## PROJECT TITLE: ECOFORE 2006: FORECASTING THE CAUSES, CONSEQUENCES AND REMEDIES FOR HYPOXIA IN LAKE ERIE

*Principal Investigator: Don Scavia, University of Michigan*

## Overview and Objectives

The overall objective of this project is to create, test, and apply models to forecast how these stresses influence hypoxia formation and ecology of Lake Erie's Central Basin, with an emphasis on fish production potential. These models will integrate the multiple factors that interact to create hypoxia on Lake Erie, such as surface water flow, phosphorus input, lake dynamics, climate variation, fish movement patterns and fish and Dreissenid biology and physiology. The forecasts will be conducted within an Integrated Assessment (IA) framework, which is a formal approach to synthesizing existing natural and social scientific information in the context of a natural resources policy or management question.

## Accomplishments

**WATERSHED TEAM**

Many activities in the Watershed Team are being conducted and completed concurrently. Nutrient (TP, NO2+NO3, TKN, TN, TSS, and SRP) loading data are being compiled and summarized to be used as model inputs for the Hypoxia Team. Watershed nitrogen (N) and P budgets are being created to better understand N and P sources over time as well as to aid in forecasting scenarios. The Distributed Large Basin Runoff Model (DLBRM) and the Soil and Water Assessment Tool (SWAT) are be parameterized and calibrated to be later used in climate and land management practice change forecasting scenarios.

***Nutrient loading efforts***

Monthly and daily river export load series for the Raisin, Maumee, Sandusky, Vermilion, Cuyahoga, and Grand Rivers have been completed for the period of record. Missing data have been filled in, and the complete time series have been posted to the project website.

Daily Lake Erie nutrient loading estimates for CY2005 at 26 spatial nodes have been completed with the exception of atmospheric estimates which are pending data from Environment Canada. CY1976 nutrient loads have been reconstructed from archived historical data with the exception of unmonitored area estimates. Collection of point source and tributary data for 2006 and 2007 is still ongoing as many data sources are still unavailable.

***N and P budgets***

For all watersheds of the Lake Erie Basin in the U.S., historical N and P budgets were completed for agricultural census years from 1934 to 1974 at every decennial, and from 1974 to 2002 at every five years. Similar to the NAPI budgets, Nitrogen budget was estimated using net anthropogenic N inputs

approach. NANI was constructed by quantifying all known anthropogenic N inputs (fertilizer, crop fixation, atmospheric deposition, imports of N in crop and animal products), outputs (volatilization of N from applied manure and fertilizer and crop senescence, and exports of N in food and feed) as well as the net balances between inputs and outputs, resulting in an estimate of net anthropogenic N inputs (NANI).

In addition, we developed relationships between watershed P inputs and river TP exports for the selected watersheds of the Lake Erie Basin (Huron, Raisin, Maumee, Sandusky, Cuyahoga, and Grand in OH) for 5 agricultural census years from 1978 to 2002 to figure out how the input: export relationship has changed over time and how the changes in relationships would be linked to the re-occurrence of the Hypoxia in Lake Erie.

Multiple databases of land use, soil, digital elevation model (DEM), hydrography, and agricultural management practices have been acquired, processed, and analyzed to develop dynamic input parameters for the DLBRM and the revised universal soil loss equation (version 2) (RUSLE2) for the 6 watersheds on the U.S. side (Grand-OH, Cuyahoga, Sandusky, Maumee, Huron-MI, and Raisin). We have acquired and processed multiple databases of land use, soil, digital elevation model (DEM), and hydrography for the Grand River –Ontario. A computer program was written to spatially link the Ontario soil attribute database with the polygon database for extracting the soil input parameters. Input parameters for the DLBRM were derived. We are currently working to derive the N and P loading input for the DLBRM on the Grand River –Ontario.

We have also built basic model application databases (daily meteorology, land use, soils, elevation, and hydrography) for all 17 US Lake Erie watersheds and are working on the same for the Grand (Ontario) and we completed DLBRM daily calibrations for five Erie watersheds: Huron, Raisin, Maumee, Sandusky, and Grand (Ohio). We are now calibrating the DLBRM for the remaining 12 US Erie watersheds. We estimated sediment and nutrient transport for two non-Erie watersheds and are doing the same now for the Maumee watershed on Lake Erie. We are now adding transport mechanics to the DLBRM. We developed automatic near real time "Resource Shed" processing for 18 watersheds, including the five Erie watersheds mentioned previously. Resource shed maps for the last 31 days are available daily and will soon be accessible via the WWW.

