PRACTICAL TOOLS FOR ESTUARINE NUTRIENT CONTROL

Wu-Seng Lung

Department of Civil Engineering
University of Virginia
Charlottesville, Virginia

Introduction

Nutrient control has become a commonly used measure to reverse eutrophication for many estuaries in the United States. While nutrient control will reduce nutrient loads to an estuarine system, it is not clear to what extent that load reductions will impact the water quality of the estuary. For example, a phosphorus control program may only reduce phosphorus concentrations but not necessarily the phytoplankton biomass. The nutrient effect on phytoplankton, therefore, is a marked contrast to other types of water quality problems where reductions in input load (as in BOD reduction) can generally be considered as being advantageous. Given the expensive nature of nutrient control programs, it is wise to evaluate various control alternatives prior to selecting and implementing one. Estuarine water quality models are useful tools which can be used to evaluate control alternatives and assist decision-making in establishing a sound nutrient control strategy.

In this paper, two estuarine modeling studies are presented to demonstrate the use of models to guide nutrient controls. The first study uses a one-dimensional tidally averaged steady state model for the upper James River Estuary in Virginia. In that study, phytoplankton growth and nutrient dynamics are approximated as a seasonal event, an approximation particularly valid under summer low and steady flow conditions. The model was used to evaluate point source phosphorus control alternatives in the James River Basin and assess the water quality impacts by comparing the reduction of summer peak chlorophyll _a_ levels in the estuary.

The second modeling study is development of a model for blue-greens algal blooms in the lower Neuse River in North Carolina. The study area is a tidal and estuarine portion of the river with repeated blue-green algal blooms during the past decade. Spring/summer/fall blooms at times coat the river with green paint-like blooms. The water quality model developed includes four different algal groups (diatoms, greens, non-nitrogen fixing and nitrogen fixing blue-greens) in addition to nutrients and dissolved oxygen. Seasonal variations of phytoplankton nutrient dynamics are simulated on a tidally averaged time-variable basis. The model is able to mimic the observed phytoplankton growth in 1983, 1984, and 1985 with different hydrologic conditions. Based on the modeling results, a hypothesis for the initiation and maintenance of blue-green blooms has been developed.

Evaluating Phosphorus Controls in the James River Basin

Concerns on accelerated eutrophication in the Chesapeake Bay and its tributary estuaries (Figure 1) have been widespread in recent years. One of the control alternatives to reverse eutrophication is reduction of point source phosphorus loads (primarily from municipal wastewaters) to the Bay. The James River basin in Virginia contributes a significant amount of phosphorus loads to the Bay, ranging from 24 % to 36 % (Figure 2) depending on the hydrologic conditions (Lung, 1986a). One of the reasons that the James River basin has such a high phosphorus input is that none of the publicly owned treatment works (POTWs) in the basin currently practice phosphorus removal. In addition, there is no other form of nutrient control existing in the James River basin. As a result, approximately 15% to 30% of the total phosphorus loads to the Bay, again depending on the hydrologic conditions, are from the POTWs in the James River basin.

