Simulating Shallow Water Hydrodynamics Coupled with ICM Water Quality Model Using Finite Volume Method on Unstructured Grids

In response of RFP: EPA-R3-CBP-14-02, Activity 1: Application of a Shallow-water Model for Use in Supporting Chesapeake Bay Management Decision-making

1. Name, address (street and email), and contact information of the applicant

Yinglong Joseph Zhang (yjzhang@vims.edu), Virginia Institute of Marine Science (VIMS), College of William & Mary, 1375 Greate Road, P.O. Box 1346, Gloucester Point, VA 23062. Phone: 804-684-7466

2. Background

i) Project title: see above

ii) Brief description of your organization

The Virginia Institute of Marine Science (VIMS) has a three-part mission to conduct interdisciplinary research in coastal ocean and estuarine science, educate students and citizens, and provide advisory service to policy makers, industry, and the public. Chartered in 1940, VIMS is currently among the largest marine research and education centers in the United States.

iii) Documentation of non-profit status, if applicable: N/A

iv) Brief biographies of applicant lead(s) including resumes and/or curriculum vitae

(a) Joseph Zhang (PI)

<u>Professional Preparation</u>

1996 Doctor of Philosophy in Applied Mathematics and Fluid Mechanics, University of Wollongong, Wollongong, NSW 2522, Australia

1993 Master of Science (Hon.) in Applied Mathematics, University of Wollongong, Wollongong, NSW 2522, Australia

1991 Bachelor of Science in Engineering Mechanics, Beijing University, Beijing, China

<u>Appointments</u>

2012-present, Research Associate Professor, Virginia Institute of Marine Science, College of William and Mary;

2006-2012, Research Assistant Professor, NSF Science and Technology Center for Coastal Margin Observation and Prediction, Oregon Health & Science University;

2001-2006, Associate Research Scientist, Department of Environmental and Biomolecular Systems, OGI School of Science & Engineering, Oregon Health & Science University;

1999-2001, Postdoctoral Research Associate, Department of Environmental Science and Engineering, Oregon Graduate Institute of Science and Technology (OGI);

1998-1999, Project Manager and Senior Research Engineer, Institute of High Performance Computing, Singapore.

<u>Selected publications</u>

See References [20,17,6,25,26,18].

<u>Synergistic Activities</u>

<u>VIMS & CMOP:</u> Zhang co-developed a three-dimensional finite-volume/difference circulation code (ELCIRC), and developed a finite-element/ finite-volume circulation model (SELFE). The two open-source community models enabled the use of exceptionally large time steps due to the implicit time stepping and the Eulerian-Lagrangian treatment of the advection, and have been proved ideal for cross-scale applications commonly found in coastal oceans and marginal seas. The models have been the forecast and hindcast engine at the heart of the Columbia River forecasting system (and adopted by NOAA; http://tidesandcurrents.noaa.gov/ofs/creofs/creofs.html), and have also been extensively exported to other parts of the world. In collaboration with external users he has successfully built SELFE into a comprehensive modeling system for sediment transport, water quality, ecology/biology, oil spill, and wave-current interaction.

Zhang is collaborating with California Department of Water Resource (DWR) and UCLA in implementing SELFE for the San Francisco Bay and Delta. The two projects look at different aspects of the water quality related issues for this system. Several related publications are now in preparation.

Zhang is collaborating with the Oregon Department of Geology & Mineral Industry in assessing tsunami hazards along the Oregon Coast. State-of-the-art tsunami model (SELFE) enables ensemble simulations (based on geophysical constraints) which are used to help prepare digital inundation maps and design evacuation routes.

Zhang is awarded the highly selective HWK (Institute of Advanced Study, Germany) Fellowship in 2014. As part of the Fellowship requirement, he will collaborate with German scientists to implement SELFE model for the large-scale coupled North and Baltic Seas, and look at the long-term morphological change and responses to storm surges for this system using the SELFE modeling system.
Education: Taught geophysical fluid dynamics, advanced numerical methods in engineering and two reading group courses on numerical ocean circulation models. Co-supervised two M.S. (thesis) students and 2 PhD students. Currently serving as the major advisor of 1 PhD student.
Recent Collaborators: Emil Stanev (HZG), Aron Roland (TU-Darmsdadt). Ulrich Zanke (TU- Darmsdadt), Eli Ateljevich (DWR), Harry Wang (VIMS), Todd Leen & Antonio Baptista (OHSU), Rob Witter (USGS) & George Priest (DOGAMI).

(b) Harry Wang (Co-PI)

Education

B.S. Atmospheric Sciences; National Taiwan University, 1975

Ph.D. Geophysical Fluid Dynamics, The Johns Hopkins University, 1983

Professional Experiences

1998 - present, Professor, Department of Physical Sciences, Virginia Institute of Marine Science

1992 - 1998, Research Physical Scientist, US Army Corps of Engineers, WES

1985 - 1992, Water Resource Engineer, Maryland Department of the Environment

1983 - 1985, Research Associate, Chesapeake Bay Institute/Applied Physics Laboratory, The Johns Hopkins University

Research Interests:

My long-term research interests are the estuarine and coastal physical processes and their consequence on the transport properties, specifically, the transports driven by wind, wave, tide, density and affected by the Coriolis force and turbulent mixing. My recent works emphasize on the use of numerical computational methods to simulate the current, water level, salinity, temperature and the associated environmental conditions such as water quality, sediment, toxic concentration, and larval transport.

