DEPARTMENT OF COMMERCE (DOC)
NATIONAL OCEANIC ATMOSPHERIC ADMINISTRATION (NOAA)
OCEANIC AND ATMOSPHERIC RESEARCH (OAR)
GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY (GLERL)

Lake Erie FVCOM-ERSEM Model (Phase 4)

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2. Purpose: Application of the FVCOM-ERSEM biophysical model to Lake Erie: Phase 4.

3. Background: The Finite Volume Community Ocean Model (FVCOM, http://fvcom.smast.umassd.edu/) has been applied to each of the Great Lakes, and is the basis of NOAA's Great Lakes Operational Forecast System. There is a need to develop advanced ecosystem models linked to FVCOM to support management of harmful algal blooms and hypoxia in support of the Great Lakes Water Quality Agreement. The European Regional Seas Ecosystem Model (ERSEM, https://www.pml.ac.uk/Modelling_at_PML/Models/ERSEM) is an advanced biogeochemical and lower food web ecosystem model that has been linked to FVCOM by Plymouth Marine Laboratory (PML), and has been applied to various aquatic ecosystems. In phases 1-3 of this work, PML conducted initial setup and assessment of an FVCOM-Framework for Aquatic Biogeochemical Models (FABM)-ERSEM application to Lake Erie, established realistic nutrient concentrations for Lake Erie, and established a representation of the Lake Erie planktonic food web using the DRAMA plankton model, including toxic and non-toxic strains of *Microcystis*.

4. Scope: The scope of this contract is to develop and assess aspects of the Lake Erie FVCOM-ERSEM model needed to simulate harmful algal blooms and hypoxia in response to nutrient loading and meteorological scenarios.

5. Objectives: The work will deliver an FVCOM-FABM-ERSEM implementation of Lake Erie that fulfils via simulations spanning the time period 2014-2020 the required characteristics (consistent with empirical data) of 1) phytoplankton community composition, including harmful algal bloom (HAB) biomass, spatial and temporal extent, and microcystin toxin concentrations produced by *Microcystis* 2) concentrations of phosphorus and nitrogen containing constituents (particulate, dissolved, organic, inorganic), basin scale phosphorus and nitrogen budgets, 3) spatial and temporal extent of hypoxia, 4) and pH average values and extremes associated with HABs and hypoxia. Simulations shall be mass conserving and free of numerical instabilities.

6. Tasks: To develop the products as outlined in the specific tasks section of this statement of work.

7. Specific Tasks: The contractor will coordinate with Government POC to achieve the following activities for this project:

1. Starting with the model structure developed in Phase 3, and FVCOM physical model consistent with the GLERL FVCOM application in terms of thermal structure and ice

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simulation, add a functional type representing nitrogen fixing cyanobacteria, and a functional type representing the cryptophyte/dinoflagellate community having traits established in coordination with GLERL. Incorporate a version of the ERSEM benthic filter feeder module modified by GLERL to represent invasive dreissenid mussels.

2. Develop and apply a spatially-simplified application of Erie ERSEM for rapid calibration simulations as either A) a 1-dimensional vertical water column version of the Erie ERSEM model to simulate 3 stations in Lake Erie, representing the western, central, and eastern basins, or B) a coarse-grid 3D application of FABM-ERSEM to Lake Erie. The selection of option A or B will be made in consultation with GLERL, and depending on preliminary trials.

3. Reparameterization: Review all parameter values to ensure consistency with available scientific understanding of aquatic ecology. Conduct sensitivity analysis to determine which parameters are most important with respect to the model performance objectives. The reparameterization will include investigating simulation of toxic versus non-toxic *Microcystis*, zooplankton selective grazing, anoxic phosphorus release, sensitivity tests on the benthic adsorption model, and simulation of central basin hypoxia.

4. Implement and run the automated optimization software ParSAC to calibrate the spatially-simplified application of Erie ERSEM in comparison to observational water quality and ecological data provided by GLERL focused on the model performance objectives listed in the Objectives section above.

5. Apply a 0-dimensional version of the Erie ERSEM model to conduct calibration and sensitivity simulations of phosphorus adsorption, *Microcystis* growth, and toxin production, in comparison to laboratory experimental results provided by GLERL under varying conditions of temperature, light, nitrogen and phosphorus.

6. Extend three-dimensional FVCOM-FABM-ERSEM simulations of Lake Erie to cover the years 2014-2020 with the optimized parameter set, and conduct quantitative comparison with observational data focused on the model performance objectives listed in the Objectives section above. GLERL will provide the input files required to run FVCOM for the years indicated, including boundary forcings, restart files, and quantitative observational data for validation

7. The contractor shall organize virtual meetings at least quarterly with GLERL to monitor progress and ensure the timely delivery of the project.

8. Create a GitHub repository shared with GLERL including all code and transfer all input files needed for the simulations in the Tasks, in addition to analysis and visualization scripts to GLERL.

9. Provide technical support to NOAA GLERL to install and run the simulations developed under the tasks above on the NOAA GLERL HPC system, and reproduce the results provided by PML.

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10. All data and computer code required to run the model test cases described above will be shared with NOAA GLERL, and results will be documented in a final report and presentation. A summary of changes to the model code, and summary of changes made to model parameters during calibration, will be provided.

8. Deliverables and milestones:

Month 5: Complete Tasks 1 and 2 (M1).

Month 6: Complete Task 3 (M2).

Month 10: Complete Task 4 (M3)

Month 11: Draft report describing the work undertaken shared with GLERL contacts (D1).

Month 11: Complete Tasks 6.

Month 12: Complete Task 8, 9 and 10.

To avoid dependencies on commercial licensed products, the work undertaken here on the setup and analysis of model outputs will use the programming language Python (version >= 3.7). All documented python scripts used in the implementation and evaluation of the FVCOM-ERSEM for Lake Erie will be provided at the end of the project as a git repository. The contact points at GLERL will be given access to the git repository at the beginning of the project. All necessary Python scripts will be based on the freely available PyFVCOM toolbox and fviz developed by PML (https://pypi.org/project/PyFVCOM/ and https://github.com/pmlmodelling/fviz.

9. Place of Performance:
Work will be performed at the contractor's facility. Travel to NOAA GLERL is not required. Meetings may be conducted virtually.

10. Period of Performance: NOT USED

11. Government Furnished Equipment: No GFE will be provided. The contractor will not have access to the government network. Information shared will be of the public domain nature. Transfer sites may be utilized at the discretion of the government.

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