NOAA Great Lakes Environmental Research Laboratory

Strategic Plan 2016-2020

A commitment to integrated scientific research on the Great Lakes and coastal ecosystems

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research

NOAA Great Lakes Environmental Research Laboratory

Vision

A trusted scientific enterprise to advance observation, modeling, understanding, and prediction of the Great Lakes and coasts to sustain resilient ecosystems, communities, and economies.

Mission

Conduct integrated scientific research on the Great Lakes and coastal ecosystems; develop and transition products and services; and share knowledge and information to advance science, service and stewardship.

A Message From Director Deborah Lee

The Great Lakes—a vital freshwater resource falling within U.S. and Canadian borders—enrich the lives of those who live, work, and recreate in the lakes' basin. My life has been enriched by the Great Lakes and it has been a privilege to serve as a member of the binational Great Lakes stewardship community for the past 30 years. Recognizing the irreplaceable ecological and socio-economic value of the Great Lakes, I have worked closely with my colleagues over these past three decades on an array of Great Lakes issues. As a community, we've learned about the daunting challenges that must be met to protect and restore the Great Lakes, and have participated in the accelerating evolution of Great Lakes management to meet these challenges.

Once thought of as a limitless resource, our awareness and understanding has grown for the fragile, complex, and interconnected nature of the Great Lakes and their health. This awareness and understanding spans across the watersheds, nearshore, and open water habitats, which are under dynamic forces of human-induced stressors, as well as a changing climate. A number of policy developments and management programs have emerged on a regional level in response to the lessons learned on this unique freshwater ecosystem. Those of particular relevance to Great Lakes environmental research and management include: the binational Great Lakes Water Quality Agreement (GLWQA) (1972; amended 2012), the International Joint Commission's Upper Lakes Study and Lake Ontario-St. Lawrence River Study, and the Great Lakes Restoration Initiative Action Plans I and II. A common thread of these efforts is application of adaptive management to evaluate the effectiveness of approaches to reaching management objectives. To reach the objective of maintaining the biological, chemical, and physical integrity of the Great Lakes ecosystem, the need has emerged for monitoring, modeling and periodic assessment. Critical elements for realizing ecosystem research and management include rapid development of new technology enabling observing and monitoring at higher temporal and spatial resolution, increased computational power enabling complex systemic ecosystem modeling and prediction, and communication of the observations and predictions in products customized to the user.

As director of NOAA's Great Lakes Environmental Research Laboratory (GLERL), I embrace the challenges of continuing NOAA's commitment to science, service and stewardship in the Great Lakes region. GLERL is poised to contribute to formal ecosystem management as a key provider of observing technology innovation, leader in cutting edge experimental research, developer of advanced ecosystem models, and communicator of science-based products and services, as well as contributor of science advice to the Great Lakes management community. To advance ecological forecasting services, NOAA has developed an operational framework—The Ecological Forecasting Roadmap—for a NOAA-wide ecological forecasting capability to effectively and efficiently provide dependable, high quality forecast products on a broader scale with consistent delivery. GLERL is focused on transitioning these new approaches to NOAA's operational offices (National Weather Service, National Ocean Service, and National Environmental Satellite and Data Information Service) and our regional partners in state, federal, and binational agencies and commissions.

This strategic plan aims to ensure that GLERL continues to stand at the forefront in providing the scientific intelligence needed by the Great Lakes community to manage this globally unique and exceptional resource and safeguard its long-term sustainability. I look forward to an exciting five years in leading the implementation of GLERL's strategic plan with the commitment to integrated scientific research.

Best Regards,

Deborah H. Lee, PE, PH, D.WRE
Director

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Note: For an in-depth look at the priorities, paths, and milestones set forth to advance GLERL's Strategic Plan, an Implementation Plan has been developed as an extension of this document. A copy of the Implementation Plan is available upon request.

Acknowledgments

We are grateful to all of the individuals who contributed to the completion of this 5-year science strategic plan, developed under the motivating leadership of GLERL Director, Deborah Lee. In acknowledgment of this collaborative effort, we extend our thanks to the writing team of Katherine Glassner-Shwayder, Linda Novitski, Rochelle Sturtevant, and Doran M. Mason who demonstrated an unwavering commitment to produce a comprehensive strategic plan built upon the consensus of GLERL staff; the formatting and graphics team of Margaret Lansing, Nicole Rice, and Kaye LaFond who provided their cutting-edge skills and knowledge in formatting, editing, and in the creation of original graphics to convey key strategic messages; and the Strategic Planning Advisory Committee of Henry Vanderploeg, Steve Ruberg, Philip Chu, Margaret Lansing, Craig Stow, Andrew Gronewold, Brent Lofgren, and Kim Kulpanowski who collectively shared their expertise in the development of GLERL's strategic plan—a commitment to integrated scientific research at GLERL. We also thank the numerous staff members who have provided advice and feedback throughout the strategic planning process. Lastly, we acknowledge the guidance on the plan provided by Senior Leadership at NOAA Headquarters.

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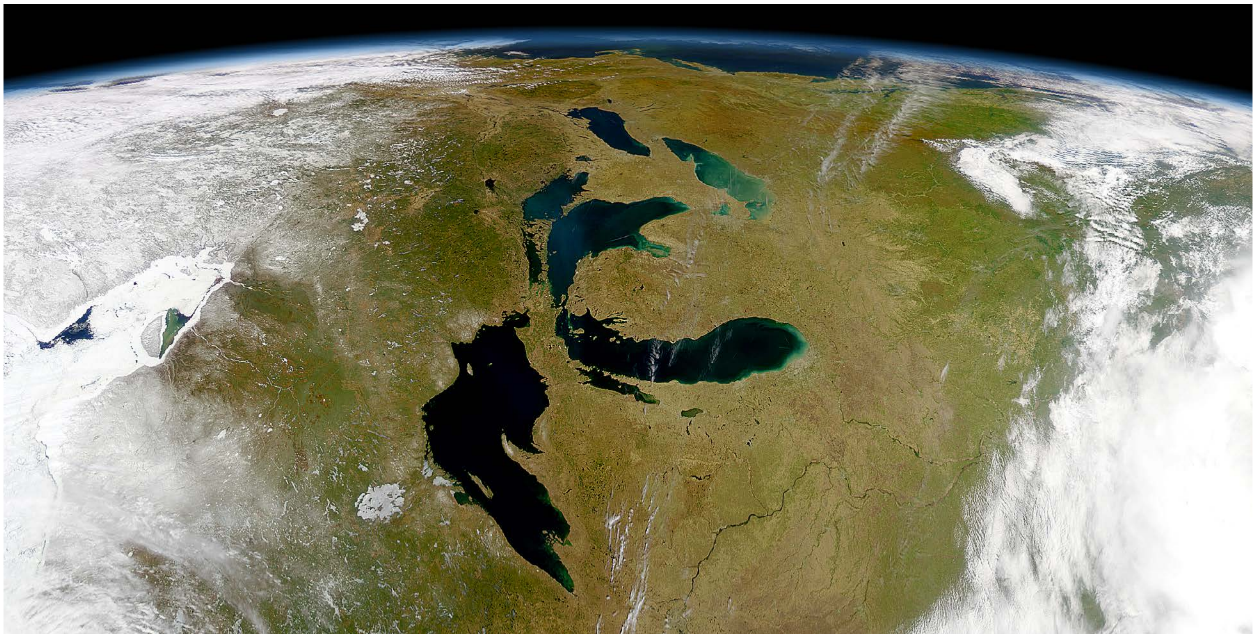
Introduction



Visionary Pioneers in Great Lakes Environmental Research

The Great Lakes Environmental Research Laboratory (GLERL) is a scientific research facility based in Ann Arbor, Michigan, operating as part of the National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research (OAR). GLERL's Ann Arbor facility houses experimental and marine instrumentation laboratories furnished with state-of-the-art equipment and technology to support GLERL's scientific research. Integral to GLERL's operation is the Lake Michigan Field Station (LMFS), strategically located on the eastern shore of Lake Michigan in Muskegon, Michigan. The LMFS serves as the home base for field operations, research, and GLERL vessel operations—critical assets in providing physical access to the Great Lakes and advancing NOAA's mission in the region. GLERL's research capacity is further strengthened by its in-house partnership with NOAA's Great Lakes Cooperative Institute, comprised of a consortium of academic institutions in the region. In addition, NOAA's Great Lakes Sea Grant Network serves as a vital in-house partnership that functions to connect NOAA research to the communication and outreach capabilities of NOAA Sea Grant.

GLERL's strategic plan for 2016-2020 has been developed to guide the laboratory over the next five years in the conduct of integrated scientific research built upon organizational excellence, integrity, and preeminence. Before charting the course of GLERL's strategic plan, it is worth reflecting on the vitality of the Great Lakes ecosystem, the risks threatening its vitality, and some of the policy developments that have evolved to address these risks. These are important factors that have contributed to shaping GLERL's unique approach to Great Lakes environmental research, since its inception in 1974.

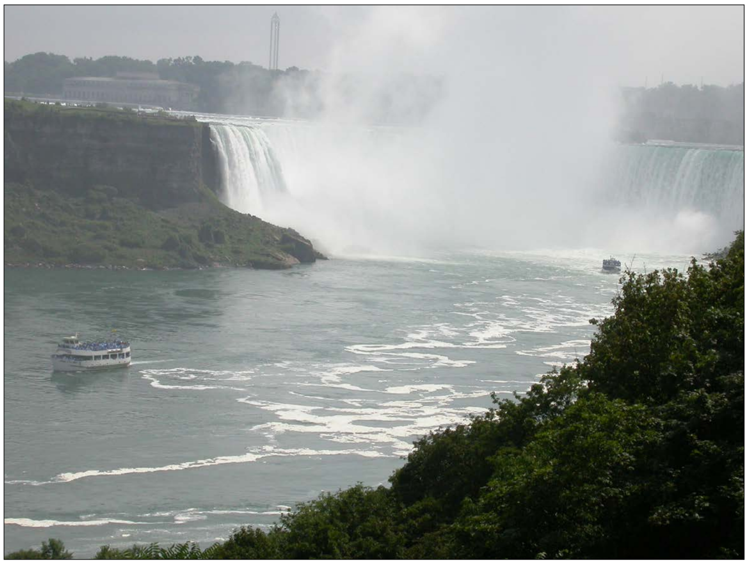
GLERL's Establishing Order

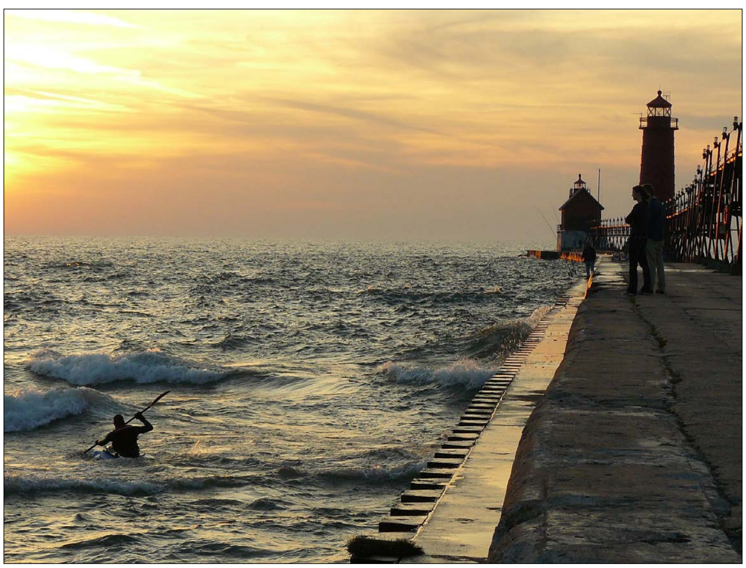
Office of the Secretary [Dept. Organization Order 25-5B] NOAA Organization and Function, April 25, 1974

"The Great Lakes Environmental Research Laboratory shall conduct research directed toward an understanding of the environmental processes in the Great Lakes and their watersheds. Emphasis shall be placed upon an interdisciplinary systems approach to solving problems in resource management and environmental services for that region."

