Nutrient Management in Water Resources

Nutrient pollution, caused by excessive nitrogen and phosphorus in our water resources, is one of the most widespread, costly, and challenging water quality problems in the United States today. Excessive nitrogen and phosphorus in water can cause algae to grow faster than ecosystems can assimilate. Resulting large algae "blooms" can harm water quality, food resources, and habitats, and can decrease dissolved oxygen in waters that fish and other aquatic life need to survive.

Excessive nutrients that enter our waterbodies are most often the result of human activities. The primary sources of nutrients include agriculture, stormwater, wastewater, fossil fuels, and materials from in and around our homes, including fertilizers, yard and pet waste, and certain soaps and detergents. Agriculture has drawn increased attention recently because fertilizer and animal manure applied to crops and fields and soil erosion make this sector one of the largest sources of nitrogen and phosphorus pollution. Wet weather runoff from impervious surfaces like rooftops, sidewalks and roads can carry excess nutrients into local waterways. Wastewater treatment plants and septic systems do not always remove enough nitrogen and phosphorus before discharging their effluents into waterways. Electric power generation, industry, and transportation contribute nitrogen in the air through the burning of fossil fuels.

Regulatory agencies and the regulated community have been challenged by the need to find solutions to nutrient pollution because there is wide variability in how individual waterbodies respond to excessive nutrient inputs, and because the adverse impacts of these nutrient inputs can be manifested in a variety of symptoms. LimnoTech is helping to meet these challenges through participation in many projects addressing nutrient pollution. Our projects have targeted a number of nutrient-related issues including watershed modeling to characterize the fate and transport of nutrients; exploring improved agricultural practices to reduce the introduction of nutrients to water resources; development and review of nutrient guidelines; compilation and management of data to support the establishment and evaluation of nutrient standards; and developing nutrient load-response models and modeling guidance to help users select and apply nutrient models to support informed eutrophication management decision-making.

The following descriptions provide a brief overview of some of LimnoTech's nutrient-related projects.

SELECTED PROJECT SUMMARIES

Modeling Approaches to Developing Site-Specific Nutrient Goals and Criteria. Nutrient over-enrichment is one of the most common causes of waterbody impairment in the nation. Both regulatory agencies and the regulated community have been challenged by the need to find regulatory solutions to nutrient issues while also acknowledging the wide variability in individual waterbody response to nutrient enrichment. LimnoTech led a team of researchers to develop a guidance document describing the process for development, calibration and application of models to support development of site-specific nutrient goals and criteria. LimnoTech also developed a Nutrient Modeling Toolbox (Toolbox) containing 30 process-based and empirical models that link nutrients to ecological response indicators for aquatic systems. Accompanying the Toolbox is a Model Selection Decision Tool (MSDT) that helps users select appropriate models from the Toolbox, considering site-specific factors such as waterbody type, ecological response indicators (endpoints), type of application, and physical and temporal variability. Throughout the development of the guidance document and Toolbox, WERF's advisory committee and a stakeholder advisory panel provided input to ensure that the final product would be useful to both regulators and the regulated community.

Agriculture has drawn increased attention because fertilizer and animal manure applied to crops and fields, and soil erosion make this sector a significant source of nutrient pollution.

Agricultural Management Watershed Modeling for Maumee River Watershed Tributaries. The U.S. Army Corps of Engineers, Buffalo District, has been planning and working within the Maumee Basin to reduce the loading of solids and nutrients to the Maumee River and the western basin of Lake Erie. The primary goals of this work are to simulate erosion, sediment delivery pathways, and sediment delivery loads; simulate fate and transport of nutrients; project benefits of conservation treatment strategies; and support efforts to reduce erosion and sediment and associated nutrient delivery. LimnoTech is collaborating with several government agencies and universities to develop, calibrate, and apply a detailed, agriculturally based watershed model for tributary watersheds to quantify sediment and nutrient loadings to the Maumee River. The model will also be used to:

- Determine spatial and temporal distribution of sediment and nutrient sources and pathways of export;
- Estimate potential benefits and prioritize alternative land conservation and agricultural management practices; and
- Support broader sediment and nutrient modeling efforts of the lower Maumee River and Maumee Bay.