SWAT models are being developed for the same 7 Lake Erie watersheds being modeled by DLBRM – Huron, Raisin, Maumee, Sandusky, Cuyahoga, Grand (in Ohio), and Grand (in Ontario, Canada). Primary SWAT modeling efforts are currently parameterizing and calibrating the individual models. Data gathering and reformatting for model input has been completed over recent months except for some Canadian data to be used for the Grand (in Ontario) watershed. All 7 SWAT models have been delineated with DEMs, stream channels, sub-basin boundaries, and impoundments. The Raisin and Huron models are completely parameterized and are being calibrated. Other models are in various stages of parameterization. All watershed models have also been recently upgraded to the ArcSWAT 2.1.4a interface using ArcGIS 9.2.

**HYPOXIA TEAM**

Our level 2 hypoxia model was developed and applied for the period 1982-2005. The goal of this model is to expand on the level 1 model (focused primarily on thermal structure) to assess how the relative role of growth and decay processes in the lower foodweb affect hypoxia. The level 2 model maintains the 1-dimensional vertical domain. This framework incorporated basin phosphorus and carbon loads, available light (including phytoplankton self-shading), and the mixing and temperature structures from the 1D thermal model. The model estimates phytoplankton biomass, zooplankton biomass, autochthonous detritus, and dissolved oxygen by quantifying nutrient uptake and cycling in the water column. The application was calibrated for 2005 observations, and confirmed using data from 1982-2004.

A 2 km hydrodynamic model of Lake Erie was developed (based on the Princeton Ocean Model) with a goal to calculate lake-wide circulation and thermal structure in 2004 and 2005. Daily inflows at 22 major tributaries and hourly meteorological data at 12 land stations and 3 meteorological buoys were assembled, edited and interpolated to create gridded forcing functions for the hydrodynamic model. Complete 3D hydrodynamic model simulation was accomplished for both years and model results are now being compared with observations of temperature and currents. This modeling work has demonstrated the potential importance of nearshore-offshore gradients of important biogeochemical materials, making the exchange of material between the nearshore and offshore an important aspect to be considered in our level 3 modeling.

Our level 3A model is currently being developed to incorporate the 3-dimenstional hydrodynamic output for 2004 and 2004. The model will integrate the level 2 lower food web model into the 3-dimensional domain. The goal of this application is to assess how the food web impacts on dissolved oxygen resources vary spatially, particularly in near shore regions. The level 3A model is preliminarily applied for 2004 and 2005. We have also begun developing the code for our level 3B model, which will be a complex hypoxia model, incorporating Dreissenids and nearshore lower food web dynamics that may be different from offshore dynamics. This model will be linked to the same 3D hydrodynamic model as is being used for the level 3A model.

Additionally, we have continued to assess and incorporate uncertainty in our modeling applications. We have conducted preliminary, exploratory analyses of our level 1 model using PEST (a parameter estimation and optimization software) and WinBUGS (a Bayesian reference software). These analyses are intended to assess the variability of the calibration terms in the model.

**ECOLOGICAL EFFECTS**

The Ecological Effects team is developing a suite of models to explore how hypolimnetic hypoxia impacts ecological interactions and fisheries production in the central basin of Lake Erie. We are using a parallel modeling approach including: 1) Empirical, statistical models; 2) Bioenergetics models (Growth rate potential models [GRP] and Individual-based models [IBM]); and 3) Foodweb models (Ecopath with Ecosim and CASM [Comprehensive Aquatic Simulation Model]). Our ultimate goal is to apply these models to forecast how fish production in Lake Erie would be affected by potential, future nutrient loading scenarios and hypoxia dynamics.

