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MODELING BLUE-GREEN ALGAL BLOOMS IN THE LOWER NEUSE RIVER, NC

by

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INTRODUCTION

Segments of the lower Neuse River between Goldsboro and New Bern, North Carolina (Figure 1) have, over the past decade, revealed alarming symptoms of advanced eutrophication, culminating in the appearance and persistence of nuisance blue-green algal blooms. Specific symptoms of eutrophication in the lower Neuse are generally high rates of primary productivity and standing stocks of algal biomass; periodic spring and summer blooms of nuisance blue-green algae; and both nitrogen (ammonia and nitrate) and phosphorus (orthophosphate) concentrations exceeding levels which are considered to be growth-limiting to nuisance species (1).

Concerns for mitigative steps being asked from a management perspective include:

- Will major reductions of nutrient (nitrogen and/or phosphorus) inputs (either from point or nonpoint sources) to the lower Neuse River help to control further eutrophication and specifically arrest the occurrence and persistence of nuisance blue-green algal blooms?
- What magnitude of nitrogen and/or phosphorus input cutbacks are required to control and ultimately eliminate nuisance blue-green algal bloom potentials on the lower Neuse River?

To help address these questions, a mathematical model of the lower Neuse River has been developed. The modeling effort focuses on the understanding of the mechanisms initiating and sustaining algal blooms in the lower Neuse River. Water quality data collected by the Institute of Marine Sciences, University of North Carolina in 1983 and 1984 were used for model development. This paper presents the model development and results of model calibration analyses.

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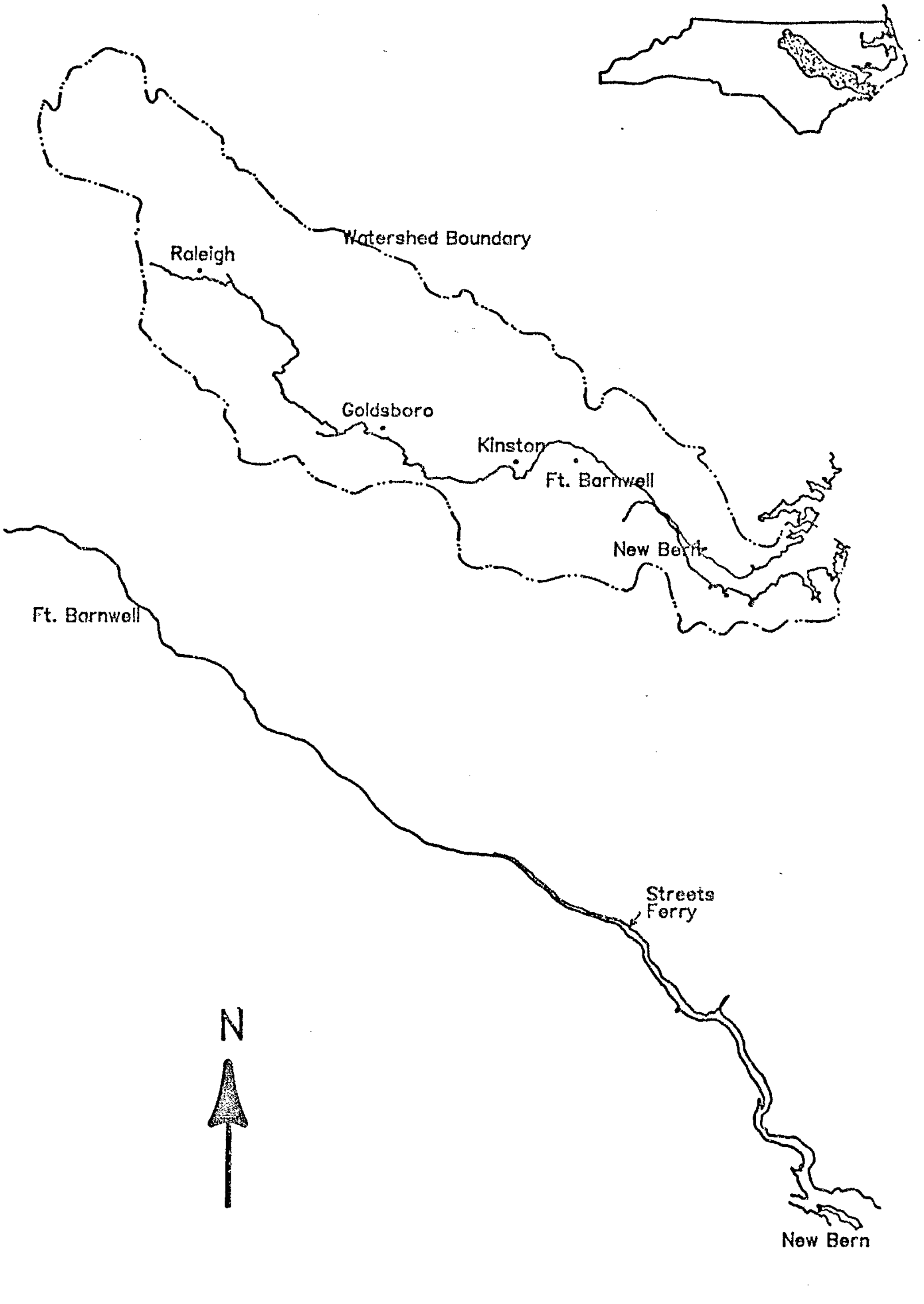


Figure 1. The Neuse River Watershed and the Study Area

BLUE-GREEN ALGAL BLOOMS IN THE LOWER NEUSE RIVER

Paerl (1) has been studying blue-green algal blooms in the lower Neuse since 1981. His data show that 1981 was a "bloom year" for blue-green algal nuisance species, dominated by the surface dwelling non-nitrogen fixing colonial species *Microcystis aeruginosa*. In contrast, 1982 turned out to be a "non-bloom year", although periods of high overall primary production as well as algal biomass occurred during 1982. The ecological responses of nuisance blooms to physical characteristics of the water column play a major part in explaining this difference. Blue-green algal blooms tend to proliferate near the water's surface, particularly during periods of low river flow and resultant stagnation (periodic vertical stratification). Sub-surface waters are severely shaded when surface blooms proliferate, thereby restricting photosynthetic potentials of underlying algae. During periods *not* dominated by blue-green algal surface blooms, increased transparency occurs throughout the water column. As a result, photosynthetically active radiation (PAR) penetrates deeper into the water column and underlying algae are able to photosynthesize. In addition, vertically mixed periods not favoring blue-green species readily allow desirable algae to be circulated into surface waters. With a larger portion of the water column receiving PAR, total primary productivity per unit area as well as chlorophyll *a* can exceed levels recorded during surface blue-green algal blooms. That is, during May and early September 1982, increased water column transparency combined with nutrient sufficiency led to aerial primary production rates as well as chlorophyll *a* levels in excess of levels recorded during blue-green algal blooms in 1981.

