Application of the Water Quality Analysis Simulation Program (WASP) to Evaluate Dissolved Nitrogen Concentrations in the Altamaha River Estuary, Georgia

by

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(Under the Direction of Merryl Alber)

ABSTRACT

The Water Quality Analysis Simulation Program (WASP v.7.4) and a water flow model, SqueezeBox, were used to model concentrations of dissolved nitrogen (DN) in the Altamaha River estuary, Georgia. Model development was guided by previous studies using WASP, literature surveys, and sensitivity analyses. The model was calibrated and validated against observations from the Georgia Coastal Ecosystems Long Term Ecological Research project. Average error between model predicted and observed concentrations was 39.8 % for NH_3, 23.6 % for NO_3^-, and 7.8 % for DON. Results from the calibrated model showed that riverine DN input had an approximately 6-fold greater influence on predicted DN in the estuary than either flow or temperature. Overall, predicted DN concentrations were highest for high DN input, high flows, and low and medium temperatures.

INDEX WORDS: Nitrogen, Georgia, Altamaha, Estuary, WASP, SqueezeBox, Model

APPLICATION OF THE WATER QUALITY ANALYSIS SIMULATION PROGRAM (WASP) TO EVALUATE DISSOLVED NITROGEN CONCENTRATIONS IN THE ALTAMAHA RIVER ESTUARY, GEORGIA

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B.S., University of Florida, 2003

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2011

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August 2011

ACKNOWLEDGEMENTS

I am incredibly thankful for all of the assistance that I have received during my journey through graduate school. I have been very fortunate to have the support and friendship of many wonderful people.

I would first like to thank my advisor, Dr. Merryl Alber, for all of her help and hard work in showing me what was needed to put together a project that I could be proud of. She provided me with so much valuable guidance. Dr. Alber's advice and patience throughout my time in graduate school helped me to learn a great deal and navigate the trials of being a student.

I would also like to thank the rest of my committee for the extremely valuable and key support that they provided me throughout my project. Dr. Christof Meile acted as my co-advisor, generously providing me with so much of his time to help me learn the intricacies of model development and theory and guide my work. The contribution of time, energy, and resources that Dr. Samantha Joye and her lab have put in to collecting and maintaining the data that I used is immense and very much appreciated. She also provided very helpful guidance on the processes affecting nitrogen in estuaries. Mr. Ambrose gave me a lot of support learning WASP and provided so many answers about WASP and the details behind its functions, helping me to become very comfortable with the model and how it works.

I was also very fortunate to have Joan Sheldon's generous assistance not only in teaching me SqueezeBox and modifying SqueezeBox for this project, but also in teaching me many of the aspects of estuarine hydrodynamics and ecology.

The endless work of the GCE LTER field crew, data managers, and everyone involved with the collection, processing, and management of the GCE LTER long term monitoring data is very much appreciated. In particular, I am thankful for the help of Wade Sheldon in supplying me with data and the use of computer resources and for the data and assistance given to me by Kimberly Hunter.

I am very grateful to Lester Yuan for the help he gave me using R. Without him the application of this model would look very different.

Tim Wool was also another great resource to teach me the finer points of WASP and to help me use the model in the ways needed for this project.

I also owe a huge debt of gratitude to the people not directly involved with my project who provided their love and friendship throughout my trials. They kept me smiling and moving ahead, and were the best people that anyone could ask for. First and foremost, I would like to thank my family. They have always been 100% behind me 100% of the way. Their unwavering love and support has helped me with everything I have faced in life. Danielle Holm gave me endless encouragement and emotional support; it has meant the world to me and I will be eternally grateful for it. The friends that I have made while in graduate school are the best that anyone could wish for and they became like family during my time in Athens. Thank you to each of them for all of the good times, laughter, and memories.

Thank you to Sharon Barnhart, who provided me with so much help keeping computers running and finding me computers to run the many, many model simulations.

The Alber Lab has been a never-ending source of support. For mud fights, support in hot muddy marshes, and constant laughter I am very thankful.

The time, help, and encouragement given to me by the staff of the US EPA Office of Water, Health and Ecological Criteria Division has been invaluable; they made working full time while finishing this project much more bearable.

The ever-supportive office staff in the Department of Marine Sciences also helped me navigate the perils of paperwork and satisfy the requirements needed to graduate. In particular, I would like to thank Jennifer Pressey for the many times she went out of her way to help me.

I am very appreciative of the financial support for this project from the Georgia Coastal Ecosystems LTER, a University of Georgia University Wide Fellowship, The National Sea Grant College Program Dean John A. Knauss Marine Policy Fellowship, and the US EPA Student Career Experience Program.

To hundreds of other people that helped me along the way, thank you. It is through all of your collective help that I have finished this work.

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INTRODUCTION

Nitrogen is one of the nutrients most commonly found in excess in estuarine environments (Howarth et al., 2002; Bricker et al., 2007). Although nitrogen (N) occurs naturally in estuaries, the presence of high levels can be problematic because its preeminent role in eutrophication (Bowen and Valiela, 2001; Howarth and Marino, 2006). For this reason it is important to understand its distributions and dynamics in estuaries. However, this is often difficult to accomplish because of the many complicated processes at play. Both natural and anthropogenic sources affect the amount of nitrogen that enters an estuary, although, increasingly, anthropogenic inputs frequently exceed natural ones (Howarth et al., 1996; Vitousek et al., 1997). Sources of nitrogen include transport from rivers or the coastal ocean, local runoff and groundwater inflow, atmospheric deposition, and nitrogen fixation. Human activities can increase these inputs via runoff from urban and agricultural lands, domestic wastewater input from municipal treatment facilities and septic tanks, and atmospheric deposition from anthropogenic sources (Howarth et al., 1996; Castro et al., 2003). Estuaries receive these inputs not only from local sources, but also from upstream areas in their watersheds.

Once N enters an estuary its processing is strongly controlled by autotrophic and heterotrophic microbial dynamics (Figure 1; Nixon and Pilson, 1983; Blackburn and Sorensen, 1988; Herbert, 1999). Accordingly, factors that affect these organisms such as water temperature, inorganic and organic substrate quality and quantity, sunlight availability, and dissolved oxygen (DO) levels can all affect nitrogen cycling. Physical transport mechanisms also play a large role in determining the spatial and temporal distribution of nitrogen in an estuary. Examples of these mechanisms include settling, resuspension, and burial of particles as well as exchange with rivers, the coastal ocean, and intertidal marshes through riverine advection, tides, and waves (Nixon and Pilson, 1983; Herbert, 1999; Dettmann, 2001). Direct chemical controls on nitrogen levels are generally less important, but diffusive gradients, redox species, and salinity have been shown to also have direct effects on nitrogen concentrations in estuaries (Nixon and Pilson, 1983; Joye and Hollibaugh, 1995; Hopkinson et al., 1999). All of the above processes determine not only the amount, but the speciation of nitrogen into both inorganic (nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3)) and organic (dissolved organic nitrogen (DON), particulate nitrogen) forms. Speciation of nutrients can strongly affect the growth rates of phytoplankton and microbes in an estuary, with bioavailable dissolved forms being most influential (McCarthy et al., 1977; Paasche, 1988; Berman and Bronk, 2003).

There have been numerous efforts to model N dynamics in estuaries. Many of these have used the U.S. Environmental Protection Agency's Water Quality Analysis Simulation Program (WASP). WASP is an interactive compartment-modeling application that integrates stand-alone hydrodynamic and water quality modeling modules. The WASP modules are based on principles of conservation of momentum and mass, respectively. The WASP model allows one, two, and three-dimensional representation of a system through both vertical and horizontal segmentation and accounts for both water column and benthic processes. The EUTRO sub-model of WASP contains the kinetic routines that simulate nutrient enrichment, eutrophication, and DO depletion processes (Figure 2). The basic EUTRO module is capable of tracking the movement and transformation of up to 8 environmental parameters that are involved in the interaction of 4 main systems: phytoplankton, nitrogen, phosphorus (P), and dissolved oxygen.

The WASP model has been used in several estuaries in the southeastern United States, including Tampa Bay, Florida (Wang et al., 1999); Charleston Harbor, South Carolina (Yassuda et al., 2000); the Neuse River estuary, North Carolina (Wool et al., 2003); and the Satilla River estuary, Georgia (Zheng et al., 2004). These studies were primarily concerned with the prediction of phytoplankton and DO responses to changes in nutrient loading, often in support of Total Maximum Daily Load (TMDL) calculations and waste load allocations for point sources. Although the model results do not always match observations, they are fairly good at reproducing the overall distributions of various nitrogen species in the water column. For example, NO_3^- concentrations predicted for four points in the Neuse River estuary (Wool et al., 2003) only differ 7.2 % on average from the observed concentrations. In general, WASP slightly under-predicted upstream NO_3^- concentrations, or predicted in the low range of observed values while slightly over-predicting downstream values (see Wool et al., 2003; Zheng et al., 2004). The overall pattern of ammonia distribution was also adequately represented in these studies. However, model predicted ammonia values tended to be overestimated, with larger differences between modeled and observed values occurring at downstream stations (see Wang et al., 1999; Wool et al., 2003; Yassuda et al., 2004; Zheng et al., 2004). Organic nitrogen was not analyzed in all of the studies, but in Tampa Bay and Charleston Harbor WASP generally over-predicted concentrations (Wang et al., 1999; Yassuda et al., 2004).

The goal of this study was to simulate nitrogen dynamics in the Altamaha River estuary, Georgia and examine the influence that changes in flow, nutrient loading, and temperature would have on nitrogen concentrations. The Altamaha River has one of the largest watersheds on the

East Coast, draining approximately 36,000 km^2 into the South Atlantic Bight in the central coast of Georgia (Figure 3). The river channels water from approximately one-quarter of the state of Georgia as it flows through the Piedmont and Coastal physiographic provinces (Asbury and Oaksford, 1997). River discharge over the period of record (1931-present) ranges from 40-5289 $m^3 s^{-1}$ with a median value of 240 $m^3 s^{-1}$ and a mean of 398 $m^3 s^{-1}$. Highest flows of freshwater are usually concentrated during the spring, while low flows typically occur during the summer months. Although much of the watershed is sparsely populated, watershed sources of anthropogenic nitrogen have been found to contribute to riverine nutrient concentrations (Weston et al., 2009). Primary anthropogenic sources include fertilizer inputs, livestock wastes, and human wastes from populations centers such as Macon and portions of suburban Atlanta (Asbury and Oaksford, 1997; Schaefer and Alber, 2007; Weston et al., 2009). The population in the watershed is rapidly expanding, increasing the potential that river and estuarine water quality could be negatively impacted by increased anthropogenic nitrogen inputs (Weston et al., 2009). A budget constructed to evaluate N inputs to the estuary showed that riverine N is the dominant input to the estuary (Appendix A).

The Altamaha River estuary extends from just seaward of the mouth of the river to the typical upstream extent of the salinity mixing zone, about 24 km upstream from the mouth (Figure 4). Much of the estuary is braided and shallow, with an average upstream depth of approximately 4 m, tapering to approximately 3 m around the mouth. Although it is generally partially to well mixed, parts of the lower Altamaha can become stratified under high flow conditions (DiIorio and Kang, 2007). The region is marked by expansive tidal marshes that are linked to the estuary by an extensive network of tidal tributaries. The area experiences large diurnal tides (average range is approximately 2 m).

The goal of this project was to model nitrogen concentrations in the Altamaha River estuary using WASP v. 7.4, along with a simple hydrodynamic modeling platform. I then used the calibrated model to examine the influence of flow, temperature, and riverine nitrogen input on nitrogen concentrations in the estuary, as each of these factors are likely to change in the future in response to human activities and climate change.

CHAPTER 1

MODEL DEVELOPMENT

1.1 Overview of Model Development

I used two models to produce steady state simulations of the Altamaha River estuary. WASP v. 7.4 was used to model water quality, while the hydrodynamic information required by WASP was provided by SqueezeBox, a simple box modeling program (Sheldon and Alber, 2002). As described below, I initially populated the hydrodynamic routines of WASP with the information from the SqueezeBox modeling system, and then compared the outputs of the two models to ensure that SqueezeBox and WASP were calculating the hydrodynamics of the system faithfully to each other and reproducing the dynamics observed in the system.

After I confirmed that the hydrodynamic routines of the models were acceptable I then developed the water quality components. Because Yassuda et al. (2000) clearly detailed the parameters they used in their application of WASP to Charleston Harbor, South Carolina and took an approach similar to the one to be used in this study, their work was a suitable starting point upon which to base modeling efforts for this study. For my initial effort, I combined the inputs used in Yassuda et al. (2000) with Altamaha estuary specific conditions. Next, I conducted both a local and global sensitivity analysis to determine the effect of the model inputs on the output values of N concentrations. The sensitivity analyses helped focus efforts to parameters that were most relevant to the model. I used the sensitivity analyses in combination with a literature search and relevant environmental data to the Altamaha River estuary to refine some of the inputs to the model.

I calibrated the model using four dates to further inform the final parameterization of the model. The final parameter set was selected based on the results of the calibrations, the literature searches, and the analyses of data. To validate the predictive capabilities of the model, I populated the WASP model with the calibrated parameter set for four dates independent of those used in the calibration and examined the resulting output N concentrations. Next, I conducted sensitivity analyses of the final model parameterization to demonstrate responsiveness of the final model set-up to the inputs used. Finally, I simulated various scenarios using the final model parameterization and conditions typically observed in the Altamaha River estuary.

1.2. GCE LTER Water Quality Data

Much of the water quality and environmental data I used for this project came from the Georgia Coastal Ecosystems Long Term Ecological Research (GCE LTER) program's long term monitoring in the Altamaha River estuary, with nutrient analyses conducted in the laboratory of Dr. Samantha Joye at the University of Georgia. At the outset of the monitoring in 2001, samples were primarily collected quarterly at the eight sites shown in Figure 4. Since November 2006 samples have been collected monthly at the stations located at 4 km, 14 km, and 24 km upstream of the mouth, with an additional site 2 km seaward of the mouth added in June of 2008. Water quality samples are collected 1 m from the bottom and just below the surface at both high and low tides. Water quality data collected as part of the GCE LTER monitoring program that can be used as inputs to WASP are listed in Table 1. Sample collection and processing methods are detailed in the metadata associated with the GCE LTER cruises (found at http://gce-lter.marsci.uga.edu/public/app/data_catalog.asp). In addition to collection of water samples, the water column is also profiled using a conductivity, temperature, and depth recorder (CTD) and a sensor to quantify photosynthetically active radiation (PAR). Because the models used for this study are run as steady state simulations and the Altamaha River estuary is generally well mixed, water quality observations were tidally (high and low tide on a given cruise date) and vertically (surface and bottom samples on a given tide and date) averaged to provide average values over time and depth.

I used eight sampling dates between September 2003 and September 2005 for this study. These dates cover a variety of conditions experienced in the Altamaha River estuary, as shown in Table 2. They also represent an equal number of flows above and below the long term median. Five of the eight dates were sampled during summer or fall, while three of them represent winter conditions. These dates also have an extensive set of observations, both in terms of spatial resolution (i.e. numbers of sample stations longitudinally up the estuary and vertically through the water column) and temporal coverage (i.e. high and low tide).

I used half of the eight sample dates to calibrate the model and the remaining four dates to examine the predictive capability of the model (Table 2). Selection of dates for calibration and verification was made so that each subset covered a range of conditions. I used three of the five dates sampled during warmer months in the calibration. During warmer conditions nitrogen concentrations are typically more affected by increased biological activity (Bowie et al., 1985). Using these dates in the calibration helped to create a calibrated model that would best represent the periods during which nitrogen is most influenced by important estuarine processes.

Some general patterns in the dissolved nitrogen constituents monitored during the GCE LTER sampling can be seen in Table 2 and Figures 5, 6. (It should be noted that the standard deviations observed around the points in Figures 5 and 6, as well as Figures 7-10 (discussed below) are the result of averaging observations taken at high and low tide at the surface and bottom of the water column). In most cases, concentrations of NO_x^- and DON decrease with distance down the estuary. Zones of tidal mixing are marked by higher standard deviation and by steadily decreasing values as they mix with the comparatively nutrient poor seawater endmember. NH_3 often exhibits a mid-estuary peak, or, at higher flows, remains fairly constant throughout the estuary, indicating a possible internal source within the estuarine region. NH_3 concentrations are also generally higher at low flows, both in terms of concentrations entering the estuary and peaks observed within the estuary.

Because of their influence on the biological processes in the estuary and their role in the WASP model I also examined the patterns of other water quality constituents (Table 2, Figures 7-10). Particulate components in the estuary (particulate nitrogen, total suspended solids (TSS), and particulate carbon) as well as PO_4^{3-} and chlorophyll *a* generally exhibit lower concentration during the dates with lower temperatures. Particulate nitrogen, particulate carbon, TSS, and chlorophyll *a* typically increase in overall concentration from upstream to downstream, often exhibiting higher values around the stations at 2 km and 6 km upstream of the mouth of the estuary. Dissolved organic phosphorus exhibit relatively little pattern spatially or temporally through the sample dates.

1.3. Transport Parameters

To drive water movement the WASP model requires information on dispersion coefficients to characterize mixing between model segments, as well as information describing the geometry of the system. I obtained this information using SqueezeBox, a modeling framework developed as a way to estimate mixing time scales (e.g., residence time) and track the transport of inert tracers in well-mixed riverine estuaries such as the Altamaha (Sheldon and Alber, 2002). SqueezeBox generates tidally averaged 1-dimensional optimum-boundary box models constructed so that simulations of flows among boxes are numerically stable. It uses smoothed approximations for cross-sectional area and upstream flow of seawater vs. distance along the longitudinal axis of the estuary so that box boundaries may be drawn at any points along the estuary and the characteristics of the resulting boxes (e.g., salinity) may be determined. SqueezeBox has been calibrated for the Altamaha estuary, and can be used to predict salinities and transit times for given river flow rates that correlate well with observed values (Figure 11).

To make optimal use of the available water quality data and allow spatial comparisons of nutrient concentrations for the various cruises I used SqueezeBox with a set of boxes, assumed to contain homogenous water masses and have a constant volume, which incorporated each of the GCE LTER water quality sample stations as box centers. Because SqueezeBox simulates mixing to head of tide, which is farther upstream than the focus of this study, boxes upstream of 24 km were included in the SqueezeBox runs. These boxes were set up to help ensure stability of flows within the estuary (Table 3). Numerical stability of the model output was also maintained by ensuring a throughflow:volume ratio between 0.2-0.4 (see Sheldon and Alber, 2002). To do so required adjusting the time step used from 6 hrs for the lowest flow to 0.5 hrs for the highest flows. I built SqueezeBox models for each of the dates used in the calibration and verification.

To calculate the river discharge used to drive SqueezeBox, as well as WASP, I used the date specific discharge calculation method described in Alber and Sheldon (1999). Using this iterative method, discharge is averaged for the number of days that result in a flushing time of an equal number of days for the date of interest. Calculating date-specific, flow-averaged discharge in this manner has been shown to predict salinity distributions that best correspond with observed data (Alber and Sheldon, 1999). For the Altamaha, the daily discharge I used in the averaging is estimated from measurements made at the USGS gage at Doctortown, Georgia, adjusted for the ungaged portion of the watershed below the gage station.

Using the estuarine boxes and flows described above I ran SqueezeBox to calculate the dispersion coefficients needed for WASP. WASP requires traditional dispersion coefficients, which are measures of bulk exchange of water between boxes. Although SqueezeBox uses bulk dispersion coefficients, the two measures can be related using a formula that includes the distance between box centers and the area at the interface of two boxes (Soetaert and Herman, 1995). SqueezeBox was therefore modified to output traditional dispersion coefficients as part of its routine calculations (courtesy Joan Sheldon).

I created five WASP segments using the geometric properties of the five downstream boxes of SqueezeBox. I calculated the average depths for each segment by averaging the depths that have been measured over the length of the boxes in the data used to develop SqueezeBox. Average width was calculated by dividing the SqueezeBox calculated volume by the average length and depth of the box. A description of the boxes can be found in Table 4. I also added a benthic segment representing the upper 10 cm of the sediment underlying each box, to provide a reservoir through which benthic components could exchange with water column constituents. The benthic segments shared the lengths and widths of each respective overlying surface segment.

To establish WASP's transport functions I ran WASP for each of the eight dates selected for model calibration and validation. First, to confirm that WASP and SqueezeBox were both similarly representing transport in the estuary, as shown by salinity distributions, I ran WASP with only transport parameters (no rate processes were included), SqueezeBox calculated dispersion coefficients, and boundary salinities output by SqueezeBox. Segment salinities independently calculated by WASP for individual boxes closely matched salinities in corresponding SqueezeBox models (average difference between WASP and SqueezeBox salinities over all dates= 0.003±0.001 psu (s.d.)), providing confirmation that the two model transport structures were consistent. The slight differences between the salinities predicted by the two models are caused by rounding differences used internally in each model. I then used observed salinities as boundaries for WASP and ran the model for the eight calibration and validation dates with only transport parameters (no rate processes were included) and SqueezeBox calculated dispersion coefficients. Differences between average salinities observed in the estuary and salinity values computed by WASP were small, with an average difference of 1.3±1.3 psu (Figure 12, Table 5). WASP calculated salinities typically fell within the window of salinities observed at high and low tide. Although the WASP model generally under-predicted mean observed salinities at lower flows, predicted salinities still provided estimates within the bound of typical salinities observed at each sampling point. The general model-data agreement suggested that the physical model was providing a reasonable approximation of overall transport in the estuary.

1.4. Initial Water Quality Model

1.4.1. Background

In addition to the transport parameters described above, a wide variety of inputs can be used in the EUTRO sub-model of WASP, the component of the WASP model that simulates water quality processes. Some inputs to WASP, if not defined, will not be used in model calculations, while others, if not defined, will default to well accepted values. To narrow down the appropriate parameters to use in EUTRO, as well as determine reasonable first estimates of default parameters values for the Altamaha River estuary I made use of several resources. The Yassuda et al. (2000) study in Charleston Harbor produced reasonable results in a system similar to the Altamaha River estuary and provided a relatively complete documentation of inputs used in the WASP model. Therefore, I based my initial model set-up on a combination of the inputs of Yassuda et al. (2000), transport parameters specific to the Altamaha River estuary (described above), water quality observations made in the estuary, literature values, and local observations (as described below). The full set of parameters used can be seen in Table 6. The equations governing the processes represented by the parameters can be found in Wool et al. (2001). This initial parameterization was tested on four sample dates, which were also used for calibration.

1.4.2. Initial Water Quality Model Setup

1.4.2.1. Boundary Conditions

I used water quality data collected as part of the GCE LTER long term monitoring program in the Altamaha at the stations at 24 km and -2 km to provide the respective upstream and downstream boundary concentrations of water quality variables for the WASP simulations (Table 7).

It should be noted that concentrations of oxidized nitrogen are measured by the GCE LTER data as the sum of nitrate and nitrite (NO_x) concentrations whereas WASP uses nitrate concentrations. However, observations from the NSF-funded Land-Margin Ecosystem Research (LMER) project showed that concentrations of nitrite are typically very low in the Altamaha River estuary: over a series of nine cruises (n=108 samples) median concentrations of nitrite were only approximately two percent of median nitrate concentrations. For this reason NO_x measurements in the GCE LTER data were input as NO_3^- concentrations for WASP.

1.4.2.2. Temperature

I used GCE LTER data to calculate an estuary wide value for water temperature for each sample date. On average, standard deviation of water temperatures throughout the estuary on a given sample date was approximately 3.3 percent. Given the low amount of variation it seemed appropriate for simplification to set a single temperature value for the estuary for each date.

1.4.2.3. Dissolved Oxygen

I chose to include dissolved oxygen as a parameter in the WASP model because DO can be highly influential to estuarine processes. However, dissolved oxygen measurements were only available for four of the eight dates used in this study (September 2003, December 2003, March 2004, May 2004). Because DO measurements were available for dates outside of this study I made use of these observations to select dates with measured DO that matched the seasons and temperatures of the dates used in this study as closely as possible to provide a reasonable approximation for the unmeasured dates (Table 8). An evaluation of all of these measurements showed little spatial variation in the concentration of dissolved oxygen along the axis of the estuary. Additionally, DO was generally high in the estuary and very rarely reached levels that would inhibit biological processes. Despite a bias towards samples taken in the summer, DO concentrations below 4 mg O_2 L^{-1} only occurred in approximately 0.1% of the observations, and of those none were below 3.9 mg O_2 L^{-1}. For this reason I used the median DO concentration observed over the selected dates, 6.6 mg O_2 L^{-1}, throughout the model domain for all model simulations.

1.4.2.4. Light and Light Attenuation

I obtained the amount of solar radiation incident to the estuary from the climate monitoring station at nearby Marsh Landing on Sapelo Island, Georgia (http://gce-lter.marsci.uga.edu/portal/monitoring.htm). The mean daily total solar radiation observed at the station was calculated from observations made from July 2002 – June 2009. Although a wide range of variation occurred in daily radiation, both the mean and median were about 200 Langleys d^{-1} (mean=200, median=202) so this value was used throughout the estuary. Length of day was provided by the United States Naval Observatory, and used as a yearly mean (http://aa.usno.navy.mil/). I used an estimate of light attenuation of 2 m^{-1}, which was near the middle of the range used in Yassuda et al (2000).

1.4.2.5. Benthic Nutrient Fluxes

WASP can be linked to an external sediment diagenesis model to simulate the flux of nutrients from benthic sediments to the estuarine water column. However, this requires detailed information regarding sediment physical and chemical characteristics. Since this level of detail was not available, I made an initial estimate of benthic flux of NH_3 and PO_4^{3-} from the sediments based on a study in a nearby system. In the model developed for the Cooper and Wando Rivers near Charleston, South Carolina, Conrads and Smith (1997) used a variable range of benthic phosphorus flux of 0.5-2.0 mg P m^{-2} d^{-1} and a variable ammonia flux rate of approximately 4-7 mg N m^{-2} d^{-1}. Because some initial guidance provided by Dr. Samantha Joye (pers. comm.) indicated that fluxes in the Altamaha may be high, the upper values of these ranges were used. These fluxes were set to be constant throughout the estuary.

1.4.2.6. Oxygen Fluxes

I estimated an average reaeration rate constant using the Covar method option in EUTRO. To do so, estimates of river velocity and water temperatures from GCE LTER cruises, wind speeds and air temperatures from the climate monitoring station at Marsh Landing, and estuary depths from SqueezeBox were added to WASP. I then ran model simulations for a variety of wind and flow conditions (often the major sources of reaeration in estuaries, see Bowie et al., 1985; Ro et al., 2007) expected in the Altamaha River estuary. I then compared the results to reaeration rates used in modeling efforts in the nearby Savannah River estuary (Tetra Tech, 2006). Estimates of reaeration using the simulated reaeration rate constants for the Altamaha River estuary produced reaeration rates (1.2-2.0 mg O_2 L^{-1} d^{-1}) that were consistent with the range of values observed in the Savannah River estuary (approximately 0-3.0 mg O_2 L^{-1} d^{-1}) and thus were assumed to provide conservative reaeration values. Because date specific conditions were not always available, I used an estimate of the average reaeration rate constant for the estuary that produced the reaeration rates described above (0.39 mg O_2 L^{-1} d^{-1}).

I estimated sediment oxygen demand (SOD) from results of a sediment flux study done in the nearby Savannah River estuary (ATM, 2003). I used the mean of observed sediment oxygen fluxes at four stations throughout the Savannah River estuary (1.5 g O_2 m^{-2} d^{-1}) in the model simulations. The Savannah River study (ATM, 2003) was also used to estimate carbonaceous biological oxygen demand (CBOD) decay rate for the estuary (0.06 mg O_2 L^{-1} d^{-1}). In addition, I estimated ultimate carbonaceous biological oxygen demand (CBODu) as an average of high and low tide samples taken at the mouth of Savannah Harbor as part of the Savannah Harbor TMDL (CBODu=2.98 mg O_2 L^{-1}; ATM, 2003).

1.4.3. Results of initial parameterization

I evaluated the results of the initial model simulations based on agreement between WASP modeled results of NH_3, NO_3^-, and DON in each segment in the estuary and observed concentrations of those N species for each date. The initial model simulation with the inputs described above produced reasonable estimates of the pattern and magnitude of observed nitrogen concentrations (Figure 13). There was a 21.4 % percent difference between observed and model predicted values when averaging over all dates, nitrogen species, and stations (Table 9). Overall the fit of the model predicted values tended to improve with increasing flow. Agreement between observed and predicted values was, in general, best for NH_3, although DON predictions were similar to concentrations observed in overall average value. A large misfit in May 2004 skewed the fit of WASP predicted NO_3^- concentrations to those observed; otherwise there was general agreement between predicted and observed values.

1.5. Sensitivity Analyses of the Initial Model

1.5.1. Background

Following initial efforts to populate the model with Altamaha specific input values and confirming that the initial model parameterization would provide a reasonable representation of concentrations observed in the system I conducted the first of two sensitivity analyses. In general, sensitivity analyses quantify the effect that changes in model inputs have on the variability of model outputs. This can help improve the efficiency of the calibration by helping focus attention on the most influential parameters of the model. The first of the sensitivity analyses was used for this purpose. I later conducted a second sensitivity analysis on the parameters of the calibrated model to assess sensitivity of the model after calibration to guide future applications of the model.

Sensitivity analyses are initiated by altering the value of each uncertain parameter in a model, one at a time or in combination. Sensitivity of the model is then assessed by running the model with the perturbed value(s) and calculating the absolute or relative change of an output(s) of interest. The larger the amount of change of the output, the more sensitive the model is to the perturbation of a parameter(s).

Sensitivity analyses can be performed to test both local and global sensitivity. I chose to do both for the initial analyses discussed in this section. In a local sensitivity analysis parameter values are perturbed a small fraction. By perturbing an input a small percentage of its value the resulting output value is expected to change linearly compared to its value in the unperturbed simulation. In a global sensitivity analysis perturbations are made over the entire range, or the likely range, of expected values of a parameter. This can reveal the possible ranges of model responses that could be expected under a plausible range of parameter conditions. However, the assumption of linearity of responses cannot be made, thus complicating the interpretation of the results. By including global sensitivity analysis at this stage of the modeling process I was able to estimate the sensitivity of the model at the bounds of the range of likely values that could be used in the later calibration of the model. Although the result may not necessarily reflect global maxima of model output response it provides an indication of what may be expected.

1.5.2. Methods

I performed both local and global sensitivity analyses on the initial model. I tested local sensitivity by adjusting each input value ten percent above and below the value used in the initial model setup. Because I perturbed all inputs the same percentage, the response of the outputs could be assessed relative to each other, thus indicating differential sensitivity of the model to a relatively equal perturbation in each parameter.

For the global analyses the amount of perturbation of each input was determined using a range of commonly observed values collected from a search of available literature, meta-analyses of benthic flux data from pertinent literature (Appendix B), and analyses of GCE LTER and other monitoring data. The values used as ranges in this analysis, along with the rationale for selecting these ranges, can be found in Table 10.

I used two sample dates (September 2003 and March 2005) representing contrasting environmental conditions (Table 2) to assess sensitivity. September 2003 was a low flow (flow=140 $m^3 s^{-1}$), high temperature (T=26.4 $^{\circ}$C) period while March 2005 represented a high flow (flow=572 $m^3 s^{-1}$), low temperature (T=11.9 $^{\circ}$C) condition. Using these dates allowed model sensitivity to be judged near the extremes of the conditions that would be used in the calibration and validation of the model, thus revealing an estimate of the full range of model sensitivity.

Sensitivity of the model was calculated by evaluating the mean response of NH_3, NO_3^-, and DON to changes in the various inputs, including observed environmental parameters, kinetic parameters, and physical transport parameters. The inputs were perturbed individually, both up and down, and the model run for each perturbation. In total, 282 perturbations were made: 115 perturbations related to water transport or estuarine geometry; 96 to environmental parameters, including temperature, light field, boundary concentrations of nutrients, and benthic nutrient fluxes; and 71 related to kinetic variables affecting nutrient processing, including phytoplankton dynamics and nutrient cycling rates.

The model response for each N species was assessed by calculating the relative response of the model output nitrogen species compared to its value in the simulation with no perturbed parameters. The equation used is defined by:

$$S = \frac{\sum_{i=1}^{n} \frac{|Cp_i - Cb_i|}{Cb_i}}{n} \qquad \text{Eq. 1}$$

where,

S is the sensitivity for all segments

Cp_i is the output concentration in segment i for the simulation with the perturbed parameter value

Cb_i is the output concentration in segment i for the simulation with the base (unperturbed) parameter value

n is the number of segments

As the equation indicates, to provide a summary of the mean model response through the estuary, the output concentrations simulated in the segments were averaged for each nitrogen species. Results for all three N species were then averaged to determine the effect of parameter changes on overall dissolved nitrogen concentrations. Larger values of S indicate greater sensitivity of the model to a perturbation of an input value while a value close to zero indicates that the model is insensitive to the variation of the given input.

1.5.3. Results

The various sensitivity analyses revealed a wide range of responses in total nitrogen concentration to changes in inputs. The 25 parameters that had the largest effect on total N concentration in the local sensitivity analysis for September 2003, causing a range of model sensitivity from 28.5 % to 2.9 %, are shown in Table 11 (for a complete listing, see Appendix C). In general, the parameters associated with the kinetics of phytoplankton growth, through light or temperature influences, had the most effect on model outputs, with the maximum change in nitrogen concentration (28.5 %) observed in response to the 10 % increase in the base value of the Phytoplankton Maximum Growth Rate Temperature Coefficient. The model exhibited the next greatest sensitivity to turning off the Light Option (20.0 %). The Light Option determines how light intensities are represented throughout the course of a day. With the Light Option turned off a constant value of light is used throughout the period defined for daylight. When the Light Option is turned on the model calculates light levels through the course of daylight hours to reflect peak intensities at mid-day and lower intensities early and late in the day. Other influential inputs affecting phytoplankton growth kinetics included the Phytoplankton Respiration Rate Temperature Coefficient and the Phytoplankton Maximum Growth Rate. Note that each of these factors have two values for sensitivity because parameters were perturbed by both increasing and decreasing the base value. The effect of Light Extinction was also among the influential inputs, although its influence was lower than other light terms (2.9 %). Inputs defining the kinetics of nutrient cycling, such as the DON Mineralization Temperature Coefficient, Nitrification Temperature Coefficient, and Fraction of Phytoplankton Death Recycled to Organic Nitrogen were also included in the top 25 (sensitivities ranging from 12.3-4.6 %). Other parameters on the list included environmental parameters such as Upstream Boundary Concentrations for NO_3^- and DON, as well as segment Temperature. Segment geometry, reflected through segment Depth, was also among the influential inputs.

Overall sensitivity for the March 2005 local sensitivity analysis was much lower than that observed for September 2003; maximum sensitivity for March 2005 was 3.2 % and sensitivities of the 25 parameters that caused the largest change in model output ranged from 3.2 % to 0.6 % (Table 12; see Appendix C for complete listing). In this case perturbations of Upstream Boundary Concentration of NO_3^- were the most consequential (3.2 % for both perturbations), closely followed by perturbations of Upstream Boundary Concentration of DON (3.0 % for both). Many of the parameters included in the top 25 for this analysis affected phytoplankton uptake and nitrogen cycling and were the same or similar to those observed in the September 2003 local analysis: perturbations of the Phytoplankton Maximum Growth Rate Temperature Coefficient and Phytoplankton Respiration Rate Temperature Coefficient, DON Mineralization Temperature Coefficient, Nitrification Temperature Coefficient, and Fraction of Phytoplankton Death Recycled to Organic Nitrogen were influential in both analyses. However, the range of sensitivity values for those parameters for the March 2005 local analysis only spanned from 2.9-1.0 %, whereas the range for the September 2003 local analysis was 28.5-4.2 %. This analysis also showed sensitivity to Phytoplankton Carbon to Chlorophyll Ratio. Compared to the September 2003 analysis more factors affecting water transport and segment geometry were included in the top 25 for March 2005, including Surface Water Flow, Dispersive Mixing Between Segments, Surface Area Between Segments, Segment Length, and Segment Volume, although again their influence was low compared to the top parameters for September 2003 (1.3-0.6 %).

The model was more sensitive to parameter changes in the global analyses; maximum sensitivity for the September 2003 local analysis was 28.5 %, compared to 42.8 % for the global analysis for that date, and maximum sensitivity for the March 2005 local analysis was 3.2 %, compared to 71.2 % for the global analysis for that date (Tables 11-14; Appendix C). Because I did not alter inputs in the global analyses by the same percent relative to the initial value used, as was done in the local analyses, large model sensitivity may reflect either the dynamics of the model or the amount of change in the input. The equation used to evaluate the sensitivity (Eq.1) does not normalize output response relative to change in input. In the local sensitivity analyses this was implicitly accounted for because all parameters were altered by the same percent relative to the original value. Additionally, the results of the global analyses may not necessarily reflect a global maximum in response to inputs. This is because response to perturbations over a range of values may be nonlinear, with maximum response possibly occurring somewhere through the range, and not necessarily at the bounds. However, the global analyses still provide information regarding model sensitivity within the expected range of each parameter.

The top 25 parameters that produced the greatest sensitivities in model output in the September 2003 global analysis all caused a change in outputs greater than 19.4 %, with overall average sensitivity of 28.7 % (Table 13; Appendix C). In this analysis the model was most sensitive to Surface Water Flow (41.8 %), however, there were no other transport inputs of significance. Many of the same factors affecting phytoplankton kinetics and nitrogen cycling were important in this analysis as in the local analysis for September 2003, including two of the most influential, Light Extinction (40.0 %) and Phytoplankton Carbon to Chlorophyll Ratio (39.2 %). Other important inputs shared with the local analysis included Phytoplankton Maximum Growth Rate Temperature Coefficient, Phytoplankton Respiration Rate Temperature Coefficient, Phytoplankton Maximum Growth Rate, use of the Light Option, and Fraction of Phytoplankton Death Recycled to Organic Nitrogen. However, the DON Mineralization Rate, a parameter that was not important in the local analysis, was second on this list (with a sensitivity of 41.7 %). Several other inputs affecting phytoplankton uptake kinetics not seen in the local analyses were also important in the global analysis, including the Half-Saturation Constant for N Uptake, Half-

Saturation Constant for P Uptake, Phytoplankton Respiration Rate, and Phytoplankton Nitrogen to Carbon Ratio. Environmental parameters such as Upstream Boundary Concentration of NO_3^- and DON were again influential. The Upstream Boundary Concentration of Chlorophyll *a*, the Downstream Concentration of NH_3, the Temperature of segments, and Benthic Ammonia Flux were other parameters on this list that were not in the top 25 of the local sensitivity analyses.

The sensitivity of the model to global changes in March 2005 was very high for the most influential input (the Upstream Boundary Concentration of NH_3, which had a sensitivity of 71.2 %) although sensitivity decreased greatly for all other inputs (Table 14, Appendix C). In total, 8 of the 25 most influential inputs for this date were Upstream Boundary Concentrations, and another three were for Downstream Boundary Concentrations. The important role of Upstream (but not Downstream) Boundary Concentrations was also seen in the local analysis for this date. Also similar to the local analysis for March 2005 and the global analysis for September 2003 was the important role of Surface Water Flows (26.7 % and 3.5 %). The influential factors affecting phytoplankton kinetics and nitrogen cycling for the March 2005 global analysis were common to those observed to be important in both local analyses as well as the global analysis for September 2003.

1.5.4. Alterations to the Model Following Sensitivity Analyses

I used the results of the sensitivity analyses, as well as information from literature used to guide the sensitivity analyses, to make some modifications to the input parameters used in the initial model, as well as provide further support for some of the values initially selected.

1.5.4.1. Light Attenuation

From both the local and global sensitivity analyses for September 2003 it was evident that light attenuation was an important factor in the models. In addition, I was concerned that the light extinction values initially used in the model may not be fully representative of actual light extinction in the estuary. I therefore replaced the estimate of the light extinction coefficient I initially used by calculating a light extinction coefficient for each of the GCE LTER sampling dates, in each segment (Table 15). To do so I used the PAR profiles collected during the GCE LTER cruises to calculate date specific light extinction coefficient values using the Beer-Lambert law:

$$I_z = I_o e^{-Kz} \qquad \text{Eq. 2}$$

or,

$$\ln\left(\frac{I_z}{I_o}\right) = -Kz \qquad \text{Eq. 3}$$

where,

I_z = light intensity at depth z

I_o = light intensity at water surface

K = extinction coefficient (m^{-1})

z = water depth measured from surface (m)

1.5.4.2. Benthic Ammonia Fluxes

Literature I gathered after the initial sensitivity analyses (Jahnke et al., 2003; Bailey, 2005; Boynton and Bailey, 2007) indicated that benthic nitrogen fluxes were likely higher than those used in the initial parameterization and sensitivity analyses of the model. Given the highly organic sediments of the estuary and surrounding marsh and the interlacing of sandy and organic sediments of the coastal region of Georgia (Hopkinson and Wetzel, 1982; Jahnke et al., 2003), fluxes in the Altamaha estuary are likely in the upper portion of those observed in the meta-analysis. Because previous information indicated the possibility of high fluxes in the Altamaha estuary and because benthic nitrogen flux was also shown to be important by the sensitivity analyses I decided to use a higher minimum and maximum range for later work. This higher range was based on the work of Bailey (2005), Bailey and Boynton (2007), and the meta-analysis conducted for this study. As a lower bound I used the 75th percentile of observations from the meta-analysis (44 mg N m^{-2} d^{-1}, Appendix C). Because the studies of Bailey (2005) and Bailey and Boynton (2007) used fluxes from a wider range of environments than were used for the meta-analysis done for this study the more conservative 50th percentile from their work was considered (42 mg N m^{-2} d^{-1}). The upper bound was based on the 95th percentile of the meta-analysis (111 mg N m^{-2} d^{-1}, Appendix C). The 75th percentile of Bailey (2005) and Bailey and Boynton (2007) was slightly higher (126 mg N m^{-2} d^{-1}). 111 mg N m^{-2} d^{-1} was used as the upper bound to provide a somewhat conservative estimate.

1.5.4.3. Benthic Phosphate Fluxes

Estimates of flux of phosphate in the literature provided additional support for the values I chose to use in the initial model runs. The meta-analysis of Bailey et al. (2005) found that median phosphate flux from coastal and estuarine environments worldwide was approximately 3 mg P m^{-2} d^{-1}. Information from Twilley et al. (1999) also confirmed that the value used in the initial model setup was within the range of values observed in these studies (-4-12.6 mg P m^{-2} d^{-1}).

1.5.4.4. CBODu

Additional literature examined during the sensitivity analyses also confirmed the appropriateness of the estimate of the ultimate carbonaceous biological oxygen demand (CBODu=2.98 mg O_2 L^{-1}). This value agreed well with a range of values observed throughout the Savannah River in later work (Table 16; Tetra Tech, 2006) as well as with work done by Rodriguez and Peene (2002) in Brunswick Harbor, Georgia.

1.6. Model Calibration

1.6.1. Background

The goal of model calibration was to minimize the difference between observed and predicted concentrations of NH_3, NO_3^-, and DON throughout the Altamaha River estuary. The process used to do so is described below. In general, parameters used in calibration were selected using the results of the sensitivity analysis as well as some exploratory calibrations. Four dates, representing a variety of flow, temperature, and nutrient conditions were used to calibrate the model over the range of conditions experienced in the estuary (Table 7).

1.6.2. Methods

1.6.2.1. Parameter Selection

I used the results of the four sensitivity analyses described above in Section 1.5.3. to guide the selection of parameters to be used in model calibration. Although many different input parameters were tested in the sensitivity analyses, only those that were not directly measured or known with some degree of certainty were considered for calibration. I did not calibrate the measured environmental parameters (e.g. boundary conditions, temperature) for the system because their values were known; altering their values for the purpose of calibration would create artificial conditions in the estuary. Although input parameters affecting transport (e.g. flow, channel width or depth, dispersion rates) could be altered, I felt that transport in the model was being represented appropriately given the general fit of the model predicted salinity to observed salinity (Figure 12, Table 5).

The list of 14 inputs considered for calibration can be found in Table 17. For the most part these were parameters affecting model kinetics, selected because they were found to be highly influential to model outputs in the various sensitivity analyses (Table 17). Several of the parameters were influential in all four analyses (e.g. Phytoplankton Respiration Rate Temperature Coefficient and Fraction of Phytoplankton Death Recycled to ON). Others were influential either in both local or both global analyses. In the end, all kinetic parameters that were in the top 25 parameters that produced the greatest sensitivities in model output in any of the four analyses were included. Two environmental parameters, Benthic Ammonia Flux and the Light Option, were also considered for calibration. Benthic Ammonia Flux values are based on the literature as compared to other environmental parameters that were measured directly in the estuary, so that was allowed to vary in the calibration. As described above, the Light Option is a categorical variable so I was interested in comparing results with it on or off.

1.6.2.2. Optimization Function

I performed calibrations using the DEoptim package, v.2.0-4 (Mullen et al., 2011), in the R software environment, v.2.10.1. The DEoptim application implements evolutionary global optimization through the differential evolution algorithm to minimize the difference between the variables of interest and the desired value. This is done by supplying the program with a range of values for each parameter. The user also supplies an objective function that the program uses to calculate the difference between observed and predicted concentrations. The application then iteratively selects combinations of parameter values to attempt to find a global minimum of the objective function.

Because different objective functions can produce unique fits, I tested four to determine which produced the most appropriate fit between observed and predicted NH_3, NO_3^-, and DON concentrations. Appropriate fit was judged by examining how the model output values from each objective function predicted overall patterns (e.g. trends, outliers) of the observed data. Each objective function tested is given below:

Absolute Difference

$$OF_1 = \sum_{i=1}^{n} \frac{|Cp_i - Co_i|}{Co_i} \qquad \text{Eq. 4}$$

Absolute Difference Scaled by Standard Deviation

$$OF_2 = \sum_{i=1}^{n} \frac{|Cp_i - Co_i|}{\sigma_{oi}} \qquad \text{Eq. 5}$$

Least Squares

$$OF_3 = \sum_{i=1}^{n} \frac{(Cp_i - Co_i)^2}{Co_i} \qquad \text{Eq. 6}$$

Least Squares Scaled by Standard Deviation

$$OF_4 = \sum_{i=1}^{n} \frac{(Cp_i - Co_i)^2}{\sigma_{oi}} \qquad \text{Eq. 7}$$

where,

OF is the objective function

Cp_i is the WASP predicted nitrogen concentration in segment i

Co_i is the observed concentration in segment i

σ_{oi} is the standard deviation of the observed values in segment i

I tested the objective functions by populating the WASP model with the environmental conditions from September 2003 and the parameters and parameter values established following the initial sensitivity analysis. I optimized the parameters noted in Table 17 using each objective function listed above in its own DEoptim routine. Ranges of values used in the optimization routine were determined using the ranges applied in the global sensitivity analysis (Table 10). I ran several preliminary optimizations using the above setup to determine the number of iterations that would produce an objective function value and parameter values that were stable from one iteration to the next. Stability of these values indicates that the optimization routine has found optimal solutions for the objective function and parameters. Acceptable stability was typically reached around 1000 iterations for the above configuration of DEoptim. Accordingly, I used each objective function in the model setup described above and ran the optimization for 1000 iterations. The preliminary optimizations were also used to determine the number of population members (NP), step size (F), and the crossover probability (CR) used in DEoptim that would allow the function to reach convergence in a reasonable amount of time but would estimate parameter values at a fine enough resolution. I found that using NP equal to 10 times the number of parameters being optimized, as recommended by Mullen et al. (2011), facilitated convergence. I also found that the default values of F=0.8 and CR=0.9 allowed convergence in a reasonable amount of time and estimated parameter values at an acceptable resolution.