The Great Lakes System: A Vital Resource at Risk

The Laurentian Great Lakes—the largest system of freshwater lakes on Earth—is a vital and highly valued resource, providing ecological, economic, and societal benefits for the region. In a world where water is increasingly in demand, the five Great Lakes—Superior, Michigan, Huron, Erie, and Ontario—hold 95 percent of our country's surface freshwater and 20 percent of the world's surface freshwater. Shared with Canada, these "freshwater seas" are valuable assets that provide Great Lakes communities with drinking water, agriculture, transportation, commercial shipping, hydroelectric power, a wide variety of recreational opportunities, and a world-class fishery assessed at $7 billion.[1] The positive regional economic impact generated by the Great Lakes is demonstrated by 1.5 million jobs directly connected to the lakes, resulting in $62 billion in wages.[2] Also treasured is the quality of life along the shores of the Great Lakes, creating a cultural identity for those residing in the region—a priceless legacy passed from generation to generation.





Great Lakes water provides valuable economic assets to communities including hydroelectric power and an array of recreational opportunities. Pictured above: The Niagara Falls, which straddle the border between Canada and the United States, have the capacity to output almost 4.9 million kilowatts, nearly enough to power 3.8 million homes. The "freshwater seas" of the Great Lakes also provide recreational opportunities, such as sport fishing and kayaking, as seen in the bottom photo, taken from the Grand Haven pier on Lake Michigan.

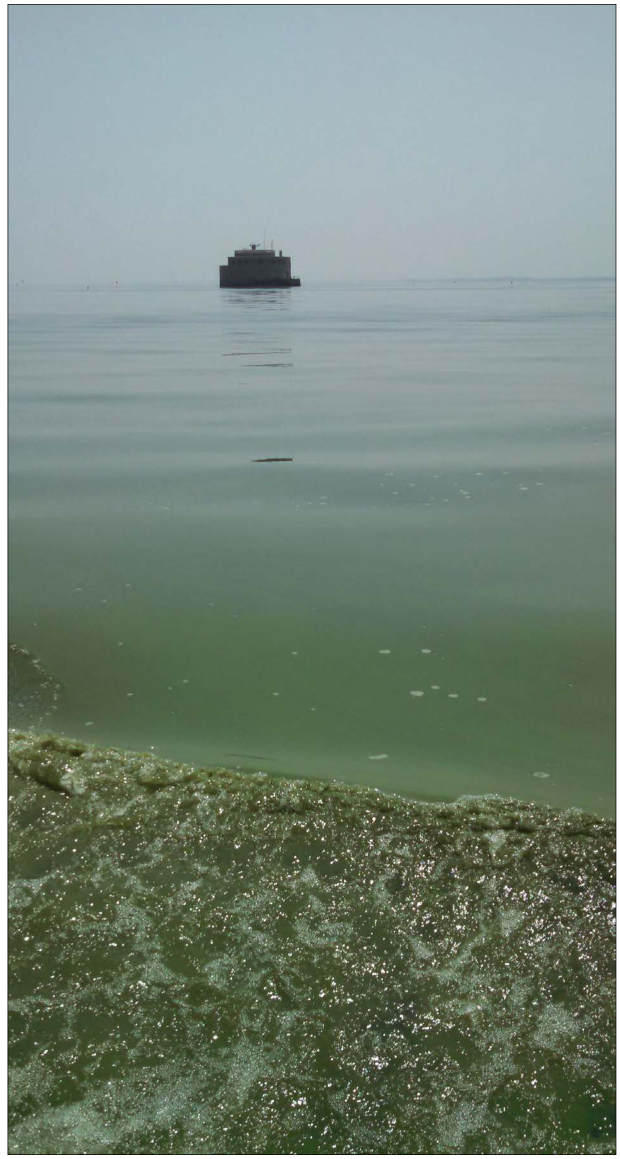
Great Lakes resources, however, are at risk. As human settlement in the Great Lakes basin has continued to intensify since the 19th century, so has dependency on the lakes and surrounding watersheds. The resulting human-induced stressors generated from industry and land use changes—deforestation, urbanization, and agricultural activity—threaten the lakes' water quantity, water quality, and ecological health. Human settlement and habitat destruction across the basin also jeopardize the lakes' resiliency. As natural areas are developed for industrial, agricultural, and residential purposes, the destruction of coastal wetlands reduces the capacity to mitigate runoff as well as to buffer the constant fluctuations of Great Lakes water levels, placing coastal properties

1 American Sportfishing Association. Jan. 2013. American Sportfishing in America: An Economic Force for Conservation. Alexandria, VA. Available at: http://asafishing.org/uploads/2011_ASASportfishing_in_America_Report_January_2013.pdf

2 Michigan Sea Grant College Program. 2011. Vital to Our Nation's Economy: Great Lakes Job Report. Michigan Sea Grant, Ann Arbor, Mich. Available at: http://www.miseagrant.umich.edu/downloads/economy/11-203-Great-Lakes-Jobs-report.pdf

at risk. Currently, one of the most critical concerns is increasing levels of nutrient run-off from rural and urban land that drain into the lakes, particularly during periods of heavy precipitation. The resulting excess phosphorus and nitrogen loading into the western basin of Lake Erie stimulate the growth of harmful algal blooms (HABs) that can produce toxins, such as cyanobacteria e.g., *Microcystis*, thus posing human health risks.

The resiliency of the Great Lakes ecosystem has also been jeopardized for decades by the introduction of nonindigenous aquatic nuisance species from waters around the world. For example, sea lamprey entered the Great Lakes and decimated native lake trout populations. In the absence of a top predator, invasive alewife proliferated; Pacific salmon were then introduced to control the alewife. Invasive dreissenid e.g., zebra and quagga mussels, introduced via ballast water from the Baltic Sea, are now abundant throughout the lower Great Lakes. These mussels directly undermine the base of the food web and ultimately threaten the sustainability of a lucrative fishery based on non-native Pacific salmon and alewife.



In recent decades, harmful algal blooms in Lake Erie have become a priority issue of concern. Considering climate change projections, the current trend of larger and more intense blooms will likely continue. Warming lake temperatures, increasing rainfall, and high amounts of nutrients entering the system encourage toxic algae growth.

In August 2014, a large bloom near the Toledo water intake (pictured above) threatened the drinking water of communities around the western basin of Lake Erie. Now commonly referred to as the "Toledo Water Crisis," toxins within the bloom were not able to be effectively removed by the water treatment plant, resulting in a multi-day shutdown of the plant, leaving nearly half a million people without fresh drinking water.

Climate variability—another stressor to the Great Lakes—is under investigation at GLERL for its effect on the Great Lakes thermal and hydrologic regime, driving extreme fluctuations in Great Lakes water levels and extent in ice cover. A relevant case in point is the unprecedented period of below-average water levels in Lake Michigan-Huron and Lake Superior that occurred over a period of roughly 14 years, beginning in 1998. This period of low water levels—correlated with warmer air temperatures—was characterized by high surface water temperatures, below average ice cover, and high over-lake evaporation rates. The impact of prolonged low water levels on the roughly 17,000 kilometers of Great Lakes coastline bore negatively on waterway navigation, hydropower generation and tourism, and led to economic adversities around the region. Soon after new low records were set on Lake Michigan-Huron, this 14-year period of low water levels on the upper Great Lakes came to a dramatic end with the most rapid two-year rise in water levels ever observed on the Great Lakes. Following the return to above average water levels, two consecutive years of extreme cold produced long winters and notably high ice cover. The abrupt change in the Great Lakes thermal and hydrologic regime—in this case resulting in colder temperatures and higher water levels—exemplifies the need for incorporating resiliency principles in planning and management.

Policy Developments Relevant to Great Lakes Environmental Research

With the advent of public awareness for environmental problems in the 1970s, the need emerged to observe, understand, and predict environmental conditions for solving these problems. Established in 1970 under the U.S. Department of Commerce, NOAA began working together with other federal agencies to advance capabilities in the areas of environmental science and technology. In 1974, NOAA founded the Great Lakes Environmental Research Laboratory as well as other environmental research laboratories across the country, all unified by the purpose to "predict and assess significant changes in the ocean, coastal and Great Lakes environments [that] ensure the safe, efficient, and cost-effective use of those marine environments and their resources, and promotes the development of associated industry." (Source: www.history.noaa.gov.)

The stage for addressing the environmental challenges of the binational Great Lakes watershed was set as far back as 1909, with the signing of the Great Lakes Boundary Waters Treaty by the United States and Canada. Almost 70 years later, in 1972, the two countries reaffirmed their rights and obligations to restore and maintain the chemical, physical, and biological integrity of the Great Lakes basin ecosystems, through the signing of the Great Lakes Water Quality Agreement (GLWQA). In the same year, the United States further strengthened their commitment to environmental protection with the passage of the Clean Water Act. The GLWQA—amended in 1983, 1987, and 2012—is driven by ongoing efforts to advance the restoration and protection of the Great Lakes.

Although progress followed these policy developments, recovery from severe disruptions to the Great Lakes system required expanded efforts for ecological recovery, which led to the enactment of the Great Lakes Regional Collaboration (GLRC). Built upon a Presidential Executive Order in 2004, a unique partnership of federal, state, tribal, and local governments convened under the GLRC to develop recommendations for

Great Lakes Restoration Initiative (GLRI)

The Great Lakes Restoration Initiative (GLRI) is the largest multi-agency effort in U.S. history aimed at restoring and protecting the health of the Great Lakes. Since 2010, GLRI resources have been used to create measurable benefits for Great Lakes communities and habitats in five focus areas:

- *Toxic Substances and Areas of Concern (AOC)*
- *Invasive Species*
- *Nonpoint Source Pollution Impacts on Nearshore Health*
- *Habitats and Species*
- *Accountability, Education, Monitoring, Evaluation, Communication, and Partnership*

A significant example of GLRI-funded efforts at GLERL is the Great Lakes Synthesis, Observations, and Response System (SOAR) program, which coordinates and integrates coastal ecosystem observations, supporting Great Lakes restoration projects. GLRI funds have been integral to developing and honing the system, which uses scientific models and observations taken on the water and from remote sensing platforms to create database products for assessment and decision support. While SOAR is focused on restoration projects within the Great Lakes, its value extends far beyond the region, since SOAR observations feed into a global observation network.

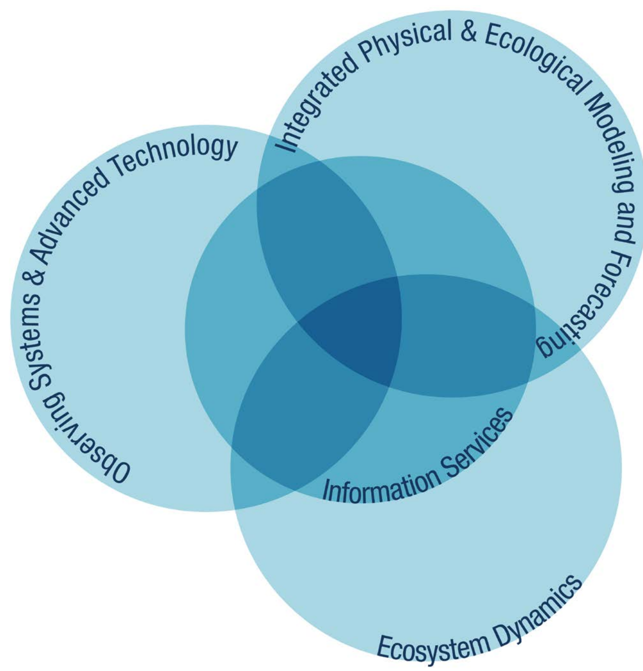
Pictured above is GLERL scientist, Eric Anderson, deploying a drifter near an ecosystem observation buoy in Lake Erie as part of the GLRI SOAR program. These drifter buoys aid in tracking currents and movement of harmful algal blooms in the Great Lakes, which plays an integral role in understanding dynamic physical and water quality conditions of the western basin of Lake Erie and enables scientists to evaluate changes to the lake environment in response to restoration efforts.

action that are based on more than three decades of restoration planning, water quality study, and resource management. In 2010, Congress appropriated funding to implement these recommendations under the Great Lakes Restoration Initiative (GLRI). Serving as a catalyst for federal agency coordination, the GLRI has funded the implementation of more than 2,669 projects from 2011-2015 that address Great Lakes environmental problems, such as water quality improvement, restoration and protection of native habitat, and the prevention and control of invasive species.

