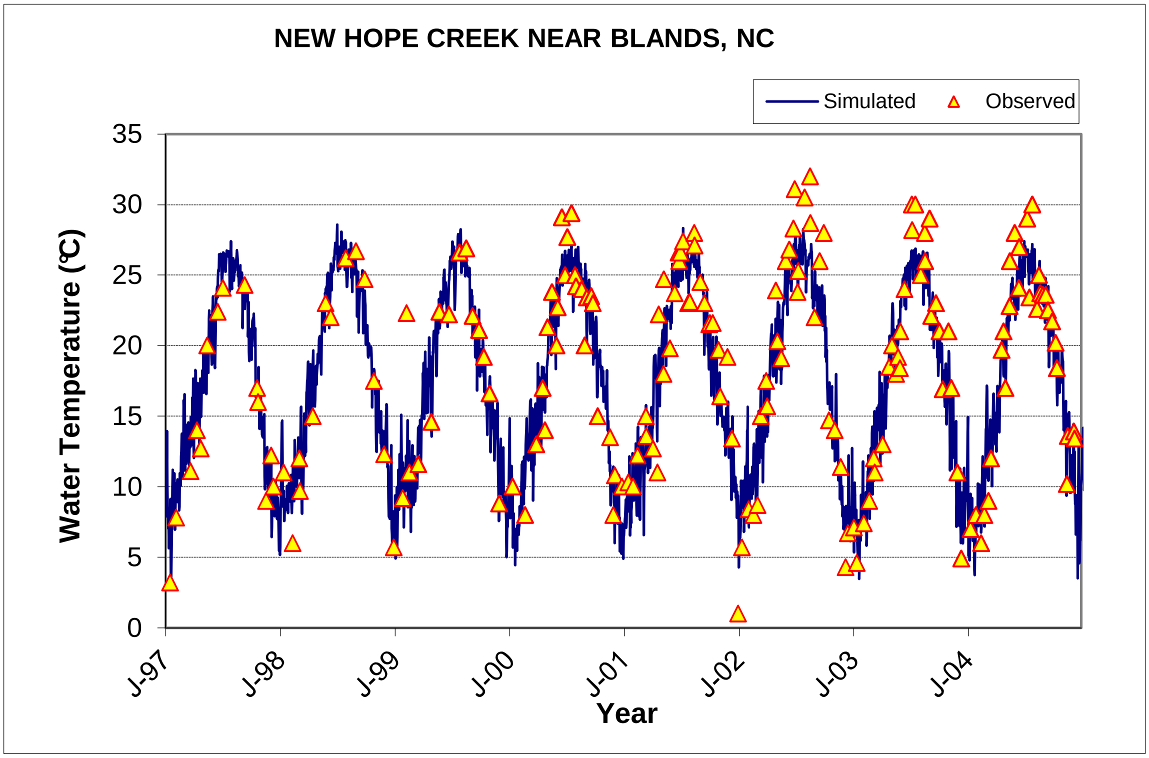


Figure 4-9. Temperature Simulation for New Hope Creek near Blands, Calibration Period

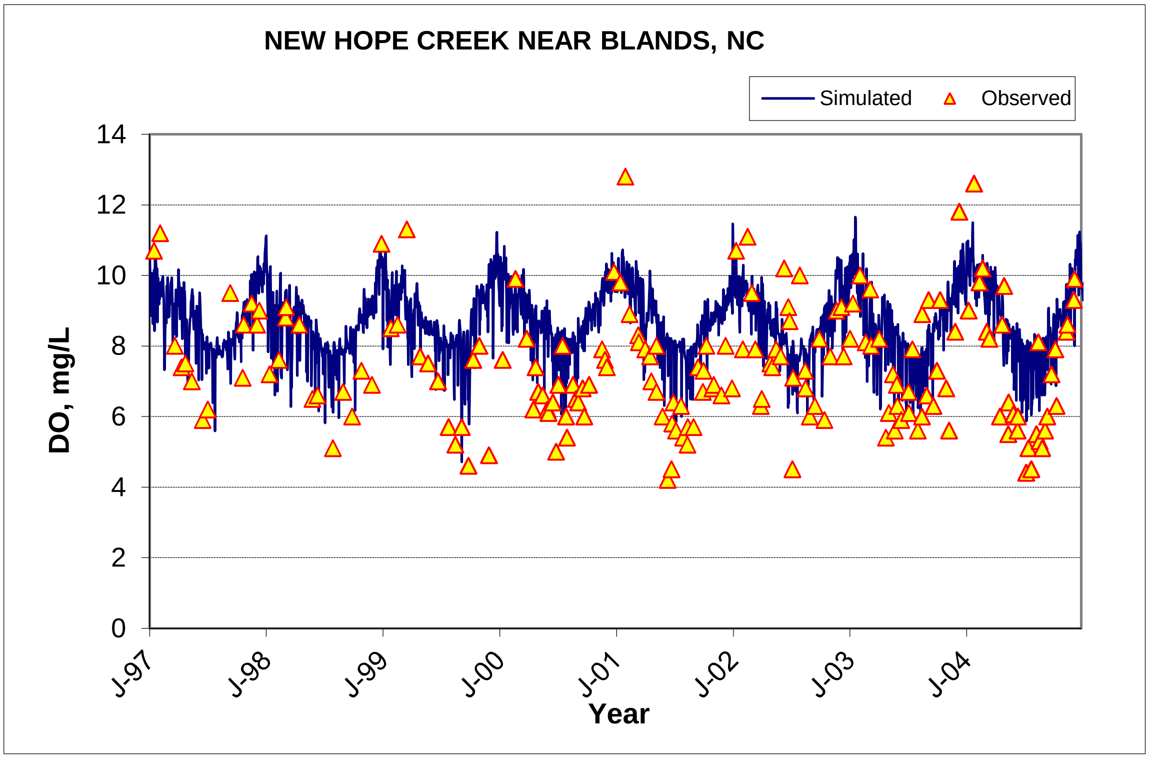


Figure 4-10. DO Simulation for New Hope Creek near Blands, Calibration Period

Simulation of sediment is also not a major endpoint for the model; however, as noted above, a reasonable simulation of sediment is needed to represent the transport of phosphorus and organic nutrients. Time series for the sediment calibration (Figure 4-11) are not particularly informative, except to demonstrate that both observations and modeled results are highly dynamic and cover approximately the same range. Statistically, for the calibration time period the average error in paired concentrations (simulated minus observed) is -54 percent, indicating an under-prediction of observed concentrations; however, the average error in paired load estimates is 54 percent, suggesting an over-estimation of load, although the median error in paired loads is only 7 percent.

Other diagnostic plots are more informative. Analysis in terms of loads is particularly important for the purposes of the model; however, the quality of statistical fit for loads may be strongly affected by a few observations at high flows, so this type of calibration metric can be subject to considerable uncertainty. A scatterplot of simulated load versus same day load estimated from discrete samples shows reasonable agreement (Figure 4-12) except in the lower range, where observed loads are generally higher than simulated. A power plot of load versus flow (Figure 4-13) confirms these relationships, indicating TSS load is under-predicted at low flows. On the other hand, the large positive error in total paired load is largely due to only two high flow observations (the two points at the right, noting the log scales).

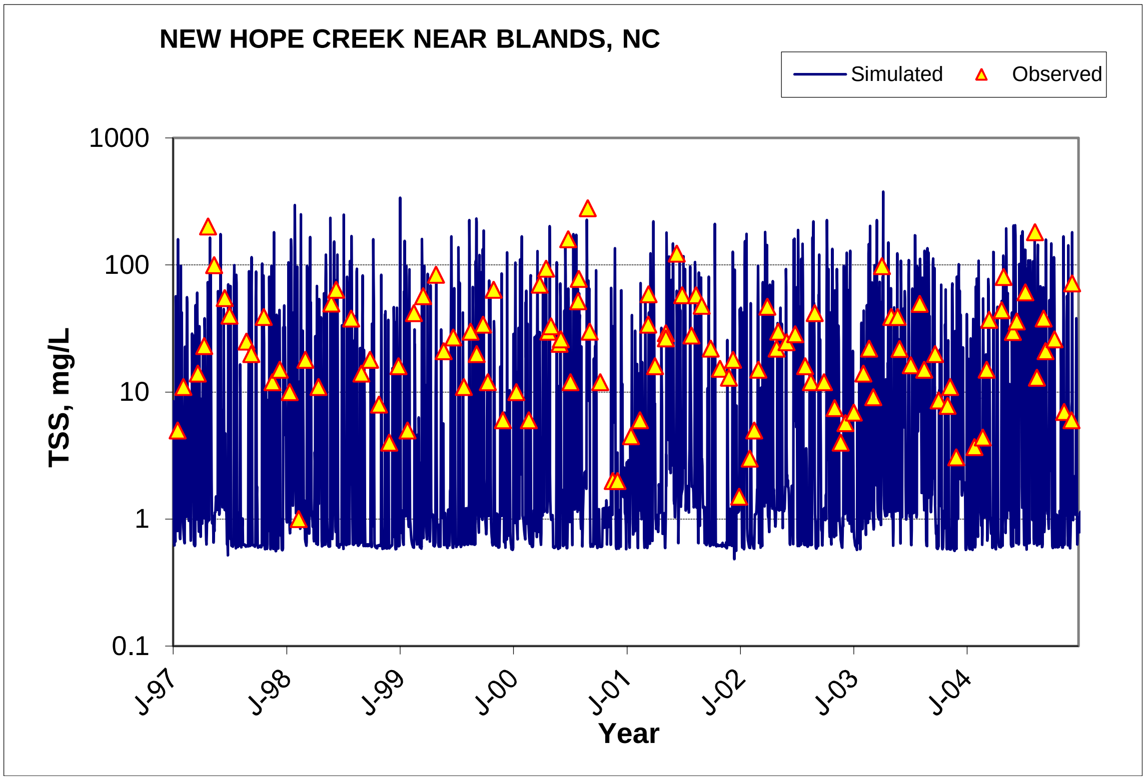


Figure 4-11. TSS Simulation for New Hope Creek near Blands, Calibration Period

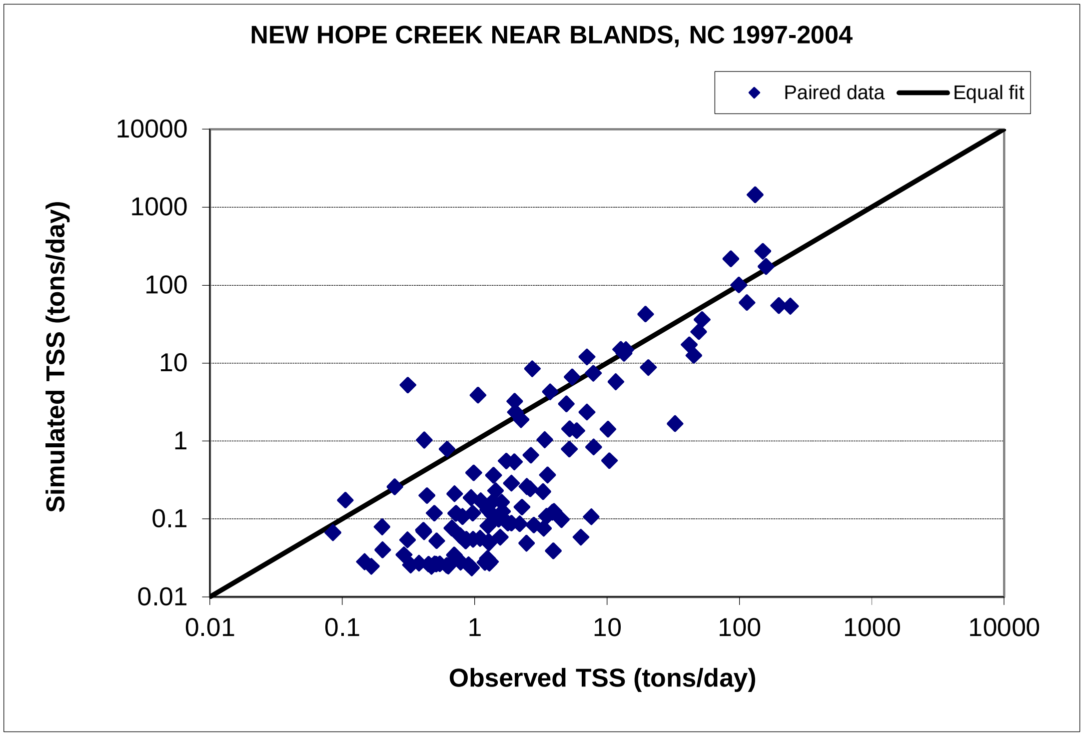


Figure 4-12. Scatterplot of Simulated vs. Observed TSS Load, New Hope Creek near Blands, Calibration Period

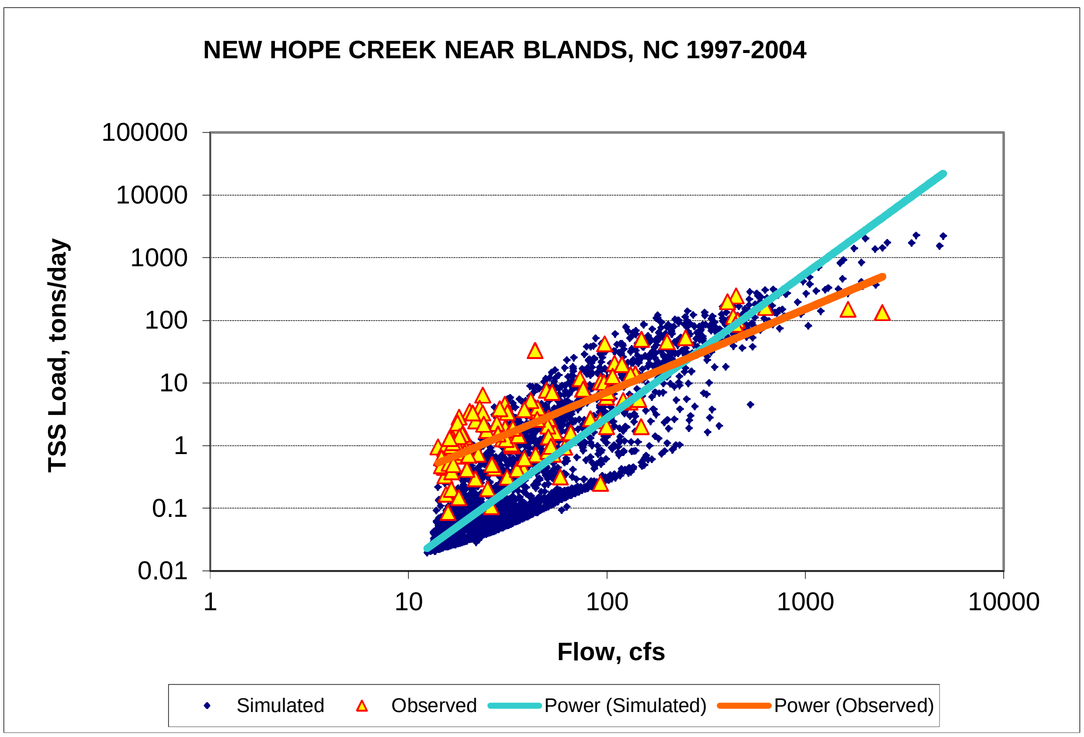


Figure 4-13. Power Plot of Observed and Predicted TSS Load vs. Simulated Flow, New Hope Creek near Blands, Calibration Period

As part of the calibration process, the differences between simulated and observed values were checked for bias against flow (Figure 4-14) and month (Figure 4-15). The plot versus flow confirms that TSS observations are generally under-estimated (simulated minus observed < 0) at lower flows, perhaps in part due to mechanical disturbances in the stream channel and floodplain that are not incorporated in the model. Simulated TSS is over-estimated relative to observations at the highest flows, resulting in a net over-estimation of paired loads; however, this result is again dependent on just a few data points. The plot versus month (for which the line shows the median) indicates that the under-estimated concentrations are primarily in the spring and summer.

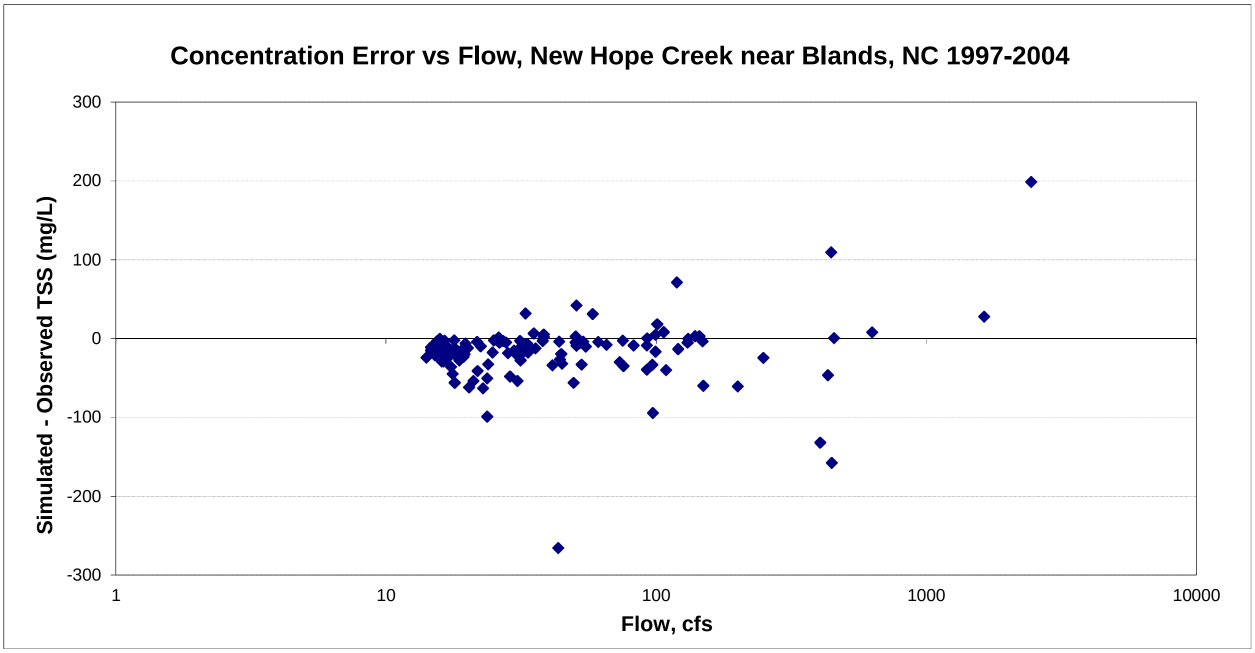


Figure 4-14. Distribution of TSS Simulation Error vs. Flow, New Hope Creek near Blands

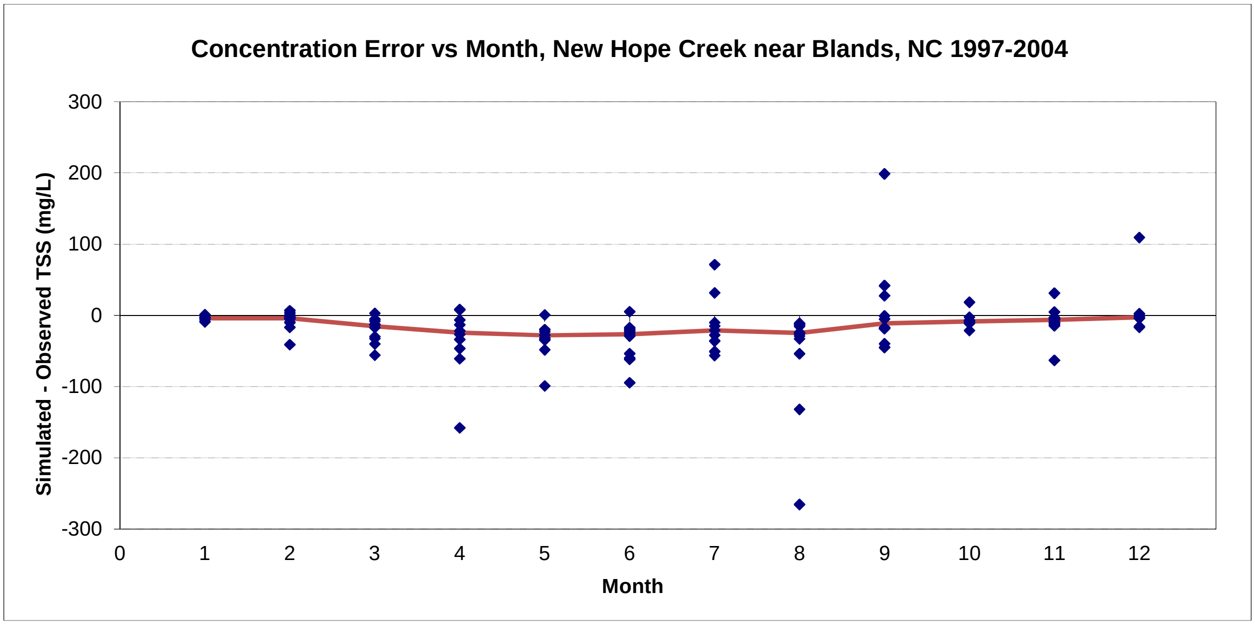


Figure 4-15. Distribution of TSS Simulation Error vs. Month, New Hope Creek near Blands

Following calibration for sediment, calibration was pursued for P and N. Phosphorus time series (Figure 4-16) show a close match, in part because the load is strongly affected by the wastewater discharge.

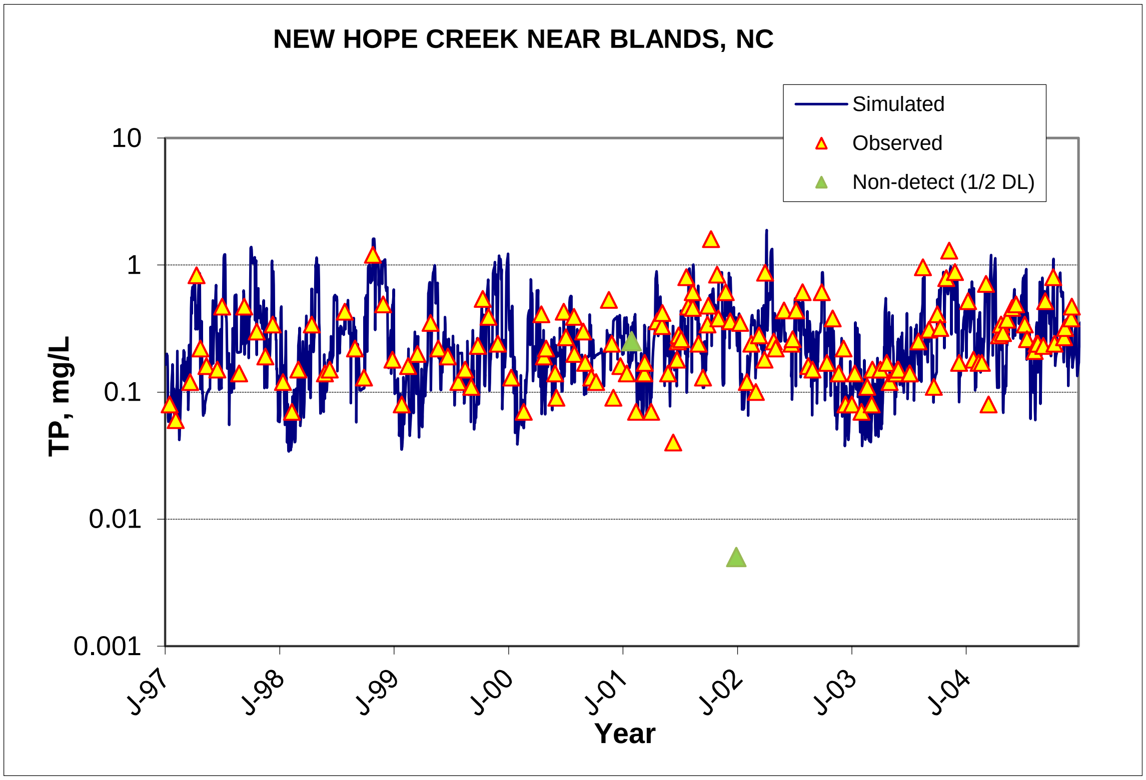


Figure 4-16. Total P Simulation for New Hope Creek near Blands, Calibration Period

The influence of the point source is clearly seen in a plot of concentration versus flow, where the declining relationship represents dilution of point source loads with higher streamflow. From this figure it will also be noted that the model does not fully match a few higher concentrations at the highest flows (Figure 4-17), which is also confirmed by a plot of simulation error versus flow (Figure 4-18). These higher flow concentrations strongly influence the total load calculation. As a result, the average error on paired load observations is -19 percent (simulated minus observed); however, the median error is near zero percent. Notably, the sign of the apparent error on total P is opposite that of TSS shown above, suggesting erosional processes have access to sediment more highly enriched in P during high flow events – perhaps from material stored within the wildfowl impoundment upstream of this site.

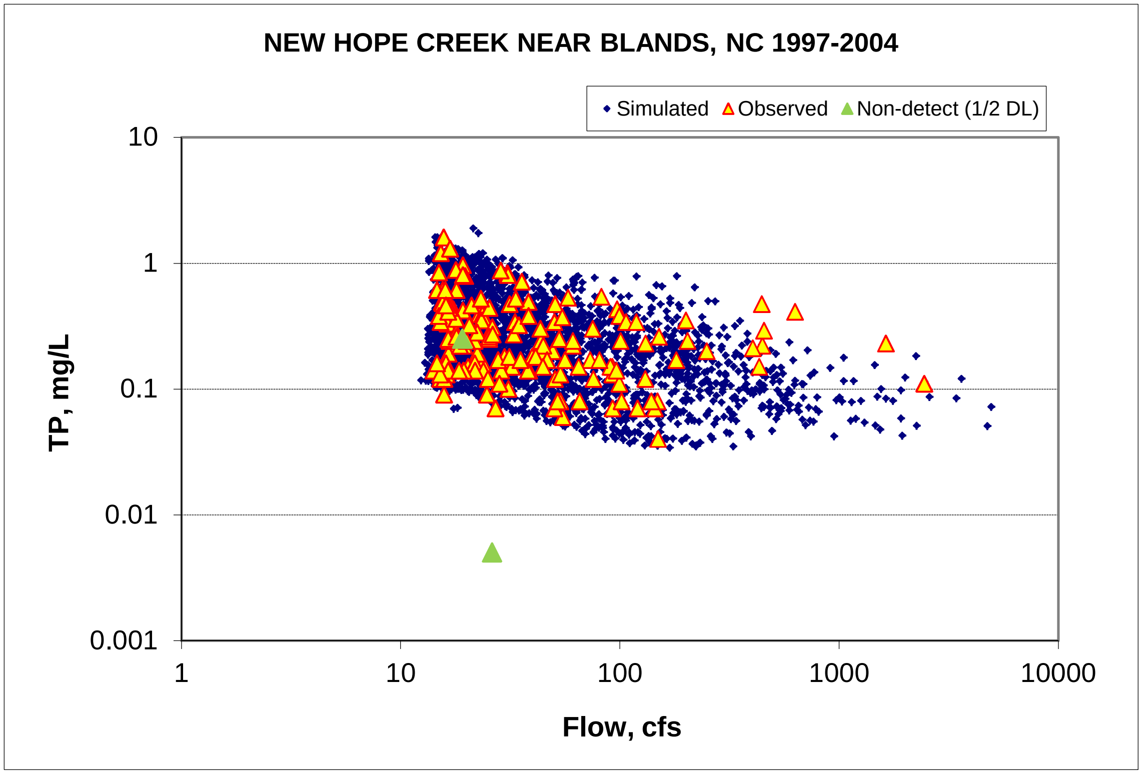


Figure 4-17. Total Phosphorus Concentration vs. Simulated Flow, New Hope Creek near Blands, Calibration Period

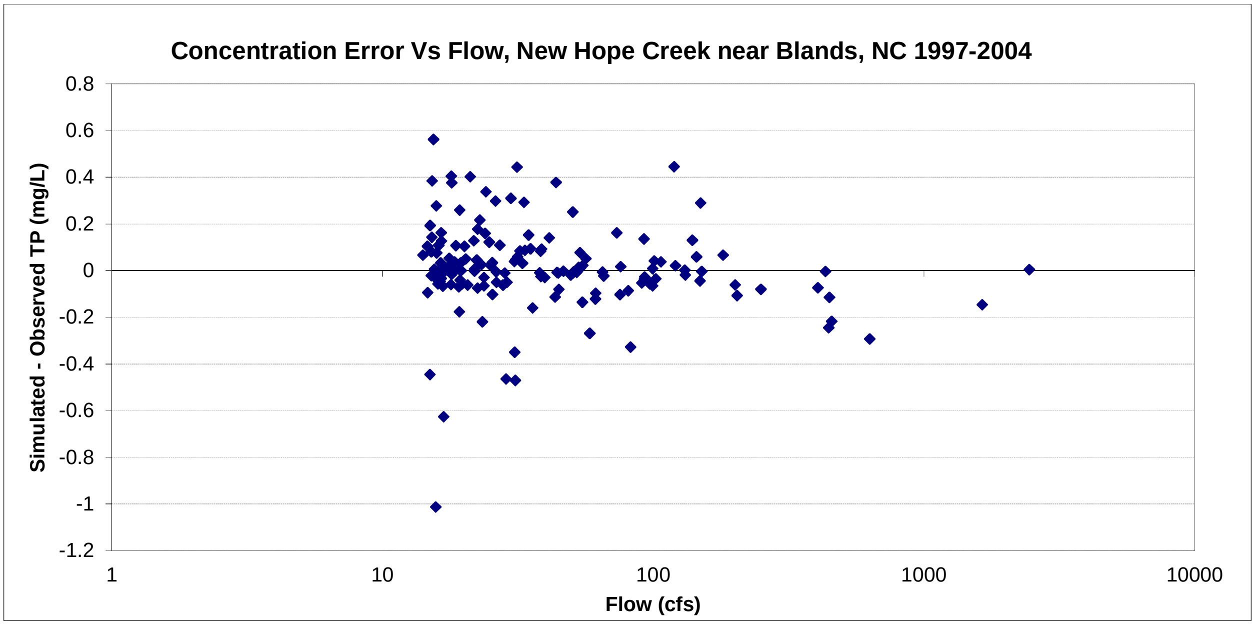


Figure 4-18. Distribution of Total P Simulation Error vs. Flow, New Hope Creek near Blands

Only very limited observations are available on P species; however, the data that are available are consistent with the model (Figure 4-19).

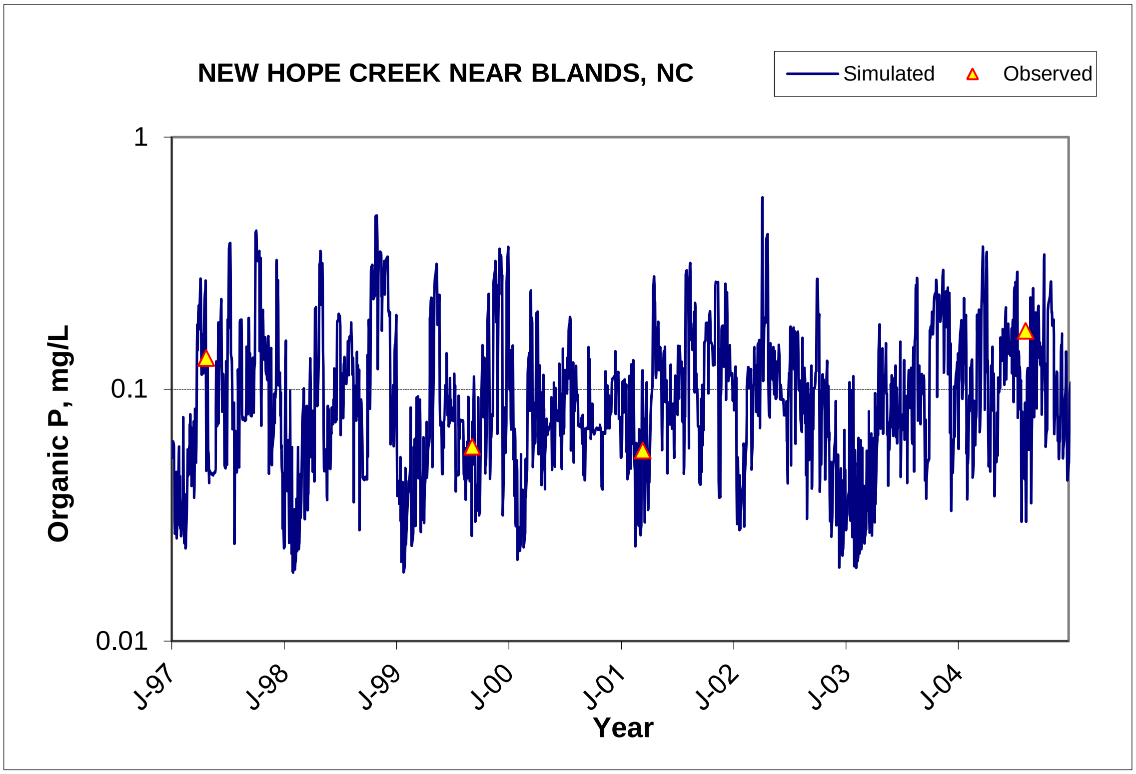


Figure 4-19. Organic P Simulation for New Hope Creek near Blands, Calibration Period

In contrast to phosphorus, the different inorganic and organic forms play a more important role in the calibration of nitrogen. The total nitrogen simulation (Figure 4-20) during the calibration period appears quite good, and there is little bias relative to flow (Figure 4-21), with the exception of one large outlier at low flow. As a result the calibration error statistics are good (10 percent relative error on average concentration, 8 percent relative error on paired loads).

