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Management modeling of suspended solids in the Chesapeake Bay, USA

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ABSTRACT

The Chesapeake Bay, USA, suffers from multiple water quality impairments including poor water clarity. A management strategy aimed at improving water clarity through reduction of nutrient and solids loads to the bay is under development. The strategy is informed through the use of the Chesapeake Bay Environmental Modeling Package. We describe herein aspects of the model devoted to suspended solids, a major contributor to poor water clarity. Our approach incorporates a dynamic model of inorganic solids into an eutrophication model, in order to account for interactions between physical and biotic factors which influence suspended solids transport and fate. Solids budgets based on the model indicate that internal production of organic solids is the largest source of suspended solids to the mainstem bay. Scenario analysis indicates that control of solids loads reduces solids concentration in the vicinity of the loading sources. Control of nutrient loads provides more widespread but lesser reductions in suspended solids.

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1. Introduction

Chesapeake Bay is the largest estuary in the United States. The physical characteristics and the environmental problems prevalent in the bay have been described extensively (Hagy et al., 2004; Kemp et al., 2005) and are repeated only briefly here. The mainstem of the bay (Fig. 1) is a drowned river valley which extends roughly 300 km from the Atlantic Ocean to the Susquehanna River. The bay channel achieves depths of 30 m but adjoins extensive shoal areas so that the average depth is ≈6 m. The Susquehanna River provides the majority (≈60%) of the freshwater to the bay. The remainder is primarily from five major western tributaries. The bay is described as partially-mixed and demonstrates classic estuarine circulation in which residual flow is predominantly downstream at the surface and upstream near the bottom. The actions of wind and other climatic events can interrupt this classic pattern, however. Salinity ranges from nearly oceanic, at the mouth, to freshwater in the vicinity of the Susquehanna. The mean tide range is 0.78 m at the mouth and decreases to less than 0.4 m in the upper bay.

Chesapeake Bay exhibits multiple signs of cultural eutrophication, which has accelerated since the 1950s. Primary among these are resource depletion (Newell, 1988), bottom-water anoxia (Hagy et al., 2004), and disappearance of submerged aquatic vegetation (SAV, Orth and Moore, 1983). The modern era of water quality management in the bay commenced in the early 1980s with the formation of the US EPA Chesapeake Bay Program (CBP). Formation of the CBP coincided with widespread publicity about deteriorating conditions in the bay and with renewed interest in restoring water quality and living resources. Since then, a primary management goal has been restoration of the bay through reduction of nutrient loads. According to recently-formulated water quality criteria (USEPA, 2008), the bay suffers from specific water quality impairments in three areas: dissolved oxygen, water clarity, and chlorophyll concentration. A set of mandatory Total Maximum Daily Loads (TMDLs) of nutrients from the watershed, designed to alleviate the impairments, is under development.

1.1. The Chesapeake Bay environmental model package

Predictive, mechanistic models have informed management actions since the inception of the CBP. The models have been continuously revised and improved to reflect new knowledge and to meet increasingly stringent demands on their capabilities. The present suite of management models is denoted as The Chesapeake Bay Environmental Model Package (CBEMP). The suite includes: an atmospheric deposition model which computes atmospheric nutrient loads to the watershed and water surface (Grimm and Lynch, 2004; Dennis et al., 2010), a watershed model which

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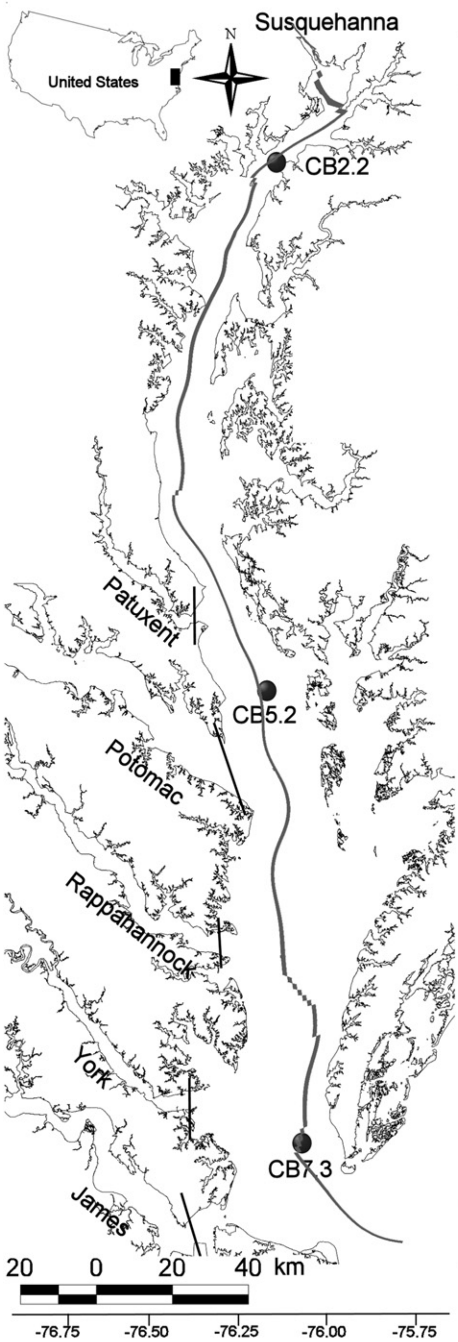