To assess the results I put the calibrated parameters back into the model for September 2003 and ran the model. I then compared model predicted values of NH_3, NO_3^-, and DON produced by each objective function to observed concentrations. For each of the nitrogen species the various objective functions produced little difference in fit to observed concentrations (Table 18). OF_1 (absolute difference, Eq. 4) generally provided the best fit, and was least sensitive to outliers so I performed the calibrations using this function.

1.6.2.3. Modifications to Parameters Initially Selected for use in Calibration

The number of parameters to be optimized was reduced by performing some exploratory calibrations. The first of these calibration runs was used to explore the range of values that could be expected for the calibrated parameters. I performed the simulations by running several calibrations using the model setup described above for the objective function tests with combinations of the parameters mentioned in Section 1.6.2.1. From these runs it became clear that the Phytoplankton Respiration Rate remained relatively constant in each of the calibration simulations and could be set as a constant value (0.05 mg O_2 L^{-1} d^{-1}). Benthic Ammonia Flux was also consistently minimized to the lower boundary of the range allowed. For this reason I made an estimate of Benthic Ammonia Flux based on the lower range of the Benthic Ammonia Flux as discussed in Section 1.5.4.2. (44 mg N m^{-2} d^{-1}). By reducing the number of parameters used in the calibration I greatly reduced the calibration run time and promoted parsimony of the calibration.

I conducted an additional calibration run to determine the contribution of the Light Function to the overall sensitivity of the model. With the Light Function turned off the model uses a single, constant value of light throughout the period defined for daylight. When the light function is turned on the model calculates light levels through the course of daylight hours to reflect peak intensities at mid-day and lower intensities early and late in the day. Because the Light Function is a categorical variable (i.e. it is either turned on or off) it could not be altered in the application used to perform the calibrations and its effect on the model had to be assessed by setting up two simulations, one with the Light Function turned on and one with it turned off. The results showed that the Light Function had little influence in improving the fit of the overall output of the model for the test, however because it was shown to be important in the sensitivity analyses, and turning on the Light function produced more realistic light conditions, the Light Function was turned on for the calibrations.

1.6.2.4. Final Parameterization

The final parameter set I used in calibration contained 11 parameters (Table 19). The range of typical parameter values with which to calibrate the model was provided by the literature used to set the range of values for the global sensitivity analyses (Table 10). I calibrated for four dates simultaneously (September 2003, May 2004, March 2005, and June 2005) (Table 7). The final objective function I used in the calibration can be seen below:

$$OF = \frac{\dfrac{\sum_{i=1}^{n} \dfrac{\left|Cp_{NH4i} - Co_{NH4i}\right|}{Co_{NH4i}}}{n} + \dfrac{\sum_{i=1}^{n} \dfrac{\left|Cp_{NO3i} - Co_{NO3i}\right|}{Co_{NO3i}}}{n} + \dfrac{\sum_{i=1}^{n} \dfrac{\left|Cp_{DONi} - Co_{DONi}\right|}{Co_{DONi}}}{n}}{3} \qquad \text{Eq. 8}$$

where,

OF is the objective function

Cp_{NH4i} is the WASP predicted ammonia concentration in segment i

Co_{NH4i} is the observed ammonia concentration in segment i

Cp_{NO3i} is the WASP predicted nitrate concentration in segment i

Co_{NO3i} is the observed nitrate concentration in segment i

Cp_{DONi} is the WASP predicted DON concentration in segment i

Co_{DONi} is the observed DON concentration in segment i

n is the number of segments

This objective function gives equal weights to each of the nitrogen species, allowing the model to be calibrated equally for each. I ran the final calibration for 1200 iterations, with 110 runs within each iteration (i.e. NP=110), evaluating the objective function approximately 132,100 times. The exploratory analyses described above indicated that this number of iterations would be sufficient to calculate a stable objective function value and parameter values.

The final values of the calibrated parameters can be seen in Table 19. The progression of objective function values and parameter values resulting from each iteration can be seen in

Figures 14 and 15, respectively. The final objective function and parameter values were very stable by the final iteration. Several of the parameters were adjusted by the calibration to one of the bounds set by the range of acceptable parameter values. Some of the parameters adjusted to their boundary values (Phytoplankton Respiration Rate Temperature Coefficient, DON Mineralization Temperature Coefficient, and Phytoplankton Half-Saturation Constant for P Uptake) were similar to, or the same as, the value used in the original model setup. The original ranges of the parameters were selected carefully to insure that the values at the bounds were reasonable values that could be expected in the estuary.

To examine the success of the calibrated models at representing the conditions observed in the estuary I populated the models for each date with the calibrated parameters. The results are presented in Figure 16 and Table 20. In general, the concentrations of N species predicted by the calibrated model closely match those observed in the estuary, although again the fits were poorer at low flows. The overall fit between observed and modeled dissolved nitrogen species (the sum of DON, NO_3^-, and NH_3) improved for three of the four dates evaluated: agreement between modeled and observed DN concentrations improved from 47.1% in the initial model to 35.7% in the calibrated model for May 2004, from 24.3 % to 8.4 % for September 2003, and from 11.9 % to 9.2 % for March 2005, whereas fit for the initial fit was 9.6 % in June 2005 as compared to 19.9 % for the calibrated model.

The improvement of fit relative to the initial model is also evident when comparing Table 9 to Table 20. The overall average difference between observed and predicted NO_3^- concentrations for the four dates improved from 31.1 % in the initial model to 19.5 % for the calibrated model, and that for DON improved from 17.9 % to 7.6 %. Although average differences for NH_3 improved for September 2003 and March 2005, the poorer fit for the calibrated models for May 2004 and June 2005 caused the overall average difference to be increase from 20.7 % in the initial model to 27.8 % in the calibrated model.

1.7. Model Validation

I tested the calibrated model's predictive capability against four validation dates (December 2003, March 2004, September 2004, and September 2005; Table 2). Boundary conditions for the dates used can be seen in Table 21. As described above for the calibration step, I evaluated the calibrated model by comparing model outputs of NH_3, NO_3^-, and DON, as well as total dissolved nitrogen, throughout the estuary to the concentrations observed on the dates of the respective model simulations. Model skill was evaluated graphically by comparing model simulated values to concentrations observed on the dates of interest (Figure 17). Quantitative fit was also measured using Eq. 1 (Table 22).

Overall there was agreement between the model predicted concentrations for the validation dates and the concentrations observed in the estuary on those dates. Agreement was highest for DON on all dates (averaging 7.9 %). The agreement for DON is important because it makes up a large percentage of dissolved nitrogen in the estuary. Although the DON in the estuary can be less bioavailable and labile than other dissolved nitrogen species and distributions are often dominated by conservative mixing, DON can be an important source of N to organisms because it is in such high concentrations and does contain some bioavailable fractions (Bronk et al., 2007). In general, the model also does well at reproducing the patterns and magnitudes of NO_3^- (average agreement = 27.7 %). The poorest fit was for the low-flow date (Sept. 2005), where the model severely under-predicted NO_3^-. As was observed in the calibration runs, the NH_3 fit was the poorest (average = 51.9 %), with both under- and over-predictions apparent

(Figure 17). The worst fit was for September 2005, where neither the magnitude nor the pattern of NH_3 was adequately captured.

1.8. Sensitivity Analyses of the Calibrated Model

I performed a final local sensitivity analysis of the calibrated model to explore the sensitivity of model output NH_3, NO_3^-, and DON concentrations to changes in model inputs. This analysis provided information about the inputs that are most influential on model outputs, and thus need to be carefully considered when applying the model. To perform this analysis I used similar methods to those described in Section 1.5.2. As before, I perturbed model inputs ten percent and assessed sensitivity using Eq.4. I did this for each of the four dates used for model validation (December 2003, March 2004, September 2004, and September 2005; Tables 2, 21).

Results of the top 25 parameters in each sensitivity analysis can be seen in Tables 23-26 (full results in Appendix C). The overall patterns seen in the initial sensitivity analyses are generally evident in these analyses as well. Similar to the September 2003 local analysis, a low flow (140 m^3s^{-1}), high temperature (26.4 $^{\circ}$C) date, September 2005 (flow=110 $m^3\,s^{-1}$, T=28.7 $^{\circ}$C) also showed high sensitivity to model inputs (Table 23). The top three parameters; Phytoplankton Maximum Growth Rate Temperature Coefficient, Light Option, and DON Mineralization Temperature Coefficient had sensitivity values of 115.2, 88.8, and 55.3, respectively. Both the Phytoplankton Maximum Growth Rate Temperature Coefficient and the Light Option were the first and second most influential parameters in the September 2003 local analysis, and DON Mineralization Temperature Coefficient the fifth most influential. The high sensitivity of the September 2005 model to changes in temperature, phytoplankton uptake kinetics, and nitrogen cycling inputs is also similar to the September 2003 local analysis.

Although the Nitrification Temperature Coefficient, Phytoplankton Respiration Rate Temperature Coefficient, and Phytoplankton Nitrogen to Carbon Ration were similar between the local analyses for September 2003 and September 2005, the majority of the remaining important inputs were not shared between the two dates.

The other three validation dates, which represented higher flows, as well as lower temperatures, showed lower sensitivity to model parameters (Tables 24-26, Appendix C), which is again consistent with the initial analyses. For December 2003 (flow=221 $m^3 s^{-1}$, T=14.2 $^{\circ}C$), March 2004 (flow=452 $m^3 s^{-1}$, T=14.1 $^{\circ}C$), and September 2004(flow=796 $m^3 s^{-1}$, T= 23.1 $^{\circ}C$) maximum sensitivities were 4.1, 2.9, and 3.2, respectively. While upstream boundary concentrations, flow, and estuarine geometry are less influential than other parameters for September 2005, they are among the most influential parameters for these other dates, although they still have relatively low influence. Benthic Ammonia Flux is also relatively more important for these other dates compared to both the September 2005 analysis and the local analyses for the September 2003 and March 2005 calibration runs.

1.9. Discussion

The overall patterns and magnitudes of dissolved nitrogen concentrations predicted by the WASP model are similar to those observed in the Altamaha River estuary. When I ran the calibrated model for the 8 calibration and validation dates used in this study the average error for NH_3 was 39.8%, NO_3^- was 23.6%, and DON was 7.8%, but these numbers decrease to 39.0 %, 13.2 %, and 6.6%, respectively, when the two lowest flows are excluded. The errors reported here are comparable to those reported for other WASP model applications: for four stations in the Neuse River estuary average mean error for NH_3 was 37% and 7% for NO_3^- (Wool et al., 2003). In the application of the WASP model to Tampa Bay Wang et al. (1999) found that the mean error of prediction for organic nitrogen was approximately 35%.

Based on extensive experience with water quality modeling, Donigian (2000) provides general quality thresholds for various outputs that are commonly examined in water quality modeling. This guidance indicates that the predictive capability for water quality and nutrient outputs from water quality models is considered "Very Good" if the difference between model predicted and observed concentrations is less than 15 percent, "Good" if the difference is between 15 and 25 percent, and "Fair" if between 25 and 35 percent. Based on this rough guidance, all but two of the model predicted concentrations (NH_3 for May 2004 and September 2003) fall within these levels of agreement (7=Very Good, 2=Good, 1=Fair).

Despite acceptable overall performance, few models, this one included, have perfect predictive accuracy. Some of the misfit between modeled and observed concentrations may be explained by the fact that I averaged the objective function for all flows, thereby optimizing the model to fit overall conditions and not specific situations. However, the model generally over-predicts the concentrations of nitrogen in the estuary (Figures 16, 17), and this may provide insight into processes in the model and the estuary that should be examined further. The mis-match between modeled and observed data is particularly noticeable where there is a mid-estuary peak in concentrations. This could be a result of the optimization trying to reproduce some of the higher values in the model. To achieve some of the peaks in concentration the optimization routine may have decreased some of the rate coefficients controlling uptake (e.g. phytoplankton growth or respiration rates) or changed processes controlling nutrient transformations (e.g. DON mineralization rate or nitrification temperature coefficient), allowing the higher values to be better matched, but causing general over-prediction.

The observed mis-match in peak concentrations may also indicate that the model is not capturing a process(es) that causes those peaks or is not accounting for the processes that cause the decrease of that peak downstream. Mid-estuary peaks are most common for NH_3, and the peaks are often coincident with the portion of the estuary where there are extensive tidal salt marshes. Tidal salt marshes have been shown to act as sources of NH_3 to several estuaries (Childers, 1994; Childers et al., 2000; Odum, 2000). Childers (2000) found that in estuaries with higher tidal amplitudes and younger marshes, both conditions which characterize the marshes found near the mouth of the Altamaha River estuary, fluxes of NH_3 are likely to occur from the marshes to the estuary. If this is the reason for the peak of NH_3 concentrations around the mid-estuary, it would not be captured in the model the way it is currently used because the flux from marshes is not modeled. To decrease concentrations downstream of the peaks there are processes included in the model that may need to be better represented to uptake or transform the NH_3 peaks. Phytoplankton uptake is a dominant process affecting nitrogen concentrations in the model and NH_3 is the preferred nitrogen source for phytoplankton uptake. A more realistic representation of this term could help explain the drop of NH_3 seen after some peaks. Nitrification is another process that could decrease NH_3, however it will also increase the NO_3^- concentrations, which in some cases are already slightly over predicted. Decreasing the flux of NH_3 from sediments may also be useful.

Over-prediction is typically more pronounced toward the downstream segments, particularly for NH_3. This misfit may be partly due to the boundary value at the station at -2 km; at that station the mean concentration of NH_3 is often higher than those in the model domain. This may cause predicted concentrations in the model domain to be higher than expected as the model tries to match the concentrations observed at the boundaries. This suggests that setting the model boundaries farther from the region of interest may be important to allow processes in the model domain to have a greater influence on predicted concentrations in the estuary and relieve the direct influence of boundary concentrations.

There were also some specific cases in which the model did a poorer job at predicting observed nitrogen concentrations. Some of the larger percent misfit for NH_3 on June 2005 and March 2004 and NO_3^- on September 2005 can be explained by the low concentrations on these dates. Although the magnitude of predicted and observed concentrations is similar for each of those dates, differences appear large when expressed as a percent difference of a low concentration. These are also both cases where the misfit in NH_3 is partially caused by the boundary concentration at -2 km being slightly higher than the observed concentrations in the estuary (Figure 6).

The sensitivity analyses and results of the calibrated model also provided insight into both the dynamics of the model and the processing of N in the estuary. The overall sensitivity of model-predicted nitrogen concentrations was higher during low flows and higher temperatures in all sensitivity analyses. For example, in the initial local sensitivity analyses the model had higher sensitivities to more parameters for September 2003, a low flow, high temperature date (flow=140 $m^3 s^{-1}$, T=26.4 $^{\circ}$C) than for March 2005, a high flow, low temperature date (flow=572 $m^3 s^{-1}$, T=11.9 $^{\circ}$C, see Table 2). This was again apparent when comparing the sensitivity of the calibrated model for September 2005 (flow=110 $m^3 s^{-1}$, T=28.7 $^{\circ}$C) with that of March 2004 (flow=452 $m^3 s^{-1}$, T=14.1 $^{\circ}$C, see Table 2). During low flow and high temperature, the model showed high sensitivity to model parameters affecting phytoplankton dynamics and those controlling components of nitrogen cycling.

Increased sensitivity at low flows can be explained by the extended residence time of the water during low flows, which provides additional time for uptake and transformation of nitrogen. During high flows flushing time is increased, leaving little time for the many factors affecting nutrient uptake or transformations to act on nitrogen species within the estuary and thus alter their concentrations. Based on general physical principles, and the results of the nutrient budget for the estuary (Appendix A), the influence of flow is also to be expected: as flows increase, so too does importance of riverine nitrogen to the overall nitrogen concentrations in the estuary, causing the river to contribute increasingly more nitrogen to the estuary than in-estuary processes. This is reflected by the increased sensitivity to upstream boundary conditions during high flow periods.

Increased sensitivity at high temperatures likely reflects the temperature dependence of rates of biological processing and transformation; when temperatures are higher a greater amount of nitrogen is used by organisms. Conversely, when temperatures are low biological activity is suppressed, decreasing the relative amount of biological processing of nitrogen. This results in lower sensitivity to rate processes associated with phytoplankton growth and nutrient cycling.

In keeping with the results of the sensitivity analysis, the largest misfit of the model generally occurred during low flow, high temperature dates when the terms controlling biological processing become more influential than transport. The misfit for NH_3 and NO_3^- on May 2004 (flow=117 $m^3 s^{-1}$) is mostly due to the model reproducing the pattern at the upstream end of the estuary but then failing to remove the additional ammonia. One likely explanation for the misfit upstream can be tied to the extremely high chlorophyll a concentrations at the upstream stations at 18 km and 14 km (Figure 9). The high amount of phytoplankton upstream may be taking up these bioavailable forms of nitrogen, contributing to the rapid drop in both NH_3

and NO_3^- after the station at 14 km. A better representation of phytoplankton uptake may help to better simulate these decreases in concentration. The influence of phytoplankton dynamics on concentrations of nitrogen during low flow may also explain the misfit for September 2005 (flow=110 $m^3 s^{-1}$). For all nitrogen species for that date the model is under predicting nitrogen concentrations. For that date the model over-predicts chlorophyll *a* concentrations (data not shown) causing excess nitrogen to be taken up and the predicted values to be less than observed. Despite the misfit at the two lowest flows, the model exhibits strong predictive capability at the next lowest flow on September 2003 (flow=140 $m^3 s^{-1}$). Thus, although the parameterization may cause some misfit at lower flows this may not be the case for all lower flows.

The results of the model calibration also suggest some potential gaps in the model parameterization. Several of the optimized parameters in the final calibrated model had values that were at the bounds of the ranges assigned to them in the calibration routine (Table 19). Although this may be an indication that the ranges of the parameter values were too restrictive, the bounds for those ranges were carefully selected to represent values that could be confidently expected in estuarine settings. These results, along with the observed misfit between data and observation at low flows, may also indicate that additional parameters may need to be used in the calibration or additional parameters included in the model to account for additional processing of nitrogen and relax some of the need to rely on the processes that are being optimized to their bounds. However, the inclusion of additional parameters in the model calibration presents a dilemma inherent to modeling; the balance between a simple, parsimonious model, in which the most well justified and influential parameters are being calibrated to produce a model that fits overall conditions, and a model in which additional parameters are included in an attempt to represent some of the more unique patterns in the data. Because I was interested in capturing the overall pattern of nitrogen in the estuary I calibrated the model using a simple set of parameters that represent the major processes in the estuary. These parameters were selected based on the consistently high influence that they exhibited in the sensitivity analyses, which allowed a level of parsimony in calibration supported by the mechanics of the model and helped to avoid calibrating the model to an excessive number of parameters and possibly over tuning the model. If additional parameters were used in calibration it would require an additional sensitivity analysis to determine their influence and justify or discount their inclusion.

The ability of the model to generally capture the patterns and magnitudes of the data suggests that it is successfully representing the overall dynamics of DN in the estuary. However, there are some direct sources and sinks of nitrogen that are not currently included in the model that would make it more realistic and could potentially improve its performance. Atmospheric deposition of nitrogen to the estuary represents an input that is not currently accounted for in the model. However, atmospheric deposition is probably a small part of the nitrogen flux to the estuary (see Appendix A). The influence of nitrogen fluxes to and from marshes on estuarine nitrogen concentrations was discussed above and could also help explain patterns of nitrogen in the estuary.

There are also several processes which are not included in the model or which a better knowledge of their dynamics. Phytoplankton dynamics are extremely influential in the model. Additional knowledge of the processes controlling phytoplankton nitrogen uptake and release could help provide a clearer picture of how phytoplankton interact with nitrogen in the estuary. As I currently have the model setup there is one group of phytoplankton. WASP is capable of simulating three groups of phytoplankton, each with distinct kinetics and responses to environmental conditions. The model results indicated that it may be necessary to model more than a single type of phytoplankton. On some dates observed phytoplankton concentrations decrease down the estuary. Because this is not the case for all dates it may indicate that there are different groups of phytoplankton in the estuary with different responses to environmental conditions (e.g. marine vs. freshwater species). For example, on May 2004 there is a rapid drop in phytoplankton concentrations around 6 km. Because this does not fit the mixing patterns of other water quality parameters (except the particulate concentrations, which are correlated to phytoplankton biomass as a result of sampling methods) this could indicate sensitivity of riverine phytoplankton on this date to the higher salinities near the mouth. Additionally, WASP does not currently model the transformation and release of dissolved nitrogen species from living phytoplankton. By including this in the model transformations between different nitrogen species could be better modeled.

Other processes involved in the nitrogen cycle could also improve the model. One process which is included in the model but could be more realistically simulated is the influence of denitrification. This nitrogen sink could be particularly important given the tendency of the model to over-predict nitrogen concentrations. Currently denitrification in the model is oxygen limited by a term that designates the maximum DO concentration at which denitrification can occur. Because DO concentrations in the estuary are high denitrification is almost completely inhibited with the current way that the model represents denitrification. However, it is known that denitrification can take place on particulate matter in the water column, despite high DO concentrations (Dr. Samantha Joye, pers. comm.). Because the water in the Altamaha River estuary typically has high amounts of particulate matter (Figures 7, 8) this may be a significant source of nitrogen loss that is not being taken into account. Adding an additional denitrification term to the model that is less dependent on nitrogen concentrations could help better represent the dynamics of this process in the estuary. WASP also does not model nitrogen fixation and this could provide an additional source of nitrogen to the model.

Some key factors related to hydrodynamics could also help to improve the model. Because the model is run as a steady state simulation it is not capturing the effect of tidal movement on nutrient concentrations. By representing the effects of tides in the model the variability of water quality constituents would be more realistically represented. Finally, by extending the boundaries of the model the influence of boundary conditions on the model could be relieved. By having model boundaries farther out the concentrations in the estuary would be less influenced by the boundary concentrations and be more reflective of the influence of estuarine processes.

CHAPTER 2

APPLICATION OF THE MODEL

2.1. Background

The sensitivity analyses of the calibrated model showed that several key environmental variables have highly influential roles in affecting the predicted levels of nitrogen in the estuary. The effect of flow on the model predicted concentrations of nitrogen can be seen through the decreased sensitivity of the model at higher flows (Tables 11-14, 23-26). For example, the average sensitivity of the calibrated model in the local sensitivity analyses to the top 25 parameters was 25.7 % for the lowest flow date (May 2004, flow=117 $m^3 s^{-1}$), compared to 1.8% for the highest flow date (September 2004, flow=796 $m^3 s^{-1}$). This is expected as the increase in flow decreases the amount of time that constituents such as nitrogen remain within the estuary, thus decreasing the amount of time that nitrogen can be processed through uptake or remineralization processes. The influence of temperature is manifest through the temperature dependence of rate processes controlling phytoplankton dynamics and microbial processing. This is shown by the large number of temperature related parameters in the list of the top 25 parameters the calibrated model is most sensitive to at higher temperatures: eight of the top 25 parameters for September 2005 were related to temperature. The concentration of nutrients coming into the estuary through the upstream boundary is also important in controlling the concentrations of nutrients in the estuary. The dominance of the river in influencing estuarine nutrient concentrations is evident as indicated both by the nutrient budget (Appendix A) and the sensitivity analyses of the calibrated model to changes in input concentrations. These environmental variables (temperature, flow, and nutrient input) have also been shown to play strong roles in estuarine nitrogen dynamics in numerous studies conducted in estuaries (Bowie et al. 1985; Ambrose and Martin 1990; Dame and Allen 1996; Nixon et al. 1996).

I used the calibrated model to examine the predicted response of nutrient concentrations in the Altamaha River estuary to changes in temperature, flow, and nitrogen inputs.

2.2. Methods

I set up the calibrated model for three flows (129 $m^3 s^{-1}$, 240 $m^3 s^{-1}$, and 479 $m^3 s^{-1}$), which represent the 25th, 50th, and 75th percentiles of flows observed in the Altamaha River from 1931-2010. Within each flow rate I ran the model multiple times, varying estuary-wide temperature, as well as upstream boundary concentrations of NH_3, NO_3^-, DON, particulate nitrogen, particulate carbon, TSS, chlorophyll *a*, PO_4^{3-}, and DOP in each run. I selected the range of temperatures to use in these runs based on the maximum and minimum values observed in the estuary over the period of record for the GCE LTER sampling program. Although I was only concerned with the model predicted concentrations of the dissolved nitrogen species, the upstream boundary concentrations of the other water quality constituents were varied to yield results covering the full range of conditions in the estuary. I used the maximum and minimum values observed over the period of record of the GCE LTER sampling program at the sample stations at 24 km and -02 km to represent the upstream and downstream boundary conditions, respectively. Although the influence of light was not examined I needed to set a value that could be used in the simulations. To represent average light conditions I used the mean of the light extinction values at each station for the dates used in this study. Because there was little difference between light extinction coefficients at high or low flows, an average in each segment for all flows was used.

I wrote an application to implement a Monte Carlo simulation that randomly selected a value for each of the above inputs from their respective ranges, and then ran the model at one of the three flows using this combination of values. This was repeated 5000 times for each of the three flows, for a total of 15,000 model runs, each representing a specific combination of input parameters from within the set ranges. As described above, the three flow cases were selected to represent the 25^{th}, 50^{th} and 75^{th} percentiles of observed river flow. I used these to represent low, medium, and high flow conditions in my evaluation of model results. For analyzing the model results in terms of temperature and input upstream DN concentrations, I used the 25^{th}, 50^{th}, and 75^{th} percentiles of the temperature and input upstream DN that were used within each of the three flow cases to represent low, medium, and high values. In these two cases (temperature and input upstream DN), I approximated the 25^{th}, 50^{th}, and 75^{th} percentiles by averaging all of the input values of either temperature or input upstream DN that fell between the 20^{th}-30^{th}, 45^{th}-55^{th}, and 70^{th}-80^{th} percentiles, respectively, for each flow case. The values that represent the bounds of each of these designations can be seen in Table 27.

For each simulation model predicted concentrations of NH_3, NO_3^-, and DON are output for each segment of the estuary. To estimate values for the whole estuary I calculated the mean of the predicted values for each of the five segments for each simulation. To evaluate total DN concentrations I summed the estuary-wide average concentrations of NH_3, NO_3^-, and DON for each run. Note, however that calculated statistics for DN may not reflect the sum of the corresponding statistics of NH_3, NO_3^-, DON because a certain percentile for an individual constituent is not necessarily the same value at the same percentile for DN. I analyzed the predicted nitrogen concentrations for the various combinations of flow, temperature, and input upstream DN at low, medium and high values (Table 27). To compare flows only, I calculated basic statistics (25^{th}, 50^{th}, and 75^{th} percentiles; mean; standard deviation) of each predicted nitrogen constituent for all 5000 model runs at each flow. To compare the effect of variations in temperature and input upstream DN I used the predicted nitrogen values that corresponded to each input designation (e.g. predicted nitrogen values that corresponded to model runs where the input temperature fell within the low temperature interval for a given flow case were evaluated as a subset of the data to get the average predicted nitrogen at low temperature for that flow). This resulted in 500 observations of predicted nitrogen observations used in each case. I then calculated basic statistics (25^{th}, 50^{th}, and 75^{th} percentiles; mean; standard deviation) for each subset of the data.

2.3. Results

To determine if DN concentrations predicted by the Monte Carlo simulations were similar to those observed in the estuary I examined the concentrations observed in the estuary by the GCE LTER monitoring program during flows similar to those used in the model application. The low, medium, and high flows used in the Monte Carlo simulation represented the 25^{th}, 50^{th}, and 75^{th} percentiles of the long term flow data for the Altamaha, and I compared these to dates in the GCE LTER data with flows that fell within the 20^{th}-30^{th}, 45^{th}-55^{th}, and 70^{th}-80^{th} percentiles, respectively. For most of these dates there were only observations in the model domain at the stations at 14 km and 4 km. I compared the average DN concentrations observed at 14 km to the simulated predictions of DN in the segment at 14 km. Because there is no model segment surrounding the station at 4 km (4 km is the interface between the segment from 0-4 km and that from 4-8 km) I averaged the predictions for these two model segments to compare to the observed concentrations at 4 km (Table 28). Although all of the observed concentrations fell within the range of values predicted by the Monte Carlo simulations, all but one fell below the median of model predicted concentrations. This could indicate that the model is over-predicting concentrations, but it could also just be a result of the few dates examined not representing all of the conditions covered by the simulation. It should be remembered that the parameter ranges used for the Monte Carlo simulations covered the range of all values observed in the Altamaha, not just those most commonly observed.

I examined the model-predicted estuary-wide concentration of NH_3, NO_3^-, DON, and total dissolved nitrogen in response to changes in flow, temperature, and input upstream nitrogen concentrations (Figures 18-20, Tables 29-35). In general, each of the predicted nitrogen constituents responded similarly to variations in each of the inputs; where one constituent had a positive (or negative) relationship to an input, so too did the others.

Predicted estuary-wide concentrations of NH_3, NO_3^-, DON, and total dissolved nitrogen all responded positively to increases in flow, with highest concentrations at highest flows (Tables 29, 30). Absolute response to flow, as reflected by the difference in mean nitrogen concentrations between the low and high flow model runs, was the greatest for DN (an increase of 0.067 mg N L^{-1}). Among the individual nitrogen species response was greatest for NO_3^- (an increase of 0.037 mg N L^{-1}), followed by DON (0.025 mg N L^{-1}). Changing flows had little effect on the mean predicted concentrations of NH_3 (an increase of 0.005 mg N L^{-1}). When the change of mean values from low to high flows was expressed as a percent change relative to the low flow concentration, the difference was greatest for NO_3^- (13.6 %) followed by DN (9.1 %), NH_3 (8.5 %), and DON (6.1%). In addition to an increase in mean predicted concentration with flow the standard deviation also increased positively, indicating a greater spread of values at higher flows. The increase of mean and standard deviation can be attributed to an increase in the occurrence of values in the higher concentrations in the range as opposed to an upward shift of the lower concentrations (Table 30, compare changes in 25th vs. 75th percentile).

In general there was a negative relationship between temperature and predicted concentrations of nitrogen in the estuary, with highest mean predicted estuary nitrogen concentrations occurring at low temperatures (Figure 18, Tables 31, 32). The relationship between temperature and predicted nitrogen concentrations is most apparent for NH_3 (see Figure 18), which showed an obvious decrease with increasing temperature, especially above approximately 20 $^{\circ}$C. The overall relationship between predicted concentrations and temperature is less clear for the NO_3^-, DON, and DN. For any given flow the greatest absolute difference in mean predicted concentration between low and high temperatures was greatest for DN and lowest for DON (Table 31). Absolute response to temperature was greater between the medium and high temperatures compared to the response between the low and medium temperatures. A different pattern emerged when examining the effect of temperatures on the relative change in predicted concentrations, calculated by dividing the amount of change between the low and high temperatures by the concentration predicted at low temperatures. At a given flow relative response to changes in temperature was greatest for NH_3 followed by NO_3^-, DN, and DON, in order.

The response of predicted nitrogen concentrations to temperature is affected by flow. At high flows predicted concentrations at a given temperature are consistently higher than at low flows (Tables 31, 32). For all nitrogen species mean concentrations at high temperatures are more responsive to changes in flow (i.e. change in predicted concentrations at high temperature are larger than changes in low temperature concentrations between low and high flow). For example, between low and high flows the low temperature concentration of NO_3^- increases by 0.03 mg N L^{-1} while the high temperature concentration increases by 0.70 mg N L^{-1}. When comparing low and high flows the absolute difference between concentrations at low and high temperature is greatest for DN (0.08 mg N L^{-1}), followed by NO_3^- (0.04 mg N L^{-1}), DON (0.3 mg N L^{-1}), and NH_3 (0.2 mg N L^{-1}). For a given temperature, at different flows upper percentiles of all predicted concentrations increase positively with flows while no pattern can be seen for lower percentiles, except for a slight negative relationship for DON at low temperatures (Table 32).

Model predicted average estuary nitrogen concentrations showed a clear positive relationship to the amount of DN input at the upstream boundary (Figures 19, 20; Tables 33, 34). This was strongest for total DN but is also obvious for both NO_3^-, and DON. This is not surprising, as it shows that increased N input results in increased N in the estuary. The lack of response in NH_3 is due to the fact that NH_3 comprises only a small part of DN (about 8 % of input DN), such that higher DN input does not necessarily correspond to greater NH_3 input (if NH_3 inputs are plotted against NH_3 output, it does result in a strong correlation, not shown). NO_3^- and DON are proportionately more important to DN (DN is approximately 52% of inputs and NO_3^- is approximately 40% of input DN), and hence their predicted concentrations are better correlated with total DN input. Because it is difficult to separate out these input effects on the results, the discussion below is focused on the total DN response rather than that of the individual constituents

As stated above, increasing input upstream DN results in increasing DN concentrations in the estuary, for any flow case (Figures 19, 20). However, as flow increases the relationship shifts up (the mean DN increases from 0.736 mg N L^{-1} to 0.805 mg N L^{-1} from the low to high flow case), showing that for the same DN input there are higher predicted concentrations at higher flows. In addition, the standard deviations decrease, showing that as flows increase the relationship between input upstream DN and model predicted DN becomes less variable. This is demonstrated by the increasing R^2 with increasing flow in Figure 20. The slopes of the regressions are all less than 1, which shows that DN is removed in the estuary in comparison to inputs. There is less removal at higher flows, as indicated by the steeper slope.

2.4. Discussion

The influence of flow on predicted nitrogen concentrations is clear in all of the simulations, with highest predicted nitrogen concentrations occurring at the highest flows. As discussed previously, the positive relationship between flow and predicted nitrogen concentration is the result of the shorter residence times at higher flows causing less nitrogen to be processed in the estuary. Taken to the extreme, as flows increase the concentration of nitrogen throughout the estuary becomes homogenous, with the concentrations coming in at the upstream boundary from the river becoming the concentration throughout the estuary. For example, in the plots for NH_3 in Figure 18 the slope flattens with increasing flow. As flows decrease more nitrogen is taken up by organisms within the estuary, causing a decrease in estuarine nitrogen concentrations with distance down the estuary. The connection between increased estuarine residence time and decreases in dissolved nitrogen has also been demonstrated in other estuaries (Nixon et al., 1996; Mortazavi et al., 2000).

Response of estuarine nitrogen concentrations to changes in temperature was also clear. For given flows the highest predicted concentration typically occurs at low temperatures and the highest concentration at high temperatures. The contrasting interactions of temperature dependent rate processes may explain some of the variability in predicted concentrations. At a given temperature one rate-affecting nitrogen transformation may be dominant while at a different temperature another, possibly counteracting process may become dominant. It is clear for the most part that the change in temperature between the 50^{th} and 75^{th} percentiles has a larger effect than the change from 25^{th} and 50^{th} percentile temperatures. This can be tied to the nature of how temperature affects the rates of processes in the model. In the model the effect of temperature on reactions is the product of a temperature adjustment coefficient and a rate measure at a base temperature, where the adjustment coefficient (C_T) is given as:

$C_T = \Theta^{T-Tb}$

where:

Θ= Coefficient

T= Temperature

Tb= Base temperature

The base temperature for WASP is 20 $^{\circ}$C. As temperature changes so too does the power of the factor affecting that process. The 25^{th}, 50^{th}, and 75^{th} percentiles of temperature used here are approximately 16 $^{\circ}$C, 23 $^{\circ}$C, and 29 $^{\circ}$C. Because the 75^{th} percentile is farther from 20 $^{\circ}$C it has disproportionately larger effect on the rate processes.

The model predicted DN concentrations also showed a clear and positive response to increases in input upstream DN (Figure 20). As input upstream DN increases so too does predicted DN concentration. The deviation of the slope of the regression line below the 1:1 input upstream DN to predicted DN line indicates that at higher concentrations of DN more DN is being take up in the estuary. The decrease in that slope with decreasing flows also indicates that at lower flows more nitrogen is being taken up. This is consistent with the idea that under low flow the increased residence time allows for more uptake of nitrogen.

There are also situations where the input upstream DN is low and the model predicted DN concentrations are actually higher than what was input (points above the 1:1 line). This situation becomes more pronounced at lower flows. To see if observed concentrations of DN ever actually increase in the estuary I used the GCE LTER data to compare concentrations of DN measured at the upstream boundary to the average concentrations of DN in the estuary. On 7 of the 57 dates average observed concentrations of DN in the estuary were higher than those coming into the estuary at the upstream boundary, confirming that this phenomenon does occur. The higher amounts of predicted DN compared to input upstream DN is likely caused by benthic fluxes of ammonia from the sediments to the water column and recycling of dead phytoplankton to the nitrogen pool.

To evaluate the relative influence of flow, temperature, and input upstream DN on average estuary DN concentrations, I compared the difference in predicted concentrations for the 25th (low) vs. 75th (high) percentiles for each variable. As flow increases from the low to high, average predicted DN from the model runs increases significantly from 0.738 to 0.805 mg N L^{-1} (t-test, p< 2.2E^{-16}) for a difference of 0.067 mg N L^{-1} (Table 29). At average flow, average predicted DN decreases significantly from 0.808 to 0.747 mg N L^{-1} (t-test, p=1.65E^{-05}, Table 31) between the low and high temperature input, for a difference of 0.061 mg N L^{-1}. Similarly, at average flows, average predicted DN increases significantly from 0.624 to 0.918 mg N L^{-1} between low and high input upstream DN (t-test, p< 2.2E^{-16}, Table 33) for DN inputs, for an increase of 0.294 mg N L^{-1}. Note that the range of input conditions evaluated here were based on the range of observed conditions in the estuary. These results indicate that upstream DN is by far the dominant factor affecting DN concentrations in the estuary, with an influence that is 6-fold greater than either flow or temperature effects. However, flow and temperature still have an influence, as can be seen in Table 35, which shows the average predicted concentrations observed in model simulations from all combinations of flow, temperature, and input DN. This table indicates that the predicted concentration of DN in the estuary will likely be highest at high input upstream DN, high flows, and low or medium temperatures. Alternately, concentrations will be lowest with low input upstream DN, low flow, and high temperatures.

CONCLUSIONS

The WASP model is a widely respected tool for predicting estuarine nitrogen concentrations (Wang et al., 1999; Yassuda et al., 2000; Wool et al., 2003; Zheng et al., 2004). In a recent review of available models, the USEPA determined that WASP was the most appropriate mechanistic model to simulate estuarine nutrient dynamics for a major nutrient criteria development effort (USEPA, 2010). In this study, I have shown that the WASP model can be successfully used to model concentrations of nitrogen in the Altamaha River estuary. Running the calibrated model with a range of input conditions I evaluated the influence of flow, temperature, and input nitrogen concentrations on the predicted nitrogen concentrations in the estuary. This analysis found that estuarine nitrogen concentrations are positively correlated with flows and upstream nitrogen concentrations, while negatively correlated to temperature. I showed that input upstream DN has the highest influence on estuarine nitrogen concentrations, with temperature and flow having a similar range of effects. At high flows, low and medium temperatures, and high input upstream DN the concentration of DN in the estuary will likely be highest, whereas, at low flow, low input upstream DN and high temperatures estuarine concentrations will be lowest.

The Altamaha River estuary model was set-up using the long term monitoring data collected in the estuary by the GCE LTER program, guidance from literature that used the WASP model in similar systems, a wide range of literature derived values, and meta-analyses of data relevant to the estuary. It was then refined through sensitivity analyses and calibration of key model parameters. Through the sensitivity analyses and model application I determined that the calibrated model exhibited higher sensitivity to input parameters at lower flows and higher temperatures. The higher sensitivity under these conditions reflected the larger amount processing of nitrogen at lower flows due to longer residence time and the influence of higher temperatures on rate terms affecting nitrogen cycling and phytoplankton kinetics. At higher flows model geometry and boundary conditions were the dominant factors affecting model predicted nitrogen concentrations. Once calibrated, the model performed well in general, reproducing both the magnitude and patterns of observed data.

There is an inherent tradeoff in modeling that is centered around the balance between a complex model that requires extensive time and computing resources but is capable of reproducing the finer patterns in a system, and a simpler model that can predict the overall patterns of a system and be run more easily and quickly. The approach taken here is less complex than some of the models used in other studies. Although I was unable to reproduce some of the more intricate details of the observed concentrations, model simulations captured the overall patterns of the nitrogen observed in the Altamaha River estuary. This allowed the use of a relatively simple model to explore processes and patterns in the estuary by running many simulations in an achievable amount of time.

Because of the model misfit at low flows the ability of the model to accurately simulate nitrogen concentrations at those flows must be carefully considered. Further research on the processes and estuarine inputs that affect nitrogen concentrations may help improve the predictive capability at these lower flows. Additional refinement could be provided by using a model that does not vertically and temporally average observed water quality observations. Similarly, a hydrodynamic component that could account for the effects of the significant tidal variations in the estuary would also help improve model skill. Finally, by extending the boundaries of the model the influence of boundary conditions on the model could be lessened.

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APPENDIX A. NITROGEN BUDGET FOR THE ALTAMAHA RIVER ESTUARY

A.1. Introduction

I calculated a nitrogen budget for the Altamaha River estuary to help guide the selection of model parameters and investigate critical inputs to the estuary. The budget included estimates of N loadings to the estuary from the atmosphere, river, marshes, subtidal sediments, and mixing from the ocean.

A.2. Methods

A.2.1. Riverine Fluxes

I used two approaches to estimate advective nutrient loading from the Altamaha River to the estuary. The first method I used to calculate monthly riverine loading of NH_3, NO_x^-, and DON employed a statistical model developed by the United States Geological Survey to estimate constituent loading in lotic systems, called the Load Estimator (LOADEST) program. The LOADEST program uses observed concentrations of water quality variables, observed streamflow measurements, as well as other variables over a user specified calibration period to create a regression model of estimated loading. This model is then used to estimate loads during a time period of interest.

To calculate loading using this method I used flows and nitrogen concentrations observed in the Altamaha River near Gardi, Georgia (USGS station 02226010) from 1974-2009 (n=501 observations). I tested various calibration and estimation dates to find a combination that best predicted flows over the dates of interest for this study. It became clear that there was a different relationship between loads and flows observed early in the available data compared to the relationship observed in later dates. This was determined by calibrating the model with all dates and then with just the later dates (1989-2009, n=340 observations). The results were noticeably different, with the later dates generally producing higher estimated loads and better predictive capability. Because the more contemporary dates were more reflective of conditions observed over the period of interest for this study I ultimately used observations made from January 1989-December 2008 for the calibration period. I considered several ranges of dates were for the estimation period also. Ultimately, the period from March 2003-April 2006 provided the most complete dataset and generally coincided with the dates of interest for the modeling study, so I used this timeframe.

I had to estimate loading of particulate nitrogen to the estuary differently because very little data were available to use the method above. To estimate particulate nitrogen loading I multiplied concentrations from GCE LTER monitoring at the station 24 km upstream of the mouth by the flow on the observation date to estimate daily loading. I did this for all observations where the sample date had a complete set of samples (i.e. surface and bottom samples for high and low water), resulting in 204 calculations between June 2003-June 2010. The median of these numbers was used to represent typical loading. The station at 24 km is generally considered to be the upstream extent of mixing with ocean waters, as is reflected by salinities at the site (Table 5), and thus a good reflection of the riverine input to the estuary.

A.2.2. Subtidal Sediment Fluxes

I estimated nitrogen fluxes from subtidal sediments using results from the meta-analysis of data from systems similar to the Altamaha River estuary (Appendix B). I applied the median flux of NH_4^+ and NO_x^- observed in dark conditions over the low water area of the estuary. Median DON flux in the meta-analysis was zero and thus was not used in overall sediment flux calculations.

A.2.3. Marsh Fluxes

I estimated flux of nitrogen from estuarine marshes using a synthesis of values from flux studies conducted in marsh systems in the southeastern United States in environments similar to the Altamaha River estuary (Table 36). I assumed that marsh fluxes in a large marsh/estuary system such as the Altamaha would occur through tidal creeks of various geomorphologies, as classified by Odum et al. (1979); ages, as per Dame (1994); and marsh systems of various sizes. Based on these assumptions, I used studies in a variety of systems to reflect the range of conditions that would be expected over the Altamaha estuary. However, it was important that the studies used were in marshes that are similar in overall character to those in the Altamaha River estuary system, thus the focus on the Southeast. Additionally, I only used studies that measured system fluxes, as opposed to studies conducted in smaller scale marsh flumes.

To estimate marsh flux I applied the median areal flux from these studies over the area of the marshes in the Altamaha River estuary. Marsh area was estimated with data used to develop the SqueezeBox model for the Altamaha (J. Sheldon, unpublished data).

A.2.4. Atmospheric Fluxes

I calculated total annual atmospheric deposition of N to the estuary surface as the sum of wet and dry deposition. Wet deposition data from 2002-2007 of NH_4^+ and NO_3^- was obtained from National Atmospheric Deposition Program (NADP) measurements taken on Sapelo Island, Georgia (NADP site GA33). Dry deposition of NH_4^+, NO_3^-, and HNO_3 was calculated from measurements taken from 1992-2007 by the USEPA's Clean Air Status and Trends Network

(CASTNET) at two stations: Pike County (CASTNET site GAS153) in inland Georgia and coastal North Carolina in Beaufort (CASTNET site BFT142). I estimated DON deposition to be 30% of the total deposition of nitrogen to the estuary (Neff et al., 2002). All sources were summed to get total nitrogen deposition. I applied the median annual areal deposition over the open water area of the estuary at low tide. Nitrogen deposition to the areas flooded by high tides was not estimated because it was assumed that this input of nitrogen would be accounted for in the estimates of input from the marshes. I calculated monthly deposition of nitrogen by dividing annual deposition by the number of days in a given month.

A.2.5. Oceanic Fluxes

Finally, I estimated nitrogen inputs to the estuary from the ocean. I only considered nitrogen that would be considered "new" to the estuary as ocean input, that is, N derived from an oceanic source as opposed to riverine derived nitrogen recirculated into the estuary through tidal action. I approximated this “new nitrogen” by using the net upstream mixing coefficient, Qe, calculated by SqueezeBox at the -02 km GCE LTER sampling station at the mouth of the estuary. By only using the Qe at the lower boundary of the estuary (and not the Qe at each estuarine box) only what is coming into the downstream model segment at the mouth of the estuary is represented. However, over time what goes into that box will also be mixed upstream to the next box along with “new water” from downstream of the first box. It is difficult, however, to distinguish which nitrogen (from a given box or from downstream of that box) is being mixed upstream. We know though that with increasing distance upstream there is less net upstream mixing of "new water" from outside the estuary boundary because of the increased dominance of riverine advection over tidal forces. Thus, there is going to be progressively less “new nitrogen” from outside the downstream boundary of the estuary introduced with distance upstream. Because new nitrogen is mixed throughout the estuary, and not just from the downstream boundary into the first estuarine segment “new” nitrogen to the system may be somewhat underestimated. However, because the true downstream boundary of the estuary, where oceanic water instead of river water is dominant, is likely further seaward than the station at -02 km, the amount of “new” nitrogen from the ocean that is actually making it to -02 km is probably small. For this reason the mass of "new" nitrogen loaded to the estuary from downstream the seaward boundary is probably overestimated, although less so at lower flows as the oceanic/riverine boundary moves closer to the mouth of the estuary.

