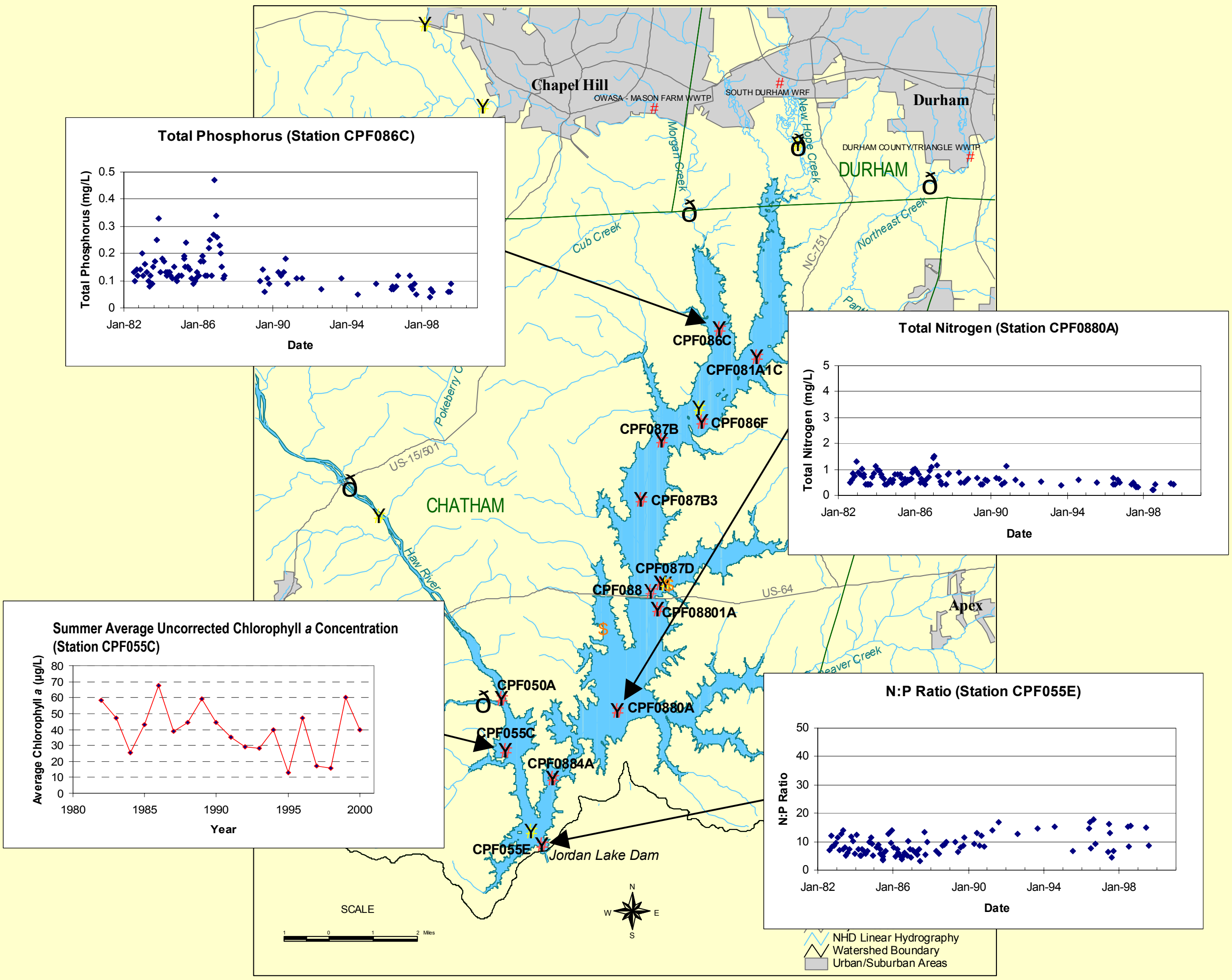
Jordan Lake
Nutrient Response Model

(Final)



Prepared for
The Jordan Lake Project Partners

by Tetra Tech, Inc.

November 13, 2002

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1. Introduction

B. Everett Jordan Lake ("Jordan Lake") is a multi-use impoundment operated by the U.S. Army Corps of Engineers and located on Haw River and New Hope Creek in the Cape Fear River Basin in the eastern Piedmont of North Carolina (Figure 1-1). The lake is operated for augmentation, recreation, and water supply. It has an estimated water supply yield of 100 million gallons per day, and currently serves as a regional source of drinking water supply.

Jordan Lake consists of two distinct arms – the Haw River arm and the New Hope arm. Major inflows are the Haw River and New Hope and Morgan Creeks. The Haw River arm of the lake has an average hydraulic retention time of five days and accounts for 70 to 90 percent of the annual flow through Jordan Lake. The New Hope Creek arm of the lake has an average hydraulic retention time of 418 days. Maximum depth of the lake is approximately 66 feet (20 meters) with a mean depth of five meters and a total volume of 265 million cubic meters (NCDEHNR, 1992).

Since the reservoir was impounded in 1982, it has been monitored extensively by the NC Division of Water Quality (DWQ) as well as local governments and other agencies. According to DWQ, Jordan Lake has historically been one of the most eutrophic reservoirs in North Carolina (NC DWQ, 1999). Excursions of the state water quality standard for chlorophyll *a* (a measure of algal density) have been noted frequently, and nutrient concentrations in the lake are high. The elevated nutrient concentrations result from a combination of point and nonpoint source loads. The point source loads include three major wastewater treatment plants at the headwaters of the New Hope arm and seven major wastewater treatment plants upstream on the Haw River. There are also several smaller dischargers. Nonpoint loading includes runoff from urban areas in Durham, Chapel Hill, Cary, Burlington, Greensboro, and several other small municipalities, as well as a variety of rural sources (Figure 1-1).

In 1983 Jordan Lake was designated as a Nutrient Sensitive Water. In the 1980s, the major wastewater treatment facilities within the watershed were required to meet effluent limits on total phosphorus (TP). All facilities have a TP limit of 2.0 mg/L or less and several, including Orange Water and Sewer Authority, the City of Durham, and Durham County have substantially lower TP limits. State legislation enacted in 1997 (House Bill 515) requires that wastewater treatment facilities located in any Nutrient Sensitive Watershed, including Jordan Lake, meet annual mass load limits for total nitrogen (TN) and total phosphorus (TP). The TN limit is based on an average concentration of 5.5 mg/L, and the TP limit is based on an average concentration of 2.0 mg/L. Those limits were not based on any specific analysis of nutrient response in Jordan Lake.

NC General Statute 143-215.1 provides for, as an alternative approach, the determination of appropriate point source nutrient limits through use of a calibrated in-lake nutrient response model developed specifically for the water body of concern.

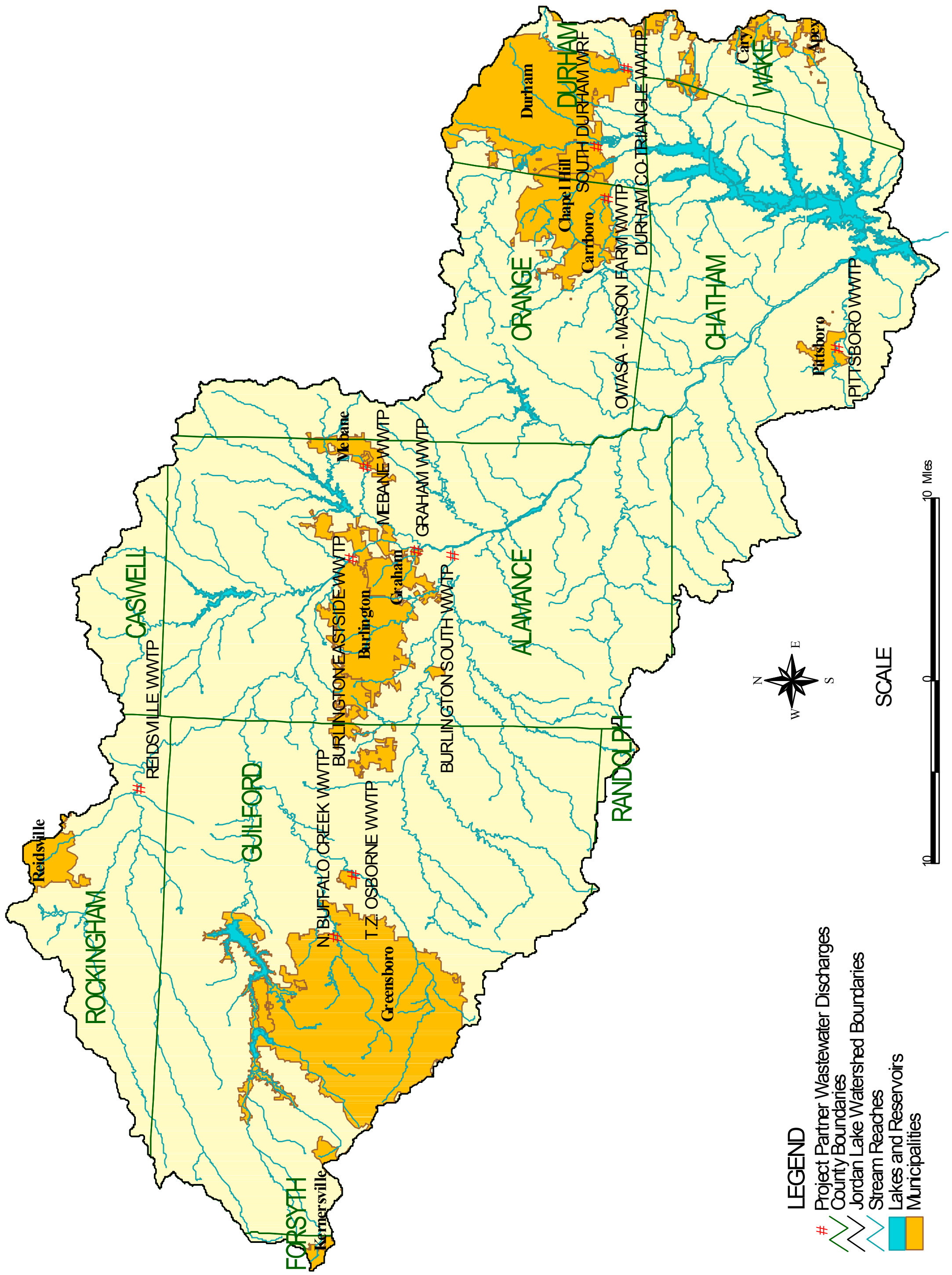


Figure 1-1. Lake B. Everett Jordan and Watershed

The statute requires that the nutrient response model must be capable of predicting the impact of nitrogen and phosphorus loading on water quality. The statute also provides that once a State-approved calibrated nutrient response model has been developed, future point source nutrient limits must be substantiated by the model.

Seven local governments with wastewater treatment facilities in the watershed (hereinafter referred to as the "Project Partners"), with assistance from the Triangle J and Piedmont-Triad Councils of Governments, agreed to work together with the state and watershed stakeholder organizations to develop and calibrate a nutrient response model for B. Everett Jordan Lake. The original seven local governments were: Burlington, Graham, Greensboro, Mebane, Orange Water and Sewer Authority, Pittsboro, and Reidsville. Apex and Cary joined as project partners once the project was underway. These local governments funded this project at a local cost of more than $400,000.

The North Carolina Environmental Management Commission (NC EMC) approved the Project Partners plan and approach for developing the model, and required that the model be completed and submitted to the State by April 2002. The primary purpose of the model is to predict the physical and ecological response of Jordan Lake to various point source nutrient-loading scenarios. This information provides a basis to evaluate the most appropriate and cost-effective point and nonpoint source nutrient load management strategies for long-term protection of Jordan Lake water quality.

In April 2002 a Final Provisional Report and the modeling tools were submitted to the State. Technical comments received from DWQ and others were received and are incorporated in this final report, which documents the Jordan Lake Nutrient Response Model and its application for the evaluation of an initial set of nutrient loading and management scenarios.

In July 2002, the NC EMC officially determined that the model meets the requirements of North Carolina General Statute 143-215.1, and the Project Partners have met the applicable requirements relating to this effort. The NC EMC has directed that the modeling tools described in this report be used to determine appropriate nutrient loading targets, and to evaluate the predicted water quality response of alternative nutrient management strategies for the lake.

Model Selection

Tetra Tech, Inc. was selected by the Project Partners to develop the Jordan Lake Nutrient Response Model. In conjunction with the Project Partners, Tetra Tech developed several general objectives that drove the model selection and development process. These objectives include

- Development of procedures to estimate current and future nutrient loads delivered from dischargers in the watershed to Jordan Lake.
- Spatially and temporally explicit estimation of nutrient transport within Jordan Lake.
- Spatially and temporally explicit modeling of ecological dynamics of Jordan Lake.
- Calibration and validation of the resulting models
- Prediction of ecosystem responses to various watershed nutrient loading scenarios.

Several possible modeling approaches were considered for the nutrient response model. These approaches varied widely in complexity and data requirements. Our general approach to model selection was to: (1) analyze existing data and previous studies of the lake; (2) apply a simple scoping model in conjunction with the analysis of existing data; and (3) make final model selection based on a detailed evaluation of technical requirements of the study and user decision support needs.

The analysis of existing data and documentation of the scoping model are provided in Tetra Tech's *Existing Data Memorandum* (August 2001). The scoping model application used the U.S. Army Corps of Engineers' BATHTUB model (Walker, 1987), which is designed for analysis of eutrophication in morphometrically complex reservoirs. The program performs water and nutrient balance calculations in a steady-state, spatially segmented hydraulic network that accounts for advective transport, diffusion, and nutrient sedimentation. The model predicts algal response (as chlorophyll *a* concentration), transparency, and oxygen depletion rate as growing season averages, using semi-empirical relationships developed and tested on a wide range of reservoirs (Walker 1985). Key conclusions of the scoping model application were:

- Excessive algal growth in the lake is supported by high levels of nutrient input.
- Several lines of evidence, including the scoping model, suggest that algal response in the lake is sensitive to nitrogen loading, with less sensitivity to phosphorus loading.
- Nonalgal turbidity and consequent reduction in light penetration plays an important role in controlling algal growth in the lake.
- Because of the complex responses of different algal groups to nutrient loads, chlorophyll *a* concentrations provide only an approximate and rough indicator of responses that may degrade or impair uses of the lake.
- Mixing patterns in the lake are complex, and involve exchanges between the Haw River and New Hope arms. These two segments have very different hydraulic characteristics and residence times, and may exhibit qualitatively different responses to changes in nutrient loads.

- The scoping model did an adequate job of explaining the spatial gradients in average chlorophyll *a* concentrations in the lake in a given year. A single set of scoping model parameters does not, however, appear to fully capture the year-to-year variability in lake response. This likely reflects: (1) variability in nutrient loss to sedimentation associated with differing hydraulic patterns, (2) the complex, time-dependent interaction between the New Hope and Haw River segments, and (3) the inability of the model to fully distinguish between algal responses in the short residence time Haw River arm versus the longer residence time New Hope arm.

The BATHTUB model application to Jordan Lake suggested that neither nitrogen nor phosphorus alone was strictly limiting on algal growth throughout the lake. This suggested that predictive water quality models need to evaluate the simultaneous effects of nitrogen, phosphorus, and light availability on algal response, along with other factors. Examination of trends by station also indicated qualitatively different responses to nutrient loads in the Haw River and New Hope Creek arms. The difference in responses between the lake arms is a significant factor in selecting a modeling approach capable of evaluating management scenarios that address impacts of individual point sources in the watershed. These results indicated that a more sophisticated modeling approach is required to meet the needs for a calibrated nutrient response model, as specified in NC General Statute 143-215.1. Specifically, it was determined that the modeling tool should be able to address dynamic changes in response on an intra-seasonal scale, should represent the actual pattern of mixing between lake segments, and should include a representation of nutrient cycling that can simulate nutrient-algal and water column-sediment interactions at a sophisticated, process-based level.

Based on the results of the scoping model and analysis of existing data, it was concluded that a relatively sophisticated model was needed to address the complex hydraulics and water quality responses of the lake. The EFDC hydrodynamic model was selected to model the hydraulics of Jordan Lake. The output of the EFDC hydrodynamic and temperature simulation was used to drive an application of EPA's WASP/EUTRO water quality model, as described in Section 2.

In addition to modeling nutrient dynamics within Jordan Lake it is important to examine the delivery of nutrient loads from the watershed. Many possible model approaches exist for estimating nutrient delivery. These range from complex dynamic, spatially explicit watershed models to estimation of simple delivery coefficients. The Project Partners decided not to develop a spatially explicit model of nonpoint pollutant load generation for the entire Jordan Lake watershed. Instead, the combined delivery of point source and nonpoint source nutrient loads to Jordan Lake is calculated under current conditions using the FLUX model applied to observed tributary data, while the portion of point source discharges reaching the lake is estimated using the Jordan Lake Point Source Delivery Model (JLPSDM) model.

This approach yields a balance between model complexity and predictive power that is well suited to address the requirements of General Statute 143-215.1. Selection of the most appropriate components of several accepted models results in a decision support system that will aid in establishing ecologically and economically appropriate total nitrogen wasteload allocations for point source dischargers in the watershed.

The remainder of this document describes in greater detail the structure of the Jordan Lake

Nutrient Response Model, the calibration and validation framework for the model, and the results of various future scenario model runs that are targeted at supporting the selection of appropriate total nitrogen discharge limits for the Jordan Lake watershed.

1.1 References

NCDEHNR. 1992. North Carolina Lake Assessment Report. North Carolina Department of Environment, Health, and Natural Resources, Division of Environmental Management, Raleigh, NC.

NCDWQ. 1999. Water Quality Conditions, B. Everett Jordan Reservoir, 1996-1997. North Carolina Division of Water Quality, Environmental Sciences Branch, Raleigh, NC. March 1999.

Tetra Tech. 2001. Jordan Lake Nutrient Response Modeling Project: Existing Data Memorandum. Prepared for Triangle J. Council of Governments and the Jordan Lake Project Partners. Tetra Tech, Inc., Research Triangle Park, NC. August 2001.

2. Modeling Framework

This section describes the components of the Jordan Lake Nutrient Response Model. To provide a complete evaluation of nutrient response a number of factors must be addressed, including sources, transport, and fate of nutrients. A key component of algal response is the amount of nutrient loads entering the waterbody. Nutrient loads reaching a lake depend on load generation within the watershed, including both point and nonpoint sources, and the delivery of this load to the lake through the stream network. The response of a reservoir to nutrient loads depends on a variety of factors such as hydrologic residence time, flow patterns, morphology, water clarity, historical enrichment of lake sediments, and internal ecological dynamics.

All of these components are addressed within the Jordan Lake Nutrient Response Model. This modeling system is composed of several linked constituent models. The constituent models fall into three categories:

1. Lake Nutrient Cycling and Response;
2. Lake Flow and Temperature; and
3. External Loading to the Lake.

2.1 Lake Nutrient Cycling and Response - WASP/EUTRO5

The simulation of nutrient response within the lake is carried out using the WASP/EUTRO5 modeling system. The Water Quality Analysis Simulation Program –5 (WASP5) model (Ambrose et al., 1993a) is a dynamic compartment model that may be used to analyze a variety of water quality problems. The WASP5 model helps users interpret and predict water quality responses to natural phenomenon and man-made pollution for various management decisions. WASP5 permits models to structure one, two, and three-dimensional models. Earlier versions of WASP have been used to examine eutrophication and PCB pollution of the Great Lakes (Thomann, 1975; Thomann et al., 1976; Thomann et al, 1979; Di Toro and Connolly, 1980), and eutrophication of the Potomac Estuary (Thomann and Fitzpatrick, 1982). In addition to these, numerous applications are listed by Di Toro et al. (1983). WASP is structured to permit easy substitution of kinetic subroutines into the overall package to form problem-specific models.

The primary criteria used in the selection of WASP5 are that the model:

- Supports analysis of relative roles of phosphorus and nitrogen in the lake's trophic response.
- Supports evaluation of short-term trophic responses (daily, weekly). For example, how do chlorophyll *a* concentrations vary during a two-week period following a large storm?
- Recognizes spatial differences in water quality. For example, how does water quality in a tributary cove compare with that in the mainstem of the lake?

- Can be linked to simulated hydrodynamics.
- Includes advection, dispersion, transformations, and sediment interactions.

2.1.1 The WASP5 Simulation Package

WASP5 is an EPA-supported dynamic water quality simulation model that can be configured for simulation of eutrophication or toxics (Ambrose et al., 1993). The version compiled for simulation of eutrophication and related processes is called EUTRO5. The program may be linked to output from a hydrodynamic model to describe advective transport. Because of the complex hydrodynamics of Jordan Lake, the EFDC model, described in Section 2.2, was used to simulate the flows and temperature within the lake.

The model consists of linked differential equations that are simultaneously solved through time using finite difference approximation. The equations solved by WASP5 are based upon the principal of conservation of mass that requires all mass entering the model system be accounted for either by moving through the system, remaining within the system, or being transformed. All material entering or leaving the system is accounted for.

A general mass balance for an infinitesimally small fluid volume may be expressed in terms of a partial differential equation describing the rate of change over time. This is expressed mathematically in Equation 2-1, where the x- and y-coordinates are in the horizontal plane, and the z-coordinate is in the vertical plane.

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial \chi}\left(U_{\chi} C\right) - \frac{\partial}{\partial y}\left(U_{y} C\right) - \frac{\partial}{\partial z}\left(U_{z} C\right) + \frac{\partial}{\partial \chi}\left(E_{x} \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(E_{y} \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(Ez \frac{\partial C}{\partial z}\right) + S_{L} + S_{B} + S_{k} \qquad (2\text{-}1)$$

where:

C = concentration of the water quality constituent, mg/L or g/m^3

t = time, days

U_x,U_y,U_z= longitudinal, lateral, and vertical advective velocities, m/day

E_x,E_y,E_z= longitudinal, lateral, and vertical diffusion coefficients, m^2/day

S_L= direct and diffuse loading rate, g/m^3-day

S_B = boundary loading rate (including upstream, downstream, benthic, and atmospheric), g/m3-day

S_K = total kinetic transformation rate; positive is source, negative is sink, g/m^3-day

To perform these "mass balance" calculations the model must be supplied with input data in six distinct categories:

1. Simulation and output control.
2. Model segmentation.
3. Kinetic parameters, constants, and time functions.

4. Initial concentrations.

5. Advective and diffusive transport.

6. Point source and nonpoint source nutrient loads.

Input categories 1 through 4 are entered in the model's input file. The physical transport of chemical constituents within a lake system is simulated using the processes of advection, dispersion, diffusion, and sedimentation. Advective fluxes are simulated by the EFDC model and are input to the EUTRO5 model through a hydrodynamic link file (.hyd file). Similarly, the tributary loads are specified through a file linkage to the tributary simulation model. A diagram of the relationship between components of the complete Jordan Lake nutrient response modeling system and WASP/EUTRO is presented in Figure 2-1.

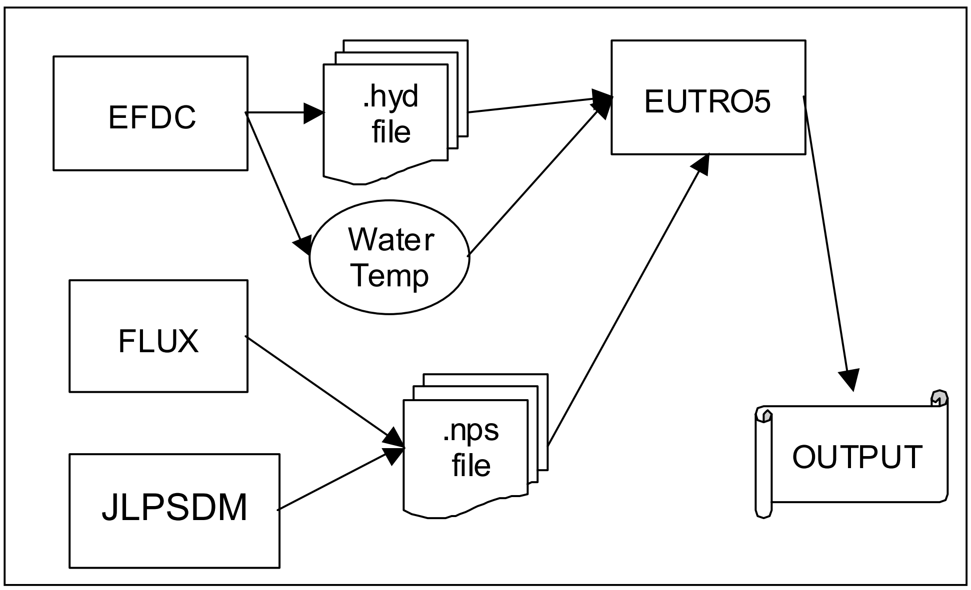


Figure 2-1. Relationship between Components of the Jordan Lake Nutrient Response Modeling System

Transport includes advection and dispersion of water quality constituents. Transport in WASP is specified for six distinct types or transport "fields." The first transport field represents the movement of water between model segments (advective flow and dispersive mixing). Advective flow carries water quality constituents "downstream" with the water, while dispersion causes mixing between regions of higher concentrations and regions of lower concentrations. The second transport field specifies the movement of pore water between the sediment bed and water column. The third, fourth, and fifth transport fields specify the transport of particle-associated pollutants by the settling and resuspension of solids. The three solids fields can be used to represent different net settling rates for inorganic nutrients, organic nutrients, and algae.

Simulation of nonpoint source loading is accomplished by linking WASP5 to a loading simulation model described in Section 2.3. The linkage is accomplished through a formatted external file, referred to in the WASP5 documentation as a "nonpoint source file," although, in this case, it includes both point and nonpoint source loads.

2.1.2 Nutrient Response Simulation with EUTRO5

The version of WASP5 designed for the simulation of nutrient response is known as EUTRO5. This model simulates movement and transformation of nutrients, algal response, and the dissolved oxygen cycle.

Simulation models of eutrophication have been implemented for approximately 35 years. The equations implemented in EUTRO5 were derived from the Potomac Eutrophication Model, PEM (Thomann and Fitzpatrick, 1982), and are fairly standard. Sections of this text are modified from the PEM documentation report and the WASP5 documentation report.

EUTRO5 can be considered as four interacting systems: phytoplankton kinetics, the phosphorus cycle, the nitrogen cycle, and the dissolved oxygen balance (Figure 2-2). The general WASP5 mass balance equation is solved for each state variable. To this general equation, the EUTRO5 subroutines add specific transformation processes to customize the general mass balance for eight state variables (ammonia nitrogen, nitrate nitrogen, inorganic phosphorus, phytoplankton carbon, carbonaceous BOD, dissolved oxygen, organic nitrogen, and organic phosphorus) in the water column and benthos. Following a short summary of the material cycles, the rest of this section covers the specific details for the several transformation sources and sinks.

Phosphorus Cycle

Dissolved or available inorganic phosphorus (DIP) interacts with particulate inorganic phosphorus via a sorption-desorption mechanism. DIP is taken up by phytoplankton for growth, and is incorporated into phytoplankton biomass. Phosphorus is returned from the phytoplankton biomass pool to dissolved and particulate organic phosphorus and to dissolved inorganic phosphorus through endogenous respiration and nonpredatory mortality. Organic phosphorus is converted to dissolved inorganic phosphorus at a temperature-dependent mineralization rate.

Nitrogen Cycle

The kinetics of the nitrogen species are similar to those of the phosphorus system. Ammonia and nitrate are taken up by phytoplankton for growth, and incorporated into phytoplankton biomass. The rate at which each is taken up is a function of its concentration relative to the total inorganic nitrogen (ammonia plus nitrate) available. Nitrogen is returned from the phytoplankton biomass pool to dissolved and particulate organic nitrogen and to ammonia through endogenous respiration and nonpredatory mortality. Organic nitrogen is converted to ammonia at a temperature dependent mineralization rate, and ammonia is then converted to nitrate at a temperature- and oxygen-dependent nitrification rate. Nitrate may be converted to nitrogen gas in the absence of oxygen at a temperature- and oxygen-dependent denitrification rate.

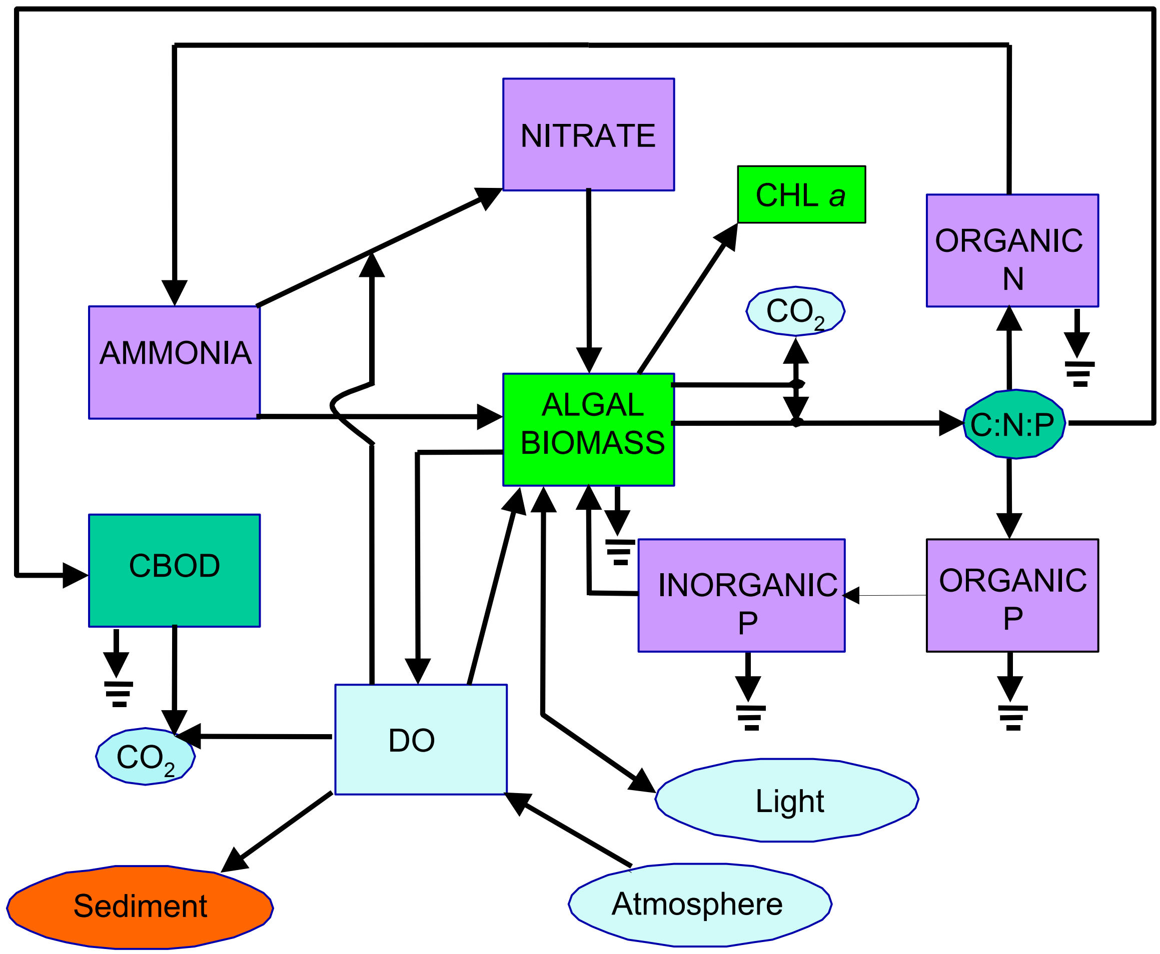


Figure 2-2. Schematic Representation of EUTRO5

Dissolved Oxygen

Dissolved oxygen is coupled to the other state variables. The sources of oxygen considered are reaeration and evolution by phytoplankton during growth. The sinks of oxygen are algal respiration, oxidation of detrital carbon and carbonaceous material from waste effluents and nonpoint discharges in the water column, nitrification of ammonia, and sediment oxygen demand.

Phytoplankton

Phytoplankton kinetics assumes a central role in eutrophication, affecting all other systems. The model simulates growth (production), death, respiration, advection, and settling of a single aggregated state variable representing all phytoplankton. For internal computational purposes EUTRO uses phytoplankton carbon as a measure of algal biomass. Using either a fixed or variable carbon to chlorophyll ratio, phytoplankton chlorophyll *a* may be computed and used as the calibration and verification variable to be compared against observed chlorophyll *a* field data.

Growth of phytoplankton in the model is controlled by temperature and the availability of light, phosphorus, and nitrogen. Light availability for photosynthesis depends on incident radiation, attenuation by non-algal turbidity in the water column, and self-shading by algae. Nutrient limitations on growth are represented by Michaelis-Menten kinetics.

2.2 Flow and Temperature Simulation: EFDC Hydrodynamic Model

Jordan Lake exhibits complex hydrodynamic behavior. A sophisticated hydrodynamic model is required to capture this behavior and provide an accurate platform for water quality simulation. Accordingly, the Environmental Fluid Dynamics Code (EFDC) Model was selected to simulate hydrodynamic and transport processes for this study. The EFDC hydrodynamic model was developed by Hamrick (1992a), and is supported by U.S. EPA. The model formulation is based on the principles expressed by the equations of motion, conservation of volume, and conservation of mass. Quantities computed by the model included three-dimensional velocities, surface elevation, vertical viscosity (frictional resistance to flow in a fluid) and diffusivity (mixing due to molecular motion), temperature, salinity, and density.

2.2.1 General Description of EFDC

EFDC is a general purpose modeling package for simulating three-dimensional flow, transport, and biogeochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications and is public domain software. In addition to hydrodynamic simulation, EFDC is capable of simulating transport of sediment (both cohesive or aggregating and noncohesive or discrete fractions), near field and far field discharge dilution from multiple sources, eutrophication processes, the transport and fate of toxic contaminants, and the transport and fate of various life stages of finfish and shellfish. Special enhancements to the hydrodynamic portion of the code, including vegetation resistance, drying and wetting, hydraulic structure representation, wave-current boundary layer interaction, and wave-induced currents, allow refined modeling of wetland marsh systems, controlled flow systems, and nearshore wave induced currents and sediment transport. The EFDC model has been extensively tested and documented for more than 20 modeling studies. The model is presently being used by a number of organizations including universities, governmental agencies, and environmental consulting firms.

Extensive documentation of the EFDC model is available. Theoretical and computational aspects of the model are described by Hamrick (1992a). The model user's manual (Hamrick 1996) provides details on use of the GEFDC preprocessor and set-up of the EFDC input files. Input file templates are also included. A number of papers describe model applications and capabilities (Hamrick 1992b; Hamrick 1994; Moustafa and Hamrick 1994; Hamrick and Wu 1996; and Wu et al. 1996).

The complete EFDC model includes four major modules: (1) a hydrodynamic model, (2) a water quality model, (3) a sediment transport model, and (4) a toxics model (see Figure 2-3). The EFDC hydrodynamic model itself, which was used for this study, is composed of six transport modules including dynamics, dye, temperature, salinity, near field plume, and drifter (see Figure 2-4). The water quality portion of the EFDC code was not applied to Lake Jordan due to its complexity, extensive data requirements, and very long run times. Rather, the output of the EFDC hydrodynamic and temperature simulation was used to drive an application of EPA's

WASP/EUTRO water quality model, as described in Section 2.1. The calibrated hydrodynamic application of EFDC can, however, provide a basis for future application of the EFDC water quality components.

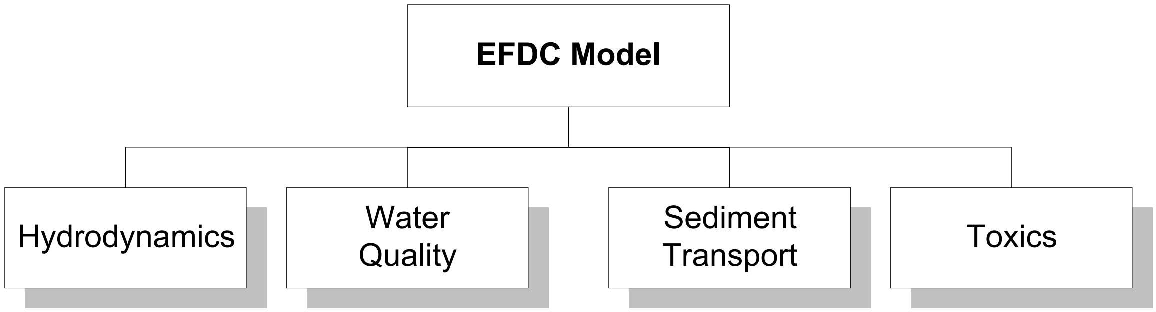


Figure 2-3. Primary Modules of the EFDC Model.

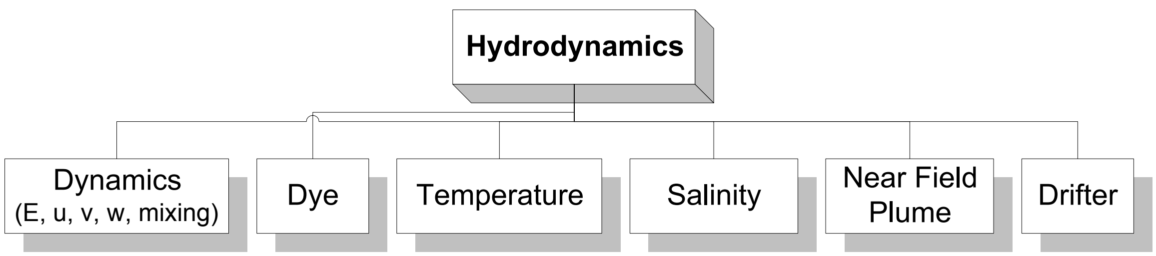


Figure 2-4. Structure of the EFDC Hydrodynamic Model

2.2.2 Hydrodynamics and Temperature Transport

The physics of the EFDC model and many aspects of the computational scheme are equivalent to the widely used Blumberg-Mellor model (Blumberg and Mellor, 1987). The EFDC model solves the three-dimensional, vertically hydrostatic, free surface, turbulent averaged equations of motions for a variable density fluid. Dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity, and temperature are also solved. The two turbulence parameter transport equations implement the Mellor-Yamada level 2.5 turbulence closure scheme (Mellor and Yamada, 1982; Galperin et al. 1988). The EFDC model uses a stretched or sigma vertical coordinate and either a Cartesian or curvilinear, orthogonal horizontal coordinate system. The sigma vertical coordinate system employs the same number of vertical layers at all points, with thickness "stretched" to match local water depth. The curvilinear-orthogonal horizontal coordinate system transforms the natural irregular boundaries of a waterbody to an equivalent orthogonal (or "right-angled") grid.

EFDC solves the equations of motion via a finite difference scheme in which the partial derivatives are approximated by gradients or differencing calculated at points on a regular grid. The specific numerical scheme employed in EFDC uses second order accurate spatial finite differencing on a staggered or C grid. The model's time integration employs a second-order accurate, three-time level, finite difference scheme with an internal-external mode splitting procedure to separate the internal shear or baroclinic mode from the external free surface gravity wave or barotropic mode. The external mode solution is semi-implicit and simultaneously computes the two-dimensional (2-D) surface elevation field by a preconditioned conjugate gradient numerical optimization procedure. The external solution is completed by the calculation of the depth averaged barotropic velocities using the new surface elevation field. The model's semi-implicit external solution allows large time steps that are constrained only by the stability criteria of the explicit central difference or high order upwind advection scheme (Smolarkiewicz and Margolin, 1993) used for the nonlinear accelerations. Horizontal boundary conditions for the external mode solution include options for simultaneously specifying the surface elevation only, the characteristic of an incoming wave (Bennett and McIntosh, 1982), free radiation of an outgoing wave (Bennett, 1976; Blumberg and Kantha, 1985), or the normal volumetric flux on arbitrary portions of the boundary. The EFDC model's internal momentum equation solution, at the same time step as the external solution, is implicit with respect to vertical diffusion. The internal solution of the momentum equations is in terms of the vertical profile of shear stress and velocity shear, which results in the simplest and most accurate form of the baroclinic pressure gradients and eliminates the over determined character of alternate internal mode formulations. Time splitting inherent in the three-time-level scheme is controlled by periodic insertion of a second order accurate two-time-level trapezoidal step.

The EFDC model implements a second order (accurate in space and time), mass conservation fractional step solution scheme for the Eulerian transport equations for salinity, temperature, suspended sediment, water quality constituents, and toxic contaminants. The transport equations are temporally integrated at the same time step or twice the time step of the momentum equation solution (Smolarkiewicz and Margolin, 1993). The advective step of the transport solution uses a hierarchy of positive definite upwind difference schemes. The highest accuracy upwind scheme, second order accurate in space and time, is based on a flux-corrected transport version of Smolarkiewicz's transport algorithm (Smolarkiewicz and Clark, 1986; Smolarkiewicz and Grabowski, 1990), which is monotonic and minimizes numerical diffusion. The NOAA Geophysical Fluid Dynamics Laboratory's atmospheric heat exchange model (Rosati and Miyakoda, 1988) is implemented for the temperature transport equation.

2.2.3 Simulation Extension for Drying/Wetting Areas

The EFDC model provides a number of enhancements for the simulation of flow and transport in wetlands, marshes, and tidal flats. The code allows for drying and wetting in shallow areas by a mass conservative scheme. The drying and wetting formulation is coupled to the mass transport equations in a manner that prevents negative concentrations of dissolved and suspended materials. A number of alternatives are in place in the model to simulate general discharge control structures such as weirs, spillways, culverts, and water surface elevation activated pumps. The effect of submerged and emergent vegetation is incorporated into the turbulence closure model and flow resistance formulation. Plant density and geometric characteristics of individual and composite plants are required as input for the vegetation resistance formulation. A simple soil moisture model, allowing rainfall infiltration and soil water loss due to evapotranspiration under dry conditions, is implemented. To represent narrow channels and canals in wetland, marsh and tidal flat systems, a subgrid scale channel model is implemented. The subgrid channel model allows a 1-D network in the horizontal channels to be dynamically coupled to the two-dimensional horizontal grid representing the wetland, marsh, or tidal flat system. Volume and mass exchanges between 2-D wetland cells and the 1-D channels are accounted for. The channels may continue to flow when the 2-D wetland cells become dry.

2.2.4 User Interface

The EFDC modeling package's user interface is based on text input file templates. This choice was selected in the interest of maintaining model portability across a range of computing platforms and readily allows the model user to modify input files using most text editing software. The text interface also allows modification of model files on remote computing systems and in heterogeneous network environments. All input files have standard templates available with the EFDC code and in the digital version of the user's manual. The file templates include extensive built-in documentation and an explanation of numerical input data quantities. Actual numerical input data are inserted into the text template in a flexible free format as internally specified in the file templates. Extensive checking of input files is implemented in the code and diagnostic on-screen messages indicate the location and nature of input file errors. All input files involving dimensional data have unit conversion specifications for the Meters-Kilograms-Seconds (MKS) international system of units used internally in the model.

The EFDC modeling package includes a grid generating preprocessor code, GEFDC, which is used to construct the horizontal model grid, and interpolate bathymetry and initial fields such as water surface elevation, salinity, and temperature to the grid cells. EFDC input files specifying the grid geometry and initial fields are generated by the preprocessor. The preprocessor is capable of generating Cartesian and curvilinear-orthogonal grids using a number of grid generation schemes (Mobley and Stewart, 1980; Ryskin and Leal, 1983; Kang and Leal, 1992).

2.3 Tributary Loading Simulation

Water quality in Jordan Lake is driven by external loads of nutrients in tributary inflows, and these must be specified to simulate in-lake nutrient response. Creation of a watershed nutrient delivery model was outside the scope of the current project. Instead, the approach used was to estimate continuous series of tributary loads from observed data for the calibration and validation periods. This approach is adequate for calibration, but does not by itself allow evaluation of future alternative management scenarios for point sources, as the observed data combine both point and nonpoint source loads.

To evaluate scenarios, it is necessary to estimate the portion of the observed nutrient load in each tributary that is due to point and nonpoint sources. This is done by combining information on discharges in the watershed with estimates of the fraction of that load delivered to the lake.

The tributary load simulation portion of the Jordan Lake Nutrient Response model thus includes two components: an analysis of the total tributary nutrient load from observed data, which is provided by the FLUX model, and an analysis of the delivery fraction of individual point source loads, which is provided by the JLPSDM model. Both are described below.

2.3.1 FLUX

FLUX is an interactive program developed by the U.S. Army Corps of Engineers' Waterways Experiment Station and designed for use in estimating loads of nutrients or other water quality constituents from concentration monitoring data (Walker, 1997). The model may be used to estimate long-term load estimates or daily series based on relationships between concentration and flow. Data requirements include (a) point-in-time water quality concentration measurements, (b) flow measurements coincident with the water quality samples, and (c) a complete flow record (mean daily flows) for the period of interest.

Estimating constituent mass loads from point-in-time measurements of water-column concentrations presents many difficulties. Load is determined from concentration multiplied by flow, and while measurements of flow are continuous (daily average), only intermittent (e.g., monthly or tri-weekly grab) measurements of concentration are available. Calculating total load therefore requires "filling in" concentration estimates for days without samples. The process is further complicated by the fact that concentration and flow are often highly correlated with one another, and many different types of correlation may apply. For instance, if a load occurs primarily as a result of nonpoint soil erosion, flow and concentration will tend to be positively correlated; that is, concentrations will increase during high flows, which correspond to precipitation-washoff events. On the other hand, if load is attributable to a relatively constant point discharge, concentration will decrease as additional flow dilutes the constant load. In most cases, a combination of processes is found.

Preston et al. (1989) undertook a detailed study of advantages and disadvantages of various methods for calculating annual loads from tributary concentration and flow data. Their study demonstrates that simply calculating load for days when both flow and concentration have been measured and using results as a basis for averaging is seldom a good choice. Depending on the nature of the relationship between flow and concentration, more reliable results may be obtained by one of three approaches:

1. *Averaging Methods:* An average (e.g., yearly, seasonal, or monthly) concentration value is combined with the complete time series of daily average flows;
2. *Regression Methods:* A linear, log-linear, or exponential relationship is assumed to hold between concentration and flow, thus yielding a rating-curve approach; and
3. *Ratio Methods:* Adapted from sampling theory, load estimates by this method are based on the flow-weighted average concentration times the mean flow over the averaging period and performs best when flow and concentration are only weakly related.

No single method provided superior results in all cases examined by Preston et al.; the best method for extrapolating from limited sample data depends on the nature of the relationship between flow and concentration, which is typically not known in detail. Preston et al. show that *stratification* of the sample data and analysis method, however, can reduce error in estimation. Stratification refers to dividing the sample into two or more parts, each of which is analyzed separately to determine the relationship between flow, concentration, and load. Sample data are usually stratified into high- and low-flow portions, allowing a different relationship between flow and load at low-flow (e.g., diluting a constant base load) and high-flow regimes (e.g., increasing load and flow during nonpoint washoff events). Stratification could also be based on time or season to account for temporal or seasonal changes in loading.

The FLUX package implements all three of the general approaches described by Preston et al., including a number of variants on the regression approach, and allows flexible specification of stratification. FLUX also calculates error variances for the estimates.

FLUX applications were developed for the gaged and monitored tributaries (Morgan Creek, New Hope Creek, Northeast Creek, and Haw River), as described in the *Existing Data Memorandum*. Techniques to estimate loads from unmonitored areas are addressed in Section 3.2.2.2 of this document.

2.3.2 Jordan Lake Point Source Delivery Model

Point source nutrient loads into the streams of the Jordan Lake watershed can be estimated from discharge monitoring data. However, because both phosphorus and nitrogen may be lost in transport through the stream network, only a fraction of the nutrients discharged to streams will actually be delivered to Jordan Lake. The delivery of point source nutrient loads to Jordan Lake was estimated using a customized model, the Jordan Lake Point Source Delivery Model (JLPSDM).

A complete description of the JLPSDM application to Jordan Lake tributaries is provided in Appendix A and summarized here. Delivery is a function of time in transit and rate of removal or loss. Time of travel through each stream reach connecting a point source to the lake was estimated using standard engineering assumptions and information on flow, channel slope, channel geometry, and channel roughness. Delivered nutrient concentrations were then calculated using first order decay equations that are a function of time-of-travel:

$$C_t = C_o \cdot e^{-kt}$$

where

C_o= concentration at time zero

C_t= concentration at time t

k= decay rate (1/t)

t= time of travel

The analysis used default decay rates specified by USGS as a function of flow (Smith et al., 1997) and time-of-travel based on reach-specific hydraulic calculations using standard engineering assumptions for open channel flow. These equations can estimate contaminant transport and concentration in all stream reaches. Given estimates of the delivered amount of each point source load, the nonpoint load component (under current conditions) can then be obtained as the difference between the total load (estimated by FLUX) and the delivered point source load (estimated by JLPSDM). Use of this approach to create application scenarios is addressed in further detail in Chapter 4.

2.4 References

Ambrose, R.B., Jr., T.A. Wool, and J.L. Martin. 1993. The Water Quality Analysis Simulation Program, WASP5. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Bennett, A.F. 1976. Open boundary conditions for dispersive waves. J. Atmos. Sci. 32: 176-182.

Bennett, A.F., and P.C. McIntosh. 1982. Open ocean modeling as an inverse problem: tidal theory. *J. Phys. Ocean.* 12: 1004-1018.

Blumberg, A.F., and L.H. Kantha. 1985. Open boundary condition for circulation models. *J. Hydr. Engr.* 111: 237-255.

Blumberg, A.F., and G.L. Mellor. 1987. A description of a three-dimensional coastal ocean circulation model. *Three-Dimensional Coastal Ocean Models, Coastal and Estuarine Science, Vol. 4*, ed. N.S. Heaps, pp. 1-19. American Geophysical Union.

Di Toro, D.M. and J.P. Connolly. 1980. Mathematical Models of Water Quality in Large Lakes, Part 2: Lake Erie. EPA-600/3-80-065. pp. 90-101.

Di Toro, D.M., J.J. Fitzpatrick, and R.V. Thomann. 1981, rev. 1983. Water Quality Analysis Simulation Program (WASP) and Model Verification Program (MVP) - Documentation. Hydroscience, Inc., Westwood, NY, for U.S. EPA, Duluth, MN, Contract No. 68-01-3872.

Hamrick, J.M. 1992a. A Three-Dimensional Environmental Fluid Dynamics Computer Code: Theoretical and Computational Aspects, Special Report 317. The College of William and Mary, Virginia Institute of Marine Science. 63 pp.

Hamrick, J.M. 1992b. Estuarine environmental impact assessment using a three-dimensional circulation and transport model. Estuarine and Coastal Modeling, Proceedings of the 2nd International Conference, M. L. Spaulding et al, Eds., American Society of Civil Engineers, New York, 292-303.

Hamrick, J. M. 1994: Linking hydrodynamic and biogeochemcial transport models for estuarine and coastal waters. *Estuarine and Coastal Modeling, Proceedings of the 3rd International Conference*, ed. M.L. Spaulding et al., pp. 591-608. American Society of Civil Engineers, New York.

Hamrick, J.M. 1996. A User's Manual for the Environmental Fluid Dynamics Computer Code (EFDC), Special Report 331. The College of William and Mary, Virginia Institute of Marine Science. 234 pp.

Hamrick, J.M., and T.S. Wu. 1996. Computational design and optimization of the EFDC/HEM3D surface water hydrodynamic and eutrophication models. *Computational Methods for Next Generation Environmental Models*, ed. G. Delich. Society of Industrial and Applied Mathematics, Philadelphia.

Kang, I.S., and L.G. Leal. 1992. Orthogonal grid generation in a 2D domain via the boundary integral technique. *J. Comp. Phys.* 102: 78-87.

Mellor, G.L., and T. Yamada. 1982. Development of a turbulence closure model for geophysical fluid problems. *Rev. Geophys. Space Phys.*, 20: 851-875.

Mobley, C.D., and R.J. Stewart. 1980. On the numerical generation of boundary-fitted orthogonal curvilinear coordinate systems. *J. Comp. Phys.* 34: 124-135.

Moustafa, M.Z., and J.M. Hamrick. 1994. Modeling circulation and salinity transport in the Indian River Lagoon. *Estuarine and Coastal Modeling, Proceedings of the 3rd International Conference*, ed. M. L. Spaulding et al., pp. 381-395. American Society of Civil Engineers, New York.

Preston, S.D., V.J. Bierman, Jr., and S.B. Silliman. 1989. An evaluation of methods for the estimation of tributary mass loads. *Water Resources Research*, 25(6): 1379-1389.

Rosati, A.K., and K. Miyakoda. 1988. A general circulation model for upper ocean simulation. *J. Phys. Ocean*, 18: 1601-1626.

Ryskin, G. and L.G. Leal. 1983. Orthogonal mapping. *J. Comp. Phys.* 50:71-100.

Smith, R.A., G.E. Schwartz, and R.B. Alexander. 1997. Regional interpretation of water-quality monitoring data. *Water Resources Research*, 33(12): 2781-2798.

Smolarkiewicz, P.K., and T.L. Clark. 1986. The multidimensional positive definite advection transport algorithm: further development and applications. *J. Comp. Phys.* 67: 396-438.

Smolarkiewicz, P.K., and W.W. Grabowski. 1990. The multidimensional positive definite advection transport algorithm: nonoscillatory option. *J. Comp. Phys.* 86: 355-375.

Smolarkiewicz, P.K., and L.G. Margolin. 1993. On forward-in-time differencing for fluids: extension to a curvilinear framework. *Mon. Weather Rev.* 121: 1847-1859.

Thomann, R.V. 1975. Mathematical Modeling of Phytoplankton in Lake Ontario, 1. Model Development and Verification. U.S. Environmental Protection Agency, Corvallis, OR. EPA-600/3-75-005.

Thomann, R.V., R.P. Winfield, D.M. Di Toro, and D.J. O'Connor. 1976. Mathematical Modeling of Phytoplankton in Lake Ontario, 2. Simulations Using LAKE 1 Model. U.S. Environmental Protection Agency, Grosse Ile, MI, EPA-600/3-76-065.

Thomann, R.V., R.P. Winfield, and J.J. Segna. 1979. Verification Analysis of Lake Ontario and Rochester Embayment Three Dimensional Eutrophication Models. U.S. Environmental Protection Agency, Grosse Ile, MI, EPA-600/3-79-094.

Thomann, R.V. and J.J. Fitzpatrick. 1982. Calibration and Verification of a Mathematical Model of the Eutrophication of the Potomac Estuary. Prepared for Department of Environmental Services, Government of the District of Columbia, Washington, D.C.

Walker, W. W. 1985. Empirical methods for predicting eutrophication in impoundments; Report 3, Phase III: Model refinements, Technical Report E-8 1-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Walker, W. W., Jr. 1987. Empirical Methods for Predicting Eutrophication in Impoundments: Report 4—Phase III: Applications Manual. Technical Report E-81-9. U.S. Army Corps of

Engineers Waterways Experiment Station, Vicksburg, MS.

Wu, T.S., J.M. Hamrick, S.C. McCutechon, and R.B. Ambrose. 1996. *Benchmarking the EFDC/HEM3D surface water hydrodynamic and eutrophication models. Computational Methods for Next Generation Environmental Models*, ed. G. Delich. Society of Industrial and Applied Mathematics, Philadelphia.

3. Model Implementation

The primary components of the nutrient response modeling system for Jordan Lake are the EFDC model of lake hydraulics and thermal structure, and the WASP/EUTRO model of lake water quality. This chapter describes the implementation of the models, and includes model setup and data sources, model code modifications, model calibration, and model validation and uncertainty analysis.

The chapter is divided into two major sections. Section 3.1 addresses the implementation of the EFDC hydrodynamic model for Lake Jordan, while Section 3.2 addresses the implementation of the WASP/EUTRO water quality model. Both modeling components were successfully calibrated and validated. Together they form the Jordan Lake Nutrient Response Model, which is now ready for application. Sample applications of the modeling system for evaluation of management scenarios is provided in Chapter 4.

3.1 EFDC Model of Lake Hydraulics and Thermal Structure

3.1.1 EFDC Model Setup

3.1.1.1 Lake Morphometry and Segmentation

B. Everett Jordan Reservoir ("Jordan Lake") is a large and physically complex waterbody. Significant features include a deep, narrow section along the Haw River arm and a wide shallow section along the New Hope arm (Figure 3-1). In addition, flow between sections of the lake is restricted by man-made causeways and natural constrictions.

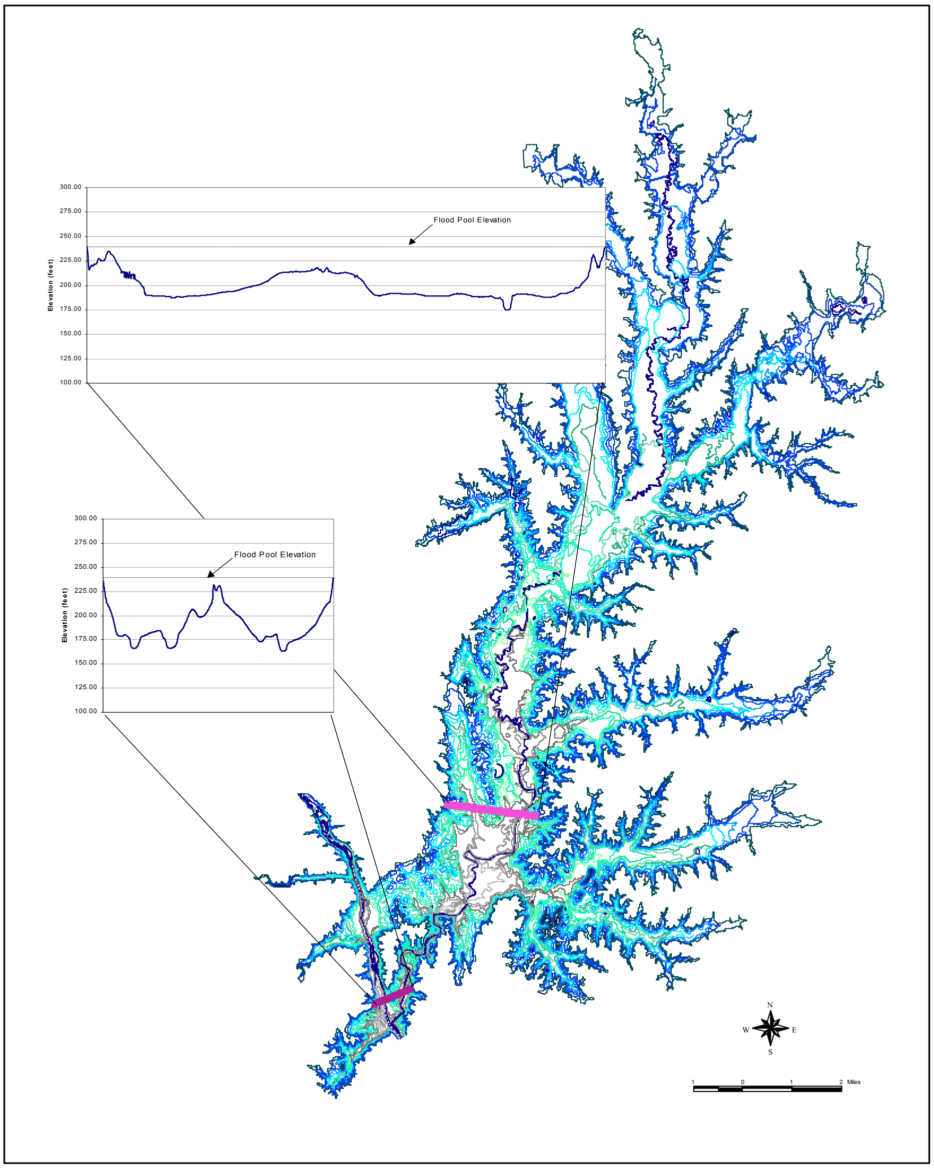


Figure 3-1. Jordan Lake Bathymetry

Figure 3-1 shows two representative lake cross sections to demonstrate the shallower nature of the New Hope Arm. A complete resurvey of lake bathymetry was undertaken in 1997 by the Corps of Engineers (USACOE, 1997). Bathymetry for the model is thus supported by recent detailed survey data that account for sedimentation since reservoir construction. The Corps reported a decrease in total capacity of 6,720 acre-feet between 1979 and 1997; however only 310 acre-feet of storage were lost between 1990 and 1997.

EFDC performs calculations on a finite-difference grid, which is a representation of the lake as a set of discrete points on a regular spacing. The first step in model setup is the definition of the model grid. The grid must provide a good approximation of the actual physical dimensions (morphometry) of the water body; however, specification of too complex a grid results in very long and inefficient simulations. EFDC is set up to use a curvilinear-orthogonal grid in the horizontal plane, consisting of an orthogonal grid that is stretched to provide a realistic representation of the curvature of the actual water body. Vertical structure is represented by specification of a fixed number of vertical subdivisions for each lateral grid cell. Different vertical cells thus have different thicknesses and elevations, depending on the bottom contours of the lake.

EFDC's automatic grid-generating capabilities were used to generate a smoothed, interpolated representation of the lake, using contour information provided in USACOE (1997). The resulting horizontal grid is shown in Figure 3-2, consisting of 386 cells. Four vertical layers are also specified, for a total of 1544 simulation cells.

An important feature of Jordan Lake is the presence of large areas that wet or dry depending upon the water level in the lake. These wetting/drying areas play an important role in the hydrology of the lake. Model cells that contain water at normal pool are shown in blue on Figure 3-2, while cells that are dry at normal pool are shown in pink.

The effects of causeway/bridge constrictions on inter-segment flow are also included in the model through use of the MASK option. This option inserts a thin (no-flow) barrier between adjacent cells, and was used to represent the constrictions caused by the Mount Carmel Church Road and U.S. 64 causeways across the lake.

Using 386 lateral cells, it is not possible to achieve an exact representation of the complete details of the Jordan Lake shoreline within the curvilinear-orthogonal grid. Cell depths (and thus volumes) were adjusted to obtain a representation that accurately reflects the stage-storage relationships reported for sections of the lake by USACOE (1997). The resulting model stage-volume curve is shown in Figure 3-3.

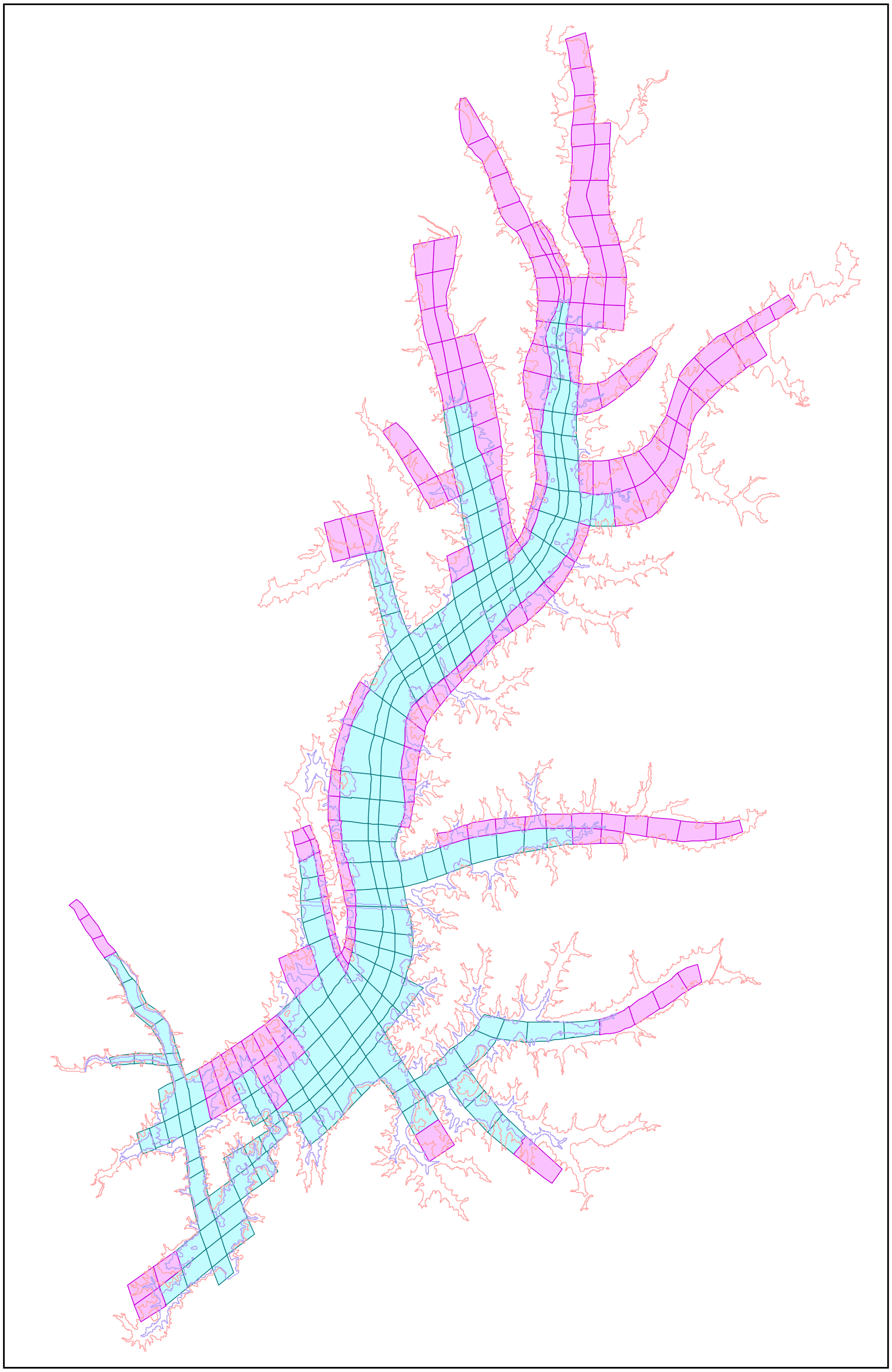


Figure 3-2. EFDC Simulation Grid for Jordan Lake. Cells shown in pink are represented as dry at lake normal pool elevation.

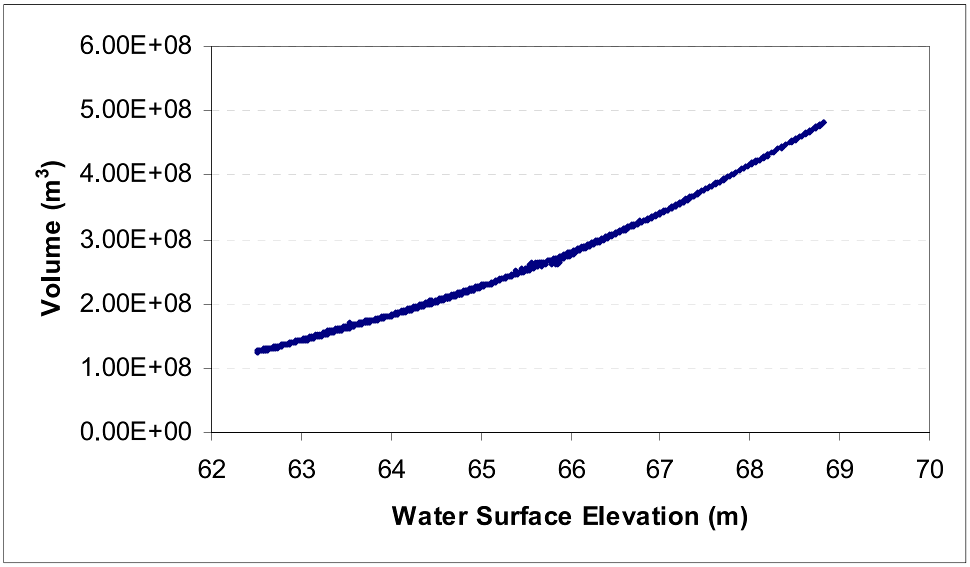


Figure 3-3. Stage-Volume Representation in EFDC Model of Jordan Lake

3.1.1.2 External Forcing Functions

The EFDC simulation requires specification of a number of external data series to implement the hydrodynamic and thermal simulation, including flows, precipitation, temperature, etc. These are documented below.

Flows

Both inflows to and outflows from the lake must be specified in the file Qser.inp. The majority of the inflows are gaged, and the flow series are represented from USGS gage data in Haw River near Bynum, Morgan Creek, New Hope Creek, and Northeast Creek. Approximately 15 percent of the drainage area, primarily areas near the lake, is not represented by flow gaging.

It is necessary to estimate realistic continuous flow series for the ungaged areas, although they are not expected to have a major effect on the flow balance in the lake. None of the available gages in the basin is ideally suited for this purpose. The Morgan Creek, New Hope, and Northeast Creek gages have similar spatial scales to the unmonitored areas, but each of these gages receives wastewater flow upstream. High impervious coverage in the watersheds of New Hope Creek (south Durham) and Northeast Creek (Research Triangle Park) are likely to lead to greater stormflow response than in more pervious watersheds. In addition, flow in Morgan Creek is affected by University Lake storage and withdrawals, while flow in New Hope Creek is influenced by greentree impoundments. On the other hand, flow from many of the more rural unmonitored areas is influenced by retention in farm ponds and wetlands. Finally, the watersheds of New Hope and Northeast Creeks are much more urbanized than most of the unmonitored areas.

This problem would best be addressed through the development of a watershed model; however, this effort was outside the scope of the current project. Accordingly, the aim was to create reasonable time series of surrogate flows for the unmonitored areas that reflect major precipitation events and long term average water yield. To do this, an *ad hoc* approach was adopted in which discharge rates per square mile from the less intensely developed unmonitored areas were estimated from the observed water yield at monitored gages. The New Hope and Northeast Creek gage records were used for adjacent areas with similar land use coverage. These gages are not appropriate for estimating flows from the more pervious rural areas. Instead, these were estimated from the Morgan Creek gage multiplied by 90 percent to adjust for wastewater effluent flow contributions. The intent was to provide a reasonable surrogate for high-flow runoff from more pervious areas. As is shown in Figure 3-4, this approach results in flow series (as yield per area) that are similar to those observed at the Northeast Creek gage (after subtracting the estimated wastewater treatment plant flow component from the Durham Triangle plant), but with reduced peak response to storm events and annual flow amounting to 93 percent of the Northeast Creek nonpoint flow. The reduced peak response and slightly lower total flow relative to Northeast Creek were judged to be appropriate for the unmonitored areas that have substantially lower impervious coverage than the Northeast Creek drainage.

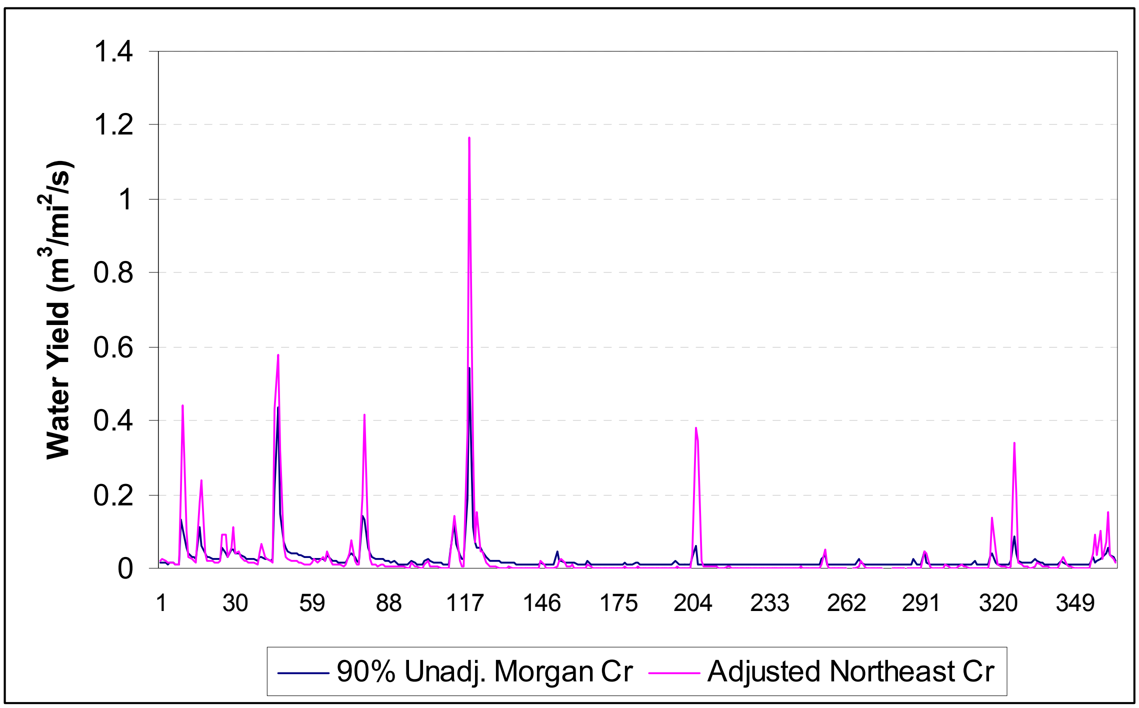


Figure 3-4. Comparison of Surrogate Water Yield Estimated from Morgan Creek Gage to Observed Water Yield at Northeast Creek Adjusted to Remove Wastewater Treatment Plant Flows.

A total of 13 flow series are specified to the model, as summarized in Table 3-1.

Table 3-1. Specification of External Flow Series.

Flow Series	Description	Data Source
1	Haw River at Bynum	USGS Gage 02096960
2	Morgan Creek plus area to mouth of Morgan Creek Arm of lake, inc. Cub Creek	USGS Gage 02097517 prorated for additional drainage area. (1.25 · gage), where the factor 1.25 represents the ratio of drainage area at the mouth of Morgan Creek Arm to the drainage area at the gage.
3	New Hope Creek, Little Creek	USGS Gage on New Hope (02097314) prorated for additional drainage area (1.32 · gage)
4	Northeast Creek, Panther Creek	USGS Gage on Northeast Creek (0209741955) prorated for additional drainage area (2.24 · gage)
5	Outflow at dam	USACOE operational records
6	Beaver Creek, Little Beaver Creek	Estimated from relationship to Morgan Creek gage. (0.80 · gage)
7	White Oak Creek	Estimated from relationship to Morgan Creek gage. (0.54 · gage)
8	Folkner Br., Lick Br., Indian Creek	Estimated from relationship to Morgan Creek gage. (0.20 · gage)
9	Crooked Creek	Estimated from relationship to Morgan Creek gage. (0.22 · gage)
10	Bush Cr., Overcup Cr.	Estimated from relationship to Morgan Creek gage. (0.28 · gage)
11	Parkers Creek	Estimated from relationship to Morgan Creek gage. (0.49 · gage)
12	Haw River below gage, Roberson Cr.	Estimated from relationship to Morgan Creek gage. (1.10 · gage)
13	Cary withdrawal	USACOE operational records.

Precipitation

Daily precipitation data were obtained from the RDU International Airport station (WBAN 13722) via the National Climatic Data Center. Daily precipitation was assigned as a rate to an entire calendar day of simulation.

Air Temperature

Daily maximum and minimum air temperatures were obtained from the RDU International Airport through September 2000. Data for the last three months of 2000 were obtained from the North Carolina Agricultural Research Service Agricultural Weather Network (AgNET) station at the Turfgrass Field Laboratory in Raleigh. Air temperatures were represented by three time points per day: daily temperature cycles were approximated by assigning the minimum daily temperature to 6 AM, maximum daily temperature to noon, and daily median temperature to 6 PM. The actual temperature maximum will usually occur later in the day; however, it was desirable to use the noon point in the cycle for assigning solar radiation values. Wet bulb temperatures were also obtained from RDU International Airport through September 2000. For the last three months of 2000, wet bulb temperatures were estimated from relative humidity values reported by AgNET.

Solar Radiation

Daily solar radiation at the surface ceased collection at the RDU International Airport in 1990. Surrogate time series through 1995 have been created as part of the BASINS system by applying a simplified cloud cover correction to irradiance at the edge of the atmosphere (Lahlou et al., 1998). While these data are useable, they are expected to be somewhat uncertain due to the calculation method. The North Carolina Agricultural Automated Weather Network (AgNET) began collecting direct measurements of ground solar radiation in 1997, using a pyranometer sensor with reported accuracy of plus or minus 3 percent (Parameshwara et al., 2000). Data from the AgNet Turfgrass station in Raleigh were used for the period after March 1997, except for March through May 1997, which were filled in from the AgNet Clayton station. Long term average solar radiation values were used to fill in the missing data for January and February 1997. No local solar radiation data were available for 1996.

A comparison of the BASINS and AgNet solar radiation data showed an apparent significant difference. AgNet data for 1997 through 2000 had a daily average irradiance of 256 Joules/m^2/s, with interannual variability of less than 5 Joules/m^2/s, while the BASINS data had a daily average irradiance of 186 Joules/m^2/s. The BASINS data thus appear to be biased low, probably because of the method used to infer surface radiation from cloud cover. The BASINS estimates of daily radiation were accordingly scaled up by a factor of 1.374 to provide a comparable time series.

As with air temperature, total daily solar radiation was represented by three time points per day. This was done by assigning a triangular distribution between 6 AM and 6 PM, with peak at noon. This peak is equal to four times the total daily insolation rate, yielding the correct total daily solar radiation on integration.

Atmospheric Pressure

Atmospheric pressure data (as a daily average) were also obtained from RDU International Airport, except for the last three months of 2000, which were filled in using AgNET data.

Wind Movement

Daily wind movement (converted to m/s) and average wind direction were input as daily averages. These data were also obtained from RDU International Airport through September 2000 and from AgNET data at Turfgrass Field Laboratory thereafter. It should be noted that intra-day wind cycles have not been simulated at this time. Particularly under summer conditions, a daily cycle of dropping wind speeds at night may affect the diurnal dissolved oxygen cycle in the lake. The model could thus be enhanced by specifying wind movement on an hourly, rather than daily basis. This is not, however, anticipated to be a significant factor in the simulation of water movement and temperature distribution by EFDC.

Evaporation Rate

Daily pan evaporation (in inches) was estimated from other meteorological variables by the method of Kohler, Nordensen, and Fox (1955), in which

$$E = \frac{\exp\left|(Ta - 212)\cdot(0.1024 - 0.01066 \ln R) - 0.0001 + Ea \cdot 0.0105\right|}{0.0105 + \left[7482.6/(Ta + 398.36)^2\right]\cdot \exp\left[15.674 - 7482.6/(Ta + 398.36)\right]}$$

where E is pan evaporation in inches per day, Ta is air temperature (Fahrenheit), R is daily solar radiation (langleys), and Ea is pan evaporation under the assumption that air temperature equals water temperature. Ea is calculated from

$$Ea = (0.37 + 0.0041 \cdot Up) \cdot (es - ea)^{0.88}$$

where Up is the daily wind movement (miles), es is the saturation vapor pressure at the ambient temperature, and ea is the actual surface vapor pressure.

Cloud Cover

Because solar radiation at the surface is directly specified to the model, cloud cover is used only in the calculation of net longwave radiation exchange. Daily cloud cover data at RDU International Airport were available through 1995, but not thereafter. For the 1997—2000 simulations, cloud cover was input based on the 1970—1995 average per calendar day. This approximation introduces some small scale errors into the simulation of surface temperature, but the error is expected to be small because the surface temperature balance is largely driven by solar radiation, convective heat exchange with the atmosphere, and influent temperature load.

Tributary Water Temperature

Each influent tributary flow has associated heat energy, and the temperature balance in the lake is sensitive to the temperatures of these inflows. Both USGS and NC DWQ have collected scattered surface temperature measurements for Morgan Creek, New Hope Creek, Northeast Creek, and Haw River at Bynum, and additional data are available for Durham Southside and OWASA self-monitoring in Morgan Creek and Northeast Creek. Continuous data are not available, so interpolation was required to represent daily water temperatures. Plotting data for all four creeks showed strong similarity in temperatures between locations, reflecting the fact that the influent water temperature is strongly related to atmospheric temperature. Data were combined from all four locations to decrease the amount of interpolation and used to represent the temperature of each inflow as a daily average.

Tributary water temperature was input as a series of daily values. Available temperature observations in the tributaries are primarily mid-day surface observations. These observations are likely to over-estimate actual average daily influent thermal energy due to both daily cycles in temperature, and potential vertical gradients in the temperature profile. Daily cycles apply in all tributaries, while vertical gradients in temperature were judged to be more significant in the Haw River inflow. Therefore, the measured and interpolated tributary water temperatures should be adjusted downward. No data were available to establish the appropriate coefficients, so these were estimated during model calibration. Accordingly, the estimated series of inflow temperatures were adjusted downward, to 80 percent in the Haw River inflow, and to 90 percent of reported values in the other tributaries.

3.1.1.3 Initial Conditions

EFDC simulations are implemented on a yearly basis, commencing on January 1. Initial conditions must be specified for lake surface elevation and water temperature. The elevations are set at the start of each year from ACOE project data with the assumption that the lake surface is level. Starting temperatures for the simulation are assigned as 5 degrees Centigrade throughout (no thermal stratification), which is a typical condition for this time of year.

3.1.2 EFDC Code Enhancements and Model Options

The EFDC simulation code is a highly flexible package that can be applied to a wide variety of riverine, lacustrine, and estuarine water bodies. The model contains a large number of built-in options that must be selected by the user. In addition, a variety of enhancements to the code were made to improve application to Jordan Lake.

3.1.2.1 EFDC Code Enhancements

Some site-specific enhancements were made to improve model applicability to the specific conditions present in Jordan Lake. These site-specific conditions include extensive wetting and drying areas, rapidly varying inflows, and complex morphometry. While the native EFDC code is capable of handling these situations, practical problems arise because the finite difference solution requires a very small time step to assure numeric stability, and thus a very long simulation time.

Within the native EFDC code, the length of the simulation time step is constrained to maintain stability at all locations and under all flow conditions. The major limitation on time step is imposed by model cells that are near the cutoff points between wetting and drying under conditions of rapidly varying in-lake surface levels. But, infrequent and temporary instabilities at these marginal locations will have little effect on the overall simulation, as long as the instabilities are prevented from propagating into adjacent cells. In other words, the model time step must become very short to resolve conditions in model cells that are not important to the overall simulation.

Code enhancements were therefore made to allow use of a more reasonable (longer) time step, and thus more efficient simulations. The general approach was to perform the simulation using a time step that provides a stable simulation in most cells at most times, while trapping and correcting any marginal instabilities.

Additional code modifications were made in two areas. First, the formulation for estimating vertical transport velocities in the internal mode solution was improved to give greater stability. Second, the routine for internal heating of the water column was enhanced to allow for slow propagation of geothermal heat from depth.

The code modifications implemented for the Jordan Lake model are summarized below:

Subroutine CALPUV5 (external mode solution)

- Changed logic of flags for active cells so that only cells that are within a specified distance of current pool level are included within the active set of cells for simulation.
- Only update depths for active cells, except for precipitation and evaporation.
- Allow cells to go completely dry rather than maintaining a nominal water content when their bottom elevation is above the surface level of adjacent cells.
- Turn off interfacial boundaries for cells that are completely dry and inactive. This prevents the program from calculating an averaged depth, and potential flow, from or to inactive cells.
- Allow the program to proceed when non-linear iterations are unable to resolve positive depths in drying cells.
- If the program overshoots and converges to a negative depth in a cell, adjust the flows to and from adjacent cells such that zero depth/volume is achieved.

Subroutine CONGRAD (conjugate gradient solver for the internal mode solution)

- Calculate fit on only those cells that are wet and flagged as active in CALPUV5.

Subroutine CALUVW (internal mode solution)

- If the program overshoots and converges to a negative depth in a cell, adjust the flows to and from adjacent cells such that zero depth/volume is achieved. When depth is set to zero in the external mode solution, set a flag so that the internal mode solution knows that the cell is dry.
- Enforce zero horizontal transport across boundaries between wet and dry cells. Allow rewetting of cells only in internal mode solution.
- Set vertical mixing to zero for cells with water depth less than 1/5 of the specified "dry" depth.
- Calculate vertical mixing vector for transport, W2, based on current time step only rather than as a leapfrog average of time steps. This change is consistent with the theoretical

development of the model (Hamrick, 1992) and results in a more stable calculation of transport.

Subroutine CALTRAN

- Only update concentration calculations due to advective transport for cells that are wet.
- Only apply antidiffusive flux corrections to cells that are not dry.

Subroutine CALHEAT

- When depth is less than 1/5 of the specified dry-equivalent depth, assume that temperature converges gradually to atmospheric temperature.
- Apply upper and lower bounds to empirical equations for calculation of saturation vapor pressure and longwave radiation.
- Modify 1B option to respond to calibration factor REVC on latent heat.
- Modify 1A option so that layers become isothermic when the layer thickness is very small.
- Modify 1A option for bed heating to address frozen water.
- Modify 1A option to include isothermal geothermal temperature at depth in sediment, communicated to surface layer according to parameter HTBED2.
- Modify 1A option so that heating equation coefficients are consistent with 1B option.

Subroutine INPUT

- Added option to allow specification of external outflow series that changes layer from which water is drawn in accordance with dam operating policies.
- Added option to scale influent temperatures by a specified factor.

3.1.2.2 EFDC Program Options

EFDC is a highly flexible code, providing a wide variety of user options. The Jordan Lake simulation uses the following options:

Time Steps

A time step of 30 seconds (2880 steps per day) provides a stable solution for the vast majority of cells and times. Occasional instabilities in drying/wetting cells are handled by program modifications. The number of reference periods between insertion of the two time-level trapezoidal correction (NTSTBC) is set to six.

Solver for External Mode Solution

Use pre-conditioned (red-black ordered) conjugate gradient solver (IRVEC=2).

Simulation of Drying/Wetting Cells

Solution implemented as a constant wetting depth with linear iterations (ISDRY=11). The depth at which a cell is considered to become wet and thus active in the solution is HWET = 0.10 m; the depth at which a cell becomes dry and inactive is HDRY = 0.06 m. Up to 20 iterations are allowed per drying check, and once a cell becomes dry it is required to remain dry for at least eight time steps before rewetting (NDRYSTP=8).

Temperature Transport Mode

Thermal structure is simulated with full surface and internal heat transfer (ISTOPT=1). Transport is simulated with the standard upwind donor cell scheme (ISCDCA=0), with addition of anti-numerical diffusion correction (ISADAC=1) with flux limiting (ISFCT = 1). These options correct for spurious numerical diffusion and oscillations potentially introduced by the upwind donor solution scheme (Smolarkiewicz and Clark, 1986; Smolarkiewicz and Grabowski, 1990).

3.1.3 EFDC Model Calibration

3.1.3.1 EFDC Calibration and Validation Period

The available years for calibration and validation of the EFDC model application to Jordan Lake are 1992-1995 and 1997-2000. Years prior to 1992 were not included in the modeling for several reasons:

- Earlier years are likely to exhibit significant lake start-up effects, and are therefore of less use in calibrating a nutrient response model that is representative of current conditions.
- The base bathymetric data are from the 1997 resurvey (USACOE, 1997), and will decrease in accuracy for years progressively farther away in time.
- The rapid pace of development in the watershed has changed runoff conditions to the lake, again rendering earlier years less representative of current conditions.

Year 1996 was omitted from simulation because complete meteorological data were not readily available (particularly incident solar radiation). Tributary inflow data were incomplete for 2001.

The base calibration began with the 1997-1999 time period, which represents a wide range of meteorological conditions. The EFDC calibration was refined using the 2000 intensive study data collected by NC DWQ. Finally, the 1992-1995 time period was used as a validation test.

3.1.3.2 Hydrodynamic Calibration

The primary outputs of the hydrodynamic simulation are series of segment volumes, depths, and flow velocities. Calibration to flow velocities would provide the most rigorous test of the EFDC simulation; however, this is not possible as neither current metering nor drifter studies have been undertaken in the lake. The possibility of collecting such data was evaluated during the planning phase of the project, but was rejected due to a combination of cost and the difficulty anticipated in obtaining accurate measurements in the presence of high levels of recreational boat traffic.

Direct calibration of the hydrodynamic model thus consists of comparison of model output to lake surface elevations reported by the Corps of Engineers. If the modeled and actual series of inflows, outflows, and the stage-storage relationship match, then the resulting water surface elevations should also match.

The simple test on reservoir stage does not of itself validate the representation of flow patterns in the body of the lake. Flow is, however, governed by well known physical principles, and the simulation of flow velocity is expected to be accurate if the representation of external inflows, other forcing functions (such as wind and bottom drag), and segment morphometry are accurate. In addition, flow patterns determine the distribution of water quality constituents within the lake. EFDC is used directly to simulate distribution of temperatures in the lake, and EFDC flows (summarized at a larger spatial scale) are used to drive the water quality model application. Thus the ability to obtain reasonable representations of thermal structure and the distribution of water quality constituents indirectly demonstrates the accuracy of the hydrodynamic simulation.