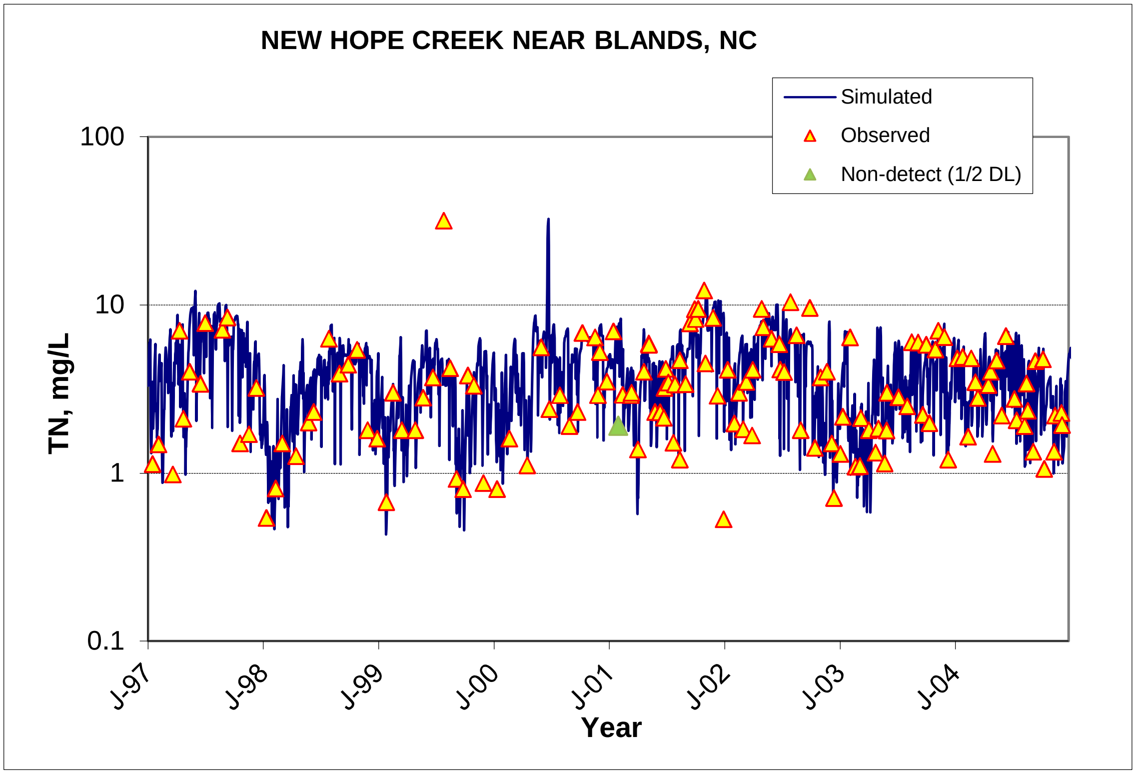


Figure 4-20. **Total N Simulation for New Hope Creek near Blands, Calibration Period**

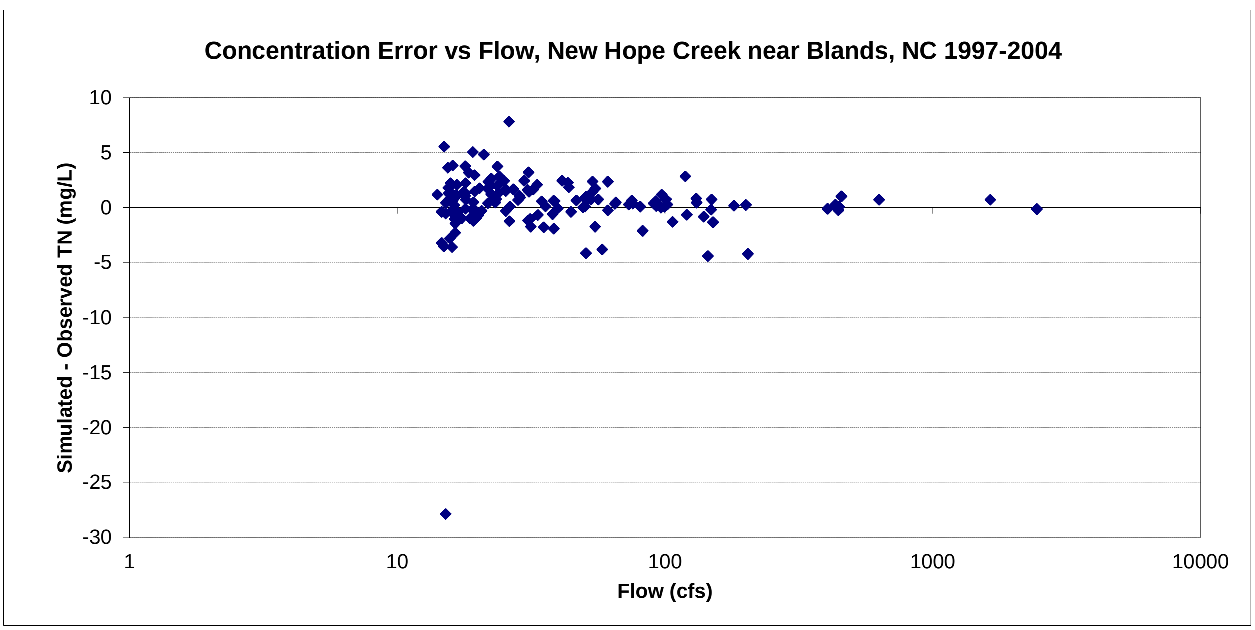


Figure 4-21. **Distribution of Total N Simulation Error vs. Flow, New Hope Creek near Blands**

Individual species of nitrogen are not always predicted as well. The dominant form under most conditions is oxidized inorganic N (NO_3+NO_2-N; nitrate plus nitrite N). The fit for oxidized inorganic N (Figure 4-22) is generally good. In contrast, the model appears to systematically under-estimate organic N concentrations beginning in 2002 (Figure 4-23), suggesting that changes in the details of plant operations have not been fully captured in the specification of effluent loading series.

Following calibration, model corroboration was undertaken using data from 2005 – 2011. Graphical results (Figure 4-24 and Figure 4-25) are qualitatively similar to the calibration period, as are the statistics (shown previously in Table 4-7), confirming that model performance is maintained across a separate time period. Full statistical results are presented in the next section.

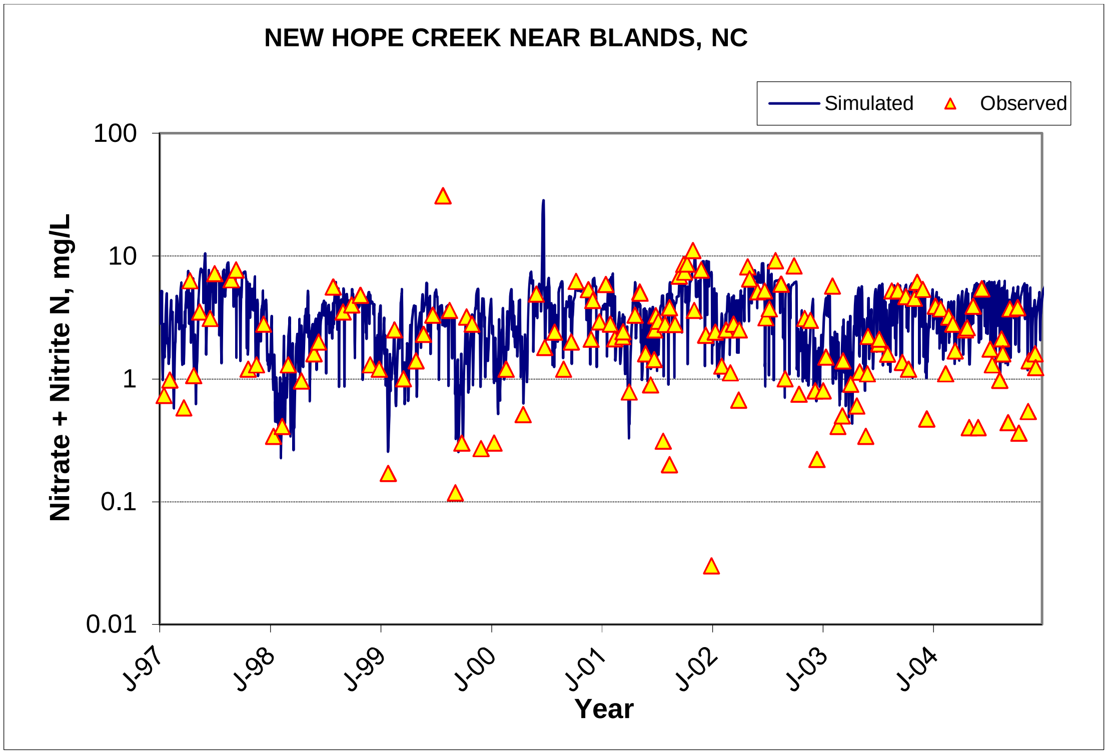


Figure 4-22. Nitrate plus Nitrite-N Calibration, New Hope Creek near Blands

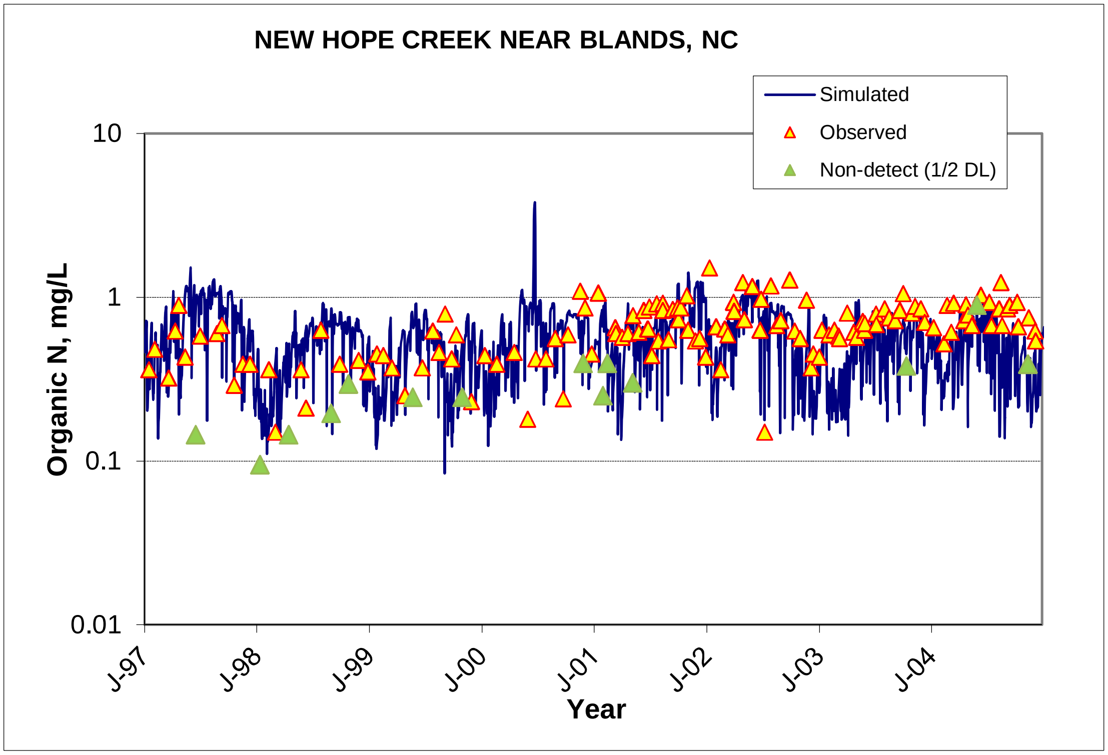


Figure 4-23. Organic N Calibration, New Hope Creek near Blands

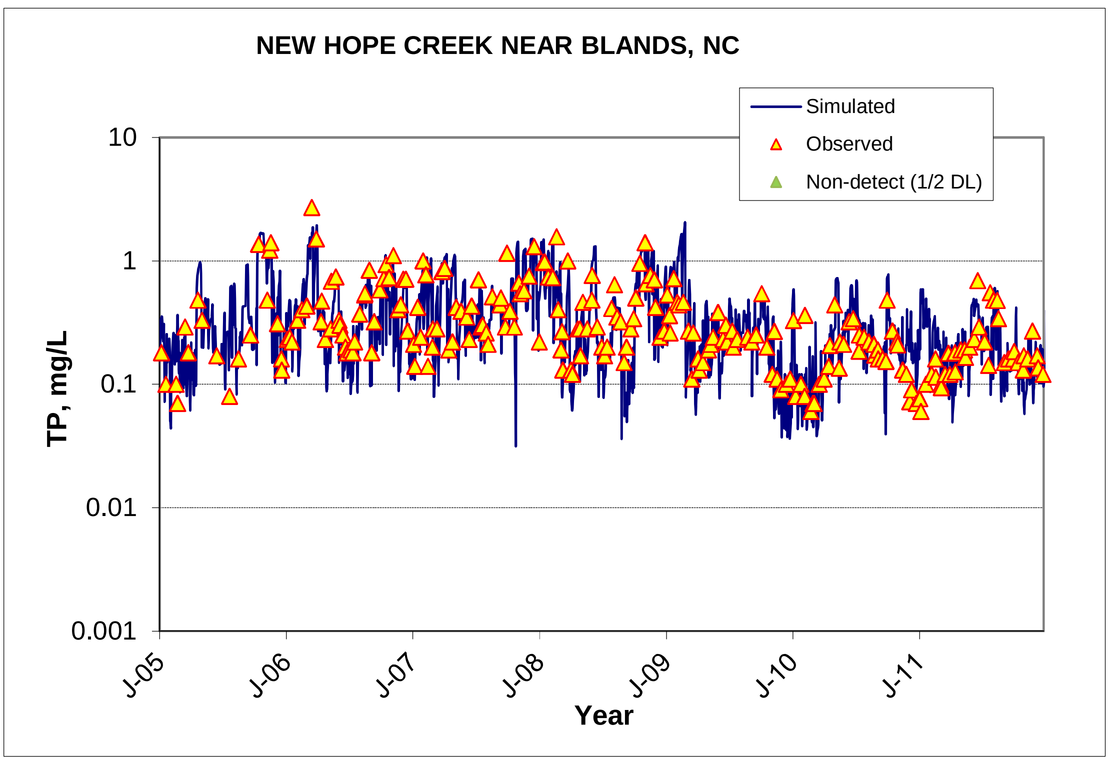


Figure 4-24. Total P Simulation for New Hope Creek near Blands, Corroboration Period

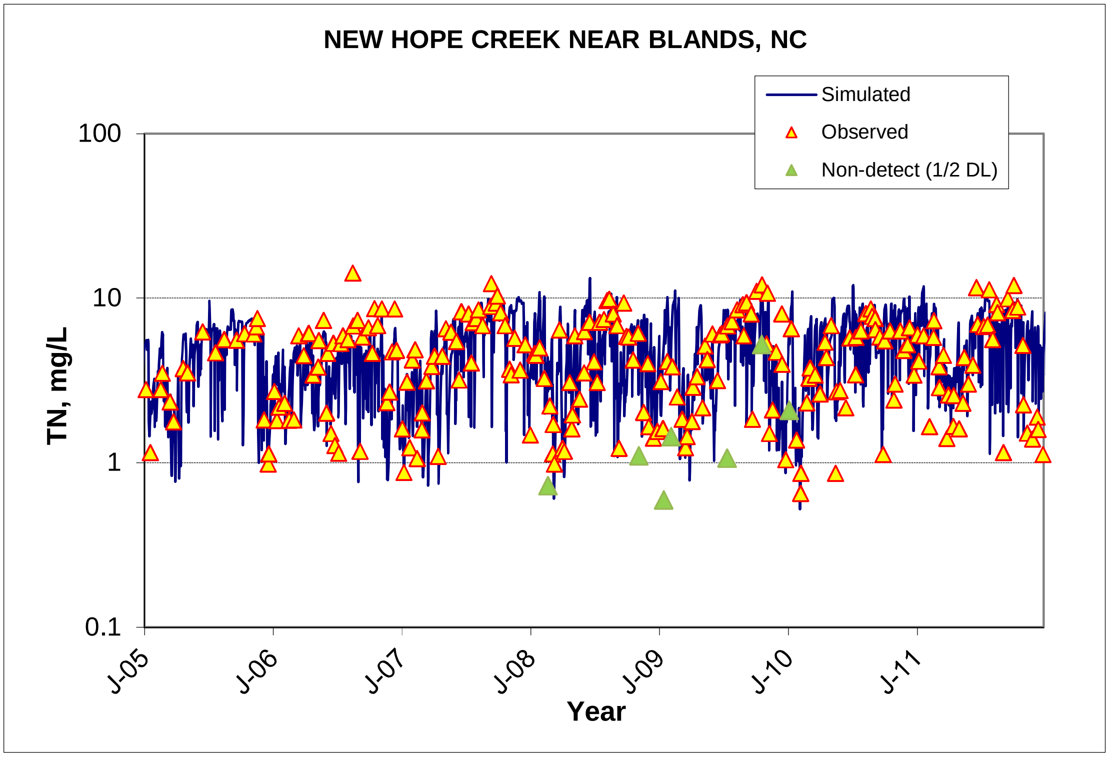


Figure 4-25. Total N Simulation for New Hope Creek near Blands, Corroboration Period

The excellent fit to observed nutrient concentrations at New Hope Creek near Blands is due in part to knowledge of the loads generated by South Durham WRF. The model is also calibrated to a station upstream of the point source, New Hope Creek at NC 54 nr Durham (B3020000). Nutrient concentrations are lower at this station and the fit somewhat noisier (Figure 4-26 and Figure 4-27); however both total phosphorus and total nitrogen predictions follow the monitored trends and are generally unbiased relative to flow regime. It is important to note that the model for New Hope Creek was not fit in isolation but rather used a common set of parameters (by RMU) that are applied across the entire Jordan Lake watershed and varied spatially only in accordance with known differences in soils and geology.

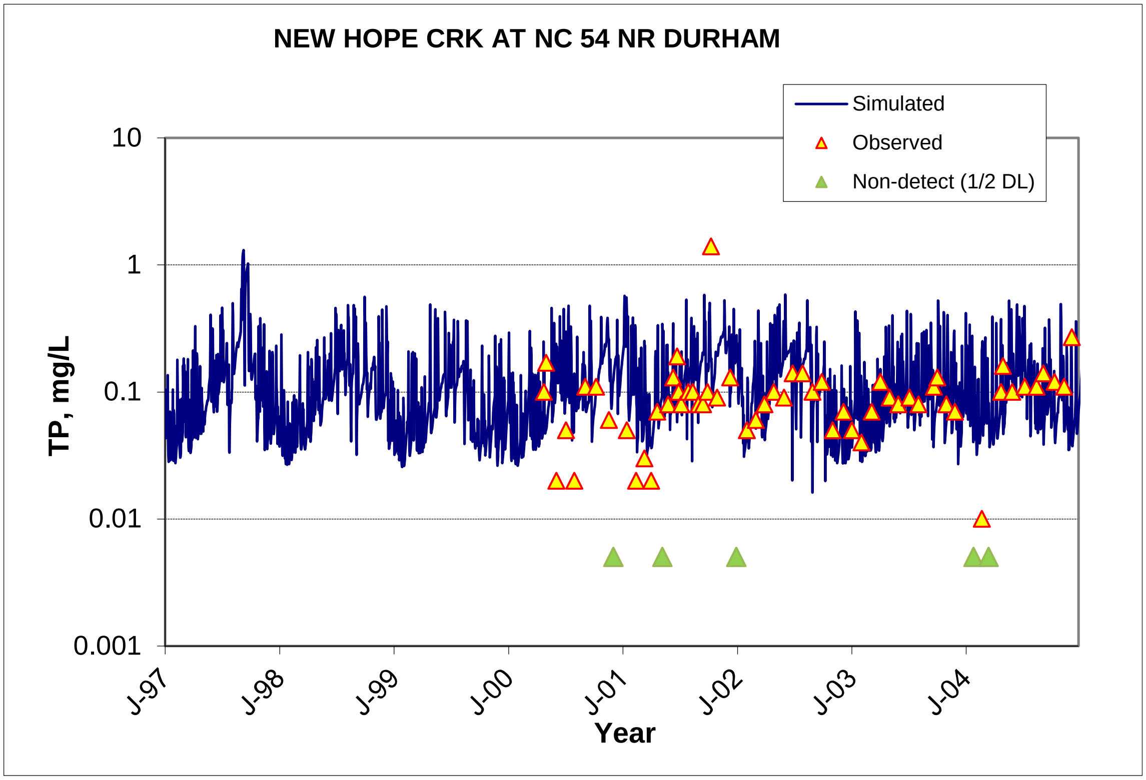


Figure 4-26. Total Phosphorus Calibration, New Hope Creek at NC 54

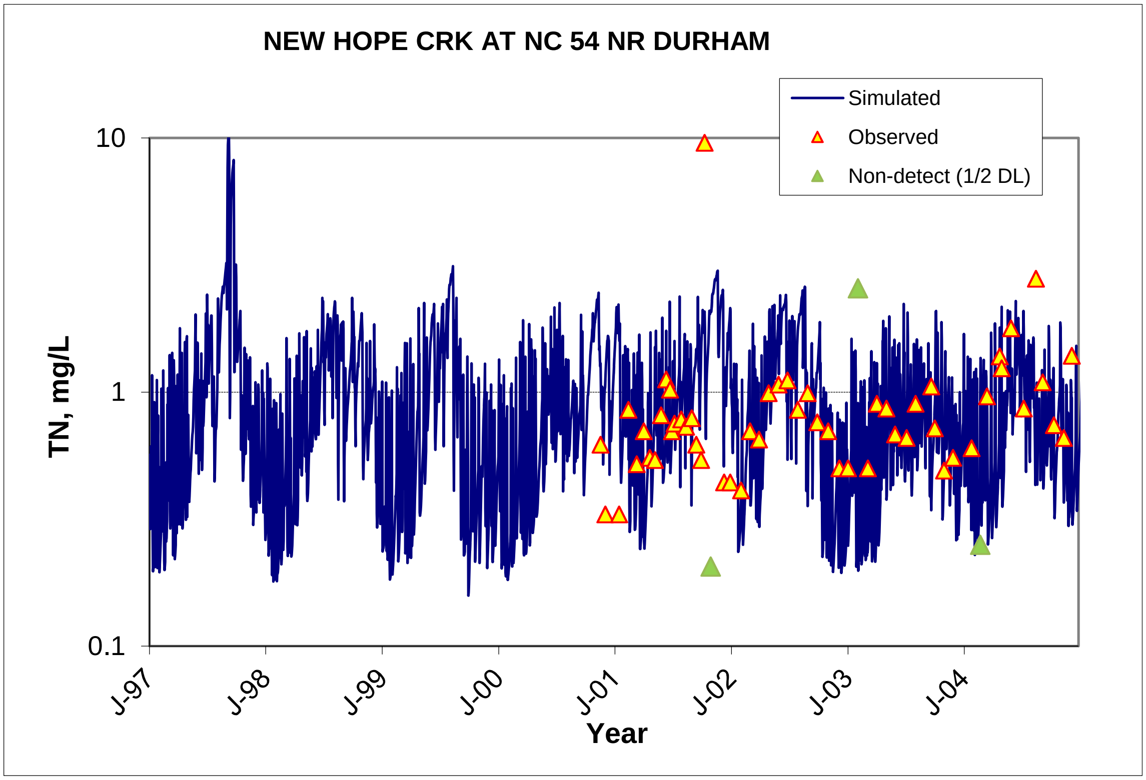


Figure 4-27. Total Nitrogen Calibration, New Hope Creek at NC 54

4.2.3 Water Quality Calibration Performance Evaluation

Due to the large number of stations calibrated, results are presented sequentially for the primary, secondary, and tertiary stations. Table 4-8 provides the performance results for the calibration period (which varies by location) at the primary stations. The primary stations have co-located water quality monitoring and flow gaging and, therefore, provide the greatest value for calibrating load estimates. As with hydrology, results are color-coded using the ranking scheme described above in Table 3-2, with blue representing a “very good” fit, green “good”, yellow “fair”, and orange representing a “poor” fit.

Rankings are shown for both concentration and load, in accordance with the QAPP; although, for the intended uses of the model, load estimates are of most importance. However, load estimates are also poorly known due to limited sampling and a high degree of intraday variability during the large storms that transport much of the total load. As a result, statistics comparing the average relative error between simulated and observed loads can be inflated by a small discrepancy in a few observations at high flows. To help adjust for this issue the median relative error is also provided as an alternative measure of model fit that is less sensitive to outliers.

Table 4-8 and the following tables focus on the percentage errors, consistent with the process laid out in the QAPP for evaluation of the calibration and described in Section 3.1.2. It is important to note, however, that a relatively large percentage error may reflect a comparatively small difference in concentration if the average observed concentration is low. The table entries for Concentration Average Error and Concentration Median Error show the error as a percentage, but also include the magnitude of the error (with units of mg/L) in parentheses. From this it will be noted, for example that an apparently large concentration percentage average error for total N of -44.7 percent at South Buffalo Creek station B0670000 corresponds to a discrepancy of only about 0.3 mg/L - because the average observed total N concentration at this station is less than 1 mg/L.

The primary stations were selected based on data availability, not watershed characteristics, and contain a mix of watershed sizes, settings, and point source influences (see below). As noted above, model parameters were optimized across all stations and not fine-tuned to individual station drainage areas. Inevitably this results in some stations having a better fit than others. Overall, for total N the average relative error (RE) on paired load estimates ranges from fair to very good, with one poor rating (USGS 0209782609). The median REs on total N load are all good or very good. For total P paired loads, the median REs are all very good; however, five stations received a fair or poor rating for average load RE. These stations generally under-predicted total P concentrations at high flows. Notes regarding individual stations are provided below the table, while the issue of potential under-prediction of total P is addressed in detail in Section 4.3.

Table 4-8. Water Quality Performance for the Calibration Period at the Primary Stations

Calibration Period		2005 - 2112	1997 - 2004	2005 - 2112	1997 - 2004	1997 - 2004	2005 - 2112	1997 - 2004	1997 - 2004	1997 - 2004	1997 - 2004	1997 - 2004	2005 - 2112
Model Constituent	Model Component	B0400000 Reedy Fk	B0540000 N Buffalo	B0670000 S Buffalo	B1140000 Haw at Haw	B2100000/ 02096960 Haw Bynum	B3025000 Third Fk	B3040000/ 02097314 New Hope	B3660000/ 0209741955 NE Crk	B3899180 Morgan Crk	USGS 02096846 Cane Crk	USGS 02097464 Morgan Crk	USGS 0209782609 White Oak
Total Suspended Sediment	Sample Count	85	53	86	52	147	85	120	65	57	51	59	47
	Concentration Average Error	-27.3% (-2.0)	24.1% (3.7)	-36.0% (-5.4)	17.3% (3.4)	13.3% (3.6)	-3.7% (-0.7)	-53.8% (-18.1)	-64.6% (-21.8)	106.1% (9.5)	-45.3% (-12.5)	-55.5% (-21.6)	-62.0% (-28.2)
	Concentration Median Error	-47.1% (-3.4)	2.2% (0.3)	-6.5% (-1.0)	9.6% (1.9)	7.4% (2.0)	-30.0% (-5.6)	-40.2% (-13.5)	-36.8% (-12.4)	1.3% (0.1)	-14.9% (-4.1)	-13.5% (-5.3)	-24.8% (-11.3)
	Load Ave Error	-48.8%	15.1%	-7.1%	-10.0%	9.7%	61.4%	54.3%	-45.0%	54.2%	221.9%	153.9%	-51.2%
	Load Median Error	-2.4%	0.3%	-0.2%	1.7%	0.4%	-0.4%	-6.6%	-3.9%	0.1%	-0.2%	-0.2%	-1.0%
Total Nitrogen	Sample Count	84	85	86	85	174	85	151	96	57	54	62	49
	Concentration Average Error	31.4% (0.1)	-8.1% (-0.7)	-44.7% (-0.3)	24.3% (0.7)	19.5% (0.3)	22.7% (0.2)	9.6% (0.4)	20.3% (1.9)	21.5% (0.2)	-21.0% (-0.2)	-23.5% (-0.2)	-39.7% (-0.3)
	Concentration Median Error	29.7% (0.1)	-10.0% (-0.9)	-33.7% (-0.2)	25.8% (0.7)	18.0% (0.3)	-10.1% (-0.1)	15.0% (0.6)	22.6% (2.1)	38.6% (0.3)	-28.5% (-0.3)	-18.3% (-0.2)	-49.7% (-0.3)
	Load Ave Error	4.8%	-6.4%	-18.7%	29.0%	20.6%	18.7%	8.0%	33.3%	-3.6%	1.3%	-24.6%	-41.8%
	Load Median Error	2.5%	-5.5%	-11.0%	17.7%	7.5%	-0.3%	10.6%	16.1%	3.5%	-1.1%	-1.2%	-3.9%
Total Phosphorus	Sample Count	80	85	81	85	161	80	157	95	64	51	60	49
	Concentration Average Error	62.0% (0.02)	10.6% (0.09)	-0.3% (0.00)	-0.9% (0.00)	3.1% (0.01)	-2.8% (-0.01)	3.6% (0.01)	19.5% (0.09)	55.7% (0.04)	-44.5% (-0.04)	-71.4% (-0.10)	-32.8% (-0.02)
	Concentration Median Error	78.7% (0.03)	6.6% (0.05)	-2.9% (0.00)	9.9% (0.03)	0.7% (0.00)	-15.9% (-0.03)	-0.3% (0.00)	5.0% (0.02)	48.1% (0.03)	-6.2% (-0.01)	-35.6% (-0.05)	-20.0% (-0.01)
	Load Ave Error	-44.4%	-0.9%	0.5%	-23.2%	-34.3%	-20.5%	-19.3%	-1.5%	41.6%	-18.1%	-51.2%	-59.5%
	Load Median Error	5.7%	5.1%	-0.2%	5.7%	0.4%	-0.7%	-0.1%	1.9%	11.7%	-0.1%	-1.2%	-0.7%

Note: Error statistics are based on simulated minus observed values.

The individual stations shown in Table 4-8 are as follows (see Table 3-14 and Figure 3-3 for the map key numbers and locations in the watershed):

Map Key 7: B0400000 Reedy Fork at SR 2179 High Rock Road near Monticello, NC. Average RE on paired loads is very good for total N and poor for total P. This station is located downstream of Lake Townsend, which controls most of the flow and the model appears to under-predict phosphorus trapping within the lake at low flows. The fit is unbiased, although imprecise, at high flows, and discrepancies in load estimates are due to a few extreme values. This is also suggested by a change in sign in the total P load REs during the corroboration period (Table 4-11).

Map Key 9: B0540000 North Buffalo Creek at SR 2832 near Greensboro, NC. This station is downstream of a major point source and total nutrient load is well simulated.

Map Key 11: B0670000 South Buffalo Creek at SR 3000 near Greensboro, NC. The drainage is urban but does not contain major point sources. REs on nutrient loads are good or very good, despite some issues with total N concentrations at low flows.

Map Key 16: B1140000 Haw River at NC 49N at Haw River, NC. This mainstem station is downstream of multiple lakes and point sources. Load average RE for total N is only fair during the calibration period, but resolves to very good during the corroboration period. The average RE on total P load is good for calibration and fair for corroboration, noting that both values are close to the good/fair threshold. The simulation appears to show some consistent under-estimation of total P load at high flows.

Map Key 24: B2100000/USGS02096960 Haw River at SR 1713 near Bynum, NC. This downstream station on the Haw River is below many lakes and point sources. Total N loads are well simulated, rating good during calibration and very good during corroboration; however, total P loads appear to be under-estimated during high flow events, as with the previous station.

Map Key 26: B3025000 Third Fork Creek at NC 54 near Durham, NC. This is an urban stream with no major point sources. Average REs are good during the calibration period.

Map Key 27: B3040000/USGS02097314 New Hope Creek at SR 1107 near Blands, NC. Details on the calibration process for this station, which is downstream of the South Durham WRF, are presented above in Section 4.2.2. The load simulation is rated good to very good during calibration.

Map Key 29: B3660000/USGS0209741955 Northeast Creek at SR 1100 near Nelson, NC. This station is downstream of the Triangle WWTP. Fit was only fair for total N during the calibration period, likely reflecting uncertainty in the representation of point source loads, but improved to very good during the corroboration period.