Paerl (1) evaluated factors affecting the bloom potential in the lower Neuse River (see Table 1). River flow is considered one of the key factors affecting the establishment of a blue-green algal bloom. Its effect was clearly demonstrated in 1983 when the summer months were characterized by low flows and warmer than usual temperatures. Physical conditions such as low flow, high sunlight, and low wind speed led to periods of thermal stratification. As a result, blooms rapidly developed, proliferated and persisted in the lower Neuse River. The observed data in 1983 shows significant blue-green blooms in July and August. The nutrient loads provided by extensive spring runoff in 1983 resulted in ample supply of nutrients for the growth of the blue-greens and other phytoplankton groups in the summer. Relatively high nitrogen concentrations throughout the year resulted in persistent dominance by a non-nitrogen fixing genus *Microcystis*.

Physical conditions in 1984 contrasted those in 1983 in that a wet summer was encountered. No significant bloom of blue-greens was observed while nutrient adequacy supported a good population of phytoplankton in the summer months. Examination of surface currents and chlorophyll *a* concentrations in 1983 and 1984 indicates that the chlorophyll *a* level decreases as currents increase, suggesting that river flow played a crucial role in initiating blooms.

Table 1. Factors Affecting the Bloom Potential

Factor	Effect
River Flow	Sustained (more than several weeks) summer low flow periods provide favorable conditions for the bloom
Temperature	Long warm summer months (June-October) favor blue-green algal blooms
Hydrodynamics	Affecting mixing, salinity intrusion, stratification and mass transport, and success of nuisance surface bloom persistence
Salinity Intrusion	Secondary impact on algal bloom by negatively affecting the growth rate of some nuisance blue-green algae (including _Microcystis_)
Turbidity	Limit the growth of diatom and green (non-surface growing algae) in deeper waters and the growth of the near surface non-buoyant blue-greens
Carbon	Dissolved inorganic carbon levels are relatively low compared to phosphorus and nitrogen in terms of requirement for algal growth
Phosphorus	Consistently high phosphorus (particularly orthophosphate) levels provide more than sufficient phosphorus for algal growth and bloom
Nitrogen	High ammonia and nitrate levels exist. What is especially crucial is the fact that nitrate sufficiency is common during the initial stages of bloom formation (May - July).

While factors in Table 1 are associated with the bloom potential, factors which limit algal growth in the lower Neuse are also worth noting. For example, Paerl _et al_. (2) suggested that salinity in excess of 2 ppt plays a role in controlling the growth of the freshwater algae in the lower Neuse. An examination of the salinity data shows that salinity intrusions reached above New Bern during the low flow periods in the summer of 1983.

MODEL DEVELOPMENT

Based on the preceding discussions, it is necessary to include the following features in the model:

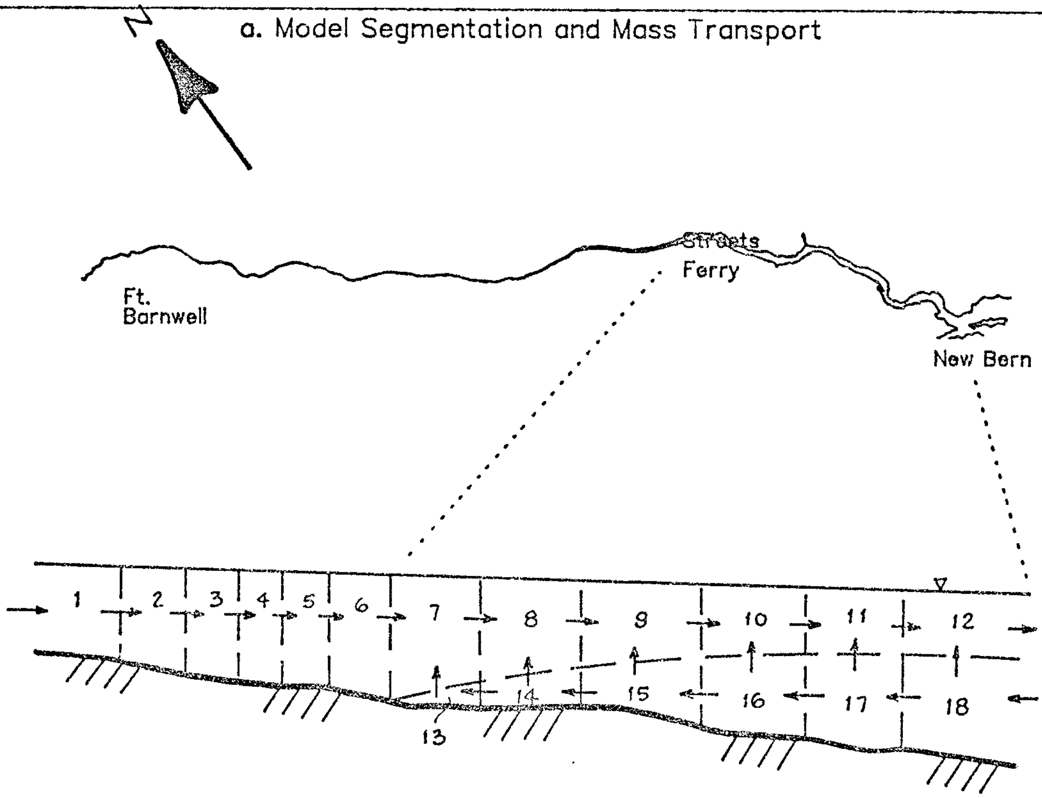
1. Time-variable simulation (tidally averaged) for seasonal variations of algal growth
2. Multiple functional groups of phytoplankton (diatoms, green algae, non-nitrogen fixing and nitrogen fixing blue-greens)
3. Two layer mass transport in estuarine and tidal portions of the lower Neuse River to characterize the surface-dwelling blue-greens in the surface layer
4. Salinity effects on growth rates of freshwater algae.