Nitrogen concentrations representative of oceanic conditions were provided by measurements made at Gray's Reef National Marine Sanctuary, approximately 30 km east of the mouth of the Altamaha. I used 25th, 50th, and 75th percentiles of NH_4^+ ($5.6E^{-4}$, $1.7E^{-3}$, and $7.3E^{-3}$ mg L^{-1}) and NO_x^- ($1.4E^{-4}$, $2.1E^{-3}$, and $3.8E^{-3}$ mg L^{-1}) concentrations from 2/16/2005-5/22/2008. DON concentrations were often negligible, so I did not include them in the calculations. I used the above concentrations in Squeezebox (run at median flow observed during this time period) to estimate the amount of oceanic nitrogen that would be mixed upstream during typical flows.

A.3. Results

Riverine nitrogen inputs clearly dominate the nitrogen inputs to the Altamaha River estuary under median conditions (Figure 21). Riverine flux accounts for 94.9 % (11,560,937 kg yr^{-1}) of the total annual nitrogen flux (12,184,382 kg yr^{-1}), whereas none of the other sources accounted for more than 2.5% of the annual flux. Under typical flux conditions (the 50th percentile), organic nitrogen accounts for 54% of total inputs, followed by nitrate (30%), particulate nitrogen (11%), and ammonium (5%) (Table 37).

Estimates of the 25^{th} and 75^{th} percentile inputs are presented in Table 37. Note that the riverine nitrogen contribution includes particulate nitrogen (PN) whereas the marsh, subtidal, and oceanic fluxes did not include this component, which means that the relative contribution of riverine inputs may be slightly lower than the percentages reported here.

Because some of the flux information had to be calculated as an annual estimate the most useful time period for overall comparisons is on an annual basis. However, given that the riverine input is dominant one can look at the monthly input to provide insight into temporal variations in nitrogen loading (Figure 22). There is great variability in riverine inputs, with high nitrogen inputs typically occurring during spring months and low inputs during the summer, thus, during summer months other sources will make up a larger portion of the estuarine nitrogen budget. Contributions of these other sources also vary in time, and all of them except mixing from the ocean are independent of river flow, increasing the likelihood that their importance relative to riverine inputs increases during low flows. Of particular note is the flux of ammonium from the subtidal sediments, which can be high at some times and places. For example, the 75^{th} percentile of benthic ammonium flux (504,384 kg yr^{-1}) exceeds the 50^{th} percentile flux of ammonium from the river, suggesting it can be the most important source of ammonium. However, despite the possible significance of nitrogen sources other than riverine input during the lowest flows, these conditions only occur a small portion of the time (Figure 22).

APPENDIX B. BENTHIC FLUX META-ANALYSIS

B.1. Introduction

In many estuaries benthic fluxes of nutrients can provide significant inputs of nitrogen to the water column (Table 38). However, the flux of nitrogen from sediments has only been measured in a limited number of places. I conducted a meta-analysis of relevant literature to put bounds on the potential contribution of benthic fluxes of nitrogen to the Altamaha River estuary, as well as characterize the relationship of those fluxes to other environmental variables (Table 39). I examined benthic fluxes of NH_4^+, NO_3^-, and DON measured in sunlit or dark conditions, as well as net fluxes (sum of light and dark fluxes). I also recorded values of other factors that may affect flux rates including temperature, salinity, nutrients in the overlying water column, depth, sediment characteristics, and oxygen conditions, among others. Other associated rates were also noted (e.g. denitrification, nitrification, sediment oxygen consumption).

B.2. Methods

To ensure uniformity of sampling environments and consistent sampling methods I applied several criteria to filter the data (Table 40). I excluded measurements in depths greater than 30 meters because I wanted to data from shallow rather than open ocean environments. In addition, I selected riverine dominated estuaries (excluding lagoonal and shallow oceanic systems). I did not use measurements made in intertidal areas because the periodic exposure of intertidal sediments to air creates conditions unique to those areas and I was interested in subtidal environments. I also excluded heavily impacted environments and studies that examined the effects of artificial fertilization because I was interested in natural conditions. Finally, there are a wide variety of methods used to measure benthic fluxes. Benthic fluxes measured in-situ and from laboratory incubations of sediment cores have been found to comparable (Miller-Way et al. 1994) so both were included in the analysis. However, I only used measurements in which sediment cores were intact, as opposed to those which used homogenized sediments from cores.

In all cases, NH_4^+ was assumed to be the sum of NH_4^+ and NH_3, and NO_3^- was assumed to be the sum of NO_3^- and NO_2^- because of the lack of sensitivity of some of the analytical methods used to measure these constituents. Organic carbon measurements were converted to ignition loss values according to results of Craft et al. (1991). Where ranges of values were given instead of single point measurements I averaged them when the range was a small percent of the values, otherwise the measurements were not used. When reported values were the result of an average of multiple observations I used the average as a single observation. Lastly, a small number (n=13) of observations were below analytical detection limits. I recorded these as half of the detection limit.

The final analysis included 23 papers (Table 41) but the number of papers and observations associated with each factor varied widely. After compiling the data it became clear that I did not have sufficient numbers of observations or associated studies to warrant further analyses for some of the factors I was initially interested in evaluating. For example, there were very few flux measurements taken in the light, nor were there many studies that measured net flux (light+dark measurements). There were, however, sufficient observations to consider the flux of nitrogen species in the dark. Since light attenuation is high in the Altamaha River estuary and it is likely that little light reaches most of the benthos, the use of these measurements seemed like a reasonable way to approximate benthic fluxes in the estuary.

B.3. Results

I compiled a total of 221 observations of benthic NO_3^- flux, 243 observations of NH_4^+, and 65 observations of DON under dark conditions. The flux of nitrate from the sediments was typically small and negative, but had a very large standard deviation (mean=-2.2 ± 35.3 (s.d.) mg N m^{-2} d^{-1}, median=0.7 mg N m^{-2} d^{-1}). There were several observations of zero and negative flux (i.e. from the water to the sediments). The flux of ammonium from the sediments was, on average, greater than that of nitrate, although again the standard deviation was large (mean = 29.7 ± 37.9 mg N m^{-2} d^{-1}; median =16.8 mg N m^{-2} d^{-1}). In cases where both were measured, the flux of ammonium was higher for 76 percent of the observations (Figure 23,160 of 210 observations). Although in some instances DON flux from sediments can be large, the average and median values were low and the standard deviation was again high (mean = 2.8 ± 74.2 mg N m^{-2} d^{-1}; median = 0), making it difficult to draw any firm conclusions, especially given the small number available of observations.

Because ammonium represented the largest benthic N flux in these observations, I examined the relationship of ammonium flux to environmental variables in the estuary. Temperature (R^2 = 0.02, p=0.04), ammonium in the overlying water (R^2 = 0.29, p=1.70E^{-11}), and sediment oxygen consumption (R^2 = 0.24, p=5.66E^{-12}) all had significant but weak correlations with ammonium flux (Figures 24-26).

B.4. Discussion

The benthic flux of nitrogen can be input as a boundary flux to the WASP model. Given that the NO_3^- flux was near zero and the DON flux measurements were not robust, I only used the results of this analysis to estimate the benthic flux of NH_4^+ in the model. I used the 25th and 75th percentile of these observations (3.36 mg N m^{-2} d^{-1} and 43.87 mg N m^{-2} d^{-1}), as the range for the global sensitivity analyses and the 79th and 95th percentile of these observations for the exploratory calibrations (43.87 mg N m^{-2} d^{-1} and 11.20 mg N m^{-2} d^{-1}).

APPENDIX C. RESULTS OF SENSITIVITY ANALYSES

This appendix contains the full results for the initial and final sensitivity analyses. "% Sensitivity" indicates the model sensitivity, as indicated by the average absolute percent response of NH_3, NO_3^-, and DON, to variations in the given input. "U" and "D" following the input name indicate an upward or downward perturbation of the input.

C.1. Initial Sensitivity Analysis

C.1.1. September 2003 Local Analysis

Input	% Sensitivity
Phytoplankton Maximum Growth Temperature Coefficient-U	28.55
Light Option (1=input light; 2=calculated diel light)-D	19.99
Phytoplankton Respiration Rate Temperature Coefficient-U	17.62
Phytoplankton Maximum Growth Temperature Coefficient-D	16.40
DON Mineralization Temperature Coefficient-U	12.33
Phytoplankton Respiration Rate Temperature Coefficient-D	7.12
Nitrification Temperature Coefficient-U	5.89
DON Mineralization Temperature Coefficient-D	5.86
Fraction Phytoplankton Death Recycled to Organic N-D	4.78
Fraction Phytoplankton Death Recycled to Organic N-U	4.65
Temperature - Segment 1-5-U	4.59
Depth - Segment 1-5-D	4.37
Phytoplankton Maximum Growth Rate -D	4.24
Phytoplankton Maximum Growth Rate -U	4.18
Temperature - Segment 2-5-U	4.17
Temperature - Segment 1-4-U	4.01
Upstream Boundary Concentration NO3-U	3.90
Upstream Boundary Concentration NO3-D	3.88
Temperature - Segment 1-5-D	3.77
Depth - Segment 1-5-U	3.61
Temperature - Segment 2-5-D	3.49
Temperature - Segment 3-5-U	3.47
Light Extinction - Segment 1-5-D	3.26

C.1.1. September 2003 Local Analysis (continued)

Temperature - Segment 1-4-D	3.23
Upstream Boundary Concentration DON-U	2.92
Upstream Boundary Concentration DON-D	2.92
Temperature - Segment 3-5-D	2.90
Light Extinction - Segment 1-5-U	2.90
Temperature - Segment 1-3-U	2.77
Phytoplankton Respiration Rate-D	2.77
Phytoplankton Respiration Rate-U	2.61
Phytoplankton Carbon to Chlorophyll Ratio-D	2.48
Phytoplankton Carbon to Chlorophyll Ratio-U	2.39
Solar Radiation-D	2.33
Phytoplankton Optimal Light Saturation-D	2.26
Temperature - Segment 1-3-D	2.19
Fraction Daily Light-D	2.18
Phytoplankton Nitrogen to Carbon Ratio-D	2.14
Temperature - Segment 4-5-U	2.13
Phytoplankton Optimal Light Saturation-U	2.10
Phytoplankton Nitrogen to Carbon Ratio-U	2.10
Surface Water Flow-D	2.09
Volume - Segment 1-5-D	2.05
Solar Radiation-U	2.05
Nitrification Temperature Coefficient-D	2.02
Surface Water Flow-U	1.97
Volume - Segment 1-5-U	1.96
Fraction Daily Light-U	1.91
Phytoplankton Half-Saturation N Uptake-D	1.81
Temperature - Segment 4-5-D	1.75
Phytoplankton Half-Saturation N Uptake-U	1.66
Temperature - Segment 3-U	1.51
DON Mineralization Rate-D	1.50
DON Mineralization Rate-U	1.49
Temperature - Segment 4-U	1.44
Upstream Boundary Concentration Chl-a-D	1.42
Temperature - Segment 1-2-U	1.38
Upstream Boundary Concentration Chl-a-U	1.37
Depth - Segment 3-D	1.32
Dispersive Mixing Between Segments - Boundary:Boundary-D	1.21

C.1.1. September 2003 Local Analysis (continued)

Surface Area Between Segments - Boundary:Boundary-D	1.21
Depth - Segment 4-D	1.20
Segment Length - Boundary:Boundary-D	1.20
Temperature - Segment 3-D	1.19
Temperature - Segment 4-D	1.16
Temperature - Segment 1-2-D	1.12
Segment Length - Boundary:Boundary-U	1.09
Surface Area Between Segments - Boundary:Boundary-U	1.08
Dispersive Mixing Between Segments - Boundary:Boundary-U	1.08
Depth - Segment 3-U	1.08
Downstream Boundary Concentration DON-U	1.05
Downstream Boundary Concentration DON-D	1.05
Depth - Segment 4-U	0.99
Light Extinction - Segment 3-D	0.98
Temperature - Segment 2-U	0.93
Depth - Segment 2-D	0.92
Light Extinction - Segment 4-D	0.89
Phytoplankton Half-Sat. for Mineralization Rate-D	0.89
Nitrification Rate-D	0.88
Light Extinction - Segment 3-U	0.86
Nitrification Rate-U	0.83
Phytoplankton Half-Sat. for Mineralization Rate-U	0.80
Light Extinction - Segment 4-U	0.78
Downstream Boundary Concentration Chl-a-D	0.75
Depth - Segment 2-U	0.75
Downstream Boundary Concentration Chl-a-U	0.73
Temperature - Segment 2-D	0.72
Temperature - Segment 5-U	0.71
Light Extinction - Segment 2-D	0.69
Downstream Boundary Concentration NO3-U	0.68
Downstream Boundary Concentration NO3-D	0.68
Light Extinction - Segment 2-U	0.60
Depth - Segment 5-D	0.59
Downstream Boundary Concentration NH3-U	0.58
Downstream Boundary Concentration NH3-D	0.58
Temperature - Segment 5-D	0.58
Upstream Boundary Concentration NH3-U	0.57

C.1.1. September 2003 Local Analysis (continued)

Upstream Boundary Concentration NH3-D	0.57
Volume - Segment 3-D	0.57
Volume - Segment 3-U	0.56
Dispersive Mixing Between Segments - Segment5:Boundary-D	0.55
Surface Area Between Segments - Segment5:Boundary-D	0.55
Volume - Segment 4-D	0.53
Volume - Segment 4-U	0.52
Segment Length - Segment5:Boundary-D	0.52
Segment Length - Segment5:Boundary-U	0.50
Temperature - Segment 1-U	0.50
Depth - Segment 5-U	0.49
Dispersive Mixing Between Segments - Segment5:Boundary-U	0.47
Surface Area Between Segments - Segment5:Boundary-U	0.47
Light Extinction - Segment 5-D	0.45
Surface Area Between Segments - Segment 4:Segment5-D	0.44
Dispersive Mixing Between Segments - Segment 4:Segment5-D	0.44
Segment Length - Segment 4:Segment5-D	0.43
Temperature - Segment 1-D	0.42
Volume - Segment 2-D	0.40
Segment Length - Segment 4:Segment5-U	0.40
Depth - Segment 1-D	0.39
Light Extinction - Segment 5-U	0.39
Volume - Segment 2-U	0.39
Surface Area Between Segments - Segment 4:Segment5-U	0.39
Dispersive Mixing Between Segments - Segment 4:Segment5-U	0.39
Depth - Segment 1-U	0.32
Light Extinction - Segment 1-D	0.30
Dispersive Mixing Between Segments - Segment 3:Segment4-D	0.30
Surface Area Between Segments - Segment 3:Segment4-D	0.30
Segment Length - Segment 3:Segment4-D	0.29
Segment Length - Boundary:Segment1-D	0.27
Volume - Segment 1-D	0.27
Segment Length - Segment 3:Segment4-U	0.27
Surface Area Between Segments - Segment 3:Segment4-U	0.26
Dispersive Mixing Between Segments - Segment 3:Segment4-U	0.26
Phytoplankton Death Rate-D	0.26
Phytoplankton Death Rate-U	0.26

C.1.1. September 2003 Local Analysis (continued)

Volume - Segment 1-U	0.26
Volume - Segment 5-D	0.26
Light Extinction - Segment 1-U	0.26
Dispersive Mixing Between Segments - Boundary:Segment1-D	0.26
Surface Area Between Segments - Boundary:Segment 1-D	0.26
Volume - Segment 5-U	0.25
Benthic Ammonia Flux - Segment 1-5-U	0.25
Benthic Ammonia Flux - Segment 1-5-D	0.25
Denitrification Temperature Coefficient-U	0.25
Dispersive Mixing Between Segments - Boundary:Segment 1-U	0.24
Surface Area Between Segments - Boundary:Segment 1-U	0.24
Segment Length - Boundary:Segment 1-U	0.23
Dispersive Mixing Between Segments - Segment 2:Segment3-D	0.21
Surface Area Between Segments - Segment 2:Segment3-D	0.21
Segment Length - Segment 2:Segment3-D	0.20
Half Saturation Nitrification Oxygen Limit-D	0.20
Half Saturation Nitrification Oxygen Limit-U	0.20
Segment Length - Segment 2:Segment3-U	0.19
Surface Area Between Segments - Segment 2:Segment3-U	0.19
Dispersive Mixing Between Segments - Segment 2:Segment3-U	0.18
Segment Length - Segment 1:Segment2-D	0.18
Surface Area Between Segments - Segment 1:Segment2-D	0.18
Dispersive Mixing Between Segments - Segment 1:Segment2-D	0.18
Surface Area Between Segments - Segment 1:Segment2-U	0.17
Dispersive Mixing Between Segments - Segment 1:Segment2-U	0.17
SOD Temperature Correction-U	0.17
Segment Length - Segment 1:Segment2-U	0.17
Denitrification Temperature Coefficient-D	0.12
Upstream Boundary Concentration DO-D	0.08
Upstream Boundary Concentration DO-U	0.07
Benthic Ammonia Flux - Segment 3-U	0.07
Benthic Ammonia Flux - Segment 3-D	0.07
Benthic Ammonia Flux - Segment 4-U	0.07
Benthic Ammonia Flux - Segment 4-D	0.07
CBOD Decay Rate Temperature Correction Coefficient-U	0.05
Benthic Ammonia Flux - Segment 2-U	0.05
Benthic Ammonia Flux - Segment 2-D	0.05

C.1.1. September 2003 Local Analysis (continued)

SOD Temperature Correction-D	0.05
Downstream Boundary Concentration DO-D	0.05
Downstream Boundary Concentration DO-U	0.04
Benthic Ammonia Flux - Segment 5-U	0.04
Benthic Ammonia Flux - Segment 5-D	0.04
Denitrification Rate-D	0.03
Denitrification Rate-U	0.03
Half Saturation Denitrification Oxygen Limit-D	0.03
Half Saturation Denitrification Oxygen Limit-U	0.03
Benthic Ammonia Flux - Segment 1-U	0.02
Benthic Ammonia Flux - Segment 1-D	0.02
Global Reaeration Rate-D	0.02
SOD - Segment 1-5-U	0.02
SOD - Segment 1-5-D	0.02
Global Reaeration Rate-U	0.02
CBOD Decay Rate Temperature Correction Coefficient-D	0.01
Downstream Boundary Concentration Salinity-D	0.01
Downstream Boundary Concentration Salinity-U	0.01
CBOD Rate-D	0.01
CBOD Rate-U	0.01
SOD - Segment 3-U	0.01
SOD - Segment 3-D	0.01
SOD - Segment 4-U	0.01
SOD - Segment 4-D	0.01
Upstream Boundary Concentration CBOD-U	0.00
Upstream Boundary Concentration CBOD-D	0.00
SOD - Segment 2-U	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-D	0.00
Pore Water Flow-D	0.00
SOD - Segment 2-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-D	0.00
Settling Rate for Solids Group 1-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-U	0.00

C.1.1. September 2003 Local Analysis (continued)

Settling Rate for Solids Group 1-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-U	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-U	0.00
Pore Water Flow-U	0.00
Downstream Boundary Concentration CBOD-U	0.00
Downstream Boundary Concentration CBOD-D	0.00
SOD - Segment 5-U	0.00
SOD - Segment 5-D	0.00
SOD - Segment 1-U	0.00
SOD - Segment 1-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-U	0.00

C.1.1. September 2003 Local Analysis (continued)

Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-U	0.00
CBOD Half Saturation Oxygen Limit-D	0.00
CBOD Half Saturation Oxygen Limit-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-U	0.00
Upstream Boundary Concentration Salinity-U	0.00
Downstream Boundary Concentration Inorganic Solids-D	0.00
Downstream Boundary Concentration Inorganic Solids-U	0.00
Upstream Boundary Concentration Inorganic Solids-D	0.00
Upstream Boundary Concentration Salinity-D	0.00
Upstream Boundary Concentration Inorganic Solids-U	0.00
Resuspension Rate for Solids Group 1-U	0.00
Resuspension Rate for Solids Group 1-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-U	0.00

C.1.1. September 2003 Local Analysis (continued)

Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-D	0.00
Upstream Boundary Concentration Detrital N-D	0.00
Upstream Boundary Concentration Detrital C-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-D	0.00
Upstream Boundary Concentration Detrital N-U	0.00
Downstream Boundary Concentration Detrital N-U	0.00
Downstream Boundary Concentration Detrital N-D	0.00

C.1.2. March 2005 Local Analysis

Input	% Sensitivity
Upstream Boundary Concentration NO3-D	3.16
Upstream Boundary Concentration NO3-U	3.16
Upstream Boundary Concentration DON-U	3.05
Upstream Boundary Concentration DON-D	3.05
Phytoplankton Maximum Growth Temperature Coefficient-D	2.87
Phytoplankton Respiration Rate Temperature Coefficient-U	2.51
DON Mineralization Temperature Coefficient-D	2.14
Nitrification Temperature Coefficient-U	2.09
Phytoplankton Respiration Rate Temperature Coefficient-D	1.83
Phytoplankton Maximum Growth Temperature Coefficient-U	1.68
DON Mineralization Temperature Coefficient-U	1.33
Nitrification Temperature Coefficient-D	1.31
Light Option (1=input light; 2=calculated diel light)-D	1.31
Surface Water Flow-D	1.27
Surface Water Flow-U	1.09
Fraction Phytoplankton Death Recycled to Organic N-D	1.04
Fraction Phytoplankton Death Recycled to Organic N-U	1.04
Segment Length - Boundary:Boundary-D	0.82
Dispersive Mixing Between Segments - Boundary:Boundary-D	0.78
Surface Area Between Segments - Boundary:Boundary-D	0.78
Dispersive Mixing Between Segments - Boundary:Boundary-U	0.74
Surface Area Between Segments - Boundary:Boundary-U	0.74
Segment Length - Boundary:Boundary-U	0.71
Phytoplankton Carbon to Chlorophyll Ratio-D	0.57
Volume - Segment 1-5-D	0.56
Phytoplankton Carbon to Chlorophyll Ratio-U	0.56
Volume - Segment 1-5-U	0.54
Dispersive Mixing Between Segments - Segment5:Boundary-D	0.49
Surface Area Between Segments - Segment5:Boundary-D	0.49
Segment Length - Segment5:Boundary-D	0.49
Downstream Boundary Concentration DON-U	0.48
Downstream Boundary Concentration DON-D	0.48
Segment Length - Segment5:Boundary-U	0.45
Phytoplankton Respiration Rate-D	0.45
Dispersive Mixing Between Segments - Segment5:Boundary-U	0.45

C.1.2. March 2005 Local Analysis (continued)

Surface Area Between Segments - Segment5:Boundary-U	0.45
Phytoplankton Respiration Rate-U	0.44
Phytoplankton Nitrogen to Carbon Ratio-D	0.39
Phytoplankton Nitrogen to Carbon Ratio-U	0.38
Nitrification Rate-D	0.37
Nitrification Rate-U	0.36
Upstream Boundary Concentration Chl-a-D	0.34
Upstream Boundary Concentration Chl-a-U	0.34
Benthic Ammonia Flux - Segment 1-5-U	0.34
Benthic Ammonia Flux - Segment 1-5-D	0.34
Phytoplankton Maximum Growth Rate -U	0.32
Phytoplankton Maximum Growth Rate -D	0.31
Light Extinction - Segment 1-5-D	0.30
Downstream Boundary Concentration NO3-D	0.26
Downstream Boundary Concentration NO3-U	0.26
Light Extinction - Segment 1-5-U	0.25
DON Mineralization Rate-U	0.25
DON Mineralization Rate-D	0.25
Downstream Boundary Concentration Chl-a-D	0.23
Downstream Boundary Concentration Chl-a-U	0.23
Segment Length - Segment 4:Segment5-D	0.22
Depth - Segment 1-5-D	0.22
Surface Area Between Segments - Segment 4:Segment5-D	0.22
Dispersive Mixing Between Segments - Segment 4:Segment5-D	0.22
Phytoplankton Half-Sat. for Mineralization Rate-D	0.22
Surface Area Between Segments - Segment 4:Segment5-U	0.20
Dispersive Mixing Between Segments - Segment 4:Segment5-U	0.20
Segment Length - Segment 4:Segment5-U	0.20
Phytoplankton Half-Sat. for Mineralization Rate-U	0.18
Depth - Segment 1-5-U	0.18
Solar Radiation-D	0.17
Phytoplankton Optimal Light Saturation-D	0.17
Fraction Daily Light-D	0.16
Phytoplankton Optimal Light Saturation-U	0.16
Solar Radiation-U	0.15
Temperature - Segment 1-5-U	0.14
Volume - Segment 4-D	0.14

C.1.2. March 2005 Local Analysis (continued)

Volume - Segment 4-U	0.14
Volume - Segment 3-D	0.13
Temperature - Segment 1-5-D	0.13
Volume - Segment 3-U	0.13
Volume - Segment 5-D	0.12
Volume - Segment 5-U	0.12
Temperature - Segment 2-5-U	0.12
Temperature - Segment 2-5-D	0.11
Segment Length - Segment 3:Segment4-D	0.11
Surface Area Between Segments - Segment 3:Segment4-D	0.10
Dispersive Mixing Between Segments - Segment 3:Segment4-D	0.10
Temperature - Segment 1-4-U	0.10
Benthic Ammonia Flux - Segment 3-U	0.10
Benthic Ammonia Flux - Segment 3-D	0.10
Volume - Segment 2-D	0.10
Volume - Segment 2-U	0.10
Dispersive Mixing Between Segments - Segment 3:Segment4-U	0.10
Surface Area Between Segments - Segment 3:Segment4-U	0.10
Segment Length - Segment 3:Segment4-U	0.09
Temperature - Segment 3-5-U	0.09
Temperature - Segment 1-4-D	0.09
Light Extinction - Segment 4-D	0.09
Benthic Ammonia Flux - Segment 4-U	0.09
Benthic Ammonia Flux - Segment 4-D	0.09
Phytoplankton Death Rate-D	0.09
Phytoplankton Death Rate-U	0.09
Temperature - Segment 3-5-D	0.09
Half Saturation Nitrification Oxygen Limit-D	0.08
Half Saturation Nitrification Oxygen Limit-U	0.08
Light Extinction - Segment 4-U	0.08
Light Extinction - Segment 3-D	0.08
Benthic Ammonia Flux - Segment 2-U	0.07
Benthic Ammonia Flux - Segment 2-D	0.07
Depth - Segment 3-D	0.07
Temperature - Segment 1-3-U	0.07
Temperature - Segment 4-5-U	0.07
Temperature - Segment 4-5-D	0.06

C.1.2. March 2005 Local Analysis (continued)

Light Extinction - Segment 3-U	0.06
Temperature - Segment 1-3-D	0.06
Light Extinction - Segment 5-D	0.06
Volume - Segment 1-D	0.06
Volume - Segment 1-U	0.06
Depth - Segment 3-U	0.06
Depth - Segment 2-D	0.06
Upstream Boundary Concentration DO-D	0.05
Segment Length - Segment 2:Segment3-D	0.05
Light Extinction - Segment 5-U	0.05
Dispersive Mixing Between Segments - Segment 2:Segment3-D	0.05
Surface Area Between Segments - Segment 2:Segment3-D	0.05
Depth - Segment 4-D	0.05
Upstream Boundary Concentration DO-U	0.05
Surface Area Between Segments - Segment 2:Segment3-U	0.05
Dispersive Mixing Between Segments - Segment 2:Segment3-U	0.05
Depth - Segment 2-U	0.05
Light Extinction - Segment 2-D	0.05
Segment Length - Segment 2:Segment3-U	0.05
Temperature - Segment 1-2-U	0.05
Benthic Ammonia Flux - Segment 5-U	0.04
Benthic Ammonia Flux - Segment 5-D	0.04
Temperature - Segment 1-2-D	0.04
Depth - Segment 4-U	0.04
Temperature - Segment 5-U	0.04
Light Extinction - Segment 2-U	0.04
Temperature - Segment 5-D	0.04
Benthic Ammonia Flux - Segment 1-U	0.03
Benthic Ammonia Flux - Segment 1-D	0.03
Segment Length - Segment 1:Segment2-D	0.03
Depth - Segment 5-D	0.03
Temperature - Segment 4-U	0.03
Segment Length - Boundary:Segment1-D	0.03
Surface Area Between Segments - Segment 1:Segment2-D	0.03
Dispersive Mixing Between Segments - Segment 1:Segment2-D	0.03
Surface Area Between Segments - Boundary:Segment 1-D	0.03
Dispersive Mixing Between Segments - Boundary:Segment1-D	0.03

C.1.2. March 2005 Local Analysis (continued)

Dispersive Mixing Between Segments - Segment 1:Segment2-U	0.03
Surface Area Between Segments - Segment 1:Segment2-U	0.03
Depth - Segment 1-D	0.03
Temperature - Segment 4-D	0.03
Segment Length - Segment 1:Segment2-U	0.03
Dispersive Mixing Between Segments - Boundary:Segment 1-U	0.03
Surface Area Between Segments - Boundary:Segment 1-U	0.03
Denitrification Temperature Coefficient-D	0.03
Segment Length - Boundary:Segment 1-U	0.03
Depth - Segment 5-U	0.02
Temperature - Segment 3-U	0.02
Temperature - Segment 2-U	0.02
Temperature - Segment 1-U	0.02
Depth - Segment 1-U	0.02
Temperature - Segment 3-D	0.02
Temperature - Segment 2-D	0.02
Temperature - Segment 1-D	0.02
Light Extinction - Segment 1-D	0.02
Light Extinction - Segment 1-U	0.02
Denitrification Temperature Coefficient-U	0.02
Downstream Boundary Concentration DO-D	0.01
Downstream Boundary Concentration DO-U	0.01
SOD Temperature Correction-U	0.01
SOD Temperature Correction-D	0.01
Global Reaeration Rate-D	0.01
Global Reaeration Rate-U	0.01
CBOD Decay Rate Temperature Correction Coefficient-U	0.01
Denitrification Rate-U	0.00
Half Saturation Denitrification Oxygen Limit-U	0.00
Denitrification Rate-D	0.00
Half Saturation Denitrification Oxygen Limit-D	0.00
CBOD Decay Rate Temperature Correction Coefficient-D	0.00
Pore Water Flow-D	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-D	0.00
SOD - Segment 1-5-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-D	0.00

C.1.2. March 2005 Local Analysis (continued)

SOD - Segment 1-5-D	0.00
Pore Water Flow-U	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-U	0.00
CBOD Rate-U	0.00
Fraction Daily Light-U	0.00
Upstream Boundary Concentration CBOD-U	0.00
CBOD Rate-D	0.00
SOD - Segment 3-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-U	0.00
SOD - Segment 4-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-U	0.00
Downstream Boundary Concentration Salinity-U	0.00
Upstream Boundary Concentration CBOD-D	0.00
SOD - Segment 2-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-D	0.00
Downstream Boundary Concentration CBOD-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-D	0.00
SOD - Segment 3-D	0.00
SOD - Segment 5-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-D	0.00
Settling Rate for Solids Group 1-U	0.00
SOD - Segment 1-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-U	0.00

C.1.2. March 2005 Local Analysis (continued)

Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-U	0.00
SOD - Segment 4-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-U	0.00
Downstream Boundary Concentration Salinity-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-U	0.00
CBOD Half Saturation Oxygen Limit-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-U	0.00
SOD - Segment 2-D	0.00
Downstream Boundary Concentration Inorganic Solids-D	0.00
Upstream Boundary Concentration Inorganic Solids-U	0.00
Downstream Boundary Concentration Inorganic Solids-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-U	0.00
Upstream Boundary Concentration Detrital C-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-U	0.00
Upstream Boundary Concentration Detrital C-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-D	0.00
Resuspension Rate for Solids Group 1-D	0.00
Downstream Boundary Concentration Detrital N-U	0.00
Downstream Boundary Concentration Detrital C-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-U	0.00

C.1.2. March 2005 Local Analysis (continued)

Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-D	0.00
Upstream Boundary Concentration Inorganic Solids-D	0.00
Downstream Boundary Concentration Detrital N-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-D	0.00
Resuspension Rate for Solids Group 1-U	0.00
Upstream Boundary Concentration Salinity-D	0.00
Upstream Boundary Concentration Salinity-U	0.00
Upstream Boundary Concentration NH3-D	0.00
Upstream Boundary Concentration NH3-U	0.00
Downstream Boundary Concentration NH3-D	0.00
Downstream Boundary Concentration NH3-U	0.00
Upstream Boundary Concentration PO4-D	0.00
Upstream Boundary Concentration PO4-U	0.00
Downstream Boundary Concentration PO4-D	0.00
Downstream Boundary Concentration PO4-U	0.00
Upstream Boundary Concentration DOP-D	0.00
Upstream Boundary Concentration DOP-U	0.00
Downstream Boundary Concentration DOP-D	0.00
Downstream Boundary Concentration DOP-U	0.00
Downstream Boundary Concentration Detrital C-U	0.00
Upstream Boundary Concentration Detrital N-D	0.00
Upstream Boundary Concentration Detrital N-U	0.00
Benthic Ammonia Flux-D	0.00
Benthic Ammonia Flux-U	0.00
DOP Mineralization Rate-D	0.00
DOP Mineralization Rate-U	0.00
DOP Mineralization Rate Temperature Coefficient-D	0.00
DOP Mineralization Rate Temperature Coefficient-U	0.00
Fraction Phytoplankton Death Recycled to Organic P-D	0.00
Fraction Phytoplankton Death Recycled to Organic P-U	0.00
Algal Self Shading Light Extinction (Yes/No)-D	0.00
Phytoplankton Half-Saturation N Uptake-D	0.00
Phytoplankton Half-Saturation N Uptake-U	0.00

C.1.2. March 2005 Local Analysis (continued)

Phytoplankton Half-Saturation P Uptake-D	0.00
Phytoplankton Half-Saturation P Uptake-U	0.00
Phytoplankton Phosphorus to Carbon Ratio-D	0.00
Phytoplankton Phosphorus to Carbon Ratio-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-D	0.00
CBOD Half Saturation Oxygen Limit-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-D	0.00
Settling Rate for Solids Group 1-D	0.00
SOD - Segment 5-D	0.00
SOD - Segment 1-D	0.00
Downstream Boundary Concentration CBOD-D	0.00

C.1.3. September 2003 Global Analysis

Input	% Sensitivity
Surface Water Flow-U	41.79
DON Mineralization Rate-U	41.70
Light Extinction - Segment 1-5-D	40.05
Phytoplankton Carbon to Chlorophyll Ratio-U	39.24
Upstream Boundary Concentration DON-U	37.90
Phytoplankton Half-Saturation N Uptake-U	36.98
Upstream Boundary Concentration NO3-D	34.74
Phytoplankton Half-Saturation P Uptake-U	32.64
Phytoplankton Maximum Growth Temperature Coefficient-U	31.85
Phytoplankton Respiration Rate Temperature Coefficient-U	31.64
Phytoplankton Maximum Growth Rate -D	30.57
Upstream Boundary Concentration Chl-a-U	29.12
Phytoplankton Respiration Rate-D	26.18
Light Option (1=input light; 2=calculated diel light)-D	25.51
Phytoplankton Nitrogen to Carbon Ratio-D	24.54
Light Extinction - Segment 3-D	24.06
Upstream Boundary Concentration NO3-U	23.67
Fraction Phytoplankton Death Recycled to Organic N-U	22.43
Light Extinction - Segment 2-D	21.94
Temperature - Segment 1-5-D	21.81
Upstream Boundary Concentration Chl-a-D	21.24
Phytoplankton Maximum Growth Temperature Coefficient-D	20.34
Downstream Boundary Concentration NH3-U	19.81
Light Extinction - Segment 4-D	19.60
Benthic Ammonia Flux - Segment 1-5-U	19.35
Upstream Boundary Concentration NH3-U	17.88
Downstream Boundary Concentration NO3-U	17.77
DON Mineralization Rate-D	16.65
Fraction Phytoplankton Death Recycled to Organic N-D	16.49
Downstream Boundary Concentration DON-U	16.18
Temperature - Segment 1-5-U	16.15
Surface Water Flow-D	15.30
Upstream Boundary Concentration DON-D	14.41
Light Extinction - Segment 1-D	14.16
Phytoplankton Maximum Growth Rate -U	13.55

C.1.3. September 2003 Global Analysis (continued)

Phytoplankton Carbon to Chlorophyll Ratio-D	13.38
Phytoplankton Optimal Light Saturation-D	13.36
Solar Radiation-D	13.07
Nitrification Rate-D	12.40
Downstream Boundary Concentration NO3-D	11.90
Phytoplankton Respiration Rate-U	11.86
Downstream Boundary Concentration Chl-a-U	11.58
Phytoplankton Nitrogen to Carbon Ratio-U	11.55
Temperature - Segment 4-D	11.35
Phytoplankton Death Rate-U	11.35
Solar Radiation-U	11.27
Temperature - Segment 3-D	10.98
Phytoplankton Respiration Rate Temperature Coefficient-D	10.82
Fraction Daily Light-D	10.71
Temperature - Segment 3-U	10.40
Depth - Segment 1-5-D	10.31
Benthic Ammonia Flux - Segment 4-U	10.28
Upstream Boundary Concentration NH3-D	10.00
DON Mineralization Temperature Coefficient-D	9.85
Depth - Segment 1-5-U	9.79
Benthic Ammonia Flux - Segment 3-U	9.77
Downstream Boundary Concentration Chl-a-D	9.72
Downstream Boundary Concentration DON-D	9.69
Temperature - Segment 4-U	9.67
Phytoplankton Optimal Light Saturation-U	9.59
Fraction Daily Light-U	9.57
Light Extinction - Segment 5-D	9.47
Nitrification Rate-U	9.40
Benthic Ammonia Flux - Segment 5-U	9.37
Temperature - Segment 5-D	9.23
Light Extinction - Segment 1-5-U	9.16
Temperature - Segment 2-D	9.08
Temperature - Segment 2-U	9.03
Phytoplankton Half-Saturation N Uptake-D	8.67
Volume - Segment 1-5-D	8.44
Temperature - Segment 1-D	8.27
Volume - Segment 1-5-U	8.24

C.1.3. September 2003 Global Analysis (continued)

Benthic Ammonia Flux - Segment 2-U	8.23
Depth - Segment 3-D	8.02
Temperature - Segment 5-U	7.90
Dispersive Mixing Between Segments - Boundary:Boundary-D	7.90
Surface Area Between Segments - Boundary:Boundary-D	7.90
Phytoplankton Death Rate-D	7.90
Nitrification Temperature Coefficient-U	7.83
Depth - Segment 4-U	7.81
Segment Length - Boundary:Boundary-U	7.79
Segment Length - Boundary:Boundary-D	7.77
Depth - Segment 3-U	7.75
Depth - Segment 2-D	7.73
Dispersive Mixing Between Segments - Boundary:Boundary-U	7.68
Surface Area Between Segments - Boundary:Boundary-U	7.68
Light Extinction - Segment 4-U	7.60
Depth - Segment 4-D	7.57
Light Extinction - Segment 3-U	7.54
Depth - Segment 5-U	7.41
Dispersive Mixing Between Segments - Segment5:Boundary-D	7.36
Surface Area Between Segments - Segment5:Boundary-D	7.36
Nitrification Temperature Coefficient-D	7.34
Benthic Ammonia Flux - Segment 1-5-D	7.32
Segment Length - Segment5:Boundary-U	7.31
Light Extinction - Segment 5-U	7.30
Volume - Segment 4-U	7.30
Volume - Segment 3-U	7.30
Volume - Segment 3-D	7.29
DON Mineralization Temperature Coefficient-U	7.28
Phytoplankton Half-Sat. for Mineralization Rate-D	7.27
Volume - Segment 4-D	7.24
Dispersive Mixing Between Segments - Segment 4:Segment5-D	7.22
Surface Area Between Segments - Segment 4:Segment5-D	7.22
Segment Length - Segment 4:Segment5-D	7.22
Depth - Segment 1-D	7.22
Temperature - Segment 1-U	7.20
Segment Length - Segment5:Boundary-D	7.19
Segment Length - Segment 4:Segment5-U	7.19

C.1.3. September 2003 Global Analysis (continued)

Dispersive Mixing Between Segments - Segment 4:Segment5-U	7.18
Surface Area Between Segments - Segment 4:Segment5-U	7.18
Volume - Segment 2-D	7.16
Phytoplankton Half-Sat. for Mineralization Rate-U	7.16
Surface Area Between Segments - Segment5:Boundary-U	7.16
Dispersive Mixing Between Segments - Segment5:Boundary-U	7.16
Depth - Segment 2-U	7.13
Surface Area Between Segments - Segment 3:Segment4-D	7.12
Dispersive Mixing Between Segments - Segment 3:Segment4-D	7.12
Segment Length - Segment 3:Segment4-D	7.12
Segment Length - Segment 3:Segment4-U	7.10
Surface Area Between Segments - Segment 3:Segment4-U	7.09
Dispersive Mixing Between Segments - Segment 3:Segment4-U	7.09
Volume - Segment 5-U	7.09
Segment Length - Boundary:Segment1-D	7.07
Global Reaeration Rate-U	7.06
Volume - Segment 1-D	7.05
CBOD Rate-U	7.05
Light Extinction - Segment 2-U	7.04
Dispersive Mixing Between Segments - Boundary:Segment 1-U	7.04
Surface Area Between Segments - Boundary:Segment 1-U	7.04
Benthic Ammonia Flux - Segment 2-D	7.04
Surface Area Between Segments - Segment 2:Segment3-D	7.03
Dispersive Mixing Between Segments - Segment 2:Segment3-D	7.03
Benthic Ammonia Flux - Segment 3-D	7.03
Volume - Segment 2-U	7.03
Segment Length - Segment 2:Segment3-U	7.01
Upstream Boundary Concentration DO-U	7.01
Volume - Segment 5-D	7.00
Downstream Boundary Concentration DO-D	6.99
Segment Length - Segment 2:Segment3-D	6.99
Surface Area Between Segments - Segment 2:Segment3-U	6.98
Dispersive Mixing Between Segments - Segment 2:Segment3-U	6.98
Surface Area Between Segments - Segment 1:Segment2-D	6.98
Dispersive Mixing Between Segments - Segment 1:Segment2-D	6.98
Settling Rate for Solids Group 1-U	6.97
Segment Length - Segment 1:Segment2-U	6.96

C.1.3. September 2003 Global Analysis (continued)

Segment Length - Segment 1:Segment2-D	6.94
Denitrification Rate-D	6.94
Benthic Ammonia Flux - Segment 1-D	6.94
Depth - Segment 5-D	6.93
Surface Area Between Segments - Segment 1:Segment2-U	6.93
Dispersive Mixing Between Segments - Segment 1:Segment2-U	6.93
SOD - Segment 1-5-U	6.92
Denitrification Temperature Coefficient-D	6.92
Surface Area Between Segments - Boundary:Segment 1-D	6.90
Dispersive Mixing Between Segments - Boundary:Segment1-D	6.90
Depth - Segment 1-U	6.90
Segment Length - Boundary:Segment 1-U	6.90
Half Saturation Nitrification Oxygen Limit-U	6.89
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-U	6.88
Upstream Boundary Concentration DO-D	6.88
Light Extinction - Segment 1-U	6.87
SOD - Segment 1-5-D	6.87
Pore Water Flow-D	6.87
Half Saturation Nitrification Oxygen Limit-D	6.87
Half Saturation Denitrification Oxygen Limit-U	6.86
SOD - Segment 4-U	6.86
Half Saturation Denitrification Oxygen Limit-D	6.86
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-U	6.85
SOD - Segment 2-D	6.85
Upstream Boundary Concentration PO4-D	6.85
Denitrification Rate-U	6.85
SOD - Segment 3-D	6.85
SOD - Segment 5-U	6.85
Denitrification Temperature Coefficient-U	6.85
Global Reaeration Rate-D	6.85
CBOD Rate-D	6.85
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-U	6.85
Pore Water Flow-U	6.85
SOD Temperature Correction-U	6.84
Settling Rate for Solids Group 1-D	6.84
SOD - Segment 3-U	6.84

C.1.3. September 2003 Global Analysis (continued)

Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-U	6.84
SOD - Segment 1-D	6.84
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-D	6.84
SOD Temperature Correction-D	6.84
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-U	6.84
CBOD Decay Rate Temperature Correction Coefficient-U	6.84
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-D	6.84
Upstream Boundary Concentration CBOD-D	6.84
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-D	6.84
Downstream Boundary Concentration Salinity-U	6.84
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-D	6.84
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-U	6.84
Downstream Boundary Concentration Salinity-D	6.84
Resuspension Rate for Solids Group 1-U	6.84
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-D	6.84
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-D	6.83
Downstream Boundary Concentration CBOD-D	6.83
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-U	6.83
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-U	6.83
CBOD Decay Rate Temperature Correction Coefficient-D	6.83
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-D	6.83
Downstream Boundary Concentration CBOD-U	6.83
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-U	6.83
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-D	6.83
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-U	6.83
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-D	6.83
SOD - Segment 4-D	6.83
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-D	6.83

C.1.3. September 2003 Global Analysis (continued)

Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-D	6.83
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-U	6.83
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-U	6.83
Upstream Boundary Concentration CBOD-U	6.83
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-U	6.83
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-U	6.83
Downstream Boundary Concentration Inorganic Solids-D	6.83
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-D	6.83
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-D	6.83
Upstream Boundary Concentration Salinity-D	6.83
Upstream Boundary Concentration Inorganic Solids-D	6.83
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-D	6.83
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-U	6.83
CBOD Half Saturation Oxygen Limit-U	6.83
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-U	6.83
CBOD Half Saturation Oxygen Limit-D	6.83
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-D	6.83
Resuspension Rate for Solids Group 1-D	6.83
Downstream Boundary Concentration Inorganic Solids-U	6.83
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-U	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-U	6.83
Upstream Boundary Concentration Inorganic Solids-U	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-D	6.83
SOD - Segment 2-U	6.83
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-D	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-U	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-U	6.83

C.1.3. September 2003 Global Analysis (continued)

Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-D	6.83
Upstream Boundary Concentration Salinity-U	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-D	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-U	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-D	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-U	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-D	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-U	6.83
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-D	6.83
Upstream Boundary Concentration Detrital N-D	6.83
Upstream Boundary Concentration Detrital N-U	6.83
Downstream Boundary Concentration Detrital N-D	6.83
Downstream Boundary Concentration Detrital N-U	6.83
Upstream Boundary Concentration Detrital C-D	6.83
Upstream Boundary Concentration Detrital C-U	6.83
Downstream Boundary Concentration Detrital C-D	6.83
Downstream Boundary Concentration Detrital C-U	6.83
Upstream Boundary Concentration PO4-U	6.83
Downstream Boundary Concentration PO4-D	6.83
Downstream Boundary Concentration PO4-U	6.83
Upstream Boundary Concentration DOP-D	6.83
Upstream Boundary Concentration DOP-U	6.83
Downstream Boundary Concentration DOP-D	6.83
Downstream Boundary Concentration DOP-U	6.83
Benthic Ammonia Flux-D	6.83
Benthic Ammonia Flux-U	6.83
DOP Mineralization Rate-D	6.83
DOP Mineralization Rate-U	6.83
DOP Mineralization Rate Temperature Coefficient-D	6.83
DOP Mineralization Rate Temperature Coefficient-U	6.83
Fraction Phytoplankton Death Recycled to Organic P-D	6.83
Fraction Phytoplankton Death Recycled to Organic P-U	6.83
Algal Self Shading Light Extinction (Yes/No)-D	6.83

C.1.3. September 2003 Global Analysis (continued)