Map Key 31: B3899180 Morgan Creek at Mason Farm WWTP entrance at Chapel Hill, NC. This station is upstream of the OWASA discharge, but downstream of University Lake. The fit to total N loads is very good, while total P is overestimated during calibration, and less so corroboration. There are discrepancies in individual concentration predictions, likely due to model representation of lake hydraulics and nutrient processing.

Map Key 33: USGS02096846 Cane Creek near Orange Grove, NC. This rural station is upstream of Cane Creek Reservoir in an area with dairy farms. Total N and total P load RE are very good and good, respectively during calibration. However, during corroboration sediment, total N, and total P load REs rate poor, and appear to be under-estimated at high flows for this station.

Map Key 34: USGS02097464 Morgan Creek near White Cross, NC. Station is upstream of University Lake and has no major point sources. Somewhat similar to Cane Creek, calibration and corroboration total N and total P loads all appear to be under-estimated for high flows at this station, while sediment is overestimated.

Map Key 35: USGS0209782609 White Oak Creek at mouth near Green Level, NC. Calibration is generally poor at this station, for unknown reasons. The watershed is on the east side of Jordan Lake in a rapidly developing area. Both N and P loads tend to be under-predicted.

The secondary water quality stations consist of the remaining sites that are without impacts from major point sources, but do not have flow gaging. Table 4-9 and Table 4-12 provide the performance results for the calibration and corroboration periods respectively at the secondary stations.

Model prediction of individual load events is somewhat limited for these stations, with four stations receiving a poor rating on average RE for total N load and five stations receiving a poor rating on average RE for total P load. However, the median REs are all in the good to very good range, with the exception of one headwater station with a poor RE rating for total P. On the other hand, the magnitude of the errors expressed as concentration is generally small. Discrepancies in the average REs are both positive and negative, suggesting there may be more local variability than is accounted for in the unified set of parameters adopted for the model.

Table 4-9. Water Quality Performance for the Calibration Period at the Secondary Stations

Calibration Period		1997 - 2004	1997 - 2004	2005 - 2112	1997 - 2004	1997 - 2004	1997 - 2004	2005 - 2112	1997 - 2004	1997 - 2004	1997 - 2004	1997 - 2004
Model Constituent	Model Component	B0040000 Haw R	B0050000 Haw R	B0070010 Troublesome	B0210000 Haw R	B0480050 N Buffalo	B1095000 Jordan Crk	B1260000 Town Br	B1940000 Alamance	B1960000 Alamance	B3020000 New Hope	B3300000 NE Crk
Total Suspended Sediment	Sample Count	51	109	85	47	57	50	29	57	107	57	57
	Concentration Average Error	-10.9% (-0.7)	37.0% (2.4)	-53.2% (-3.8)	19.7% (1.6)	73.6% (4.7)	-13.4% (-2.0)	-86.4% (-15.4)	134.8% (13.3)	65.5% (8.2)	-30.1% (-7.9)	-17.8% (-3.9)
	Concentration Median Error	-43.6% (-3.0)	-31.9% (-2.1)	-51.4% (-3.7)	2.6% (0.2)	-25.6% (-1.6)	-25.8% (-3.8)	-12.2% (-2.2)	25.4% (2.5)	-1.9% (-0.2)	-35.0% (-9.2)	-37.2% (-8.2)
	Load Ave Error	9.6%	581.6%	0.6%	11.2%	445.6%	30.2%	51.5%	560.5%	265.7%	-8.0%	60.0%
	Load Median Error	-19.0%	-6.8%	-10.9%	0.7%	-1.7%	-2.2%	-4.7%	0.4%	-0.1%	-1.4%	-0.9%
Total Nitrogen	Sample Count	85	139	85	65	56	46	87	57	105	57	58
	Concentration Average Error	10.4% (0.0)	-17.9% (-0.1)	-10.1% (-0.1)	25.9% (0.2)	-69.0% (-1.3)	8.1% (0.0)	-52.8% (-0.5)	44.8% (0.3)	13.4% (0.3)	-1.5% (0.0)	20.6% (0.2)
	Concentration Median Error	13.9% (0.1)	-17.7% (-0.1)	-15.5% (-0.1)	20.8% (0.1)	-29.8% (-0.5)	-0.6% (0.0)	-36.8% (-0.3)	48.7% (0.4)	24.9% (0.5)	4.8% (0.0)	1.2% (0.0)
	Load Ave Error	4.1%	30.3%	-1.6%	18.1%	-56.9%	32.7%	-44.1%	75.7%	67.9%	11.5%	-10.0%
	Load Median Error	8.5%	-4.9%	-3.1%	11.8%	-12.0%	-0.3%	-3.7%	4.6%	11.3%	0.5%	0.2%
Total Phosphorus	Sample Count	87	147	80	66	64	46	87	64	110	64	64
	Concentration Average Error	70.9% (0.02)	15.6% (0.01)	37.4% (0.02)	27.4% (0.03)	-48.0% (-0.14)	0.8% (0.00)	-37.4% (-0.02)	63.1% (0.03)	9.1% (0.02)	24.3% (0.03)	159.8% (0.12)
	Concentration Median Error	72.0% (0.02)	26.2% (0.01)	92.8% (0.04)	24.1% (0.02)	-10.3% (-0.03)	-3.3% (0.00)	-8.8% (-0.01)	77.9% (0.04)	8.0% (0.02)	18.9% (0.02)	93.4% (0.07)
	Load Ave Error	50.9%	20.5%	-24.0%	9.7%	-40.9%	-7.1%	-19.6%	48.5%	43.4%	2.8%	55.5%
	Load Median Error	35.6%	8.6%	10.1%	15.8%	-3.2%	-0.2%	-0.4%	4.4%	5.4%	0.9%	3.4%

Note: Error statistics are based on simulated minus observed values.

The individual stations contained in the secondary station set are as follows (see Table 3-14 and Figure 3-3 for the map key numbers and locations in the watershed):

Map Key 1: B0040000 Haw River at SR 2109 near Oak Ridge, NC. This represents a small, unsewered watershed at the headwaters of the Haw. Over-prediction of phosphorus at this station, especially at low flow, appears to be associated with the assumptions for failure rate and phosphorus loading from onsite wastewater disposal systems.

Map Key 2: B0050000 Haw River at Business US 29 near Benaja, NC. The station is downstream of the previous site, but still upstream of the influence of major point sources. Total P load estimates improve to good at this site, while total N declines to a fair rating.

Map Key 3: B0070010 Troublesome Creek at Business US 29 near Reidsville, NC. This station is downstream of Reidsville Lake and nutrient processes within the lake have a sizable influence on the quality of model predictions. Load RE rates very good and good at this station for total N and total P, respectively.

Map Key 6: B0210000 Haw River at SR 1561 near Altamahaw, NC. Nutrient load estimates are good to very good. Although this station is included in the secondary set, it does have some point source influence as it is downstream of the Reidsville WWTP.

Map Key 8: B0480050 North Buffalo Creek at North Buffalo Creek WWTP influent conduit pier at Greensboro, NC. Nutrient loads appear to be under-estimated at this urban station. This occurs across the range of flows for nitrogen and may indicate an additional unknown source. RE for phosphorus loads, but not nitrogen loads, improves during the corroboration period.

Map Key 15: B10950000 Jordan Creek at SR 1754 near Union Ridge, NC. RE for load estimates appears to be mostly affected by random noise in this small tributary.

Map Key 18: B1260000 Town Branch at SR 2109 near Graham, NC. Concentrations and loads of both total N and total P tend to be under-estimated at low to moderate flows, suggesting groundwater contributions may be elevated in this area. The fit for storm flows is better, but the average RE on N loads is poor during calibration. The total N fit improves to very good during corroboration, though concentrations remain low.

Map Key 20: B1940000 Big Alamance Creek at NC 87 near Swepsonville, NC. This site is just upstream of the Burlington Southside discharge. In contrast to many of the other secondary stations, loads of N and P tend to be over-estimated at this station across the range of flows, resulting in poor ratings during calibration. Possibly this is due to an over-estimate of onsite wastewater disposal contributions in the upstream watershed.

Map Key 21: B1960000 Alamance Creek at SR 2116 at Swepsonville, NC. This site is downstream of the Burlington Southside discharge, but was included in the secondary group due to the relative size of the upstream watershed. The apparent over-prediction of load at the previous site persists.

Map Key 25: B3020000 New Hope Creek at NC 54 near Durham, NC. A very good fit for phosphorus loads is obtained at the upstream New Hope Creek station. Nitrogen loads tend to be over-estimated during the corroboration period, with occasional over-prediction occurring in all flow ranges and all seasons; nonetheless, the median RE for nitrogen is very good during corroboration. Calibration N loads rate very good for both average and median RE.

Map Key 28: B3300000 Northeast Creek at SR 1102 Sedwick Road near Research Triangle Park, NC. This station is located upstream of the Durham Triangle WWTP discharge. The unified parameter set provides a very good fit to nitrogen loads during both the calibration and corroboration periods. The average RE on phosphorus load is only poor during the calibration period, but increases to very good during the corroboration period and is thus not believed to represent a problem.

The remaining stations are presented in the tertiary group and include many stations affected by point sources, but without flow gaging. A majority of these stations are close to other monitored stations in the primary group; thus, the amount of additional information provided by these stations is somewhat limited. Table 4-10 and Table 4-13 provide the performance results for the calibration and corroboration periods respectively at the tertiary stations.

Table 4-10. Water Quality Performance for the Calibration Period at the Tertiary Stations

Calibration Period		2005 - 2112	1997 - 2004	1997 - 2004	2005 - 2112	1997 - 2004	1997 - 2004	1997 - 2004	1997 - 2004	1997 - 2004	1997 - 2004	1997 - 2004	1997 - 2004
Model Constituent	Model Component	B0160000 L Trouble	B0170000 Haw R	B0540050 N Buffalo	B0750000 S Buffalo	B0840000 Reedy Fk	B0850000 Haw R	B1200000 Haw R	B1440000 Haw R	B1980000 Haw R	B2000000 Haw R	B3300000 NE Crk	B3900000 Morgan Ck
Total Suspended Sediment	Sample Count	29	57	57	94	81	57	58	57	53	52	57	113
	Concentration Average Error	-37.8% (-4.9)	46.6% (4.6)	15.6% (1.6)	-23.3% (-3.0)	-34.7% (-6.7)	47.8% (7.3)	48.2% (7.5)	55.6% (8.7)	4.3% (0.8)	-6.1% (-1.2)	-68.8% (-34.9)	-29.7% (-5.5)
	Concentration Median Error	-23.5% (-3.1)	-22.2% (-2.2)	5.9% (0.6)	-1.8% (-0.2)	7.7% (1.5)	5.8% (0.9)	15.7% (2.4)	16.7% (2.6)	3.1% (0.6)	10.4% (2.1)	-41.8% (-21.2)	-11.1% (-2.1)
	Load Ave Error	-13.3%	251.5%	50.7%	-50.5%	-66.8%	217.6%	241.1%	229.2%	18.7%	-33.1%	-68.8%	-9.0%
	Load Median Error	-7.8%	-2.0%	0.6%	-0.3%	0.9%	0.5%	1.0%	1.2%	1.2%	0.8%	-2.6%	-3.1%
Total Nitrogen	Sample Count	87	58	57	149	115	57	58	56	46	58	57	146
	Concentration Average Error	162.0% (1.2)	-2.2% (0.0)	13.4% (1.1)	10.6% (0.7)	9.2% (0.5)	-6.0% (-0.2)	16.2% (0.5)	14.1% (0.4)	2.0% (0.1)	14.1% (0.3)	37.5% (3.5)	71.9% (3.4)
	Concentration Median Error	154.2% (1.2)	-2.1% (0.0)	6.4% (0.5)	7.9% (0.5)	10.7% (0.5)	-4.9% (-0.2)	13.3% (0.4)	13.2% (0.4)	6.2% (0.2)	17.0% (0.3)	34.3% (3.2)	53.2% (2.5)
	Load Ave Error	107.7%	33.8%	-4.4%	6.3%	-12.1%	-7.5%	32.2%	32.7%	1.4%	25.1%	4.9%	63.4%
	Load Median Error	86.2%	-0.6%	7.4%	7.0%	9.2%	-3.1%	14.6%	10.3%	6.1%	11.3%	22.4%	55.8%
Total Phosphorus	Sample Count	87	65	64	144	120	64	65	64	53	58	64	152
	Concentration Average Error	157.2% (0.13)	11.6% (0.01)	53.4% (0.30)	14.3% (0.10)	12.6% (0.07)	20.2% (0.07)	40.0% (0.11)	17.7% (0.05)	6.4% (0.02)	-4.1% (-0.01)	65.7% (0.17)	97.5% (0.19)
	Concentration Median Error	115.6% (0.10)	21.5% (0.03)	49.1% (0.28)	7.8% (0.05)	16.9% (0.09)	20.2% (0.07)	30.4% (0.08)	10.0% (0.03)	9.3% (0.03)	1.7% (0.00)	32.3% (0.08)	39.6% (0.08)
	Load Ave Error	89.4%	-1.7%	29.2%	-4.4%	-25.7%	-7.1%	40.0%	11.4%	-10.3%	-30.1%	9.3%	57.9%
	Load Median Error	66.3%	8.5%	39.4%	6.1%	9.2%	9.1%	20.0%	7.4%	8.1%	1.1%	9.4%	24.3%

Note: Error statistics are based on simulated minus observed values.

The individual stations contained in the tertiary station set are as follows (see Table 3-14 and Figure 3-3 for the map key numbers and locations in the watershed):

Map Key 4: B0160000 Little Troublesome Creek at SR 2600 near Reidsville, NC. This station is downstream of the Reidsville WWTP. Over-prediction of both nitrogen and phosphorus load and concentration suggests the load from this point source might be over-estimated.

Map Key 5: B0170000 Haw River at SR 2620 High Rock Road near Williamsburg, NC. Located downstream of both Little Troublesome Creek and Reidsville Lake, this station is influenced by both the WWTP and lake outflow. Performance is mixed at this station.

Map Key 10: B0540050 North Buffalo Creek at SR 2770 Huffine Mill Road near Mcleansville, NC. Downstream of the Greensboro discharge and also downstream of primary station B0540000.

Map Key 12: B0750000 South Buffalo Creek at SR 2821 at Mcleansville, NC. Downstream of primary station B0750000.

Map Key 13: B0840000 Reedy Fork at NC 87 at Ossipee, NC. Station is downstream of the confluence with Buffalo Creek and is thus affected by both Greensboro WWTP discharges

Map Key 14: B0850000 Haw River at SR 1530 Gerringer Mill Road near Ossipee, NC. Mainstem Haw River below Reedy Fork.

Map Key 17: B1200000 Haw River at NC 54 near Graham, NC. Mainstem, downstream of primary station B1140000.

Map Key 19: B14400000 Haw River at SR 2158 Swepsonville Road near Swepsonville, NC. Downstream of previous station, upstream of Alamance Creek.

Map Key 22: B19800000 Haw River at SR 2171 at Saxapahaw, NC. Mainstem, below Alamance Creek.

Map Key 23: B2000000 Haw River at SR 1005 near Saxapahaw, NC. Mainstem, downstream of previous station. When this station and the previous three are examined as a group, the trend is that total N tends to be overestimated throughout the simulation. Results are mixed for total P with a tendency towards under-prediction.

Map Key 30: B3670000 Northeast Creek at SR 1731 O'Kelly Church Road near Durham, NC. This station is downstream of the Triangle WWTP discharge. Fit for loads is very good.

Map Key 32: B3900000 Morgan Creek at SR 1726 near Farrington, NC. Morgan Creek below the OWASA discharge. Total N and total P loads are often over-estimated at low to moderate flows during calibration, suggesting potential inaccuracies in the point source discharge record. Performance improves to very good during corroboration.

4.2.4 Water Quality Corroboration Performance Evaluation

Model parameters were developed on the calibration period results for each station. After calibration, the resulting model was then applied to a separate corroboration period. The results are presented below in Table 4-11 through Table 4-13 for the primary, secondary, and tertiary stations, respectively.

Table 4-11. Water Quality Performance for the Corroboration Period at the Primary Stations

Corroboration Period		1997 - 2004	2005 - 2112	1997 - 2004	2005 - 2112	2005 - 2112	1997 - 2004	2005 - 2112	2005 - 2112	2005 - 2112	2005 - 2112	2005 - 2112	1997 - 2004
Model Constituent	Model Component	B0400000 Reedy Fk	B0540000 N Buffalo	B0670000 S Buffalo	B1140000 Haw at Haw	B2100000/ 02096960 Haw Bynum	B3025000 Third Fk	B3040000/ 02097314 New Hope	B3660000/ 0209741955 NE Crk	B3899180 Morgan Crk	USGS 02096846 Cane Crk	USGS 02097464 Morgan Crk	USGS 0209782609 White Oak
Total Suspended Sediment	Sample Count	35	30	57	30	258	57	247	194	85	45	42	38
	Concentration Average Error	67.0% (6.4)	17.6% (1.6)	-5.5% (-0.7)	101.2% (7.5)	36.5% (4.5)	-15.4% (-3.7)	-9.1% (-1.8)	-18.6% (-3.8)	8.8% (1.3)	-62.5% (-31.3)	25.2% (2.5)	29.3% (5.8)
	Concentration Median Error	-27.9% (-2.7)	-10.9% (-1.0)	-17.9% (-2.4)	71.7% (5.3)	33.9% (4.2)	-27.3% (-6.5)	-47.9% (-9.5)	-30.2% (-6.2)	-0.5% (-0.1)	-8.2% (-4.1)	-35.6% (-3.5)	-39.8% (-7.9)
	Load Ave Error	259.1%	8.4%	48.0%	60.2%	-7.0%	2.8%	138.4%	43.3%	21.1%	-64.5%	120.1%	207.2%
	Load Median Error	-1.0%	-1.1%	-0.4%	23.1%	2.4%	-0.3%	-9.9%	-3.0%	0.0%	-0.2%	-2.3%	-2.5%
Total Nitrogen	Sample Count	34	86	57	86	261	57	252	198	85	62	43	38
	Concentration Average Error	-0.2% (0.0)	8.9% (0.8)	-56.9% (-0.6)	5.3% (0.2)	19.0% (0.3)	-14.5% (-0.2)	10.5% (0.5)	4.1% (0.1)	-5.0% (-0.1)	-44.8% (-0.6)	3.1% (0.0)	-38.6% (-0.2)
	Concentration Median Error	10.5% (0.1)	2.5% (0.2)	-45.2% (-0.5)	3.5% (0.1)	9.6% (0.2)	-10.7% (-0.1)	8.9% (0.4)	2.9% (0.1)	10.9% (0.1)	-31.8% (-0.4)	3.2% (0.0)	-47.1% (-0.3)
	Load Ave Error	38.2%	-6.3%	-45.8%	-5.1%	4.7%	-29.9%	-9.1%	4.3%	11.1%	-56.3%	-36.5%	-23.5%
	Load Median Error	0.5%	1.7%	-8.7%	3.9%	6.8%	-1.2%	5.9%	1.4%	1.6%	-7.8%	0.5%	-4.3%
Total Phosphorus	Sample Count	35	86	64	86	256	64	246	197	80	62	43	34
	Concentration Average Error	37.8% (0.02)	44.3% (0.18)	5.8% (0.00)	14.3% (0.03)	18.0% (0.03)	15.9% (0.02)	0.5% (0.00)	-0.8% (0.00)	11.9% (0.01)	-67.1% (-0.11)	-39.8% (-0.03)	1.2% (0.00)
	Concentration Median Error	52.4% (0.03)	35.7% (0.14)	-7.0% (-0.01)	14.3% (0.03)	16.9% (0.02)	0.0% (0.00)	-0.3% (0.00)	-5.6% (-0.02)	24.4% (0.02)	-11.9% (-0.02)	-22.2% (-0.02)	-1.4% (0.00)
	Load Ave Error	70.3%	22.0%	-28.7%	-25.0%	-38.5%	-8.4%	-26.5%	-16.8%	18.2%	-73.7%	-57.7%	-38.6%
	Load Median Error	5.9%	19.3%	-0.3%	6.0%	5.4%	0.0%	-0.1%	-2.1%	13.3%	-0.9%	-2.3%	-0.1%

Note: Error statistics are based on simulated minus observed values.

Table 4-12. Water Quality Performance for the Corroboration Period at the Secondary Stations

Corroboration Period		2005 - 2112	2005 - 2112	1997 - 2004	2005 - 2112	2005 - 2112	2005 - 2112	1997 - 2004	2005 - 2112	2005 - 2112	2005 - 2112	2005 - 2112
Model Constituent	Model Component	B0040000 Haw R	B0050000 Haw R	B0070010 Troublesome	B0210000 Haw R	B0480050 N Buffalo	B1095000 Jordan Crk	B1260000 Town Br	B1940000 Alamance	B1960000 Alamance	B3020000 New Hope	B3300000 NE Crk
Total Suspended Sediment	Sample Count	29	86	57	29	85	27	51	85	80	84	85
	Concentration Average Error	182.6% (10.8)	92.8% (5.3)	-35.8% (-2.4)	66.2% (5.6)	94.6% (3.9)	87.1% (13.1)	76.2% (6.9)	19.1% (1.7)	-0.5% (0.0)	-12.8% (-2.5)	-10.2% (-1.7)
	Concentration Median Error	-35.0% (-2.1)	-26.8% (-1.5)	-35.6% (-2.4)	12.6% (1.1)	-25.5% (-1.0)	-19.9% (-3.0)	-5.5% (-0.5)	10.9% (1.0)	-11.1% (-0.9)	-46.2% (-9.0)	-51.6% (-8.8)
	Load Ave Error	361.4%	246.1%	151.1%	75.3%	166.8%	298.7%	272.4%	25.7%	11.5%	147.1%	216.4%
	Load Median Error	-11.7%	-6.0%	-2.9%	1.5%	-0.6%	-1.4%	-0.1%	1.5%	-1.5%	-4.6%	-2.1%
Total Nitrogen	Sample Count	87	87	55	87	87	1	84	85	131	85	85
	Concentration Average Error	19.0% (0.1)	5.3% (0.0)	-20.4% (-0.2)	-0.6% (0.0)	-56.0% (-0.4)	N/A	-43.7% (-0.3)	77.0% (0.4)	9.3% (0.2)	63.4% (0.4)	47.0% (0.3)
	Concentration Median Error	9.1% (0.0)	-7.2% (0.0)	-7.2% (-0.1)	5.6% (0.0)	-54.2% (-0.4)		-40.1% (-0.3)	85.5% (0.5)	11.3% (0.2)	24.8% (0.2)	14.4% (0.1)
	Load Ave Error	39.1%	34.8%	7.1%	-5.5%	-49.5%		-8.4%	56.9%	17.7%	41.4%	-4.1%
	Load Median Error	3.2%	-2.2%	-1.1%	3.6%	-20.3%		-2.7%	25.7%	10.0%	3.5%	0.8%
Total Phosphorus	Sample Count	87	83	64	87	82	1	84	80	131	80	80
	Concentration Average Error	48.5% (0.02)	5.5% (0.00)	19.4% (0.01)	3.6% (0.00)	-14.3% (-0.01)	N/A	-30.4% (-0.02)	99.3% (0.04)	18.4% (0.05)	24.3% (0.03)	72.4% (0.07)
	Concentration Median Error	33.9% (0.01)	23.0% (0.01)	59.1% (0.03)	13.2% (0.01)	-7.0% (0.00)		-11.8% (-0.01)	119.4% (0.05)	10.6% (0.03)	14.5% (0.02)	33.5% (0.03)
	Load Ave Error	61.6%	-20.9%	20.5%	-29.9%	-15.6%		-13.3%	-3.5%	-10.1%	-10.7%	-0.5%
	Load Median Error	17.0%	5.5%	4.8%	4.3%	-2.6%		-0.1%	21.7%	9.7%	1.6%	1.5%

Note: Error statistics are based on simulated minus observed values.

Table 4-13. Water Quality Performance for the Corroboration Period at the Tertiary Stations

Corroboration Period		1997 - 2004	2005 - 2112	2005 - 2112	1997 - 2004	2005 - 2112	2005 - 2112	2005 - 2112	2005 - 2112	2005 - 2112	2005 - 2112	2005 - 2112	2005 - 2112
Model Constituent	Model Component	B0160000 L Trouble	B0170000 Haw R	B0540050 N Buffalo	B0750000 S Buffalo	B0840000 Reedy Fk	B0850000 Haw R	B1200000 Haw R	B1440000 Haw R	B1980000 Haw R	B2000000 Haw R	B3300000 NE Crk	B3900000 Morgan Ck
Total Suspended Sediment	Sample Count	56	85	86	111	28	64	85	85	30	85	85	262
	Concentration Average Error	-20.0% (-3.3)	-9.9% (-1.3)	93.3% (3.8)	-19.3% (-3.6)	102.0% (8.1)	31.4% (2.5)	35.6% (4.1)	65.3% (6.6)	38.1% (4.7)	32.0% (4.0)	-58.2% (-17.8)	-24.2% (-3.5)
	Concentration Median Error	-25.5% (-4.2)	-9.5% (-1.3)	26.8% (1.1)	2.4% (0.5)	47.9% (3.8)	10.3% (0.8)	24.6% (2.8)	29.9% (3.0)	18.9% (2.3)	12.5% (1.6)	-37.5% (-11.5)	-25.9% (-3.7)
	Load Ave Error	-6.8%	-31.3%	230.7%	-34.3%	83.0%	0.3%	-5.1%	13.5%	14.5%	-7.9%	-23.2%	52.6%
	Load Median Error	-13.6%	-1.7%	8.6%	0.3%	11.4%	2.6%	4.6%	7.7%	7.5%	1.5%	-5.1%	-9.6%
Total Nitrogen	Sample Count	87	85	86	126	86	64	85	85	1	85	85	265
	Concentration Average Error	130.0% (1.5)	4.7% (0.0)	28.9% (2.2)	0.2% (0.0)	13.4% (0.6)	34.3% (0.9)	34.6% (0.9)	27.0% (0.7)	N/A	21.6% (0.4)	23.7% (0.5)	13.9% (0.9)
	Concentration Median Error	86.6% (1.0)	-1.9% (0.0)	22.5% (1.7)	0.1% (0.0)	9.6% (0.5)	28.3% (0.8)	32.5% (0.8)	20.8% (0.5)		13.9% (0.3)	17.1% (0.4)	12.3% (0.8)
	Load Ave Error	80.3%	1.7%	22.7%	-2.1%	4.1%	19.0%	24.6%	19.2%		18.2%	9.2%	10.2%
	Load Median Error	68.0%	-1.5%	20.8%	0.0%	5.7%	20.2%	21.6%	19.3%		8.3%	9.3%	10.7%
Total Phosphorus	Sample Count	89	80	81	130	86	59	80	80	1	80	80	259
	Concentration Average Error	229.4% (0.33)	-13.3% (-0.01)	46.4% (0.17)	18.9% (0.16)	-34.2% (-0.21)	32.3% (0.08)	20.5% (0.04)	10.3% (0.02)	N/A	17.0% (0.03)	20.2% (0.06)	16.1% (0.04)
	Concentration Median Error	172.4% (0.25)	10.9% (0.01)	38.7% (0.14)	12.7% (0.11)	6.7% (0.04)	21.2% (0.05)	26.7% (0.06)	18.6% (0.04)		16.2% (0.03)	8.8% (0.03)	4.3% (0.01)
	Load Ave Error	105.7%	-42.7%	31.5%	5.0%	-36.6%	-4.1%	-15.1%	-26.0%		-33.7%	3.7%	9.6%
	Load Median Error	108.5%	3.4%	25.7%	10.1%	4.5%	17.0%	14.7%	11.5%		7.6%	6.0%	2.6%

Note: Error statistics are based on simulated minus observed values.

4.2.5 Consistency and Bias Evaluation

Statistics on fit, especially for paired loads, are difficult to interpret because they may be thrown off by a few outliers or temporary changes in conditions, resulting in spurious poor ratings. It is useful to perform a check of consistency between the calibration and corroboration periods to help identify areas of consistent bias. The consistency check is shown in Table 4-14. In this table, a code of 0 is assigned when the average relative error achieves a rating of good or very good. If the rating is fair or poor, the sign of the RE is shown, with "+" indicating over-prediction and "-" for under-prediction. Two stations lacked sufficient total N and total P monitoring data during corroboration for statistical assessment, so only the calibration bias rating is shown.

For total N, at 30 of 35 stations a good or better rating (symbol "0") was achieved on load relative error in either the calibration or corroboration period or both. One of the stations without a corroboration bias rating had positive bias during calibration. At only four stations is the bias consistent and significant, three having a consistently positive relative error and one having a consistently negative relative error.

For total P, 26 of 35 stations attain a good or better fit in either the calibration or corroboration period or both. Of the remaining nine stations, three had consistently significant positive REs, five had consistently negative REs, and one switched from positive to negative bias (indicating absence of a consistent bias).

Table 4-14. Bias Consistency Check on Nutrient Load Relative Error for Water Quality Calibration and Corroboration

Station	Group	Total N	Total P
B0400000	Primary	0 / +	- / +
B0540000	Primary	0 / 0	0 / 0
B0670000	Primary	0 / -	0 / -
B1140000	Primary	+ / 0	0 / -
B2100000/USGS 02096960	Primary	0 / 0	- / -
B3025000	Primary	0 / -	0 / 0
B3040000/USGS 02097314	Primary	0 / 0	0 / -
B3660000/USGS 0209741955	Primary	+ / 0	0 / 0
B3899180	Primary	0 / 0	+ / 0
USGS 02096846	Primary	0 / -	0 / -
USGS 02097464	Primary	0 / -	- / -
USGS 0209782609	Primary	- / 0	- / -
B0040000	Secondary	0 / +	+ / +
B0050000	Secondary	+ / +	0 / 0
B0070010	Secondary	0 / 0	0 / 0
B0210000	Secondary	0 / 0	0 / -
B0480050	Secondary	- / -	- / 0
B1095000	Secondary	+ / ND	0 / ND
B1260000	Secondary	- / 0	0 / 0
B1940000	Secondary	+ / +	+ / 0
B1960000	Secondary	+ / 0	+ / 0
B3020000	Secondary	0 / +	0 / 0
B3300000	Secondary	0 / 0	+ / 0
B0160000	Tertiary	+ / +	+ / +

Station	Group	Total N	Total P
B0170000	Tertiary	+ / 0	0 / -
B0540050	Tertiary	0 / 0	+ / +
B0750000	Tertiary	0 / 0	0 / 0
B0840000	Tertiary	0 / 0	- / -
B0850000	Tertiary	0 / 0	0 / 0
B1200000	Tertiary	+ / 0	+ / 0
B1440000	Tertiary	+ / 0	0 / -
B1980000	Tertiary	0 / ND	0 / ND
B2000000	Tertiary	+ / 0	- / -
B3670000	Tertiary	0 / 0	0 / 0
B3900000	Tertiary	+ / 0	+ / 0

While the percentage discrepancies between observed and simulated concentration is variable across the watershed, the actual magnitude of the differences is generally small. Average concentration errors across all stations are summarized in Table 4-15. For the primary and secondary stations, the average concentration error for total N is well less than 0.2 mg/L, while the average concentration error for total P is less than or equal to 0.02 mg/L. Substantially larger concentration errors are estimated for the tertiary stations. These are generally stations that are downstream of major point source discharges, but lack flow gaging. The additional uncertainty in hydrology due to lack of gaging may contribute to the apparent concentration discrepancies, but it is likely that these discrepancies are primarily attributable to day-to-day variations in point source loading that are not captured in available discharge monitoring.

Table 4-15. Summary of Average Concentration Errors (mg/L) across All Stations

	Primary Stations	Secondary Stations	Tertiary Stations
Calibration			
Total N Average Error	0.164	-0.074	0.951
Total P Average Error	0.007	0.010	0.101
Corroboration			
Total N Average Error	0.030	0.056	0.794
Total P Average Error	0.013	0.020	0.064

4.2.6 Evaluation of Delivered Loads

Analyses in the previous section reported paired comparison of simulated loads to same-day loads estimated from observations. A further check was done by comparing complete load time series. For this exercise, observed concentrations and loads were converted to total load estimates using the USGS LOADEST software, with the adjusted maximum likelihood estimation (AMLE) procedure that accounts for censored values and automated selection of best model form based on maximizing information and minimizing variance (Runkel et al., 2004).

LOADEST provides multiple model forms for fitting load series with logarithmic transform, including options for linear and non-linear terms on flow and multiple terms related to a time variable, *dtime*, which is a measure of the distance from the center of the monitored time period. We used automated selection of model form based on the Akaike Information Criterion. LOADEST analyses were conducted at seven monitoring locations where both water quality observations and flow gaging are available. This includes stations representing each of the major river inputs into Jordan Lake. These are the Haw River at Bynum (representing the majority of the drainage area), Morgan Creek, New Hope Creek, and Northeast Creek. These seven stations generally had extensive coverage in time and include samples that cover the majority of the range of gaged flows. Detailed information on the LOADEST model selection, sample size, and temporal and flow range coverage is provided in Table 4-16. These stations have generally large data sets that cover the period of interest and include high flow samples. In all cases, less than 1 percent of flows were larger than the largest sampled flow.