Upon completion of model development and application, a technology transfer will distribute the tool to watershed stakeholders.

Great Lakes Watershed Ecological Sustainability Strategy: Transactions for Agricultural Ecosystem Services. The summer of 2011 saw a Harmful Algal Bloom (Microcystis sp.) of unprecedented size and severity in the Western Basin of Lake Erie. This bloom was primarily fueled by agricultural runoff from the Maumee Watershed. Similar coastal eutrophication problems have been evident in other predominantly agricultural Great Lakes watersheds. To help address this problem, a team of researchers led by The Nature Conservancy and including Michigan State University and LimnoTech have undertaken a project funded by the Great Lakes Protection Fund to explore methods to identify and implement agricultural conservation and best management practices that will lead to the greatest possible reduction in damaging environmental impacts without placing undue risk on farm productivity. The project will create a framework of information and tools necessary to manage agricultural landscapes, to move toward optimal ecosystem improvement returns and understand the return on investments. At the core of the framework are modeling tools that compute the dose-response curve relationships between ecosystem improvements and the placement, timing, and type of agricultural best management practices. This framework can inform producers, agricultural agencies, agribusinesses, and governing bodies so that they can set, and then farm for, measurable contributions to aquatic ecosystem improvement goals.

Algae "blooms" can harm water quality, food resources, and habitats, and can decrease dissolved oxygen in waters that fish and other aquatic life need to survive.

Integrated Hydrodynamic–Sediment Transport–Water Quality Model for the Lower Maumee River and Western Basin of Lake Erie. Through a series of projects, LimnoTech has developed a linked hydrodynamic–sediment transport–advanced eutrophication model (A2EM) to inform restoration and management decisions in the lower Maumee River and western basin of Lake Erie. The model has been applied to inform management decisions for a number of sediment- and nutrient-related problems in this system. Among them are:

- Identifying and quantifying the relationship between watershed nutrient sources and Harmful Algal Blooms (largely *Microcystis*) in the Western Basin of Lake Erie;
- Quantifying the reduction of sedimentation in the Toledo Harbor and navigation channel that results from Maumee Watershed sediment reduction actions;
- Quantifying the relative impact of open-lake placement of dredged material on bioavailable phosphorus and HABs in the Western Basin of Lake Erie; and
- Use as a component of a set of linked management model frameworks for the assessment of and adaptation to climate-induced extreme events on eutrophication endpoints in the Western Basin of Lake Erie.

Development of a Process-oriented Aquatic Ecosystem Model to Investigate Multi-stressor Interactions in Saginaw Bay, Lake Huron. Synergistic effects of multiple stressors may result in complex ecosystem-level effects in aquatic ecosystems. LimnoTech is a subcontractor to the NOAA Great Lakes Environmental Research Laboratory on a project in Saginaw Bay to research and develop an Adaptive Integrated Framework (AIF) to understand and manage large aquatic ecosystems subject to multiple stressors. LimnoTech developed an integrated aquatic ecosystem modeling framework to identify, understand, and support management of the alterations in the Saginaw Bay ecological structure and function in response to stressors such as ecosystem changes induced by the invasion of non-indigenous zebra mussels, nutrient loads, sediment loads, hydrology and water levels, and climate conditions. The framework, coupled with a unique post-processor/visualization package developed by LimnoTech, forms a fully integrated model for this system. This model has quantified the relationship between nutrient loads, Dreissenid density, and physical factors such as stressors and algal blooms that lead to shoreline fouling and diversion of energy from the fish community. Model results have been used to advise water quality and fishery managers with regard to management decisions, and to recommend research and monitoring activities of project partners to develop a better quantitative understanding of the system, both components of the Adaptive Integrated Framework.