Phytoplankton Half-Saturation P Uptake-D	6.83
Phytoplankton Phosphorus to Carbon Ratio-D	6.83
Phytoplankton Phosphorus to Carbon Ratio-U	6.83
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-U	6.83
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-D	6.83
SOD - Segment 1-U	6.83
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-D	6.83
SOD - Segment 5-D	6.83
Downstream Boundary Concentration DO-U	6.80
Benthic Ammonia Flux - Segment 4-D	6.75
Volume - Segment 1-U	6.73
Benthic Ammonia Flux - Segment 5-D	6.68
Benthic Ammonia Flux - Segment 1-U	6.42
Downstream Boundary Concentration NH3-D	4.44

C.1.4. March 2005 Global Analysis

Input	% Sensitivity
Upstream Boundary Concentration NH3-U	71.22
Upstream Boundary Concentration NO3-U	45.10
Upstream Boundary Concentration Chl-a-U	38.31
Upstream Boundary Concentration DON-U	38.31
Upstream Boundary Concentration NO3-D	27.53
Surface Water Flow-D	26.68
Downstream Boundary Concentration NH3-U	21.09
Benthic Ammonia Flux - Segment 1-5-U	18.12
Upstream Boundary Concentration NH3-D	11.12
Phytoplankton Carbon to Chlorophyll Ratio-U	10.76
Light Extinction - Segment 1-5-D	9.40
Upstream Boundary Concentration DON-D	7.49
DON Mineralization Rate-U	6.14
Temperature - Segment 1-5-U	5.60
Fraction Phytoplankton Death Recycled to Organic N-U	5.60
Benthic Ammonia Flux - Segment 3-U	5.33
Downstream Boundary Concentration NO3-U	5.08
Benthic Ammonia Flux - Segment 4-U	4.67
Benthic Ammonia Flux - Segment 2-U	3.92
Downstream Boundary Concentration DON-U	3.91
Phytoplankton Respiration Rate-D	3.56
Surface Water Flow-U	3.52
Phytoplankton Respiration Rate Temperature Coefficient-U	3.18
Phytoplankton Nitrogen to Carbon Ratio-D	3.00
Upstream Boundary Concentration Chl-a-D	2.81
Nitrification Rate-D	2.62
Light Extinction - Segment 4-D	2.61
Phytoplankton Half-Saturation N Uptake-U	2.58
Phytoplankton Half-Saturation P Uptake-U	2.54
Fraction Phytoplankton Death Recycled to Organic N-D	2.41
Light Extinction - Segment 3-D	2.38
Phytoplankton Maximum Growth Temperature Coefficient-D	2.32
DON Mineralization Rate-D	2.28
Benthic Ammonia Flux - Segment 5-U	2.28
Nitrification Rate-U	2.26

C.1.4. March 2005 Global Analysis (continued)

Downstream Boundary Concentration NH3-D	2.20
Downstream Boundary Concentration Chl-a-U	2.04
Phytoplankton Death Rate-U	1.96
Downstream Boundary Concentration NO3-D	1.94
Downstream Boundary Concentration DON-D	1.90
Phytoplankton Maximum Growth Rate -D	1.86
Benthic Ammonia Flux - Segment 1-U	1.82
Phytoplankton Maximum Growth Temperature Coefficient-U	1.79
Benthic Ammonia Flux - Segment 1-5-D	1.77
Phytoplankton Carbon to Chlorophyll Ratio-D	1.75
Light Extinction - Segment 5-D	1.71
Light Extinction - Segment 2-D	1.67
DON Mineralization Temperature Coefficient-D	1.46
Phytoplankton Respiration Rate Temperature Coefficient-D	1.37
Light Option (1=input light; 2=calculated diel light)-D	1.31
Downstream Boundary Concentration Chl-a-D	1.24
Temperature - Segment 4-U	1.22
Temperature - Segment 5-U	1.18
Temperature - Segment 3-U	1.11
Phytoplankton Respiration Rate-U	1.08
Nitrification Temperature Coefficient-U	0.99
Temperature - Segment 2-U	0.97
Phytoplankton Nitrogen to Carbon Ratio-U	0.95
Light Extinction - Segment 1-D	0.94
Temperature - Segment 1-U	0.84
Segment Length - Boundary:Boundary-D	0.82
Dispersive Mixing Between Segments - Boundary:Boundary-D	0.78
Surface Area Between Segments - Boundary:Boundary-D	0.78
Dispersive Mixing Between Segments - Boundary:Boundary-U	0.74
Surface Area Between Segments - Boundary:Boundary-U	0.74
Segment Length - Boundary:Boundary-U	0.71
Phytoplankton Maximum Growth Rate -U	0.63
Phytoplankton Optimal Light Saturation-D	0.61
Nitrification Temperature Coefficient-D	0.61
Phytoplankton Death Rate-D	0.59
Phytoplankton Half-Saturation N Uptake-D	0.59
Volume - Segment 1-5-D	0.56

C.1.4. March 2005 Global Analysis (continued)

Volume - Segment 1-5-U	0.54
Solar Radiation-D	0.53
Benthic Ammonia Flux - Segment 3-D	0.52
Dispersive Mixing Between Segments - Segment5:Boundary-D	0.49
Surface Area Between Segments - Segment5:Boundary-D	0.49
Segment Length - Segment5:Boundary-D	0.49
Benthic Ammonia Flux - Segment 4-D	0.46
Segment Length - Segment5:Boundary-U	0.45
Dispersive Mixing Between Segments - Segment5:Boundary-U	0.45
Surface Area Between Segments - Segment5:Boundary-U	0.45
Solar Radiation-U	0.42
Benthic Ammonia Flux - Segment 2-D	0.39
Fraction Daily Light-D	0.35
Fraction Daily Light-U	0.27
Upstream Boundary Concentration DO-D	0.26
Phytoplankton Optimal Light Saturation-U	0.25
Light Extinction - Segment 1-5-U	0.25
Benthic Ammonia Flux - Segment 5-D	0.22
Segment Length - Segment 4:Segment5-D	0.22
Depth - Segment 1-5-D	0.22
Surface Area Between Segments - Segment 4:Segment5-D	0.22
Dispersive Mixing Between Segments - Segment 4:Segment5-D	0.22
Phytoplankton Half-Sat. for Mineralization Rate-D	0.22
Upstream Boundary Concentration DO-U	0.20
Surface Area Between Segments - Segment 4:Segment5-U	0.20
Dispersive Mixing Between Segments - Segment 4:Segment5-U	0.20
Segment Length - Segment 4:Segment5-U	0.20
Phytoplankton Half-Sat. for Mineralization Rate-U	0.18
Depth - Segment 1-5-U	0.18
Benthic Ammonia Flux - Segment 1-D	0.18
DON Mineralization Temperature Coefficient-U	0.18
Temperature - Segment 1-5-D	0.15
Volume - Segment 4-D	0.14
Volume - Segment 4-U	0.14
Volume - Segment 3-D	0.13
Volume - Segment 3-U	0.13
Volume - Segment 5-D	0.12

C.1.4. March 2005 Global Analysis (continued)

Volume - Segment 5-U	0.12
Global Reaeration Rate-U	0.11
Segment Length - Segment 3:Segment4-D	0.11
Surface Area Between Segments - Segment 3:Segment4-D	0.10
Dispersive Mixing Between Segments - Segment 3:Segment4-D	0.10
Volume - Segment 2-D	0.10
Volume - Segment 2-U	0.10
Dispersive Mixing Between Segments - Segment 3:Segment4-U	0.10
Surface Area Between Segments - Segment 3:Segment4-U	0.10
Segment Length - Segment 3:Segment4-U	0.09
Half Saturation Nitrification Oxygen Limit-D	0.08
Half Saturation Nitrification Oxygen Limit-U	0.08
Light Extinction - Segment 4-U	0.08
Depth - Segment 3-D	0.07
Light Extinction - Segment 3-U	0.06
Volume - Segment 1-D	0.06
Volume - Segment 1-U	0.06
Depth - Segment 3-U	0.06
Depth - Segment 2-D	0.06
CBOD Rate-U	0.06
Segment Length - Segment 2:Segment3-D	0.05
Light Extinction - Segment 5-U	0.05
Dispersive Mixing Between Segments - Segment 2:Segment3-D	0.05
Surface Area Between Segments - Segment 2:Segment3-D	0.05
Depth - Segment 4-D	0.05
Surface Area Between Segments - Segment 2:Segment3-U	0.05
Dispersive Mixing Between Segments - Segment 2:Segment3-U	0.05
Depth - Segment 2-U	0.05
Segment Length - Segment 2:Segment3-U	0.05
Downstream Boundary Concentration DO-U	0.04
Downstream Boundary Concentration DO-D	0.04
Temperature - Segment 5-D	0.04
Depth - Segment 4-U	0.04
Light Extinction - Segment 2-U	0.04
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-U	0.04
Pore Water Flow-U	0.04
Settling Rate for Solids Group 1-U	0.04

C.1.4. March 2005 Global Analysis (continued)

Temperature - Segment 4-D	0.03
Pore Water Flow-D	0.03
Segment Length - Segment 1:Segment2-D	0.03
Depth - Segment 5-D	0.03
Segment Length - Boundary:Segment1-D	0.03
Surface Area Between Segments - Segment 1:Segment2-D	0.03
Dispersive Mixing Between Segments - Segment 1:Segment2-D	0.03
Surface Area Between Segments - Boundary:Segment 1-D	0.03
Dispersive Mixing Between Segments - Boundary:Segment1-D	0.03
Surface Area Between Segments - Segment 1:Segment2-U	0.03
Dispersive Mixing Between Segments - Segment 1:Segment2-U	0.03
Depth - Segment 1-D	0.03
Segment Length - Segment 1:Segment2-U	0.03
Dispersive Mixing Between Segments - Boundary:Segment 1-U	0.03
Surface Area Between Segments - Boundary:Segment 1-U	0.03
Segment Length - Boundary:Segment 1-U	0.03
Temperature - Segment 3-D	0.03
Depth - Segment 5-U	0.02
Temperature - Segment 2-D	0.02
Temperature - Segment 1-D	0.02
Depth - Segment 1-U	0.02
Global Reaeration Rate-D	0.02
Denitrification Temperature Coefficient-D	0.02
SOD - Segment 1-5-U	0.02
SOD - Segment 1-5-D	0.02
Light Extinction - Segment 1-U	0.02
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-D	0.01
Denitrification Rate-D	0.01
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-U	0.01
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-U	0.01
Upstream Boundary Concentration PO4-D	0.01
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-U	0.01
CBOD Rate-D	0.01
SOD - Segment 3-U	0.01
SOD - Segment 3-D	0.01
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-U	0.01
SOD - Segment 4-U	0.01

C.1.4. March 2005 Global Analysis (continued)

SOD - Segment 4-D	0.00
SOD Temperature Correction-D	0.00
SOD - Segment 2-U	0.00
SOD Temperature Correction-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-D	0.00
SOD - Segment 2-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-D	0.00
Half Saturation Denitrification Oxygen Limit-U	0.00
Half Saturation Denitrification Oxygen Limit-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-D	0.00
Denitrification Rate-U	0.00
Denitrification Temperature Coefficient-U	0.00
Downstream Boundary Concentration Salinity-U	0.00
SOD - Segment 5-U	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-D	0.00
CBOD Decay Rate Temperature Correction Coefficient-U	0.00
SOD - Segment 1-U	0.00
Settling Rate for Solids Group 1-D	0.00
SOD - Segment 5-D	0.00
Upstream Boundary Concentration CBOD-D	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-U	0.00
SOD - Segment 1-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-D	0.00
CBOD Decay Rate Temperature Correction Coefficient-D	0.00
Downstream Boundary Concentration Salinity-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-D	0.00
Upstream Boundary Concentration CBOD-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-D	0.00

C.1.4. March 2005 Global Analysis (continued)

Resuspension Rate for Solids Group 1-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-D	0.00
Downstream Boundary Concentration CBOD-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-U	0.00
Upstream Boundary Concentration Salinity-U	0.00
Downstream Boundary Concentration Inorganic Solids-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-U	0.00
Upstream Boundary Concentration Inorganic Solids-U	0.00
Downstream Boundary Concentration CBOD-D	0.00
CBOD Half Saturation Oxygen Limit-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-U	0.00
Downstream Boundary Concentration Inorganic Solids-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-U	0.00
Upstream Boundary Concentration Inorganic Solids-D	0.00
Resuspension Rate for Solids Group 1-D	0.00
Upstream Boundary Concentration Detrital N-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-U	0.00
Upstream Boundary Concentration Detrital C-D	0.00
Downstream Boundary Concentration Detrital C-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-U	0.00
Downstream Boundary Concentration Detrital N-U	0.00
Upstream Boundary Concentration Detrital C-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-D	0.00

C.1.4. March 2005 Global Analysis (continued)

Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-D	0.00
Downstream Boundary Concentration Detrital C-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-D	0.00
Upstream Boundary Concentration Detrital N-D	0.00
Downstream Boundary Concentration Detrital N-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-D	0.00
Upstream Boundary Concentration PO4-U	0.00
Downstream Boundary Concentration PO4-D	0.00
Downstream Boundary Concentration PO4-U	0.00
Upstream Boundary Concentration DOP-D	0.00
Upstream Boundary Concentration DOP-U	0.00
Downstream Boundary Concentration DOP-D	0.00
Downstream Boundary Concentration DOP-U	0.00
Benthic Ammonia Flux-D	0.00
Benthic Ammonia Flux-U	0.00
DOP Mineralization Rate-D	0.00
DOP Mineralization Rate-U	0.00
DOP Mineralization Rate Temperature Coefficient-D	0.00
DOP Mineralization Rate Temperature Coefficient-U	0.00
Fraction Phytoplankton Death Recycled to Organic P-U	0.00
Algal Self Shading Light Extinction (Yes/No)-D	0.00
Phytoplankton Half-Saturation P Uptake-D	0.00
Phytoplankton Phosphorus to Carbon Ratio-D	0.00
Phytoplankton Phosphorus to Carbon Ratio-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-U	0.00

C.1.4. March 2005 Global Analysis (continued)

Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-U	0.00
CBOD Half Saturation Oxygen Limit-U	0.00
Upstream Boundary Concentration Salinity-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-D	0.00
Fraction Phytoplankton Death Recycled to Organic P-D	0.00

C.2. Final Sensitivity Analyses

C.2.1. September 2005

Input	% Sensitivity
Phytoplankton Maximum Growth Temperature Coefficient-D	115.23
Light Option (1=input light; 2=calculated diel light)-D	88.81
DON Mineralization Temperature Coefficient-U	55.26
Temperature - Segment 1-5-D	28.95
Temperature - Segment 1-D	28.94
Temperature - Segment 2-D	28.94
Temperature - Segment 3-D	28.94
Temperature - Segment 4-D	28.94
Temperature - Segment 5-D	28.94
DOP Mineralization Rate Temperature Coefficient-D	18.74
Phytoplankton Nitrogen to Carbon Ratio-D	18.56
DON Mineralization Temperature Coefficient-D	17.92
Phytoplankton Maximum Growth Temperature Coefficient-U	17.07
DOP Mineralization Rate Temperature Coefficient-U	15.55
Phytoplankton Phosphorus to Carbon Ratio-U	14.10
Nitrification Temperature Coefficient-U	13.54
Phytoplankton Nitrogen to Carbon Ratio-U	12.89
Phytoplankton Phosphorus to Carbon Ratio-D	10.54
Temperature - Segment 1-5-U	10.30
Temperature - Segment 1-U	10.29
Temperature - Segment 2-U	10.29
Temperature - Segment 3-U	10.29
Temperature - Segment 4-U	10.29
Temperature - Segment 5-U	10.29
Phytoplankton Respiration Rate Temperature Coefficient-U	7.73
Downstream Boundary Concentration PO4-D	6.58
Upstream Boundary Concentration NO3-U	6.10
Upstream Boundary Concentration NO3-D	5.95
Upstream Boundary Concentration DON-U	5.61
Upstream Boundary Concentration DON-D	5.57
DON Mineralization Rate-D	4.69
DON Mineralization Rate-U	4.65
Downstream Boundary Concentration PO4-U	4.49
Dispersive Mixing Between Segments - Boundary:Boundary-D	4.42

C.2.1. September 2005 (continued)

Surface Area Between Segments - Boundary:Boundary-D	4.42
Benthic Ammonia Flux - Segment 1-U	4.28
Benthic Ammonia Flux - Segment 2-U	4.28
Benthic Ammonia Flux - Segment 3-U	4.28
Benthic Ammonia Flux - Segment 4-U	4.28
Benthic Ammonia Flux - Segment 5-U	4.28
Benthic Ammonia Flux - Segment 1-5-U	4.28
Phytoplankton Maximum Growth Rate -D	4.25
Benthic Ammonia Flux - Segment 1-D	4.22
Benthic Ammonia Flux - Segment 2-D	4.22
Benthic Ammonia Flux - Segment 3-D	4.22
Benthic Ammonia Flux - Segment 4-D	4.22
Benthic Ammonia Flux - Segment 5-D	4.22
Benthic Ammonia Flux - Segment 1-5-D	4.22
Segment Length - Boundary:Boundary-U	3.98
Phytoplankton Respiration Rate Temperature Coefficient-D	3.86
Upstream Boundary Concentration PO4-D	3.74
Upstream Boundary Concentration PO4-U	3.54
Downstream Boundary Concentration NH3-U	3.49
Downstream Boundary Concentration NH3-D	3.42
Segment Length - Boundary:Boundary-D	3.41
Upstream Boundary Concentration DOP-D	3.24
Upstream Boundary Concentration DOP-U	3.20
Surface Area Between Segments - Boundary:Boundary-U	3.19
Dispersive Mixing Between Segments - Boundary:Boundary-U	3.19
Surface Water Flow-D	3.16
DOP Mineralization Rate-D	3.14
Upstream Boundary Concentration NH3-U	3.13
Upstream Boundary Concentration NH3-D	3.10
Surface Water Flow-U	3.02
Phytoplankton Maximum Growth Rate -U	2.87
Fraction Phytoplankton Death Recycled to Organic N-D	2.87
DOP Mineralization Rate-U	2.85
Fraction Phytoplankton Death Recycled to Organic N-U	2.84
Depth - Segment 1-5-D	2.63
Downstream Boundary Concentration NO3-U	2.46
Dispersive Mixing Between Segments - Segment 4:Segment5-D	2.42

C.2.1. September 2005 (continued)

Surface Area Between Segments – Segment 4:Segment5-D	2.42
Downstream Boundary Concentration NO3-D	2.40
Phytoplankton Carbon to Chlorophyll Ratio-D	2.31
Downstream Boundary Concentration DON-U	2.26
Downstream Boundary Concentration DON-D	2.26
Segment Length – Segment 4:Segment5-D	2.25
Segment Length – Segment 4:Segment5-U	2.18
Nitrification Temperature Coefficient-D	2.12
Volume – Segment 1-5-U	2.07
Depth – Segment 1-5-U	2.06
Dispersive Mixing Between Segments – Segment5:Boundary-D	2.06
Surface Area Between Segments – Segment5:Boundary-D	2.06
Dispersive Mixing Between Segments – Segment 4:Segment5-U	2.04
Surface Area Between Segments – Segment 4:Segment5-U	2.04
Phytoplankton Carbon to Chlorophyll Ratio-U	2.03
Segment Length – Segment5:Boundary-D	1.95
Solar Radiation-D	1.92
Light Extinction – Segment 1-5-U	1.90
Segment Length – Segment5:Boundary-U	1.86
Light Extinction – Segment 1-5-D	1.84
Volume – Segment 1-5-D	1.83
Fraction Daily Light-D	1.78
Dispersive Mixing Between Segments – Segment5:Boundary-U	1.76
Surface Area Between Segments – Segment5:Boundary-U	1.76
Phytoplankton Optimal Light Saturation-U	1.73
Phytoplankton Optimal Light Saturation-D	1.63
Solar Radiation-U	1.48
Downstream Boundary Concentration DOP-D	1.48
Downstream Boundary Concentration DOP-U	1.47
Phytoplankton Half-Saturation N Uptake-D	1.35
Nitrification Rate-D	1.33
Nitrification Rate-U	1.28
Phytoplankton Respiration Rate-D	1.17
Phytoplankton Half-Saturation N Uptake-U	1.15
Phytoplankton Respiration Rate-U	1.13
Depth – Segment 5-D	1.04
Depth – Segment 3-D	0.98

C.2.1. September 2005 (continued)

Depth - Segment 5-U	0.88
Fraction Phytoplankton Death Recycled to Organic P-D	0.85
Fraction Phytoplankton Death Recycled to Organic P-U	0.85
Volume - Segment 3-U	0.81
Dispersive Mixing Between Segments - Segment 3:Segment4-D	0.77
Surface Area Between Segments - Segment 3:Segment4-D	0.77
Volume - Segment 3-D	0.76
Segment Length - Segment 3:Segment4-D	0.75
Depth - Segment 3-U	0.74
Volume - Segment 5-D	0.73
Volume - Segment 5-U	0.72
Depth - Segment 2-D	0.70
Phytoplankton Half-Sat. for Mineralization Rate-D	0.70
Segment Length - Segment 3:Segment4-U	0.70
Surface Area Between Segments - Segment 3:Segment4-U	0.68
Dispersive Mixing Between Segments - Segment 3:Segment4-U	0.68
Benthic Ammonia Flux-D	0.68
Benthic Ammonia Flux-U	0.67
Light Extinction - Segment 5-D	0.67
Depth - Segment 2-U	0.66
Phytoplankton Half-Sat. for Mineralization Rate-U	0.63
Light Extinction - Segment 5-U	0.62
Phytoplankton Half-Saturation P Uptake-D	0.60
Phytoplankton Half-Saturation P Uptake-U	0.59
Downstream Boundary Concentration Chl-a-D	0.59
Downstream Boundary Concentration Chl-a-U	0.57
Light Extinction - Segment 2-D	0.54
Upstream Boundary Concentration Chl-a-D	0.53
Light Extinction - Segment 2-U	0.52
Denitrification Temperature Coefficient-U	0.52
Volume - Segment 2-D	0.51
Upstream Boundary Concentration Chl-a-U	0.51
Volume - Segment 2-U	0.50
Depth - Segment 4-D	0.49
Volume - Segment 4-D	0.46
Volume - Segment 4-U	0.42
Light Extinction - Segment 4-U	0.41

C.2.1. September 2005 (continued)

Surface Area Between Segments - Segment 2:Segment3-D	0.39
Dispersive Mixing Between Segments - Segment 2:Segment3-D	0.39
Segment Length - Segment 2:Segment3-D	0.38
Phytoplankton Death Rate-D	0.38
Light Extinction - Segment 4-D	0.38
Phytoplankton Death Rate-U	0.37
Depth - Segment 4-U	0.35
Segment Length - Segment 2:Segment3-U	0.35
Surface Area Between Segments - Segment 2:Segment3-U	0.35
Dispersive Mixing Between Segments - Segment 2:Segment3-U	0.35
SOD Temperature Correction-U	0.32
Segment Length - Boundary:Segment1-D	0.29
Depth - Segment 1-D	0.29
Segment Length - Segment 1:Segment2-D	0.29
Surface Area Between Segments - Segment 1:Segment2-D	0.29
Dispersive Mixing Between Segments - Segment 1:Segment2-D	0.29
Surface Area Between Segments - Boundary:Segment 1-D	0.28
Dispersive Mixing Between Segments - Boundary:Segment1-D	0.28
Half Saturation Nitrification Oxygen Limit-D	0.28
Light Extinction - Segment 1-D	0.27
Half Saturation Nitrification Oxygen Limit-U	0.27
Dispersive Mixing Between Segments - Boundary:Segment 1-U	0.27
Surface Area Between Segments - Boundary:Segment 1-U	0.27
Dispersive Mixing Between Segments - Segment 1:Segment2-U	0.26
Surface Area Between Segments - Segment 1:Segment2-U	0.26
Segment Length - Segment 1:Segment2-U	0.26
Segment Length - Boundary:Segment 1-U	0.25
Depth - Segment 1-U	0.24
Light Extinction - Segment 1-U	0.23
Denitrification Temperature Coefficient-D	0.20
Volume - Segment 1-U	0.15
Volume - Segment 1-D	0.15
Light Extinction - Segment 3-U	0.13
Light Extinction - Segment 3-D	0.12
CBOD Decay Rate Temperature Correction Coefficient-U	0.10
Upstream Boundary Concentration DO-D	0.08
Upstream Boundary Concentration DO-U	0.08

C.2.1. September 2005 (continued)

SOD Temperature Correction-D	0.07
Downstream Boundary Concentration DO-D	0.05
Downstream Boundary Concentration DO-U	0.04
Denitrification Rate-D	0.04
Denitrification Rate-U	0.04
Half Saturation Denitrification Oxygen Limit-D	0.04
Half Saturation Denitrification Oxygen Limit-U	0.04
SOD – Segment 1-U	0.02
SOD – Segment 2-U	0.02
SOD – Segment 3-U	0.02
SOD – Segment 4-U	0.02
SOD – Segment 5-U	0.02
SOD – Segment 1-5-U	0.02
SOD – Segment 1-D	0.02
SOD – Segment 2-D	0.02
SOD – Segment 3-D	0.02
SOD – Segment 4-D	0.02
SOD – Segment 5-D	0.02
SOD – Segment 1-5-D	0.02
CBOD Decay Rate Temperature Correction Coefficient-D	0.02
Settling Rate for Solids Group 1-D	0.01
Interfacial Surface Area Between Segments for Flows/Settling – Boundary:Boundary-D	0.01
Interfacial Surface Area Between Segments for Flows/Settling – Boundary:Boundary-U	0.01
Settling Rate for Solids Group 1-U	0.01
Fraction Daily Light-U	0.01
CBOD Rate-D	0.01
CBOD Rate-U	0.01
Downstream Boundary Concentration Salinity-D	0.01
Downstream Boundary Concentration Salinity-U	0.01
Interfacial Surface Area Between Segments for Exchange – Boundary:Boundary-D	0.01
Pore Water Flow-D	0.01
Distance Between Segments (Depth of Benthic Layer) – Boundary:Boundary-U	0.01
Distance Between Segments (Depth of Benthic Layer) – Boundary:Boundary-D	0.01
Interfacial Surface Area Between Segments for Exchange – Boundary:Boundary-U	0.01
Pore Water Flow-U	0.01

C.2.1. September 2005 (continued)

Global Reaeration Rate-D	0.01
Upstream Boundary Concentration CBOD-U	0.01
Upstream Boundary Concentration CBOD-D	0.01
Global Reaeration Rate-U	0.01
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-U	0.00
Downstream Boundary Concentration CBOD-U	0.00
Downstream Boundary Concentration CBOD-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-D	0.00

C.2.1. September 2005 (continued)

Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-U	0.00
CBOD Half Saturation Oxygen Limit-D	0.00
CBOD Half Saturation Oxygen Limit-U	0.00
Resuspension Rate for Solids Group 1-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-D	0.00
Resuspension Rate for Solids Group 1-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-U	0.00
Downstream Boundary Concentration Inorganic Solids-U	0.00
Downstream Boundary Concentration Inorganic Solids-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-D	0.00
Upstream Boundary Concentration Salinity-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-U	0.00
Upstream Boundary Concentration Salinity-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-U	0.00
Upstream Boundary Concentration Inorganic Solids-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-D	0.00
Upstream Boundary Concentration Inorganic Solids-D	0.00

C.2.1. September 2005 (continued)

Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-U	0.00
Upstream Boundary Concentration Detrital C-D	0.00
Upstream Boundary Concentration Detrital C-U	0.00
Downstream Boundary Concentration Detrital C-D	0.00
Downstream Boundary Concentration Detrital C-U	0.00
Upstream Boundary Concentration Detrital N-D	0.00
Upstream Boundary Concentration Detrital N-U	0.00
Downstream Boundary Concentration Detrital N-D	0.00
Downstream Boundary Concentration Detrital N-U	0.00
Algal Self Shading Light Extinction (Yes/No)-D	0.00

C.2.2. December 2003

Input	% Sensitivity
Nitrification Temperature Coefficient-U	4.08
Upstream Boundary Concentration NO3-D	2.86
Upstream Boundary Concentration NO3-U	2.86
Upstream Boundary Concentration DON-U	2.77
Upstream Boundary Concentration DON-D	2.77
Surface Water Flow-D	2.14
Segment Length - Boundary:Boundary-D	1.55
Surface Area Between Segments - Boundary:Boundary-D	1.54
Dispersive Mixing Between Segments - Boundary:Boundary-D	1.54
Depth - Segment 1-5-D	1.47
Surface Area Between Segments - Boundary:Boundary-U	1.40
Dispersive Mixing Between Segments - Boundary:Boundary-U	1.40
Upstream Boundary Concentration NH3-U	1.40
Upstream Boundary Concentration NH3-D	1.39
Segment Length - Boundary:Boundary-U	1.39
Benthic Ammonia Flux - Segment 1-U	1.39
Benthic Ammonia Flux - Segment 2-U	1.39
Benthic Ammonia Flux - Segment 3-U	1.39
Benthic Ammonia Flux - Segment 4-U	1.39
Benthic Ammonia Flux - Segment 5-U	1.39
Benthic Ammonia Flux - Segment 1-5-U	1.39
Benthic Ammonia Flux - Segment 1-D	1.38
Benthic Ammonia Flux - Segment 2-D	1.38
Benthic Ammonia Flux - Segment 3-D	1.38
Benthic Ammonia Flux - Segment 4-D	1.38
Benthic Ammonia Flux - Segment 5-D	1.38
Benthic Ammonia Flux - Segment 1-5-D	1.38
Surface Water Flow-U	1.35
DON Mineralization Temperature Coefficient-D	1.25
Depth - Segment 1-5-U	1.21
Nitrification Temperature Coefficient-D	1.01
DON Mineralization Temperature Coefficient-U	0.95
Surface Area Between Segments - Segment5:Boundary-D	0.93
Dispersive Mixing Between Segments - Segment5:Boundary-D	0.93
Segment Length - Segment5:Boundary-D	0.89

C.2.2. December 2003 (continued)

Volume - Segment 1-5-D	0.89
Nitrification Rate-D	0.88
Volume - Segment 1-5-U	0.85
Segment Length - Segment5:Boundary-U	0.84
Nitrification Rate-U	0.84
Surface Area Between Segments - Segment5:Boundary-U	0.81
Dispersive Mixing Between Segments - Segment5:Boundary-U	0.81
Downstream Boundary Concentration DON-U	0.77
Downstream Boundary Concentration DON-D	0.77
Phytoplankton Maximum Growth Temperature Coefficient-D	0.63
Surface Area Between Segments - Segment 4:Segment5-D	0.46
Dispersive Mixing Between Segments - Segment 4:Segment5-D	0.46
Downstream Boundary Concentration NH3-U	0.46
Downstream Boundary Concentration NH3-D	0.46
Segment Length - Segment 4:Segment5-D	0.45
Depth - Segment 3-D	0.43
Segment Length - Segment 4:Segment5-U	0.42
Surface Area Between Segments - Segment 4:Segment5-U	0.41
Dispersive Mixing Between Segments - Segment 4:Segment5-U	0.41
Depth - Segment 4-D	0.39
Downstream Boundary Concentration NO3-D	0.37
Downstream Boundary Concentration NO3-U	0.37
Depth - Segment 3-U	0.36
Depth - Segment 2-D	0.32
Depth - Segment 4-U	0.32
Phytoplankton Maximum Growth Temperature Coefficient-U	0.27
Depth - Segment 2-U	0.26
Light Option (1=input light; 2=calculated diel light)-D	0.26
Volume - Segment 4-D	0.26
Volume - Segment 3-D	0.25
Volume - Segment 4-U	0.25
Volume - Segment 3-U	0.25
DON Mineralization Rate-D	0.22
DON Mineralization Rate-U	0.22
Phytoplankton Half-Sat. for Mineralization Rate-D	0.21
Dispersive Mixing Between Segments - Segment 3:Segment4-D	0.21
Surface Area Between Segments - Segment 3:Segment4-D	0.21

C.2.2. December 2003 (continued)

Segment Length - Segment 3:Segment4-D	0.21
Depth - Segment 5-D	0.19
Segment Length - Segment 3:Segment4-U	0.19
Half Saturation Nitrification Oxygen Limit-D	0.19
Dispersive Mixing Between Segments - Segment 3:Segment4-U	0.19
Surface Area Between Segments - Segment 3:Segment4-U	0.19
Half Saturation Nitrification Oxygen Limit-U	0.18
Phytoplankton Half-Sat. for Mineralization Rate-U	0.18
Volume - Segment 2-D	0.17
Volume - Segment 2-U	0.16
Phytoplankton Carbon to Chlorophyll Ratio-D	0.16
Phytoplankton Carbon to Chlorophyll Ratio-U	0.16
Depth - Segment 5-U	0.16
Volume - Segment 5-D	0.15
Volume - Segment 5-U	0.15
Depth - Segment 1-D	0.14
Segment Length - Segment 2:Segment3-D	0.14
Dispersive Mixing Between Segments - Segment 2:Segment3-D	0.14
Surface Area Between Segments - Segment 2:Segment3-D	0.14
Downstream Boundary Concentration Chl-a-D	0.13
Downstream Boundary Concentration Chl-a-U	0.13
Dispersive Mixing Between Segments - Segment 2:Segment3-U	0.13
Surface Area Between Segments - Segment 2:Segment3-U	0.13
Segment Length - Segment 2:Segment3-U	0.13
Depth - Segment 1-U	0.12
Temperature - Segment 1-5-U	0.11
Temperature - Segment 1-5-D	0.11
Temperature - Segment 1-U	0.10
Temperature - Segment 2-U	0.10
Temperature - Segment 3-U	0.10
Temperature - Segment 4-U	0.10
Temperature - Segment 5-U	0.10
Phytoplankton Respiration Rate Temperature Coefficient-U	0.10
Temperature - Segment 1-D	0.10
Temperature - Segment 2-D	0.10
Temperature - Segment 3-D	0.10
Temperature - Segment 4-D	0.10

C.2.2. December 2003 (continued)

Temperature - Segment 5-D	0.10
Segment Length - Segment 1:Segment2-D	0.10
Surface Area Between Segments - Segment 1:Segment2-D	0.10
Dispersive Mixing Between Segments - Segment 1:Segment2-D	0.10
Segment Length - Boundary:Segment1-D	0.09
Dispersive Mixing Between Segments - Segment 1:Segment2-U	0.09
Surface Area Between Segments - Segment 1:Segment2-U	0.09
Dispersive Mixing Between Segments - Boundary:Segment1-D	0.09
Surface Area Between Segments - Boundary:Segment 1-D	0.09
Segment Length - Segment 1:Segment2-U	0.09
Surface Area Between Segments - Boundary:Segment 1-U	0.08
Dispersive Mixing Between Segments - Boundary:Segment 1-U	0.08
Upstream Boundary Concentration DO-D	0.08
Segment Length - Boundary:Segment 1-U	0.08
Upstream Boundary Concentration DO-U	0.08
Phytoplankton Maximum Growth Rate -U	0.07
Light Extinction - Segment 1-5-D	0.07
Phytoplankton Maximum Growth Rate -D	0.07
Phytoplankton Respiration Rate Temperature Coefficient-D	0.07
Fraction Phytoplankton Death Recycled to Organic N-D	0.06
Fraction Phytoplankton Death Recycled to Organic N-U	0.06
Light Extinction - Segment 1-5-U	0.06
Volume - Segment 1-D	0.05
Volume - Segment 1-U	0.05
Denitrification Temperature Coefficient-D	0.04
Solar Radiation-D	0.04
Phytoplankton Optimal Light Saturation-D	0.04
Light Extinction - Segment 3-D	0.04
Light Extinction - Segment 5-D	0.04
Phytoplankton Nitrogen to Carbon Ratio-D	0.03
Phytoplankton Nitrogen to Carbon Ratio-U	0.03
Fraction Daily Light-D	0.03
Phytoplankton Half-Saturation N Uptake-D	0.03
Phytoplankton Optimal Light Saturation-U	0.03
Solar Radiation-U	0.03
Downstream Boundary Concentration DO-D	0.03
SOD Temperature Correction-U	0.03

C.2.2. December 2003 (continued)

Downstream Boundary Concentration DO-U	0.03
Phytoplankton Half-Saturation N Uptake-U	0.03
Denitrification Temperature Coefficient-U	0.03
Upstream Boundary Concentration Chl-a-D	0.03
Upstream Boundary Concentration Chl-a-U	0.03
Light Extinction - Segment 3-U	0.03
Light Extinction - Segment 5-U	0.03
Global Reaeration Rate-D	0.02
Phytoplankton Respiration Rate-D	0.02
Light Extinction - Segment 4-D	0.02
SOD Temperature Correction-D	0.02
Phytoplankton Respiration Rate-U	0.02
Global Reaeration Rate-U	0.02
Light Extinction - Segment 4-U	0.02
Phytoplankton Death Rate-D	0.02
Phytoplankton Death Rate-U	0.02
CBOD Decay Rate Temperature Correction Coefficient-U	0.02
SOD - Segment 1-U	0.01
SOD - Segment 2-U	0.01
SOD - Segment 3-U	0.01
SOD - Segment 4-U	0.01
SOD - Segment 5-U	0.01
SOD - Segment 1-5-U	0.01
SOD - Segment 1-D	0.01
SOD - Segment 2-D	0.01
SOD - Segment 3-D	0.01
SOD - Segment 4-D	0.01
SOD - Segment 5-D	0.01
SOD - Segment 1-5-D	0.01
Denitrification Rate-D	0.01
Denitrification Rate-U	0.01
Half Saturation Denitrification Oxygen Limit-D	0.01
Half Saturation Denitrification Oxygen Limit-U	0.01
Light Extinction - Segment 2-D	0.01
CBOD Decay Rate Temperature Correction Coefficient-D	0.01
Phytoplankton Half-Saturation P Uptake-D	0.01
Phytoplankton Half-Saturation P Uptake-U	0.01

C.2.2. December 2003 (continued)

Light Extinction - Segment 2-U	0.01
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-D	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-D	0.00
Pore Water Flow-D	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-U	0.00
Pore Water Flow-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-U	0.00
Downstream Boundary Concentration Salinity-D	0.00
Downstream Boundary Concentration Salinity-U	0.00
CBOD Rate-D	0.00
CBOD Rate-U	0.00
Downstream Boundary Concentration PO4-D	0.00
DOP Mineralization Rate Temperature Coefficient-D	0.00
Downstream Boundary Concentration PO4-U	0.00
Upstream Boundary Concentration CBOD-U	0.00
Upstream Boundary Concentration CBOD-D	0.00
DOP Mineralization Rate Temperature Coefficient-U	0.00
Upstream Boundary Concentration PO4-D	0.00
Upstream Boundary Concentration PO4-U	0.00
Light Extinction - Segment 1-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-D	0.00
Light Extinction - Segment 1-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-U	0.00
Downstream Boundary Concentration CBOD-U	0.00
Downstream Boundary Concentration CBOD-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-D	0.00

C.2.2. December 2003 (continued)

Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-U	0.00
Benthic Ammonia Flux-D	0.00
Benthic Ammonia Flux-U	0.00
DOP Mineralization Rate-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-D	0.00
DOP Mineralization Rate-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-D	0.00
Settling Rate for Solids Group 1-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-U	0.00
Settling Rate for Solids Group 1-U	0.00
Upstream Boundary Concentration DOP-D	0.00
Upstream Boundary Concentration DOP-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-U	0.00
Fraction Daily Light-U	0.00
CBOD Half Saturation Oxygen Limit-D	0.00
CBOD Half Saturation Oxygen Limit-U	0.00
Downstream Boundary Concentration DOP-D	0.00
Downstream Boundary Concentration DOP-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-U	0.00
Phytoplankton Phosphorus to Carbon Ratio-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-U	0.00
Phytoplankton Phosphorus to Carbon Ratio-D	0.00

C.2.2. December 2003 (continued)

Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-U	0.00
Fraction Phytoplankton Death Recycled to Organic P-U	0.00
Fraction Phytoplankton Death Recycled to Organic P-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-D	0.00
Upstream Boundary Concentration Salinity-U	0.00
Downstream Boundary Concentration Inorganic Solids-D	0.00
Upstream Boundary Concentration Salinity-D	0.00
Downstream Boundary Concentration Inorganic Solids-U	0.00
Upstream Boundary Concentration Inorganic Solids-D	0.00
Upstream Boundary Concentration Inorganic Solids-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-D	0.00
Resuspension Rate for Solids Group 1-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-D	0.00
Upstream Boundary Concentration Detrital N-D	0.00
Downstream Boundary Concentration Detrital N-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-D	0.00
Resuspension Rate for Solids Group 1-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-U	0.00

C.2.2. December 2003 (continued)

Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-U	0.00
Upstream Boundary Concentration Detrital C-D	0.00
Upstream Boundary Concentration Detrital C-U	0.00
Downstream Boundary Concentration Detrital C-D	0.00
Downstream Boundary Concentration Detrital C-U	0.00
Upstream Boundary Concentration Detrital N-U	0.00
Downstream Boundary Concentration Detrital N-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-U	0.00
Algal Self Shading Light Extinction (Yes/No)-D	0.00

C.2.3. March 2004

Input	% Sensitivity
Upstream Boundary Concentration DON-U	2.88
Upstream Boundary Concentration DON-D	2.88
Upstream Boundary Concentration NO3-U	2.86
Upstream Boundary Concentration NO3-D	2.86
Nitrification Temperature Coefficient-U	2.76
Depth - Segment 1-5-D	2.20
Benthic Ammonia Flux - Segment 1-U	2.06
Benthic Ammonia Flux - Segment 2-U	2.06
Benthic Ammonia Flux - Segment 3-U	2.06
Benthic Ammonia Flux - Segment 4-U	2.06
Benthic Ammonia Flux - Segment 5-U	2.06
Benthic Ammonia Flux - Segment 1-5-U	2.06
Benthic Ammonia Flux - Segment 1-D	2.06
Benthic Ammonia Flux - Segment 2-D	2.06
Benthic Ammonia Flux - Segment 3-D	2.06
Benthic Ammonia Flux - Segment 4-D	2.06
Benthic Ammonia Flux - Segment 5-D	2.06
Benthic Ammonia Flux - Segment 1-5-D	2.06
Surface Water Flow-D	2.03
Volume - Segment 1-5-D	1.88
Volume - Segment 1-5-U	1.84
Depth - Segment 1-5-U	1.80
Surface Water Flow-U	1.78
DON Mineralization Temperature Coefficient-D	1.20
Segment Length - Boundary:Boundary-D	1.00
Surface Area Between Segments - Boundary:Boundary-D	0.96
Dispersive Mixing Between Segments - Boundary:Boundary-D	0.96
DON Mineralization Temperature Coefficient-U	0.91
Dispersive Mixing Between Segments - Boundary:Boundary-U	0.90
Surface Area Between Segments - Boundary:Boundary-U	0.90
Segment Length - Boundary:Boundary-U	0.87
Upstream Boundary Concentration NH3-D	0.79
Nitrification Temperature Coefficient-D	0.72
Phytoplankton Maximum Growth Temperature Coefficient-D	0.71
Downstream Boundary Concentration DON-U	0.66

C.2.3. March 2004 (continued)

Downstream Boundary Concentration DON-D	0.66
Depth - Segment 3-D	0.64
Nitrification Rate-D	0.61
Nitrification Rate-U	0.59
Dispersive Mixing Between Segments - Segment5:Boundary-D	0.57
Surface Area Between Segments - Segment5:Boundary-D	0.57
Segment Length - Segment5:Boundary-D	0.56
Volume - Segment 3-D	0.53
Depth - Segment 2-D	0.53
Depth - Segment 3-U	0.52
Volume - Segment 3-U	0.52
Segment Length - Segment5:Boundary-U	0.52
Depth - Segment 4-D	0.52
Surface Area Between Segments - Segment5:Boundary-U	0.51
Dispersive Mixing Between Segments - Segment5:Boundary-U	0.51
Volume - Segment 2-D	0.46
Volume - Segment 2-U	0.45
Depth - Segment 2-U	0.43
Volume - Segment 4-D	0.42
Depth - Segment 4-U	0.42
Volume - Segment 4-U	0.42
Downstream Boundary Concentration NH3-U	0.39
Downstream Boundary Concentration NH3-D	0.39
Downstream Boundary Concentration NO3-U	0.37
Downstream Boundary Concentration NO3-D	0.37
Phytoplankton Maximum Growth Temperature Coefficient-U	0.32
Light Option (1=input light; 2=calculated diel light)-D	0.29
Depth - Segment 1-D	0.27
Volume - Segment 1-D	0.25
Volume - Segment 1-U	0.25
Depth - Segment 5-D	0.24
Depth - Segment 1-U	0.22
DON Mineralization Rate-D	0.21
Volume - Segment 5-D	0.21
DON Mineralization Rate-U	0.21
Volume - Segment 5-U	0.21
Phytoplankton Half-Sat. for Mineralization Rate-D	0.21

C.2.3. March 2004 (continued)

Phytoplankton Carbon to Chlorophyll Ratio-D	0.20
Depth - Segment 5-U	0.20
Phytoplankton Carbon to Chlorophyll Ratio-U	0.20
Segment Length - Segment 2:Segment3-D	0.19
Surface Area Between Segments - Segment 2:Segment3-D	0.19
Dispersive Mixing Between Segments - Segment 2:Segment3-D	0.19
Segment Length - Segment 4:Segment5-D	0.18
Dispersive Mixing Between Segments - Segment 2:Segment3-U	0.18
Surface Area Between Segments - Segment 2:Segment3-U	0.18
Surface Area Between Segments - Segment 4:Segment5-D	0.18
Dispersive Mixing Between Segments - Segment 4:Segment5-D	0.18
Phytoplankton Half-Sat. for Mineralization Rate-U	0.17
Segment Length - Segment 2:Segment3-U	0.17
Segment Length - Segment 1:Segment2-D	0.17
Segment Length - Segment 3:Segment4-D	0.16
Dispersive Mixing Between Segments - Segment 1:Segment2-D	0.16
Surface Area Between Segments - Segment 1:Segment2-D	0.16
Surface Area Between Segments - Segment 4:Segment5-U	0.16
Dispersive Mixing Between Segments - Segment 4:Segment5-U	0.16
Segment Length - Segment 4:Segment5-U	0.16
Dispersive Mixing Between Segments - Segment 3:Segment4-D	0.16
Surface Area Between Segments - Segment 3:Segment4-D	0.16
Dispersive Mixing Between Segments - Segment 1:Segment2-U	0.15
Surface Area Between Segments - Segment 1:Segment2-U	0.15
Segment Length - Boundary:Segment1-D	0.15
Phytoplankton Respiration Rate Temperature Coefficient-U	0.15
Segment Length - Segment 1:Segment2-U	0.15
Dispersive Mixing Between Segments - Segment 3:Segment4-U	0.15
Surface Area Between Segments - Segment 3:Segment4-U	0.15
Upstream Boundary Concentration Chl-a-D	0.14
Segment Length - Segment 3:Segment4-U	0.14
Upstream Boundary Concentration Chl-a-U	0.14
Dispersive Mixing Between Segments - Boundary:Segment1-D	0.14
Surface Area Between Segments - Boundary:Segment 1-D	0.14
Half Saturation Nitrification Oxygen Limit-D	0.13
Surface Area Between Segments - Boundary:Segment 1-U	0.13
Dispersive Mixing Between Segments - Boundary:Segment 1-U	0.13

C.2.3. March 2004 (continued)

