

Hydrodynamic and Sediment Dynamics Modeling

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Objectives

This project is concerned with developing and testing a numerical model for predicting resuspension, transport, and deposition of fine grained sediments in Lake Michigan. The model will provide significant insight into the mechanisms of cross-margin transport in the Great Lakes, and semi-enclosed seas. The results from the model will lead to better understanding of the response of the Great Lakes ecosystem to the impact of natural and anthropogenic stressors.

Project Rationale

Wind-driven transport is a dominant feature of circulation in the lakes. In addition to the spatial and temporal variability of the wind forcing, the earth's rotation, basin topography, and vertical density structure are all important influences in the dynamical response of the lake. The response of an enclosed basin with a sloping bottom to a uniform wind stress often consists of longshore, downwind currents in shallow water, and a net upwind return flow in deeper water. The streamlines of the flow field form two counter-rotating closed gyres (Figure 1a), a cyclonic gyre to the right of the wind and an anticyclonic gyre to the left (in the northern hemisphere). In this classic two gyre pattern, there are two points along the shoreline where cross isobath transport occurs, one on the upwind shore where diverging longshore currents are accompanied by onshore flow, and one on the downwind shore where converging longshore currents are accompanied by offshore flow. As the wind relaxes, the two-cell streamline pattern rotates cyclonically within the basin (Fig. 1a-c.), with a characteristic period corresponding to the lowest mode vorticity wave of the basin. For a Coriolis parameter and geometry representative of the Great Lakes, this period is on the order of 3-5 days, closely corresponding to the periodicity of storm forcing. Numerical models approximating actual lake geometry have proven to be remarkably effective in explaining observed circulation patterns in lakes. Modeling exercises have shown that the actual bathymetry of each of the Great Lakes tends to act as a combination of bowl-shaped sub-basins, each of which tends to support its own two-gyre circulation pattern.

In conjunction with the wind-driven circulation pattern, storm-generated waves will tend to be highest on the downwind end of the lake, coincident with the initial location of the convergence zone. If storm waves are large enough to resuspend bottom sediments, this will also be the zone of highest water column concentration of suspended sediments. Our hypothesis is that these two hydrodynamic factors combine to generate a preferential zone of offshore transport in the southeastern part of Lake Michigan.

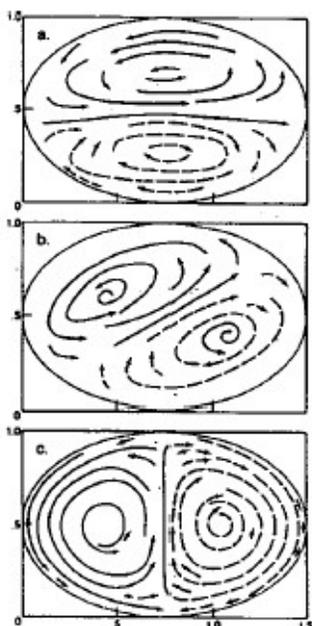


Figure 1: *Two-gyre Vorticity Wave in a Circular Paraboloid.*

Accomplishments

In 2004, Lake Michigan meteorological data for 2001-2003 were assembled, quality checked and interpolated to 2 km model grid. The hydrodynamic model was run for January 1, 2001 to December 31, 2003 period. The results were used in particle trajectory model calculations for June-August 2001-2003. As in previous biological model runs, we are testing the model for two food availability scenarios that would allow larvae to feed at a maximum rate, and half their maximum rate (P_{val} equals 1 and 0.5). Again, larvae were released only in one area known for yellow perch spawning between Chicago, IL and Waukegon, IL. The model run begins on day 150 (May 30) and ends on day 239 (August 27). Particles were released at 3 depths (surface, mid-depth, bottom) in waters less than 10 m deep (246 particles total). We are making calculations for two settlement sizes, 30 and 50 mm.

We also obtained a bioenergetics model for larval alewife and are currently testing this model before linking it with the particle trajectory model. The model will be run for a 1998-2003 period with initial sources of larval alewife near Twin Rivers, WI.