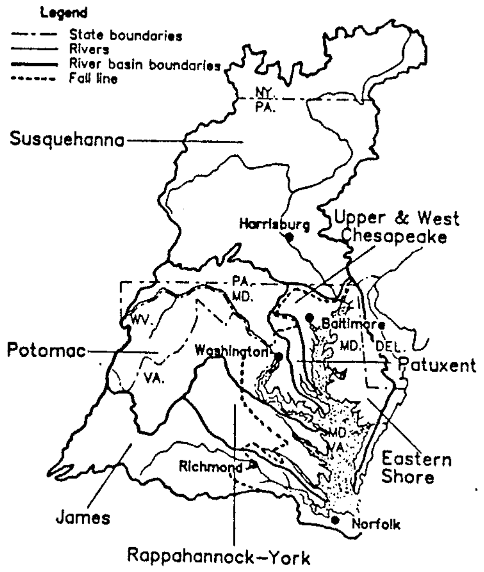

Figure 1. Chesapeake Bay drainage basin

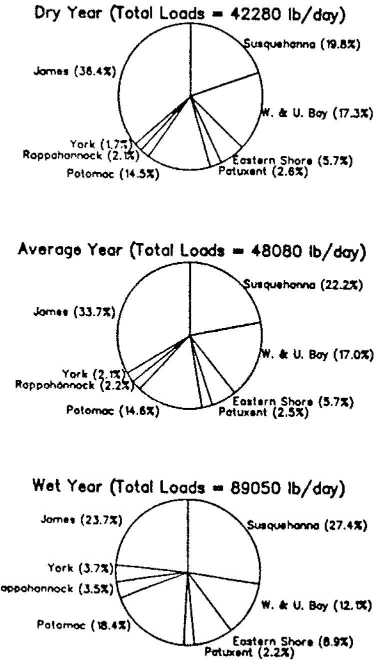

Figure 2. Phosphorus loads to Chesapeake Bay

In the past few years, point source phosphorus control programs at POTWs have been contemplated for the James River basin as part of the overall effort to control eutrophication in the Chesapeake Bay. The foremost question raised by any phosphorus control program is: what response, in terms of phytoplankton biomass levels, can be expected as a result of phosphorus control programs?

A modeling study was conducted to put this question into perspective through an analysis of the most recent water quality data and through a series of mathematical modeling simulations designed to show trends in peak phytoplankton biomass levels in the upper James River Estuary as a function of alternative loading scenarios. The study employed an existing water quality model of the upper James River Estuary to assess the water quality impacts of potential point source phosphorus control programs.

Since a detailed presentation of the model results can be found elsewhere (Lung, 1986b), only the salient features of the model results are summarized in this paper. Figure 3 shows the model calibration using two recent data sets collected in 1983. The model calculations match the observed data reasonably well. Subsequent model sensitivity analyses substantiated the calibration (Lung, 1986b). Note that the relatively higher flow in July slightly reduced the nutrient concentrations as compared with the September concentrations. Further, the July condition (associated with an average freshwater flow of 2,200 cfs near Richmond) supported a phytoplankton biomass peak near river mile 70 while the September condition (at a lower freshwater flow of 1,100 cfs) moved the peak further upstream to river mile 75 (see Figure 3).

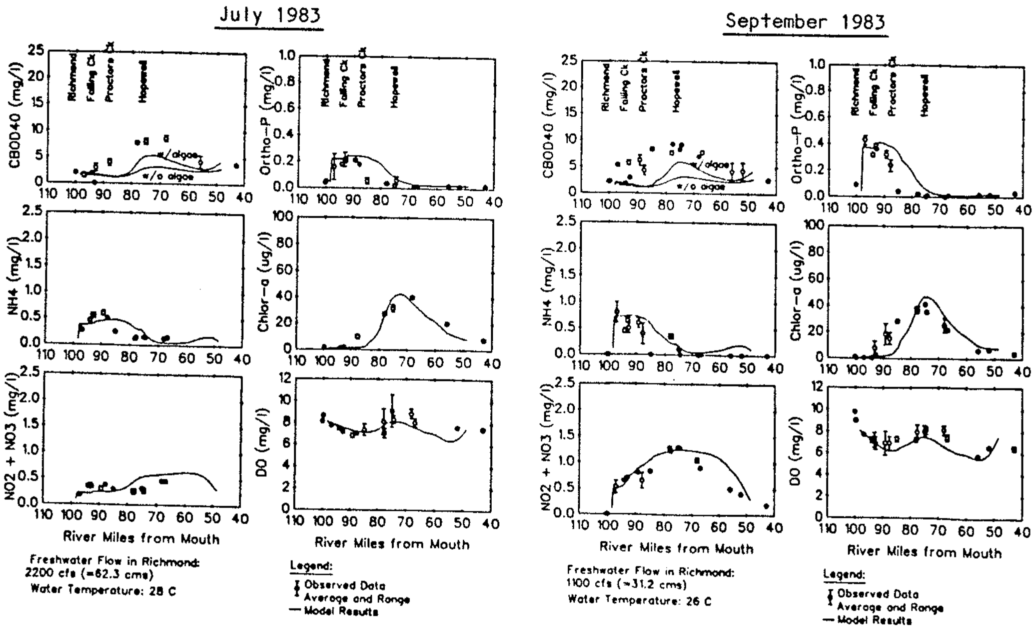

Figure 3. Upper James River Estuary model calibration - July and September, 1983

Next, the question of nutrient limitation can be explored using the calibrated model. Neither nitrogen nor phosphorus were limiting the growth rate since the Michaelis-Menton limitation ratios were found to be close to 1.0 (no reduction in growth rate). The results indicate that nutrients are in sufficient supply in the upper James River Estuary to initiate phytoplankton growth reaching modest peak chlorophyll a levels. At the same time, high turbidity in the estuary prevents further growth by limiting the light available for algal growth (Lung, 1986b).