The Foundation of GLERL's Integrated Scientific Research

From the beginning, GLERL's research has aimed to advance understanding of the vital Great Lakes ecosystem. Since its establishment, the seminal investigations at GLERL have focused on the water/sediment interface, community and foodweb interactions, sediment resuspension and transport, eutrophication, hydrological and hydrodynamic modeling, and climate modeling, among others. For further information on the history of scientific research at GLERL, refer to www.glerl.noaa.gov.

GLERL's approach to scientific research—integrated around physical, chemical and biological interactions—serves as a framework to address the complex environmental challenges posed by a large-lake system in a state of flux as well as to serve as a model for other freshwater and coastal ecosystems. GLERL is uniquely organized to maintain its integrated scientific research program. GLERL's organizational structure is built upon the following four branches that drive GLERL's research agenda:



- Observing Systems and Advanced Technology
- Ecosystem Dynamics
- Integrated Physical and Ecological Modeling and Forecasting
- Information Services

Interaction and engagement across GLERL's four branches is fundamental to conducting scientific research and the dissemination of research outcomes. This integrated approach builds upon long-term observations, data collection, experimentation, modeling, prediction, and forecasting. The integration of research focuses scientific questions to strengthen understanding of the Great Lakes and toward solving environmental problems posing risks to the vitality and resiliency of the Great Lakes. This results-driven research, based on scientific inquiry, generates outcomes for application, such as marine watches and warnings, technology development, ecological forecasting, food web modeling, and a long-term database on the Great Lakes water budget.

This integrated scientific approach continues to evolve as GLERL science has begun to consider the practice of adaptive management as part of the laboratory's research. Adaptive integrated research purposively integrates lessons learned as part of the process of scientific inquiry, thus strengthening the next iteration of research investigations. In addition, GLERL continues to emphasize the development and application of prediction and forecasting tools, which extends GLERL's research capacity in HABs tracking, water level and ice cover fluctuation monitoring, and impacts of invasive species—all essential for informing management and decisions regarding Great Lakes resources to address the critical issues of today.

To address current and future challenges for Great Lakes environmental research, it is critical that GLERL maintains a balance of expertise on staff in the conduct of Great Lakes research on an integrated, multidisciplinary level that also is adaptable in addressing emerging Great Lakes ecosystem issues. Staffing needs must not only account for the constraints of NOAA's new FTE (Full-time Employee) cap and expected level base funding, but also retirements in critical positions over the next five years. In response to this set of circumstances, a staff succession plan for GLERL has been developed and is presented in the Implementation Plan, an extension of this document that is available upon request.

Ultimately, GLERL strives to be fully equipped, adaptable, and resilient in the conduct of scientific research in its commitment to advance NOAA's mission of science, service and stewardship.

Shared office space in the Ann Arbor laboratory (top) serves as a base for staff from a variety of NOAA programs, partners and visiting scientists. The facility also serves as a physical hub for regional collaboration within its conference spaces. The Lake Michigan Field Station (bottom) is strategically positioned on Lake Michigan to provide support to the local and regional community by further developing NOAA's role in freshwater ecology, ecosystems management, coastal management, and water-based commerce. This field station promotes long-term observations, field work, and process studies essential for understanding and developing future ecological services. Additionally, the proximity of the field station to Lake Michigan provides a unique opportunity for engagement with tourists, recreational users, and members of the community.

Aims
What principles guide GLERL research?

Vision

A trusted scientific enterprise to advance observation, modeling, understanding, and prediction of the Great Lakes and coasts to sustain resilient ecosystems, communities, and economies.

Mission

Conduct integrated scientific research on the Great Lakes and coastal ecosystems; develop and transition products and services; and share knowledge and information to advance science, service and stewardship.

Organizational Goals[1]

Preeminent Research | Conduct preeminent research, aligned with NOAA goals, to advance the state of science and knowledge that promotes sound decision making and ecosystem management.

Organizational Excellence | Achieve excellence by building the capacity of NOAA personnel, infrastructure, and business practices that advance and support NOAA's mission of science, service, and stewardship.

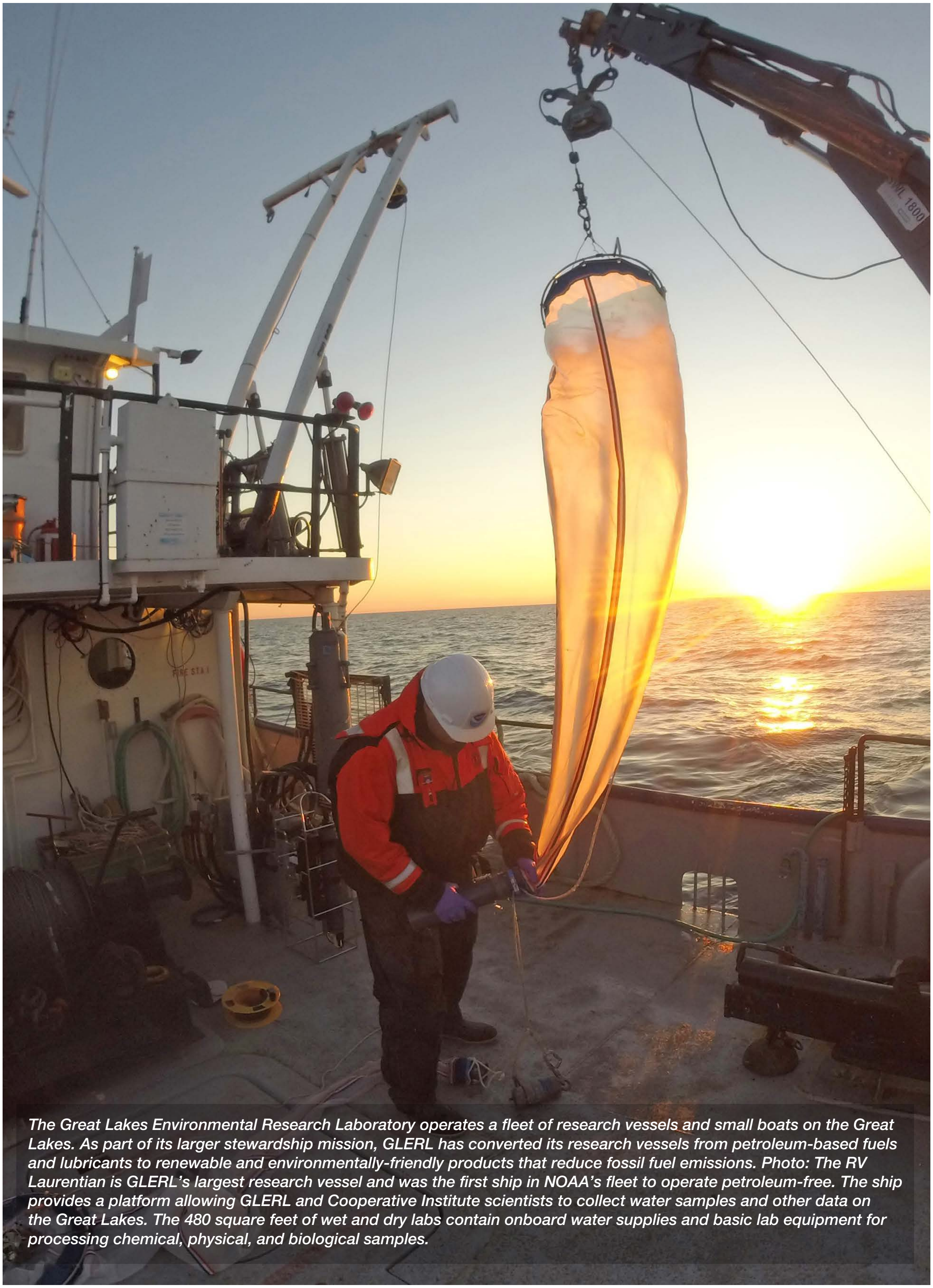
Integrity and Quality | Execute research with integrity and quality, abiding by quality management, safety standards, and environmental compliance, as well as acknowledging uncertainty.

Diversity | Secure a diverse workforce that is supported by an organizational culture of inclusiveness.

Interdisciplinary and Partnership Approach | Integrate an interdisciplinary approach and use partnerships, such as those with the NOAA Cooperative Institutes, to strengthen capacity in reaching institutional goals.

Addressing Stakeholder Needs | Serve NOAA's customers by integrating their priority needs in the development and implementation of research, inclusive of the transition of research to operations and application (R2X), and accessibility of GLERL's observations and data, scientific knowledge and information, and products and services.

1 The organizational goals in the Aims section of GLERL's strategic plan serve as the framework for program development, implementation and evaluation as presented in the Evaluation section of the plan.

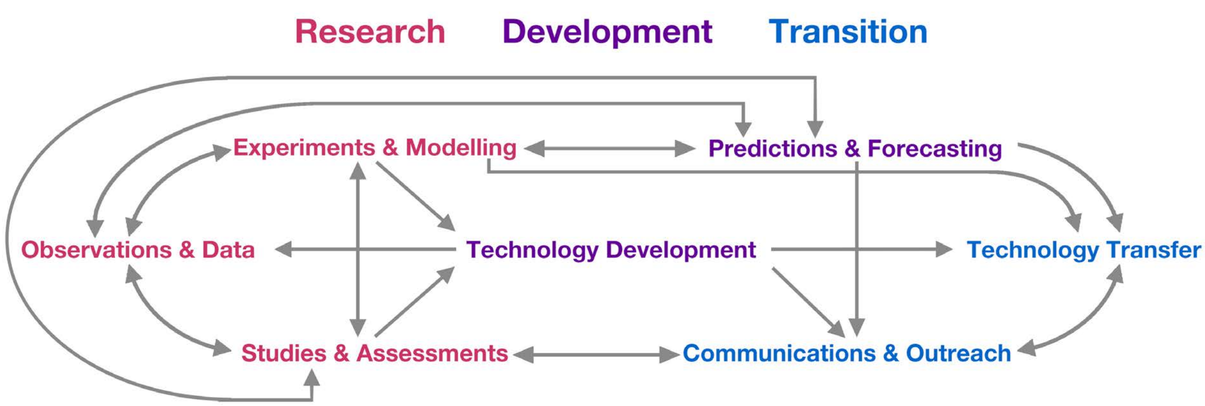


The Great Lakes Environmental Research Laboratory operates a fleet of research vessels and small boats on the Great Lakes. As part of its larger stewardship mission, GLERL has converted its research vessels from petroleum-based fuels and lubricants to renewable and environmentally-friendly products that reduce fossil fuel emissions. Photo: The RV Laurentian is GLERL's largest research vessel and was the first ship in NOAA's fleet to operate petroleum-free. The ship provides a platform allowing GLERL and Cooperative Institute scientists to collect water samples and other data on the Great Lakes. The 480 square feet of wet and dry labs contain onboard water supplies and basic lab equipment for processing chemical, physical, and biological samples.

Activities

What are the processes and types of products that allow GLERL to achieve its aims?

GLERL conducts interdisciplinary science across three phases: research, development, and transition (see schematic below), facilitated by communication and outreach. In collaboration with both internal and external partners, such activities include observations, inquiry-based thinking, experiments, concept development, modeling, forecasting, product development, application, and communication. GLERL's investments in research, development, and transition to application advance the vision, mission, and organizational goals as presented in the Aims section of this strategic plan. The products and services are communicated to resource managers, policymakers, and other stakeholder groups, to address Great Lakes and coastal issues.



Schematic of the research-development-transition process at GLERL.