Expert Review of the EPA's Draft Numeric Nutrient Criteria for Florida. In January 2010, the U.S. EPA published a proposed rule to establish numeric nutrient criteria (NNC) for lakes and streams in Florida to meet the terms of a settlement agreement with non-governmental organizations. These organizations claimed that the agency had failed to protect Florida's waters by not requiring the State to develop a numeric standard. The Clay County Utility Authority (CCUA) implemented advanced wastewater treatment at several of its facilities. CCUA also established a public access reclaimed water distribution network to provide for beneficial reuse of wastewater. CCUA also, along with other stakeholders, helped develop total maximum daily loads and basin management action plans to meet Florida's narrative criteria to protect against excessive nutrient loads. EPA's actions threatened to jeopardize CCUA's efforts to protect the environment. CCUA needed expert help to identify the scientific and technical concerns with EPA's proposed actions. LimnoTech evaluated existing water quality standards, and TMDLs and CCUA's operations. We identified several criteria that should have been included in the proposed rule. We also provided critical insight on EPA's regulations and procedures.

LimnoTech developed a state-of-the-science model for the Potomac River Estuary to address its unique characteristics and water quality problems.

Development of a Phosphorus Mass Balance Model for Missisquoi Bay, Lake Champlain. Missisquoi Bay has suffered from an increased recurrence of nuisance cyanobacteria blooms that have produced toxins and severely limited use of the Bay for drinking water supply and recreation. LimnoTech was contracted to develop a water quality model that captures the major cycling pathways of phosphorus in Missisquoi Bay as they relate to future management of the system and its watershed. To study problems in the Bay, LimnoTech developed the Missisquoi Bay Phosphorus Model, MBPHOS, which uses available atmospheric, hydrologic, and nutrient monitoring data to simulate transport of phosphorus from major tributaries, deposition and release from the sediment bed, and export through the Bay. The results of the model application provided useful insights into the phosphorus cycle in the Bay. Future work can expand the phosphorus model to dynamically simulate algal abundance, more specifically the abundance of nuisance blue-green algae.

State-of-the-Science Potomac Water Quality Model. The Potomac River Estuary is the largest estuarine tributary to Chesapeake Bay. The Potomac is plagued with many of the same problems as the mainstem bay. These include oxygen depletion in bottom waters, excess chlorophyll concentrations, and diminished living resources. The Potomac is also host to problems that are unique in occurrence or magnitude. These include blooms of blue-green algae, elevated pH, and the role of phosphorus limitation of algal growth (rather than nitrogen limitation) in the tidal freshwater portion. The U.S. EPA Chesapeake Bay Program and the U.S. Army Corps of Engineers have developed a third-generation Water Quality and Sediment Transport Model (WQSTM). This model was used to support development of bay-wide total maximum daily loads (TMDLs) for nutrients and solids. As part of this overall effort, multiple management agencies expressed a desire to create a separate state-of-the-science model for the Potomac that would build on the whole-bay WQSTM, but would address the unique characteristics and water quality problems in the Potomac.

Working in collaboration with the Corps of Engineers and Metropolitan Washington Council of Governments, LimnoTech developed a new sub-model for estuarine phosphorus dynamics. This sub-model was based on extensive literature and data reviews, and an experimental program conducted by the University of Maryland Center for Environmental Science, a collaborating partner with LimnoTech. LimnoTech also developed a revised sub-model for pH, alkalinity, calcium and sediment-water phosphorus flux. This work was conducted in collaboration with HydroQual, Inc., and included modification of the calcium carbonate equilibrium chemistry in the original Potomac Eutrophication Model and coupling it with the sediment diagenesis component of the WQSTM. Finally, LimnoTech developed a revised algal speciation model for the Potomac and calibrated it to available data for 1994-2000. This model includes five algal groups that represent tidal freshwater diatoms, lower estuary diatoms, greens plus cryptophytes, dinoflagellates, and blue-greens. The model represents the spatial and temporal distributions of these groups as functions of temperature, light, salinity and available nutrients. This project demonstrated the feasibility of a regional-scale application of a portion of the full 57,000-cell WQSTM, as well as the feasibility of developing and calibrating a multi-algal group model for a major Chesapeake Bay tributary. This revised Potomac model is currently a research testbed, and consideration will be given to incorporating its capabilities into other portions of the WQSTM in the future.