The calibration to stage and volume included two tests. The first is a calculation of accumulated internal model error on total volume. This error accumulates from numeric approximations in the finite difference solution, and should be minimal when the model is performing properly. An arbitrarily small criterion of less than 0.1 percent was specified for this test. The second test involves comparison of calculated and reported surface elevations. Some inaccuracies in the simulation are expected due to uncertainty associated with inflow gage records, outflow estimates, and estimates of flows from ungaged areas. In addition, direct precipitation on the lake during major rainfall events may differ significantly from the precipitation reported at the airport. Based on best professional judgment, targets of an average absolute difference in the annual series of lake elevations of less than 0.5 meters and 99th percentile absolute difference of less than 1 meter were selected as appropriate tests of model performance.

Initial simulations showed that model estimates of stage occasionally diverged from the reported lake stage. This is evident in the model calibration plot for 1997 (Figure 3-5). Two types of discrepancies are present in this simulation. First, errors may occur during periods of high inflow and outflow (e.g., around day 50 and day 125 in Figure 3-5). These discrepancies could reflect either errors in estimated inflow volume (both gaged and ungaged), or in the Corps' estimates of outflow volume. A more gradual discrepancy occurs after day 300 (which in this case compensates for the underestimate earlier in the year). This is a low flow period, in which releases from the lake were generally low and actively controlled. It is known that the dam operators have experienced problems in maintaining an exact gate height during low flows. Therefore, this type of gradual error is most likely due to accumulation of small errors in the Corps' estimates of dam releases.

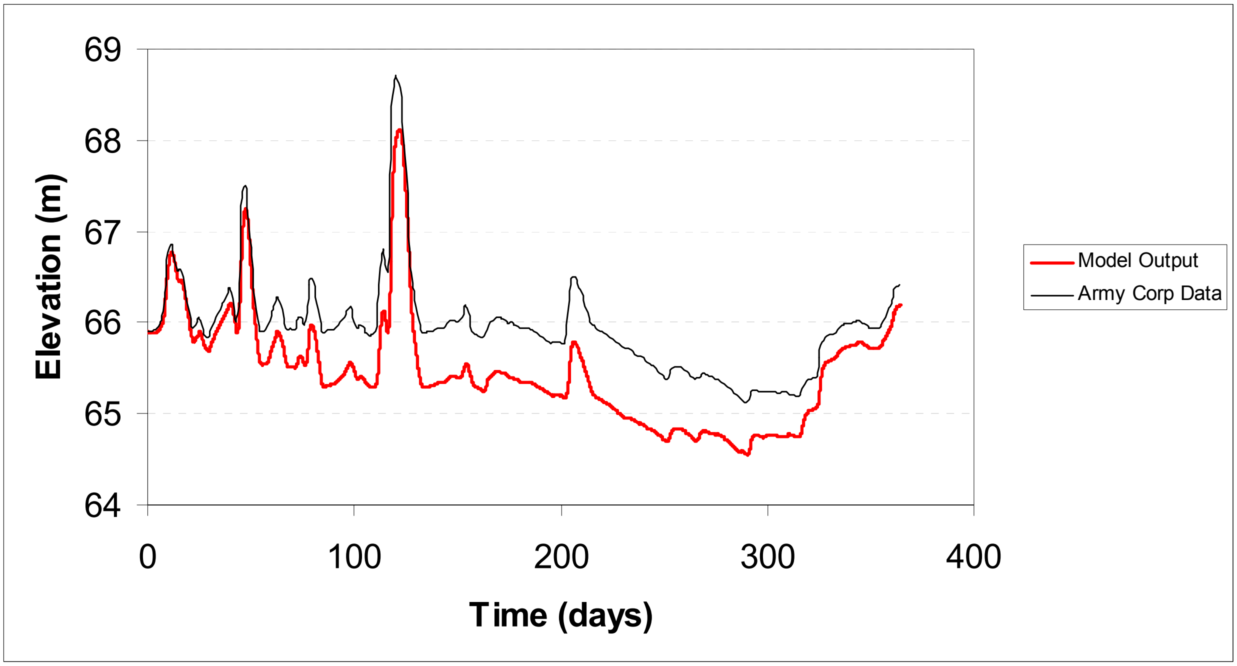


Figure 3-5. Jordan Lake Hydrologic Calibration for 1997.

While small discrepancies are present in the simulation of lake surface elevation for 1997, the model meets criteria, so no adjustments were made. In some other years, adjustments were necessary to meet the pre-specified calibration criteria. These were made according to the following rules:

- Discrepancies associated with high flow events were assumed to be due to mis-estimation of total inflow volume and were corrected by assigning additional flow input to the Haw River arm, which contributes the majority of flow.
- Gradual accumulation of error during fall low flow periods was assumed to be due to inaccurate estimates of outflow volume, and was corrected by adjusting the outflow series.
- Gradual accumulation of error across an entire year could be due to small inaccuracies in the calibration of either inflow gages, outflow estimates, or extrapolation of gaged data to unmonitored areas. As no single cause of these discrepancies is self evident, they were corrected through specification of an additional constant flow in the Haw River arm.

The application of flow adjustments to achieve closure on reported surface elevations is summarized in Table 3-2.

Table 3-2. Application of Flow Adjustments.

Year	High Flow Inflow	Low Flow Outflow	Constant
1992			X
1993			X
1994	X		
1995	X		X
1997			
1998		X	
1999	X		
2000	X	X	

Figure 3-6 displays the water surface elevation fit for 1992-1995 and 1998-2000. Statistics for all years are summarized in Table 3-3.

Figure 3-6. Water Surface Elevation Results for 1992-1995 and 1998-2000.

Table 3-3. Calibration Statistics for Hydrologic Calibration of EFDC Model

	Internal Volume Error (%)	Average Absolute Error in Elevation (m)	99th Percentile Absolute Error in Elevation (m)
Criterion	*< 0.1 %*	*< 0.50*	*< 1.00*
1992	0.015%	0.13	0.33
1993	0.024%	0.37	0.85
1994	0.009%	0.09	0.35
1995	0.015%	0.18	0.63
1997	0.016%	0.48	0.86
1998	0.016%	0.19	0.64
1999	0.020%	0.14	0.58
2000	0.026%	0.17	0.36

As noted above, data are not available for direct calibration of internal flow patterns. EFDC simulates the velocity distribution primarily from physically based principles, using the Blumberg-Mellor model approach (Blumberg and Mellor, 1987) for the three-dimensional, vertically hydrostatic, free surface, turbulent-averaged equations of motion for a variable density fluid. Flow patterns are strongly influenced by viscosity and density gradients due to temperature and/or salinity. The temperature simulation is discussed below. There is no evidence of any significant salinity gradients within Jordan Lake.

An important control on both the thermal structure of the reservoir and the vertical distribution of flow patterns is provided by the location from which outflows are drawn. Dam operators have a choice in selecting controlled flows from one of several gates. This choice is represented in the model by the assignment of fractions of the total outflow to one or more of the four layers simulated in the model. The operators practice selective flow withdrawal, with primarily surface withdrawals in summer and bottom withdrawals in winter. The operator instructions are summarized in the 1992 Water Control Manual for the B. Everett Jordan project (7-05.d): "During times of the year when the lake is stratified, surface waters are released through the multilevel intake structure. This is done to reduce surface water residence time in the lake, and thereby to reduce the potential for in-lake nuisance algae blooms. The policy for this release is that each year when operational conditions permit (i.e., except during flood events), only surface waters are released from May 1 through November 14, preferably through the water quality gate having an invert elevation of 207 feet m.s.l. From November 15 through April 30, when the lake is practically isothermal, water may be released from any intake gate, but preferably through the emergency gates." These operational rules are incorporated into the model representation of outflows. Inflows are assumed to mix across all model layers.

Other than the thermal simulation, external forcing functions, and lake morphometry, the primary user-specified controls on internal flow velocity distribution are the specifications of minimum kinematic eddy viscosity, minimum eddy diffusivity, and representation of drag due to bottom roughness. The first two parameters were set to default values recommended by the model developers ($1 \cdot 10^{-6}$ and $1 \cdot 10^{-8}$ m^2/s, respectively). Bottom drag is controlled by the specification of a log law bottom roughness height, which was set to 0.02 m in all segments. Model representation of flow patterns in nearshore areas could likely be improved (if documented) by a more detailed representation of bottom roughness patterns and vegetative resistance.

3.1.3.3 Temperature Calibration

As noted above, the parameters such as solar radiation and air temperature that control the heating and cooling of the water column are input as either three or one time points per day, due to data availability. This simplified approximation introduces fine-scale errors into the simulation of the temperature cycle (for instance, the peak in solar radiation and atmospheric temperature are not in fact expected to coincide in time). There are, however, also unresolvable data uncertainties regarding important forcing functions such as tributary inflow temperature, as well as the vertical discretization into four layers. In addition, the temperature data available for calibration are limited. As a result, the temperature calibration was expected to provide a good representation of monthly and seasonal trends, but cannot be expected to reproduce all daily variability experienced by the system. With this in mind, and based on past experience with other systems, a calibration goal was established that the annual average error in simulated daily water temperature in the uppermost and lowermost layers of the water column at each station not differ from observations by more than 2 degrees C.

Four monitoring stations were selected for temperature calibration, based on frequency of observations and a representative coverage of portions of the lake. The relevant DWQ monitoring stations are CPF0880A (lower New Hope arm), CPF055E (Haw River arm), CPF086F (upper New Hope Arm above SR 1008), and CPF087D (middle New Hope Arm at U.S. 64), as shown in Figure 3-7. In addition, USGS water temperature measurements from co-located or nearby stations, obtained as part of the Triangle Area Water Supply Monitoring Project, were used to supplement the DWQ measurements. For each of these stations, water temperatures in the top and bottom water layers were calibrated to observed water temperatures in the same depth range. In many cases, several observations fall within the depth range of an EFDC layer, in which case the observations were averaged.

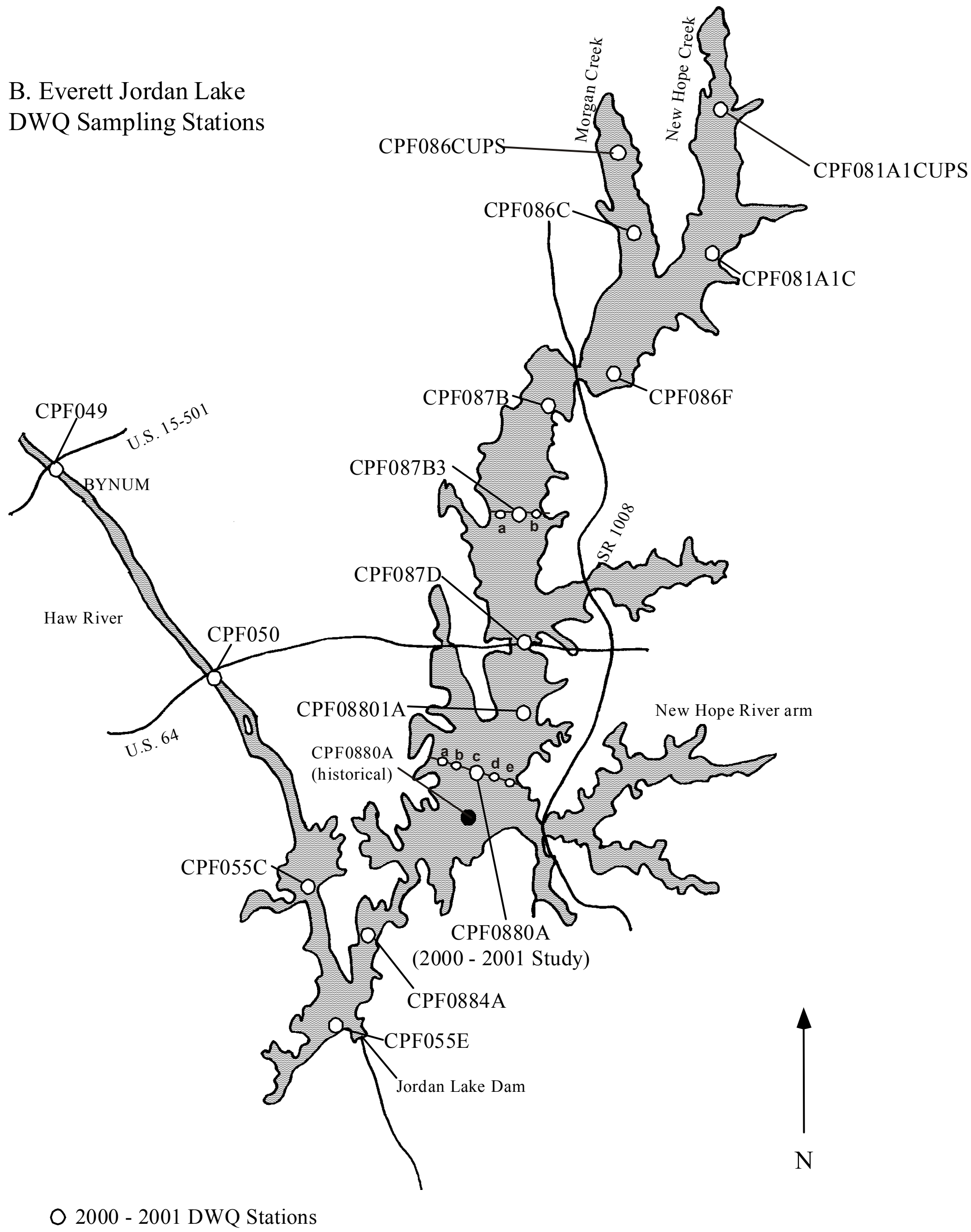


Figure 3-7. DWQ Water Quality Sampling Locations in Jordan Lake

Sensitivity analysis demonstrated that the water temperature profile in Jordan Lake is most sensitive to atmospheric temperature and the temperature of inflows. Finer details are determined by solar heat gain, longwave radiation exchange, convective heat transfer, and heat gain/loss of evaporation and condensation. These processes, however, tend to be dominated by the atmospheric temperature. For instance, if solar heating raises the water temperature above the atmospheric temperature then heat is rapidly lost by exchange with the atmosphere. Therefore, the most important calibration parameters are the ratio of atmospheric temperature above the lake to those at the meteorological station, and the temperature of inflows, which is poorly constrained by data.

Calibration parameters for the thermal simulation are summarized in Table 3-4. Notes on the determination of these parameter values follow.

Table 3-4. Parameters for Temperature Calibration.

Parameter Name	Parameter Identification	Calibrated Value
SOLRCVT	Ratio of solar radiation at meteorological station to solar radiation entering water	0.65 (for AgNet data)
REVC	Calibration factor on evaporative heat transfer	1.5
SWRATNF	Fast-scale solar attenuation in water column	$2.57\ m^{-1}$
HTBED1	Dimensionless heat coefficient between bed and bottom water layer	$1.0 \cdot 10^{-6}$
HTBED2	Heat transfer coefficient between bed and bottom water layer	$2.0 \cdot 10^{-7}$ m/s
DABEDT	Active bed thickness	1 m
{DBEDT)	Deep subsurface constant temperature	15 ° C
{TEMCVT}	Adjustment to gage atmospheric temp.	0.923

SOLRCVT

Solar radiation data are obtained from the Turfgrass AgNET station for 1997 onward, and for RDU International Airport for 1992-1995. These upland stations are expected to receive greater net solar insolation than the lake for several reasons:

- Reflectance or albedo of the lake surface is expected to reduce solar radiation entering the water column by approximately 10 percent.
- Insolation at the lake surface is expected to be less than that at upland stations due to the presence of increased water vapor and occasional fog over the lake.
- Shading by trees significantly reduces solar radiation reaching the lake surface, particularly in shallow near-shore areas, where heat gain would otherwise be expected to be greatest.

In calibrating the model, it appears that a value of SOLRCVT of 0.65 (applied to the AgNet data) provides reasonable results. For the BASINS 1992-1995 data, this is adjusted upward by 1.374, as noted above, to yield a factor of 0.893. It should be noted, however, that the simulated thermal profile is not overly sensitive to the value specified for SOLRCVT --- because much of the heat gain in surface water in excess of atmospheric temperature is readily exchanged back into the atmosphere.

REVC

The calibration factor on evaporative heat transfer was set to 1.5, a value used in various other EFDC applications. As with SOLRCVT, the Jordan Lake model is not very sensitive to the specification of this parameter.

SWATRNF

SWRATNF determines the extent to which incident solar radiation is captured within the uppermost layer of the model. Solar attenuation in the water column is based on an average reported Secchi disk depth of 0.7 meters and the relationship between Secchi disk and light extinction summarized in Thomann and Mueller (1987). Given the representation of the lake by four vertical layers, most of the solar energy will be captured within the top layer in most segments. The model represents the extinction coefficient as a constant, global parameter with no provision for variation among segments or with time. During algal blooms in quiescent conditions, the light attenuation may be much higher, but much of the captured heat is confined to a thin top layer and re-equilibrated with the atmosphere overnight. Empirically, this is compensated in the model by setting a relatively low value on SOLRCVT.

HTBED1, HTBED2, DABEDT, and DBEDT

The two heat transfer coefficients and the thickness of the active sediment layer were set to values recommended by the EFDC model developer. Sediments below the active layer are assumed to maintain an approximately constant temperature over the year. These were assigned a temperature of 15° C, representative of the average annual air temperature.

TEMCVT

TEMCVT represents the ratio between air temperatures at the meteorological station and at the water surface. This ratio is not known from data because few temperature measurements are available at the lake water surface. It is expected, however, that the lake exerts a damping effect on local air temperature, particularly during extreme summer heat, when temperatures at the lake will be somewhat lower than those at the airport. The model is highly sensitive to the specification of this parameter. Use of a value of TEMCVT of 0.923 appeared to provide reasonable results during calibration.

Temperature Calibration Results

Figure 3-8 provides a comparison of model predictions and observed temperatures for the 1997-2000 calibration period. Figure 3-9 shows the application of the same parameters to the 1992-

1995 validation period. Average errors for each year are summarized in Table 3-5. While there is some discrepancy in results for individual years and locations, the annual average errors all fall within the desired bounds of plus or minus 2° C for the calibration period. Comparison of the same model to the 1992-1995 validation period is hampered by limited data. However, the validation period is also fit fairly well, except for 1995, when water temperatures at the near-dam station (CPF055E) are, in particular, under-predicted.

The discrepancies that are present in the temperature calibration are due to a variety of causes. The most significant factor for the surface water prediction is believed to be the specification of atmospheric forcing functions, particularly air temperature and solar radiation. As these are extrapolated from the Raleigh area, the measured values may not always be representative of conditions at the lake. As noted above, the estimated solar radiation is particularly uncertain for the validation period. In addition, the three time point representation of atmospheric forcing introduces intra-day uncertainty into the simulation. For bottom water temperatures, the most important source of uncertainty is likely the specification of inflow temperatures. These are based on fairly sparse data, and thus are inherently uncertain. Finally, the model employs a constant light extinction coefficient, whereas the actual depth of penetration of light is expected to vary both in space and in time. This parameter primarily affects the distribution of thermal energy between upper and lower levels in the water column.

Despite these uncertainties, the temperature calibration meets criteria and provides a realistic representation of the seasonal distribution of temperatures. Perhaps most importantly for water quality modeling, the temperature model generally does a good job of reproducing both summer stratification and intermittent mixing events. The ability of the model to represent the vertical mixing pattern is key to an accurate representation of nutrient recycling from bottom to surface waters.

Table 3-5. Annual Average Error in Temperature Prediction (Predicted minus Observed in Degrees Celsius).

Year	Count	CPF0880A		CPF055E		CPF086F		CPF087D	
		Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Calibration Period									
1997	5-10	-0.14	-1.30	-1.31	-1.82	+0.03	-1.15	+0.07	-0.55
1998	2-5	+0.55	-1.23	-0.21	-0.17	+1.07	-0.87	+0.51	+0.32
1999	6	+1.36	+0.80	+1.06	+0.07	+0.97	-0.31	+1.57	+1.31
2000	13	-0.11	-0.29	-0.47	+0.20	+0.83	-0.02	+0.56	+1.38
Validation Period									
1992	0-1	--	--	-1.54	-1.35	+0.18	+1.33	-0.27	-1.77
1993	1-5	-0.58	+2.52	-0.65	+0.08	+0.06	-1.24	+0.35	+1.27
1994	1-6	-1.06	+2.51	-0.58	+0.05	-0.23	-1.09	-0.25	-0.59
1995	0-4	--	--	-1.46	-2.34	+0.06	-2.11	+0.30	-1.31
Median Across All Years									
1992-2000		-0.12	+0.26	-0.58	+0.05	+0.18	-0.87	+0.35	+0.32

Notes: Negative values indicate under-prediction by model.
Shaded cells have less than 2 observations.

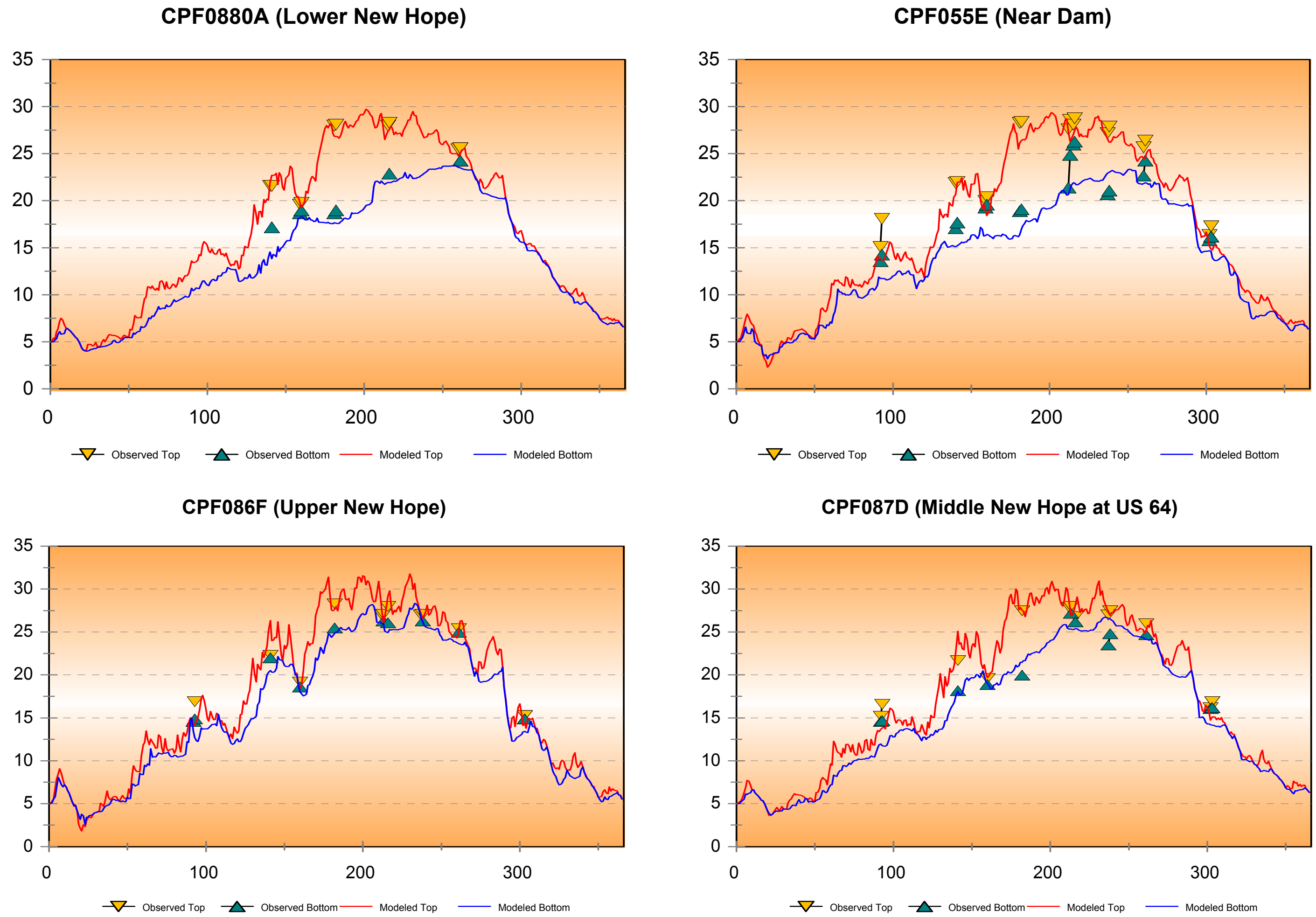


Figure 3-8a. Jordan Lake Temperature Calibration Results, 1997 (°C).

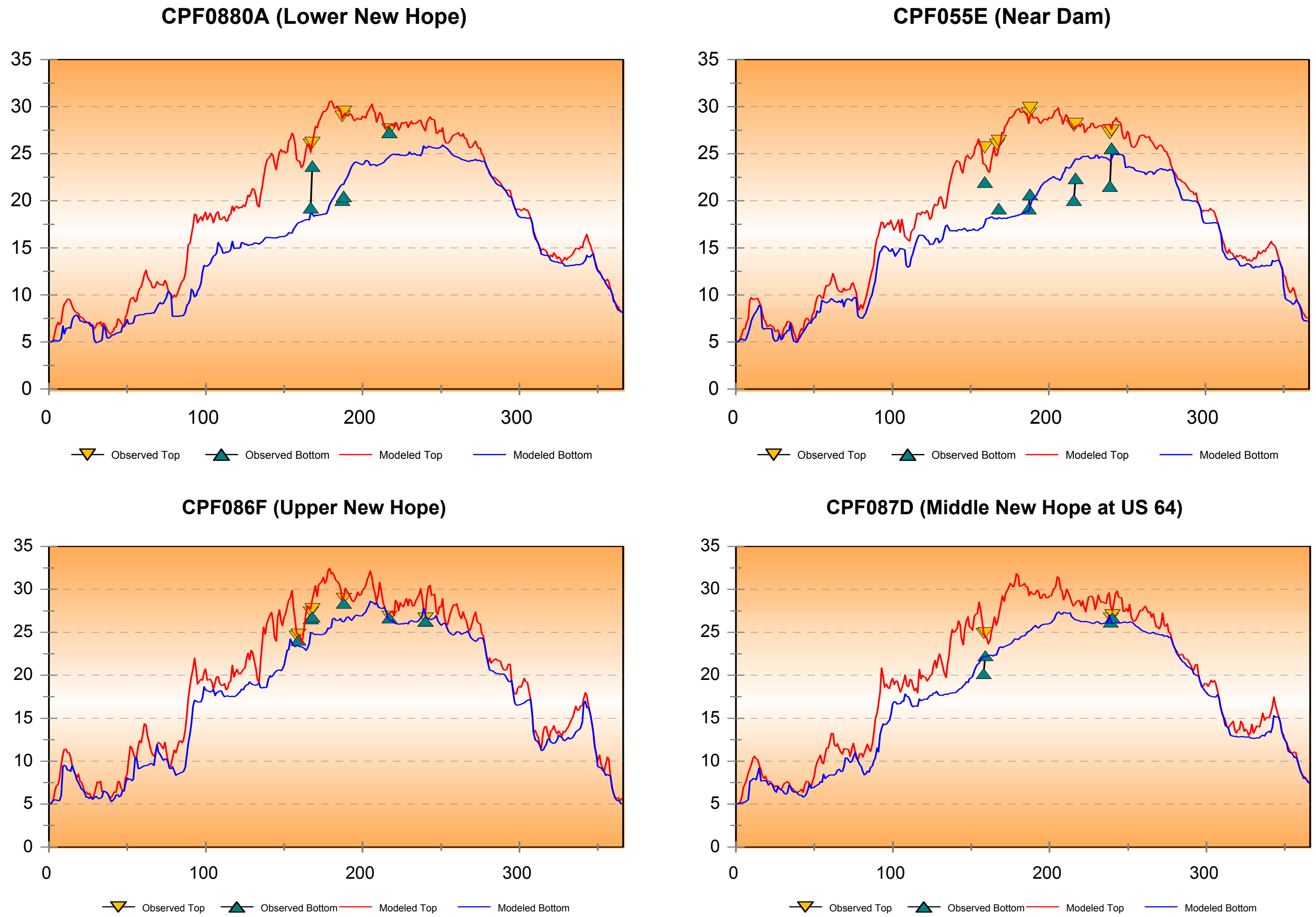


Figure 3-8b. Jordan Lake Temperature Calibration Results, 1998 (°C).

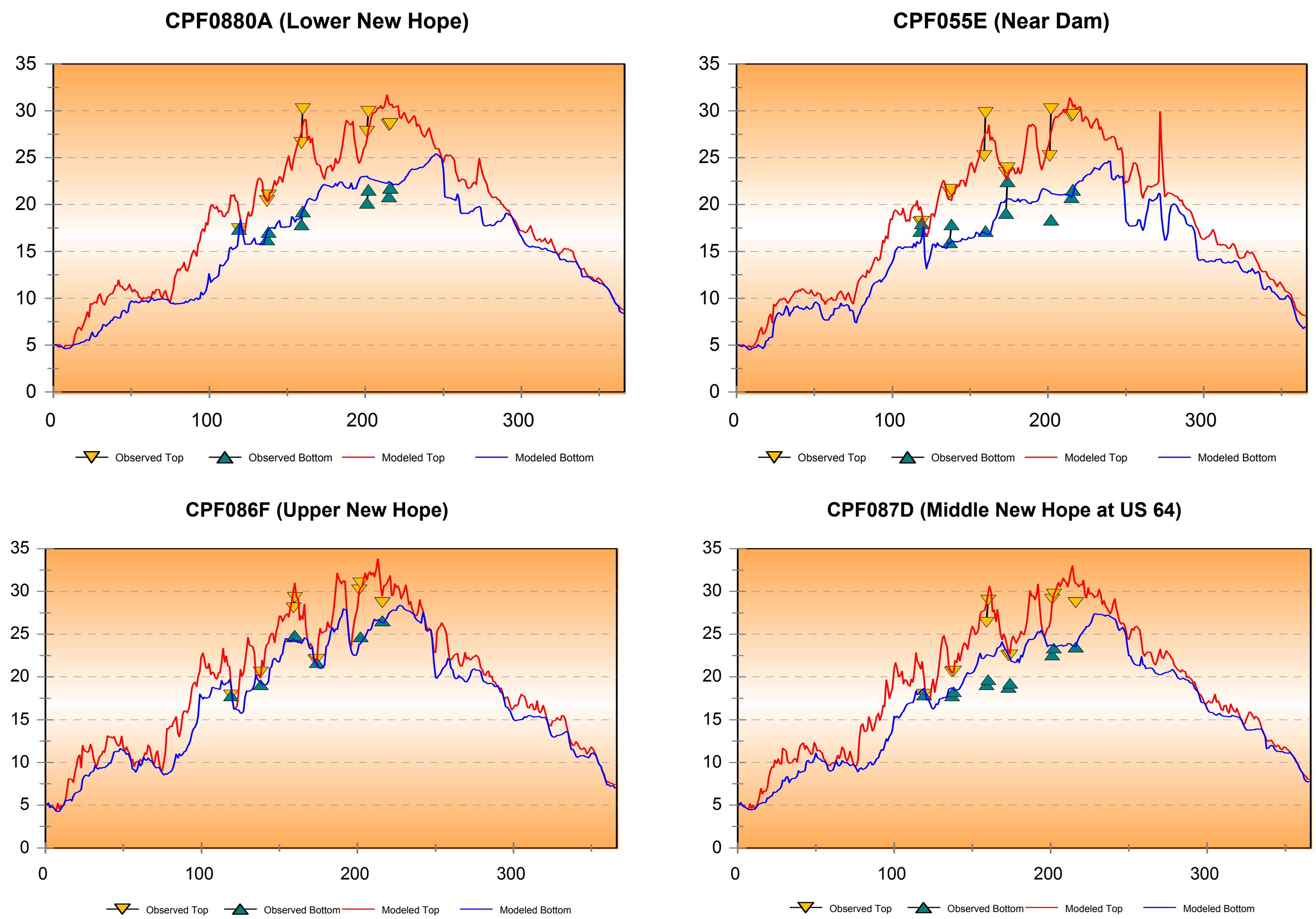


Figure 3-8c. Jordan Lake Temperature Calibration Results, 1999 (°C).

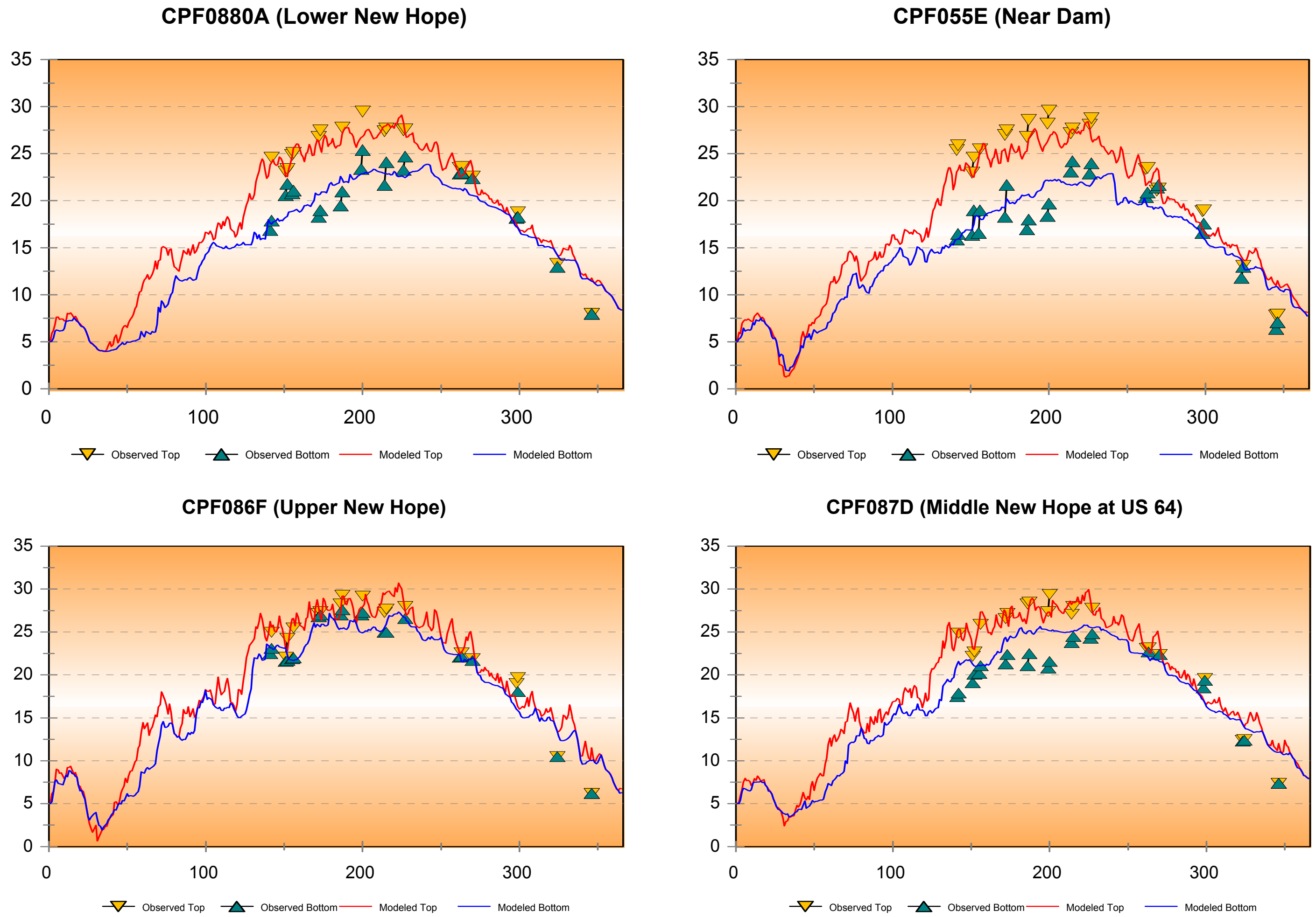


Figure 3-8d. Jordan Lake Temperature Calibration Results, 2000 (°C).

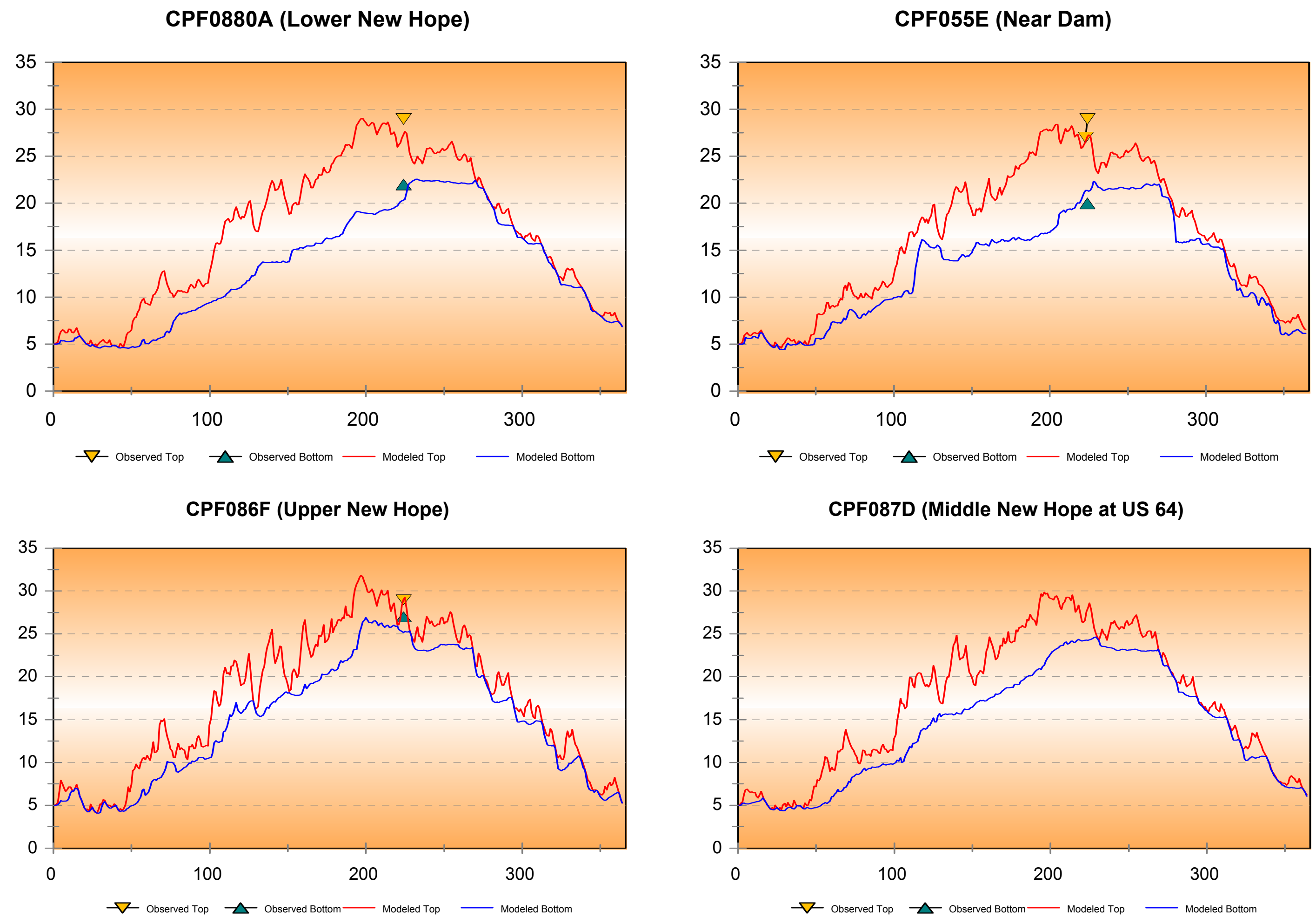


Figure 3-9a. Jordan Lake Temperature Validation, 1992 (°C).

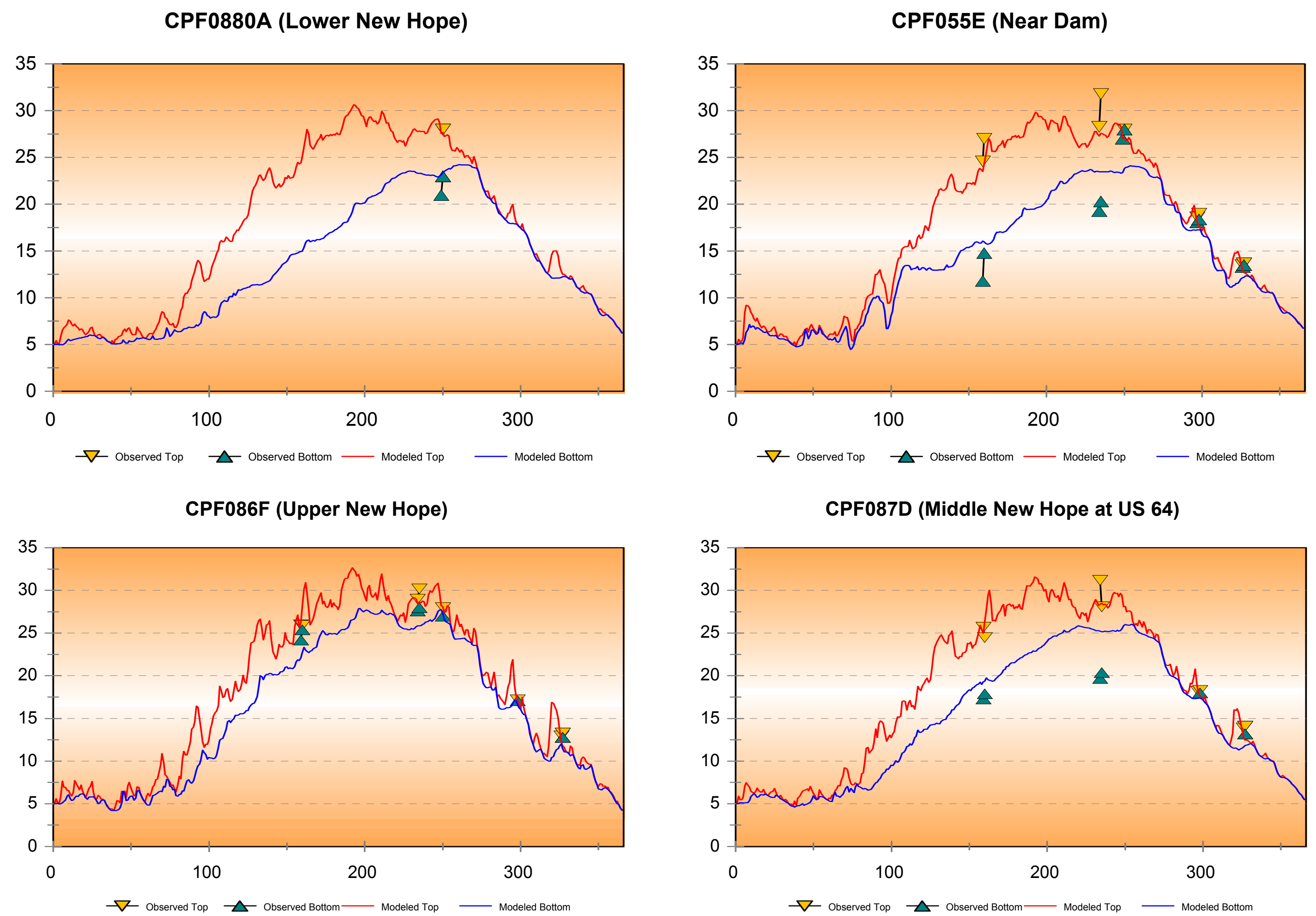


Figure 3-9b. Jordan Lake Temperature Validation, 1993 (°C).

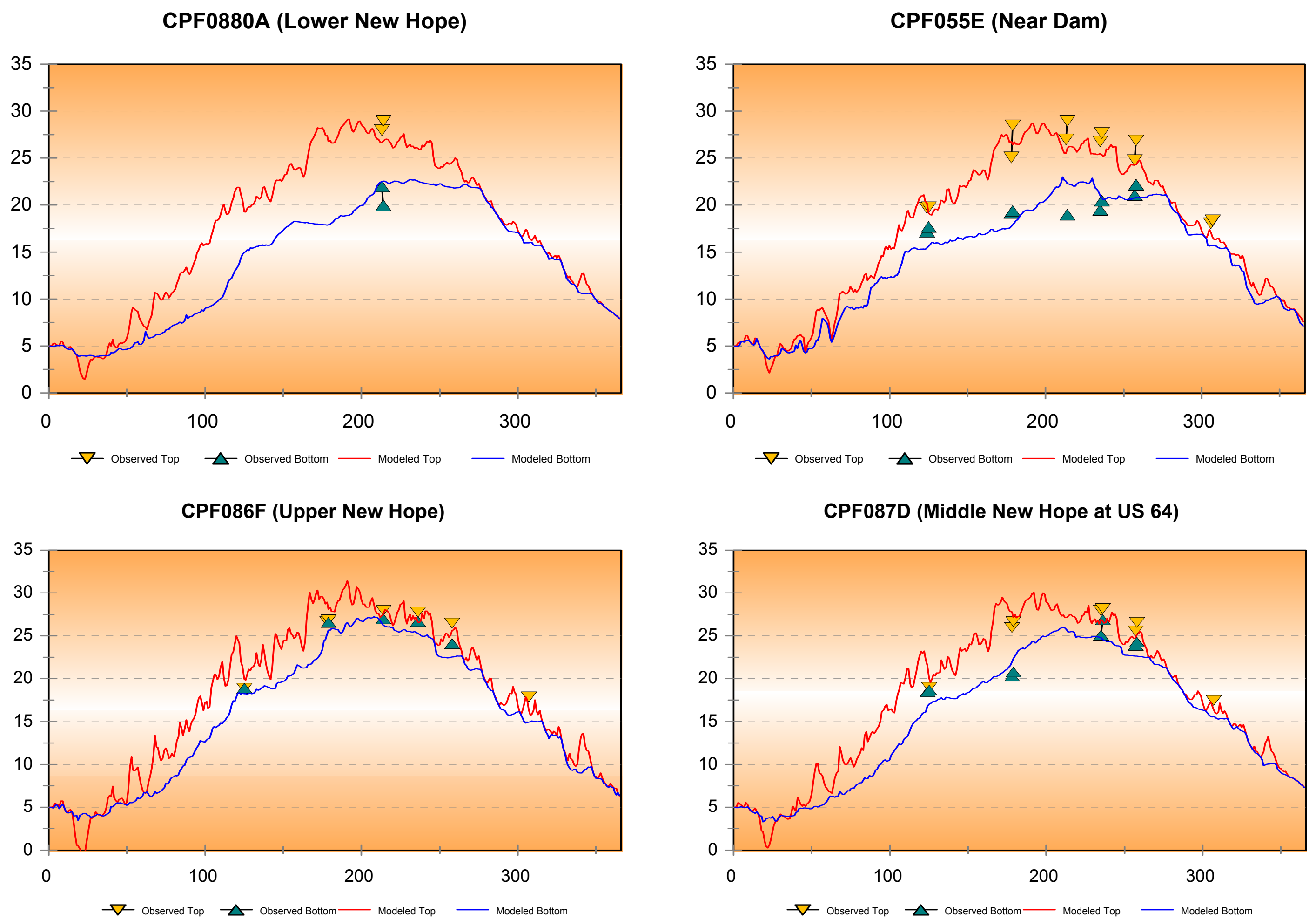


Figure 3-9c. Jordan Lake Temperature Validation, 1994 (°C).

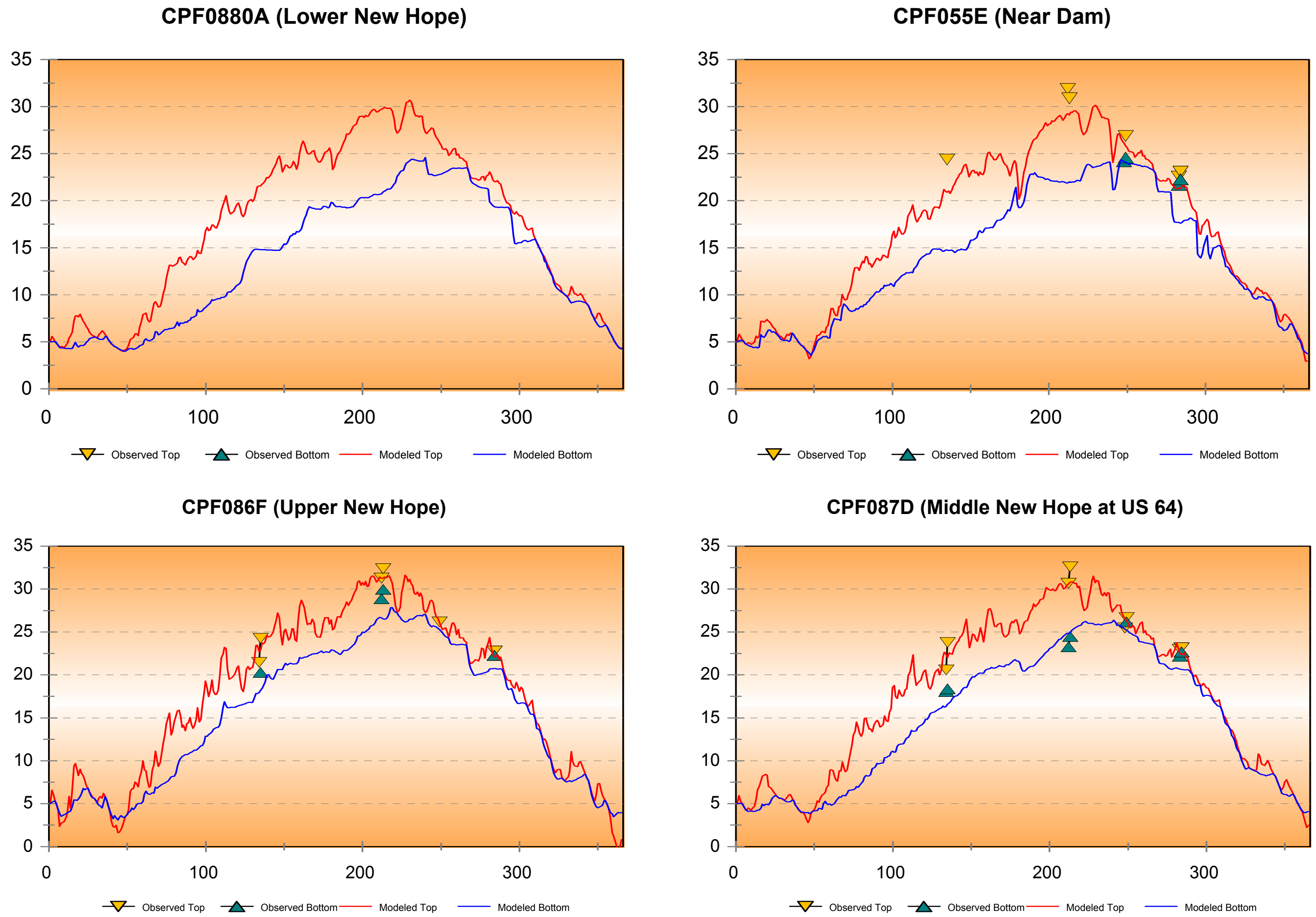


Figure 3-9d. Jordan Lake Temperature Validation, 1995 (°C)

3.1.4 Discussion of Hydrodynamic Model Simulation Implications for Transport between Haw and New Hope Arms of Jordan Lake

The EFDC hydrodynamic model output provides a tool for the evaluation of the movement of water within and between segments of Jordan Lake at a fine spatial scale. One of the key questions for the assessment of allocation scenarios is the degree to which the Haw and New Hope segments of the lake interact. That is, do loads coming from the Haw River propagate upstream through the Narrows to the lower embayment of the New Hope Arm (south of US 64), and further, past the US 64 causeway, into the middle New Hope segment?

Clearly, the net movement of water in the New Hope arm must be to the south, or downstream. However, this segment is, under some conditions, refilled from the Haw River arm, and opposing flows may exist at different depths due to variable temperature and the stress induced by the prevailing wind, which is from the southwest during most times of the year.

Figures 3-10a through 3-10d show the cumulative movement of water in the north-south direction through the Narrows for 1997 through 2000. Results are expressed in total km traveled, and are shown for the four vertical simulation layers at EFDC cell 21-17. In these figures, net movement north is represented by a positive value, and movement south by a negative value.

In all years, the net movement through the Narrows is southward. This southward movement is fairly consistent in the middle water layers (Layers 2 and 3, counting upward from the bottom), but varies in the surface and bottom layers. The seasonal pattern of flows is affected by wind direction and operation of the dam. In general, water is released from the bottom before about day 130 and after day 319, with surface releases during the summer. Except in 1998, the net movement in the surface layer is northward through day 130, then stabilizes and declines over the period of surface releases. The bottom layer tends to move northward during surface releases. After the cessation of surface releases, movement in the surface layer slows or reverses.

Results for 1998 differ somewhat due to inflow patterns. In this year there were several large flow events in the spring, with no subsequent large inflows until the end of the year, accompanied by a drawdown in lake level. This set up a situation in which southward movement in the surface layer was more consistent than in other years.

In all years, the strongest southward movement is in Layers 2 and 3 during the period of surface releases. Net northward movement of constituents delivered to the Haw River arm is thus likely to occur in two ways: (1) in the surface layer during later winter and spring high flows, and (2) in the bottom layer over the course of the summer.

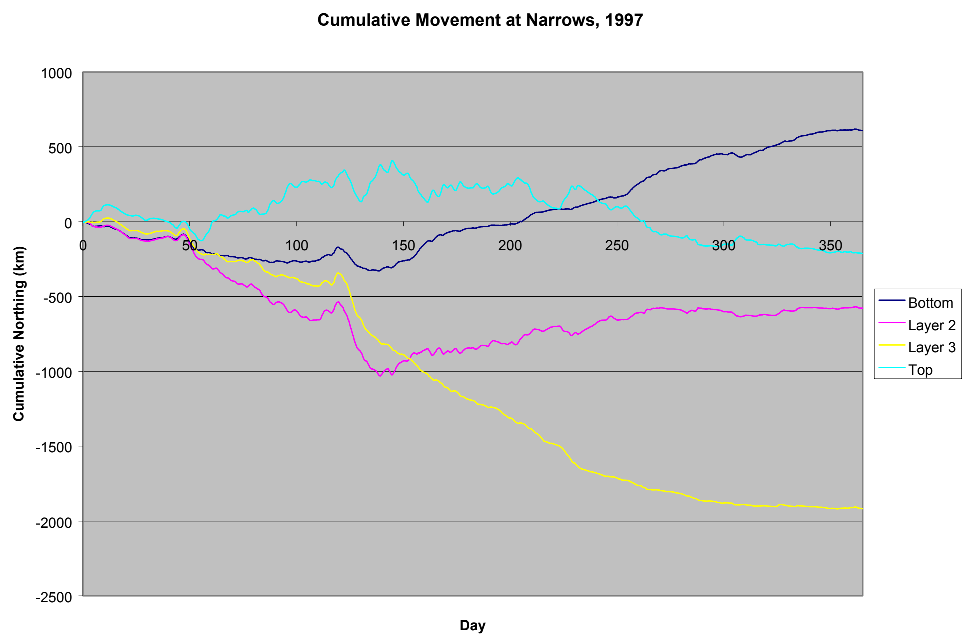


Figure 3-10a. Cumulative Water Movement through the Narrows between New Hope and Haw River Arms of Jordan Lake, 1997.

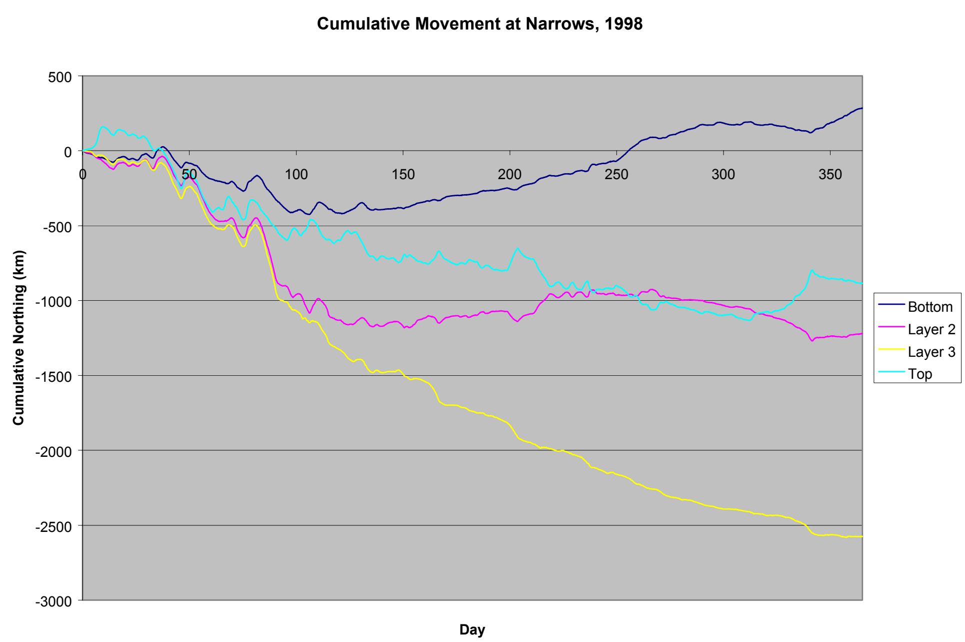


Figure 3-10b. Cumulative Water Movement through the Narrows between New Hope and Haw River Arms of Jordan Lake, 1998.

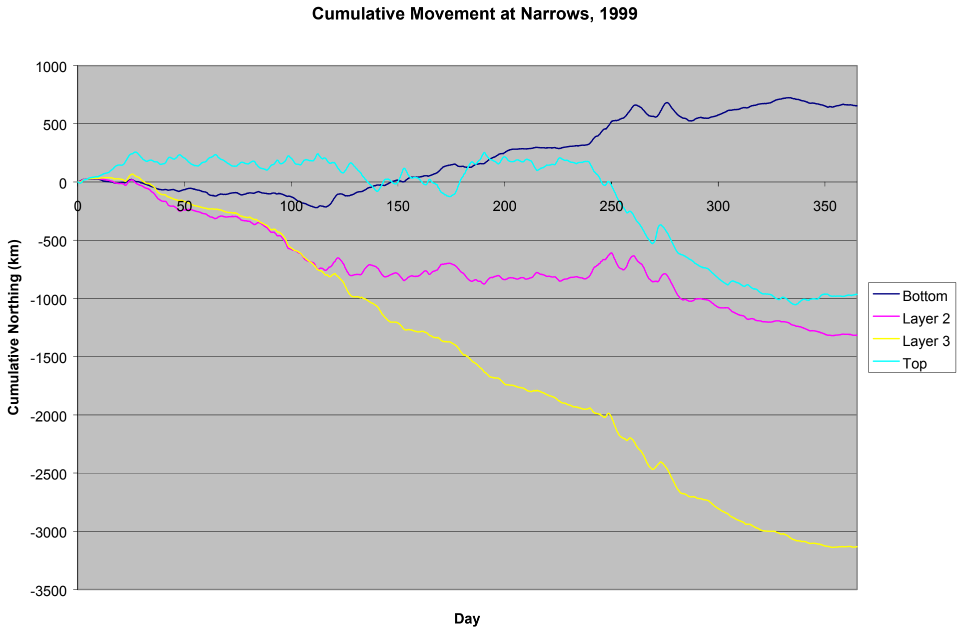


Figure 3-10c. Cumulative Water Movement through the Narrows between New Hope and Haw River Arms of Jordan Lake, 1999.

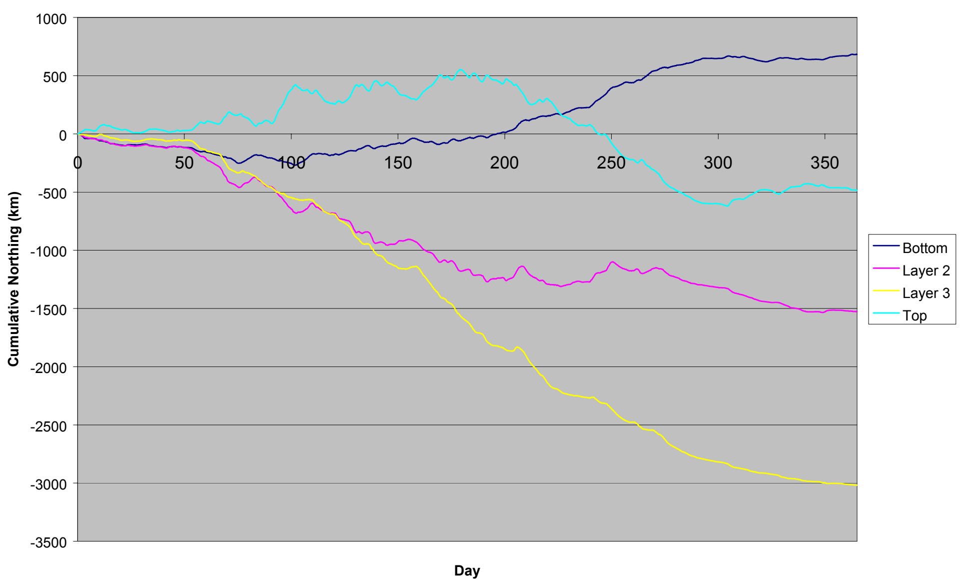


Figure 3-10d. Cumulative Water Movement through the Narrows between New Hope and Haw River Arms of Jordan Lake, 2000.

The model also reveals several other notable features of the circulation pattern. The restriction at the US 64 causeway results in a cyclical pattern of water movement in the middle portion of the New Hope, with water flowing north along the surface in response to wind stress, south along the bottom, and upwelling to the surface at the causeway. The model also predicts that upwelling is likely to occur in the lower portion of the New Hope where the channel narrows. A schematic diagram of the net water movement pattern for the 2000 simulation is shown in Figure 3-11, with the width of the arrows summarizing the relative magnitude of the flux. In this diagram, the four EFDC layers have been grouped into two vertical layers (corresponding to the water quality model) and laterally averaged across the width of the reservoir. Note that the flows past the dam depend on the operating policy: During the summer, water is discharged primarily from the surface layer, while during the winter, flow is discharged primarily from the bottom layer.

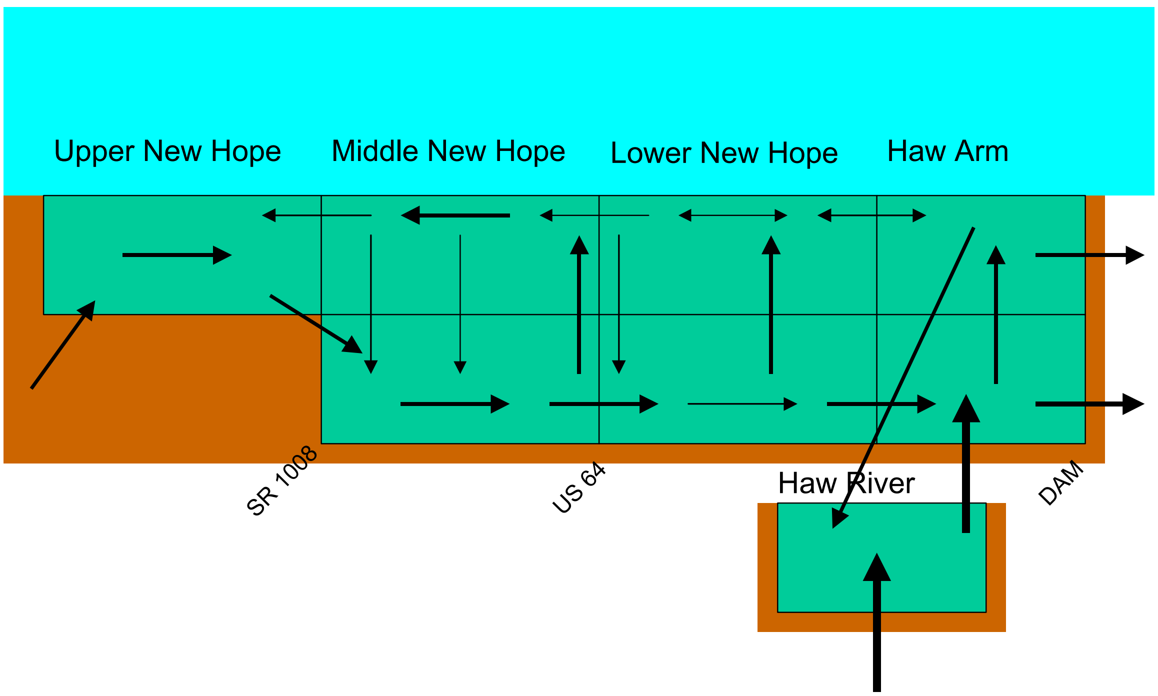


Figure 3-11. Schematic Diagram of Net Water Movement over Year 2000.

3.2 Water Quality Model Development

3.2.1 WASP/EUTRO Model Setup

The EFDC hydrodynamic simulation is used to drive the WASP/EUTRO water quality model. While EFDC is operated on a fine spatial grid and short time step to resolve the complex hydrodynamic behavior of the lake, WASP is operated on a coarser spatial grid and longer time step. This enables run times short enough to calibrate the model, and is also consistent with NC DWQ's objectives of examining lake response at the spatial scale of sampling locations and temporal scale of days to weeks.

3.2.1.1 WASP Representation of Lake Jordan and Linkage to EFDC Hydrodynamic Model

WASP Model Simulation Grid

The spatial "collapsing" of the EFDC grid to the WASP network, in plan view is shown in Figure 3-12. The 386 horizontal cells represented in EFDC are combined to represent 15 cells in WASP. In addition, the four vertical layers in EFDC are collapsed in WASP, where a maximum of two vertical layers are used to represent the lake.

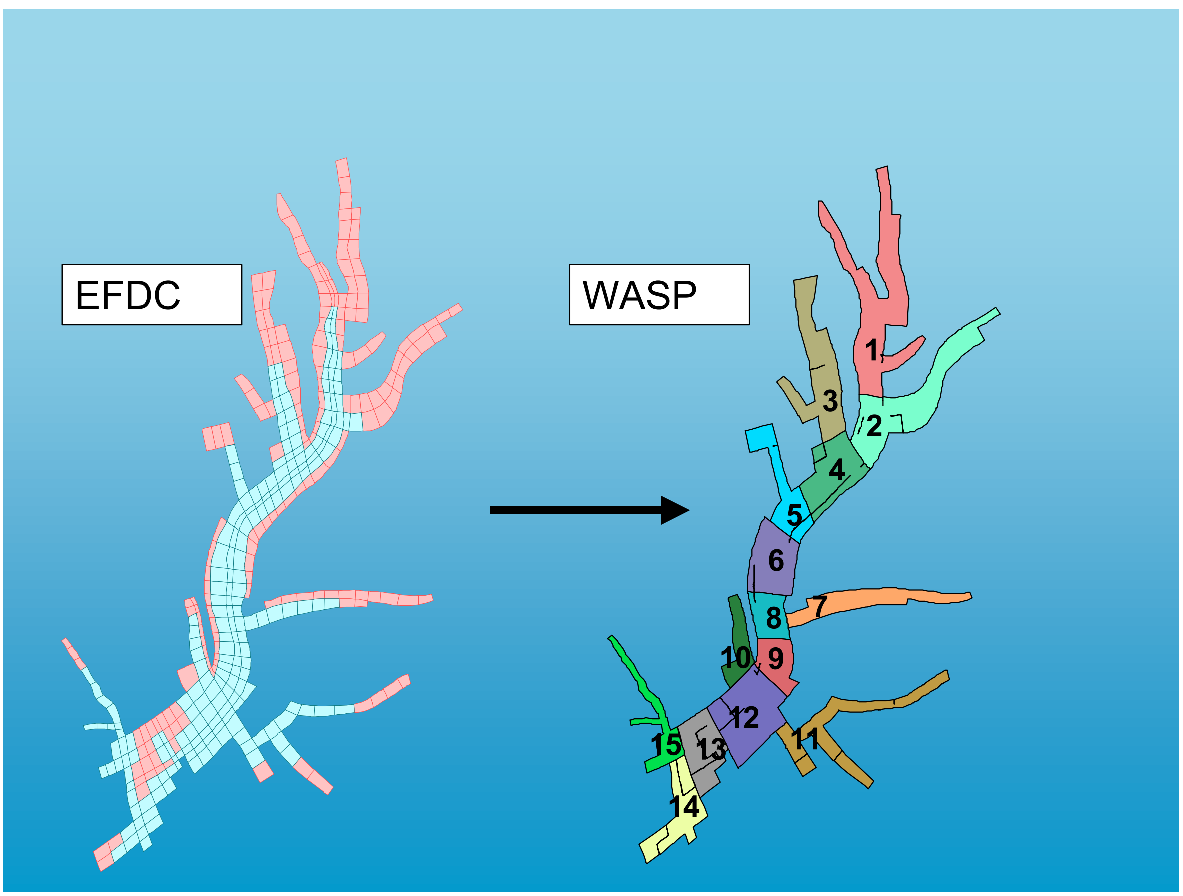


Figure 3-12. Relationship of EFDC to WASP Simulation Networks.

A utility program (WASPCONV.EXE) was written to convert the EFDC output to a formatted external hydrodynamic file (".hyd" file) for use by WASP. Two vertical WASP layers were specified throughout most of the lake. However, in the shallow upstream segments (segments 1 through 4 of the New Hope Arm and segment 15 of the Haw River arm) only a single vertical layer was specified, as these segments tend not to establish stable stratification. In the mapping from EFDC to WASP the upper layer (in areas where two layers are specified) was established with a thickness of approximately 2.5 m at normal pool. This allows the upper layer to correspond to the approximate depth of light penetration to support algal growth, as well as approximating the depth of the thermocline during stratification. The thickness of the upper layer is not constant from segment to segment, however, due to the complications inherent in mapping the EFDC sigma grid to the WASP fixed layer representation.

Locations of lateral segments were also selected to correspond to DWQ monitoring stations, as summarized in Table 3-6. The segmentation also serves to isolate the points at which major wasteflows enter, the Cary withdrawal, and the lake outfall (Figure 3-13).

Table 3-6. WASP Segment Locations and Corresponding DWQ Monitoring Stations.

WASP Segment	Location	DWQ Monitoring Stations
1	New Hope Creek	CPF081A1CUPS
2	New Hope Arm above Morgan Creek, Northeast Creek	CPF081A1C
3	Morgan Creek	CPF086C, CPF086CUPS
4	New Hope Arm above SR 1008 and below Morgan Creek	CPF086F
5	New Hope Arm below SR 1008	CPF087B
6	Middle New Hope Arm	CPF87B3
7	White Oak Creek	
8	New Hope Arm above US 64 Causeway	CPF087D
9	New Hope Arm below US 64	CPF08801A
10	Parkers Creek	
11	Beaver Creek	
12	Lower New Hope Arm near Beaver Creek	CPF0880A
13	Lower New Hope Arm at Narrows	CPF0884A
14	Jordan Lake at Dam	CPF055E
15	Haw River Arm	CPF055C

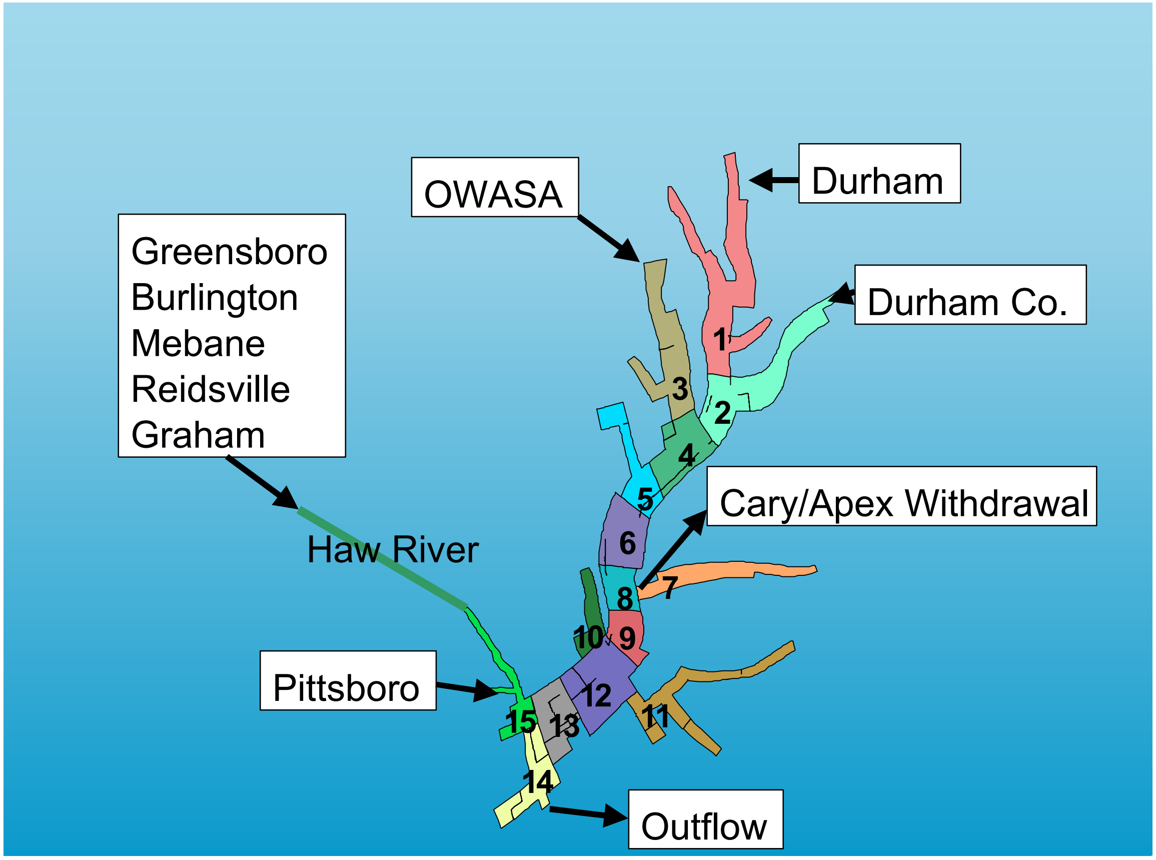


Figure 3-13. Relationship of WASP Model Segments, Major Dischargers, and Withdrawal from Jordan Lake.

Fluxes across each of the WASP segment boundaries are obtained by summing all the corresponding boundary fluxes estimated for the smaller EFDC cells. In moving to a coarser scale (in space and time), the WASP model represents an averaging of the EFDC simulation of the movement of water. Some fine-scale detail of water movement is potentially lost in this process; however, the effect on the movement of pollutants can be incorporated into the macrodispersion (mixing) coefficients in the WASP model. These dispersion coefficients were taken as calibration parameters in the WASP application. The EFDC to WASP linkage does not result in any conservation of energy problems as both momentum and thermal energy simulation are handled exclusively within EFDC. Testing of the resulting WASP model showed that mass is conserved and stability maintained within the water quality simulation. Thus, the WASP model is a simplified representation, but firmly based in the detailed flow and temperature simulation of the lake provided by EFDC.

Simulation Time Step

The solution method used in the WASP model requires specification of a time step length that is not greater than a stability criterion that is determined by the rates of movement of mass between model segments. It is preferable to set the time step as close as possible to the stability criterion as this helps to minimize numerical dispersion (essentially roundoff error). Through examination of the stability diagnostics, a simulation time step of 45 minutes (0.03125 days) was found to be appropriate. This is contrasted to the EFDC time step of 30 seconds.

Thermal Simulation Linkage

Water temperature is important in the water quality model as many reaction rates may be simulated as exhibiting a temperature dependence. As described in Section 3.1, the EFDC model was also used to develop the thermal simulation of Lake Jordan. Water temperatures are input to WASP as a time series in the input file. The continuous predicted temperature time series at CPF086F (WASP segment 4) was selected as representative of the Upper and Middle New Hope sections of the lake, while the predicted time series at CPF055E (WASP segment 15) was selected to represent water temperatures in the Lower New Hope and Haw River arms.

3.2.1.2 Tributary Flows and Loads

The calibration, validation, and baseline simulations with WASP are driven primarily by measured flows in the major tributaries and loads estimated from measured concentrations. These measurements represent both the point and nonpoint loads upstream of a monitoring station. The baseline loads were then modified to represent different wasteload allocation scenarios, as described in Chapter 4.

Lake segments 1, 3, and 15 are strongly driven by external tributary loads. During calibration it became apparent that there were some shifts in nutrient speciation between the tributary monitoring sites and the lake segment that could not be readily explained by internal lake dynamics. Notably, the station on the Haw River at Bynum is several miles upstream of the normal pool of the lake, and there is dense riparian cover in the intervening reach that can be expected to extract soluble inorganic nitrogen from the river. At the upper end of the New Hope arm, New Hope Creek, Little Creek, Northeast Creek, and Morgan Creek enter the lake through extensive wetland areas. There are also "greentree" impoundments present on New Hope and Little Creeks. These areas may be expected to process nutrients, converting inorganic to organic forms, as well as to provide some nutrient trapping.

To address these issues, the FLUX-estimated nutrient loads present at the monitoring stations were adjusted to better represent the observed concentrations in the upstream lake segments. Specifically, organic nitrogen was reduced by 20 percent and the remainder partially shifted to ammonia nitrogen in the New Hope and Northeast Creek inputs, while uptake losses of nitrate nitrogen and a shift from ammonia to organic nitrogen forms were added to the Haw to represent transformations in the reach between Bynum and the lake. The net impact of these changes is to reduce the FLUX-estimated total nitrogen load in New Hope Creek by 7 percent, in Northeast Creek by 5 percent and in Haw River by 23 percent. The relatively large loss estimated for the lower Haw River was necessary to achieve an approximate mass balance with observed nutrient concentrations in the Haw arm.

External tributary flows are simulated in the EFDC model, and the resulting segment-to-segment movement of water is brought into the WASP model via the linkage to EFDC. Tributary pollutant loads were estimated using the U.S. Army Corps of Engineers' FLUX package, as described in Section 2.3.

Pollutant Load Time Series for Unmonitored Areas

The majority of the watershed area draining to Jordan Lake is gaged and monitored. Loading estimates from these monitored areas are obtained using the FLUX model. There are, however, approximately 250 square miles of the watershed—primarily in areas immediately surrounding the lake—that are not gaged or monitored. These areas are summarized in Figure 3-14, with the numbers indicating the associated section of the lake water quality model.

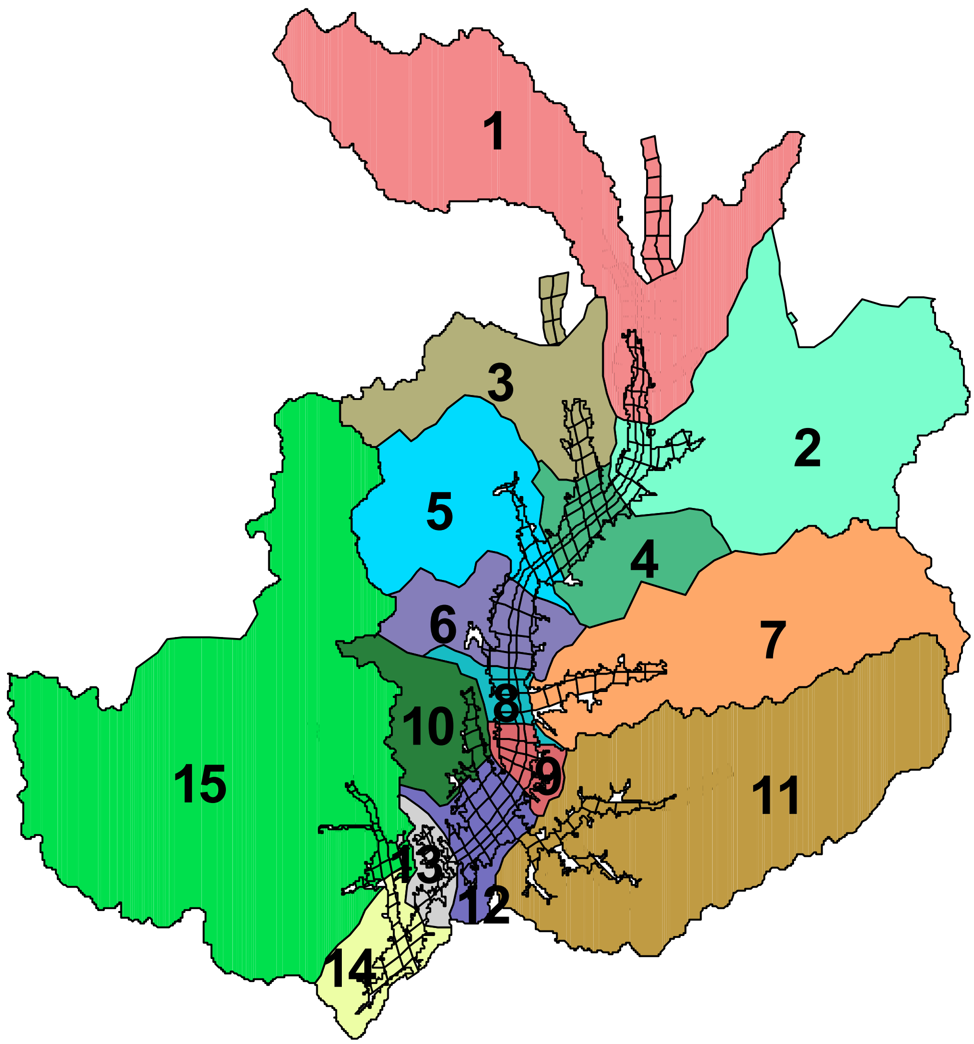


Figure 3-14. Unmonitored Drainage Areas, Jordan Lake

Loading time series must be estimated for these unmonitored areas, but creation of a watershed loading model was outside the scope of the project. The initial approach proposed was to use the monitored time series of loads in Morgan Creek, New Hope Creek, and Northeast Creek, minus the daily estimates of delivered or "exerted" point source load to estimate the nonpoint loading rates. This approach proved infeasible due to high levels of uncertainty in the estimates of loading from the wastewater treatment plants (e.g., monitoring of total nitrogen only on a monthly basis), coupled with uncertainty in the FLUX estimates of load, which results in frequent dates on which the exerted point source load is greater than the FLUX estimated load. Over the longer term, results appear more reasonable, in most cases, but are still apparently subject to a high level of uncertainty. This is shown in Table 3-7, which summarizes the *apparent* nonpoint loading rates (pound per acre load minus the estimated delivered portion of the point source load) for 1996-1998. Some of these rates are clearly too low (in particular, the nonpoint nitrogen load in Morgan Creek cannot be less than zero, while the per acre loading rate from New Hope Creek appears much lower than would be expected for this largely urbanized watershed). In contrast, the estimated nonpoint load from Northeast Creek appears high, perhaps reflecting an underestimate of point source loading.

Table 3-7. Apparent Nonpoint Loading Rates (lb/acre) for 1996-1998 Calculated from FLUX Load Series minus Exerted Point Source Load.

Watershed	Total Nitrogen (lb/acre)	Total Phosphorus (lb/ac)
Haw River	3.1	0.51
Northeast Creek	5.5	1.06
New Hope Creek	4.2	0.06
Morgan Creek	< 0	0.14

Due to the high level of uncertainty evident in Table 3-7, it appeared prudent to estimate the loading from unmonitored areas based on literature values of loading factors. Loading factors for total nitrogen and total phosphorus (by land use and soil hydrologic class) summarized in CDM (1989) are based on a combination of local and national studies, and have been generally accepted as reasonable estimates for the area.

The long-term average loading factors must be converted to surrogate time series of daily loads. Loads will vary with flow, and total annual loads will vary from year to year depending on flow patterns. The objective is to specify a default concentration value that will yield a reasonable load estimate from the unmonitored areas. This is done by using a scaled flow pattern from a gaged area coupled with a constant concentration value specified such that the desired average annual load is achieved.

The annual load from an unmonitored area, assuming constant concentration, is given by

$$L = \sum_{i=1}^{365} QR_i \bullet Scal \bullet C$$

where L is the annual load (kg), QR_i is the reference flow at the gaged station (cubic hectometers or hm^3/day), *Scal* is a scaling factor, approximately equal to the ratio of land areas for the unmonitored area relative to the gaged area, and *C* is the concentration (ppb).

To select a value of *C* sufficient to set the long-term average annual load equal to an externally estimated value, this equation may be rearranged to yield

$$C = \overline{L} / (\overline{Q} \bullet Scal)$$

where the overbars indicate the annual average of the load from the unmonitored area and the flow at the gage respectively.

For example, to achieve an average load of 1000 kg for an unmonitored area with *Scal* = 0.45 and average annual flow at the reference gage of 90 hm^3/yr, C would be set equal to 24.7 ppb (0.0247 mg/L). Note that this approach is guaranteed to yield the specified average load regardless of whether the flow from the unmonitored area is accurately predicted by application of the scale factor to the gage. Essentially, the externally specified load is: (1) scaled to the relationship of flow in a given year to long-term average flow, and (2) partitioned among days in the year according to the flow pattern observed at the gage.

Two reference gages are used to set the pattern for the unmonitored areas. The USGS gage on New Hope Creek near Blands is used as a template for flows from the Little Creek drainage, as both watersheds are influenced by greentree impoundments. The remaining unmonitored areas use the USGS gage on Northeast Creek as a template, as this gage represents a watershed without significant upstream impoundment. The other available gage, on Morgan Creek, is not used as a template because of the influence of University Lake on observed flows. The long-term average flows for these gages are summarized in Table 3-8.

Table 3-8. Long-Term Average Flows at USGS Gaging Stations.

Station	Record Used	Average Annual Flow (hm^3)	Upstream Area (mi^2)
New Hope Creek near Blands	10/85-9/00	89.46	75.68
Northeast Creek	10/85-9/00	29.76	20.98

Total nutrient loads from each of the unmonitored areas shown in Figure 3-14 were calculated using the loading factors given in CDM (1989) and the project land use coverage. About 87 percent of the land area is shown in the GIS as in forest or shrub cover; however, it is known that the satellite imagery does not identify larger lot rural and suburban residences. Therefore, the loading rates for rural residential land use (5 acre lot size) were assumed to be the most appropriate for the forest land use class, except for those areas in which the land area is predominantly controlled by the Corps of Engineers (unmonitored areas 8, 9, 12, 13, and 14), for which the forest loading factors were used. Nitrogen and phosphorus loading factors are presented by landuse and hydrologic soil group in Table 3-9. Only the landuses and soil groups within the unmonitored areas are listed.

Table 3-9. Nutrient Loading Factors by Landuse

Landuse	Total Phosphorus (lb/ac/yr)			Total Nitrogen (lb/ac/yr)		
	B	C	D	B	C	D
Forest	0.08	0.08	0.08	0.6	0.6	0.6
Conventional Tillage	4.7	5.6	6.6	15.9	17.9	20.4
Pasture	0.5	0.5	0.5	2.6	2.6	2.6
Low Density Residential	0.8	0.9	0.9	6.7	6.6	6.5
Commercial	1.6	1.6	1.6	13.2	13.2	13.2

The 15 unmonitored areas shown in Figure 3-14 were aggregated to a more manageable set by combining several adjacent areas and assigning the load input to a single model node. This approximation is consistent with the assignment of inflows in the hydraulic model and is not expected to introduce significant error into the water quality model. The aggregate concentrations of total nitrogen and total phosphorus estimated by this procedure are summarized in Table 3-10.

Table 3-10. Average Concentration Specifications for Unmonitored Areas

Input Segment	Unmonitored Areas	Area (ac)	Scale Factor	TN Load (kg/yr)	TP Load (kg/yr)	TN Conc (mg/L)	TP Conc (mg/L)
1	1	22725	0.47	37368	3715	0.89	0.089
2	2	19703	1.47	29956	3318	0.69	0.076
3	3,4	12271	0.91	18362	1918	0.68	0.071
5	5	8653	0.64	13393	1352	0.70	0.070
7	6,7,8	20654	1.54	33688	4276	0.74	0.093
11	9, 11	25448	1.90	41710	5288	0.74	0.094
10	10,12,13	6391	0.48	6559	585	0.46	0.041
15	14,15	44123	3.29	63855	6393	0.65	0.065

For input to the WASP model, the total nutrient concentrations must be further subdivided to inorganic phosphorus, organic phosphorus, nitrate nitrogen, ammonia nitrogen, and organic nitrogen. Based on patterns observed at the monitoring stations, these fractions were assigned for the unmonitored areas as follows: Total phosphorus was assumed to be 45 percent organic P, while total nitrogen was partitioned as 75 percent nitrate nitrogen, 5 percent ammonia nitrogen, and 20 percent organic nitrogen. Unmonitored area 1 (largely consisting of Little

Creek), with extensive wetlands and a greentree impoundment, was assumed to experience a shift in nutrient speciation to organic forms similar to that assumed for the monitored load in New Hope Creek.