Research

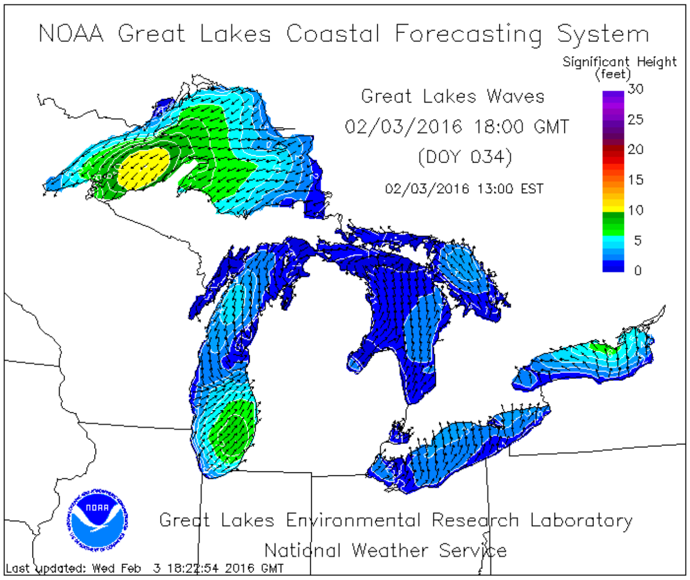
Research yields ideas, knowledge, and understanding of systems. GLERL conducts research—ranging from fundamental to applied—on the Great Lakes and other coastal locations to advance the missions of GLERL, OAR, and NOAA.

Observations and Data

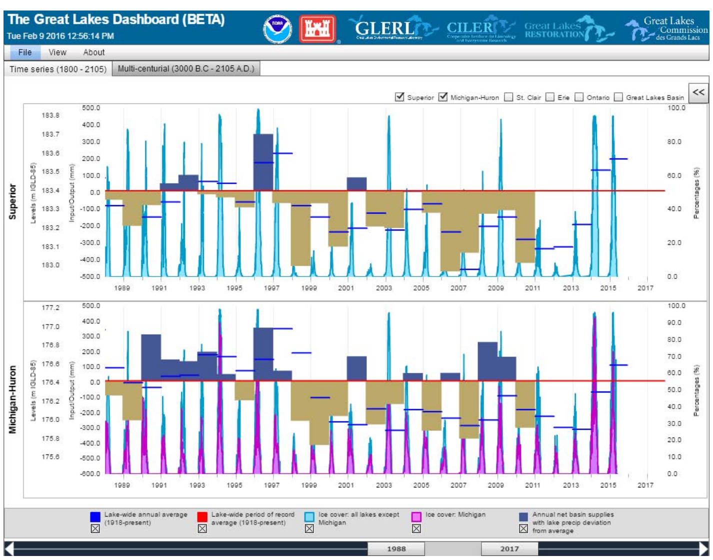
GLERL collects observations and data through a variety of techniques. These techniques include: direct biological sampling, satellite remote sensing, *in situ* sensors and observing systems, and mobile platforms, such as vessels and autonomous vehicles. Observations and data on the physical, chemical, and biological components of the Great Lakes and coastal ecosystems supports studies and assessments, informs experiments and models, and ultimately predictions and forecasts. Integral to this process is the procurement and maintenance of observing systems, quality assurance and control, and data management. *Examples: Great Lakes CoastWatch node, Real-time Coastal Observation Network (ReCON), long-term Great Lakes water level observations, long-term ice cover observations, long-term observations on the Lake Michigan ecosystem, monitoring of harmful algal bloom conditions in Lake Erie, exploration of the under-ice environment, and Great Lakes Surface Environmental Analysis (next page).*

Experiments and Modeling

Scientific experimentation is used to explore the potential mechanisms and processes operating within the ecosystem to understand the dynamic interaction between the physical, chemical, and biological components. Experiments are performed both in the field and in the laboratory, at multiple spatial and temporal scales. Models integrate the knowledge gained from observations, data, and experimental studies and provide qualitative and quantitative understanding of the characteristics and processes of the Great Lakes and coastal ecosystems. Model outcomes inform future field studies and experimentation.



Output from the experimental Great Lakes Coastal Forecasting System (GLCFS) is posted on GLERL's website on a daily basis. GLCFS is a real-time coastal prediction system developed for forecasting wind waves, surface water level fluctuations, and the horizontal and vertical structure of temperatures and currents in the Great Lakes. ***The GLCFS advances the NOAA Science goal of Weather Ready Nation: Reduced loss of life, property, and disruption from high-impact events.***



The Great Lakes Dashboard by Smith et al. (2016), allows for the display of time series data for multiple variables describing water levels and other related Great Lakes environmental variables. ***The dashboard is a valuable tool that can be used to advance several NOAA goals: Climate Adaptation and Mitigation, Weather Ready Nation, Resilient Coastal Communities and Economies, and Science-Informed Society.***

Examples: Filtering capacity and bioenergetics of dreissenid mussels; buoyancy behavior of Microcystis; sediment oxygen demand relative to dissolved oxygen and temperature; and the use of models to close the water budget; predict future risk of invasive species e.g., Asian carp, etc.

Studies and Assessments

Studies and assessments synthesize scientific knowledge gained from observational data, experimental results and model outputs of the Great Lakes and coastal systems and are used for decision-making and the consideration of future research. This phase of research contributes to dialogue among scientists, managers and stakeholders for the ecological and economic sustainability of the Great Lakes.

Examples: Peer-reviewed publications and reports on topics such as Lake Erie harmful algal blooms and Asian carp impacts; the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS); lake levels assessments for the Intergovernmental Panel on Climate Change; the National Climate Assessment; Great Lakes ecosystem characterizations.

Development

Development is the systematic use of knowledge or understanding that yields techniques, technologies, algorithms, models, and other methodologies. Development-related activities are critical to improving the capabilities for conducting scientific research, transitioning research to applications, and for other operations across NOAA as well as with regional, national, and international partners.

Predictions and Forecasting

GLERL develops and applies advanced models of Great Lakes and coastal systems to make real-time, near-term, and long-term predictions and forecasts. These models include scenario-based and pre-operational products for resource management, decision-making, and exploration for practical application. Prediction and forecasting require data, advanced computing architecture, algorithms, synthesis and interpretation, and transfer of information to users.

Examples: Forecasts of water levels (based on regional water budget projections); physical conditions e.g., Great Lakes Coastal Forecasting System: waves, water temperature, currents, ice; and harmful algal blooms (HABs). Others include scenario-based predictions of ecosystem changes from stressors such as invasive species, climate, and nutrient loading.

Michigan high school students competing at the Great Lakes National Ocean Sciences Bowl (NOSB), a national academic competition where teams of high school students compete for the regional and national title. The matches feature quiz-bowl style rounds and challenge questions that test a team's ocean and Great Lakes knowledge. GLERL and CILER scientists and outreach staff provide support to run this annual competition, hosted by NOAA OAR's Michigan Sea Grant. ***GLERL's participation in this initiative advances the NOAA Education goal of Science-informed Society: Youth and adults from all backgrounds improve their understanding of NOAA-related science by participating in education and outreach opportunities.***

Technology Development

GLERL's development work broadens and improves the application of technology for observations and system infrastructure. GLERL develops tools for real-time information delivery that strengthens stakeholder engagement. Typically, this involves the development or application of new hardware and software, adaptation of existing technology to new applications, and the integration of a suite of technologies.

Examples: Adapting marine technologies to freshwater systems; development of real-time transmission e.g., software interfaces and integration of existing technologies; and the display of information e.g., observing systems, ReCON (Real-time Coastal Observation Network), and the Great Lakes Water Level Dashboard (previous page).

Transition

Transition includes activities of transferring knowledge, technology, models, and forecasts to NOAA and other partners for application and operational use. GLERL science and technology anticipates and responds to partners' needs in ways that are relevant to society and are consistent with NOAA's mission. GLERL recognizes the value of products and services that can be deployed by partners into applications. Integral to the successful transfer of valuable products and services, is targeted communication with potential partners and end users.

Communication and Outreach

GLERL promotes and translates research and development outcomes through a variety of communication products that are customized to the user. Integral to GLERL's research program is the capacity to understand and identify priority needs of stakeholders and user groups and conduct research in response to those needs. Through collaboration with NOAA's line offices, as well as a network of Great Lakes science communicators, GLERL delivers cohesive messages on its scientific research in ways that are meaningful and actionable. GLERL also participates in educational events and initiatives that help to cultivate a science-informed society. Additionally, internal communication among GLERL staff facilitates an overall understanding of the research, development, and transition activities underway, to help advance organizational excellence.

Examples: Connecting NOAA science and scientists with stakeholders and the general public through media interviews and teleconferences, community outreach activities, Great Lakes Webinar Series, Congressional briefings, stakeholder needs assessments, peer-reviewed publications, technical reports, presentations, website content, social media, factsheets, infographics, and data visualizations.

Technology Transfer

GLERL collaborates with partners to transfer the product outcomes of research and development for application and operational use by stakeholders. Technology transfer varies and is dependent upon user needs, how research and development can meet those needs, and effective communication and outreach to end users.

Examples: Future transfer of FVCOM (Finite Volume Community Ocean Model) operational modeling and next generation of HABs Tracker to NOS (National Ocean Service); transfer of water level forecasts to the U.S. Army Corps of Engineers; transfer of Great Lakes CoastWatch sea surface temperature to Sea Grant; transfer of ReCON data to the National Weather Service.

Research Product Technical Readiness Level Definitions

9: Actual system "mission proven" through successful operations.

8: Actual system completed and "mission qualified" through test and demo in operational environment.

7: System prototyping demonstration in an operational environment.

6: System/subsystem model or prototyping demonstration in a relevant end-to-end environment.

5: System/subsystem validation in relevant environment.

4: Component/subsystem validation in laboratory environment.

3: Analytical and experimental critical function and/or characteristic proof-of-concept.

2: Technology concept and/or application has been formulated.

1: Basic principles have been observed and reported.

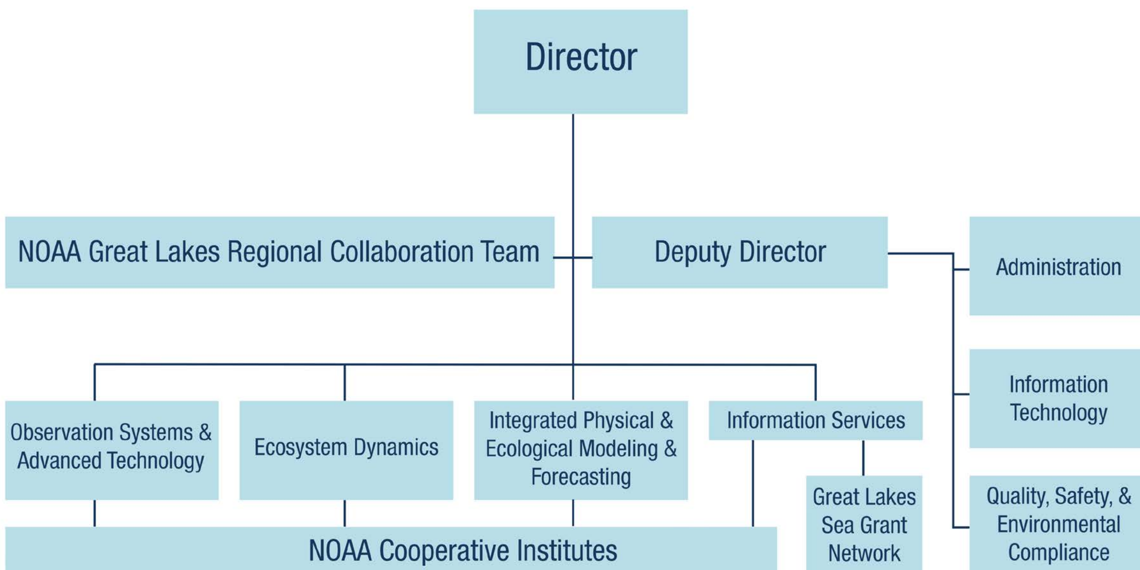
GLERL develops a wide range of products that aid decision-making to sustain resilient ecosystems, communities, and economies. Transferable products include observational data sets, visualization tools, analysis and forecast products, decision support and situational awareness tools, physical process model parameterizations, assessments, model outputs, climate, ice-hydrodynamic, water budget analyses and reanalyses, etc. These tools are developed in partnership with operational entities across NOAA, foreign and domestic governmental agencies, academic institutions, private industry, and region-specific stakeholders. These products and services can be found within the Technology Transfer section of the Implementation Plan, an extension of this document, available upon request.