During the initial phase of the project, we primarily work to develop and parameterize ecological models. To accomplish this goal, we rely on a variety of existing data: physical measures (temperature, water clarity, oxygen concentration), fisheries harvest data, annual fisheries-independent stock assessments, hydro-acoustic estimates of fish biomass, benthic macroinvertebrate surveys, zooplankton surveys (from optical plankton counter, net collections and pump samples), and fish samples (midwater and bottom trawl caught fish allowing for quantification species-specific vertical distributions and diet contents). Most of these data were collected through the IFYLE (International Field Years on Lake Erie) program and state/provincial agency-based monitoring efforts. Most of the data which we use for model development and parameterization have been previously collected and analyzed (primarily through IFYLE-related efforts). However, some previously collected data require compilation, processing and analyses before they can be used for model development and parameterization. To this end, we have analyzed biological data (zooplankton, benthic macro-invertebrate, and fish) and compiled historical fisheries and fisheries-independent data (including manual data entry from paper copies).

In applying our models, we build directly on the efforts of other project components (i.e., we use output from Watershed and Hypoxia forecasting models as input for our models). As these other project components have realized model outputs, our modeling efforts have ramped up. During 2008, we hired three postdoctoral research associates (Arend [Purdue; Bioenergetics modeling and CASM], Hosack [Ohio State; Empirical analyses], and Zhang [NOAA-GLERL and U. Michigan; EcoPath]).

***Empirical analyses***

We are exploring the effects of hypoxia on commercial catch rates of walleye using both commercial and fishery independent data in Lake Erie. Hypoxia, as estimated by the 1-D model, positively correlates with annual catch rates of walleye. Monthly analyses, however, show that catch rate and harvest response to hypoxia varies by region. Spatial data available from IFYLE 2005 shows that hypoxia is constrained to the central basin, and fishery independent survey data suggests that the probability of walleye occurrence exhibits unimodal relationships with respect to bottom dissolved oxygen and temperature. Ongoing work investigates how spatial IFYLE abiotic data relates to walleye distribution and the distribution of a primary prey species, rainbow smelt. We are continuing these analyses and in the future will use similar data sets to consider how spatial distributions and harvest of yellow perch and other species respond to hypoxia.

***Bioenergetic models***

To date, we have developed bioenergetics growth rate potential models for emerald shiner, rainbow smelt, round goby, yellow perch, and walleye. We have applied these models 1) using physical, chemical and biological data collected during 2005/2007 IFYLE cruises in central Lake Erie and 2) using output from 1-dimensional hypoxia models. Analyses based on output from 1-dimensional hypoxia models suggest that hypoxia effects on habitat quality vary inter-annually and differentially affect various species and life-stages. In addition, we are in the process of incorporating dynamic behavior and movement into growth rate potential models. In the near future, we will start development of individual-based bioenergetics models for rainbow smelt, walleye and yellow perch. These models will

build on growth rate potential models and on-going individual-based modeling efforts for walleye and yellow perch in other systems.

***Foodweb models***

CASM is a bioenergetics foodweb model useful for considering how stressor impacts on certain portions of a food-web may cascade to influence various other components. CASM Lake Erie (CASM-LE) is being developed and applied to evaluate how hypoxia impacts may cascade through the foodweb of Lake Erie's central basin. The impacts of hypoxia are somewhat different than many other stressors (e.g., contaminants) and this has required a restructuring of CASM. For instance, CASM-LE includes 3-layer vertical structure and allows foodweb constituents to move vertically. Further, CASM-LE includes a transect of vertically-structured foodweb compartments, moving from nearshore to offshore (thereby allowing for horizontal migration in response to hypoxia). We are using a variety of information to develop foodweb connections, initial model biomasses and physio-chemical conditions in CASM-LE (e.g., physical, chemical and biological data from IFYLE; literature values; agency reports). We have developed initial structure for the CASM-LE foodweb and will shortly begin model simulations.

Ecopath with Ecosim (EwE) is a suite of food web models that is designed to address ecological questions, to evaluate ecosystem effects of fishery management, to explore management policy options, and to evaluate effect of environmental changes, etc. Our Ecopath model will be focused on the central basin of Lake Erie, and aims to evaluate the impacts of hypoxia on the lake ecosystem structure and function, and to explore water quality management and fisheries management scenarios. Our EwE team has been compiling and analyzing data since December 2008 to modify an existing Ecopath model for Lake Erie developed by Johnson and Zhu to investigate the effects of invasive species on the Lake Erie food web. Our EwE team has consulted lower trophic level experts regarding merging taxa into functional trophic groups in Ecopath. We estimated biomass of the lower trophic-level groups based on literature review and data sources including IFYLE field studies and the LEPAS (Lake Erie Plankton Abundance Study at Ohio State University). Currently, we are modeling 41 age/size groups of fish in our Ecopath model: biomass estimated from IFYLE trawl and acoustic data, and from surveys by state and provincial agencies. Our EwE team also is working with Lake Erie fisheries managers to design relevant management simulations and to ensure the final EwE model is a useful management tool.