Table 4-16. LOADEST Model Application Details

	Buffalo Creek	Haw River - Bynum	Haw River - Haw River	Morgan Creek	New Hope Creek	Northeast Creek	Reedy Fork
Maximum sampled flow	1,143	31,100	7,570	814	1,000	1,120	3,910
Maximum gaged flow	2,493	39,300	14,300	2,261	6,000	1,940	3,910
Percent of days above maximum sampled flow	0.40%	0.10%	0.50%	0.30%	0.80%	0.10%	0.00%
Sample Count	205	442	175	471	470	299	120
Date Range	04/24/2000-01/23/2012	01/30/1997-04/18/2012	01/30/1997-04/16/2012	01/30/1997-04/18/2012	01/15/1997-09/19/2012	01/15/1997-09/19/2012	02/04/2002-01/23/2012
TN model	7	6	5	9	9	7	3
TP model	9	9	8	9	9	7	7

The following LOADEST models are used (Runkel et al., 2004):

3: $a0 + a1 \ln Q + a2\,dtime$

5: $a0 + a1 \ln Q + a2 \ln Q2 + a3\,dtime$

7: $a0 + a1 \ln Q + a2 \sin(2\pi\,dtime) + a3 \cos(2\pi\,dtime) + a4\,dtime$

8: $a0 + a1 \ln Q + a2 \ln Q2 + a3 \sin(2\pi\,dtime) + a4 \cos(2\pi\,dtime) + a5\,dtime$

9: $a0 + a1 \ln Q + a2 \ln Q2 + a3 \sin(2\pi\,dtime) + a4 \cos(2\pi\,dtime) + a5\,dtime + a6\,dtime2$

In these equations, ln*Q* = ln(streamflow) - center of ln(streamflow); *dtime* = decimal time - center of decimal time.

LOADEST is subject to uncertainty, as are all load estimates based on non-continuous data; however, the use of automated selection of model form in LOADEST removes user selection bias and provides a firm basis for comparison. In addition, LOADEST provides estimates of uncertainty based on the variability in the relationship between flow and observed concentration (but not accounting for any measurement error). Graphical comparisons for the four downstream stations are shown in Figure 4-28 through Figure 4-43, separated by calibration and corroboration periods. A summary of loading results for all seven stations over the entire period of simulation is presented in Table 4-17.

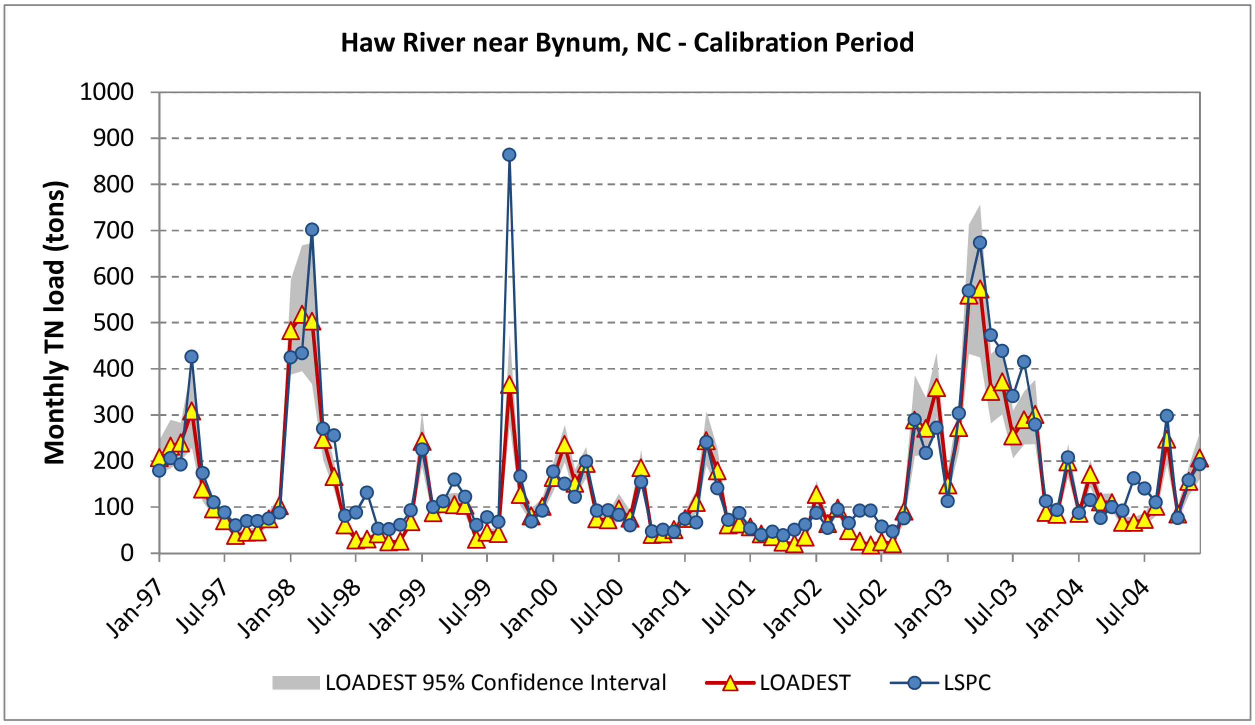


Figure 4-28. Simulated and LOADEST Observed Monthly Total Nitrogen Loads, Haw River at Bynum (B2100000), Model Calibration Period

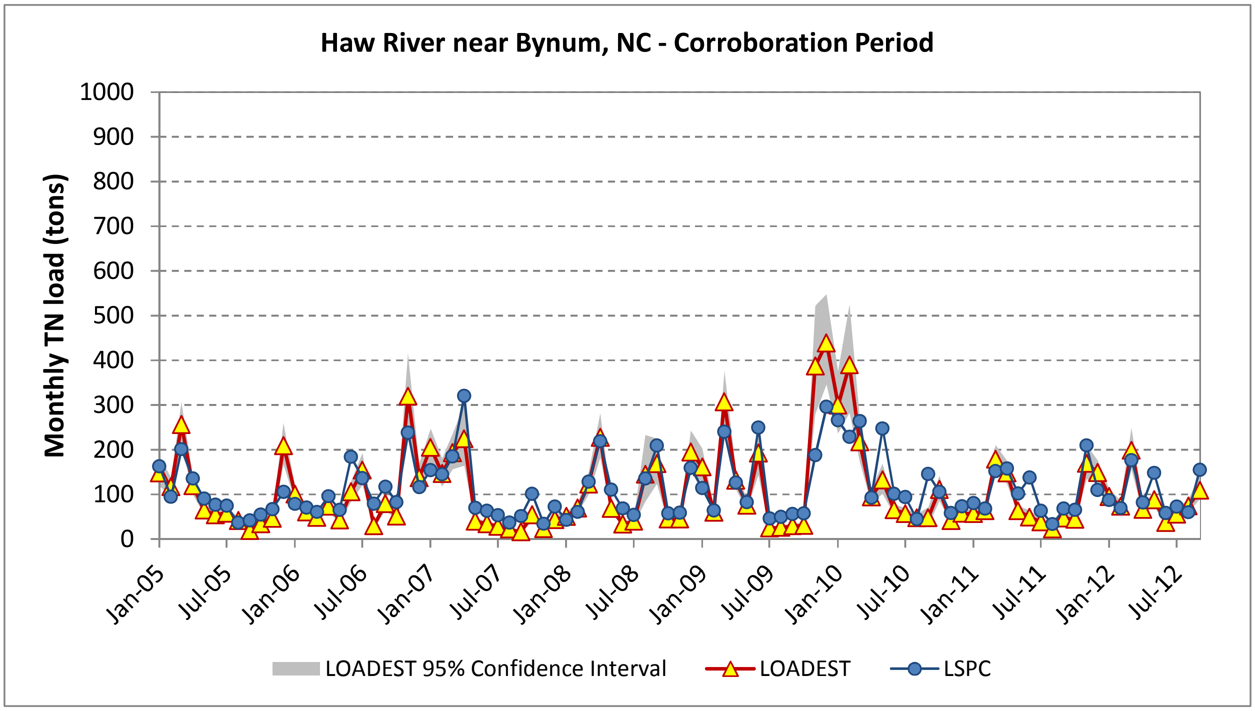


Figure 4-29. **Simulated and LOADEST Observed Monthly Total Nitrogen Loads, Haw River at Bynum (B2100000), Model Corroboration Period**

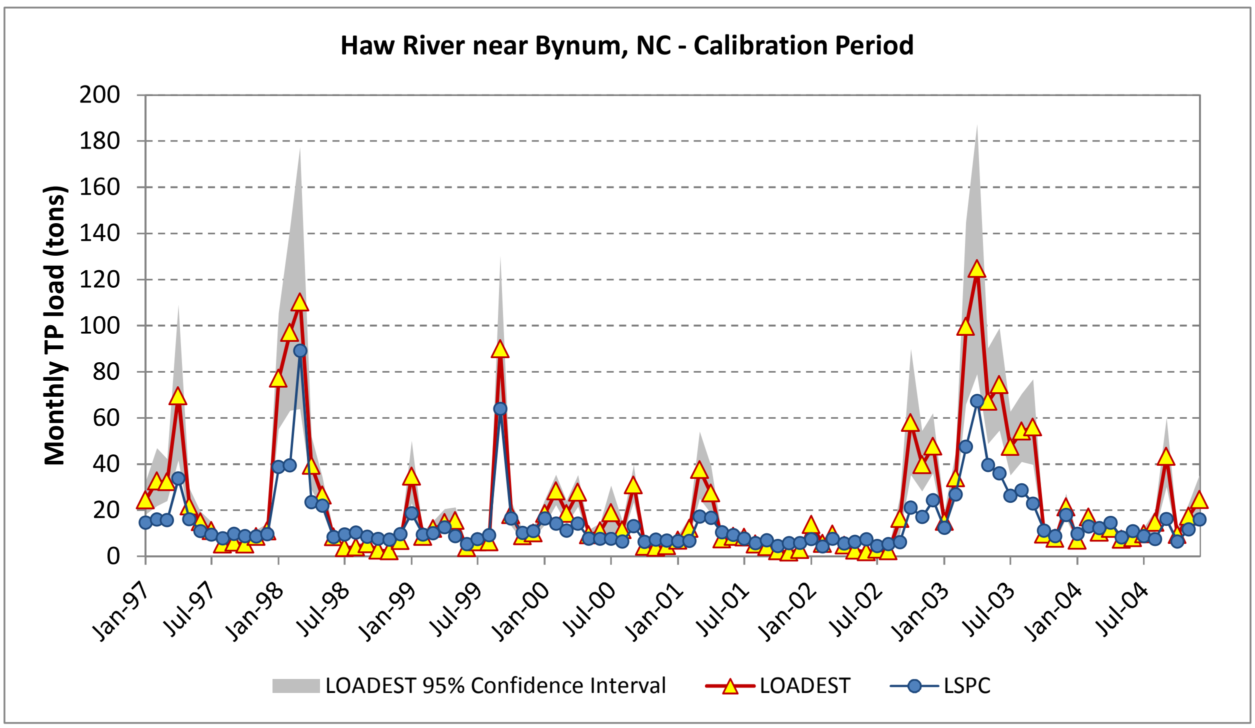


Figure 4-30. **Simulated and LOADEST Observed Monthly Total Phosphorus Loads, Haw River at Bynum (B2100000), Model Calibration Period**

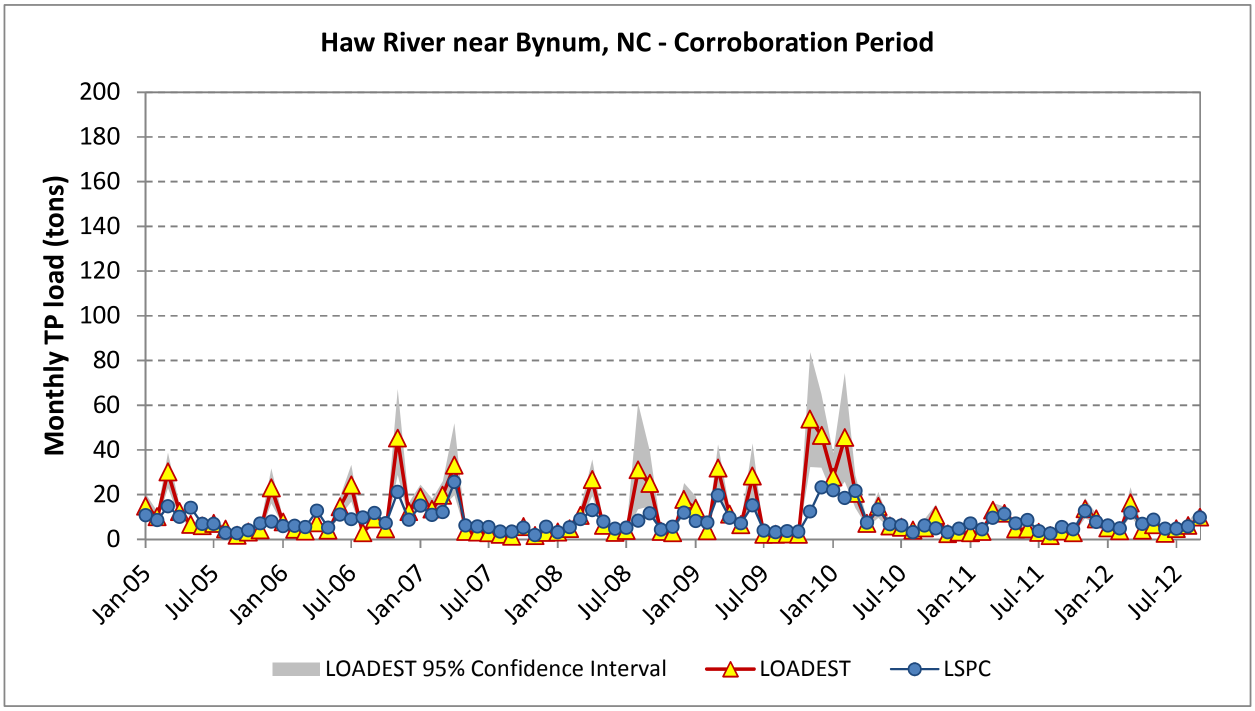


Figure 4-31. **Simulated and LOADEST Observed Monthly Total Phosphorus Loads, Haw River at Bynum (B2100000), Model Corroboration Period**

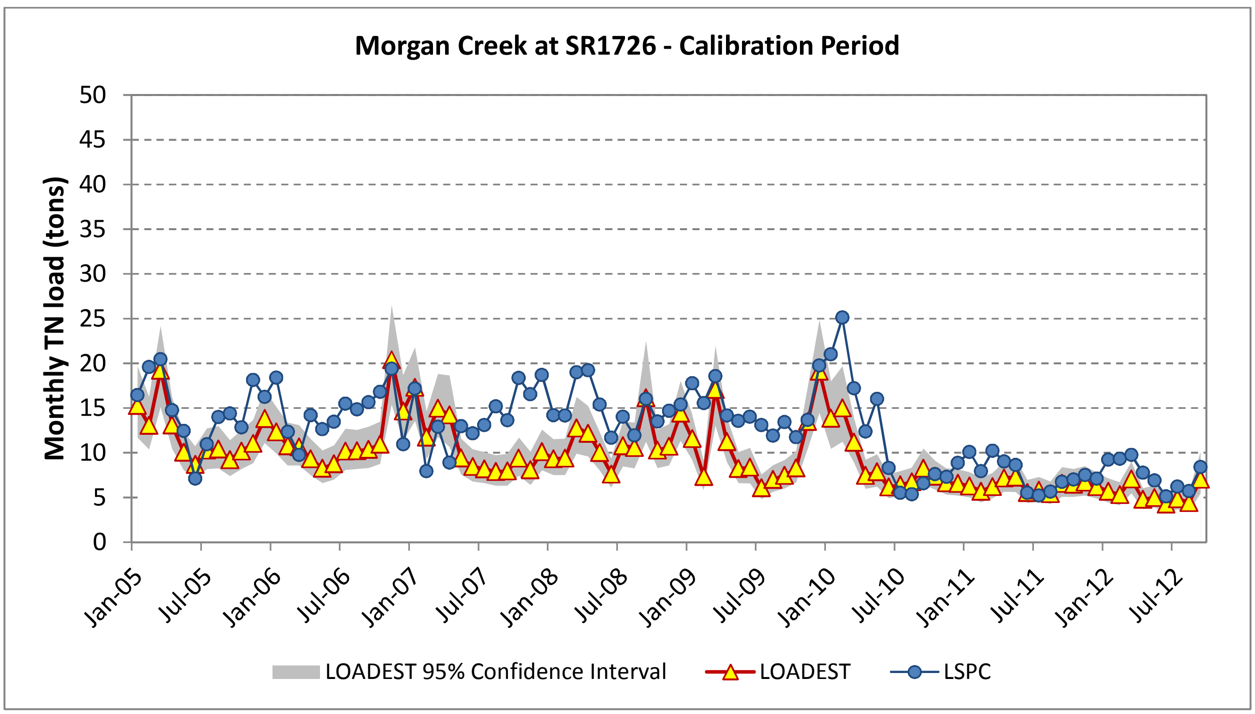


Figure 4-32. **Simulated and LOADEST Observed Monthly Total Nitrogen Loads, Morgan Creek at SR 1726 (B3900000), Calibration Period**

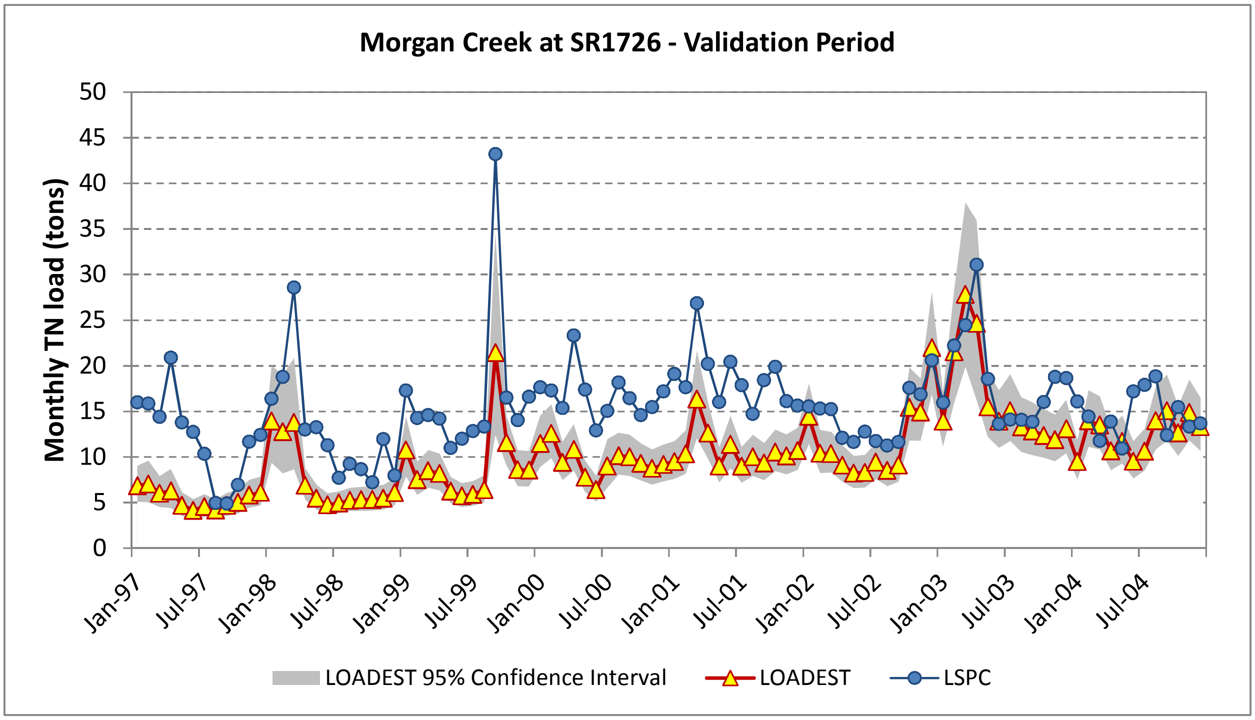


Figure 4-33. Simulated and LOADEST Observed Monthly Total Nitrogen Loads, Morgan Creek at SR 1726 (B3900000), Corroboration Period

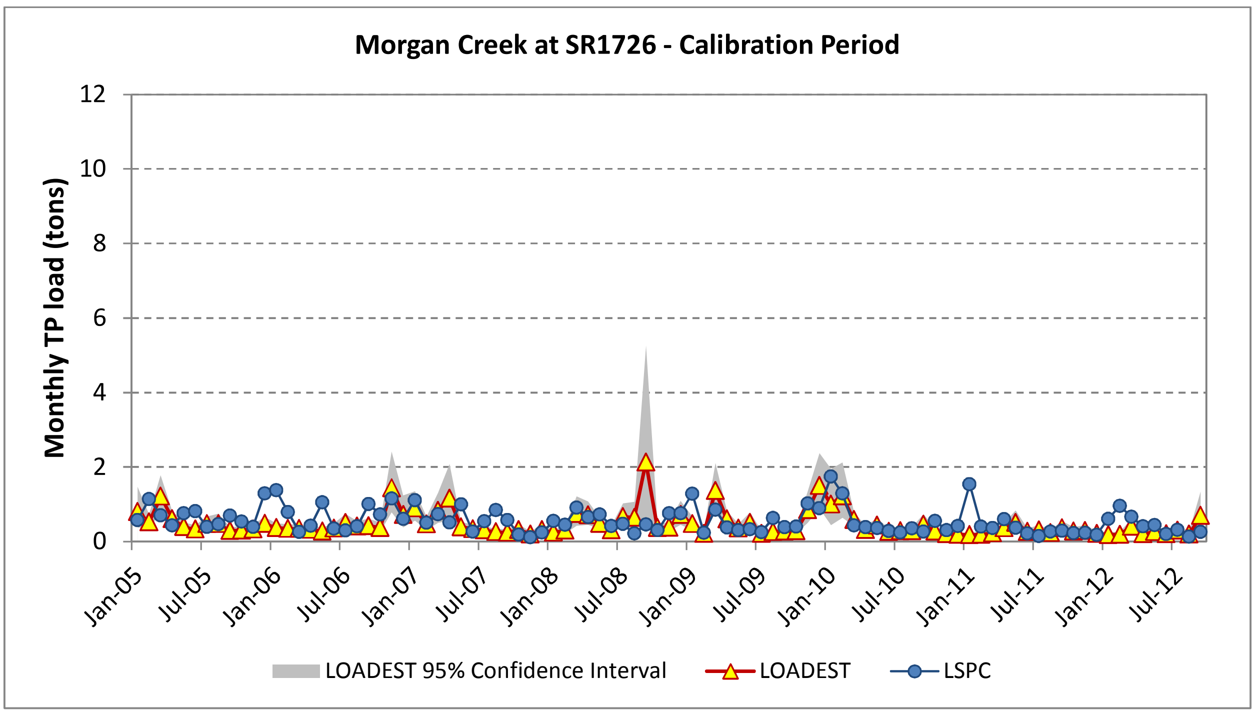


Figure 4-34. Simulated and LOADEST Observed Monthly Total Phosphorus Loads, Morgan Creek at SR 1726 (B3900000), Calibration Period

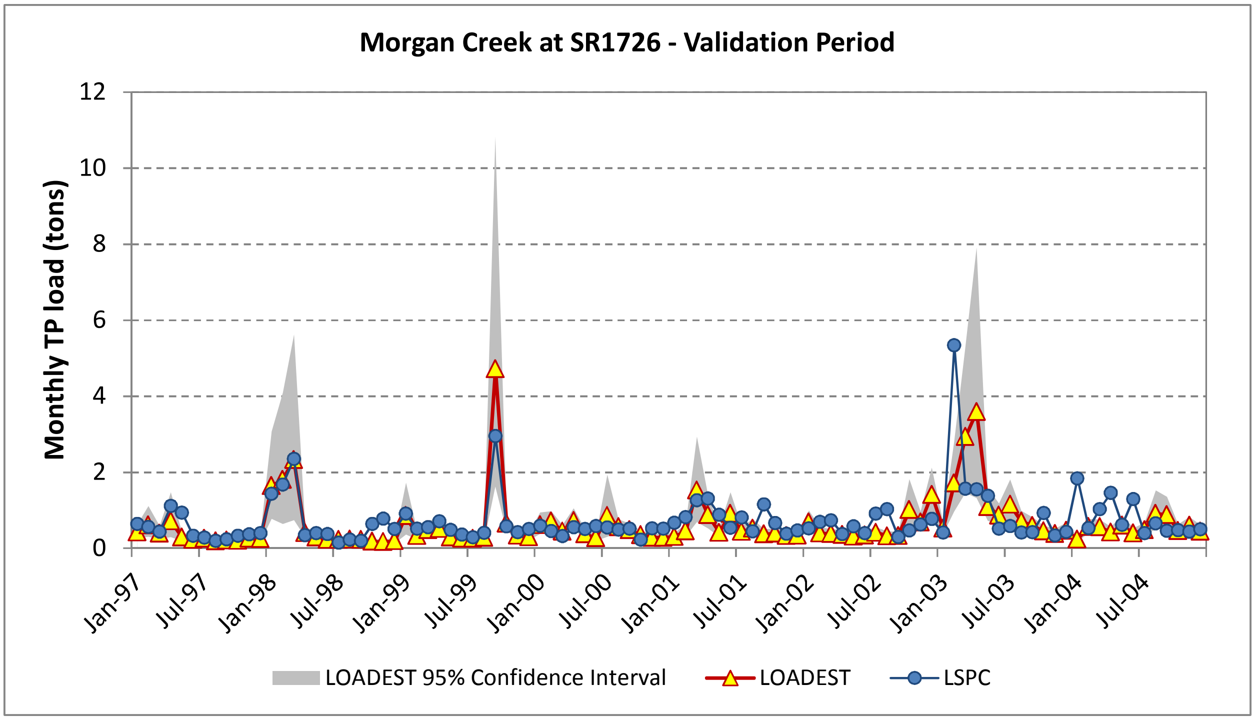


Figure 4-35. **Simulated and LOADEST Observed Monthly Total Phosphorus Loads, Morgan Creek at SR 1726 (B3900000), Corroboration Period**

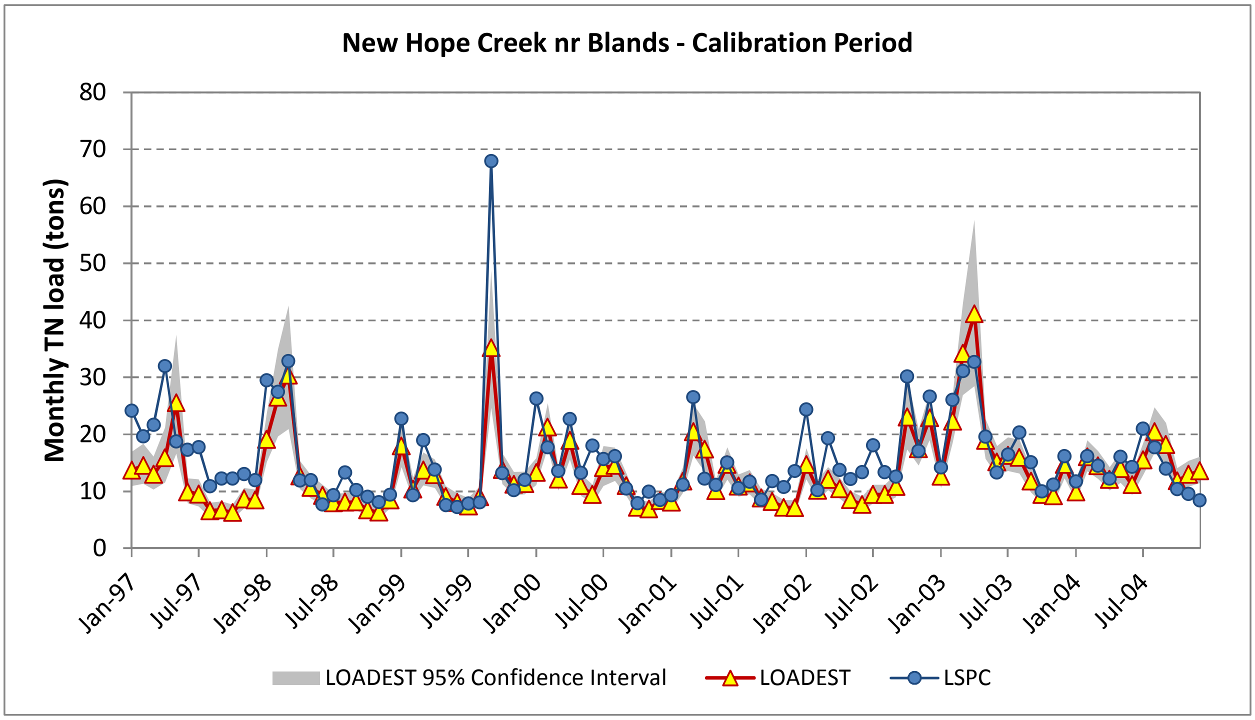


Figure 4-36. **Simulated and LOADEST Observed Monthly Total Nitrogen Loads, New Hope Creek at SR 1107 (B3040000), Calibration Period**

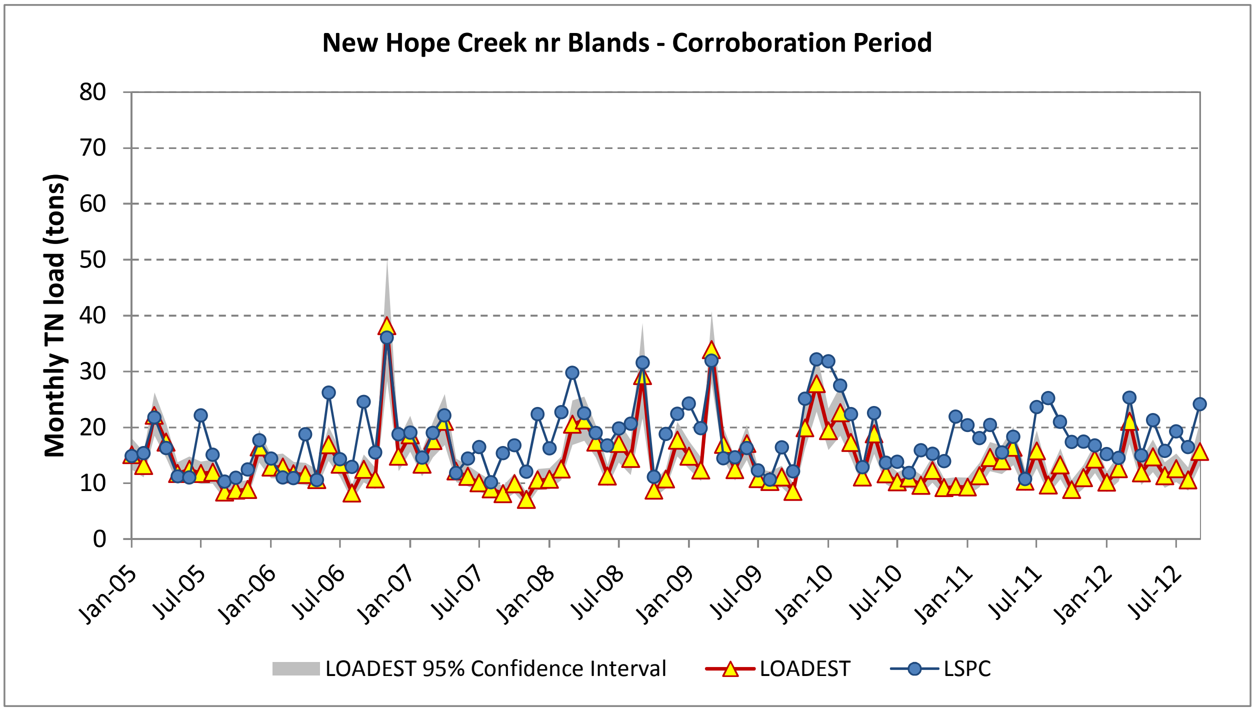


Figure 4-37. Simulated and LOADEST Observed Monthly Total Nitrogen Loads, New Hope Creek at SR 1107 (B3040000), Corroboration Period