Fig. 1. The mainstem of Chesapeake Bay. The figure shows the axis for plotting longitudinal solids distribution and three stations for plotting time series. Transects for computing solids transport across the mouths of major tributaries are shown.

provides computations of runoff, nutrient loads, and solids loads (USEPA, 2010), a hydrodynamic model which computes transport processes (Johnson et al., 1993), and a eutrophication model which computes water quality and living resources (Cerco and Cole, 1993).

1.2. Management modeling of suspended solids

The disappearance of SAV is primarily attributed to increased light limitation (Kemp et al., 1983; Twilley et al., 1985) imposed by diminished water clarity and by epiphytes attached to SAV leaves and stems. Light is attenuated in the water column by particulate and dissolved organic matter and by inorganic particles (Gallegos, 2001). Epiphytic material is composed of periphyton and organic and inorganic particulate matter which associates with the periphyton to form a matrix of materials (Carter et al., 1985). Reduction of nutrients in the water column improves water clarity by limiting the production of phytoplankton and periphyton. In some regions of the bay system, however, light attenuation by inorganic solids is significant and SAV will not propagate without a reduction of both organic and inorganic material in the water column (Cerco and Moore, 2001). Consequently reduction of inorganic solids loads to the system may be a feasible management option to reduce light attenuation and promote production of SAV. Inorganic solids originate from multiple external sources. Their residence time in the water column is extensive due to continuous deposition and resuspension. A realistic predictive model must account for resuspension as well as external loads and transport. We report here on a management model of suspended solids in Chesapeake Bay that includes both organic and inorganic particulate material. Our model is distinctive in that a mechanistic model of inorganic solids transport is incorporated into the eutrophication portion of the CBEMP. Our motivation is that biological processes, as well as physical processes, influence the formation and transport of inorganic solids. Consequently, processes which determine transport and fate of inorganic solids must be considered simultaneously with the suite of eutrophication processes and living resources. We focus on model results in the mainstem of the bay and in smaller tributaries and embayments which adjoin it (Fig. 1). Complete results, including the major western tributaries, may be found in Cerco et al. (2010).

2. Material and methods

2.1. Model basics

The computation of inorganic suspended solids (ISS) requires interactions of multiple models and algorithms (Fig. 2). Loads originate in the watershed and as bank erosion. Transport processes are determined by the CH3D-WES hydrodynamic model (Johnson et al., 1993). Volumetric flows and vertical diffusivities are output from CH3D-WES, on an hourly basis, and stored as a data set for repeated use by the CE-QUAL-ICM eutrophication model (Cerco and Cole, 1993; Cerco and Meyers, 2000). For computation of inorganic solids, current-generated bottom shear stresses were added to the information output by the hydrodynamic model. Wave-generated bottom stresses were computed by a separate wind-wave model and combined into a single data set of bottom skin friction (Harris et al., in press). Wave action also

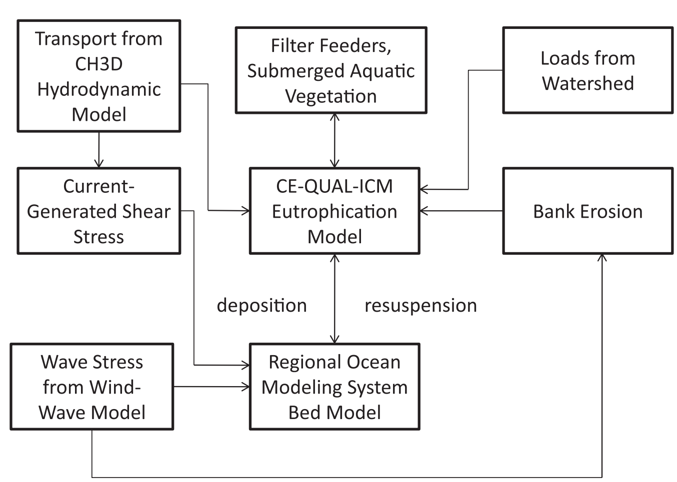

Fig. 2. Schematic of the inorganic suspended solids model.