Like many other estuarine eutrophication models (3,4,5,6), the Neuse Estuary eutrophication model is based on the principle of conservation of mass. The modeling framework developed in this study is made up of three components--transport, due to freshwater flow and dispersion, kinetic interactions between variables, and external inputs. Descriptions of these components are presented below.

Model Segmentation and Mass Transport -- The study area from Ft. Barnwell to New Bern (the portion of the river with repeated blooms) was divided into 18 segments, the first 6 being in the riverine portion of the model, segments 7 through 12 being the surface layer and segments 13 through 18 the bottom layer (Figure 2a). Each segment was considered completely mixed. Figure 2a shows the mass transport pattern on a tidally averaged basis. The reverse flows in the two-layer structure occurred during summer 1983 when low freshwater flows caused salinity intrusion. In 1984, however, a reverse flow pattern was not necessary for the model because the increased flow in the summer pushed salinity downstream of the study area. A simple and efficient method of analysis of this type of mass transport has been developed by O'Connor and Lung (7,8) for partially mixed estuaries.

Model Variables and Kinetics -- Due to some data limitations, the model includes as few state variables as possible while mimicking the growth dynamics associated with multiple functional groups of algal species. As a result, the following eleven state variables were incorporated into the model framework:

(1) Diatom chlorophyll a
(2) Green algal chlorophyll a
(3) Non-nitrogen fixing blue-green algal chlorophyll a
(4) Nitrogen fixing blue-green algal chlorophyll a
(5) Organic nitrogen



a. Model Segmentation and Mass Transport

b. Kinetics

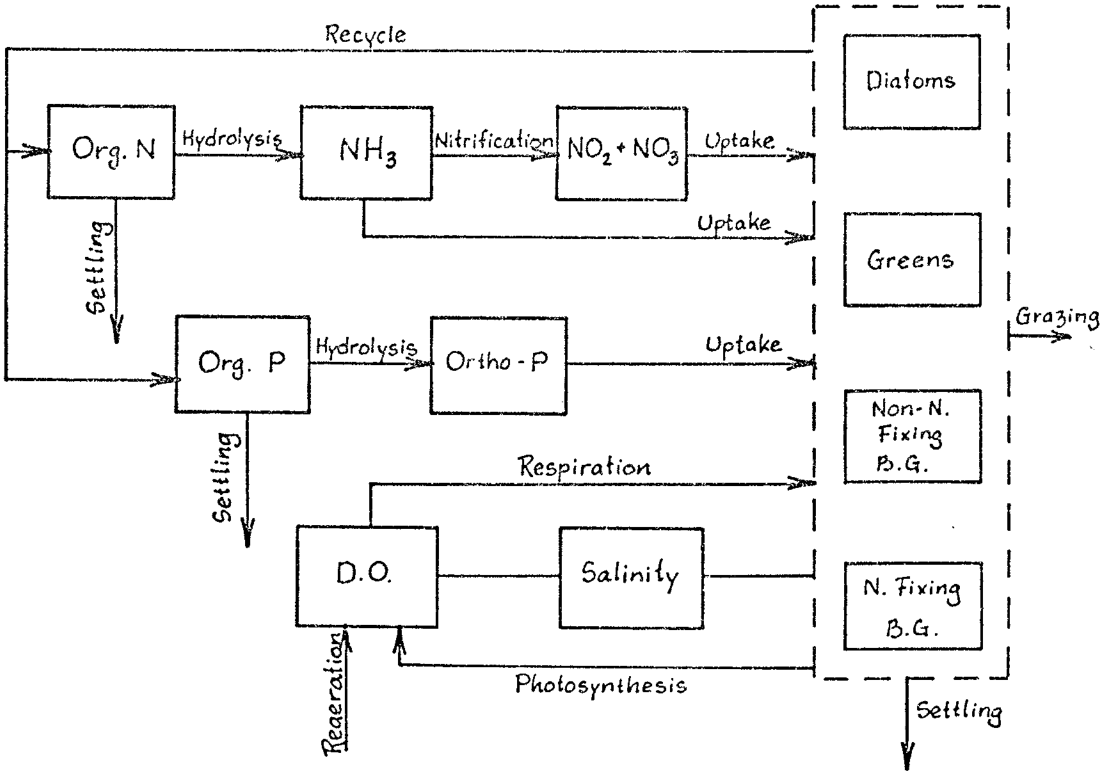


Figure 2. Model Segmentation/Mass Transport/Kinetics

(6) Ammonia nitrogen
(7) Nitrite and nitrate nitrogen
(8) Organic phosphorus
(9) Orthophosphate
(10) Salinity
(11) Dissolved oxygen

Other variables, derived from these primary variables, were also tracked through the lower Neuse River. The most important secondary variables included total phytoplankton chlorophyll a, total nitrogen and total phosphorus.

Figure 2b shows the principal kinetic interactions for the nutrient cycles, dissolved oxygen, and four algal functional groups. While a complete description of the model's kinetics can be found in another document (9), only the salient features of the model kinetics are described in the following paragraphs.

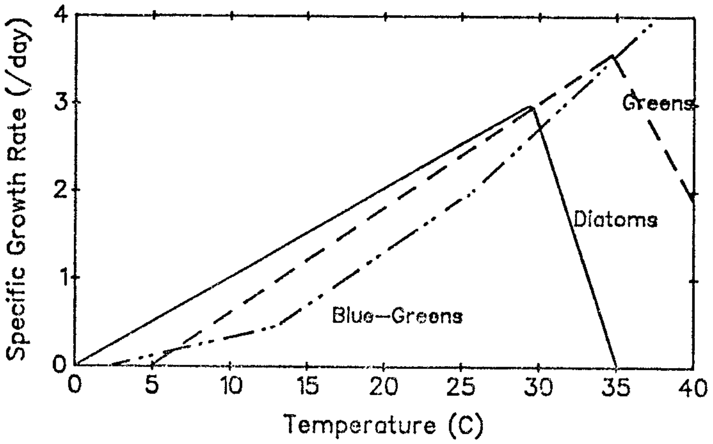
Orthophosphate is utilized by algae for growth. Phosphorus is returned from the phytoplankton biomass pool to organic phosphorus and to orthophosphate through re-excretion and non-predatory mortality. Organic phosphorus is converted to orthophosphate via microbial-mineralization and hydrolysis at a temperature dependent rate.