The nonpoint loading series inputs were also used to account for several minor point source loads that are not upstream of monitoring points (Cole Park, Fearrington Village, Nature Trail MHP, and Pittsboro WWTP; note that the minor discharge from Carolina Meadows is upstream of the Morgan Creek water quality monitoring site and so is included in the FLUX estimates). Each of these sources is specified as a constant daily load based on discharger monitoring and RTI's estimates of delivered load fractions at the lake (Table 3-11). These are calculated separately for 1992-95 and 1996-99 to account for changes over time.

Table 3-11. Estimated Delivered Loads from Minor Point Sources

Discharger	Receiving Water	Model Segment	Period	TN delivered		TP delivered	
				kg/d	kg/yr	kg/d	kg/yr
Cole Park Plaza *plus* Nature Trail MHP	Cub Creek	3	1996-99	1.21	442	0.38	139
			1992-95	1.66	606	0.20	73
Fearrington Village	Bush Creek	5	1996-99	4.45	1624	0.81	296
			1992-95	4.11	1500	0.41	150
Pittsboro WWTP	Robeson Creek	15	1996-99	11.62	4241	1.77	646
			1992-95	14.10	5147	1.29	471

Tetra Tech created a utility program (EXTNPS.EXE) that automatically creates the NPS file, based on the specifications above, and formats the file as required for input by WASP.

3.2.1.3 Meteorological Forcing Functions

Solar Radiation

Solar radiation data for use by WASP used the same data sources as the EFDC model. A daily time series of total solar radiation at the surface (langleys per day) was developed from North Carolina AgNET observations from March 1997 onward. For the first two months of 1997, no local observations are available, and average values for these dates in subsequent years are used.

Light Extinction Coefficients

As revealed in the scoping model application, availability of light for photosynthesis is an important limiting factor on algal growth in Jordan Lake. High levels of dissolved organic material, fine suspended solids, and color all scatter light and limit the zone in which algae can grow. Observed Secchi disk depths (the depth to which a standard optical target is visible from the surface) are often less than 0.5 meters.

WASP models the light available for photosynthesis from the incident solar radiation at the water surface and the rate of light attenuation or "extinction" in the water column. Light extinction is represented by an extinction coefficient (*Ke*), such that light remaining at depth *z* is equal to $e^{-Ke \cdot z}$.

The model estimates *Ke* as the combined effects of algal self-shading, which can be important under bloom conditions, and a non-algal component, represented through a user-supplied extinction coefficient (*Ke'*) that can vary in time and space.

The total light extinction coefficient in a body of water can be estimated from the empirical relationship recommended by Thomann and Mueller (1986) as

$$K_e \approx 1.8 / z_s$$

where z_s is the Secchi depth in meters. The general validity of this relationship for Jordan Lake is confirmed by comparison to measured depth of 1 percent light penetration measured by NC DWQ for samples in 2000 as the depth of 1 percent light penetration is equal to $4.61/K_e$. The non-algal component of light extinction was in turn estimated by the relationship developed by Riley (1956), which is the approach recommended by Thomann and Mueller (1986) for waterbodies in which chlorophyll *a* concentrations exceed 15 µg/L:

$$Ke' = Ke - 0.0088\, C - 0.054\, C^{2/3}$$

where *C* is the chlorophyll *a* concentration in µg/L.

Temporal changes in light extinction, such as may occur after storm washoff raises turbidity, likely play an important role in the dynamics of algae in Jordan Lake. Unfortunately, the measurements of water clarity are sparse for most years, ranging from five per year in 1997 to 12 per year in 2000 over the calibration/validation period. In addition, the relationships to Secchi depth and chlorophyll *a*, as well as the reported chlorophyll *a* measurements, are imprecise, and there is considerable uncertainty associated with individual measurements. For example, a shift in reported Secchi depth from 0.3 to 0.4 results in a 33 percent change in the estimated extinction coefficient. Finally, there are almost no late fall-winter-spring observations prior to 2000. It was therefore judged that insufficient data are available to specify the exact time history of light extinction in the lake. But, there do appear to be some annual and seasonal trends in water clarity. As a compromise, the time series of extinction coefficients was represented as follows:

January – May	Use long term median values for 1990-2001 (data primarily from 2000-2001).
June – September	Use the median value for a given year.
October – December	Use long term median values for 1990-2001 (data primarily from 2000-2001).

Four series of *Ke'* values were specified for different areas of the lake. The final representation is summarized in Table 3-12. A comparison was also run for straight interpolation through each *Ke'* estimate. The differences in chlorophyll *a* predictions are small between the two methods.

Table 3-12. Representation of Non-algal Light Extinction Coefficient, *Ke′* (1/m)

Location	Upper New Hope Arm	Middle New Hope Arm	Lower New Hope Arm	Haw River Arm
DWQ Station	CPF086F	CPF087B3	CPF0880A(c)	CPF055E
Jan.-May	3.11	2.15	2.09	1.52
Summer 1997	2.71	1.81	1.43	1.57
Summer 1998	4.01	1.83	1.43	2.11
Summer 1999	2.52	1.57	1.06	2.17
Summer 2000	2.47	1.55	1.04	1.58
Oct.-Dec.	2.19	1.70	1.46	1.41

Day Fraction for Phytoplankton Growth

WASP uses an empirical formulation to distribute the total daily solar radiation over the daytime period. A daily time series was created to describe the fraction of simulation day *i* with sufficient light for algal growth (F_i^*). Daylight period was calculated from sunrise and sunset times at Raleigh Durham International Airport. Because of low light intensity near sunrise and sunset, a total of one hour (30 minutes in the morning and 30 minutes in the evening) was subtracted from the total daylight period to yield the active photosynthetic period at simulation day *i* (APP_i). F_i^* is then described using the equation:

$$F_i^* = \frac{(APP_i)}{24}$$

Daily Average Wind Velocity

WASP uses wind velocity to estimate reaeration of the water column; the effects of wind stress on water movement are calculated separately in the hydrodynamic model. A daily time series for wind speed was created using data for average wind speed (m/sec) from Raleigh Durham International Airport for early 1997 and data from the North Carolina State University Turfgrass Field Laboratory from May 1997 on.

Ammonia Generation

WASP includes provisions to simulate the decay of organic matter and the production of ammonia/ammonium in benthic sediments. The model does not, however, adequately account for all sources of nitrogen regeneration associated with near-shore wetlands and macrophytes, nor is its representation of sediment processes sufficiently sophisticated to simulate seasonal patterns of reduced nitrogen release. These sources may contribute significant amounts of both organic and reduced nitrogen on a seasonal basis. The model can represent these only as an ammonia source. The ammonium flux was described by a repeating function that adds sediment release primarily in the September through November period with a peak of 50 mg/m^2-day. This maximum rate is consistent with the limited data available in the literature and summarized in U.S. EPA (1997).

Phosphate Generation

Similarly to ammonia generation, the model simulates the production and release of inorganic phosphorus in bed sediments in a simplified manner, but does not represent the true seasonal pattern of benthic phosphate release nor explicitly represent the regeneration of phosphorus from decaying macrophytes and near-shore swamps. Therefore, a fall phosphate release function was also specified, with peak value of 6.9 mg/m^2-day. The peak release of phosphate is set in accordance with the stoichiometric ratio for organic matter (1 mg P/7.2 mg N) described by Redfield et al. (1963).

3.2.2 WASP/EUTRO Model Code Enhancements and Model Options

Minor modifications were made to the WASP/EUTRO code. First, the program was recompiled to allow a larger number of time points in external forcing functions sufficient to address a 4-year simulation with forcing functions specified at a daily time step. A logic error in subroutine BENTFLUX was fixed to allow correct representation of additional user-specified benthic fluxes when porewater exchange with sediment segments is also simulated. Subroutine WAS6A was modified to allow specification of the tributary input file in the input string, allowing batch processing of multiple runs. Subroutines WAS4A, EULER, DERIV, and HYDROIN were modified to allow the simulation time step to be an even fraction of the external hydrodynamic time step. The program was also modified to eliminate non-essential screen writes, thus speeding run time for optimization. Finally, some additional diagnostic checks for undefined values were inserted into a number of subroutines.

3.2.3 WASP/EUTRO Model Calibration Targets

The model is intended to evaluate "nutrient response" in Jordan Lake. According to direction provided by NC DWQ, the key factor in evaluating nutrient response for Jordan Lake will be algal response, and, in particular, the response of chlorophyll *a*, for which a regulatory standard exists in North Carolina. To provide a defensible prediction of algal response, however, it is also necessary to accurately simulate the nutrients on which algae depend for growth. Algae utilize the inorganic forms of nitrogen and phosphorus (ammonium, nitrate, nitrite, and phosphate), but these inorganic forms are rapidly recycled in the lake, and are often at or below analytical detection limits used by DWQ. During the growing season, most of the nitrogen and phosphorus present in the lake is found in organic forms. There are also potential problems associated with sampling and analysis for individual nutrient species (e.g., uptake by bacteria or decay of living matter between collection and analysis). Also, nutrient speciation (as opposed to total nutrient concentration) may be subject to high spatial variability, depending on whether a sample was collected at a location and depth coincident with high algal activity. The inorganic nutrient concentration estimates should therefore be considered as relatively imprecise compared to total nitrogen and phosphorus measurements. Therefore, total nitrogen and total phosphorus concentrations are taken as primary calibration targets, while the concentrations of inorganic and organic nitrogen and phosphorus species are treated as secondary calibration targets.

Algal Calibration Data

The primary concern for nutrient response in Jordan Lake is the effect of nutrient loads in promoting algal blooms. Such blooms lead to unaesthetic conditions, can cause treatability problems for drinking water supplies, and can have significant secondary effects on dissolved oxygen concentrations and pH of water. From a regulatory perspective, a key is the existence of a North Carolina water quality standard of 40 µg/L chlorophyll *a* (corrected). Chlorophyll *a* is the primary photosynthetic pigment in algae, and is often used as a surrogate for algal density. However, the ratio of algal biomass to chlorophyll *a* can show considerable variability, both as a result of inter-species differences and as a result of light conditions.

Direct measurements of algal biomass are difficult to obtain, and have not been undertaken in Jordan Lake. NC DWQ has constructed some estimates of algal biovolume (for a limited number of stations and at a limited number of sampling times) based on taxonomic identification and cell counts; however, the conversions of algal cell counts to biovolume and the conversion of biovolume to biomass are both subject to high levels of uncertainty. As a result, and in accordance with the water quality standard, it is most appropriate to base the analysis of algal response on chlorophyll *a* concentrations.

Problems with Chlorophyll a *Data for Jordan Lake*

In January of 2001, NC DWQ became aware of a variety of problems with their chlorophyll *a* monitoring data. Specifically, split samples from the Neuse MODMON project revealed that DWQ results were apparently biased high, and that "corrected" chlorophyll *a* results on occasion exhibited a very large bias. Subsequently, DWQ discovered that there were a variety of analytical problems with chlorophyll *a* data statewide, starting in/or about September 1996. Quality problems with chlorophyll *a* data, and their potential resolution, have a variety of implications for Jordan Lake modeling. It appears, however, that the problems are not fatal, and should not preclude the ability to create a calibrated nutrient response model for Jordan Lake.

To understand the data quality issues, it is first necessary to summarize a few facts about chlorophyll *a* analysis. First, chlorophyll *a* may be analyzed in three major ways: by high-pressure liquid chromatography (HPLC), by spectrophotometry, and by fluorometry. Of these methods, HPLC is the most accurate, but also the most expensive and time-consuming. Fluorometry is the quickest and least expensive method of analysis, but potentially yields reasonably accurate results, when the instrument is calibrated against a spectrophotometer using a known chlorophyll *a* standard.

Both spectrophotometry and fluorometry are subject to interference from other pigments, including breakdown products from "dead" chlorophylls (e.g., pheophytin). The North Carolina water quality standard is based on a corrected estimate of chlorophyll *a* that is designed to estimate only the concentration associated with living cells. The correction for pheophytin *a* is used because it absorbs and fluoresces light in the same range of the spectrum as chlorophyll *a* (APHA, 1985). For fluorometric determination of chlorophyll *a* concentration, measurements are taken before and after acidification of the sample. The ratio of these two measurements (the acid ratio) is then used to calculate corrected chlorophyll *a* concentrations (without interference from pheophytin *a*). Because of this adjustment procedure, corrected values will always be less than or equal to uncorrected values depending on the amount of pheophytin *a* in each sample. Unfortunately, the acid ratio can only be calculated at the time of lab analysis: "the acid ratio is instrument specific and must be determined for each instrument at the time of calibration" (Baker et al., 1983). DWQ reports both an uncorrected, and a corrected chlorophyll *a* concentration.

DWQ has relied on fluorometry for chlorophyll *a* since June 1981. (Previous to this, a spectrophotometer was used.) Problems with the fluorometric analyses began in 1996 and primarily involved choice of chlorophyll *a* standards, calculation/calibration of the acidification ratio, and computer calculation problems. Key points are summarized as (NC DWQ memo of February 26, 2001):

- DWQ chlorophyll *a* data (both uncorrected and corrected) should be useable *as is* up through August 1996.
- Data from September 1996 through January 1999 used correct standards but had poor calibration quality assurance on the acidification ratio. For this time period, the uncorrected chlorophyll *a* results are relatively accurate, but the corrected data may be inaccurate.
- From February 1999 through January 2001, both standards and analytical procedures were in error. There are also issues with use of incorrect filters beginning in May 1999. For this time period, the corrected chlorophyll *a* results are inaccurate and cannot be recovered. DWQ went back to the original laboratory documentation to generate revised "uncorrected" chlorophyll *a* concentrations.

In sum, for the period in which the best data are available for flow, temperature, and tributary loads, reliable corrected chlorophyll *a* data are not available. The DWQ *uncorrected* chlorophyll *a* data are useable throughout the calibration period, but may be subject to increased uncertainty in the period beginning in May 1999 due to filtration issues.

Examination of data prior to the start of analytical problems (e.g., through August 1996) shows that the uncorrected and corrected chlorophyll *a* data generally track well for stations in Jordan Lake, indicating that the correction for pheophytin *a* is generally small. Figure 3-15 compares these data for station CPF086F, which is located in the downstream portion of the Upper New Hope segment. The correlation coefficient for these two data sets is 0.81 (note that a value of 1.0 would indicate absolute correlation whereas a value of 0.0 would indicate no correlation), and for most observations the corrected chlorophyll *a* concentration is nearly equal to the uncorrected concentration. Given the high correlation, and lack of valid corrected chlorophyll *a* data after August 1996, it is appropriate to use the uncorrected data for model calibration.

It should be recognized, however, that the corrected and uncorrected values are expected to diverge at times, such as may occur after the die-off a major algal bloom. The observation for August 23, 1993 is a good case in point. On this date, the uncorrected chlorophyll *a* concentration was 340 μg/L, while the corrected concentration was only 24 μg/L, indicating a large concentration of pheophytin. Note however that if the pheophytin is presumed to represent predominantly recently deceased algae, an uncorrected chlorophyll *a* measurement with large pheophytin component may actually be a reasonably good indicator of algal concentrations shortly prior to the observation time. Following this reasoning, use of uncorrected chlorophyll *a* for calibration is likely to introduce small errors in the simulation of timing of algal blooms, but will not introduce major errors in the overall simulation of algal response. Finally, use of the uncorrected chlorophyll *a* data in calibration provides a small margin of safety on predictions of corrected chlorophyll *a*. On average, the uncorrected values (excluding outliers such as 8/23/93) are about 15 to 20 percent higher than the corrected values.

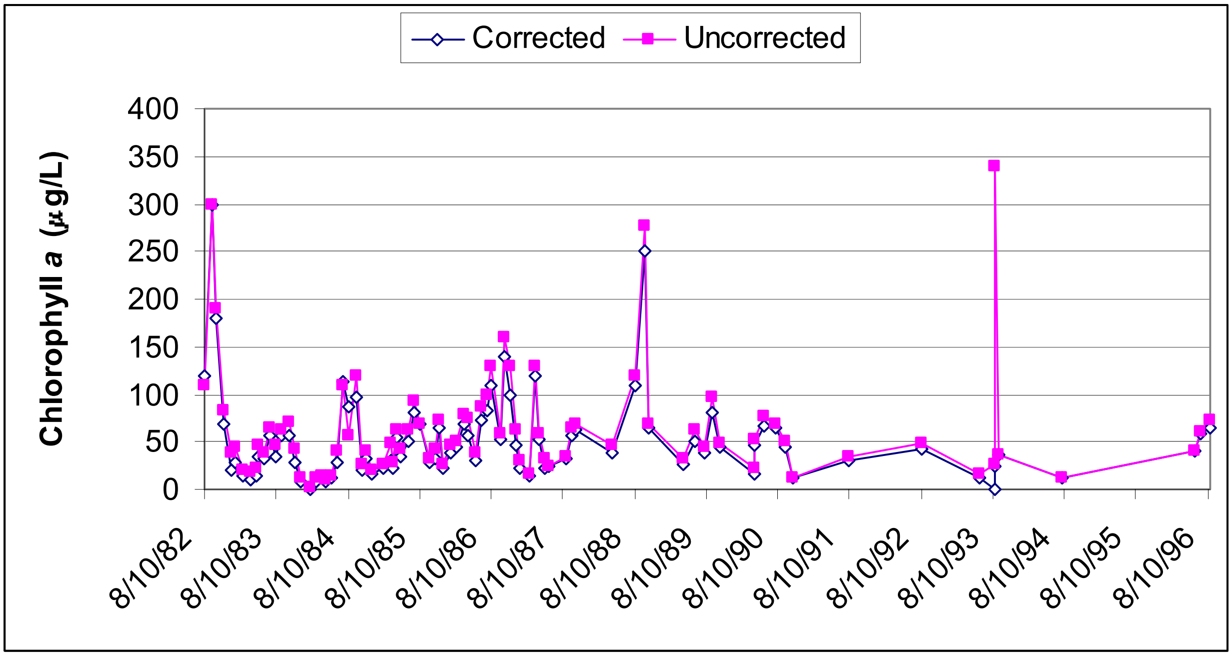


Figure 3-15. Correlation of Corrected and Uncorrected Chlorophyll *a* Observations at CPF086F

Corrections for Depth Support

Some adjustments to the reported chlorophyll *a* data are also required to account for discrepancies between the spatial support of what is measured by DWQ and what is predicted by the model. The model represents the lake as two vertical segments below Mt. Carmel Church Rd. (segments 5 and above), and a single vertical water column segment above (segments 1 through 4). Because of this decision, as well as the presence of shallow nearshore areas, the different top segments have varying depths, with a maximum (at typical pool) around 3 m.

In general, this is not expected to pose a large problem for water quality calibration, because the top 3 m of the water column are expected to be fairly well mixed under most conditions. This assumption may not hold, however, for algae. Under typical conditions in the upper New Hope Arm, twice the Secchi disk depth may be less than 1 m, and the majority of algal photosynthetic activity is expected to take place within this depth range. The algal population during blooms is dominated by blue greens with flotation vacuoles that enable them to adjust vertical position; there may also be a large population of euglenophytes and other mobile algae. This suggests that the algal biomass is likely to be concentrated within a vertical range that is smaller than the vertical scale of some of the WASP segments.

The chlorophyll *a* data obtained by DWQ are composites taken over twice the Secchi disk depth (or to the bottom, if that is less). The model predictions are integrated over the segment depth. These two numbers may diverge if the segment depth is much greater than twice the Secchi disk depth. For instance, if the model segment had a depth of 2 m, then model predictions would represent the algal biomass divided into a slab of 2 m thickness. But, if the Secchi disk depth was 0.5 m and the algae were concentrated in the top 1 m, then the measured data cover only the top 1 m of the segment, and might be up to two times the model-predicted segment average.

The key contrast here is between model segments 2 and 3 (in the upper New Hope and Morgan Creek arms), which are shallow, and model segment 4, just downstream of 2 and 3, which is much deeper yet is still represented by a single vertical segment. Because the average depth in segment 4 exceeds twice the Secchi depth, the vertically-averaged chlorophyll *a* predictions in Segment 4 tend to be low relative to DWQ observations.

In sum, the calibration should be driven by adjusted values that compensate for situations in which the segment depth is greater than the depth over which samples are integrated (note that no correction is needed for shallow segments; this is automatically handled by the calculation of light extinction in the model. Adjusted chlorophyll *a* observations that are consistent with model segmentation can be expressed as follows:

1. For segments in which the model segment depth is less than or equal to the sampling depth of two times the Secchi disk depth, no adjustment is needed (C* = C).
2. For segments in which the model segment depth is greater than the sampling depth of two times the Secchi disk depth:

$$C^* = \frac{C \cdot 2\,SD + \alpha \cdot C \cdot (Depth - 2\,SD)}{Depth}$$

in which C is the reported (uncorrected) chlorophyll *a* concentration, C* is the adjusted value for use in calibration, SD is the Secchi disk depth (m), α is the fraction of the living algal population found below a depth of twice the Secchi disk depth, and Depth is the area-weighted average depth of the segment as used in the model.

The majority of the reported chlorophyll *a* data are for the summer period; therefore it is appropriate to calculate corrected calibration data based on typical summer conditions. Secchi disk depths were summarized by the median at each station over 1997-2000 observations, while α was assumed to be 10 percent. Resulting correction factors are summarized in Table 3-13.

Table 3-13. Correction Factors for Use in Model Calibration to Observed Chlorophyll *a* Concentration to Reflect Model Segment Depth Greater than the Photic Zone

WASP segment	DWQ Station	Median Secchi Depth (SD, m)	Typical Model Summer Depth	Depth > 2 · SD?	Depth Correction
2	CPF081A1C	0.4	0.604	N	1.0
3	CPF086C	0.4	0.101	N	1.0
4	CPF086F	0.5	1.88	Y	0.58
6	CPF087B3	0.8	1.14	N	1.0
8	CPF087D	0.8	1.46	N	1.0
9	CPF08801A	0.85	1.66	N	1.0
12	CPF0880A	0.9	2.19	Y	0.84
15	CPF055C	0.7	1.8	Y	0.80
14	CPF055E	0.8	2.66	Y	0.64

It should be noted that these depth corrections are used during the calibration step, to compare model predictions to observations. For the evaluation of scenarios, the correction is applied in reverse to assure consistency with measurements. For instance, model predictions in Segment 15 are multiplied by 1/0.80 = 1.25 for comparison with the North Carolina water quality standards.

3.2.4 WASP/EUTRO Model Calibration

Calibration of the model consisted of attempting to replicate DWQ observations of total nitrogen, total phosphorus, and chlorophyll *a* (primary calibration targets), as well as concentrations of organic and inorganic nitrogen and phosphorus (secondary targets) over the 1997-1999 calibration period. Model performance was then tested through application to 2000 conditions (the validation period). Some discrepancies observed in fitting the 2000 data caused us to revisit the calibration and make adjustments consistent with the calibration period data. The revised calibration was then re-tested on the validation period.

Data available for 1997-1999 consist primarily of summer observations. During most summers, there is little in the way of consistent temporal trends in nutrient concentrations at a given location in the lake. There is also significant random variability within a segment (as is confirmed by the lateral transect samples taken at three locations around CPF0880A during 2000). As a result, it is most important that the model represent the spatial gradients in nutrient concentrations, while some unexplained variability in temporal gradients is expected.

OPTSHELL Calibration Tool

Calibration of the model requires adjustment of a large number of internal parameters controlling settling rates, reaction rates, and temperature dependence of reaction rates. The values selected for these parameters interact in complex ways, which makes the calibration process tedious. The general strategy for calibration involved starting parameters at values obtained from the literature and varying the values within reasonable ranges to improve the fit between simulation output and observed data.

The calibration process was greatly expedited through use of RTI's OPTSHELL software. OPTSHELL is a stand-alone software package that provides rigorous mathematical optimization capability to external programs that it "shells" to, as illustrated in the Figure 3-16. OPTSHELL uses rigorous optimization algorithms to automate the parameter adjustments and iterative running of the model. OPTSHELL contains a suite of robust optimization options and other capabilities that are described in Appendix B.

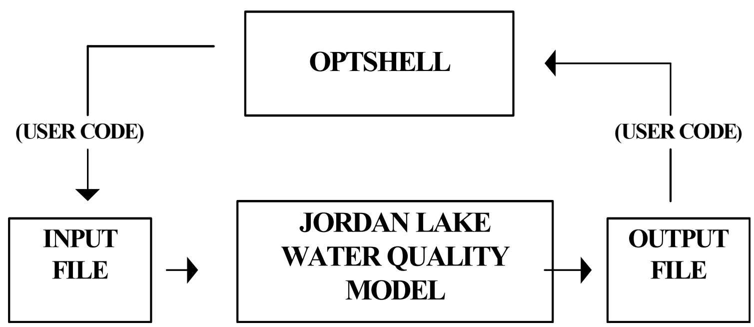


Figure 3-16. OPTSHELL Calibration Software.

It should be emphasized that OPTSHELL was used as an aid to calibration, and does not supplant the modeler's professional judgment. What OPTSHELL's methods do allow, however, is significant streamlining of the part of the calibration process that is time-consuming, expensive, ambiguous, and, indeed, not well suited to human performance.

OPTSHELL was used to find apparent optimal parameter values within limited, "reasonable" ranges over the calibration period (the validation period was excluded from all OPTSHELL runs). Up to 17 parameters were included in optimization, addressing dispersive exchange, porewater exchange, settling rates, scaling ratio on light extinction coefficients estimated from Secchi depth, and kinetic parameters. The optimization was an interactive process, involving multiple runs over several months. In many of the early runs, the best fit obtained by OPTSHELL still provided a relatively poor fit to observed data. This suggested changes in the ways segments were grouped (e.g., to which set of water quality segments a given settling rate is applied), as well as certain changes to external forcing functions (e.g., the benthic ammonia and phosphate generation time series described in the previous section). Finally, some inconsistencies in model fit to the validation period provided cause to revisit some aspects of the calibration. At the end of the iterative process all parameters were reviewed for consistency with ranges reported in literature. The end result is a calibrated model that does an excellent job of reproducing observed concentrations of nutrients and chlorophyll *a*.

Calibrated Parameter Values

Final calibration values of key parameters are summarized in Tables 3-14 and 3-15. A complete set of model input is provided in Appendix C.

Table 3-14. Calibrated Parameter Values for Jordan Lake WASP/EUTRO Model – Dispersion and Settling Parameters.

Parameter	Value	Notes
Horizontal Dispersion Coefficient (m^2/s)	0.002 to 0.2	Multiplied by interfacial area divided by characteristic length to obtain dispersion. Shows range of optimized coefficients for different segments.
Vertical Dispersion Coefficient (m^2/s)	$6.4 \cdot 10^{-5}$	Optimized. Thomann and Mueller (1987) cite range of 10^{-6} to 10^{-1}.
Porewater Exchange Coefficient (m^2/s)	$4.4 \cdot 10^{-8}$	Represents dispersive exchange only; a porewater flux is also specified in Group D.2.
Settling Rate, Organic Nutrients, Segments 1-3, 7, 10, 11 (m/d)	0.34	Optimized.
Settling Rate, Organic Nutrients, Segment 4 (m/d)	0.30	Optimized.
Settling Rate, Organic Nutrients, Segments 5, 6, 8, 9, 12 (m/d)	0.73	Optimized.
Settling Rate, Organic Nutrients, Segments 13-15 (m/d)	1.0	Optimized.
Settling Rate, Algae, Segments 1-3, 7, 10, 11 (m/d)	0.064	Optimized. USEPA (1997) cites range of 0.0 to 30.0
Settling Rate, Algae, Segment 4 (m/d)	0.075	Optimized.
Settling Rate, Algae, Segments 5, 6, 8, 9, 12 (m/d)	0.060	Optimized.
Settling Rate, Algae, Segments 13-15 (m/d)	0.070	Optimized.
Settling Rate, Organic Nutrients, Segments 1-3, 7, 10, 11 (m/d)	4.1	Optimized.
Settling Rate, Organic Nutrients, Segments 5, 6, 8, 9, 12 (m/d)	2.0	Optimized.
Settling Rate, Organic Nutrients, Segments 13-15 (m/d)	5.0	Optimized.

Table 3-15. Calibrated Parameter Values for Jordan Lake WASP/EUTRO Model – Selected Kinetic Parameters.

Parameter	Value	Notes
KESG – Scale factor on light extinction coefficients estimated from Secchi Depth	0.80	Optimized – within range of uncertainty expected on estimated extinction coefficients.
k12c – Nitrification rate at 20°C, per day	0.12	Optimized, USEPA (1997) cites range of 0.05 – 0.20.
k12t – Arrhenius temperature coefficient for nitrification	1.08	Literature value (USEPA, 1997)
k20c – Denitrification rate at 20°C	0.09	Recommended default (Ambrose et al., 1993)
k1c – Saturated growth rate of phytoplankton (per day)	3.87	Optimized value – exceeds example value of 2.0 cited by Ambrose et al. (1993); USEPA (1997) cites range of 1-3.
k1t – Temperature coefficient for phytoplankton growth	1.08	Optimized value – Ambrose et al. (1993) cite value of 1.06; USEPA (1997) cites range of 1.01 – 1.18.
cchl – Carbon to chlorophyll ratio	50	Range 20-50 (Ambrose et al., 1993); blue-green dominance suggests high value for Jordan Lake.
is1 – Saturation light intensity for phytoplankton growth (Ly/d)	568	Must be determined via calibration; typically around 400-500.
kmng1 – Nitrogen half-saturation constant for phytoplankton growth (mg-N/L)	0.13	Optimized value, example value cited by Ambrose et al. (1993) is 0.25.
kmpg1 – Phosphorus half-saturation constant for phytoplankton growth (mg-P/L)	$6.47 \cdot 10^{-4}$	Optimized value, example value cited by Ambrose et al. (1993) is $1 \cdot 10^{-3}$.
k1rc – Endogenous respiration rate for phytoplankton (per day)	0.226	Thomann and Mueller (1986) cite range of 0.05 – 0.25. Presence of high bacterial populations may elevate the apparent rate.
k1rt – Temperature coefficient for phytoplankton respiration	1.045	Recommended default.
k1d – Phytoplankton background death rate (per day)	0.0132	Optimized value, example value cited by Ambrose et al. (1993) is 0.02.

Parameter	Value	Notes
pcrb – Phosphorus to carbon ratio in phytoplankton	0.025	Default value.
ncrb – nitrogen to carbon ratio in phytoplankton.	0.25	Default value.
k71c – Mineralization rate of dissolved organic nitrogen (per day)	0.15	Optimized value, example value cited by Ambrose et al. (1993) is 0.075.
k71t – Temperature coefficient for organic nitrogen mineralization	1.08	Value cited by Ambrose et al. (1993).
fon – Fraction of dead and respired phytoplankton nitrogen recycled to organic nitrogen	0.95	Optimized value, example values cited by Ambrose et al. (1993) range from 0.5 to 1.0.
k83c – Mineralization rate of dissolved organic P (per day)	0.18	Optimized value, example value cited by Ambrose et al. (1993) is 0.22.
k83t – Temperature coefficient for mineralization of dissolved organic P	1.06	Optimized value, example value cited by Ambrose et al. (1993) is 1.08.
fop – Fraction of dead and respired phytoplankton phosphorus recycled to organic P	0.95	Constrained to be equal to fon.

Calibration Results

A comparison of model predictions to observations for the calibration period of 1997-1999 is provided in Figures 3-17 through 3-23. In general, the model appears to do an excellent job of reproducing the spatial trends in nutrient and chlorophyll *a* concentrations. The model also captures many, but not all, of the temporal variations in concentrations at individual stations. A key cause of discrepancy in individual predictions is likely the estimation of tributary boundary conditions from sparse data. For instance, a major pulse of nutrients may have been missed in the tributary monitoring (or, alternatively, an unsampled high flow event may be attributed to too much nutrient load), leading to uncertainty in in-lake predictions.

Basic statistics on the calibration are presented in Table 3-16 for total nitrogen, total phosphorus, and chlorophyll *a*. Over time, the fit at all stations appears good. Average absolute error is small for both total nitrogen and total phosphorus, and there is not consistency of sign in the average errors, suggesting a lack of bias. For chlorophyll *a*, the model appears to yield a small over-prediction of observed values at most stations (positive average error), although the model reproduces the general spatial and temporal pattern of algal response. This apparent bias could be removed by increasing the carbon-to-chlorophyll *a* ratio in the model to a value higher than the recommended range. However, it was decided not to implement this modification, for the following reasons:

- The kinetic parameter values included in the calibrated model are believed to be within the range of reasonable values based on past research.
- Chlorophyll *a* data from the period of calibration are subject to a high level of uncertainty due to analytical problems.
- A significant portion of the aggregate error at most stations is due to over-prediction of observations in May 1997. For this period, the model predicts a strong bloom in response to storm runoff loading of nutrients – but the data do not show a response of this magnitude in either nutrient or algal concentrations. The error present here is thus apparently due to uncertainties in characterizing tributary loads rather than to internal biases in the model.
- The current set of model parameters ensures that there is not an under-prediction bias at any of the observation stations during the calibration period. Adjusting the model to replicate the mean chlorophyll *a* concentrations would result in under-estimation of higher concentration values for certain locations and times.
- Algal concentrations are highly variable in space and time, and are likely to exhibit a skewed (lognormal) distribution. A result of this is that small samples will tend to underestimate the true mean.

As a consequence, the model is believed to provide a small over-estimation of chlorophyll *a* concentrations. The average amount of over-prediction across all observation pairs at all stations is 3.7 µg/L. The nutrient response model may thus be thought of as containing ***a built-in margin of safety***. In other words, chlorophyll *a* response is simulated on the high side to compensate for potential uncertainties in the modeling and observed data.

Given that summer observations of nutrient and chlorophyll *a* concentrations exhibit a consistent difference between stations, whereas at-station observations are likely subject to random noise, the most appropriate statistical tests are on the means at individual stations. The observed data have inherent uncertainty: in addition to the problems associated with chlorophyll *a* data, observations of inorganic nitrogen and phosphorus are often near the practical quantitation limit for the methods used by DWQ, and are thus imprecise. The most appropriate statistical test on the calibration is thus a Student's *t* test on whether the average absolute error between the model and observations at individual stations is within a specified magnitude (Reckhow et al., 1990). Target magnitudes for the accuracy of predictions, evaluated as the average absolute error between predictions and observations, were established based on best professional judgment and consideration of quantitation limits as follows:

Total N:	Within 0.25 mg/L.
Total P:	Within 0.025 mg/L.
Chlorophyll *a*:	Within 10 µg/L (reflecting the high uncertainty in reported data for this time period).
Organic N:	Within 0.25 mg/L (as the dominant component of total N).
Inorganic N:	Within 0.10 mg/L.

Organic P: Within 0.025 mg/L.

Inorganic P: Within 0.015 mg/L.

The selection of a relatively large criterion for variability in chlorophyll *a* concentrations is consistent with information provided by DWQ (Memorandum from Jay Sauber, NC DWQ, "Re: Chlorophyll Meetings and Issues with Lab Data," February 26, 2001):

> EPA performance information for the fluorometric chlorophyll *a* method was based on the participation of 21 laboratories. 11 used the acid correction method and 10 used the Welchemeyer (non-acid) method. Using the HPLC method values as a true value, the % relative standard deviation was most frequently in the 20-25% range. The total range was 14.6 to 33.2 [%] for different species and concentrations.

This information suggests that 95 percent confidence limits on reported observations are on the order of plus or minus 40 to 50 percent of the reported value (2 standard deviations) – even in the absence of the analytical problems experienced by DWQ in 1999-2000. As concentrations in the upper part of Jordan Lake are often around 30 μg/L, the selected criterion for model fit is only on the order of one standard deviation.

The *t* statistic for evaluating whether the average model absolute error is within a specified magnitude is constructed as follows (Reckhow et al., 1990):

$$t = \left(\bar{x} - x_0\right) \Big/ \left(\frac{s}{\sqrt{n}}\right)$$

in which x represents the absolute value of the residuals, x_0 represents the desired magnitude of the residual to be tested, s is the sample standard deviation of the absolute errors, and n is the sample size. This may be compared to tabulated values of the *t*-statistic at n-1 degrees of freedom to determine the probability value that the observed magnitude of the residuals is less than or equal to x_0.

Resulting probability values are displayed in Table 3-17. The null hypothesis for the statistical test is set up to reject if the paired simulated and observed values are proven to be different, as shown by a *small* probability value (p-value). Thus, a p-value approaching 1 is a sign of excellent model fit. Most of the p-values reported in the table are high, showing a good agreement between predictions and observations.

Only one contrast between observations and predictions fails the *t*-test at a 95-percent confidence level (p-value less than 0.05). This is for total inorganic nitrogen in model segment 15 (Haw River arm). Interestingly, the average error for total inorganic nitrogen here is low (−0.004 mg/L), but the average absolute error is high (0.17). This indicates that the predictions are unbiased, but imprecise. This segment is dominated by inflows from the Haw River, which are highly variable in time. Further, the model fit to total nitrogen in this segment is acceptable. Thus, the low p-value for inorganic nitrogen primarily reflects imprecise knowledge of Haw River influent nutrient loads (particularly the distribution among organic and inorganic forms of nitrogen) resulting from infrequent sampling.

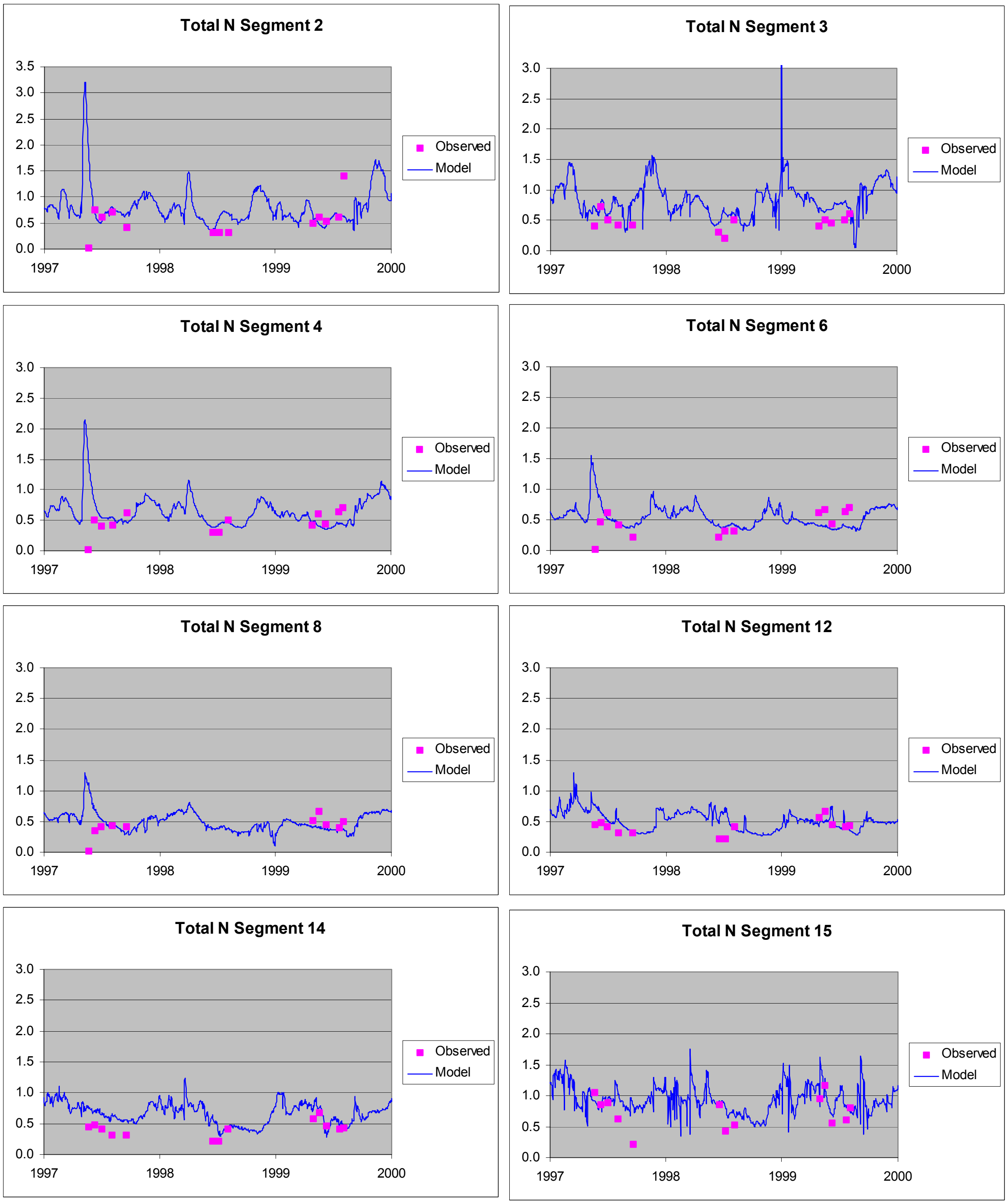


Figure 3-17. Total Nitrogen Calibration, 1997-1999 (mg/L).

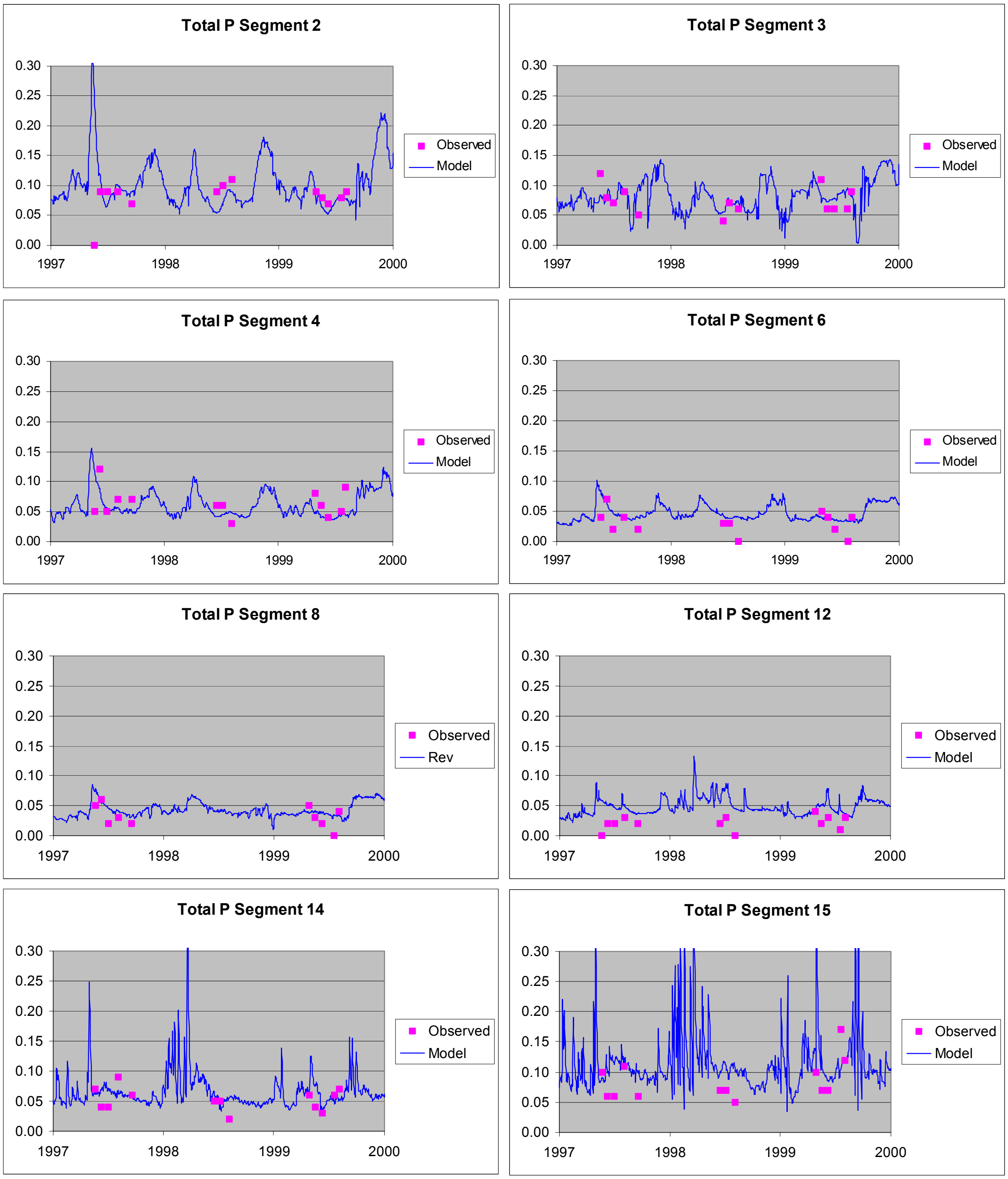


Figure 3-18. Total Phosphorus Calibration, 1997-1999 (mg/L).

Figure 3-19. Organic Nitrogen Calibration, 1997-1999 (mg/L).

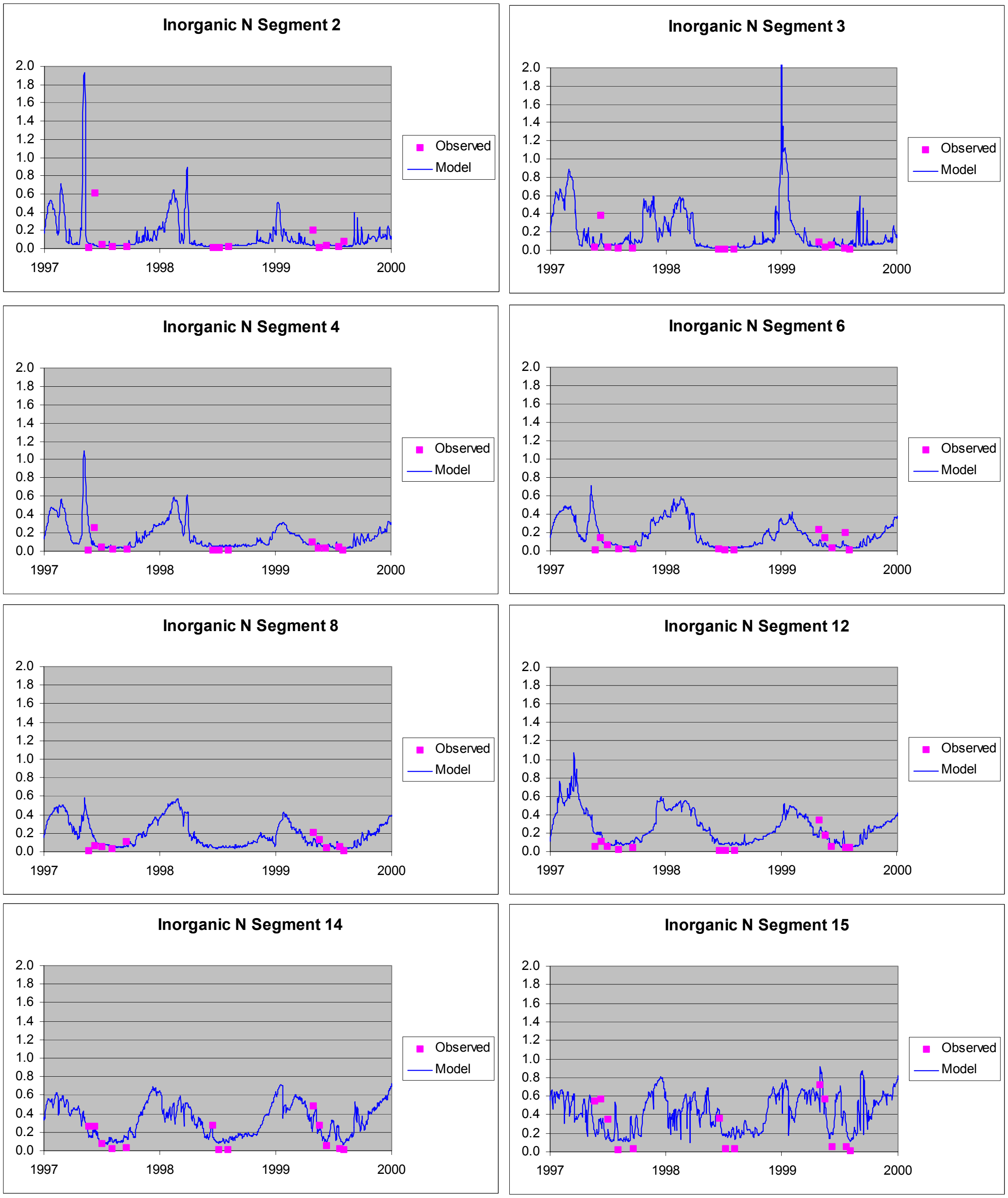


Figure 3-20. Inorganic Nitrogen Calibration, 1997-1999 (mg/L).

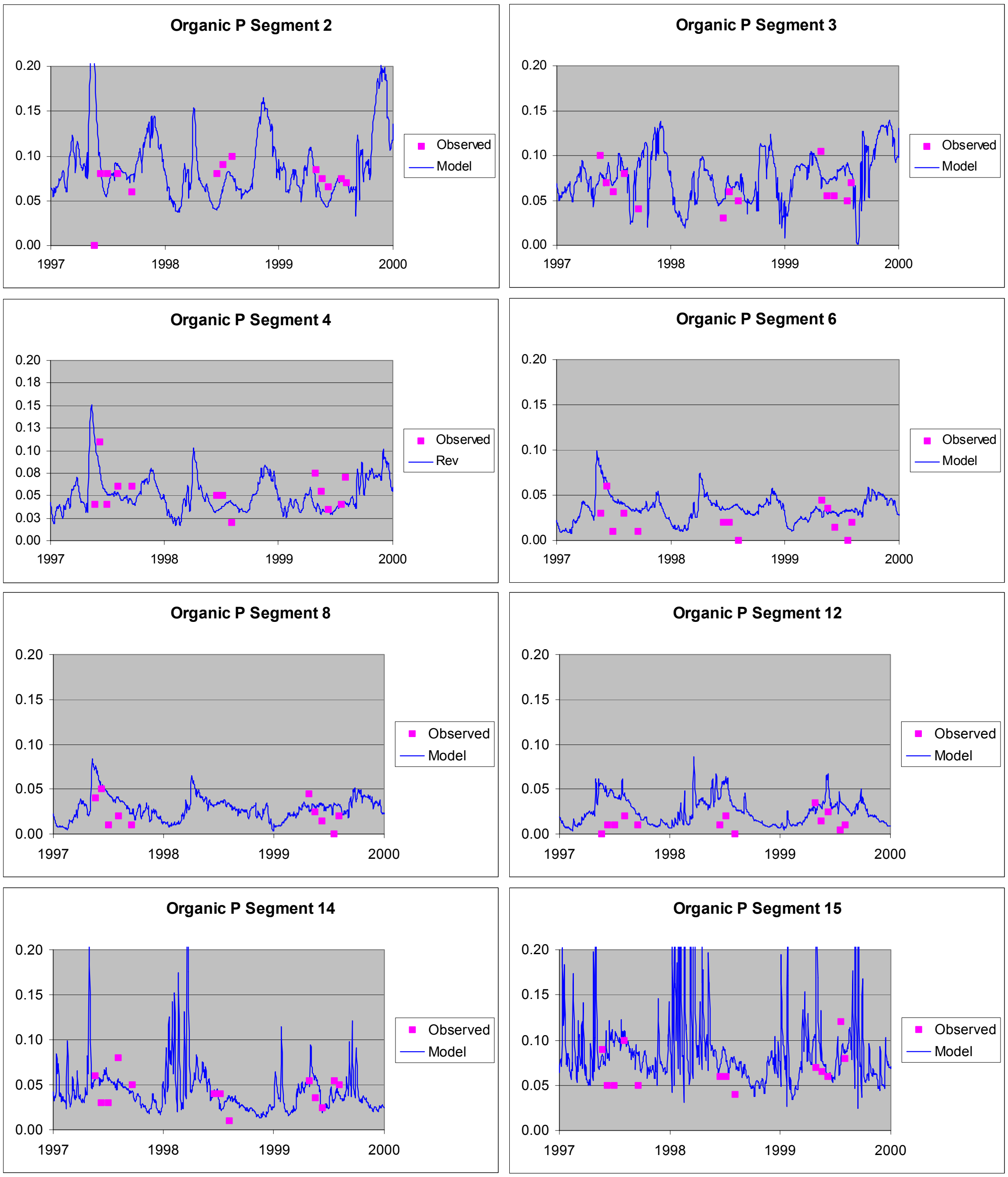


Figure 3-21. Organic Phosphorus Calibration, 1997-1999 (mg/L).

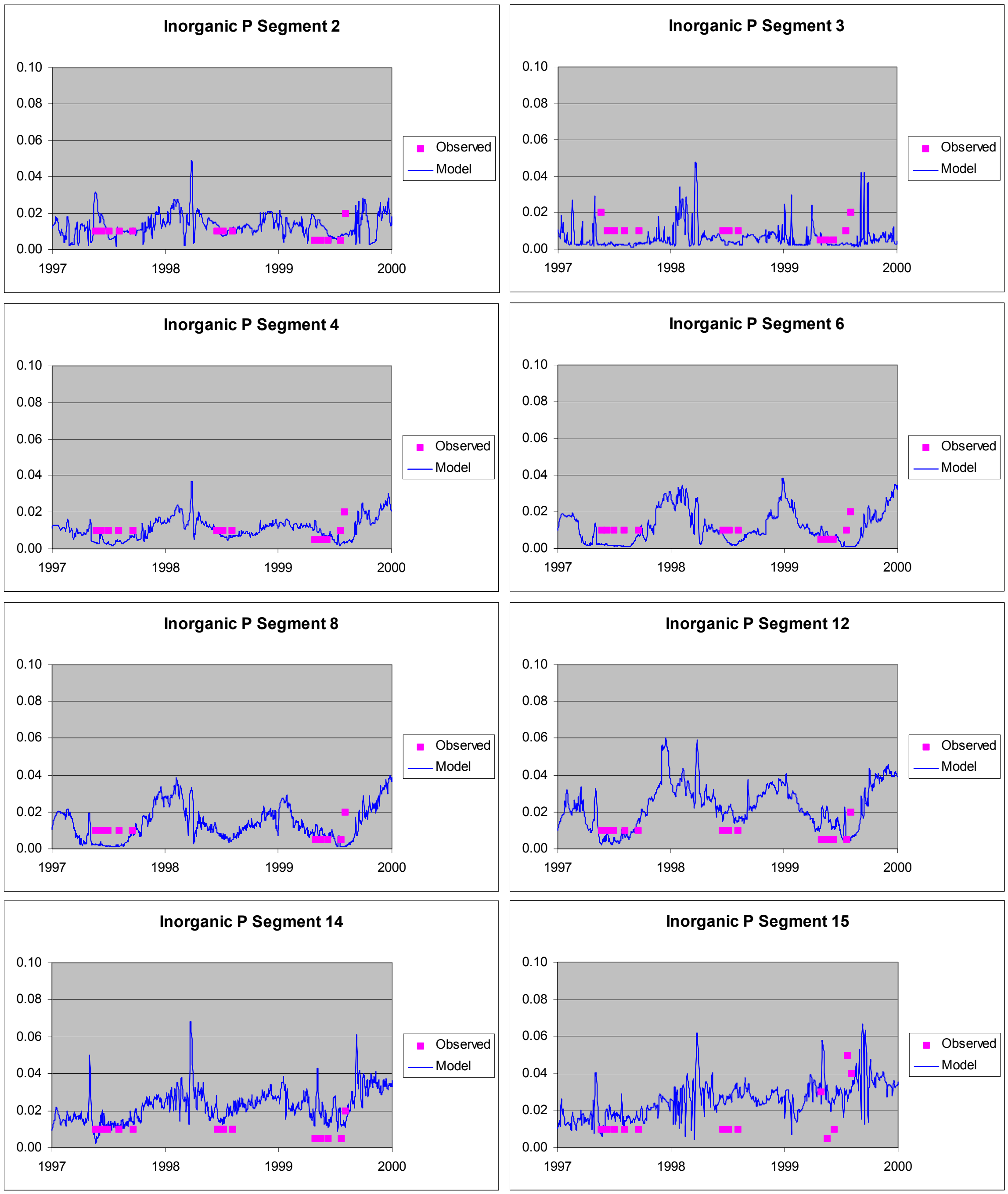


Figure 3-22. Inorganic Phosphorus Calibration, 1997-1999 (mg/L).

Note: Many observed values are at or below a detection limit of 0.01 mg/L. Observations reported as non-detect are plotted at 0.005 mg/L.

Figure 3-23. Chlorophyll *a* Calibration, 1997-1999 (µg/L).

Note: Observed values in segments 4, 12, 14, and 15 are adjusted in accordance with Table 3-16 to account for depth of segment simulated versus depth of sampling.

Table 3-16. Calibration Statistics for Total Nutrients and Chlorophyll *a*, 1997-1999.

Segment	2	3	4	6	8	9	12	14	15
TN – AvObs	0.59	0.46	0.49	0.47	0.46	0.47	0.41	0.54	0.73
TN – AvSim	0.68	0.68	0.55	0.50	0.50	0.49	0.52	0.58	0.85
TP – AvObs	0.082	0.074	0.064	0.032	0.033	0.025	0.022	0.052	0.085
TP – AvSim	0.090	0.078	0.055	0.045	0.043	0.044	0.052	0.059	0.103
Chl – GMObs	28.0	25.5	13.2	11.9	12.4	12.9	10.5	10.4	14.3
Chl – GMSim	25.6	31.4	17.0	15.9	15.1	15.1	15.6	17.2	22.8
TN – AvErr	0.005	0.214	-0.012	-0.026	-0.028	-0.026	0.109	0.041	0.115
TP – AvErr	0.0083	0.0043	-0.0088	0.0126	0.0110	0.0194	0.0295	0.0063	0.0177
Chl – AvErr	0.41	6.00	4.41	4.46	3.45	-0.80	4.07	6.48	4.86
TN - Av ABSErr	0.19	0.21	0.15	0.18	0.13	0.14	0.17	0.14	0.18
TP - Av ABSErr	0.034	0.018	0.023	0.016	0.016	0.021	0.030	0.018	0.031
Chl -Av ABSErr	12.6	8.2	9.1	6.9	6.0	9.9	8.0	7.5	13.5
TN - RMSE	0.29	0.26	0.17	0.22	0.17	0.21	0.22	0.16	0.26
TP - RMSE	0.068	0.025	0.030	0.021	0.019	0.025	0.035	0.022	0.038
Chl - RMSE	17.9	10.8	12.6	9.2	7.4	17.4	9.6	9.2	19.0

Key:

TN:	Total Nitrogen (mg/L)	GMObs:	Obs. geometric mean
TP:	Total Phosphorus (mg/L)	AvErr:	Average error
Chl:	Chlorophyll a (μg/L)	AvABSErr:	Average absolute error
AvObs:	Average observed concentration	RMSE:	Root mean squared error
AvSim:	Average simulated concentration		

Notes: Because chlorophyll *a* is expected to have a strongly skewed distribution, central tendency is represented by the geometric mean (GM) rather than the arithmetic average. Observed chlorophyll *a* concentrations in segments 4, 12, 14, and 15 are adjusted in accordance with Table 3-16.

Table 3-17. Probability Values for *t*-tests on Calibration, 1997-1999.

Parameter	TN	TP	Chl	TON	TIN	TOP	TIP
Criterion	0.25	0.025	10	0.25	0.1	0.025	0.015
Seg 2	0.82	0.29	0.24	0.63	0.74	0.31	1.00
Seg 3	0.84	0.93	0.80	0.89	1.00	0.83	1.00
Seg 4	1.00	0.67	0.64	0.98	0.95	0.68	1.00
Seg 6	0.98	0.99	0.96	0.99	0.89	0.81	1.00
Seg 8	1.00	1.00	0.99	1.00	0.88	0.92	1.00
Seg 9	0.97	0.83	0.51	0.97	0.99	0.84	1.00
Seg 12	0.97	0.12	0.91	1.00	0.99	0.15	1.00
Seg 14	1.00	0.97	0.95	0.99	0.91	1.00	1.00
Seg 15	0.90	0.17	0.18	0.99	0.01	0.87	0.92

Note: Values reported represent the probability that the average absolute error (absolute value of model predicted value minus observed value) is less than the specified criterion. Small probability values indicate a relatively large probability that the average absolute error is greater than the criterion.

Key:

TN: Total Nitrogen (mg/L)

TP: Total Phosphorus (mg/L)

Chl: Chlorophyll *a* (μg/L)

TON: Total Organic Nitrogen (mg/L)

TIN: Total Inorganic Nitrogen (mg/L)

TOP: Total Organic Phosphorus (mg/L)

TIP: Total Inorganic Phosphorus (mg/L)

3.2.5 Water Quality Model Validation

Model validation consists of application of the calibrated model to a second set of data separate from that used for calibration. This is done to help insure against a spurious calibration, in which a set of parameters result in model predictions matching a specific set of data but are not robust enough to extend to other periods. Successful validation increases assurance that the model provides a reasonable representation of actual physical, chemical, and biological processes.

Year 2000 data were selected for model validation. Choice of 2000 was based on several factors. Most notably, DWQ pursued intensive data collection during 2000-2001 to support the modeling effort. In addition, complete meteorological and hydrological data are available for 2000 to drive the simulation, whereas such data were not readily available for the complete year of 2001.

The choice of 2000 for model validation also presents some challenges. Most notably, the chlorophyll *a* data for this year are highly uncertain. As discussed in section 3.2.3, the 1999 data are affected by a host of problems, including use of incorrect analytical standards, problems with the acid ratio, and use of incorrect filters. DWQ has re-calculated "uncorrected" chlorophyll *a* values for this period (that is, chlorophyll *a* without correction for pheophytin); however, these values appear to be subject to a high level of uncertainty.

Plots of observed versus simulated values for the calibration period are shown in Figures 3-24 through 3-29. No plot is shown for inorganic phosphorus, as all the observations reported in 2000 were at or below a detection limit of 0.01 mg/L. Statistics, similar to those presented for the calibration period, are shown in Tables 3-18 and 3-19. Two additional segments (1 and 13) appear in this table, as data is available for these segments during the validation period, but not during the calibration period.

The overall fit for the validation period is clearly not as good as obtained for the calibration period. For total nitrogen and phosphorus, the model fit is generally good for segments 4 through 15, but is of much poorer quality in segments 1 through 3. In particular, total nitrogen appears to be over-estimated in these segments. As these are inflow segments it is suspected that the discrepancy is largely due to uncertainty in the estimates of external tributary loads. During 2000 there were three significant summer-fall storm inflow events (July 26, September 6, and September 27). There are between 9 and 13 tributary water quality samples per station in 2000, but none that captured these summer-fall high flow events. Better characterization of tributary inflows during 2000 would likely lead to improved model performance in these upstream segments.

In the Haw River influent (segment 15), simulation of total nitrogen is adequate, but simulation of inorganic nitrogen is not. As in the calibration period, this reflects inadequate sampling data to capture day-to-day variability in nutrient speciation in the Haw.

Inorganic phosphorus observations are all reported at or below a detection limit of 0.01 mg/L during 2000, unlike earlier years. Precise statistical comparisons thus cannot be made for total inorganic phosphorus, although the model appears to overpredict inorganic phosphorus in the Haw influent (segment 15). Again, this problem is most likely due to uncertainty in the characterization of tributary loads.

The validation period also differs from the calibration period including a number of fall samples. During the fall, the model appears to experience some problems in representing organic nutrient concentrations. This may reflect organic loading from decay of macrophytes and leaf litter, which are processes not explicitly incorporated into the model.

Chlorophyll *a* results for 2000 merit special discussion. In general, the model fits the data well up through the beginning of August. From mid-August on, the reported chlorophyll *a* values are much greater than model predictions – which results in low probability values on the statistical tests. It should be recalled that the data are DWQ's recalculated "uncorrected" chlorophyll *a* measurements, and are subject to a variety of analytical uncertainties during this period. Reported values in the fall are very high (up to 140 µg/L), and are not consistent with data observed during the validation period. The model simulation of the nutrients that support algal growth is adequate during this period and, if anything, is biased high. Further, an examination of the physical data collected by DWQ provides no evidence of major algal blooms coincident with these observations (bloom conditions would tend to be associated with elevated dissolved oxygen and pH during daylight hours, which were not observed). Unfortunately, there are no algal cell counts corresponding to any of the high chlorophyll *a* concentrations reported for late 2000. It appears that the high uncorrected chlorophyll *a* concentrations for this period are not valid indicators of high algal biomass.

Despite the many data issues discussed above, the statistical tests reported in Table 3-19 reveal that 69 of the 77 validation comparisons (90 percent) are acceptable at a 95 percent confidence level (i.e., the null hypothesis cannot be rejected). Of the eight contrasts that fail the test, four are for chlorophyll *a*, where the observed values from the fall are apparently biased high by the lack of a pheophytin correction, as described above. The other four failures are associated with nutrient speciation in inflow segments, and are thus more likely attributable to inadequate data on tributary concentrations than to errors in the nutrient response model. Therefore, the validation exercise was judged to be successful. It would, however, be desirable to further test the theories presented above by application to 2001 when all the necessary data become available.

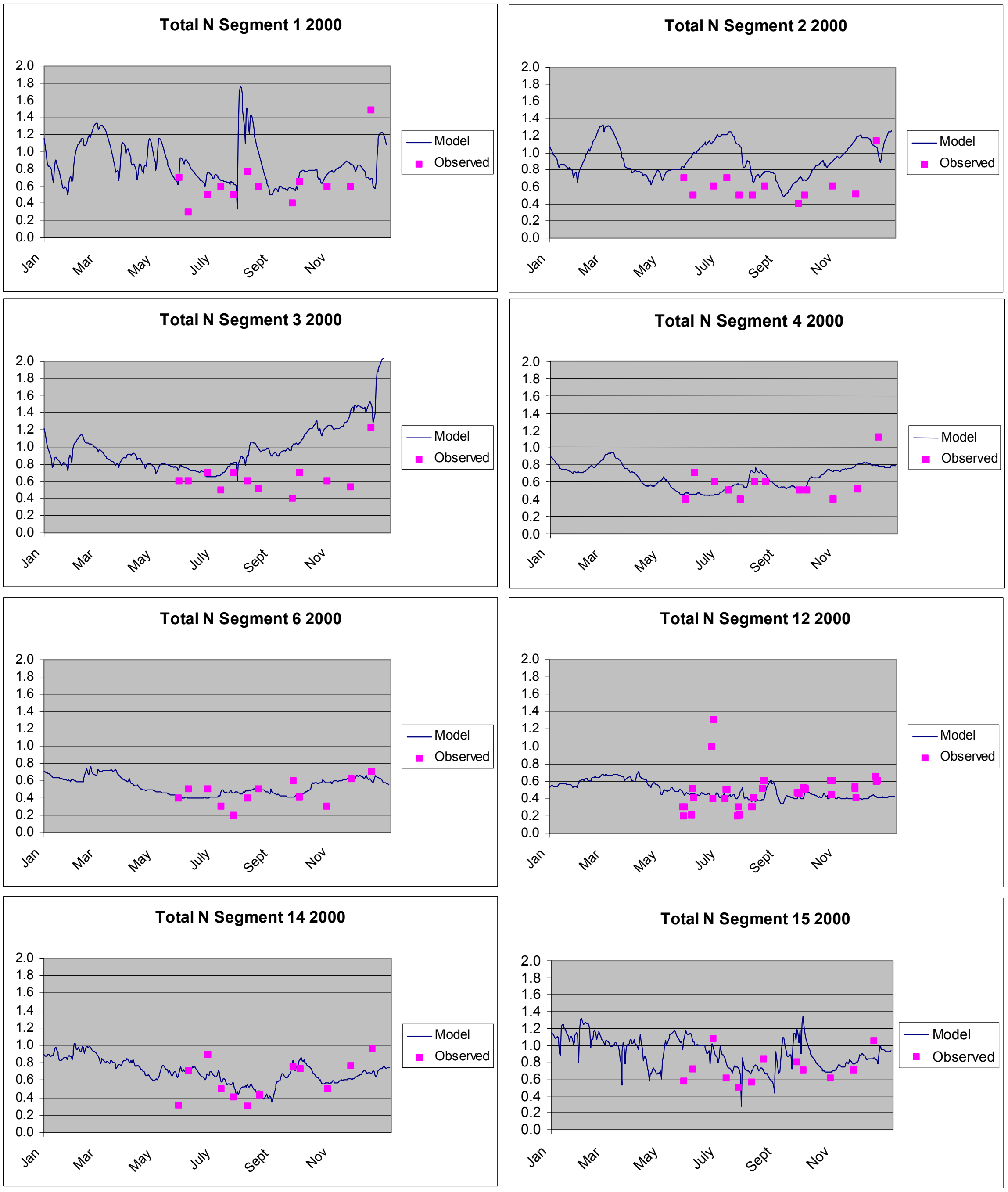


Figure 3-24. Total Nitrogen Validation, 2000 (mg/L).

Note: Segment 12 observations include stations CPF0880A a, b, and c.

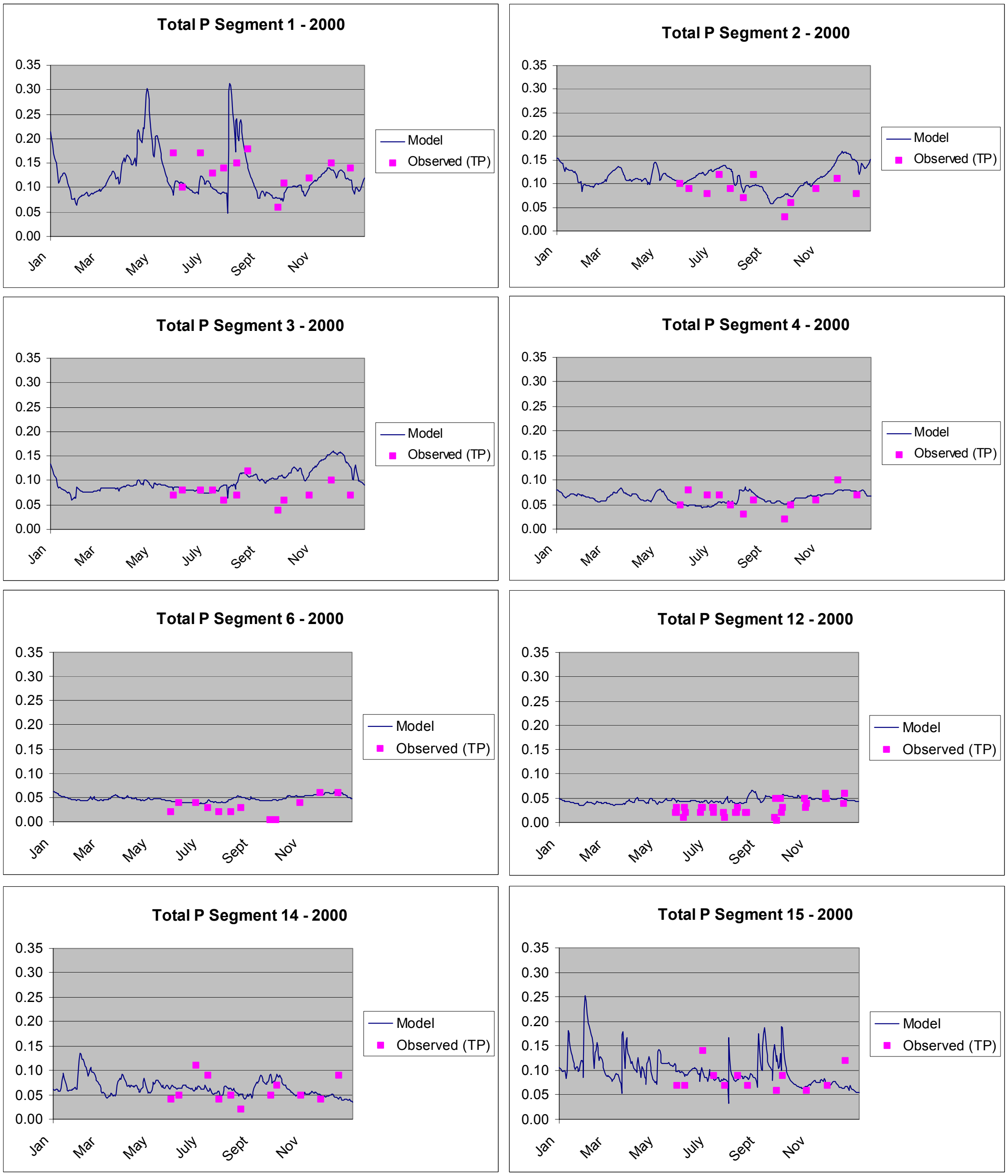


Figure 3-25. Total Phosphorus Validation, 2000 (mg/L).

Note: Segment 12 observations include stations CPF0880A a, b, and c.

Figure 3-26. Organic Nitrogen Validation, 2000 (mg/L).

Note: Segment 12 observations include stations CPF0880A a, b, and c.

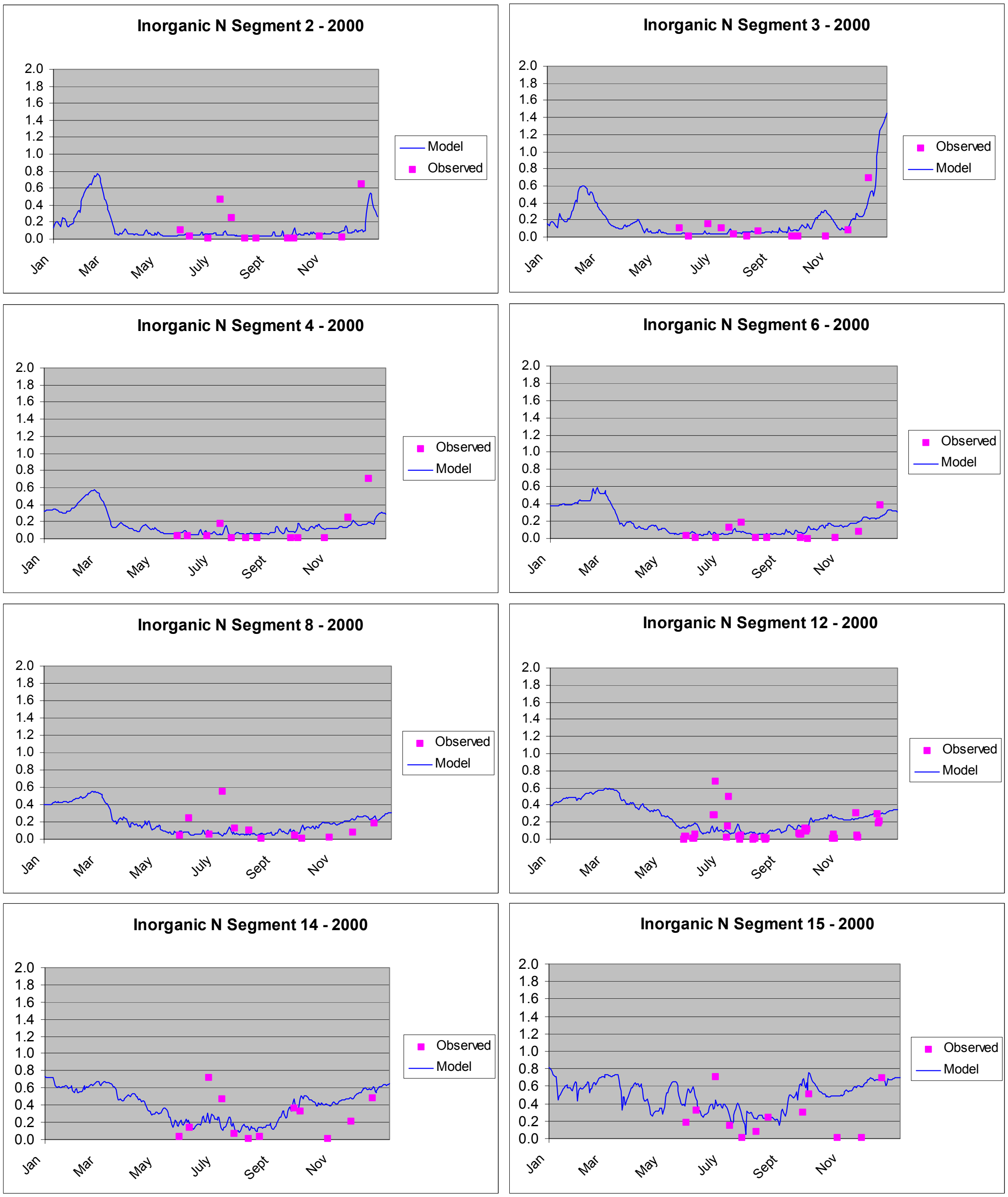


Figure 3-27. Inorganic Nitrogen Validation, 2000 (mg/L).

Note: Segment 12 observations include stations CPF0880A a, b, and c.

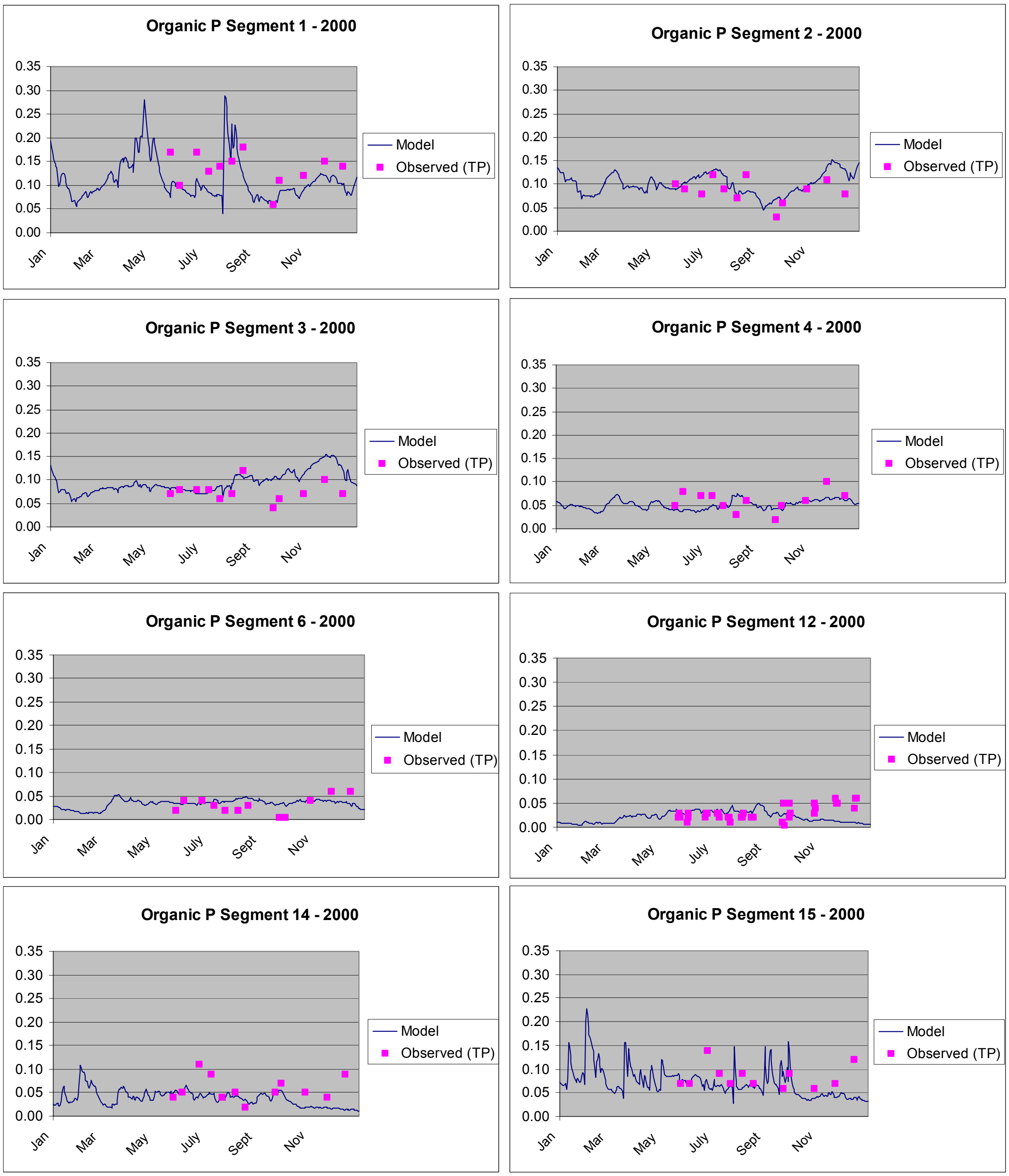


Figure 3-28. Organic Phosphorus Validation, 2000 (mg/L).

Note: Segment 12 observations include stations CPF0880A a, b, and c.

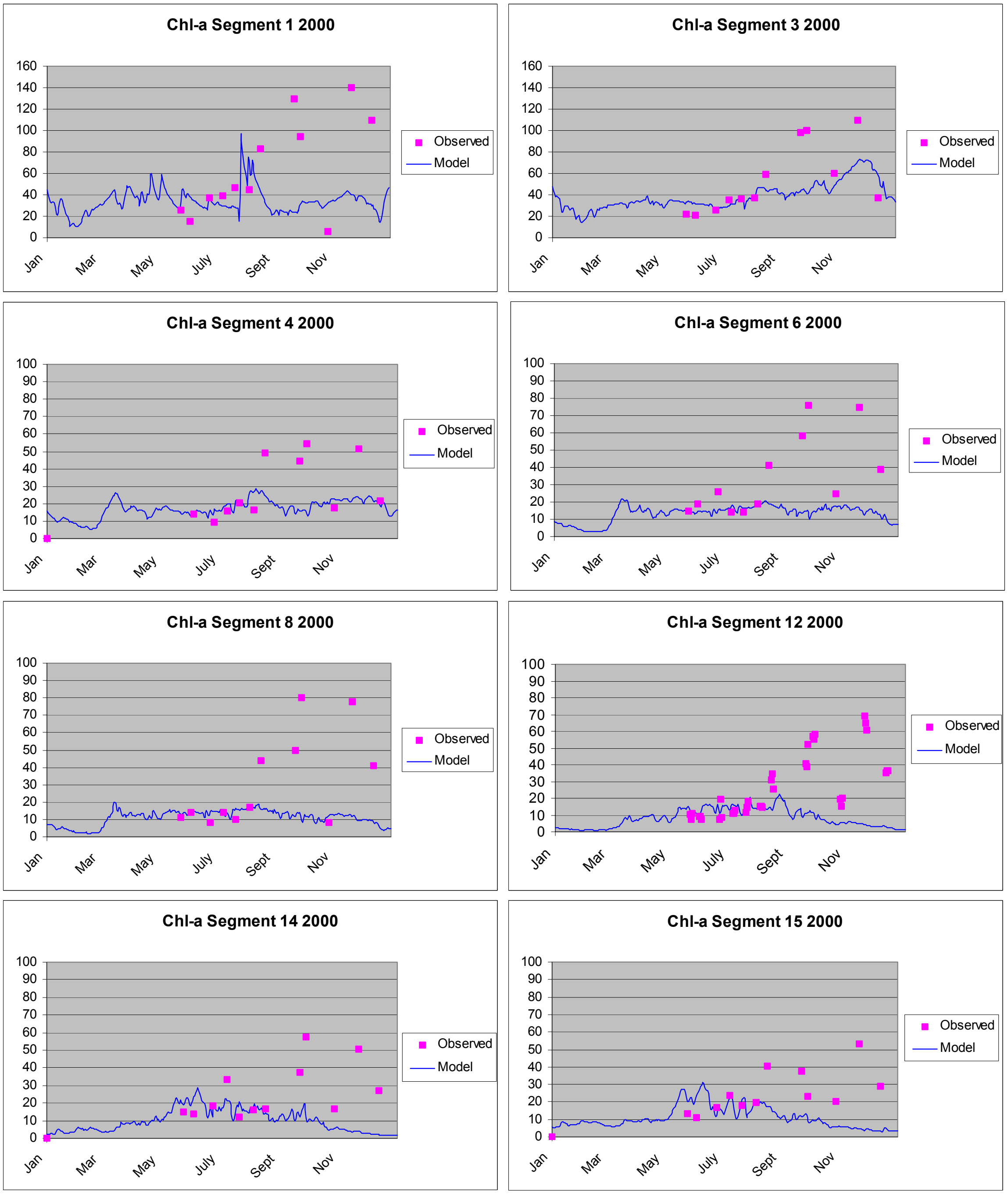


Figure 3-29. Chlorophyll *a* Validation, 2000 (µg/L).

Notes: Segment 12 observations include stations CPF0880A a, b, and c. Observed values in segments 4, 12, 14, and 15 are adjusted in accordance with Table 3-13 to account for depth of segment simulated versus depth of sampling.

Table 3-18. Validation Statistics for Total Nutrients and Chlorophyll *a*, 2000.

Segt.	1	2	3	4	6	8	9	12	13	14	15
TN - AvObs	0.65	0.61	0.64	0.57	0.46	0.46	0.69	0.48	0.57	0.61	0.73
TN - AvSim	0.81	0.93	0.98	0.61	0.48	0.45	0.42	0.43	0.49	0.65	0.91
TP - AvObs	0.135	0.087	0.075	0.060	0.032	0.030	0.038	0.029	0.043	0.058	0.083
TP - AvSim	0.118	0.110	0.102	0.062	0.046	0.044	0.044	0.046	0.049	0.061	0.095
Chl - GMObs	46.8	48.5	45.5	22.5	29.1	22.0	23.1	23.8	25.5	18.3	28.8
Chl - GMSim	35.1	36.5	40.7	18.9	15.3	12.9	11.9	9.4	12.8	11.4	12.0
TN - AvErr	0.168	0.327	0.339	0.033	0.026	-0.012	-0.265	-0.058	-0.079	0.044	0.183
TP - AvErr	-0.0170	0.0235	0.0269	0.0016	0.0141	0.0137	0.0066	0.0169	0.0060	0.0031	0.0115
Chl - AvErr	-27.78	-19.02	-11.27	-7.76	-19.63	-18.13	-16.56	-19.30	-16.24	-6.95	-17.59
TN - Av ABSErr	0.30	0.34	0.35	0.15	0.11	0.11	0.28	0.14	0.15	0.15	0.25
TP - Av ABSErr	0.037	0.028	0.030	0.018	0.016	0.016	0.031	0.019	0.016	0.025	0.030
Chl -Av ABSErr	41.7	30.1	19.4	13.1	20.6	21.4	18.3	20.4	20.9	13.4	19.9
TN - RMSE	0.41	0.41	0.44	0.20	0.15	0.14	0.50	0.19	0.20	0.19	0.32
TP - RMSE	0.047	0.035	0.039	0.023	0.021	0.020	0.044	0.021	0.020	0.030	0.043
Chl - RMSE	56.9	40.6	28.7	19.3	31.7	34.1	29.0	32.1	29.8	18.3	27.5

Key:

TN:	Total Nitrogen (mg/L)	GMObs:	Obs. geometric mean
TP:	Total Phosphorus (mg/L)	AvErr:	Average error
Chl:	Chlorophyll *a* (µg/L)	AvABSErr:	Average absolute error
AvObs:	Average observed concentration	MSE:	Root mean squared error
AvSim:	Average simulated concentration		

Notes: Because chlorophyll *a* is expected to have a strongly skewed distribution, central tendency is represented by the geometric mean (GM). Observed values in segments 4, 12, 14, and 15 are adjusted in accordance with Table 3-13 to account for depth of segment simulated versus depth of sampling.

Table 3-19. Probability Values for *t*-tests on Validation, 2000.

Parameter	TN	TP	Chl	TON	TIN	TOP	TIP
Criterion	0.25	0.025	10	0.25	0.1	0.025	0.015
Seg 1	0.26	0.07	0.01	0.35	0.34	0.04	1.00
Seg 2	0.07	0.29	0.01	0.04	0.26	0.46	1.00
Seg 3	0.11	0.23	0.07	0.15	0.68	0.21	1.00
Seg 4	0.99	0.94	0.23	0.99	0.39	0.93	1.00
Seg 6	1.00	0.99	0.07	1.00	0.94	0.99	1.00
Seg 8	1.00	0.99	0.08	1.00	0.26	1.00	0.99
Seg 9	0.40	0.24	0.11	0.46	0.54	0.19	0.92
Seg 12	1.00	0.98	0.08	1.00	0.15	0.98	0.48
Seg 13	0.99	1.00	0.04	0.98	0.37	0.94	0.95
Seg 14	1.00	0.51	0.33	0.95	0.00	0.68	0.08
Seg 15	0.49	0.28	0.04	0.84	0.01	0.38	0.29

Note: Values reported represent the probability that the average absolute error (absolute value of model predicted value minus observed value) is less than the specified criterion. Small probability values indicate a relatively large probability that the average absolute error is greater than the criterion.