Organizational Structure

How is GLERL organized and who does what?

GLERL's organizational structure lays the groundwork for an integrated scientific approach closely connected with dissemination of research outcomes. Led by GLERL's director, the science and information services branches are supported by an infrastructure team that helps facilitate the laboratory's operations. While the chart depicted below provides a model for defining roles, responsibilities and operational direction in the conduct of scientific research at GLERL, there are no rigid boundaries. A collaborative work environment is highly valued, as GLERL personnel strive to accomplish the mission, vision and goals through cross-disciplinary interaction.

Note: The following section will describe the organization and roles of GLERL's staff, including those partners directly integrated into the operation of the laboratory. For more information on GLERL's co-located and external partners, see www.glerl.noaa.gov/par.



Scientific Leadership

Leadership at GLERL includes the director, deputy director, and the branch chiefs of the following four themes: Observing Systems and Advanced Technology (OSAT), Ecosystem Dynamics (EcoDyn), Integrated Physical and Ecological Modeling and Forecasting (IPEMF), and Information Services (IS). There is a strong emphasis at GLERL to work on a cohesive level across the science and information services branches as well as the advising councils and NOAA's cooperative programs.

Director

GLERL's director serves as the laboratory's visionary leader, providing guidance through conceptual development, implementation, and management of integrated, interdisciplinary scientific research and communications programs. The director is also responsible for evaluation of research quality, priority-based acquisition and administration of resources, as well as exploration of new and promising lines of research. Other responsibilities include contract administration, budget development and justification, and personnel management.

GLERL's workforce is diverse and inclusive. At present, staff makeup includes 41 federal employees, 25 CILER (Cooperative Institute for Limnology and Ecosystems Research) employees and 13 contractors, with an additional 10-15 Summer Fellows per year, mostly hired through CILER, and approximately 10 Visiting Scientists through a series of CILER, UCAR-PACE (University Corporation for Atmospheric Research-Postdocs Applying Climate Expertise) and NSF (National Science Foundation) Fellowships.

In facilitating GLERL's research and development, the director collaborates with external stakeholders to ensure that the laboratory's research addresses identified regional and national priorities and its products, tools, and services help to inform resource management and decision-making on coastal and water resources issues. The director also plays a vital role in securing non-base funding support for GLERL programs. Another important role played by the director is to maintain collaboration internally with other NOAA line offices and externally with other federal agencies to advance common goals that promote Great Lakes protection and restoration. Currently and into the immediate future, the GLERL director chairs the NOAA Great Lakes Regional Collaboration Team (GLRCT).

Deputy Director

The deputy director oversees all non-scientific aspects of laboratory operations including those related to budget, administration, facilities, safety and security, environmental compliance, data management, and information technology. In addition, the deputy director serves as an advisor on scientific issues, providing input and ensuring integration between science and operations support. The deputy director provides information and recommendations to the director along with effective guidance and coordination to GLERL staff in addressing laboratory goals. The deputy director also helps facilitate the process of developing external and internal proposals as well as GLERL's Annual Operating Plan (AOP).

Science and Information Services Branch Chiefs

The primary duties of the science branch chiefs are to manage and oversee the work of the principal investigators (PIs) and support staff within their branches, and to coordinate research activities with the other science branches. The science branch chiefs also engage with internal and external partners in the conduct of scientific research and related outreach and communication products, such as seminars, stakeholder workshops, and presentations. The Information Services branch chief oversees the dissemination of research outcomes and is responsible for making research findings accessible to the general public and community stakeholders on issues of interest and concern as well as to inform resource managers and decision-makers.

Advising Councils

Science Council

The Science Council meets monthly to discuss the needs and issues of science-related matters. The GLERL director chairs the Council with membership including the director, deputy director, the four branch leads, and a liaison to NOAA's Cooperative Institute serving the Great Lakes region. The purpose of the Council is to advance GLERL's collaboration with NOAA partners, oversight of GLERL's scientific research, science personnel management, and the future direction of the laboratory's research.

Director's Council

The Director's Council meets weekly to facilitate operational information flow for effective business administration. Members include the director, deputy director, director's office support, leads from the Information Services branch, administration, and the quality, safety and environmental compliance officer.

Infrastructure Council

The Infrastructure Council, led by GLERL's deputy director, meets biweekly to discuss GLERL operations, provide infrastructure updates, and address emerging issues. Membership includes the branch leads from administration, information services, information technology, vessel operations, the Marine and Instrumentation Laboratory, and the quality, safety, and environmental compliance officer.

Partnership Council

The Partnership Council is comprised of union and management representatives. The Partnership Council meets monthly with standing members including the GLERL director and the administrative team lead serving as the facilitator. Rotating membership includes three union members and two GLERL managers. The forum provides an opportunity for constructive and proactive problem-solving.

Co-located NOAA Partners

NOAA Cooperative Institutes

The NOAA Cooperative Institutes are academic and non-profit research institutions that demonstrate the highest level of performance in the conduct of research, supporting NOAA's mission goals and strategic plan. The geographic locations of Cooperative Institutes extend from Hawaii to Maine and from Alaska to Florida. Currently, GLERL's Cooperative Institute is the Cooperative Institute for Limnology and Ecosystems Research, led by the University of Michigan. The current cooperative agreement extends from 2012-2017.

NOAA Great Lakes Regional Collaboration Team (GLRCT)

Currently led by GLERL director, the GLRCT reflects NOAA's presence in the region. The membership is comprised of representatives from each NOAA line office as well as core partners from other collaborative initiatives. The GLRCT serves to unify and integrate NOAA initiatives in the Great Lakes region by providing services that meet the evolving needs of stakeholders.

Great Lakes Sea Grant Network

The Great Lakes Sea Grant Network is comprised of the eight Great Lakes state Sea Grant programs. In 2001, an innovative position was established to enhance connectivity between GLERL research and Great Lakes Sea Grant programs. Located at GLERL, the Regional Sea Grant Specialist position facilitates information exchange between GLERL and Sea Grant regarding Great Lakes-related research, extension, education, and other programs. Additionally, the specialist develops collaborative extension, communications, and outreach programs that draw upon the work of GLERL and Sea Grant, directed towards specific Great Lakes stakeholder audiences and/or the general public.

NOAA's Cooperative Institute for Limnology and Ecosystems Research (CILER) is a consortium of Great Lakes academic institutions working to enhance the preservation, protection and understanding of the Great Lakes and its ecosystem services. CILER is administered through the University of Michigan and many of its researchers are co-located at GLERL. CILER and GLERL scientists collaborate closely in the laboratory as well as in the field, which enables a robust science synergy between GLERL and CILER. Established in 1989, CILER research is currently focused in the following five areas: protection and restoration of ecosystem services, Great Lakes observing and forecasting systems, invasive species, ecological risk assessment, and education and outreach.

Pictured above: CILER summer fellow Kyle Dettloff and his mentor, GLERL scientist Ashley Baldridge, sieving a sediment sample collected from Lake Michigan during the 2015 Coordinated Science and Monitoring Initiative (CSMI) benthic survey, July 23, 2015.

Approaches

How does GLERL approach its role as a scientific environmental research laboratory?

This section is the core of GLERL's strategic plan, and focuses on how GLERL pursues scientific environmental research, development, and transition to operations and applications. Within Approaches, a road map is charted for each of GLERL's four branches—Observing Systems and Advanced Technology (OSAT), Ecosystem Dynamics (EcoDyn), Integrated Physical and Ecological Modeling and Forecasting (IPEMF) and Information Services (IS). The identity of each branch is defined by goals, inquiry-based questions or drivers, paths, and milestones. In this portion of the strategic plan, the goals and inquiry-based questions/drivers are presented for each of the four branches. The paths and milestones of these branches are presented in GLERL's implementation plan, which provides more detail on the process for execution of the strategic plan.

GLERL research is committed to the needs of the Great Lakes and coastal communities, the implementation of NOAA's Ecological Forecasting Roadmap (see below), as well as to the goals and objectives presented in NOAA's Next Generation Strategic Plan "to improve human welfare and sustain the ecosystems upon which society depends." NOAA's core goals include:

- Climate Adaptation and Mitigation: An informed society anticipating and responding to climate and its impacts.
- Weather-Ready Nation: Society is prepared for and responds to weather-related events.
- Healthy Oceans: Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems.
- Resilient Coastal Communities and Economies: Coastal and Great Lakes communities that are environmentally and economically sustainable.

The matrix presented at the end of this section, illustrates the research performed across GLERL's four branches that addresses NOAA goals and associated objectives. As reflected in the matrix, GLERL is a microcosm of NOAA, serving specific needs of Great Lakes and coastal stakeholders.

Ecological forecasts are used to predict likely changes in ecosystems and ecosystem components in response to environmental drivers and resulting impacts on people, economies, and communities that depend on ecosystem services. GLERL is a leading partner with the National Ocean Service (NOS) on NOAA's Ecological Forecasting Roadmap, a program built upon the goals presented above. A priority research area at GLERL is the development of numerical models to predict the physical, chemical, biological and ecological response in the Great Lakes due to weather, climate, and human induced changes. The outcomes of these forecast models provide valuable information to support informed decisions for optimal management of the Great Lakes system.

This section is comprised of individual branch plans based on a five year trajectory. Each plan is developed within an integrated context—fundamental to how GLERL conducts research. The integrated nature of GLERL's research is primarily a function of the interconnected nature of the Great Lakes ecosystem, driven by the physical, chemical, and biological forces of change. Because of this, many research questions are interdisciplinary and require collaboration across all GLERL branches and with NOAA Cooperative Institutes, other governmental agencies, and academic institutions. Also characteristic of GLERL research is an adaptive management approach, providing a feedback-based framework aimed at strengthening the laboratory's capacity to investigate the complex dynamics of the lakes. Overall, GLERL's unique approach to integrated scientific research promotes the advancement of Great Lakes ecosystem management by sound science and collaboration, while acknowledging uncertainty. In taking this approach, GLERL serves as a scientific and information hub for the Great Lakes community.

Uncertainty in Scientific Research & Communication

"In science, there's often not absolute certainty. But, research reduces uncertainty. In many cases, theories have been tested and analyzed and examined so thoroughly that their chance of being wrong is infinitesimal. Other times, uncertainties linger despite lengthy research. In those cases, scientists make it their job to explain how well something is known. When gaps in knowledge exist, scientists qualify the evidence to ensure others don't form conclusions that go beyond what is known." – Union of Concerned Scientists (www.ucsusa.org/global_warming/science_and_impacts/science/certainty-vs-uncertainty.html)

GLERL strives to both reduce uncertainty and conduct its research in a culture of transparency in which scientists describe and communicate the degree of certainty and confidence in their findings.