Effects of Extreme Climate Change-Induced Events on the Great Lakes. Climate change-induced extreme events are expected to increasingly affect the Great Lakes ecosystem and ecosystem services, with associated impacts on social and economic well-being. Despite mounting evidence of the severity of these effects, knowledge is limited about how the climate, ecological, and social systems in the Great Lakes interact. LimnoTech is working as a subcontractor to the University of Michigan on an NSF-funded, five-year project to develop models to predict the impact of climate change-related extreme events on nutrient loading and associated ecological responses. The Maumee watershed and Western Basin of Lake Erie are being used as a site for development of these models. The project team will also develop management systems that support adaptation to these conditions. This study will advance scientific understanding of coupled human-climate-water quality systems, and inform and influence future decision-making in the Great Lakes region.

LimnoTech is working with the University of Michigan to develop models to predict the impact of climate change-related extreme events on nutrient loading and associated ecological responses.

Technical Development for Nutrient Water Quality Standards Review in Truckee River, NV. A triennial review of numeric nutrient water quality standards conducted by the Nevada Division of Environmental Protection (NDEP) will be informed by a technical analysis completed by LimnoTech. The effort has been a collaboration of a third-party-driven working group which includes City of Reno, City of Sparks, Washoe County, Truckee Meadows Water Authority [TMWA], NDEP, and USEPA.

The foundation of the technical effort is the application of a set of watershed (WARMF) and river (TRHSPF) water quality models, developed by LimnoTech, that examine the linkage between instream nutrient concentrations, periphtyon (attached algae), and response of the river in terms of dissolved oxygen concentrations. LimnoTech incorporated peer-reviewed empirical and theoretical equations into TRHSPF to improve the simulation of periphyton. The models were used to better understand the nutrient-DO criterion compliance relationship in the Truckee River. This information will help NDEP identify appropriate numeric nutrient water quality criteria that are protective of beneficial uses. Within the State of Nevada, the Truckee River historically has been challenged by a limited water supply and competing water demands. LimnoTech's technical effort involved extensive engagement with watershed stakeholders including municipalities, Native American tribes, irrigation districts and the general public. It is anticipated that the after NDEP completes the triennial review process for the nutrient water quality standards, the effort will progress towards a review of the existing nutrient TMDL.

Development and Application of a Water Quality Model for the Lake Pepin, Minnesota, TMDL. Lake Pepin is a natural impoundment in the Upper Mississippi River on the border of Minnesota and Wisconsin, near Minneapolis-St. Paul. The Minnesota Pollution Control Agency included Lake Pepin and reaches of the Upper Mississippi River on the 303(d) list of impaired waters as a result of excess turbidity and nutrient enrichment. The Minnesota Pollution Control Agency is developing a TMDL to address these impairments. To support the TMDL, a three-dimensional linked hydrodynamic-sediment transport-water quality-ecological response model was developed for the Upper Mississippi River below Lake Pepin. Because the goals for the nutrient TMDL included a range of parameters (phosphorus concentration, chlorophyll *a*, blue-green algal blooms, and submerged aquatic vegetation restoration), the modeling framework was enhanced to include simulation of multiple algal groups and zooplankton kinetics. The hydrodynamic and water quality models were also linked to process-based models of key submerged aquatic vegetation (SAV) species. Reduced nutrient loadings predicted by an HSPF watershed model of the Minnesota River were linked to a UMR-LP model to provide an integrated assessment of the likely impact of watershed management practices on turbidity, eutrophication, and SAV indicators in Lake Pepin. Model results and data were incorporated into a "Management Analysis Tool" (MAT) to allow stakeholders to assess modeling results and data in a user-friendly format. The modeling results and MAT have been instrumental in developing site-specific criteria and associated load reductions for turbidity and suspended solids concentrations in the river, and phosphorus, chlorophyll *a*, and Secchi depth in Lake Pepin.

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