Selected Relevant Publications

1. P. Wang, H. Wang, L. Linker (2013): "Relative importance of nutrient load and wind on regulating Inter-annual summer hypoxia in the Chesapeake Bay", submitted to *Coast and Estuaries*.
2. K-H. Cho, H. Wang, J. Shen, A. Valle-Levinson and Y-C. Teng (2012): "A modeling study on the response of the Chesapeake Bay to Hurricane Events of Floyd and Isabel", *Ocean Modeling*, Vol. 49-50, p22-46.
3. J. Gao, J. Li, H. Wang, F. Bai, Y. Cheng, and Y. Wang (2012): "Rapid changes of sediment dynamic processes in Yalu River Estuary under anthropogenic impacts", *Int. J. of Sediment Res.*, Vol. 27,No. 1, p37-49.
4. H. Wu, J. Zhu, J. Shen and H. Wang (2011): "Tidal modulation on the Changjiang River Plume in Summer". *J. of Geophys. Res*. 116, C08017, doi:10.1029/2011JC007209.
5. X. Fei, Y. Wang, and H. Wang (2011): "Tidal hydrodynamics and fine-grained sediment transport over the radial sand ridge, southern Yellow Sea", *Marine Geology*, MARGO-04673, 2011.
6. H. Wang, and W.H. Johnson (2001): "Validation and application of the second generation three-dimensional hydrodynamic model of Chesapeake Bay", Water Quality and Ecosystem Modeling, Vol 1, pp51-90.

Synergistic Activities: A member of EPA Chesapeake Bay Program modeling sub-committee; A members of SURA Consortium, SCOOP program and engaged in a super-regional test bed project (http://testbed.sura.org/).
Collaborators and Other Affiliations: Collaborators and Co-editors: John Billet, Shenn-Yu Chao, Raleigh Hood, Billy H. Johnson, John Klinck, Michael Koterba, Jay Titlow, Leonidas Linardakis. PhD Students: Derek Loftis, and Zhengui Wang.
Thesis Advisor: Yi-Cheng Teng (UC-Irvine); Yuepeng Li (Florida International University), Joe Cho (Oregon Graduate Institute), Taiping Wang (Pacific Northwest National Lab.), Tao Shen (DHI). Total student advised: 7, and postdoctoral scholars sponsored: 5.

v) Funding requested

$84,747 for 2 years, with 7% cost sharing from VIMS.

vi) DUNS number: 169516213

3. Work plan

i) Narrative description

3i.1 Rationale

Chesapeake Bay (hereafter "Bay") exhibits complex geometry and bathymetry, and is particularly so in the tributaries and littoral areas, which support potential habitat for submerged aquatic vegetation (SAV) and other living resources. Shallow subtidal waters often are abundant with microbes, invertebrates, micro- and macro-fauna, benthic micro- and macro-algae, and meadows of SAV. Shallow water habitats provide a variety of ecological services that directly benefit humans. Specifically, SAV provides wildlife with food and habitat, adds oxygen to the water, absorbs nutrient pollution, traps sediment, reduces erosion, and improves water clarity. In the Bay, the SAV has, in the past, been very abundant; but a marked decline occurred throughout the estuary from 1960 to 1970s. Since 1978, scientists have annually gathered data on the abundance of SAV. In 2002, SAV coverage reached 89658 acres, or more than twice the level first recorded in 1978. While this increase is impressive, it is still far less than the historical level on the order of 200,000 acres or more.

SAV distribution and abundance are affected by habitat conditions that are influenced by a variety of water quality characteristics, of which light availability is the most important. The amount of light reaching SAV living in the shallow waters is influenced by many factors. The most important ones are the distributions of TSS, concentration of chlorophyll-a, and water color (usually discussed as dissolved organic carbon). Collectively, these constituents decrease the amount of light reaching the leaf surface of SAV. The inorganic mineral component of TSS, which commonly comprises greater than 50 percent of total TSS, generally consists of fine-grained silts and clays. Chesapeake Bay Program's (CBP) work, with both monitoring and numerical modeling, demonstrated that SAV decline is highly correlated with changing of water quality condition. From the historical perspective, the decline of SAV is thus likely caused by the combination of increase of nutrients, and chlorophyll-a concentration coupled with the increase of sediment concentration, due to increased eutrophication from point source, agricultural runoff, and increase of suspended sediment inputs [7].

In 2009, the CBP requested that the Scientific and Technical advisory Committee (STAC) formally review the updated water clarity and SAV components of the estuarine water quality sediment transport model. The objective of the review was to determine the suitability of these components for setting tidal sediment and nutrient allocation as part of the Total Maximum Daily Load (TMDL) process. Cerco et al. [8]'s work using CBP environmental model package in the shallow water indicated that the model framework for SAV, sediment resuspension, and their interactions with light attenuation (Ke) within 2 m contour of bathymetry requires significant overhaul and improvement before it can be used for predictive purpose. Specifically, the model performance in computation of TSS and Ke in shallow water is distinctly different from that in the deep, open waters of the bay: it under-predicts observed values for 90% of the time in cumulative distribution. The larger the scale of SAV distribution is, the better model performs. The greatest relative difference between computed and observed SAV is at the lowest ends of the scales of 0.001 km^2–0.01 km^2. They recommended (1) investigating suspended solids dynamics including the wind wave–generated bottom shear stress to improve the model representation of Ke and TSS; (2) extending the comparison period to 2011 to incorporate additional shallow water observations in widespread region of the Bay; (3) increasing resolution to improve fit between model domain and the environment; (4) improving the present SAV model to provide feedback between SAV and sediment resuspension. The emphasis is that a combination of both process-based investigation and model improvements is required for development of a fully predictive SAV model. Obviously, this presents challenges for the current suite of CBP Partnership estuarine hydrodynamic and water quality models, and therefore new and complementary modeling strategy needs to be pursued.

3i.2 Proposed approach

Our guiding principle for this project is based on a two-pillar approach. The first is to increase the model resolution in spatial and temporal resolution. The second pillar is to improve the representation of sediment resuspension dynamics including direct coupling with a wind-wave model rather than the present fetch-limited wave formulation.

It has long been recognized that models based on unstructured grids are ideally suited for complex geometry and bathymetry due to its flexibility for local refinement to achieve high spatial resolution, and thus better representation of features that bear implications for various physical and biological processes. For instance, in 2012, the CBP Partnership requested that the STAC convene an expert workshop "to frame a shallow-water, multiple model comparison pilot project that would provide the foundation for future modeling in the productive littoral areas of the Bay and would demonstrate the potential use of multiple models in routine CBP modeling activities". In the workshop report (http://www.chesapeake.org/pubs/291_Pyke2012.pdf), Friedrichs et al. [10] suggested that an unstructured grid model would adequately simulate shallow-water living resource areas around the Bay.