The kinetics of the nitrogen species are fundamentally the same as these for phosphorus. Ammonia and nitrate are used by phytoplankton for growth. Nitrogen is returned from algal biomass and follows pathways similar to phosphorus. Organic nitrogen is converted to ammonia via hydrolysis and mineralization at a temperature dependent rate, while ammonia is converted to nitrate (nitrification) at a temperature dependent rate.

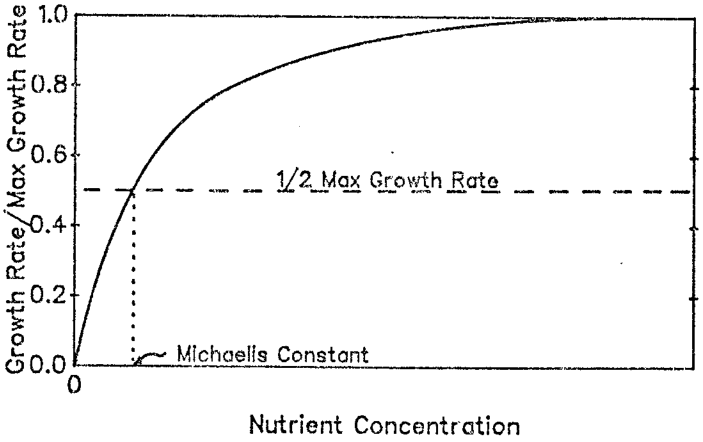
Dissolved oxygen is coupled to other system variables. The sources of oxygen considered are reaeration and evolution by phytoplankton photosynthetic production. Sinks of dissolved oxygen are algal and bacterial respiration, oxidation of detrital carbon, nitrogen, and phosphorus and carbonaceous material from waste effluents and nonpoint discharges, sediment oxygen demands, and nitrification, if any. The reaeration process is formulated in such a way that during dissolved oxygen supersaturation periods, oxygen can be lost to air.

Algal growth and death kinetics are formulated for each algal group on an individual basis. Growth rates are a function of temperature, light, nutrient concentration and salinity level. Growth rates are directly related to temperature in moderate climates. Auer and Canale (10) and Canale and Vogel (11) summarized data from phytoplankton growth experiments conducted at various temperatures. Their results, plotted as the solid and dashed lines in Figure 3a, illustrate the different temperature optimums for different phyla of phytoplankton and also the differences in the way temperature influences growth rate.

a. Growth Rate as Function of Temperature
(from Reference No. 10)



b. Nutrient Effect on Algal Growth Rate



c. Salinity Effect on Algal Growth Rate

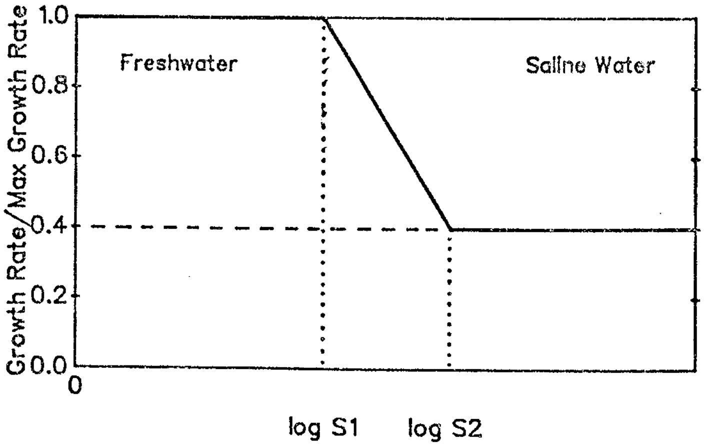


Figure 3. Effect of Temp/Nutrient/Salinity on Algal Growth

Phytoplankton growth rates are also dependent on light intensity up to a saturating condition, greater than which it may decrease with light (12). Because light energy available to phytoplankton varies with depth and time of day, an appropriate expression of light availability for use in analyses should account for these changes as follows (12):

$$r_L = \frac{2.718f}{KeHT}\left(e^{-\frac{I_f}{I_s}e^{-KeH}} - e^{-\frac{I_f}{I_s}}\right) \qquad (1)$$

where r_L = light limitation factor
f = photoperiod - daylight fraction of averaging period
T = averaging period (1.0 day)
Ke = light extinction coefficient (1/ft)
H = average depth of segments (ft)
I_a = average of incident light on water surface over 24 hour day
I_f = average of incident light over photoperiod ($=I_a/f$)
I_s = saturated light intensity

Growth rates are also a function of nutrient concentrations up to saturation. Such a relationship is described by a Michaelis-Menton formulation, whose significant parameter is that concentration at which the growth rate is equal to one-half of that at the saturated concentration (Figure 3b). When both nitrogen and phosphorus are utilized, growth rates are assumed to be proportional to the product of the Michaelis expressions for each of the nutrients. In the lower Neuse River, silica is not considered a limiting nutrient for diatoms and therefore is not included in the model. The Michaelis constant (half-saturation concentration) values usually range from 5 μg/l to 25 μg/l for nitrogen and from 1 μg/l to 5 μg/l for phosphorus, depending on the species. In the model, different Michaelis constant values are allowed for different phytoplankton functional groups.

There is a general consensus that most freshwater algal species exhibit a decrease in biomass in low salinity waters (2,13,14,15). In the model, the salinity effect is quantified using specific algal thresholds for salinity (Figure 3c). The thresholds (salinity in parts per thousand, ppt) describe that particular algal species' tolerance to saline conditions. The growth rate is not affected by salinity until the salinity level in the water column reaches the first thresholds, S_1. The salinity reduction factor (i.e., ratio of growth rate to maximum growth rate) decreases linearly between log S_1 and log S_2. When the salinity reaches the second threshold, S_2, the growth rate is significantly reduced to a minimum level. In the model, the values of 1 ppt and 2 ppt are used as S_1 and S_2, respectively, while the minimum growth rate/maximum growth rate is set at 0.4. These values are based on observations showing a narrow range of salinity tolerance for freshwater algal species (16).