A number of phosphorus control alternatives for the POTWs in the James River basin were evaluated using the calibrated model. They ranged from phosphate detergent bans in the basin to phosphorus removal at POTWs. It is expected that phosphate detergent bans would reduce phosphorus levels at POTWs about 15-25%, depending on the characteristics of the localities (Lung, 1985). The POTW effluent phosphorus concentrations considered in the phosphorus removal scenarios are 2 mg/l, 1 mg/l, 0.5 mg/l, and 0.1 mg/l, respectively. The model projection runs were conducted at the 7-day 10-year low flow condition associated with a water temperature of 28°C. The model projections results, which are summarized in Figure 4, indicate that under the 7-day 10-year low flow conditions, phosphate detergent bans are expected to reduce the peak chlorophyll a levels in the James River Estuary from the existing 70-79 μ g/l to 61-72 μ g/l. Greater reduction of chlorophyll a levels may be achieved by removing phosphorus at POTWs. Phosphorus removal would reduce the peak chlorophyll a levels by 50% if a phosphorus limit of 2 mg/l is applied. Additional reduction in peak chlorophyll a levels may be achieved with effluent limits of 1 mg/l, 0.5 mg/l, and 0.1 mg/l. That is, phosphorus limitation starts to show under the phosphorus removal scenarios.

Under the phosphorus removal scenarios inorganic nitrogen (NH_3, NO_2^- + NO_3^-) would increase in the downstream direction because they would not be utilized by the reduced algal biomass. This result raises an interesting question: would phosphorus removal cause nitrogen increase and associated algal growth in the lower estuary and the Chesapeake Bay? A related management question is whether dual control of nutrients is required to control the Bay eutrophication. The modeling results suggest that further studies of dual control of phosphorus and nitrogen at POTWs are needed.

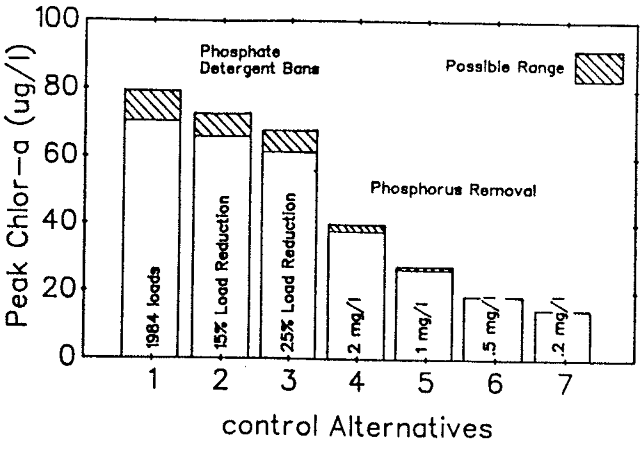

Figure 4. Effect of phosphorus load reduction

Modeling Blue-Green Algal Blooms in the Neuse River Estuary

Questions arising during considerations of management options for controlling eutrophication in the Neuse River Estuary (Figure 5) have included:

- Would major reductions of nutrient (nitrogen and/or phosphorus) inputs (either from point or nonpoint sources) to the Neuse Estuary 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 the nuisance blue-green algal bloom potential on the Neuse Estuary?

To help address these questions, a mathematical model of the Neuse Estuary has been developed. The modeling effort focuses on the understanding of the mechanisms initiating and sustaining algal blooms in the Neuse Estuary.

Figure 6 shows the model segmentation, mass transport, model variables, and kinetics. A complete description of the model design can be found in another document (Lung and Paerl, 1986). The model has been calibrated using data collected in 1983 and 1984. Due to space constraints, only the results of 1983 calibration are presented (Figure 7). Both model results and observed data indicate that orthophosphate ia always in ample supply for algal growth throughout the year. Nitrogen supply preceding the algal blooms appears sufficient. During the bloom period, ammonia and nitrate levels are reduced significantly. The two-layer mass transport pattern reproduced temporal and spatial salinity distributions very well, suggesting that the mass transport pattern is valid. Figure 8 presents a close comparison between calculated and measured chlorophyll a levels in 1983 for four different groups of phytoplankton. Non-nitrogen fixing blue-green algae are the dominating group. Diatoms are dominant during early spring but are progressively replaced by the blue-greens during the blooms.