We have been developing the next-generation unstructured-grid based modeling suite since 2000. The current suite is based on SELFE (Semi-implicit Eulerian-Lagrangian Finite Element; [25]). SELFE is an open-source, community-supported modeling system, based on unstructured grids in the horizontal and hybrid terrain-following *S* coordinates and shaved *Z* coordinates in the vertical, designed for the effective simulation of 3D baroclinic circulation across river-to-ocean scales. It employs a highly efficient semi-implicit finite-element/finite-volume method together with an Eulerian-Lagrangian method to solve the Navier-Stokes equations (in either hydrostatic or non-hydrostatic form). As a result, numerical stability is greatly enhanced and the errors from the "mode splitting" method are avoided; in fact, the only stability constraints are related to the explicit treatment of the horizontal viscosity and baroclinic pressure gradient, which are much milder than the stringent CFL condition. The implicit scheme used in SELFE often enables 'hyper resolution' (on the order of a few meters) with little penalty on the time step. The default numerical scheme is 2nd-order accurate in space and time, but optional higher-order schemes have been developed as well. The model also incorporates wetting and drying in a natural way, and has been rigorously benchmarked for inundation problems [26] and certified by National Tsunami Hazard Mitigation Program (NTHMP) as a tsunami inundation model [16]. SELFE-enabled Columbia River forecast has also been adopted by NOAA (http://tidesandcurrents.noaa.gov/ofs/creofs/creofs.html). Currently there are two web sites dedicated to this model, one at OHSU (http://www.stccmop.org/CORIE/modeling/selfe/) and the other, SELFE wiki (http://ccrm.vims.edu/w/index.php/Main_Page), at VIMS.

In collaboration with external users, we have also built a comprehensive modeling system around SELFE (http://ccrm.vims.edu/w/index.php/File:SELFE-modules.jpg), which now incorporates a wide range of physical and biological processes. The whole system has also been fully parallelized using domain decomposition with MPI protocol, with good parallel scalability. The SELFE modeling system has been well demonstrated to be accurate, efficient, robust and flexible, with a wide range of world-wide applications, ranging from general circulation [5,6], storm surge [4], tsunami [26], ecology [18], sediment transport [17], oil spill [3], and water quality studies (Section 3i.3); for a complete list of SELFE-related publications, see [http://www.stccmop.org/CORIE/modeling/elcirc/elcircjour.html].

As an open-source community model, SELFE has a global appeal, with 14 developers (with the PI being the lead) in USA, Germany, Portugal, France, New Zealand, China and Taiwan, and a rapidly growing user base. The official version of SELFE is managed using svn, and the central repository includes unit and regression tests that are carried out on a regular basis.

In the following we will briefly introduce the components that are relevant to this proposal.

<u>Water quality module: CE-QUAL-ICM (Integrated Compartment Model)</u>

The ICM model has now been fully incorporated into SELFE as a subroutine based on the finite-volume method. The coupled SELFE-ICM model is forced by a hydrological model (HSPF) that provides point and non-point source loadings. The coupled system has been applied to decadal simulations of bay and estuarine systems near Maryland coast, as well as multi-year simulations for the Upper Bay (Section 3i.3).

<u>Wind Wave Model (WWM-II)</u>

The coupled SELFE-WWMII model is a community-driven, parallel and innovative numerical framework that can be utilized to study the wave-current interaction processes based on unstructured meshes in geographical space. In particular we have rewritten WWM-II [19] as a subroutine inside SELFE, accounting for the wave induced momentum flux from waves to currents, based on the radiation stress formulations according to [15], the Wave Boundary Layer according to the theory of [12], surface mixing following [9], and the current induced Doppler shift for waves [14]. In addition, the whole system has been parallelized via domain decomposition; the two models also share same sub-domains, but may use different time steps and different integration strategy in order to maximize efficiency. Therefore the new model is especially suitable for the study of the combined wave-current action in very large field-scale applications on massively parallel HPC clusters. More details about the model and several of its applications can be found in [20]. Since then, the wave-current interaction theory has been extend to take into account the full 3D vortex force coming from the surface waves following the theory of [2], which is especially important near-shore.

<u>Sediment modules (SED3D & TIMOR)</u>

SED3D is adapted from [24], and has been fully integrated into SELFE and WWMII to account for the combined effect of wave and current on multi-class sediment transport. The coupled model has been applied to studies of

German Bight and Portuguese lagoons. Pinto et al. [17] showed some application cases of SED3D. We expect improved results from adopting a high-resolution unstructured Bay grid like ours.

In addition, we'll also advance the state-of-the-science by incorporating more advanced sediment formulation. As an alternative to SED3D, we'll also integrate into SELFE a German Sediment Transport model, TIMOR (Tidal Morphodynamics), originally developed and continuously improved by consultant Zanke [28] of the vice president of the WASER foundation (http://www.waser.cn/). TIMOR has been used in many research and engineering projects for over 20 years. It solves the multigrain and multilayer bedload based on a bedload transport formula derived from basic principles with only the turbulence mixing being parameterized (e.g. [27]). The suspended load takes into account buoyancy effects and mimics non-Newtonian behavior when high sediment concentrations are present and turbulence is damped due to stratification. This extension, called FLMUD was recently included and tested in SELFE [21]. Therefore we expect improved representation of sediment resuspension process with TIMOR.

3i.3 Past performance

We have started applying SELFE modeling system to the Chesapeake Bay. In particular, we have built multiple unstructured grids for this system. With the whole-bay grid (which has ~19000 nodes), we have conducted a multi-year salt intrusion study. With modest resolution used in the model, the model is already able to capture some small-scale flow structures in shallow areas, as shown in Fig. 1.

Funding from Maryland Environmental Service (MES) allowed us to study the localized water quality issue around Masonville dredged material contained facility in Baltimore Harbor. The coupled SELFE-ICM was used on a grid with 9434 nodes and fine resolution in the study site down to 20m. The model calibration was done using observation data in deeper channels (e.g. WT5.1; Fig. 2). However, the model seems to already have some skill in shallow water areas (Fig. 2). The summer hypoxic condition in the deep channel of Baltimore Harbor was well simulated and the summer hypoxia was also observed in the shallow water stations. At the moment, it takes 90 hours to simulate one year on 64 CPUs for the entire Upper Bay. We will work on improving model efficiency during this project in order to conduct decadal simulations in the future (Section 3i.4).