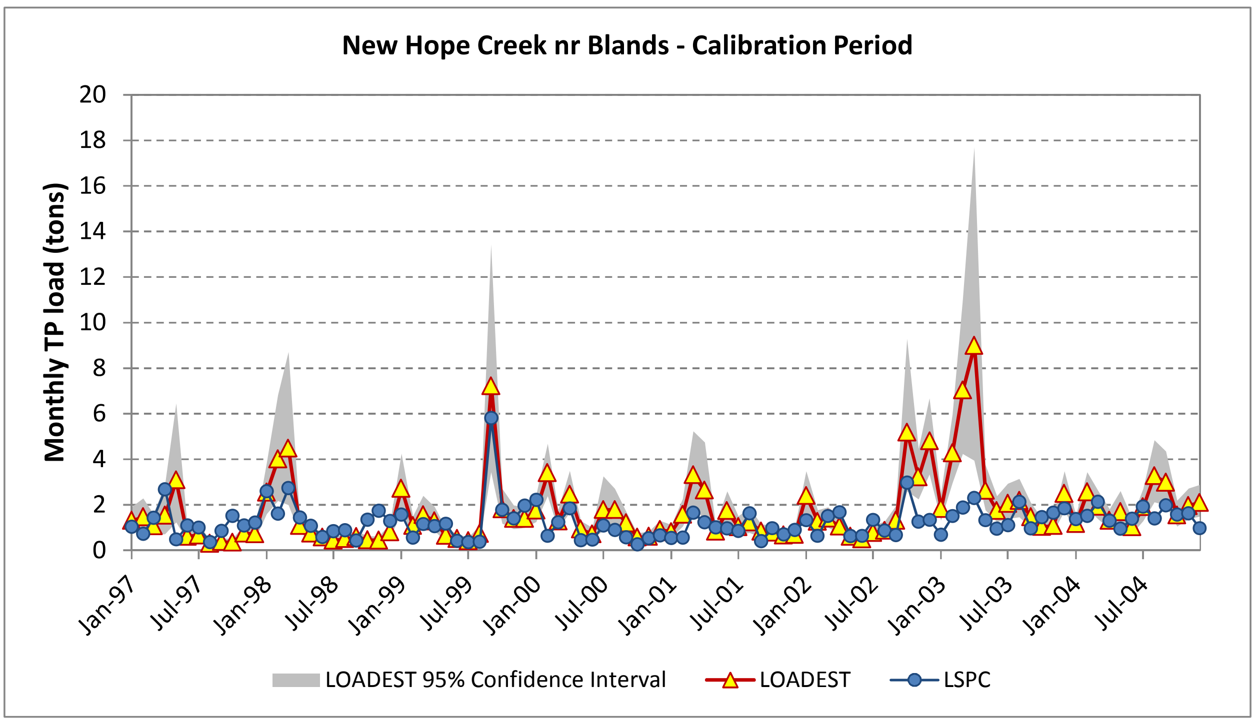


Figure 4-38. Simulated and LOADEST Observed Monthly Total Phosphorus Loads, New Hope Creek at SR 1107 (B3040000), Calibration Period

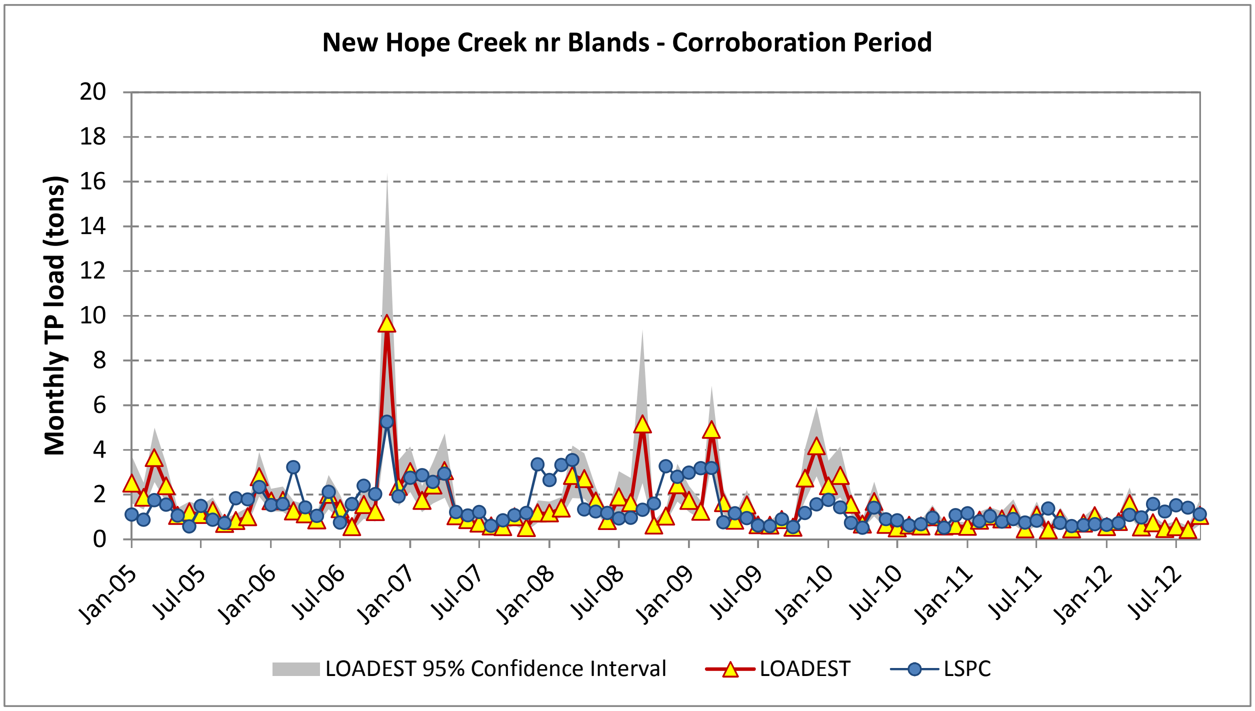


Figure 4-39. Simulated and LOADEST Observed Monthly Total Phosphorus Loads, New Hope Creek at SR 1107 (B3040000), Corroboration Period

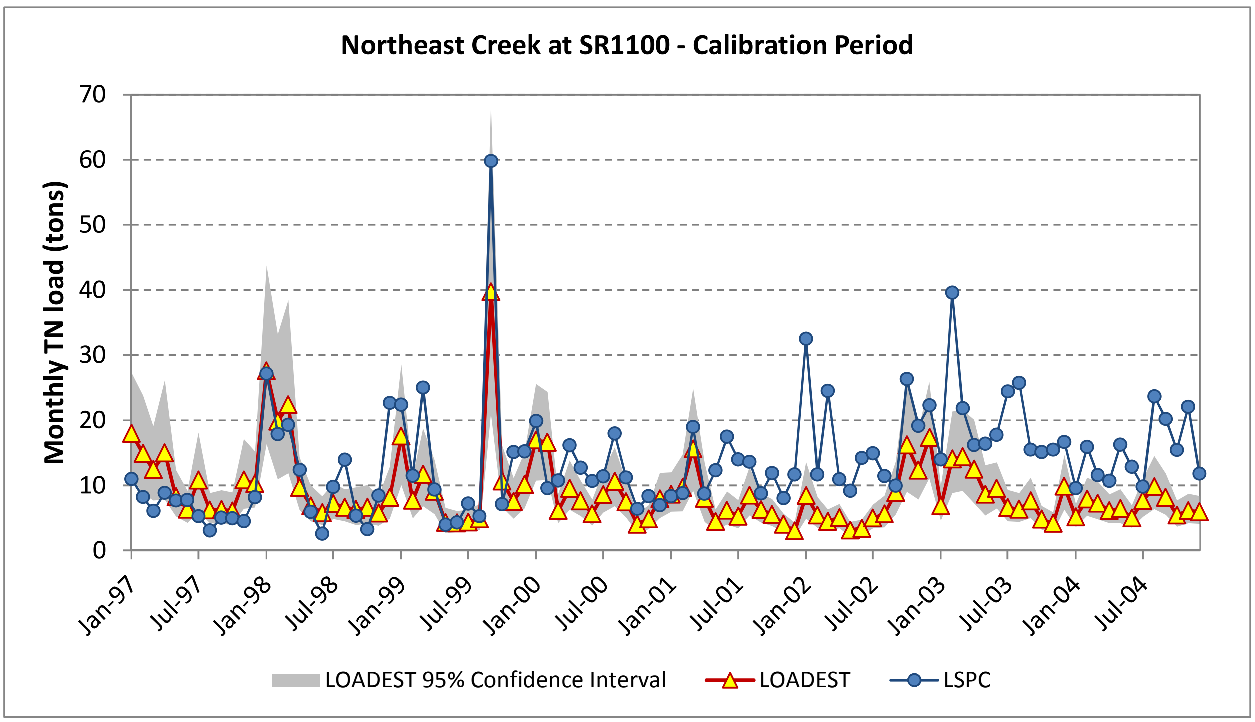


Figure 4-40. Simulated and LOADEST Observed Monthly Total Nitrogen Loads, Northeast Creek at SR1100 (B3660000), Calibration Period

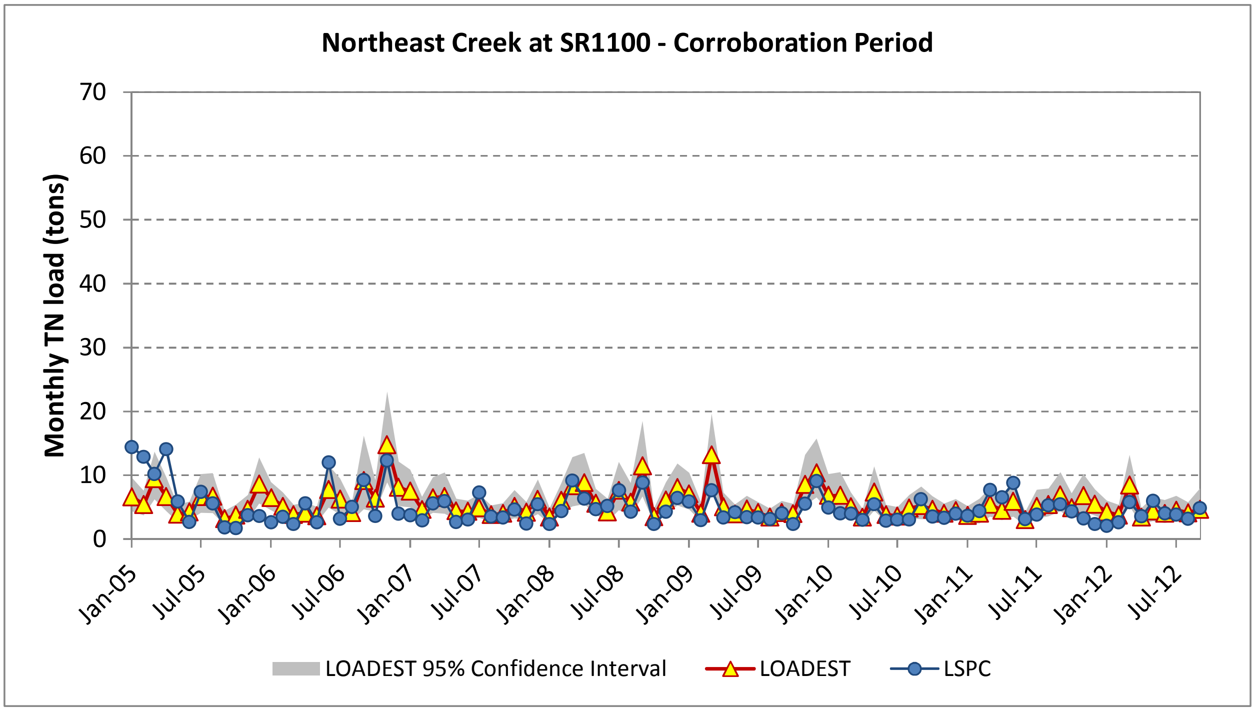


Figure 4-41. Simulated and LOADEST Observed Monthly Total Nitrogen Loads, Northeast Creek at SR1100 (B3660000), Corroboration Period

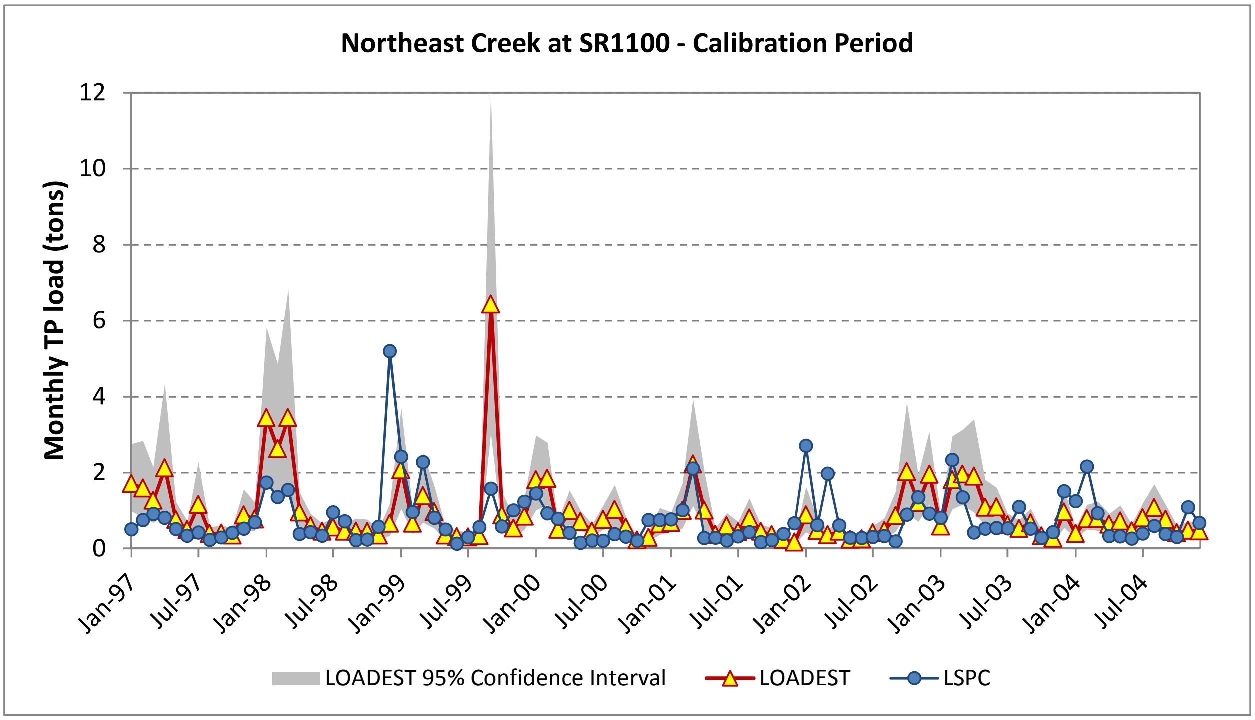


Figure 4-42. Simulated and LOADEST Observed Monthly Total Phosphorus Loads, Northeast Creek at SR1100 (B3660000), Calibration Period

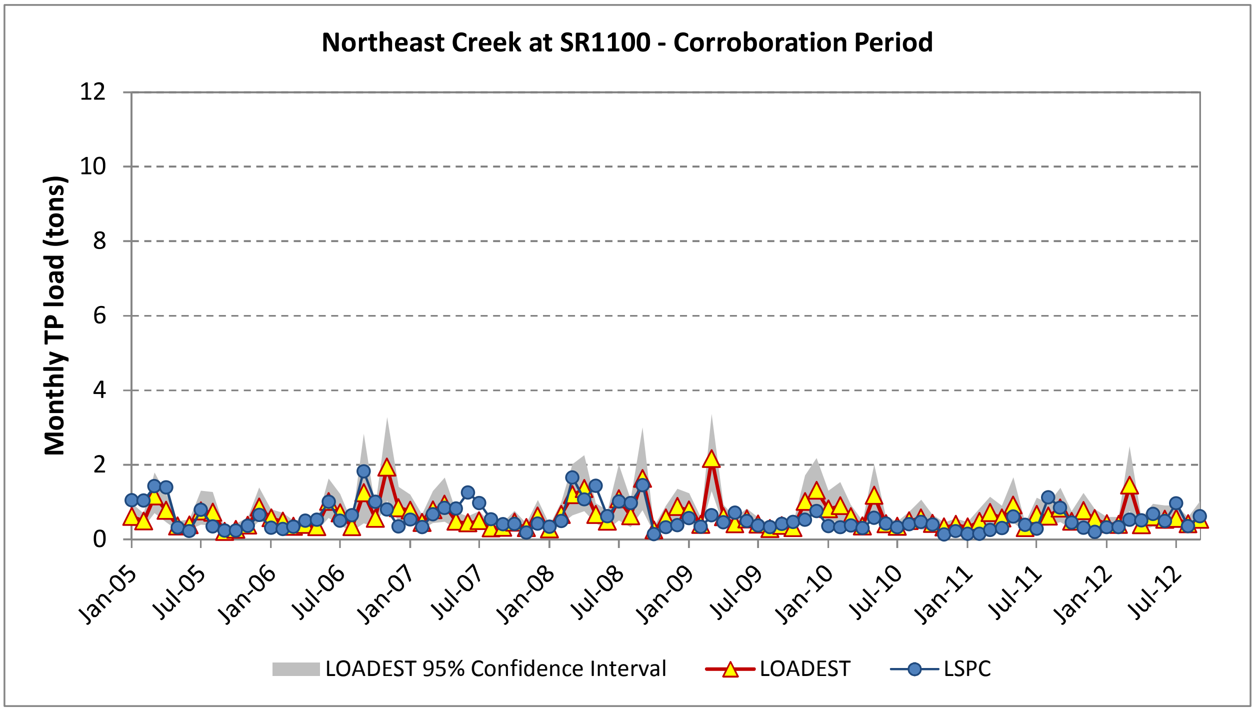


Figure 4-43. Simulated and LOADEST Observed Monthly Total Phosphorus Loads, Northeast Creek at SR1100 (B3660000), Corroboration Period

Table 4-17. Comparison of LSPC and LOADEST Average Annual Loads, 1997 - 2012

Station	Total Nitrogen (tons / yr)			Total Phosphorus (tons / yr)		
	LOADEST	LSPC	Relative Error	LOADEST	LSPC	Relative Error
Haw River at Bynum (B2100000 and gage 02096960)	1,513 (1,418 - 1,611)	1,672	10.5%	200 (179 - 222)	141	-29.6%
Morgan Creek at SR 1726 (B3900000 and gage 02097517)	120 (112 - 129)	169	41.1%	7 (5 - 8)	8	15.7%
New Hope Creek at SR 1107 (B3040000 and gage 02097314)	164 (155 - 174)	204	24.0%	19 (17 - 22)	16	-15.4%
Northeast Creek at SR 1100 (B3660000 and gage 0209741955)	88 (77 - 101)	114	28.7%	9 (8 - 11)	8	-12.9%
Haw River at Haw River, NC (B210000 and gage 02096500)	1,043 (956 - 1,136)	1,269	-24.4%	141 (115 - 171)	107	-24.4%
North Buffalo Creek at SR 2770 (B0540050 and gage 0209553650)	356 (307 - 410)	340	-4.4%	22 (18 - 28)	29	30.8%
Reedy Fork near Gibsonville, NC (B0400000 and gage 02094500)	63 (50 - 77)	52	-17.2%	6 (4 - 9)	5	-17.5%

In terms of annual loads, the model achieves a “very good” fit to LOADEST loads of total phosphorus in Northeast Creek, and a “good” fit in Morgan Creek, New Hope Creek, Haw River at Haw River, and Reedy Fork. For the Haw River at Bynum, the fit for total phosphorus is only fair, with the load generally being under-estimated. This discrepancy is believed to be associated with loads derived instream, as discussed further below in Section 4.3.2. For total nitrogen, the fit is rated as “very good” for Haw River at Bynum, and North Buffalo Creek, while the fit is rated as “good” for New Hope Creek, Haw River at Haw River, and Reedy Fork. In Northeast Creek the fit is only fair, with over-estimation by the model relative to LOADEST. This problem may be associated with the quantification of the point source discharge to Northeast Creek. Likewise in Morgan Creek the fit is poor, with over-estimation by the model relative to LOADEST. The Morgan Creek monitoring stations is downstream of the OWASA WWTP discharge, so quantification of the point source may have contributed to the discrepancy.

4.3 Model Assessment and Interpretation

4.3.1 Summary of Hydrology Simulation

Hydrologic calibration was successful and provides a reasonable basis for the water quality model, despite some localized discrepancies. Hydrology is well represented at key points for dominant inflows into Jordan Lake: Haw River, New Hope Creek, and Northeast Creek. Total flow volume is over-simulated for Morgan Creek downstream of University Lake, likely due to the influence of active management of the lake. The error on the highest 10 percent of flows at the downstream Morgan Creek gage during calibration is acceptable, so dominant loading events are well represented.

Locations with fair or poor ratings on hydrology calibration measures are largely confined to the Buffalo Creek drainage system. Sources of error are not known but may be related to variation in soils or poor representation of local precipitation by the Greensboro Airport station. This station is on the western edge of the watershed. Annual precipitation totals increase from west to east (from 42.2 in/yr at Greensboro Airport to 46.93 in/yr at Chapel Hill) and also from south to north in the watershed. The Greensboro Airport station has the lowest annual precipitation total of all the weather stations used, and the east-west precipitation gradient may account for under-prediction of flows in the Buffalo Creek watershed.

4.3.2 Summary of Water Quality Simulation

The water quality model was built with a unified set of parameters that vary according to land use, soils, and geology. The model was calibrated simultaneously to 35 different stations, ensuring a broad and representative sample of watershed conditions. Available monitoring data provide an imprecise target, as laboratory analytical results have associated uncertainty, especially when concentrations are near practical quantification limits. In addition, most sample data are point-in-time grab samples, which are expected to be imprecise estimates of the daily average concentration predictions produced by the model. Calibration thus consists of comparing two uncertain numbers. The calibration strategy avoided arbitrary adjustments to upland parameter values to obtain better fit statistics in individual catchments as good practice to avoid over-fitting to data that are limited in coverage, particularly for high-flow events.

As a result of these considerations, relatively large apparent percent differences between observations and predictions are acceptable at some stations as long as the unified parameter set provides reasonable results across stations in aggregate. Analysis shows that the absolute magnitude of errors is generally small, and that higher percentage errors generally reflect low baseline concentrations.

The water quality calibration included assuring reasonable simulation of water temperature, DO, sediment, and nutrients, examining both concentrations and loads; however, the evaluation relative to the intended uses of the model should focus primarily on ability to predict nutrient loads. Evaluation of the accuracy of load predictions is difficult because load is not directly measured, but inferred from infrequent concentration monitoring and flows. Statistical comparison of paired daily estimated and simulated loads show that a majority of stations rank as "good" or "very good" in either the calibration or corroboration period or both, suggesting that model predictions of load at most stations do not have any consistent bias. Comparison to LOADEST estimates of mass flux showed a good or very good fit for total phosphorus, except for Haw River and North Buffalo Creek, and a good or very good fit for total nitrogen, except for Northeast Creek and Morgan Creek. The discrepancies in mass flux in North Buffalo Creek, Northeast Creek, and Morgan Creek appear primarily attributable to uncertainty in the specification of daily time series of point source loads.

Discrepancies relative to LOADEST for total phosphorus, in which load appears under-predicted at high flows, are seen in the Haw River at Bynum and Haw River at Haw River. Data at the Bynum station suggest that the "missing" phosphorus load is primarily in organic form. Because loading rates by land use appear reasonable and there is not a consistent under-prediction of phosphorus load in small headwater streams, it is likely that the un-simulated excess load is derived from instream sources. Specifically, it appears likely that high flow events may mobilize organic detritus stored behind the several run-of-river dams present in the Haw, including the dam at Bynum, resulting in increased total P concentrations at high flows. Solids in these areas are likely to be highly enriched in organic matter due to historical WWTP and textile mill discharges. LSPC (as does the parent HSPF model) includes an algorithm to associate orthophosphate with eroded inorganic sediment; however, the model does not include any mechanism to represent the mobilization of organic muck and associated organic nutrients from behind low head dams during high flow events. Thus, the additional loading from these areas may need to be estimated external to the watershed model.

In New Hope Creek, Northeast Creek, and Morgan Creek, the LOADEST analysis suggests over-estimation of total nitrogen load by the model. For New Hope Creek, LOADEST continuous time series of loads of N appear to be generally over-predicted by the model from 2005 to present, despite the fact that the paired comparison of loads on days with water quality samples yielded good fit ratings. For Northeast Creek, downstream of the Durham Triangle WWTP, apparent over-prediction of TN load occurs for the 2001 – 2006 period, while in Morgan Creek below the OWASA discharge TN load is estimated in most years. For all three waterbodies the discrepancies seem likely to be associated with estimates of point source loading resulting from interpolation of approximately weekly measurements of effluent concentrations of total N to continuous time series.

For nonpoint source loads the model appears to be approximately unbiased, although imprecise in simulating responses to individual events. Given that the purpose of the model is to evaluate the relative magnitude of annual loads the model is adequate to task, although further improvement could be pursued.

4.3.3 Sensitivity Analyses

Several detailed sensitivity analyses were undertaken to further elucidate model performance and predictions. The first two sensitivity analyses addressed key areas of uncertainty in source load estimation: the nitrogen load from atmospheric deposition and the nitrogen and phosphorus load derived from onsite wastewater systems. Specifically, the atmospheric deposition scenario investigated the implications of using the higher loading estimates from the CMAQ model as opposed to estimates from CASTNET (see discussion in Section 2.5.2). The delivered loads attributed to onsite wastewater systems are also known to be subject to high levels of uncertainty (Section 2.7). The potential implications of this uncertainty are investigated by re-running the model with all onsite waster system loads removed.

A third sensitivity analysis was undertaken to examine the relative importance of point source loads. Similar to the onsite wastewater scenario, this sensitivity analysis was accomplished by re-running the model with point source loads removed.

The impacts associated with these sources differ according to the characteristics of sub-areas of the watershed. To address this variability, results were evaluated at five stations with different land use, point source, and onsite system characteristics (Table 4-18).

Table 4-18. Sensitivity Analysis Assessment Location Characteristics

Station	Name	Drainage area (acres)	Point Source (MGD)	Percent Impervious		Onsite Flow (cfs / mi^2)	
				2001	2010	2001	2010
B3025000	Third Fork Creek near Durham	10,639	0	19.6%	31.4%	0.0037	0.0044
B0040000	Haw River at SR 2109 near Oak Ridge	9,053	0.04	2.1%	5.8%	0.0225	0.0305
B0670000	South Buffalo Creek at SR 300 near Greensboro	22,011	0	18.1%	28.0%	0.0000	0.0000
B0840000	Reedy Fork at NC 87 at Ossipee	163,373	57.7	7.6%	13.5%	0.0062	0.0082
B2100000	Haw River at SR1713 near Bynum	814,686	96	4.0%	8.0%	0.0079	0.0100

Results of the sensitivity analyses are presented in Table 4-19 through Table 4-21, summarized over the complete calendar years of 1997 through 2011. In examining these results, note that the dry atmospheric deposition scenario was done using the final calibrated model, whereas the onsite wastewater and permitted point sources scenarios were completed with an earlier version, prior to the final calibration. As a result; the baseline loads for the dry atmospheric deposition scenario are different than baseline loads for the onsite wastewater and permitted point sources scenarios. Despite this discrepancy, the results still provide a useful indication of the relative magnitude of the sensitivity of the model to different load input sources.

Table 4-19. Sensitivity Analysis: Switch from CASTNET to CMAQ Estimates of Atmospheric Deposition of N, 1997-2011

Station	TN Baseline (lb/yr)	TN Scenario (lb/yr)	Percent Change	TP Baseline (lb/yr)	TP Scenario (lb/yr)	Percent Change
B3025000	32,024	38,353	19.76%	4,489	4,455	-0.75%
B0040000	13,011	14,265	9.64%	1,466	1,462	-0.31%
B0670000	68,819	82,883	20.44%	8,346	8,307	-0.47%
B0840000	1,560,554	1,611,183	3.24%	142,397	139,845	-1.79%
B2100000	3,250,174	3,504,568	7.83%	264,636	260,449	-1.58%

Table 4-20. Sensitivity Analysis: Removal of Onsite Wastewater Systems, 1997-2011

Station	TN Baseline (lb/yr)	TN Scenario (lb/yr)	Percent Change	TP Baseline (lb/yr)	TP Scenario (lb/yr)	Percent Change
B3025000	38,185	34,581	-9.44%	3,833	3,261	-14.91%
B0040000	14,265	13,109	-8.10%	1,287	1,261	-2.05%
B0670000	82,351	82,351	0.00%	6,295	6,295	0.00%
B0840000	1,624,059	1,621,080	-0.18%	132,451	132,315	-0.10%
B2100000	3,332,443	3,297,804	-1.04%	209,446	207,995	-0.69%

Table 4-21. Sensitivity Analysis: Removal of Point Source Discharges, 1997-2011

Station	TN Baseline (lb/yr)	TN Scenario (lb/yr)	Percent Change	TP Baseline (lb/yr)	TP Scenario (lb/yr)	Percent Change
B3025000	38,185	38,185	0.00%	3,833	3,833	0.00%
B0040000	14,265	13,698	-3.97%	1,287	1,171	-9.02%
B0670000	82,351	82,351	0.00%	6,295	6,295	0.00%
B0840000	1,624,059	466,349	-71.28%	132,451	24,457	-81.54%
B2100000	3,332,443	2,065,494	-38.02%	209,446	102,112	-51.25%

Table 4-19 shows that use of CMAQ estimates of dry atmospheric deposition of N (which are about 5 times greater than CASTNET) leads to an increase in predicted watershed nitrogen load. The increase is on the order of 19 – 20 percent of the total simulated N load in watersheds where point sources are not present. The relative contribution declines for watersheds where there are large point source discharges. Increased atmospheric deposition N loads simulated with CMAQ inputs is also predicted to result in a small decreases in total P delivery due to increased algal activity in headwater streams.

Table 4-20 examines the importance of loading simulated from onsite wastewater systems. This source is seen to contribute nearly 10 percent of the total N load and nearly 15 percent of the total P load in some headwater streams with large numbers of onsite systems. No effect is seen in streams whose watersheds are fully sewered (e.g., South Buffalo Creek station B0670000). In streams with a large summer onsite wastewater contribution due to failing systems (e.g., Third Fork Creek) the effect on total nutrient load is sufficiently large that it makes a significant impact on model calibration. However, at the large watershed scale represented by the Haw River at Bynum (B2100000), the onsite systems contribute just over 1 percent of the total N load and less than 1 percent of the total P load.

Point sources, summarized in Table 4-21, have variable importance, but obviously dominate in certain streams. For example, in Reedy Fork (B0840000), point source discharges contribute over 70 percent of the simulated total N load and over 80 percent of the total P load. For the integrative station on the Haw River at Bynum (B2100000), point sources contributed 38 percent of the simulated total N load and over

50 percent of the total P load.

4.3.4 Appropriate Uses and Applications

The Jordan watershed model generally meets the criteria for model acceptability specified in the QAPP for addressing the decision purposes of estimating baseline nutrient loads by regulated entity for establishing load allocations under the Jordan Lake Rules. Tetra Tech thus recommends that the calibrated model performance is sufficiently well demonstrated to be applied for that purpose, including evaluation of both current nutrient loads and changes in nutrient loads since the 1997 – 2001 baseline established in the Rules. The results of the loading analysis are presented in Section 5.1.

The model is thus judged to be *useful* for the intended purposes, but, like all simulation models, is not a perfect representation of reality. The true state of reality is not known due to data that are imprecise or incomplete; however, it is also likely that the accuracy of the model could be improved through additional efforts that were outside the scope of the current effort, including both additional data collection and refinements to model calibration. A discussion of potential improvements in the model is provided in Section 5.2.1. It is important to note that, while these additional efforts have the potential to increase the accuracy of the model and reduce uncertainty in individual entity allocations, they are not a necessary pre-requisite to use of the model to establish allocations.

5 Model Application

5.1 Use of Model for Jurisdictional Loads

The calibration/corroboration LSPC model was configured to span the entire time period between baseline (beginning in 1997) through current (ending in 2012, but using 2010 land use) conditions. As discussed in Section 2.4.2, time-variable land use was implemented allowing the model to use distinct land use from the two time periods in a single, uninterrupted simulation. The model represents meteorology in real time, thus providing predictions of hydrology and water quality that are directly comparable to monitoring data.

However, the goals for establishing jurisdictional loads are fundamentally different. The model becomes a tool to provide a reasonable and equitable estimate of nonpoint nutrient loading originating from the land area in each jurisdiction during two distinct time periods. Other loading sources should also be represented in a manner appropriate for the time periods. When models are used to answer questions in multiple scenarios, it is important to make the models as equivalent as possible and vary only the inputs related to the study questions. In this case, the first three study questions laid out in Section 1.2 guided development of model application provided in this report:

1. What are the baseline (1997 – 2001) loads of nutrients associated with each jurisdiction in the watershed?
2. How much of the load generated in specific source areas is ultimately transported to Lake Jordan?
3. How have those loads changed in the period from baseline to current conditions?

Each of the three questions was considered carefully for development of the model application strategy. The questions are discussed out of order since the answer to the third question was pivotal in setting the approach in response to the second question.

To address the first question, a version of the model (called “Baseline”) was created using the 1999 land use divided and tabulated spatially by jurisdictional boundaries from the same time period. The GIS file maintained the same resolution as the file used for model calibration/corroboration (cell size of 1 m^2). The Baseline simulation ran using input meteorology from January 1, 1996 through December 31, 2001; 1996 was used for model spin-up, so output was gathered for the five year period from 1997 through 2001. Five years of output were used (rather than a single year) to a) allow averaging across multiple years so results would not be overly influenced by using a wet or dry year, and b) to correspond with the regulatory definition of baseline loading (which spans 1997 through 2001).