***Coordination and application***

We are working to ensure that our models and simulations are highly relevant for Lake Erie fisheries managers and that our collective analyses provide insight regarding tradeoffs between nutrient loading and fisheries production. We are engaging with managers via presentations at stakeholder meeting, personal conversations, and distribution of project literature (including series of questions for managers). While we are developing a multitude of models which have unique advantages and disadvantages. An ultimate goal of our efforts is to be able to compare model predictions. While this may not always be feasible (given the differential forms of our models), when possible we are facilitating model comparisons by initially structuring models in a similar manner. For instance, we have

communicated during CASM-LE and EwE development to ensure that the foodweb connections of these models are similar.

## Publications

He, C. C. DeMarchi, and T.E. Croley II. 2008. Modeling Spatial Distributions of Nonpoint Source Pollution Loadings in the Great Lakes Watersheds by Using the Distributed Large Basin Runoff Model. Proc. Papers of American Water Resources Association GIS and Water Resources V, San Mateo, California, March 17-19.

Croley, T. E., II, D. F. Raikow, C. He, and J. F. Atkinson, 2008. Hydrological Resource Sheds. Journal of Hydrologic Engineering (SCI) Vol.13 (9):873-885/

Croley, T. E., II, J. F. Atkinson, and D. F. Raikow, 2007. Hydrologic-hydraulic-ecologic resource sheds. Proceedings of Water Resources Management 2007 Conference, Honolulu, Hawaii, International Association of Science and Technology for Development, Calgary, Canada, August 20-22, 2007, 6 pp.

McCone, M. T.A. Endreny, J. Atkinson, J. DePinto, and J. Manno. 2006. “Role of International Policy and Science in Addressing Great Lakes Management and Lake Erie Eutrophication”, in Hydrology and Water Law – Bridging the Gap, Edited by J. S. Wallace and P. Wouters, Title in the Water Law and Policy Series, Edited by P. Wouters and S. Vinogradov, International Water Association Publishing, London UK, pp. 78-107.

Roberts, J.J., T.O. Höök, S.A. Ludsin, S.A. Pothoven, H.A. Vanderploeg, and S. B. Brandt. In press. Effects of hypolimnetic hypoxia on foraging and distributions of Lake Erie yellow perch. Journal of Experimental Biology and Ecology.

Schwab, D.J., D. Beletsky, J.V. DePinto, and D.M. Dolan. 2009. A hydrodynamic approach to modeling phosphorus distribution in Lake Erie. Journal of Great Lakes Research, 35(1):50-60.

Xing, F., C. DeMarchi, T. E. Croley, and Y. Wang. Application of Distributed Large Basin Runoff Model to Lake Erie: Model Calibration and Analysis of Parameter Spatial Variation. Submitted.

## Presentations

Allan, J.D., and H. Han. 2008. Phosphorus Loading to Lake Erie Watersheds: A Mass Balance Approach. 51st International Association for Great Lakes Research, May 19-23.

Arend, K., T. Höök, S. Ludsin, D. Rucinski, J. DePinto, and D. Scavia. 2008. Effects of hypoxia on yellow perch habitat suitability in the central basin of Lake Erie. Midwest Fish and Wildlife Conference, Columbus

Arend, K., T. Höök, S. Ludsin, D. Rucinski, J. DePinto, and D. Scavia. 2009. Evaluating and forecasting effects of hypoxia on yellow perch habitat suitability in central Lake Erie. Indiana American Fisheries Society Annual Meeting, Indianapolis

Arend, K., T. Höök, S. Ludsin, D. Rucinski, D. Beletsky, J. DePinto, D. Scavia, and D. Schwab. 2009. Hypolimnetic hypoxia effects on yellow perch and rainbow smelt habitat quality in central Lake Erie. 2009. International Association for Great Lakes Research, Toledo, OH.

Beletsky, D., and D. Schwab. 2008. Modeling thermal structure in Lake Erie. IAGLR 2008. May 19-23, 2008, Peterborough, ON.