Half Saturation Nitrification Oxygen Limit-U	0.13
Segment Length - Boundary:Segment 1-U	0.13
Phytoplankton Respiration Rate Temperature Coefficient-D	0.10
Light Extinction - Segment 1-5-D	0.08
Phytoplankton Maximum Growth Rate -U	0.08
Phytoplankton Maximum Growth Rate -D	0.08
Upstream Boundary Concentration DO-D	0.08
Upstream Boundary Concentration DO-U	0.07
Temperature - Segment 1-5-U	0.07
Fraction Phytoplankton Death Recycled to Organic N-U	0.07
Fraction Phytoplankton Death Recycled to Organic N-D	0.07
Temperature - Segment 1-U	0.07
Temperature - Segment 2-U	0.07
Temperature - Segment 3-U	0.07
Temperature - Segment 4-U	0.07
Temperature - Segment 5-U	0.07
Light Extinction - Segment 1-5-U	0.06
Downstream Boundary Concentration Chl-a-D	0.06
Downstream Boundary Concentration Chl-a-U	0.06
Phytoplankton Half-Saturation N Uptake-D	0.05
Temperature - Segment 1-5-D	0.05
Temperature - Segment 1-D	0.05
Temperature - Segment 2-D	0.05
Temperature - Segment 3-D	0.05
Temperature - Segment 4-D	0.05
Temperature - Segment 5-D	0.05
Phytoplankton Half-Saturation N Uptake-U	0.04
Solar Radiation-D	0.04
Phytoplankton Optimal Light Saturation-D	0.04
Fraction Daily Light-D	0.04
Phytoplankton Optimal Light Saturation-U	0.04
Solar Radiation-U	0.04
Phytoplankton Respiration Rate-D	0.03
Phytoplankton Respiration Rate-U	0.03
Phytoplankton Nitrogen to Carbon Ratio-D	0.03
Phytoplankton Nitrogen to Carbon Ratio-U	0.03
Phytoplankton Death Rate-D	0.02

C.2.3. March 2004 (continued)

Phytoplankton Death Rate-U	0.02
Denitrification Temperature Coefficient-D	0.02
Light Extinction - Segment 4-D	0.02
Light Extinction - Segment 3-D	0.02
Downstream Boundary Concentration DO-D	0.02
Light Extinction - Segment 4-U	0.02
Downstream Boundary Concentration DO-U	0.02
Denitrification Temperature Coefficient-U	0.02
Light Extinction - Segment 3-U	0.02
SOD Temperature Correction-U	0.02
Global Reaeration Rate-D	0.01
Light Extinction - Segment 2-D	0.01
Global Reaeration Rate-U	0.01
Light Extinction - Segment 5-D	0.01
SOD Temperature Correction-D	0.01
Light Extinction - Segment 2-U	0.01
Light Extinction - Segment 5-U	0.01
Upstream Boundary Concentration NH3-U	0.01
CBOD Decay Rate Temperature Correction Coefficient-U	0.01
Light Extinction - Segment 1-D	0.01
Light Extinction - Segment 1-U	0.00
Denitrification Rate-D	0.00
Denitrification Rate-U	0.00
Half Saturation Denitrification Oxygen Limit-D	0.00
Half Saturation Denitrification Oxygen Limit-U	0.00
SOD - Segment 1-U	0.00
SOD - Segment 2-U	0.00
SOD - Segment 3-U	0.00
SOD - Segment 4-U	0.00
SOD - Segment 5-U	0.00
SOD - Segment 1-5-U	0.00
SOD - Segment 1-D	0.00
SOD - Segment 2-D	0.00
SOD - Segment 3-D	0.00
SOD - Segment 4-D	0.00
SOD - Segment 5-D	0.00
SOD - Segment 1-5-D	0.00

C.2.3. March 2004 (continued)

CBOD Decay Rate Temperature Correction Coefficient-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-D	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-D	0.00
Pore Water Flow-D	0.00
Pore Water Flow-U	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-U	0.00
CBOD Rate-D	0.00
CBOD Rate-U	0.00
Upstream Boundary Concentration CBOD-D	0.00
Upstream Boundary Concentration CBOD-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-U	0.00
Downstream Boundary Concentration Salinity-D	0.00
Downstream Boundary Concentration Salinity-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-D	0.00
Downstream Boundary Concentration CBOD-D	0.00
Downstream Boundary Concentration CBOD-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-U	0.00

C.2.3. March 2004 (continued)

Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-D	0.00
Settling Rate for Solids Group 1-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-U	0.00
Settling Rate for Solids Group 1-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-U	0.00
Fraction Daily Light-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-U	0.00
CBOD Half Saturation Oxygen Limit-U	0.00
CBOD Half Saturation Oxygen Limit-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-U	0.00
Downstream Boundary Concentration Inorganic Solids-U	0.00
Downstream Boundary Concentration Inorganic Solids-D	0.00
Upstream Boundary Concentration Inorganic Solids-U	0.00
Upstream Boundary Concentration Salinity-D	0.00
Upstream Boundary Concentration Inorganic Solids-D	0.00
Resuspension Rate for Solids Group 1-U	0.00

C.2.3. March 2004 (continued)

Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-U	0.00
Upstream Boundary Concentration Salinity-U	0.00
Resuspension Rate for Solids Group 1-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-D	0.00
Upstream Boundary Concentration Detrital C-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-D	0.00
Phytoplankton Half-Saturation P Uptake-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-U	0.00
Upstream Boundary Concentration Detrital C-D	0.00
Upstream Boundary Concentration Detrital N-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-U	0.00
Downstream Boundary Concentration PO4-D	0.00
Downstream Boundary Concentration Detrital C-D	0.00
Benthic Ammonia Flux-D	0.00
Downstream Boundary Concentration Detrital N-U	0.00
Upstream Boundary Concentration PO4-D	0.00
Upstream Boundary Concentration PO4-U	0.00
Downstream Boundary Concentration PO4-U	0.00
Upstream Boundary Concentration DOP-D	0.00
Upstream Boundary Concentration DOP-U	0.00
Downstream Boundary Concentration DOP-D	0.00
Downstream Boundary Concentration DOP-U	0.00
Downstream Boundary Concentration Detrital C-U	0.00
Upstream Boundary Concentration Detrital N-U	0.00
Downstream Boundary Concentration Detrital N-D	0.00

C.2.3. March 2004 (continued)

Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-U	0.00
Benthic Ammonia Flux-U	0.00
DOP Mineralization Rate-D	0.00
DOP Mineralization Rate-U	0.00
DOP Mineralization Rate Temperature Coefficient-D	0.00
DOP Mineralization Rate Temperature Coefficient-U	0.00
Fraction Phytoplankton Death Recycled to Organic P-D	0.00
Fraction Phytoplankton Death Recycled to Organic P-U	0.00
Algal Self Shading Light Extinction (Yes/No)-D	0.00
Phytoplankton Half-Saturation P Uptake-D	0.00
Phytoplankton Phosphorus to Carbon Ratio-D	0.00
Phytoplankton Phosphorus to Carbon Ratio-U	0.00

C.2.4. September 2004

Input	% Sensitivity
Upstream Boundary Concentration DON-U	3.22
Upstream Boundary Concentration DON-D	3.22
Surface Water Flow-D	3.05
Surface Water Flow-U	2.55
Upstream Boundary Concentration NO3-U	2.04
Upstream Boundary Concentration NO3-D	2.03
Segment Length - Boundary:Boundary-D	1.63
Nitrification Temperature Coefficient-U	1.52
Depth - Segment 1-5-D	1.50
Surface Area Between Segments - Boundary:Boundary-D	1.50
Dispersive Mixing Between Segments - Boundary:Boundary-D	1.50
Benthic Ammonia Flux - Segment 1-U	1.47
Benthic Ammonia Flux - Segment 2-U	1.47
Benthic Ammonia Flux - Segment 3-U	1.47
Benthic Ammonia Flux - Segment 4-U	1.47
Benthic Ammonia Flux - Segment 5-U	1.47
Benthic Ammonia Flux - Segment 1-5-U	1.47
Benthic Ammonia Flux - Segment 1-D	1.47
Benthic Ammonia Flux - Segment 2-D	1.47
Benthic Ammonia Flux - Segment 3-D	1.47
Benthic Ammonia Flux - Segment 4-D	1.47
Benthic Ammonia Flux - Segment 5-D	1.47
Benthic Ammonia Flux - Segment 1-5-D	1.47
Dispersive Mixing Between Segments - Boundary:Boundary-U	1.47
Surface Area Between Segments - Boundary:Boundary-U	1.47
Volume - Segment 1-5-D	1.39
Volume - Segment 1-5-U	1.37
Upstream Boundary Concentration NH3-U	1.36
Upstream Boundary Concentration NH3-D	1.36
Segment Length - Boundary:Boundary-U	1.36
Depth - Segment 1-5-U	1.23
Downstream Boundary Concentration NO3-U	1.20
Downstream Boundary Concentration NO3-D	1.20
DON Mineralization Temperature Coefficient-U	0.81
Segment Length - Segment5:Boundary-D	0.72

C.2.4. September 2004 (continued)

Surface Area Between Segments – Segment5:Boundary-D	0.72
Dispersive Mixing Between Segments – Segment5:Boundary-D	0.72
Dispersive Mixing Between Segments – Segment5:Boundary-U	0.65
Surface Area Between Segments – Segment5:Boundary-U	0.65
Segment Length – Segment5:Boundary-U	0.65
DON Mineralization Temperature Coefficient-D	0.50
Nitrification Rate-D	0.48
Segment Length – Segment 4:Segment5-D	0.47
Nitrification Rate-U	0.47
Surface Area Between Segments – Segment 4:Segment5-D	0.46
Dispersive Mixing Between Segments – Segment 4:Segment5-D	0.46
Depth – Segment 3-D	0.46
Phytoplankton Maximum Growth Temperature Coefficient-U	0.44
Downstream Boundary Concentration NH3-U	0.43
Downstream Boundary Concentration NH3-D	0.43
Dispersive Mixing Between Segments – Segment 4:Segment5-U	0.43
Surface Area Between Segments – Segment 4:Segment5-U	0.43
Light Option (1=input light; 2=calculated diel light)-D	0.42
Segment Length – Segment 4:Segment5-U	0.41
Volume – Segment 3-D	0.41
Volume – Segment 3-U	0.40
Depth – Segment 2-D	0.39
Depth – Segment 3-U	0.37
Volume – Segment 2-D	0.35
Downstream Boundary Concentration DON-U	0.35
Downstream Boundary Concentration DON-D	0.35
Volume – Segment 2-U	0.35
Depth – Segment 4-D	0.34
Depth – Segment 2-U	0.32
Phytoplankton Maximum Growth Temperature Coefficient-D	0.32
Volume – Segment 4-D	0.31
Volume – Segment 4-U	0.31
Temperature – Segment 1-U	0.30
Temperature – Segment 2-U	0.30
Temperature – Segment 3-U	0.30
Temperature – Segment 4-U	0.30
Temperature – Segment 5-U	0.30

C.2.4. September 2004 (continued)

Temperature - Segment 1-5-U	0.30
Depth - Segment 4-U	0.28
Segment Length - Segment 3:Segment4-D	0.28
Nitrification Temperature Coefficient-D	0.28
Surface Area Between Segments - Segment 3:Segment4-D	0.27
Dispersive Mixing Between Segments - Segment 3:Segment4-D	0.27
Surface Area Between Segments - Segment 3:Segment4-U	0.25
Dispersive Mixing Between Segments - Segment 3:Segment4-U	0.25
Phytoplankton Half-Sat. for Mineralization Rate-D	0.25
DON Mineralization Rate-D	0.24
DON Mineralization Rate-U	0.24
Segment Length - Segment 3:Segment4-U	0.24
Phytoplankton Half-Sat. for Mineralization Rate-U	0.21
Depth - Segment 1-D	0.21
Phytoplankton Carbon to Chlorophyll Ratio-D	0.19
Phytoplankton Carbon to Chlorophyll Ratio-U	0.19
Volume - Segment 1-D	0.18
Volume - Segment 1-U	0.18
Temperature - Segment 1-D	0.17
Temperature - Segment 2-D	0.17
Temperature - Segment 3-D	0.17
Temperature - Segment 4-D	0.17
Temperature - Segment 5-D	0.17
Temperature - Segment 1-5-D	0.17
Depth - Segment 1-U	0.17
Segment Length - Segment 2:Segment3-D	0.16
Surface Area Between Segments - Segment 2:Segment3-D	0.16
Dispersive Mixing Between Segments - Segment 2:Segment3-D	0.16
Dispersive Mixing Between Segments - Segment 2:Segment3-U	0.15
Surface Area Between Segments - Segment 2:Segment3-U	0.15
Depth - Segment 5-D	0.14
Segment Length - Segment 2:Segment3-U	0.14
Volume - Segment 5-D	0.13
Volume - Segment 5-U	0.13
Light Extinction - Segment 1-5-D	0.13
Phytoplankton Maximum Growth Rate -U	0.13
Phytoplankton Maximum Growth Rate -D	0.12

C.2.4. September 2004 (continued)

Depth - Segment 5-U	0.12
Phytoplankton Nitrogen to Carbon Ratio-D	0.11
Phytoplankton Nitrogen to Carbon Ratio-U	0.11
Half Saturation Nitrification Oxygen Limit-D	0.11
Half Saturation Nitrification Oxygen Limit-U	0.11
Light Extinction - Segment 1-5-U	0.10
Downstream Boundary Concentration Chl-a-D	0.10
Downstream Boundary Concentration Chl-a-U	0.10
Segment Length - Segment 1:Segment2-D	0.09
Upstream Boundary Concentration Chl-a-D	0.09
Upstream Boundary Concentration Chl-a-U	0.09
Surface Area Between Segments - Segment 1:Segment2-D	0.09
Dispersive Mixing Between Segments - Segment 1:Segment2-D	0.09
Dispersive Mixing Between Segments - Segment 1:Segment2-U	0.09
Surface Area Between Segments - Segment 1:Segment2-U	0.09
Segment Length - Segment 1:Segment2-U	0.08
Upstream Boundary Concentration DO-D	0.08
Upstream Boundary Concentration DO-U	0.07
Phytoplankton Half-Saturation N Uptake-D	0.07
Segment Length - Boundary:Segment1-D	0.07
Solar Radiation-D	0.07
Phytoplankton Optimal Light Saturation-D	0.07
Surface Area Between Segments - Boundary:Segment 1-D	0.06
Dispersive Mixing Between Segments - Boundary:Segment1-D	0.06
Fraction Daily Light-D	0.06
Surface Area Between Segments - Boundary:Segment 1-U	0.06
Dispersive Mixing Between Segments - Boundary:Segment 1-U	0.06
Phytoplankton Optimal Light Saturation-U	0.06
Solar Radiation-U	0.06
Phytoplankton Half-Saturation N Uptake-U	0.06
Segment Length - Boundary:Segment 1-U	0.06
Phytoplankton Respiration Rate Temperature Coefficient-U	0.06
Light Extinction - Segment 4-D	0.05
Light Extinction - Segment 5-D	0.04
Light Extinction - Segment 4-U	0.04
Light Extinction - Segment 5-U	0.04
Fraction Phytoplankton Death Recycled to Organic N-D	0.03

C.2.4. September 2004 (continued)

Fraction Phytoplankton Death Recycled to Organic N-U	0.03
Light Extinction - Segment 3-D	0.02
Phytoplankton Respiration Rate Temperature Coefficient-D	0.02
Light Extinction - Segment 3-U	0.02
Phytoplankton Respiration Rate-D	0.02
Phytoplankton Respiration Rate-U	0.02
Denitrification Temperature Coefficient-U	0.02
Downstream Boundary Concentration DO-D	0.01
Downstream Boundary Concentration DO-U	0.01
SOD Temperature Correction-U	0.01
Denitrification Temperature Coefficient-D	0.01
Phytoplankton Death Rate-U	0.01
Phytoplankton Death Rate-D	0.01
Global Reaeration Rate-D	0.01
Global Reaeration Rate-U	0.01
CBOD Decay Rate Temperature Correction Coefficient-U	0.01
Light Extinction - Segment 2-D	0.01
Denitrification Rate-U	0.00
Denitrification Rate-D	0.00
Half Saturation Denitrification Oxygen Limit-D	0.00
Half Saturation Denitrification Oxygen Limit-U	0.00
SOD Temperature Correction-D	0.00
Light Extinction - Segment 2-U	0.00
SOD - Segment 1-U	0.00
SOD - Segment 2-U	0.00
SOD - Segment 3-U	0.00
SOD - Segment 4-U	0.00
SOD - Segment 5-U	0.00
SOD - Segment 1-5-U	0.00
SOD - Segment 1-D	0.00
SOD - Segment 2-D	0.00
SOD - Segment 3-D	0.00
SOD - Segment 4-D	0.00
SOD - Segment 5-D	0.00
SOD - Segment 1-5-D	0.00
Light Extinction - Segment 1-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-D	0.00

C.2.4. September 2004 (continued)

Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-D	0.00
Pore Water Flow-D	0.00
Light Extinction - Segment 1-U	0.00
Pore Water Flow-U	0.00
Interfacial Surface Area Between Segments for Exchange - Boundary:Boundary-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Boundary:Boundary-U	0.00
CBOD Rate-U	0.00
CBOD Rate-D	0.00
Upstream Boundary Concentration CBOD-U	0.00
Upstream Boundary Concentration CBOD-D	0.00
CBOD Decay Rate Temperature Correction Coefficient-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 3:Segment 8-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 4:Segment 9-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-U	0.00
Settling Rate for Solids Group 1-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Boundary:Boundary-D	0.00
Settling Rate for Solids Group 1-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 2:Segment 7-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 2:Segment 7-U	0.00
Downstream Boundary Concentration Salinity-U	0.00
Downstream Boundary Concentration Salinity-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-D	0.00
Fraction Daily Light-U	0.00

C.2.4. September 2004 (continued)

Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-D	0.00
Downstream Boundary Concentration CBOD-U	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 5:Segment 10-U	0.00
Downstream Boundary Concentration CBOD-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-D	0.00
Distance Between Segments (Depth of Benthic Layer) - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 4:Segment 9-D	0.00
Interfacial Surface Area Between Segments for Exchange - Segment 1:Segment 6-U	0.00
CBOD Half Saturation Oxygen Limit-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 5:Segment 10-D	0.00
CBOD Half Saturation Oxygen Limit-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-U	0.00
Downstream Boundary Concentration Inorganic Solids-U	0.00
Downstream Boundary Concentration Inorganic Solids-D	0.00
Interfacial Surface Area Between Segments for Flows/Settling - Segment 1:Segment 6-D	0.00
Resuspension Rate for Solids Group 1-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-D	0.00
Upstream Boundary Concentration Inorganic Solids-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-D	0.00

C.2.4. September 2004 (continued)

Upstream Boundary Concentration Inorganic Solids-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-U	0.00
Resuspension Rate for Solids Group 1-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Boundary:Boundary-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-D	0.00
Upstream Boundary Concentration Salinity-D	0.00
Upstream Boundary Concentration Salinity-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 1:Segment 6-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 2:Segment 7-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 3:Segment 8-D	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 4:Segment 9-U	0.00
Interfacial Surface Area Between Segments for Flows/Resuspension - Segment 5:Segment 10-U	0.00
Upstream Boundary Concentration PO4-D	0.00
Upstream Boundary Concentration PO4-U	0.00
Downstream Boundary Concentration PO4-D	0.00
Downstream Boundary Concentration PO4-U	0.00
Upstream Boundary Concentration Detrital C-D	0.00
Upstream Boundary Concentration Detrital C-U	0.00
Downstream Boundary Concentration Detrital C-D	0.00
Downstream Boundary Concentration Detrital C-U	0.00
Upstream Boundary Concentration Detrital N-D	0.00
Upstream Boundary Concentration Detrital N-U	0.00
Downstream Boundary Concentration Detrital N-D	0.00
Downstream Boundary Concentration Detrital N-U	0.00
Benthic Ammonia Flux-D	0.00
Benthic Ammonia Flux-U	0.00
DOP Mineralization Rate-D	0.00
DOP Mineralization Rate-U	0.00
DOP Mineralization Rate Temperature Coefficient-D	0.00

C.2.4. September 2004 (continued)

DOP Mineralization Rate Temperature Coefficient-U	0.00
Fraction Phytoplankton Death Recycled to Organic P-D	0.00
Fraction Phytoplankton Death Recycled to Organic P-U	0.00
Algal Self Shading Light Extinction (Yes/No)-D	0.00
Phytoplankton Half-Saturation P Uptake-D	0.00
Phytoplankton Half-Saturation P Uptake-U	0.00
Phytoplankton Phosphorus to Carbon Ratio-D	0.00
Phytoplankton Phosphorus to Carbon Ratio-U	0.00

FIGURES AND TABLES

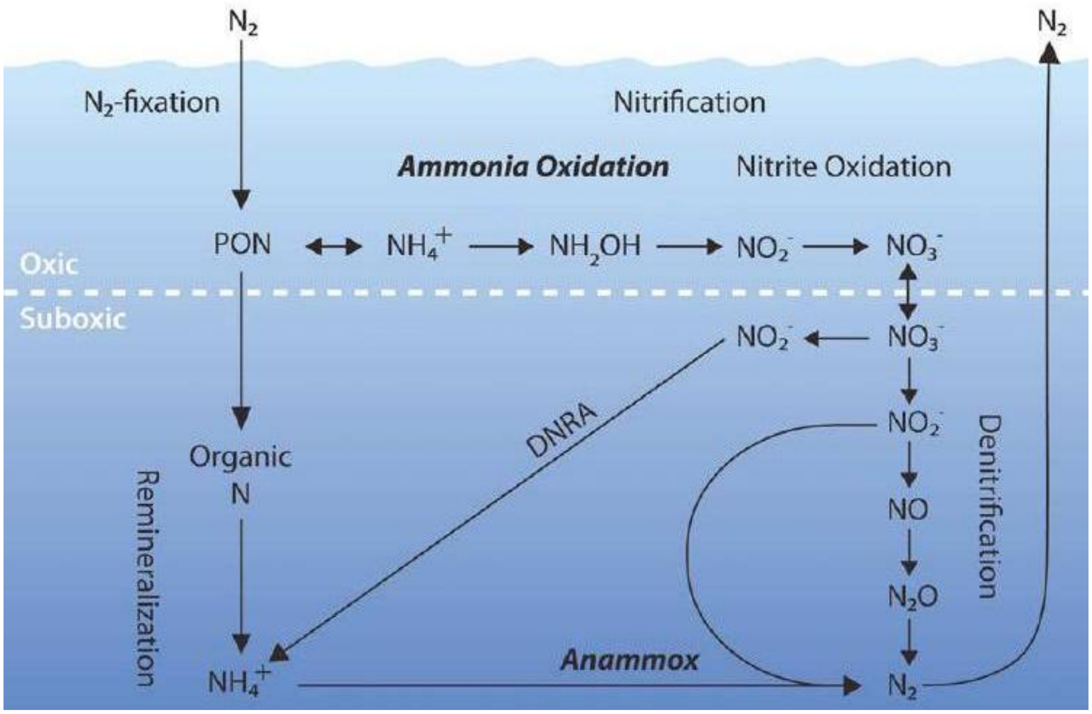


Figure 1. Dynamics of nitrogen transformations in aquatic systems (adapted from Francis et al. 2007).

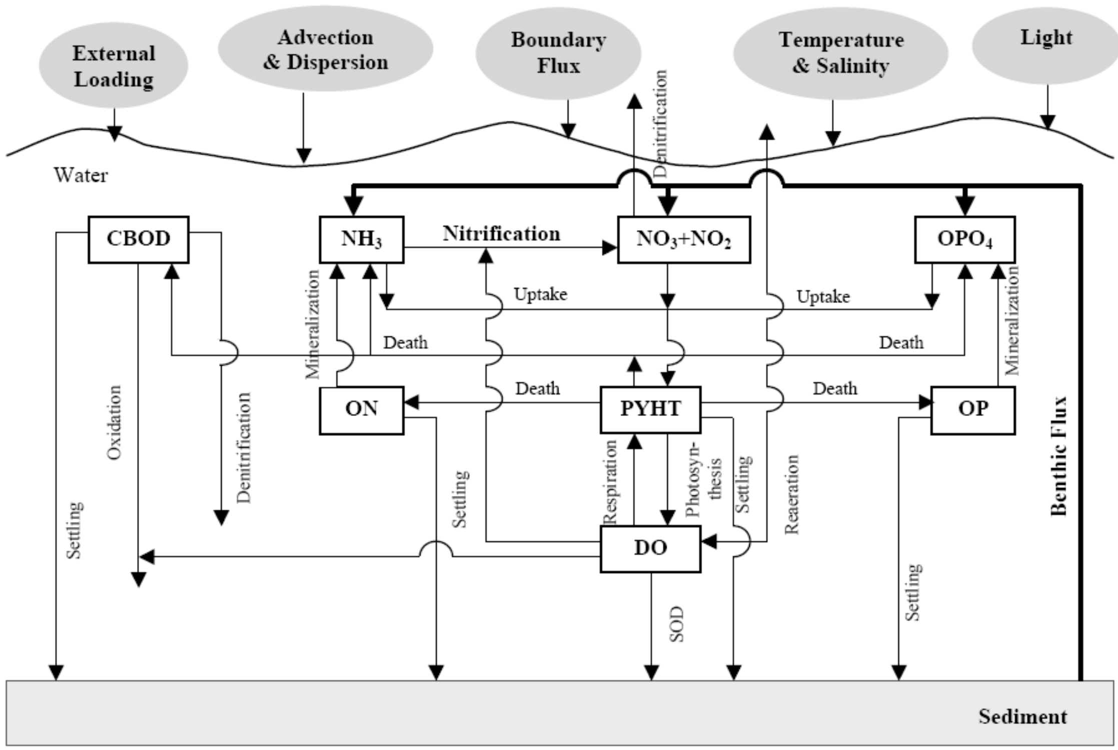


Figure 2. Major processes and variables included in the WASP EUTRO module. Environmental parameter are in boxes, external drivers are in ovals, and arrows indicate inputs and outputs due to various processes (figure from Zheng et al., 2004).

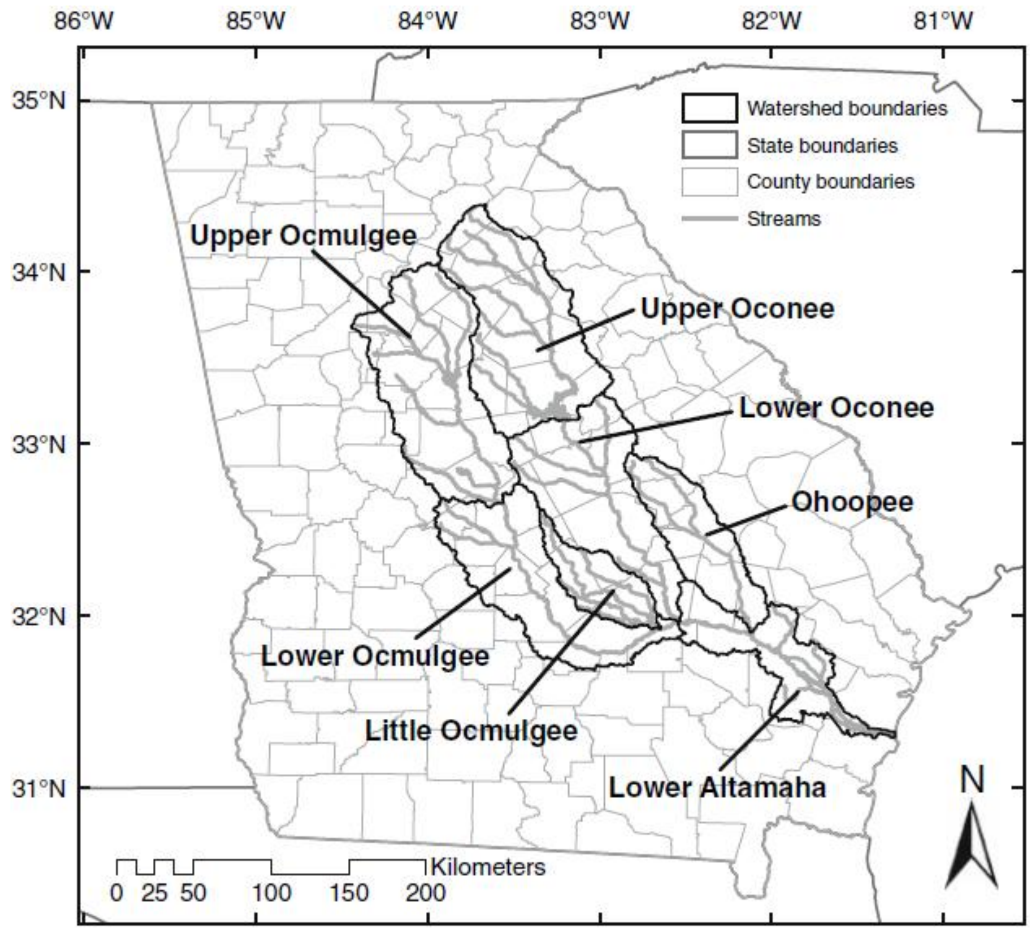


Figure 3. Altamaha River watershed and major sub-watersheds (figure from Schaefer and Alber, 2007).

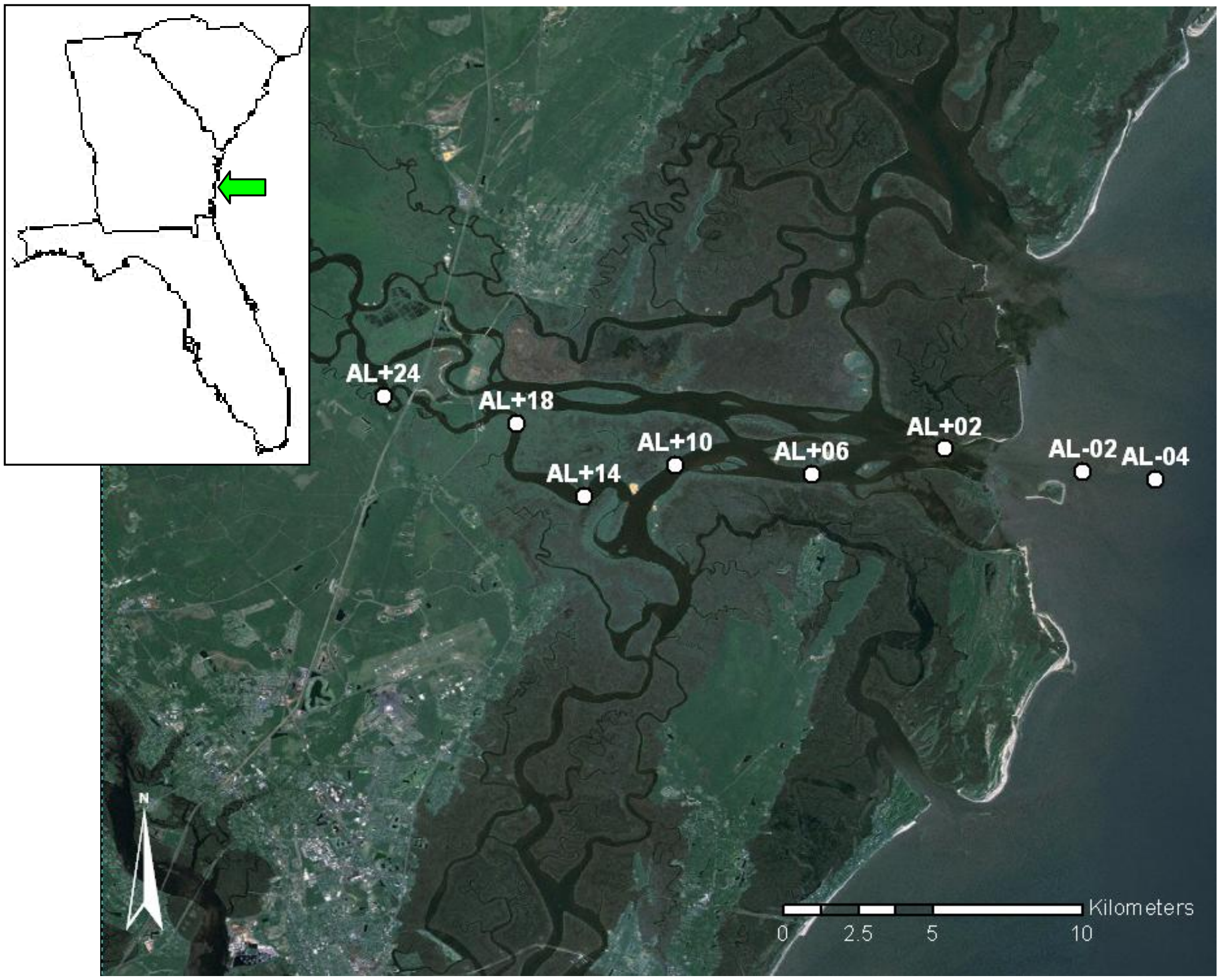


Figure 4. Map indicating the location of Altamaha River estuary and sample sites used for this study. Text in detailed map indicates sample sites used for this study. Numbers indicate distance from the river mouth (km).

Table 1. WASP inputs measured in GCE-LTER sampling.

• Temperature	• Chlorophyll *a*
• Salinity	• Total Suspended Solids
• Ammonia (NH_3)	• Particulate Carbon
• Nitrate + Nitrite (NO_2^- + NO_3^- or NO_x)	• Phosphate (PO_4^{3-})
• Dissolved Organic Nitrogen	• Dissolved Organic Phosphorus
• Detrital Nitrogen	• PAR

Table 2. Mean concentrations (stations 24 through -04) for the Altamaha River estuary for dates used in calibration and validation. Italics indicate dates used for validation. FAD=Flushing averaged discharge (m^3s^{-1}), Sal=Salinity, Temp=Temperature (^oC), NH_3=Ammonia, NO_x=Nitrate+Nitrite, DON=Dissolved Organic Nitrogen, PN=Particulate Nitrogen, Chla=Chlorophyll *a*, TSS= Total Suspended Solids, PC=Particulate Carbon, PO_4=Phosphate, DOP=Dissolved Organic Phosphorus. All concentrations are mg L^{-1}, except chlorophyll *a*, which is $\mu g\ L^{-1}$.

Date	**FAD**	**Temp**	**NH_3**	**NO_x**	**DON**	**PN**	**Chla**	**TSS**	**PC**	**PO_4**	**DOP**
9/27/2005	*110*	*28.66*	*0.041*	*0.064*	*0.286*	*0.193*	*31.74*	*73.09*	*2.342*	*0.026*	*0.018*
5/28/2004	117	28.18	0.020	0.085	0.186	0.428	44.09	58.80	3.763	0.020	0.010
9/26/2003	140	26.37	0.027	0.158	0.280	0.543	32.27	115.22	5.465	0.021	0.009
12/2/2003	*221*	*14.22*	*0.023*	*0.242*	*0.545*	*0.213*	*12.75*	*47.99*	*2.146*	*0.009*	*0.032*
3/13/2004	*452*	*14.13*	*0.006*	*0.050*	*0.392*	*0.210*	*8.77*	*34.21*	*2.336*	*0.009*	*0.013*
3/4/2005	572	11.87	0.011	0.120	0.272	0.126	13.47	33.38	1.786	0.008	0.047
6/17/2005	603	28.19	0.022	0.135	0.383	0.216	31.99	29.75	2.004	0.015	.
9/22/2004	*796*	*23.01*	*0.013*	*0.064*	*0.557*	*0.256*	*10.55*	*52.74*	*2.970*	*0.015*	.

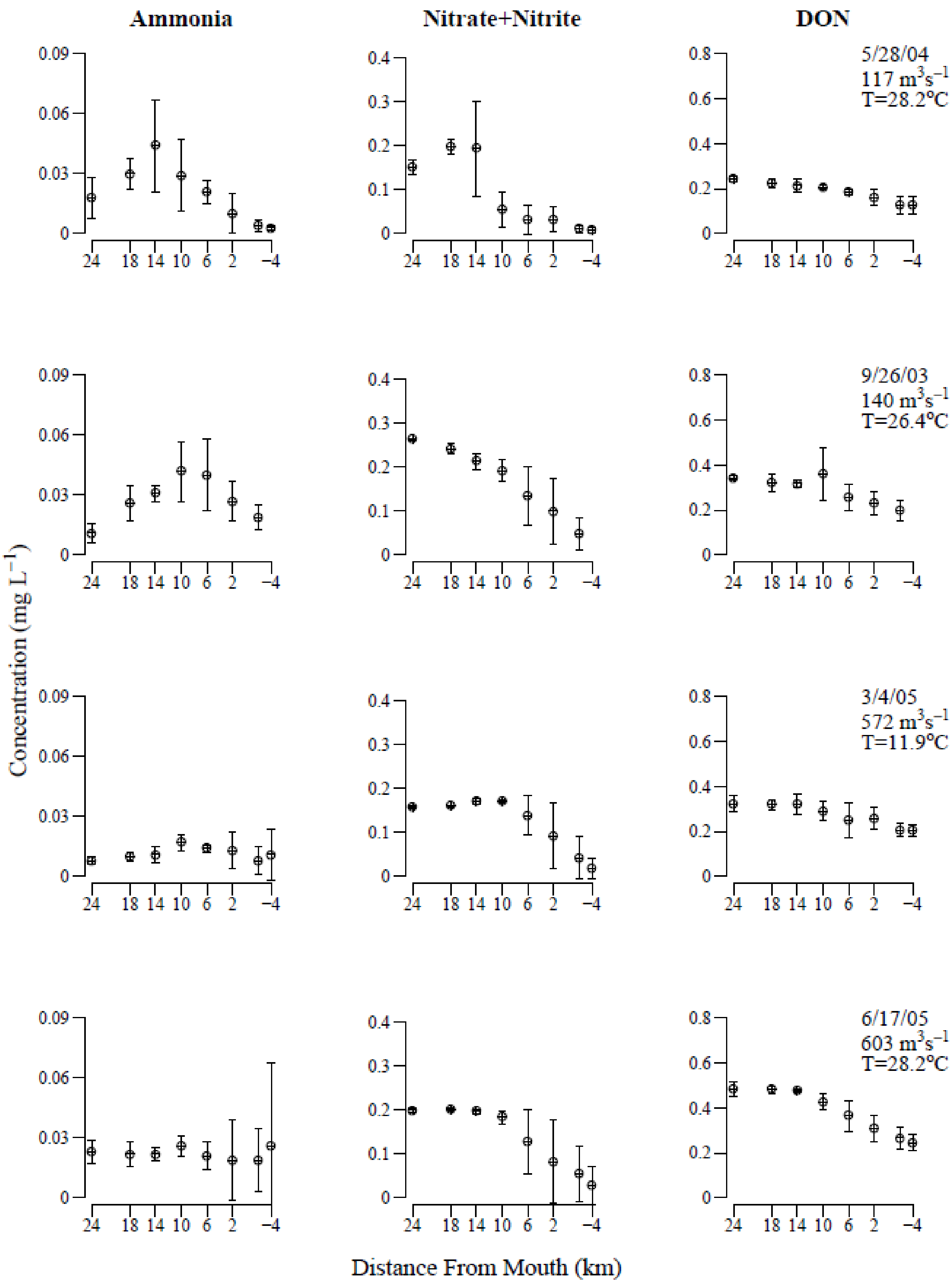


Figure 5. Mean observed dissolved nitrogen concentrations at stations 24 to -04 for dates used in initial model setup and model calibration. Error bars represent one standard deviation.

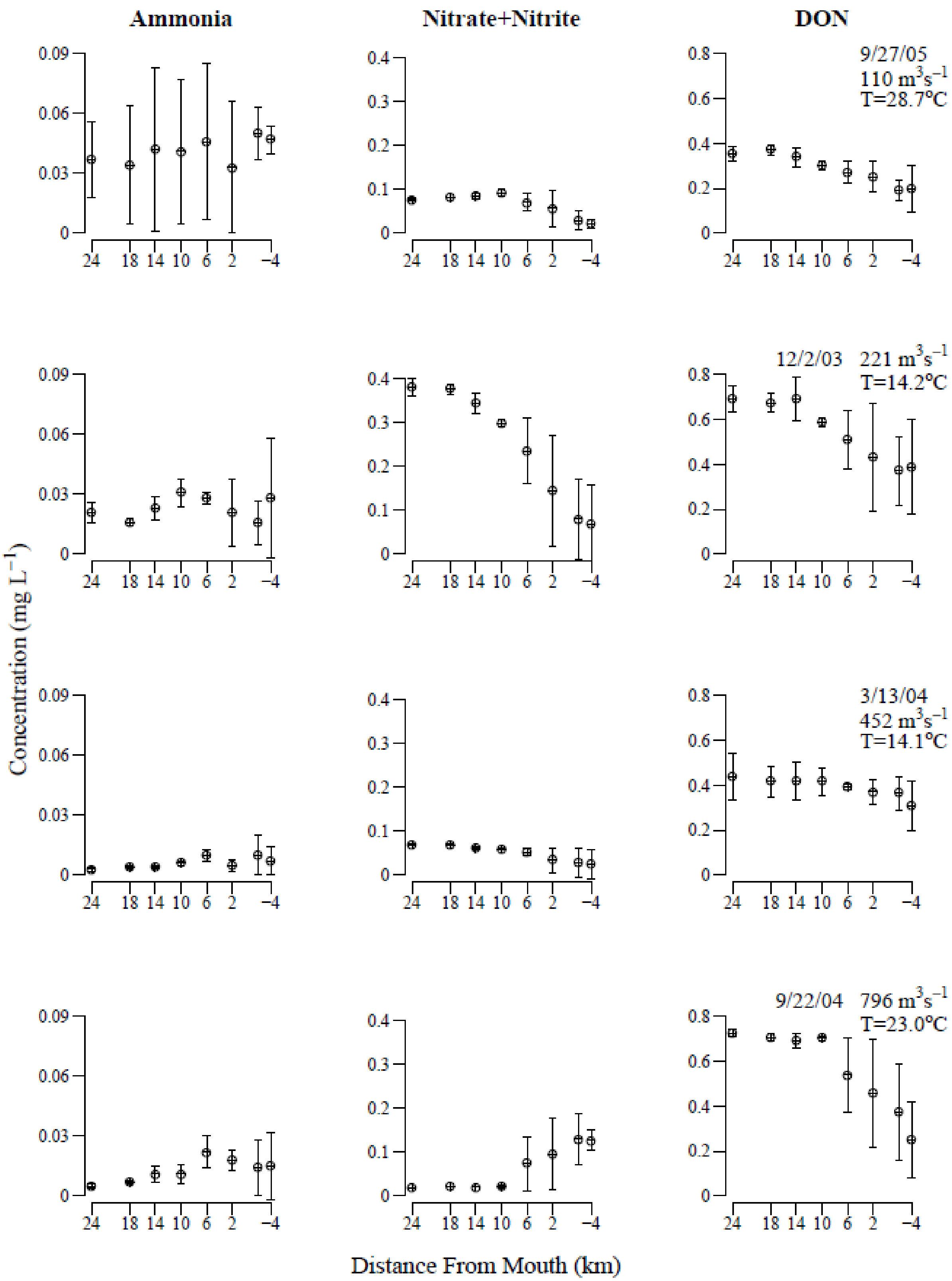


Figure 6. Mean observed dissolved nitrogen concentrations at stations 24 to -04 for dates used in model validation. Error bars represent one standard deviation.

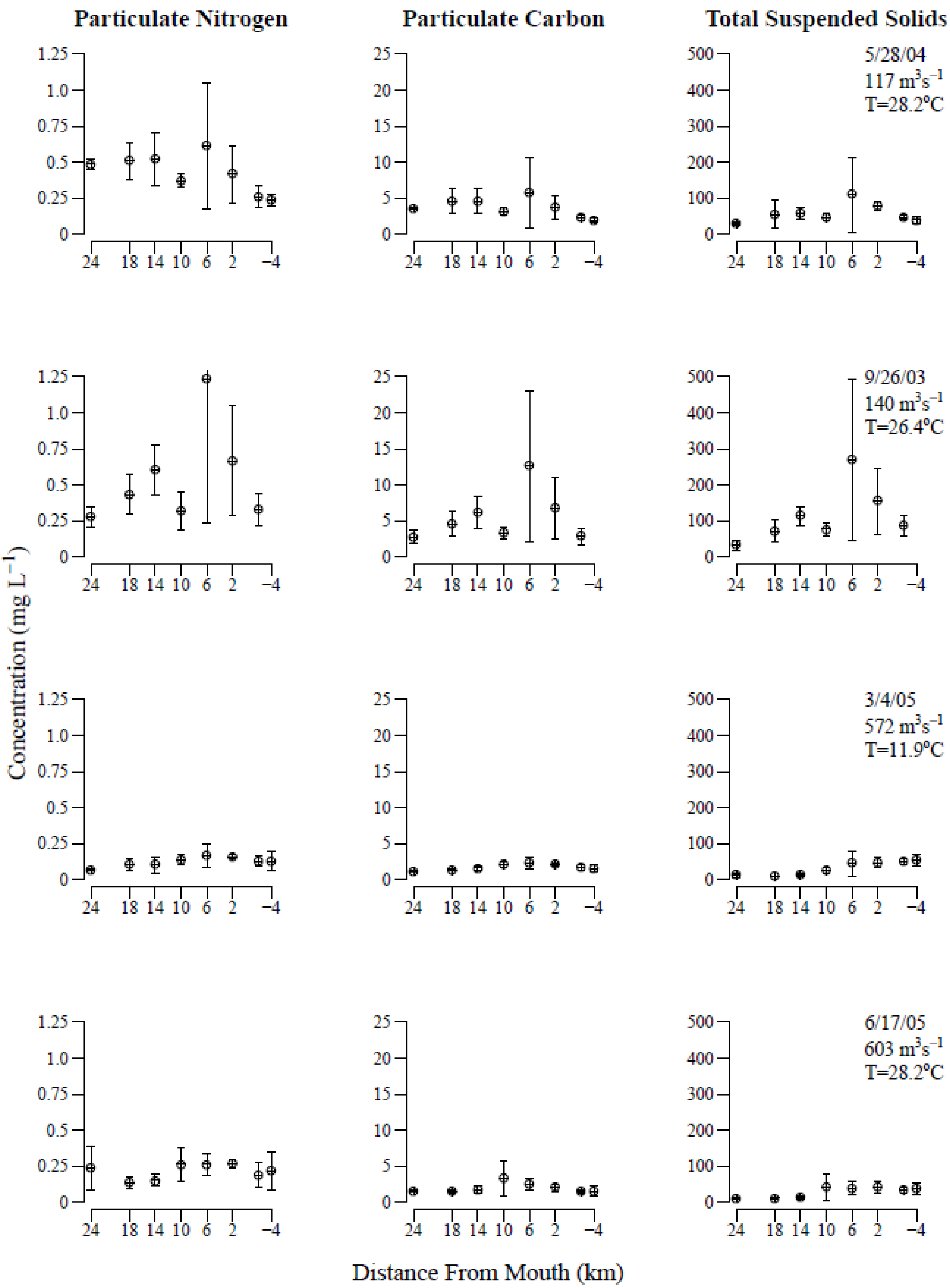


Figure 7. Mean observed particulate nitrogen, particulate carbon, and total suspended solids concentrations at stations 24 to -04 for dates used in initial model setup and model calibration. Error bars represent one standard deviation.