Physical limnology field studies were conducted in June-July, 2003 on Lake Michigan in support of hydrodynamic modeling efforts to estimate the trajectories of larval yellow perch. Satellite-tracked and GPS reporting drifting buoys were released in the coastal waters of southern Lake Michigan. Drifting buoys were placed in the vicinity of a known perch spawning areas. Resulting drifter trajectories are presented in Figure 2 and 3.



Figure 2: Drifter 4746 Track.

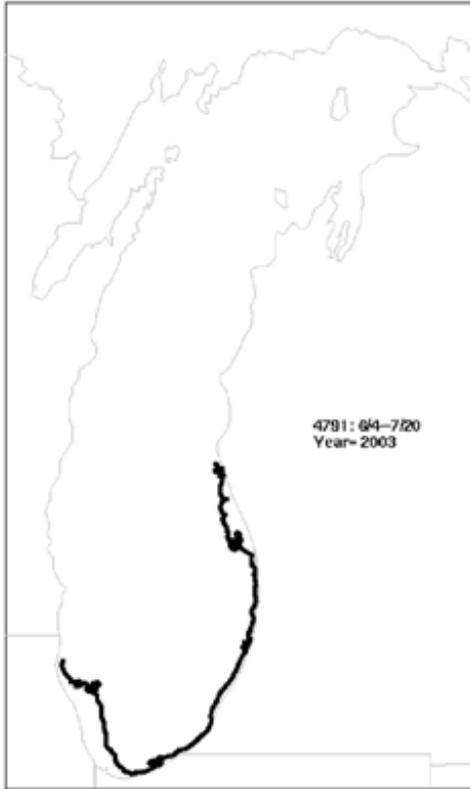


Figure 3: *Drifter 4791 Track*

The sediment dynamics modeling part of this project will be merged with N. Hawley's project on Measurement and modeling of wave-induced sediment resuspension in nearshore water. Progress in FY04 included successful retrieval of Lake Michigan moorings and addition of data from these moorings to other time series measurements of turbidity and wave forcing for additional model validation.



Figure 4: GLERL Wave Measuring ADCP



Figure 5: Wu Sediment Dynamics Quadrapod

Methods

Sediment Dynamics

In the fall of 2002 and 2003 we deployed the two new wave-measuring ADCP's along with self-recording transmissometer packages at 10m and 20m depths off of St. Joseph, MI to simultaneously measure the turbidity gradient and associated wave and current fields. This data is crucial for testing the validity of the new sediment dynamics model. An NRC post-doc, Cheegwan Lee, will be comparing this data as well as other data collected during the EEGLE program to long-term sediment model predictions. In addition, in 2003 Chin Wu (University of Wisconsin) deployed a sophisticated sediment dynamics instrumentation package between the GLERL moorings and is planning to collaborate on the data analysis.

Particle Transport

A Great Lakes Fisheries Trust project (Modeling the Influence of Lake Circulation Patterns, Upwelling Events, and Turbulence on Fish Recruitment Variability in Lake Michigan) was initiated in 2002 to use the hydrodynamic transport model of Lake Michigan to investigate the impacts of lake circulation on dispersal of yellow perch larvae. The model uses 3D currents generated by the Great Lakes version of the Princeton Ocean Model driven by observed momentum and heat fluxes in June-August 1998, 1999 and 2000. Virtual larvae were released in the nearshore region with the most abundant preferred substrate for yellow perch spawning, rocks. We will be investigating the potential for physical transport mechanisms to affect recruitment of Lake Michigan yellow perch by coupling the hydrodynamic model results with individual-based particle models of fish larvae to study variation in larval distributions, growth rates, and potential recruitment.

Advective Processes

In collaboration with M. Stein (U. Chicago Statistics Dept.) we are studying statistical approaches to data assimilation for advective transport. These results could be used to improve circulation model simulations based on observed data from current meters, as well as incorporating satellite imagery into sediment dynamics models. This year we will compare modeled and observed currents in Lake Michigan using an autoregressive basis function model.

Products

Beletsky, D., D. J. Schwab, 2001. Modeling circulation and thermal structure in Lake Michigan: Annual cycle and interannual variability. *J. Geophys. Res* 106:19745-19771.