3i.4 Proposed Tasks

We have obtained 10m DEM tiles from FEMA that cover the entire Region III. This high-resolution datasets will be used in generating unstructured grids at the study sites that resolve shallow-water areas in high resolution.

The most important variables for SAV abundance are dissolved oxygen (DO), chlorophyll a (Chl-a), total suspended solids (TSS), and water clarity. SELFE-ICM calculates the first 2 variables, and SELFE-SED3D (or SELFE-WWMII-SED3D) calculates TSS. With this information we will then use empirical formula of [11] to calculate water clarity. The outputs will then be used to feed the empirical SAV model provided by CBP Partnership's Modeling Team, in order to predict the SAV abundance at the study sites.

The choice of sites will be determined by the availability of long-term data and different types of environment they represent (high/low energy, high/low SAV abundance, sandy/muddy etc). Therefore we suggest the following study sites: (1) Upper Bay–Susquehanna flat (freshwater SAV); (2) Tangier and Pocomok Sound (saltwater SAV); (3) Upper York River (4) Upper James River; (5) Potomac River, Gunston Cove. However, our model can be applied to any sites in the Bay.

The initial and boundary conditions will be obtained from the CH3D-ICM model and interpolated into SELFE grid format. Eleven major tasks in this project are listed below and Table 1 illustrates the project timeline.

Year 1

Task 1: Generate high resolution unstructured model grids, calibrate and validate simulation with SELFE for the selected sites (Zhang & Ye)

Although SELFE has been calibrated for the whole-bay domain, we have not applied it to any tributaries in sufficient high resolution details, and this will be done as the 1st task of the project.

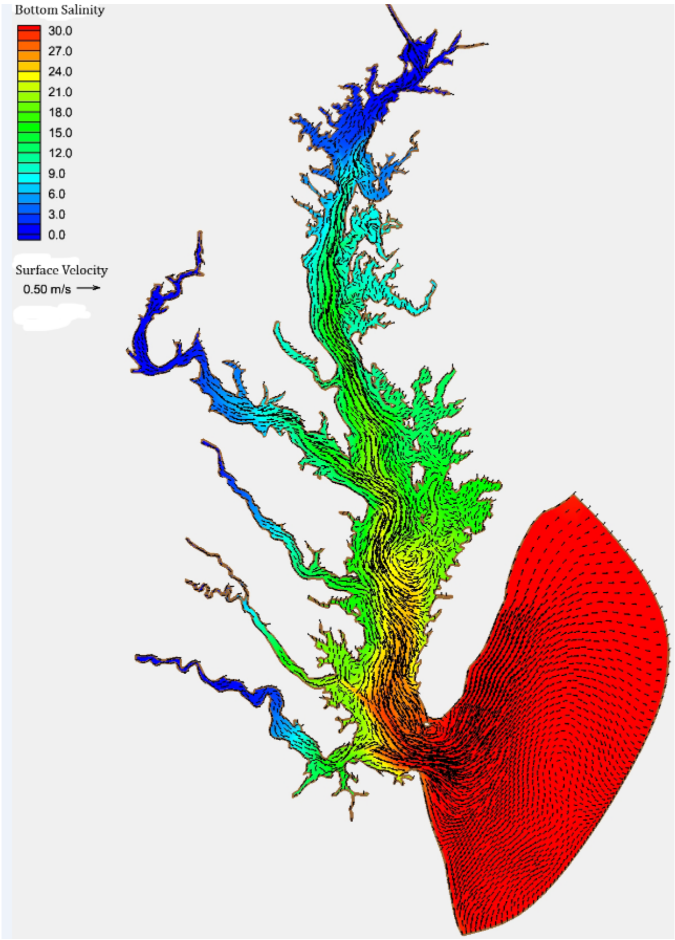


Fig. 1: Averaged surface velocity and bottom salinity from June to August 2004, generated by SELFE3D model for the entire Chesapeake Bay. With modest unstructured grid refinement, the model is already able to capture some small-scale flow structures in shallow areas,

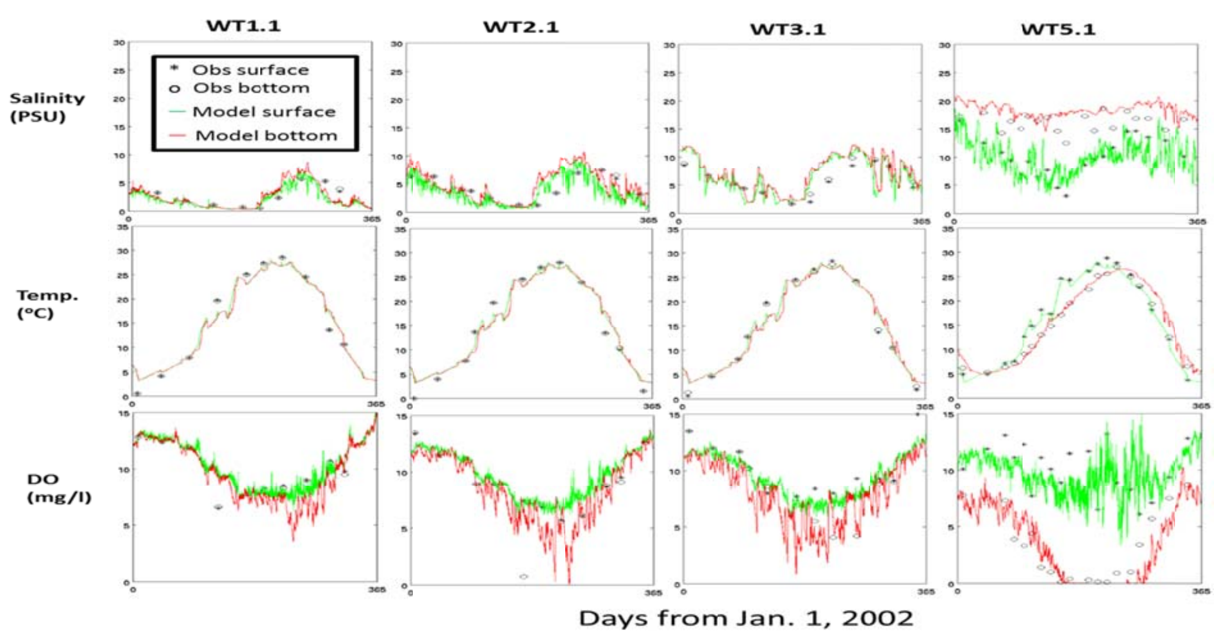


Fig. 2: Comparison of 3 water quality variables at 4 sites in Upper Bay (WT1.1, WT2.1 and WT3.1 in shallow areas, and WT5.1 in deeper channel) for year 2002.