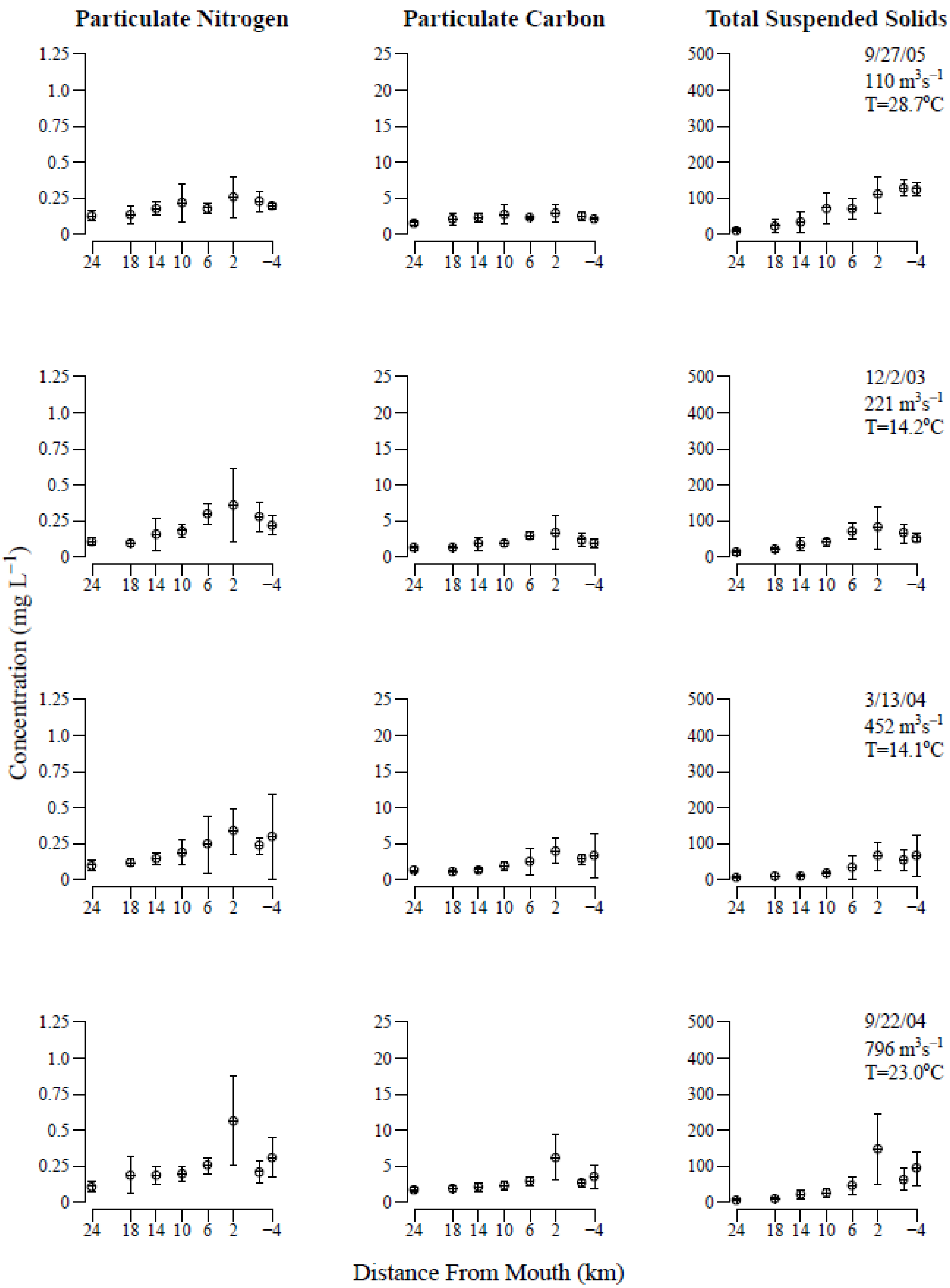


Figure 8. Mean observed particulate nitrogen, particulate carbon, and total suspended solids concentrations at stations 24 to -04 for dates used in model validation. Error bars represent one standard deviation.

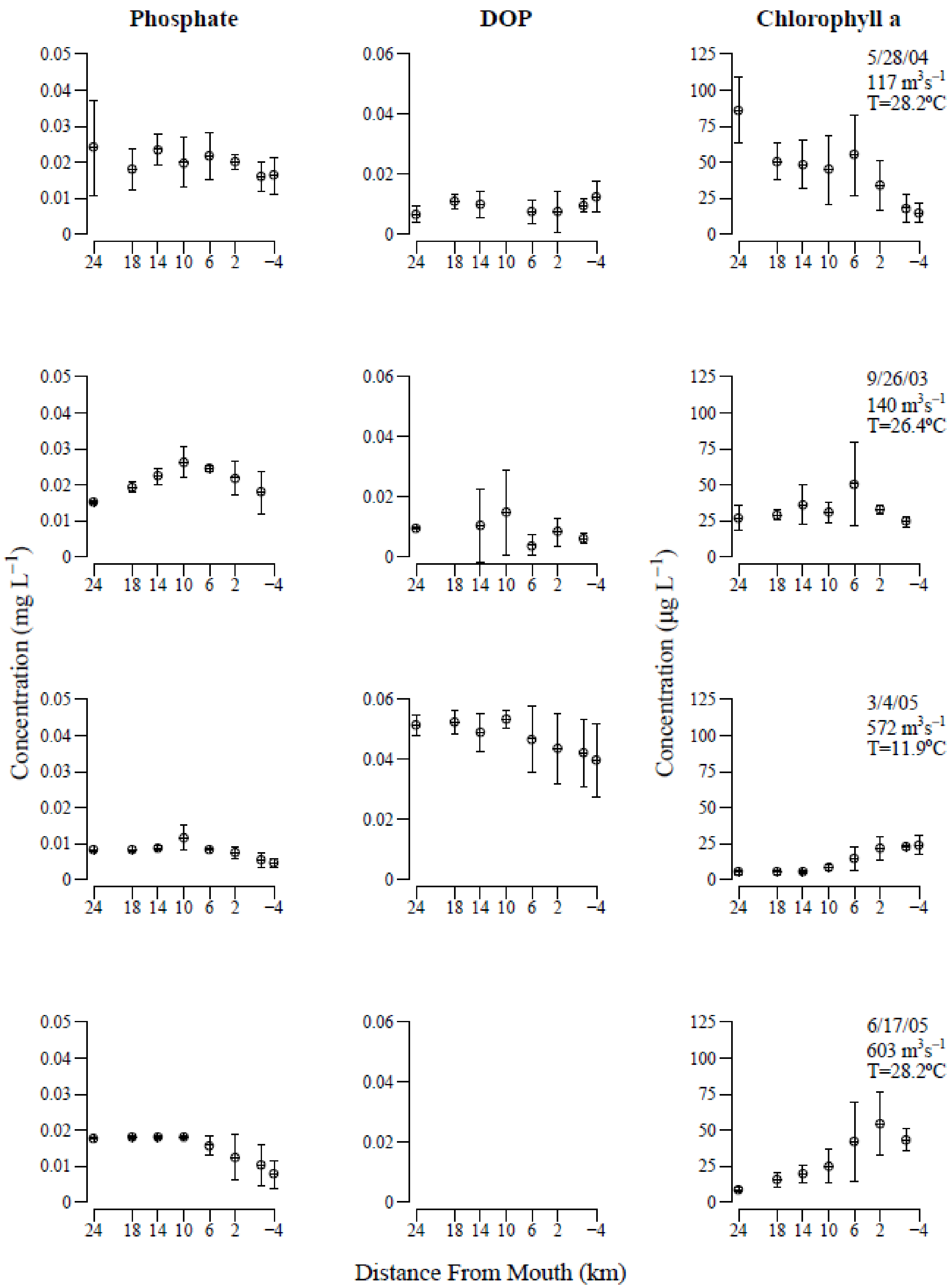


Figure 9. Mean observed phosphate, DOP, and chlorophyll *a* concentrations at stations 24 to -04 for dates used in initial model setup and model calibration. Error bars represent one standard deviation.

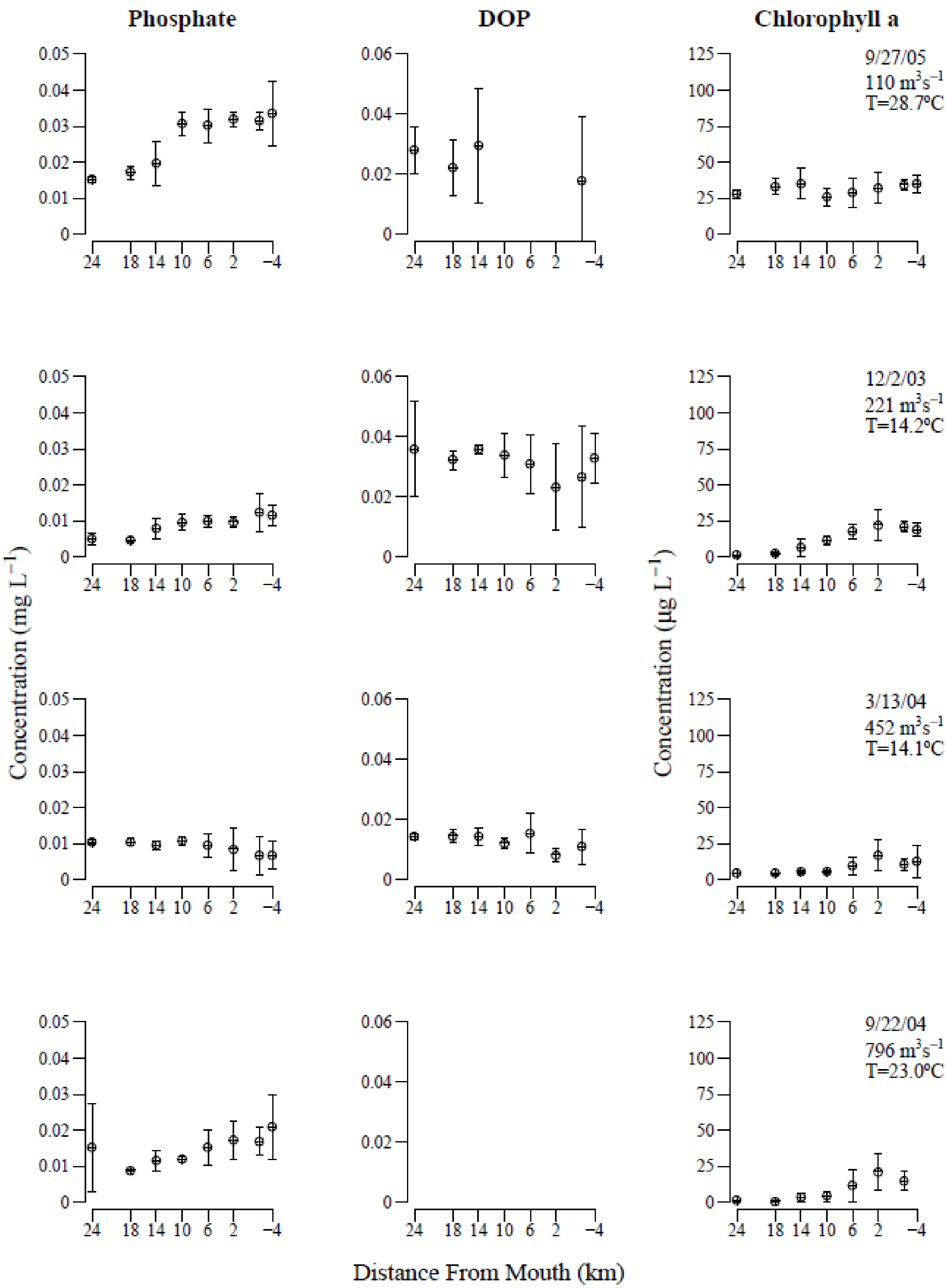


Figure 10. Mean observed phosphate, DOP, and chlorophyll *a* concentrations at stations 24 to -04 for dates used in model validation. Error bars represent one standard deviation.

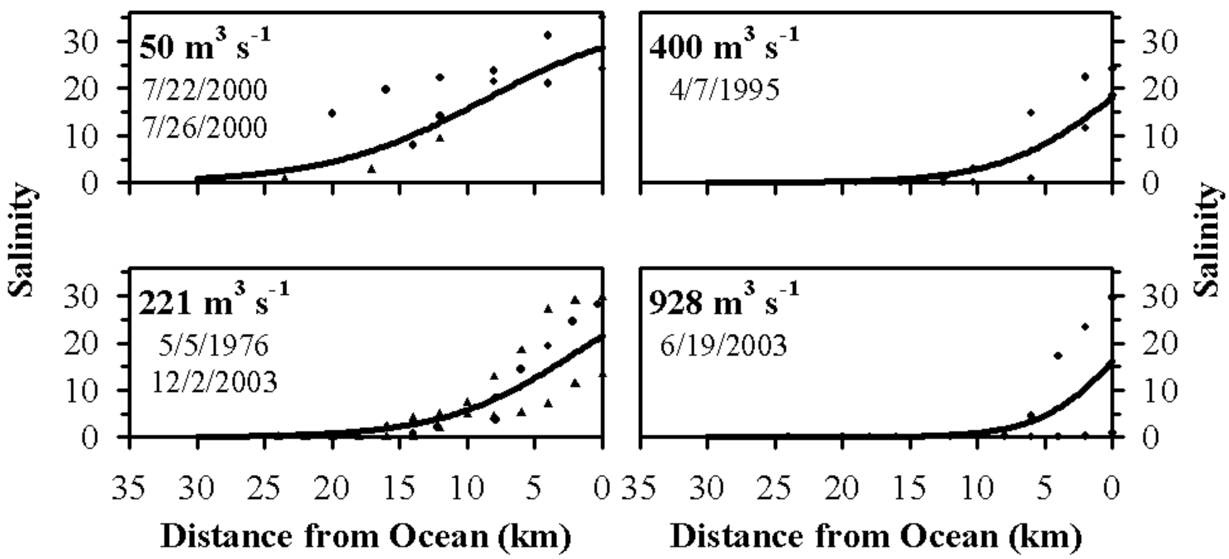


Figure 11. Altamaha River estuary salinity predicted by SqueezeBox (lines) compared to observations (symbols) taken near mid-tide or during paired high and low water transects (J. Sheldon, pers. comm.). Different symbols indicate salinities observed on different dates.

Table 3. Table representing boxes and segments used in SqueezeBox and WASP. All boxes were used in SqueezeBox, while boxes with numbers in bold were used as segments in WASP. Cell heights represent box length.

Box Length (km)	**Boundary Distances (km)**	**Box Center (km)**
12	48 36	42
8	28	32
8	20	24
4	**16**	**18**
4	**12**	**14**
4	**8**	**10**
4	**4**	**6**
4	**0**	**2**

Table 4. Geometry of segments used in WASP.

Segment	Depth (m)	Width (m)	Length (m)	Volume (m^3)
1 (Upstream)	6.74	308	4000	8291190
2	4.44	728	4000	12931100
3	3.77	1337	4000	20167640
4	3.55	1861	4000	26422630
5 (Downstream)	3.81	1938	4000	29531280

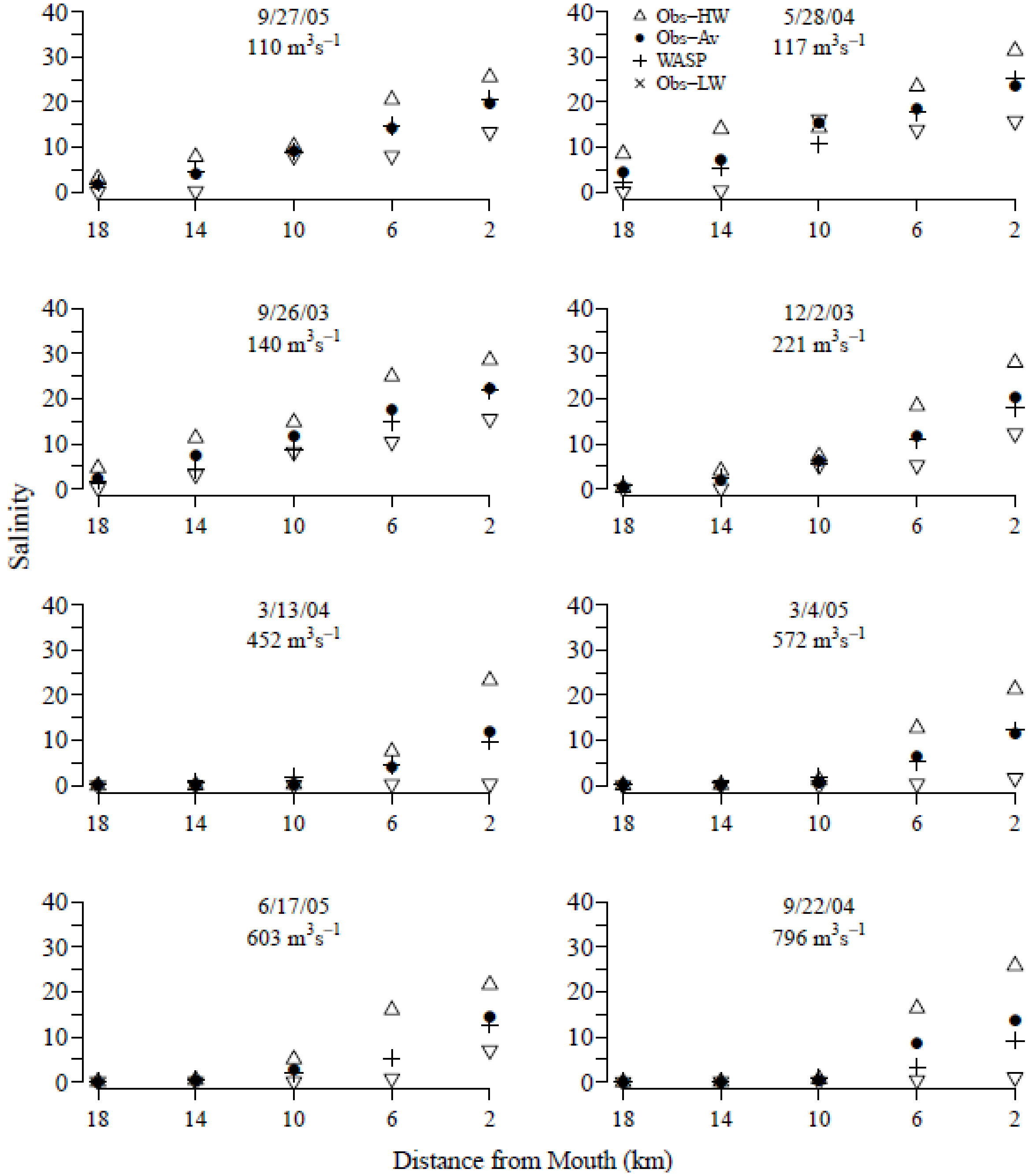


Figure 12. Comparisons of observed salinities to salinities predicted by WASP using SqueezeBox predicted salinities as boundary concentrations.

Table 5. Comparisons of observed salinities to salinities predicted by WASP using SqueezeBox predicted salinities as boundary concentrations. Dist=Distance (km), HW Obs=Observed high water salinity, LW Obs=Observed low water salinity, Av Obs=Average of observed high water and low water salinity, WASP= WASP predicted salinity, WASP vs. Obs= Difference between WASP predicted salinity and average observed salinity, Av WASP vs Obs=Average of difference between WASP predicted salinity and average observed salinity. Flow= $m^3 s^{-1}$,

Date	Flow	Dist	HW Obs	LW Obs	Av Obs	WASP	WASP vs. Obs	Av WASP vs Obs
Sep. 2005	110	18	3.2	0.1	1.6	2.0	0.4	0.6
		14	7.9	0.2	4.1	4.7	0.7	
		10	10.3	8.1	9.2	9.1	0.1	
		6	20.6	8.1	14.4	14.8	0.4	
		2	25.6	13.4	19.5	20.7	1.2	
May 2004	117	18	8.6	0.1	4.4	2.4	2.0	2.1
		14	14.1	0.4	7.3	5.5	1.7	
		10	14.4	16.2	15.3	10.7	4.5	
		6	23.5	13.9	18.7	17.7	0.9	
		2	31.5	15.8	23.6	25.1	1.5	
Sep. 2003	140	18	4.7	0.3	2.5	1.8	0.6	1.8
		14	11.3	3.2	7.3	4.4	2.9	
		10	14.8	8.2	11.5	8.7	2.8	
		6	25.0	10.4	17.7	14.9	2.8	
		2	28.6	15.5	22.0	21.9	0.1	
Dec. 2003	221	18	0.3	0.1	0.2	1.0	0.8	1.0
		14	4.1	0.1	2.1	2.6	0.5	
		10	7.3	5.3	6.3	5.6	0.6	
		6	18.5	5.3	11.9	10.9	0.9	
		2	28.0	12.3	20.1	18.0	2.1	
Mar. 2004	452	18	0.0	0.0	0.0	0.2	.	1.2
		14	0.1	0.1	0.1	0.7	0.6	
		10	0.3	0.1	0.2	1.8	1.6	
		6	7.6	0.3	4.0	4.6	0.7	
		2	23.3	0.4	11.8	9.8	2.0	

Table 5(continued). Comparisons of observed salinities to salinities predicted by WASP using SqueezeBox predicted salinities as boundary concentrations. Abbreviations and concentrations as noted above.

Date	Flow	Dist	HW Obs	LW Obs	Av Obs	WASP	WASP vs. Obs	Av WASP vs Obs
Mar. 2005	572	18	0.1	0.0	0.1	0.2	0.2	0.8
		14	0.2	0.1	0.2	0.6	0.5	
		10	1.2	0.1	0.7	1.9	1.2	
		6	12.8	0.4	6.6	5.2	1.4	
		2	21.4	1.7	11.5	12.2	0.7	
Jun. 2005	603	18	0.1	0.1	0.1	0.2	0.1	0.7
		14	0.5	0.1	0.3	0.6	0.3	
		10	5.1	0.1	2.6	1.9	0.7	
		6	16.0	0.8	.	5.3	.	
		2	21.6	7.1	14.3	12.7	1.6	
Sep. 2004	796	18	0.0	0.0	0.0	0.1	.	2.5
		14	0.1	0.1	0.1	0.3	0.2	
		10	0.7	0.1	0.4	1.0	0.6	
		6	16.4	0.4	8.4	3.3	5.1	
		2	25.9	1.1	13.5	9.3	4.2	

Table 6. Parameters and parameter values used in WASP.

Constant	Initial Value	Constant	Initial Value
Nitrification Rate (day^{-1})	0.3	Phytop. Grazing By Zooplankton (day^{-1})	0
Nitrification Rate Temp. Coeff.	1.04	Phytop. P:C (mg P/mg C)	0.025
Nitrification Half Saturat. Constant (mg O_2 L^{-1})	2	Phytop. N:C (mg N/mg C)	0.2
Denitrification Rate (day^{-1})	0.15	Half-Sat for P and N Recycle (mg Phytop C L^{-1})	1
Denitrification Rate Temp. Coeff.	1.08	Solar Radiation (Langleys day^{-1})	200
Denitrification Half Saturat. Constant (mg O_2 L^{-1})	0.1	Fraction of Day that is Light	0.5
DON Mineralization Rate (day^{-1})	0.04	Phytop. Optimal Light Saturat. (Ly day^{-1})	300
DON Mineralization Rate Temp. Coeff.	1.08	CBOD Decay Rate Constant (day^{-1})	0.06
Fraction Phytop. Recycled to ON	0.65	CBOD Decay Rate Temp. Coeff.	1.03
DOP Mineralization Rate (day^{-1})	0.2	CBOD Half Saturat. Oxygen Limit (mg O_2 L^{-1})	0.5
DOP Mineralization Rate Temp. Coeff.	1.08	Global Reaeration Rate Constant (day^{-1})	0.3881
Benthic Ammonia Flux (mg m^{-2} day^{-1})	7	Sediment Oxygen Demand (SOD) (g O_2 m^{-2} day^{-1})	1.5
Benthic Phosphate Flux (mg m^{-2} day^{-1})	2	SOD Temp. Correction Factor	1.047
Fraction Phytop. Recycled to OP	0.2	Light Option	Input Light
Phytop. Maximum Growth Rate (day^{-1})	2.5	Light Extinction for Segments (m^{-1})	Vary with Segment
Phytop. Maximum Growth Rate Temp. Coeff.	1.08		
Phytop. Self Shading	0 (Yes)		
Phytop. Carbon:Chl a (mg C/mg Chl)	30		
Phytop. Half Saturat. for N Uptake (mg N L^{-1})	0.025		
Phytop. Half Saturat. for P Uptake (mg P L^{-1})	0.001		
Phytop. Respiration Rate (day^{-1})	0.2		
Respiration Rate Temp. Coeff.	1.045		

Table 7. Boundary conditions for initial parameterization and calibration dates. FAD=Flushing averaged discharge, Bnd=Boundary (Upstream/Downstream), Sal=Salinity, Temp=Temperature ($^{\circ}C$), NH_3=Ammonia, NO_x=Nitrate+Nitrite, DON=Dissolved Organic Nitrogen, PN=Particulate Nitrogen, Chla=Chlorophyll *a*, TSS= Total Suspended Solids, PC=Particulate Carbon, PO_4=Phosphate, DOP=Dissolved Organic Phosphorus. All concentrations are in mg L^{-1} except Chl-a which is in $\mu g\ L^{-1}$.

Date	FAD	Bnd	Sal	Temp	NH_3	NO_x	DON	PN	Chla	TSS	PC	PO_4	DOP
May 2004	117	U	0.1	29.3	0.02	0.15	0.24	0.49	86.21	30.28	3.68	0.02	0.01
		D	31.1	27.3	0.00	0.01	0.13	0.26	18.33	48.51	2.34	0.02	0.01
Sep. 2003	140	U	0.2	26.4	0.01	0.26	0.34	0.28	27.12	33.57	2.80	0.02	0.01
		D	27.8	26.2	0.02	0.05	0.20	0.33	24.74	87.04	2.92	0.02	0.01
Mar. 2005	572	U	0.1	11.3	0.01	0.16	0.32	0.07	5.29	12.85	1.23	0.01	0.05
		D	21.9	12.0	0.01	0.04	0.21	0.13	22.62	52.40	1.77	0.01	0.04
June 2005	603	U	0.1	27.6	0.02	0.20	0.48	0.24	8.97	12.03	1.63	0.02	.
		D	23.2	28.4	0.02	0.06	0.27	0.19	43.27	34.79	1.53	0.01	.

Table 8. Dates, seasons, and temperatures used to calculate DO for the dates used for this study. Dates in italics indicate the overlapping dates. Temperature=$^{\circ}$C.

Dates with DO	**Temp-DO Dates**	**Dates for This Study**	**Temp-This Study**	**Season**
June 2002	27.93	September 2005	23.01	Summer
September 2002	28.38	September 2004	28.66	Summer
June 2003	26.99	June 2005	28.19	Summer
September 2003	*26.37*	*September 2003*	*26.37*	*Summer*
March 2003	18.48	March 2005	11.87	Winter
December 2003	*14.22*	*December 2003*	*14.22*	*Winter*
March 2004	*14.13*	*March 2004*	*14.13*	*Winter*
May 2004	*28.18*	*May 2004*	*28.18*	*Summer*

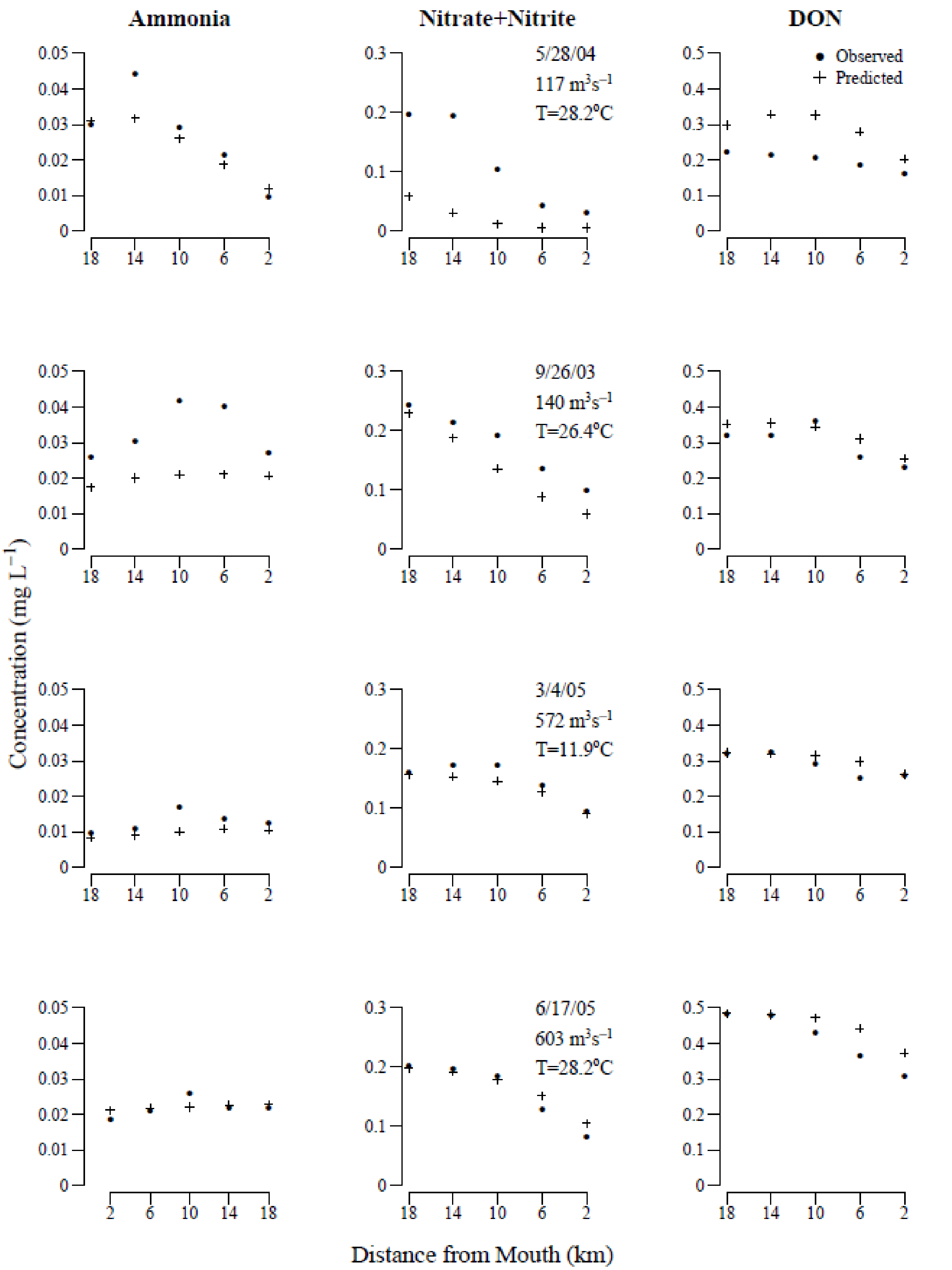


Figure 13. Observed and WASP predicted nitrogen concentrations using basic setup of Yassuda et al. (2000) and Altamaha specific boundary conditions, temperatures, DO, light, light attenuation, benthic nutrient fluxes, and oxygen fluxes.

Table 9. Observed and WASP predicted concentrations and absolute percent difference between observed and WASP predicted nitrogen concentrations, using basic setup of Yassuda et al. (2000) and Altamaha specific boundary conditions, temperatures, DO, light, light attenuation, benthic nutrient fluxes, and oxygen fluxes. Units are as follows: Flow = $m^3\ s^{-1}$, Distance = km from mouth, and nutrient concentrations = mg N L^{-1}. Percent differences are absolute percent difference as shown in Eq. 4.

Date	Flow	Dist.	NH_3 Obs	NH_3 Pred	NH_3 % Diff	NH_3 Av % Diff	NO_3^- Obs	NO_3^- Pred	NO_3^- % Diff	NO_3^- Av % Diff	DON Obs	DON Pred	DON % Diff	DON Av % Diff
May 2004	117	18	0.030	0.031	3.4	15.5	0.198	0.059	70.4	82.1	0.224	0.299	33.5	43.7
		14	0.044	0.032	28.4		0.194	0.032	83.8		0.215	0.329	52.7	
		10	0.029	0.026	10.4		0.104	0.013	87.9		0.208	0.327	57.0	
		6	0.021	0.019	12.1		0.044	0.006	86.9		0.186	0.280	50.2	
		2	0.010	0.012	23.5		0.032	0.006	81.4		0.162	0.203	25.2	
Sep. 2003	140	18	0.026	0.018	31.9	37.3	0.243	0.230	5.5	24.4	0.322	0.352	9.4	11.1
		14	0.031	0.020	34.2		0.214	0.188	12.1		0.319	0.355	11.4	
		10	0.042	0.021	49.7		0.193	0.136	29.3		0.361	0.345	4.5	
		6	0.040	0.021	47.2		0.135	0.089	34.3		0.259	0.311	20.2	
		2	0.027	0.021	23.3		0.100	0.060	40.7		0.232	0.256	10.1	
Mar. 2005	572	18	0.010	0.009	13.1	21.8	0.161	0.156	3.0	7.9	0.321	0.322	0.4	6.0
		14	0.011	0.009	16.5		0.172	0.154	10.7		0.323	0.321	0.6	
		10	0.017	0.010	41.1		0.172	0.146	15.3		0.292	0.315	8.1	
		6	0.014	0.011	21.7		0.139	0.128	8.0		0.250	0.299	19.5	
		2	0.013	0.011	16.2		0.093	0.091	2.4		0.259	0.262	1.1	
Jun. 2005	603	18	0.022	0.023	4.5	8.0	0.201	0.198	1.6	10.1	0.482	0.484	0.4	10.6
		14	0.022	0.023	3.7		0.197	0.192	2.2		0.478	0.481	0.7	
		10	0.026	0.022	14.4		0.184	0.179	2.6		0.428	0.472	10.1	
		6	0.021	0.022	3.5		0.129	0.151	17.0		0.365	0.443	21.3	
		2	0.019	0.021	13.9		0.083	0.106	27.1		0.310	0.373	20.5	

Table 10. Ranges of inputs used in the global sensitivity analysis and the method used to derive those ranges.

Parameter	Range	Method to Derive Range Used in Global Sensitivity Analysis
Transport		
– Segment Depth – Segment Volume – Surface Area Between Segments – Segment Length – Dispersive Mixing Between Segments – Interfacial Surface Area Between Benthic and Surface Segments for Exchange – Distance Between Segments (Depth of Benthic Layer)	Varies by segment	10% increase or decrease assumed to be reasonable measurement error.
– Flow from the Benthic Layer	$0.1E^{-04}$–$10E^{-04}$ m^3 s^{-1}	No estimates for flow from the benthic layer to the surface layer were found in the literature or monitoring data. Therefore, recognizing that benthic flux could vary greatly, the lower bound for flow from the benthic layer to the surface layer was set an order of magnitude lower than the value used in the initial model setup and the upper bound was set an order of magnitude higher than the value used in the initial model setup.
– Surface Water Flows	77-796 m^3 s^{-1}	Lower 25^{th} percentile of the dates in the GCE LTER monitoring data used as the lower boundary. The upper boundary was the highest flow in the dates used for calibration and validation and represents the higher range of flows observed in the greater GCE LTER monitoring data.
– Particle Settling Rate – Resuspension Rate	$0.5E^{-04}$–$50E^{-04}$ m s^{-1} $0.5E^{-05}$–$50E^{-05}$ m s^{-1}	Given a lack of data bounds were set by varying the value used in the initial model setup by order of magnitude

Table 10 (continued). Ranges of inputs used in the global sensitivity analysis and the method used to derive those ranges.

Light		
– Light Extinction	0.1-2.2 m^{-1}	Range was set based on an estimate of likely values based on literature from similar systems (Wang et al. 1999; Yassuda et al. 2002; Zheng et al. 2004; Rodriguez-Borelli et al 2006).
– Solar Radiation	145-262 Langleys d^{-1}	The 25th and 75th percentiles of observed values from the data collected by the GCE LTER at Marsh Landing, Georgia from November 2003 to July 2009 were used as the lower and upper bounds, respectively.
– Fraction Daily Light	0.4-0.6	A range was determined from the United States Naval Observatory (http://aa.usno.navy.mil/cgi-bin/aa_durtablew2.pl); minimum and maximum day lengths observed throughout the year used for the lower and upper ranges, respectively.
Benthic Fluxes		
– Benthic Ammonia Flux	3.36-43.87 mg N m^{-2} d^{-1}	Information was gathered from the meta-analysis done on literature values for riverine estuaries (Appendix B). The 25th and 75th percentiles were used. The meta-analysis indicated that a single estuary-wide value for sediment flux of N was appropriate. The analyses did not indicate a relationship between salinity or other spatially variable factors and N flux.
– Benthic Phosphate Flux	0.3-10 mg P m^{-2} d^{-1}	Based on an estimate from Fisher et al. (1982), Conrads and Smith (1997), Mortimer et al. (1998), and Hopkinson et al. (1999).
– Sediment Oxygen Demand	0-3.0 g O_2 m^{-2} d^{-1}	Range was based on a combination of meta-analysis values and those found in Bowie et al. (1985). The general range of values found in Bowie et al. (1985) was 0.1-3.9 g O_2 m^{-2} d^{-1}. The mean of observed values from the meta-analysis was approximately 1.0 g O_2 m^{-2} d^{-1} with a standard deviation of approximately 1.0 g O_2 m^{-2} d^{-1}. The lower bound for both studies was approximately zero so this was used for the lower bound while the upper bound was an average of the upper bound of Bowie et al. (1985) and the mean+standard deviation from the meta-analysis. The upper bound agreed with the median value observed in Bailey et al. (2005).

Table 10 (continued). Ranges of inputs used in the global sensitivity analysis and the method used to derive those ranges.

Temperature Coefficients		
– SOD Temperature Correction – Nitrification Temperature Coefficient – Denitrification Temperature Coefficient – DON Mineralization Temperature Coefficient – Phytoplankton Maximum Growth Temperature Coefficient – CBOD Decay Rate Temperature Correction Coefficient	1.02-1.08 1.02-1.08 1.02-1.09 1.02-1.09 1.01-1.2 1.02-1.06	Based on a range of values presented in Bowie et al. (1985). Extreme values were excluded to present a range of the most commonly observed values.
– DOP Mineralization Rate Temperature Coefficient	0.972-1.188	Only indicated in Bowie et al. (1985) and other publications as 1.08. For this reason it was only given a small range, varying the value by 10 percent in either direction.
– Phytoplankton Respiration Rate Temperature Coefficient	1.01-1.2	Values were found in DiToro and Matystik (1980, 1.045), Wang et al., (1999, 1.05), Rodriguez-Borrelli et al. (2006, 1.08), and Bowie et al. (1985, 1.01-1.2). The range of values from these studies was used for the range.
Boundary Concentrations		
– NH_3 – NO_3^- – DON – Particulate Nitrogen – Particulate Carbon – TSS – Chlorophyll *a* – PO_4^{3-} – DOP	Varies by location (up/downstream)	The maximum and minimum of the tidal and depth averaged nutrient concentrations for the sample dates used in calibration in validation was used to set a range of values. Where the maximum or minimum concentration occurred on September 2003 or March 2005 (the dates used for the sensitivity analysis) the value was decreased by 10 percent to get the lower limit or increased by 10 percent to set the upper limit.

Table 10 (continued). Ranges of inputs used in the global sensitivity analysis and the method used to derive those ranges.

Boundary Concentrations (continued)		
– DO	4.0-10.0 mg O_2 L^{-1}	Used a range of values that covered the majority of concentrations commonly observed during cruises when DO was collected.
– CBOD	2.3-3.2 mg O_2 L^{-1}	Determined from a range of values used in the Brunswick Harbor, Georgia TMDL modeling effort described in Rodriguez and Peene (2001) as well as work done in the Savannah River (ATM 2003; Tetra Tech 2006).
– Temperature	Varies by date	Temperatures observed on the dates used for calibration and validation of the model were similar to the range of values observed in the estuary in the Altamaha estuary monitoring dataset as a whole, although they did not cover the full range. Temperatures observed in the estuary at each of the boundaries were also consistently similar for each date. To set a range of values of temperatures I widened the range of values observed on the calibration and validation dates by 10% at each of the boundaries, giving a range that was closer to that of what may be observed in the estuary over a longer time period.
N, P, DO, Phytoplankton Process Rates		
– Nitrification Rate Constant – DON Mineralization Rate Constant – Phytoplankton Maximum Growth Rate Constant – Phytoplankton Death Rate Constant – CBOD Decay Rate Constant	0.1-0.5 d^{-1} 0.003-0.14 d^{-1} 1.0-3.0 d^{-1} 0.01-0.1 d^{-1} 0.02-0.3 d^{-1}	Estimated from the range of values presented in Bowie et al. (1985). Extreme or outlier values were excluded.
– Denitrification Rate Constant	0.09-0.16 d^{-1}	The value used in the initial model run was taken from Yassuda et al. (2000). It is slightly higher than the Denitrification Rates in Bowie et al. (1985). The lower range of values used in Bowie et al. (1985) was used for the lower bound, while the upper range was raised slightly from the value taken from Yassuda et al. (2000) that was used in the initial model.

Table 10 (continued). Ranges of inputs used in the global sensitivity analysis and the method used to derive those ranges.

N, P, DO, Phytoplankton Process Rates (continued)		
– DOP Mineralization Rate Constant	0.18-0.22 d^{-1}	The common value in Bowie et al. (1985) was 0.20-0.22 d^{-1}. The upper end of the range used was 0.22 d^{-1} in accordance with Bowie et al. (1985). Because the lower value in Bowie et al. (1985) was the same as the value used in the initial model parameterization the lower bound was estimated by lowering the observed value by 10 percent.
– Phytoplankton Respiration Rate Constant	0.05-0.25 d^{-1}	In Bowie et al. (1985) the range of values was commonly 0.05-0.2 d^{-1}. The lower range value of 0.05 d^{-1} was taken from Bowie et al. (1985) while the upper value was adjusted slightly above the value used in the model to 0.25 d^{-1}.
Nutrient Cycling		
– Half Saturation Denitrification Oxygen Limit – Half Saturation Nitrification Oxygen Limit	0.09-0.11 mg O_2 L^{-1} 1.8-2.2 mg O_2 L^{-1}	Information for was not found in searches of relevant literature so the parameters were adjusted by 10 percent.
– Fraction of Phytoplankton Death Recycled to Organic N	0.5-1.0	In literature (Rim et al. 1999, Wicomico TMDL, WASP Users Manual) values ranged from 0.5-1.0.
– Fraction of Phytoplankton Death Recycled to Organic P	0.2-0.7	A range was estimated from the Wicomico TMDL documentation (0.5), Yassuda et al. (2000, 0.2), and Ambrose et al. (1993, 0.7).
– Phytoplankton Half Saturation for N and P Mineralization Rate	0.9-0.1 mg Phyto. C L^{-1}	Few data were available so the range was determined by varying the value used in the model by 10 percent.
Phytoplankton		
– Phytoplankton Carbon to Chlorophyll a Ratio	20-100	Values were determined from Bowie et al. (1985, values 10-112, with 20-100 common), Ambrose et al. (1993, 12-68), Cloern et al. (1995, approximately 30-100), Riemann et al (1989, 27-67), Wienke and Cloern (1987, 47-54), and Montagne et al. (1994, 21-86).

Table 10 (continued). Ranges of inputs used in the global sensitivity analysis and the method used to derive those ranges.

Phytoplankton (continued)		
– Phytoplankton Phosphorus to Carbon Ratio	0.0225-0.0275	Values in Bowie et al. (1985) varied around 0.025. Because 0.025 was used in the initial model setup a 10 percent variation around 0.025 was used.
– Phytoplankton Nitrogen to Carbon Ratio	0.05-0.25	Bowie et al. (1985) found a range of approximately 0.05-0.25. Laboratory growth experiments by Verity et al. (1992) found values generally ranging between 0.1-0.2.
– Phytoplankton Half-Saturation for N Uptake – Phytoplankton Half-Saturation for P Uptake	0.02-0.23 mg N L^{-1} 0.0009-0.052 mg P L^{-1}	The average of the upper and the average of the lower observation values of Bowie et al. (1985) were used.
– Phytoplankton Optimal Light Saturation	200-350 Langleys d^{-1}	The common range of values for "Total Phytoplankton" from Bowie et al. (1985) was used to bound values.
DO Balance		
– Global Reaeration	0.00001-0.5 d^{-1}	Estimated from several sources. The maximum value predicted in the TMDL work done for Brunswick Harbor (Rodriguez and Peene, 2001) was 0.2 d^{-1}. For the average depth of the Altamaha River a figure of reaeration rates in Bowie et al. (1985) created from the predictions of 13 different reaeration equations showed observed reaeration coefficients of approximately 0-8 d^{-1}. The work done to calculate the initial reaeration rate used in the model indicated values generally closer to zero. To be conservative and not overly influence already high DO levels in the Altamaha an upper range value of 0.5 d^{-1} was used.

Table 11. Top 25 model inputs for the September 2003 local sensitivity analysis. "% Sensitivity" indicates the model sensitivity, as indicated by the average absolute percent response of NH_3, NO_3^-, and DON, to variations in the given input. "U" and "D" following the input name indicate an upward or downward perturbation of the input.

Input	% Sensitivity
Phytoplankton Maximum Growth Temperature Coefficient-U	28.5
Light Option-D	20.0
Phytoplankton Respiration Rate Temperature Coefficient-U	17.6
Phytoplankton Maximum Growth Temperature Coefficient-D	16.4
DON Mineralization Temperature Coefficient-U	12.3
Phytoplankton Respiration Rate Temperature Coefficient-D	7.1
Nitrification Temperature Coefficient-U	5.9
DON Mineralization Temperature Coefficient-D	5.9
Fraction Phytoplankton Death Recycled to Organic N-D	4.8
Fraction Phytoplankton Death Recycled to Organic N-U	4.6
Temperature - Segment 1-5-U	4.6
Depth - Segment 1-5-D	4.4
Phytoplankton Maximum Growth Rate -D	4.2
Phytoplankton Maximum Growth Rate -U	4.2
Temperature - Segment 2-5-U	4.2
Temperature - Segment 1-4-U	4.0
Upstream Boundary Concentration NO_3-U	3.9
Upstream Boundary Concentration NO_3-D	3.9
Temperature - Segment 1-5-D	3.8
Depth - Segment 1-5-U	3.6
Temperature - Segment 2-5-D	3.5
Temperature - Segment 3-5-U	3.5
Light Extinction - Segment 1-5-D	3.3
Temperature - Segment 1-4-D	3.2
Upstream Boundary Concentration DON-U	2.9

Table 12. Top 25 model inputs for the March 2005 local sensitivity analysis. "% Sensitivity" indicates the model sensitivity, as indicated by the average absolute percent response of NH_3, NO_3^-, and DON, to variations in the given input. "U" and "D" following the input name indicate an upward or downward perturbation of the input.

Input	% Sensitivity
Upstream Boundary Concentration NO_3-D	3.2
Upstream Boundary Concentration NO_3-U	3.2
Upstream Boundary Concentration DON-U	3.0
Upstream Boundary Concentration DON-D	3.0
Phytoplankton Maximum Growth Temperature Coefficient-D	2.9
Phytoplankton Respiration Rate Temperature Coefficient-U	2.5
DON Mineralization Temperature Coefficient-D	2.1
Nitrification Temperature Coefficient-U	2.1
Phytoplankton Respiration Rate Temperature Coefficient-D	1.8
Phytoplankton Maximum Growth Temperature Coefficient-U	1.7
DON Mineralization Temperature Coefficient-U	1.3
Nitrification Temperature Coefficient-D	1.3
Light Option-D	1.3
Surface Water Flow-D	1.3
Surface Water Flow-U	1.1
Fraction Phytoplankton Death Recycled to Organic N-D	1.0
Fraction Phytoplankton Death Recycled to Organic N-U	1.0
Segment Length - Boundary:Boundary-D	0.8
Dispersive Mixing Between Segments - Boundary:Boundary-D	0.8
Surface Area Between Segments - Boundary:Boundary-D	0.8
Dispersive Mixing Between Segments - Boundary:Boundary-U	0.7
Surface Area Between Segments - Boundary:Boundary-U	0.7
Segment Length - Boundary:Boundary-U	0.7
Phytoplankton Carbon to Chlorophyll Ratio-D	0.6
Volume - Segment 1-5-D	0.6

Table 13. Top 25 model inputs for the September 2003 global sensitivity analysis. "% Sensitivity" indicates the model sensitivity, as indicated by the average absolute percent response of NH_3, NO_3^-, and DON, to variations in the given input. "U" and "D" following the input name indicate an upward or downward perturbation of the input.