Decreases in algal biomass concentrations are brought about by three processes: algal respiration, death, grazing, and algal settling.

Computational Framework and Effort -- A set of variables, interactions and numerical specifications within the context of the lower Neuse River has been developed in the form of a set of interactive equations in time and space. In order to calculate the levels of the system variables, a computational scheme or framework must be used. In this modeling study, the Water Quality Analysis Simulation Program (WASP) first developed by Hydroscience, Inc. and later documented for U.S. EPA (17) was used.

The Neuse Estuary Eutrophication Model (NEEM) was run on a Compaq microcomputer system installed with an 8087 math co-processor. The IBM Professional FORTRAN was used to compile the program. A one-year simulation run of the model took 5.5 hours on the Compaq. The results from the model runs were processed using a Hewlett-Packard 7470A personal computer plotter.

MODEL CALIBRATION AND SENSITIVITY ANALYSIS

Derivation of Model Input -- During summer 1983, freshwater flows in the lower Neuse River were relatively low, resulting in salinity intrusion into the study area. The simplified method developed by Lung and O'Connor (8) was employed to derive the two-layer transport pattern for the summer of 1983 using the data on freshwater flows (from the U.S.G.S. surface water records) and salinity distribution of the lower Neuse. That is, time-variable two-layer transport patterns were developed in a 15-day interval for input to the model. The derived mass transport patterns were eventually validated by reproducing the salinity distribution in the lower Neuse on a time-variable basis. Figure 2a shows one of the transport patterns derived for the summer of 1983. The freshwater flow is in the downestuary direction in the upper layer and the upestuary flow is in the bottom layer. The sum of the horizontal flows is equal to the net freshwater flow at any given location. Vertical flows (in the upward direction) are introduced to maintain the hydraulic balance (see Figure 2a). Such an effort is not needed for the 1984 calibration as salinity did not reach the study area in 1984.

The model coefficients associated with algal growth are derived using data from the Institute of Marine Sciences, University of North Carolina. First, the temperatures of the water column (in a two-layer fashion) were obtained from temperature measurements in the field. Similarly, surface light intensity (as photosynthetically active radiation (PAR), the light energy of wavelengths between 400 and 700 nm) is also obtained from the field data. The photoperiod as a function of time over the year was derived from climatological data at Kinston. The penetration of light in the water column is limited by suspended materials such as clay and silt particles, by colored dissolved organic matter of humic nature and by phytoplankton. Available measurements of light intensity at different depths in the water column were used to derive light extinction coefficient values. In addition, self-shading of algal biomass is eliminated in the derivation. The resulting value is input into the model which calculates the algal self-shading effect, particularly due to surface gathering blue-greens during the bloom period and adds to the light extinction due to suspended particles. Light extinction is formulated such that the total light extinction for the diatoms and greens also included the shading effect due to the blue-greens as the blue-greens usually stay near the water surface during the blooms. Other model parameters and coefficients related to algal growth and nutrient interactions are derived from laboratory and field empirical estimates reported in the literature. Their values for the Neuse Estuary Eutrophication Model are summarized in Table 2 along with the values for other estuarine systems.

Finally, the boundary conditions, initial conditions, and waste loads were directly obtained from data collected in 1983 and 1984.

Model Calibration of 1983 Data -- The model was first calibrated using the hydrologic and environmental conditions of 1983. The results of modeling analyses are presented in Figure 4 for four different locations along the estuary. Only model results from surface segments are presented because the bottom segments do not support significant algal growth. In Figure 4, a comparison between the observed data and model results is presented for the key water quality variables: NH_4^+, $NO_2^- + NO_3^-$, orthophosphate, salinity, total chlorophyll a, and dissolved oxygen. In general, the model results match the data for all six variables reasonably well. The model shows that orthophosphate is always in adequate supply for phytoplankton growth throughout the year. Nitrogen supply (NH_4^+ and $NO_2^- + NO_3^-$) prior to the blue-green blooms appears sufficient. During the bloom period, nitrate levels reduce significantly while ammonia nitrogen concentrations remain high during the peak of the bloom period. The elevated ammonia levels between Stations 74 and 52 is most likely due to Weyerhauser's input although nitrogen recycling from algal biomass may also contribute to the increase.

The two-layer mass transport pattern reproduces temporal and spatial salinity distributions very well, suggesting that the mass transport pattern is valid. An increase in salinity in the downstream area (Station 52) beginning around day 195 is reproduced. Elevated salinity levels reduce the phytoplankton growth rates in both surface and bottom layers slightly. High dissolved oxygen levels at the beginning of the year are followed by gradual decreases as the temperature of the water column increases. Such a steady drop in dissolved oxygen is due to the decrease of saturation dissolved oxygen levels as temperature increases. By mid-year, the dissolved oxygen starts to increase as a result of the increase in algal photosynthesis.

Table 2. Phytoplankton and Nutrient Kinetics Coefficients

Parameter	Units	Sacramento Delta	Patuxent Estuary	Potomac Estuary	James Estuary	Neuse Estuary
Saturating Light Intensity	langley/day	300	350	300	300	200 * 100 **
Saturated Growth Rate	/day @ 20°C	2.5	2.4	2.0	2.0-2.5	+
Endogenous Respiration Rate	/day @ 20°C	0.1	0.125	0.125	0.1	0.1
Death Rate	/day @ 20°C	--	0.125	0.02	0.1	0.05
Settling Velocity	ft/day	--	--	0.3	0.75	1.31* 0.49**
Michaelis Constant (P)	mg/l	--	1.0	1.0	1.0	5.0
Michaelis Constant (N)	mg/l	25.0	5.0	25.0	5.0	25.0[@]
Salinity Thresholds	ppt	1.0-4.0	--	--	--	1.0,2.0
Maximum Salinity Effect		0.4	--	--	--	0.4
Carbon/ Chlorophyll	mg/mg	50	50	50	25	50
Nitrogen/ Chlorophyll	mg/mg	7	7	10	7	7
Phosphorus/ Chlorophyll	mg/mg	--	1	1	1	1
Oxygen/ Chlorophyll	mg/mg	--	133	-	66.75	66.75
Org.N Hydrolysis Rate	/day @ 20°C		0.02	0.075	0.10~ 0.15	0.1
θ for Hydrolysis Rate	unitless		1.045	1.08		1.08
Org.P Hydrolysis Rate	/day @ 20°C		0.02	0.22	0.05~ 0.10	0.1
θ for Hydrolysis Rate	unitless		1.045	1.08		1.08
Nitrification Rate	/day @ 20°C		--	0.09~ 0.13	0.05~ 0.15	0.05