Task 2: Calibrate and validate simulations with SELFE-ICM for the selected sites (H. Wang & Z. Wang)

We'll first request hydrological forcing data from CBP and carry out a 5-year simulation to obtain the initial condition for the sediment flux model, followed by calibration and validation using the water quality monitoring data.

Task 3: Conduct short-term simulations with SELFE-WWMII-SED3D to assess the impact of waves in shallow waters, and provide these results to the Model Evaluation Team (MET), for comparison with the CBP models (Zhang & Ye)

We have successfully applied the coupled models to German Bight and a few lagoons in Portugal. The wave boundary condition may be taken from the whole Bay grid run we have conducted before [20]. The results from this task will shed light on the adequacy of the wave parameterization schemes used in CBP models. Currently we are constrained by the efficiency of WWM-II for long-term simulations, but will work on the efficiency issue in Task 5.

Task 4: Calibrate and validate 3-5 year simulations with SELFE-SED3D for the selected sites (Zhang & Ye)

Besides the information that we'll receive from the CBP Partnership's Modeling Team on sediment characteristics in each site, at CCRM we also have access to extensive datasets collected by various parties in many tributaries. The small size of the sites allows us to avoid using any morphological factor in the simulation. The main output from this task is the TSS.

Task 5: Improve the efficiency of the WWMII and the transport algorithm inside SELFE to facilitate long-term simulations (Zhang, Roland, Ye and Z. Wang)

Currently the TVD transport scheme inside SELFE is fully explicit, and the Courant condition in the vertical dimension has proved to be a major performance killer. We'll explore implicit transport schemes [13,1] to significantly speed up the transport solver. We'll also work directly with the developer of WWM-II, Dr. Aron Roland (who will be a paid consult in this project) to improve its efficiency. The results from Task 3 will guide us in terms of implementing a simplified wave model. One possibility is to experiment with the new fully implicit solver of WWM-II. Another approach to use a simple JONSWAP sea state forecast with shallow water sources terms without the propagation part.

Year 2

Task 6: Improve the sediment transport simulation by incorporating TIMOR into SELFE (Zhang, Roland, and Zanke)

Consultants Zanke and Roland will travel to PI's place and work on integrating TIMOR into SELFE system, and conduct preliminary tests on the study sites with an aim to improve the simulation of sediment resuspension process. Comparison with the SED3D (Task 3) will shed light on what characteristics of TIMOR leads to improved results and by how much.

Task 7: Work with MET for model skill assessment and conducting data analysis (all)

It's important to deliver model results in a format that the MET can correctly interpret. Right now the netcdf standard for unstructured grid is still being developed by an IOOS/UGRID group [https://github.com/ugrid-conventions/ugrid-conventions/blob/v0.9.0/ugrid-conventions.md], and therefore we'll deliver most of modeling product in simple ASCII format. However, we'll also deliver the raw model outputs in either binary or netcdf format (using the latest UGRID convention) for future analysis.

Task 8: Additional fine-tuning and adjustments of the hydrodynamic, water quality and sediment model parameters using the site-specific dataset provided by MET (all)

At the end of year 1, we will have finished most of modeling exercise required by the project except for the site specific conditions. In our 1st year interim report we'll detail our modeling approach for each study sites, including preparation of initial conditions, re-calibrated parameters, boundary conditions and post-processing plots we generate. We'll also report preliminary findings and lessons we have learned during the 1st year. During the 2nd year, we'll further calibrate the model based on the feedback from MET and the site-specific data we receive, including results of nutrient load reduction scenarios.

Task 9: Sensitivity tests and inter-model comparisons (Zhang, H. Wang and Z. Wang)

In the 2nd year, one of the critical tasks is to test how sensitive the shallow water system is to different parameters provided and used. Different models may be calibrated with different set of the parameters, with different results. Thus, it is also very important to compare the results from different models and analyze individual performance.