Input	% Sensitivity
Surface Water Flow-U	41.8
DON Mineralization Rate-U	41.7
Light Extinction - Segment 1-5-D	40.0
Phytoplankton Carbon to Chlorophyll Ratio-U	39.2
Upstream Boundary Concentration DON-U	37.9
Phytoplankton Half-Saturation N Uptake-U	37.0
Upstream Boundary Concentration NO_3-D	34.7
Phytoplankton Half-Saturation P Uptake-U	32.6
Phytoplankton Maximum Growth Temperature Coefficient-U	31.9
Phytoplankton Respiration Rate Temperature Coefficient-U	31.6
Phytoplankton Maximum Growth Rate -D	30.6
Upstream Boundary Concentration Chl-a-U	29.1
Phytoplankton Respiration Rate-D	26.2
Light Option-D	25.5
Phytoplankton Nitrogen to Carbon Ratio-D	24.5
Light Extinction - Segment 3-D	24.1
Upstream Boundary Concentration NO_3-U	23.7
Fraction Phytoplankton Death Recycled to Organic N-U	22.4
Light Extinction - Segment 2-D	21.9
Temperature - Segment 1-5-D	21.8
Upstream Boundary Concentration Chl-a-D	21.2
Phytoplankton Maximum Growth Temperature Coefficient-D	20.3
Downstream Boundary Concentration NH_3-U	19.8
Light Extinction - Segment 4-D	19.6
Benthic Ammonia Flux - Segment 1-5-U	19.4

Table 14. Top 25 model inputs for the March 2005 global sensitivity analysis. "% Sensitivity" indicates the model sensitivity, as indicated by the average absolute percent response of NH_3, NO_3^-, and DON, to variations in the given input. "U" and "D" following the input name indicate an upward or downward perturbation of the input.

Input	% Sensitivity
Upstream Boundary Concentration NH3-U	71.2
Upstream Boundary Concentration NO3-U	45.1
Upstream Boundary Concentration Chl-a-U	38.3
Upstream Boundary Concentration DON-U	38.3
Upstream Boundary Concentration NO3-D	27.5
Surface Water Flow-D	26.7
Downstream Boundary Concentration NH3-U	21.1
Benthic Ammonia Flux - Segment 1-5-U	18.1
Upstream Boundary Concentration NH3-D	11.1
Phytoplankton Carbon to Chlorophyll Ratio-U	10.8
Light Extinction - Segment 1-5-D	9.4
Upstream Boundary Concentration DON-D	7.5
DON Mineralization Rate-U	6.1
Temperature - Segment 1-5-U	5.6
Fraction Phytoplankton Death Recycled to Organic N-U	5.6
Benthic Ammonia Flux - Segment 3-U	5.3
Downstream Boundary Concentration NO3-U	5.1
Benthic Ammonia Flux - Segment 4-U	4.7
Benthic Ammonia Flux - Segment 2-U	3.9
Downstream Boundary Concentration DON-U	3.9
Phytoplankton Respiration Rate-D	3.6
Surface Water Flow-U	3.5
Phytoplankton Respiration Rate Temperature Coefficient-U	3.2
Phytoplankton Nitrogen to Carbon Ratio-D	3.0
Upstream Boundary Concentration Chl-a-D	2.8

Table 15. Calculated light extinction (Kd) values for dates used in calibration and validation. Dist.= Distance, Av. Kd= Average Kd. Flow=m^3s^{-1}, Dist.=km, Kd=m^{-1}.

Date	Flow	Dist.	Av. Kd	Date	Flow	Dist.	Av. Kd
May 2004	117	18	4.5	Sep. 2005	110	18	3.6
		14	6.3			14	3.0
		10	2.8			10	2.4
		6	3.1			6	2.3
		2	3.0			2	1.9
Sep. 2003	140	18	8.8	Dec. 2003	221	18	3.2
		14	11.4			14	3.0
		10	6.8			10	3.1
		6	6.3			6	3.5
		2	5.5			2	3.1
Mar. 2005	572	18	2.6	Mar. 2004	452	18	2.3
		14	2.4			14	2.6
		10	3.1			10	2.8
		6	2.5			6	2.7
		2	2.5			2	3.0
Jun. 2005	603	18	3.4	Sep. 2004	796	18	4.5
		14	3.0			14	5.7
		10	2.3			10	2.6
		6	2.5			6	2.2
		2	2.1			2	2.3

Table 16. CBODu values observed in Savannah Harbor, Georgia (Tetra Tech, 2006). Units= mg O_2 L^{-1}).

Location	Survey	Tide	CBODu
Ft Pulaski, River Mile 0.8	1	High	2.99
	2	High	4.25
	3	High	2.62
	1	Low	2.81
	2	Low	3.09
	3	Low	3.52
Ft. Jackson, River Mile 10.6	1	High	3.03
	2	High	3.24
	3	High	2.46
	1	Low	2.88
	2	Low	2.96
	3	Low	2.54
Corps Dock, River Mile 16.6	2	High	2.38
	3	High	2.58
	1	Low	2.64
	2	Low	2.38
	3	Low	2.33
I-95 Bridge, River Mile 27.7	3	High	1.69
	1	Low	2.29
	2	Low	2.19
	3	Low	1.87
Clyo, Georgia, River Mile 61	1	---	3.1
	2	---	3.65
	3	---	1.68

Table 17. Inputs from local and global sensitivity analyses considered for calibration, and the associated sensitivity values. Inputs with multiple values for an analysis were either sensitive to upward and downward perturbations or had multiple segments in which they were influential (i.e. Benthic Ammonia Flux for the March 2005 global analysis and Light Extinction for the September 2003 global analysis).

Parameter	Local		Global	
	Sept. 2003	Mar. 2005	Sept. 2003	Mar. 2005
Benthic Ammonia Flux	.	.	19.4	18.1, 5.3, 4.7, 3.9
DON Mineraliz. Rt.	.	.	41.7	6.1
Phyto. Carbon:Chlorophyll	.	0.6	39.2	10.8
Phyto. Half-Sat. N Uptake	.	.	37	.
Phyto. Half-Sat. P Uptake	.	.	32.6	.
Phyto. Max. Growth Temp. Coeff.	28.5, 16.4	2.9, 1.7	31.9, 20.3	.
Phyto. Respiration Rt. Temp. Coeff.	17.6, 7.1	2.5, 1.8	31.6	3.2
Phyto. Max. Growth Rt.	4.2, 4.2		30.6	.
Phyto. Respiration Rt.	.	.	26.2	3.6
Light Option	20	1.3	25.5	.
Phyto. Nitrogen:Carbon	.	.	24.5	3
Fraction Phyto. Death Recyc. to ON	4.8, 4.6	1.0, 1.0	22.4	5.6
DON Mineraliz. Temp. Coeff.	12.3, 5.9	2.1, 1.3	.	.
Nitrification Temp. Coeff.	5.9	2.1, 1.3	.	.

Table 18. Average difference between observed concentrations and model predicted concentrations using the parameter values produced by using four different objective functions to calibrate the model. Differences are absolute difference. Concentrations= mg N L^{-1}.

Species	OF	OF Values by Distance					Av. Value
		18	14	10	6	2	
NH_3	OF_1	0.04	0.15	0.02	0.00	0.17	0.08
	OF_2	0.16	0.00	0.12	0.08	0.11	0.09
	OF_3	0.10	0.07	0.07	0.03	0.15	0.08
	OF_4	0.13	0.05	0.08	0.04	0.14	0.09
NO_3^-	OF_1	0.02	0.05	0.04	0.00	0.14	0.05
	OF_2	0.01	0.04	0.05	0.00	0.14	0.05
	OF_3	0.02	0.06	0.02	0.04	0.11	0.05
	OF_4	0.02	0.04	0.04	0.01	0.13	0.05
DON	OF_1	0.03	0.00	0.18	0.03	0.01	0.05
	OF_2	0.03	0.00	0.18	0.02	0.02	0.05
	OF_3	0.05	0.04	0.14	0.08	0.02	0.07
	OF_4	0.04	0.01	0.16	0.04	0.00	0.05

Table 19. Parameters used in calibration, ranges of parameters, the initial value of the parameter, and the final calibrated value.

Parameter	Lower Value	Upper Value	Initial Value	Calibrated Value
1. Phyto. Growth Rt. Temp. Coeff.	1.01	1.2	1.08	1.15908
2. Phyto. Respiration Rt. Temp. Coeff.	1.045	1.08	1.045	1.045
3. DON Mineraliz. Temp. Coeff.	1.02	1.08	1.08	1.08
4. Nitrification Temp. Coeff.	1.02	1.08	1.04	1.02
5. Phyto. Max. Growth Rt. (d^{-1})	1	3	2.5	2.99998
6. Phyto. Half-Sat. Constant-N Uptake (mg N L^{-1})	0.015	0.23	0.025	0.015
7. Fraction of Phyto. Death Recycled to ON	0.5	1	0.65	0.5
8. Phyto. Nitrogen:Carbon (mg N/mg C)	0.05	0.25	0.2	0.08739
9. Phyto. Half-Sat. Constant-P Uptake (mg P L^{-1})	0.001	0.052	0.001	0.00100001
10. Phyto. Carbon:Chlorophyll (mg C/mg Chl)	20	100	30	20.00001
11. DON Mineraliz. Rt. Constant (d^{-1})	0.003	0.1	0.04	0.0382231

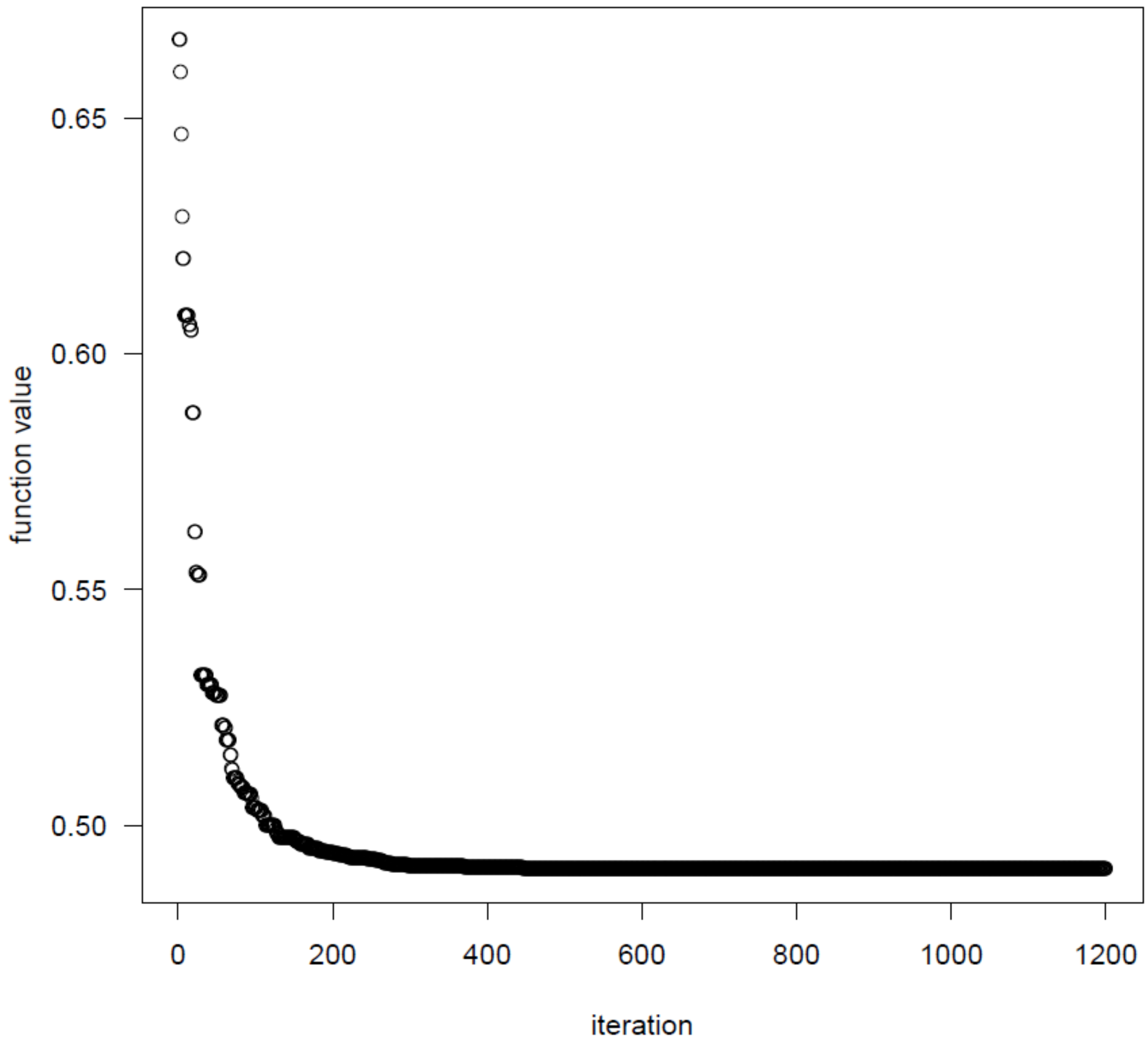
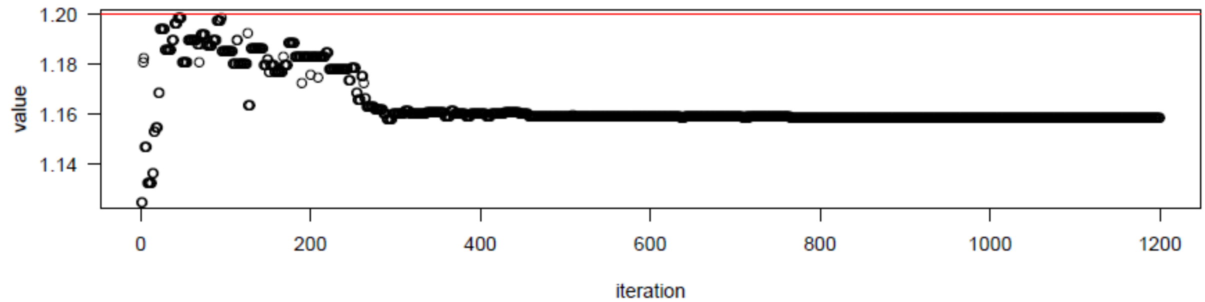
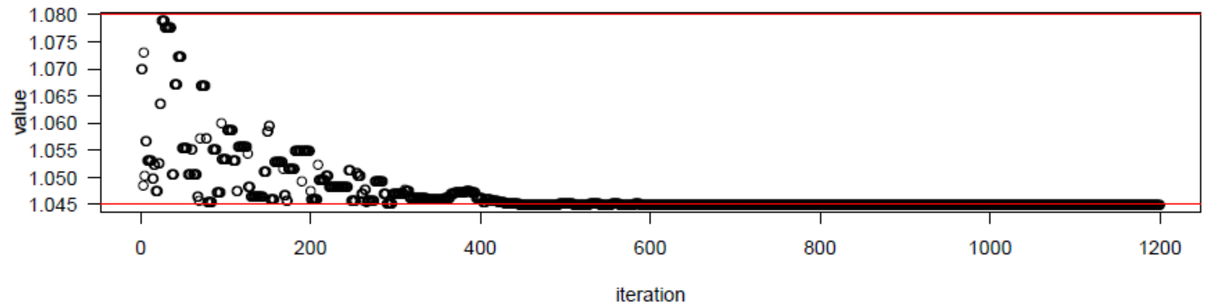


Figure 14. Objective function value resulting from each iteration of the calibration routine.

Phytoplankton Growth Rate Temperature Coefficient



Phytoplankton Respiration Rate Temperature Coefficient



DON Mineralization Temperature Coefficient

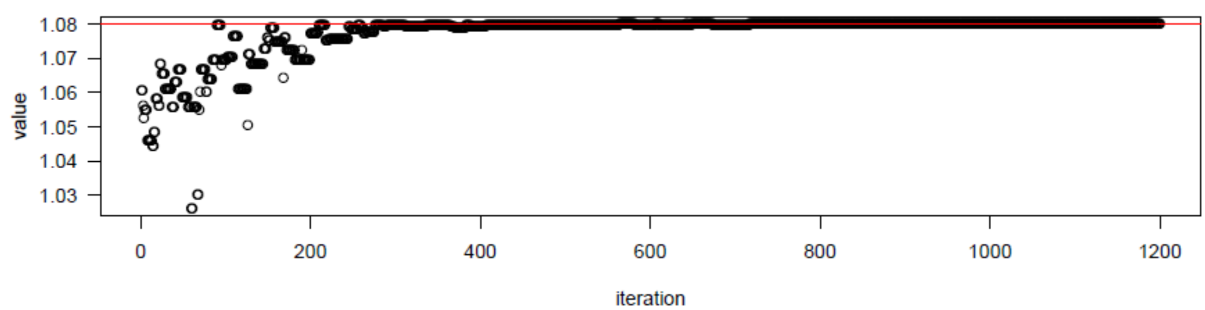


Figure 15. Parameter values resulting from each iteration of the calibration routine. Horizontal line in figure indicates a boundary value for that parameter.

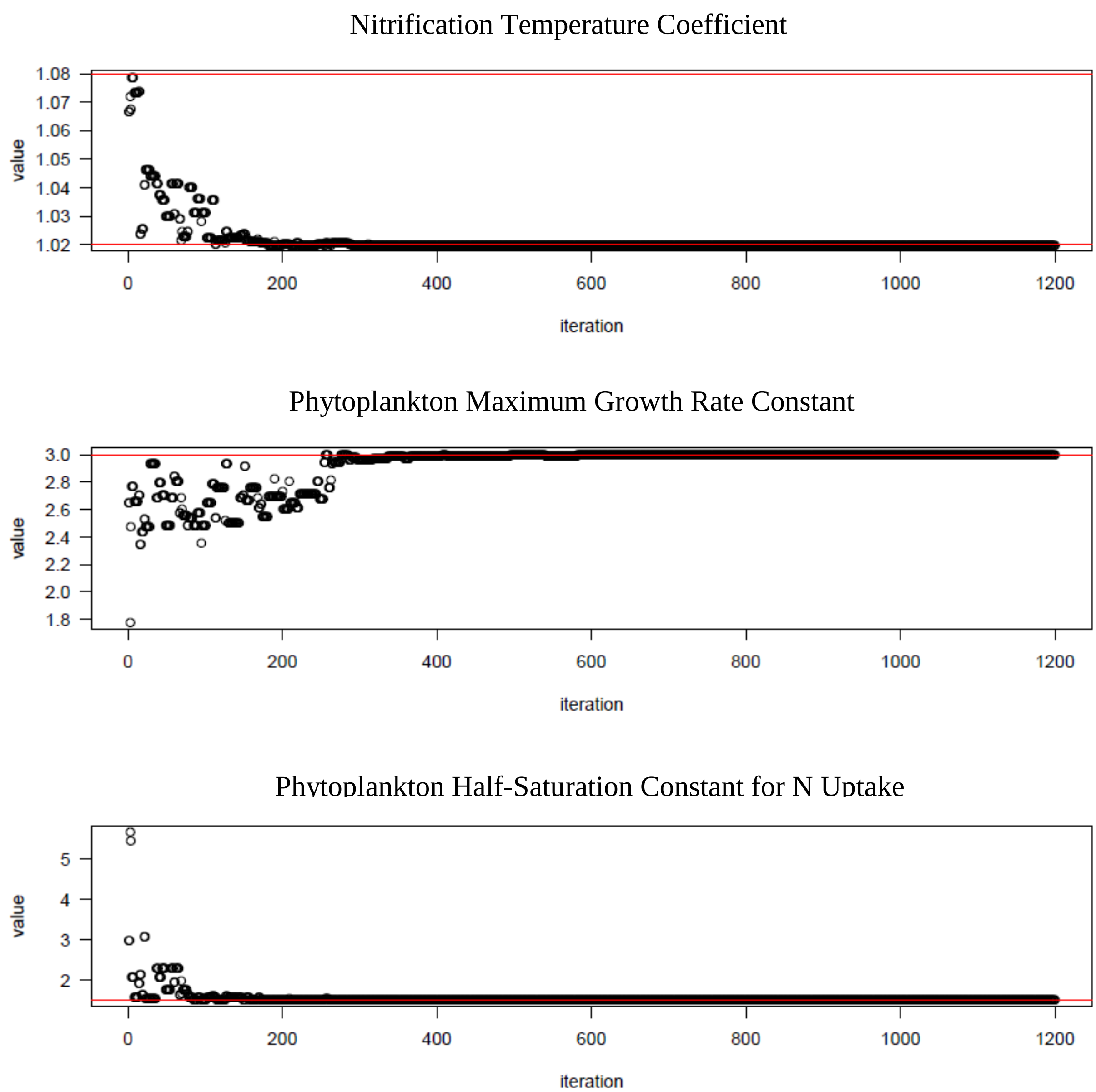


Figure 15 (continued). Parameter values resulting from each iteration of the calibration routine. Line in figure indicates boundary value for that parameter.

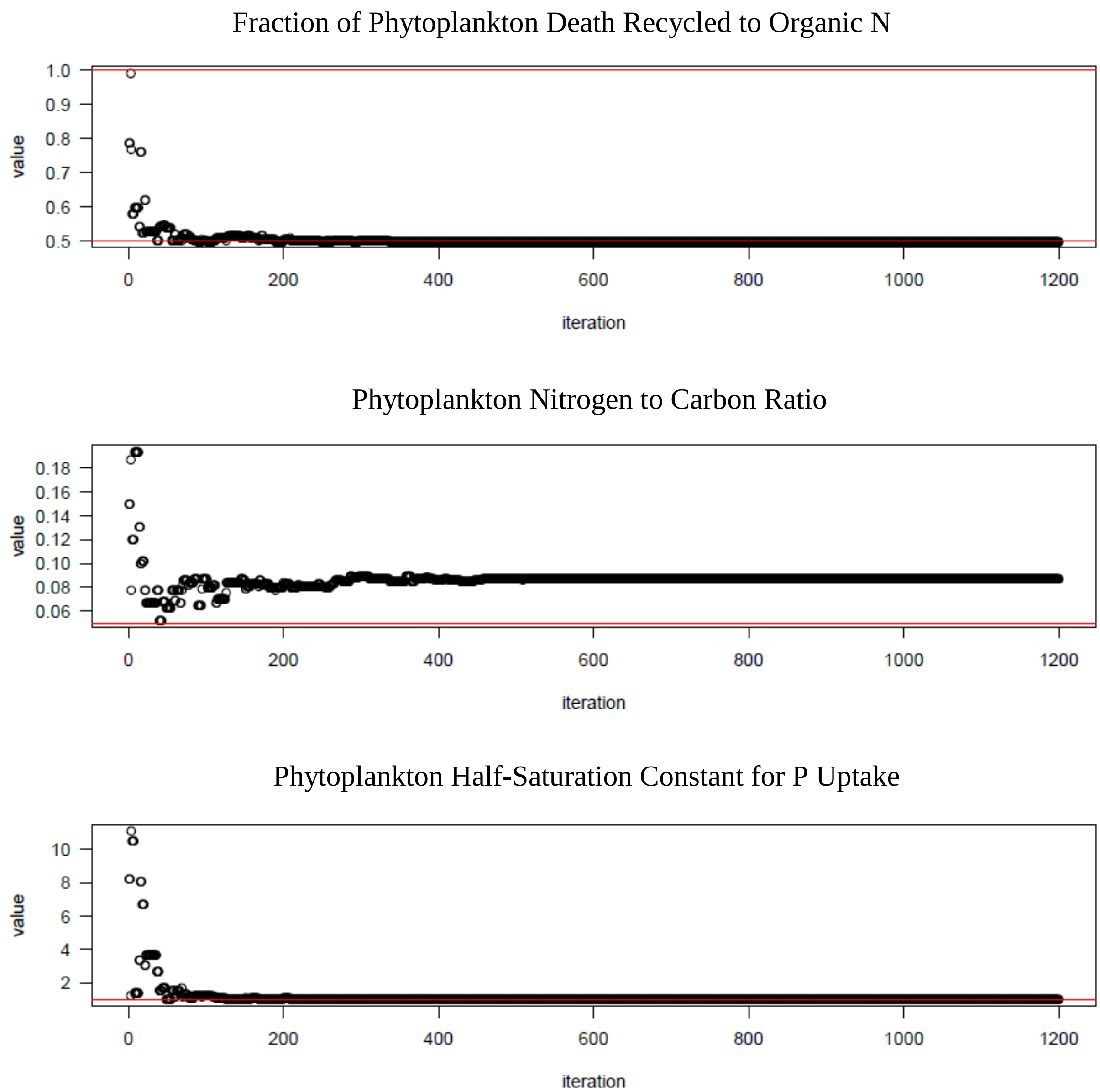


Figure 15 (continued). Parameter values resulting from each iteration of the calibration routine. Line in figure indicates boundary value for that parameter.

Phytoplankton Carbon to Chlorophyll Ratio

Dissolved Organic Nitrogen Mineralization Rate Constant

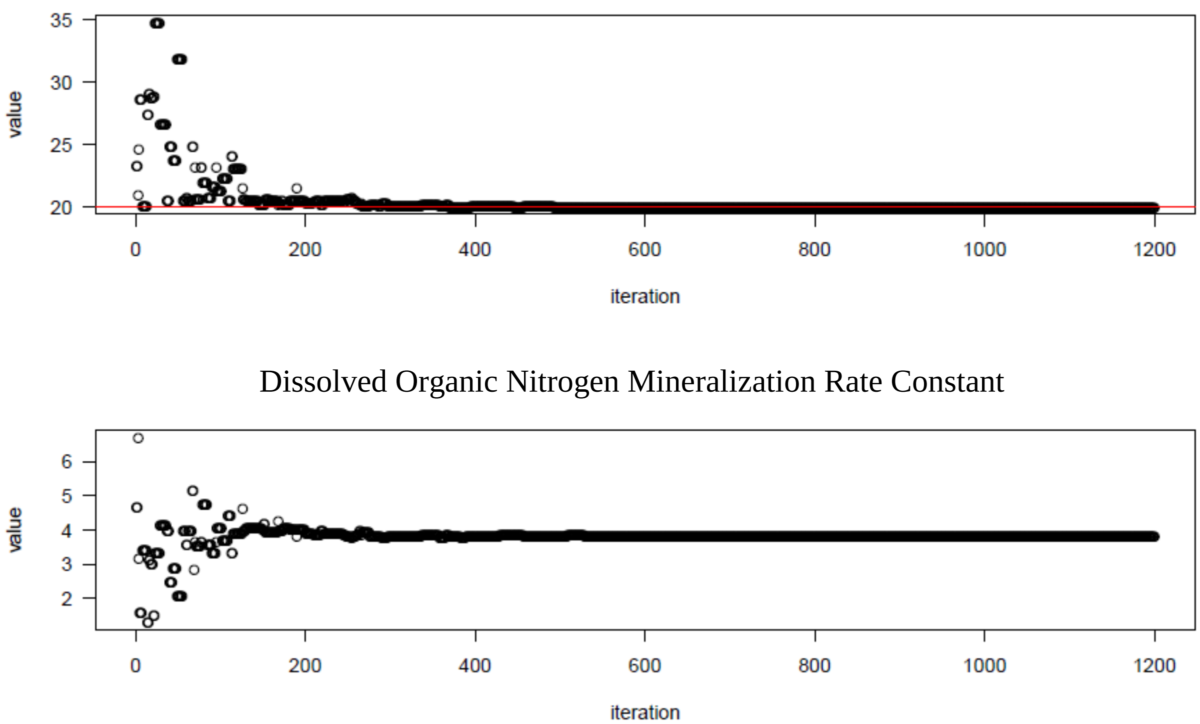


Figure 15 (continued). Parameter values resulting from each iteration of the calibration routine. Line in figure indicates boundary value for that parameter.

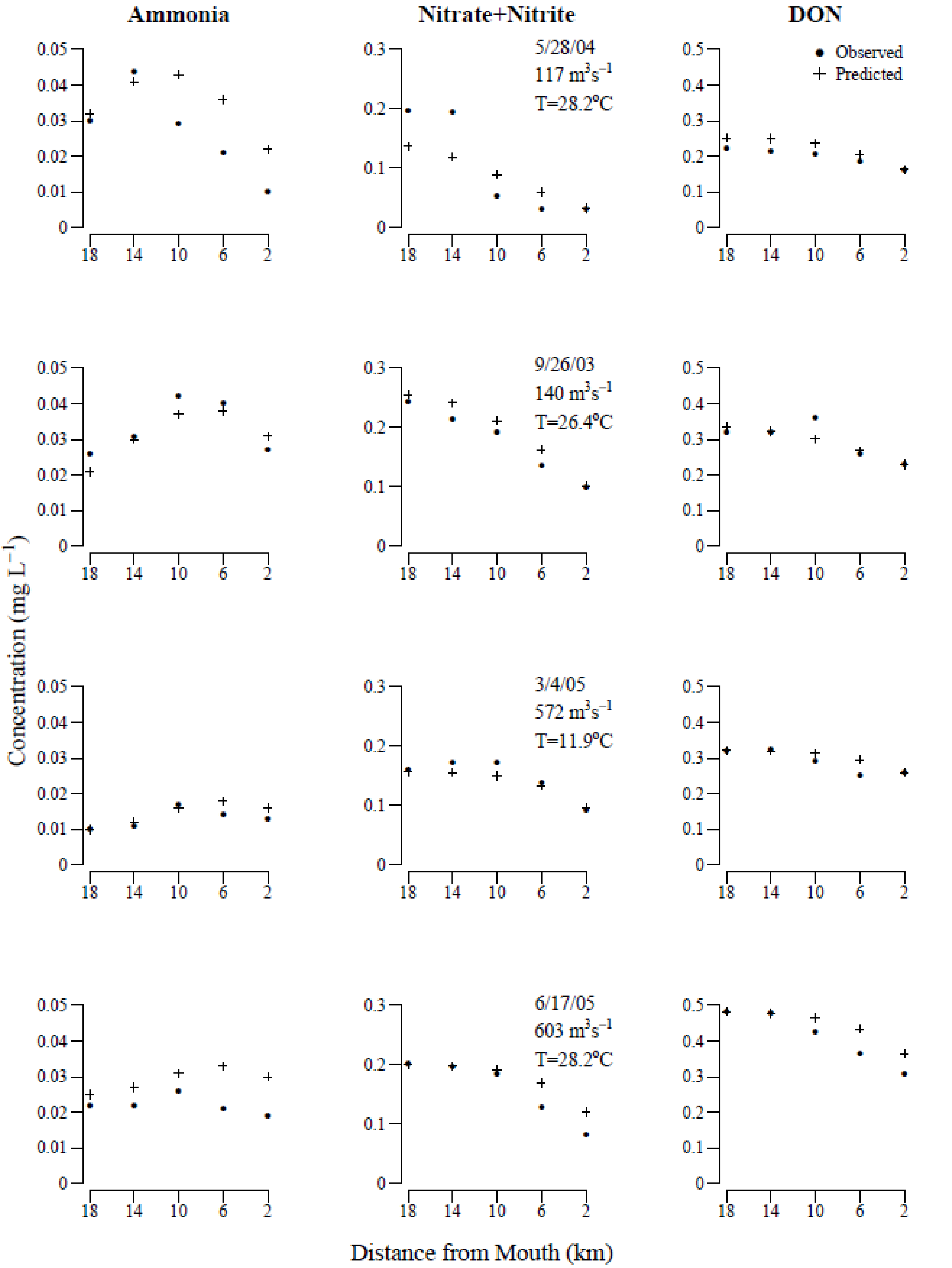


Figure 16. Observed and model predicted nitrogen concentrations using calibrated parameters in the models for the dates used in calibrations.

Table 20. Observed and WASP predicted concentrations and absolute percent difference between observed and WASP predicted nitrogen concentrations using calibrated parameters in the models for the dates used in calibrations. Units are as follows: Flow = $m^3 s^{-1}$, Dist = km, and nutrient concentrations = mg N L^{-1}. Percent differences are absolute percent difference as shown in Eq. 4.

Date	Flow	Dist	NH_3 Obs	NH_3 Pred	NH_3 % Diff	NH_3 Av % Diff	NO_3^- Obs	NO_3^- Pred	NO_3^- % Diff	NO_3^- Av % Diff	DON Obs	DON Pred	DON % Diff	DON Av % Diff
May 2004	117	18	0.030	0.032	6.7	51.2	0.198	0.137	30.8	45.2	0.224	0.251	12.2	10.6
		14	0.044	0.041	7.7		0.194	0.119	38.8		0.215	0.250	16.3	
		10	0.029	0.043	46.6		0.054	0.090	66.8		0.208	0.236	13.4	
		6	0.021	0.036	70.9		0.032	0.060	88.2		0.186	0.205	9.9	
		2	0.010	0.022	124.2		0.032	0.033	1.7		0.162	0.163	1.1	
Sep. 2003	140	18	0.026	0.021	16.7	9.7	0.243	0.256	5.3	10.2	0.322	0.335	4.1	5.3
		14	0.031	0.030	0.5		0.214	0.242	12.9		0.319	0.323	1.3	
		10	0.042	0.037	11.0		0.193	0.212	10.1		0.361	0.301	16.6	
		6	0.040	0.038	5.0		0.135	0.163	20.9		0.259	0.269	3.7	
		2	0.027	0.031	15.3		0.100	0.102	2.0		0.232	0.230	0.8	
Mar. 2005	572	18	0.010	0.010	0.1	15.9	0.161	0.157	2.5	6.3	0.321	0.322	0.3	5.4
		14	0.011	0.012	13.3		0.172	0.156	9.4		0.323	0.320	0.9	
		10	0.017	0.016	7.0		0.172	0.150	12.8		0.292	0.314	7.4	
		6	0.014	0.018	31.7		0.139	0.134	3.6		0.250	0.296	18.4	
		2	0.013	0.016	27.3		0.093	0.096	3.0		0.259	0.259	0.1	
Jun. 2005	603	18	0.022	0.025	12.1	34.4	0.201	0.200	0.5	16.3	0.482	0.483	0.1	9.1
		14	0.022	0.027	24.4		0.197	0.198	0.7		0.478	0.478	0.1	
		10	0.026	0.031	18.0		0.184	0.191	3.7		0.428	0.466	8.8	
		6	0.021	0.033	57.0		0.129	0.169	30.8		0.365	0.434	18.9	
		2	0.019	0.030	60.4		0.083	0.121	45.8		0.310	0.365	17.7	

Table 21. Boundary conditions for validation dates. FAD=Flushing averaged discharge, Bnd=Boundary (Upstream/Downstream), Sal=Salinity, Temp=Temperature ($^{\circ}C$), NH_3=Ammonia, NO_x=Nitrate+Nitrite, DON=Dissolved Organic Nitrogen, PN=Particulate Nitrogen, Chla=Chlorophyll *a*, TSS= Total Suspended Solids, PC=Particulate Carbon, PO_4=Phosphate, DOP=Dissolved Organic Phosphorus. All concentrations are in mg L^{-1} except Chla which is in $\mu g\ L^{-1}$.

Date	FAD	Bnd	Sal	Temp	NH_3	NO_x	DON	PN	Chla	TSS	PC	PO_4	DOP
Sep. 2005	110	U	0.1	28.8	0.04	0.08	0.35	0.13	27.87	12.61	1.63	0.02	0.03
		D	25.4	28.6	0.05	0.03	0.19	0.23	34.65	129.3	2.54	0.03	0.02
Dec. 2003	221	U	0.1	12.5	0.02	0.38	0.70	0.11	1.34	13.43	1.26	0.01	0.04
		D	25.0	15.3	0.02	0.08	0.37	0.28	21.01	65.79	2.45	0.01	0.03
Mar. 2004	452	U	0.0	14.2	0.00	0.07	0.44	0.10	4.48	8.32	1.28	0.01	0.01
		D	16.4	13.9	0.01	0.03	0.36	0.24	10.94	56.03	2.91	0.01	0.01
Sep. 2004	796	U	0.0	22.8	0.00	0.02	0.73	0.11	1.15	7.77	1.81	0.02	.
		D	18.5	23.4	0.01	0.13	0.37	0.21	15.07	64.98	2.73	0.02	.

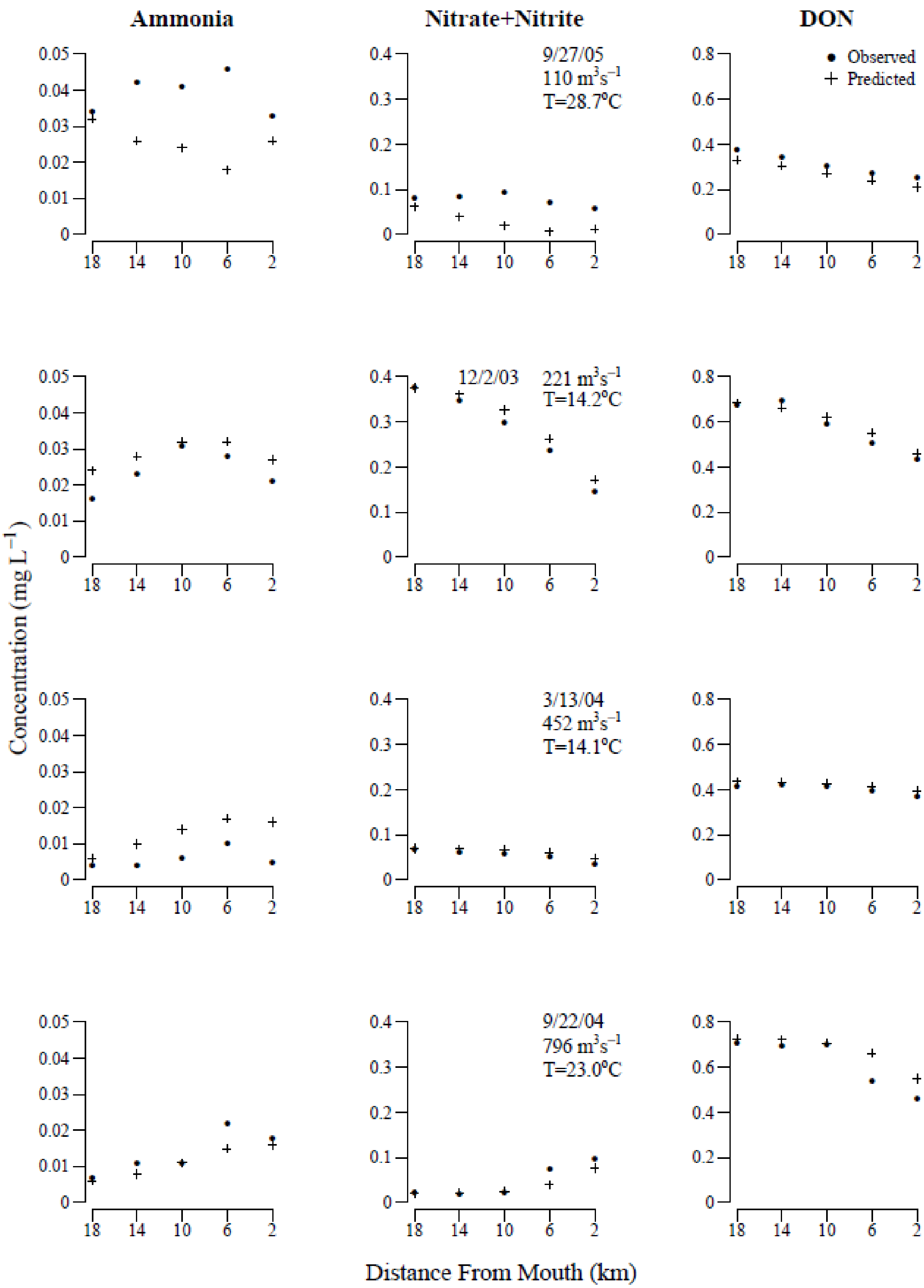


Figure 17. Comparison of model predicted and observed nutrient concentrations for dates used in validation.

Table 22. Observed and WASP predicted concentrations and absolute percent difference between observed and WASP predicted nitrogen concentrations for validation dates. Units are as follows: Flow = $m^3 s^{-1}$, Dist. = km, and nutrient concentrations = mg N L^{-1}. Percent differences are absolute percent difference as shown in Eq. 4.

Date	Flow	Dist.	NH_3 Obs	NH_3 Pred	NH_3 % Diff	NH_3 Av % Diff	NO_3^- Obs	NO_3^- Pred	NO_3^- % Diff	NO_3^- Av % Diff	DON Obs	DON Pred	DON % Diff	DON Av % Diff
Sep. 2005	110	18	0.034	0.032	5.4	33.6	0.082	0.062	24.9	64.4	0.373	0.331	11.4	12.1
		14	0.042	0.026	37.0		0.084	0.040	52.4		0.341	0.305	10.7	
		10	0.041	0.024	41.8		0.093	0.020	78.3		0.304	0.273	10.1	
		6	0.046	0.018	61.6		0.070	0.007	89.3		0.272	0.240	11.7	
		2	0.033	0.026	22.5		0.057	0.013	77.2		0.253	0.212	16.5	
Dec. 2003	221	18	0.016	0.024	50.1	23.8	0.377	0.376	0.3	8.9	0.675	0.683	1.2	5.3
		14	0.023	0.028	22.2		0.346	0.361	4.2		0.695	0.662	4.7	
		10	0.031	0.032	3.2		0.299	0.327	9.5		0.590	0.621	5.2	
		6	0.028	0.032	16.7		0.236	0.263	11.7		0.508	0.552	8.6	
		2	0.021	0.027	26.8		0.145	0.172	18.8		0.432	0.461	6.8	
Mar. 2004	452	18	0.004	0.006	60.3	134.1	0.069	0.070	0.8	16.2	0.418	0.436	4.2	4.2
		14	0.004	0.010	157.1		0.062	0.069	11.8		0.422	0.434	2.7	
		10	0.006	0.014	151.8		0.059	0.067	15.1		0.417	0.428	2.6	
		6	0.010	0.017	76.7		0.053	0.061	15.0		0.394	0.416	5.4	
		2	0.005	0.016	224.3		0.034	0.047	38.2		0.371	0.393	5.9	
Sep. 2004	796	18	0.007	0.006	6.4	15.9	0.021	0.020	3.0	21.3	0.707	0.727	2.7	10.1
		14	0.011	0.008	27.6		0.020	0.022	9.2		0.692	0.723	4.4	
		10	0.011	0.011	0.3		0.021	0.026	27.1		0.704	0.708	0.7	
		6	0.022	0.015	33.5		0.074	0.040	45.5		0.540	0.663	22.8	
		2	0.018	0.016	11.8		0.096	0.076	21.6		0.458	0.549	20.0	

Table 23. Top 25 model inputs for the September 2005 local sensitivity analysis. "% Sensitivity" indicates the model sensitivity, as indicated by the average absolute percent response of NH_3, NO_3^-, and DON, to variations in the given input. "U" and "D" following the input name indicate an upward or downward perturbation of the input.

Input	% Sensitivity
Phytoplankton Maximum Growth Temperature Coefficient-D	115.23
Light Option-D	88.81
DON Mineralization Temperature Coefficient-U	55.26
Temperature - Segment 1-5-D	28.95
Temperature - Segment 1-D	28.94
Temperature - Segment 2-D	28.94
Temperature - Segment 3-D	28.94
Temperature - Segment 4-D	28.94
Temperature - Segment 5-D	28.94
DOP Mineralization Rate Temperature Coefficient-D	18.74
Phytoplankton Nitrogen to Carbon Ratio-D	18.56
DON Mineralization Temperature Coefficient-D	17.92
Phytoplankton Maximum Growth Temperature Coefficient-U	17.07
DOP Mineralization Rate Temperature Coefficient-U	15.55
Phytoplankton Phosphorus to Carbon Ratio-U	14.10
Nitrification Temperature Coefficient-U	13.54
Phytoplankton Nitrogen to Carbon Ratio-U	12.89
Phytoplankton Phosphorus to Carbon Ratio-D	10.54
Temperature - Segment 1-5-U	10.30
Temperature - Segment 1-U	10.29
Temperature - Segment 2-U	10.29
Temperature - Segment 3-U	10.29
Temperature - Segment 4-U	10.29
Temperature - Segment 5-U	10.29
Phytoplankton Respiration Rate Temperature Coefficient-U	7.73

Table 24. Top 25 model inputs for the December 2003 local sensitivity analysis. "% Sensitivity" indicates the model sensitivity, as indicated by the average absolute percent response of NH_3, NO_3^-, and DON, to variations in the given input. "U" and "D" following the input name indicate an upward or downward perturbation of the input.

Input	% Sensitivity
Nitrification Temperature Coefficient-U	4.08
Upstream Boundary Concentration NO3-D	2.86
Upstream Boundary Concentration NO3-U	2.86
Upstream Boundary Concentration DON-U	2.77
Upstream Boundary Concentration DON-D	2.77
Surface Water Flow-D	2.14
Segment Length - Boundary:Boundary-D	1.55
Surface Area Between Segments - Boundary:Boundary-D	1.54
Dispersive Mixing Between Segments - Boundary:Boundary-D	1.54
Depth - Segment 1-5-D	1.47
Surface Area Between Segments - Boundary:Boundary-U	1.40
Dispersive Mixing Between Segments - Boundary:Boundary-U	1.40
Upstream Boundary Concentration NH3-U	1.40
Upstream Boundary Concentration NH3-D	1.39
Segment Length - Boundary:Boundary-U	1.39
Benthic Ammonia Flux - Segment 1-U	1.39
Benthic Ammonia Flux - Segment 2-U	1.39
Benthic Ammonia Flux - Segment 3-U	1.39
Benthic Ammonia Flux - Segment 4-U	1.39
Benthic Ammonia Flux - Segment 5-U	1.39
Benthic Ammonia Flux - Segment 1-5-U	1.39
Benthic Ammonia Flux - Segment 1-D	1.38
Benthic Ammonia Flux - Segment 2-D	1.38
Benthic Ammonia Flux - Segment 3-D	1.38
Benthic Ammonia Flux - Segment 4-D	1.38

Table 25. Top 25 model inputs for the March 2004 local sensitivity analysis. "% Sensitivity" indicates the model sensitivity, as indicated by the average absolute percent response of NH_3, NO_3^-, and DON, to variations in the given input. "U" and "D" following the input name indicate an upward or downward perturbation of the input.