Key:

TN: Total Nitrogen (mg/L)

TP: Total Phosphorus (mg/L)

Chl: Chlorophyll *a* (µg/L)

TON: Total Organic Nitrogen (mg/L)

TIN: Total Inorganic Nitrogen (mg/L)

TOP: Total Organic Phosphorus (mg/L)

TIP: Total Inorganic Phosphorus (mg/L)

3.2.6 Discussion of Water Quality Model Results

Simulated Nutrient Response

Model simulations show a system in which nutrient concentrations, and nutrient response, are high in the influent segments of the lake (segments 1, 2, 3, and 15), due to loading from a combination of point and nonpoint sources. Concentrations of nutrients and algae generally decline with distance downstream in the New Hope, reaching relatively low levels in segments 8 through 12.

Conditions in the middle portion of the New Hope arm appear to be strongly forced by loads transported from the upper New Hope, while conditions near the dam depend strongly on Haw River inputs. Backflow of water from the Haw into the New Hope arm does have a measurable effect on conditions in the New Hope; however, this effect appears to be quite small north (upstream) of segment 13 relative to the impact of loads deriving from the New Hope.

The system is predicted to be sensitive to pulse inputs associated with stormflow, particularly in the New Hope arm. It appears that the small tributary systems receiving discharge from the Durham City, Durham County, and OWASA wastewater treatment plants store significant amounts of nutrients that may be washed through during high flow events. One of the major limitations on the predictive ability of the model is the sparseness of data with which to characterize inflowing tributary loads.

The calibrated WASP/EUTRO model provides important insights on the factors controlling algal growth in the reservoir. Figure 3-30 shows the limits imposed on algal growth by the availability of light, nitrogen, and phosphorus. The figure shows growth limiting factors, such that a value of 1 indicates no limitation on the intrinsic growth rate, and a value of 0 indicates complete suppression of algal growth. The model calculates algal growth as the intrinsic (temperature-dependent) growth rate times the light limitation factor times the nutrient limitation factor, where the nutrient limitation factor is the *lower* of the limits imposed by nitrogen and phosphorus availability. Thus, in the figure when the line for nitrogen limitation is lower than the line for phosphorus limitation, nitrogen is the limiting nutrient.

Consistent with the findings of the scoping model, it appears that nitrogen is most often the limiting nutrient in Jordan Lake. In the upper New Hope arm, phosphorus is the limiting nutrient at times, particularly later in the growing season. In the Haw River arm it appears that nitrogen is almost always the limiting nutrient. Light is, however, the most important factor in limiting algal growth in the reservoir. In other words, the high turbidity and color of Jordan Lake water limit the penetration of light, and thus the availability of light energy to support algal growth. Light limitation in the headwater sections of the lake serves, however, to slow the rate of uptake of inorganic nutrients by algae, and may thus spread algal blooms further down the lake.

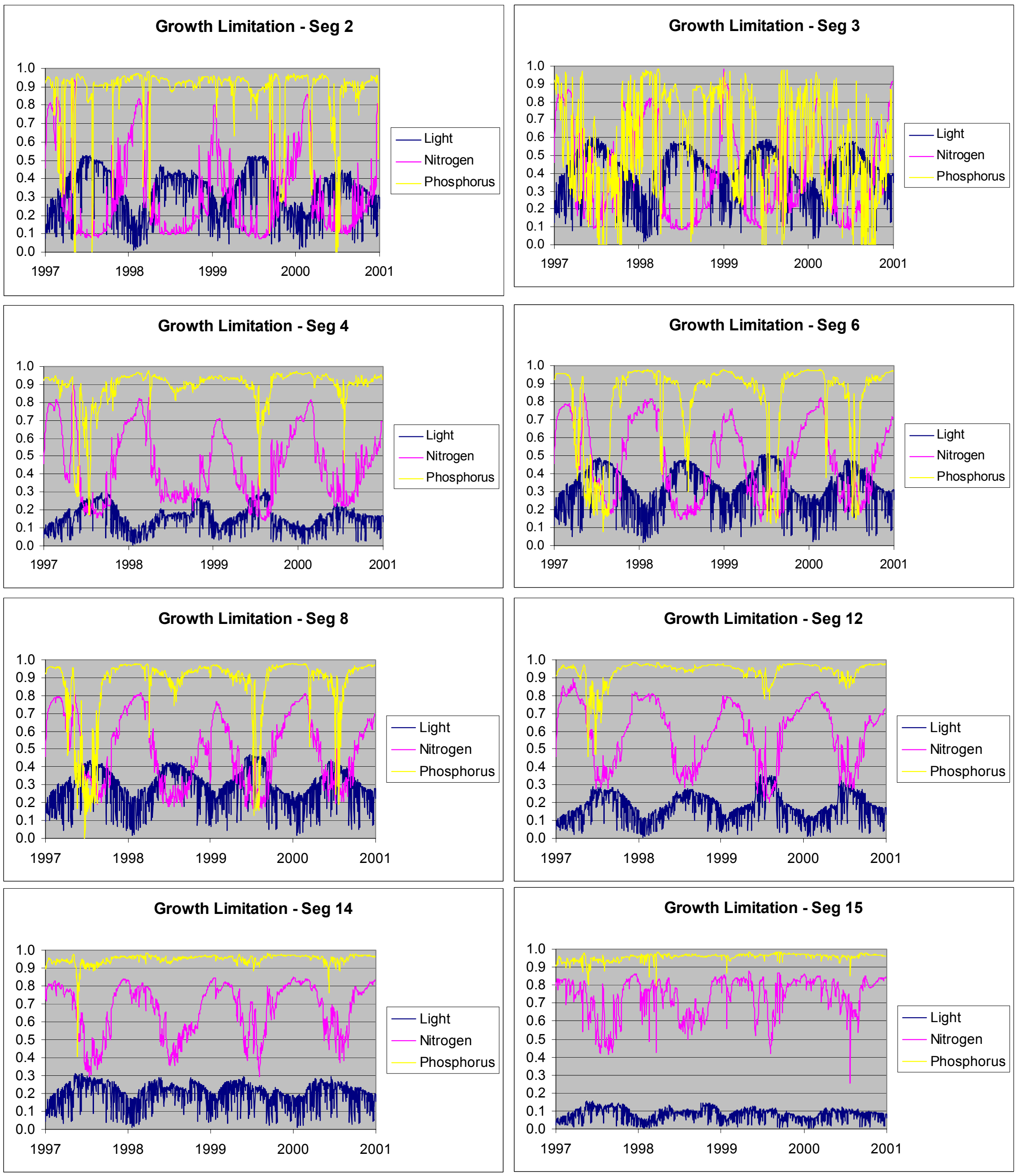


Figure 3-30. Factors Limiting Algal Growth in Jordan Lake, 1997-2001.

Model Sensitivity to Assumptions

WASP/EUTRO is a complex simulation model. Predictions from the model depend on the specification of boundary conditions and the values assigned to internal parameters. Like most models of this type, individual parameters have complex interactions with one another, and predicting the sensitivity of the model to a single parameter is not straightforward, nor is it intrinsically meaningful without considering the interactions between parameters. For instance, algal biomass is directly sensitive to changes in the maximum algal growth parameter. Increasing this parameter yields a linear response when nutrients and light are available to support growth. But, there are also several feedback effects: higher algal growth rates will increase algal self-shading, and thus suppress light penetration and growth at depth. At the same time, higher growth rates increase the rate of depletion of inorganic nutrients and can shift algal growth immediately downstream while increasing growth at distances far enough away to allow regeneration of inorganic nutrients from dead algal matter. As another example, increased settling rates of inorganic matter can actually increase average inorganic nutrient concentrations when material is removed from the photosynthetic zone, stored in bottom waters, then mixed back to the surface in overturn events.

In general, the model is most sensitive to the specification of external boundary conditions, particularly the influent nitrogen loads to the upper New Hope and Haw River arms. Uncertainty in the characterization of these loads is a key source of uncertainty in the simulation of nutrient response.

Model predictions of algal response are also sensitive to the specification of non-algal light extinction. Chlorophyll *a* predictions are highly responsive to the light available for photosynthesis, which depends on both the incident solar radiation (which is affected by shading and cloud cover) and the light extinction coefficient. The time series of non-algal light extinction is interpolated from a rather sparse series of Secchi disk observations. It is highly probable that much of the short-term variability in algal concentrations that is not captured by the model may be due to variations in water clarity not captured by the monitoring program.

Because nutrient limitations on algal growth are predominantly determined by inorganic nitrogen availability, the model is highly sensitive to those parameters that control the distribution, cycling, and uptake of nitrogen. The most sensitive parameters controlling nitrogen cycling include the following:

- Settling rate of inorganic nutrients, which directly effects the vertical distribution of inorganic nitrogen and its loss to the sediments.
- Settling rate of algae, which provides a mechanism for removing organic nitrogen from regeneration.
- Settling rate of organic nutrients, which also removes organic nutrients from regeneration in the water column.
- Nitrogen half-saturation constant for phytoplankton growth (*kmng1*).
- Endogenous respiration rate for phytoplankton (*k1rc*), which determines the rate of re-release of nutrients from algae. Note that optimization is not able to clearly resolve losses of

algal biomass due to respiration and death of algae as both are simulated as a reduction in biomass.

- Mineralization rate of dissolved organic nitrogen (*k71c*), which determines the rate of regeneration of available inorganic nitrogen from the organic nitrogen pool.
- Fraction of dead and respired phytoplankton nitrogen recycled to organic nitrogen rather than directly to ammonia (*fon*).

The optimization method employed by OPTSHELL does not require estimation of second derivatives, and thus does not directly yield a parameter covariance matrix. Control against convergence on a non-optimal solution is provided in several ways:

1. The objective function for the optimization seeks a simultaneous fit to organic and inorganic nitrogen and phosphorus and chlorophyll *a* concentration. Thus the optimized parameter set must satisfy all the available data simultaneously.
2. OPTSHELL continuously generates new trial solutions throughout the parameter space, helping to assure against convergence to local optima.
3. OPTSHELL simulations were run simultaneously on multiple computers, in most cases including seven simultaneous runs. Each of these runs had randomly generated starting positions, so consistency among optimized parameter sets could be checked.
4. Optimized parameter values were compared to literature values to help ensure physically realistic solutions.
5. Parameter values were determined on a calibration data set and checked against an independent validation data set.

Because of the complex interaction of parameters and boundary conditions in WASP/EUTRO, it is not particularly useful to report model sensitivity to individual parameter value assumptions. A change in the value of one parameter would generally require adjustments in several related parameters. Instead, it is most relevant to examine the uncertainty in the model in terms of the output statistics shown in Tables 3-16 and 3-18. The validation statistics (Table 3-18), involving a test on independent data, are formally most relevant for assessing uncertainty in total nitrogen and total phosphorus predictions. For these parameters, the coefficient of variation (standard deviation divided by the mean) for individual observations at all stations is approximately 0.5. Average absolute errors for these parameters meet criteria in all segments (Table 3-19). For chlorophyll *a*, "uncorrected" data from the latter half of 2000 are suspected to be unrepresentative of living algal biomass, so the statistics presented for the calibration period (Table 3-16) likely provide a better estimate of prediction uncertainty.

A more important question regarding model uncertainty is the applicability of results for assessment of compliance with the water quality standard for chlorophyll *a*. As noted in Section 3.2.4, the calibration fit for chlorophyll *a* is good, with all segments passing calibration criteria and seven out of nine segments having average absolute errors of less than 10 µg/L, which is of the same order of magnitude as the analytical method uncertainty, as cited by DWQ, for concentrations around the 40 µg/L criterion. The apparent fit was not as good for the validation period, but these results appear to be biased by fall samples including significant pheophytin interference. Model fit to proper analytical determinations of corrected chlorophyll *a* should yield a tighter fit. In addition, the model simulations of chlorophyll *a* for the calibration period appear to have a small positive bias (on the order of 4 µg/L) when compared to observed uncorrected chlorophyll *a*. Model predictions are thus conservative in relation to the standard, and will be even more conservative when compared to corrected chlorophyll *a* concentrations, which should be less than or equal to the uncorrected concentrations.

Accordingly, the calibrated model is believed to provide a strong and defensible, yet conservative estimate of the probability of exceeding water quality standards. Sampling probabilities of exceeding the 40 µg/L criterion may be calculated (e.g., using the methods in Gilbert, 1987). Perhaps more importantly, the model does not exhibit any strong bias. As a result, the model provides a firm basis for evaluating the relative performance of different wasteload allocation scenarios.

3.3 References

Ambrose, R.B., Jr., T.A. Wool, and J.L. Martin. 1993. The Water Quality Analysis Simulation Program, WASP5. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Blumberg, A.F. and G.L. Mellor. 1987. A description of a three-dimensional coastal ocean circulation model. pp. 1-16 in N. Heaps, ed., *Three-Dimensional Coastal Ocean Models*. American Geophysical Union, Washington, DC.

CDM. 1989. Watershed Management Study: Lake Michie and Little River Reservoir Studies, June 1989.

Gilbert, R.O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold, New York.

Hamrick, J.M. 1992. A Three-Dimensional Environmental Fluid Dynamics Computer Code: Theoretical and Computational Aspects. Special Report No. 317 in Applied Marine Science and Ocean Engineering. Virginia Institute of Marine Science, The College of William and Mary, Gloucester Point, VA.

Hamrick, J.M. 1996. User's Manual for the Environmental Fluid Dynamics Computer Code. Special Report No. 331 in Applied Marine Science and Ocean Engineering. Virginia Institute of Marine Science, The College of William and Mary, Gloucester Point, VA.

Kohler, M.A., T.J. Nordenson, and W.E. Fox. 1955. Evaporation from Pans and Lakes. Research Paper No. 38. U.S. Weather Bureau.

Lahlou, M., L. Shoemaker, S. Choudhury, R. Elmer, A. Hu, H. Manguerra, and A. Parker. 1998. Better Assessment Science Integrating Point and Nonpoint Sources, BASINS, Version 2.0, User's Manual. EPA-823-B-98-006. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

NCDWQ. 2001. Memorandum from Jay Sauber to Coleen Sullins et al., February 26, 2001, "Re: Chlorophyll Meetings and Issues with Lab Data."

Parameshwara, V.K., S. Raman, D.S. Niyogi, K.B. Perry, A. Syed, A. Sims, and R. Boyles. 2000. Enhancement of North Carolina Agricultural Automated Weather Network and Development of Advanced Communication, Data Acquisition, and Dissemination Systems. State Climate Office of North Carolina, North Carolina State University, Raleigh, NC.

Reckhow, K.H., Jr., J.T. Clements, and R.C. Dodd. 1990. Statistical evaluation of mechanistic water-quality models. *Journal of Environmental Engineering*, 116(2): 250-268.

Redfield, A.C., B.H. Ketchum, and F.A. Richards. 1963. The influence of organisms on the composition of seawater. pp. 26-77 in *The Sea*, vol. 2., ed. M.N. Hill. Wiley-Interscience, New York.

Riley, G.A. 1956. Oceanography of Long Island Sound, 1952-1954. II. Physical oceanography. Bulletin Bingham. Oceanog. Collection 15: 15-46.

Smolarkiewicz, P.K. and T.L. Clark. 1986. The multidimensional positive definite advection transport algorithm: further development and applications. *J. Comp. Phys.*, 67: 396-438.

Smolarkiewicz, P.G. and W.W. Grabowski. 1990. The multidimensional positive definite advection transport algorithm: nonoscillatory option. *J. Comp. Phys.*, 86: 355-375.

Thomann, R.V. and J.A. Mueller. 1987. *Principles of Surface Water Quality Modeling and Control*. Harper & Row, New York.

USACOE. 1997. B. Everett Jordan Dam and Lake Project, Cape Fear River Basin, NC., Report of Sedimentation Resurvey, Year 1997. Wilmington District, U.S. Army Corps of Engineers, Wilmington, NC. August 1997.

U.S. EPA. 1997. Technical Guidance Manual for Developing Total Maximum Daily Loads, Book II: Streams and Rivers, Part I: Biochemical Oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication. Office of Science and Technology, U.S. Environmental Protection Agency, Washington, DC.

4. Jordan Lake Nutrient Response Scenario Evaluation

It is impractical to conduct real-world nutrient loading and management experiments on Jordan Lake. The Jordan Lake Nutrient Response Model allows simulation of the water quality changes that would result from changes in nutrient loading to the lake. These simulations, or "scenarios," allow prediction of the positive or negative impacts on lake water quality.

The calibrated nutrient response model was used to investigate and compare a number of different wasteload allocation scenarios as well as to conduct sensitivity analyses of nutrient response. The term "scenario" is used to refer to a model run under specific conditions that is used to provide a basis for comparison. For instance, an application of the model with all dischargers meeting the proposed NSW nitrogen effluent limitations constitutes one scenario for comparison.

Multiple scenarios were tried with the model, many of which are reported briefly under the heading "Sensitivity Analysis" in Section 4.3. However, only four scenarios were developed with full rigor and quality control checking by the Project Partners. These four scenarios are designed to address the core issues raised by HB 515. Specifically, the scenarios investigate: (A) current conditions, (B) current conditions with the nitrogen effluent limitations set forth in HB 515, (C) future conditions with proposed expansions in wastewater discharges under current regulations, and (D) future conditions with proposed expansions under the nitrogen effluent limitations proposed in HB 515.

The two future condition scenarios examine projected point source nutrient discharge conditions in the year 2010. A relatively short time horizon was adopted for two primary reasons. First, the models that were developed in accordance with the mandate of HB 515 do not contain a complete watershed nonpoint loading simulation, so it is not currently feasible to examine the long-term impacts that could be expected to result from alternative land use management practices. Second, the rapid pace of innovation in wastewater treatment technology suggests that it may be prudent and cost-effective to impose progressively more stringent requirements in the future, as needed, and it is thus appropriate to address more short-term needs in the current or near-term NPDES permitting cycle.

4.1 Scenario Development

To provide a coherent and consistent basis for comparison among different scenarios, all scenarios must be run using the same underlying hydrology and meteorology. All scenarios are therefore run using the 1997-2000 data, i.e., the period for which the model is calibrated and validated. The 1997-2000 time period includes both wet and dry periods, as well as several extreme (tropical storm) events, and thus provides a reasonable basis for comparison among alternatives. In addition, the 1997-2000 tributary loading time series are used to estimate the nonpoint source loading component, which is assumed to remain constant across all scenarios. Evaluation of changes in nonpoint nutrient loads was outside the scope of the current project, which is designed to evaluate impacts of potential changes in point source loads. However, assumptions regarding the total nutrient load input to the lake can be modified in the model to reflect expected changes in total delivered nonpoint source loads, thereby providing a general capability to evaluate the relative effects of different levels of point and nonpoint source loads to the lake.

4.1.1 Scenario Identification

The four model scenarios are described below, and methods for implementing the changes in tributary loading corresponding to a scenario are described in Section 4.1.2. The projected loading associated with a given scenario is summarized in Section 4.1.3.

Scenario A – Baseline Conditions. This scenario represents existing conditions, with tributary inputs represented by FLUX model interpolation of daily total phosphorus and total nitrogen loads. This scenario is thus identical to the calibration plus validation runs. The baseline conditions represent actual observed, rather than maximum permitted flows and loads from the wastewater treatment plants. This is the appropriate approach recommended by U.S. EPA (1991) for analysis with a dynamic model, as opposed to a steady state design condition analysis. To comply with a specified limit, a wastewater discharger must keep discharges below the maximum specified in the permit. In addition, flows and loads in wastewater treatment discharges respond to weather conditions, and will increase during wet weather events. It is important to preserve the observed correlation between regional hydrology that is captured in the tributary monitoring time series in order to provide realistic simulation results. Actual flows observed in 1997-2000 are compared to permitted capacity in Table 4-1. This table also gives the total phosphorus concentration limits now in place for each plant. At present, there are no limits on total nitrogen discharges.

Scenario B – HB 515 Nitrogen Requirements. This scenario combines existing flow and total phosphorus loads (as delivered to or "exerted" at the lake) with a hypothetical reduction in total nitrogen discharges from major wastewater treatment plants to the lesser of 5.5 mg/L at end-of-pipe with future flows or the load from 5.5 mg/L at current permitted flows (mass-based limit). Since all existing major wastewater facilities are already at or below the 2.0 mg/L total phosphorus limit in HB 515, this scenario is thus equivalent to the proposed HB 515 nitrogen removal requirements and can be used to evaluate the potential response to the proposed nitrogen removal requirements. Minor dischargers of less than 0.5 MGD in existence as of 1997 are exempted from the NSW nitrogen requirement and so are not modified in the scenario. Scenario adjustment method 2 is used to adjust the tributary time series.

Scenario C – Future Wasteflows with Current Limits. This scenario examines the impacts of increased wastewater treatment facility discharges anticipated by 2010. This relatively short-term planning horizon was adopted because the current modeling system does not specifically provide the capability to model potential changes in nonpoint source loads associated with changes in land use. To model this scenario, the portion of each tributary input attributable to a point source load is multiplied by the expected increase in flow for that plant. The Durham County Triangle Wastewater Treatment Plant has already received a draft permit for expansion that contains mass-based permit limits (see notes to Table 4-1). This mass-based limit is incorporated into the 2010 projections for the Triangle Plant in both future scenarios (C and D). Projected waste flows for 2010 are summarized in Table 4-2.

Scenario D – Future Wasteflows with HB 515 Nitrogen Limits. This scenario also examines the impacts of increased discharges anticipated by 2010, but with nitrogen concentrations in the effluent discharges reduced according to HB 515 limits for all major dischargers. To model this scenario, tributary input load series were adjusted based on the expected change in the delivered point source long-term average load, thus maintaining a scenario consistent with simulation hydrology.

Table 4-1. Existing Permitted Capacity and Total Phosphorus Limits for Selected Major Municipal Wastewater Treatment Facilities in the Jordan Lake Watershed

Local Government/ Facility Name	NPDES Permit Number	Permitted Capacity (MGD)	1997-2000 Average Daily Flow (MGD)	Total Phosphorus Limits (mg/l)	
				Summer (April - Oct)	Winter (Nov. -Mar)
Burlington					
Burlington- East WWTP	NC0023868	12.00	6.92	2.0 (1)	2.0 (1)
Burlington- South WWTP	NC0023876	12.00	7.85	2.0 (1)	2.0 (1)
Durham					
South Durham Water Rec. Facility	NC0047597	20.00	10.32	0.5 (1)	2.0
Durham County					
Triangle WWTP (2)	NC0026051	6.00	3.89	0.5 (1)	2.0 (1)
Graham					
Graham WWTP	NC0021211	3.50	1.88	2.0 (1)	2.0 (1)
Greensboro					
T.Z. Osborne WWTP (3)	NC0047384	30.00	18.74	2.0 (1)	2.0 (1)
North Buffalo WWTP	NC0024325	16.00	13.02	2.0 (1)	2.0 (1)
Mebane					
Mebane WWTP	NC0021474	2.50	1.00	2.0 (1)	2.0 (1)
OWASA					
Mason Farm WWTP	NC0025241	12.00	7.98	0.6 (1)	0.6 (1)
Pittsboro					
Pittsboro WWTP	NC0020354	0.75	0.30	2.0 (1)	2.0 (1)
Reidsville					
Reidsville WWTP	NC0024881	7.50	3.19	2.0	2.0
TOTALS:		122.25	75.09		

NOTES:
Discharge limitations shown are monthly averages unless otherwise noted.
1. Sampling shall be based on quarterly average of weekly sampling.
2. Durham County has received a draft permit for expansion to 12 MGD. The draft includes proposed mass loading limits for nitrogen and phosphorus.
3. Greensboro also has a permit to expand to 40 MGD.

Table 4-2. Projected Wasteflows for 2010 for Selected Major Municipal Wastewater Treatment Facilities in the Jordan Lake Watershed

Local Government/Facility Name	NPDES Permit Number	Permitted Capacity (MGD)	Projected Average Daily Wastewater Discharge in the Year 2010 (MGD)
Burlington			
Burlington- East WWTP	NC0023868	12.00	7.5
Burlington- South WWTP	NC0023876	12.00	8.4
Durham			
South Durham Water Rec. Facility	NC0047597	20.00	11.73
Durham County			SEE NOTE 1
Triangle WWTP	NC0026051	6.00	10.36
Graham			
Graham WWTP	NC0021211	3.50	3.02
Greensboro			
T.Z. Osborne WWTP	NC0047384	30.00	24.0
North Buffalo WWTP	NC0024325	16.00	16.0
Mebane			
Mebane WWTP	NC0021474	2.50	3.0
OWASA			
Mason Farm WWTP	NC0025241	12.00	9.4
Pittsboro			
Pittsboro WWTP	NC0020354	0.75	2.25
Reidsville			
Reidsville WWTP	NC0024881	7.50	3.39

Prepared by TJCOG based on information provided by the Project Partners and others.

NOTE 1:
Durham County's draft NPDES for expansion to 12.0 MGD includes annual mass load limits for both nitrogen and phosphorus, as follows:
TN: 100,452 pounds per year (124.8 kg/d)
TP: 10,204 pounds per year (17.7 kg/d)

4.1.2 Methods for Calculating the Revised Scenario Loads

Implementing the scenarios described above requires modification of the tributary loading inputs for the water quality model. This section describes the procedures to accomplish these modifications. Three general methods are presented that can be used to implement a wide variety of potential discharge scenarios.

The following variables are defined:

FLUX-t FLUX estimates of daily load at time t.

EPS Exerted Point Source load as a fraction of total load delivered in a given tributary. This is best defined as the long-term delivered point source load divided by the long-term delivered total load, where the first term is derived from the RTI modeling and the latter term is derived from the FLUX analysis. The actual exerted point source load at time t may thus be approximated as FLUX-t · EPS. (See discussion below for special considerations regarding calculation of EPS for TN in Morgan Creek.)

REM Fraction remaining of a point source load in a point source reduction scenario.

C-NEW New concentration in a scenario that involves a fixed concentration replacing the existing load series.

D Site-specific delivery ratio to lake for point source loads as estimated from the JLPSDM modeling of nutrient delivery. Given the relatively small variability from month-to-month, a single summary average will be sufficient. For use in the scenarios, D will be calculated as the total delivered load divided by the total discharged load over the entire period of RTI simulation (rather than as the average of monthly delivery ratios), which results in a load-weighting of the estimate. This approach is further warranted because the cumulative loading (at the scale of weeks to months) is more significant to algal response in the lake than short-term variability in loads.

QS-t Flow in a stream at time t.

QSNew-t Revised flow in a stream at time t.

QP-t Existing effluent flow from a point source at time t.

QPNew Modified average flow from a point source.

LOAD-t Revised delivered or exerted total load (point and nonpoint) at time t.

Three methods were used for calculating the revised tributary loads associated with a given scenario. These methods are:

Method 1. In a scenario that involves a reduction in point source load to a specified fraction of current load, the revised load series may be estimated as

$$\text{LOAD-t} = \text{FLUX-t} - \text{EPS}\cdot\text{FLUX-t} + \text{REM}\cdot\text{EPS}\cdot\text{FLUX-t} = \text{FLUX-t}\cdot(1 - \text{EPS} + \text{REM}\cdot\text{EPS})$$

For tributaries with multiple loads, the last term may be replaced by a sum across all the point source loads.

Method 2. In a scenario that involves replacing the existing point source load with a constant load at a specified concentration (but the same flow), the revised load series may be estimated as

$$\text{LOAD-t} = \text{FLUX-t} - \text{EPS}\cdot\text{FLUX-t} + \text{C-NEW}\cdot\text{QP}\cdot\text{D} = \text{FLUX-t}\cdot(1 - \text{EPS}) + \text{C-NEW}\cdot\text{QP-t}\cdot\text{D}$$

Method 3. In a scenario that involves replacing the existing point source load with a constant load at a specified concentration and a new flow, the revised load series may be estimated as

$$\text{LOAD-t} = \text{FLUX-t} - \text{EPS}\cdot\text{FLUX-t} + \text{C-NEW}\cdot\text{QPNew}\cdot\text{D} = \text{FLUX-t}\cdot(1 - \text{EPS}) + \text{C-NEW}\cdot\text{QPNew}\cdot\text{D}$$

In this type of scenario, the flow in the tributary may also need to be revised (if the change is significant), as

QSNew-t = QS-t – QP-t + QPNew

For all three scenarios, the revised loads (and flows) are constrained to be greater than or equal to zero. In addition, daily loads from scenarios with HB 515 limits are constrained to be no greater than the load from the corresponding scenario without HB 515 limits. This accounts for the presence of some days in the existing load series where the nitrogen load under current conditions appears to be less than would be expected after reducing point source loads to the levels specified in HB 515. These low load days arise from natural processes in the tributaries and failure to make this adjustment would underestimate the benefits of point source nutrient reductions.

Approach for Morgan Creek Total Nitrogen Analysis

Applying the methods presented above to OWASA's discharge to Morgan Creek presents special challenges. It is clear that OWASA's discharge at present constitutes the majority of nitrogen load in Morgan Creek under low flow conditions, and that the value of EPS is thus likely to be close to 1. The RTI delivery model analysis, however, predicts a cumulative exerted point source load of TN from the OWASA plant that is slightly greater than the delivered TN load estimated by FLUX (Figure 4-1). This would lead to a value of EPS equal to 1.07. As EPS cannot be greater than 1.0, this estimate is not useable.

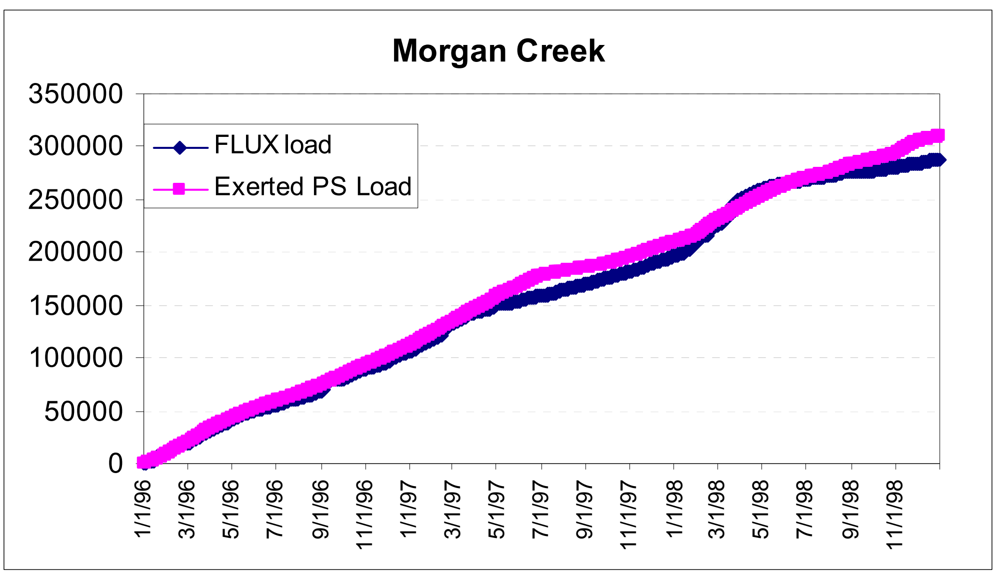


Figure 4-1. Comparison of Cumulative Total Nitrogen Load at Mouth of Morgan Creek Estimated by FLUX and Exerted Point Source Load Estimated by the RTI Delivery Model

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

- Total nitrogen in OWASA effluent is measured only once per month; thus the interpolated estimates for intervening days are highly uncertain.

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

The exact cause of the discrepancy has not been determined, although it is suspected that it is due to a combination of several of the factors cited above. It should be noted, however, that small discrepancies in the estimates of load from OWASA have little effect on the lake model or scenario evaluation. For baseline conditions, only the FLUX estimates, based directly on instream observations of total load, are needed. Small discrepancies in total loading estimates for Morgan Creek will have only a relatively minor impact on model predictions because they represent a small portion of the overall nitrogen loading to the upper New Hope arm of the lake. For the scenarios described above, it is not necessary to achieve complete mass balance closure between the two estimation methods, as long as a reasonable estimate of EPS can be developed.

A consistent estimate of EPS has been developed using a mass balance approach. Conceptually, this is based on the notion that the total load delivered from Morgan Creek is the sum of the delivered loads from OWASA and from Morgan Creek upstream of OWASA. Further, the load derived from upstream of OWASA is equal to the concentration upstream of OWASA times the flow, which may be estimated as the gaged flow (below OWASA) minus the OWASA discharge. In equation form,

$$L_{FLUX} = \left[L_{OWASA} + C_{UP} \cdot \left(Q_{GAGE} - Q_{OWASA}\right)\right] \cdot D$$

in which L represent load, C is concentration, Q is flow, and D is the delivery ratio between the OWASA plant and the lake. Rearranging this equation allows estimation of a value of EPS that is consistent with the FLUX estimates of loading to the lake:

$$EPS = \frac{L_{OWASA} \cdot D}{L_{FLUX}} = 1 - \frac{C_{UP} \cdot \left(Q_{GAGE} - Q_{OWASA}\right) \cdot D}{L_{FLUX}}$$

For calculation across a time series of multiple observations, the numerator and denominator on the right hand side of the equation are estimated as sums over time prior to calculation of the ratio. In this way, EPS represents a long-term loading average.

Application of this method requires an estimate of upstream concentration. OWASA has periodically measured concentrations upstream of the Mason Farm plant as part of their discharge self-monitoring. Examination of these data suggests that upstream concentration varies significantly at low flows, but is relatively constant at higher (Figure 4-2). This is a typical pattern for nitrogen, where subsurface pathways rather than surface washoff typically dominate loads. The presence of University Lake upstream also serves to dampen variability in high flow concentrations.

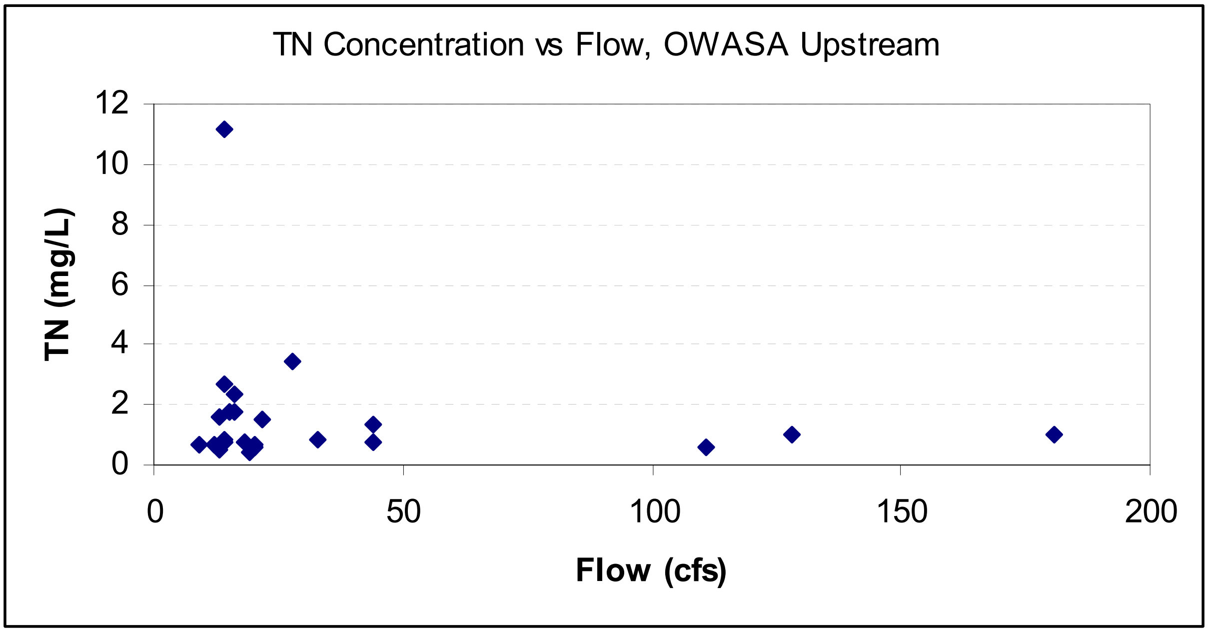


Figure 4-2. Total Nitrogen Concentrations Reported by OWASA Upstream of Mason Farm WWTP, Plotted against Flow

Variability in low flow concentration of total nitrogen has a small effect on total loading to the lake relative to the loads moved at higher flows. Based on these observations, it is appropriate to represent the upstream concentration as an approximately constant value, which was set to the median of the OWASA upstream observations, or 0.825 mg/L TN. D is also assumed to be approximately constant over time, based on the RTI analysis. The RTI analysis does calculate higher values of D for higher flows; however, the loading seen at these higher flows consists in part of wash-through of constituents stored during low flows. It is therefore most appropriate to use an estimate of D based on the comparison of discharged and delivered loads over time.

Summary of Loading and Delivery Factors

Application of the methods described above requires estimation of *EPS*, the fraction of exerted load attributable to each point source, and *D*, the delivery ratio for each point source. These are summarized in Table 4-3.

Specification of changes in tributary total nutrient load in response to a discharger scenario is relatively straightforward using the methods described above. The model, however, requires input of nitrate, ammonia, and organic nitrogen loads. The simplest approach is to assume that the revised scenario loads exhibit the same distribution among nitrogen species as is observed in the existing loading time series. This may, however, introduce inaccuracies in the representation of future scenarios if the change in the effluent proportion of total stream flow is large or significant modifications occur in treatment processes. Use of complete nitrification/denitrification to remove nitrogen tends to shift the remaining effluent to a higher proportion of nitrate with reduced fractions of ammonia and organic nitrogen. However, significant shifts in nitrogen speciation back toward organic forms can occur within a short distance downstream of a discharge due to biotic uptake and processing. It would not be correct to specify the WWTP-derived nitrogen loading to the lake as following the same speciation as expected in the effluent. These issues cannot be fully resolved without an evaluation of proposed treatment trains and a simulation of instream transformation processes. To improve the realism of the scenarios, the simulation of instream loads under HB 515 requirements is based on observed instream speciation, but was adjusted by decreasing the ammonia fraction in the proportion of delivered total nitrogen load attributed to point sources by one half and adding this mass fraction to the nitrate load.

Table 4-3. *EPS* and *D* factors for Point Source Scenario Development

Point Source	Lake Segment	Total Nitrogen		Total Phosphorus	
		EPS	*D*	*EPS*	*D*
Durham South WRF	1	52.6%	94.1%	65.8%	95.8%
Durham Co. Triangle	2	60.9%	96.7%	35.8%	97.7%
OWASA	3	82.0%	92.3%	66.7%	94.5%
Burlington – East WWTP	15	8.3%	68.6%	4.8%	74.9%
Burlington – South WWTP	15	4.4%	72.4%	2.4%	77.8%
Graham	15	1.1%	73.7%	1.8%	78.0%
Greensboro – N. Buffalo	15	6.1%	36.5%	5.8%	46.0%
Greensboro – T.Z. Osborne	15	7.7%	39.7%	7.0%	47.7%
Mebane	15	0.9%	52.7%	0.3%	57.4%
Pittsboro	15	6.1%	78.6%	9.0%	83.4%
Reidsville	15	1.0%	54.2%	0.7%	59.5%

Notes:

D is the delivery fraction, calculated as sum of discharges/sum of delivered loads

EPS is the fraction of load in a tributary attributable to a particular point source, calculated as the 1996-1998 delivered PS load divided by the 1996-1998 delivered tributary total load from FLUX

Reidsville calculations based on current discharge location to Haw River (commenced 1998)

4.1.3 Scenario Loads

The different scenarios result in a variety of combinations of loads delivered to the lake. Table 4-4 summarizes the loads discharged by each point source under the different scenarios and Table 4-5 summarizes the exerted loads at the lake for each scenario.

Table 4-4. Major Point Source Discharged Loads Associated with Each Scenario

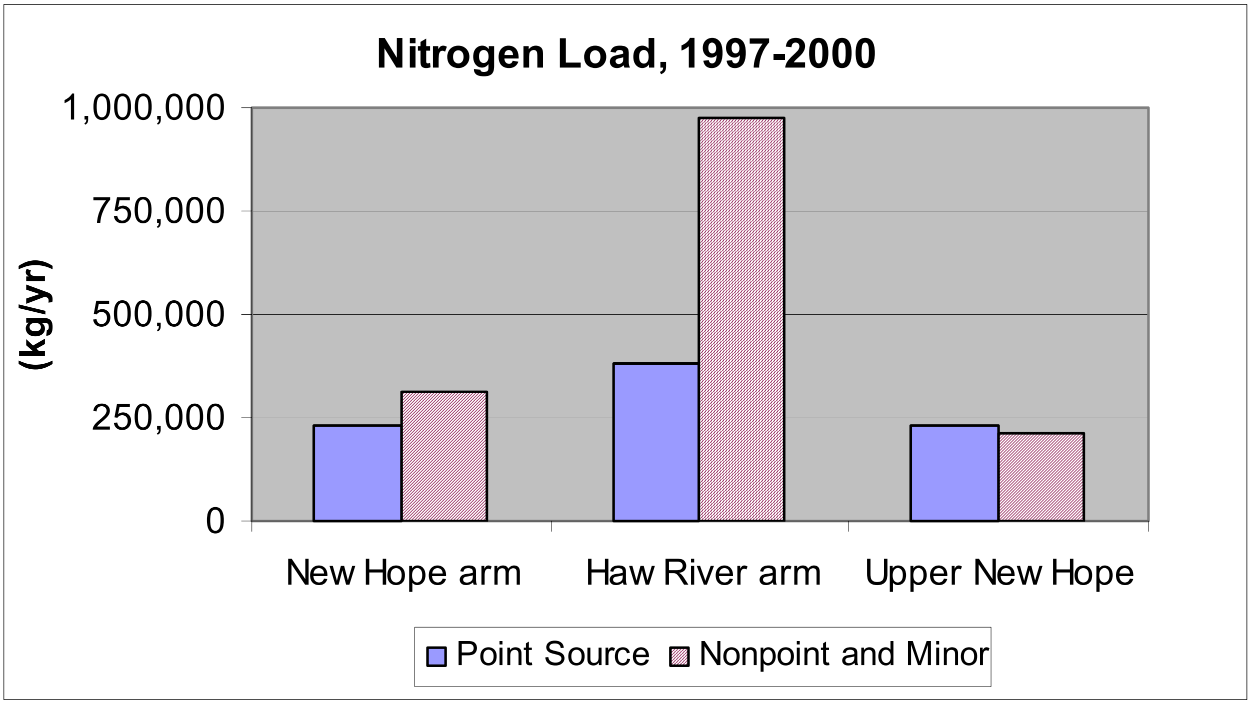
Nitrogen Discharged Loads (kg/d)											
Scenario	Burling-ton East	Burling-ton South	Durham Triangle	Durham South	Graham	Greens-boro Buffalo	Greens-boro Osborne	Mebane	OWASA	Pittsboro	Reidsville
A	420.3	245.1	198.5	245.6	64.5	621.1	712.1	31.3	359.0	15.2	72.8
B	143.6	159.5	82.0	210.7	39.0	270.8	389.0	20.8	167.3	3.9	63.1
C	455.5	262.3	124.8	279.1	103.8	763.4	912.1	93.6	422.7	112.9	77.2
D	155.6	170.7	124.8	239.5	62.8	332.8	498.3	51.8	197.0	9.6	66.9
Phosphorus Discharged Loads (kg/d)											
A	37.2	25.5	11.7	14.1	13.5	79.9	93.1	4.8	11.2	2.1	10.0
B	37.2	25.5	11.7	14.1	13.5	79.9	93.1	4.8	11.2	2.1	10.0
C	40.3	27.2	17.7	16.0	21.7	98.2	119.3	14.3	13.2	15.3	10.7
D	40.3	27.2	17.7	16.0	21.7	98.2	119.3	14.3	13.2	15.3	10.7

Notes: Table shows loads discharged by each facility not load delivered to lake.
Loads of nitrogen and phosphorus from the Durham County Triangle plant are capped at the mass limits contained in the draft permit for expansion. The mass-based limit for nitrogen is more restrictive than the concentration-based limits given in HB 515 at the flows proposed for 2010. Mass-based limits are also more restrictive for Mebane and Pittsboro at 2010 projected flows and are incorporated in Scenario D.

Table 4-5. Exerted Total Point and Nonpoint Nutrient Loads Associated with Each Scenario (kg/d)

Scenario	Total Nitrogen	Total Phosphorus
A	4441	699
B	3743	699
C	4876	752
D	3958	752

The components of the total exerted nutrient load under current conditions are shown in Figures 4-3 and 4-4. Figure 4-3 shows the portion of loads reaching the lake attributable to point and nonpoint sources for the Haw River arm, the entire New Hope Arm, and the uppermost New Hope segment (above Mt. Carmel Church Road), which receives the Durham City, Durham County, and OWASA waste discharges. In this figure, several minor point sources discharging to the Upper New Hope (Cole Park, Nature Trail Mobile Home Park, and Carolina Meadows) are lumped with the nonpoint loads, as they are not subject to HB 515 provisions. Figure 4-4 shows the breakdown to individual point sources for the loads to the Haw River Arm and Upper New Hope segment. It is important to note from these figures that the loads reaching the lake have large nonpoint source components, ranging from 48 to 78 percent of the total. This means that only a fraction of the total nitrogen load delivered to Lake Jordan can be reduced through the imposition of the provisions in HB 515.



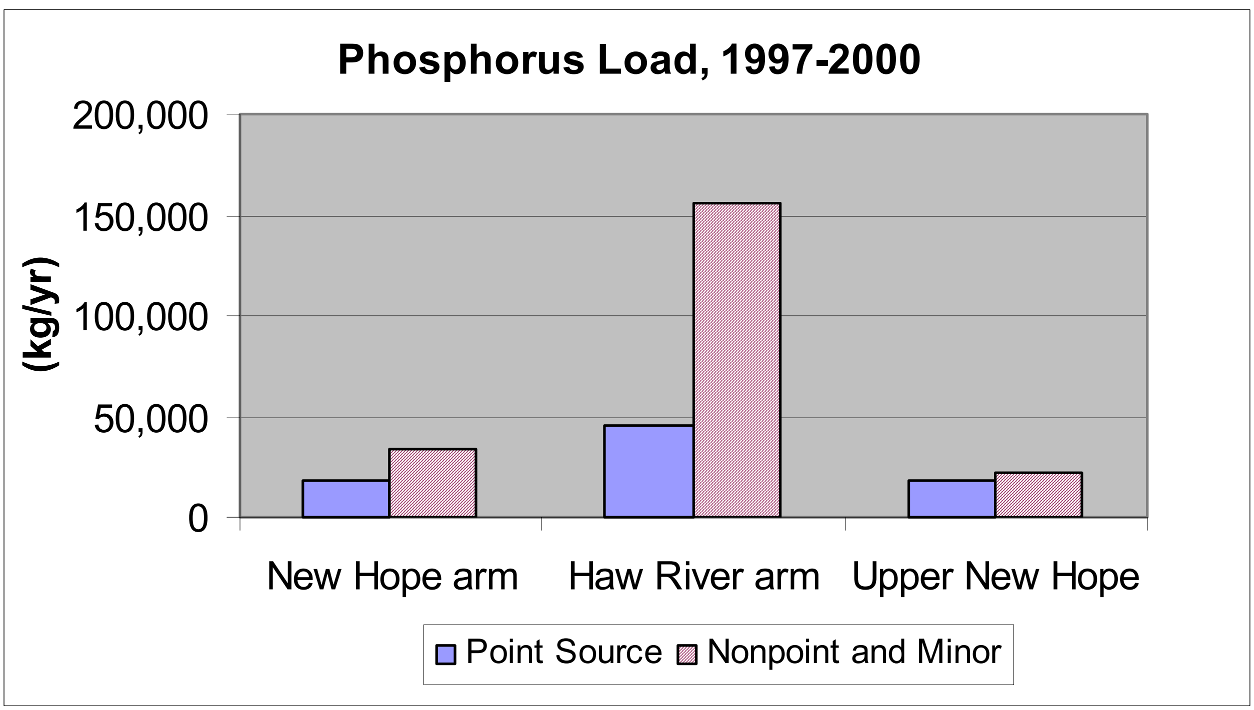


Figure 4-3. Point and Nonpoint Nutrient Loads Entering Jordan Lake, 1997-2000

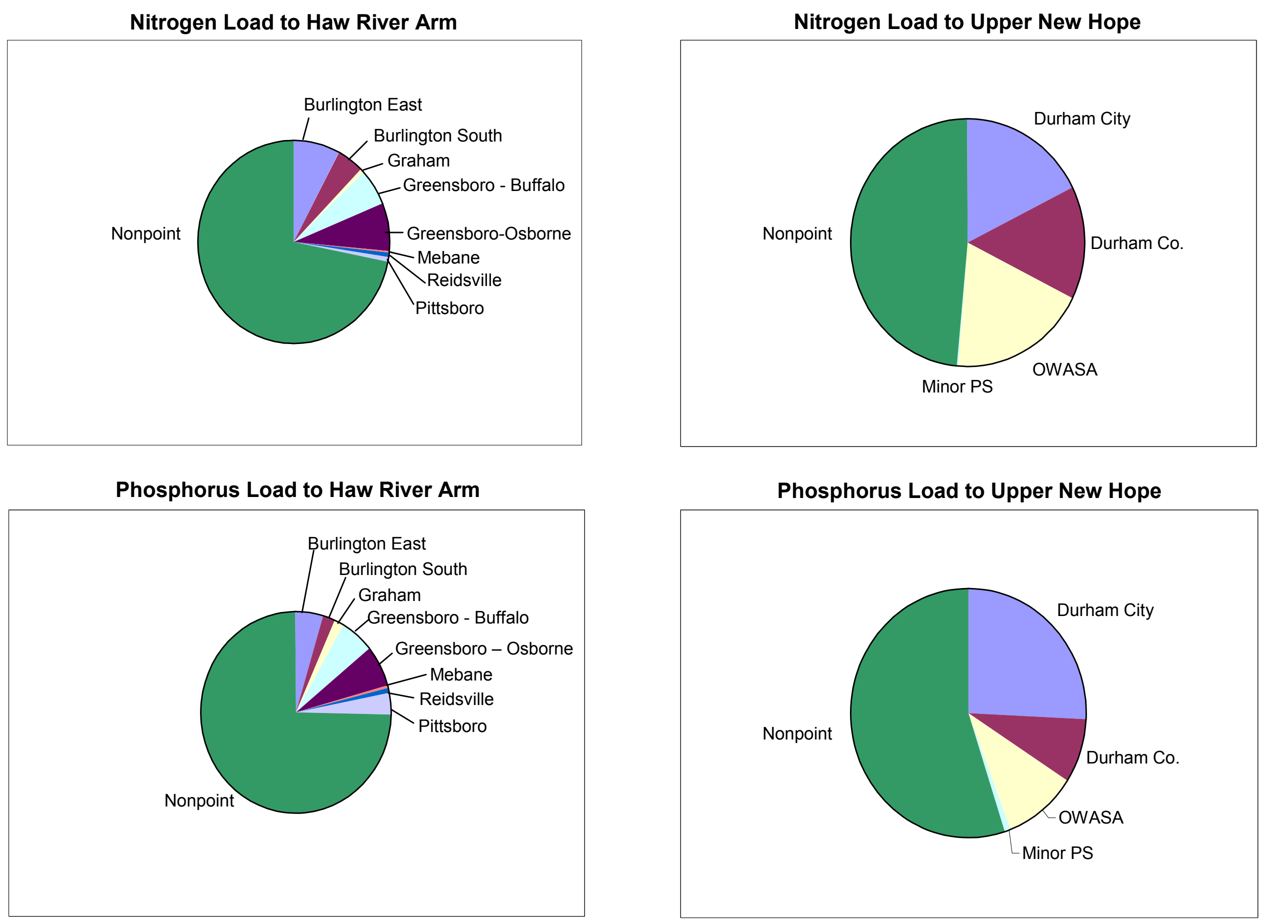


Figure 4-4. Sources of Exerted Nutrient Loads Entering Lake Jordan, 1997-2000

4.2 Scenario Results

Scenarios were run for the four-year period of 1997-2000. Results of the dynamic model applications can be compared in several ways. Based on conversations with NC DWQ, the most relevant results for comparison are the predictions regarding chlorophyll *a* concentration, for which a water quality standard of 40 µg/L exists in North Carolina.

Table 4-6 provides a numerical summary of the scenario results, displayed in two ways: the frequency of days with predicted chlorophyll *a* concentrations greater than the water quality standard of 40 µg/L and the median growing season concentration, where growing season is defined as June through September. Several comments are appropriate on the choice of these indicators.

Algal blooms are sporadic in nature and highly variable in time. In most waterbodies in this area concentrations in excess of 40 µg/L may occur occasionally, given the right combination of low flushing rates, plentiful light, and high availability of nutrients. The dynamic simulation model captures this natural variability in algal response. Chance excursions of the standard, if infrequent, should be compatible with support of the uses of the waterbody. The North

Carolina water quality standard for chlorophyll *a* does not contain an explicit statement of the frequency of excursions of the standard that are compatible with support of uses. The State has, however, established a precedent in developing the Neuse Estuary TMDL of up to 10 percent of observations in excess of 40 µg/L being consistent with support of uses. Therefore, a key criterion for evaluating the response to scenarios should be the frequency of time during which chlorophyll *a* concentrations are predicted to be in excess of 40 µg/L.

Frequency statistics are reported on a whole-year basis. Use of a whole-year basis does not, however, diminish the reported frequency relative to summer conditions. In fact, Jordan Lake experiences frequent spring and summer algal blooms, which the model replicates. As a result, the frequency of time that chlorophyll *a* concentrations are predicted to be greater than 40 µg/L is similar whether evaluated on a whole-year or summer growing season basis.

Growing season responses are reported in Table 4-6 in the form of median chlorophyll *a* concentrations. As with the frequency results, the median values are similar whether evaluated on a growing season or full-year basis. Due to the highly skewed nature of predicted chlorophyll *a* concentrations the median is a more appropriate indicator of central tendency than the mean. Variability about the central tendency is also of concern, however. For instance, it will be noted that the median concentrations in Segment 15 (Haw River arm) are generally similar to those in Segments 5 and 6 (Middle New Hope section); however, the frequency of time with predicted concentrations greater than 40 µg/L is always higher in the Middle New Hope than in the Haw arm. This reflects greater variability in algal response in the New Hope arm, where relatively stagnant conditions often apply during the summer and fall, as opposed to the Haw arm, where residence time is usually short.

Results of the scenario evaluations are summarized graphically in Figures 4-5 through 4-12. These figures display the same results shown in the table, but represented as color-coded ranges. Both summer medians and frequency of days with concentrations greater than 40 µg/L are shown. Results are not shown for the small tributary arms of the New Hope section (segments 7, 10, and 11) as these cove areas have unique physical features (such as restriction by road causeways) that make prediction of water quality unreliable without data to support modeling assumptions. Such data are not available at this time. The figures show results superimposed on the normal pool extent of the mainstem sections of the lake. Flood pool areas and side tributaries are included as a gray background for orientation purposes.

The results shown in Table 4-6 and accompanying figures suggest (and confirm existing monitoring data) that conditions vary widely among segments of the lake. Under current conditions, concentrations greater than 40 µg/L of chlorophyll *a* are predicted to occur at well in excess of 10 percent of the time throughout the Upper New Hope (segments 1 through 4), but are at a frequency of less than 10 percent throughout the remainder of the lake, although just below 10 percent in segment 5. This suggests that major water quality problems associated with nutrient loading are present primarily in the Upper New Hope section. (In interpreting this model prediction it should be recalled that all of the chlorophyll *a* data collected by DWQ since 1996 was subject to analytical errors and required recalculation. Thus, some of the high chlorophyll *a* results previously reported by DWQ are not valid. In addition, the model does not address localized conditions at the mouth of Robeson Creek, where elevated nutrient response to the Pittsboro discharge is reported by NC DWQ to be present).

Adoption of the HB 515 nitrogen effluent limits under current conditions (Scenario B) results in a noticeable reduction in both growing season median chlorophyll *a* concentrations and frequency of concentrations greater than 40 µg/L for some segments of the lake. This is expected, due to the frequency of nitrogen limitation on algal growth. The impact, however, varies greatly by lake segment. Segments 2 and 3 are dominated by effluent from the Durham County Triangle and OWASA wastewater treatment plants, respectively. Current discharges from these plants are well above 5.5 mg/L total nitrogen; thus the HB 515 limits would result in some reduction in algal growth. In contrast, segment 1 is dominated by effluent from the South Durham Water Reclamation Facility. This plant already achieves total nitrogen concentrations in its effluent that are close to the HB 515 limits; thus, from the model it is projected that the adoption of these limits would likely result in only a minor reduction of algal growth in this segment.

Within the Lower New Hope and most of the Middle New Hope, the HB 515 limits would reduce median chlorophyll *a* concentration; however, excursions of the 40 µg/L standard are expected to be infrequent whether or not the HB 515 limits are adopted. Full implementation of the HB 515 requirements is projected to also result in reductions in chlorophyll *a* in the Haw River arm. For instance, the frequency of excursions of the 40 µg/L standard is predicted to be reduced from 3 percent to 1 percent in segment 15, but excursions of the standard are not predicted to occur at a frequency above the 10 percent level established in the Neuse TMDL whether or not HB 515 limits are imposed.

Year 2010 conditions with increased wasteflow, but without HB 515 nitrogen limits (Scenario C), are predicted to result in increased chlorophyll *a* levels in most lake sections. Frequency of excursions of the 40 µg/L standard is, however, predicted to decrease in segments 2, 4, and 5 relative to current conditions. This reflects the ambitious nitrogen reduction goals that are already contained in the draft permit for the Durham County Triangle plant, which reflects the HB 515 nutrient control requirements. Algal growth is predicted to increase in the Haw River arm under Scenario C, but frequency of excursions of the standard is still predicted to remain well below the 10 percent level.

The evaluation of 2010 conditions with HB 515 nitrogen limits in place (Scenario D) also reflects the benefit gained from the proposed mass-based nitrogen and phosphorus limits for the Durham County Triangle plant. In most segments, chlorophyll *a* levels under Scenario D are predicted to be slightly greater than Scenario B (current conditions with HB 515) and slightly lower than Scenario A (current conditions).

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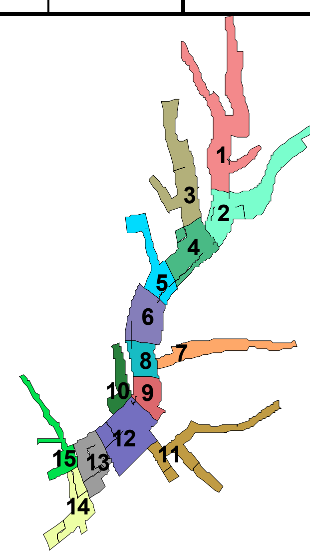
Table 4-6. Results of Evaluation of Project Partners' Scenarios

	Jordan Lake WASP Model Segment (refer to map below to see general location of the applicable segment number)											
	Upper New Hope				Middle New Hope Section				Lower New Hope		Haw River Arm	
	1	2	3	4	5	6	8	9	12	13	14	15
Predicted Frequency of Excursions of 40 µg/L Chlorophyll *a* Standard (Expressed as Predicted % of Days When Standard is Exceeded)												
Scen A	**16.9%**	**19.7%**	**26.7%**	**18.1%**	**9.9%**	**4.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**1.1%**	**3.0%**
Scen B	14.3%	6.6%	14.2%	8.4%	5.2%	3.3%	0.0%	0.0%	0.0%	0.0%	0.1%	1.0%
Scen C	20.9%	11.2%	36.1%	16.2%	9.6%	4.3%	0.0%	0.0%	0.0%	0.1%	2.2%	5.1%
Scen D	17.3%	10.3%	18.9%	11.2%	6.4%	3.6%	0.0%	0.0%	0.0%	0.0%	0.2%	3.0%
Predicted Summer Growing Season Median Chlorophyll *a* Concentration (µg/L)												
Scen A	**25.2**	**28.2**	**31.8**	**28.4**	**27.1**	**25.8**	**14.2**	**15.3**	**17.4**	**14.8**	**24.5**	**25.0**
Scen B	24.0	24.1	28.0	25.7	24.3	23.4	12.9	13.8	15.7	13.4	22.2	23.3
Scen C	26.2	27.8	35.4	28.9	27.2	26.4	14.6	15.8	18.3	15.8	26.6	27.8
Scen D	25.0	27.4	30.6	27.4	25.5	24.7	13.5	14.5	16.5	14.2	23.8	25.6

Summary Description of Scenarios:
Scen A Current Conditions (Actual Flow and TN and TP Concentrations)
Scen B All major POTWs to HB 515 TN limits
Scen C Future conditions (Projected Year 2010 flows) at current concentrations
Scen D Future conditions (Projected Year 2010 flows) with HB 515 TN limits in place

NOTE: Results for WASP Model Segments 7, 10, and 11 are not shown because there were no monitoring data available to support calibration for these segments. These cove areas have unique physical features that make prediction of water quality unreliable without data to support modeling assumptions. Year 2010 runs assume proposed mass-based limits are applied to the Durham Co. Triangle plant on expansion. Thus, concentrations are predicted to decline in Segment 2 regardless of application of HB 515. "Growing Season Median" is the 50th percentile concentration of predictions for June through September.



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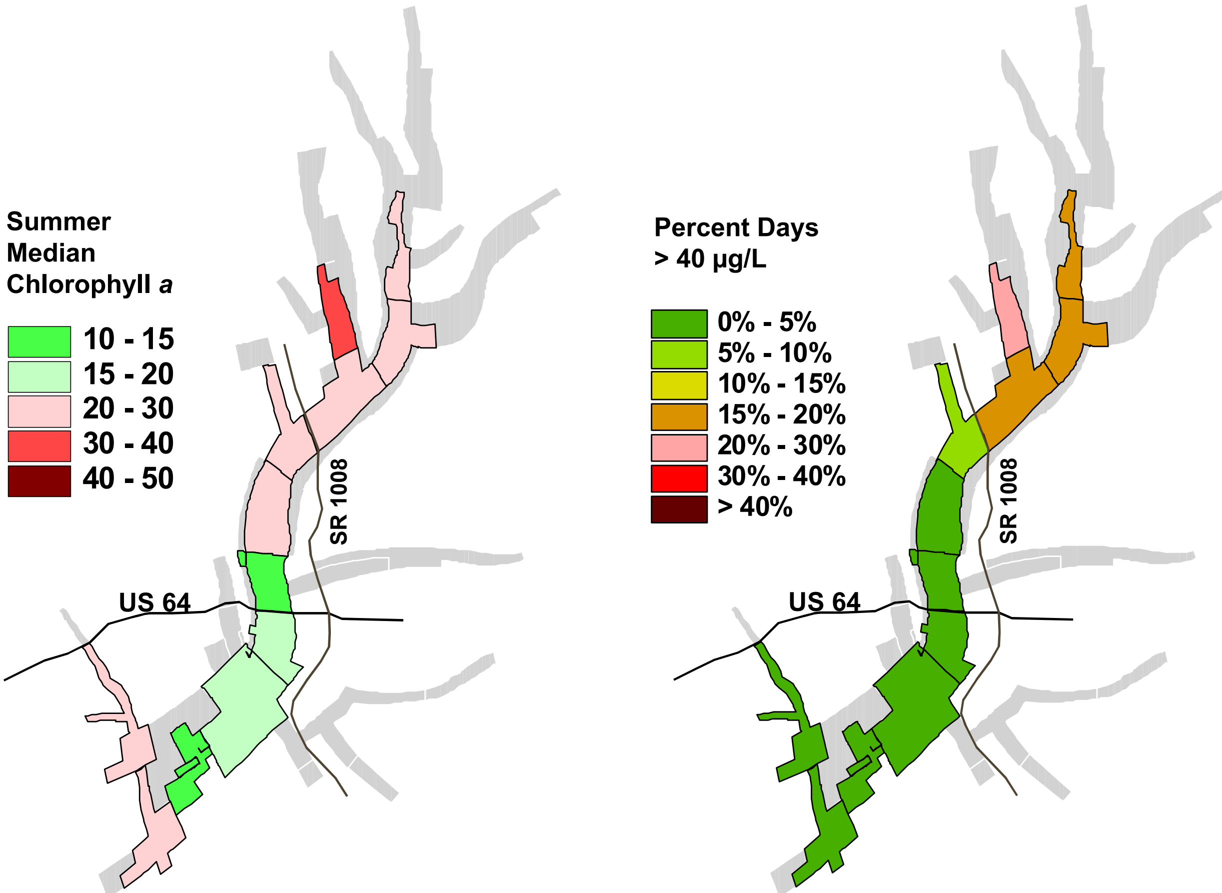

Figure 4-5. Summer Median Concentrations (µg/L) and Frequency of Chlorophyll *a* Concentration Greater than 40 µg/L for Scenario A (Current Conditions)

Notes: Based on simulation with 1997-2000 hydrology. Medians show 50th percentile of model predictions for June through September.

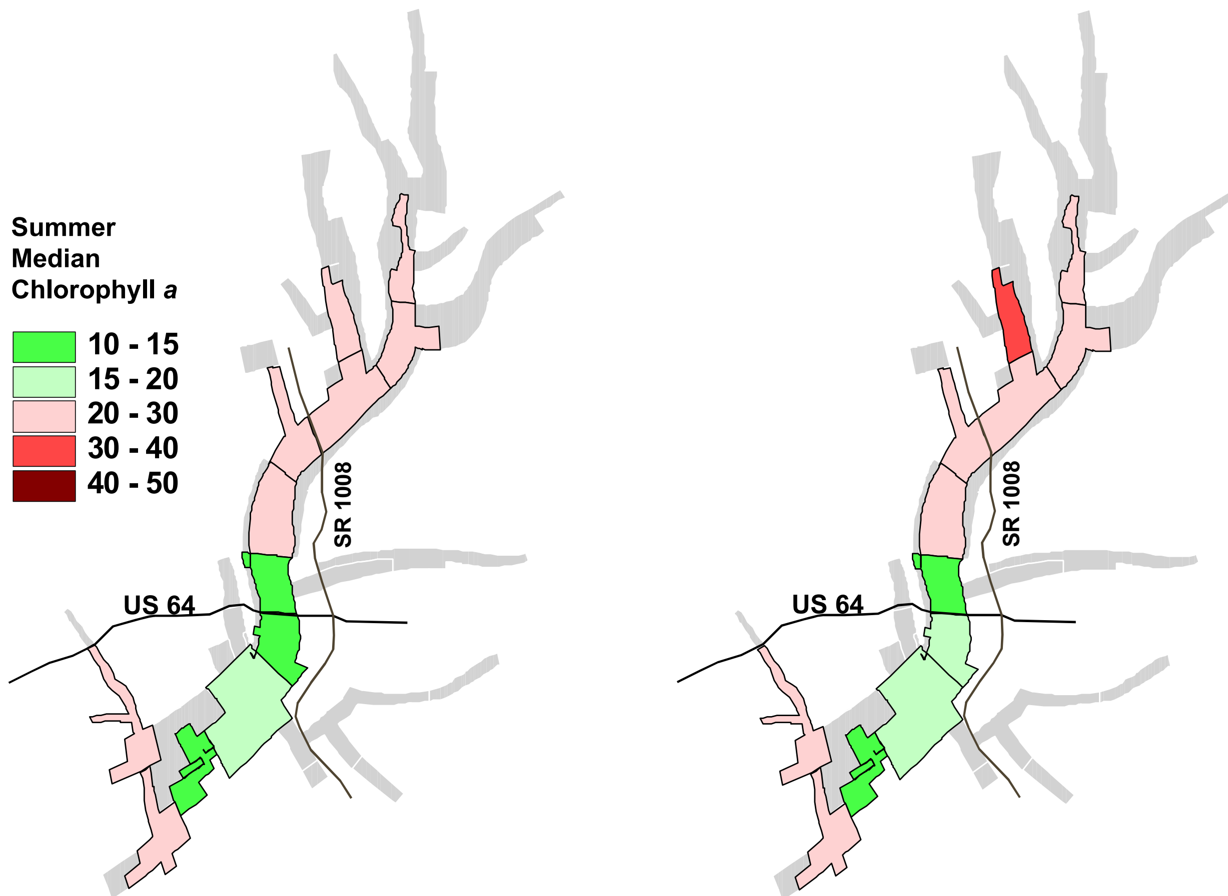

Figure 4-6. Median Chlorophyll *a* Concentration (µg/L) for Scenario B (HB 515 Nitrogen Limits; Left) and Scenario A (Current Conditions; Right)

Notes: Based on simulation with 1997-2000 hydrology. Medians show 50th percentile of model predictions for June through September.

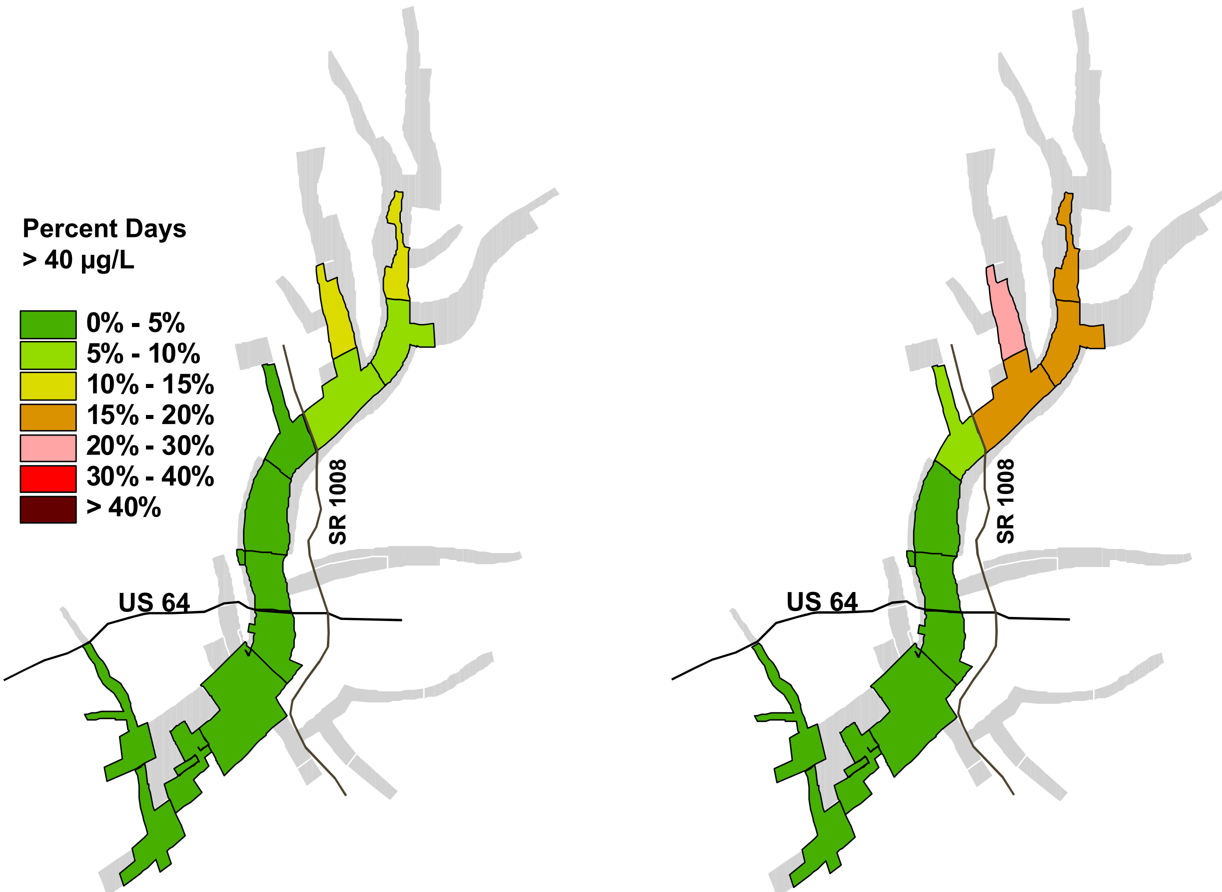

Figure 4-7. Frequency of Days with Chlorophyll *a* Concentration Greater than 40 µg/L for Scenario B (HB 515 Nitrogen Limits; Left) and Scenario A (Current Conditions; Right)

Notes: Based on simulation with 1997-2000 hydrology.

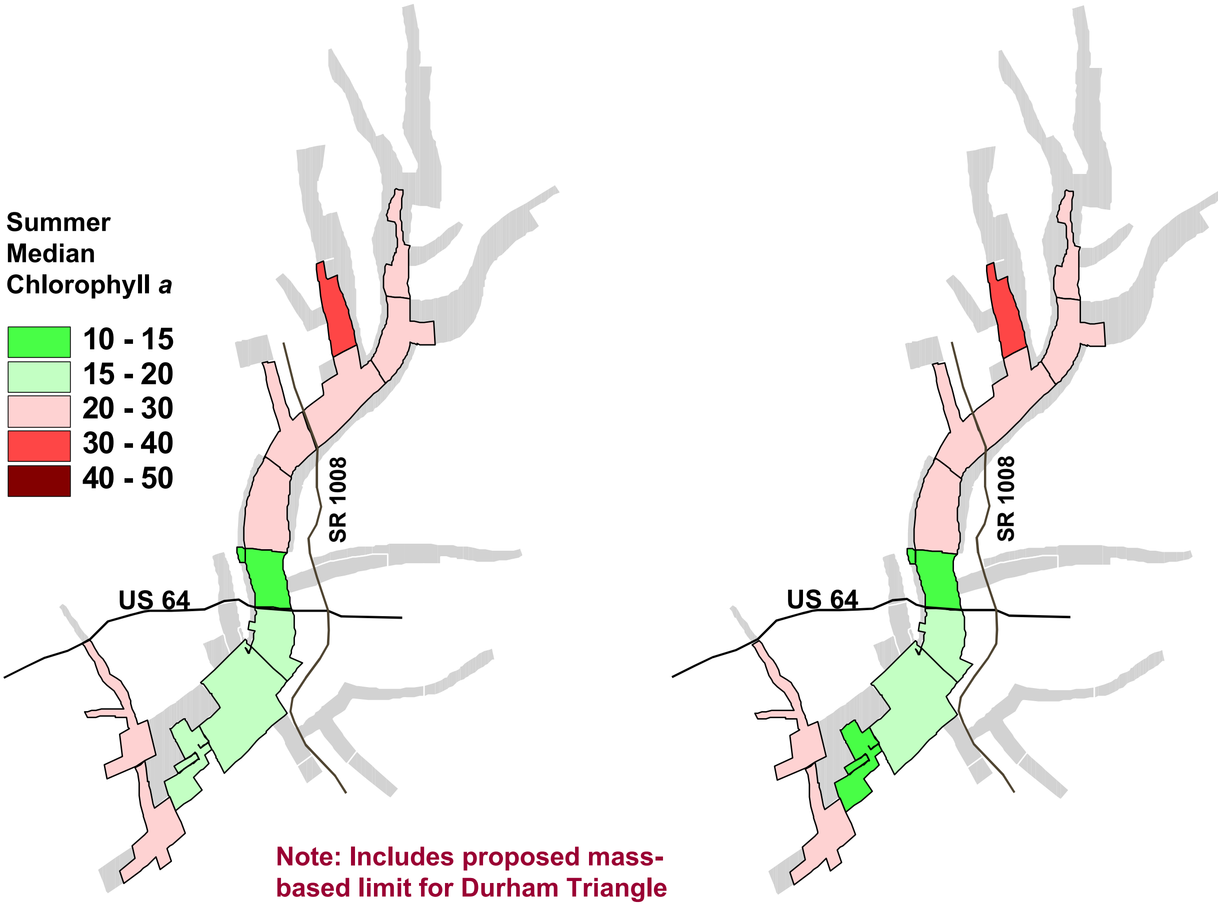

Figure 4-8. Median Chlorophyll *a* Concentration (µg/L) for Scenario C (2010 Discharges at Current Concentrations; Left) and Scenario A (Current Conditions; Right)

Notes: Based on simulation with 1997-2000 hydrology. Medians show 50th percentile of model predictions for June through September. 2010 conditions include proposed mass-based effluent limitations for expansion of the Durham Co. Triangle Plant.

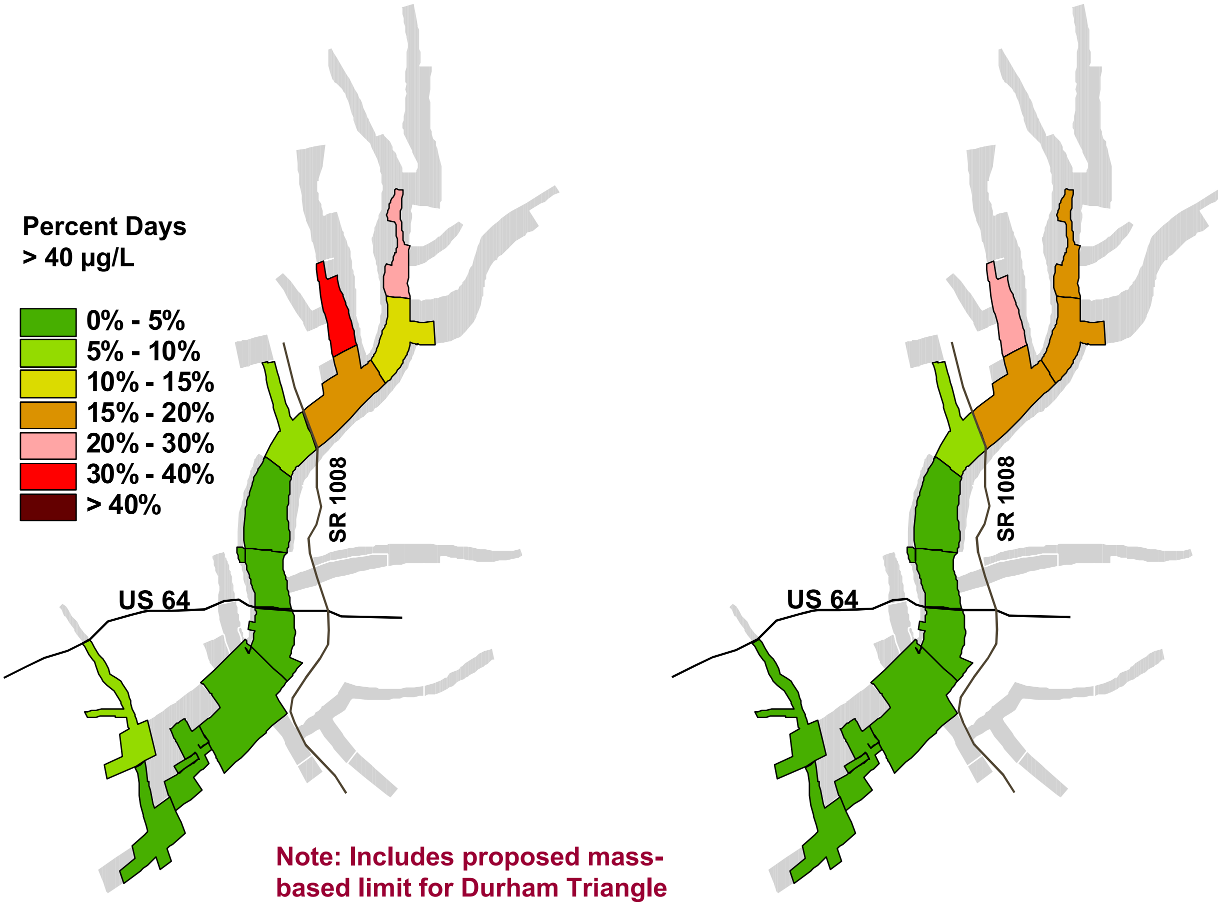

Figure 4-9. Frequency of Days with Chlorophyll *a* Concentration Greater than 40 µg/L for Scenario C (2010 Discharges with Current Nutrient Concentrations; Left) and Scenario A (Current Conditions; Right)

Notes: Based on simulation with 1997-2000 hydrology. 2010 conditions include proposed mass-based effluent limitations for expansion of the Durham Co. Triangle Plant.

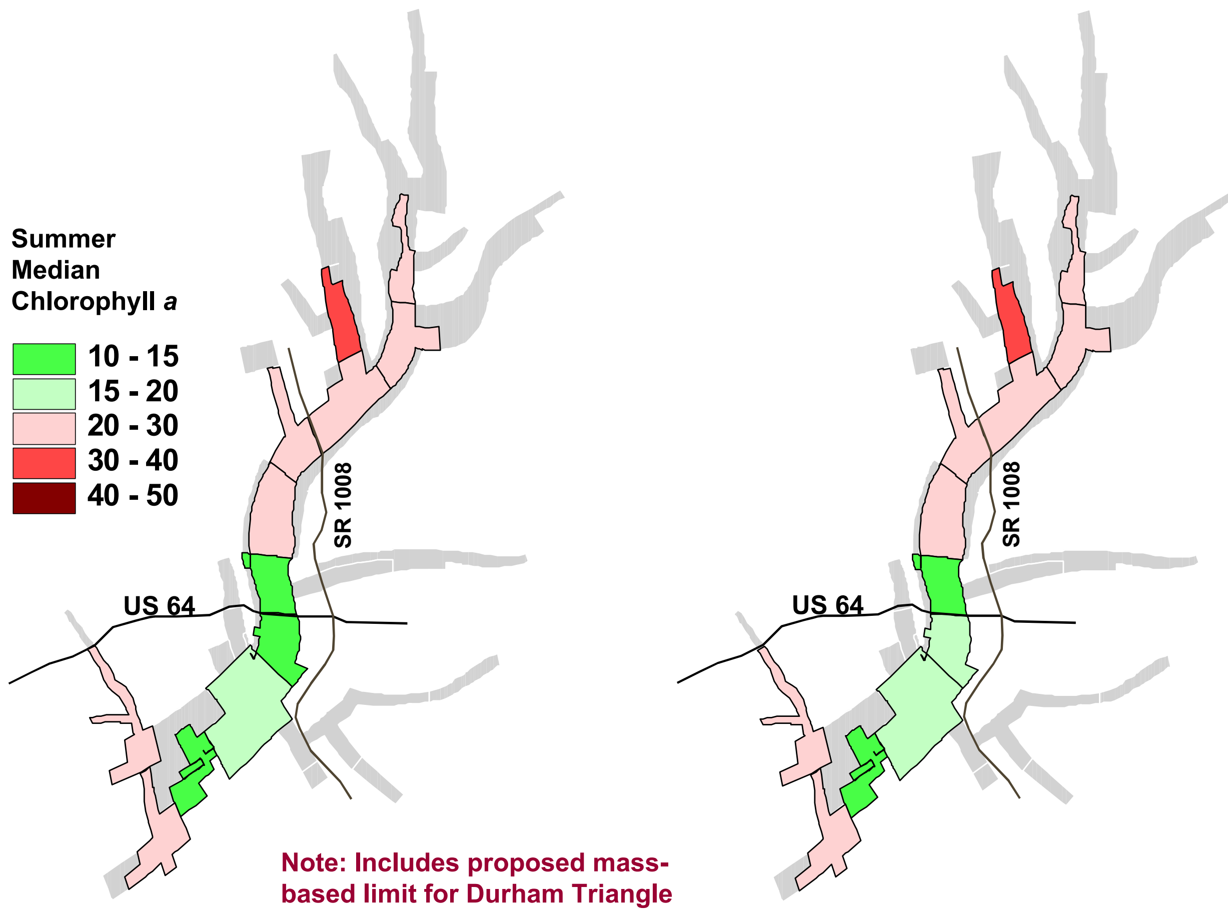

Figure 4-10. Median Chlorophyll *a* Concentration (µg/L) for Scenario D (2010 Discharges at HB 515 Nitrogen Limits; Left) and Scenario A (Current Conditions; Right)

Notes: Based on simulation with 1997-2000 hydrology. Medians show 50th percentile of model predictions for June through September. 2010 conditions include proposed mass-based effluent limitations for expansion of the Durham Co. Triangle Plant.

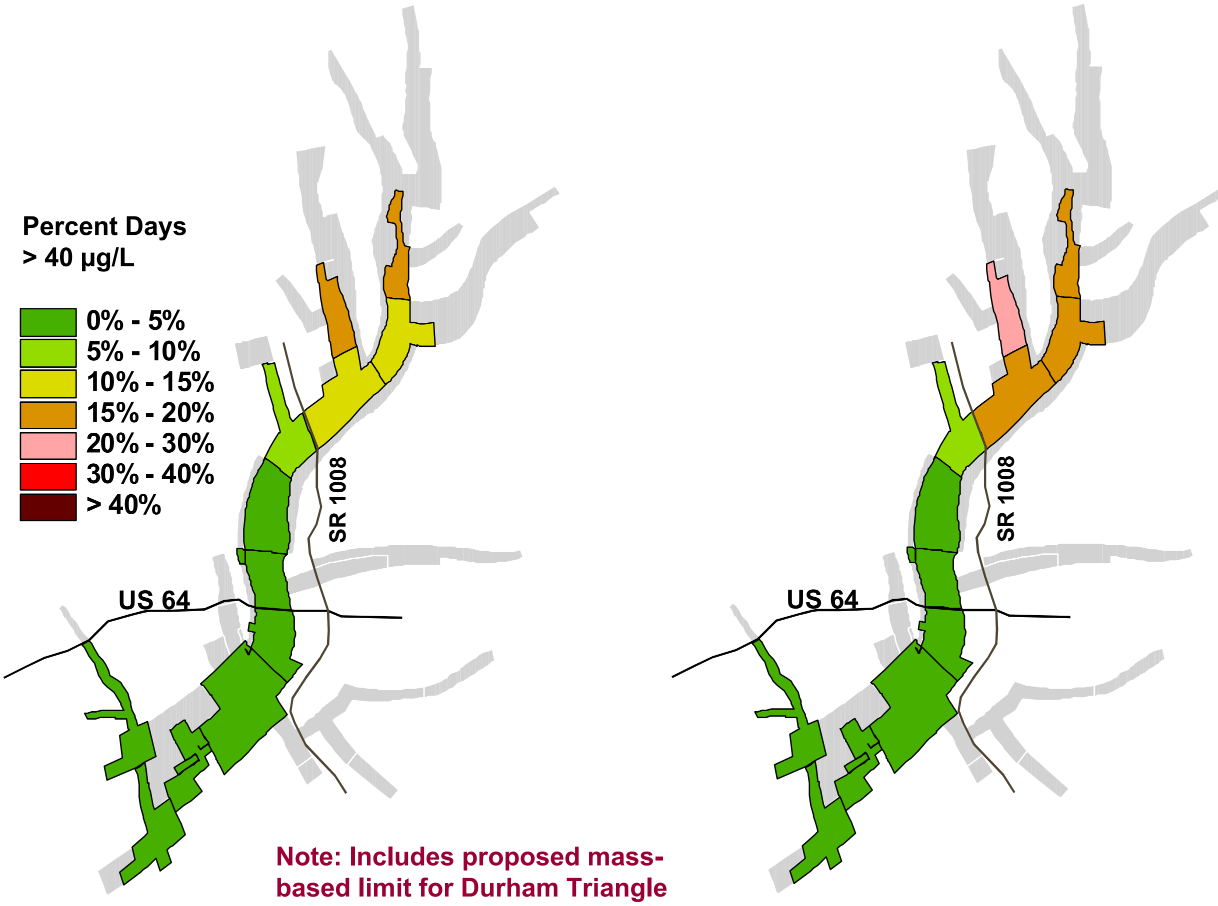

Figure 4-11. Frequency of Days with Chlorophyll *a* Concentration Greater than 40 µg/L for Scenario D (2010 Discharges with HB 515 Nitrogen Limits; Left) and Scenario A (Current Conditions; Right)

Notes: Based on simulation with 1997-2000 hydrology. 2010 conditions include proposed mass-based effluent limitations for expansion of the Durham Co. Triangle Plant.