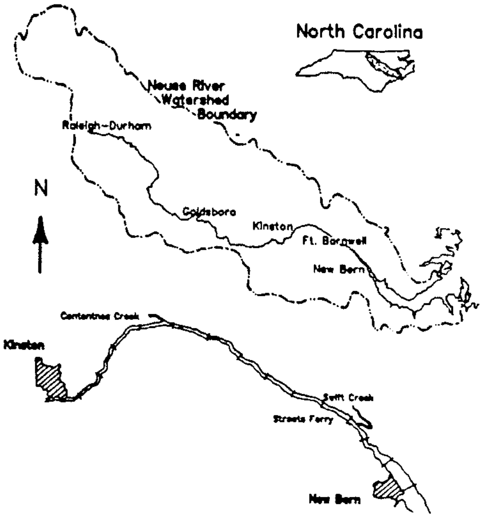

Figure 5. Neuse River Estuary

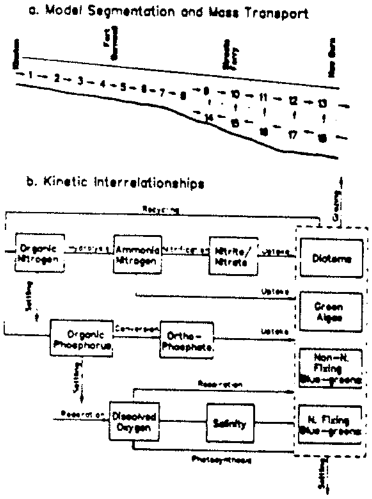

Figure 6. Neuse Estuary model

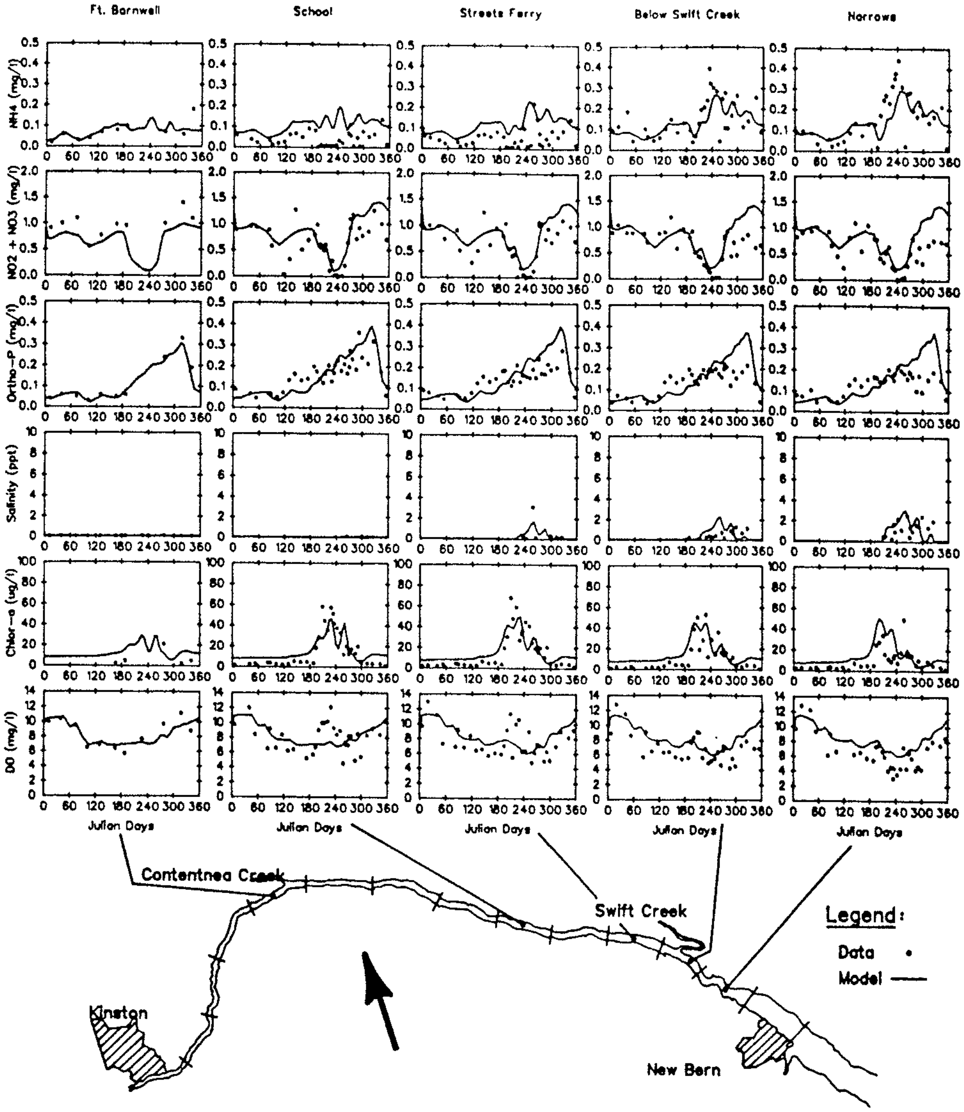

Figure 7. Neuse Estuary model calibration - 1983 data

The factors affecting blue-green algal blooms in the Neuse Estuary can be summarized to examine the potential of blooms. 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 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 Neuse Estuary. Significant blue-green algal blooms were observed in July and August 1983 (Figure 8). Nutrient loads provided by the spring runoff in 1983 resulted in ample supply of nutrients for the growth of the blue-green algae and other algal groups in the summer. Relatively sufficient nitrogen concentrations throughout the year resulted in persistent dominance by a non-nitrogen fixing genus, Microcystis.

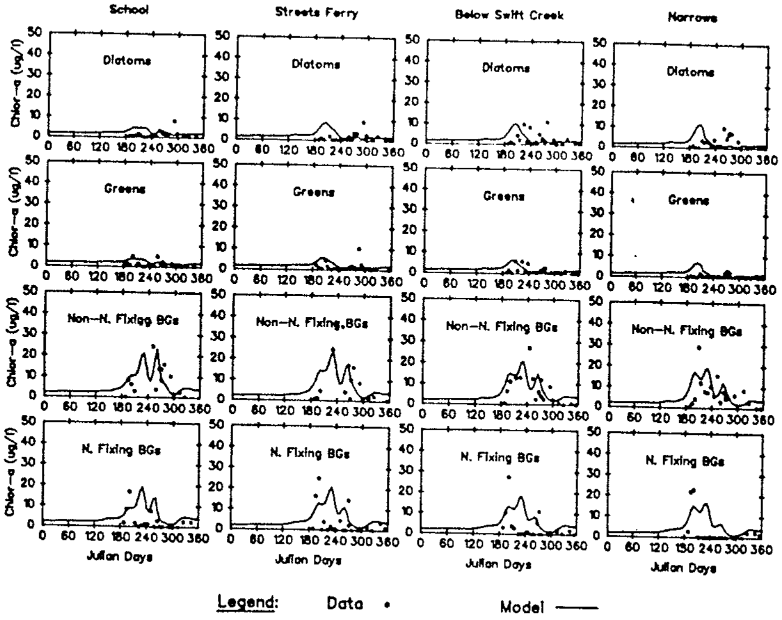

Figure 8. Algal species model calibration - 1983 data

Physical conditions in 1984 contrasted to those in 1983 in that a wet summer was encountered. No significant bloom was observed while nutrient adequacy supported a modest population of phytoplankton in the summer months. Examination of the measured river flows and chlorophyll a concentrations in 1983 and 1984 indicates that the chlorophyll a level decreased as flows increase, suggesting that river flow played a crucial role in initiating and maintaining blooms.

Acknowledgments

Financial support for these two studies was provided by the Soap and Detergent Association. Dr. Hans W. Paerl of North Carolina Institute of Marine Sciences, Morehead City, NC collaborated on the Neuse Estuary study.

References

Lung, W.S., 1985. Assessing the Water Quality Benefit of Point Source Phosphorus Control in the James River Basin. Report No. UVA/532533/CE85/101. Univ. of Virginia, Department of Civil Engineering, 60p.

Lung, W.S., 1986a. Phosphorus Loads to the Chesapeake Bay: A Perspective. Journal of Water Pollution Control Federation, 58(7), 749-756.

Lung, W.S., 1986b. Assessing Phosphorus Control in the James River Basin. Journal of Environmental Engineering, 112 (1), 44-60.

Lung, W.S. and Paerl, 1986. Modeling the Blue-Green Algal Bloom in the Neuse River Estuary. Report No. UVA/531076/CE86/101, Univ. of Virginia, Department of Civil Engineering, 90p.