The different elements of uncertainty encountered in the work of GLERL's four branches include:

- *Natural variability*
- *Observation error (or measurement/estimation uncertainty)*
- *Model uncertainty*
- *Communication uncertainty*
- *Management uncertainty*

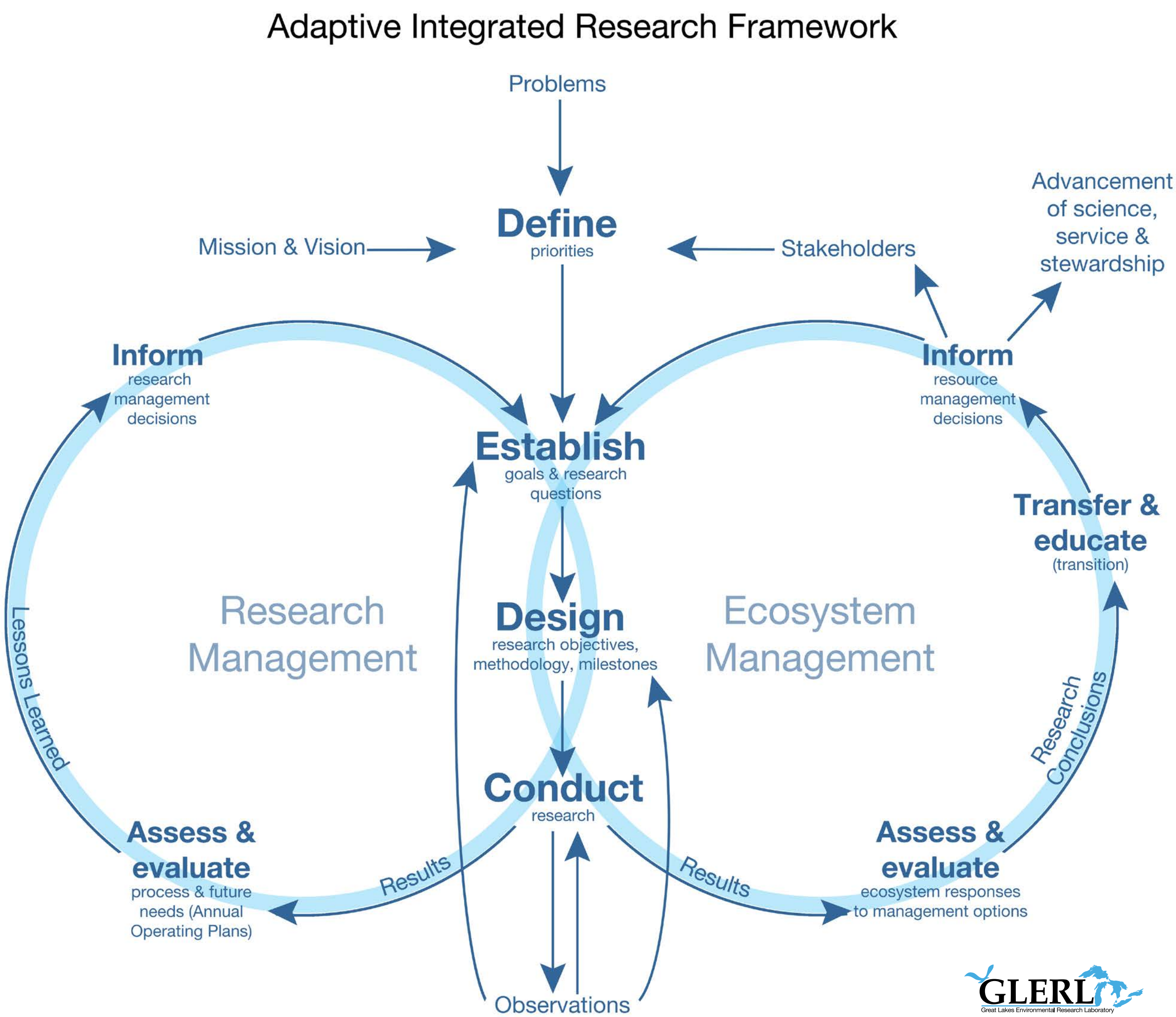
(From NOAA Technical Memorandum NMFS-F/SPO-153; "Report from the Joint OAT-NMFS Modeling Uncertainty Workshop")

GLERL's approach to adaptive integrated research can be described as a coupling of the management of research programs with the management of Great Lakes and coastal ecosystems. The coupled cycle of adaptive integrated research (see diagram on next page) represents the inter-relationship between research management and ecosystem management. Factors that play a role in defining research priorities include input from the organizational mission and vision, identified ecosystem problems, as well as input from stakeholders. These priorities help to establish research goals, questions and drivers, which then guide the design phase for developing research paths, methodologies, and milestones. An adaptive integrated research framework facilitates research that is purposefully conducted. As part of this process, observations provide additional information for feedback to hone the design and conduct of research as well as the establishment of goals and research questions.

Within the research management cycle, GLERL's Annual Operating Plans (AOPs) provide a process to assess and evaluate lessons learned in reference to the establish-design-conduct phases (including new questions and drivers that may influence research direction). The assessment and evaluation phase informs GLERL's decision-making process on future research goals and questions upon which the laboratory's projects and programs are built.

Further, GLERL strives to make scientific research more useful to stakeholders, including resource managers. In the ecosystem management cycle, results are assessed and evaluated on an iterative basis. The interpretation of research results helps to inform the scientists and stakeholders on the ecosystem response to management actions. Research conclusions are transferred through technical and non-technical dissemination. This transfer/educate phase of the adaptive integrated research framework includes scientific publications and presentations, transition to operations and applications, and outreach and education to diverse audiences. The products and services are transferred to user groups, stakeholders, and decision makers. The outcomes from transition play a key role in advancing NOAA's mission of science, service and stewardship. In completing the cycle of adaptive integrated research to initiate yet another cycle, input from decision-makers and stakeholders informs GLERL's future research goals and questions.

Overall, feedback from the coupled research management and ecosystem management cycles, as well as from stakeholders, is used to redefine priorities and reestablish goals and research questions. Thus, the coupled feedback loops of the adaptive integrated research framework drives the refinement of GLERL projects and programs—both existing and new.



The diagram above was developed to depict the adaptive, integrated approach that characterizes GLERL's research. The iterative, long-term, systematic process of using an adaptive integrated research framework provides an opportunity to refine research and ecosystem management approaches through experimental research and adaptive management. The cycle of an adaptive integrated research framework used in conjunction with the best available science, provides iterative feedback loops incorporated as part of GLERL's research methodology. The double feedback cycle shows the interrelationship between research management and ecosystem management, both driven by assessment and evaluation outcomes, informing scientific research and operations at GLERL.

Harmful Algal Bloom Research: A Case Study for Adaptive Integrated Research

The application of an adaptive integrated research approach is well demonstrated by GLERL's harmful algal blooms (HABs) research program. The HABs program involves GLERL's four branches and is conducted in collaboration with NOAA's Cooperative Institute for Limnology and Ecosystems Research (CILER) and National Centers for Coastal Ocean Science (NCCOS) and other academic partners. The primary ecological focus is determining the extent, duration and toxicity of HABs, which impact Great Lakes water quality due to human-induced stressors.

The blue-green algal bloom in Lake Erie, as seen from the MODIS satellite on September 6, 2015, highlights the worst bloom of this century in terms of extent and density. The bloom was less concentrated at the time of this photograph than in August 2015.

GLERL's interdisciplinary approach integrates physical, chemical, biological sciences as well as advanced technologies. The study of the physical component begins with the primary environmental stressor driving HABs—excess nutrient loading. The chemical component of the research involves nutrient chemistry driving bloom growth and toxin formation. Nutrients, which act as a food source for HABs, are transported through runoff from precipitation and tributary flow from the watershed into Lake Erie. The physiochemical aspects of this research are the thermal structure and hypoxic (oxygen depleted) conditions that evolve seasonally. The nutrient-induced algal blooms in the lake move horizontally and vertically, driven by currents and winds and biological processes. The biological component focuses on the seasonal genetics of algal populations, response of HAB-forming genera to specific environmental changes, and drivers of bloom toxicity. The HABs team is measuring toxin concentrations, HAB strain identity, and toxicity by applying various chemical and genetic approaches as well as use of autonomous sampling devices, such as the Environmental Sample Processor (see sidebar on page 22). HAB monitoring techniques using an aircraft high spectral resolution imagery system are being developed to classify and map HABs when satellite imaging is not available.

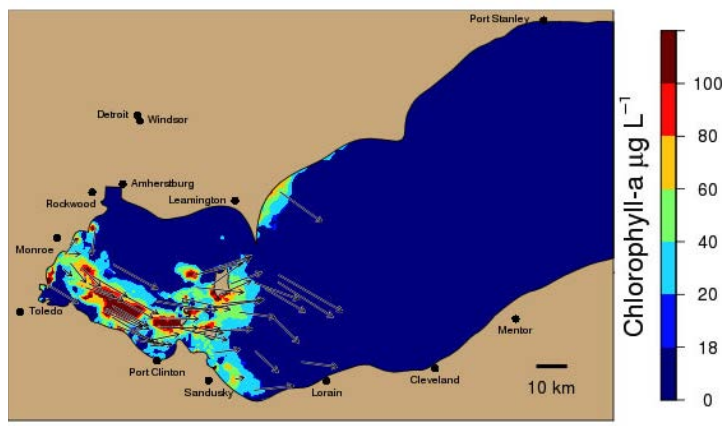
To further illustrate the integrated approach, the HABs program has a diverse range of expertise including engineers, oceanographers, limnologists, geneticists, mathematical modelers, and human dimensions and communication specialists. The program uses advanced observing systems, including satellite imaging, real-time buoys, and *in situ* monitoring in Lake Erie, coupled with advanced genetic techniques to understand the long and short-term seasonal dynamics of HAB events. The data (e.g., temperature, wind direction, currents, dissolved oxygen, and chlorophyll concentration) collected by OSAT, EcoDyn, and CILER are used to inform predictive models, led by the IPEMF branch. These models provide a nowcast and forecast of bloom extent and intensity, and, in the future, efforts will focus on how to incorporate toxicity (see Harmful Algal Bloom Tracker on right). These critical products inform stakeholder groups (drinking water managers, public health decision makers, recreational users, and land-use managers) through outreach from GLERL's IS branch and CILER, as well as through GLERL's website, to help reduce risks to human and ecosystem health from HABs.

The long-term nature of the program has strengthened GLERL's understanding of the environmental factors driving HAB growth and toxicity, leading to improved and more accurate HAB forecasting products. Additionally, an adaptive integrated research approach drives the refinement of management practices to address the problems impacting the western basin of Lake Erie and other HAB-impacted areas of the Great Lakes.

The following discussion of HAB research conducted at GLERL is illustrative of the ecosystem management cycle of the adaptive integrated research approach (refer to right feedback loop of the figure on page 19).

Harmful Algal Bloom Tracker

The development of a 5-day forecasting tool called the HAB Tracker—operated on an experimental basis—is a product of collaboration among researchers from GLERL's IPEMF branch and CILER. By combining daily satellite imagery (when available), and hydrodynamic modeling, the experimental HAB Tracker produces daily 5-day forecasts of surface chlorophyll concentrations and vertical mixing of the water column, with an estimation of extent and intensity of the bloom. Forecasted meteorological and hydrodynamic conditions are used to predict where the bloom will travel and what concentrations are likely to be seen on a 3-dimensional scale.



Define Priorities (based on input from stakeholders, problem definition, and NOAA GLERL mission and vision)

- HAB impacts on water quality and ecosystem health in the Great Lakes have been identified as a priority issue under the Great Lakes Water Quality Agreement (GLWQA) and within the NOAA goal, "Healthy Oceans: Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems."
- Specific research, nutrient management, and communications recommendations are being established under a Great Lakes-specific Harmful Algal Bloom Research and Control Act (HABHRCA) report mandated in the 2014 HABHRCA amendment.

Establish Goals and Research Questions

- Management Goals (amended 2012 GLWQA)
  - Maintain the levels of algal biomass below the level constituting a nuisance condition.
  - Maintain algal species consistent with healthy aquatic ecosystems in the nearshore waters of the Great Lakes.
  - Maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in waters of the Great Lakes.
- Research Goal: Quantitative understanding of the drivers of HABs to predict their extent,

movement, duration, timing, concentration, and toxicity.

Research questions:

- What are the roles of phosphorus and nitrogen loading and other environmental stressors in driving HAB bloom timing, abundance, toxicity, and spatial distribution?
- How will Great Lakes HABs respond to a changing climate?
- To what extent can the information from HABs research on Lake Erie be applied to aquatic ecosystems in other parts of the Great Lakes?

