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A Model Study of Hypoxia in the Rappahannock Estuary, Verginia

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Hypoxia has persisted during summer in the bottom water of the lower portion of the Rappahannock Estuary, a western shore tributary of Chesapeake Bay. A laterally integrated two-dimensional, real-time model, consisting of linked hydrodynamic and water quality models, was developed to study the contributing processes for hypoxia. The hydrodynamic model gives the information of physical transport processes, both advective and diffusive, to the water quality model, which simulates the spatial and temporal distributions of eight water quality state variables.

The hydrodynamic model, based on the principles of conservation of volume, momentum and mass, provides real-time predictions of surface elevation, current velocity and transport of a conservertive substance (salt). The model equations were solved using a two time level, finite difference scheme with a spatially staggered grid system. The model was calibrated and verified using the predicted mean tide characteristics in Tide Tables and the field data collected in 1987 and 1990. The model results from mean tide calibration described very well the tidal characteristics at equilibrium state along the river. Calibration of the vertical mixing terms using the salinity data from 1987 slackwater surveys showed that the model provided very good description of prototype salinity distributions. The model capability of reproducing advective transport was verified by comparing the model results to the time series measurments of surface elevation and current velocity in 1987. The model produced very well both the tidal and subtidal variations in surface elevation and current velocity. The model capability of reproducing diffusive transport was verified by the agreement between model predictions and 1990 slackwater survey salinity data.

The water quality model was calibrated using the slackwater survey data on July 5, 1990, and then was verified using another slackwater survey data on August 7, 1990 and the monitoring data from the Chesapeake Bay Program. The model reproduced the observed hypoxia very well. The model then was used to study the hypoxia in the Rappahannock Estuary. This paper covers only the model application for hypoxia.

Sensitivity analysis for hypoxia was performed using the calibrated and verified model. The primary purpose of this analysis was to test, using detailed hydrodynamics, geometry and biogeochemical processes, the controlling processes identified by observations and a simple dissolved oxygen (DO) budget model for bottom water (Kuo & Neilson 1987; Kuo et al, 1991; Kuo & Park 1992). The sensitivity analysis using the model provided further insight to the understanding of the processes contributing to hypoxia.

The analysis revealed that hypoxia in the Rappahannock Estuary was caused by a combiantion of physical and biogeochemical processes. Among physical processes, an increase in either residual velocity or vertical mixing could relieve the hypoxic condition. The present model, containing all terms in the governing equations, could not seperate the effects of

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vertical mixing and gravitational circuration. Oxygen demands in both sediment and water column contributed to the formation of hypoxia. Water column oxygen demand, including decay of carbonaceous biochemical oxygen demand (CBOD), nitrification and algal respiration, was as important as sediment oxygen demand. The CBOD decay was the most important DO consuming process in the water column. The bottom water would become hypoxic regardless of DO and CBOD in the incoming bay water. Hypoxia could be relieved more by eliminating CBOD than by increasing DO in the incoming bay water.

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