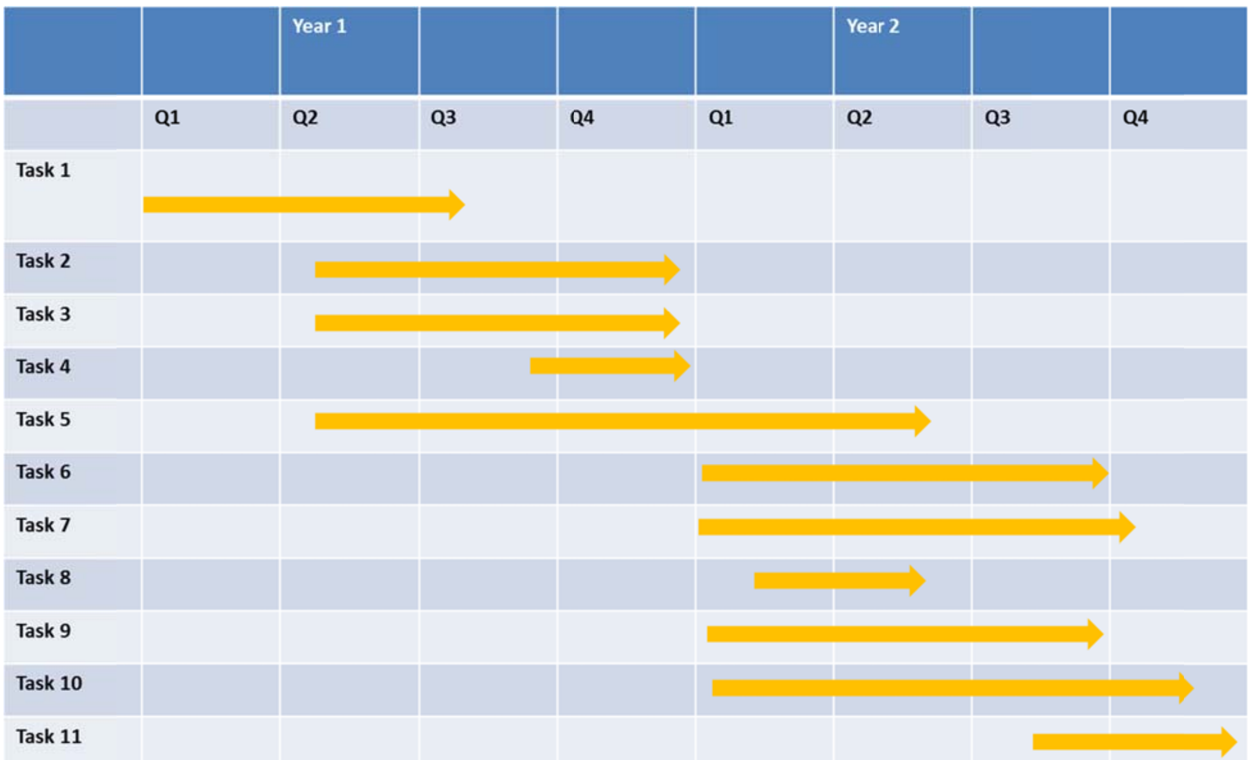
Task 10: Work with MET on a project web site to effectively disseminate model results and findings to CBP partners and stakeholders (Zhang and Ye)

We'll create a dedicated web site for this project, possibly under SELFE wiki, and a central repository to store all model related product needed by the MET. The exact exchange mechanism will be determined in consultation with MET.

Task 11: Final report and documentation for the project (Zhang & H. Wang)

In this report we'll include the results from the model enhancement effort (Task 6), major findings from the inter-model comparison exercise performed by MET, as well as our recommendation for future line of work.

Table 1: Timeline of project. Eleven tasks are overlapped as much as possible in order to maximize productivity.



ii) Budget detail

Personnel

Position/Title	Annual Salary	% of time on project	Requested	Cost sharing
		Yr1/ Yr2	Yr1/Yr2	Yr1/Yr2
Joseph Zhang	94000	7%/6%	7000/6000	0/0
Harry Wang	113000	4.4%/4.4%	5000/5000	2250/2000
Fei Ye	21288	23%/21%	4790/4658	0/0
Zhengui Wang	21288	23%/21%	4790/4658	0/0
Consultant fees			9000/4000	0/0

Projected salary increase 5%

Finge Benefits 40%		
Travel Out-of-State	0/2400	0/0
-Per diem: 4 people x $45 per day x 2 days		
-Airfare: 4 people x $345 Round trip		
-Incidental: 4 people x $5 per day x 2 days		
-Accommodation: 4 people x $80 per night x 2 nights		
Indirect charges (10%) of Total Direct Costs	4073/3632	315/280
Total	44799/39948	3465/3080
Total funds	$84,747	$6,545

iii) Environmental Results

Output of the project

The project will produce a fully calibrated unstructured-grid model for shallow water areas in the Bay to complement the existing CH3D-ICM model. In the process, the new model will be skill assessed by an expert team against observation data (including SAV abundance) and other models.

It is well known that SAV growth is highly patchy spatially, and high resolution is thus required to simulate the processes that affect SAV abundance. We believe the potential of the unstructured-grid based model developed during this project is enormous. In fact, it is feasible to apply ‘hyper resolution’ to the study sites should this become necessary; the implicit scheme used in the model makes this much less painful than otherwise. For very large areas, the computational cost can be reduced by using the one-way nesting capability inside SELFE modeling system, with no more than one layer of grid nesting needed (e.g., a ‘ribbon’ model for shallow areas as illustrated in Fig. 3). The flexibility of the unstructured grids and the efficiency of the model make it a powerful management tool.

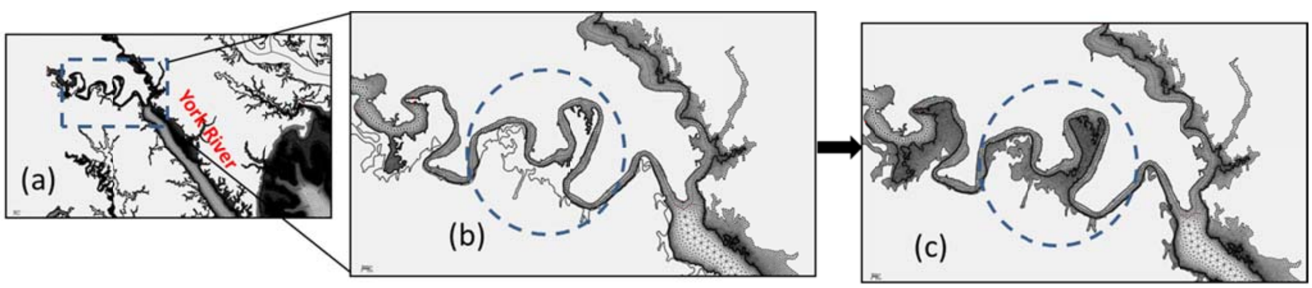


Fig. 3: Conceptual ‘ribbon’ model for the mud flats in upstream York River. (1) Zoom-out view of the Bay grid; (b) zoom-in of the mud flat area; the grid excludes the mud flat in the circled area; (c) splicing a mud flat grid onto the grid.

The highly detailed outputs from the model will serve as a very interesting component from ensemble of models used in this project, and the skill assessment of these models will provide the management with quantitative information to improve existing models and ultimately improve management decisions as well.