Design Research Objectives, Methodology, and Paths/Milestones

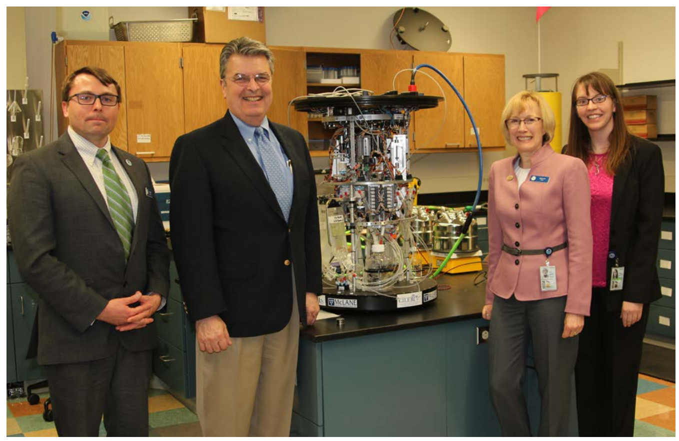
- Research Objective: Investigate environmental stressors, related impacts, and their relationship to HABs.

  Paths:

  - Focus on designing deliberate, structured experimentation to test the effect of phosphorus (P) reduction on algal growth as well as the effect of nitrogen (N) on algal growth and toxicity.
  - Develop and improve NOAA forecast products to predict HABs through *in situ* water quality observations, hyperspectral flyovers, and hydrodynamic modeling.
- Methodology is based on testable hypotheses that guide research planning and monitoring.
  - Hypothesis 1: Chlorophyll a (a surrogate for algal growth) will decrease linearly with decreasing total phosphorus concentrations.
  - Hypothesis 2: Bloom size will likely decrease with reduced total P concentrations, but toxicity will not be affected unless N inputs are changed.

Conduct Research

- Experiments are aimed at understanding how future environmental conditions may impact bloom growth and toxicity. For example, understanding the role of different nutrient types and concentrations on growth and toxicity of HABs; the role of toxins; the potential impacts of climate change (i.e., higher temperatures and more carbon dioxide) on HAB community



Environmental Sample Processor

The Environmental Sample Processor (ESP) is an electromechanical fluidic instrument designed to collect discrete water samples and automate in-situ analysis identifying microorganisms and compounds of interest. Beginning in 2016, GLERL, with CILER's support and expertise, will utilize the ESP to expand understanding of the Microcystis community composition and toxicity during harmful algal blooms in western Lake Erie. This undertaking marks the first time the ESP has been deployed in a freshwater system.

The ESP will autonomously collect samples and detect particulate microcystins at various depths in the water column, sending results back to GLERL in near real-time. In parallel, the ESP will collect and preserve samples for whole community genetic analysis. This advanced technology will allow for unprecedented monitoring not just in western Lake Erie but in any freshwater system.

Pictured above: GLERL Scientist, Tim Davis; Assistant Administrator for Oceanic and Atmospheric Research, Craig McLean; GLERL Director, Deborah Lee; and CILER Scientist, Alicia Ritzenthaler following a demonstration of the ESP, during GLERL's 2016 Science Review.

structure; and the role of dreissenid mussels in promoting HAB-forming genera.

- Models built upon the best available science, observations, and data to generate predictions and forecasts of HABs, are developed to forecast bloom size and distribution. GLERL's focus is on the development of the experimental HAB Tracker.
- Real-time and continuous observations provide information for model development and validation. Variables for HABs modeling research include measurements of temperature, chlorophyll concentration, precipitation, currents, nutrient concentrations, bloom characteristics, and particulate microcystins. Observations provide an important feedback loop on the establish-design-conduct phases of the adaptive integrative research framework. For example, the estimation of HAB areal extent and times-series observations of nutrients can lead to changes in research goals.

Assessment and Evaluation

- The assessment and evaluation of results are made in the context of management decision-making. For example, what does it mean to a manager if results indicate that bloom size is driven by P concentration, but toxicity is related to N concentration?
- The assessment of HAB model outcomes—including ground-truthing, sensitivity, and uncertainty analyses— are important in determining the models' accuracy and precision.

Transfer and Educate (transition of research outcomes to application)

- Trainings and stakeholder workshops, Great Lakes HABs website, HAB Tracker, HABs Bulletin, publications, and factsheets.
- Research to Operations (R2O) for regular operational forecasts.

Inform Management Decisions

- Land use managers use research-based information on causes of bloom size and extent to inform best management practices.
- HAB forecasts assist water intake managers in making decisions on treatment strategies for drinking water to best reduce potential HAB impacts.

Advance Science, Service and Stewardship

- A significant outcome of adaptive integrated research is to promote best practices used by water intake managers, fisheries managers, land use managers, public health agencies, environmental groups, and the general public to improve human and ecosystem health.

Redefine Priorities, Reestablish Research Goals and Questions/Drivers, and Redesign Research Objectives, Methodologies, and Paths (based on research outcomes and feedback from stakeholders).

Examples include:

- Stakeholder feedback provides input to assist scientists and managers, as well as state and federal legislators on the research priority-setting process.
- Given that prior research suggests that the effects of nitrogen, dreissenid mussels, and climate change could play a role in HAB growth and toxicity, the next cycle of experimentation is redesigned to focus specifically on these variables.
- Observing systems are retrofitted to measure additional variables identified as necessary for forecasting (e.g., retrofit ReCON buoy with N sensors)
- Based on feedback from users, the HAB Tracker is modified to provide local managers with the level of information needed for timely and accurate decision-making.

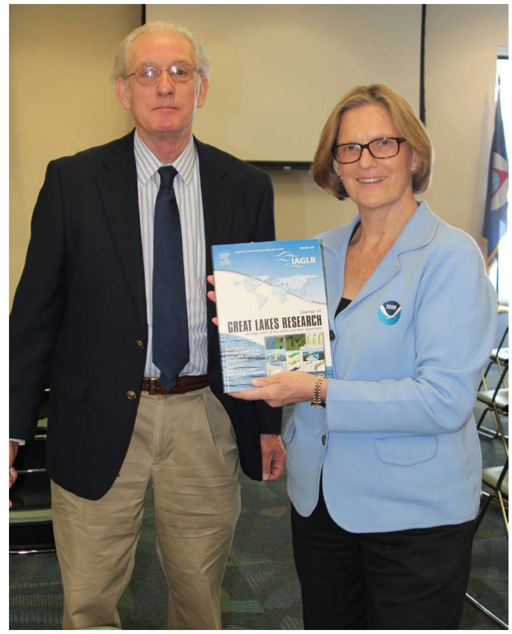
Observing Systems and Advanced Technology

Overview

NOAA's observational capacity in the Great Lakes and coastal ecosystems includes operational and developmental systems that provide an understanding of physical, biological, and chemical processes. GLERL's Observing Systems and Advanced Technology (OSAT) branch develops and operates technology that supports GLERL scientific research, meets emerging infrastructure needs, and provides environmental awareness to stakeholders. An integral part of providing environmental intelligence is the development of algorithms to retrieve geophysical products from satellite and airborne sensors that can be used in forecast models for observation and monitoring of environmental change or for operational purposes. In addition, OSAT and related programs provide the real-time and historical data necessary to increase the reliability of Great Lakes forecasting on environmental conditions such as hypoxia (reduced oxygen levels) and harmful algal blooms. Another important role of OSAT is to provide the vessel and engineering support for GLERL and its partners.

Presented as the first branch plan in the Approaches section, OSAT plays a key role in providing the technological and observational infrastructure that informs GLERL science (see figure on next page). OSAT works closely with EcoDyn and IPEMF in the collection of physical, chemical, and biological observations and data that contribute to building an ecosystem understanding and provide the input needed for environmental modeling. A framework for managing the data that is collected by OSAT, in coordination with the other branches, is presented in the Implementation Plan.

"NOAA's global observing systems are the foundation of the environmental intelligence we provide." -- Kathy Sullivan, Under Secretary of Commerce for Oceans & Atmosphere and NOAA Administrator



OSAT scientist, George Leshkevich, presents Kathy Sullivan with the Journal of Great Lakes Research special issue on the current state-of-the-art remote sensing technology used to make observations in the Great Lakes. Leshkevich and Robert Shuckman (Michigan Tech Research Institute) served as co-editors of the special issue.

Through the development of cutting-edge instrumentation, observing, and remote sensing technologies, OSAT team members acquire the data and develop information products needed to improve understanding of the Great Lakes and coastal ecosystems and support decision-making for resource managers and other stakeholders.

OSAT and partners develop, test, evaluate and implement technology, striving to improve NOAA's observational capabilities to better understand ecosystem processes. OSAT's advancements in areas such as remote sensing, persistent autonomous vehicles, and advanced coastal data-gathering technologies have built a stronger foundation for research in the Great Lakes and coastal communities.

Remote Sensing Observations

OSAT develops and uses remote sensing technology and products to record and observe the Great Lakes environment through the collection of data. Remote sensing technology enables observing, measuring, and monitoring of detailed and synoptic events on the earth's surface (land and water) and atmosphere through

OSAT provides technological and observational infrastructure that informs and is informed by GLERL science. Together OSAT and EcoDyn make physical, chemical, and biological observations that feed ecosystem understanding (EcoDyn) and environmental models (IPEMF). Ecosystem understanding and environmental modeling lead to products, such as the HAB forecast, and the rip current warning, that are produced for the benefit of GLERL's customers.

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the use of satellite-based, airborne, and ship-based sensors that are remote from the objects or events being observed. These observations directly benefit a wide range of research and operational constituents such as commercial shippers, modelers, recreational users, and regional drinking water managers.

Remote sensing systems function on either an active or passive level. Active sensors emit energy in the electro-magnetic spectrum and measure the energy reflected from the target. Radar is a widely used active sensor, sending and receiving microwaves (of various wavelength and polarization depending on the sensor) that can be used to determine the surface roughness, thickness, moisture content as well as position, direction of movement, or speed of objects. While active sensors are based on signal emission, passive sensors detect natural radiation that is emitted or reflected by the object or surrounding area. Reflected sunlight is the most common source of radiation measured by passive sensors, such as digital imaging systems. To make images meaningful in terms of desired observational information or geophysical product, analysis and interpretation are required.

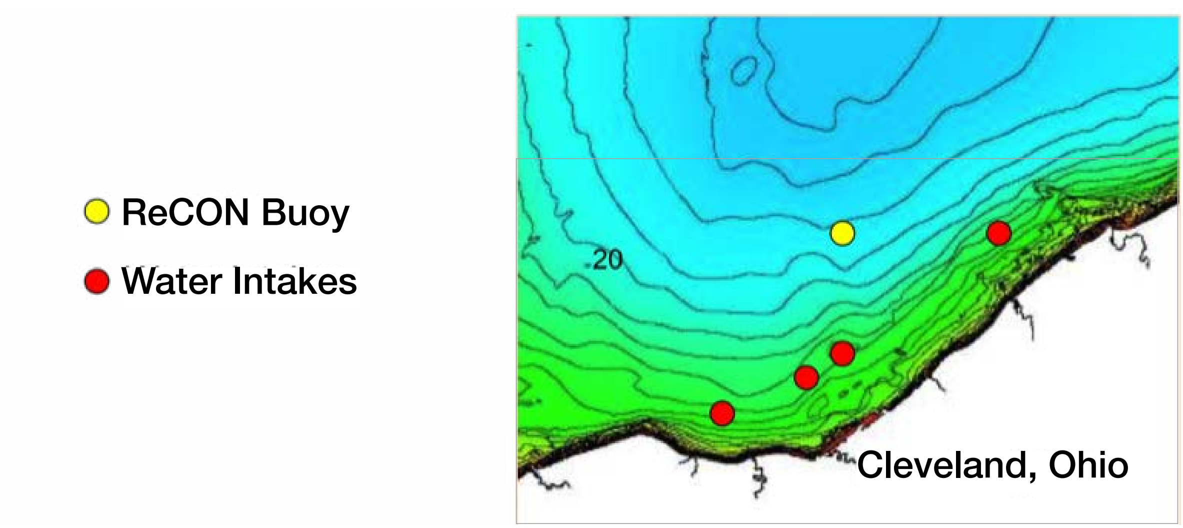
In Situ Observing Systems

The overall intent of GLERL's observing system work is to build a research and development base supporting coastal environmental observation networks, complementing NOAA's ecosystem forecasting research goals. Observation platforms such as buoys and offshore structures should be designed with consideration of modern network compatible hardware and software. These systems must be capable of supporting real-time, high bandwidth, high resolution sensing systems (such as, passive and active fisheries acoustics transducers integrated with underwater video systems; underwater and surface autonomous systems; and standard physical, chemical and biological sensors) providing observations from surface to bottom. Greater environmental awareness can be achieved by deploying a data-gathering network capable of sensing on a variety of time frames and geographic scales. This information is then integrated into a mature data management and communications system that uses models and other tools to process data, and methods that deliver processed data and information to users. Systems currently in more mature stages of development, provide valuable real-time data used by regional stakeholders such as National Weather Service (NWS) marine forecasters, water intake managers, and recreational users.

