**Water Quality Model Development and Application in Puget Sound and Georgia Basin**

This summary information was compiled in Winter 2013 by the modeling workgroup of the Puget Sound Environmental Monitoring Program (PSEMP).

 **Puget Sound/Georgia Basin Model**

*Model development leads:*

*Tarang Khangaonkar (Battelle-PNNL), Brandon Sackmann (Ecology)*

This model has been developed and documented (see reference listing below) by Ecology and PNNL with EPA funding (note: University of Washington is also a collaborator on climate change aspects). The model is the first application of a linkage between the FVCOM model (for hydrodynamics) and CE-QUAL-ICM (water quality) developed by PNNL (Kim and Khangaonkar 2011). Since the early effort to simulate phytoplankton blooms in the main basin of Puget Sound by Winter et al. (1975), it is the first model of its kind to simulate currents, temperature, salinity, nutrients, phytoplankton, and dissolved oxygen for the entire domain of Puget Sound/Georgia Basin (Khangaonkar et al. 2011, Khangaonkar et al. 2012). Ecology/PNNL/UW are currently in the process of applying the model to predict future impacts of human-caused nutrient pollution on dissolved oxygen conditions in the Sound and Georgia Basin. The focus of the current study is large scale changes to oxygen in the main basins. Analysis of shallow basins will require additional, targeted model development and calibration.

EPA and Ecology are very encouraged by the performance of this model to date and anticipate that it will become a “workhorse” model for analysis of Puget Sound water quality and circulation in support of Puget Sound Partnership goals.

**MoSSea (Modeling the Salish Sea)**

*Model development leads:*

*Parker MacCready, Neil Banas (UW Oceanography)*

The MoSSea model is a three dimensional simulation of Salish Sea and adjacent coastal waters implemented in ROMS (Regional Ocean Modeling System). A paper by Sutherland et al. (J Phys Oceanogr, 2011) documents an extensive validation against salinity, temperature, and velocity time series (Ecology monthly monitoring; ORCA high-resolution time series; moored coastal observations from NOAA and NSF projects) for a model hindcast of 2006. This model and its variants are currently being used for 1) evaluation of climate impacts on Puget Sound aquaculture using downscaled model projections of 2040s conditions; 2) mapping of connectivity between Puget Sound rivers and subbasins, including a spatially detailed attribution of fecal coliform, DIN, and freshwater loading to their watersheds of origin; 3) evaluation of climate impacts on *Alexandrium* harmful algal blooms (HABs) in Puget Sound; 4) hindcasting of *Pseudonitzschia* HABs, hypoxia, ocean-acidification patterns in Washington coastal waters, including the source waters for the Salish Sea; 5) exploration of energy dynamics and flow over rough topography; and 6) nesting within the global CESM climate model to explore effects of unresolved freshwater sources. (Funding for these projects comes from EPA, NOAA Ecohab, NSF, and DOE).

The extensively validated, custom biogeochemical model used for this coastal project (Banas et al, J Geophys Res, 2009; Davis et al. in prep, Siedlecki et al. in prep) is ready to be ported to Salish Sea waters and re-validated, pending new support. The coastal biogeochemical model includes a well-validated simulation of bottom oxygen and preliminary hindcasts of pH and other ocean-acidifcation variables (S Siedlecki, UW).

**Puget Sound Toxics Box Model**

*Model development lead:*

*Greg Pelletier (Ecology)*

This model is a coarse scale (20 model cells over the Puget Sound domain) used to analyze fate and transport of PCBs in the water column and sediments, coupled with a food web model to estimate bioaccumulation in marine biota. Building on the PCB work, a new model setup to analyze PAH, PBDEs, and selected metals is underway.

**South Sound Model**

*Model development leads:*

*Greg Pelletier, Mindy Roberts, Anise Ahmed (Ecology)*

This model is under development (see reference listing below) by Ecology with EPA funding. The model, built with the GEMSS model framework/software, simulates nutrients/dissolved oxygen for the South Sound. Ecology is currently in the process of calibrating the model for prediction of future impacts of human-caused nutrient pollution on dissolved oxygen conditions in the South Sound. The focus of the current study is large scale changes to oxygen in the main basins.