Outcome of the project

With the introduction of an unstructured-grid model into the mix of CBP Partnership modeling suite, we will demonstrate the feasibility and utility of an alternative model to complement the existing CBP Partnership models. More importantly, our long-term goal is to build an efficient and effective estuarine hydrodynamic and water quality model for the entire Bay based on unstructured-grid technology. Our experience elsewhere demonstrates that this goal is very much achievable with modest investment in HPC (High Performance Computing) resources. The high resolution resulted from such a model will provides managers with highly detailed quantitative information about the Bay system and enable adaptive management strategies by expeditiously answering ‘what if’ questions.

iv) Review Criteria

(1)V.B1: Organizational Capability and Program Description

The timeline of this project is shown in Table 1. Note that we have overlapped various tasks in order to maximize the productivity during the 2-year period.

The project team has over 20 years of collective experience with developing and applying modelling tools for Chesapeake Bay and elsewhere in the world. For the computational needs of this project, we have access to and will utilize College of William & Mary's Sciclone HPC cluster which has over 2000 CPUs.

(2) V.B2: Programmatic Capability and Environmental Results Past Performance

PI Zhang has been working with California DWR on San Francisco Bay and Delta water quality related study since 2011 (project contact: Eli.Ateljevich@water.ca.gov). So far the project has progressed as planned and we have just completed the first phase (circulation and hydraulic structures). During the project he has worked with DWR in maintaining meticulous documentation on the model-related issues, and a joint report with DWR on model calibration process and findings will be published soon. Also in the recently completed tsunami inundation hazard project (funded by NTHMP), he has always met project deadline over the past 5 years, with final reports submitted on time to NTHMP [16]. As the leader and chief educator of the SELFE user community, he has written detailed manuals on all aspects of the model in a wiki format.

PI Wang has recently successfully completed two projects: (1) Impact on Localized Water Quality Resulting from Allocation of Nutrient Loads to Dredged Material Contaminant Facilities in Baltimore Harbor (operated over entire Upper Bay domain) (funded by MES); (2) Hydrodynamic and water quality modeling and TMDL development for Maryland's Coastal Bays Systems (MCB) (funded by Maryland Department of the Environment (MDE)).

As developers of the hydrodynamic and water quality models, we are uniquely qualified as PIs of the project. During the last 2 projects on water quality modeling (Upper Bay plus MCB), we have seamlessly assembled input data from DEMs, hydrological model, forcings from various atmospheric models, as well as observational data. These are well documented in the reports [22,23]. As demonstrated in Section 3i, we have necessary experience to calibrate and validate fully coupled estuarine hydrodynamic and water quality models for the Bay. We have also worked with water quality managers from various government agencies before and conveyed our model results to them in appropriate formats that they can utilize.

Our programmatic skill has been well demonstrated during the SURA/Inundation project (http://testbed.sura.org). We have coordinated with multiple modeling teams and a model evaluation team during that project. We plan to closely coordinate with the MET and CBP Partnership during this project, with regularly scheduled progress meetings and timely dissemination of model results and findings through a dedicated web site.

(3) V.B 3: Cost-effectiveness

The requested funding will mostly pay for the 2 PhD students working on circulation and water quality models, and a small portion of PIs' time. The sub-award will be used to pay consulting fees in order to collaborate with the WWM-II and TIMOR developers. A small travel budget will be used to disseminate research results at a regional or national meeting. The cost of HPC resource is absorbed by PIs' institute.

(4) V.B 4: Transferability of Results to Similar Projects and/or Dissemination to the Public:

Under Task 9, we will create a dedicated web site, much as what we did with DWR, to document and disseminate results, and share lessons learned from the project with all interested parties. We will listen to the needs of EPA, CBP partners and stakeholders at regular meetings and prepare our documentation accordingly.

(5) V.B 5: Modernization of Methods over Time

SELFE represents a next-generation unstructured-grid model and its potential is enormous. With a vibrant user community worldwide, we fully expect it to continue to improve and thrive. Therefore we believe we can significantly contribute to the missions of CBP Partnership in the long run.

(6) V.B 6: Timely Expenditure of Grant Fund.

We have optimized the time windows for performing overlapping tasks to maximize the productivity (Table 1). Earliest start for each task ensures that we meet the project milestones and deadline and reporting responsibility, and this requires significant commitment from the PIs, students and consultants. Therefore we expect the fund to be fully spent out in the project period.

4. Broader impact

This proposal is directly related to EPA Strategic goal #2: Protecting America's Waters; Objective 2.2: Protect and Restore Watersheds and Aquatic Ecosystems; specifically, Improve the Health of the Chesapeake Bay Ecosystem. With many on-going outreach and advisory activities at CCRM, we expect ample opportunity to showcase our findings to broader audience. The funding will also directly support training of two PhD students of water quality science.