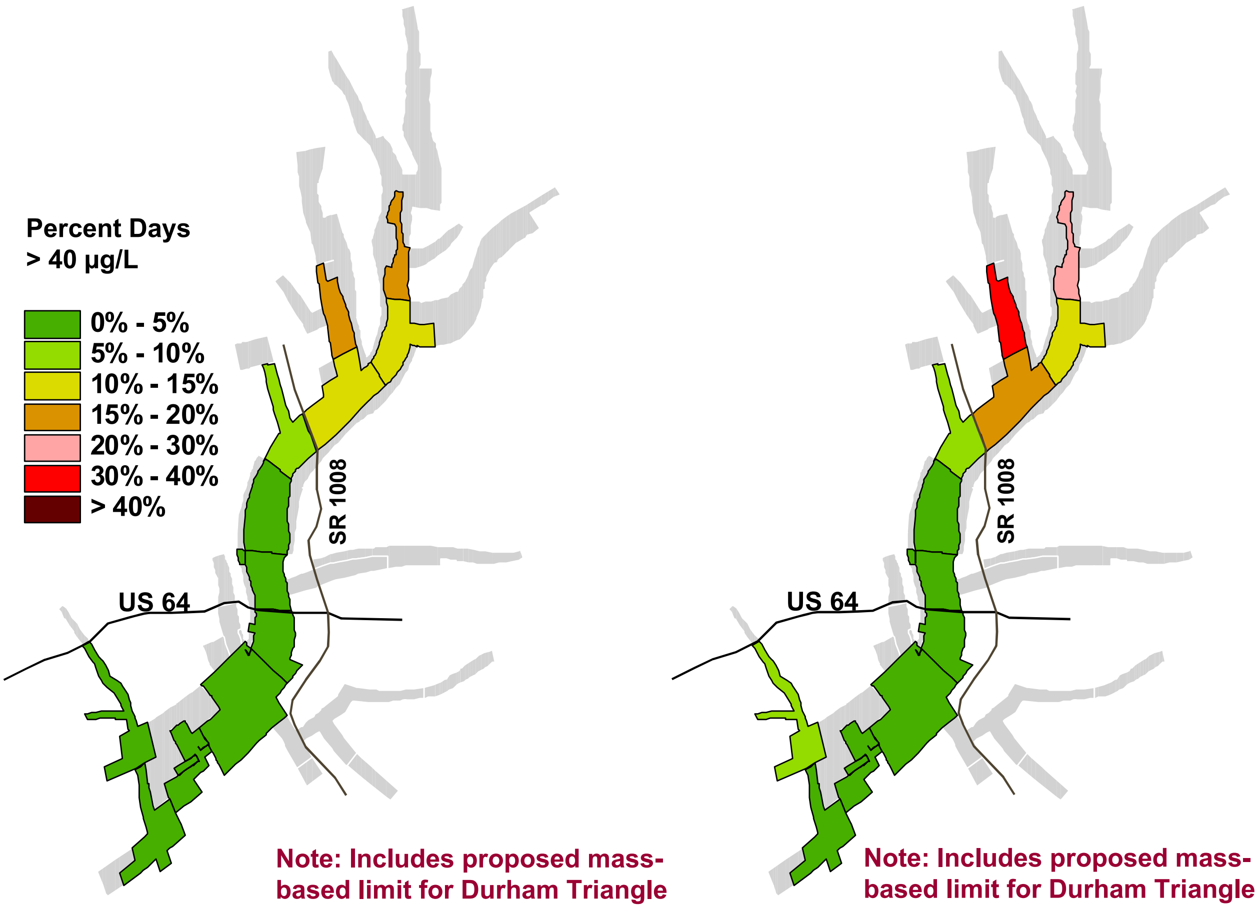

Figure 4-12. Frequency of Days with Chlorophyll *a* Concentration Greater than 40 µg/L for Scenario D (2010 Discharges with HB 515 Nitrogen Limits; Left) and Scenario C (2010 Discharges without HB 515 Nitrogen Limits; Right)

Notes: Based on simulation with 1997-2000 hydrology. 2010 conditions include proposed mass-based effluent limitations for expansion of the Durham Co. Triangle Plant.

4.3 Sensitivity Analyses

A number of additional model runs were undertaken to explore the sensitivity of the system. At this point, these runs do not constitute formal model scenario applications. Therefore, the results associated with these runs are presented as qualitative summaries only.

4.3.1 Sensitivity to Phosphorus Load Changes

There are existing permit limits for phosphorus on all the major dischargers in the basin. Most of the permittees achieve average phosphorus concentrations that are significantly less than the permitted limits. Those permits already meet or exceed total phosphorus limits required under HB515. A sensitivity analysis was conducted in which the phosphorus loading from each discharger was increased to the phosphorus load or concentration presently allowed under existing permits (see Table 4-1). Because algal response in the lake is primarily limited by nitrogen, these increases in phosphorus loading result in very little change in predicted results relative to Scenario A. Resulting increases in predicted median chlorophyll *a* concentrations were less than 1 µg/L in all segments, and only small changes occur in the frequency of days with concentration greater than 40 µg/L.

Similarly, evaluation of a 50 percent reduction in each existing point source phosphorus load appears to yield only a small water quality benefit, due to the presence of nitrogen limitation. Outside of the upper New Hope segment, there is essentially no change in predicted algal response with a 50 percent reduction in existing point source phosphorus load. Some small reductions in algal growth are predicted in the upper New Hope segment.

4.3.2 Application of Nitrogen Limits to New Hope Dischargers Only

The impacts of point source nitrogen reduction may be very different for the direct dischargers to the New Hope arm compared to the upstream dischargers to the Haw River. This is due to a combination of factors such as: (a) point sources in the New Hope arm are located much closer to the lake; (b) the New Hope arm is much shallower than the Haw River arm; and (c) the New Hope arm has a much longer residence time. As a result of natural instream processes, several of the point source nitrogen loads to the Haw are expected to be reduced by more than 50 percent before reaching the lake (Table 4-3 above), whereas greater than 90 percent of the nitrogen loads from the New Hope dischargers are estimated to reach the lake. In addition, on average much of the nitrogen load entering via the Haw River is discharged relatively quickly from the lake through the dam and has a limited effect on algal response in the New Hope arm of the lake.

Model simulations were undertaken with all Haw River dischargers at current actual nitrogen loads and New Hope dischargers meeting the HB 515 requirements. The results were compared to Scenarios A (current baseline) and B (full implementation of the HB 515 requirements). As expected, leaving the Haw River sub-basin dischargers at current nitrogen loads has little effect on the upper New Hope segment. Within the middle and lower New Hope segments, leaving Haw River nitrogen loads at current levels has a small beneficial effect on the median chlorophyll *a* concentration and the frequency of days with chlorophyll *a* concentrations greater than 40 µg/L. The difference in predicted median concentrations between full implementation of the HB 515 nitrogen limits and implementation only for the New Hope dischargers is on the order of 2 µg/L reduction in the middle New Hope section, and on the order of 3 µg/L reduction in the lower New Hope section. These differences are much less than the estimated uncertainty range for model predictions. A larger difference is seen in the Haw River arm when reductions are imposed on the New Hope dischargers only, with median concentrations and frequency greater than 40 µg/L approaching the values presented for Scenario A.

4.3.3 Sensitivity to Nonpoint Source Loads in the Upper New Hope Arm

One of the major difficulties in improving conditions in the upper New Hope segment, the area of the lake most likely to experience severe algal problems, is the fact that there are substantial nonpoint nutrient loads that are in themselves sufficient to promote excess algal growth in this shallow area that, on average, has an extended residence time. Approximately 48 percent of the total nitrogen and 54 percent of the total phosphorus loaded to the upper New Hope (model segments 1-4) is estimated to derive from nonpoint sources. Further, the South Durham Water Reclamation Facility already achieves low average total nitrogen concentrations that approach the HB 515 limits, while all three plants discharging to the upper New Hope maintain average total phosphorus concentrations well less below 1 mg/L.

Model sensitivity analyses indicate that a significant reduction in the existing nonpoint nutrient load would result in a corresponding large reduction in both median algal concentrations and frequency of days in excess of 40 µg/L chlorophyll *a* in this portion of the lake. However, it is possible that such large reductions in existing nonpoint source nutrient loads may not be feasible, or cost-effective, when compared the associated projected benefits to lake water quality and the designated uses of the lake.

4.4 Summary of Nutrient Response Scenario Evaluation

The scenarios evaluated for the Project Partners show that adoption of HB 515 nitrogen limits would have some beneficial effect on the nutrient response in the lake. The level of response, however, is predicted to differ significantly by lake section. These spatial differences should be taken into account when determining where the high costs associated with nitrogen removal are warranted in terms of benefits to the lake. Following is a general summary of the results by lake section.

Haw River Section

The modeling analysis suggests that nutrient responses in the Haw River section are within acceptable levels under current conditions (well less than 10 percent of days with concentrations greater than 40 µg/L). This reflects the typically short residence time in this portion of the lake. Nutrient response is predicted to increase under 2010 discharges, but will still remain well below the 10 percent criterion. Implementation of HB 515 nitrogen limits is predicted to have a relatively small beneficial effect on frequency of chlorophyll *a* values exceeding 40 µg/L in this section of the lake.

Lower New Hope Section

No significant water quality problems are predicted for the Lower New Hope section under either current or 2010 conditions. As a result, there is little change predicted for this part of the lake by adopting HB 515 nitrogen limits.

Middle New Hope Section

No significant water quality problems are predicted in segments 8 and 9, the lower portion of the Middle New Hope section, under either current or 2010 conditions. This bodes well for the protection of the Cary water supply, which is drawn from segment 8. Within the upper part of the Middle New Hope, in segments 5 and 6, chlorophyll *a* levels exceeding 40 µg/L are predicted to be more frequent; however, those excursions of the standard are predicted to remain below the 10 percent frequency threshold. Chlorophyll *a* levels in segments 5 and 6 are driven by nutrients transported from the Upper New Hope. Thus, management actions that affect water quality in the Upper New Hope will also affect water quality in segments 5 and 6 of the Middle New Hope.

Upper New Hope Section

As expected, the most significant levels of algal growth in the lake are predicted to occur in the Upper New Hope section, above Mt. Carmel Church Road. This shallow area receives discharges from three major wastewater treatment plants that are already meeting total phosphorus limits that are more stringent than the total limits established in HB515. Simulation of current conditions indicates that chlorophyll *a* concentrations greater than 40 µg/L are likely to occur more than 15 percent of the time in all four of the segments of the Upper New Hope. This is consistent with reports by DWQ personnel regarding conditions in this section of the lake.

Significant reductions in algal growth in segments 2 and 4 of the Upper New Hope are predicted to occur as a result of the mass-based nitrogen and phosphorus permit limits already proposed for the Durham County Triangle plant. Some additional reduction in algal growth would occur with the imposition of 5.5 mg/L total nitrogen limits at the South Durham Water Reclamation Facility and OWASA Mason Farm plants. A slightly greater beneficial change is predicted to occur through reduction in nitrogen loads from OWASA, as the South Durham Water Reclamation Facility already achieves concentrations only slightly above the 5.5 mg/L proposed limit. Even with the implementation of HB 515 nitrogen removal requirements, however, chlorophyll *a* concentrations in excess of 40 µg/L are predicted to occur at a frequency well over 10 percent in segments 1 and 3. In addition, the Upper New Hope segment is clearly sensitive to nonpoint loading of nutrients, and nonpoint loads can be expected to increase as additional urban and suburban growth occur throughout the New Hope sub-watershed.

It should be recalled that the scenario predictions are subject to a number of sources of uncertainty. These first include the uncertainty inherent in the model calibration and in the external forcing data, as discussed in Section 3.2.6. However, the model does provide a firm basis for comparison of the relative effects of different management scenarios. In addition, there is uncertainty inherent in the specification of the future scenarios themselves. The Project Partners expect to work with DWQ to refine scenario applications with the Jordan Lake Nutrient Response Model.

The Project Partners' efforts to evaluate the above scenarios indicates that long-term management and protection of water quality in Jordan Lake, and particularly in the upper reaches of the New Hope arm of the lake, will be a technically complex and challenging task. It is a task that will require further technical analyses, stakeholder involvement and discussions, and identification and evaluation of alternative management strategies. Representatives of some of the Project Partners, NCDWQ, and watershed stakeholder organizations have acknowledged the need for the development of additional watershed loading and assessment tools to support the watershed planning and decision-making process. Such tools could be linked with the Jordan Lake Nutrient Response Model to provide the ability to more fully evaluate alternative management scenarios.

4.5 References

Smith, R.A., Schwarz, G.E., and R.B. Alexander. 1997. Regional interpretation of water-quality monitoring data. *Water Resources Research*, 33(12): 2781-2798.

U.S. EPA. 1991. Technical Support Document for Water Quality-based Toxics Control. EPA/505/2-90-001. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

Appendix A
Jordan Lake Point Source Nutrient Delivery Method

Jordan Lake
Point Source Nutrient Delivery Model

Prepared for

Tetra Tech, Inc.
3200 Chapel Hill-Nelson Highway
Cape Fear Building, Suite 105
Research Triangle Park, NC 27709

And the
Jordan Lake Project Partners
c/o Triangle J Council of Governments
4222 Emperor Blvd., Suite 200
Durham, NC 27703

By

Research Triangle Institute
3040 Cornwallis Rd
Research Triangle Park, NC 27709-2194

RTI Project Number 07874.002.002

January 23, 2002

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Background and Objectives

Jordan Lake is located in the Piedmont region of North Carolina, and provides important water supply, recreation, flood control, downstream flow augmentation, and aquatic and wildlife habitat benefits for a large region. The lake is considered to be one of the most eutrophic lakes in the State of North Carolina, as evidenced by elevated levels of nutrients and chlorophyll *a*. Additionally, projected growth and development within the lake's 1,690 square mile watershed could result in increased eutrophication and associated water quality degradation within the lake.

In May of 2000, seven local governments within the Jordan Lake Watershed, acting through Triangle J Council of Governments (TJCOG), contracted for the development of a nutrient response model for Jordan Lake. This model is intended to provide much of the technical basis for establishing nutrient discharge limits applicable to point source wastewater treatment facilities within the watershed. The "Project Partners" funding this modeling project are: Burlington; Graham; Greensboro; Mebane; Orange Water and Sewer Authority; Pittsboro; and Reidsville.

In order to assess each point source facility's relative contribution to the total nutrient load to the lake, and therefore the water quality response, the Project Partners also contracted for the development of a complementary nutrient loading and delivery model to assess point source nutrient loads transported by the major tributaries within the lake's watershed. This report presents the methodology and results for modeling the delivery of nitrogen and phosphorus from major wastewater treatment plants in the Jordan Lake watershed to the lake. It is intended to directly address the current point source nutrient management questions of concern to the Project Partners and watershed stakeholders. A basic premise that guided the work is that the primary potential impacts and influences associated with the discharge of nitrogen and phosphorus occur in the deeper, more lacustrine lake waters. It is at the lake interface where nutrients in waters begin to "exert" their largest influence. At this point, the physical conditions exist in which more problematic manifestations of eutrophication are more likely to occur.

With this in mind regarding nutrient contributions to the watershed, specific questions that motivated the work covered in this report include:

- What has the end-of-pipe total nitrogen and total phosphorus loading been for each of the facilities evaluated in this study in recent years?

- In considering each discharger's end-of-pipe nutrient load, what is the estimated portion/percentage of the load that has actually reached the lake?

Methodology

A predictive modeling approach was developed to estimate point source nutrient loading and delivery. This approach was driven by consideration of the specifications for the Jordan Lake Nutrient Response Model. Key steps in developing the model included: setting up the stream network and routing system; predicting daily stream flow and channel hydraulics for each stream reach; creating input files of historical and projected wastewater treatment plant (WWTP) effluent characteristics; and modeling the instream attenuation of nitrogen and phosphorus. Each of these model components is summarized in Table 1 and discussed below.

Table 1: Primary Model Specifications

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

The delivery model development process involved deriving daily wastewater and instream flow and nutrient concentration and time-of-travel estimates based on effluent data, runoff records, and estimates of travel distances and stream channel characteristics. The principal technical challenge was to create an integrated data management and modeling application that: managed the large and previously unrelated data; defined mathematical relationships describing the delivery of nutrients; and managed model output. The general logic and model results are summarized in the main body of this report, with supporting information included in attachments. It was beyond the scope of this study to attempt to model point sources besides those specifically mentioned herein, or to model nonpoint sources. Methods and results for integrating the point source delivery model output into the lake model are described in the main body of this report.

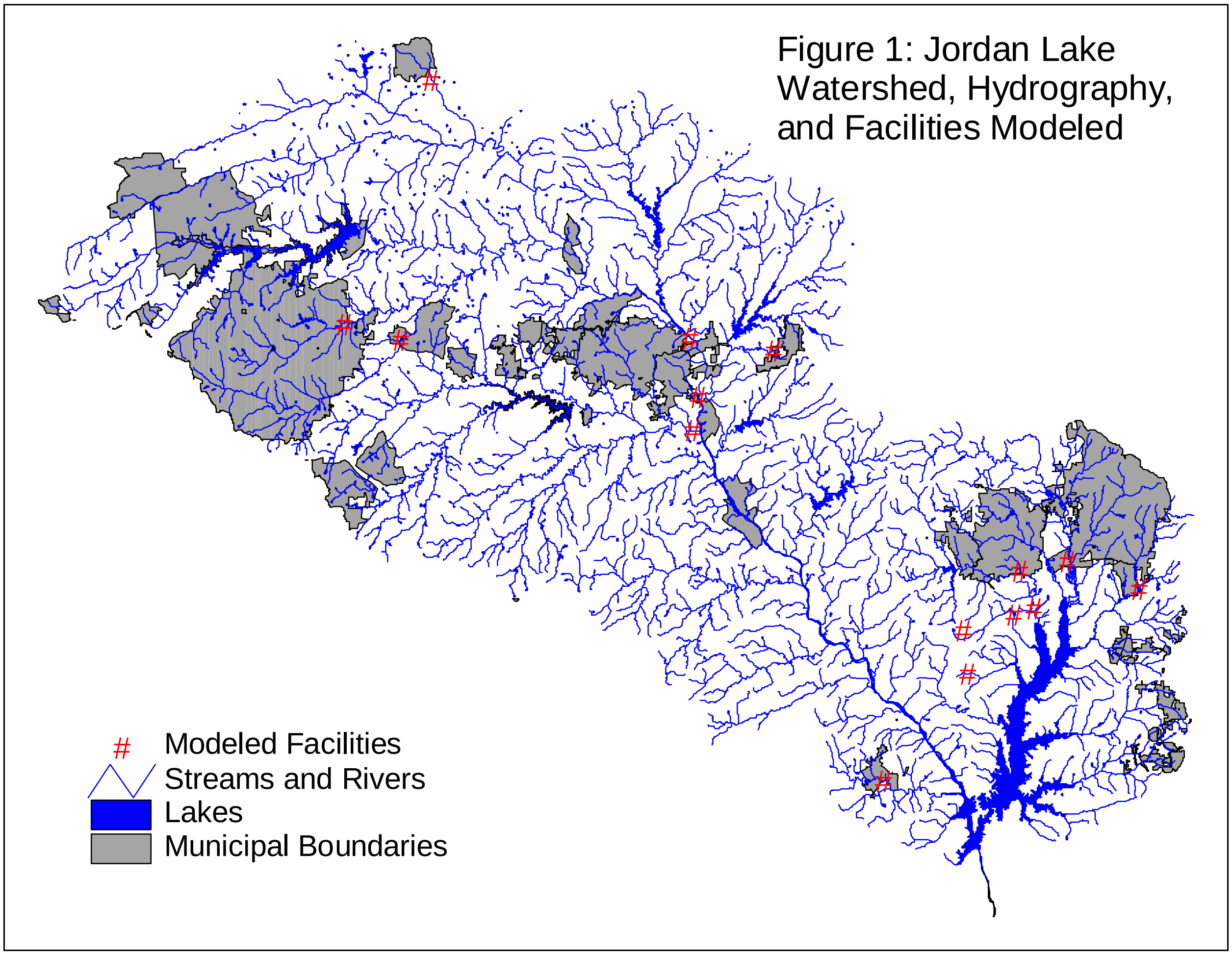
Stream Network

A database of the watershed stream network was developed to form the structural backbone of the Jordan Lake Nutrient Delivery Model (JLNDM). The stream network database required spatial referencing to associate tributaries and reaches with other locational data such as outfall and instream monitoring sites, and to estimate travel distances and times. It also required routing capabilities, or "navigational intelligence" to determine the direction of flow at stream junctions. Based on these functional requirements and recent studies, the United States Environmental Protection Agency's (USEPA) Reach File 3 (RF3) was chosen as the principal data source for the stream network.

RF3 is a hydrologic database of the surface waters of the continental United States. The RF3 network is based on national 1:100,000 scale digital line graph hydrographic data. RF3 has been designed expressly to establish hydrologic ordering, to perform hydrologic navigation for modeling applications, and to provide a unique identifier for each surface water feature. Recent projects sponsored by the USEPA and the United States Geological Survey (USGS) have resulted in improved ability of the RF3 stream network data to support modeling efforts. (Bondelid et al., 1999a, 1999b). (The National Hydrography Database (NHD), released by USGS and USEPA in 2001, was built with RF3 architecture. Therefore, employing RF3 as the modeling stream network facilitates integration with NHD if warranted for future studies.) The RF3 network used for the JLNDM includes 3153 reaches accounting for 2687stream miles (Figure 1). All of the hydrologic, hydraulic, and water quality calculations completed for this study were done for each of these reaches. Model results were reported at the stream/lake interface of the Haw River, Robeson Creek, Northeast Creek, New Hope Creek, Morgan Creek, Bush Creek, and Cub Creek, and at selected reaches in the Haw River watershed.

Stream Flow

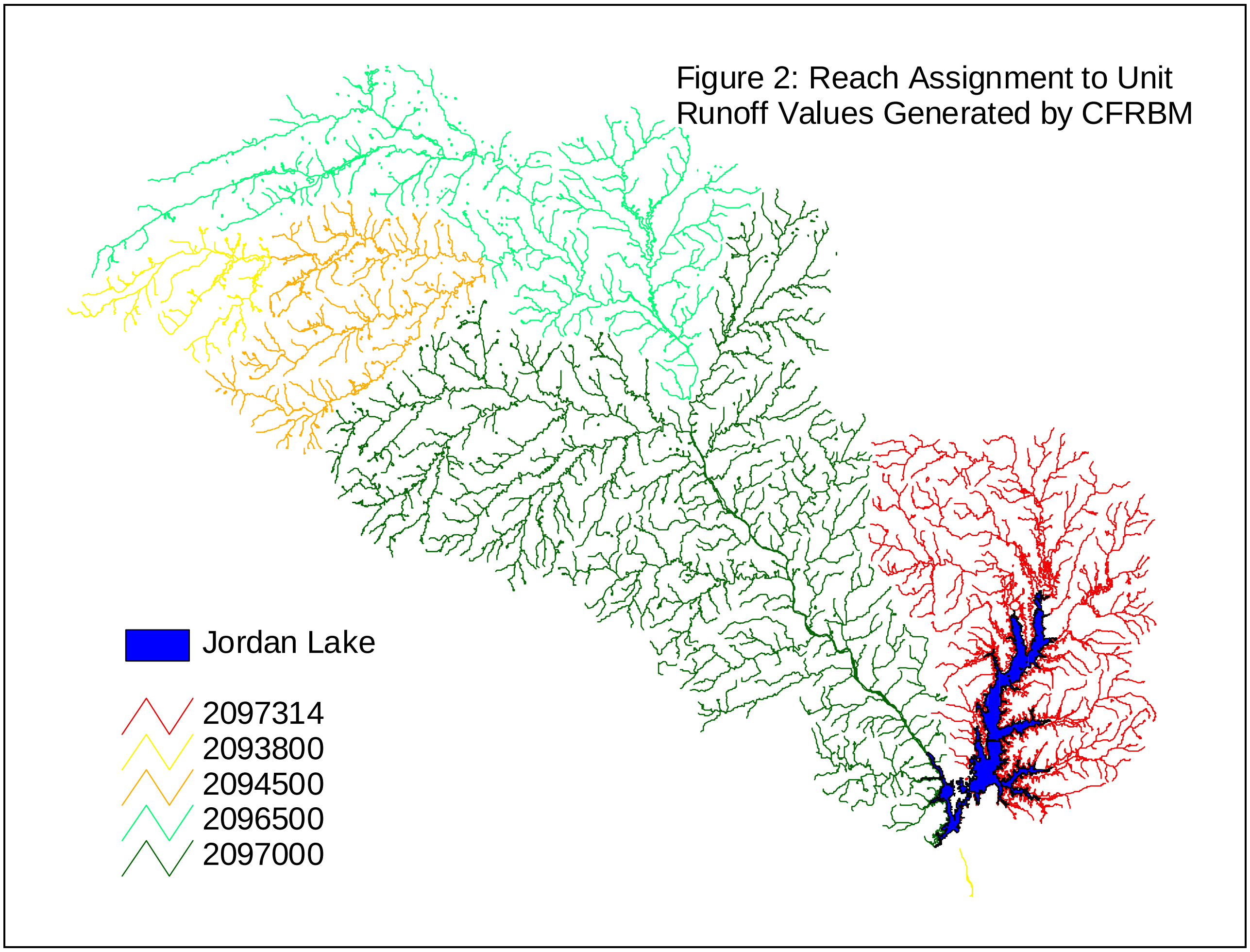
The procedure chosen to model stream flow relied on: analyses of stream gaging data; calculation of reach specific drainage areas; and code written to model flow using the RF3 database. Daily unit runoff (flow per unit area) values were obtained from the Cape Fear River Basin Model (CFRBM) (DHI and Moffett and Nichols, 2000), for each of 5 subbasins in the watershed for 1996-1998 (Figure 2), as defined by the CFRBM. Unit runoff estimates were used in combination with drainage area estimates to calculate stream flow for each reach. (Only naturalized flow was included in this analysis: withdrawals and diversions were not specifically modeled.)



Drainage area estimates were derived for each reach in RF3 using a grid overlay and proximity analysis based on the USGS national land cover characteristics database (Eidenshink, 1992). The land cover grid was overlain on RF3 to associate each cell (1 km^2) with the nearest RF3 reach. The number of cells assigned to each reach therefore approximated the direct drainage area for the reach. The cumulative drainage area for each reach was calculated by hydrologically routing all reaches and summing the reach-specific drainage areas. This approach has been validated based on comparison to drainage area estimates for USGS gaging stations (Bondelid et al., 1999(b)).

Stream Hydraulics

Time-of-travel estimates were a key requirement for estimating nutrient loss or attenuation during delivery to the lake via the stream network. Empirically based techniques were used to estimate time-of-travel for the JLNDM based on standard engineering methods for stable stream channels. These methods involved estimating stream depth, width, roughness, and sinuosity for each reach. In combination with flow and reach length data, these hydraulic parameters were then used to



calculate velocity and time-of-travel. (Additional information about hydraulic calculations is available in Bondelid et al, 1999a and 1999b.)

The relationship between stream flow and channel width used was (Keup, 1985)

(1) $$W = 5.27 * Q^{0.459}$$

W	=	channel width (ft) and
Q	=	discharge (stream flow in cubic feet per second [cfs]).

Channel depths were calculated based on the classic Manning's N formulation for channel resistance analysis. Assuming a rectangular channel cross-section, the following formula was used to calculate stream depth:

(2) $$y_0 = 0.79\ (Q*n/(W*\ (S_0)^{0.5}\ )^{0.6}$$

y_0 = channel depth (ft),

Q = discharge (stream flow in cfs),
n = Manning's N roughness coefficient,
W = channel width (ft) calculated above, and
S_0 = channel slope (ft/ft)

Sinuosity estimates were calculated as

$$S = SEGL/DIST$$

S = sinuosity measure, unitless
SEGL = segment length of the reach (mi), and
DIST = straight-line distance between upstream and downstream nodes of the reach (mi).

Manning's N was calculated, based on sinuosity, as

(3) $$\text{Manning's N} = 0.0016 + 0.0234 * S,$$

with a lower limit of Manning's N = 0.025 and an upper limit of Manning's N = 0.040 (Henderson, 1966).

Stream velocity for each reach, therefore, was calculated as

(4) $$V = Q/(W*y_0)$$

V = velocity (ft/sec),
Q = discharge (streamflow in cubic feet per second, cu ft/sec),
y_0 = channel depth (ft) calculated above, and
W = channel width (ft) calculated above.

Time-of-travel along a stream reach, corrected to units of days, was calculated as

(5) $$Tt = SL/(V*86{,}400)$$

Tt = time-of-travel along stream reach (days),
V = velocity (ft/sec) calculated above, and
SL = stream length or segment length of reach (ft).

Wastewater Effluent Characterization

Effluent data for daily flow and nitrogen and phosphorus were obtained from each of the wastewater treatment plants identified by TJCOG and Tetra Tech for inclusion in the model, with assistance from TJCOG (Table 2 and Figure 1). These facilities include those operated by Project Partner members. (Additionally, several minor facilities located in proximity to sensitive lake areas were modeled, and results provided as input into the lake model. However, results for these facilities are not presented in this report.) The facilities account for 83% of the permitted wastewater capacity in the watershed, and over 98% of the permitted domestic wastewater capacity. A daily time step for loading calculations was specified based on requirements for the Jordan Lake Nutrient Response Model. Effluent monitoring occurred at variable frequencies for flow, nitrogen and phosphorus for the facilities modeled. Typically, effluent nutrient concentrations were sampled on either a weekly or monthly basis. Therefore, to estimate daily nutrient loads for each facility, it was necessary to "fill in" or "populate" concentration estimates for each of the days in which sample results were not available. Waste flow and concentration sampling data were considered and adjusted using the following assumptions:

1) For months in which daily values were reported for each day, the data were used without additional analysis or modification.
2) For months in which one monitoring value was reported for a wastewater characteristic (flow, nitrogen, or phosphorus), that single monthly value was applied for that characteristic for all days in the month.
3) For months in which more than one value was reported for a wastewater characteristic, the actual reported values were used for the days on which they were reported and a monthly average was applied for that characteristic for all unmonitored days in the month.
4) For months in which no value was reported, an average was calculated and applied based on the values for the previous and following months, and applied to all days in the month.

Fields were included in the wastewater characterization model input table to track the method used for each record and wastewater characteristic. A summary of effluent loading by facility by year from 1996 to 2000 is presented in Figures 3 and 4, and a summary of the total effluent loading from all Project Partner facilities by year is presented in Figures 5 and 6.[1]

Instream Nutrient Loss

Experience from many water quality studies has demonstrated that a first-order decay process can be appropriate for simplified modeling of the physical, chemical and biological processes affecting many constituents in water. This kinetic definition infers that the rate of loss of a constituent from the water column is a function of the initial concentration and time. The primary challenge with this

1 These data are provisional, pending discussions between Tetra Tech, Triangle J COG, and Project Partners.

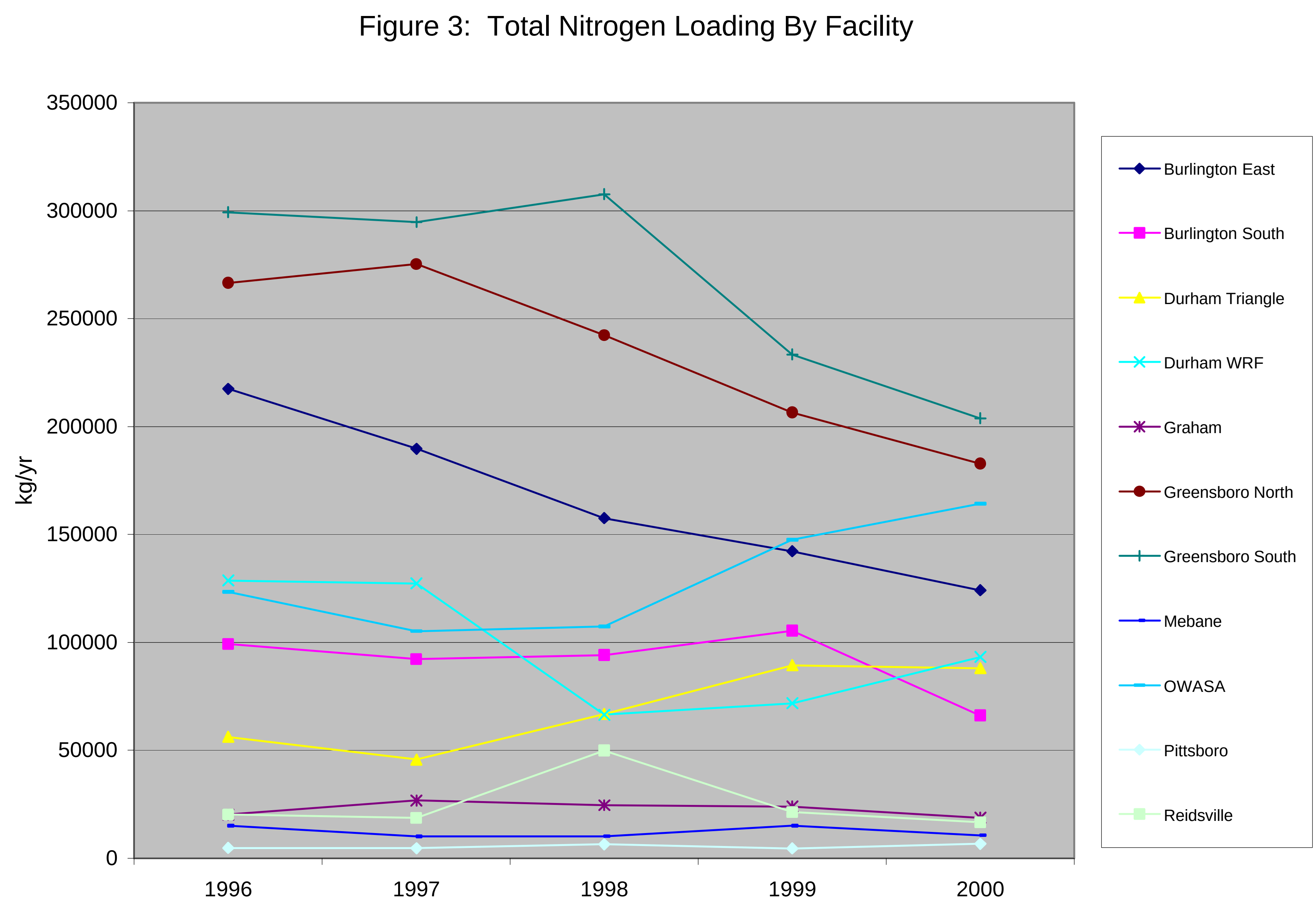


Figure 3: Total Nitrogen Loading By Facility
350000
300000
250000
200000
150000
100000
50000
0
kg/yr
1996
1997
1998
1999
2000
Burlington East
Burlington South
Durham Triangle
Durham WRF
Graham
Greensboro North
Greensboro South
Mebane
OWASA
Pittsboro
Reidsville

Figure 4: Total Phosphorus Loading By Facility

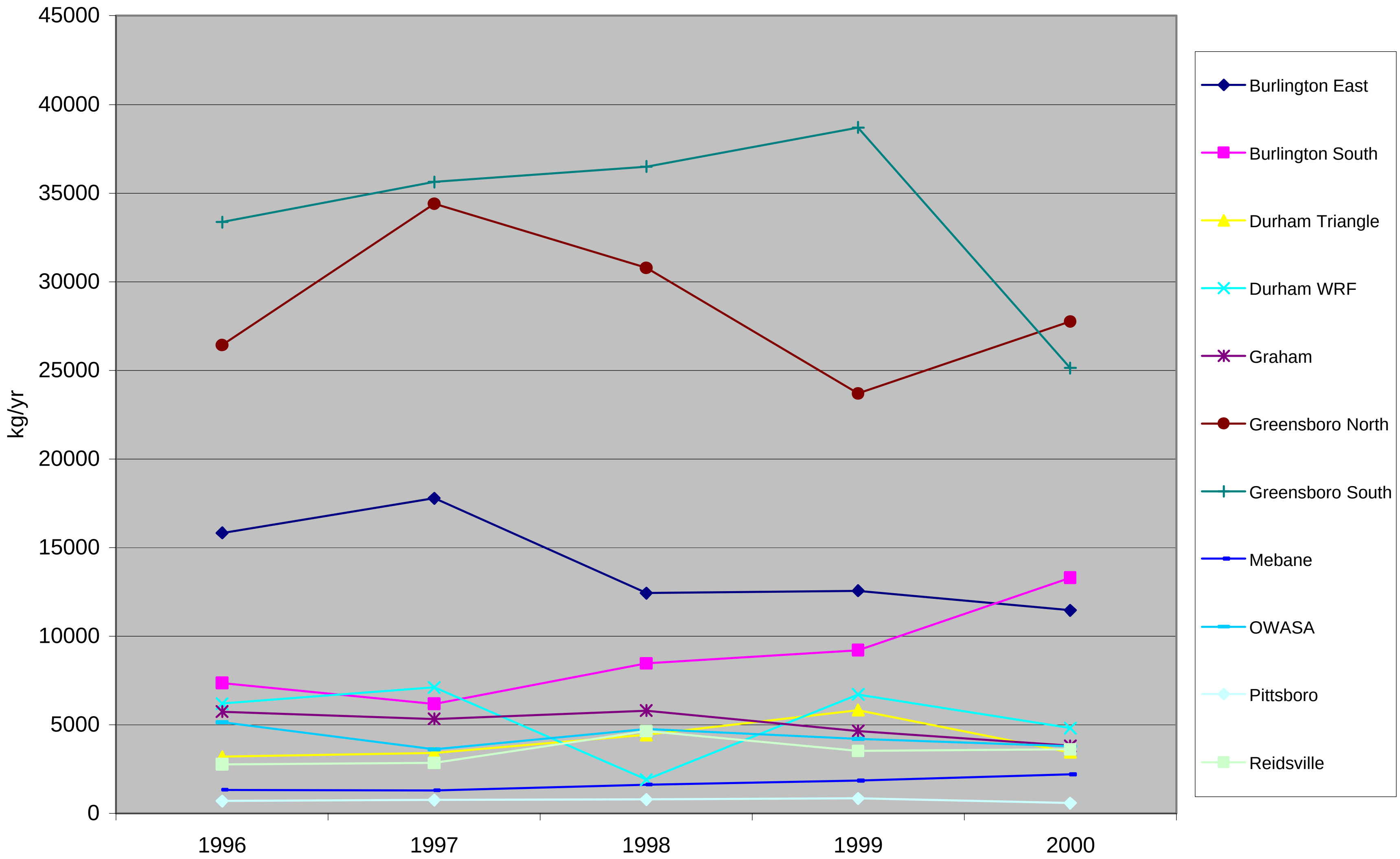


Figure 5: TN Loading from All Project Partner Facilities

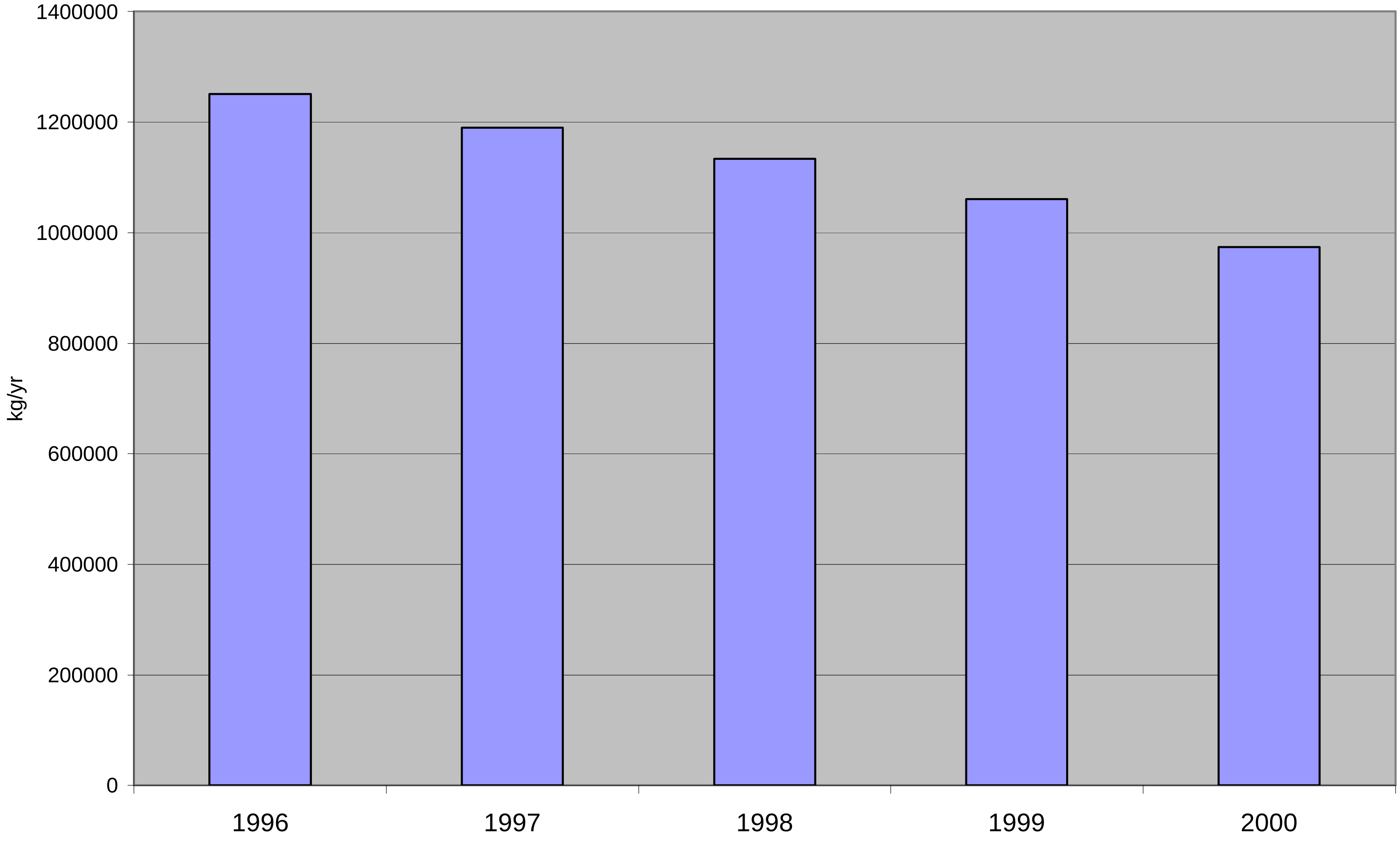


Figure 6: TP Loading from All Project Partner Facilities

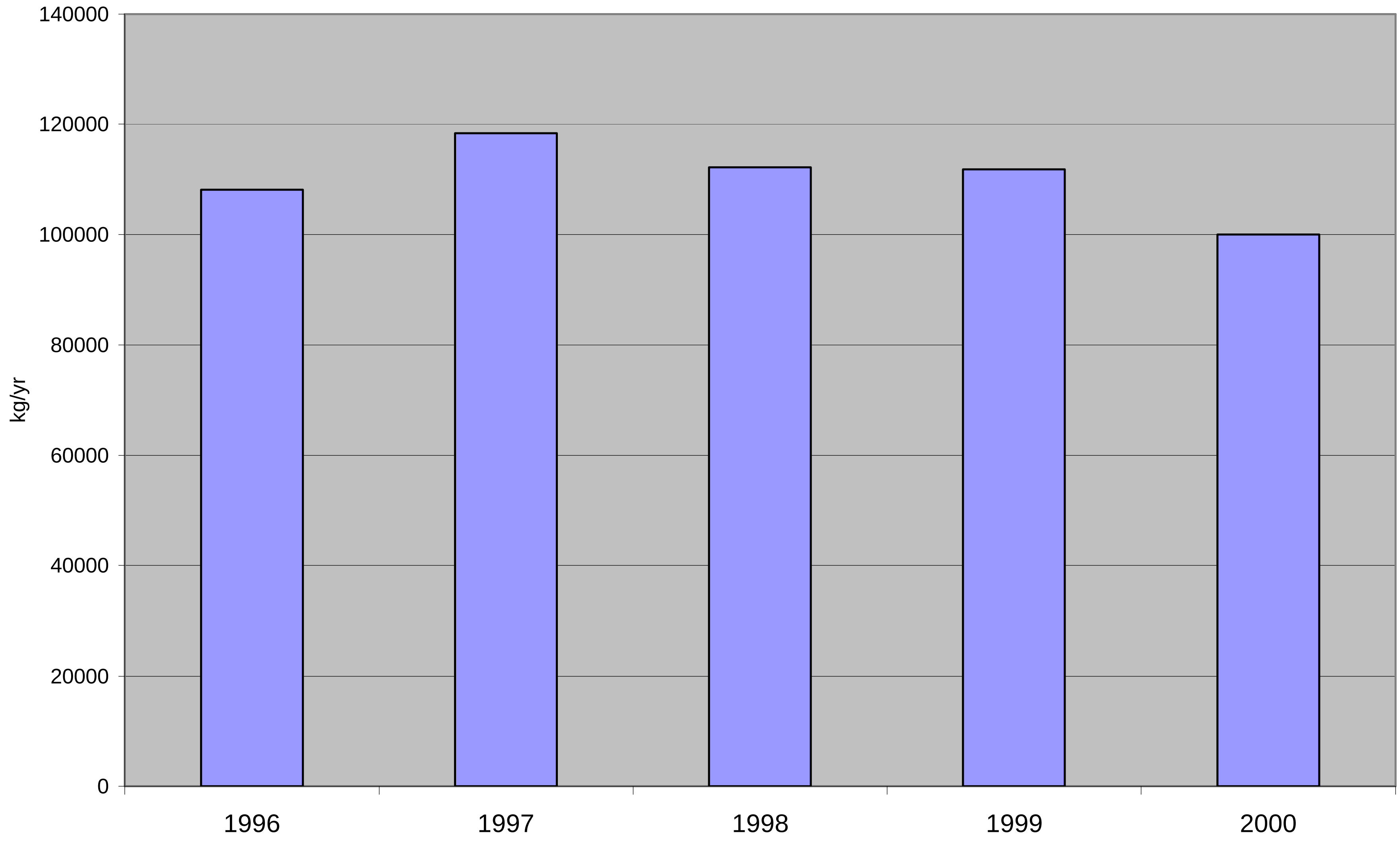


Table 2: Wastewater Treatment Plants Included in Delivery Model

PERMITNO	FACILITY	RECEIVING STREAM	MILES FROM LAKE*
NC0056413	CAROLINA MEADOWS	MORGAN CREEK	0.6
NC0043257	NATURE TRAILS MHP	CUB CREEK	2.1
NC0043559	FEARRINGTON VILLAGE	BUSH CREEK	3.4
NC0025241	OWASA	MORGAN CREEK	4.5
NC0047597	DURHAM SOUTH WRF	NEW HOPE CREEK	5.1
NC0020354	PITTSBORO	ROBERSON CREEK	5.5
NC0026051	DURHAM COUNTY TRIANGLE	NORTHEAST CREEK	6.9
NC0051314	COLE PARK PLAZA	CUB CREEK	7.6
NC0023876	BURLINGTON SOUTH	BIG ALAMANCE CREEK	29.9
NC0021211	GRAHAM	HAW RIVER	32.2
NC0023868	BURLINGTON EAST	HAW RIVER	36.6
NC0021474	MEBANE	MOADAMS CREEK	44.5
NC0024881	REIDSVILLE	LITTLE TROUBLESOME CREEK	66.7
NC0047384	GREENSBORO T. Z. OSBORNE	SOUTH BUFFALO CREEK	67.6
NC0024325	GREENSBORO N BUFFALO CREEK	NORTH BUFFALO CREEK	72.4

* Distances are based on Reach File Version 3 data, and are the sum of all reach distances from outfall location to the conservation pool, as indicated in polygon hydrography data. The shortest stream reach distances were used where braiding or hydromodification occurs. The distances do not precisely match distances from outfalls to model output reaches for Northeast, New Hope, and Morgan Creeks and the Haw River, which were based on the location of stream monitoring sites slightly upstream of the conservation pool.

approach is selecting an appropriate rate of loss from the water column (“decay rate”). It was beyond the scope of this study to collect field data and calibrate watershed specific decay rates for nitrogen and phosphorus. Therefore, for this study, empirically based rates based on a peer reviewed national study (Smith et al., 1997) were employed to estimate instream nutrient loss. The general equation for this approach is:

(6) $C_t = C_0 * e^{(-Kt)}$

where

C_0 = concentration (mg/L) at time zero
C_t = concentration (mg/L) at time t.
K = decay rate (1/t)

For total nitrogen, Smith et al. found that:

$Kn = 0.3842$ for stream flow < 1,000 cfs, and
$Kn = 0.1227$ for discharges > 1,000 cfs and <10,000 cfs
$Kn = 0.0408$ for discharges > 10,000 cfs

For total phosphorus, Smith et al. found that:

Kp = 0.268 for stream flow < 1,000 cfs, and
Kp = 0.0956 for discharges > 1,000 cfs and <10,000 cfs
Kp = 0.0 for discharges > 10,000 cfs

Therefore, a lower rate of loss was observed in a large cross section of streams and rivers at higher flow rates for both nitrogen and phosphorus. This observation is consistent with theoretical concepts that relate instream nutrient biological and chemical kinetics and processes to the relative amount of interaction between the water column and the streambed. In lower flow systems, this interaction is relatively high as compared to higher flow systems, as a higher proportion of the bed is in contact with the water column. Hence, a higher rate of "loss" or attenuation can be expected in lower order streams and during lower flow periods. The national emphasis of the USGS study resulted in rates being estimated for relatively higher flow regimes than of interest for a more local Jordan Lake application. Upon review of initial model results, a regression was developed, with the primary purpose being to provide additional differentiation at flows below 1000 cfs. The resulting equations, for nitrogen and phosphorus respectively, were:

(7) Kn = -0.082 * LN(stream flow) + 0.843
Kp = -0.058 * LN(stream flow) + 0.607

Model Application

The model was applied for 1996-1998, the three years in which both effluent data and data from the CFRBM were available. Model output at monitoring sites were reviewed to provide a qualitative sense of model performance (Attachment A). This included comparing model output to both instream concentration data and loading estimates. The instream loading estimates were generated by a regression model developed by Tetra Tech. A more rigorous, quantitative model calibration was not pursued because of the model's exclusion of nonpoint source inputs. Model runs were then completed to calculate daily tributary loadings for input to the Jordan Lake Nutrient Response Model, and the output data provided to Tetra Tech as spreadsheet files. Model output (as percent delivery for each Project Partner facility) was also summarized by month for studying wastewater management scenarios (Figures 7 and 8 and Attachment B). Percent delivery was calculated for each facility discharging to tributaries with more than one facility by running the model both with and without the facility's inclusion as a source.

The model runs indicate that, for all facilities and the entire period, 63% of both the nitrogen and the phosphorus discharged in the watershed are predicted to reach the lake. Nitrogen delivery from the three Project Partner facilities located closest to the lake along the New Hope arm all exhibited predicted delivery rates (from the outfalls to monitoring sites) above 90% for all months. Monthly delivery rates from outfalls to the lake boundary for the other facilities (in the Haw River watershed) ranged from about 20% to 80%, with lower delivery rates generally observed during summer/lower flow periods.

Figure 7: Estimated Percent Delivery of Total Nitrogen

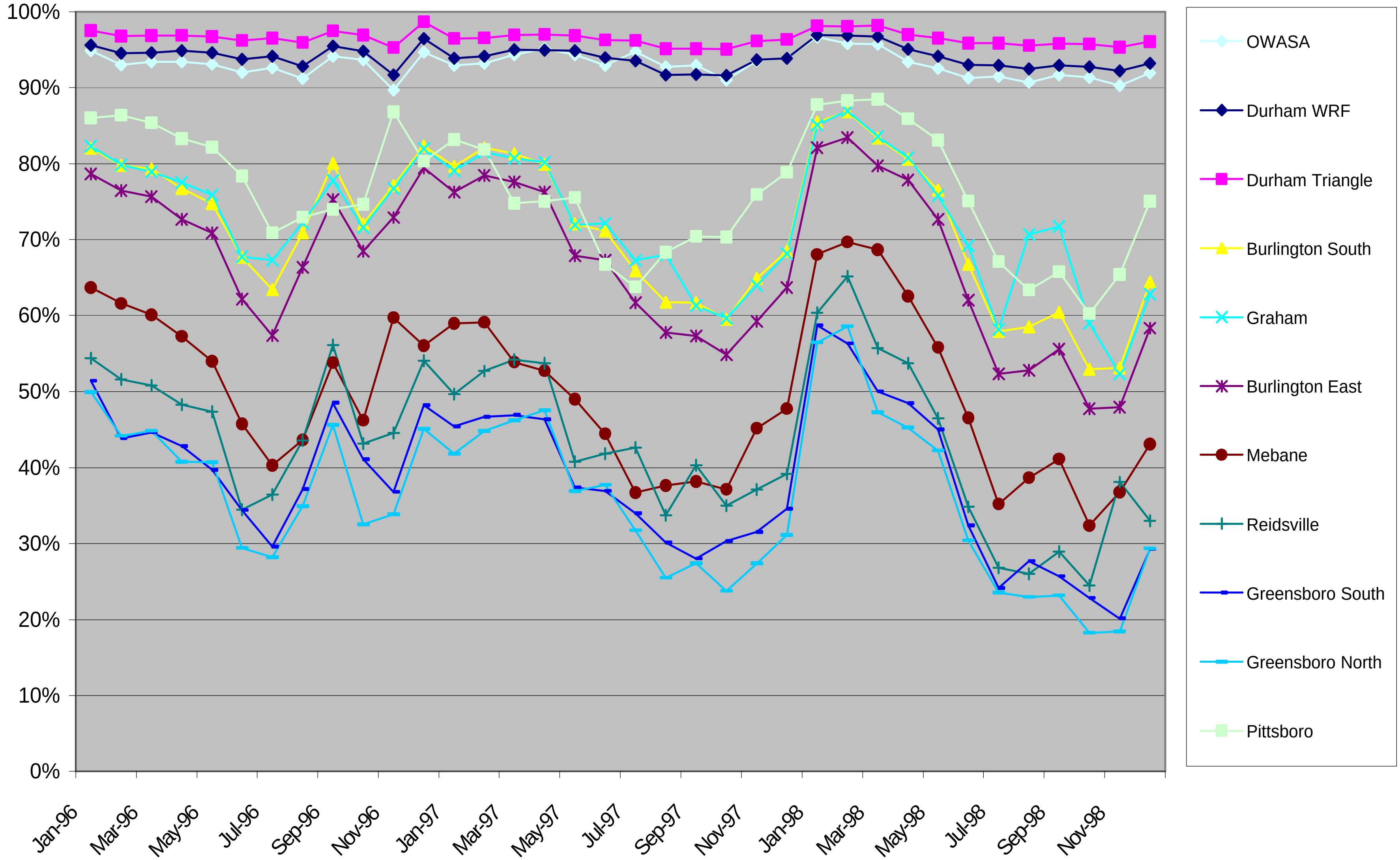
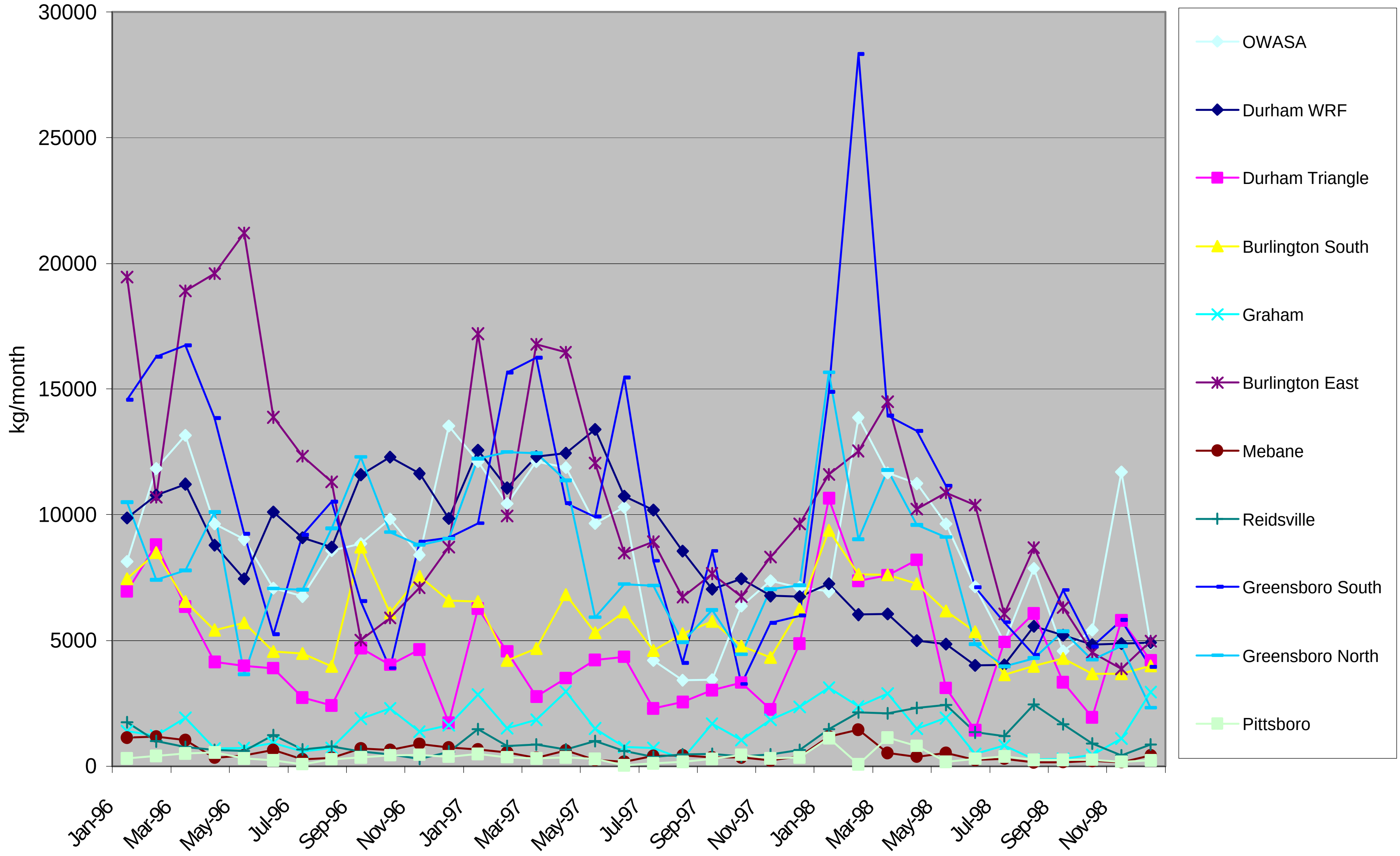


Figure 8: Estimated Delivery of Total Nitrogen



References

Alexander, R.B., R.A. Smith, and G.E. Schwarz. 2000. Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico. *Nature*, v. 403, p.758-761.

Bondelid, T., C. Griffifths, G. Van Houtven. 1999a. *A National Water Pollution Control Assessment Model*. Draft. Prepared for the United States Environmental Protection Agency Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, North Carolina. March 1999.

Bondelid, T., R. Dodd, C. Spoerri, and A. Stoddard. 1999b. *The Nutrients Version of the National Water Pollution Control Assessment Model*. Draft. Prepared for the United States Environmental Protection Agency, Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, North Carolina. December 1999.

Danish Hydrology Institute and Moffett and Nichols, 2000. Compact Disk Containing Cape Fear River Basin Model, Data, and Documentation. Provided by Pat Davis, Triangle J COG, January, 2001.

Eidenshink, J.E., 1992, The conterminous United States AVHRR data set. In *Photogrammetric Engineering and Remote Sensing*, v. 58, no. 6, p. 809-813.

Henderson, F.M. 1966. *Open Channel Flow.* New York: Macmillian Publishing Co., Inc.

Keup, L.E. 1985. Flowing Water Resources. *Water Resources Bulletin*, American Water Resources Association. v. 21, no. 2. April.

Smith, R.A., Schwarz, G.E., and R.B. Alexander. 1997. Regional interpretation of water-quality monitoring data. Water Resources Research, v. 33, no. 12, p. 2781-2798. December.

Attachment A

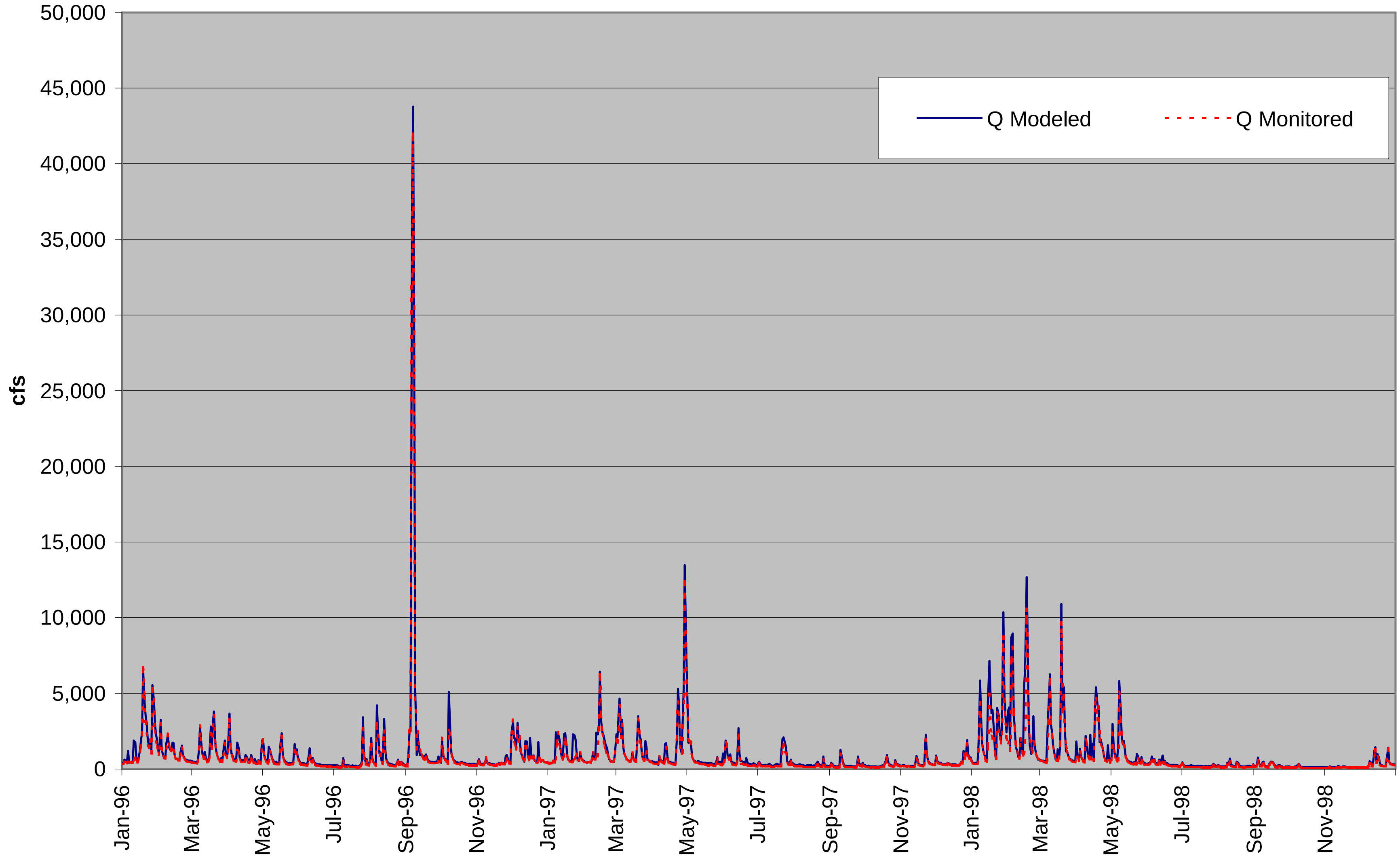
Selected Graphics Comparing Flow, Nitrogen, and Phosphorus Delivery Model Predictions, Instream Monitoring Data, and FLUX Model Output

Reference Table for Selected Stream Locations in Point Source Delivery Model

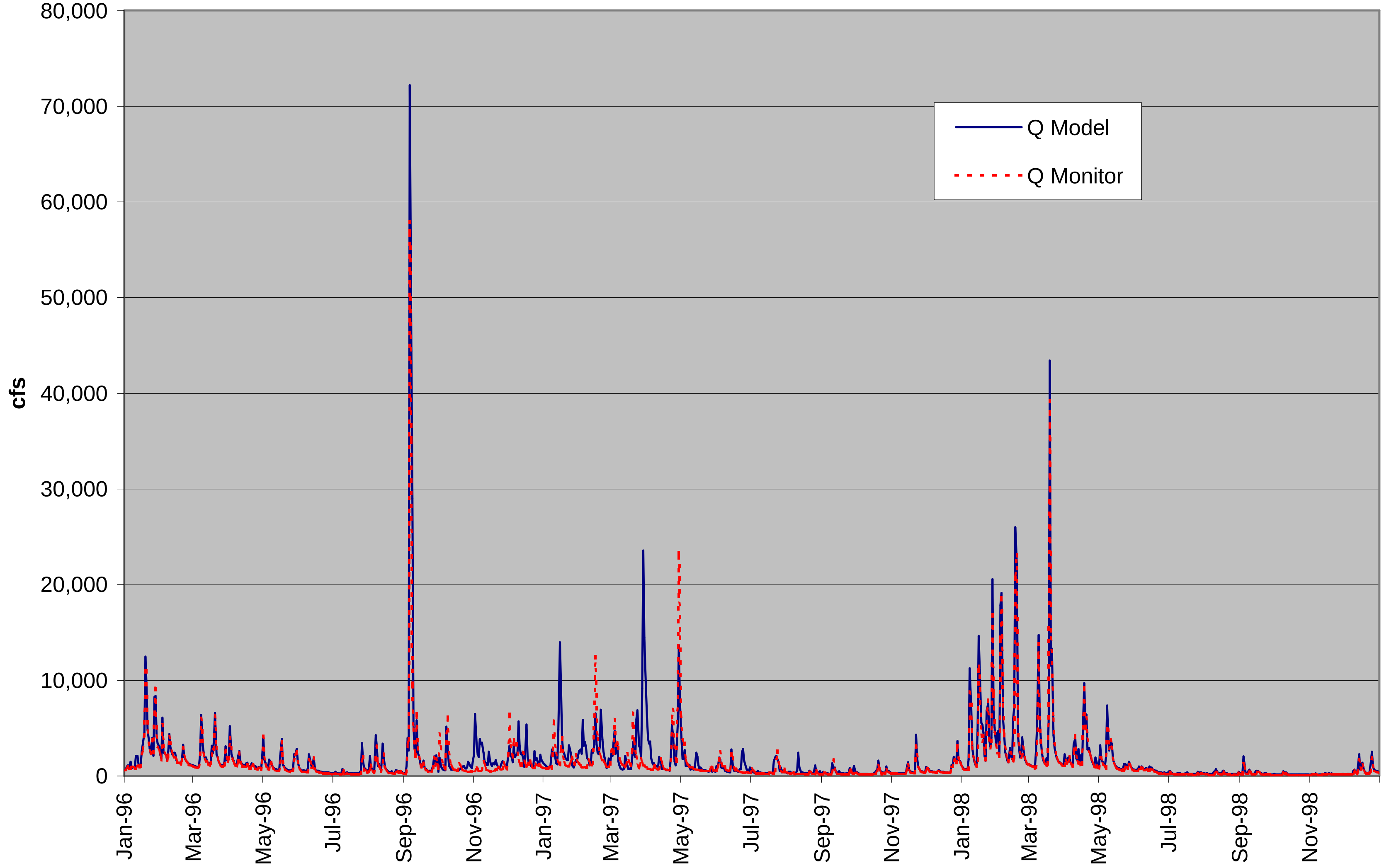
Associated With Graphics in Attachment A and Model Output Reaches

Stream Name	Monitoring ID	RF3 Reach ID	Upstream WWTPs
N. Buffalo Creek	02095500	3030002 38 2.51	Greensboro North
S. Buffalo Creek	0209505100	3030002 39 0.22	Greensboro South
Reedy Fork	B084000	3030002 28 0.00	Greensboro
Haw River at Haw River	02096500	3030002 18 2.70	Greensboro, Reidsville
Haw River at Saxapahaw	HW01	3030002 11 0.67	Reidsville, Greensboro, Burlington, Graham, Mebane
Haw River at Bynum	B214000	3030002 9 8.01	Reidsville, Greensboro, Burlington, Graham, Mebane
Robeson Creek		3030002 85 0.00	Pittsboro
Northeast Creek	0209741955	3030002 6 5.76	Durham County
New Hope Creek	020907314	3030002 7 4.36	Durham WRF
Morgan Creek	NH6	3030002 8 2.55	OWASA, Carolina Meadows
Cub Creek		0300002 64 0.22	Cole Park Plaza, Nature Village MHP
Bush Creek		0300002 1402 0.07	Fearrington Village

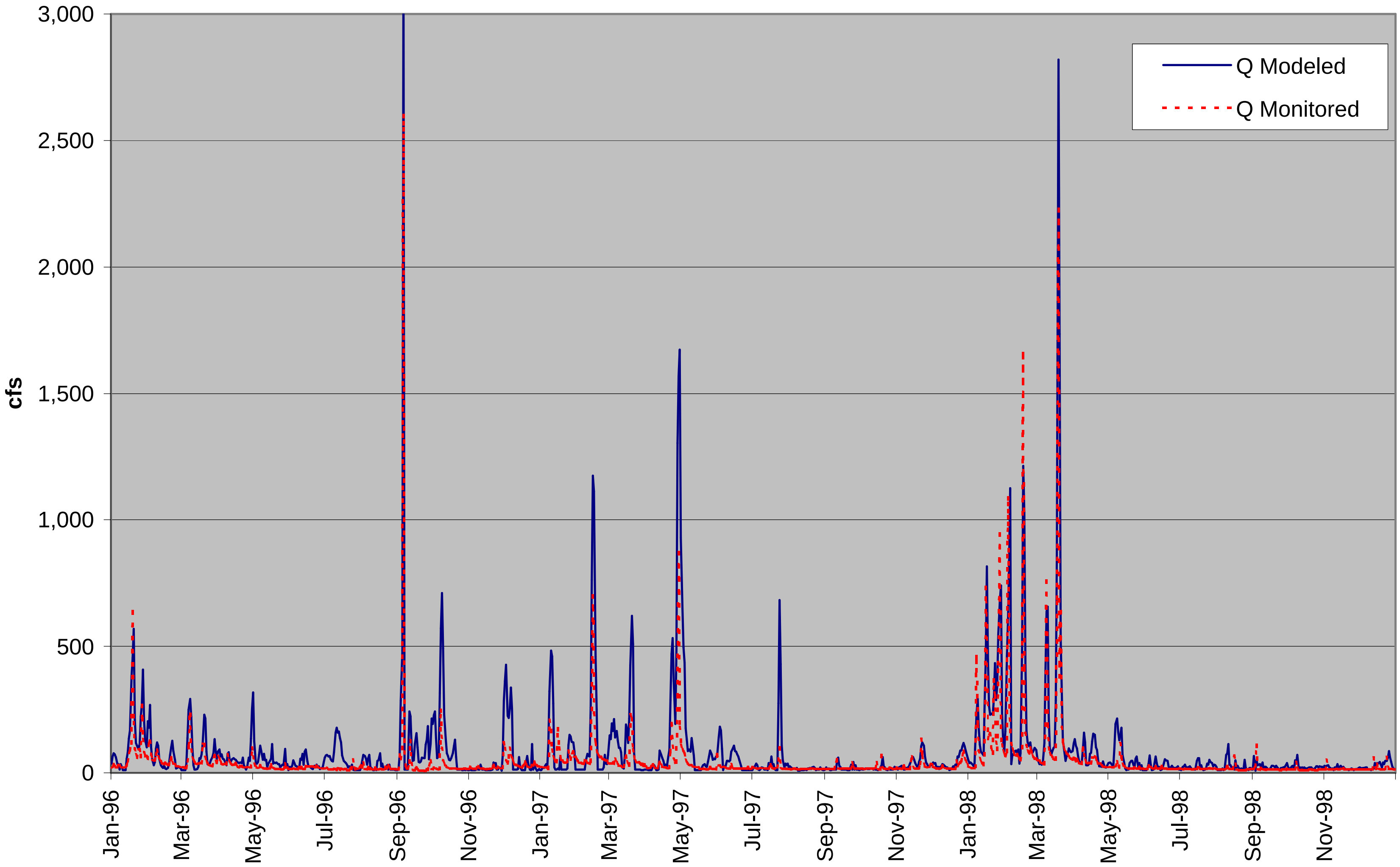
Modeled and Gaged Flow Data: Haw at Haw River

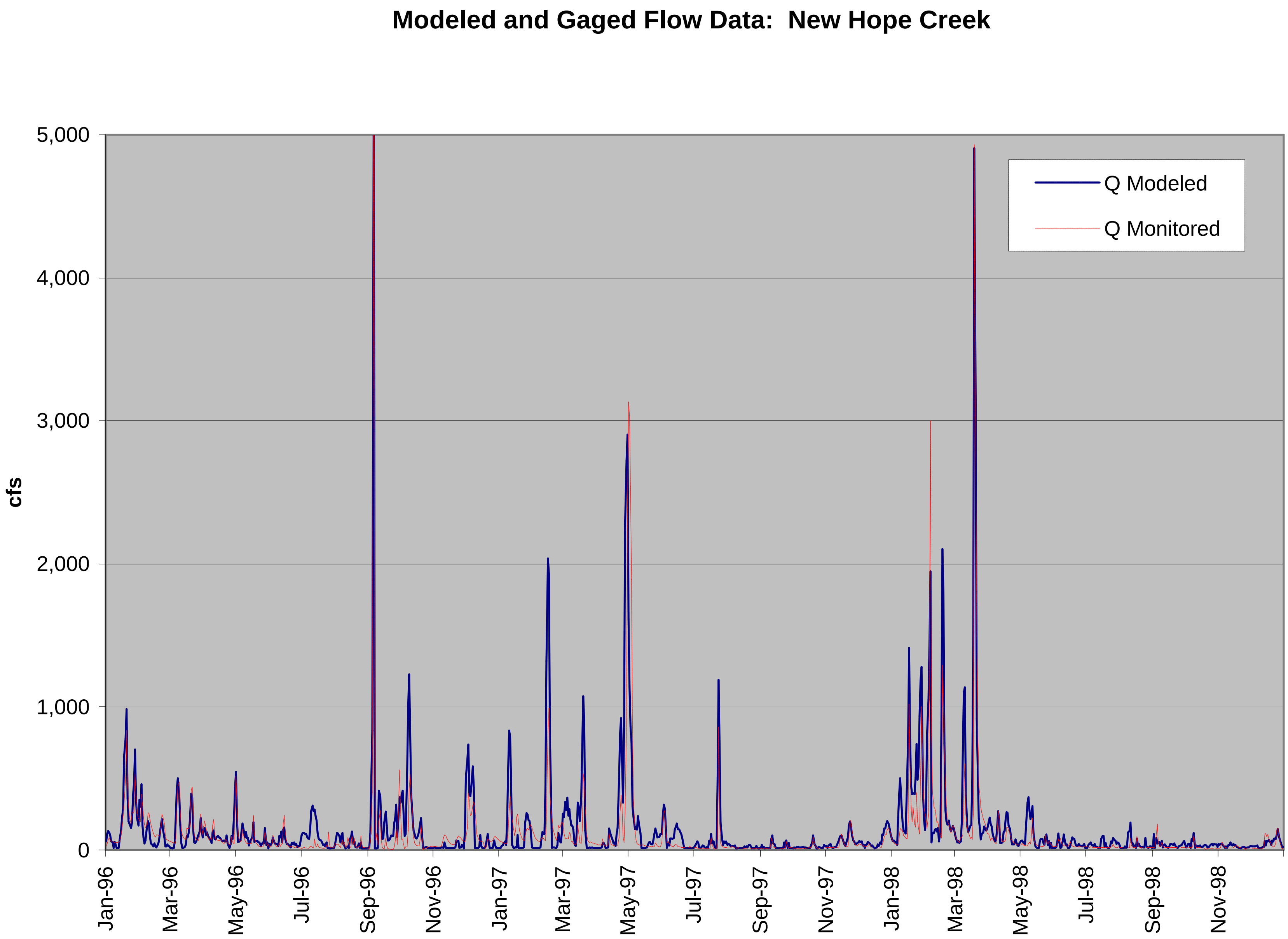


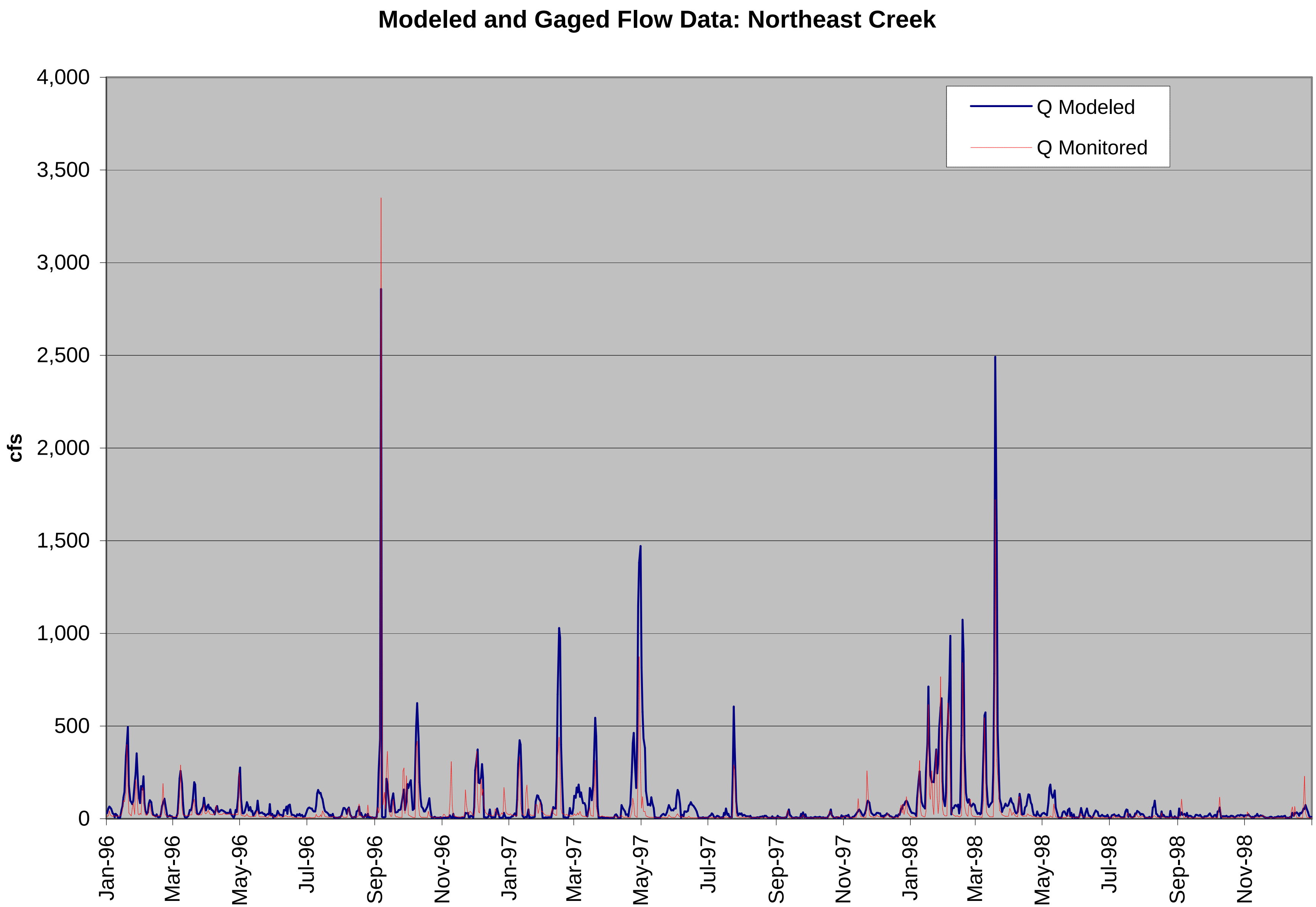
Modeled and Gaged Flow Data: Haw River @ Bynum



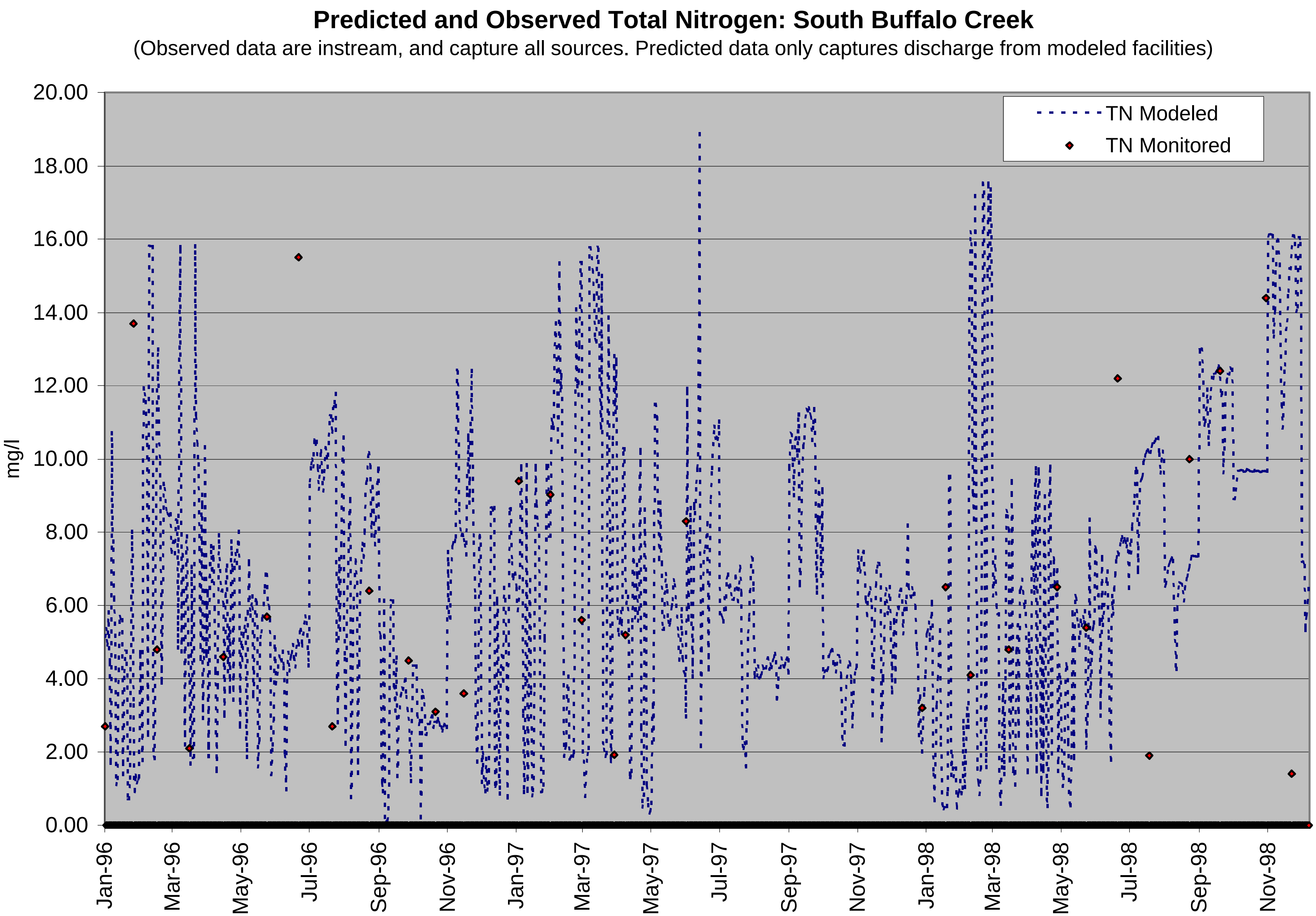
Modeled and Gaged Flow Data: Morgan Creek




Modeled and Gaged Flow Data: New Hope Creek
cfs
5,000
4,000
3,000
2,000
1,000
0
Q Modeled
Q Monitored
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98

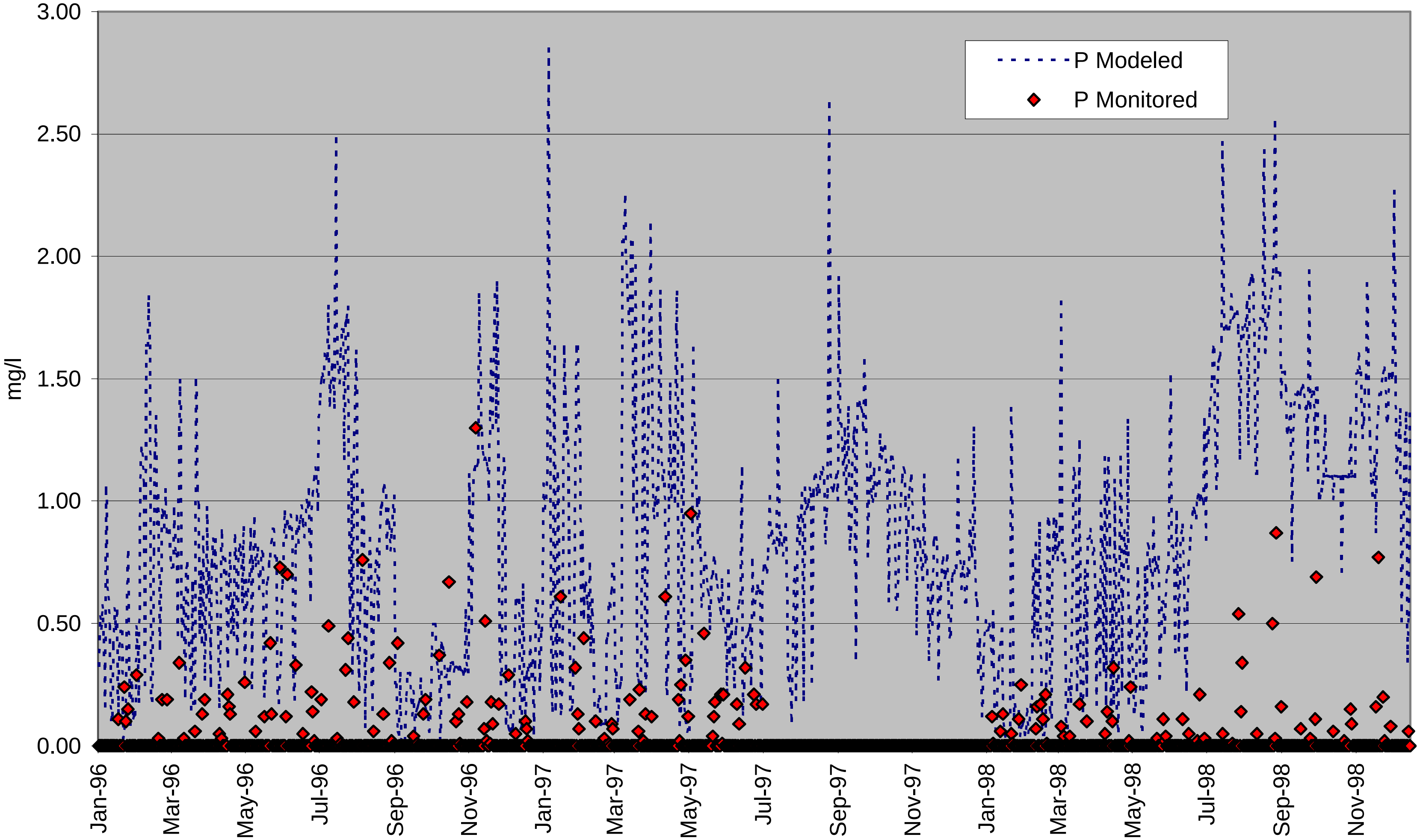


Modeled and Gaged Flow Data: Northeast Creek
cfs
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Q Modeled
Q Monitored
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98


Predicted and Observed Total Nitrogen: South Buffalo Creek
(Observed data are instream, and capture all sources. Predicted data only captures discharge from modeled facilities)
TN Modeled
TN Monitored
mg/l
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98