**Puget Sound Central Basin food web model**

*Model development lead:*

*Chris Harvey (NOAA-NMFS, NWFSC)*

This model was developed collaboratively by numerous scientists from NOAA, State of Washington agencies, and from the University of Washington. It was made in the Ecopath with Ecosim (EwE) software, which first creates a mass-balanced food web of functional groups linked through predator-prey interactions (Ecopath) and then allows the user to perturb the food web in a dynamic simulation framework (Ecosim). The model domain is the central basin of Puget Sound (marine waters from approximately Whidbey Island in the north to the Tacoma Narrows in the south); as EwE has essentially no spatial resolution, the model domain is treated as a single well-mixed box, although the developers have used some features of the model to impose some spatial dynamics (e.g., habitat effects related to eelgrass beds). The model food web is composed of over 65 functional groups, ranging from phytoplankton to marine mammals, and also includes 15 different fishing gear types.

The model is intended to be a support tool for management strategy evaluation, in relation to restoration goals outlined by the Puget Sound Partnership. Published applications to date include: reconstructions of recent time series data; evaluation of the ecosystem role of bald eagles; and estimating the ecosystem services provided by eelgrass. Work in progress includes an assessment of the performance of species and food web Vital Sign indicators as proxies for important community attributes, and estimating the potential direct and indirect impacts of ocean acidification on the community.

**Salish Sea Atlantis Ecosystem Model**

*Model development lead:*

*Chris Harvey (NOAA-NMFS, NWFSC)*

This model is in an early stage of development, led by scientists at NOAA with potential collaborators at State of Washington agencies, the University of Washington, and CSIRO-Australia. It is being developed in the Atlantis software, developed at CSIRO-Australia. When completed, the model will be a spatially and temporally explicit, biophysically coupled model that simulates ecosystem dynamics in most of the marine waters of the Salish Sea. The spatial domain will span from South Puget Sound to the southern Strait of Georgia (though likely not including the Strait of Juan de Fuca, the Fraser River delta, or north of the Fraser River). This area has been divided into >60 polygons based on circulation, bathymetry, benthic habitats, species composition, and resource management. Each polygon has multiple depth layers. Inputs from circulation models will drive the physics (water fluxes, temperature) and basic water chemistry (salinity, some nutrients, and point source inputs such as rivers or urban outfalls). Overlying the model’s three-dimensional box geometry and oceanography will be a dynamic food web model with considerably greater detail than is used in EwE (see above). For example, vertebrate groups have substantially more explicit age structure, reproductive biology, depth and habitat preferences, movement behavior, and size-specific feeding ecology in Atlantis compared to EwE. The model has >50 different food web groups, again ranging from phytoplankton to marine mammals. The model will also simulate spatially and temporally dynamic fishing fleets. Atlantis can also model scientific monitoring, such that a simulated research program is collecting samples in space and time and those limited data (i.e., limited relative to the scope of the model) can be used to assess perceived responses in space and time to natural variability and prescribed management actions. This, then, would represent a spatiotemporally explicit “end-to-end” model for comparing potential outcomes of management activities and identifying potential tradeoffs at the scale of most of the Salish Sea.

# USGS Sediment Transport Model of Salish Sea

*Model development leads:*

*Guy Gelfenbaum and Andrew Stevens (USGS, Santa Cruz, CA)*

The U.S. Geological Survey has developed a coupled hydrodynamic and sediment transport model for the Salish Sea using the Delft3D modeling system. A curvilinear grid consisting of approximately 129,000 grid cells covers the Strait of Juan de Fuca, Georgia Basin and Puget Sound. Delft3D solves the unsteady shallow water equations to simulate water motion due to tides, waves, wind, and buoyancy effects. Waves are simulated using the third-generation SWAN wave model. The wave- and flow- models are coupled: water levels, wind, and currents from the flow model are incorporated into the wave calculations and output from the wave model is used by the flow model to simulate enhanced bed stresses due to waves and wave-driven currents. Sediment transport of multiple sediment fractions, including both non-cohesive and cohesive sediment types, is included. Suspended sediment transport is solved using the advection-diffusion solver and bedload transport is calculated using standard nonlinear empirical relationships. The USGS Salish Sea model is primarily used to generate boundary conditions for detailed model applications at specific sites throughout the Salish Sea.

**Individual Embayment Models**

In addition to the large scale models described above, there are several models of individual embayments within Puget Sound, including:

* Budd Inlet (nutrients/dissolved oxygen, Ecology)
* Oakland Bay (bacteria, Ecology)
* Quartermaster Harbor (nutrients/dissolved oxygen, King County)
* Hood Canal (nutrients/dissolved oxygen, UW: Kawase et al.)
* Dyes/Sinclair Inlet (bacteria and copper, U.S. Navy)
* Nisqually Delta, Elwha River, Deschutes Estuary, and Possession Point (sediment transport, USGS)

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