5. References

1. Abgrall, R. and Mezine, M. (2002) Construction of …, J. Compt. Phys., **188**, p. 16-55.
2. Ardhuin, F., Rascle, N., and Belibassakis, K.A. (2008) Explicit wave-averaged …, Ocean Mod.,**20**, p. 35-60.
3. Azevedo, A., Oliveira, A., Fortunato, A.B. and Bertin, X. (2009) Application of ..., J. Coastal Res., SI **56**, 777-781.
4. Bertin, X., Bruneau, N., Breilh, J.-F., Fortunato, A.B. and Karpytchev, M. (2012) Importance …, Ocean Mod., **42**(0), 16-30.
5. Brovchenko I., Maderich, V. and Terletska, K. (2011) Numerical simulations ..., Int. J. Computational Civil and Structural Engineering , 7 (2): 47-53.
6. Burla, M., Baptista, A.M. Zhang, Y., and Frolov, S. (2010) Seasonal and inter-annual variability of the Columbia River plume: a perspective enabled by multi-year simulation databases. J. of Geophys. Res, 115, C00B16.
7. CBP STAC (2010) STAC review of the water clarity and SAV components of the Chesapeake Bay Program water quality and sediment transport model. March 9-10, 2010, Final report.
8. Cerco, F.C., Noel, M.R. and Wang, P. (2013) The shallow-water component of the Chesapekae Bay environmental model package. J. American Water Resources Association, **49**, p. 1091-1102.
9. Craig, P. D., and Banner, M. L. (1994) Modeling …, J. Phys. Oceano., **24**(12), p. 2546-2559.
10. Friedrichs, M., Sellner, K.G., and Jonston, M.A. (2012) Using multiple models of management in the Chesapeake Bay: a Shallow Water Pilot Project. Chesapeake Bay Program Scientific and Technical Advisory Committee Report. No. 12-003, Edgewater, MD. 2012 09.
11. Gallegos, C.L., Werdell, P.J. and McClain, C.R. (2011) Long-term ..., J. Geophys. Res., **117**, p. 1-19, doi: 10.1029/ JC2011007160.
12. Grant, W.D., and Madsen, O.S. (1979) Combined …, J. Geophys. Res., **84**(C4), p. 1797-1808.
13. Gross, E., Casulli, V., Bonaventura, L., and Koseff, J. (1998) A semi-implicit …, Int. J. Num. Meth. Fluids, **28**, p. 157-186.
14. Komen, G.J., L. Cavaleri, M. Donelan, K. Hasselmann, S. Hasselmann, and Janssen, P. A. E. M. (1994) Dynamics and Modelling of Ocean Waves. Cambridge University Press, 532 pp.
15. Longuet-Higgins, M. S., and Stewart, R. W. (1964), Radiation …, Deep Sea Research and Oceanographic Abstracts, **11**(4), 529-562.
16. NTHMP (2012) Proceedings and results of the 2011 NTHMP model benchmarking workshop. Boulder: US Depart. of Commerce/NOAA/NTHMP, NOAA Special Report 436p.
17. Pinto, L., Fortunato, A.B., Zhang, Y., Oliveira, A. and Sancho, F.E.P. (2012) Development and validation of a three-dimensional morphodynamic modelling system, Ocean Mod., **57-58**, 1-14.
18. Rodrigues, M., Oliveira, A., Queiroga, H., Fortunato, A.B., and Zhang, Y. (2009) Three-Dimensional Modeling of the Lower Trophic Levels in the Ria de Aveiro (Portugal), *Ecolog. Mod.*, 220(9-10), 1274-1290.
19. Roland, A., (2009), Development of WWM II: Spectral wave modeling on unstructured meshes. Ph.D. thesis, Technische Universit¨at Darmstadt, Institute of Hraulic and Water Resources Engineering.
20. Roland, A., Zhang, Y., Wang, H.V., Maderich, V. and Brovchenko, I. (2012) A fully coupled wave-current model on unstructured grids, J. Geophys. Res. **117**, C00J33.
21. Roland, A. and Zanke. U. (2013) On the extension of numerical morhodynamic model for the dynamics of Fluidmud, KFKI Report - 03 KIS 065, Federal Ministry of Research and Education – Coastal Research.
22. Wang, H., Wang, Z., Loftis, D. and Teng, Y. (2013). Hydrodynamic and water quality modeling and TMDL development for Maryland's Coastal Bays System. A final report submitted to Maryland

Deparment of the Environment, TMDL Technical Development Program, Science Service Administration. Baltimore MD 21230.
23. Wang, H., Wang, Z., and Zhang, Y.J. (2014) Impact on localized water quality resulting from allocation of nutrient loads to dredged material contaminant facilities in Baltimore harbor (in preparation).
24. Warner, J.C., Sherwood, C.R., Signell, R.P., Harris, C.K., Arango, H.G.(2008) Development ..., Computers & Geosciences, **34**, p. 1284-1306.
25. Zhang, Y., and Baptista, A.M. (2008) SELFE: A semi-implicit Eulerian-Lagrangian finite-element model for cross-scale ocean circulation. Ocean Mod., **21**(3-4), 71-96.
26. Zhang, Y., Witter, R.W. and Priest, G.P. (2011) Tsunami-Tide Interaction in 1964 Prince William Sound Tsunami, Ocean Mod., **40**, 246-259.
27. Nezu, I., Nakagawa, H. and Abe, T. (1995), Turbulence in Open-Channel Flows. IAHR Monograph Series, A. A. Balkema, Rotterdam, p. 1–281.
28. Zanke, U.C.E. (2003) On the influence of …, Int. J. Sediment Research, **18** (1), p. 17.

6. Letter of support

MDE

MARYLAND DEPARTMENT OF THE ENVIRONMENT
1800 Washington Boulevard • Baltimore MD 21230
410-537-3000 • 1-800-633-6101

Martin O'Malley
Governor

Anthony G. Brown
Lieutenant Governor

Robert M. Summers, Ph.D.
Secretary

January 8, 2014

Tim Roberts
U.S. Environmental Protection Agency
Chesapeake Bay Program Office
410 Severn Ave., Suite 109
Annapolis, MD 21403
(EPA-R3-CBP-14-02)

Re: Recommendation for proposal entitled "Evaluation of Multiple Shallow-water System Analyses to Improve the Assessment of Chesapeake Bay Water Clarity and Submerged Aquatic Vegetation Water Quality Standards."

Dear Mr. Roberts:

This letter is in strong support of Drs. Joseph Zhang and Harry Wang's submission of the proposal for "Evaluation of Multiple Shallow-water System Analyses to Improve the Assessment of Chesapeake Bay Water Clarity and Submerged Aquatic Vegetation Water Quality Standards."

The Total Maximum Daily Load (TMDL) Technical Development Program, at the Maryland Department of the Environment, has had the pleasure of working with the above PIs on "Hydrodynamic and Water Quality Modeling, and TMDL Development for Maryland's Coastal Bays System." The work produced by the team at Virginia Institute of Marine Science (VIMS) was an outstanding effort, and facilitated the development of Nitrogen and Phosphorus TMDLs for the sub-watersheds within the Maryland Coastal Bays system. Dr. Wang and others at VIMS have worked on numerous TMDL-related projects over the years, and we know we can count on them to produce work of impeccable quality.

We highly recommend their professional skill and modeling capability in carrying out the tasks required.

Sincerely yours,

Dinorah Dalmasy, Manager
TMDL Technical Development Program