Input	% Sensitivity
Upstream Boundary Concentration DON-U	2.88
Upstream Boundary Concentration DON-D	2.88
Upstream Boundary Concentration NO3-U	2.86
Upstream Boundary Concentration NO3-D	2.86
Nitrification Temperature Coefficient-U	2.76
Depth - Segment 1-5-D	2.20
Benthic Ammonia Flux - Segment 1-U	2.06
Benthic Ammonia Flux - Segment 2-U	2.06
Benthic Ammonia Flux - Segment 3-U	2.06
Benthic Ammonia Flux - Segment 4-U	2.06
Benthic Ammonia Flux - Segment 5-U	2.06
Benthic Ammonia Flux - Segment 1-5-U	2.06
Benthic Ammonia Flux - Segment 1-D	2.06
Benthic Ammonia Flux - Segment 2-D	2.06
Benthic Ammonia Flux - Segment 3-D	2.06
Benthic Ammonia Flux - Segment 4-D	2.06
Benthic Ammonia Flux - Segment 5-D	2.06
Benthic Ammonia Flux - Segment 1-5-D	2.06
Surface Water Flow-D	2.03
Volume - Segment 1-5-D	1.88
Volume - Segment 1-5-U	1.84
Depth - Segment 1-5-U	1.80
Surface Water Flow-U	1.78
DON Mineralization Temperature Coefficient-D	1.20
Segment Length - Boundary:Boundary-D	1.00

Table 26. Top 25 model inputs for the September 2004 local sensitivity analysis. "% Sensitivity" indicates the model sensitivity, as indicated by the average absolute percent response of NH_3, NO_3^-, and DON, to variations in the given input. "U" and "D" following the input name indicate an upward or downward perturbation of the input.

Input	% Sensitivity
Upstream Boundary Concentration DON-U	3.22
Upstream Boundary Concentration DON-D	3.22
Surface Water Flow-D	3.05
Surface Water Flow-U	2.55
Upstream Boundary Concentration NO3-U	2.04
Upstream Boundary Concentration NO3-D	2.03
Segment Length - Boundary:Boundary-D	1.63
Nitrification Temperature Coefficient-U	1.52
Depth - Segment 1-5-D	1.50
Surface Area Between Segments - Boundary:Boundary-D	1.50
Dispersive Mixing Between Segments - Boundary:Boundary-D	1.50
Benthic Ammonia Flux - Segment 1-U	1.47
Benthic Ammonia Flux - Segment 2-U	1.47
Benthic Ammonia Flux - Segment 3-U	1.47
Benthic Ammonia Flux - Segment 4-U	1.47
Benthic Ammonia Flux - Segment 5-U	1.47
Benthic Ammonia Flux - Segment 1-5-U	1.47
Benthic Ammonia Flux - Segment 1-D	1.47
Benthic Ammonia Flux - Segment 2-D	1.47
Benthic Ammonia Flux - Segment 3-D	1.47
Benthic Ammonia Flux - Segment 4-D	1.47
Benthic Ammonia Flux - Segment 5-D	1.47
Benthic Ammonia Flux - Segment 1-5-D	1.47
Dispersive Mixing Between Segments - Boundary:Boundary-U	1.47
Surface Area Between Segments - Boundary:Boundary-U	1.47

Table 27. Range of temperatures and input upstream DN concentrations used to bound low, medium, high temperatures and input upstream DN concentrations at low, medium and high flows. Flow=$m^3 s^{-1}$, DN=mg N L^{-1}.

		Low Flow ($129\ m^3s^{-1}$)	**Medium Flow ($240\ m^3s^{-1}$)**	**High Flow ($479\ m^3s^{-1}$)**
Temp	Low (20-30th)	15.1-17.6	15.0-17.6	15.4-17.9
	Med (44-55th)	21.3-23.9	21.1-23.7	21.4-23.9
	High (70-80th)	27.6-30.0	27.6-30.1	27.5-30.0
DN	Low (20-30th)	0.624-0.724	0.617-0.715	0.614-0.717
	Med (44-55th)	0.846-0.919	0.842-0.917	0.845-0.920
	High (70-80th)	1.051-1.156	1.050-1.147	1.048-1.155

Table 28. Comparison of DN concentrations predicted by Monte Carlo simulations for segments at 14 km and 4 km to concentrations observed in the estuary at the stations at 14 km and 4 km. Concentration= mg N L^{-1}.

		14 km		4 km
Flow	Model Predicted	Observed	Model Predicted	Observed
Low	min=0.13 median=0.80 max=1.51	0.77, 0.48, 0.56, 0.66	min=0.13 median=0.65 max=1.21	0.45, 0.30, 0.42
Med.	min=0.16 median=0.83 max=1.56	1.06, 0.56, 0.74, 0.72	min=0.17 median=0.68 max=1.26	0.41, 0.44, 0.51
High	min=0.15 median=0.86 max=1.60	0.41, 0.46, 0.41, 0.53, 0.49, 0.67, 0.56, 0.54, 0.51	min=0.17 median=0.73 max=1.31	0.35, 0.36, 0.36, 0.40, 0.53, 0.53, 0.44, 0.46

Table 29. Mean model predicted nitrogen concentrations (± standard deviation) at low, medium, and high flows. Concentrations=mg N L^{-1}.

Flow	Mean NH_3 ± sd	Mean NO_3^- ± sd	Mean DON ± sd	Mean DN ± sd
Low	0.059 ± 0.025	0.272 ± 0.134	0.407 ± 0.138	0.738 ± 0.208
Med.	0.062 ± 0.026	0.290 ± 0.147	0.417 ± 0.151	0.769 ± 0.222
High	0.064 ± 0.029	0.309 ± 0.161	0.432 ± 0.170	0.805 ± 0.241

Table 30. Median, 25^{th}, and 75^{th} percentiles of model predicted nitrogen concentrations at low, medium, and high flows. Median concentrations are in bold. Concentrations below the median values are the 25^{th} and 75^{th} percentile, respectively. Concentrations=mg N L^{-1}.

Flow	Median NH_3		Median NO_3^-		Median DON		Median DN	
	25th	75th	25th	75th	25th	75th	25th	75th
Low	**0.057**		**0.269**		**0.405**		**0.736**	
	0.04	0.077	0.162	0.381	0.298	0.514	0.59	0.883
Med.	**0.059**		**0.289**		**0.416**		**0.767**	
	0.041	0.081	0.165	0.412	0.295	0.544	0.612	0.927
High	**0.062**		**0.308**		**0.437**		**0.803**	
	0.04	0.086	0.171	0.446	0.285	0.576	0.634	0.982

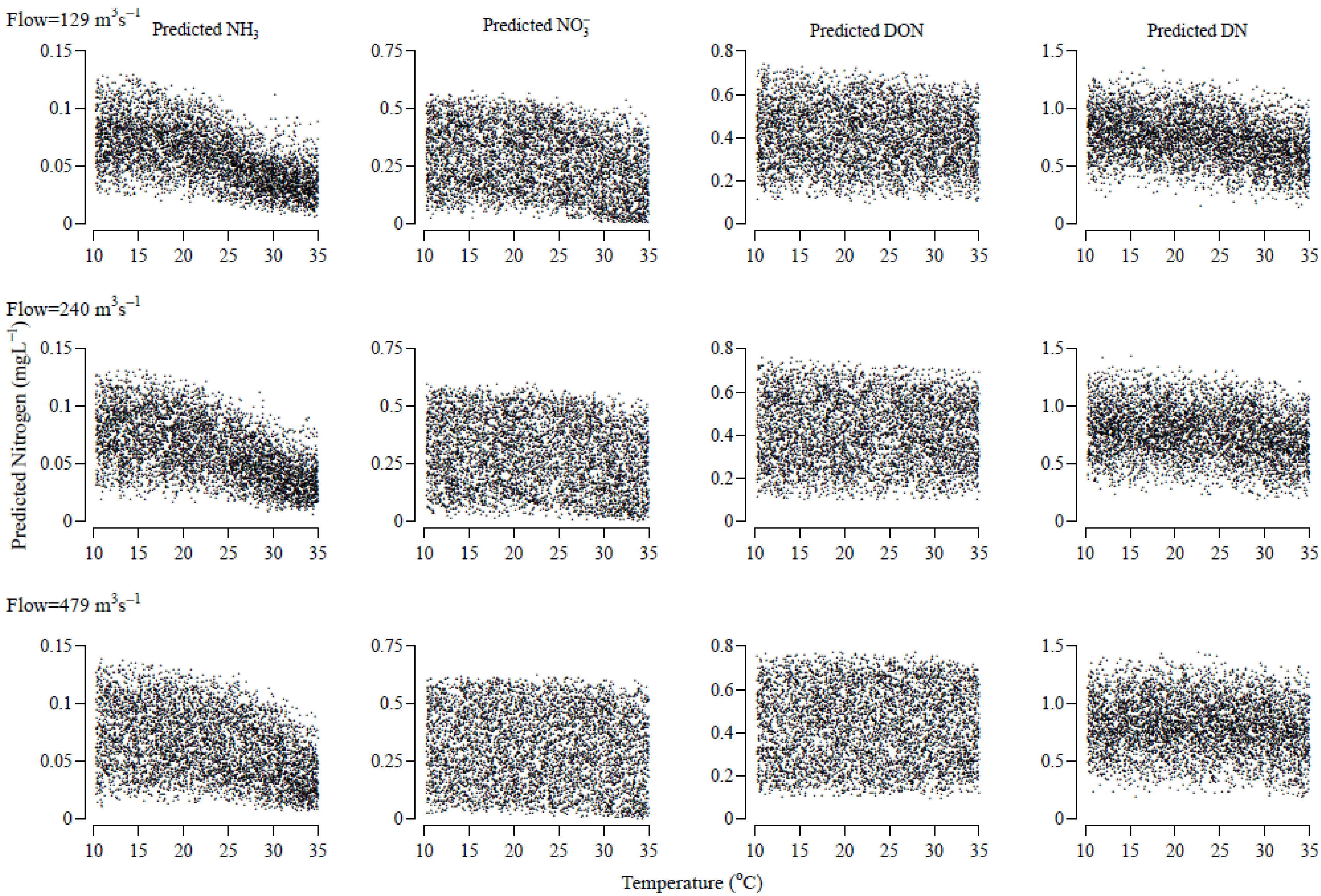


Figure 18. Full range of model predicted NH_3, NO_3^-, DON, and DN concentrations (mg N L^{-1}) vs. full range of input temperatures.

Table 31. Mean model predicted nitrogen concentrations (± standard deviation) for combinations of low, medium, and high temperatures and low, medium, and high flows. Concentration=mg N L^{-1}.

Flow	Temp	Mean NH_3 ± sd	Mean NO_3^- ± sd	Mean DON ± sd	Mean DN ± sd
Low	Low	0.074 ± 0.022	0.295 ± 0.125	0.422 ± 0.138	0.791 ± 0.192
	Med.	0.065 ± 0.020	0.300 ± 0.131	0.411 ± 0.142	0.776 ± 0.203
	High	0.042 ± 0.015	0.243 ± 0.123	0.393 ± 0.133	0.677 ± 0.186
Med.	Low	0.077 ± 0.024	0.309 ± 0.148	0.423 ± 0.155	0.808 ± 0.226
	Med.	0.069 ± 0.023	0.302 ± 0.149	0.424 ± 0.147	0.795 ± 0.214
	High	0.049 ± 0.019	0.281 ± 0.146	0.418 ± 0.148	0.747 ± 0.222
High	Low	0.073 ± 0.029	0.325 ± 0.161	0.438 ± 0.166	0.836 ± 0.246
	Med.	0.069 ± 0.027	0.312 ± 0.154	0.436 ± 0.173	0.817 ± 0.242
	High	0.056 ± 0.024	0.313 ± 0.159	0.437 ± 0.170	0.805 ± 0.232

Table 32. Median, 25th, and 75th percentiles of model predicted nitrogen concentrations for combinations of low, medium, and high temperatures and low, medium, and high flows. Median concentrations of output nitrogen are in bold. Concentrations below the median values are the 25th and 75th percentiles, respectively. Concentration=mg N L^{-1}.

Flow	Temp	Median NH_3		Median NO_3^-		Median DON		Median DN	
		25th	75th	25th	75th	25th	75th	25th	75th
Low	Low	**0.074**		**0.281**		**0.425**		**0.779**	
		0.057	0.089	0.190	0.399	0.309	0.524	0.663	0.928
	Med.	**0.064**		**0.305**		**0.405**		**0.770**	
		0.050	0.080	0.189	0.414	0.296	0.517	0.632	0.919
	High	**0.040**		**0.237**		**0.387**		**0.683**	
		0.030	0.052	0.142	0.344	0.290	0.498	0.544	0.807
Med.	Low	**0.078**		**0.299**		**0.416**		**0.793**	
		0.059	0.096	0.184	0.441	0.300	0.554	0.658	0.970
	Med.	**0.070**		**0.298**		**0.419**		**0.808**	
		0.051	0.086	0.177	0.423	0.314	0.546	0.637	0.937
	High	**0.047**		**0.281**		**0.419**		**0.754**	
		0.035	0.062	0.159	0.413	0.308	0.543	0.593	0.918
High	Low	**0.074**		**0.333**		**0.449**		**0.829**	
		0.048	0.096	0.189	0.464	0.294	0.569	0.666	1.031
	Med.	**0.068**		**0.311**		**0.440**		**0.820**	
		0.047	0.091	0.186	0.442	0.292	0.585	0.652	0.990
	High	**0.055**		**0.315**		**0.430**		**0.803**	
		0.036	0.076	0.173	0.449	0.295	0.582	0.646	0.978

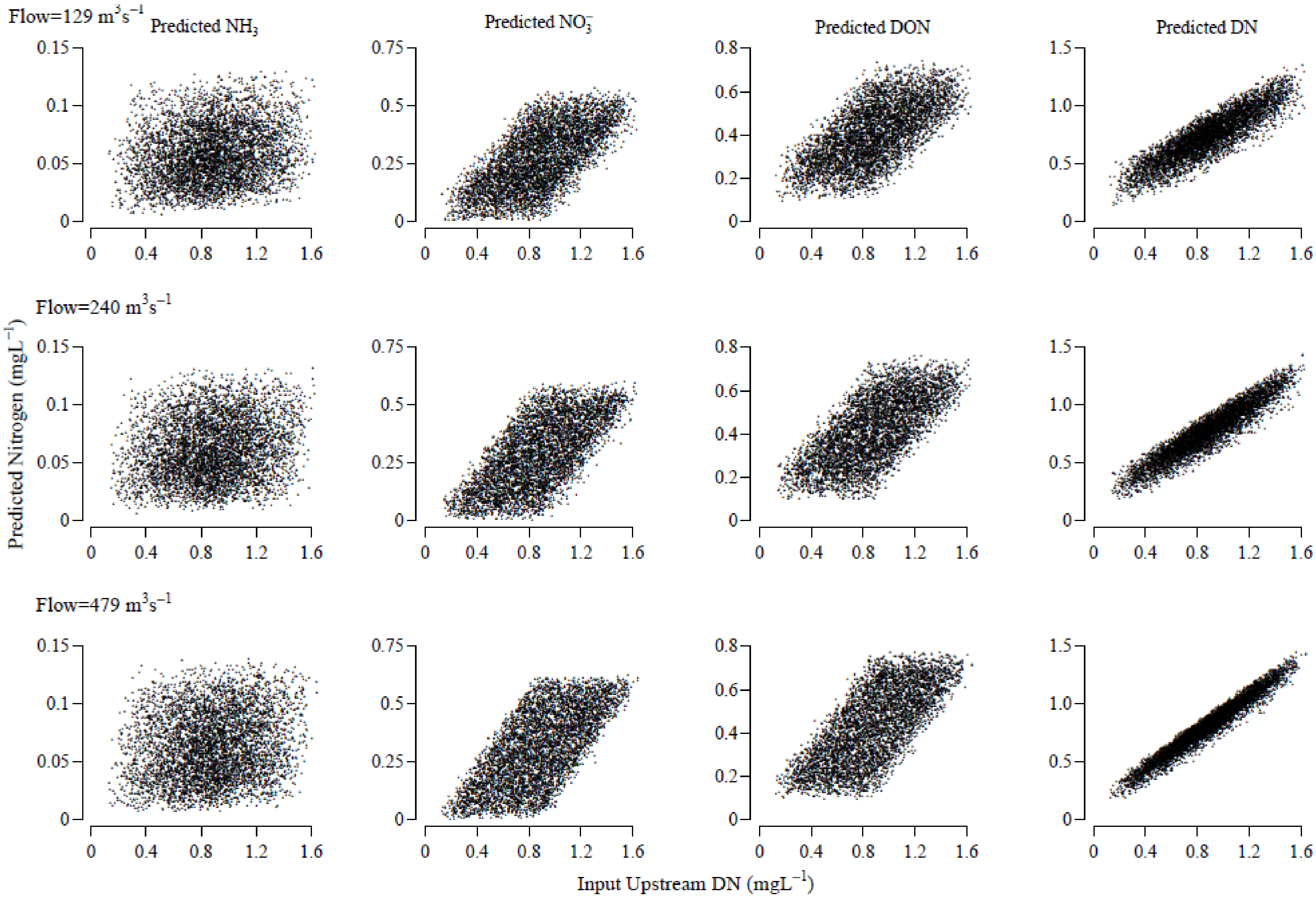


Figure 19. Full range of model predicted NH_3, NO_3^-, DON, and DN concentrations (mg N L^{-1}) vs. full range of DN input at the upstream boundary.

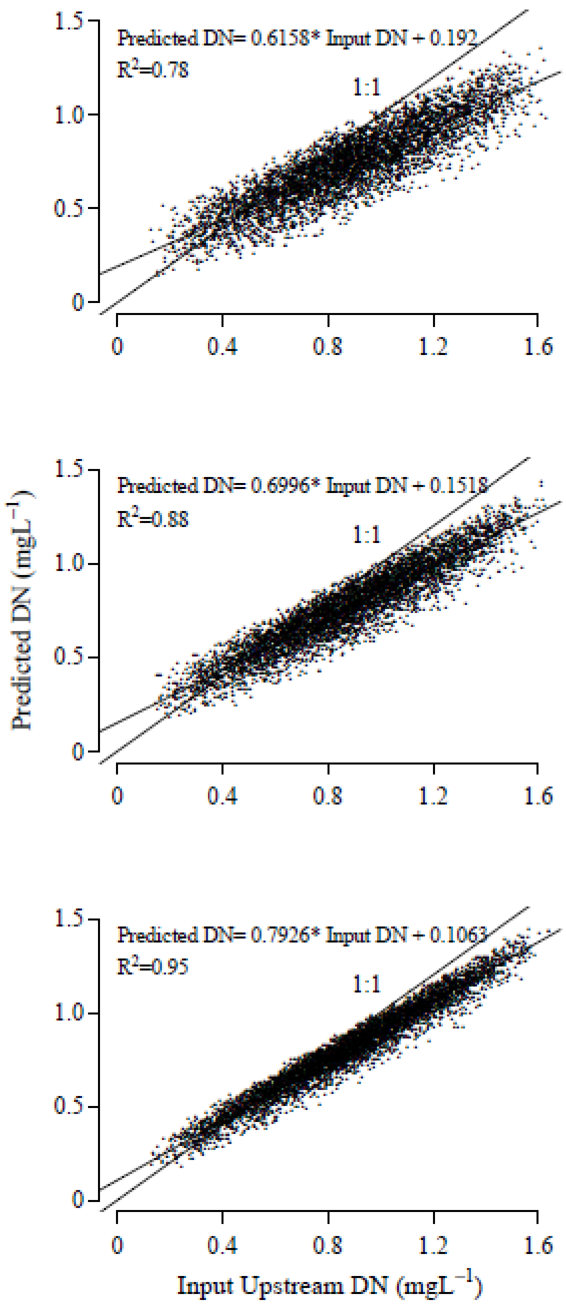


Figure 20. Model predicted DN concentrations vs. input upstream DN concentration (mg N L^{-1}).

Table 33. Mean model predicted nitrogen concentrations (± standard deviation) for combinations of low, medium, and high input upstream DN and low, medium, and high flows. Concentration=mg N L^{-1}.

Flow	Input DN	Mean NH_3 ± sd	Mean NO_3^- ± sd	Mean DON ± sd	Mean DN ± sd
129	Low	0.054 ± 0.023	0.213 ± 0.100	0.336 ± 0.110	0.603 ± 0.099
	Med.	0.059 ± 0.023	0.271 ± 0.126	0.406 ± 0.127	0.736 ± 0.099
	High	0.061 ± 0.025	0.331 ± 0.104	0.476 ± 0.107	0.868 ± 0.106
240	Low	0.061 ± 0.025	0.231 ± 0.108	0.331 ± 0.110	0.624 ± 0.076
	Med.	0.060 ± 0.027	0.288 ± 0.140	0.415 ± 0.139	0.763 ± 0.084
	High	0.066 ± 0.026	0.353 ± 0.112	0.499 ± 0.111	0.918 ± 0.084
479	Low	0.061 ± 0.029	0.233 ± 0.120	0.345 ± 0.119	0.640 ± 0.058
	Med.	0.060 ± 0.028	0.305 ± 0.152	0.439 ± 0.155	0.805 ± 0.055
	High	0.068 ± 0.027	0.386 ± 0.116	0.523 ± 0.118	0.977 ± 0.059

Table 34. Median, 25th, and 75th percentiles of model predicted nitrogen concentrations for combinations of low, medium, and high input upstream DN and low, medium, and high flows. Median concentrations of output nitrogen are in bold. Concentrations below the median values are the 25th and 75th percentiles, respectively. Concentration=mg N L^{-1}.

Flow	Input DN	Median NH_3		Median NO_3^-		Median DON		Median DN	
		25th	75th	25th	75th	25th	75th	25th	75th
Low	Low	**0.052**		**0.204**		**0.335**		**0.608**	
		0.036	0.069	0.137	0.293	0.248	0.418	0.544	0.673
	Med.	**0.058**		**0.272**		**0.403**		**0.745**	
		0.042	0.078	0.165	0.371	0.309	0.514	0.679	0.807
	High	**0.058**		**0.336**		**0.473**		**0.871**	
		0.042	0.081	0.251	0.414	0.398	0.551	0.795	0.948
Med.	Low	**0.059**		**0.235**		**0.329**		**0.628**	
		0.043	0.080	0.142	0.317	0.247	0.415	0.576	0.678
	Med.	**0.056**		**0.287**		**0.409**		**0.769**	
		0.038	0.080	0.169	0.398	0.312	0.523	0.710	0.824
	High	**0.064**		**0.350**		**0.509**		**0.926**	
		0.046	0.085	0.263	0.452	0.410	0.585	0.860	0.980
High	Low	**0.059**		**0.231**		**0.344**		**0.646**	
		0.038	0.083	0.134	0.334	0.246	0.438	0.602	0.682
	Med.	**0.059**		**0.305**		**0.438**		**0.809**	
		0.038	0.081	0.179	0.429	0.307	0.566	0.771	0.846
	High	**0.068**		**0.391**		**0.525**		**0.983**	
		0.047	0.090	0.290	0.484	0.429	0.620	0.941	1.018

Table 35. Mean model predicted DN concentration at various flows, temperatures, and input upstream DN. Concentration=mg N L^{-1}.

		Flow		
DN input	**Temp**	**Low**	**Med**	**High**
Low	**Low**	0.684	0.679	0.684
	Med	0.680	0.681	0.676
	High	0.638	0.659	0.667
Med.	**Low**	0.770	0.809	0.828
	Med	0.759	0.817	0.822
	High	0.712	0.727	0.782
High	**Low**	0.830	0.891	0.948
	Med	0.826	0.889	0.952
	High	0.770	0.847	0.930

Table 36. Marsh fluxes and system attributes of systems used to estimate marsh flux of nitrogen in the Altamaha River estuary. Units of flux of nitrogen species=g N m^{-2} y^{-1}, Tidal Range=meters, and Size=hectares. Marsh age is based on Odum et al. (1979). Type is based on Dame (1994). The size for Bly Creek reflects the area of the smaller estuary marsh in which the flux study was conducted as well as the larger watershed of the system upstream of the marsh. Negative values indicate losses from the estuary system to the marsh.

Location	NH_4^+ Flux	NO_x^- Flux	DON Flux	Marsh Age	Type	Tidal Range	Salinity	Size	Study
Bly Creek, SC	-0.54	0.27	-9.9	Young/ Mid	I	1.4	15-35	66+ 395	Dame et al., 1991
Sippewissett Creek, MA	-4.1	-3.7	-9.4	Mature	II	1.6	25-32	23	Valiela et al., 1978
Flax Pond, NY	-2.1	1.2	.	Young	I	1.8	26	57	Woodwell et al., 1979
Crommet Creek, DE	2.06	0.32	.	Young	I	2	0-31	4.1	Daly and Mathieson, 1981
Carter Creek, VA	0.29	0.34	-9.25	Mature	III	1	6-12	10	Axelrad et al., 1976
Ware Creek, VA	-2.9	2.43	-2.32	Mature	II	.	1-7	14	Axelrad et al., 1976

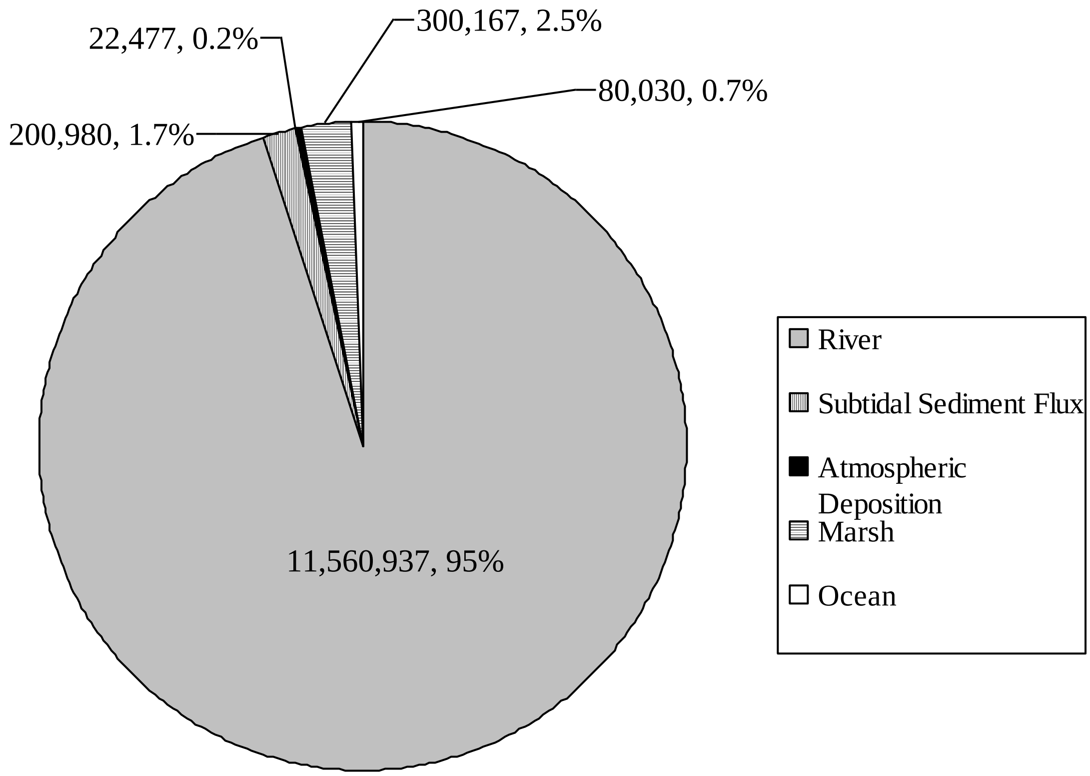


Figure 21. Median (kg N yr^{-1}) and percent flux of sources of nitrogen to the Altamaha River estuary.

Table 37. Estimated annual nitrogen fluxes for the Altamaha River estuary. Positive numbers indicate fluxes to the estuary from the given source. Flux units=kg N yr^{-1}.

Flux	25th Percentile	Median	75th Percentile
River NH_4^+	325,215	414,640	698,610
River NOx	3,041,545	3,661,680	4,902,680
River ON	4,421,245	6,152,440	10,854,005
River PN	825,342	1,332,177	2,202,445
Subtidal Sediment Flux NH_4^+	38,650	193,250	504,384
Subtidal Sediment Flux NOx	-38,650	7,730	56,816
Subtidal Sediment Flux DON	-309,201	0	173,925
Marsh NH_4^+	-2,401	38,412	78,570
Marsh NOx	-28,664	-9,603	-8,221
Marsh DON	218,759	271,358	277,178
Atmospheric Deposition NH_4^+	3,579	4,742	4,926
Atmospheric Deposition NO_3^-	17,833	24,846	30,378
Atmospheric Deposition ON	9,177	12,680	15,130
Mixing from Ocean NH_4^+	11,856	35,569	154,132
Mixing from Ocean NOx	2,964	44,461	80,030

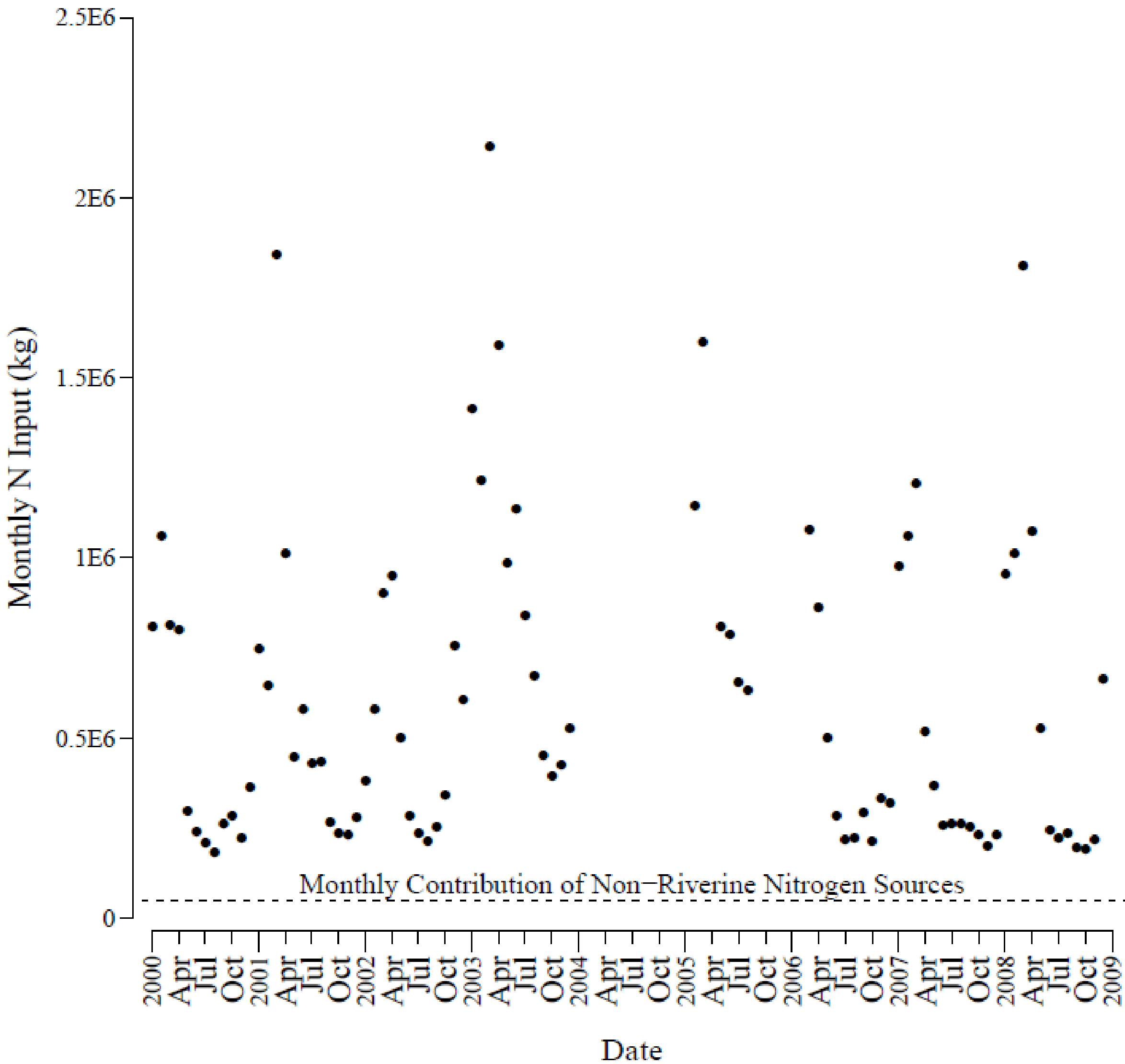


Figure 22. Monthly riverine loading of nitrogen (kg) to the Altamaha River estuary. Nitrogen input is the sum of NH_4^+, NO_x^-, DON, and particulate nitrogen.

Table 38. Percent of estuarine nitrogen requirement or percent of total estuarine nitrogen fluxes supplied by sediments. Sys=Nitrogen required by all primary producers (phytoplankton and macrophytes), Phyt=Nitrogen required by phytoplankton.

Location	% of Estuary N Requirement from Sediment Flux	% of N Input from Sediment Flux	Reference
Coastal Massachusetts	3-8 (Phyt)		Hopkinson et al., 2001
Plum Island Estuary, Massachusetts	1-190 (Sys)		Hopkinson et al., 1999
Rhode Island(lagoon)	11 (Sys), 30 (Phyt)		Nowicki and Nixon, 1985
Chesapeake Bay		13-39	Cowan and Boynton, 1996
Chesapeake Bay	13-40 (Phyt)		Boynton and Kemp, 1985
Potomac River Estuary	35 (Sys)		Callendar and Hammond, 1982
York River, Virginia	36 (Phyt)		Rizzo, 1990
North Carolina	28-35 (Sys)		Fisher et al., 1982
Georgia Bight	16 (Phyt)		Hopkinson and Wetzel, 1982
Roskeeda Bay, Ireland	20 (Phyt)		Raine and Patching, 1980
Port Phillip Bay, Australia		63-72	Berelson et al., 1998

Table 39. Variables collected for metadata to be used in meta-analysis. Parentheses indicate number of references associated with the measurement and "n" indicates number of samples.

• Latitude (23, n=298)	• Sediment Denitrification Rt. (9, n=86)
• Month (22, n=272)	• Sediment Denitrification Based on Water Column NO_3^- (2, n=5)
• Temperature (20, n=252)	• Sediment Denitrification Based on NO_3^- from Denitrification (2, n=5)
• Salinity (13, n=200)	• Sediment Nitrification Rt. (6, n=53)
• Depth (18, n=244)	• Dark NH_4 Flux Rt. (15, n=243)
• DO of Overlying Water (6, n=111)	• Light NH_4 Flux Rt. (3, n=38)
• Oxygen Penetration (2, n=10)	• Net NH_4^+ Flux Rt. (1, n=16)
• NH_4^+ of Overlying Water (9, n=147)	• Dark NO_3^- Flux Rt. (16, n=221)
• NO_3^- of Overlying Water (12, n=174)	• Light NO_3^- Flux Rt. (3, n=30)
• DON of Overlying Water (2, n=28)	• Net NO_3^- Flux Rt. (1, n=16)
• NH_4^+ of Porewater (3, n=12)	• Dark DON Flux Rt. (5, n=65)
• NO_3^- of Porewater (1, n=1)	• Light DON Flux Rt. (1, n=15)
• Sediment % Organic Matter (8, n=89)	• Net DON Flux Rt. (1, n=15)
• Sediment C:N (5, n=90)	• Dark Sediment Oxygen Consumption Rt. (15, n=190)
• Sediment Porosity (2, n=22)	• Light Sediment Oxygen Consumption Rt. (3, n=38)
• Sediment Type (6, n=44)	

Table 40. Criteria for inclusion of data in meta-analysis.

- Riverine dominated estuaries environments shallower than 30 m (no lagoonal systems, coastal environments)
- Did not use studies conducted in intertidal zones
- Did not use sites immediately adjacent point sources discharges (sewage outfalls, power plants, etc.)
- Used unfertilized sites and samples
- In situ flux measurements as well as lab/shipboard incubations were used
- Did not use homogenized sediment incubations
- Assumed $NH_4^+ = NH_3^+ NH_4^+$
- Assumed $NO_3^- = NO_3^- + NO_2^-$
- Organic carbon (OC) values converted to ignition loss values by multiplying OC value by 2
- Ranges of values were averaged when range was small, otherwise ranges discarded
- Literature values that were the result of the averaging of several observations were used as the average value
- Values below detection limit were recorded as half of detection limit

Table 41. References used for meta-analysis.

- Kana et al., 1998
- Sorensen 1978
- Seitzinger, 1987
- Nielsen et al., 1995
- Nowicki et al., 1997, Giblin et al., 1997
- Yoon and Benner, 1992
- Zimmerman and Benner, 1994
- Nishio et al., 1983
- Hansen et al., 1981
- Usui et al, 2001
- Eyre and Ferguson, 2005
- Cowan and Boynton, 1996
- Teague et al., 1988
- Fisher et al., 1982
- Lyons et al., 1982
- Gardner et al., 2006
- Boynton et al., 1980
- Hopkinson et al., 1999
- Meyer et al., 2001
- Cowan et al., 1996
- Warnken et al., 2000
- Lerat et al., 1990
- Reay et al., 1995

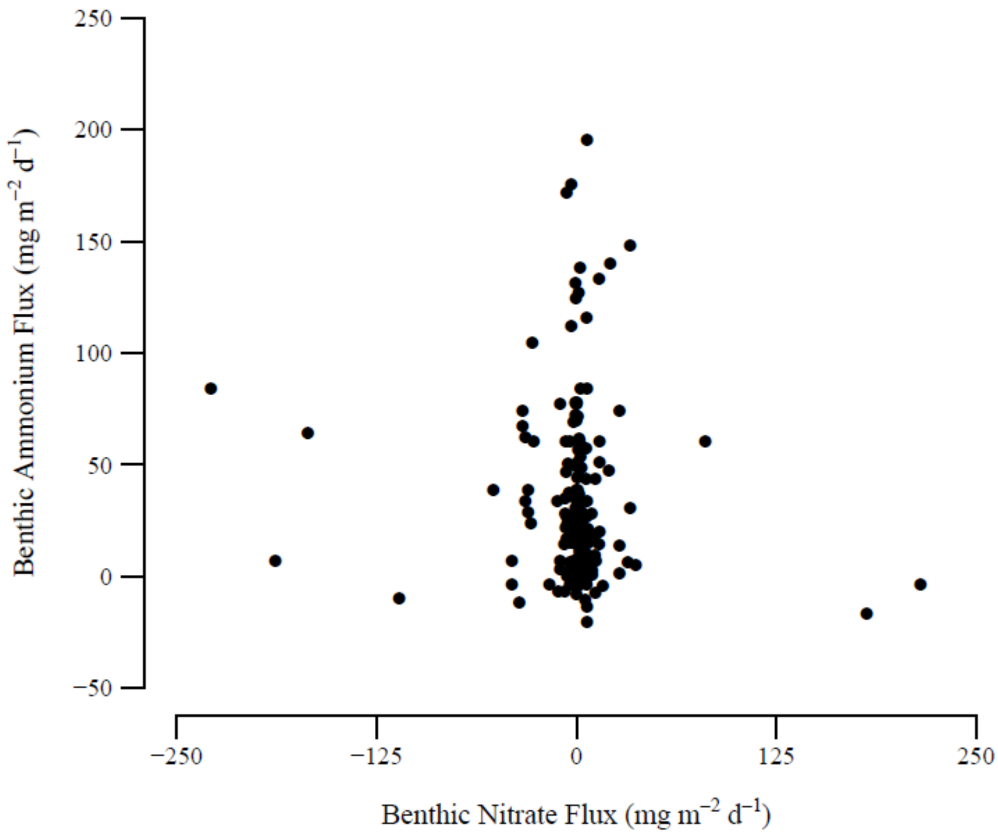


Figure 23. Ammonium flux measured in the dark vs. nitrate flux measured in the dark.

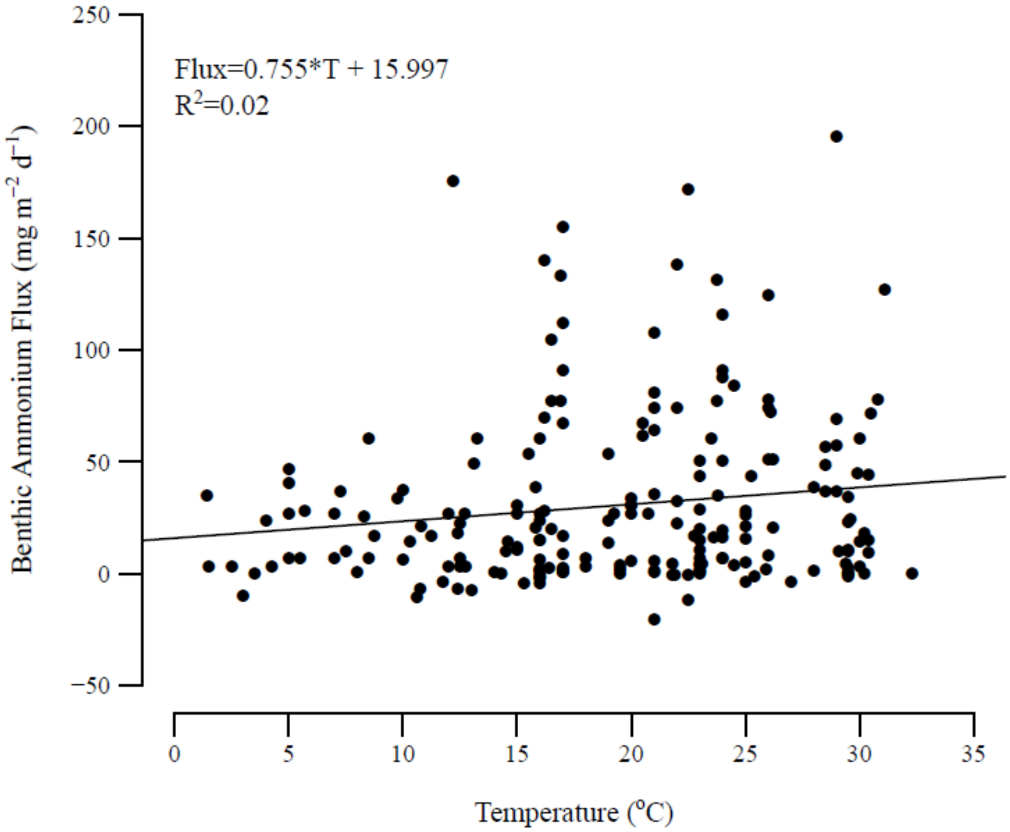


Figure 24. Ammonium flux measured in the dark vs. temperature.

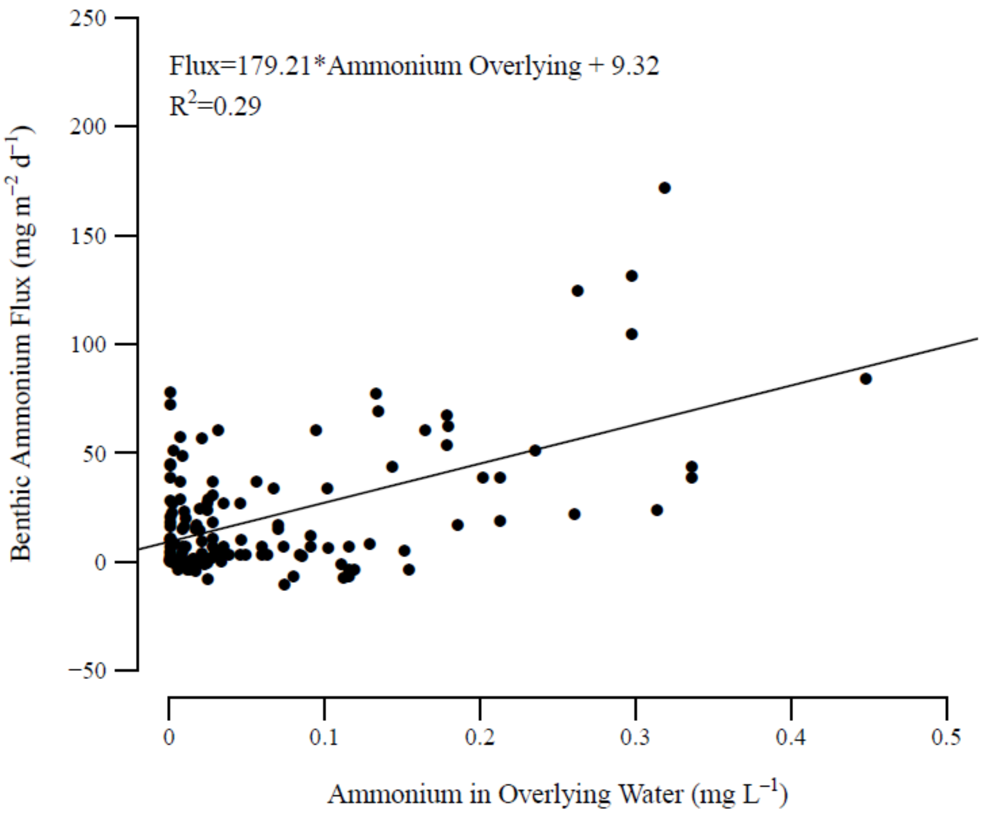


Figure 25. Ammonium flux measured in the dark vs. ammonium concentration in the overlying water.

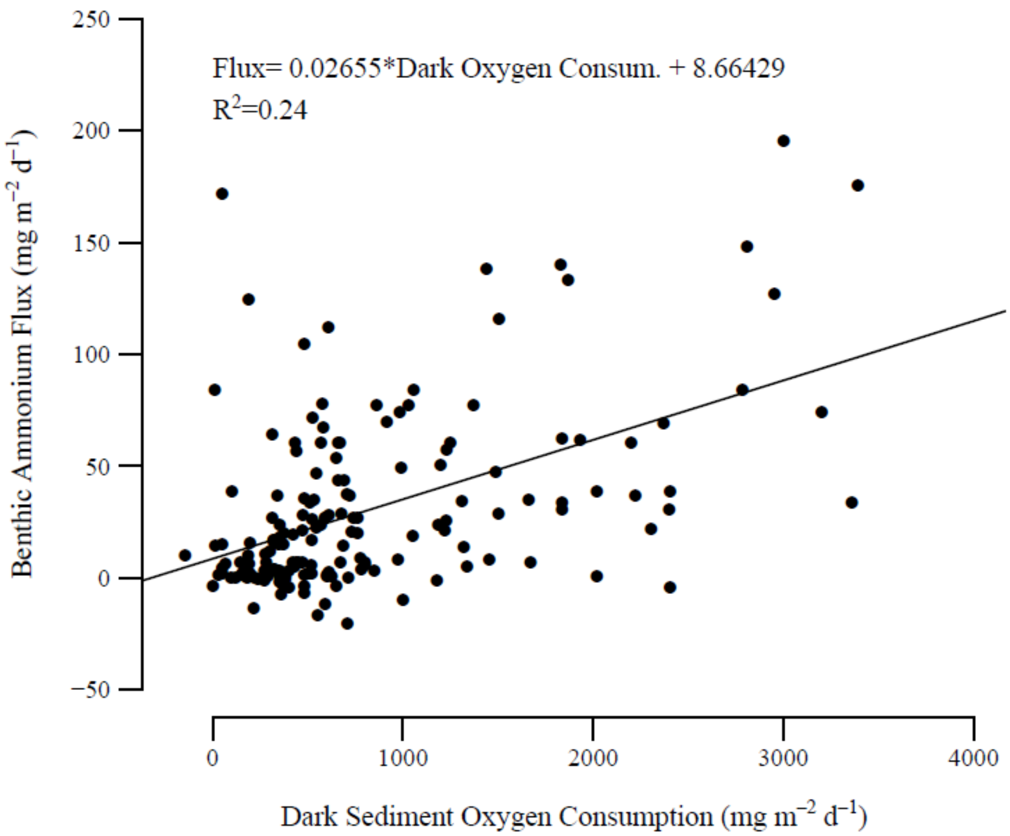


Figure 26. Ammonium flux measured in the dark vs. sediment oxygen consumption measured in the dark.