* diatoms, greens
** blue-greens
\+ see Figure 3a
@ no nitrogen limitation for the nitrogen-fixing blue-greens

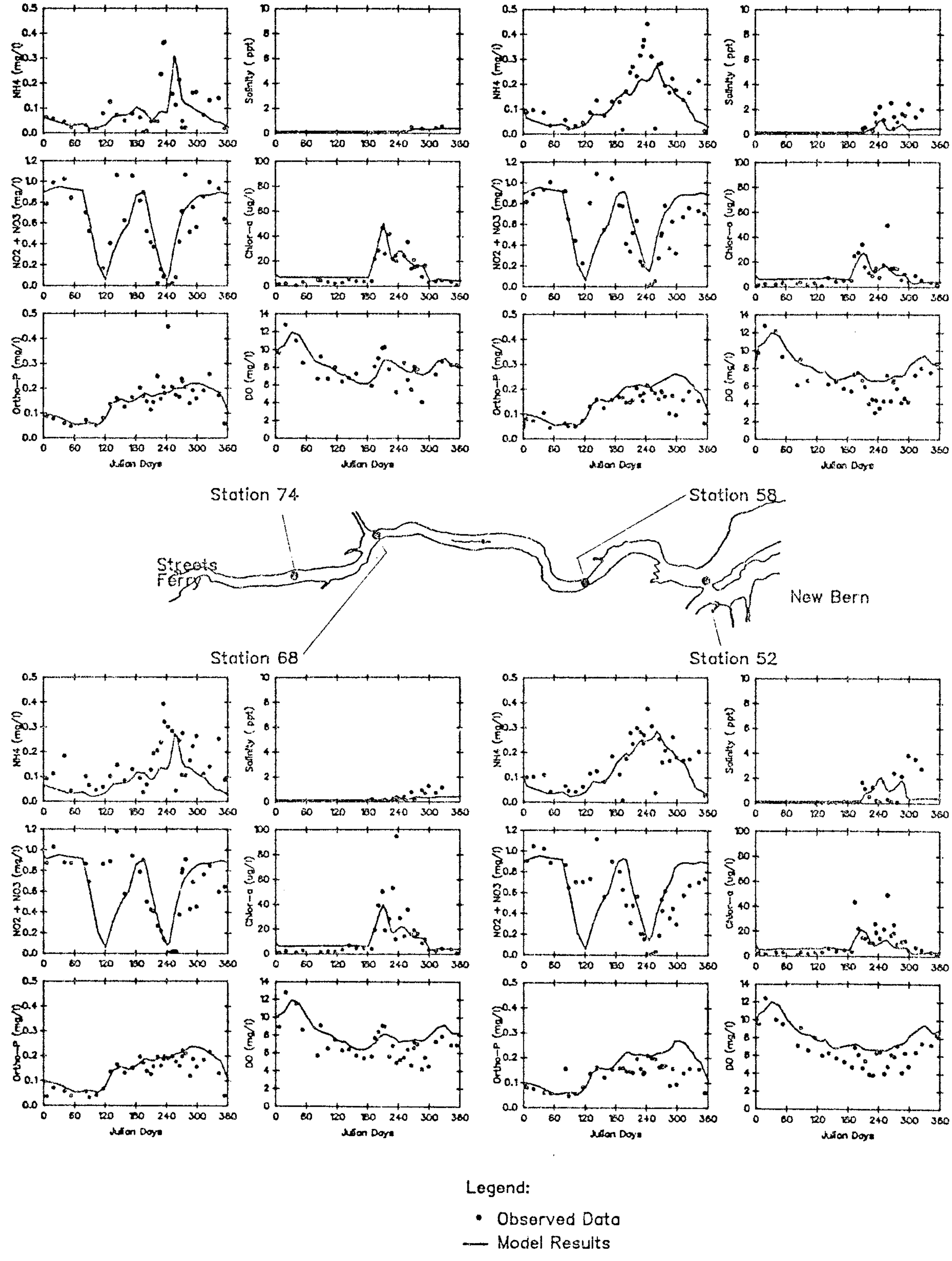


Figure 4. Model Calibration of 1983 Data

A quick calculation proves that this is indeed what the model is simulating. Based on an oxygen to chlorophyll a ratio of 66.75 mg O_2/mg Chl used in the model (see Table 2), a net increase in phytoplankton chlorophyll a of 50 µg/l around day 195 (see Station 74 in Figure 4), would result in a production of 3.34 mg/l of dissolved oxygen. The increase in dissolved oxygen calculated by the model at day 195 is very close to this value.

Figure 5 presents a close comparison between the model calculated and observed chlorophyll a levels for four different groups of phytoplankton: diatoms, greens, non-nitrogen fixing blue-greens, and nitrogen fixing blue-greens. Data and model calculations indicate that the non-nitrogen fixing blue-green algae are the dominating group. Diatoms are active in the early spring but are progressively replaced by the blue-greens. During blue-green algal blooms, diatoms do not thrive, primarily because surface dwelling blue-greens reduce the amount of light that is available to the diatoms. The model mimics this effect by including the shading of the blue-greens over the diatoms and greens, thereby reducing the available light for these two groups during the blue-green blooms.