Bosch, N.S. and J.D. Allan. 2008. An analysis of catchment nutrient inputs compared to riverine exports. International Joint Commission workshop – Loading from landscapes and coastal margin effects: Developing a framework to evaluate consequences of land management strategies. Oregon, OH.

Bosch, N.S., H. Han, R.P. Richards, and J.D. Allan. 2009. Evaluating the impact of agricultural BMPs on riverine nutrient export to Lake Erie. North American Benthological Society, May 17-22.

Brandt, S.B., M. Costantini, S.A. Ludsin, D.M. Mason, and H.A. Vanderploeg. 2008. Spatially-explicit growth predictions to assess habitat quality of walleye during hypoxia in Lake Erie. Oral presentation at the International Association for Great Lakes Research 51st Annual Conference on Great Lakes Research, Peterborough, ON. May 20.

Brandt, S.B., M. Costantini, S.A. Ludsin, D.M. Mason, and H.A. Vanderploeg. 2008. Spatially-explicit growth predictions to assess habitat quality of walleye during hypoxia in Lake Erie. International Association for Great Lakes Research, Peterborough, Ontario

Brandt, S., D. Schwab, and T. E. Croley II, 2007. Nearshore Water Quality: Linkages between Watersheds and Offshore Processes, International Joint Commission Workshop on 'Nearshore Processes,' Dearborn, Michigan, November 19-20.

Croley, T. E., II, 2007. GLERL's Hydrology Program, GLERL-NCEP-NWS-NOS Meeting, Ann Arbor, Michigan, November 28.

Croley, T. E., II, 2008. Great Lakes Hydrologic Modeling, Hydrology Laboratory, NWS Office of Hydrology, Ann Arbor, Michigan, March 6.

Croley, T. E., II, and T. S. Hunter, 2007. Great Lakes Hydrology Modeling with the Advanced Hydrologic Prediction System, Michigan Technological Institute, Houghton, Michigan, October 8.

DePinto, J.V. “How does Lake Erie process the phosphorus loading it receives, and has the dreissenid invasion changed things?” invited presentation to the Lake Erie Phosphorus Task Force, Columbus, OH (October 1, 2008).

DePinto, J.V. “Nearshore phosphorus cycling and algal growth in the western basin of Lake Erie. Invited talk at the Western Lake Erie Basin Conference, Oregon, OH (March 10-11, 2009).

DePinto, J.V.1, Vanderploeg, H.A.2, and AUER, M.T. 2008. Cladophora and open-water “desertification”: Do Dreissenids play a role? Paper presented at the 51th Annual Conference on Great Lakes Research, Trent University, Peterborough, ON (May 19-June 23, 2008).

Dolan, D, R.P. Richards, and K. McGunagle. 2008. Total Phosphorus Loading to the Great Lakes. Landscapes and Loadings Workshop, Council of Great Lakes Governors, Maumee, OH, March 18. Presented by R. Peter Richards.

Dolan, D.M., R.P. Richards, and C.M. Piette. 2008. Updated Total Phosphorus Load Estimates for Lake Erie, 2005-2007. 51st Conference on Great Lakes Research May 19-23, 2008, Trent University, Peterborough, Ontario.

Han, H. and J.D. Allan. One hundred years of nutrient loading to Lake Michigan watershed. 2009. 57th North Amercan Benthological Society. May 17-22.

He, C. and T. E. Croley. 2008. Resource Shed and Its Applications in the U.S. Great Lakes Watersheds. Lanzhou University, Lanzhou, P.R. China, Oct.29. 60 min.

He, C. and T. E. Croley. 2008. Resource Shed and Its Applications in the U.S. Great Lakes Watersheds. The Chinese Academy of Sciences Institute of Geodesy and Geophysics, Wuhan, Nov.3, 65 min.

He, C. and T. E. Croley. 2008. Resource Shed and Its Applications in the U.S. Great Lakes Watersheds. The Chinese Academy of Sciences Research Center for Eco-Environmental Sciences, Beijing, Nov.6, 65 min.

He, C., T.E. Croley, and C. DeMarchi. 2008. Application of Distributed Large Basin Runoff Model and Resource Sheds in the U.S. Great Lakes Watersheds. (50 min presentation) The Chinese Academy of Sciences Research Center of Eco-Environmental Sciences, Beijing, Jan.5.