The third question was addressed by building a version of the model using the 2010 land use (called “Existing”), also divided and tabulated spatially by jurisdiction, but with updated jurisdictional boundaries. The GIS file maintained the same resolution as the file used for model calibration/corroboration (cell size of 1 m^2). However, the Existing simulation ran using input meteorology from the exact same time period as the Baseline model: January 1, 1996 through December 31, 2001, with 1996 as spin-up and output gathered from 1997 – 2001. The reason for using the same meteorology was to minimize differences between the models due to variations in rainfall volume, large storms, hurricanes, and so forth. Question three does not simply ask “What are the loads in 1999 – 2001 and what are the loads in 2012, and how do they compare?” Rather, it asks “How do loads compare between baseline and existing conditions *due to changes in land use and jurisdictional boundaries*?” Using identical meteorology allows the question to be answered in a more equitable manner.

The second question asks to what degree loads from each jurisdiction are attenuated between source generation and delivery to Jordan Lake. No specific time period is explicit (or implicit) in this question. To provide the best answer to this question, output from the full calibration/corroboration model was used to estimate unique delivery rates for each model subwatershed. Delivery was calculated as the ratio of the total mass of the nutrient leaving the subwatershed's reach to mass entering the subwatershed's reach over the course of the simulation. For instance, if 222,000 lbs of Total N entered the reach and 214,000 lbs exited the reach, the delivery ratio would be 214,000 / 222,000, or 0.964. Using the reach connectivity network, net delivery to Jordan Lake was then calculated for each model reach. Net delivery was calculated as the product of all the delivery factors from each reach between the source reach and the outlet reach. For instance, if the reach in the previous drained through two reaches before its water reached the lake, and the two reaches had delivery rates of 0.987 and 0.991, the net delivery would be (0.964)(0.987)(0.991), or 0.943. The local and net delivery rates were used for both the Baseline and Existing scenarios. Note that output through the end of 2011 was used in the analysis; 2012 was excluded since the simulation ended 9/30/2012 and did not include the full year.

Loads from other sources are also tabulated for Baseline and Existing conditions for relative comparison to entity loads as follows:

- NPDES point source loads from 1997 through 2001 were averaged to represent Baseline conditions, while loads from 2012 alone were used for Existing conditions.
- Loads from onsite wastewater disposal systems were tabulated from the year 2000 and 2010 model inputs for Baseline and Existing conditions, respectively.
- Dry nitrogen deposition to the land surface is a natural component of accumulation, while wet deposition contributes to nitrogen in runoff. Land surface deposition (wet and dry) is considered part of entity loading, and is directly incorporated in the model. However, nitrogen deposition direct to streams and reservoirs is a separate input to the model, and is not attributable to MS4 jurisdictions. Output from the full calibration/corroboration model (1997 – 2011) was used to tabulate direct water surface nitrogen deposition, and the annual average is used in the source summaries. Output from 2012 was excluded since the simulation did not include the full year.

Further details regarding configuration are provided below, along with results.

5.1.1 Estimation of at Source Loads

5.1.1.1 Upland Loads

Baseline and existing jurisdictional boundaries are required to determine nutrient load allocations for all entities considered to have had, or now have in place after the Baseline time period, entity areas in the Jordan Lake watershed. The entities include all municipalities, counties, and state and federal entities with jurisdictional areas considered regulated under the Jordan Nutrient Strategy.

Six municipalities, three counties, NCDOT, Triangle J Council of Governments (TJCOG), and NC DENR provided GIS coverages for all entity areas subject to the Jordan Nutrient Strategy for both model time periods, using boundaries in effect in 1999 and 2010 for baseline and existing time periods respectively (the dates were selected to correspond to aerial imagery used to develop the model land use). Jurisdictional areas included as separate entities in the model are listed in Table 5-1 (color-coded by county for county and municipal jurisdictions—state and federal jurisdictional entities are orange and white, respectively) and geographically displayed in Figure 5-1. The full tabulation of areas will be provided electronically.

For both the 1999 and 2010 model scenarios, seamless GIS layers were created from GIS datasets noted above. NCDOT jurisdictional areas were always given overriding primacy. In other words, if NCDOT boundaries crossed over municipal, state, or federal areas, the assigned jurisdiction was NCDOT. State and federally-owned properties were given the next level of primacy, followed by municipalities, and ending with the counties. All areas within the watershed were assigned to a single jurisdiction.

Table 5-1. Responsible Entities Based on the Jordan Nutrient Strategy Rules

Entity	Location (County)	Baseline Scenario Boundary Source	Existing Scenario Boundary Source
Rockingham County	Rockingham	Based on remaining areas in watershed	
Reidsville	Rockingham	NC DENR	NC DENR
Forsyth County[1]	Forsyth	Based on remaining areas in watershed	
Kernersville	Forsyth	Kernersville	Kernersville
Guilford County	Guilford	Based on remaining areas in watershed	
Stokesdale	Guilford	NC DENR	Guilford County
Summerfield	Guilford	NC DENR	Guilford County
Oak Ridge	Guilford	NC DENR	Guilford County
Greensboro	Guilford	NC DENR	Guilford County
Pleasant Garden	Guilford	NC DENR	Guilford County
Whitsett	Guilford	NC DENR	Guilford County
Sedalia	Guilford	NC DENR	Guilford County
Randolph County[1]	Randolph	Based on County area within watershed	
Caswell County	Caswell	Based on County area within watershed	
Alamance County	Alamance	Based on remaining areas in watershed	
Gibsonville	Alamance, Guilford	NC DENR	Guilford County
Ossipee	Alamance	Incorporated 12/9/2002; not present in baseline period.	Guilford County
Elon	Alamance	NC DENR	Guilford County
Alamance	Alamance	NC DENR	Burlington
Burlington	Alamance	NC DENR	Burlington
Green Level	Alamance	NC DENR	Burlington
Haw River	Alamance	NC DENR	Burlington
Graham	Alamance	NC DENR	Burlington
Swepsonville	Alamance	NC DENR	Piedmont Triad Regional COG
Mebane	Alamance, Orange	NC DENR	Piedmont Triad Regional COG
Orange County	Orange	Based on remaining areas in watershed	
Chapel Hill	Orange	Chapel Hill	Chapel Hill
Carrboro	Orange	Carrboro	Carrboro
Chatham County	Chatham	Based on remaining areas in watershed	
Pittsboro	Chatham	TJCOG	Chatham County
Durham County	Durham	Based on remaining areas in watershed	
Durham	Durham	TJCOG	City of Durham
Wake County	Wake	Based on remaining areas in watershed	
Cary	Wake	Wake County	Wake County
Apex	Wake	Apex	Apex
Morrisville	Wake, Durham	Wake County	Wake County
NCDOT	All	NCDOT	NCDOT
NCSU[2]	Chatham, Durham	NC DENR	NC DENR

Entity	Location (County)	Baseline Scenario Boundary Source	Existing Scenario Boundary Source
UNC Chapel Hill[2]	Chatham, Durham, Orange	UNC Chapel Hill	UNC Chapel Hill
UNC Greensboro[2]	Alamance, Guilford	NC DENR	NC DENR
NCCU[2]	Durham	NC DENR	NC DENR
NCA&T[2]	Guilford	NC DENR	NC DENR
NC DPR[2] (Dept. of Parks & Recreation)	Chatham, Alamance, Guilford, Rockingham	Baseline Extents assumed to be same as in existing scenario	NC DENR
NC DCR[2] (Dept. of Cultural Resources)	Durham, Alamance, Guilford		NC DENR
US ACE[2] (Army Corps of Engineers)	Wake, Chatham, Durham, Orange	Baseline Extents assumed to be same as in existing scenario	NC DENR
USNPS (National Park Service[2])	Guilford		NC DENR

[1] Forsyth and Randolph counties are not called out in the Jordan rules but are reported as separate entities.
[2] Some State and Federal entities were not explicitly identified in the state regulations known as the Jordan Lake Nutrient Strategy. These entities were selected under instruction from NC DENR.

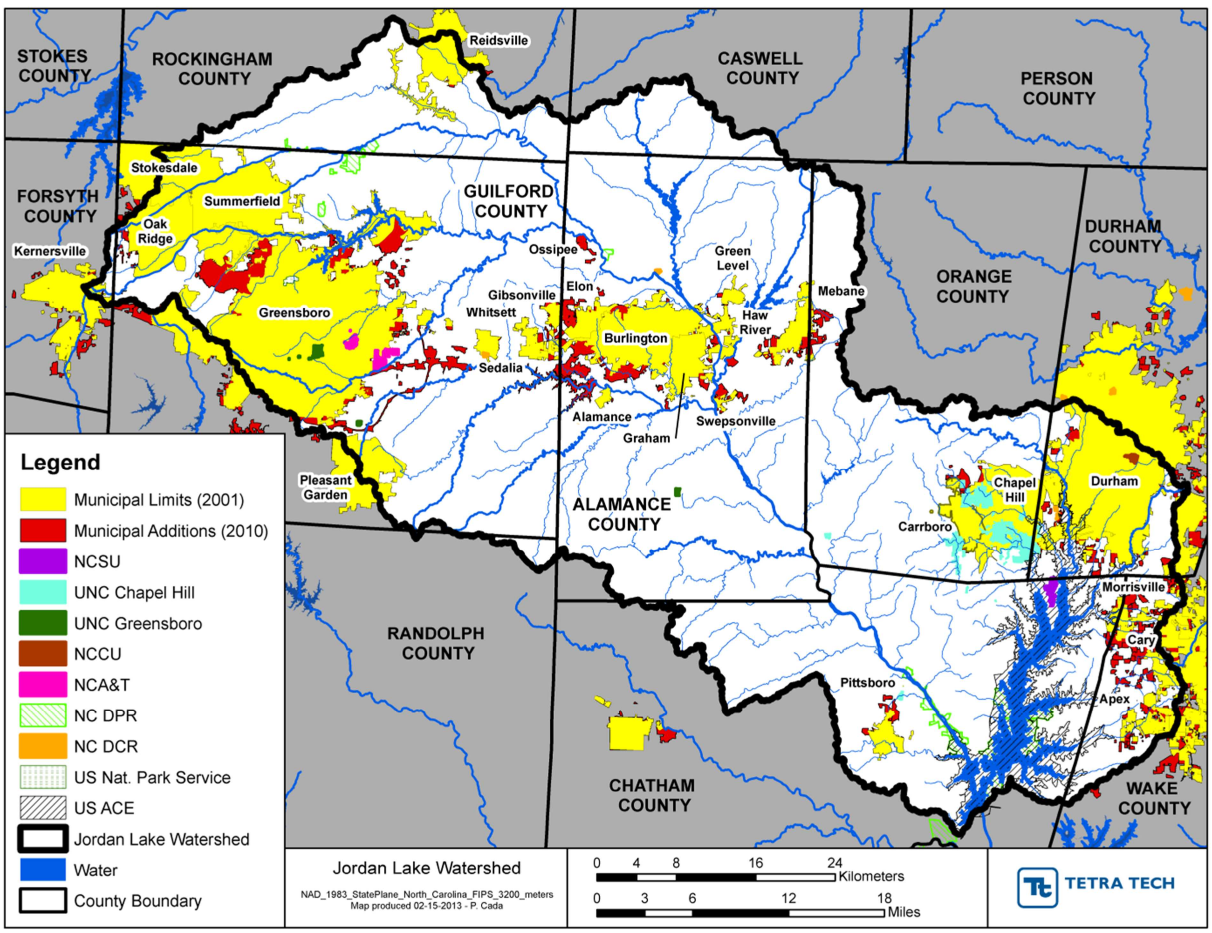


Figure 5-1. Responsible Jurisdictions within the Jordan Watershed

Note: NCDOT boundaries are not shown on this map due to their complexity.

Output from each of the two time-period models (i.e., Baseline and Existing) were tabulated by model subwatershed and jurisdiction-MRUs. Total N and total P were summed from their respective runoff components, including a fraction of BOD representing labile organic fraction. Total N was summed from output series representing NO_X, refractory organic nitrogen, total ammonia, and the labile organic N implicitly simulated as a fraction of CBOD (4.358% of CBOD), while total P was summed from orthophosphate, refractory organic phosphorus, and the labile organic P implicitly simulated as a fraction of CBOD (0.6031% of CBOD).

The Jordan rules specify loading targets by Assessment Unit (Figure 5-2). Loading results are shown in Table 5-2 for Baseline and Existing scenarios by Assessment Unit. The relative contributions by Assessment Unit for the Baseline scenario are summarized graphically in Figure 5-3. Relative contributions of upland loads by Assessment Unit are similar for the Existing scenario and are not shown here. The relative contribution of each model land cover for the Baseline and Existing Scenarios is shown in Figure 5-4. When compared to total land cover area as shown in Figure 2-9 and Figure 2-10, it is apparent that row crops and impervious surfaces contribute disproportionately to loading relative to their contributing land area.

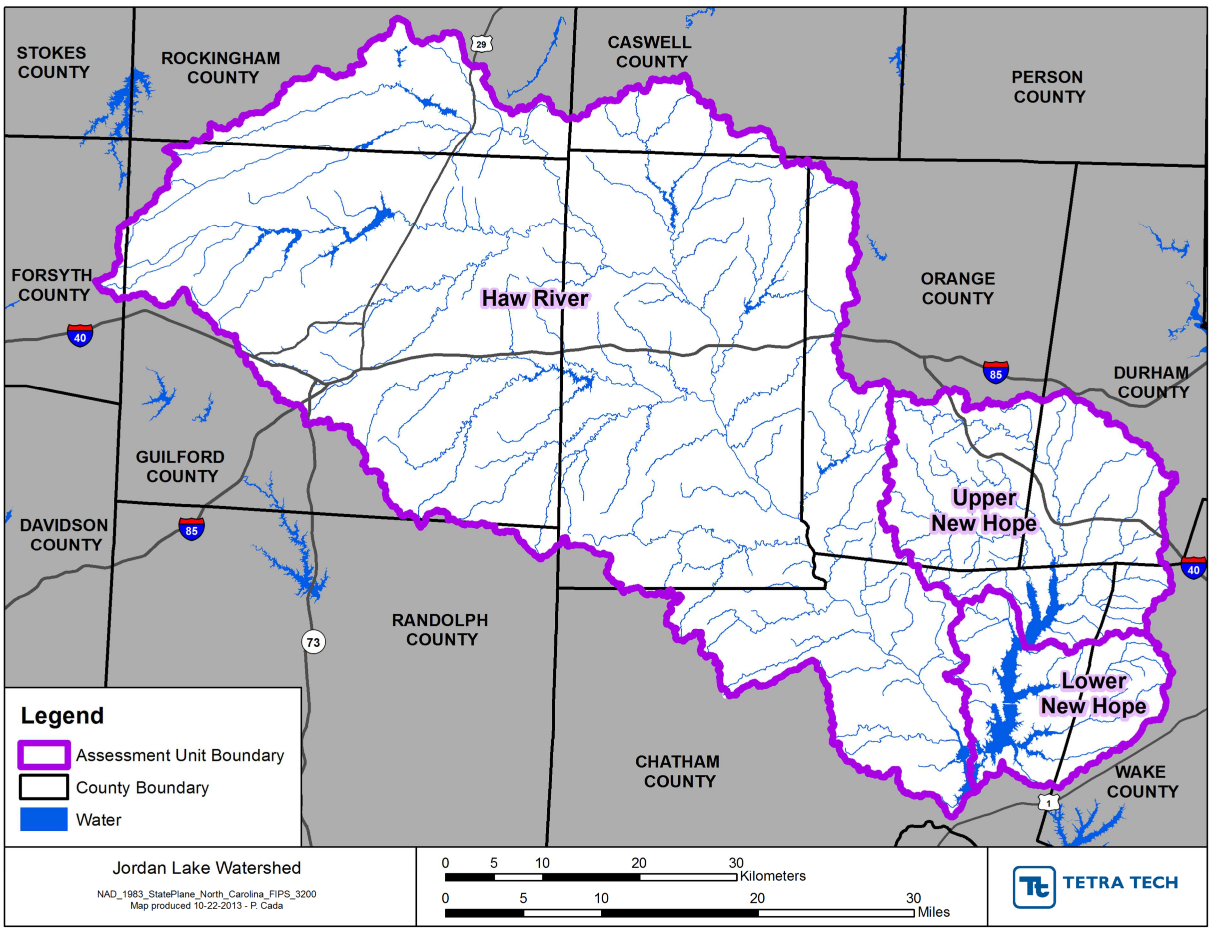


Figure 5-2. Jordan Lake Watershed Assessment Units

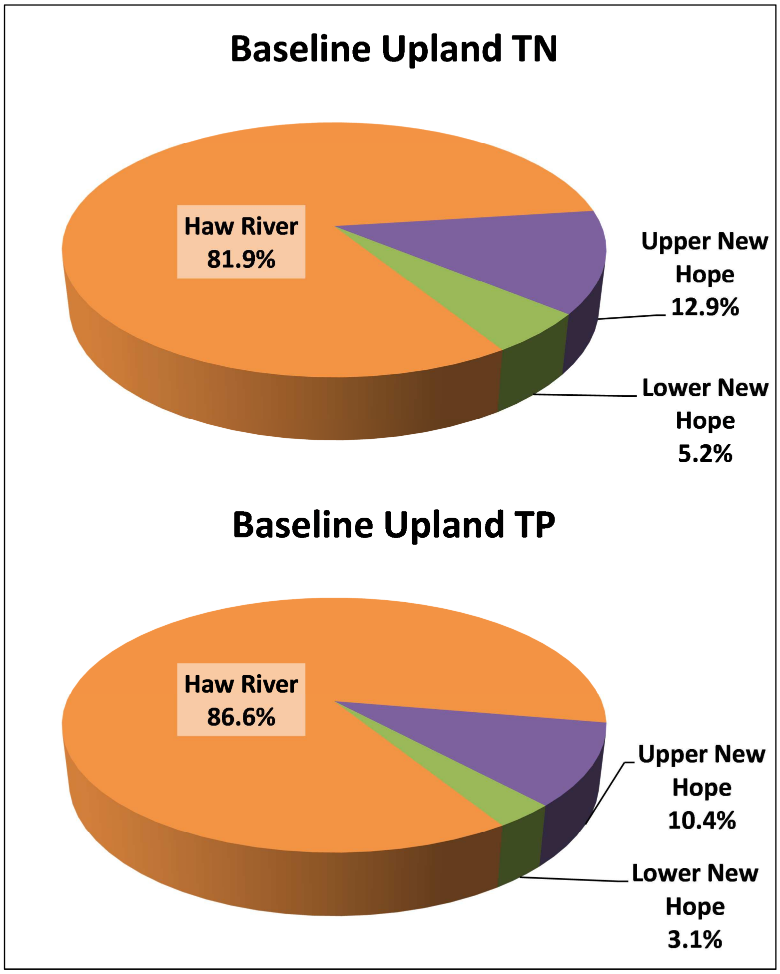


Figure 5-3. Distribution of Baseline Upland Nutrient Loads by Assessment Unit

Table 5-2. Annual Average Upland Baseline and Existing Nutrient Loads by Assessment Unit

	Upland Baseline Loads		Upland Existing Loads	
Assessment Unit	**Total N (lbs/yr)**	**Total P (lbs/yr)**	**Total N (lbs/yr)**	**Total P (lbs/yr)**
Haw River	2,917,065	314,985	3,063,380	349,055
Upper New Hope	461,125	37,679	518,038	50,764
Lower New Hope	185,045	11,169	197,945	14,062

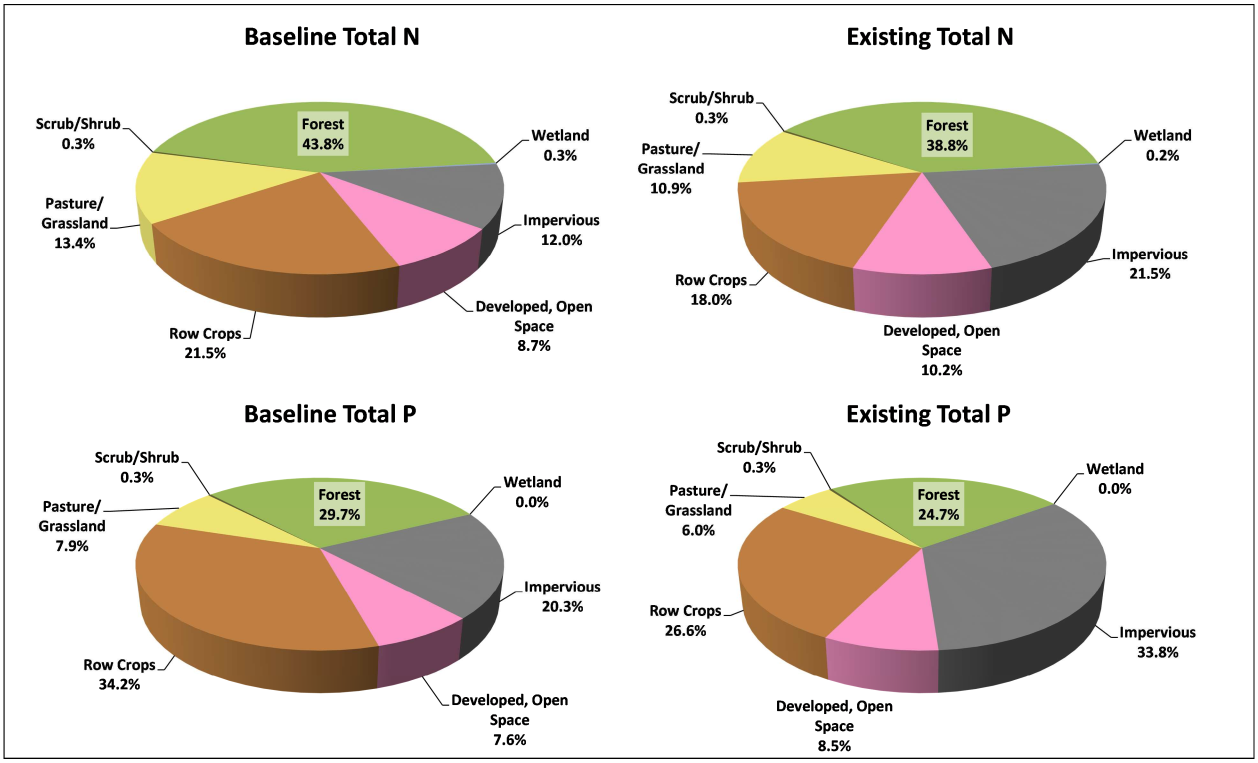


Figure 5-4. Annual Average Upland Baseline and Existing Nutrient Loads by Land Cover

5.1.1.2 Point Sources

As discussed in the Section 5.1 introduction, NPDES point source loads from 1997 through 2001 were averaged to represent Baseline conditions, while loads from 2012 alone were used for Existing conditions. Results are shown in Table 5-3 by Assessment Unit.

Table 5-3. Point Source Baseline and Existing Nutrient Loads (at Discharge) by Assessment Unit

	Point Source Baseline Loads		Point Source Existing Loads	
Assessment Unit	**Total N (lbs/yr)**	**Total P (lbs/yr)**	**Total N (lbs/yr)**	**Total P (lbs/yr)**
Haw River	1,816,027	219,729	1,383,949	92,106
Upper New Hope	711,588	38,457	503,593	25,527
Lower New Hope	7,604	723	14,462	224

5.1.1.3 Onsite Wastewater

As discussed in Section 2.7, loads from onsite wastewater disposal systems were tabulated from the year 2000 and 2010 model inputs for Baseline and Existing conditions, respectively. Results are shown in Table 5-4 by Assessment Unit.

Table 5-4. Onsite Wastewater Baseline and Existing Nutrient Loads by Assessment Unit

	Onsite Wastewater Baseline Loads		Onsite Wastewater Existing Loads	
Assessment Unit	**Total N (lbs/yr)**	**Total P (lbs/yr)**	**Total N (lbs/yr)**	**Total P (lbs/yr)**
Haw River	33,827	979	41,757	1,208
Upper New Hope	1,531	49	2,543	79
Lower New Hope	7,763	616	9,723	783

5.1.1.4 Direct Nitrogen Deposition to Water Surfaces

LSPC output provides a tabulation of pollutant deposition loads direct to reach and reservoir surfaces. The Jordan LSPC model was configured to represent both wet and dry direct depositions of nitrate and ammonia species to reaches and reservoirs. Wet and dry depositions are lumped together in model output, but nitrate and ammonia totals are retained separately. Over the course of the 15 year simulation spanning 1997 through 2011, nitrogen deposition to model reaches and reservoirs averaged on an annual basis about 47,000 lbs of nitrate species, and 38,000 lbs of ammonia species. Annual average loads by assessment unit are shown in Table 5-5. Direct deposition to Jordan Lake is not included in the analysis.

Table 5-5. Nitrogen Direct Deposition to Reach and Reservoir Surfaces by Assessment Unit

Assessment Unit	NO_X-N (lbs/yr)	Ammonia-N (lbs/yr)	Total N (lbs/yr)
Haw River	43,267	34,896	78,163
Upper New Hope	2,685	2,340	5,025
Lower New Hope	981	834	1,815

5.1.1.5 Source Loads Summary

Figure 5-5 provides a summary of total N and total P loads by source for the Baseline and Existing Scenarios. Upland areas produce the largest share of load, followed by NPDES point sources. Onsite systems contribute less than one percent of the total, though it is important to note that they can produce localized impacts as shown by the sensitivity analysis in Section 4.3.3. Improvements in point source treatment technology result in dramatic reductions in their loads, especially for total P. While upland loads increase due to development, overall loads decrease between the Baseline and Existing time periods. Total N is reduced from about 6,227,000 lbs to 5,820,000 lbs, representing a decrease of 6.5 percent. Total P decreases from about 624,000 lbs to 534,000 lbs, a 14.5 percent reduction.

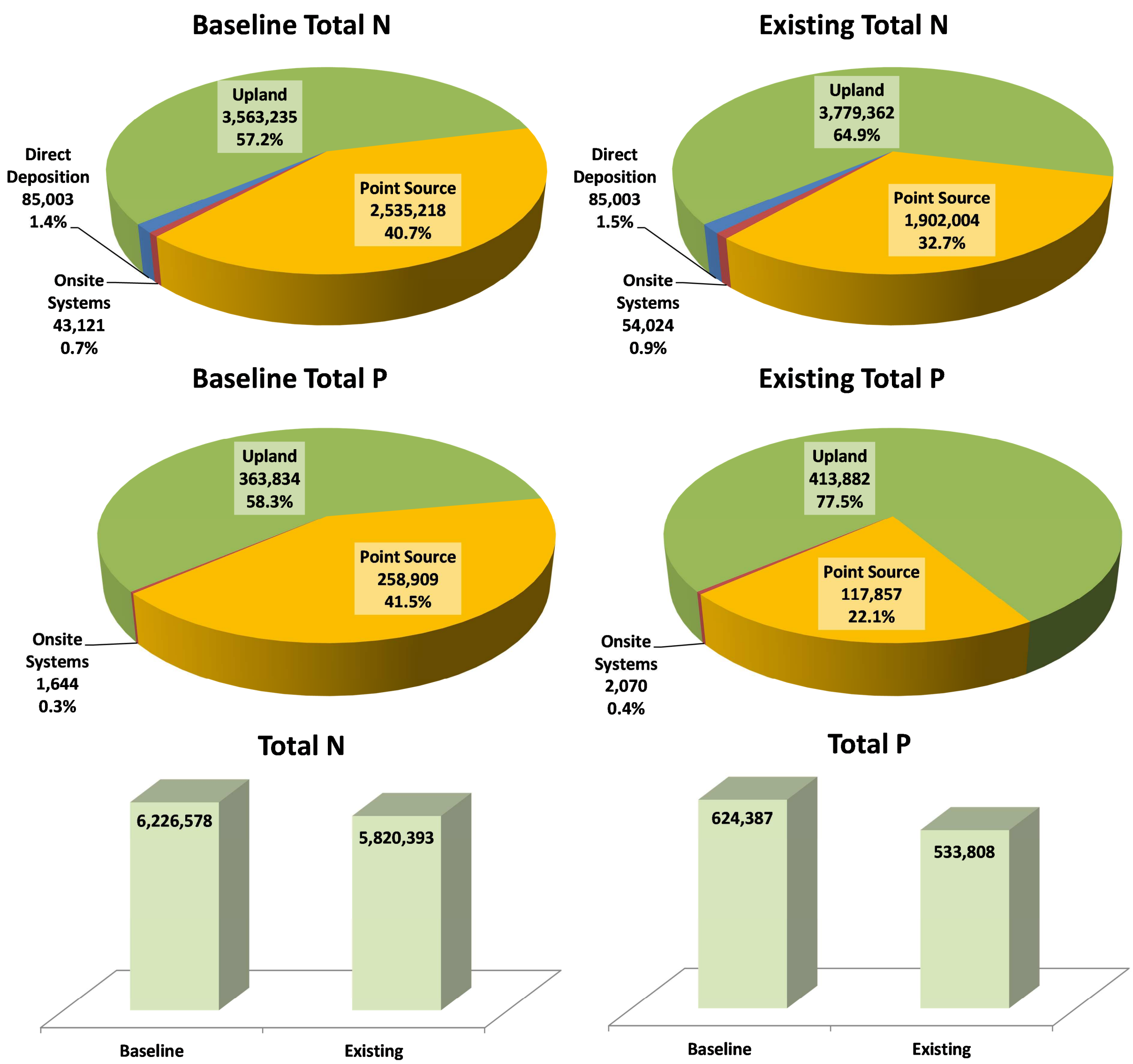


Figure 5-5. Nutrient Loads by Source Type for the Baseline and Existing Scenarios

5.1.2 Estimation of Delivered Loads

Unique delivery factors were calculated for each model subwatershed for total N and total P using output from the full calibration/corroboration simulation spanning 1997 through 2011. A network analysis was then performed to calculate the net delivery from each subwatershed to Jordan Lake. Net delivery is shown in Figure 5-6 for total N and Figure 5-7 for total P. Note that the Haw River model subwatershed closest to Jordan Lake has a delivery factor of 1.009 for total P, which indicates an increase rather than attenuation. The reason is due to scour of bed sediment with legacy attached phosphorus during large storm events. Table 5-6 provides a complete listing of the delivery factors from each model subwatershed to Jordan Lake.