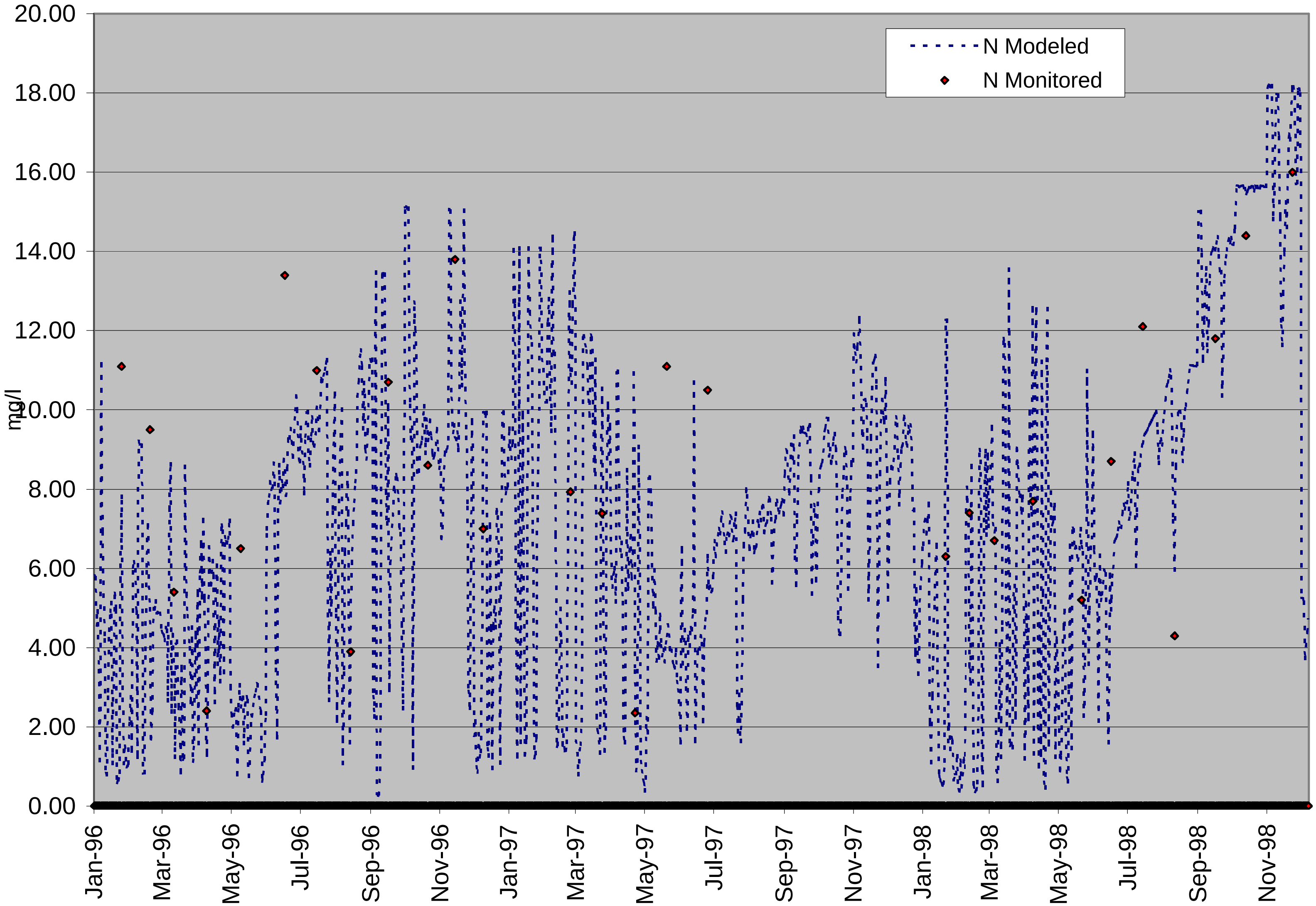
Predicted and Observed Total Phosphorus: South Buffalo Creek

(Observed data are instream, and capture all sources. Predicted data only captures discharge from modeled facilities)



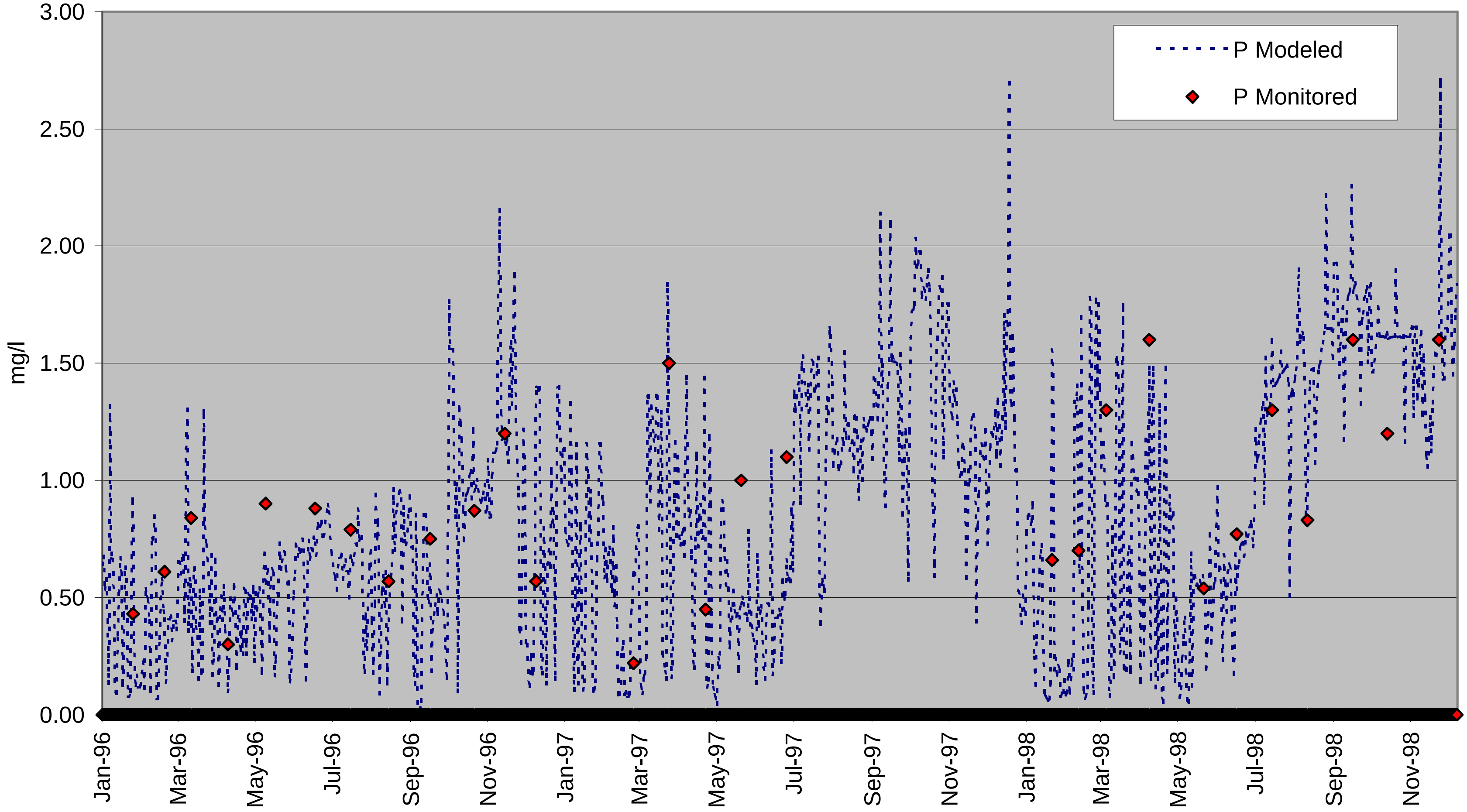
Predicted and Observed Total Nitrogen: North Buffalo Creek

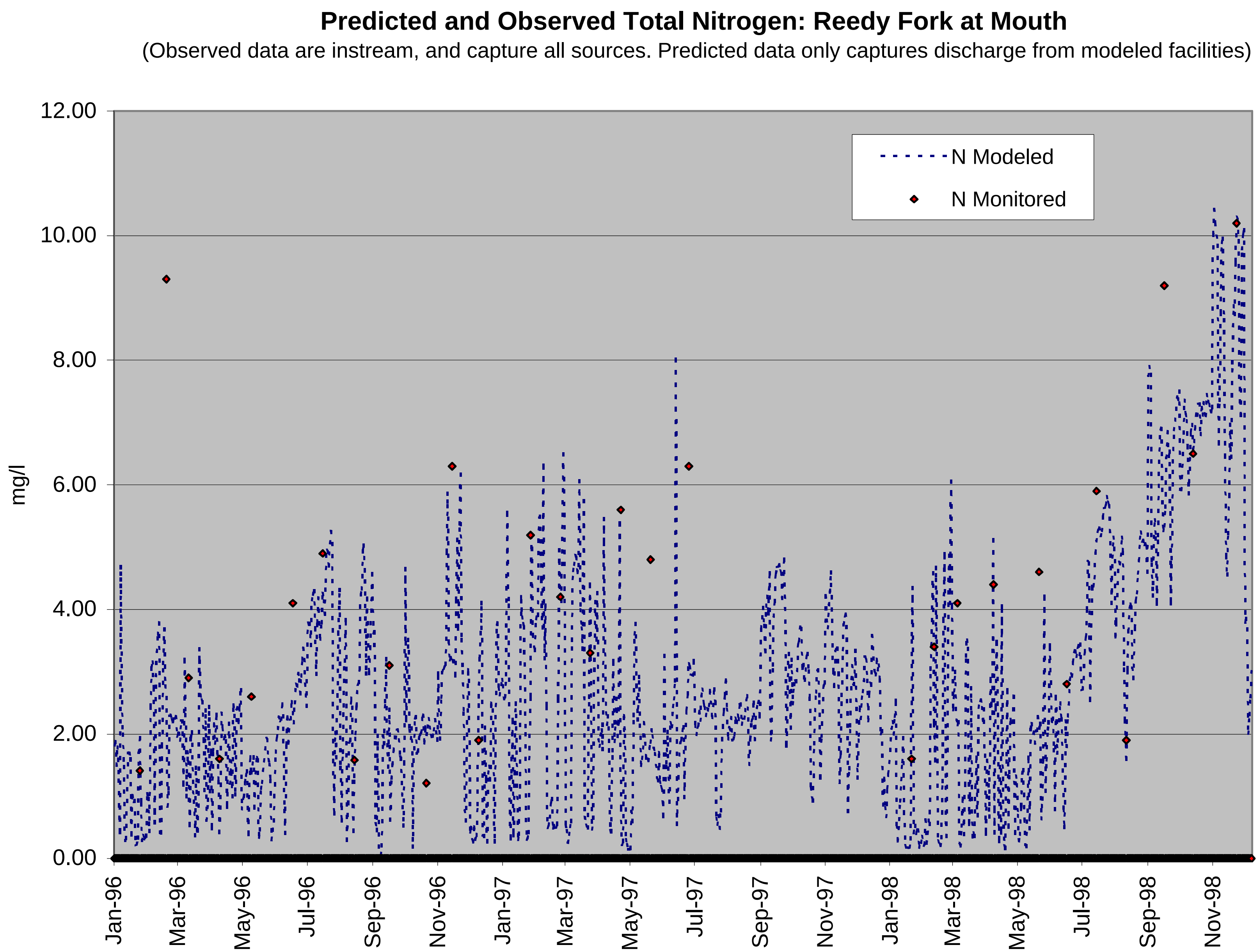
(Observed data are instream, and capture all sources. Predicted data only captures discharge from modeled facilities)



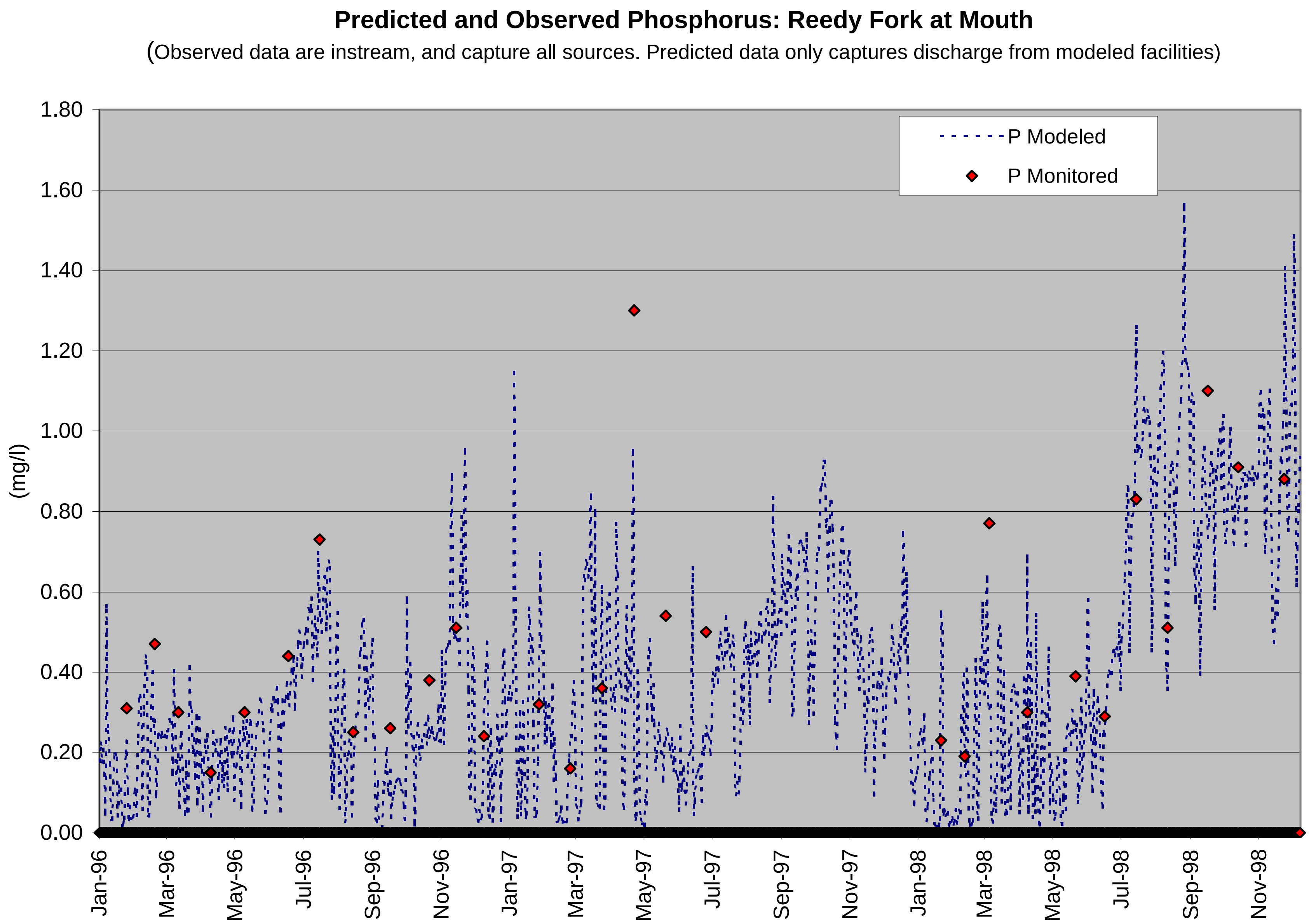
Predicted and Observed Total Phosphorus: North Buffalo Creek

(Observed data are instream, and capture all sources. Predicted data only captures discharge from modeled facilities)



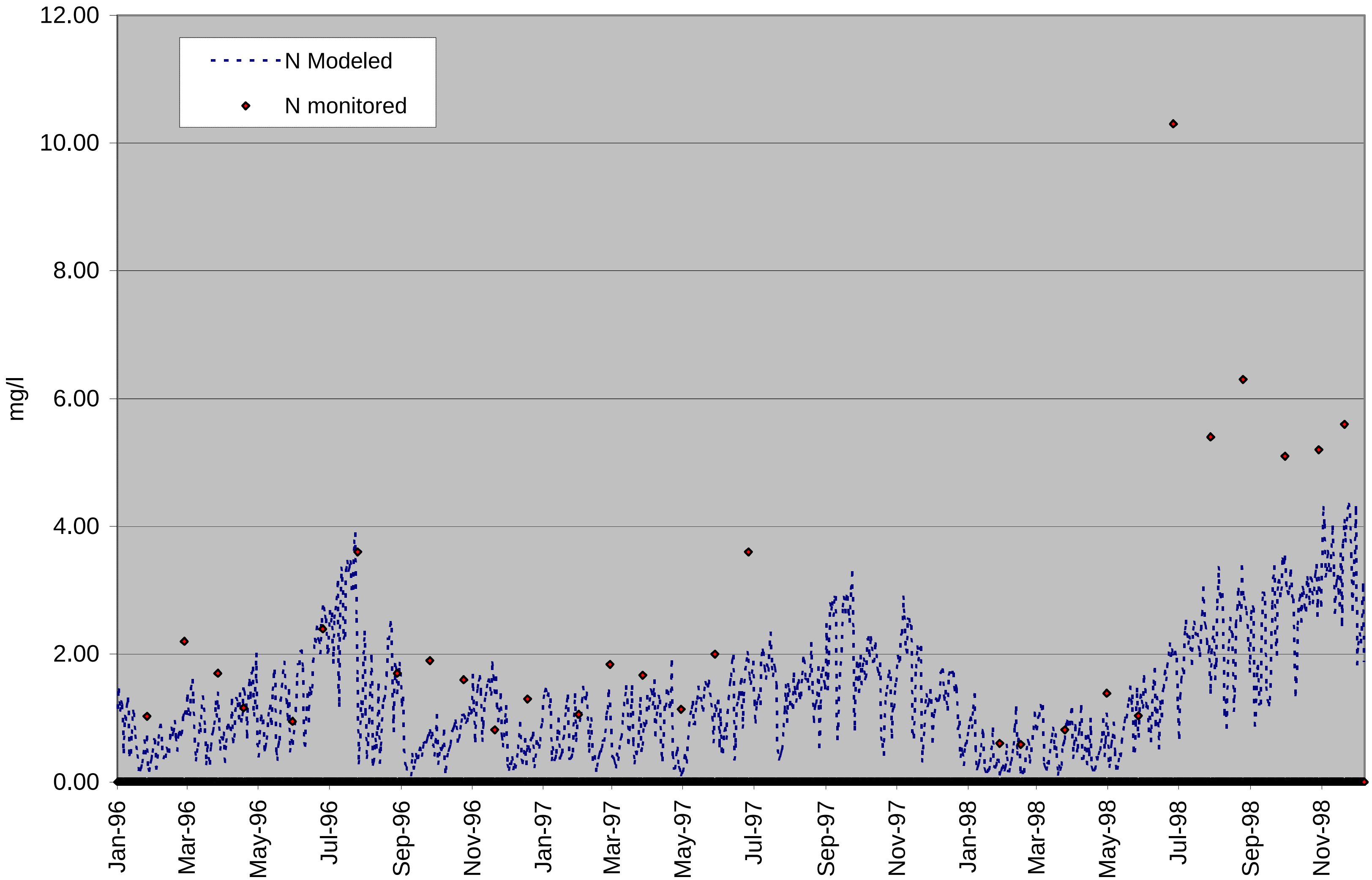


Predicted and Observed Total Nitrogen: Reedy Fork at Mouth
(Observed data are instream, and capture all sources. Predicted data only captures discharge from modeled facilities)
N Modeled
N Monitored
mg/l
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98


Predicted and Observed Phosphorus: Reedy Fork at Mouth
(Observed data are instream, and capture all sources. Predicted data only captures discharge from modeled facilities)
P Modeled
P Monitored
(mg/l)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98

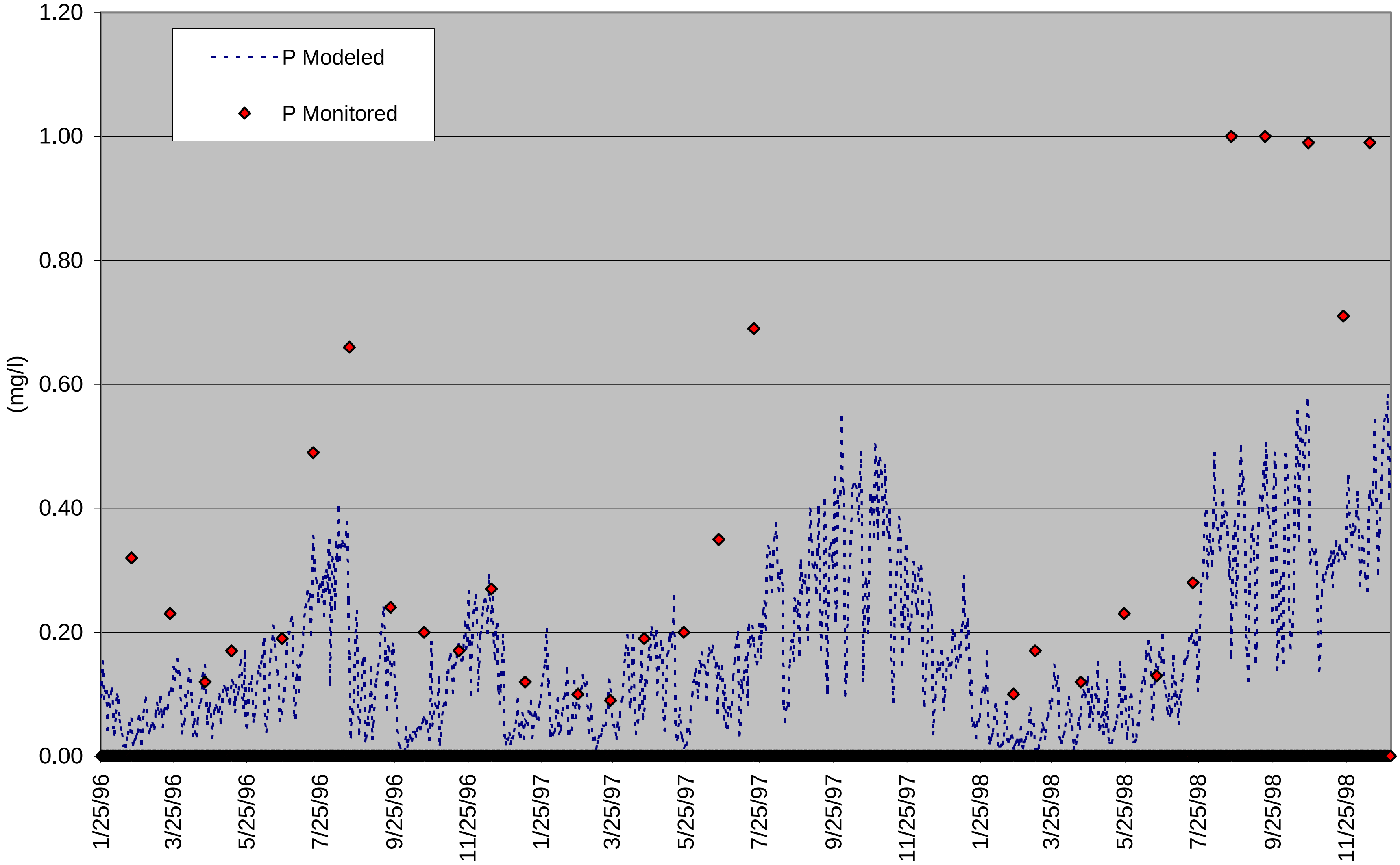
Predicted and Observed Total Nitrogen: Haw River at Haw River

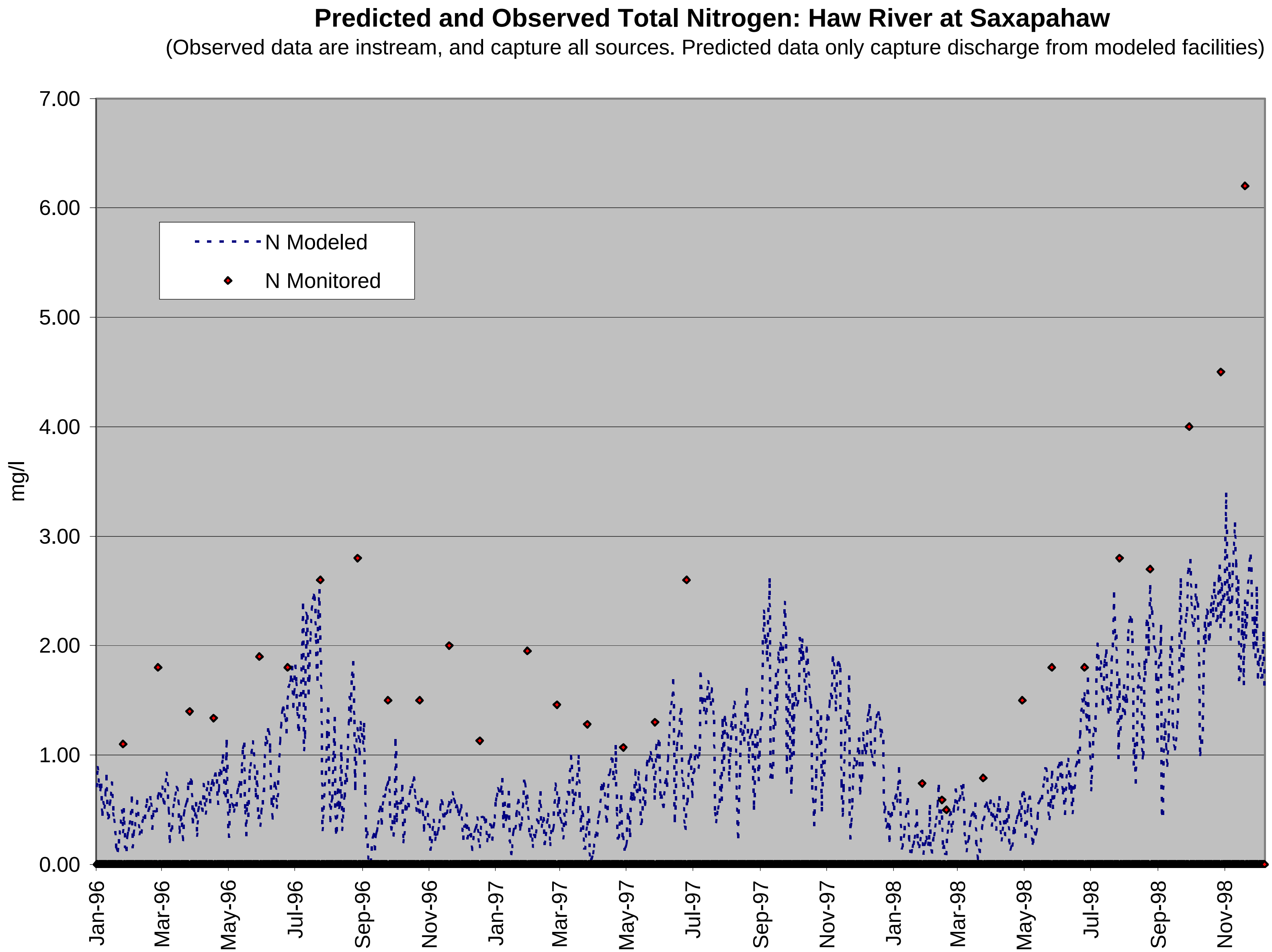
(Observed data are instream, and capture all sources. Predicted data only captures discharge from modeled facilities)



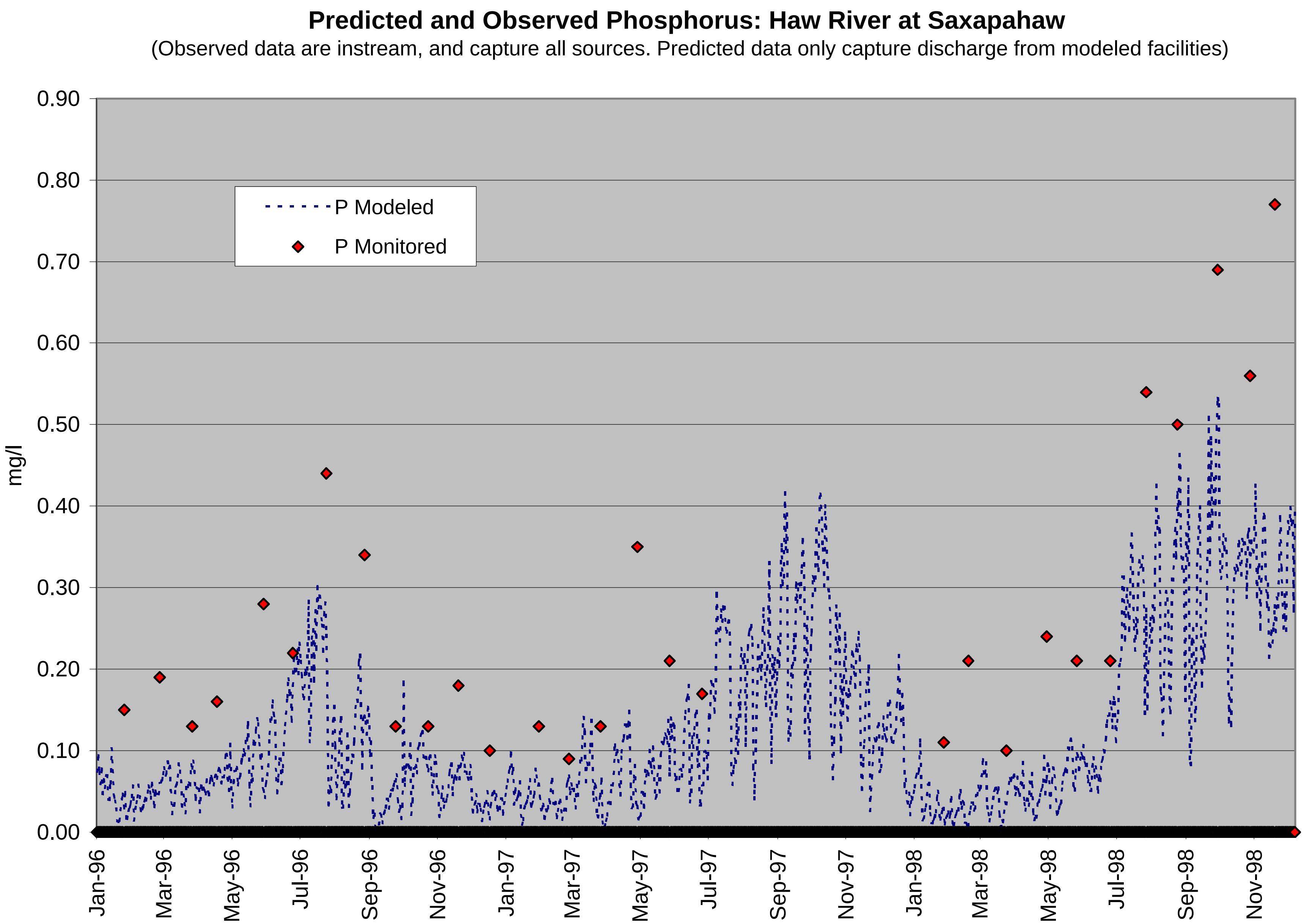
Predicted and Observed Total Phosphorus: Haw at Haw River

(Observed data are instream, and capture all sources. Predicted data only capture discharge from modeled facilities)





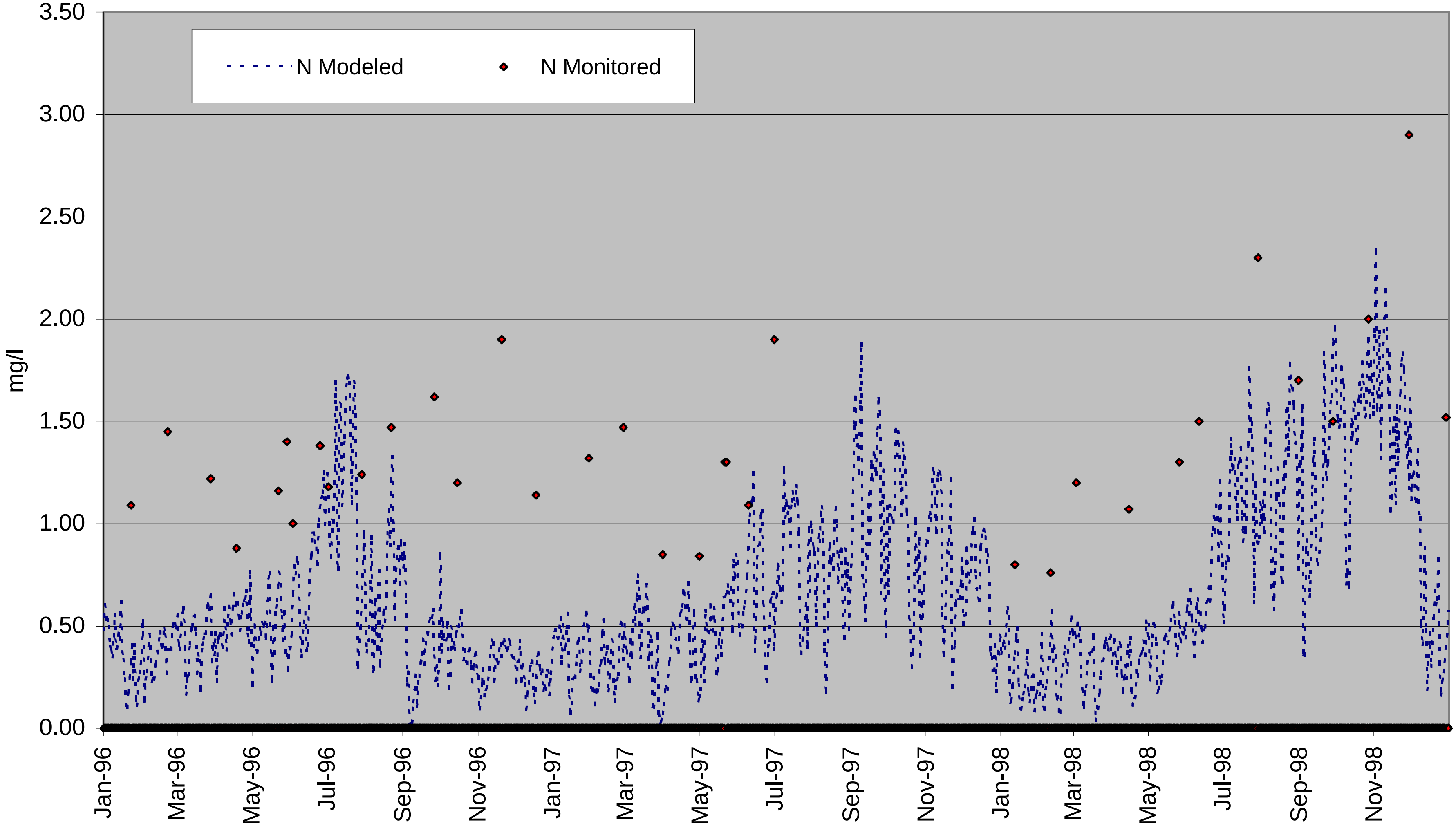
Predicted and Observed Total Nitrogen: Haw River at Saxapahaw
(Observed data are instream, and capture all sources. Predicted data only capture discharge from modeled facilities)
mg/l
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
N Modeled
N Monitored
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98

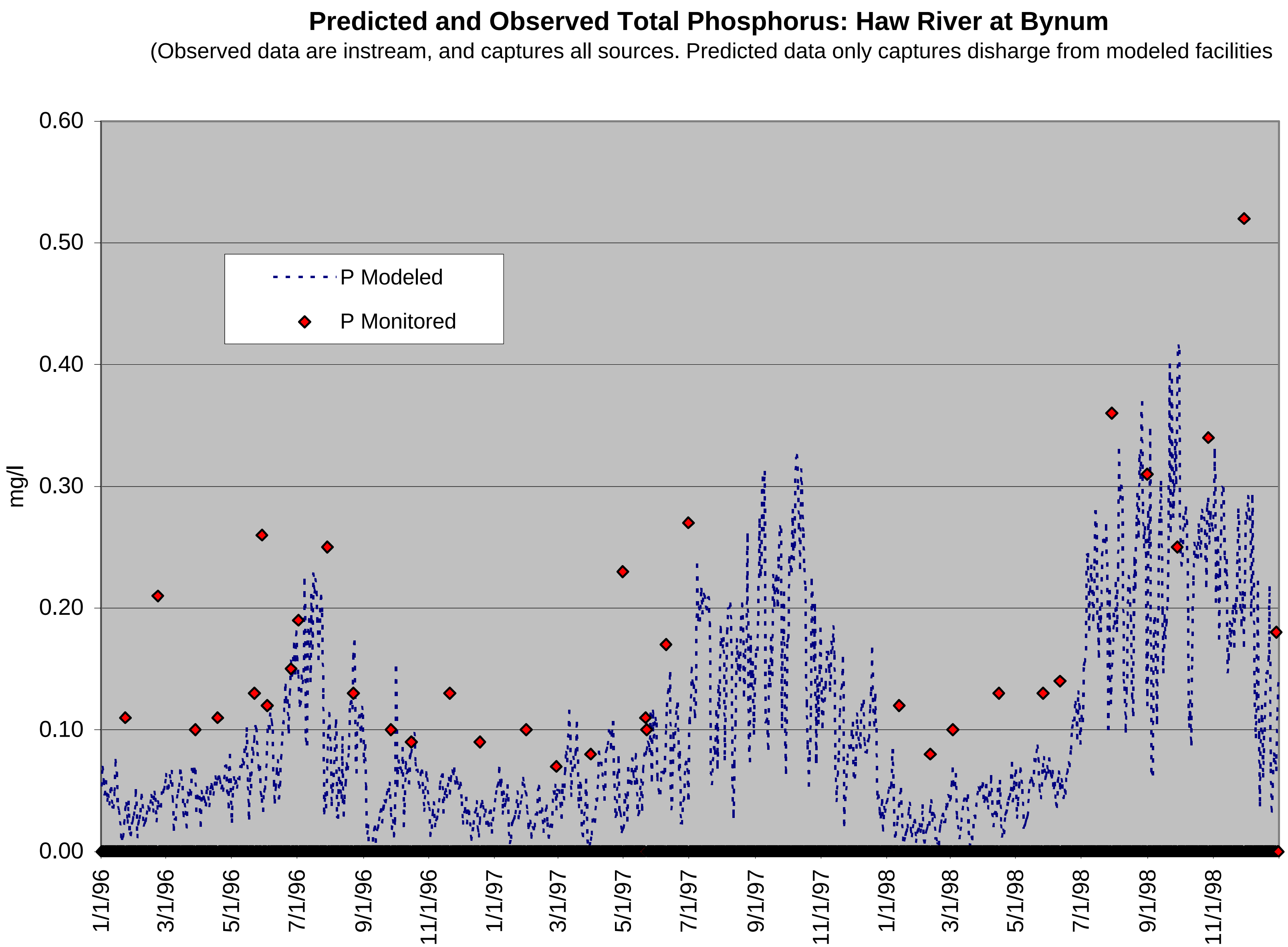


Predicted and Observed Phosphorus: Haw River at Saxapahaw
(Observed data are instream, and capture all sources. Predicted data only capture discharge from modeled facilities)
P Modeled
P Monitored
mg/l
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98

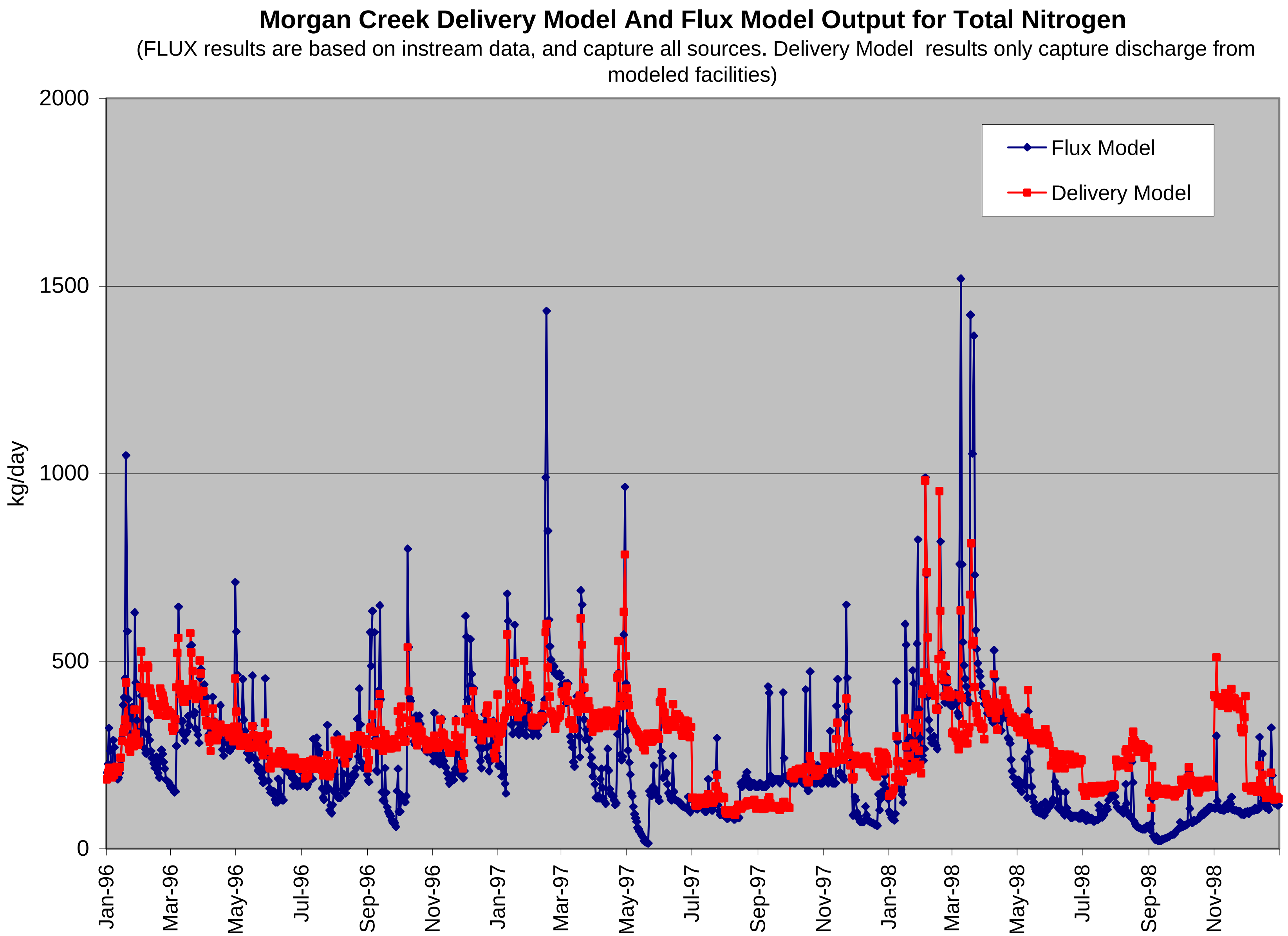
Predicted and Observed Total Nitrogen: Haw River at Bynum

(Observed data are instream, and capture all sources. Predicted data only capture discharge from modeled facilities

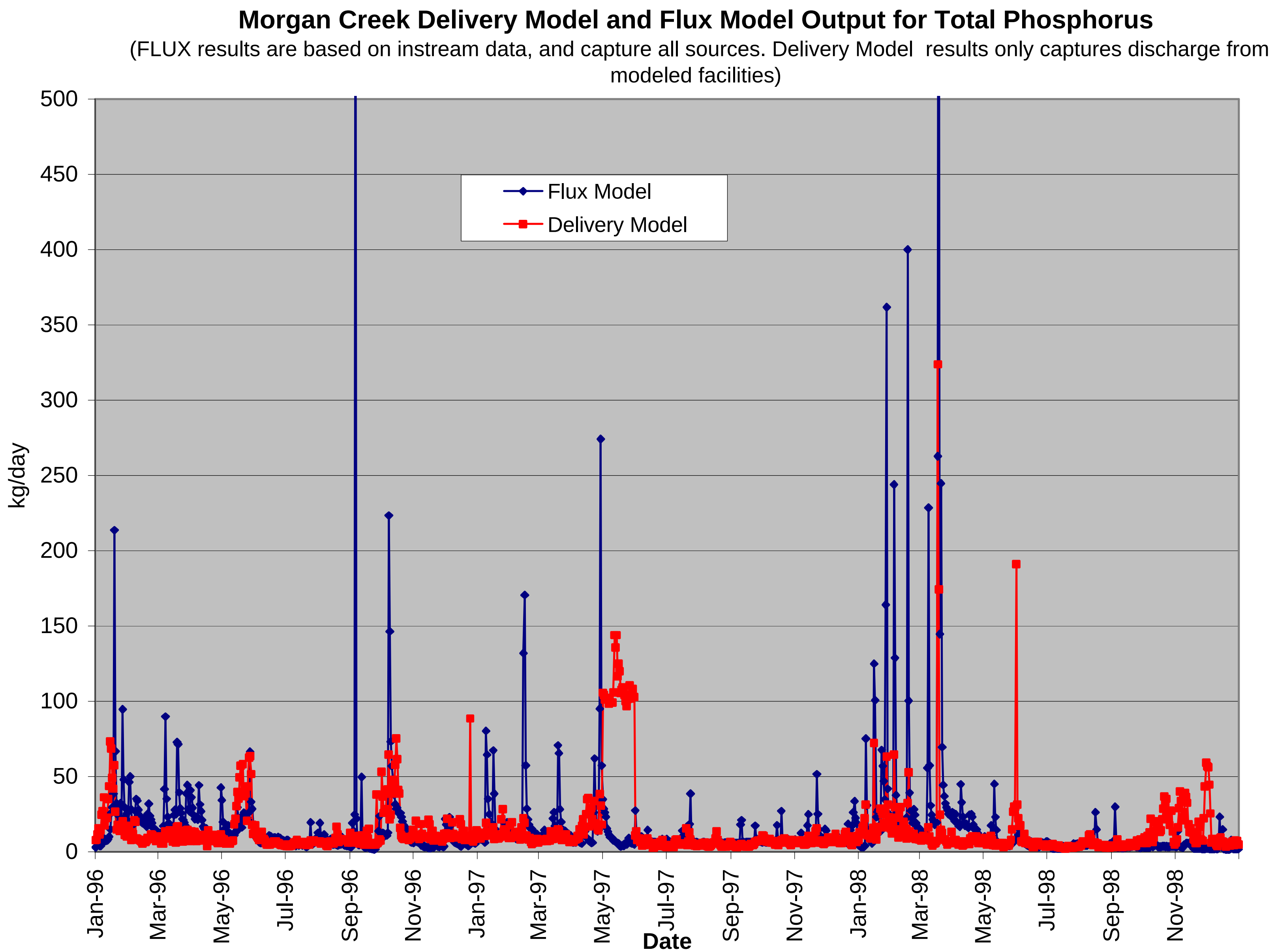




Predicted and Observed Total Phosphorus: Haw River at Bynum
(Observed data are instream, and captures all sources. Predicted data only captures disharge from modeled facilities
mg/l
0.60
0.50
0.40
0.30
0.20
0.10
0.00
P Modeled
P Monitored
1/1/96
3/1/96
5/1/96
7/1/96
9/1/96
11/1/96
1/1/97
3/1/97
5/1/97
7/1/97
9/1/97
11/1/97
1/1/98
3/1/98
5/1/98
7/1/98
9/1/98
11/1/98

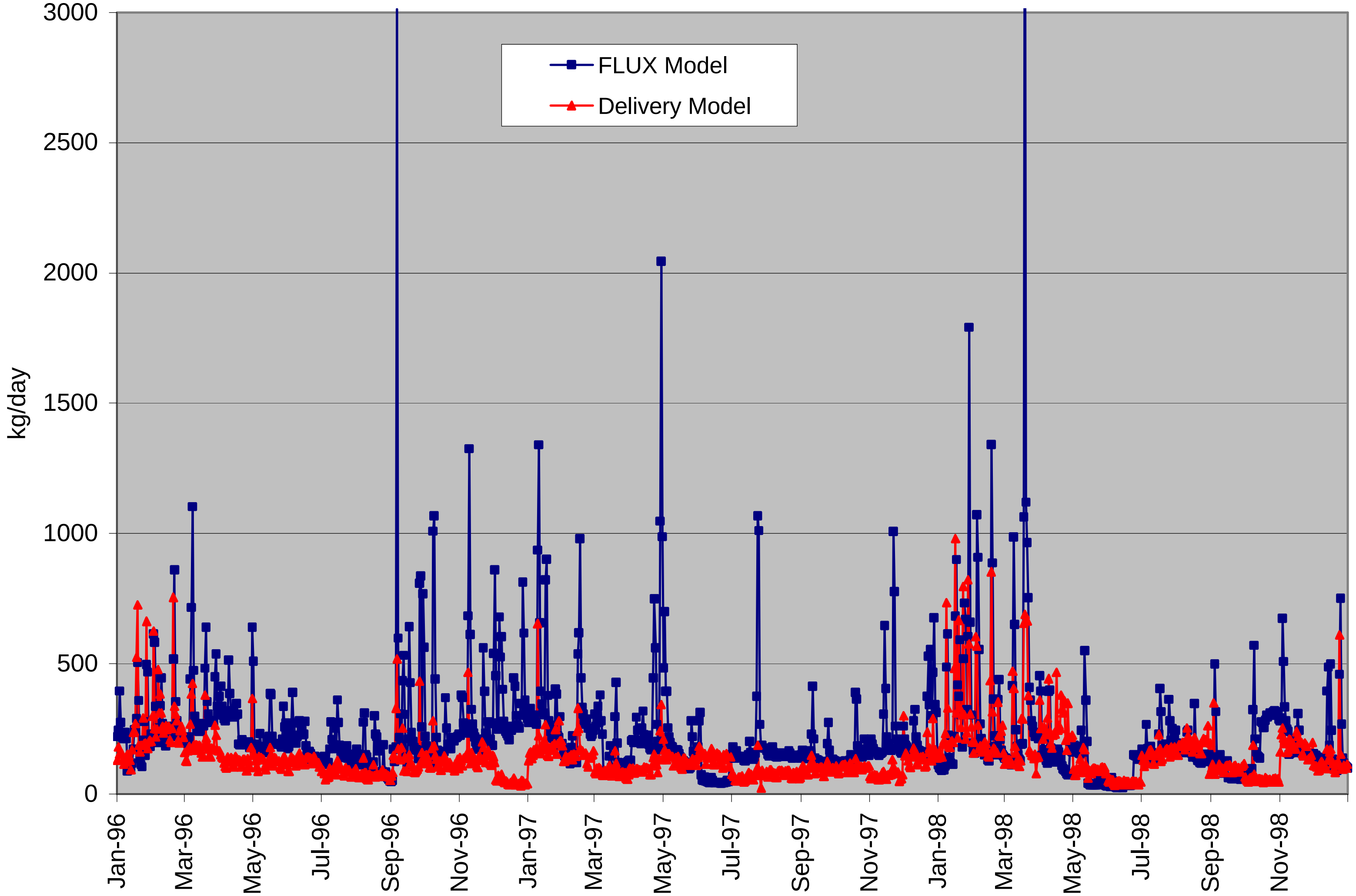


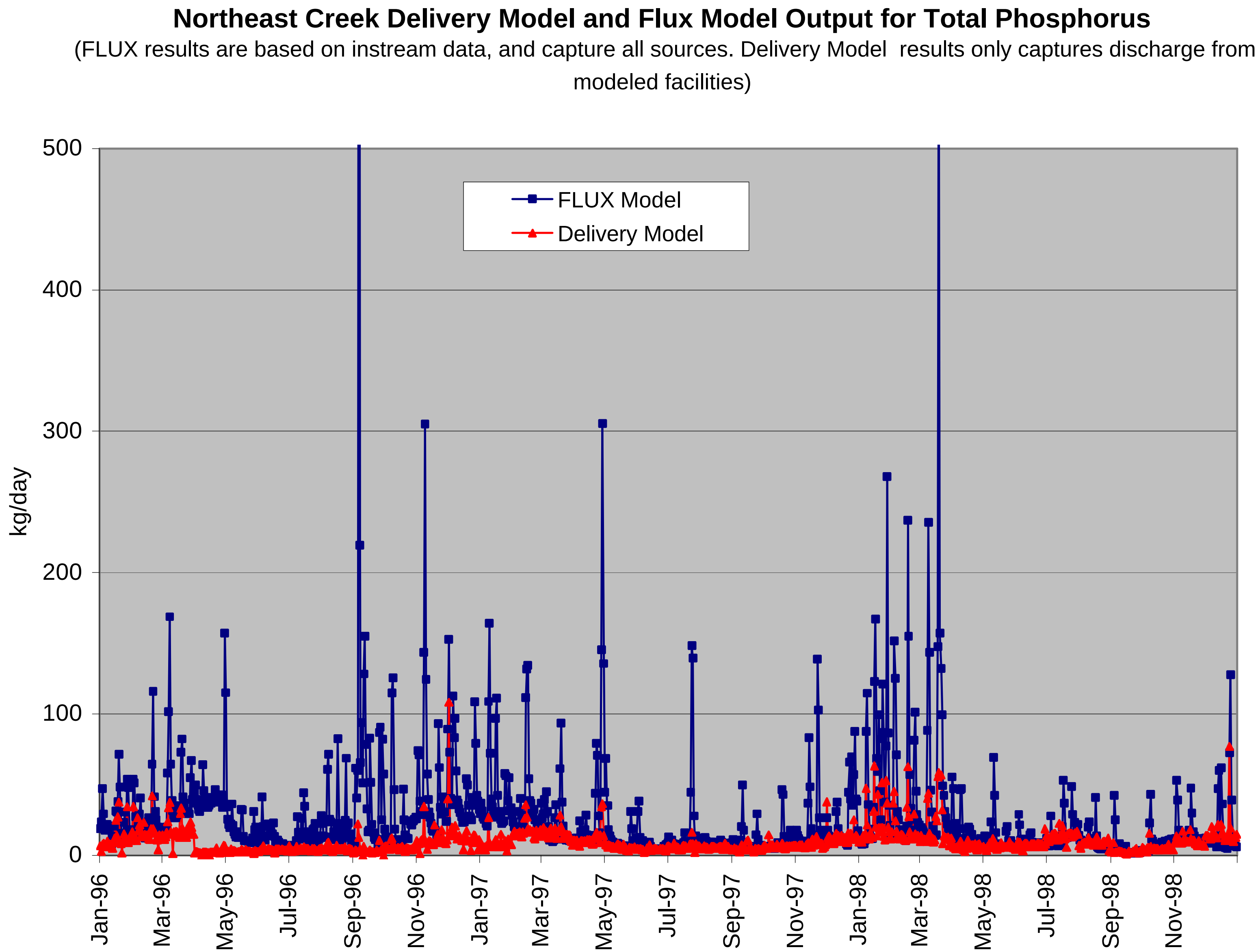
Morgan Creek Delivery Model And Flux Model Output for Total Nitrogen
(FLUX results are based on instream data, and capture all sources. Delivery Model results only capture discharge from modeled facilities)
kg/day
2000
1500
1000
500
0
Flux Model
Delivery Model
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98

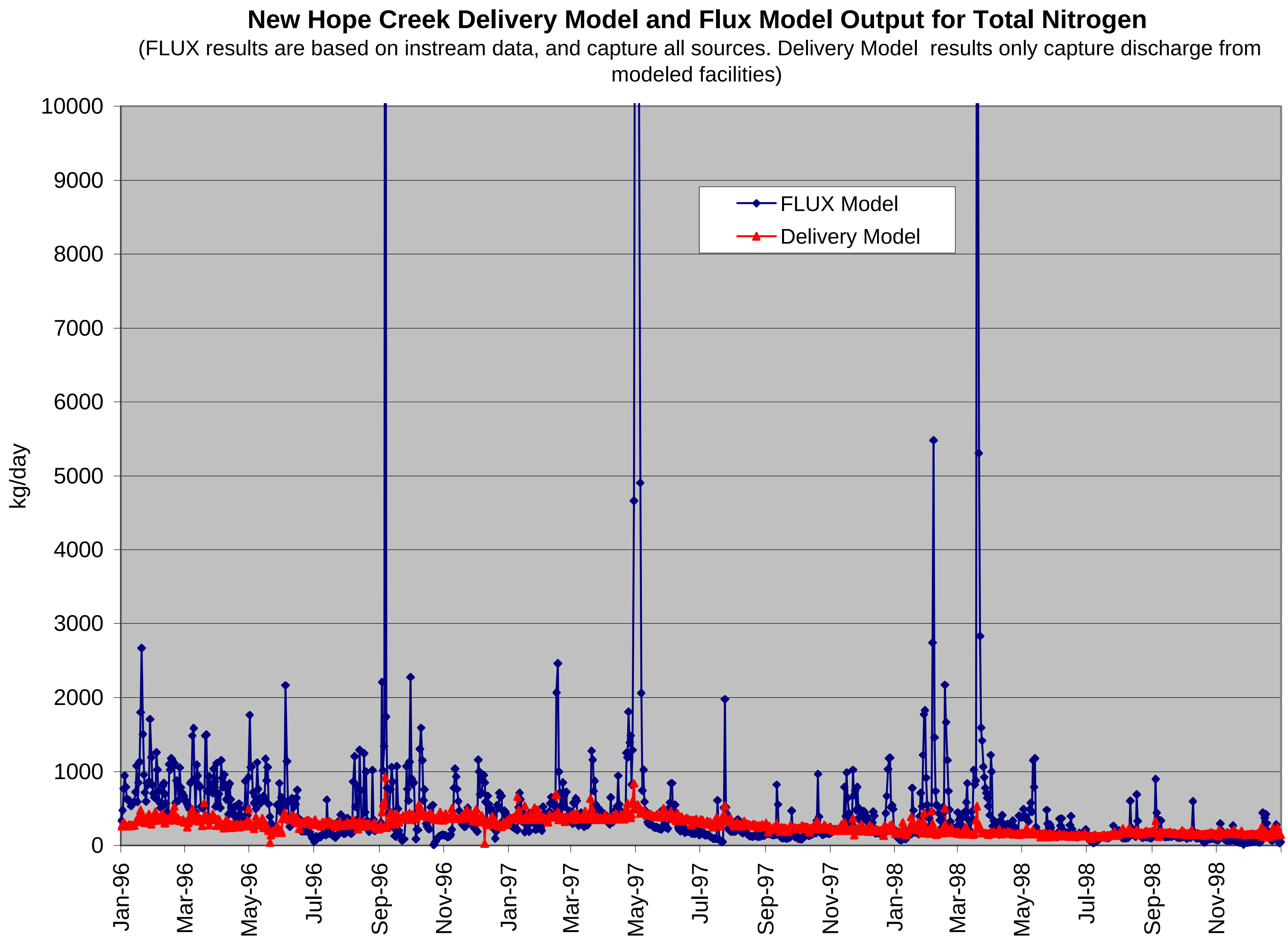

Morgan Creek Delivery Model and Flux Model Output for Total Phosphorus
(FLUX results are based on instream data, and capture all sources. Delivery Model results only captures discharge from modeled facilities)
Flux Model
Delivery Model
kg/day
500
450
400
350
300
250
200
150
100
50
0
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
Date

Northeast Creek Delivery Model and Flux Model Output for Total Nitrogen

(FLUX results are based on instream data, and capture all sources. Delivery Model results only captures discharge from modeled facilities)



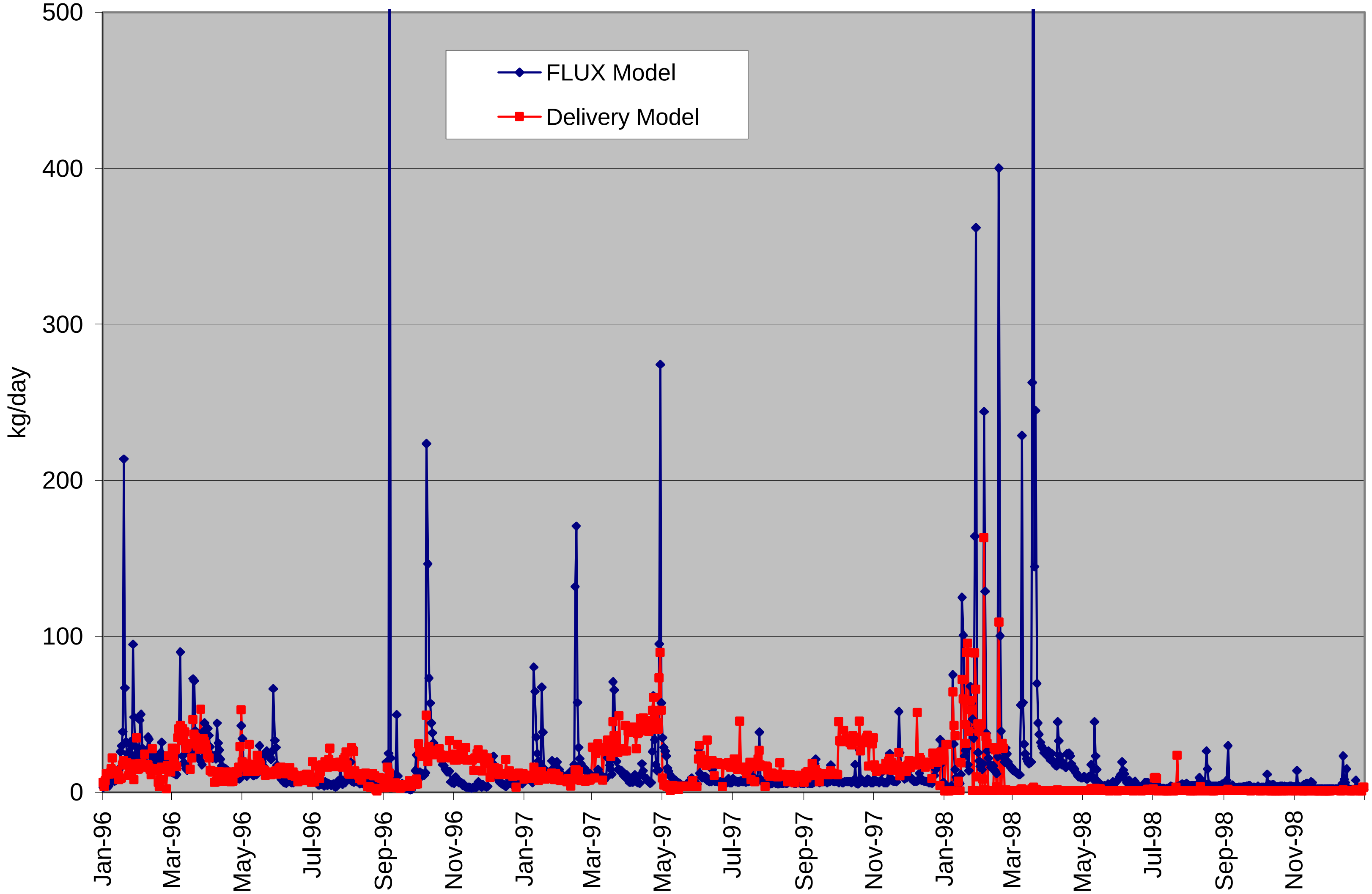

Northeast Creek Delivery Model and Flux Model Output for Total Phosphorus
(FLUX results are based on instream data, and capture all sources. Delivery Model results only captures discharge from modeled facilities)
FLUX Model
Delivery Model
kg/day
500
400
300
200
100
0
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98

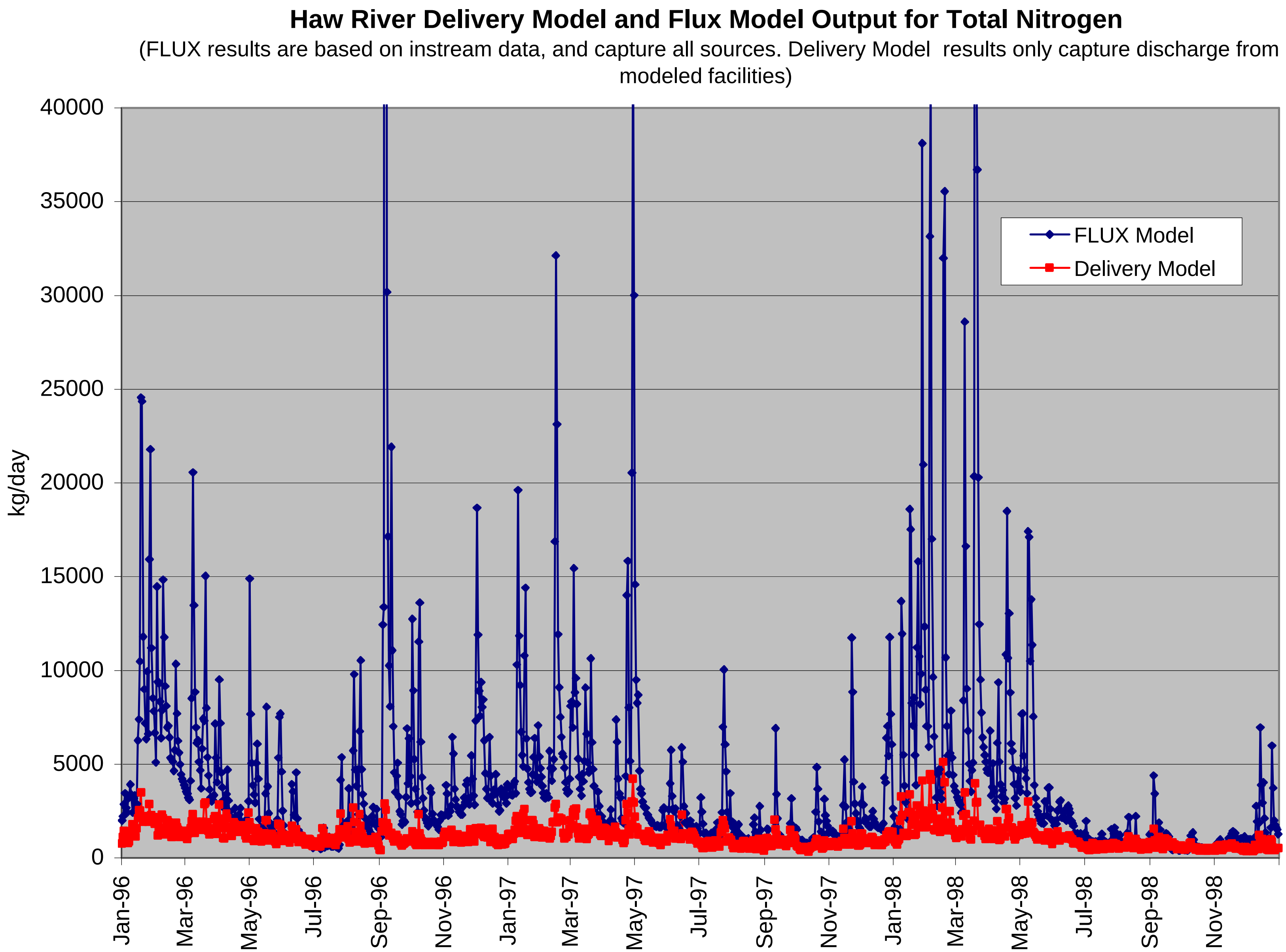


New Hope Creek Delivery Model and Flux Model Output for Total Nitrogen
(FLUX results are based on instream data, and capture all sources. Delivery Model results only capture discharge from modeled facilities)
kg/day
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
FLUX Model
Delivery Model
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98

New Hope Creek Delivery Model and Flux Model Output for Total Phosphorus

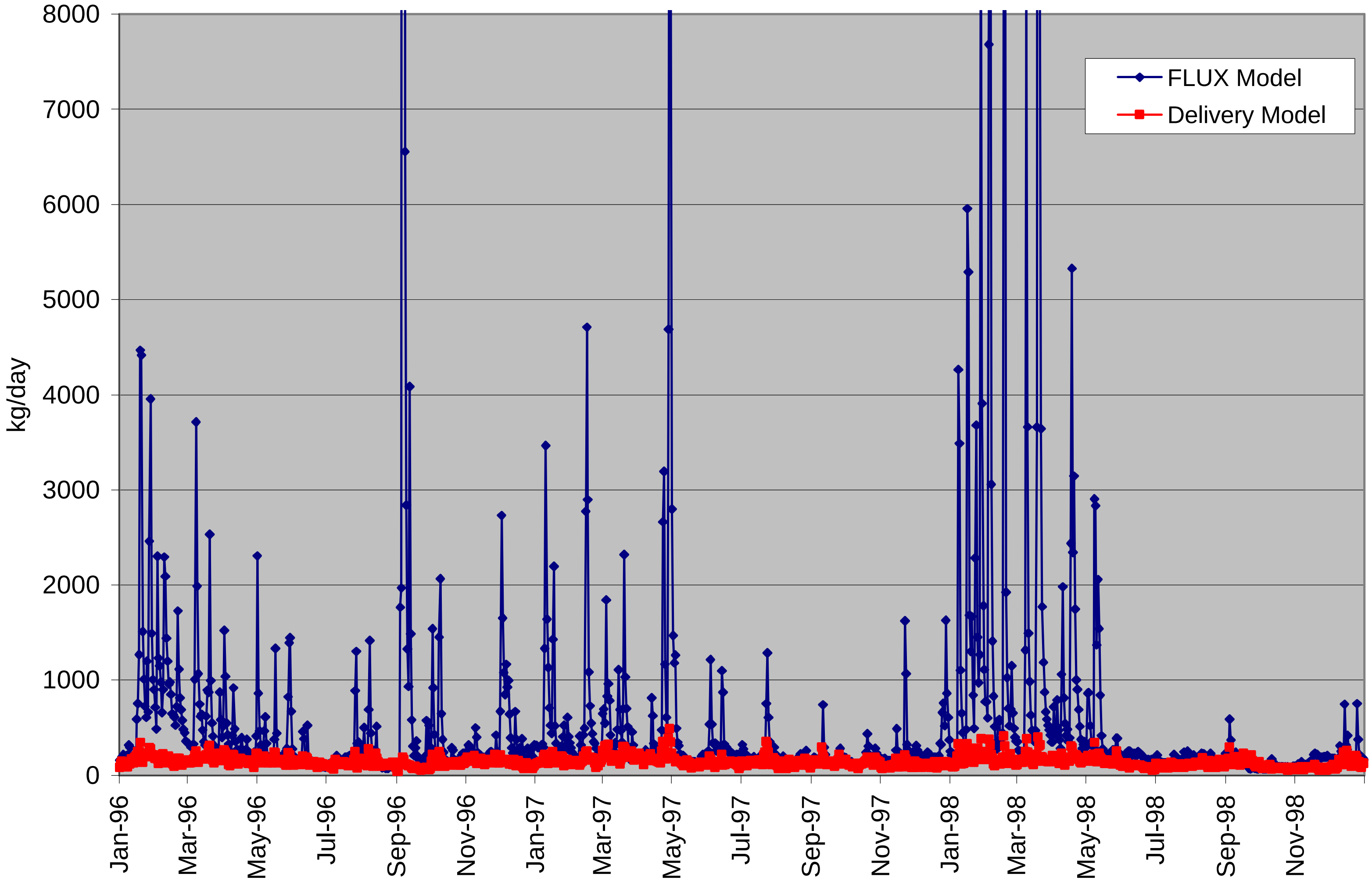
(FLUX results are based on instream data, and capture all sources. Delivery Model results only capture discharge from modeled facilities)




Haw River Delivery Model and Flux Model Output for Total Nitrogen
(FLUX results are based on instream data, and capture all sources. Delivery Model results only capture discharge from modeled facilities)
kg/day
0
5000
10000
15000
20000
25000
30000
35000
40000
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
FLUX Model
Delivery Model

Haw RiverDelivery Model and Flux Model Output for Total Phosphorus

(FLUX results are based on instream data, and capture all sources. Delivery Model results only capture discharge from modeled facilities)



Attachment B

Delivery Ratios By Facility

Percent Delivery From Project Partner Facilities to Jordan Lake
Total Nitrogen

1996

Major Tributary	Facility Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Haw River Watershed	Burlington East	79%	76%	76%	73%	71%	62%	57%	66%	75%	68%	73%	79%
	Burlington South	82%	80%	79%	77%	75%	68%	63%	71%	80%	72%	77%	82%
	Graham	82%	80%	79%	78%	76%	68%	67%	72%	78%	72%	77%	82%
	Greensboro North	50%	44%	45%	41%	41%	29%	28%	35%	46%	33%	34%	45%
	Greensboro South	51%	44%	45%	43%	40%	34%	30%	37%	48%	41%	37%	48%
	Mebane	64%	62%	60%	57%	54%	46%	40%	44%	54%	46%	60%	56%
	Pittsboro	86%	86%	85%	83%	82%	78%	71%	73%	74%	75%	87%	80%
	Reidsville	54%	52%	51%	48%	47%	34%	36%	44%	56%	43%	45%	54%
New Hope Creek Watershed	Durham Triangle	98%	97%	97%	97%	97%	96%	97%	96%	97%	97%	95%	99%
	Durham WRF	96%	95%	95%	95%	95%	94%	94%	93%	96%	95%	92%	96%
	OWASA	94%	93%	93%	93%	93%	91%	92%	91%	94%	93%	89%	95%

1997

Major Tributary	Facility Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Haw River Watershed	Burlington East	76%	78%	78%	76%	68%	67%	62%	58%	57%	55%	59%	64%
	Burlington South	80%	82%	81%	80%	72%	71%	66%	62%	62%	60%	65%	69%
	Graham	79%	82%	81%	80%	72%	72%	67%	68%	61%	60%	64%	68%
	Greensboro North	42%	45%	46%	48%	37%	38%	32%	26%	27%	24%	27%	31%
	Greensboro South	45%	47%	47%	46%	37%	37%	34%	30%	28%	30%	32%	35%
	Mebane	59%	59%	54%	53%	49%	44%	37%	38%	38%	37%	45%	48%
	Pittsboro	83%	82%	75%	75%	76%	67%	64%	68%	70%	70%	76%	79%
	Reidsville	50%	53%	54%	54%	41%	42%	43%	34%	40%	35%	37%	39%
New Hope Creek Watershed	Durham Triangle	96%	97%	97%	97%	97%	96%	96%	95%	95%	95%	96%	96%
	Durham WRF	94%	94%	95%	95%	95%	94%	94%	92%	92%	92%	94%	94%
	OWASA	92%	92%	93%	93%	93%	92%	91%	89%	89%	89%	92%	92%

1998

Major Tributary	Facility Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Haw River Watershed	Burlington East	82%	83%	80%	78%	73%	62%	52%	53%	56%	48%	48%	58%
	Burlington South	86%	87%	83%	81%	77%	67%	58%	58%	60%	53%	53%	64%
	Graham	85%	87%	84%	81%	76%	69%	58%	71%	72%	59%	52%	63%
	Greensboro North	56%	59%	47%	45%	42%	30%	24%	23%	23%	18%	18%	29%
	Greensboro South	59%	56%	50%	48%	45%	32%	24%	28%	26%	23%	20%	29%
	Mebane	68%	70%	69%	63%	56%	47%	35%	39%	41%	32%	37%	43%
	Pittsboro	88%	88%	88%	86%	83%	75%	67%	63%	66%	60%	65%	75%
	Reidsville	60%	65%	56%	54%	46%	35%	27%	26%	29%	24%	38%	33%
New Hope Creek Watershed	Durham Triangle	98%	98%	98%	97%	96%	96%	96%	96%	96%	96%	95%	96%
	Durham WRF	97%	97%	97%	95%	94%	93%	93%	92%	93%	93%	92%	93%
	OWASA	96%	96%	95%	93%	92%	91%	91%	90%	91%	90%	90%	91%

Total Phosphorus

1996

Major Tributary	Facility Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Haw River Watershed	Burlington East	83%	82%	81%	79%	77%	70%	67%	74%	81%	75%	79%	85%
	Burlington South	86%	84%	84%	82%	81%	75%	73%	77%	84%	79%	83%	87%
	Graham	86%	84%	83%	81%	80%	74%	69%	76%	82%	78%	82%	86%
	Greensboro North	59%	55%	54%	52%	49%	42%	42%	46%	55%	43%	45%	55%
	Greensboro South	61%	54%	55%	53%	50%	42%	38%	47%	58%	52%	47%	60%
	Mebane	71%	70%	69%	66%	63%	56%	49%	54%	63%	57%	68%	65%
	Pittsboro	90%	90%	89%	88%	87%	84%	78%	80%	80%	81%	90%	86%
	Reidsville	63%	60%	59%	56%	57%	47%	44%	59%	63%	53%	50%	63%
New Hope Creek Watershed	Durham Triangle	98%	98%	98%	98%	98%	97%	97%	97%	98%	98%	97%	100%
	Durham WRF	97%	96%	96%	96%	96%	95%	96%	95%	97%	96%	94%	98%
	OWASA	95%	95%	95%	95%	94%	94%	94%	93%	95%	96%	92%	96%

1997

Major Tributary	Facility Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Haw River Watershed	Burlington East	82%	83%	82%	81%	75%	74%	71%	67%	66%	64%	68%	72%
	Burlington South	84%	86%	86%	85%	80%	79%	76%	74%	71%	70%	73%	76%
	Graham	83%	85%	85%	84%	78%	76%	73%	70%	69%	68%	71%	75%
	Greensboro North	53%	55%	56%	57%	47%	47%	42%	37%	37%	34%	38%	40%
	Greensboro South	53%	57%	56%	55%	48%	49%	45%	39%	39%	39%	42%	45%
	Mebane	67%	68%	63%	62%	58%	53%	48%	49%	49%	50%	55%	59%
	Pittsboro	87%	86%	81%	81%	82%	75%	72%	76%	78%	77%	82%	84%
	Reidsville	59%	62%	65%	62%	52%	48%	47%	44%	45%	47%	46%	53%
New Hope Creek Watershed	Durham Triangle	97%	97%	98%	98%	98%	97%	97%	96%	96%	96%	97%	97%
	Durham WRF	95%	96%	96%	96%	96%	96%	95%	94%	94%	94%	95%	95%
	OWASA	94%	94%	95%	95%	94%	94%	94%	92%	92%	92%	94%	94%

1998

Major Tributary	Facility Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Haw River Watershed	Burlington East	86%	87%	85%	83%	79%	72%	63%	64%	64%	70%	63%	69%
	Burlington South	88%	89%	87%	85%	83%	76%	72%	68%	69%	62%	63%	73%
	Graham	88%	89%	87%	84%	81%	73%	65%	66%	69%	61%	61%	70%
	Greensboro North	64%	64%	57%	55%	53%	41%	34%	34%	34%	29%	29%	37%
	Greensboro South	66%	66%	58%	58%	54%	42%	34%	35%	38%	33%	31%	41%
	Mebane	75%	76%	76%	70%	64%	55%	45%	45%	47%	41%	42%	53%
	Pittsboro	91%	91%	91%	90%	87%	81%	75%	72%	74%	69%	74%	81%
	Reidsville	68%	72%	65%	63%	57%	45%	40%	39%	41%	33%	33%	44%
New Hope Creek Watershed	Durham Triangle	99%	99%	99%	98%	97%	97%	97%	97%	97%	97%	97%	97%
	Durham WRF	98%	98%	98%	96%	96%	95%	94%	95%	95%	95%	94%	95%
	OWASA	97%	97%	98%	95%	93%	92%	93%	93%	93%	93%	93%	93%

Percent Delivery From Project Partner Facilities to Jordan Lake

Average 1996-1998

Total Nitrogen

Major Tributary	Facility Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Haw River Watershed	Burlington East	79%	79%	78%	76%	70%	64%	57%	59%	63%	57%	60%	67%	67%
	Burlington South	82%	83%	81%	79%	74%	69%	62%	64%	67%	62%	65%	72%	72%
	Graham	82%	83%	81%	80%	75%	70%	64%	70%	70%	63%	64%	71%	73%
	Greensboro North	49%	49%	46%	45%	40%	33%	28%	28%	32%	25%	27%	35%	36%
	Greensboro South	52%	49%	47%	46%	41%	35%	29%	32%	34%	31%	29%	37%	39%
	Mebane	64%	63%	61%	58%	53%	46%	37%	40%	44%	39%	47%	49%	50%
	Pittsboro	86%	86%	83%	81%	80%	73%	67%	68%	70%	68%	76%	78%	76%
	Reidsville	55%	56%	54%	52%	45%	37%	35%	34%	42%	34%	40%	42%	44%
New Hope Creek Watershed	Durham Triangle	97%	97%	97%	97%	97%	96%	96%	96%	96%	96%	96%	97%	96%
	Durham WRF	95%	95%	95%	95%	95%	94%	94%	92%	93%	93%	93%	95%	94%
	OWASA	94%	93%	94%	93%	93%	91%	91%	90%	91%	91%	90%	92%	92%

Total Phosphorus

Major Tributary	Facility Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Haw River Watershed	Burlington East	83%	84%	83%	81%	77%	72%	67%	68%	70%	69%	70%	75%	75%
	Burlington South	86%	87%	85%	84%	81%	77%	74%	73%	75%	70%	73%	79%	79%
	Graham	86%	86%	85%	83%	79%	74%	69%	71%	73%	69%	71%	77%	77%
	Greensboro North	59%	58%	56%	55%	50%	43%	39%	39%	42%	35%	37%	44%	46%
	Greensboro South	60%	59%	57%	55%	51%	44%	39%	40%	45%	41%	40%	49%	48%
	Mebane	71%	71%	69%	66%	62%	54%	48%	49%	53%	49%	55%	59%	59%
	Pittsboro	89%	89%	87%	86%	85%	80%	75%	76%	77%	76%	82%	84%	82%
	Reidsville	64%	65%	63%	60%	55%	47%	44%	47%	50%	44%	43%	53%	53%
New Hope Creek Watershed	Durham Triangle	98%	98%	98%	98%	98%	97%	97%	97%	97%	97%	97%	98%	97%
	Durham WRF	97%	97%	97%	96%	96%	95%	95%	95%	95%	95%	95%	96%	96%
	OWASA	95%	95%	96%	95%	94%	93%	93%	93%	94%	94%	93%	94%	94%

Appendix B
Generic Optimization Shell (OPTSHELL) Software

Generic Optimization Shell (OPTSHELL) Software

Keith W. Little, PhD, PE

RTI International
Research Triangle Park, NC

Introduction

OPTSHELL is a proprietary computer program developed by RTI International that allows optimization and other capability to be quickly added to virtually any computer simulation model. Simulation models provide only "what-if" capability -- they transform user-specified inputs into simulated outputs. It is often desirable to go beyond "what-if" scenarios to ask not only "what-if," but "what is best, or *optimal.*" Optimal simulations, when attempted at all, are typically determined by iterative, trial-and-error use of the simulation model by the analyst. In many cases, this manual, trial-and-error interaction between the analyst and the model works well and for some tasks (such as sensitivity analysis) is in fact desirable. Often, however, the manual process suffers from excessive time requirements on the part of the analyst, as well as a major shortcoming that arises from the inability of the analyst, by limited trial-and-error, to actually achieve optimality.

OPTSHELL is designed to overcome these difficulties and is intended to be used, not as a surrogate for the analyst's judgment, but rather to facilitate that judgment. In short, OPTSHELL is a *decision support tool* for modelers and decision-makers. In contrast to classical (calculus-based) optimization methods requiring strict adherence to underlying, often restrictive, mathematical assumptions, OPTSHELL is based on robust, *search* methods that are free from these assumptions. The flexibility permitted by search methods allows OPTSHELL to accommodate all types of optimization problem -- linear or nonlinear, constrained or unconstrained. This flexibility also permits OPTSHELL to be a stand-alone, generic program, that is, independent of the simulation model's source code.

Limitations of Classical Methods

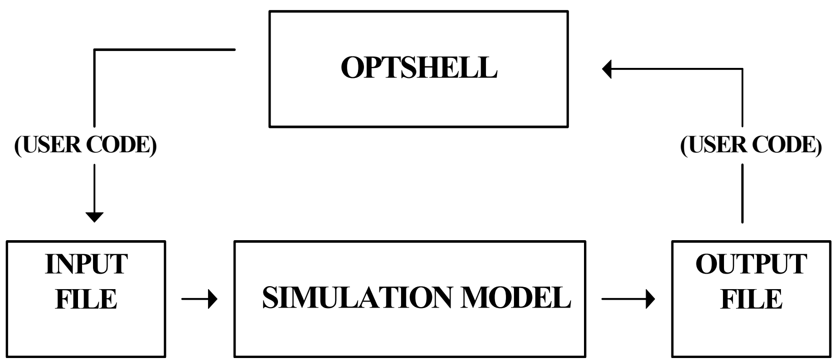
Classical optimization methods work well when their underlying mathematical assumptions, such as continuous and everywhere-differentiable functions, are satisfied. In the real world, however, functions are seldom as nicely behaved as these assumptions dictate, and even numerical approximation of derivatives can be problematic. Moreover, these methods in general are not generic -- each optimization problem must be carefully studied by a specialist, which generally results in an application-specific algorithm and customized computer program. This process is expensive and time-consuming. Finally, at the most practical level, the integral coupling of an optimization algorithm with a simulation model requires a substantial programming effort to merge and compile the two source codes. In many cases, particularly with commercial software, the source code is simply not available. Because of these impracticalities, optimization is seldom added to simulation models.

OPTSHELL Advantages

OPTSHELL was designed to avoid these difficulties, and it does so in two ways:

Search-Based Method. OPTSHELL's optimization methods are *search* methods. The advantage of search methods is that the *only* information needed by these algorithms can be obtained from the simulation model outputs -- classical method restrictions such as continuity and existence of first and second derivatives are irrelevant. Is this a "free lunch"? No. Assuming that the technical expertise, time, and budget are available, it is nearly always possible to develop application-specific optimization methods that are more computationally efficient than so-called "generic" algorithms. However, the several optimization options provided by OPTSHELL allow considerable flexibility in addressing different problems. In addition, the rapidly increasing speed and rapidly decreasing cost of today's computers greatly diminish the importance of computational efficiency, except for problems (weather forecasting for example) that must be solved in near-real time.

Stand-Alone, Generic Software. The significant fact that search methods need only access to the simulation model outputs leads directly to the second advantage of OPTSHELL -- independence from the simulation model's source code. OPTSHELL is a stand-alone, essentially generic program that is coupled to a simulation model *only* through the simulation model input and output files (see figure). The simulation model's source code does not have to be available, or even understood. After OPTSHELL is coupled to the simulation model input and output files, OPTSHELL then takes control of running the simulation model.



OPTSHELL has been designed to be as generic as possible with minimal application-specific coupling requirements. It cannot be completely generic, of course, and the user must write some OPTSHELL code to extract decision variable values from OPTSHELL and insert these values into the simulation model's input file. Similarly, code must be written to extract output data from the application output file and pass these data to OPTSHELL. OPTSHELL is written in the BASIC programming language, and BASIC's powerful string-handling capabilities make this input and output file manipulation extremely easy. Typically, only a few lines of application-specific code are needed to couple OPTSHELL to the user's simulation model. In addition to the code needed to couple the application, the user must modify those OPTSHELL subroutines that define the application-specific objective function and constraints. Again, this is quite easy to do and typically requires only a few lines of BASIC code.

Optimization Options

OPTSHELL includes four, search-based optimization options: (1) Random Search, (2) Grid Search, (3) Box's Algorithm, and (4) Genetic Algorithm. These options are briefly discussed below.

Random Search. This is a simple enumerative technique that is useful for problems with relatively few parameters or where only a general idea of the shape of the optimization response surface is needed. The method is also useful for fine-tuning a previously identified solution, i.e. exploring a relatively narrow range around a candidate optimal solution. The user specifies the number of simulations to be used in the search, upper and lower limits on the decision parameters, and upper and lower limits on any constraints that are functions of the parameters. OPTSHELL then randomly generates values for these parameters from a uniform distribution within the feasible limits, executes the simulation model for each set of parameters, records the objective function value for each set, and finds that set resulting in the best objective function value after the total number of specified simulations has been performed. Any solutions violating the constraint functions are excluded.

Grid Search. This option is also a simple enumerative search, but the user now specifies for each parameter a search increment between its upper and lower limits. OPTSHELL then executes the simulation model and records the objective function value for each combination of parameters representing the grid and, after all points on the grid have been evaluated, finds that set of parameters that results in the best objective function value, while not violating any constraints. (For example, for two decision parameters with ten increments each, the number of simulations is 10^2, or 100.)

Box's Algorithm. Unlike the Random Search and Grid Search options that are essentially "brute force" methods, the Box's Algorithm option (and the following Genetic Algorithm) provides true optimization functionality. Box's Algorithm (Box, 1965), which has been modified for OPTSHELL to improve performance, starts with a user-provided feasible solution and randomly generates several other initial feasible solutions so that the set of these solutions defines the vertices of a polygon within the optimization problem's feasible region. This polygon is then moved within the feasible region in a patterned search until user-specified stopping criteria are satisfied. The algorithm then terminates and that vertex (solution) associated with the best objective function value is reported. The time required for convergence is related to the simulation model's run time as well as the size of the feasible region (the set of all feasible solutions within which the optimal solution lies). The more narrowly defined the feasible region, the faster the convergence. (A good strategy for large problems is to first use OPTSHELL's grid search option to refine the upper and lower limits on the parameters within which the optimal solution may lie before running the Box's Algorithm option.)

Genetic Algorithm. Genetic algorithms were developed originally by John Holland at the University of Michigan (Holland, 1975). These methods have been the subject of intense research and development in recent years and are finding widespread, practical application to optimization and optimal control problems in many fields. Genetic algorithms are based on mathematical analogies to the principles of biological evolution, hence the name of "genetic" (not to be confused with "generic") algorithms. These methods are also often termed "evolutionary" algorithms. Such natural evolutionary processes as: survival of the fittest, mating, and chromosome crossover and mutation are mimicked by genetic algorithms to optimize mathematical functions. Genetic algorithms are robust and extremely powerful. They are particularly useful for optimization problems in which the "global optimum" is difficult to find due to the presence of a large number of "local optima", i.e., highly multimodal response surfaces.