He, C., T.E. Croley and C. DeMarchi. 2008. Climate Change and Nonpoint Source Pollution in the Great Lakes Basin: Opportunities and Challenges. Impact of Climate Change on the Great Lakes Ecosystem – A NOAA Science Needs Assessment Workshop to Meet Emerging Challenges. Ann Arbor, July 29-31.

He, C., T. E. Croley, and C. DeMarchi. 2008. Modeling Nonpoint Sources Pollution Loadings in the U.S. Great Lakes Basin. Shaanxi Normal University, Oct.24. 70 min.

He, C., T. E. Croley, C. DeMarchi. 2008. Modeling Spatial Distribution of Nonpoint Source Pollution in the Great Lakes Watersheds. The Association of American Geographers Annual Meeting, Boston, April 15-20.

He, C., T. E. Croley, and C. DeMarchi. 2008. Modeling Nonpoint Sources Pollution Loadings in the U.S. Great Lakes Basin. Research Institute for Protection of Yangtze Water Resources , Yangtze Water Resources Commission, Wuhan, Oct.31. 75 min.

He, C., T.E. Croley, and C.. DeMarchi. 2007. Modeling spatial distribution of nopoint source pollution loadings by using the Distributed Large Basin Runoff Model. 50th International Association for Great Lakes Research (IAGLR) Conference on Great Lakes Research, University Park, PA, 5/28-6/1/2007.

Impact of Climate Change on the Great Lakes Ecosystem – A NOAA Science Needs Assessment Workshop to Meet Emerging Challenges. Ann Arbor, July 29-31.

Ludsin, S.A., T.O. Höök, D. Rucinski, J.V. DePinto and D. Scavia. 2008. Historical exploration of hypoxia effects on fish recruitment and production in Lake Erie. Oral presentation at the International Association for Great Lakes Research 51st Annual Conference on Great Lakes Research, Peterborough, ON. May 20.

Ludsin, S.A., T.O. Höök, D. Rucinski, J.V. DePinto and D. Scavia. 2008. Historical exploration of hypoxia effects on fish recruitment and production in Lake Erie. Oral presentation at the International Association for Great Lakes Research 51st Annual Conference on Great Lakes Research, Peterborough, ON. May 20.

Ludsin, S.A. 2009. Hypoxia effects on Lake Erie fisheries. State of Lake Erie Committee Meeting, Ypsilanti, Michigan

Ludsin, S.A. 2009. Hypoxia in Lake Erie: implications for food webs and fisheries. The Great Lakes: Adapting to a Wave of Change Conference, Michigan State University, East Lansing

Ludsin, S.A. 2008. Hypoxia alters species distributions and interactions: implications for food webs and fisheries. Stone Laboratory Guest Lecture Series, Put-In-Bay, Ohio

Ludsin, S.A. 2008. Hypoxia alters species distributions and interactions: implications for food webs and fisheries. Department of Zoology, Southern Illinois University, Carbondale, IL

Ludsin, S.A. 2008. Hypoxia alters species distributions and interactions: implications for food webs and fisheries. USGS Ohio Water Science Center, Columbus, OH

Ludsin, S.A., T.O. Höök, D.K. Rucinski, J.V. DePinto, and D. Scavia. 2008. Historical exploration of hypoxia effects on fish recruitment and production in Lake Erie. International Association for Great Lakes Research, Peterborough, Ontario

Modelling and Simulation, Session 47: Nutrient Modeling Techniques to Support Water Quality Management, Christchurch, New Zealand, December 10-13.

Richards, R. P. 2008. Food, Fertilizer, Fish, and Fouled Beaches: Water Quality in the Maumee River and the Western Basin of Lake Erie, 1975 to Present. Lake Erie Center, Maumee, OH, October 16.

Richards, R.P. 2008. Record Setting Phosphorus Loads from Agricultural Watersheds in Ohio. USDA Water Quality Conference, Sparks, NV, February 6.

Richards, R. P. 2008. Testimony on Lake Erie Phosphorus Loadings. U.S. House of Representatives Committee on Transportation and Infrastructure, Subcommittee on Water Resources and Environment. Port Huron, Michigan, May 12.