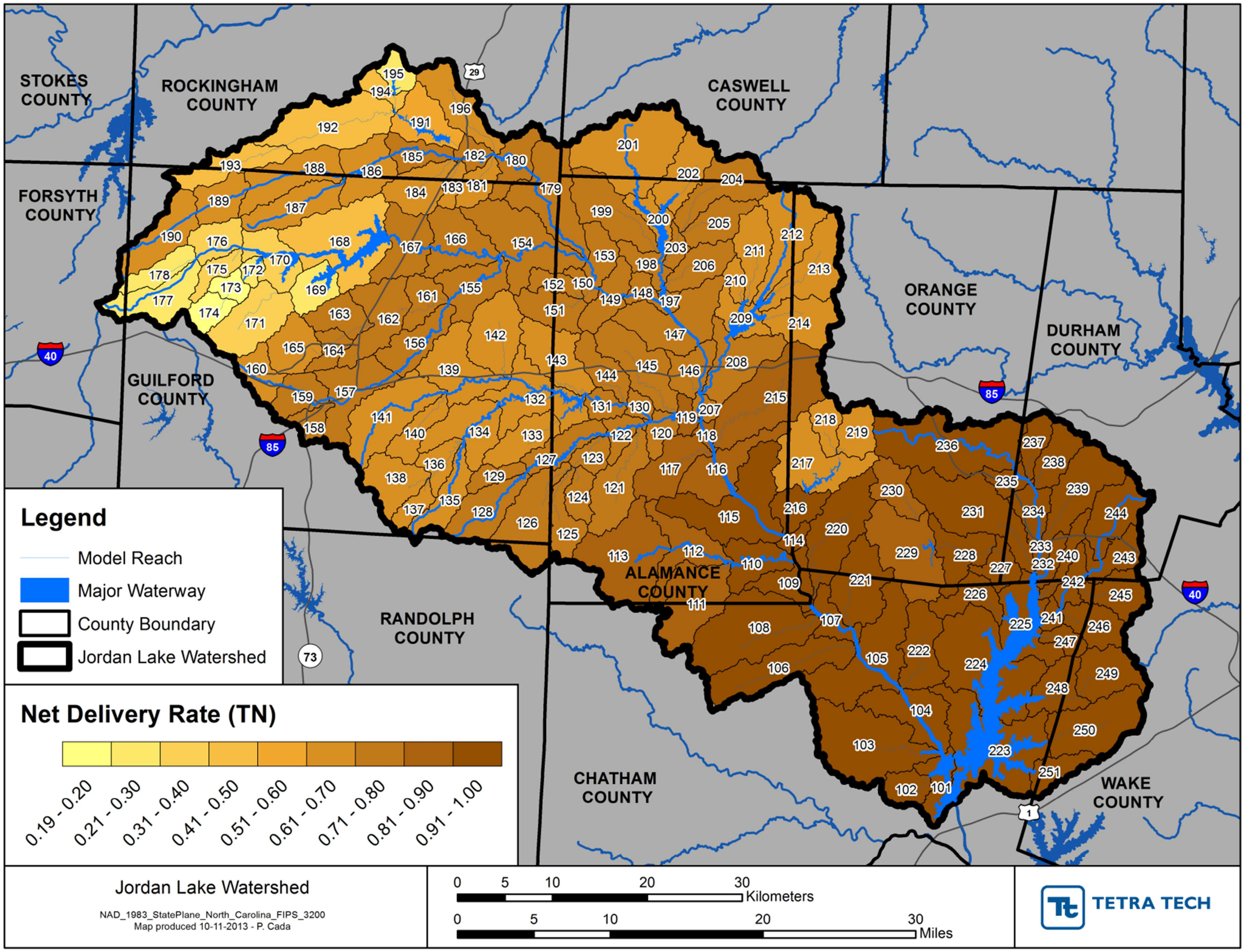


Figure 5-6. Net Delivery Factors for Total N

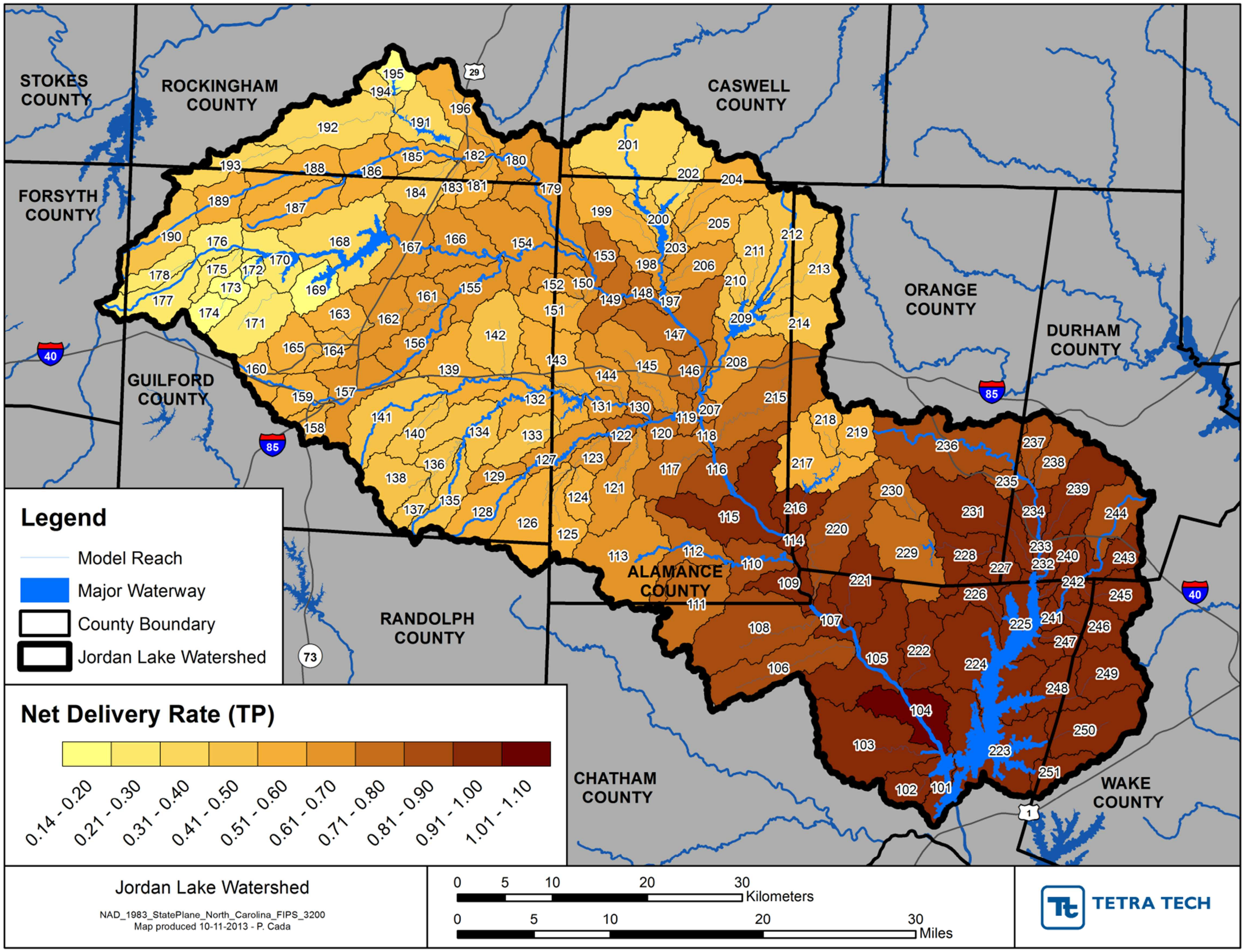


Figure 5-7. Net Delivery Factors for Total P

Table 5-6. Baseline Scenario Net Delivery Factors from Source to Jordan Lake for Regulated Land

Sub-basin	TN	TP	Sub-basin	TN	TP	Sub-basin	TN	TP	Sub-basin	TN	TP
101	0.996	0.984	139	0.657	0.508	177	0.296	0.227	215	0.813	0.753
102	0.984	0.972	140	0.638	0.476	178	0.299	0.226	216	0.964	0.942
103	0.963	0.939	141	0.637	0.488	179	0.737	0.638	217	0.675	0.585
104	0.997	1.009	142	0.646	0.479	180	0.725	0.615	218	0.652	0.537
105	0.987	0.995	143	0.670	0.568	181	0.693	0.545	219	0.664	0.564
106	0.947	0.888	144	0.771	0.687	182	0.718	0.601	220	0.938	0.900
107	0.984	0.988	145	0.716	0.657	183	0.689	0.556	221	0.953	0.926
108	0.943	0.863	146	0.795	0.752	184	0.602	0.474	222	0.960	0.931
109	0.980	0.974	147	0.792	0.742	185	0.704	0.579	223	0.991	0.971
110	0.934	0.866	148	0.783	0.721	186	0.691	0.558	224	0.992	0.973
111	0.889	0.744	149	0.780	0.711	187	0.663	0.529	225	0.989	0.965
112	0.873	0.723	150	0.764	0.665	188	0.670	0.536	226	0.963	0.943
113	0.842	0.655	151	0.733	0.584	189	0.651	0.514	227	0.991	0.970
114	0.978	0.965	152	0.743	0.619	190	0.624	0.480	228	0.969	0.936
115	0.974	0.950	153	0.778	0.702	191	0.511	0.396	229	0.877	0.761
116	0.849	0.838	154	0.755	0.659	192	0.485	0.367	230	0.855	0.730
117	0.816	0.757	155	0.749	0.642	193	0.461	0.344	231	0.975	0.947
118	0.810	0.789	156	0.741	0.627	194	0.499	0.382	232	0.993	0.979
119	0.805	0.774	157	0.727	0.601	195	0.235	0.174	233	0.987	0.961
120	0.800	0.753	158	0.715	0.570	196	0.693	0.581	234	0.967	0.917
121	0.768	0.675	159	0.713	0.576	197	0.772	0.694	235	0.948	0.879
122	0.785	0.713	160	0.699	0.545	198	0.764	0.665	236	0.915	0.843
123	0.762	0.645	161	0.744	0.630	199	0.732	0.574	237	0.947	0.882
124	0.737	0.589	162	0.739	0.619	200	0.641	0.441	238	0.948	0.876
125	0.728	0.550	163	0.725	0.598	201	0.615	0.382	239	0.962	0.918
126	0.729	0.546	164	0.711	0.572	202	0.617	0.387	240	0.974	0.955
127	0.756	0.647	165	0.700	0.545	203	0.747	0.625	241	0.989	0.974
128	0.723	0.546	166	0.741	0.630	204	0.717	0.544	242	0.975	0.944
129	0.744	0.622	167	0.731	0.609	205	0.720	0.558	243	0.965	0.923
130	0.797	0.738	168	0.442	0.376	206	0.740	0.601	244	0.943	0.887
131	0.769	0.696	169	0.210	0.187	207	0.798	0.767	245	0.955	0.911
132	0.673	0.542	170	0.316	0.248	208	0.733	0.663	246	0.963	0.932
133	0.643	0.465	171	0.306	0.235	209	0.631	0.478	247	0.974	0.970
134	0.657	0.500	172	0.202	0.153	210	0.606	0.420	248	0.976	0.972
135	0.626	0.431	173	0.198	0.148	211	0.605	0.416	249	0.947	0.933
136	0.641	0.472	174	0.195	0.142	212	0.606	0.417	250	0.969	0.966
137	0.618	0.431	175	0.308	0.237	213	0.603	0.413	251	0.986	0.982
138	0.626	0.447	176	0.308	0.239	214	0.604	0.426	252	0.775	0.705

Note: Location of numbered subwatersheds is shown in Figure 2-4.

5.1.3 Source and Delivered Loads by Jurisdiction

Jurisdictional loads, defined as load from developed land subject to the Jordan nutrient strategy, were tabulated by scenario (Baseline and Existing), nutrient (total N and total P), assessment location (locally at source versus delivered to lake), and by regulated (developed) versus non-regulated (undeveloped) area. Loads were assigned to the Developed (i.e., regulated) category solely by land cover; all developed/open space and impervious land in the model was assigned Developed, while remaining uses (forest, shrub/scrub, pasture/grassland, row crops, wetlands, and non-reach surface water) were assigned to the Undeveloped category. There was one exception: all NCDOT jurisdictional land area was assigned to the Developed category, since NCDOT is responsible for all use within the road rights-of-way. For reference, regulated land areas by entity are shown in Table 5-7 and Table 5-8 for the Baseline and Existing Scenarios, respectively. It is important to note that the GIS analysis supporting development of land areas has considerable uncertainty (as discussed in Section 2.4.2) that is less influential at subwatershed scales but of potential greater impact at local scales. As a result, the land areas in these tables should be considered approximations, particularly for 1999 impervious surface estimates.

Baseline total N and total P entity loads at source and delivered to Jordan Lake are shown in Table 5-9 and Table 5-10, respectively. In these tables, the “county” loads represent load from developed land that is within a given county but outside of the boundaries of municipal and other jurisdictions. As the tables show, there is considerable variation between jurisdictions, both in terms of load generated and fraction of source load delivered to Jordan Lake. Table 5-11 and Table 5-12 provide a comparison between jurisdictions of the magnitude of total N and total P loads from developed land delivered to Jordan Lake for the Baseline scenario. Total N and total P entity loads for the Existing (2010 condition) scenario are shown in Table 5-13 and Table 5-14, respectively.

Table 5-15 and Table 5-16 provide a comparison between the jurisdictions of total N and total P loads delivered to Jordan Lake for the existing scenario, and show that changes in land use in the previous decade have influenced the relative contribution from each of the jurisdictions (NOTE: per discussion in section 2.4.2, this difference is likely over-estimated because of canopy coverage of impervious surfaces in the 1999 LULC dataset that resulted in lower than actual impervious surface area estimates for baseline conditions. Additionally, see analysis provided in Appendix C). The increase in total N and total P loads from developed land from the Baseline to the Existing scenario is shown in Table 5-17 (NOTE: Given the issue regarding 1999 canopy cover and impervious surface estimates, the results in this table should be interpreted as approximate and not used in regulatory calculations. DWR should work with each jurisdiction to determine accurate estimates of development that has occurred since the baseline period before calculating the additional reduction requirements per the Jordan Rules). Note also that these tabulations do not account for any potential reductions in load from the construction of water quality BMPs after the baseline period.

The LSPC model provides a direct estimate of the Baseline loads delivered to Jordan Lake during the 1997-2001 period. The Jordan Purpose and Scope Rule (15A NCAC 02b .0262) defines the baseline loading amount to the three assessment segments of Jordan Lake based on earlier analyses described in the TMDL document. The estimates codified in the rule are similar to, but not identical to the current model output. It is therefore necessary to devise a means of translating between the LSPC model loads and the loads stated in the Rule (see further discussion below in Section 5.3). This translation can be done on the basis of relative percentage of loading. To accomplish the translation annual average delivered loads originating from regulated (developed) areas were tabulated by entity and lake assessment unit and converted to percentages of total loads to the assessment unit. These are expressed as a percentage of loads from all sources, including point sources and direct atmospheric deposition and thus may be used to convert from the total loading target for an assessment unit as specified in the Rule to a delivered load allocation associated with a specific regulated entity. Results are shown in Table 5-18 for the Haw River Assessment Unit, and in Table 5-19 for the Upper New Hope and Lower New Hope Assessment Units. Each table includes results for Baseline conditions and Existing conditions.

Table 5-18 and Table 5-19 also show percentages of Existing loads attributed to developed land uses in each regulated entity. These are generally higher than the Baseline percentages because developed land area has increased (see caveats noted on previous page) while many point source loads have decreased. To provide a direct comparison to the Baseline percentages, the Existing load percentages are calculated by combining the Existing scenario land use with 1997 – 2001 meteorology. There is not a model run that includes all point and nonpoint sources with 1997 – 2001 meteorology because Existing (2012) point source flow time series would not be properly scaled to 1997 – 2001 precipitation (noting that spikes in WWTP outflow occur due to infiltration and inflow associated with large storm events). Existing condition entity percentages were therefore estimated by taking the nonpoint source load increase between the Baseline scenario model (without point sources) and the Existing scenario model, and adding the increase to the total loads from the 1997 – 2001 output from the full calibration/ corroboration model.

Table 5-7. Regulated Land Areas for Baseline Scenario (1999 LU, acres)

Jurisdiction	Pervious	Impervious	Total
Rockingham County	2041.26	705.55	2746.81
Reidsville	1930.58	488.92	2419.5
Forsyth County	152.57	62.46	215.03
Kernersville	280.82	160.15	440.97
Guilford County	9969.24	4575.54	14544.78
Stokesdale	1560.26	146.82	1707.08
Summerfield	3101.17	305.86	3407.03
Oak Ridge	2650.67	131.64	2782.31
Greensboro	18291.91	7168.93	25460.84
Pleasant Garden	1005.85	135.33	1141.18
Whitsett	515.95	34.59	550.54
Sedalia	220.39	27.77	248.16
Randolph County	81.65	43.71	125.36
Caswell County	575.48	102.17	677.65
Alamance County	9836.74	4954.06	14790.8
Gibsonville	370.71	113.08	483.79
Ossipee	0	0	0
Elon	711.61	197.34	908.95
Alamance	125.69	21	146.69
Burlington	4295.64	2829.61	7125.25
Green Level	259.36	50.95	310.31
Haw River	557.46	136.51	693.97
Graham	1464.5	686.33	2150.83
Swepsonville	146.32	35.35	181.67
Mebane	1631.75	244.85	1876.6
Orange County	3177.22	787.45	3964.67
Chapel Hill	2637.92	1695.86	4333.78
Carrboro	828.4	331.58	1159.98
Chatham County	3330.16	1240.78	4570.94
Pittsboro	531.38	121.57	652.95
Durham County	1544.6	724.51	2269.11
Durham	8599.16	4677.06	13276.22
Wake County	1167.17	376.08	1543.25
Cary	755.35	275.72	1031.07
Apex	1153.89	261.73	1415.62
Morrisville	92.99	3.18	96.17
NCDOT	13072.91	13160.49	26233.4
NCSU	4.02	4.2	8.22
UNC Chapel Hill	453.72	515.6	969.32
UNC Greensboro	92.4	48.87	141.27
NCCU	39.4	54.51	93.91
NCA&T	189.41	70.02	259.43
NCDPR	12.17	9.8	21.97
NCDCR	12.26	2.32	14.58
USACE	310.72	222.42	533.14
USNPS	14.81	1.77	16.58

Table 5-8. Regulated Land Areas for Existing Scenario (2010 LU, acres)

Jurisdiction	Pervious	Impervious	Total
Rockingham County	2595.13	2255.09	4850.22
Reidsville	1693.97	906.12	2600.09
Forsyth County	179.04	65.06	244.1
Kernersville	290.27	265.22	555.49
Guilford County	10719.83	9735.63	20455.46
Stokesdale	2652.78	377.02	3029.8
Summerfield	5337.1	897.01	6234.11
Oak Ridge	3542	475.68	4017.68
Greensboro	25121.42	13982.51	39103.93
Pleasant Garden	1426.5	228.12	1654.62
Whitsett	691.03	64.94	755.97
Sedalia	279.6	47.85	327.45
Randolph County	131.33	113.12	244.45
Caswell County	755.71	1023.16	1778.87
Alamance County	12307	10445.85	22752.85
Gibsonville	828.61	412.43	1241.04
Ossipee	163.82	34.47	198.29
Elon	988.29	450.35	1438.64
Alamance	179.33	82.17	261.5
Burlington	5810.75	4603.56	10414.31
Green Level	394.71	96.99	491.7
Haw River	778.36	239.4	1017.76
Graham	2130.89	1279.63	3410.52
Swepsonville	407.2	115	522.2
Mebane	2187.71	846.31	3034.02
Orange County	4043.65	3522.01	7565.66
Chapel Hill	2612.37	3180.38	5792.75
Carrboro	1239.11	821.36	2060.47
Chatham County	4373.79	3888.01	8261.8
Pittsboro	630.18	328.09	958.27
Durham County	1768.71	898.07	2666.78
Durham	7923.51	8326.49	16250
Wake County	1234.99	903.31	2138.3
Cary	1276.62	1452.54	2729.16
Apex	1713.43	919.68	2633.11
Morrisville	247.31	187.85	435.16
NCDOT	10792.95	16535.01	27327.96
NCSU	2.82	4.76	7.58
UNC Chapel Hill	562.22	653.12	1215.34
UNC Greensboro	114.34	63.28	177.62
NCCU	28.22	74.87	103.09
NCA&T	260.95	113.83	374.78
NCDPR	24	22.64	46.64
NCDCR	17.75	4.4	22.15
USACE	371.6	349.93	721.53
USNPS	12.89	5.7	18.59

Table 5-9. Source and Delivered Jurisdictional Total N Loads for Baseline Scenario (1999 LU)

Jurisdiction	Total N at Source (lbs/yr)		Total N Delivered to Jordan Lake (lbs/yr)	
	Developed	Undeveloped	Developed	Undeveloped
Rockingham County	11,100	113,871	6,508	68,857
Reidsville	8,796	3,368	5,797	2,111
Forsyth County	941	2,847	369	1,340
Kernersville	2,136	393	633	116
Guilford County	73,610	645,180	44,562	432,808
Stokesdale	5,082	6,369	2,904	3,699
Summerfield	10,409	17,648	4,913	8,583
Oak Ridge	7,974	9,164	3,647	4,234
Greensboro	125,869	75,703	80,376	46,912
Pleasant Garden	5,249	10,892	3,301	6,854
Whitsett	2,487	3,393	1,663	2,262
Sedalia	1,180	3,044	764	1,970
Randolph County	685	13,713	496	9,957
Caswell County	3,059	107,131	1,964	67,951
Alamance County	78,642	859,572	60,412	667,813
Gibsonville	2,458	2,090	1,683	1,434
Ossipee	(n/a)	(n/a)	(n/a)	(n/a)
Elon	4,247	3,120	3,106	2,301
Alamance	670	953	514	729
Burlington	41,257	16,043	30,918	12,002
Green Level	1,455	1,458	1,012	1,013
Haw River	3,125	2,187	2,448	1,709
Graham	11,611	7,573	8,739	5,736
Swepsonville	889	471	705	376
Mebane	6,794	3,245	4,760	2,268
Orange County	17,170	294,944	14,135	237,353
Chapel Hill	24,998	15,451	24,279	15,009
Carrboro	5,964	4,320	5,749	4,151
Chatham County	21,773	338,690	21,067	325,482
Pittsboro	2,119	1,593	2,043	1,536
Durham County	11,622	33,583	11,154	32,403
Durham	69,162	33,118	66,226	31,740
Wake County	7,672	76,766	7,385	74,024
Cary	5,517	7,892	5,250	7,564
Apex	6,485	4,316	6,280	4,180
Morrisville	322	1,346	307	1,285
NCDOT	156,635	(n/a)	119,187	(n/a)
NCSU	50	836	50	827
UNC Chapel Hill	6,386	7,254	6,214	6,994
UNC Greensboro	801	481	569	359
NCCU	610	39	587	37
NCA&T	1,383	2,351	1,016	1,722
NCDPR	116	4,578	91	3,773
NCDCR	73	466	53	372
USACE	3,076	73,828	3,027	72,717
USNPS	51	251	13	59

Table 5-10. Source and Delivered Jurisdictional Total P Loads for Baseline Scenario (1999 LU)

Jurisdiction	Total P at Source (lbs/yr)		Total P Delivered to Jordan Lake (lbs/yr)	
	Developed	Undeveloped	Developed	Undeveloped
Rockingham County	1,609	11,597	758	5,675
Reidsville	1,242	345	680	179
Forsyth County	134	238	39	84
Kernersville	319	41	72	9
Guilford County	10,299	61,263	4,931	32,851
Stokesdale	584	664	254	296
Summerfield	1,190	1,799	445	685
Oak Ridge	818	898	283	316
Greensboro	16,257	4,851	8,359	2,239
Pleasant Garden	506	512	231	235
Whitsett	293	219	158	118
Sedalia	145	198	70	95
Randolph County	104	2,073	57	1,127
Caswell County	404	10,559	175	4,431
Alamance County	11,505	93,842	7,674	62,701
Gibsonville	338	141	193	80
Ossipee	(n/a)	(n/a)	(n/a)	(n/a)
Elon	597	239	378	154
Alamance	84	62	58	43
Burlington	6,098	1,111	4,202	757
Green Level	192	100	112	58
Haw River	430	161	315	117
Graham	1,631	506	1,125	353
Swepsonville	115	31	87	23
Mebane	929	287	553	169
Orange County	2,445	28,908	1,800	19,983
Chapel Hill	3,382	860	3,172	807
Carrboro	878	300	814	276
Chatham County	2,973	29,916	2,783	27,140
Pittsboro	297	129	279	122
Durham County	1,280	1,072	1,169	991
Durham	8,033	885	7,269	804
Wake County	756	3,009	715	2,867
Cary	550	229	513	214
Apex	594	181	574	175
Morrisville	14	28	12	26
NCDOT	23,678	(n/a)	15,549	(n/a)
NCSU	7	35	7	33
UNC Chapel Hill	917	439	862	403
UNC Greensboro	104	27	60	18
NCCU	86	1	79	1
NCA&T	166	134	102	82
NCDPR	18	427	13	320
NCDCR	9	25	5	17
USACE	394	3,048	380	2,949
USNPS	6	28	1	5

Table 5-11. Comparison of Baseline Scenario Delivered Total N Load from Developed Land (lb/yr)

Jurisdiction	Baseline Delivered Total N from Developed (Regulated) Land (lbs)
Rockingham County	6,508
Reidsville	5,797
Forsyth County	369
Kernersville	633
Guilford County	44,562
Stokesdale	2,904
Summerfield	4,913
Oak Ridge	3,647
Greensboro	80,376
Pleasant Garden	3,301
Whitsett	1,663
Sedalia	764
Randolph County	496
Caswell County	1,964
Alamance County	60,412
Gibsonville	1,683
Ossipee	(N/A)
Elon	3,106
Alamance	514
Burlington	30,918
Green Level	1,012
Haw River	2,448
Graham	8,739
Swepsonville	705
Mebane	4,760
Orange County	14,135
Chapel Hill	24,279
Carrboro	5,749
Chatham County	21,067
Pittsboro	2,043
Durham County	11,154
Durham	66,226
Wake County	7,385
Cary	5,250
Apex	6,280
Morrisville	307
NCDOT	119,187
NCSU	50
UNC ChapelHill	6,214
UNC Greensboro	569
NCCU	587
NCA&T	1,016
NCDPR	91
NCDCR	53
USACE	3,027
USNPS	13

Table 5-12. Comparison of Baseline Scenario Delivered Total P Load from Developed Land (lb/yr)

Jurisdiction	Baseline Delivered Total P from Developed (Regulated) Land (lbs)
Rockingham County	758
Reidsville	680
Forsyth County	39
Kernersville	72
Guilford County	4,931
Stokesdale	254
Summerfield	445
Oak Ridge	283
Greensboro	8,359
Pleasant Garden	231
Whitsett	158
Sedalia	70
Randolph County	57
Caswell County	175
Alamance County	7,674
Gibsonville	193
Ossipee	(N/A)
Elon	378
Alamance	58
Burlington	4,202
Green Level	112
Haw River	315
Graham	1,125
Swepsonville	87
Mebane	553
Orange County	1,800
Chapel Hill	3,172
Carrboro	814
Chatham County	2,783
Pittsboro	279
Durham County	1,169
Durham	7,269
Wake County	715
Cary	513
Apex	574
Morrisville	12
NCDOT	15,549
NCSU	7
UNC ChapelHill	862
UNC Greensboro	60
NCCU	79
NCA&T	102
NCDPR	13
NCDCR	5
USACE	380
USNPS	1

Table 5-13. Source and Delivered Jurisdictional Total N Loads for Existing Scenario (2010 LU)

Jurisdiction	Total N at Source (lbs/yr)		Total N Delivered to Jordan Lake (lbs/yr)	
	Developed	Undeveloped	Developed	Undeveloped
Rockingham County	25,793	106,069	15,221	64,037
Reidsville	11,784	3,215	7,765	2,019
Forsyth County	1,038	2,658	434	1,256
Kernersville	3,063	318	908	94
Guilford County	121,961	577,189	76,238	388,877
Stokesdale	9,748	4,760	5,594	2,767
Summerfield	21,093	14,171	9,906	6,965
Oak Ridge	13,210	8,027	5,876	3,814
Greensboro	206,279	66,462	124,697	40,722
Pleasant Garden	7,719	9,323	4,858	5,864
Whitsett	3,498	2,792	2,341	1,858
Sedalia	1,611	2,826	1,043	1,829
Randolph County	1,478	12,658	1,069	9,190
Caswell County	12,000	99,743	7,731	63,216
Alamance County	136,212	788,733	104,745	613,688
Gibsonville	6,851	2,986	4,741	2,059
Ossipee	869	429	658	325
Elon	7,518	2,433	5,529	1,805
Alamance	1,399	656	1,068	503
Burlington	62,792	14,923	46,617	10,849
Green Level	2,401	1,083	1,685	759
Haw River	4,814	1,977	3,772	1,548
Graham	19,255	5,960	14,565	4,521
Swepsonville	2,477	864	1,973	693
Mebane	13,578	4,277	9,802	3,020
Orange County	44,757	274,825	36,904	221,364
Chapel Hill	38,486	11,822	37,375	11,483
Carrboro	11,887	3,500	11,484	3,367
Chatham County	49,306	321,427	47,701	308,872
Pittsboro	4,222	2,080	4,091	2,022
Durham County	13,875	26,922	13,309	25,969
Durham	99,788	30,136	95,649	28,888
Wake County	12,833	56,862	12,355	54,929
Cary	18,594	14,399	17,760	13,802
Apex	14,648	4,499	14,184	4,345
Morrisville	2,460	1,293	2,349	1,235
NCDOT	183,644	0	139,551	0
NCSU	52	830	51	820
UNC Chapel Hill	8,061	6,965	7,843	6,715
UNC Greensboro	1,016	374	722	283
NCCU	756	18	728	17
NCA&T	2,057	1,793	1,510	1,315
NCDPR	258	4,516	192	3,724
NCDCR	114	439	81	354
USACE	4,459	72,089	4,385	71,014
USNPS	81	249	20	58

Table 5-14. Source and Delivered Jurisdictional Total P Loads for Existing Scenario (2010 LU)

Jurisdiction	Total P at Source (lbs/yr)		Total P Delivered to Jordan Lake (lbs/yr)	
	Developed	Undeveloped	Developed	Undeveloped
Rockingham County	4,088	10,753	1,939	5,241
Reidsville	1,803	328	987	170
Forsyth County	145	223	45	79
Kernersville	488	33	111	7
Guilford County	18,567	54,259	9,219	29,177
Stokesdale	1,197	483	525	215
Summerfield	2,638	1,417	984	545
Oak Ridge	1,567	772	528	280
Greensboro	28,805	4,347	13,928	1,972
Pleasant Garden	774	438	355	200
Whitsett	421	181	228	97
Sedalia	204	184	99	89
Randolph County	231	1,881	125	1,023
Caswell County	1,906	9,690	826	4,057
Alamance County	20,835	85,475	13,768	57,164
Gibsonville	997	202	572	116
Ossipee	120	33	79	22
Elon	1,104	183	703	118
Alamance	197	42	135	29
Burlington	9,449	1,055	6,395	681
Green Level	323	75	192	44
Haw River	674	143	494	105
Graham	2,781	405	1,932	283
Swepsonville	333	65	253	50
Mebane	2,001	375	1,250	223
Orange County	6,927	26,727	5,065	18,513
Chapel Hill	5,630	673	5,281	632
Carrboro	1,801	255	1,676	235
Chatham County	7,315	28,347	6,859	25,725
Pittsboro	634	172	603	164
Durham County	1,563	878	1,427	810
Durham	13,479	816	12,245	741
Wake County	1,577	2,298	1,493	2,197
Cary	2,448	416	2,282	389
Apex	1,701	177	1,643	170
Morrisville	308	28	280	26
NCDOT	28,581	0	18,766	0
NCSU	8	34	8	33
UNC Chapel Hill	1,157	427	1,088	392
UNC Greensboro	134	22	76	16
NCCU	116	0	107	0
NCA&T	257	103	157	63
NCDPR	42	421	27	316
NCDCR	15	24	8	16
USACE	602	3,038	579	2,938
USNPS	12	27	2	5

Table 5-15. Comparison of Existing Scenario Delivered Total N Load from Regulated Land (lb/yr)

Jurisdiction	Baseline Delivered Total N from Developed (Regulated) Land (lbs)
Rockingham County	15,221
Reidsville	7,765
Forsyth County	434
Kernersville	908
Guilford County	76,238
Stokesdale	5,594
Summerfield	9,906
Oak Ridge	5,876
Greensboro	124,697
Pleasant Garden	4,858
Whitsett	2,341
Sedalia	1,043
Randolph County	1,069
Caswell County	7,731
Alamance County	104,745
Gibsonville	4,741
Ossipee	658
Elon	5,529
Alamance	1,068
Burlington	46,617
Green Level	1,685
Haw River	3,772
Graham	14,565
Swepsonville	1,973
Mebane	9,802
Orange County	36,904
Chapel Hill	37,375
Carrboro	11,484
Chatham County	47,701
Pittsboro	4,091
Durham County	13,309
Durham	95,649
Wake County	12,355
Cary	17,760
Apex	14,184
Morrisville	2,349
NCDOT	139,551
NCSU	51
UNC ChapelHill	7,843
UNC Greensboro	722
NCCU	728
NCA&T	1,510
NCDPR	192
NCDCR	81
USACE	4,385
USNPS	20

Table 5-16. Comparison of Existing Scenario Delivered Total P Load from Regulated Land (lb/yr)

Jurisdiction	Baseline Delivered Total P from Developed (Regulated) Land (lbs)
Rockingham County	1,939
Reidsville	987
Forsyth County	45
Kernersville	111
Guilford County	9,219
Stokesdale	525
Summerfield	984
Oak Ridge	528
Greensboro	13,928
Pleasant Garden	355
Whitsett	228
Sedalia	99
Randolph County	125
Caswell County	826
Alamance County	13,768
Gibsonville	572
Ossipee	79
Elon	703
Alamance	135
Burlington	6,395
Green Level	192
Haw River	494
Graham	1,932
Swepsonville	253
Mebane	1,250
Orange County	5,065
Chapel Hill	5,281
Carrboro	1,676
Chatham County	6,859
Pittsboro	603
Durham County	1,427
Durham	12,245
Wake County	1,493
Cary	2,282
Apex	1,643
Morrisville	280
NCDOT	18,766
NCSU	8
UNC ChapelHill	1,088
UNC Greensboro	76
NCCU	107
NCA&T	157
NCDPR	27
NCDCR	8
USACE	579
USNPS	2

Table 5-17. Regulated Land Delivered Load Increase from Baseline to Existing Scenario

Jurisdiction	Total N (lbs)	Total P (lbs)
Rockingham County	8,713	1,182
Reidsville	1,968	307
Forsyth County	65	6
Kernersville	275	38
Guilford County	31,676	4,288
Stokesdale	2,690	271
Summerfield	4,993	539
Oak Ridge	2,229	244
Greensboro	44,320	5,569
Pleasant Garden	1,557	123
Whitsett	678	70
Sedalia	279	28
Randolph County	573	68
Caswell County	5,767	652
Alamance County	44,333	6,094
Gibsonville	3,057	379
Ossipee	658	79
Elon	2,422	325
Alamance	554	77
Burlington	15,699	2,192
Green Level	673	80
Haw River	1,325	180
Graham	5,826	807
Swepsonville	1,268	166
Mebane	5,042	697
Orange County	22,770	3,265
Chapel Hill	13,096	2,109
Carrboro	5,735	862
Chatham County	26,635	4,076
Pittsboro	2,049	324
Durham County	2,155	258
Durham	29,423	4,976
Wake County	4,971	777
Cary	12,510	1,769
Apex	7,903	1,069
Morrisville	2,042	268
NCDOT	20,365	3,218
NCSU	1	1
UNC ChapelHill	1,629	226
UNC Greensboro	153	17
NCCU	141	27
NCA&T	494	55
NCDPR	102	14
NCDCR	28	3
USACE	1,358	199
USNPS	7	1

Table 5-18. Percent of Delivered Nutrient Loads to Haw River Assessment Unit of Jordan Lake

AU	Jurisdiction	Percent of Baseline Load (1999 LU)		Percent of Existing Load (2010 LU)	
		TN	TP	TN	TP
Haw River	**Rockingham County**	0.187%	0.226%	0.427%	0.550%
	Reidsville	0.167%	0.203%	0.218%	0.280%
	Forsyth County	0.0106%	0.0117%	0.0122%	0.0129%
	Kernersville	0.0182%	0.0216%	0.0255%	0.0313%
	Guilford County	1.28%	1.47%	2.14%	2.61%
	Stokesdale	0.0836%	0.0760%	0.157%	0.149%
	Summerfield	0.141%	0.133%	0.278%	0.279%
	Oak Ridge	0.105%	0.0847%	0.165%	0.150%
	Greensboro	2.31%	2.50%	3.50%	3.95%
	Pleasant Garden	0.0950%	0.0692%	0.136%	0.100%
	Whitsett	0.0479%	0.0473%	0.0657%	0.0647%
	Sedalia	0.0220%	0.0210%	0.0293%	0.0280%
	Randolph County	0.0143%	0.0169%	0.0300%	0.0353%
	Caswell County	0.0565%	0.0522%	0.217%	0.234%
	Alamance County	1.74%	2.29%	2.94%	3.90%
	Gibsonville	0.0485%	0.0576%	0.133%	0.162%
	Ossipee	(N/A)	(N/A)	0.0185%	0.0225%
	Elon	0.0894%	0.113%	0.155%	0.199%
	Alamance	0.0148%	0.0174%	0.0300%	0.0382%
	Burlington	0.890%	1.26%	1.31%	1.81%
	Green Level	0.0291%	0.0335%	0.0473%	0.0545%
	Haw River	0.0705%	0.0941%	0.106%	0.140%
	Graham	0.252%	0.336%	0.409%	0.548%
	Swepsonville	0.0203%	0.0261%	0.0554%	0.0718%
	Mebane	0.137%	0.165%	0.275%	0.354%
	Orange County	0.174%	0.209%	0.469%	0.626%
	Chatham County	0.294%	0.437%	0.792%	1.21%
	Pittsboro	0.0588%	0.0834%	0.115%	0.171%
	NCDOT	2.38%	3.21%	2.74%	3.71%
	UNC Chapel Hill	0.000676%	0.00113%	0.00262%	0.00421%
	UNC Greensboro	0.0164%	0.0178%	0.0203%	0.0216%
	NCA&T	0.0292%	0.0305%	0.0424%	0.0446%
	NCDPR	0.00261%	0.00382%	0.00540%	0.00766%
	NCDCR	0.00114%	0.00118%	0.00192%	0.00200%
	USACE	0.00411%	0.00674%	0.00585%	0.00879%
	USNPS	0.000388%	0.000392%	0.000570%	0.000704%

Note: Delivered load from developed land as a percentage of the total delivered load to the assessment unit.