Other Options

OPTSHELL was developed primarily to add generic optimization functionality to simulation models, by iterating with the simulation model via only input and output files, as described above. However, this architecture also makes possible several other desirable model decision support features, which have been included in OPTSHELL. These other options are Model Calibration, Sensitivity Analysis, and Uncertainty Analysis, but are not described here.

OPTSHELL Applications

Development of OPTSHELL to refine its capabilities and enhance ease-of-use is continuing. Currently, OPTSHELL is available in DOS's QUICKBASIC programming language. A Windows version using Microsoft's VISUAL BASIC is planned. OPTSHELL applications to date include:

- Coupling to Boyle Engineering Corporation's BESTSM river basin model (FORTRAN) for the San Diego raw water supply system. This application optimizes system parameters (rule curves and pumping rates) to minimize long-term costs of imported water.
- Coupling to the US EPA's surface water quality model, WASP (FORTRAN), to facilitate optimal calibration of Eutro-WASP to Jordan Lake Reservoir, NC. Simultaneous estimation of up to 21 parameters was performed.
- Coupling to a hydraulic simulation and cost estimation model (BASIC) to determine the minimum cost design for a raw water pipeline/reservoir system under risk constraints. The risk constraints were alternative probabilities of failing to meet downstream water demands. Decision variables were the pipeline diameter and reservoir volume. OPTSHELL was used to trace out the minimum pipeline/reservoir cost and design as a function of risk.
- Coupling to the US EPA's surface water quality model, QUAL2E (FORTRAN), to facilitate least-squares model calibration.
- Coupling to the US EPA's hydrologic and water quality model, HSPF9 (FORTRAN), to facilitate least-squares model calibration.
- Coupling to a storm water routing and detention basin model (BASIC) for Fountain Creek, CO to determine minimum cost detention basin locations and sizes to meet flood control constraints.

References

Box, M.J., "A New Method of Constrained Optimization and a Comparison with Other Methods," The Computer Journal, Vol. 8, pp. 42-52, 1965.

Holland, J.H., "Adaptation in Natural and Artificial Systems." Ann Arbor: The University of Michigan Press, 1975 .

Appendix C
Sample WASP/EUTRO Input File

```
EUTRO
 JORDAN LAKE 97-00 based on jorrev.  Rev4 adj 2-14
 NSEG NSYS ICFL MFLG JMAS NSLN INTY ADFC    DD HHMM MODEL OPTIONS
   41    8    0    0    3    0    0  0.0    0. 0.0.    0.00
    1    3    4   15   14   25
    8
    .03125      180.    .03125      410.    .03125      450.    .03125      520.
    .03125      690.   .015625      731.    .03125      841.    .03125     1460.
    1
       1.0    1460.                        run 1460 only as 2000 hyd file had 365 d
    0    0    0    0    0    0    0    0
    2          DATA GROUP B: EXCHANGE COEFFICIENTS
    5  0.20D-01        1.
    3
    805.00   3450.00    2    1
   3029.00   2980.00    4    2
   1188.00   3230.00    3    4
    2
       5.0    0.0000       5.0 1461.0000
    8
    324.00   2340.00    5    4
     68.00   2340.00   16    4
    324.00   2400.00    9    8
    312.00   2400.00   20   19
    180.00   3440.00   12   11
    113.00   3440.00   23   22
    180.00   2795.00    8    7
    204.00   2795.00   19   18
    2
      10.0    0.0000      10.0 1461.0000
   10
   1132.00   3180.00    6    5
   3397.00   3180.00   17   16
   2198.00   2660.00    8    6
   6594.00   2660.00   19   17
   2739.00   2580.00   12    9
   8218.00   2580.00   23   20
    848.00   2940.00   10   12
   2545.00   2940.00   21   23
   1458.00   2620.00   13   12
   4375.00   2620.00   24   23
    2
       0.1    0.0000       0.1 1461.0000
    6
   2261.00   2460.00   14   13
   6784.00   2460.00   25   24
   1720.00   4905.00   15   14
   1720.00   4905.00   15   25
      1.00   1000.00   15   13
      1.00   1000.00   15   24
    2
      3.31    0.0000      3.31 1461.0000
   10
2363953.00      2.90    5   16
4435316.00      2.90    6   17
1989902.00      2.90    7   18
2704982.00      2.90    8   19
3128214.00      2.90    9   20
 365051.00      2.90   10   21
3479557.00      2.90   11   22
8487744.00      2.90   12   23
2453471.00      2.90   13   24
3589474.00      2.90   14   25
    2
0.32D-02  0.0000      0.32D-02   1461.00
    1  0.19D+02        1.
   15
 2426609.0       1.0    1   26
 3426040.0       1.0    2   27
 2660280.0       1.0    3   28
 4882959.0       1.0    4   29
```

```
 2362953.0       1.0   16   31
 4435316.0       1.0   17   32
 1989902.0       1.0   18   33
 2704982.0       1.0   19   34
 3128214.0       1.0   20   35
  365051.0       1.0   21   36
 3479557.0       1.0   22   37
 8487744.0       1.0   23   38
 2453471.0       1.0   24   39
 3589474.0       1.0   25   40
 2498592.0       1.0   15   30
    2
 0.231E-08    0.0000 0.231E-08  1461.0000
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    2    0  366.0000          DATA GROUP C: VOLUMES
    1.0000    1.0000
         1         26        1 .24409E+07       1.0       0.0       1.0       0.0
         2         27        1 .89892E+07       1.0       0.0       1.0       0.0
         3         28        1 .26903E+07       1.0       0.0       1.0       0.0
         4         29        1 .16923E+08       1.0       0.0       1.0       0.0
         5         16        1 .75280E+07       1.0       0.0       1.0       0.0
         6         17        1 .82004E+07       1.0       0.0       1.0       0.0
         7         18        1 .37984E+07       1.0       0.0       1.0       0.0
         8         19        1 .55560E+07       1.0       0.0       1.0       0.0
         9         20        1 .66200E+07       1.0       0.0       1.0       0.0
        10         21        1 .24869E+07       1.0       0.0       1.0       0.0
        11         22        1 .10750E+08       1.0       0.0       1.0       0.0
        12         23        1 .22199E+08       1.0       0.0       1.0       0.0
        13         24        1 .65473E+07       1.0       0.0       1.0       0.0
        14         25        1 .99260E+07       1.0       0.0       1.0       0.0
        15         30        1 .13269E+08       1.0       0.0       1.0       0.0
        16         31        2 .57901E+07       1.0       0.0       1.0       0.0
        17         32        2 .13532E+08       1.0       0.0       1.0       0.0
        18         33        2 .54898E+07       1.0       0.0       1.0       0.0
        19         34        2 .12002E+08       1.0       0.0       1.0       0.0
        20         35        2 .12739E+08       1.0       0.0       1.0       0.0
        21         36        2 .70606E+06       1.0       0.0       1.0       0.0
        22         37        2 .52520E+07       1.0       0.0       1.0       0.0
        23         38        2 .46141E+08       1.0       0.0       1.0       0.0
        24         39        2 .12616E+08       1.0       0.0       1.0       0.0
        25         40        2 .28030E+08       1.0       0.0       1.0       0.0
        26         41        3 .15604E+07       1.0       0.0       1.0       0.0
        27         41        3 .11627E+07       1.0       0.0       1.0       0.0
        28         41        3 .97844E+06       1.0       0.0       1.0       0.0
        29         41        3 .70467E+06       1.0       0.0       1.0       0.0
        30         41        3 .40000E+06       1.0       0.0       1.0       0.0
        31         41        3 .54301E+06       1.0       0.0       1.0       0.0
        32         41        3 .62213E+06       1.0       0.0       1.0       0.0
        33         41        3 .60303E+06       1.0       0.0       1.0       0.0
        34         41        3 .34048E+06       1.0       0.0       1.0       0.0
        35         41        3 .35241E+06       1.0       0.0       1.0       0.0
        36         41        3 .29670E+06       1.0       0.0       1.0       0.0
        37         41        3 .75885E+06       1.0       0.0       1.0       0.0
        38         41        3 .96823E+06       1.0       0.0       1.0       0.0
        39         41        3 .57812E+06       1.0       0.0       1.0       0.0
        40         41        3 .59202E+06       1.0       0.0       1.0       0.0
        41          0        4 .10461E+08       1.0       0.0       1.0       0.0
    3    51997-00.hyd     Data Group D: Flows
    1 0.000E+00     1.000    Data Block D.2 Pore Water Flows               in m3/s
   15
      0.10   26    1      0.10  27     2      0.10   28    3      0.10   29    4
      0.10   30   15      0.10  31    16      0.10   32   17      0.10   33   18
      0.10   34   19      0.10  35    20      0.10   36   21      0.10   37   22
      0.10   38   23      0.10  39    24      0.10   40   25
    2
0.15D+01       0.0    0.15D+01    1461.0
    5 1.000E+00 1.157E-05    Data Block D.3 Sed. #1 Transport Field
    9
0.2427E+07    1   260.3426E+07    2   270.2660E+07    3   280.1990E+07    7   18
0.3651E+06   10   210.3480E+07   11   220.1990E+07   18   330.3651E+06   21   36
0.3480E+07   22   37
```

```
    2
0.34D+00       0.0    0.34D+00    1461.0
    1
0.4883E+07    4   29
    2
0.30D+00       0.0    0.30D+00    1461.0
   10
0.2364E+07    5   160.4435E+07    6   170.2705E+07    8   190.3128E+07    9   20
0.8488E+07   12   230.2364E+07   16   310.4435E+07   17   320.2705E+07   19   34
0.3128E+07   20   350.8488E+07   23   38
    2
0.73D+00       0.0    0.73D+00    1461.0
    5
0.2453E+07   13   240.3589E+07   14   250.2499E+07   15   300.2453E+07   24   39
0.3589E+07   25   40
    2
     1.00       0.0       1.00    1461.0
   15
0.2427E+07   26   410.3426E+07   27   410.2660E+07   28   410.1990E+07   33   41
0.3651E+06   36   410.4883E+07   29   410.2364E+07   31   410.4435E+07   32   41
0.2705E+07   34   410.3128E+07   35   410.8488E+07   38   410.2499E+07   30   41
0.2453E+07   39   410.3589E+07   40   410.3480E+07   37   41
    2
0.001          0.0    0.001       1461.0
    4 1.000E+00 1.157E-05    Data Block D.4 Sed. #2 Transport Field
    9
0.2427E+07    1   260.3426E+07    2   270.2660E+07    3   280.1990E+07    7   18
0.3651E+06   10   210.3480E+07   11   220.1990E+07   18   330.3651E+06   21   36
0.3480E+07   22   37
    2
0.64D-01       0.0    0.64D-01    1461.0
    1
0.4883E+07    4   29
    2
0.75D-01       0.0    0.75D-01    1461.0
   10
0.2364E+07    5   160.4435E+07    6   170.2705E+07    8   190.3128E+07    9   20
0.8488E+07   12   230.2364E+07   16   310.4435E+07   17   320.2705E+07   19   34
0.3128E+07   20   350.8488E+07   23   38
    2
0.60D-01       0.0    0.70D-01    1461.0
    5
0.2453E+07   13   240.3589E+07   14   250.2499E+07   15   300.2453E+07   24   39
0.3589E+07   25   40
    2
  0.07D+00       0.0  0.07D+00    1461.0
    4 1.000E+00 1.157E-05    Data Block D.5 Sed. #3 Transport Field
   10
0.2427E+07    1   260.3426E+07    2   270.2660E+07    3   280.1990E+07    7   18
0.3651E+06   10   210.3480E+07   11   220.1990E+07   18   330.3651E+06   21   36
0.3480E+07   22   370.4883E+07    4   29
    2
0.41D+01       0.0    0.41D+01    1461.0
   10
0.2364E+07    5   160.4435E+07    6   170.2705E+07    8   190.3128E+07    9   20
0.8488E+07   12   230.2364E+07   16   310.4435E+07   17   320.2705E+07   19   34
0.3128E+07   20   350.8488E+07   23   38
    2
0.20D+01       0.0    0.20D+01    1461.0
    5
0.2453E+07   13   240.3589E+07   14   250.2499E+07   15   300.2453E+07   24   39
0.3589E+07   25   40
    2
      5.0       0.0       5.0    1461.0
   15
0.2427E+07   26   410.3426E+07   27   410.2660E+07   28   410.1990E+07   33   41
0.3651E+06   36   410.4883E+07   29   410.2364E+07   31   410.4435E+07   32   41
0.2705E+07   34   410.3128E+07   35   410.8488E+07   38   410.2499E+07   30   41
0.2453E+07   39   410.3589E+07   40   410.3480E+07   37   41
    2
     .002       0.0      .002    1461.0
```

```
  0    0    0    0    0    0    0    0
      17 *** Data Group E, System:  1
      1.        1.
 15    2
      0.        0.        0.     1461.
  3    2
      0.        0.        0.     1461.
  1    2
      0.        0.        0.     1461.
  2    2
      0.        0.        0.     1461.
 14    2
      0.        0.        0.     1461.
 11    2
      0.        0.        0.     1461.
  7    2
      0.        0.        0.     1461.
  4    2
      0.        0.        0.     1461.
  5    2
      0.        0.        0.     1461.
 10    2
      0.        0.        0.     1461.
  8    2
      0.        0.        0.     1461.
 25    2
      0.        0.        0.     1461.
 22    2
      0.        0.        0.     1461.
 18    2
      0.        0.        0.     1461.
 16    2
      0.        0.        0.     1461.
 21    2
      0.        0.        0.     1461.
 19    2
      0.        0.        0.     1461.
      17 *** Data Group E, System:  2
      1.        1.
 15    2
      0.        0.        0.     1461.
  3    2
      0.        0.        0.     1461.
  1    2
      0.        0.        0.     1461.
  2    2
      0.        0.        0.     1461.
 14    2
      0.        0.        0.     1461.
 11    2
      0.        0.        0.     1461.
  7    2
      0.        0.        0.     1461.
  4    2
      0.        0.        0.     1461.
  5    2
      0.        0.        0.     1461.
 10    2
      0.        0.        0.     1461.
  8    2
      0.        0.        0.     1461.
 25    2
      0.        0.        0.     1461.
 22    2
      0.        0.        0.     1461.
 18    2
      0.        0.        0.     1461.
 16    2
      0.        0.        0.     1461.
 21    2
      0.        0.        0.     1461.
```

```
  19    2
       0.        0.        0.     1461.
      17 *** Data Group E, System:  3
       1.        1.
  15    2
       0.        0.        0.     1461.
   3    2
       0.        0.        0.     1461.
   1    2
       0.        0.        0.     1461.
   2    2
       0.        0.        0.     1461.
  14    2
       0.        0.        0.     1461.
  11    2
       0.        0.        0.     1461.
   7    2
       0.        0.        0.     1461.
   4    2
       0.        0.        0.     1461.
   5    2
       0.        0.        0.     1461.
  10    2
       0.        0.        0.     1461.
   8    2
       0.        0.        0.     1461.
  25    2
       0.        0.        0.     1461.
  22    2
       0.        0.        0.     1461.
  18    2
       0.        0.        0.     1461.
  16    2
       0.        0.        0.     1461.
  21    2
       0.        0.        0.     1461.
  19    2
       0.        0.        0.     1461.
      17 *** Data Group E, System:  4
       1.        1.
  15    2
      15.        0.       10.     1461.
   3    2
       3.        0.        3.     1461.
   1    2
       3.        0.        3.     1461.
   2    2
       3.        0.        3.     1461.
  14    2
       3.        0.        3.     1461.
  11    2
       3.        0.        3.     1461.
   7    2
       3.        0.        3.     1461.
   4    2
       3.        0.        3.     1461.
   5    2
       3.        0.        3.     1461.
  10    2
       3.        0.        3.     1461.
   8    2
       3.        0.        3.     1461.
  25    2
       3.        0.        3.     1461.
  22    2
       3.        0.        3.     1461.
  18    2
       3.        0.        3.     1461.
  16    2
       3.        0.        3.     1461.
  21    2
```

```
      3.        0.        3.     1461.
 19   2
      3.        0.        3.     1461.
      17 *** Data Group E, System:  5
      1.        1.
 15   2
      0.        0.        0.     1461.
  3   2
      0.        0.        0.     1461.
  1   2
      0.        0.        0.     1461.
  2   2
      0.        0.        0.     1461.
 14   2
      0.        0.        0.     1461.
 11   2
      0.        0.        0.     1461.
  7   2
      0.        0.        0.     1461.
  4   2
      0.        0.        0.     1461.
  5   2
      0.        0.        0.     1461.
 10   2
      0.        0.        0.     1461.
  8   2
      0.        0.        0.     1461.
 25   2
      0.        0.        0.     1461.
 22   2
      0.        0.        0.     1461.
 18   2
      0.        0.        0.     1461.
 16   2
      0.        0.        0.     1461.
 21   2
      0.        0.        0.     1461.
 19   2
      0.        0.        0.     1461.
      17 *** Data Group E, System:  6
      1.        1.
 15   2
      0.        0.        0.     1461.
  3   2
      0.        0.        0.     1461.
  1   2
      0.        0.        0.     1461.
  2   2
      0.        0.        0.     1461.
 14   2
      0.        0.        0.     1461.
 11   2
      0.        0.        0.     1461.
  7   2
      0.        0.        0.     1461.
  4   2
      0.        0.        0.     1461.
  5   2
      0.        0.        0.     1461.
 10   2
      0.        0.        0.     1461.
  8   2
      0.        0.        0.     1461.
 25   2
      0.        0.        0.     1461.
 22   2
      0.        0.        0.     1461.
 18   2
      0.        0.        0.     1461.
 16   2
      0.        0.        0.     1461.
```

```
 21    2
      0.         0.         0.     1461.
 19    2
      0.         0.         0.     1461.
      17 *** Data Group E, System:  7
      1.         1.
 15    2
      0.         0.         0.     1461.
  3    2
      0.         0.         0.     1461.
  1    2
      0.         0.         0.     1461.
  2    2
      0.         0.         0.     1461.
 14    2
      0.         0.         0.     1461.
 11    2
      0.         0.         0.     1461.
  7    2
      0.         0.         0.     1461.
  4    2
      0.         0.         0.     1461.
  5    2
      0.         0.         0.     1461.
 10    2
      0.         0.         0.     1461.
  8    2
      0.         0.         0.     1461.
 25    2
      0.         0.         0.     1461.
 22    2
      0.         0.         0.     1461.
 18    2
      0.         0.         0.     1461.
 16    2
      0.         0.         0.     1461.
 21    2
      0.         0.         0.     1461.
 19    2
      0.         0.         0.     1461.
      17 *** Data Group E, System:  8
      1.         1.
 15    2
      0.         0.         0.     1461.
  3    2
      0.         0.         0.     1461.
  1    2
      0.         0.         0.     1461.
  2    2
      0.         0.         0.     1461.
 14    2
      0.         0.         0.     1461.
 11    2
      0.         0.         0.     1461.
  7    2
      0.         0.         0.     1461.
  4    2
      0.         0.         0.     1461.
  5    2
      0.         0.         0.     1461.
 10    2
      0.         0.         0.     1461.
  8    2
      0.         0.         0.     1461.
 25    2
      0.         0.         0.     1461.
 22    2
      0.         0.         0.     1461.
 18    2
      0.         0.         0.     1461.
 16    2
```

```
       0.        0.        0.     1461.
   21    2
       0.        0.        0.     1461.
   19    2
       0.        0.        0.     1461.
        0         *    +    *    +    *    (NH3)  *    +    *    F: LOADS
        0                                  (NO3)
        0                                  (PO4)
        0                                  (PHYT)
        0                                  (CBOD)
        0                                  (DO)
        0                                  (ON)
        0                                  (OP)
        1          scen1.nps                                          (NPS LOADS)
       10    +    *    +    *    +    *    +    *    +    *    G: PARAMETERS
TMPSG    3       1.0TMPFN    4       1.0  SAL    2       0.0SOD1D    9       1.0
scale factors
SODTA   12       1.0 KESG    5  8.00D-01 KEFN    6       1.0 FNH4    7      50.0
TOTLM   13       1.0 FPO4    8       6.9DUMMY    0       0.0DUMMY    0       0.0
        1
segments
TMPSG    3      1.10TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.5
SODTA   12     1.028 KESG    5     1.000 KEFN    6       4.0 FNH4    7       1.1
TOTLM   13       0.9 FPO4    8       1.0
        2
TMPSG    3      1.10TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.5
SODTA   12     1.028 KESG    5     1.000 KEFN    6       4.0 FNH4    7       1.1
TOTLM   13       0.9 FPO4    8       1.0
        3
TMPSG    3      1.05TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.5
SODTA   12     1.028 KESG    5     1.000 KEFN    6       4.0 FNH4    7       1.0
TOTLM   13       0.8 FPO4    8       1.0
        4
TMPSG    3       1.0TMPFN    4       2.0  SAL    2       0.0SOD1D    9       3.5
SODTA   12     1.028 KESG    5     1.000 KEFN    6       4.0 FNH4    7       1.1
TOTLM   13       1.0 FPO4    8       1.0
        5
TMPSG    3       1.0TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       0.7
TOTLM   13       1.0 FPO4    8       0.0
        6
TMPSG    3       1.0TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       0.5
TOTLM   13       1.0 FPO4    8       0.0
        7
TMPSG    3       1.0TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       0.2
TOTLM   13       1.0 FPO4    8       0.0
        8
TMPSG    3       1.0TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       0.2
TOTLM   13       1.0 FPO4    8       0.0
        9
TMPSG    3       1.0TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.2
TOTLM   13       1.0 FPO4    8       0.0
       10
TMPSG    3       1.0TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
       11
TMPSG    3       1.0TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
       12
TMPSG    3       1.0TMPFN    4       2.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.500 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13       0.9 FPO4    8       0.0
       13
TMPSG    3       1.0TMPFN    4       1.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.500 KEFN    6       1.0 FNH4    7       0.0
```

```
TOTLM   13      0.8 FPO4    8       0.0
        14
TMPSG    3      1.0TMPFN    4       1.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12    1.028 KESG    5     1.500 KEFN    6       1.0 FNH4    7       0.0
TOTLM   13      0.8 FPO4    8       0.0
        15
TMPSG    3      1.0TMPFN    4       1.0  SAL    2       0.0SOD1D    9       2.5
SODTA   12    1.028 KESG    5     2.000 KEFN    6       1.0 FNH4    7       0.0
TOTLM   13      0.6 FPO4    8       0.0
        16
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       3.5
SODTA   12    1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       1.0
TOTLM   13      1.0 FPO4    8       1.2
        17
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       3.5
SODTA   12    1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       1.0
TOTLM   13      1.0 FPO4    8       1.2
        18
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       3.5
SODTA   12    1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       1.0
TOTLM   13      1.0 FPO4    8       1.2
        19
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       3.5
SODTA   12    1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       1.0
TOTLM   13      1.0 FPO4    8       1.2
        20
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       2.5
SODTA   12    1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.5
TOTLM   13      1.0 FPO4    8       1.2
        21
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       2.5
SODTA   12    1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.1
TOTLM   13      1.0 FPO4    8       1.0
        22
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       2.5
SODTA   12    1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.1
TOTLM   13      1.0 FPO4    8       1.0
        23
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       2.5
SODTA   12    1.028 KESG    5     1.500 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13      0.9 FPO4    8       1.0
        24
TMPSG    3      1.0TMPFN    4       3.0  SAL    2       0.0SOD1D    9       2.5
SODTA   12    1.028 KESG    5     1.500 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13      0.9 FPO4    8       0.0
        25
TMPSG    3      1.0TMPFN    4       3.0  SAL    2       0.0SOD1D    9       2.5
SODTA   12    1.028 KESG    5     1.500 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13      0.8 FPO4    8       0.0
        26                                 start sediment segments
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12    1.028 KESG    5     1.000 KEFN    6       4.0 FNH4    7       0.0
TOTLM   13      1.0 FPO4    8       0.0
        27
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12    1.028 KESG    5     1.000 KEFN    6       4.0 FNH4    7       0.0
TOTLM   13      1.0 FPO4    8       0.0
        28
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12    1.028 KESG    5     1.000 KEFN    6       4.0 FNH4    7       0.0
TOTLM   13      1.0 FPO4    8       0.0
        29
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12    1.028 KESG    5     1.000 KEFN    6       4.0 FNH4    7       0.0
TOTLM   13      1.0 FPO4    8       0.0
        30
TMPSG    3      1.0TMPFN    4       3.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12    1.028 KESG    5     1.000 KEFN    6       1.0 FNH4    7       0.0
TOTLM   13      1.0 FPO4    8       0.0
        31
TMPSG    3      1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
```

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SODTA   12     1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
        32
TMPSG    3       1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
        33
TMPSG    3       1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
        34
TMPSG    3       1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       3.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
        35
TMPSG    3       1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
        36
TMPSG    3       1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
        37
TMPSG    3       1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
        38
TMPSG    3       1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
        39
TMPSG    3       1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
        40
TMPSG    3       1.0TMPFN    4       4.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       2.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
        41
TMPSG    3       1.0TMPFN    4       3.0  SAL    2       0.0SOD1D    9       0.0
SODTA   12     1.028 KESG    5     1.000 KEFN    6       4.0 FNH4    7       0.0
TOTLM   13       1.0 FPO4    8       0.0
    +    *    +    *    +    *    +    *    +    *    +    *    H: CONSTANTS
   GLOBALS         0         *         *         *         *
       NH3         1         *         *         *         *
  nitrific         3
      k12C        11 1.200D-01      k12t        12      1.08
      knit        13       2.0
       NO3         1         *         *         *         *
  denitrif         3
      k20c        21      0.09      k20t        22     1.045
      kno3        23       0.0
       PO4         0         *         *         *         *
      PHYT         1         *         *         *         *
      chla        19
       k1c        41 3.870D+00       k1t        42      1.08
     lghts        43        1.      cchl        46       42.
       is1        47 5.680D+02     kmng1        48 1.300D-01
     kmpg1        49 6.470D-04      k1rc        50 2.260D-01
      k1rt        51     1.045       k1d        52 1.320D-02
       k1g        53        0.    nutlim        54        0.
     kpzdc        55      0.02     kpzdt        56      1.08
      pcrb        57     0.025      ncrb        58      0.25
     kmphy        59  0.00D+00     phimx        44     720.0
       xkc        45     0.017
       BOD         1         *         *         *         *
 deoxygent         5
       kdc        71      0.16       kdt        72     1.047
      kdsc        73    0.0004      kdst        74      1.08
      kbod        75       0.5
        DO         1
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  oxygent        1
     ocrb       81    2.6667
       ON        1
  onrates        5
     k71c       91 1.500D-01      k71t        92      1.08
    kondc       93 1.000D-03     kondt        94      1.08
      fon       95  0.95D+00
       OP        1
  oprates        5
     k83c      100 1.800D-01     kopdc       102 1.000D-03
    kopdt      103      1.08       fop       104 9.500D-01
     k83t      101      1.06
       13        *************************************I: Kinetic Time Functions
TEMP1 1461    1
      5.0       1.       5.3        2.       5.4        3.       6.1        4.
      6.7       5.       7.5        6.       7.9        7.       7.6        8.
      7.1       9.       6.9       10.       6.7       11.       6.1       12.
      5.7      13.       5.2       14.       4.8       15.       4.7       16.
      3.7      17.       3.2       18.       3.0       19.       2.3       20.
      2.5      21.       2.8       22.       3.3       23.       3.7       24.
      3.8      25.       3.8       26.       3.9       27.       4.7       28.
      5.1      29.       4.9       30.       4.9       31.       5.1       32.
      5.4      33.       5.4       34.       5.2       35.       5.6       36.
      6.1      37.       6.2       38.       6.3       39.       6.3       40.
      6.3      41.       6.4       42.       6.2       43.       6.1       44.
      5.9      45.       5.8       46.       5.7       47.       5.5       48.
      5.4      49.       5.3       50.       6.3       51.       6.5       52.
      7.2      53.       8.5       54.       8.6       55.       8.3       56.
      8.2      57.       8.4       58.       9.2       59.       9.9       60.
     11.2      61.      11.1       62.      11.6       63.      11.5       64.
     11.6      65.      11.3       66.      11.3       67.      11.0       68.
     11.0      69.      11.9       70.      11.8       71.      11.1       72.
     10.8      73.      11.6       74.      11.2       75.      11.0       76.
     11.1      77.      10.9       78.      11.1       79.      10.8       80.
     11.1      81.      11.5       82.      11.3       83.      11.2       84.
     11.7      85.      11.7       86.      12.0       87.      12.7       88.
     13.3      89.      14.1       90.      13.9       91.      13.8       92.
     13.7      93.      13.7       94.      13.9       95.      14.6       96.
     15.0      97.      15.6       98.      15.5       99.      14.9      100.
     14.0     101.      13.8      102.      14.4      103.      14.0      104.
     13.6     105.      13.8      106.      14.2      107.      14.6      108.
     14.0     109.      13.9      110.      13.7      111.      13.9      112.
     13.4     113.      12.8      114.      12.4      115.      12.4      116.
     12.5     117.      12.8      118.      12.4      119.      11.8      120.
     13.2     121.      14.0      122.      14.4      123.      15.1      124.
     15.0     125.      15.1      126.      15.7      127.      16.4      128.
     16.9     129.      19.1      130.      18.5      131.      18.2      132.
     18.5     133.      18.6      134.      18.3      135.      19.8      136.
     19.6     137.      19.4      138.      20.4      139.      20.7      140.
     21.9     141.      22.0      142.      22.1      143.      22.4      144.
     21.2     145.      22.1      146.      21.3      147.      20.6      148.
     20.4     149.      21.8      150.      21.8      151.      21.8      152.
     22.8     153.      22.9      154.      21.6      155.      20.0      156.
     19.2     157.      19.6      158.      19.0      159.      18.4      160.
     18.7     161.      19.2      162.      20.4      163.      20.5      164.
     21.3     165.      21.0      166.      21.4      167.      21.8      168.
     22.0     169.      23.1      170.      24.1      171.      24.6      172.
     25.5     173.      26.3      174.      27.1      175.      27.5      176.
     28.2     177.      27.4      178.      27.1      179.      25.5      180.
     26.1     181.      26.4      182.      26.5      183.      26.4      184.
     26.7     185.      27.2      186.      27.9      187.      28.2      188.
     27.6     189.      27.3      190.      27.7      191.      27.7      192.
     27.7     193.      27.9      194.      28.2      195.      28.3      196.
     28.7     197.      29.0      198.      28.8      199.      29.0      200.
     29.4     201.      29.3      202.      29.1      203.      28.9      204.
     28.0     205.      27.2      206.      26.9      207.      27.2      208.
     27.8     209.      28.6      210.      28.7      211.      27.4      212.
     26.3     213.      26.6      214.      27.0      215.      27.5      216.
     27.8     217.      27.6      218.      26.8      219.      27.1      220.
     26.8     221.      26.8      222.      26.9      223.      26.8      224.
     27.6     225.      27.5      226.      27.8      227.      28.0      228.
```

28.8	229.	28.8	230.	29.0	231.	28.5	232.
28.5	233.	27.5	234.	27.4	235.	27.0	236.
26.6	237.	26.2	238.	26.2	239.	26.5	240.
26.8	241.	26.7	242.	26.8	243.	26.9	244.
27.1	245.	27.3	246.	27.3	247.	26.3	248.
26.0	249.	25.9	250.	25.8	251.	26.0	252.
25.8	253.	25.6	254.	24.6	255.	24.2	256.
24.4	257.	24.7	258.	24.7	259.	24.5	260.
24.5	261.	25.1	262.	25.4	263.	25.5	264.
24.6	265.	24.5	266.	24.0	267.	23.8	268.
22.9	269.	22.3	270.	22.0	271.	21.9	272.
21.4	273.	21.9	274.	21.6	275.	21.2	276.
21.1	277.	21.2	278.	21.5	279.	21.9	280.
22.2	281.	22.4	282.	22.7	283.	22.5	284.
22.5	285.	22.1	286.	22.3	287.	22.5	288.
21.6	289.	20.6	290.	19.9	291.	19.1	292.
18.3	293.	17.1	294.	17.0	295.	16.7	296.
16.1	297.	16.3	298.	16.2	299.	16.7	300.
16.0	301.	15.2	302.	14.8	303.	14.8	304.
15.3	305.	15.3	306.	15.0	307.	14.9	308.
14.5	309.	14.3	310.	14.3	311.	14.0	312.
13.8	313.	13.5	314.	13.2	315.	13.2	316.
12.9	317.	12.6	318.	12.2	319.	12.0	320.
11.6	321.	11.0	322.	10.7	323.	10.5	324.
10.3	325.	10.5	326.	10.4	327.	10.2	328.
9.8	329.	9.6	330.	9.4	331.	9.2	332.
9.1	333.	9.3	334.	10.0	335.	9.7	336.
9.4	337.	9.4	338.	9.8	339.	9.5	340.
9.0	341.	8.6	342.	8.4	343.	8.3	344.
8.1	345.	7.9	346.	7.8	347.	7.6	348.
7.3	349.	7.1	350.	7.0	351.	6.9	352.
7.2	353.	7.3	354.	7.1	355.	6.9	356.
7.2	357.	7.0	358.	7.2	359.	7.1	360.
7.3	361.	7.2	362.	6.8	363.	6.7	364.
6.4	365.	5.0	366.	5.2	367.	5.3	368.
6.0	369.	6.4	370.	6.4	371.	7.0	372.
7.5	373.	9.5	374.	9.7	375.	9.5	376.
9.6	377.	9.6	378.	9.7	379.	9.3	380.
8.9	381.	8.1	382.	7.5	383.	7.2	384.
6.7	385.	6.7	386.	6.8	387.	6.7	388.
6.6	389.	6.1	390.	6.2	391.	6.3	392.
5.8	393.	5.3	394.	6.1	395.	6.5	396.
6.7	397.	7.2	398.	7.2	399.	7.1	400.
6.8	401.	6.0	402.	5.7	403.	5.0	404.
5.4	405.	6.1	406.	6.4	407.	6.2	408.
7.2	409.	7.5	410.	7.5	411.	7.2	412.
7.2	413.	7.9	414.	8.2	415.	9.0	416.
9.7	417.	10.0	418.	10.0	419.	9.7	420.
9.7	421.	10.6	422.	11.0	423.	11.0	424.
11.1	425.	11.6	426.	12.3	427.	11.9	428.
11.3	429.	10.7	430.	10.4	431.	10.3	432.
10.3	433.	10.7	434.	10.5	435.	10.5	436.
10.6	437.	10.6	438.	11.2	439.	11.3	440.
10.7	441.	10.3	442.	8.9	443.	8.4	444.
9.0	445.	8.5	446.	9.1	447.	9.6	448.
10.3	449.	11.1	450.	11.8	451.	12.5	452.
13.2	453.	14.9	454.	16.0	455.	16.2	456.
17.0	457.	17.7	458.	17.7	459.	17.1	460.
17.3	461.	17.7	462.	17.5	463.	17.9	464.
17.5	465.	16.9	466.	17.1	467.	17.6	468.
18.0	469.	16.7	470.	18.0	471.	17.3	472.
16.2	473.	16.1	474.	15.8	475.	15.7	476.
16.7	477.	16.9	478.	17.1	479.	17.9	480.
18.7	481.	18.7	482.	18.5	483.	18.8	484.
18.8	485.	18.7	486.	19.0	487.	18.8	488.
18.0	489.	18.2	490.	19.1	491.	19.6	492.
19.5	493.	19.6	494.	20.3	495.	20.5	496.
19.9	497.	19.2	498.	19.3	499.	20.2	500.
21.3	501.	22.1	502.	22.8	503.	23.5	504.
23.9	505.	24.3	506.	24.2	507.	24.1	508.
23.4	509.	23.0	510.	23.8	511.	24.6	512.

24.9	513.	24.6	514.	24.5	515.	24.7	516.
24.9	517.	25.7	518.	26.0	519.	26.6	520.
26.2	521.	25.5	522.	23.9	523.	23.9	524.
23.7	525.	23.2	526.	23.0	527.	24.0	528.
25.0	529.	25.7	530.	24.8	531.	24.8	532.
25.6	533.	26.3	534.	27.3	535.	27.2	536.
27.8	537.	28.1	538.	28.5	539.	28.9	540.
28.8	541.	29.0	542.	29.3	543.	29.6	544.
29.7	545.	29.8	546.	29.4	547.	29.4	548.
29.5	549.	29.3	550.	29.3	551.	28.2	552.
28.9	553.	29.3	554.	28.8	555.	28.8	556.
28.9	557.	28.7	558.	28.3	559.	28.2	560.
28.5	561.	28.7	562.	28.7	563.	28.6	564.
28.9	565.	28.8	566.	28.8	567.	29.2	568.
29.6	569.	29.6	570.	29.9	571.	29.1	572.
28.9	573.	28.2	574.	28.7	575.	29.2	576.
28.9	577.	28.1	578.	28.1	579.	27.8	580.
27.7	581.	27.9	582.	27.9	583.	28.1	584.
27.9	585.	28.2	586.	28.1	587.	27.2	588.
27.5	589.	27.8	590.	27.8	591.	28.2	592.
28.3	593.	27.9	594.	27.7	595.	27.9	596.
28.0	597.	28.0	598.	27.9	599.	28.1	600.
28.1	601.	28.1	602.	28.1	603.	28.1	604.
27.6	605.	28.4	606.	28.5	607.	28.8	608.
28.5	609.	28.4	610.	28.2	611.	27.1	612.
26.6	613.	26.7	614.	27.4	615.	27.2	616.
26.2	617.	25.7	618.	25.7	619.	25.7	620.
26.0	621.	26.5	622.	26.9	623.	27.0	624.
27.0	625.	26.9	626.	26.7	627.	26.8	628.
26.8	629.	26.4	630.	26.2	631.	26.0	632.
25.6	633.	25.5	634.	25.8	635.	25.9	636.
25.9	637.	25.6	638.	25.3	639.	25.2	640.
24.9	641.	24.5	642.	23.9	643.	23.4	644.
23.0	645.	22.9	646.	22.4	647.	22.2	648.
22.3	649.	22.1	650.	22.0	651.	21.8	652.
21.6	653.	21.3	654.	21.1	655.	21.0	656.
21.0	657.	20.7	658.	20.8	659.	20.0	660.
19.6	661.	19.1	662.	18.9	663.	19.0	664.
19.0	665.	19.0	666.	18.9	667.	19.2	668.
19.0	669.	19.0	670.	18.7	671.	18.2	672.
17.6	673.	17.0	674.	16.4	675.	15.9	676.
15.3	677.	14.7	678.	14.4	679.	14.8	680.
14.5	681.	14.4	682.	14.2	683.	13.9	684.
14.2	685.	14.1	686.	14.2	687.	14.2	688.
13.9	689.	14.1	690.	13.8	691.	13.6	692.
13.8	693.	13.6	694.	13.7	695.	14.0	696.
13.8	697.	14.2	698.	14.7	699.	14.4	700.
14.5	701.	14.7	702.	14.6	703.	15.0	704.
15.1	705.	15.4	706.	15.7	707.	15.4	708.
15.3	709.	15.0	710.	14.4	711.	13.8	712.
13.3	713.	12.9	714.	12.1	715.	12.0	716.
11.1	717.	10.6	718.	10.3	719.	10.4	720.
10.8	721.	10.4	722.	9.6	723.	9.2	724.
9.0	725.	8.6	726.	8.2	727.	7.9	728.
7.7	729.	7.6	730.	5.0	731.	5.1	732.
4.8	733.	5.1	734.	5.0	735.	4.8	736.
4.7	737.	5.0	738.	4.8	739.	4.9	740.
4.9	741.	5.1	742.	5.5	743.	5.9	744.
6.6	745.	6.9	746.	6.2	747.	6.3	748.
6.7	749.	7.2	750.	8.0	751.	8.3	752.
7.4	753.	9.4	754.	9.2	755.	9.4	756.
9.7	757.	9.9	758.	9.9	759.	10.0	760.
10.0	761.	9.7	762.	9.5	763.	9.7	764.
10.0	765.	10.3	766.	10.5	767.	10.8	768.
10.7	769.	10.9	770.	10.8	771.	11.0	772.
11.0	773.	10.8	774.	10.6	775.	10.5	776.
10.6	777.	10.9	778.	10.5	779.	10.3	780.
10.3	781.	10.6	782.	10.5	783.	10.4	784.
9.8	785.	9.8	786.	9.4	787.	9.7	788.
9.8	789.	9.9	790.	10.1	791.	9.8	792.
9.8	793.	9.9	794.	10.3	795.	10.6	796.

10.8	797.	10.5	798.	10.0	799.	9.8	800.
10.4	801.	10.6	802.	10.1	803.	9.6	804.
9.4	805.	10.2	806.	10.9	807.	11.7	808.
12.0	809.	12.2	810.	12.5	811.	12.4	812.
12.2	813.	13.0	814.	12.7	815.	13.0	816.
13.4	817.	13.9	818.	14.3	819.	14.4	820.
14.0	821.	14.2	822.	14.9	823.	16.2	824.
15.9	825.	16.6	826.	16.4	827.	17.8	828.
18.5	829.	18.4	830.	19.2	831.	19.4	832.
19.3	833.	19.1	834.	18.9	835.	19.0	836.
19.6	837.	18.9	838.	18.2	839.	18.4	840.
18.2	841.	19.3	842.	19.7	843.	19.9	844.
19.9	845.	20.4	846.	19.4	847.	19.8	848.
19.2	849.	18.1	850.	16.8	851.	16.6	852.
16.9	853.	17.7	854.	19.0	855.	19.0	856.
18.7	857.	19.4	858.	20.3	859.	21.0	860.
21.7	861.	22.3	862.	22.6	863.	22.2	864.
21.1	865.	20.6	866.	20.6	867.	20.4	868.
21.1	869.	21.2	870.	22.1	871.	22.0	872.
22.0	873.	22.6	874.	22.6	875.	22.6	876.
22.0	877.	22.7	878.	23.4	879.	24.3	880.
24.5	881.	23.9	882.	23.4	883.	24.1	884.
24.7	885.	25.2	886.	26.1	887.	26.8	888.
27.2	889.	27.7	890.	27.6	891.	28.5	892.
26.9	893.	27.2	894.	26.9	895.	26.8	896.
25.6	897.	24.8	898.	24.3	899.	24.1	900.
24.0	901.	23.5	902.	23.0	903.	22.6	904.
23.6	905.	23.7	906.	23.8	907.	23.9	908.
23.3	909.	23.4	910.	23.9	911.	23.3	912.
23.4	913.	24.5	914.	25.6	915.	26.7	916.
28.1	917.	28.5	918.	28.3	919.	28.6	920.
28.5	921.	28.2	922.	26.2	923.	25.3	924.
24.3	925.	23.7	926.	24.2	927.	24.8	928.
25.7	929.	26.1	930.	26.9	931.	27.8	932.
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29.5	937.	29.7	938.	29.8	939.	30.2	940.
29.8	941.	29.9	942.	30.7	943.	31.4	944.
31.1	945.	30.4	946.	30.7	947.	30.3	948.
30.3	949.	30.4	950.	30.4	951.	28.9	952.
29.0	953.	29.4	954.	29.3	955.	29.0	956.
28.3	957.	28.2	958.	28.6	959.	28.8	960.
29.2	961.	29.1	962.	28.0	963.	28.3	964.
27.8	965.	27.0	966.	26.8	967.	26.9	968.
27.1	969.	27.1	970.	27.3	971.	27.3	972.
27.1	973.	26.5	974.	25.9	975.	25.9	976.
26.1	977.	25.4	978.	22.2	979.	22.5	980.
22.4	981.	22.6	982.	23.3	983.	23.8	984.
24.4	985.	24.5	986.	24.2	987.	23.6	988.
22.8	989.	21.2	990.	20.7	991.	21.2	992.
21.6	993.	22.0	994.	22.0	995.	21.9	996.
22.0	997.	22.0	998.	22.2	999.	22.2	1000.
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20.8	1005.	21.0	1006.	21.3	1007.	21.2	1008.
21.2	1009.	21.1	1010.	21.0	1011.	20.9	1012.
20.9	1013.	20.6	1014.	20.4	1015.	20.5	1016.
19.9	1017.	19.8	1018.	19.5	1019.	19.5	1020.
19.4	1021.	19.2	1022.	18.7	1023.	18.2	1024.
17.7	1025.	17.4	1026.	17.1	1027.	16.5	1028.
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16.6	1033.	16.8	1034.	17.0	1035.	17.3	1036.
17.0	1037.	16.2	1038.	15.7	1039.	15.8	1040.
15.6	1041.	15.8	1042.	15.7	1043.	15.7	1044.
15.4	1045.	15.3	1046.	15.4	1047.	15.7	1048.
15.8	1049.	15.6	1050.	15.1	1051.	14.6	1052.
14.3	1053.	14.3	1054.	14.3	1055.	14.4	1056.
14.8	1057.	15.1	1058.	14.9	1059.	14.8	1060.
14.9	1061.	14.7	1062.	14.3	1063.	14.0	1064.
13.7	1065.	13.3	1066.	13.0	1067.	12.8	1068.
12.9	1069.	12.8	1070.	12.4	1071.	12.2	1072.
12.0	1073.	12.1	1074.	11.9	1075.	11.6	1076.
11.3	1077.	11.6	1078.	11.7	1079.	11.5	1080.

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9.0	1089.	8.7	1090.	8.6	1091.	8.4	1092.
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6.0	1097.	5.9	1098.	7.0	1099.	7.2	1100.
7.4	1101.	7.3	1102.	7.4	1103.	7.3	1104.
7.2	1105.	7.2	1106.	7.7	1107.	7.9	1108.
8.1	1109.	7.8	1110.	7.5	1111.	7.6	1112.
7.4	1113.	6.9	1114.	6.8	1115.	6.6	1116.
6.5	1117.	6.1	1118.	5.7	1119.	5.4	1120.
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2.4	1125.	1.4	1126.	1.3	1127.	1.4	1128.
1.4	1129.	1.7	1130.	2.0	1131.	2.1	1132.
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6.1	1141.	6.8	1142.	6.8	1143.	7.1	1144.
7.0	1145.	7.4	1146.	7.6	1147.	7.7	1148.
7.9	1149.	8.5	1150.	8.7	1151.	8.9	1152.
9.1	1153.	9.7	1154.	11.0	1155.	11.4	1156.
11.4	1157.	11.9	1158.	11.2	1159.	11.4	1160.
11.7	1161.	12.2	1162.	13.2	1163.	13.3	1164.
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14.4	1169.	14.2	1170.	13.6	1171.	14.1	1172.
13.5	1173.	12.4	1174.	11.5	1175.	11.7	1176.
11.9	1177.	12.2	1178.	12.8	1179.	13.6	1180.
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13.7	1185.	13.9	1186.	14.5	1187.	14.0	1188.
14.0	1189.	14.5	1190.	15.4	1191.	15.4	1192.
15.3	1193.	15.6	1194.	16.4	1195.	16.4	1196.
15.9	1197.	15.9	1198.	15.6	1199.	15.4	1200.
15.5	1201.	16.3	1202.	16.9	1203.	16.9	1204.
16.7	1205.	16.5	1206.	16.6	1207.	16.4	1208.
16.9	1209.	16.8	1210.	16.6	1211.	16.5	1212.
16.3	1213.	15.6	1214.	15.9	1215.	16.3	1216.
17.1	1217.	16.1	1218.	17.0	1219.	18.1	1220.
19.0	1221.	19.3	1222.	19.8	1223.	20.2	1224.
19.6	1225.	19.5	1226.	20.7	1227.	21.6	1228.
22.1	1229.	22.9	1230.	23.5	1231.	23.5	1232.
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23.5	1249.	24.4	1250.	25.3	1251.	25.5	1252.
26.1	1253.	26.0	1254.	25.3	1255.	24.6	1256.
24.3	1257.	23.6	1258.	24.5	1259.	24.6	1260.
25.5	1261.	24.8	1262.	24.0	1263.	24.0	1264.
25.3	1265.	25.4	1266.	25.5	1267.	24.7	1268.
24.2	1269.	25.3	1270.	26.0	1271.	25.6	1272.
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25.3	1281.	26.6	1282.	26.8	1283.	27.1	1284.
27.4	1285.	27.7	1286.	27.4	1287.	26.7	1288.
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26.0	1293.	26.3	1294.	26.6	1295.	27.0	1296.
27.0	1297.	27.3	1298.	27.3	1299.	27.0	1300.
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26.1	1305.	26.0	1306.	26.3	1307.	27.3	1308.
27.5	1309.	27.6	1310.	27.6	1311.	27.2	1312.
27.2	1313.	27.4	1314.	27.1	1315.	27.5	1316.
27.5	1317.	28.2	1318.	28.4	1319.	28.4	1320.
27.8	1321.	26.6	1322.	26.2	1323.	26.5	1324.
26.5	1325.	26.6	1326.	26.9	1327.	26.0	1328.
25.8	1329.	25.7	1330.	25.4	1331.	25.2	1332.
24.9	1333.	25.1	1334.	25.4	1335.	25.3	1336.
24.7	1337.	24.0	1338.	24.2	1339.	24.7	1340.
25.7	1341.	25.4	1342.	24.4	1343.	23.4	1344.
22.7	1345.	22.4	1346.	22.7	1347.	22.6	1348.
23.2	1349.	23.7	1350.	24.4	1351.	24.9	1352.
24.4	1353.	23.6	1354.	23.1	1355.	22.6	1356.
21.6	1357.	21.8	1358.	22.1	1359.	21.9	1360.
22.4	1361.	23.0	1362.	23.2	1363.	23.5	1364.

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      19.7     1369.      20.0     1370.      20.4     1371.      20.2     1372.
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      19.7     1381.      19.0     1382.      19.2     1383.      19.1     1384.
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      17.7     1389.      17.7     1390.      17.7     1391.      17.5     1392.
      17.1     1393.      16.8     1394.      16.4     1395.      16.3     1396.
      16.4     1397.      16.2     1398.      16.4     1399.      16.6     1400.
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      15.2     1409.      15.3     1410.      15.0     1411.      15.4     1412.
      15.3     1413.      15.2     1414.      15.3     1415.      14.7     1416.
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      13.7     1421.      14.0     1422.      14.7     1423.      14.6     1424.
      14.4     1425.      14.6     1426.      15.0     1427.      14.6     1428.
      14.0     1429.      13.7     1430.      13.0     1431.      12.7     1432.
      12.1     1433.      11.8     1434.      11.6     1435.      11.7     1436.
      11.9     1437.      11.5     1438.      11.2     1439.      11.0     1440.
      11.5     1441.      11.1     1442.      10.8     1443.      10.8     1444.
      10.9     1445.      11.1     1446.      11.1     1447.      10.9     1448.
      10.6     1449.      10.1     1450.       9.8     1451.       9.6     1452.
       9.3     1453.       9.0     1454.       8.8     1455.       8.5     1456.
       8.3     1457.       8.2     1458.       8.2     1459.       8.2     1460.
       8.2     1461.
TEMP2 1461    2
       5.0        1.       5.3        2.       5.5        3.       6.8        4.
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       4.9       17.       4.1       18.       2.6       19.       2.1       20.
       1.8       21.       2.5       22.       2.4       23.       3.1       24.
       3.4       25.       3.5       26.       3.4       27.       3.7       28.
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       5.1       33.       4.9       34.       4.7       35.       5.4       36.
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       8.8       57.       8.7       58.      10.6       59.      11.9       60.
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14.1	293.	13.8	294.	15.0	295.	15.2	296.
14.0	297.	15.2	298.	16.2	299.	16.6	300.
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9.6	333.	10.5	334.	11.0	335.	9.8	336.
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7.6	385.	7.6	386.	6.9	387.	6.3	388.
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6.5	401.	6.3	402.	6.1	403.	5.8	404.
5.8	405.	6.2	406.	6.4	407.	6.4	408.
7.6	409.	7.6	410.	6.9	411.	6.6	412.
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11.8	437.	11.4	438.	12.2	439.	11.2	440.
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15.5	453.	17.3	454.	18.8	455.	19.9	456.
20.8	457.	22.0	458.	20.6	459.	19.0	460.
19.3	461.	19.6	462.	19.4	463.	20.4	464.

20.8	465.	19.4	466.	19.5	467.	19.6	468.
19.2	469.	18.4	470.	19.2	471.	19.8	472.
19.9	473.	19.1	474.	18.8	475.	18.9	476.
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19.3	481.	21.2	482.	19.8	483.	20.3	484.
20.7	485.	20.2	486.	20.2	487.	20.4	488.
20.7	489.	20.9	490.	21.9	491.	22.6	492.
21.8	493.	22.9	494.	22.7	495.	21.7	496.
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13.2	689.	13.5	690.	13.2	691.	12.9	692.
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16.5	705.	17.3	706.	18.0	707.	17.6	708.
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4.7	733.	5.0	734.	4.9	735.	4.6	736.
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23.5	901.	22.2	902.	21.9	903.	21.6	904.
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25.5	977.	24.7	978.	22.9	979.	22.9	980.
25.3	981.	25.7	982.	25.9	983.	26.3	984.
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       8.4     1453.       7.9     1454.       7.5     1455.       7.0     1456.
       6.7     1457.       6.5     1458.       6.8     1459.       6.8     1460.
       6.8     1461.
TEMP3 1461   3
       5.0        1.       5.0        2.       5.2        3.       5.5        4.
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       5.9        9.       6.4       10.       6.1       11.       5.0       12.
       4.8       13.       4.8       14.       4.6       15.       4.6       16.
       3.8       17.       3.5       18.       3.6       19.       3.2       20.
       3.5       21.       3.6       22.       3.7       23.       3.8       24.
       3.8       25.       3.8       26.       3.9       27.       4.4       28.
       4.5       29.       4.8       30.       4.8       31.       4.9       32.
       5.0       33.       4.9       34.       4.9       35.       4.9       36.
       5.2       37.       5.2       38.       5.4       39.       5.7       40.
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       5.3       49.       5.3       50.       5.6       51.       5.9       52.
       6.8       53.       6.8       54.       6.8       55.       6.6       56.
       6.4       57.       6.8       58.       6.7       59.       7.1       60.
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      10.2       77.       9.7       78.       9.7       79.       9.6       80.
       9.7       81.       9.8       82.       9.9       83.      10.1       84.
      10.5       85.      10.6       86.      10.7       87.      10.5       88.
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      11.7       93.      11.7       94.      11.7       95.      11.6       96.
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      12.4      109.      12.6      110.      12.2      111.      12.1      112.
      12.1      113.      11.4      114.      10.7      115.      11.1      116.
      11.4      117.      11.6      118.      11.4      119.      11.6      120.
      12.0      121.      11.9      122.      12.2      123.      13.1      124.
      13.6      125.      13.9      126.      13.9      127.      14.4      128.
      14.7      129.      14.9      130.      15.3      131.      15.5      132.
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15.2	137.	15.2	138.	15.2	139.	15.1	140.
15.2	141.	15.3	142.	15.5	143.	15.6	144.
15.5	145.	15.6	146.	15.6	147.	15.9	148.
15.9	149.	16.3	150.	16.4	151.	16.4	152.
16.2	153.	16.0	154.	16.3	155.	17.2	156.
17.0	157.	16.2	158.	16.3	159.	16.4	160.
16.4	161.	16.2	162.	16.1	163.	16.0	164.
16.2	165.	16.3	166.	16.3	167.	16.3	168.
16.2	169.	16.4	170.	16.4	171.	16.3	172.
16.1	173.	15.9	174.	15.9	175.	16.0	176.
16.3	177.	16.3	178.	16.3	179.	16.2	180.
16.4	181.	17.0	182.	17.3	183.	17.6	184.
17.9	185.	17.8	186.	17.8	187.	17.9	188.
18.0	189.	18.1	190.	18.1	191.	17.7	192.
18.3	193.	18.8	194.	19.1	195.	19.2	196.
19.2	197.	19.1	198.	19.2	199.	19.2	200.
19.2	201.	19.3	202.	19.5	203.	19.6	204.
20.1	205.	20.7	206.	20.9	207.	21.1	208.
21.1	209.	20.8	210.	20.6	211.	20.7	212.
21.2	213.	21.7	214.	21.9	215.	21.9	216.
21.7	217.	21.7	218.	21.8	219.	22.0	220.
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22.3	225.	22.4	226.	22.3	227.	22.1	228.
22.1	229.	22.1	230.	22.1	231.	22.1	232.
22.2	233.	22.2	234.	22.5	235.	22.7	236.
22.9	237.	23.0	238.	23.1	239.	23.2	240.
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22.9	245.	22.9	246.	22.7	247.	22.9	248.
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23.2	253.	23.2	254.	23.2	255.	22.0	256.
21.8	257.	21.8	258.	21.8	259.	21.8	260.
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21.4	265.	21.6	266.	22.0	267.	21.8	268.
21.8	269.	21.8	270.	20.4	271.	20.2	272.
20.2	273.	20.2	274.	20.0	275.	19.7	276.
19.7	277.	19.7	278.	19.7	279.	19.7	280.
19.6	281.	19.6	282.	19.5	283.	19.5	284.
19.4	285.	19.5	286.	19.6	287.	19.7	288.
19.4	289.	19.5	290.	19.5	291.	18.5	292.
17.4	293.	15.8	294.	15.1	295.	14.7	296.
14.5	297.	14.6	298.	14.6	299.	14.6	300.
14.6	301.	14.7	302.	14.6	303.	13.9	304.
13.7	305.	13.7	306.	13.7	307.	13.8	308.
13.9	309.	14.0	310.	14.1	311.	14.0	312.
13.8	313.	13.4	314.	12.3	315.	12.1	316.
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7.8	337.	7.9	338.	8.1	339.	8.2	340.
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9.4	425.	9.6	426.	9.5	427.	9.3	428.
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9.8	441.	9.6	442.	7.8	443.	7.6	444.
7.5	445.	7.6	446.	7.8	447.	8.1	448.
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14.9	465.	14.5	466.	14.1	467.	14.4	468.
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13.7	853.	14.2	854.	15.0	855.	15.8	856.
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16.1	869.	16.0	870.	16.1	871.	16.0	872.
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16.2	877.	16.3	878.	16.5	879.	16.4	880.
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22.3	949.	22.5	950.	22.5	951.	22.5	952.
22.9	953.	23.0	954.	23.2	955.	23.2	956.
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23.8	961.	23.8	962.	23.7	963.	24.0	964.
24.2	965.	24.4	966.	24.5	967.	24.4	968.
24.7	969.	24.6	970.	22.9	971.	22.6	972.
22.7	973.	23.0	974.	23.1	975.	22.8	976.
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19.8	1013.	19.3	1014.	19.1	1015.	18.9	1016.
18.9	1017.	18.6	1018.	18.0	1019.	17.9	1020.
17.7	1021.	17.8	1022.	17.6	1023.	17.2	1024.
16.1	1025.	14.3	1026.	14.1	1027.	14.1	1028.
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13.9	1033.	14.0	1034.	14.0	1035.	14.0	1036.
13.9	1037.	14.2	1038.	14.1	1039.	14.2	1040.
14.2	1041.	13.9	1042.	13.8	1043.	13.8	1044.
13.8	1045.	13.9	1046.	13.8	1047.	13.8	1048.
13.9	1049.	14.0	1050.	14.0	1051.	13.9	1052.
13.5	1053.	13.2	1054.	12.9	1055.	12.8	1056.
12.8	1057.	12.7	1058.	13.0	1059.	12.9	1060.
13.2	1061.	12.9	1062.	12.6	1063.	12.8	1064.
12.9	1065.	12.6	1066.	11.7	1067.	11.0	1068.
11.0	1069.	11.0	1070.	11.2	1071.	11.3	1072.
11.2	1073.	10.7	1074.	10.7	1075.	10.5	1076.
10.4	1077.	10.1	1078.	9.9	1079.	10.0	1080.
9.9	1081.	9.9	1082.	10.2	1083.	10.3	1084.
10.1	1085.	9.9	1086.	9.4	1087.	8.8	1088.
8.1	1089.	7.6	1090.	7.4	1091.	7.2	1092.
7.0	1093.	6.8	1094.	7.0	1095.	5.0	1096.
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6.2	1101.	6.2	1102.	6.3	1103.	6.2	1104.
6.3	1105.	7.0	1106.	6.8	1107.	7.3	1108.
7.3	1109.	7.2	1110.	7.5	1111.	7.2	1112.
7.2	1113.	7.0	1114.	6.7	1115.	6.6	1116.
6.3	1117.	5.6	1118.	5.3	1119.	5.4	1120.
5.1	1121.	4.2	1122.	3.4	1123.	3.7	1124.
3.6	1125.	2.7	1126.	2.0	1127.	2.0	1128.
1.9	1129.	2.3	1130.	2.3	1131.	2.6	1132.
3.0	1133.	3.4	1134.	3.6	1135.	4.0	1136.
4.6	1137.	4.4	1138.	5.2	1139.	5.6	1140.
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6.3	1145.	6.1	1146.	6.0	1147.	6.1	1148.
6.2	1149.	6.2	1150.	6.3	1151.	6.4	1152.
6.5	1153.	7.1	1154.	7.1	1155.	7.3	1156.
8.0	1157.	8.1	1158.	8.4	1159.	9.0	1160.
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9.8	1165.	9.7	1166.	10.9	1167.	11.1	1168.
11.7	1169.	12.2	1170.	12.2	1171.	12.3	1172.
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10.8	1181.	10.9	1182.	11.4	1183.	11.8	1184.
11.9	1185.	12.2	1186.	12.4	1187.	12.6	1188.
12.5	1189.	13.0	1190.	13.2	1191.	13.1	1192.
13.4	1193.	13.5	1194.	13.7	1195.	14.0	1196.
14.0	1197.	14.4	1198.	14.6	1199.	15.0	1200.
14.8	1201.	14.1	1202.	14.0	1203.	14.0	1204.
13.9	1205.	13.2	1206.	13.3	1207.	13.6	1208.
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14.8	1213.	14.8	1214.	14.5	1215.	13.5	1216.
13.5	1217.	14.2	1218.	14.6	1219.	14.9	1220.
14.6	1221.	14.5	1222.	14.5	1223.	14.6	1224.
14.4	1225.	14.4	1226.	15.1	1227.	14.9	1228.
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15.4	1233.	15.3	1234.	15.8	1235.	15.9	1236.
16.0	1237.	16.0	1238.	16.3	1239.	16.6	1240.
16.7	1241.	16.9	1242.	16.9	1243.	16.9	1244.
16.9	1245.	16.9	1246.	17.5	1247.	18.3	1248.
18.4	1249.	18.3	1250.	18.1	1251.	18.0	1252.
18.0	1253.	18.4	1254.	18.6	1255.	18.7	1256.
18.7	1257.	18.7	1258.	18.9	1259.	18.9	1260.
19.0	1261.	19.0	1262.	18.9	1263.	19.1	1264.
19.3	1265.	19.3	1266.	19.2	1267.	20.2	1268.

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      21.9     1317.      21.7     1318.      21.6     1319.      21.6     1320.
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      19.8     1341.      19.8     1342.      20.3     1343.      20.4     1344.
      20.0     1345.      19.7     1346.      20.0     1347.      20.0     1348.
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      19.9     1357.      19.4     1358.      19.4     1359.      19.4     1360.
      19.4     1361.      19.1     1362.      19.3     1363.      19.2     1364.
      19.2     1365.      19.3     1366.      19.3     1367.      19.0     1368.
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      18.4     1373.      18.2     1374.      18.3     1375.      18.3     1376.
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      18.0     1381.      17.9     1382.      18.0     1383.      17.8     1384.
      17.6     1385.      17.6     1386.      17.5     1387.      17.3     1388.
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      15.3     1397.      15.2     1398.      15.2     1399.      15.1     1400.
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      15.1     1405.      15.1     1406.      15.0     1407.      14.4     1408.
      14.2     1409.      14.3     1410.      14.3     1411.      14.4     1412.
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      10.8     1441.      10.6     1442.      10.5     1443.      10.4     1444.
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       7.8     1461.
TEMP4 1461    4
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       3.8       21.       3.6       22.       2.6       23.       3.4       24.
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       5.2       49.       5.8       50.       5.6       51.       5.6       52.
       7.3       53.       7.3       54.       7.1       55.       7.2       56.
       7.2       57.       8.5       58.       8.4       59.       8.4       60.
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      10.7       69.      10.9       70.      10.8       71.      10.8       72.
      10.9       73.      10.9       74.      10.9       75.      11.0       76.
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      10.6       81.      10.5       82.      10.5       83.      10.5       84.
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12.7	93.	12.3	94.	12.3	95.	12.8	96.
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18.8	165.	18.9	166.	19.4	167.	19.9	168.
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19.6	657.	19.3	658.	19.3	659.	19.4	660.
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16.6	665.	16.6	666.	16.7	667.	16.8	668.
17.0	669.	17.1	670.	17.1	671.	17.3	672.
15.6	673.	13.3	674.	12.5	675.	12.4	676.
12.2	677.	11.9	678.	11.2	679.	11.3	680.
11.6	681.	12.0	682.	12.5	683.	12.6	684.
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11.7	713.	10.7	714.	9.4	715.	9.3	716.
9.2	717.	9.0	718.	8.7	719.	8.3	720.
8.5	721.	8.4	722.	8.3	723.	6.9	724.
6.2	725.	5.7	726.	5.5	727.	5.5	728.
5.3	729.	5.0	730.	5.0	731.	5.3	732.
4.8	733.	4.8	734.	4.8	735.	4.6	736.
4.4	737.	4.3	738.	4.3	739.	4.5	740.
4.9	741.	5.1	742.	5.6	743.	5.6	744.
5.6	745.	5.7	746.	5.5	747.	6.1	748.
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6.8	753.	8.0	754.	8.4	755.	8.5	756.
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9.0	761.	9.7	762.	9.4	763.	9.2	764.
9.4	765.	9.3	766.	9.4	767.	9.4	768.
9.6	769.	9.7	770.	10.0	771.	9.9	772.
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27.8	953.	27.8	954.	27.8	955.	28.2	956.
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ITOT  1461     5
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823.60	225.	738.70	226.	792.80	227.	720.80	228.
836.30	229.	659.20	230.	761.20	231.	384.10	232.
724.40	233.	786.50	234.	754.50	235.	628.80	236.
774.10	237.	773.60	238.	732.10	239.	663.50	240.
803.00	241.	652.70	242.	669.00	243.	682.30	244.
695.70	245.	657.50	246.	886.00	247.	856.60	248.
824.60	249.	722.00	250.	581.00	251.	516.00	252.
233.70	253.	435.20	254.	588.40	255.	638.10	256.
558.50	257.	411.80	258.	570.50	259.	640.00	260.
484.50	261.	570.00	262.	673.30	263.	624.70	264.
672.50	265.	511.90	266.	51.60	267.	171.10	268.
411.30	269.	237.60	270.	152.50	271.	694.50	272.
692.60	273.	633.60	274.	703.40	275.	681.60	276.
642.20	277.	644.80	278.	644.30	279.	636.50	280.
581.00	281.	523.60	282.	508.40	283.	585.60	284.
593.90	285.	582.40	286.	479.90	287.	163.50	288.
168.70	289.	72.90	290.	61.70	291.	72.90	292.
568.30	293.	542.50	294.	488.50	295.	583.90	296.
268.90	297.	415.10	298.	50.90	299.	132.40	300.
555.00	301.	486.40	302.	528.90	303.	206.00	304.
331.70	305.	482.30	306.	479.40	307.	426.60	308.
478.20	309.	121.70	310.	70.50	311.	174.90	312.
463.70	313.	396.70	314.	400.80	315.	238.00	316.
43.00	317.	109.00	318.	441.70	319.	443.30	320.

456.50	321.	444.10	322.	330.80	323.	409.60	324.
123.30	325.	254.80	326.	311.20	327.	421.10	328.
412.80	329.	320.00	330.	422.30	331.	333.40	332.
305.70	333.	69.10	334.	330.50	335.	396.00	336.
261.20	337.	224.70	338.	306.90	339.	392.20	340.
389.80	341.	249.50	342.	55.20	343.	46.10	344.
241.90	345.	139.80	346.	214.40	347.	105.60	348.
381.00	349.	381.90	350.	379.30	351.	356.30	352.
373.30	353.	343.20	354.	271.70	355.	33.00	356.
254.80	357.	41.10	358.	272.20	359.	342.00	360.
39.20	361.	314.80	362.	86.80	363.	314.00	364.
361.60	365.	396.30	366.	396.30	367.	374.80	368.
375.20	369.	348.90	370.	134.60	371.	62.40	372.
46.40	373.	314.30	374.	403.70	375.	390.50	376.
221.60	377.	120.90	378.	217.30	379.	44.20	380.
59.30	381.	77.70	382.	432.40	383.	17.00	384.
346.80	385.	395.30	386.	77.90	387.	35.10	388.
56.40	389.	421.80	390.	464.10	391.	24.40	392.
102.80	393.	416.10	394.	455.30	395.	401.80	396.
510.30	397.	438.10	398.	70.50	399.	80.50	400.
82.20	401.	70.00	402.	76.70	403.	367.80	404.
390.00	405.	522.00	406.	171.40	407.	535.40	408.
350.90	409.	431.60	410.	564.80	411.	42.10	412.
231.60	413.	424.00	414.	586.30	415.	463.70	416.
407.70	417.	492.10	418.	73.40	419.	583.20	420.
665.10	421.	611.10	422.	193.80	423.	338.70	424.
496.20	425.	513.40	426.	378.30	427.	499.00	428.
544.40	429.	265.30	430.	234.50	431.	88.40	432.
583.90	433.	691.90	434.	759.30	435.	787.50	436.
749.30	437.	747.60	438.	775.60	439.	155.10	440.
105.90	441.	104.70	442.	448.10	443.	191.40	444.
136.20	445.	651.30	446.	768.10	447.	569.80	448.
647.50	449.	783.70	450.	808.30	451.	783.70	452.
772.20	453.	782.50	454.	618.30	455.	270.30	456.
896.70	457.	337.50	458.	217.30	459.	895.30	460.
934.50	461.	837.70	462.	750.90	463.	500.50	464.
339.10	465.	952.40	466.	954.80	467.	903.20	468.
119.00	469.	893.90	470.	593.90	471.	348.70	472.
152.20	473.	353.20	474.	967.70	475.	847.00	476.
314.50	477.	511.00	478.	810.90	479.	934.30	480.
899.60	481.	437.60	482.	993.00	483.	833.40	484.
414.90	485.	395.10	486.	679.70	487.	667.00	488.
540.40	489.	790.10	490.	917.30	491.	332.70	492.
731.10	493.	702.20	494.	482.30	495.	390.00	496.
297.80	497.	423.70	498.	1045.90	499.	1046.30	500.
858.20	501.	709.80	502.	1017.20	503.	1018.40	504.
673.50	505.	797.10	506.	695.00	507.	386.50	508.
450.00	509.	887.60	510.	926.10	511.	789.20	512.
463.90	513.	769.10	514.	794.40	515.	890.00	516.
889.30	517.	881.40	518.	952.70	519.	554.50	520.
382.60	521.	280.30	522.	810.70	523.	815.20	524.
338.70	525.	505.20	526.	696.40	527.	871.90	528.
788.90	529.	853.90	530.	766.20	531.	732.80	532.
918.20	533.	1044.70	534.	522.70	535.	1056.40	536.
894.10	537.	817.40	538.	947.60	539.	813.10	540.
868.30	541.	939.70	542.	895.30	543.	765.50	544.
965.30	545.	788.90	546.	869.70	547.	964.80	548.
879.30	549.	795.60	550.	631.20	551.	967.00	552.
994.00	553.	590.60	554.	600.40	555.	814.30	556.
825.00	557.	701.90	558.	803.50	559.	990.20	560.
813.80	561.	475.10	562.	558.10	563.	908.40	564.
877.10	565.	883.80	566.	967.00	567.	855.60	568.
855.40	569.	728.70	570.	466.50	571.	648.90	572.
285.10	573.	716.30	574.	874.70	575.	514.80	576.
537.30	577.	805.20	578.	697.40	579.	961.70	580.
963.20	581.	968.20	582.	940.00	583.	394.10	584.
660.60	585.	497.80	586.	358.50	587.	715.30	588.
822.40	589.	755.70	590.	772.70	591.	626.70	592.
488.30	593.	723.50	594.	812.60	595.	830.50	596.
941.90	597.	898.90	598.	872.10	599.	779.10	600.
821.90	601.	698.10	602.	244.70	603.	236.40	604.

810.70	605.	749.50	606.	718.20	607.	478.00	608.
717.70	609.	694.50	610.	152.70	611.	561.90	612.
749.50	613.	705.10	614.	729.70	615.	297.80	616.
766.50	617.	830.00	618.	812.80	619.	774.40	620.
755.20	621.	742.60	622.	667.30	623.	660.80	624.
667.50	625.	648.90	626.	411.10	627.	581.20	628.
336.30	629.	566.00	630.	706.20	631.	725.80	632.
693.30	633.	656.10	634.	705.80	635.	584.60	636.
345.40	637.	378.30	638.	562.80	639.	714.60	640.
648.20	641.	218.70	642.	291.30	643.	194.50	644.
428.80	645.	223.00	646.	571.90	647.	645.50	648.
639.80	649.	580.50	650.	548.70	651.	570.70	652.
608.50	653.	585.10	654.	585.80	655.	574.30	656.
414.70	657.	522.70	658.	232.10	659.	409.90	660.
571.20	661.	561.40	662.	556.60	663.	540.40	664.
515.30	665.	488.00	666.	524.10	667.	448.40	668.
499.70	669.	501.20	670.	316.40	671.	45.20	672.
96.80	673.	453.60	674.	370.70	675.	492.60	676.
202.70	677.	333.20	678.	315.20	679.	121.70	680.
454.80	681.	190.00	682.	90.60	683.	400.60	684.
286.10	685.	404.10	686.	416.30	687.	192.20	688.
197.70	689.	395.30	690.	420.60	691.	390.30	692.
379.80	693.	301.40	694.	401.80	695.	407.00	696.
399.40	697.	402.50	698.	330.30	699.	384.30	700.
393.40	701.	320.00	702.	345.80	703.	278.00	704.
347.50	705.	351.30	706.	217.30	707.	288.50	708.
372.10	709.	267.40	710.	142.70	711.	54.70	712.
369.00	713.	243.50	714.	332.70	715.	153.90	716.
367.60	717.	114.70	718.	206.00	719.	215.30	720.
128.80	721.	56.20	722.	42.80	723.	287.00	724.
135.80	725.	345.60	726.	176.90	727.	48.80	728.
354.40	729.	238.00	730.	368.80	731.	50.70	732.
128.10	733.	342.20	734.	395.50	735.	341.50	736.
367.30	737.	96.10	738.	167.50	739.	407.30	740.
384.30	741.	389.80	742.	335.60	743.	271.50	744.
375.90	745.	403.00	746.	301.60	747.	168.50	748.
423.30	749.	374.30	750.	289.90	751.	214.10	752.
260.70	753.	90.10	754.	434.00	755.	440.50	756.
348.90	757.	444.10	758.	363.50	759.	311.70	760.
277.70	761.	99.70	762.	208.90	763.	420.90	764.
321.00	765.	518.40	766.	373.60	767.	312.60	768.
528.20	769.	397.90	770.	522.90	771.	437.80	772.
244.30	773.	481.60	774.	592.50	775.	573.60	776.
574.30	777.	409.60	778.	153.20	779.	228.50	780.
589.60	781.	590.10	782.	649.60	783.	225.10	784.
569.50	785.	184.70	786.	644.60	787.	442.40	788.
189.00	789.	479.20	790.	663.70	791.	371.60	792.
702.40	793.	619.00	794.	451.50	795.	730.40	796.
685.70	797.	120.20	798.	305.90	799.	743.30	800.
755.20	801.	370.00	802.	41.60	803.	196.20	804.
752.40	805.	728.50	806.	744.50	807.	739.70	808.
732.80	809.	160.60	810.	804.70	811.	699.60	812.
570.70	813.	451.90	814.	461.00	815.	619.20	816.
828.10	817.	677.80	818.	817.90	819.	713.90	820.
152.00	821.	666.30	822.	653.70	823.	625.00	824.
613.30	825.	421.80	826.	789.90	827.	796.30	828.
675.70	829.	784.90	830.	420.40	831.	652.20	832.
936.60	833.	943.60	834.	289.70	835.	918.50	836.
715.60	837.	636.90	838.	653.40	839.	745.00	840.
893.10	841.	893.90	842.	764.80	843.	575.80	844.
990.90	845.	414.70	846.	826.70	847.	90.80	848.
125.50	849.	338.70	850.	627.60	851.	576.90	852.
990.90	853.	967.00	854.	476.10	855.	647.50	856.
727.80	857.	814.50	858.	965.10	859.	970.60	860.
838.20	861.	566.70	862.	682.30	863.	99.90	864.
712.50	865.	676.10	866.	412.80	867.	868.00	868.
448.60	869.	1036.80	870.	1012.40	871.	852.30	872.
874.50	873.	692.40	874.	672.50	875.	317.90	876.
1038.90	877.	1036.10	878.	1033.40	879.	948.80	880.
793.00	881.	1000.20	882.	861.10	883.	762.90	884.
933.10	885.	1015.80	886.	1007.40	887.	1017.40	888.

975.10	889.	917.50	890.	796.80	891.	397.70	892.
904.60	893.	534.40	894.	881.70	895.	184.00	896.
113.00	897.	282.30	898.	1059.00	899.	697.90	900.
168.30	901.	282.00	902.	288.20	903.	1036.80	904.
886.90	905.	414.20	906.	417.50	907.	477.30	908.
500.90	909.	622.40	910.	239.20	911.	490.70	912.
766.70	913.	881.20	914.	864.20	915.	950.00	916.
676.60	917.	777.20	918.	785.10	919.	881.90	920.
782.50	921.	128.10	922.	140.50	923.	130.70	924.
215.80	925.	572.60	926.	753.10	927.	768.40	928.
769.80	929.	907.50	930.	822.40	931.	764.60	932.
834.10	933.	823.80	934.	639.80	935.	913.70	936.
922.10	937.	746.90	938.	829.60	939.	723.70	940.
884.80	941.	918.00	942.	780.80	943.	935.70	944.
945.50	945.	939.00	946.	686.40	947.	777.90	948.
808.50	949.	756.40	950.	371.20	951.	755.20	952.
805.90	953.	832.20	954.	615.90	955.	490.70	956.
525.60	957.	640.80	958.	611.10	959.	706.20	960.
565.20	961.	319.80	962.	774.40	963.	755.50	964.
631.00	965.	586.70	966.	382.40	967.	544.20	968.
816.20	969.	767.90	970.	509.10	971.	721.30	972.
645.30	973.	533.70	974.	700.50	975.	522.50	976.
204.10	977.	66.70	978.	324.10	979.	670.60	980.
588.40	981.	497.10	982.	709.80	983.	790.10	984.
767.90	985.	751.90	986.	177.30	987.	42.30	988.
385.00	989.	763.60	990.	741.10	991.	668.50	992.
565.20	993.	400.80	994.	602.50	995.	742.30	996.
728.20	997.	646.70	998.	457.40	999.	203.90	1000.
80.10	1001.	140.10	1002.	708.60	1003.	677.30	1004.
654.60	1005.	312.40	1006.	350.90	1007.	288.20	1008.
627.10	1009.	544.20	1010.	610.60	1011.	419.70	1012.
239.00	1013.	209.60	1014.	421.80	1015.	152.50	1016.
606.30	1017.	586.70	1018.	382.40	1019.	44.00	1020.
535.80	1021.	347.00	1022.	50.90	1023.	495.40	1024.
551.10	1025.	532.30	1026.	475.10	1027.	542.50	1028.
535.40	1029.	522.90	1030.	500.70	1031.	479.40	1032.
481.30	1033.	484.90	1034.	430.20	1035.	289.00	1036.
506.70	1037.	498.30	1038.	475.10	1039.	454.30	1040.
482.30	1041.	452.70	1042.	401.50	1043.	414.70	1044.
182.10	1045.	332.00	1046.	397.90	1047.	407.30	1048.
447.90	1049.	429.50	1050.	394.10	1051.	413.50	1052.
372.60	1053.	384.30	1054.	249.50	1055.	309.70	1056.
307.10	1057.	125.00	1058.	143.60	1059.	141.20	1060.
388.60	1061.	370.50	1062.	247.10	1063.	369.70	1064.
391.00	1065.	375.90	1066.	314.80	1067.	352.30	1068.
346.30	1069.	100.90	1070.	373.10	1071.	371.60	1072.
364.20	1073.	145.60	1074.	370.20	1075.	201.20	1076.
136.70	1077.	328.10	1078.	361.80	1079.	352.00	1080.
340.80	1081.	210.30	1082.	67.40	1083.	57.60	1084.
70.00	1085.	62.10	1086.	248.10	1087.	189.50	1088.
359.00	1089.	360.90	1090.	357.80	1091.	347.30	1092.
360.40	1093.	360.40	1094.	360.40	1095.	284.90	1096.
221.50	1097.	262.20	1098.	143.40	1099.	327.30	1100.
253.10	1101.	265.90	1102.	271.10	1103.	87.80	1104.
127.70	1105.	337.80	1106.	330.60	1107.	215.30	1108.
355.20	1109.	349.80	1110.	262.00	1111.	354.30	1112.
15.50	1113.	239.70	1114.	214.30	1115.	367.40	1116.
196.10	1117.	25.40	1118.	75.40	1119.	144.00	1120.
381.20	1121.	413.00	1122.	302.10	1123.	271.30	1124.
25.00	1125.	349.20	1126.	411.20	1127.	422.90	1128.
381.20	1129.	320.70	1130.	434.30	1131.	426.70	1132.
374.40	1133.	315.10	1134.	297.10	1135.	387.40	1136.
324.60	1137.	31.00	1138.	78.10	1139.	245.00	1140.
475.60	1141.	398.10	1142.	447.50	1143.	108.30	1144.
220.70	1145.	506.40	1146.	507.00	1147.	501.00	1148.
463.60	1149.	411.60	1150.	478.10	1151.	470.50	1152.
258.10	1153.	560.70	1154.	480.00	1155.	546.50	1156.
515.30	1157.	138.60	1158.	570.50	1159.	565.50	1160.
564.70	1161.	566.10	1162.	472.10	1163.	540.30	1164.
457.40	1165.	492.60	1166.	628.50	1167.	624.20	1168.
556.40	1169.	154.30	1170.	529.50	1171.	664.90	1172.

396.90	1173.	67.10	1174.	253.70	1175.	215.10	1176.
513.20	1177.	632.20	1178.	621.70	1179.	674.60	1180.
213.80	1181.	490.70	1182.	671.10	1183.	152.70	1184.
700.80	1185.	699.00	1186.	206.60	1187.	434.50	1188.
177.90	1189.	743.00	1190.	713.00	1191.	721.50	1192.
409.50	1193.	778.30	1194.	740.30	1195.	684.30	1196.
365.70	1197.	76.90	1198.	140.10	1199.	155.40	1200.
523.30	1201.	536.00	1202.	128.30	1203.	681.80	1204.
711.80	1205.	545.90	1206.	462.40	1207.	741.10	1208.
445.50	1209.	102.30	1210.	511.80	1211.	440.30	1212.
66.90	1213.	604.50	1214.	800.20	1215.	781.60	1216.
343.80	1217.	819.60	1218.	802.30	1219.	793.80	1220.
781.20	1221.	813.00	1222.	776.20	1223.	681.60	1224.
657.60	1225.	807.90	1226.	763.80	1227.	771.90	1228.
692.40	1229.	825.20	1230.	792.60	1231.	566.30	1232.
690.50	1233.	754.10	1234.	657.90	1235.	285.70	1236.
593.00	1237.	436.20	1238.	675.00	1239.	423.80	1240.
833.70	1241.	539.70	1242.	376.90	1243.	189.50	1244.
520.70	1245.	735.10	1246.	864.70	1247.	744.40	1248.
659.50	1249.	806.60	1250.	878.10	1251.	870.90	1252.
879.50	1253.	843.00	1254.	793.20	1255.	688.80	1256.
343.80	1257.	782.00	1258.	462.00	1259.	762.20	1260.
159.10	1261.	97.70	1262.	244.00	1263.	915.50	1264.
603.30	1265.	145.50	1266.	243.80	1267.	249.20	1268.
896.30	1269.	766.70	1270.	358.10	1271.	361.00	1272.
412.60	1273.	433.10	1274.	538.00	1275.	206.80	1276.
424.20	1277.	662.80	1278.	761.80	1279.	747.10	1280.
821.30	1281.	584.90	1282.	671.90	1283.	678.70	1284.
762.40	1285.	676.40	1286.	110.70	1287.	121.50	1288.
113.00	1289.	186.60	1290.	495.00	1291.	651.00	1292.
664.30	1293.	665.50	1294.	784.50	1295.	711.00	1296.
661.00	1297.	721.10	1298.	712.20	1299.	553.10	1300.
789.90	1301.	797.10	1302.	645.70	1303.	717.10	1304.
625.60	1305.	764.90	1306.	793.60	1307.	675.00	1308.
808.90	1309.	817.40	1310.	811.80	1311.	593.40	1312.
672.50	1313.	699.00	1314.	653.90	1315.	320.90	1316.
652.90	1317.	696.70	1318.	719.40	1319.	532.40	1320.
424.20	1321.	454.30	1322.	553.90	1323.	528.30	1324.
610.50	1325.	488.60	1326.	276.40	1327.	669.40	1328.
653.10	1329.	545.50	1330.	507.20	1331.	330.60	1332.
470.50	1333.	705.60	1334.	663.80	1335.	440.10	1336.
623.60	1337.	557.90	1338.	461.40	1339.	605.60	1340.
451.70	1341.	176.40	1342.	57.60	1343.	280.20	1344.
579.80	1345.	508.70	1346.	429.80	1347.	613.60	1348.
683.10	1349.	663.80	1350.	650.00	1351.	153.30	1352.
36.60	1353.	332.90	1354.	660.10	1355.	640.70	1356.
577.90	1357.	488.60	1358.	346.50	1359.	520.90	1360.
641.70	1361.	629.50	1362.	559.10	1363.	395.50	1364.
176.20	1365.	69.20	1366.	121.10	1367.	612.60	1368.
585.50	1369.	565.90	1370.	270.00	1371.	303.30	1372.
249.20	1373.	542.10	1374.	470.50	1375.	527.90	1376.
362.80	1377.	206.60	1378.	181.20	1379.	364.70	1380.
131.80	1381.	524.20	1382.	507.20	1383.	330.60	1384.
38.00	1385.	463.20	1386.	300.00	1387.	44.00	1388.
428.30	1389.	476.40	1390.	460.10	1391.	410.70	1392.
469.00	1393.	462.80	1394.	452.10	1395.	432.90	1396.
414.50	1397.	416.10	1398.	419.20	1399.	371.90	1400.
249.80	1401.	438.00	1402.	430.80	1403.	410.70	1404.
392.80	1405.	416.90	1406.	391.30	1407.	347.10	1408.
358.50	1409.	157.40	1410.	287.00	1411.	344.00	1412.
352.10	1413.	387.20	1414.	371.30	1415.	340.70	1416.
357.40	1417.	322.10	1418.	332.20	1419.	215.70	1420.
267.80	1421.	265.50	1422.	108.10	1423.	124.20	1424.
122.10	1425.	336.00	1426.	320.20	1427.	213.60	1428.
319.60	1429.	338.00	1430.	325.00	1431.	272.10	1432.
304.50	1433.	299.40	1434.	87.20	1435.	322.50	1436.
321.30	1437.	314.90	1438.	125.80	1439.	320.00	1440.
174.00	1441.	118.20	1442.	283.70	1443.	312.80	1444.
304.30	1445.	294.60	1446.	181.80	1447.	58.30	1448.
49.80	1449.	60.50	1450.	53.70	1451.	214.50	1452.
163.80	1453.	310.30	1454.	312.00	1455.	309.30	1456.