Model Calibration of 1984 Data -- The Neuse Estuary Eutrophication Model was then applied to analyze the 1984 data. The same kinetic constant and coefficient values used in the 1983 model analysis were used for the 1984 analysis. Only exogenous variables such as river flow, light extinction coefficient, average daily surface light intensity, temperature, and the mass transport pattern were changed according to the 1984 condition. The results of the model analysis are presented in Figure 6. In general, the model results match the observed data very well. The results of model analyses are encouraging since the 1984 hydrologic conditions are quite different than those exhibited in 1983. That is, the summer flow in 1984 is significantly higher than that in 1983; the salinity intrusion did not reach the study area in 1984. The model calculations, based on revised mass transport patterns (no upestuary flow in the bottom layer), are able to reproduce the salinity distributions in 1984. In addition, the summer temperature in 1984 is slightly lower than that in 1983. As a result, no blue-green bloom occurs under the 1984 condition although the nutrient concentrations are more or less the same levels as those observed in 1983.

Model Sensitivity Analyses -- Since nutrients are usually in sufficient supply for the algal growth in the lower Neuse, the sensitivity analyses focus on other parameters associated with phytoplankton growth and death. The 1983 calibration is used as a basis in the sensitivity analyses. The phytoplankton endogenous respiration rate is estimated for the model input as 0.1/day based on literature values. Running the model with a range of endogenous respiration rates from 0.08/day to 0.125/day (Table 2) indicates that there is no significant change in any of the system variables modeled. Thus, the

