Development and Application of Coupled Hydrodynamic and Water Quality Models in the Chesapeake Bay Region

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The Chesapeake Bay and the Coastal Bays of the Maryland/Virginia Atlantic shore are highly valuable and productive ecosystems that are increasingly threatened by degraded water quality and loss of habitat due to both anthropogenic and natural disturbances. In an effort to reverse this trend, federal and state governments have implemented a Total Maximum Daily Load (TMDL) program to control point source and non-point source pollution in each watershed. In order to quantify these controls and better understand cause and effect relationships, we are developing numerical hydrodynamic and water quality models and linking them together as a tool for predicting and measuring success of the TMDL effort.

Environmental pollution in these ecosystems is a very complicated, large-scale process involving physical, chemical, and biological phenomena. The modeling framework is correspondingly complex, including a watershed model, hydrodynamic model, 3D water quality model, and sediment process model. Simulations at the required scale, resolution, and complexity can only be undertaken with the assistance of high performance computing.

VIMS is currently involved in two TMDL projects in the Chesapeake Bay region:

1. TMDL scenario development and implementation for the Maryland and Virginia Coastal Bays system.
2. Impact on localized water quality resulting from allocation of nutrient loads to dredged material contaminant facilities in Baltimore Harbor.

Both projects involve coupling a state-of-the-art unstructured grid hydrodynamic model (SELFE—Semi-implicit Eulerian-Lagrangian Finite Element) and 3D water quality model (ICM—Integrated Compartment Model).

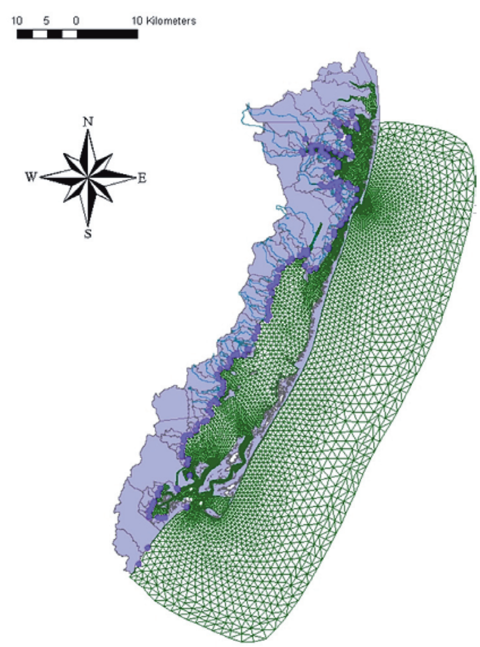

Figure 1: Modeling domain for Maryland and Virginia Coastal Bays.

Case 1: Maryland and Virginia Coastal Bays

Maryland's Department of the Environment has been providing support for development of a water quality model aimed at better planning for restoration and protection of the Coastal Bay ecosystem. To assist with environmental management decisions, we have developed a comprehensive hydrodynamic and water quality model on the domain shown in Figure 1. Once the model is calibrated and verified, it will be ready for use as a management tool by setting up TMDL scenarios and "what-if" conditions. Preliminary simulation results for dissolved oxygen from the coupled hydrodynamics-water quality model agree quite well with observed data collected at several stations in the Maryland Coastal Bay.

Case 2: Allocation of Nutrient Loads in Baltimore Harbor

In 2007, EPA approved a nitrogen and phosphorus TMDL for Baltimore Harbor. This included allocations for all regulated municipal and industrial point sources, as well as the CSX/Cox Creek dredge disposal site. The Maryland Port Authority is constructing a new Dredged Material Contaminant Facility (DMCF) in Baltimore Harbor directly south of Fort McHenry, known as Masonville. The goal of this project is to consider the local ramifications of reallocating a portion of the currently authorized Cox Creek DMCF to the Masonville DMCF and other potential facilities.

Development of the Baltimore Harbor nutrient TMDL as it relates to DMCF discharge is a challenging technical project because of the complex hydrodynamic features of the Harbor, the numerous sources of nutrients (point, non-point, sediment), and the effects of the adjoining Chesapeake Bay. The computational framework for this project is the three-dimensional, time-variable Baltimore Harbor Eutrophication Model (BHEM). The BHEM package includes a watershed model, hydrodynamic model, water quality model, and sediment-flux sub-model. It represents 22 water quality parameters from the water column and sediment bed. Since many studies have shown the significant influence of the Chesapeake Bay on its tributaries, the spatial domain of the BHEM extends longitudinally from the mouth of the Susquehanna River southward to the mouth of the Patuxent River, as shown in Figure 2.

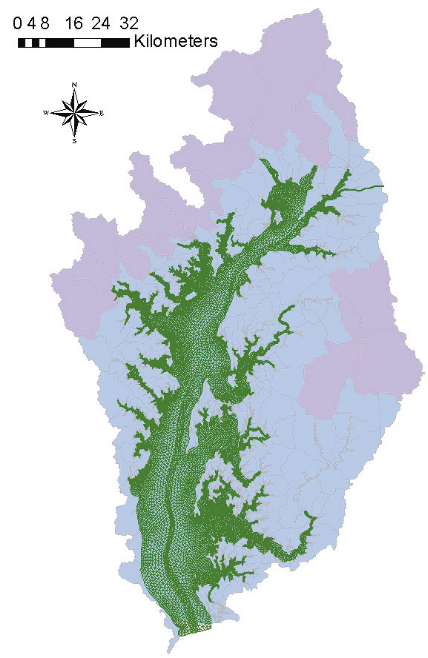

Figure 2: Baltimore Harbor and Upper Bay model domain.

The model recently developed using SciClone's "typhoon" subcluster has about 10 times higher resolution than any model used in the past. We achieve acceptable runtimes by parallelizing the application using MPI (Message Passing Interface) for interprocessor communication and distributing the problem across multiple nodes within the cluster. Preliminary results from the high resolution hydrodynamic model are shown in Figure 3.

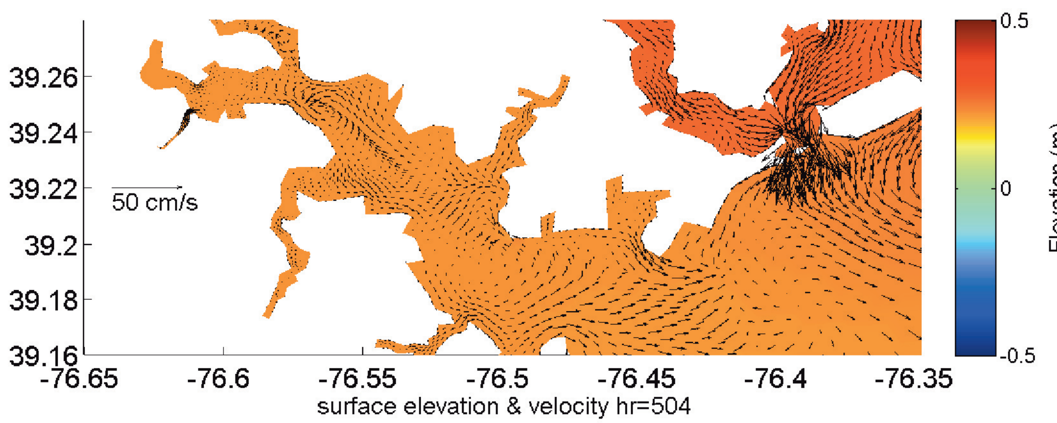

Figure 3: SELFE results for water elevation and circulation pattern in Baltimore Harbor and the Back River.