Table 5-19. Percent Contributions of Delivered Nutrient Loads to Upper New Hope and Lower New Hope Assessment Units of Jordan Lake

AU	Jurisdiction	Percent of Baseline Load (1999 LU)		Percent of Existing Load (2010 LU)	
		TN	TP	TN	TP
Upper New Hope	**Orange County**	0.707%	1.56%	1.68%	3.47%
	Chapel Hill	2.12%	4.50%	3.12%	6.43%
	Carrboro	0.503%	1.15%	0.958%	2.04%
	Chatham County	0.476%	0.913%	0.767%	1.43%
	Durham County	0.975%	1.66%	1.11%	1.74%
	Durham	5.79%	10.3%	7.98%	14.9%
	Wake County	0.181%	0.290%	0.266%	0.471%
	Cary	0.132%	0.158%	0.762%	1.46%
	Morrisville	0.0268%	0.0175%	0.196%	0.341%
	NCDOT	2.53%	5.35%	2.84%	5.54%
	NCSU	0.00433%	0.0100%	0.00426%	0.00936%
	UNC Chapel Hill	0.541%	1.22%	0.646%	1.31%
	NCCU	0.0513%	0.112%	0.0607%	0.130%
	NCDCR	0.00116%	0.00147%	0.00105%	0.00153%
	USACE	0.131%	0.265%	0.156%	0.306%
Lower New Hope	**Chatham County**	2.80%	5.74%	5.00%	9.71%
	Wake County	2.76%	4.34%	4.46%	7.62%
	Cary	1.94%	3.41%	4.19%	7.47%
	Apex	3.26%	4.87%	6.90%	11.3%
	NCDOT	3.97%	8.84%	3.89%	7.82%
	UNC Chapel Hill	0.000244%	0.000560%	0.0000888%	0.000176%
	USACE	0.722%	1.45%	1.12%	2.04%

Note: Delivered load from developed land as a percentage of the total delivered load to each assessment unit.

5.2 Future Uses of the Model

5.2.1 Potential Improvements

5.2.1.1 Land Use and Imperviousness

Land use/land cover classifications based on aerial imagery are always subject to uncertainty and classification error. Of particular interest in the Jordan watershed is the potential under-estimation of impervious surface area due to overhanging tree canopy, as is discussed in Section 2.4.2.4 and Appendix C. At the same time, it proved infeasible to determine the extent to which impervious surface runoff is mitigated by existing stormwater BMPs (Section 2.4.6) and, as a result of these issues, the model was calibrated without an adjustment for the directly connected fraction of impervious area.

The accuracy of the model calibration could likely be improved by a better tabulation of impervious area and accounting for the fraction of impervious area that is directly connected to runoff pathways. Doing this is, however, problematic, especially for the baseline period. The LULC analysis for the baseline period has higher uncertainty due to the quality of the available aerial photography. Further, it is not possible to go back in time and verify either the extent or connectedness of impervious surface cover in 1999 except where detailed planimetric surveys are available. The City of Durham does have impervious surface coverages for 1999 (see discussion in Appendix C), but similar spatial coverages are not available for most other jurisdictions. Partial results could likely be created through detailed analysis of development engineering designs, but this would be prohibitively expensive and would likely still not yield complete coverage of the watershed. Similar considerations apply to the accounting of existing stormwater BMPs.

For both connected imperviousness and stormwater BMPs, the conclusions presented in the BMP discussion remain valid: Both the State and stakeholders are likely best served by applying the watershed model to the Baseline conditions without including BMPs or corrections for other forms of impervious disconnection explicitly. Interested entities could then use approved accounting methods to estimate total reductions for installed BMPs and subtract that from the model predictions to compare with observed loads where data are available. If funding were available to undertake more detailed analyses of impervious surface area and connection for both the Baseline and Existing periods then the calibration status of the model could likely be improved. This is not, however, likely to make a substantive difference in the attribution of loads and calculation of allocations for individual entities.

5.2.1.2 Hydrology

The hydrology model appears acceptable in its current formulation. However, further refinements could be pursued in the following areas.

Precipitation. Rain gages represent a point in space and do not always reflect the spatially averaged precipitation experienced by a watershed, especially during summer convective storms. Additional sources of precipitation station data could be investigated and added to the model (e.g., USGS monitoring, county data if available) to provide greater spatial coverage. Alternatively, a grid-based precipitation data product that uses Doppler radar output (e.g., NEXRAD level III products from the National Weather Service) or applies more sophisticated spatial interpolation techniques (e.g., Oak Ridge National Laboratory's DAYMET, http://daymet.ornl.gov) might help adjust for spatial variability in precipitation not captured with the fixed station approach, although a significant amount of additional processing and effort would be required to use these in the model.

Reservoir Operations. Overflow from reservoirs is represented based on stage-storage-discharge curves without regard for intentional water level management. Reservoir withdrawals are estimated only at the monthly scale, from OASIS. A more detailed, daily representation of reservoir withdrawals and releases would improve hydrologic performance at gages downstream of reservoirs, and could also improve the water quality simulation by improving accuracy in the simulation of lake residence time.

Water Land Use. Small ponds and other isolated waterbodies are not explicitly represented in the model, although their influence on the hydrology of the whole watershed model is approximated. While this simplified approach provides for an accounting of the balance of precipitation and evaporation on small ponds, as well as providing a means to account for limited nutrient load generation within the footprint of the pond itself, the representation is not optimal because it does not explicitly account for the trapping of water, sediment, and nutrients from upland areas that drain to the ponds. A more sophisticated approach could be designed in which upland areas within a subwatershed that do drain to ponds are routed through an aggregate pond representing the total storage volume provided by such features. (This is similar to the approach that is employed by the SWAT model [Neitsch et al., 2005]). The hydraulic performance simulated for the water land use should also be examined in greater detail. Note, however, that nutrient removal credits for existing and future ponds can still be calculated in the model as currently formulated through application of accounting methods to model output, similar to the approach that will be used for other upland BMPs (Section 2.4.6).

5.2.1.3 Water Quality

It is Tetra Tech's opinion that the water quality model is usable in its current form for the intended purposes of calculating the relative magnitude of allocations to be assigned to different entities and to provide a basis for evaluating changes since the baseline period. The model was developed under a limited budget and schedule and, like any complex model, could likely be further refined and strengthened if additional time and budget were available. Some suggestions on potential enhancements are provided below.

Monitoring Sites. High quality data sets with relatively frequent water quality monitoring are available throughout the watershed and provide a firm foundation for model development. It is understandably the case, however, that many of the monitoring locations have been chosen relative to needs to evaluate point source discharges and loading to local water supply reservoirs. The result is that portions of the watershed have relatively sparse monitoring data – notably southeastern Guilford Co., southern Alamance County, and Chatham County. An additional monitoring station on a stream near the Alamance-Chatham line would broaden the geographic coverage of monitoring, but is not deemed essential.

Onsite Wastewater Systems. The representation of onsite wastewater systems and their impact on surface waters was designed to capture available information and to be consistent with work developed for the Chesapeake Bay. The revised estimates appear more reasonable than those previously developed with the GWLF model; however, considerable uncertainty still remains and it is likely that failure and attenuation rates vary spatially in much more complex ways than is now accounted for. Data are not available to directly test the adequacy of the representation of onsite wastewater systems. However, the sensitivity analysis (Section 4.3.3) shows that the predicted nutrient loads are not particularly sensitive to this input. The calibration process did suggest that nutrient loads from failing onsite systems might be over-estimated in some areas and collecting additional information on rates and types of system failures might be useful.

Point Source Discharges. Model calibration for some effluent-dominated streams suggested that there may be some issues in the representation of point sources that contribute to uncertainty in the prediction of nutrient loads. To some extent, these uncertainties may be unresolvable if they are due to infrequent monitoring of parameters such as total N load. More sophisticated representation of interpolated periods might be possible, for instance through building empirical regression models that represent effluent concentrations as a function of flow, air temperature, and other factors.

Impoundments. The LSPC model provides only a simplified, one-dimensional representation of the many impoundments within the watershed. This simplified representation is a source of uncertainty in the water quality simulation because stratification and lake algal dynamics cannot be fully incorporated into a one-dimensional model segment. Detailed analyses of lake input, output, and trapping might be used to refine the impacts of impoundments on downstream water quality.

Additional Phosphorus Loads. In the mainstem of the Haw River (stations B1140000, B2000000, and B2100000, from Haw River to Bynum), it appears that organic phosphorus load is generated during high flow events from legacy material stored behind the several run-of-river dams. LSPC does not provide a mechanism for direct representation of this phenomenon, but an empirical correction could be made in the allocation process for the average annual load apparently generated in this manner. Additional study of these areas – as well as other stream segments where the phosphorus load simulation at high flows is imprecise – could lead to improved methods to accomplish such accounting.

Treatment of SSOs. Known spill events do not appear to have left a clear signature on available monitoring data. In most cases, the volume of spills is small relative to the amount of flow in monitored streams. Further, in some cases it may be that ongoing subsurface leaks contribute greater loads of soluble nutrients over time than occasional spills. Given the lack of direct impact on the model it appears most appropriate to analyze the contribution of SSOs and other sanitary wastewater system losses independently of the watershed model.

5.2.2 Use for Remodeling of Future Time Periods

The Jordan watershed model can readily be adapted to address future changes in land use or jurisdictional boundaries. Doing so requires only an update of the Land Use Information table in the LSPC database. This table identifies the areas of all HRUs (including entity tags) within each subwatershed. Excel spreadsheets have been developed to assist in this process.

The model can also be modified to use additional periods of weather time series. This would require only appending data to the end of the existing *air* files and specifying a new end date for simulation in Card 50 of the input file.

For the purposes of the Jordan nutrient strategy, it is likely that a revised version of the model will be desired to represent conditions at whatever date is finally adopted for implementation of the new development requirements. This would require a land use update, but not a weather update, as the current conditions should be compared to the 1997-2001 baseline conditions using the 1997-2001 meteorology. The weather update option may be of interest for other purposes, such as evaluating the potential effects of climate change on the nutrient strategy.

5.3 Relationship of Model to Load Reduction Accounting Methods

The watershed modeling effort described in this report provides new estimates of nutrient loading to Jordan Reservoir during the 1997 – 2001 baseline period. It should be noted, however, that the Jordan Purpose and Scope Rule (15A NCAC 02b .0262) explicitly defines the baseline loading to the three segments of Jordan Lake (Upper New Hope Arm, Lower New Hope Arm, and Haw River Arm). The load estimates in the rule are in turn derived from Table 8 in the Jordan TMDL (NC DENR, 2007). As described in the TMDL document, the loads in this table are those estimated for the Jordan Lake nutrient response model (Tetra Tech, 2002, 2003c). These estimates were based on an estimate of delivered loads based on water quality monitoring data and flow gaging in major tributaries, plus an extrapolation to ungaged areas. The delivered load estimates were computed using the FLUX tool (Walker, 1987), and a separate analysis was used to back out the delivered contribution of point sources, with the remainder attributed to nonpoint sources.

While the current LSPC watershed model is calibrated to the same data used in the earlier FLUX analyses, the estimates of delivered load during the baseline period, while similar, are not identical to those specified in the Purpose and Scope Rule. Reconciliation of the loads estimated by the LSPC model and those set forth in the Rule will be the responsibility of NC DWR; however, it is anticipated that the LSPC model results for the baseline period will be used to determine the percentage of nonpoint source baseline loading delivered to the lake that is generated by existing developed land cover in each jurisdictional entity. These percentages (provided above in Table 5-18) can be applied to the baseline loads set forth in the Rule to determine each entity's baseline loading as defined in the Rule.

Current conditions in the model represent 2010 land use. Changes in delivered loading from developed land (by entity) can be calculated from 2001 to 2010 by comparison of the modeling runs. However, it is anticipated that future updates will be needed to the land use corresponding to the point in time at which the final new development regulations take effect. The difference between the developed load generated by that land use (with 1997 – 2001 meteorology) and the developed load estimated by the model for the 1997 – 2001 baseline period represents the incremental interim delivered load for each entity.

The rules also specify allowable loading rates for new development. These loading rates are calculated as a reduction from "greenfield average loading rates," and are thus at-source, rather than delivered loading rates. Therefore, it will be necessary to calculate the change in source loading rates for each entity since the baseline period. The extent to which interim developed source load exceeds the interim allowable source load will determine the amount that each entity is required to reduce from its interim development.

Performing these calculations will require two additional considerations. The first is accounting for additional development that occurs between the 2010 model land use and the end of the interim period. The second is accounting for stormwater water quality BMPs that have been installed since the baseline period.

Estimates of loading with land use changes since 2010 could be derived by rerunning the model with altered land use (and 1997-2001 meteorology), as described in Section 5.1. Alternatively, and more simply, the effect of changes since 2010 could be estimated by applying the average loading rate (for developed land use classes within an entity) to the change in land use area.

As discussed in Section 2.4.6, the watershed model does not account for the effects of the relatively small number of water quality BMPs installed on new development since 2001. Instead, it is anticipated that jurisdictional entities will, at their discretion, calculate and claim credit for BMPs installed during the interim period.

The method for calculating credits for BMPs will be determined by NC DWR. It is, however, likely that the method will use the Jordan/Falls Lake Stormwater Nutrient Load Accounting Tool or JF SW Tool (NCSU BAE, 2011), a spreadsheet-based tool designed for calculating nutrient loads and assessing the impact of BMPs at the scale of a development or individual site. The JF SW Tool addresses stormwater loads, and does not account for onsite wastewater systems or subsurface transport in groundwater; however, it is an appropriate method for addressing the changes in stormwater source loads from development after installation of BMPs.

Regulated entities may also wish to claim credit for reductions associated with management measures not represented in the JF SW Tool – for example, the reduction in nutrient loads achieved by providing sewer service to a neighborhood with poorly performing onsite wastewater disposal systems. Analyses of this sort should generally be made relative to the representation of the source in the watershed model.

For future updates of the watershed model it may be desirable to incorporate direct simulation of BMPs. This can readily be done in LSPC, although it increases model complexity as it requires routing an appropriate fraction of runoff from each developed land HRU through BMP modules. To do this, a full tabulation of water quality BMPs and the land area draining to such BMPs is needed. Lack of such data was the primary reason for not including water quality BMPs in the current version of the model. Thus, this type of update is feasible but would require an extensive data gathering effort to implement.

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Appendix A. Guide to Modeling Files

A complete set of files for the calibrated model is provided electronically.

There are four file types needed for execution of the LSPC model: first is the model executable, second is the ACCESS database, third is the model input file, and fourth is the model weather or *.air files.

The model executable (*LSPCModel_082013.exe*) contains a graphical user interface (GUI) that allows the user to either load an ASCII input file or retrieve the model from the database. The GUI allows the user to select which modules to execute (i.e. hydrology, water quality, sediment, etc.) and allows the user to change the model parameters, simulation period, output location and type, etc. Once the model is calibrated the GUI of the executable can write the calibrated parameters back to the database or save it as an ASCII input file. The GUI simply loads and runs the model and there are no post processing capabilities built into the interface.

The ACCESS database (suffix *mdb*) contains all of the information needed by the executable, sans the atmospheric forcing time series in the weather files. Initially, the user populates the database with all of the watershed specific and pertinent information and then "gets" the model from the ACCESS database. After completing the calibration of a specific module or the suite of modules being simulated, the user stores the calibration parameters in the database by writing the parameters back to the database. The ACCESS database is always needed when running the LSPC model as it contains the input time series for point sources, water withdrawals, and time variable land use (if it is being utilized).

The input file (suffix *inp*) contains the same information as the database but does not contain the input time series for point sources, water withdrawals, time variable land use, or the weather files. The input file contains a file path and name to the ACCESS database and weather files so the executable knows where to go to obtain these items. After the user gets the model from the database they save an input file. While calibrating, the user makes parameter modification directly to the input file or through the GUI and subsequently saves an input file and keeps a record of the changes that were made. After the model has been calibrated the parameters are written back to the database so if/when the retrieval from the database is performed again the calibrated parameters are brought into the GUI and saved into a new input file if one chooses to save one.

The weather files (suffix *air*) contain all of the atmospheric forcing information to drive the simulation in a text file format. The weather files are created at the time step of the model simulation (hourly for the Jordan watershed model). The weather file must encompass the entire simulation period but is not limited to only the simulation period (i.e. if the simulation period is January 1st, 1997 – December 31st, 2012 then the weather file must at a minimum be from January 1st, 1997 – December 31st, 2012, but the time series can start earlier and end later if wanted).

To use the model, one simply updates the file paths to the weather file and output directory in the database in the Input-Output File Paths Table, opens the GUI and performs the "get from database" procedure. Once the model is loaded the user hits run and the model will execute. An alternative approach is to update the file paths to the output directory and weather files (Card 30), point source file path (Card 31), time-variable land (Card 32) in the input file, open the GUI and then open the newly modified input file. Once the model is loaded the user hits run and the model will execute. LSPC will write the simulation results to the directed output folder. If outputs from a previous execution exist in that folder they will be replaced with the new output. If one wishes to save a particular set of outputs they must either manually transfer them to a different folder or direct the model to write the outputs to a different folder. Output files include the following:

- A unique file for a subwatershed/reach with outputs at the model time step (hourly) for parameters selected in the General Output Controls table (Card 45) or the User Specified Output

Parameter List table (Card 46). Files are given a name corresponding to the subwatershed/reach number used in the model, with an extension of *.out*. The user selects the subwatersheds/reaches for output in the Channel Routing Network table (Card 405).

- Depending on the options selected in the General Output Controls table (Card 45), a file is produced with output for each model subwatershed and DELUID at the selected time step (monthly, annual, or entire simulation). The output file (landuse.csv) includes a suite of parameters providing detailed hydrology and pollutant loading values. An additional file, landuse.out provides a description of each parameter.
- Depending on the options selected in the General Output Controls table (Card 45), a file is produced with output for each model reach at the selected time step (monthly, annual, or entire simulation). The output file (stream.csv) includes a suite of parameters providing detailed hydrology, hydraulic, and pollutant concentration/load values. An additional file, stream.out provides a description of each parameter

When executing the model, it is normal for a message to appear stating the number of user-defined F-tables in the model and listing the model outlets. Also it is important to note that significant computation time is needed to execute the scenario files. If the user wishes to reproduce the exact model output provided in the electronic files, the input file method should be used to run the model.

Appendix B. QAPP

(Provided in separate file.)

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TETRA TECH

Appendix C. Analysis of Baseline Imperviousness Classification

Background

During the period of review of the draft Jordan Watershed Model, the City of Durham presented new information from analysis that the City had conducted comparing impervious surface data generated from 1999 planimetric data to that generated from aerial imagery interpretation used for the model baseline input dataset. Durham's analysis showed that, due largely to canopy cover interference for the imagery interpretation, the baseline model impervious surface assumption for the Durham jurisdictional area underestimated actual impervious area by a significant amount (4,677 acres compared to 6,358 acres). For well-established (older) urban and suburban areas, it is not surprising that canopy could cover 26 percent (what the Durham findings represent) of impervious areas along streets, driveways, buildings and parking lots. However, since the LSPC model applied for the Jordan watershed lumps land use and land cover (LULC) by hydrologic modeling unit, there is error and uncertainty in all LULC assumptions and calibration by modeling unit can serve to minimize the impact of such error. Therefore, it was unclear how much this error impacts the modeling results. For this reason, Tetra Tech conducted an additional modeling analysis in the Upper New Hope assessment unit to further evaluate the implications of this error.

This memorandum summarizes Tetra Tech's methods and findings for the additional modeling analysis.

Methods

For this analysis Tetra Tech modified the baseline 1999 land use model assumptions for the City of Durham by burning in the 1999 impervious surface coverage. To accomplish this, Tetra Tech clipped the polygons provided by the City of Durham to the Jordan LSPC model subwatershed polygons. QA/QC measures demonstrated that the total impervious surface area (polygon-based estimate) in the City's datasets within the LSPC model boundary is 6,302 acres, which corresponds well with Tetra Tech's raster-based area of 6,298 acres applied to the model. The minor difference can be attributed to the difference between raster grid and polygon configuration.

The Jordan watershed LSPC calibration model was modified to incorporate the revised land use coverage for the City of Durham's modeling subwatersheds located in the Upper New Hope assessment unit. In the calibration model setup, the 1999 (baseline) land use was input at the beginning of the simulation (1/1/1997 through 1/1/2002) and then switched to the 2010 land use for the rest of the simulation (1/2/2002 through 9/30/2012). Thus, only the land use at the beginning of the simulation was modified for the City of Durham impervious scenario. Tetra Tech reran the model with this revised setup, and examined the impact (before and after) the change made on the calibration model results for hydrology and water quality at gages within and downstream of the modified area.

Results and Interpretation

Hydrology

The hydrology calibration period was from 1/1/2002 through 9/30/2012. The coincident timeframe of modified land use and the hydrology calibration period is only a single day (1/1/2002). Therefore there is no impact of the baseline impervious surface estimation error on the Jordan LSPC model hydrology calibration. From this perspective, the calibration procedure increased model robustness to this type of model input error.

While the 1999 imperviousness has no impact on model calibration for hydrology it will affect model performance during the earlier (corroboration) period 1997-2002, which uses the 1999 land use. The revised assumptions increase impervious surface area and thus should increase the flashiness of storm event response for the corroboration period, although the effect is likely to be muted by the very low infiltration capacity of most soils in the Triassic Basin.

Examination of impact on hydrology for the Durham watersheds during the corroboration period (Table C-1) shows no change for Morgan Creek (most of the watershed being in Chapel Hill and Orange County). For New Hope Creek and Northeast Creek, the correction to impervious area results in an improvement in performance, helping mitigate the previous under-prediction of total volume and highest flow volumes, although NSE and R^2 statistics decrease slightly.

Table C-1. Model Hydrology Error Evaluation for Hydrology Corroboration Period (1997 – 2001)

	USGS # 02097517 – Morgan Creek		USGS # 02097314 – New Hope Creek		USGS # 0209741955 – Northeast Creek	
Model Metric	**Original Calibration**	**Revised Scenario**	**Original Calibration**	**Revised Scenario**	**Original Calibration**	**Revised Scenario**
1. Error in Total Volume	-7.25%	-7.25%	-12.75%	-8.16%	-18.62%	-15.30%
2. Error in 50% lowest flow volumes	-8.89%	-8.89%	-0.50%	-0.20%	-3.14%	-3.33%
3. Error in 10% highest flow volumes	-2.30%	-2.30%	-11.16%	-5.79%	-23.48%	-19.32%
4. Error in Storm Volume	41.40%	41.40%	0.65%	9.24%	-7.44%	-0.74%
5. Winter volume error	-20.21%	-20.21%	-17.13%	-14.99%	-29.62%	-28.19%
6. Spring volume error	1.34%	1.34%	-37.50%	-33.71%	-6.44%	-1.80%
7. Summer volume error	1.62%	1.62%	23.50%	33.53%	-4.64%	1.30%
8. Fall volume error	-10.16%	-10.16%	5.91%	14.21%	-12.45%	-7.59%
9. Monthly NSE	0..821	0..821	0.669	0.659	0.879	0.889
10. R^2 daily values	0.705	0.705	0.442	0.431	0.499	0.488
11. R^2 monthly values	0.867	0.867	0.699	0.690	0.942	0.939

Water Quality

The ultimate purpose of the Jordan watershed model is to predict annual average nutrient loads delivered to Jordan Lake, by source area and jurisdiction. It is therefore most relevant to examine the extent to which different impervious surface assumptions would affect the estimates of nutrient loads in Durham watersheds.

For the Jordan watershed LSPC model, the water quality calibration period was different from the hydrology calibration period (2002 – 2012). For the majority of monitoring sites, including all the sites on Durham watersheds, the water quality calibration period was 1997-2004 and is thus potentially affected by the revised imperious area.

Table C-2 presents the instream water quality concentrations and load statistics for all eight water quality calibration sites in the Upper New Hope arm of the Jordan Lake watershed model for the existing calibration run and for the scenario run with the revised 1999 impervious cover. These include tributaries that are entirely within the Durham jurisdiction (e.g., Third Fork Creek) and others that are only partially within Durham (e.g., Morgan Creek).

In all cases, the difference between the calibration run and the scenario with the revised 1999 Durham impervious area is small, amounting at most to a few percentage points. Calibration for total N and total P relied in large part on the average and median concentration errors. For total N concentrations, the median error, on average, improves (decreases) slightly with the revised imperviousness while the average error increases slightly. The largest magnitude change in median error is -1.9 percent (Third Fork Creek) while the largest magnitude in average error is 2.1 percent (Northeast Creek B3300000). For total P concentrations, the median and average error increase slightly, with the median error increasing by up to 1.1% (New Hope Creek) and the average error increasing by up to 5,4 percent (Northeast Creek B3300000). These changes are small relative to the prediction uncertainty of the model (for instance, the Northeast Creek B3300000 calibration had TN and TP average errors of 20.6 and 159.8 percent, respectively). It thus appears that the alternative representation of 1999 impervious area would have a limited impact, if any, on the calibration of model parameters.

Of most relevance to the intended uses of the model is the ability to predict long-term average loads. The change in average error on total nitrogen loads ranges from -3.0 to +3.3 percent. The change in average error on total phosphorus loads ranges from -0.5 to +3.8 percent.

Table C-2. Comparison of Water Quality Model Error Between the Calibration and Refined Durham Imperviousness Scenario (1997 – 2004)

Model Constituent	Station Location	B3020000 New Hope Creek		B3025000 Third Fork Creek		B3040000 / 02097314 New Hope Creek		B3300000 Northeast Creek		B3660000 / 0209741955 Northeast Creek		B3670000 Northeast Creek		B3899180 Morgan Creek		B3900000 Morgan Creek	
	Simulation	Calibration	Scenario	Calibration	Scenario	Calibration	Scenario	Calibration	Scenario	Calibration	Scenario	Calibration	Scenario	Calibration	Scenario	Calibration	Scenario
Total Suspended Sediment	Concentration Average Error	-30.1%	-29.3%	-15.4%	-15.9%	-53.8%	-52.8%	-17.8%	-17.9%	-64.6%	-63.8%	-68.8%	-68.8%	106.1%	106.1%	-29.7%	-29.7%
	Concentration Median Error	-35.0%	-35.0%	-27.3%	-28.7%	-40.2%	-40.1%	-37.2%	-34.5%	-36.8%	-36.8%	-41.8%	-41.8%	1.3%	1.3%	-11.1%	-11.1%
	Load Average Error	-8.0%	-8.5%	2.8%	1.3%	54.3%	47.8%	60.0%	58.3%	-45.0%	-45.5%	-68.8%	-68.8%	54.2%	54.2%	-9.0%	-9.0%
	Load Median Error	-1.4%	-2.0%	-0.3%	-0.3%	-6.6%	-6.2%	-0.9%	-0.8%	-3.9%	-3.9%	-2.6%	-2.6%	0.1%	0.1%	-3.1%	-3.1%
Total Nitrogen	Concentration Average Error	-1.5%	-1.1%	-14.5%	-13.2%	9.6%	9.2%	20.6%	22.7%	20.3%	20.3%	37.5%	37.1%	21.5%	21.5%	71.9%	71.9%
	Concentration Median Error	4.8%	4.7%	-10.7%	-12.7%	15.0%	13.3%	1.2%	1.2%	22.6%	22.7%	34.3%	34.3%	38.6%	38.6%	53.2%	53.2%
	Load Average Error	11.5%	12.5%	-29.9%	-26.6%	8.0%	6.8%	-10.0%	-8.8%	33.3%	31.9%	4.9%	1.9%	-3.6%	-3.6%	63.4%	63.4%
	Load Median Error	0.5%	0.5%	-1.2%	-1.2%	10.6%	10.1%	0.2%	0.2%	16.1%	16.0%	22.4%	21.6%	3.5%	3.5%	55.8%	55.8%
Total Phosphorus	Concentration Average Error	24.3%	25.7%	15.9%	18.3%	3.6%	3.8%	159.8%	165.2%	19.5%	19.9%	65.7%	65.8%	55.7%	55.7%	97.5%	97.5%
	Concentration Median Error	18.9%	19.3%	0.0%	-0.8%	-0.3%	0.8%	93.4%	93.4%	5.0%	5.8%	32.3%	33.1%	48.1%	48.1%	39.6%	39.6%
	Load Average Error	2.8%	6.5%	-8.4%	-4.8%	-19.3%	-19.1%	55.5%	58.5%	-1.5%	-2.0%	9.3%	9.7%	41.6%	41.6%	51.9%	57.9%
	Load Median Error	0.9%	0.9%	0.0%	0.0%	-0.1%	0.3%	3.4%	3.3%	1.9%	1.9%	9.4%	9.4%	11.7%	11.8%	24.3%	24.3%

Summary

In sum, use of revised impervious assumptions for Durham would result in no change to hydrologic calibration of the model and only a small change to the hydrologic simulation results prior to 2002. The effects on simulated nutrient concentrations and loads are also small and suggest there is no need to modify the model calibration. The model predictions of existing nutrient loads (using 2010 land use) would not change at all, while the estimates of nutrient loads ca. 2000 might change by at most a few percentage points.

Planimetric impervious coverage for 1999 similar to that provided by Durham is not available for most other jurisdictions in the watershed, and results for Durham may not be applicable elsewhere (due, for instance, to Durham's tree protection ordinance). Given the insignificant impact on calibration and subsequent loading estimates, Tetra Tech does not recommend spending the considerable resources that it would take to refine the baseline impervious surface data estimates watershed-wide from additional planimetrics analysis. It does not appear that recalibrating the model for this change would be beneficial or result in appreciable change to load estimates. Rather, it is likely more important to develop alternatives for jurisdictions to work with DWR outside of the model to establish the appropriate amount of additional developed area that each jurisdiction will be responsible for offsetting between baseline and the effective date for new development requirements.

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