```
   300.20     1457.    311.60     1458.    306.40     1459.    205.80     1460.
   205.80     1461.
****F 1461    6
     0.41        1.      0.41        2.      0.41        3.      0.41        4.
     0.41        5.      0.41        6.      0.41        7.      0.41        8.
     0.41        9.      0.41       10.      0.41       11.      0.41       12.
     0.41       13.      0.41       14.      0.41       15.      0.41       16.
     0.42       17.      0.42       18.      0.42       19.      0.42       20.
     0.42       21.      0.42       22.      0.42       23.      0.42       24.
     0.42       25.      0.42       26.      0.42       27.      0.43       28.
     0.43       29.      0.43       30.      0.43       31.      0.43       32.
     0.43       33.      0.43       34.      0.43       35.      0.44       36.
     0.44       37.      0.44       38.      0.44       39.      0.44       40.
     0.44       41.      0.44       42.      0.44       43.      0.45       44.
     0.45       45.      0.45       46.      0.45       47.      0.45       48.
     0.45       49.      0.45       50.      0.46       51.      0.46       52.
     0.46       53.      0.46       54.      0.46       55.      0.46       56.
     0.47       57.      0.47       58.      0.47       59.      0.47       60.
     0.47       61.      0.47       62.      0.48       63.      0.48       64.
     0.48       65.      0.48       66.      0.48       67.      0.48       68.
     0.49       69.      0.49       70.      0.49       71.      0.49       72.
     0.49       73.      0.49       74.      0.50       75.      0.50       76.
     0.50       77.      0.50       78.      0.50       79.      0.50       80.
     0.51       81.      0.51       82.      0.51       83.      0.51       84.
     0.51       85.      0.51       86.      0.52       87.      0.52       88.
     0.52       89.      0.52       90.      0.52       91.      0.52       92.
     0.53       93.      0.53       94.      0.53       95.      0.53       96.
     0.53       97.      0.53       98.      0.54       99.      0.54      100.
     0.54      101.      0.54      102.      0.54      103.      0.54      104.
     0.55      105.      0.55      106.      0.55      107.      0.55      108.
     0.55      109.      0.55      110.      0.55      111.      0.56      112.
     0.56      113.      0.56      114.      0.56      115.      0.56      116.
     0.56      117.      0.56      118.      0.57      119.      0.57      120.
     0.57      121.      0.57      122.      0.57      123.      0.57      124.
     0.57      125.      0.58      126.      0.58      127.      0.58      128.
     0.58      129.      0.58      130.      0.58      131.      0.58      132.
     0.58      133.      0.58      134.      0.59      135.      0.59      136.
     0.59      137.      0.59      138.      0.59      139.      0.59      140.
     0.59      141.      0.59      142.      0.59      143.      0.59      144.
     0.59      145.      0.59      146.      0.60      147.      0.60      148.
     0.60      149.      0.60      150.      0.60      151.      0.60      152.
     0.60      153.      0.60      154.      0.60      155.      0.60      156.
     0.60      157.      0.60      158.      0.60      159.      0.60      160.
     0.60      161.      0.60      162.      0.60      163.      0.60      164.
     0.60      165.      0.60      166.      0.60      167.      0.60      168.
     0.60      169.      0.60      170.      0.60      171.      0.60      172.
     0.60      173.      0.60      174.      0.60      175.      0.60      176.
     0.60      177.      0.60      178.      0.60      179.      0.60      180.
     0.60      181.      0.60      182.      0.60      183.      0.60      184.
     0.60      185.      0.60      186.      0.60      187.      0.60      188.
     0.60      189.      0.60      190.      0.60      191.      0.60      192.
     0.60      193.      0.60      194.      0.60      195.      0.60      196.
     0.59      197.      0.59      198.      0.59      199.      0.59      200.
     0.59      201.      0.59      202.      0.59      203.      0.59      204.
     0.59      205.      0.59      206.      0.59      207.      0.58      208.
     0.58      209.      0.58      210.      0.58      211.      0.58      212.
     0.58      213.      0.58      214.      0.58      215.      0.58      216.
     0.57      217.      0.57      218.      0.57      219.      0.57      220.
     0.57      221.      0.57      222.      0.57      223.      0.57      224.
     0.56      225.      0.56      226.      0.56      227.      0.56      228.
     0.56      229.      0.56      230.      0.56      231.      0.55      232.
     0.55      233.      0.55      234.      0.55      235.      0.55      236.
     0.55      237.      0.54      238.      0.54      239.      0.54      240.
     0.54      241.      0.54      242.      0.54      243.      0.54      244.
     0.53      245.      0.53      246.      0.53      247.      0.53      248.
     0.53      249.      0.53      250.      0.52      251.      0.52      252.
     0.52      253.      0.52      254.      0.52      255.      0.52      256.
     0.51      257.      0.51      258.      0.51      259.      0.51      260.
     0.51      261.      0.50      262.      0.50      263.      0.50      264.
     0.50      265.      0.50      266.      0.50      267.      0.49      268.
     0.49      269.      0.49      270.      0.49      271.      0.49      272.
```

0.49	273.	0.48	274.	0.48	275.	0.48	276.
0.48	277.	0.48	278.	0.48	279.	0.47	280.
0.47	281.	0.47	282.	0.47	283.	0.47	284.
0.47	285.	0.46	286.	0.46	287.	0.46	288.
0.46	289.	0.46	290.	0.46	291.	0.46	292.
0.45	293.	0.45	294.	0.45	295.	0.45	296.
0.45	297.	0.45	298.	0.45	299.	0.44	300.
0.44	301.	0.44	302.	0.44	303.	0.44	304.
0.44	305.	0.44	306.	0.43	307.	0.43	308.
0.43	309.	0.43	310.	0.43	311.	0.43	312.
0.43	313.	0.43	314.	0.43	315.	0.42	316.
0.42	317.	0.42	318.	0.42	319.	0.42	320.
0.42	321.	0.42	322.	0.42	323.	0.42	324.
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0.41	329.	0.41	330.	0.41	331.	0.41	332.
0.41	333.	0.41	334.	0.41	335.	0.41	336.
0.41	337.	0.41	338.	0.41	339.	0.41	340.
0.41	341.	0.41	342.	0.41	343.	0.41	344.
0.41	345.	0.40	346.	0.40	347.	0.40	348.
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0.40	353.	0.40	354.	0.40	355.	0.40	356.
0.40	357.	0.40	358.	0.40	359.	0.40	360.
0.40	361.	0.41	362.	0.41	363.	0.41	364.
0.41	365.	0.41	366.	0.41	367.	0.41	368.
0.41	369.	0.41	370.	0.41	371.	0.41	372.
0.41	373.	0.41	374.	0.41	375.	0.41	376.
0.41	377.	0.41	378.	0.41	379.	0.41	380.
0.41	381.	0.42	382.	0.42	383.	0.42	384.
0.42	385.	0.42	386.	0.42	387.	0.42	388.
0.42	389.	0.42	390.	0.42	391.	0.42	392.
0.43	393.	0.43	394.	0.43	395.	0.43	396.
0.43	397.	0.43	398.	0.43	399.	0.43	400.
0.44	401.	0.44	402.	0.44	403.	0.44	404.
0.44	405.	0.44	406.	0.44	407.	0.44	408.
0.45	409.	0.45	410.	0.45	411.	0.45	412.
0.45	413.	0.45	414.	0.45	415.	0.46	416.
0.46	417.	0.46	418.	0.46	419.	0.46	420.
0.46	421.	0.47	422.	0.47	423.	0.47	424.
0.47	425.	0.47	426.	0.47	427.	0.48	428.
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0.50	445.	0.51	446.	0.51	447.	0.51	448.
0.51	449.	0.51	450.	0.51	451.	0.52	452.
0.52	453.	0.52	454.	0.52	455.	0.52	456.
0.52	457.	0.53	458.	0.53	459.	0.53	460.
0.53	461.	0.53	462.	0.53	463.	0.54	464.
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0.54	469.	0.55	470.	0.55	471.	0.55	472.
0.55	473.	0.55	474.	0.55	475.	0.55	476.
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0.57	485.	0.57	486.	0.57	487.	0.57	488.
0.57	489.	0.57	490.	0.58	491.	0.58	492.
0.58	493.	0.58	494.	0.58	495.	0.58	496.
0.58	497.	0.58	498.	0.58	499.	0.59	500.
0.59	501.	0.59	502.	0.59	503.	0.59	504.
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0.60	545.	0.60	546.	0.60	547.	0.60	548.
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0.60	553.	0.60	554.	0.60	555.	0.60	556.

0.60	557.	0.60	558.	0.60	559.	0.60	560.
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0.59	569.	0.59	570.	0.59	571.	0.59	572.
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0.55	597.	0.55	598.	0.55	599.	0.55	600.
0.55	601.	0.55	602.	0.54	603.	0.54	604.
0.54	605.	0.54	606.	0.54	607.	0.54	608.
0.54	609.	0.53	610.	0.53	611.	0.53	612.
0.53	613.	0.53	614.	0.53	615.	0.52	616.
0.52	617.	0.52	618.	0.52	619.	0.52	620.
0.52	621.	0.51	622.	0.51	623.	0.51	624.
0.51	625.	0.51	626.	0.50	627.	0.50	628.
0.50	629.	0.50	630.	0.50	631.	0.50	632.
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0.49	637.	0.49	638.	0.48	639.	0.48	640.
0.48	641.	0.48	642.	0.48	643.	0.48	644.
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0.45	661.	0.45	662.	0.45	663.	0.45	664.
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0.43	673.	0.43	674.	0.43	675.	0.43	676.
0.43	677.	0.43	678.	0.43	679.	0.43	680.
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0.42	689.	0.42	690.	0.42	691.	0.41	692.
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0.41	697.	0.41	698.	0.41	699.	0.41	700.
0.41	701.	0.41	702.	0.41	703.	0.41	704.
0.41	705.	0.41	706.	0.41	707.	0.41	708.
0.41	709.	0.41	710.	0.40	711.	0.40	712.
0.40	713.	0.40	714.	0.40	715.	0.40	716.
0.40	717.	0.40	718.	0.40	719.	0.40	720.
0.40	721.	0.40	722.	0.40	723.	0.40	724.
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0.41	733.	0.41	734.	0.41	735.	0.41	736.
0.41	737.	0.41	738.	0.41	739.	0.41	740.
0.41	741.	0.41	742.	0.41	743.	0.41	744.
0.41	745.	0.41	746.	0.42	747.	0.42	748.
0.42	749.	0.42	750.	0.42	751.	0.42	752.
0.42	753.	0.42	754.	0.42	755.	0.42	756.
0.42	757.	0.43	758.	0.43	759.	0.43	760.
0.43	761.	0.43	762.	0.43	763.	0.43	764.
0.43	765.	0.44	766.	0.44	767.	0.44	768.
0.44	769.	0.44	770.	0.44	771.	0.44	772.
0.44	773.	0.45	774.	0.45	775.	0.45	776.
0.45	777.	0.45	778.	0.45	779.	0.45	780.
0.46	781.	0.46	782.	0.46	783.	0.46	784.
0.46	785.	0.46	786.	0.47	787.	0.47	788.
0.47	789.	0.47	790.	0.47	791.	0.47	792.
0.48	793.	0.48	794.	0.48	795.	0.48	796.
0.48	797.	0.48	798.	0.49	799.	0.49	800.
0.49	801.	0.49	802.	0.49	803.	0.49	804.
0.50	805.	0.50	806.	0.50	807.	0.50	808.
0.50	809.	0.50	810.	0.51	811.	0.51	812.
0.51	813.	0.51	814.	0.51	815.	0.51	816.
0.52	817.	0.52	818.	0.52	819.	0.52	820.
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0.53	825.	0.53	826.	0.53	827.	0.53	828.
0.54	829.	0.54	830.	0.54	831.	0.54	832.
0.54	833.	0.54	834.	0.55	835.	0.55	836.
0.55	837.	0.55	838.	0.55	839.	0.55	840.

0.55	841.	0.56	842.	0.56	843.	0.56	844.
0.56	845.	0.56	846.	0.56	847.	0.56	848.
0.57	849.	0.57	850.	0.57	851.	0.57	852.
0.57	853.	0.57	854.	0.57	855.	0.58	856.
0.58	857.	0.58	858.	0.58	859.	0.58	860.
0.58	861.	0.58	862.	0.58	863.	0.58	864.
0.59	865.	0.59	866.	0.59	867.	0.59	868.
0.59	869.	0.59	870.	0.59	871.	0.59	872.
0.59	873.	0.59	874.	0.59	875.	0.59	876.
0.60	877.	0.60	878.	0.60	879.	0.60	880.
0.60	881.	0.60	882.	0.60	883.	0.60	884.
0.60	885.	0.60	886.	0.60	887.	0.60	888.
0.60	889.	0.60	890.	0.60	891.	0.60	892.
0.60	893.	0.60	894.	0.60	895.	0.60	896.
0.60	897.	0.60	898.	0.60	899.	0.60	900.
0.60	901.	0.60	902.	0.60	903.	0.60	904.
0.60	905.	0.60	906.	0.60	907.	0.60	908.
0.60	909.	0.60	910.	0.60	911.	0.60	912.
0.60	913.	0.60	914.	0.60	915.	0.60	916.
0.60	917.	0.60	918.	0.60	919.	0.60	920.
0.60	921.	0.60	922.	0.60	923.	0.60	924.
0.60	925.	0.60	926.	0.59	927.	0.59	928.
0.59	929.	0.59	930.	0.59	931.	0.59	932.
0.59	933.	0.59	934.	0.59	935.	0.59	936.
0.59	937.	0.58	938.	0.58	939.	0.58	940.
0.58	941.	0.58	942.	0.58	943.	0.58	944.
0.58	945.	0.58	946.	0.57	947.	0.57	948.
0.57	949.	0.57	950.	0.57	951.	0.57	952.
0.57	953.	0.57	954.	0.56	955.	0.56	956.
0.56	957.	0.56	958.	0.56	959.	0.56	960.
0.56	961.	0.55	962.	0.55	963.	0.55	964.
0.55	965.	0.55	966.	0.55	967.	0.54	968.
0.54	969.	0.54	970.	0.54	971.	0.54	972.
0.54	973.	0.54	974.	0.53	975.	0.53	976.
0.53	977.	0.53	978.	0.53	979.	0.53	980.
0.52	981.	0.52	982.	0.52	983.	0.52	984.
0.52	985.	0.52	986.	0.51	987.	0.51	988.
0.51	989.	0.51	990.	0.51	991.	0.50	992.
0.50	993.	0.50	994.	0.50	995.	0.50	996.
0.50	997.	0.49	998.	0.49	999.	0.49	1000.
0.49	1001.	0.49	1002.	0.49	1003.	0.48	1004.
0.48	1005.	0.48	1006.	0.48	1007.	0.48	1008.
0.48	1009.	0.47	1010.	0.47	1011.	0.47	1012.
0.47	1013.	0.47	1014.	0.47	1015.	0.46	1016.
0.46	1017.	0.46	1018.	0.46	1019.	0.46	1020.
0.46	1021.	0.46	1022.	0.45	1023.	0.45	1024.
0.45	1025.	0.45	1026.	0.45	1027.	0.45	1028.
0.45	1029.	0.44	1030.	0.44	1031.	0.44	1032.
0.44	1033.	0.44	1034.	0.44	1035.	0.44	1036.
0.43	1037.	0.43	1038.	0.43	1039.	0.43	1040.
0.43	1041.	0.43	1042.	0.43	1043.	0.43	1044.
0.43	1045.	0.42	1046.	0.42	1047.	0.42	1048.
0.42	1049.	0.42	1050.	0.42	1051.	0.42	1052.
0.42	1053.	0.42	1054.	0.42	1055.	0.42	1056.
0.41	1057.	0.41	1058.	0.41	1059.	0.41	1060.
0.41	1061.	0.41	1062.	0.41	1063.	0.41	1064.
0.41	1065.	0.41	1066.	0.41	1067.	0.41	1068.
0.41	1069.	0.41	1070.	0.41	1071.	0.41	1072.
0.41	1073.	0.41	1074.	0.41	1075.	0.40	1076.
0.40	1077.	0.40	1078.	0.40	1079.	0.40	1080.
0.40	1081.	0.40	1082.	0.40	1083.	0.40	1084.
0.40	1085.	0.40	1086.	0.40	1087.	0.40	1088.
0.40	1089.	0.40	1090.	0.40	1091.	0.41	1092.
0.41	1093.	0.41	1094.	0.41	1095.	0.41	1096.
0.41	1097.	0.41	1098.	0.41	1099.	0.41	1100.
0.41	1101.	0.41	1102.	0.41	1103.	0.41	1104.
0.41	1105.	0.41	1106.	0.41	1107.	0.41	1108.
0.41	1109.	0.41	1110.	0.41	1111.	0.42	1112.
0.42	1113.	0.42	1114.	0.42	1115.	0.42	1116.
0.42	1117.	0.42	1118.	0.42	1119.	0.42	1120.
0.42	1121.	0.42	1122.	0.43	1123.	0.43	1124.

0.43	1125.	0.43	1126.	0.43	1127.	0.43	1128.
0.43	1129.	0.43	1130.	0.44	1131.	0.44	1132.
0.44	1133.	0.44	1134.	0.44	1135.	0.44	1136.
0.44	1137.	0.44	1138.	0.45	1139.	0.45	1140.
0.45	1141.	0.45	1142.	0.45	1143.	0.45	1144.
0.45	1145.	0.46	1146.	0.46	1147.	0.46	1148.
0.46	1149.	0.46	1150.	0.46	1151.	0.47	1152.
0.47	1153.	0.47	1154.	0.47	1155.	0.47	1156.
0.47	1157.	0.48	1158.	0.48	1159.	0.48	1160.
0.48	1161.	0.48	1162.	0.48	1163.	0.49	1164.
0.49	1165.	0.49	1166.	0.49	1167.	0.49	1168.
0.49	1169.	0.50	1170.	0.50	1171.	0.50	1172.
0.50	1173.	0.50	1174.	0.50	1175.	0.51	1176.
0.51	1177.	0.51	1178.	0.51	1179.	0.51	1180.
0.51	1181.	0.52	1182.	0.52	1183.	0.52	1184.
0.52	1185.	0.52	1186.	0.52	1187.	0.53	1188.
0.53	1189.	0.53	1190.	0.53	1191.	0.53	1192.
0.53	1193.	0.54	1194.	0.54	1195.	0.54	1196.
0.54	1197.	0.54	1198.	0.54	1199.	0.55	1200.
0.55	1201.	0.55	1202.	0.55	1203.	0.55	1204.
0.55	1205.	0.55	1206.	0.56	1207.	0.56	1208.
0.56	1209.	0.56	1210.	0.56	1211.	0.56	1212.
0.56	1213.	0.57	1214.	0.57	1215.	0.57	1216.
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0.58	1221.	0.58	1222.	0.58	1223.	0.58	1224.
0.58	1225.	0.58	1226.	0.58	1227.	0.58	1228.
0.58	1229.	0.59	1230.	0.59	1231.	0.59	1232.
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0.60	1253.	0.60	1254.	0.60	1255.	0.60	1256.
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0.60	1261.	0.60	1262.	0.60	1263.	0.60	1264.
0.60	1265.	0.60	1266.	0.60	1267.	0.60	1268.
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0.60	1273.	0.60	1274.	0.60	1275.	0.60	1276.
0.60	1277.	0.60	1278.	0.60	1279.	0.60	1280.
0.60	1281.	0.60	1282.	0.60	1283.	0.60	1284.
0.60	1285.	0.60	1286.	0.60	1287.	0.60	1288.
0.60	1289.	0.60	1290.	0.60	1291.	0.59	1292.
0.59	1293.	0.59	1294.	0.59	1295.	0.59	1296.
0.59	1297.	0.59	1298.	0.59	1299.	0.59	1300.
0.59	1301.	0.59	1302.	0.58	1303.	0.58	1304.
0.58	1305.	0.58	1306.	0.58	1307.	0.58	1308.
0.58	1309.	0.58	1310.	0.58	1311.	0.57	1312.
0.57	1313.	0.57	1314.	0.57	1315.	0.57	1316.
0.57	1317.	0.57	1318.	0.57	1319.	0.56	1320.
0.56	1321.	0.56	1322.	0.56	1323.	0.56	1324.
0.56	1325.	0.56	1326.	0.55	1327.	0.55	1328.
0.55	1329.	0.55	1330.	0.55	1331.	0.55	1332.
0.54	1333.	0.54	1334.	0.54	1335.	0.54	1336.
0.54	1337.	0.54	1338.	0.54	1339.	0.53	1340.
0.53	1341.	0.53	1342.	0.53	1343.	0.53	1344.
0.53	1345.	0.52	1346.	0.52	1347.	0.52	1348.
0.52	1349.	0.52	1350.	0.52	1351.	0.51	1352.
0.51	1353.	0.51	1354.	0.51	1355.	0.51	1356.
0.50	1357.	0.50	1358.	0.50	1359.	0.50	1360.
0.50	1361.	0.50	1362.	0.49	1363.	0.49	1364.
0.49	1365.	0.49	1366.	0.49	1367.	0.49	1368.
0.48	1369.	0.48	1370.	0.48	1371.	0.48	1372.
0.48	1373.	0.48	1374.	0.47	1375.	0.47	1376.
0.47	1377.	0.47	1378.	0.47	1379.	0.47	1380.
0.46	1381.	0.46	1382.	0.46	1383.	0.46	1384.
0.46	1385.	0.46	1386.	0.46	1387.	0.45	1388.
0.45	1389.	0.45	1390.	0.45	1391.	0.45	1392.
0.45	1393.	0.45	1394.	0.44	1395.	0.44	1396.
0.44	1397.	0.44	1398.	0.44	1399.	0.44	1400.
0.44	1401.	0.43	1402.	0.43	1403.	0.43	1404.
0.43	1405.	0.43	1406.	0.43	1407.	0.43	1408.

```
     0.43     1409.      0.43     1410.      0.42     1411.      0.42     1412.
     0.42     1413.      0.42     1414.      0.42     1415.      0.42     1416.
     0.42     1417.      0.42     1418.      0.42     1419.      0.42     1420.
     0.42     1421.      0.41     1422.      0.41     1423.      0.41     1424.
     0.41     1425.      0.41     1426.      0.41     1427.      0.41     1428.
     0.41     1429.      0.41     1430.      0.41     1431.      0.41     1432.
     0.41     1433.      0.41     1434.      0.41     1435.      0.41     1436.
     0.41     1437.      0.41     1438.      0.41     1439.      0.41     1440.
     0.40     1441.      0.40     1442.      0.40     1443.      0.40     1444.
     0.40     1445.      0.40     1446.      0.40     1447.      0.40     1448.
     0.40     1449.      0.40     1450.      0.40     1451.      0.40     1452.
     0.40     1453.      0.40     1454.      0.40     1455.      0.40     1456.
     0.41     1457.      0.41     1458.      0.41     1459.      0.41     1460.
     0.41     1461.
 WIND 1461    7
     6.20        1.      7.50        2.      7.30        3.      4.40        4.
    11.00        5.      4.50        6.      3.10        7.      3.00        8.
     1.80        9.     14.00       10.      7.10       11.      2.40       12.
     2.00       13.      0.00       14.      3.70       15.      6.60       16.
     7.10       17.      6.60       18.      3.70       19.      5.10       20.
     3.90       21.      8.50       22.      3.20       23.      4.70       24.
     6.90       25.      0.40       26.      4.40       27.      3.90       28.
     5.50       29.      6.60       30.      5.40       31.      4.40       32.
     4.00       33.      1.00       34.      7.40       35.      2.10       36.
     1.30       37.      3.00       38.      6.10       39.      1.30       40.
     1.10       41.      1.30       42.      1.30       43.      7.90       44.
     1.80       45.      3.20       46.      2.60       47.      1.60       48.
     6.70       49.     10.00       50.      4.80       51.      9.80       52.
    10.00       53.      0.90       54.      1.90       55.      2.10       56.
     2.60       57.     12.00       58.      1.80       59.      2.60       60.
     3.60       61.      2.60       62.      1.60       63.      2.00       64.
     2.90       65.      1.40       66.      2.50       67.      2.30       68.
     1.80       69.      1.60       70.      0.70       71.      1.20       72.
     1.70       73.      2.40       74.      1.90       75.      1.80       76.
     2.10       77.      3.10       78.      1.60       79.      1.90       80.
     3.10       81.      1.60       82.      1.80       83.      2.50       84.
     2.80       85.      1.40       86.      1.80       87.      3.40       88.
     1.90       89.      2.60       90.      2.90       91.      1.50       92.
     1.20       93.      1.60       94.      1.80       95.      2.40       96.
     2.10       97.      2.20       98.      2.40       99.      1.70      100.
     1.30      101.      1.00      102.      2.80      103.      1.70      104.
     0.80      105.      1.40      106.      1.90      107.      1.90      108.
     1.80      109.      1.60      110.      2.10      111.      2.20      112.
     4.00      113.      1.40      114.      1.10      115.      1.40      116.
     1.00      117.      1.70      118.      2.90      119.      1.10      120.
     2.90      121.      1.50      122.      3.00      123.      1.50      124.
     1.50      125.      0.40      126.      0.20      127.      0.30      128.
     0.20      129.      0.30      130.      0.20      131.      0.40      132.
     0.20      133.      0.30      134.      0.50      135.      0.30      136.
     0.30      137.      0.20      138.      0.50      139.      0.30      140.
     0.10      141.      0.10      142.      0.10      143.      0.30      144.
     0.40      145.      0.30      146.      0.30      147.      0.30      148.
     0.20      149.      0.10      150.      0.10      151.      0.10      152.
     0.10      153.      0.20      154.      0.10      155.      0.30      156.
     5.60      157.      4.70      158.      2.40      159.      2.60      160.
     2.10      161.      3.10      162.      5.80      163.      6.50      164.
     3.50      165.      4.10      166.      2.00      167.      4.90      168.
     7.20      169.      4.00      170.      1.60      171.      3.90      172.
     4.20      173.      2.80      174.      1.90      175.      6.60      176.
     8.10      177.      1.40      178.      3.30      179.      3.70      180.
     2.20      181.      2.30      182.      1.60      183.      5.40      184.
     4.00      185.      2.40      186.      2.10      187.      2.10      188.
     2.50      189.      3.50      190.      3.80      191.      4.10      192.
     1.70      193.      2.60      194.      2.70      195.      4.20      196.
     3.90      197.      3.60      198.      4.90      199.      2.60      200.
     2.70      201.      2.40      202.      2.70      203.      1.30      204.
     2.00      205.      1.30      206.      1.30      207.      2.60      208.
     2.10      209.      1.50      210.      1.70      211.      1.60      212.
     1.10      213.      1.50      214.      2.60      215.      2.00      216.
     1.10      217.      1.00      218.      1.50      219.      0.90      220.
     1.00      221.      1.00      222.      1.00      223.      1.90      224.
```

3.60	225.	2.20	226.	1.90	227.	2.50	228.
3.10	229.	2.50	230.	1.50	231.	2.30	232.
1.40	233.	1.10	234.	0.90	235.	1.00	236.
1.00	237.	1.20	238.	0.90	239.	1.20	240.
1.40	241.	1.40	242.	1.20	243.	1.20	244.
1.20	245.	1.80	246.	1.70	247.	0.80	248.
2.20	249.	2.20	250.	1.50	251.	1.30	252.
1.30	253.	1.40	254.	0.80	255.	1.00	256.
1.40	257.	1.00	258.	1.00	259.	0.90	260.
1.30	261.	1.10	262.	2.90	263.	2.20	264.
1.20	265.	1.50	266.	2.50	267.	1.70	268.
0.90	269.	2.70	270.	1.70	271.	3.20	272.
3.70	273.	1.10	274.	1.50	275.	1.00	276.
1.90	277.	1.60	278.	1.00	279.	0.80	280.
0.90	281.	1.20	282.	2.40	283.	1.50	284.
1.30	285.	1.10	286.	1.70	287.	1.50	288.
1.40	289.	1.20	290.	1.60	291.	1.20	292.
1.30	293.	1.30	294.	1.00	295.	1.10	296.
1.70	297.	2.20	298.	2.00	299.	3.10	300.
1.10	301.	1.60	302.	0.80	303.	1.30	304.
2.60	305.	3.30	306.	3.00	307.	1.70	308.
1.50	309.	1.40	310.	1.30	311.	1.30	312.
2.20	313.	1.00	314.	0.90	315.	0.80	316.
2.50	317.	2.30	318.	1.70	319.	1.80	320.
1.20	321.	1.30	322.	1.70	323.	1.10	324.
1.10	325.	1.80	326.	1.10	327.	1.70	328.
1.40	329.	4.00	330.	1.70	331.	2.40	332.
1.50	333.	1.80	334.	2.10	335.	1.00	336.
1.30	337.	1.80	338.	2.80	339.	2.60	340.
2.10	341.	1.00	342.	0.80	343.	2.10	344.
1.00	345.	1.00	346.	1.50	347.	1.40	348.
1.60	349.	1.10	350.	0.80	351.	1.00	352.
2.90	353.	2.40	354.	2.50	355.	2.10	356.
2.40	357.	2.20	358.	1.80	359.	0.80	360.
2.10	361.	1.10	362.	2.90	363.	4.80	364.
2.70	365.	1.90	366.	2.90	367.	2.20	368.
1.20	369.	1.20	370.	1.40	371.	2.10	372.
3.40	373.	4.00	374.	0.70	375.	0.80	376.
1.50	377.	2.10	378.	2.70	379.	1.80	380.
1.70	381.	1.80	382.	1.60	383.	1.00	384.
1.20	385.	1.00	386.	2.10	387.	2.00	388.
1.70	389.	1.80	390.	1.40	391.	3.10	392.
3.10	393.	2.20	394.	2.20	395.	1.50	396.
0.90	397.	1.20	398.	3.60	399.	3.80	400.
2.70	401.	1.10	402.	2.30	403.	2.40	404.
1.30	405.	0.80	406.	2.10	407.	4.50	408.
1.00	409.	1.80	410.	2.10	411.	4.10	412.
4.00	413.	4.30	414.	2.20	415.	2.40	416.
2.20	417.	1.70	418.	2.90	419.	4.50	420.
3.30	421.	1.20	422.	1.50	423.	1.50	424.
2.10	425.	1.70	426.	3.10	427.	2.60	428.
1.50	429.	2.00	430.	1.60	431.	2.40	432.
5.70	433.	3.90	434.	2.30	435.	2.30	436.
2.00	437.	3.80	438.	1.70	439.	2.80	440.
2.80	441.	1.20	442.	1.20	443.	2.10	444.
2.80	445.	2.60	446.	1.40	447.	1.10	448.
1.80	449.	3.00	450.	3.60	451.	3.50	452.
2.80	453.	3.10	454.	3.50	455.	4.00	456.
3.50	457.	1.70	458.	2.40	459.	1.60	460.
1.60	461.	2.50	462.	3.80	463.	4.20	464.
1.90	465.	1.20	466.	1.20	467.	2.10	468.
3.50	469.	3.50	470.	3.40	471.	3.80	472.
2.20	473.	2.10	474.	1.50	475.	2.20	476.
1.60	477.	1.60	478.	3.00	479.	2.70	480.
4.10	481.	2.50	482.	0.90	483.	1.70	484.
1.60	485.	1.60	486.	3.60	487.	2.80	488.
1.90	489.	2.20	490.	1.20	491.	1.80	492.
1.80	493.	1.10	494.	1.40	495.	1.20	496.
1.10	497.	1.50	498.	1.30	499.	0.90	500.
1.40	501.	0.90	502.	1.20	503.	2.80	504.
2.50	505.	1.90	506.	1.60	507.	1.60	508.

1.30	509.	1.60	510.	1.50	511.	1.30	512.
1.20	513.	1.50	514.	2.10	515.	3.00	516.
1.80	517.	3.10	518.	2.70	519.	1.20	520.
1.00	521.	1.30	522.	1.50	523.	2.20	524.
1.40	525.	1.90	526.	1.10	527.	2.40	528.
2.60	529.	2.50	530.	3.10	531.	4.10	532.
2.50	533.	1.70	534.	2.20	535.	1.60	536.
1.00	537.	0.90	538.	1.00	539.	0.90	540.
0.80	541.	2.30	542.	1.80	543.	1.30	544.
1.80	545.	3.40	546.	1.70	547.	1.00	548.
0.80	549.	2.20	550.	1.50	551.	1.80	552.
1.10	553.	2.40	554.	1.30	555.	0.90	556.
1.60	557.	1.40	558.	1.30	559.	1.50	560.
1.20	561.	1.00	562.	1.70	563.	0.90	564.
1.70	565.	2.90	566.	3.10	567.	3.30	568.
3.50	569.	1.50	570.	1.20	571.	1.00	572.
1.30	573.	0.90	574.	1.70	575.	1.40	576.
2.20	577.	2.40	578.	2.50	579.	2.00	580.
1.70	581.	1.40	582.	1.70	583.	1.90	584.
1.30	585.	0.80	586.	1.60	587.	1.10	588.
0.80	589.	1.90	590.	1.90	591.	1.00	592.
1.30	593.	3.10	594.	1.80	595.	1.80	596.
1.10	597.	1.00	598.	1.40	599.	1.90	600.
2.20	601.	1.80	602.	3.40	603.	2.80	604.
1.90	605.	2.30	606.	0.90	607.	0.90	608.
1.20	609.	1.80	610.	2.70	611.	2.40	612.
1.20	613.	1.70	614.	3.50	615.	2.30	616.
1.20	617.	1.00	618.	1.20	619.	1.60	620.
1.10	621.	1.00	622.	1.50	623.	1.70	624.
0.70	625.	1.70	626.	1.80	627.	0.90	628.
1.10	629.	1.30	630.	2.20	631.	1.20	632.
1.40	633.	1.60	634.	3.10	635.	3.20	636.
1.70	637.	2.20	638.	2.20	639.	1.50	640.
1.40	641.	1.50	642.	1.60	643.	1.80	644.
1.90	645.	1.70	646.	0.90	647.	0.90	648.
0.90	649.	0.80	650.	1.30	651.	1.50	652.
1.20	653.	0.90	654.	0.80	655.	1.90	656.
2.70	657.	1.00	658.	0.80	659.	1.60	660.
1.00	661.	1.20	662.	1.10	663.	0.70	664.
1.00	665.	1.60	666.	1.40	667.	1.30	668.
1.00	669.	1.20	670.	1.30	671.	2.10	672.
1.30	673.	1.40	674.	1.00	675.	0.70	676.
0.90	677.	1.10	678.	2.40	679.	3.20	680.
0.90	681.	0.80	682.	2.30	683.	2.20	684.
1.40	685.	2.10	686.	1.40	687.	1.00	688.
2.60	689.	1.60	690.	1.00	691.	2.80	692.
1.80	693.	1.50	694.	3.60	695.	2.30	696.
1.20	697.	2.10	698.	2.60	699.	2.10	700.
1.60	701.	3.00	702.	2.50	703.	2.00	704.
2.70	705.	3.80	706.	2.50	707.	2.20	708.
0.90	709.	1.40	710.	1.90	711.	1.70	712.
2.20	713.	1.80	714.	2.10	715.	2.70	716.
1.50	717.	0.90	718.	0.90	719.	1.50	720.
3.70	721.	1.90	722.	0.40	723.	0.40	724.
0.40	725.	1.00	726.	1.10	727.	1.40	728.
2.80	729.	1.30	730.	1.40	731.	3.40	732.
4.20	733.	1.90	734.	1.50	735.	2.80	736.
2.60	737.	1.50	738.	3.40	739.	2.20	740.
2.70	741.	3.80	742.	3.10	743.	1.70	744.
2.30	745.	2.20	746.	1.30	747.	4.00	748.
2.10	749.	1.50	750.	1.30	751.	1.30	752.
2.50	753.	1.90	754.	1.70	755.	1.70	756.
3.50	757.	3.00	758.	2.20	759.	1.80	760.
3.20	761.	2.40	762.	2.80	763.	1.50	764.
3.60	765.	1.20	766.	2.30	767.	2.90	768.
2.50	769.	2.10	770.	1.40	771.	1.70	772.
4.40	773.	2.80	774.	1.60	775.	2.10	776.
3.00	777.	2.80	778.	2.00	779.	2.60	780.
1.40	781.	2.40	782.	2.00	783.	1.30	784.
1.50	785.	2.00	786.	1.50	787.	2.50	788.
3.60	789.	3.50	790.	1.60	791.	5.40	792.

4.80	793.	1.40	794.	3.70	795.	2.90	796.
1.80	797.	2.20	798.	1.80	799.	2.00	800.
2.20	801.	1.40	802.	2.60	803.	2.20	804.
2.50	805.	2.80	806.	4.20	807.	1.60	808.
2.00	809.	2.40	810.	2.90	811.	1.80	812.
2.20	813.	2.00	814.	3.40	815.	1.80	816.
2.80	817.	2.00	818.	1.60	819.	2.00	820.
2.20	821.	1.40	822.	1.90	823.	3.70	824.
2.80	825.	2.10	826.	2.70	827.	2.70	828.
5.00	829.	1.80	830.	2.00	831.	2.50	832.
1.80	833.	1.70	834.	1.90	835.	4.70	836.
3.70	837.	2.40	838.	2.00	839.	2.50	840.
2.20	841.	3.70	842.	4.80	843.	2.20	844.
1.40	845.	2.60	846.	2.30	847.	2.90	848.
3.80	849.	4.40	850.	3.60	851.	2.80	852.
1.50	853.	1.30	854.	1.90	855.	3.30	856.
3.10	857.	3.80	858.	1.50	859.	1.30	860.
1.60	861.	1.60	862.	1.20	863.	2.90	864.
2.70	865.	2.10	866.	1.40	867.	1.20	868.
0.80	869.	1.00	870.	1.30	871.	3.70	872.
3.30	873.	3.80	874.	2.10	875.	2.20	876.
1.30	877.	0.90	878.	1.00	879.	1.70	880.
1.90	881.	2.90	882.	3.80	883.	2.70	884.
1.80	885.	1.90	886.	1.20	887.	2.50	888.
1.80	889.	1.30	890.	2.00	891.	1.90	892.
1.80	893.	1.00	894.	3.60	895.	1.30	896.
1.90	897.	1.20	898.	1.90	899.	2.90	900.
2.30	901.	1.50	902.	1.10	903.	1.40	904.
1.30	905.	1.40	906.	1.20	907.	2.50	908.
3.10	909.	3.30	910.	1.90	911.	2.80	912.
2.50	913.	2.70	914.	3.10	915.	2.00	916.
1.90	917.	2.80	918.	2.00	919.	3.60	920.
3.60	921.	1.80	922.	2.10	923.	1.50	924.
1.30	925.	0.90	926.	0.90	927.	1.90	928.
2.80	929.	3.20	930.	1.60	931.	1.30	932.
1.20	933.	1.00	934.	1.60	935.	2.20	936.
1.60	937.	0.90	938.	1.40	939.	2.70	940.
2.00	941.	1.30	942.	1.40	943.	1.60	944.
2.00	945.	1.70	946.	2.40	947.	1.20	948.
1.60	949.	2.70	950.	1.40	951.	1.40	952.
1.90	953.	1.30	954.	2.10	955.	2.60	956.
1.10	957.	1.40	958.	2.00	959.	1.90	960.
1.90	961.	1.30	962.	1.00	963.	1.10	964.
1.30	965.	1.80	966.	1.50	967.	1.80	968.
0.90	969.	0.90	970.	1.60	971.	3.10	972.
1.90	973.	1.30	974.	1.90	975.	2.10	976.
2.20	977.	3.00	978.	2.10	979.	1.50	980.
1.50	981.	1.50	982.	1.00	983.	0.80	984.
1.20	985.	1.10	986.	1.00	987.	2.30	988.
3.20	989.	0.90	990.	0.90	991.	0.80	992.
1.30	993.	1.80	994.	1.80	995.	1.30	996.
2.20	997.	1.20	998.	1.20	999.	1.50	1000.
1.20	1001.	1.50	1002.	1.20	1003.	0.90	1004.
1.20	1005.	1.20	1006.	1.80	1007.	1.20	1008.
0.90	1009.	1.40	1010.	1.10	1011.	1.10	1012.
1.60	1013.	1.20	1014.	2.30	1015.	1.50	1016.
1.70	1017.	1.50	1018.	1.70	1019.	1.90	1020.
1.40	1021.	1.30	1022.	1.00	1023.	1.00	1024.
2.20	1025.	1.70	1026.	1.70	1027.	1.00	1028.
2.50	1029.	1.10	1030.	0.90	1031.	0.70	1032.
0.80	1033.	0.70	1034.	1.10	1035.	3.90	1036.
3.40	1037.	1.40	1038.	2.20	1039.	2.90	1040.
0.90	1041.	1.10	1042.	2.10	1043.	3.70	1044.
2.30	1045.	1.40	1046.	1.90	1047.	3.20	1048.
1.60	1049.	1.90	1050.	0.90	1051.	0.80	1052.
1.20	1053.	0.90	1054.	1.20	1055.	1.10	1056.
1.50	1057.	0.60	1058.	0.70	1059.	2.20	1060.
1.60	1061.	1.00	1062.	1.40	1063.	2.10	1064.
1.30	1065.	1.20	1066.	2.60	1067.	3.10	1068.
2.80	1069.	2.80	1070.	1.30	1071.	0.90	1072.
1.30	1073.	2.90	1074.	1.20	1075.	0.90	1076.

1.00	1077.	3.50	1078.	2.30	1079.	2.80	1080.
1.80	1081.	1.30	1082.	2.50	1083.	2.10	1084.
1.40	1085.	1.30	1086.	1.10	1087.	1.60	1088.
1.70	1089.	3.30	1090.	1.80	1091.	1.70	1092.
1.90	1093.	1.90	1094.	1.90	1095.	1.00	1096.
1.00	1097.	2.40	1098.	2.80	1099.	4.80	1100.
1.80	1101.	1.00	1102.	1.30	1103.	0.80	1104.
1.00	1105.	4.00	1106.	5.00	1107.	1.10	1108.
4.90	1109.	2.20	1110.	1.50	1111.	5.00	1112.
1.90	1113.	1.00	1114.	1.70	1115.	2.70	1116.
2.40	1117.	1.20	1118.	1.10	1119.	2.50	1120.
4.20	1121.	1.90	1122.	1.90	1123.	0.80	1124.
1.60	1125.	1.40	1126.	2.00	1127.	2.90	1128.
2.10	1129.	3.30	1130.	1.60	1131.	2.40	1132.
1.30	1133.	2.10	1134.	2.20	1135.	0.70	1136.
0.90	1137.	2.60	1138.	2.70	1139.	1.10	1140.
3.60	1141.	1.60	1142.	3.10	1143.	2.80	1144.
2.20	1145.	3.80	1146.	1.70	1147.	1.10	1148.
1.00	1149.	0.90	1150.	1.70	1151.	2.20	1152.
1.70	1153.	1.80	1154.	1.80	1155.	2.60	1156.
2.10	1157.	1.20	1158.	1.10	1159.	2.20	1160.
0.90	1161.	2.00	1162.	2.90	1163.	4.60	1164.
2.00	1165.	3.90	1166.	3.40	1167.	1.30	1168.
0.80	1169.	1.30	1170.	1.90	1171.	3.30	1172.
3.00	1173.	2.70	1174.	3.70	1175.	1.80	1176.
2.40	1177.	2.10	1178.	0.90	1179.	3.20	1180.
2.30	1181.	1.70	1182.	3.40	1183.	2.10	1184.
0.90	1185.	1.30	1186.	1.50	1187.	2.10	1188.
3.80	1189.	4.60	1190.	3.20	1191.	4.00	1192.
3.00	1193.	4.50	1194.	4.10	1195.	2.90	1196.
4.00	1197.	2.70	1198.	2.70	1199.	1.90	1200.
0.70	1201.	1.20	1202.	1.60	1203.	1.80	1204.
1.40	1205.	1.60	1206.	3.60	1207.	1.30	1208.
1.50	1209.	1.90	1210.	2.20	1211.	0.90	1212.
1.20	1213.	1.60	1214.	1.00	1215.	1.00	1216.
3.40	1217.	2.70	1218.	1.80	1219.	1.20	1220.
2.20	1221.	2.40	1222.	2.90	1223.	3.60	1224.
3.50	1225.	4.10	1226.	1.10	1227.	3.20	1228.
3.00	1229.	1.00	1230.	1.40	1231.	1.40	1232.
2.80	1233.	4.20	1234.	3.00	1235.	2.10	1236.
1.30	1237.	2.40	1238.	1.70	1239.	3.40	1240.
2.20	1241.	1.00	1242.	2.30	1243.	1.20	1244.
1.70	1245.	2.10	1246.	1.10	1247.	2.90	1248.
3.80	1249.	2.70	1250.	1.80	1251.	1.90	1252.
1.20	1253.	2.50	1254.	1.80	1255.	1.30	1256.
2.00	1257.	1.90	1258.	1.80	1259.	1.00	1260.
3.60	1261.	1.30	1262.	1.90	1263.	1.20	1264.
1.90	1265.	2.90	1266.	2.30	1267.	1.50	1268.
1.10	1269.	1.40	1270.	1.30	1271.	1.40	1272.
1.20	1273.	2.50	1274.	3.10	1275.	3.30	1276.
1.90	1277.	2.80	1278.	2.50	1279.	2.70	1280.
3.10	1281.	2.00	1282.	1.90	1283.	2.80	1284.
2.00	1285.	3.60	1286.	3.60	1287.	1.80	1288.
2.10	1289.	1.50	1290.	1.30	1291.	0.90	1292.
0.90	1293.	1.90	1294.	2.80	1295.	3.20	1296.
1.60	1297.	1.30	1298.	1.20	1299.	1.00	1300.
1.60	1301.	2.20	1302.	1.60	1303.	0.90	1304.
1.40	1305.	2.70	1306.	2.00	1307.	1.30	1308.
1.40	1309.	1.60	1310.	2.00	1311.	1.70	1312.
2.40	1313.	1.20	1314.	1.60	1315.	2.70	1316.
1.40	1317.	1.40	1318.	1.90	1319.	1.30	1320.
2.10	1321.	2.60	1322.	1.10	1323.	1.40	1324.
2.00	1325.	1.90	1326.	1.90	1327.	1.30	1328.
1.00	1329.	1.10	1330.	1.30	1331.	1.80	1332.
1.50	1333.	1.80	1334.	0.90	1335.	0.90	1336.
1.60	1337.	3.10	1338.	1.90	1339.	1.30	1340.
1.90	1341.	2.10	1342.	2.20	1343.	3.00	1344.
2.10	1345.	1.50	1346.	1.50	1347.	1.50	1348.
1.00	1349.	0.80	1350.	1.20	1351.	1.10	1352.
1.00	1353.	2.30	1354.	3.20	1355.	0.90	1356.
0.90	1357.	0.80	1358.	1.30	1359.	1.80	1360.

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     1.80     1361.      1.30     1362.      2.20     1363.      1.20     1364.
     1.20     1365.      1.50     1366.      1.20     1367.      1.50     1368.
     1.20     1369.      0.90     1370.      1.20     1371.      1.20     1372.
     1.80     1373.      1.20     1374.      0.90     1375.      1.40     1376.
     1.10     1377.      1.10     1378.      1.60     1379.      1.20     1380.
     2.30     1381.      1.50     1382.      1.70     1383.      1.50     1384.
     1.70     1385.      1.90     1386.      1.40     1387.      1.30     1388.
     1.00     1389.      1.00     1390.      2.20     1391.      1.70     1392.
     1.70     1393.      1.00     1394.      2.50     1395.      1.10     1396.
     0.90     1397.      0.70     1398.      0.80     1399.      0.70     1400.
     1.10     1401.      3.90     1402.      3.40     1403.      1.40     1404.
     2.20     1405.      2.90     1406.      0.90     1407.      1.10     1408.
     2.10     1409.      3.70     1410.      2.30     1411.      1.40     1412.
     1.90     1413.      3.20     1414.      1.60     1415.      1.90     1416.
     0.90     1417.      0.80     1418.      1.20     1419.      0.90     1420.
     1.20     1421.      1.10     1422.      1.50     1423.      0.60     1424.
     0.70     1425.      2.20     1426.      1.60     1427.      1.00     1428.
     1.40     1429.      2.10     1430.      1.30     1431.      1.20     1432.
     2.60     1433.      3.10     1434.      2.80     1435.      2.80     1436.
     1.30     1437.      0.90     1438.      1.30     1439.      2.90     1440.
     1.20     1441.      0.90     1442.      1.00     1443.      3.50     1444.
     2.30     1445.      2.80     1446.      1.80     1447.      1.30     1448.
     2.50     1449.      2.10     1450.      1.40     1451.      1.30     1452.
     1.10     1453.      1.60     1454.      1.70     1455.      3.30     1456.
     1.80     1457.      1.70     1458.      1.90     1459.      2.80     1460.
     1.30     1461.
  KE1   24     8
   1.52088       1.     1.521      150.     1.574      152.     1.574      273.
   1.41350     274.     1.414      365.     1.521      366.     1.521      515.
   2.10801     517.     2.108      638.     1.414      639.     1.414      730.
   1.52088     731.     1.521      880.     2.167      882.     2.167     1003.
   1.41350    1004.     1.414     1095.     1.521     1096.     1.521     1246.
   1.58106    1248.     1.581     1369.     1.414     1370.     1.414     1461.
  KE2   24     9
  2.090049       1.     2.090      150.     1.427      152.     1.427      273.
  1.460534     274.     1.461      365.     2.090      366.     2.090      515.
  1.433968     517.     1.434      638.     1.461      639.     1.461      730.
  2.090049     731.     2.090      880.     1.062      882.     1.062     1003.
  1.460534    1004.     1.461     1095.     2.090     1096.     2.090     1246.
  1.042883    1248.     1.043     1369.     1.461     1370.     1.461     1461.
  KE3   24    10
  2.150553       1.     2.151      150.     1.811      152.     1.811      273.
  1.699176     274.     1.699      365.     2.151      366.     2.151      515.
  1.834483     517.     1.834      638.     1.699      639.     1.699      730.
  2.150553     731.     2.151      880.     1.571      882.     1.571     1003.
  1.699176    1004.     1.699     1095.     2.151     1096.     2.151     1246.
  1.551330    1248.     1.551     1369.     1.699     1370.     1.699     1461.
  KE4   24    11
  3.107417       1.     3.107      150.     2.712      152.     2.712      273.
  2.185969     274.     2.186      365.     3.107      366.     3.107      515.
  4.013138     517.     4.013      638.     2.186      639.     2.186      730.
  3.107417     731.     3.107      880.     2.522      882.     2.522     1003.
  2.185969    1004.     2.186     1095.     3.107     1096.     3.107     1246.
  2.471301    1248.     2.471     1369.     2.185     1370.     2.185     1461.
TFNH4   37    13
     0.00       1.      0.00       90.       0.1      160.       0.5      190.
      0.2     220.       0.2      250.       0.4      265.      0.80      280.
     1.00     320.       0.0      365.       0.0      455.      0.10      525.
     0.50     555.       0.2      585.      0.20      615.      0.40      630.
      0.8     645.       1.0      685.      0.00      730.      0.00      820.
      0.1     890.       0.5      920.      0.2       950.      0.20      980.
      0.4     995.      0.80     1010.      1.00     1050.       0.0     1095.
      0.0    1185.      0.10     1235.      0.50     1285.       0.2     1315.
     0.20    1345.      0.40     1360.       0.8     1375.       1.0     1415.
     0.00    1461.
TFPO4   13    14
     0.00       1.      0.00      220.       1.0      330.       0.0      366.
     0.00     585.      1.00      695.       0.0      731.       0.0      950.
     1.00    1060.      0.00     1096.       0.0     1315.       1.0     1425.
     0.00    1461.
NH3                                      3   0.0     1.0E08    J:INITIAL CONC.
```

```
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  10:      0.01       0.87  11:       0.01       0.87 12:       0.01       0.80
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  19:      0.05       0.95  20:       0.05       0.95 21:       0.05       0.95
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  37:      9.00        0.1  38:       9.00        0.1 39:       9.00        0.1
  40:      9.00        0.1  41:       9.00        0.1
NO3                                         5  0.0    1.0E08
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   4:      0.10        1.0   5:       0.10        1.0   6:      0.10        1.0
   7:      0.10        1.0   8:       0.10        1.0   9:      0.10        1.0
  10:      0.10        1.0  11:       0.10        1.0  12:      0.10        1.0
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PO4                                         5  0.0    1.0E08
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  19:      0.01       0.90  20:       0.01       0.90  21:      0.01       0.90
  22:      0.01       0.90  23:       0.01       0.90  24:      0.01       0.90
  25:      0.01       0.90  26:       2.50       0.50  27:       2.5        0.5
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  37:      2.00        0.5  38:       2.00        0.5  39:       2.0        0.5
  40:      2.00        0.5  41:       2.00        0.5
PHYT                                        4  0.0    1.0E08
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  40:      0.00        0.0  41:       0.00        0.0
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  25:      9.00        0.9  26:       9.00        0.3  27:      9.0        0.3
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  31:      9.00        0.3  32:       9.00        0.3  33:      9.0        0.3
```

```
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  37:      9.00        0.3  38:        9.00        0.3  39:       9.0        0.3
  40:      9.00        0.3  41:        9.00        0.3
DO                                           5  0.0    1.0E08
   1:      10.0        1.0   2:        10.0        1.0   3:      10.0        1.0
   4:      10.0        1.0   5:        10.0        1.0   6:      13.0        1.0
   7:      13.0        1.0   8:        12.0        1.0   9:      12.0        1.0
  10:      12.0        1.0  11:        12.0        1.0  12:      12.0        1.0
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  37:      0.00        1.0  38:        0.00        1.0  39:       0.0        1.0
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ON                                           3  1.5    1.0E08
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  37:     15.00        0.1  38:       15.00        0.1  39:      15.0        0.1
  40:     15.00        0.1  41:       15.00        0.1
OP                                           3  0.0    1.0E08
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   7:      0.02       0.85   8:        0.02       0.85   9:      0.02       0.85
  10:      0.02       0.85  11:        0.01       0.85  12:      0.01       0.90
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  37:      2.00        0.1  38:        2.00        0.1  39:       2.0        0.1
  40:      2.00        0.1  41:        0.50        0.1
```

Appendix D
Comments and Response

1.1 JORDAN LAKE NUTRIENT RESPONSE MODEL

1.2 RESPONSE TO NC DWQ COMMENTS

On May 7, 2002, NC DWQ provided comments on the draft Jordan Lake Nutrient Response model report. Responses to each of the comments are interleaved below, and will be incorporated in a revised version of the report.

• Section 1. Fifth paragraph. Provide additional background information describing why total nitrogen is the target nutrient as opposed to total phosphorus or both nutrients.
Both nitrogen and phosphorus are target nutrients. This was clarified in the April 10th version of the document.

• Section 1, Sixth paragraph. Provide additional text to explain why a watershed model was not developed.
This issue is addressed by inclusion of additional text on p. 1-4. A watershed model was not developed as this was not required by General Statute 143-216.1 and would have diverted limited resources away from the lake model.

• Section 2.1. The discussion on other modeling efforts that utilized the WASP modeling frameworkshould be limited to applications similar to the Jordan Lake Model (i.e., eutrophication).
Done

• Section 2.1.2 Second and third paragraphs. References to the eight "state" variables should be supplemented by a list of those variables.
Done

• Section 2.3.1. Third paragraph. Change first sentence to "Preston et al. (1989) undertook a detailed study of advantages and disadvantages of various methods for calculating annual loads from tributary concentration and flow data."
Done

• Section 2.3.1. Fourth paragraph. Change second sentence to "Preston et al. show that stratification of the sample data and analysis method, however, can reduce error in estimation." (Preston et al 1989 was testing sampling strategies as well as estimation techniques. In fact, in one section of the paper he states that stratification with regression produced poor results with low structure in sampling. See also Preston et al 1992, Richards & Hollaway 1987, and Robertson & Roerish 1999.)
Done

• Figure 3-1. Discuss why these two cross sections were displayed and how representative they are of the lake. A discussion of how bathymetry has changed since lake construction would be useful.
More discussion has been added. Bathymetry for the model is based on the 1997 resurvey by the Corps and is thus believed to be current and accurate.

• Table 3-1. Describe how the ratio that modifies the gage data was derived (e.g., for flow series 2: 1.25 x gage).
This factor is the ratio of total area of the drainage to drainage at the gage. An explanatory note has been added to the table.

• Section 3.1.4. Figure 3-10b. Please provide an explanation in the text for the constant cumulative southward movement of the top layer for 1998. This is contrary to the other three years presented which have some portion of the year with net northward movement. Additionally, the text mentions that the strongest southward movement is in Layer 2. This seems contrary to the figures that show a strong southward movement in Layer 3.
Lake hydraulic behavior in 1998 is somewhat different from other years because of unusual inflow patterns in this year (strong spring flows, essentially no major flows until winter) that minimized backflow from the Haw into the New Hope Arm. A discussion has been added to the text. The comment is correct regarding the location of strong southward movement. This occurs in both layers 2 and 3, and the text has been corrected to reflect this.

• Section 3.1. Please provide additional information regarding the linkage between EFDC and WASP. Address conservation of energy and stability issues associated with collapsing the grid between the models.
Added the following discussion: Fluxes across each of the WASP segment boundaries are obtained by summing all the corresponding boundary fluxes estimated for the smaller EFDC cells. In moving to a coarser scale (in space and time), the WASP model represents an averaging of the EFDC simulation of the movement of water. Some fine-scale detail of water movement is potentially lost in this process; however, the effect on the movement of pollutants can be incorporated into the macrodispersion (mixing) coefficients in the WASP model. These dispersion coefficients were taken as calibration parameters in the WASP application. The EFDC to WASP linkage does not result in any conservation of energy problems as both momentum and thermal energy simulation are handled exclusively within EFDC. Testing of the resulting WASP model showed that mass is conserved and stability maintained within the water quality simulation. Thus, the WASP model is a simplified representation, but firmly based in the detailed flow and temperature simulation of the lake provided by EFDC.

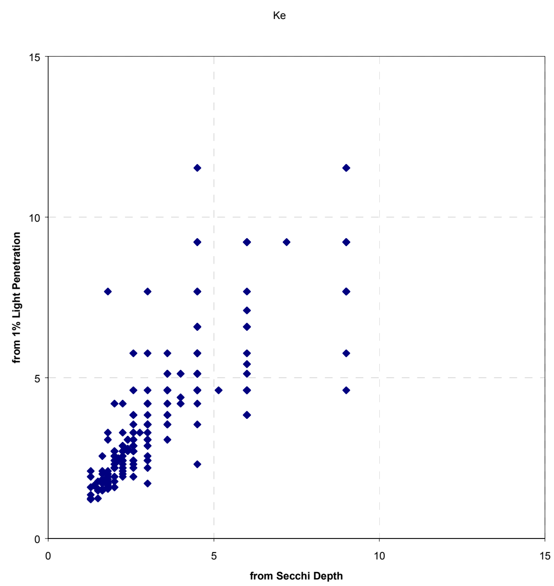
• Section 3.2.1.1. WASP Simulation Grid. First paragraph. Change third sentence to "In addition, the four vertical layers in EFDC are collapsed in WASP."
Text modified.

• Section 3.2.1.1. Thermal Simulation Linkage. First paragraph. Provide rationale for using temperature from WASP segment 4 (CPF086F) for the upper and middle New Hope sections. Temperatures in Segments 1 through 3 would be expected to be warmer than Segment 4 during summer, and colder during the winter. Additionally, temperatures in Segment 2 would be expected to be closely associated with effluent temperature given the discharge proximity and volume.
Temperature at CPF086F was selected because this is a calibration point, with a long-running series of observed data. We agree that daytime temperatures in Segments 1 through 3 are likely to be slightly warmer than those observed at CPF086F, although the

difference in surface temperatures among water quality stations in these segments (CPF086F, CPF086C, CPF086UPS, CPF081A1C, CPF081A1CUPS) generally appears to be less than 2 degrees Celsius. In the WASP simulation, temperature affects reaction rates (the effects of the temperature gradient on water movement are addressed directly in the EFDC model). Some small improvement in the water quality simulation might result from specification of additional temperature profiles to the model. However, the impact would be small, and a considerable amount of effort would be required to implement the change. As a result, the temperature simulation has not been changed at this time, although this could be considered as a future enhancement of the model. No changes have been made to the text.

• Section 3.2.1.3. Sixth paragraph. Describe how the light extinction coefficient and Secchi depth relationship is confirmed by a comparison to DWQ sampling in 2000.

The differential equation for light penetration can be integrated to express the depth at which 1 percent of the surface radiation remains (z1) as z1 = 4.61/Ke. This is now explained in the text. A comparison of extinction coefficients (Ke; m^{-1}) is shown in the inset figure. (Note: This figure has not been included in the report). The two estimates of Ke are in general agreement, although there is considerable scatter, and a few outlying cases in which either the Secchi depth or the depth of 1 percent light penetration appear suspect. Because light penetration was not measured in other years, it is preferable to estimate the temporal variability in light extinction from Secchi depth.



• Table 3-11. Provide the coefficients for combined effects of algal self-shading and non-algal shading (Ke).

Total light extinction (Ke) is not an input to the model. Rather, the model calculates Ke on a dynamic basis from user input non-algal light extinction (Ke′) and the chlorophyll a concentration simulated by the model. Therefore, it is not appropriate to include a table of Ke values in the section on model forcing functions.

• Table 3-14. Should the KSEG value be different from the scaling factor (1.8) used in section 3.2.1.3? Also, are the values not already scaled?

The factor 1.8 in Section 3.2.1.3 is an empirical coefficient for the conversion of Secchi depth to a light extinction coefficient (Ke). As noted above, this conversion factor appears reasonable for Jordan Lake; however, because it is an empirical factor it is subject to uncertainty. In particular, the total light extinction coefficient is not an exact representation of the rate of extinction of light energy in the photosynthetic range. Therefore, adjustment of KESG was allowed (within limited ranges) during the calibration. The value presented in Table 3-15 is an additional multiplicative

adjustment on the light extinction coefficient obtained from optimization of observed chlorophyll a data. (No changes in text necessary.)

• Section 3.2.5. Ninth paragraph. The suggestion that high uncorrected chl *a* values reported during 2000 could have resulted from pheophytin derived from decaying terrestrial vegetation is not very convincing. If this explanation is retained in the text, please discuss other scenarios. Large pheophytin components could have resulted from die off or heavy grazing of blooms that were not captured in the sampling. What role might physical changes (light extinction, incoming irradiance, temperature or flow) conditions have played in contributing to high chl *a* levels? There appears to be considerable uncertainty regarding light extinction in the lake. What role could this have played in model predictions during 2000?
We agree that there are many sources of uncertainty – the largest of which may be in the reported chlorophyll a data themselves, which were affected by a range of analytical problems during this period. The comment is correct that the discussion of terrestrial pheophytin is purely speculative and not based on data. This discussion has been removed from the text.

• Section 3.2.6. Provide a sensitivity analysis to examine light extinction. Discuss how light extinction data might impact prediction uncertainty for chlorophyll *a*. This seems quite relevant considering the strong light limitation in Jordan.
Chlorophyll a predictions are highly sensitive to the light available for photosynthesis, which depends on both the incident solar radiation (which is affected by shading and cloud cover) and the light extinction coefficient. Sensitivity to light extinction is primarily an issue of data uncertainty. That is, the time series of non-algal light extinction must be estimated from a rather sparse series of Secchi disk observations. It is highly probable that much of the short-term variability in algal concentrations that is not captured by the model may be due to variations in water clarity not captured by the monitoring program. A discussion to this effect has been included in Section 3.2.6.

• Figure 3-30. Provide similar plots for the other segments (i.e., Segments 1,5,7,9,10,11, and 13).
The light limitation plots included in 3-30 are representative of the range of conditions throughout the lake. As a result, we do not feel it is necessary to include additional plots for the remaining segments within the report. However, a complete set of light limitation plots for all segments is attached to this response for DWQ's information.

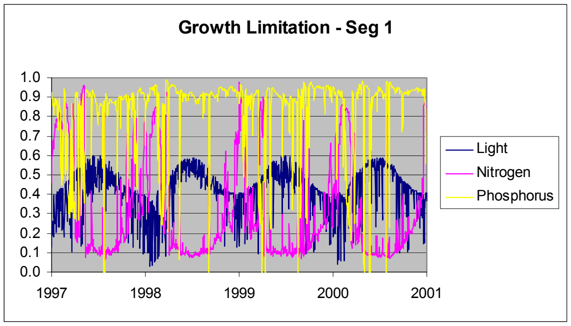
• Section 3. Model Results. A section should be added to discuss and present model results independently of scenario analysis in Section 4. This section should contain a scenario with a conservative tracer load to Segment 2 (or 3) and to Segment 15. (Both pulse and continuous loads should be evaluated.) This section should also contain results of the sensitivity analysis of light extinction, in addition to other model sensitivity analyses conducted.
The suggestions contained in this comment are good ones, and model experiments of conservative tracer dilution are indeed being performed. We do not, however, feel that it is necessary or appropriate to include this type of information in the Calibration report. Rather, these types of model results will be generated and documented as model scenario application proceeds. In that context, we should clarify that the scenarios

presented in the Chapter 4 of the Calibration report are presented primarily as an example of the type of applications possible with the modeling tool. We fully anticipate that all the future scenarios will be revised as a result of ongoing discussions with DWQ. It should also be noted that Figure 4-4 in the draft report used incorrect data and has been corrected. Finally, the future scenario runs contained in the report have been revised to reflect some refinements in the calculation of EPS values in Table 4-5.

• Table 4-2. Projected Wasteflows for 2010 for Selected Major Municipal Wastewater Treatment Facilities in the Jordan Lake Watershed. Discuss these projects and consistency with each municipal facility Waste and Sewer Master Plan and/or 201 Facilities Plan.
The Project Partners were not required to develop and analyze a Year 2010 Wastewater Discharge Scenario, but voluntarily did this to demonstrate how the model could be used to evaluate alternative scenarios. Year 2010 flow projections for several facilities were based on relatively recent 201 wastewater facility plans or sewer utility system master plans. However, Year 2010 flow projections for a few facilities were based on an initial analysis and projection developed by local utility staff. The Year 2010 (or later) flow projections for some systems will need to be refined at such time as additional point and nonpoint source loading and management scenarios are defined and evaluated.

• Section 4. Final paragraph. It would be useful to include a brief discussion of prediction uncertainty with respect to the modeled scenarios. Also, how might the model be improved? It appears that better chlorophyll *a* data (via Welschmeyer/non-acidified method) and light extinction data (using a light meter) would provide for better fits and improved confidence in scenarios. This will be particularly important for the ensuing management strategy.
Regarding uncertainty in scenario results, the following text has been added to the end of Chapter 4: "It should be recalled that the scenario predictions are subject to a number of sources of uncertainty. These first include the uncertainty inherent in the model calibration and in the external forcing data, as discussed in Section 3.2.6. However, the model does provide a firm basis for comparison of the relative effects of different management scenarios. In addition, there is uncertainty inherent in the specification of the future scenarios themselves. The Project Partners expect to work with DWQ to refine scenario applications with the Jordan Lake Nutrient Response Model."

Issues of data collection and model improvement as a result of additional data collection are being addressed in Monitoring Program recommendations that the Project Partners hope to pass along to DWQ in the near future.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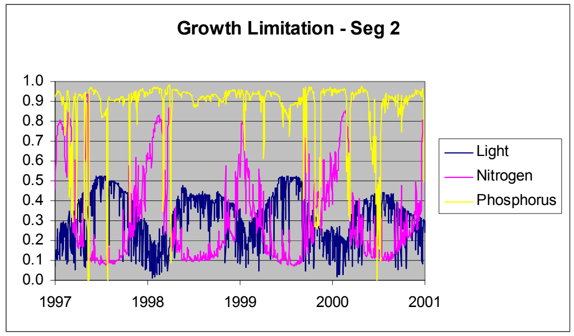
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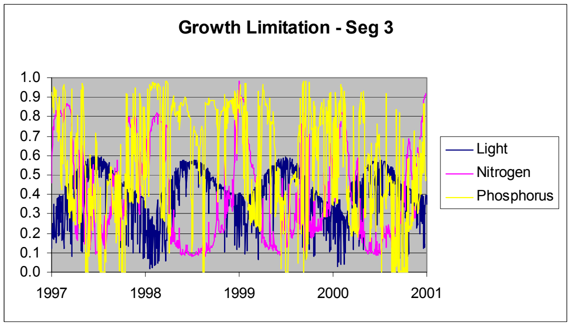
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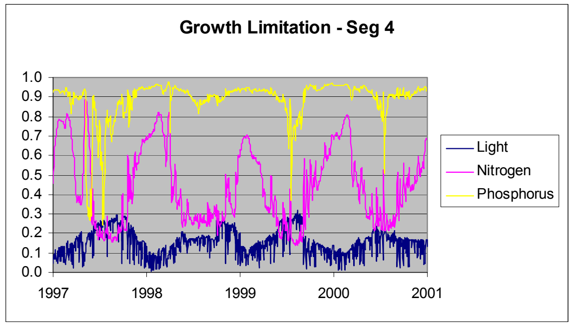
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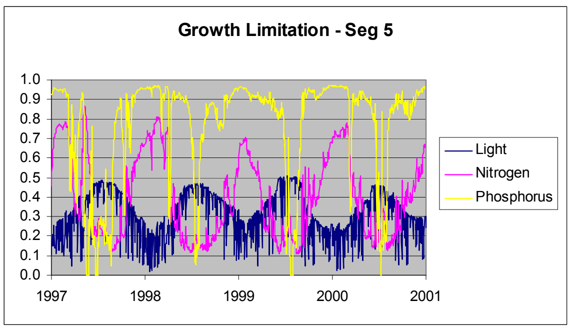
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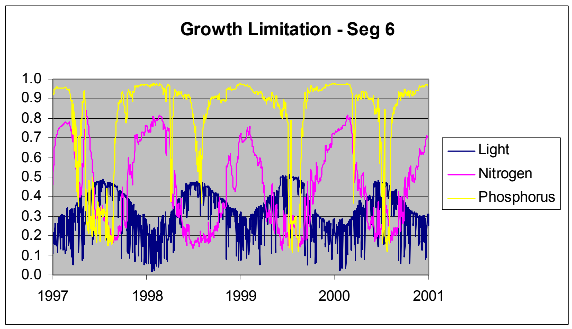
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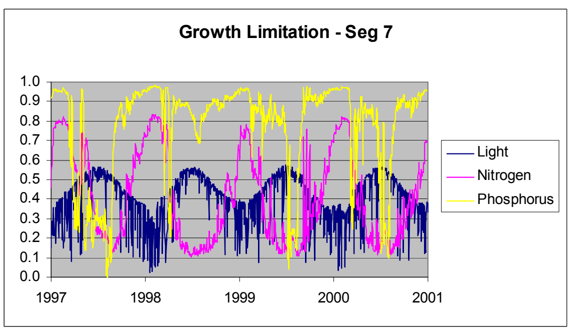
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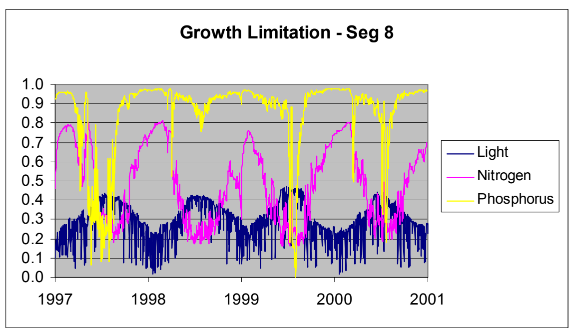
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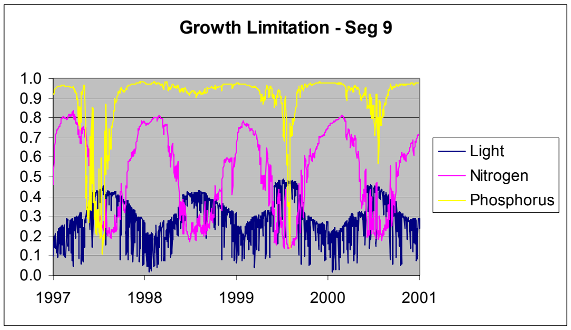
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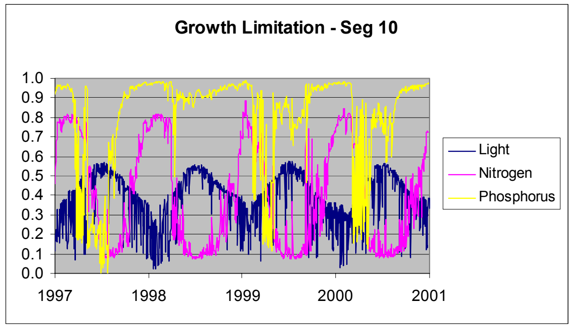
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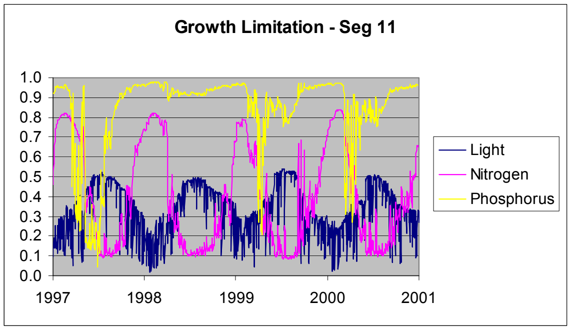
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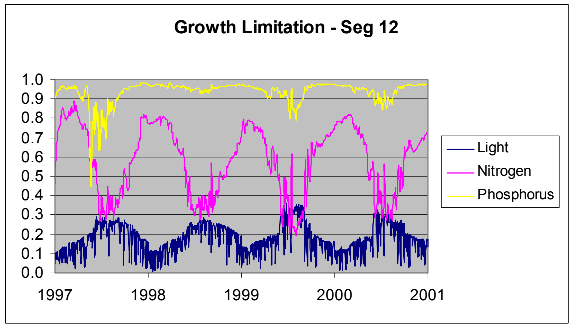
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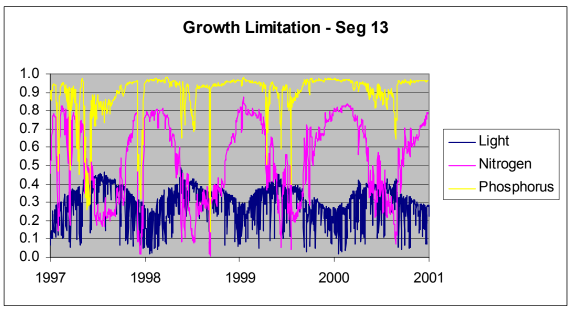
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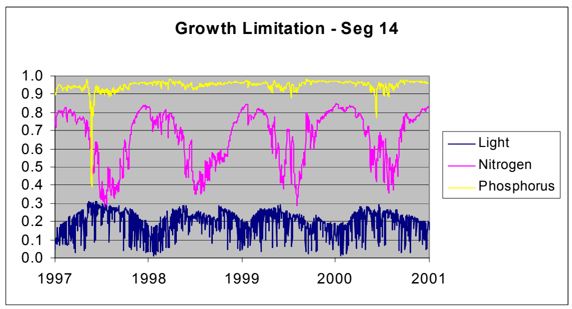
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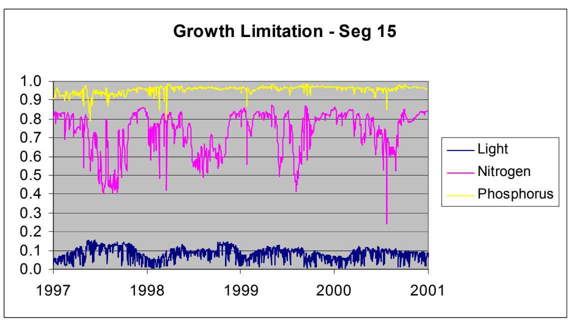
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Appendix E
Recommendations for Additional Monitoring in Jordan Lake and its Tributaries

Background

The project consulting team has completed development of a modeling framework for evaluating nutrient response in Jordan Lake. Through analysis of existing water quality monitoring data for the project, Tetra Tech has identified data gaps or limitations of existing monitoring information available for continued refinement of the Jordan Lake Nutrient Response Model. As requested by the Jordan Lake Modeling Project Partners, this Technical Memorandum includes recommendations for additional monitoring that could be used to fill those information gaps and/or provide additional information of interest to the Jordan Lake Modeling Project Partners and other stakeholders in the Jordan Lake watershed.

Additional and/or redirected technical and financial resources will be required to implement the monitoring activities recommended below. This memorandum does not include any estimates of potential costs, or suggestions regarding appropriate roles and responsibilities for funding or conducting these monitoring efforts. It is expected that Triangle J Council of Governments will provide the Project Partners with supplemental information regarding potential approaches for accomplishing the monitoring tasks identified in this memorandum.

Potential Purposes for Additional Monitoring in Jordan Lake and its Tributaries

Tetra Tech has identified the following potential purposes for collecting additional monitoring data to support continuing management efforts for Jordan Lake:

- Track conditions over time
- Improve Modeling
  - Reduce uncertainty
  - Improve model calibration
  - Allow extension of the model to additional years
- Support study of additional lake processes that fall outside of the scope of the model but that may be of interest to the Project Partners or other stakeholders. For example, it may be desirable to collect data that help to describe the relationship between in-lake conditions, particularly algal blooms, and uses for drinking water, recreation, and fisheries.

Monitoring recommendations can be divided into three groups: In-lake, tributary, and meteorological. Recommendations under each category are noted as high priority, moderate priority, or "research." The latter category generally includes high-effort projects that would require further scoping and planning.

1. In-lake Monitoring

Figure 1 shows the locations of the North Carolina Division of Water Quality's (DWQ) in-lake water quality monitoring stations at Jordan Lake. To enhance the calibration and verification of the Jordan Lake Nutrient Response Model, DWQ collected more intensive in-lake monitoring data in 2000-2001 at most stations (shown by open circles on the map). This additional monitoring was very useful, but DWQ staff have indicated that DWQ cannot continue to maintain that level of in-lake monitoring. Therefore, it is important to determine the key aspects that should be continued or expanded.

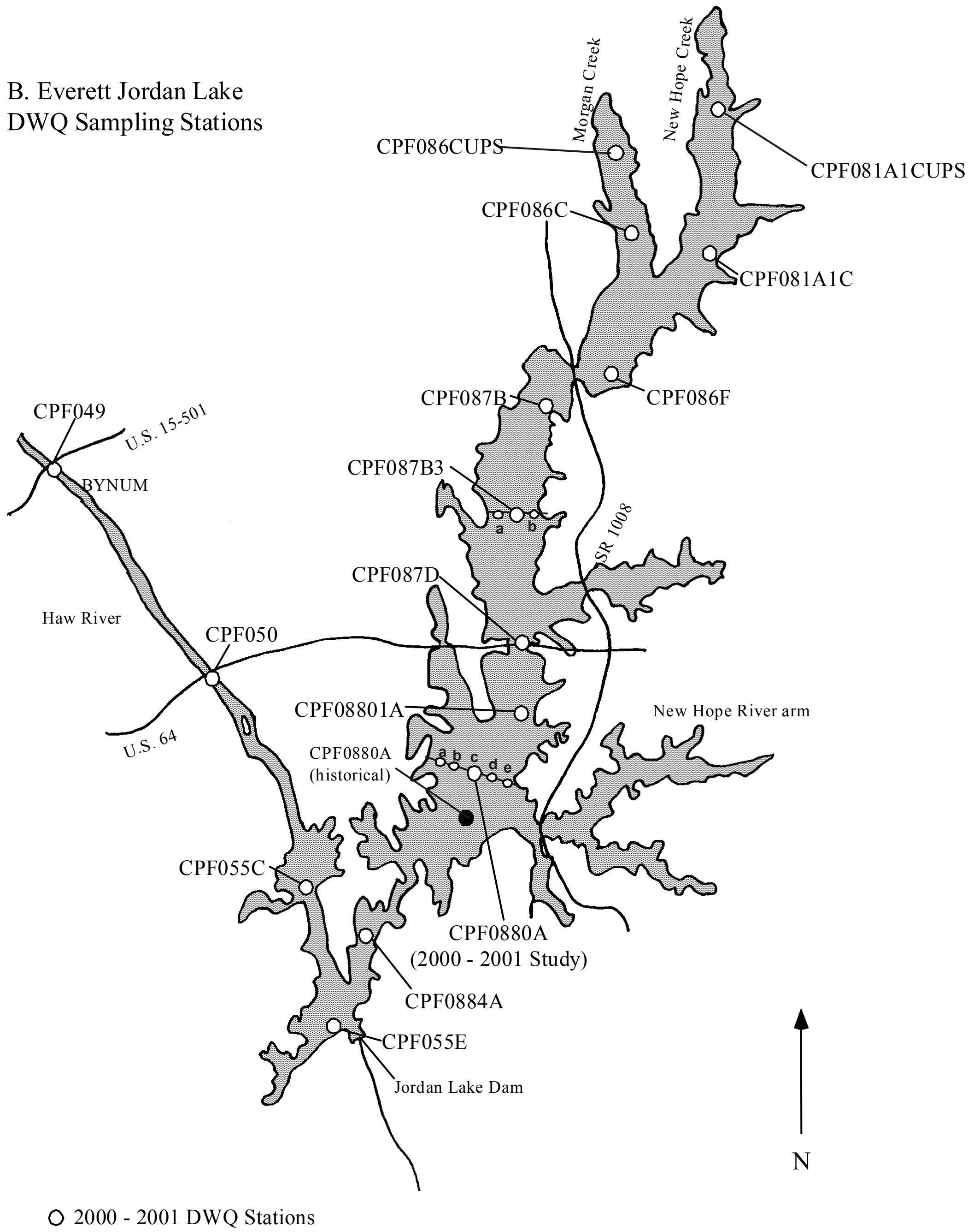

Figure 1. DWQ Water Quality Sampling Locations in Jordan Lake

1.1 (*High priority*) In 2000-2001, the data provided good coverage both temporally and spatially. One lesson learned from observing these data is that the nutrient and chlorophyll *a* concentrations vary only gradually in space, with the exception of sharp breaks at the causeways. On the other hand, conditions vary rapidly in time. It would be desirable to improve temporal coverage for laboratory parameters, even at the expense of less spatial coverage. It is recommended that at least monthly measurements be taken throughout the year, with biweekly samples taken during the growing season at a subset of stations. Key stations for continued monitoring with recommended sampling frequency are as follows:

	Winter Frequency	Growing Season Frequency
Upper New Hope		
CPF086C	monthly	monthly
CPF081A1C	monthly	monthly
CPF086F	monthly	bi-weekly
Middle and Lower New Hope		
CPF087B3	monthly	monthly
CPF087D	monthly	monthly
CPF0880A	monthly	bi-weekly
Haw Arm		
CPF055C	monthly	monthly
CPF055E	monthly	bi-weekly

1.2 (*High priority*) Significant algal blooms may occur during Fall but have been infrequently monitored; therefore, continued collection of Fall data is of particular importance. 2000 data suggested that the model may have some problems representing conditions in Fall, but poor reliability of chlorophyll *a* results for that year makes it difficult to tell.

1.3 (*High priority*) Physical data should continue to be collected at all current stations, including vertical profiles. Temperature, Secchi depth, and DO are the most important parameters, and collecting the data more frequently (e.g., weekly) at a limited number of stations could improve model calibration.

1.4 (*High priority*) The 2000-2001 monitoring provided middle- and bottom-level nutrient concentrations for the first time since the 1980s. Rates of nutrient evolution from the sediments appear to be generally low, but this phenomenon does occur, particularly during summer stratification in the deeper areas of the lake. Collection of bottom nutrient samples should continue, but can be at a lesser level than in 2000-2001. Late summer is the key time for collection. It is recommended that, at a minimum, middle- and bottom-level nutrient monitoring be conducted at the following stations: CPF055C, CPF055E, CPF0880A, and CPF087B or B3.

1.5 (*High priority*) It is essential that the issue of suspect chlorophyll *a* measurements be resolved using good quality assurance/quality control (QA/QC) measures. Split sampling (by two or more laboratories using the same analytical methods) should be an integral part of a QA/QC program to improve confidence in analytical results, and to aid in better understanding and quantifying error and uncertainty.

1.6 (*High priority*) A full analysis of the 2000-2001 water quality monitoring data should be undertaken. All of the data for that 2-year period was not ready in time for the project consulting team to consider during the preparation of the Technical Memorandum on existing water quality data.

1.7 (*Moderate priority*) No water quality data are available for several minor tributary arms of the lake. Given the potential for future growth in near-lake watershed areas, and the associated potential for water quality impacts, water quality monitoring should be commenced in the White Oak Creek and Beaver Creek embayments.

1.8 (*Moderate priority*) The water quality model currently provides a reasonable representation of dissolved oxygen in the lake. However, it has not been intensively calibrated as a DO model. To improve the DO calibration a series of diurnal DO and temperature measurements would be necessary.

1.9 (*Moderate priority*) It has been suggested that to better address water supply treatability issues, the model should be enhanced to predict algal response for various algal groups – separating blue-greens (and perhaps diatoms) from other algal groups. To support the calibration and verification of an algal species response model, more taxonomic and algal biovolume monitoring work is needed. Algal monitoring for the existing water supply intake site should be enhanced. Similar monitoring should be commenced at the proposed intake on the west side of the lake at the Bell's Landing area. Algal collection, identification and enumeration efforts should continue at stations in the Upper New Hope (CPF086F) and near the dam (CPF055E).

1.10 (*Research*) Modeling response of algal communities to nutrient loading changes is a very challenging task with a large degree of uncertainty involved. Conducting algal bioassay work similar to what Hans Paerl has done for the Neuse estuary studies could provide an empirical way of predicting response. Through in situ monitoring, algal community composition could be evaluated under different nutrient concentrations to determine potential species changes associated with various nutrient management scenarios.

1.11 (*Research*) The models have thus far been calibrated to scattered point-in-time observations. This type of data does not allow resolution of the role of short-term variability and daily cycles. The only way to fully resolve these issues is to undertake an intensive monitoring study with greater temporal frequency. While considerable thought should be invested in planning any such program, it would appear desirable to undertake a study that included daily laboratory (chemical, chlorophyll *a*) measurements and automated hourly physical measurements over a period of several weeks at three (or more) locations in the lake – in the Upper New Hope, Lower New Hope, and near Dam segments.

1.12 (*Research*) To support determination of use impacts, it would be desirable to correlate algal measures/predictions with other measures of use. Of interest here may be (1) taste and odor problems reported by Cary water customers, (2) reports of fish kills, (3) complaints regarding aesthetics by recreational users, and (4) possible health problems associated with water-body contact recreation in the lake. A system would need to be established to report and analyze these qualitative data.

2. Tributary Data

2.1 (*High priority*) Algal response in the lake is strongly controlled by external nutrient loads. Existing tributary monitoring efforts by DWQ, USGS in partnership with the Triangle Area Water Supply Monitoring Project, the Upper Cape Fear River Basin Association, and others needs to be continued and enhanced to improve accuracy of nutrient loading estimates over time.

2.2 (*High priority*) It is clear that management and modeling of the lake requires better knowledge of high-flow nutrient transport from the tributaries. Special emphasis is needed to better assess variations in tributary nutrient loads during high flow and low flow conditions. It is recommended that at least 50% of water quality sampling data be from high flow events. The protocols for determining "events" for sampling need to be carefully defined to assure that event sampling actually coincides with a well-defined storm hydrograph.

2.3 (*High priority*) Continuous streamflow gaging stations need to be maintained at the major tributaries to the lake. In light of the problems with vandalism at the Northeast Creek gage, all stations should be reviewed and "hardened" to reduce vulnerability to vandalism.

2.4 (*Moderate priority*) Algal concentrations in the tributaries and wildlife sub-impoundments are basically unknown, but may help seed some algal blooms in the lake. Some chlorophyll *a* analyses should be added to the tributary monitoring.

2.5 (*Research*) The in-stream nutrient transport loss rates assumed in the Tributary Nutrient Delivery Model (Research Triangle Institute, 2002) were based on empirical values. Those rates should be validated with field investigations, and refined where appropriate. The primary focus should be on the Haw River loss rates, as total losses appear to be small in the New Hope tributaries. However, the effect of the wildlife sub-impoundments should be assessed. The basic concept would be to assess and compare loads at several sequential stations along the tributary mainstems. This could be done on two levels, examining both event transport (tracking a single "parcel" of water along the river) and on a long-term loading basis. The task is not a simple one, however, as it is necessary to account for additional inputs (both surface and subsurface) as well as losses between stations. Final resolution of the loss component might need to await completion of a watershed model; however, collection of data to support such an effort could begin now.

3. Meteorological Data and Atmospheric Deposition

3.1 (*Moderate priority*) The model is using data from RDU Airport and the Turfgrass and Reedy Creek AgNet stations, all of which are northeast of the lake and may not be very representative of on-lake conditions. An automated meteorological station at the dam would be useful in reducing this source of uncertainty.

3.2 (*Research*) Research in other regions (Chesapeake Bay area, Neuse River Basin) has indicated that atmospheric deposition of nitrogen is a significant source of total nitrogen load in those areas. Consideration should be given to conducting atmospheric deposition monitoring in the Jordan Lake watershed to better quantify direct wet and dry depositional fluxes to the watershed.