Richards, R. P. 2009. Trends in sediment concentrations and loads in Northwest Ohio tributaries to Lake Erie, 1975-2008. Western Lake Erie Basin Conference, March 10.

Richards, R.P., D.B. Baker, and J.P. Crumrine. 2007. Increased Dissolved Phosphorus Loading to Lake Erie from Agricultural Watersheds. Great Lakes Protection Fund Project Workshop, Tiffin, OH, December 18.

Richards, R.P., D.B. Baker, and J.P. Crumrine. 2008. Trends in Dissolved Reactive Phosphorus in Lake Erie Tributaries. Landscapes and Loadings Workshop, Council of Great Lakes Governors, Maumee, OH, March 19.

Richards, R.P, D.B. Baker, and J.P. Crumrine. 2008. Trends in Dissolved Reactive Phosphorus in Lake Erie Tributaries. Millennium Network Conference, Windsor, ON, April 29.

Richards, R.P., D.B. Baker, and J.P. Crumrine. 2008. Water Quality Trends in Lake Erie Watersheds. Western Lake Erie Basin Partnership Roundtable, Toledo, OH, February 20.

Roberts, J.J., T.O Höök, S.A. Ludsin, S.A. Pothoven, and H.A. Vanderploeg. 2008. Bioenergetics model to explore the effects of hypoxia on yellow perch habitat quality in Lake Erie's central basin. Oral presentation at the International Association for Great Lakes Research 51st Annual Conference on Great Lakes Research, Peterborough, ON. May 20.

Roberts, J.J., T.O. Höök, S.A. Ludsin, S.A. Pothoven, and H.A. Vanderploeg. 2009. Implications of hypoxia for yellow perch habitat quality in Lake Erie's central basin: a spatially-explicit bioenergetics modeling approach. Oral presentation at the Michigan Chapter of the American Fisheries Society Annual Meeting, Dundee, MI.

Roberts, J.J., T.O. Höök, S.A. Ludsin, S.A. Pothoven, and H.A. Vanderploeg. 2008. Response of yellow perch to hypoxia in Lake Erie's central basin: Spatial patterns. American Fisheries Society 138th Annual Conference, Ottawa, ON.

Rucinski, D.K., D. Beletsky, J.V. DePinto, D. Scavia, D. Schwab. 2007. Model analysis of climate effects on dissolved oxygen in the central basin of Lake Erie. Oral presentation at the International Association for Great Lakes Research 50th Annual Conference on Great Lakes Research, University Park, PA. June 1.

Rucinski, D.K., D. Beletsky, J.V. DePinto, D. Scavia, D. Schwab. 2008. Development and Application of 1D Eutrophication Models for the Central Basin of Lake Erie. Oral presentation at the International Association for Great Lakes Research 51th Annual Conference on Great Lakes Research, Peterborough, Ont. May 20.

Rucinski, D.K., D. Beletsky, J.V. DePinto, D. Scavia, D. Schwab. 2008. Long-Term Application of a Climate-Driven Dissolved Oxygen Model for the Central Basin of Lake Erie. Oral presentation at the International Association for Great Lakes Research 51th Annual Conference on Great Lakes Research, Peterborough, Ont. May 20.

Sellinger, C., and T. E. Croley II, 2008. GLERL's Hydrology Program, NOAA-USGS Committee on Hydrology Meeting, Silver Springs, Maryland, January 16.

Sharpley, Andrew and R. Peter Richards. 2008. Adaptive Management and Water Quality: Is there anything to be learnt from outside the U.K.. Agriculture, Water Management, and Climate Change, Bath, England, March

Zhang, H., Rutherford, E.S., Mason, D.M., Adamack, A.T., Johnson, T., and Zhu, X. 2009. Ecopath with Ecosim and Ecospace: Hypoxia impacts on the fisheries of Lake Erie. Pre-Lake Erie Committee meeting. London, Ontario.

## Awards

Best Professional Paper: Indiana American Fisheries Society Annual Meeting, Indianapolis. (K. Arend, T. Höök, S. Ludsin, D. Rucinski, J. DePinto, and D. Scavia.)

## Thesis Defended (M.S.)

Regression Analysis of Total Phosphorus Loading for the Maumee River, Water Years 2003-2005, by Charlie Piette, University of Wisconsin-Green Bay, December, 2008.