Beletsky, D., D. J. Schwab, D. M. Mason, E. S. Rutherford, M. J. McCormick, H. A. Vanderploeg, and J. J. Janssen. Modeling the transport of larval yellow perch in Lake Michigan. *Proceedings of the Estuarine and Coastal Modeling 8th International Conference*, Monterey, CA, November 3-5, 2003. American Society of Civil Engineers, 439-454 pp. (2004).

Chen, C., R. Ji, D. J. Schwab, D. D. Beletsky, G.L. Fahnenstiel, M. Jiang, T. H. Johengen, H.A. Vanderploeg, B. J. Eadie, J.W. Budd, M.H. Bundy, W. Gardner, J.B. Cotner, and P.J.

- Lavrentyev. 2002. A model study of the coupled biological and physical dynamics in Lake Michigan. *Ecol. Modeling* 152:145-168
- Chen, C., L. Wang, J. Qi, H. Liu, J. W. Budd, D. J. Schwab, D. Beletsky, H. A. Vanderploeg, B. J. Eadie, T. H. Johengen, J. Cotner, and P. J. Lavrentyev. A modeling study of benthic detritus flux's impacts on heterotrophic processes in Lake Michigan. *Journal of Geophysical Research* 109(C10S11):13 (2004).
- Chen, C., L. Wang, R. Ji, J. W. Budd, D. J. Schwab, D. Beletsky, G. L. Fahnenstiel, H. A. Vanderploeg, B. J. Eadie, and J. Cotner. Impacts of suspended sediment on the ecosystem in Lake Michigan: A comparison between the 1998 and 1999 plume events. *Journal of Geophysical Research* 109(C10S05):18 (2004).
- Eadie, B.J., D. Schwab, T. Johengen, P. Lavrentyev, G. Miller, R. Holland, G. Leshkevich, M. Lansing, N. Morehead, J. Robbins, N. Hawley, D. Edgington, and P. Van Hoof. 2002. Particle transport, nutrient cycling, and algal community structure associated with a major winter-spring sediment resuspension event in southern Lake Michigan. *J. Great Lakes Res* 28(3):324-337.
- Hawley, N., B. M. Lesht, and D. J. Schwab. A comparison of observed and modeled surface waves in southern Lake Michigan and the implications for models of sediment resuspension. *Journal of Geophysical Research* 109(C10S03):11 (2004).
- Hook, T. O., E. S. Rutherford, S. J. Brines, D. J. Schwab, and M. J. McCormick. Relationship between surface water temperature and Steelhead distributions in Lake Michigan. *North American Journal of Fisheries Management* 24:211-221 (2004).
- Ji, R., C. Chen, J.W. Budd, D.J. Schwab, D. Beletsky, G.L. Fahnenstiel, T.H. Johengen, H.A. Vanderploeg, B.J. Eadie, J.B. Cotner, W. Gardner, and M.H. Bundy. 2002. Influences of suspended sediments on the ecosystem in Lake Michigan: a 3-D coupled bio-physical modeling experiment. *Ecol. Modeling* 152:169-190.
- Lou, J., D.J. Schwab, D. Beletsky, and N. Hawley. 2000. A model of sediment resuspension and transport dynamics in southern Lake Michigan. *J. Geophys. Res* 05:6591-6610.
- Raudsepp, U., D. Beletsky and D.J. Schwab, 2003. Basin-scale Topographic Waves in the Gulf of Riga. *J. Phys. Oceanogr.* 33, 1129-1140.
- Schwab, D.J., D. Beletsky, and J. Lou. 2000. The 1998 coastal turbidity plume in Lake Michigan. *Estuarine, Coastal, and Shelf Science* 50:49-58.
- Schwab, D.J. and D. Beletsky. 2003. The relative effect of wind stress curl, topography, and stratification on large-scale circulation in Lake Michigan. *J. Geophys. Res.* 108(C2), 26-1:26-10.
- Schwab, D.J. and D. Beletsky. 2002. Hydrodynamic and sediment transport modeling of episodic resuspension events in Lake Michigan. *Proceedings of the 7th International Conference of Estuarine and Coastal Modeling*, November 5-7, 2001, St. Petersburg, Florida, 266-279.