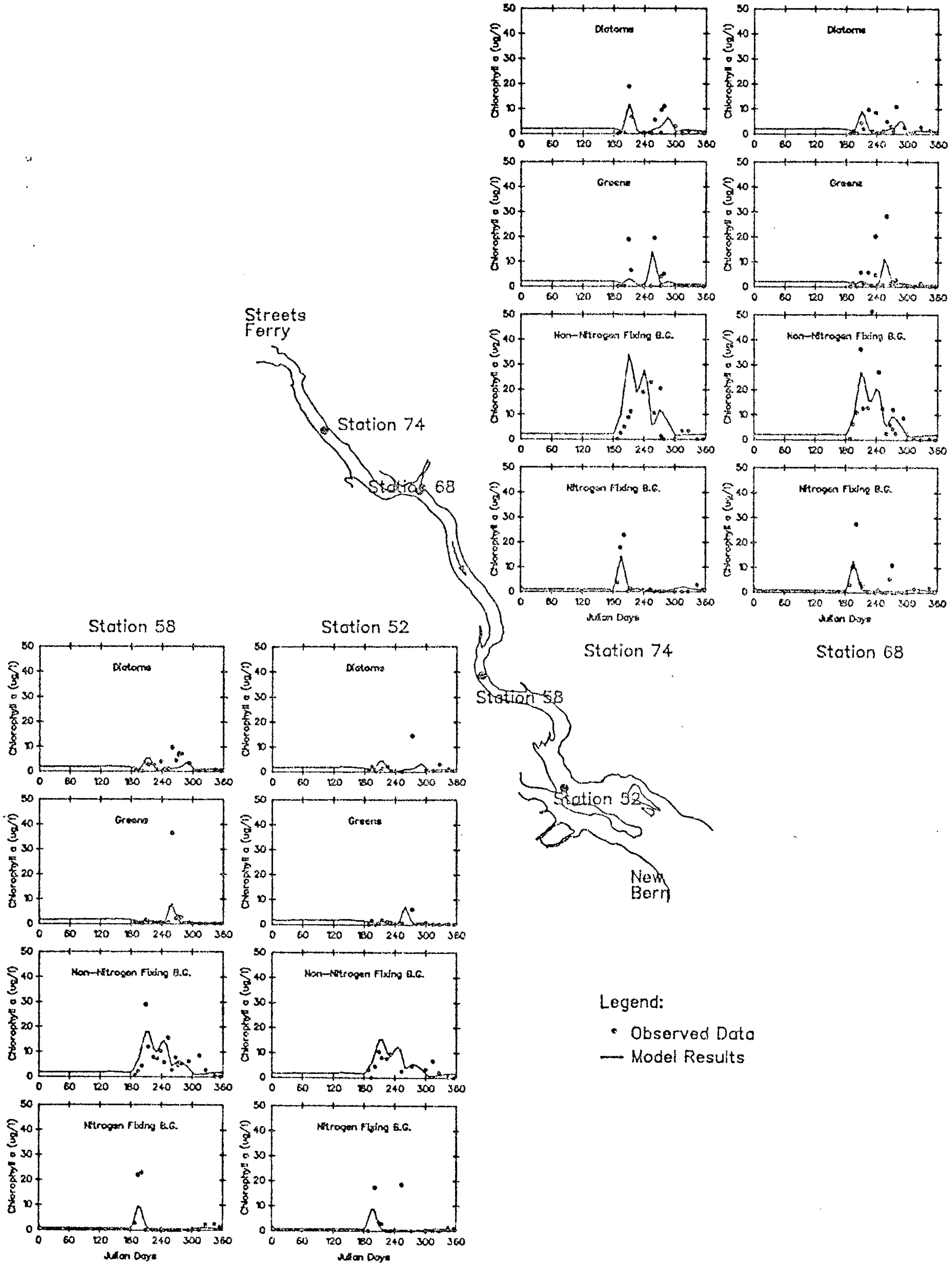


Figure 5. Model Calibration of Algal Species Data, 1983

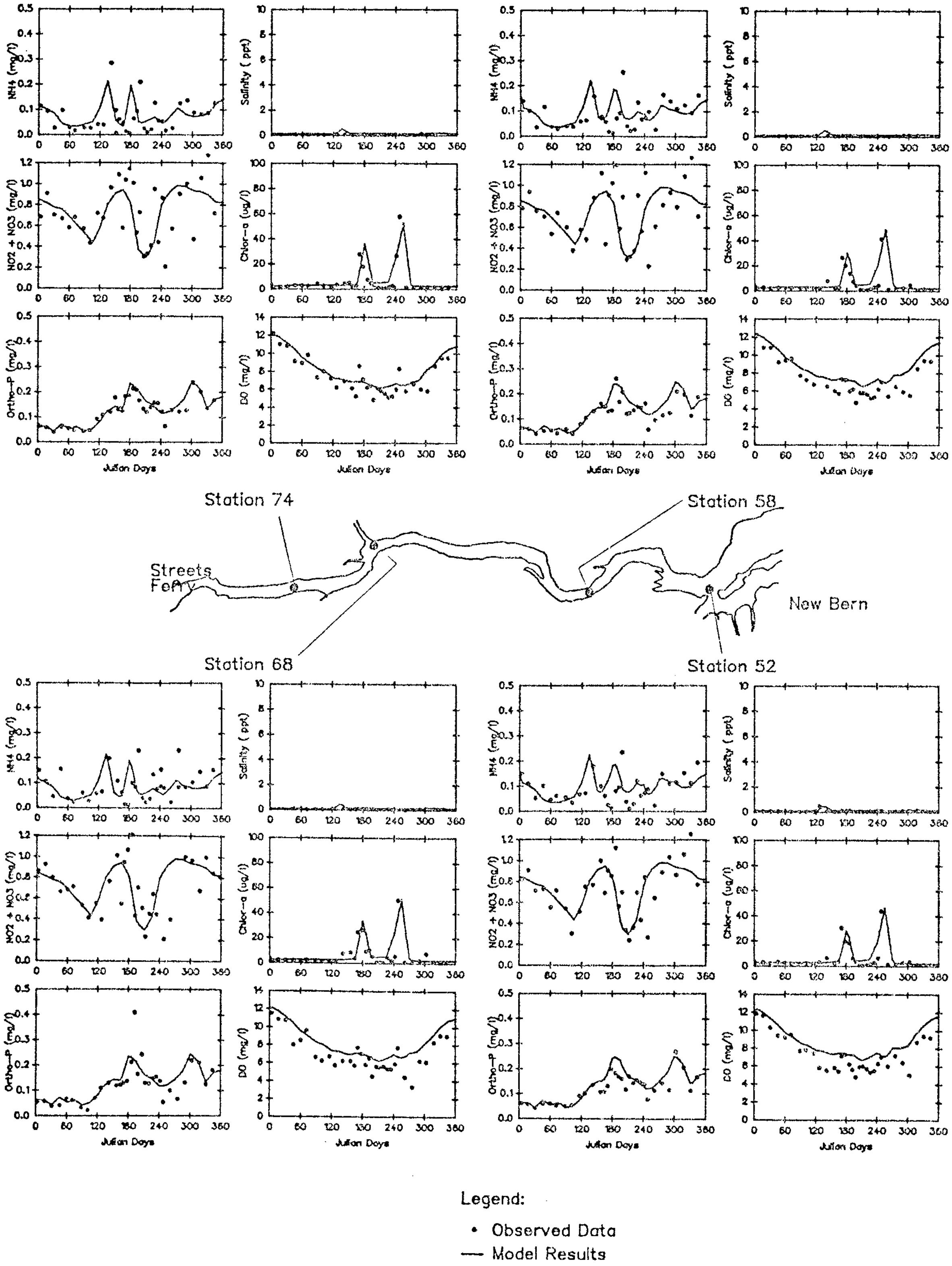


Figure 6. Model Calibration of 1984 Data

value of 0.1/day is considered acceptable for all four phytoplankton groups in the modeling analysis. Next, the non-predatory death rate of phytoplankton was varied from 0.02/day to 0.1/day (Table 2) in the model while the model calibrations use a value of 0.05/day. Again, the model sensitivity analysis shows no significant changes in the model results resulting from the variations. Perhaps the most significant factor in the phytoplankton growth may be the light extinction coefficient in the water column. A variation of ± 50% of the light extinction coefficient, Ke, in the model results in modest changes in model calculations. The Ke values used in the model calibration appear to be most appropriate to reproduce all system variables concurrently.

DISCUSSIONS

The model calibration results are consistent with the hypothesis for the cause of blue-green blooms in the lower Neuse as stated earlier in this paper. That is, the initiation of the blue-green algal blooms is strongly regulated by the nutrient supply from the spring months as well as the river flow condition in the summer months. Both 1983 and 1984 had relatively high runoff in the spring. However, the summer of 1983 was characterized by very low flow, warmer than usual temperature and calm weather. On the other hand, the 1984 summer was relatively wet. As a result, blue-green blooms occurred in the summer of 1983 but not the summer of 1984. The Neuse Estuary Eutrophication Model (NEEM) is able to mimic these trends reasonably well.

To put the proposed hypothesis into a better perspective, one may examine the observed trends in 1985. Preliminary data collected by the Institute of Marine Sciences, University of North Carolina indicates no Microcystis bloom in 1985 in which a dry spring followed by a moderately wet summer was recorded. It will be interesting to see whether NEEM would be able to reproduce the observed data in 1985. Model calibration work is under way to analyze the 1985 condition. A successful reproduction of the 1985 data by the model would further validate the above hypothesis and would provide additional confidence in the modeling framework.

SUMMARY AND CONCLUSIONS

An estuarine eutrophication model has been developed to predict and quantify blue-green algal blooms in the lower Neuse River, North Carolina. Important features of the model include four functional groups of phytoplankton: diatoms, greens, non-nitrogen fixing blue-greens, and nitrogen fixing blue-greens; a two-layer mass transport pattern to characterize the surface dwelling blue-greens; and the effect of salinity on algal growth. In addition, each of the two layers in the water column is further divided into six longitudinal segments to account for the concentration gradients of the water quality constituents. Water quality constituents simulated by the model are separate chlorophyll a levels associated with the four algal groups, organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogen, organic phosphorus, orthophosphate, dissolved oxygen, and salinity. Biochemical, biological, and chemical interactions between the water quality constituents are incorporated into the model to quantify phytoplankton growth and death, algal species competition, nutrient uptake and recycling, and photosynthetic reproduction and respiration of oxygen by algae.

A large data base consisting of water quality data in 1983 and 1984 was used in the model development, model calibration, and sensitivity analyses. The modeling framework is able to reproduce the data of both years very well. Further, the model results confirm a hypothesis that the initiation of the blue-green blooms is strongly regulated by river flow and the associated nutrient conditions in the spring and summer months. The calibrated model can be used to evaluate water quality management scenarios for the Neuse River. Finally, the model may also improve existing sampling strategy by pointing out data gaps.

ACKNOWLEDGEMENT

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