Operational Service, Products, and Activities

The Great Lakes node of the operational NOAA CoastWatch program provides products and services including near real-time and historical satellite observations of algal blooms, plumes, ice cover, wind, lake surface temperatures, and two and three dimensional modeling of Great Lakes physical parameters (such as wave height and currents). In addition, through a cooperative project with Michigan Sea Grant, Great Lakes CoastWatch satellite-derived surface temperature imagery is contoured and made available via Michigan Sea Grant's website. Great Lakes CoastWatch data and products benefit researchers as well as riparians, commercial and recreational users.

OSAT's mission for vessel operations is to provide support for field research and to develop new technology. To advance observational capacity in Great Lakes research, OSAT personnel develop scientific instrumentation and gear that ensures the effective operation of our scientific fleet of vessels. Vital to this effort is OSAT's work in improving navigation, field communications, and data collection and storage on-board our vessels. The Green Ship Initiative—also conducted under OSAT's vessel operations—uses advanced technology to convert research vessels from petroleum-based fuels and lubricants to renewable and environmentally-friendly products that reduce fossil fuel emissions.



OSAT supplies ReCON buoy technology for real-time dissolved oxygen observations, providing advanced warning to drinking water intake managers. Drinking water quality issues can develop when hypoxic (low oxygen) conditions result in high levels of manganese and iron which can be transported from the hypolimnion (bottom waters) to water intakes by coastal upwelling. OSAT's Experimental Hypoxia Warning System, servicing Cleveland, a coastal region of more than 2 million residents, allows water intake managers to implement alternative processing procedures to ensure safe drinking water. The system has been transitioned to the Great Lakes Observing System (GLOS) for operations. In the future, OSAT will expand Hypoxia Warning System efforts to other impacted areas in the Great Lakes.

Guiding Principles

- Enhance environmental intelligence and situational awareness
- Develop technology to better observe the ecosystem
- Transition technology to operational sector
- Create freshwater remote sensing algorithms
- Provide observational infrastructure for EcoDyn and IPEMF (e.g., boats, buoys, hardware)

Research Goals and Drivers

Goal	Drivers
1. Expanded use and application of technology to enhance remote sensing capacity to assess ecosystem impacts and for use in modeling and operations.	• Measure and improve ice classification, ice thickness, and transmission of light through ice using remote sensing to better understand changes in ice characteristics. • Use remote sensing to improve measurement of chlorophyll, suspended sediment, and dissolved organic carbon. • Explore the use of surrogates to estimate spatial extent of water column features e.g., deep chlorophyll layer, hypoxic zones, using remote sensing technologies. • Classify and map algal and cyanobacterial groups for use in physical/biological models and forecasts e.g., HAB Tracker. • Explore and evaluate unmanned aerial systems (UAS) (e.g., hexacopter; quadracopter) to provide real-time ice surface characteristics and thickness for research and operational use.
2. Improved *in situ* observational capacity to increase number of sites and number of instruments and sensors at those sites.	• Determine temporal and spatial resolution required to adequately observe the Great Lakes ecosystem. • Improve capacity for in situ observations of nutrients for use in adaptive management feedback, HAB forecasting, and hypoxia forecasting. • Improve ecological observational capacity through use of active and passive acoustics in pelagic and benthic environments. • Use a network of fixed and mobile platforms using covariance technology to improve over-water evaporation estimation for use in determining the Great Lakes water budget.
3. Observational infrastructure (e.g., instrumentation and equipment, mobile and fixed platforms, and data management) provides reliability and flexibility needed for innovation on a long-term basis.	• Develop long-term and year-round observing systems that are functional, adaptable, and sustainable. • Develop autonomous, persistent observation technologies. • Improve vessel capacity for innovation, development, and deployment capabilities (including vessel recapitalization) • Determine the most effective way to ingest, organize, archive, and deliver data in real-time.
4. Operational capacity that supports research and the transition of products to operations.	• Provide observational capacity for measuring ecological conditions (e.g., real time physical measurements, ice classification, and chlorophyll detection) through products and services (e.g., CoastWatch and ReCON) • Provide vessel infrastructure needed for *in situ* observations.

Ecosystem Dynamics

Overview

The Ecosystem Dynamics (EcoDyn) branch makes long-term ecological observations, conducts targeted fundamental research on ecological processes, and provides data to develop models critical to understanding ecosystem structure and function. EcoDyn also develops models to forecast impacts of multiple stressors e.g., invasive species, climate, and nutrients on water quality, food webs and fisheries. EcoDyn observations, laboratory, and field experiments support the development of new concepts, models, forecasting tools and applications to evaluate and forecast impacts of, and mitigation strategies for, present and future stressors.

The EcoDyn branch strives to anticipate, monitor, analyze, understand, and forecast changes in the Great Lakes and coastal ecosystems to strengthen capacity for managing water quality, fisheries, and ecosystem and human health.

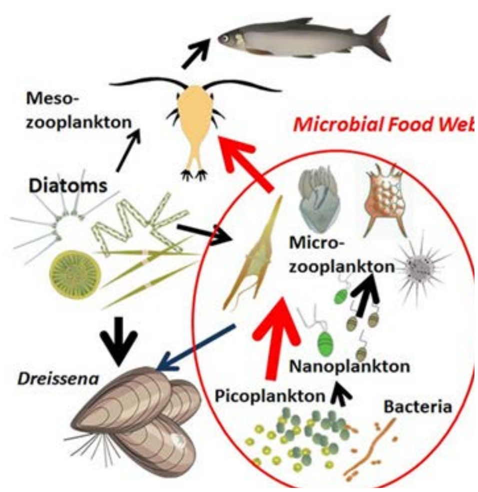
Observations and Experiments

EcoDyn's field observations and process-based studies are supported by the laboratory facilities in Ann Arbor as well as the laboratories and vessel fleet housed at the Lake Michigan Field Station (LMFS) in Muskegon. GLERL's largest vessel, the R/V Laurentian, is equipped with gear capable of sampling the entire food web from microbes to fishes (see sidebar). The LMFS's proximity to Lake Michigan provides the capacity to process time-critical samples immediately after collection and the ability to sample during episodic events e.g., upwelling, spring flooding or short weather windows during inclement periods. The laboratories in Ann Arbor allow measurement of a suite of variables in support of field observations and process experiments. Key to EcoDyn's operation is acquisition and maintenance of critical equipment. For more details, see the Lifecycle Management of Critical Equipment section of GLERL's Implementation Plan.

EcoDyn's Long-Term Research (LTR) program on Lake Michigan integrates a core set of long-term observations on biological, chemical, and physical variables, accompanied by process studies and field experiments, for understanding and forecasting ecosystem change. The LTR program makes seasonal observations of pelagic (water column) and benthic (bottom) habitats of food webs in nearshore and offshore waters. For pelagic observations, two sampling strategies are used: (1) biweekly sampling from March to December at fixed stations for nutrients, phytoplankton, zooplankton and Mysis; and (2) seasonal

GLERL Dreissenid Mussel Research

GLERL experiments and observations have shown that dreissenid mussels have caused a variety of extreme and unexpected changes in the Great Lakes pelagic food web due to their filtering and re-engineering of nutrient cycling and food web interactions. Despite moderate P loading, Lake Michigan is now the one of the most oligotrophic of the Great Lakes in terms of high water clarity, low in-lake P concentration, and loss of the spring phytoplankton bloom. One of the most surprising changes is the shift in dominance from large diatoms to picophytoplankton (< 2µm). As a result, more energy is likely moving through the microbial food web (MFW) leading to loss of energy relative to the classic phytoplankton to zooplankton food web (see schematic below). In many respects, the low abundance and small size of the phytoplankton make offshore Lake Michigan resemble the unproductive far offshore regions of the oceans.



Above: The classic food web on left hand side of the figure (diatoms -> mesozooplankton -> fish) has been decimated by the mussels. It is suspected that much of the energy now flows indirectly to zooplankton through the microbial food web, potentially leading to less zooplankton and fish.

spatial cruises using towed sampling gear (Plankton Survey System and fisheries acoustics), advanced net technology (MOCNESS- Multiple Opening Closing Net Environmental Sampling System) and water sample analyses. An important outcome of LTR pelagic observations is quantifying fine-scale diel spatial interactions among nutrients, environmental factors, and the food web. EcoDyn's process and experimental research includes impacts of dreissenid mussels and other invasive species.

In addition to the LTR program in Lake Michigan, the EcoDyn branch carries out observations and experiments in other Great Lakes (including Lake Erie and Lake Huron) and coastal ecosystems. An important focus is understanding and forecasting species, abundance, distribution, and toxicity of harmful algal blooms (HABs) in western Lake Erie and other eutrophic regions of the Great Lakes. EcoDyn is part of a large cross-branch and CILER program that has been monitoring the HAB events in Lake Erie and Saginaw Bay since 2009 using discrete sampling as well as a suite of remote sensing equipment. This is one of the longest HAB monitoring datasets in both of these regions. An overview of the HABs program, as adaptive integrated research, is presented in the case study on pages 20-23.

Models & Applications

EcoDyn modeling consists of nowcasts and scenario-based forecasts to predict the effects of invasive species, climate, nutrient loadings, and meteorology on food webs, fisheries productivity, and water quality. Data, observations and related process studies are used in ecosystem models to forecast the effects of stressors and management options.

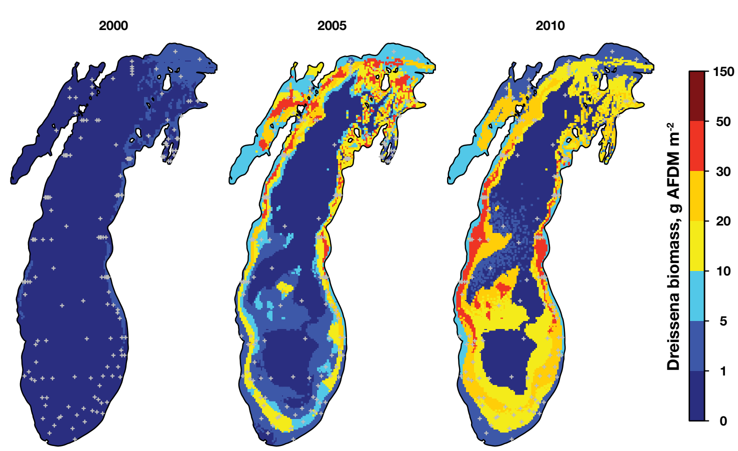
Guiding Principles

- Collaborate efforts with focus on priority ecological problems in the Great Lakes and coastal ecosystems.
- Quantify measurements of important ecosystem variables, at appropriate time and space scales, to serve as a basis for describing and understanding ecosystem processes.
- Complement observations with experiments and models for understanding the dynamics of Great Lakes and coastal ecosystems.
- Develop forecasts and applications that are built on a solid foundation of empirical observations and understanding.

Long-term Benthic Monitoring Program

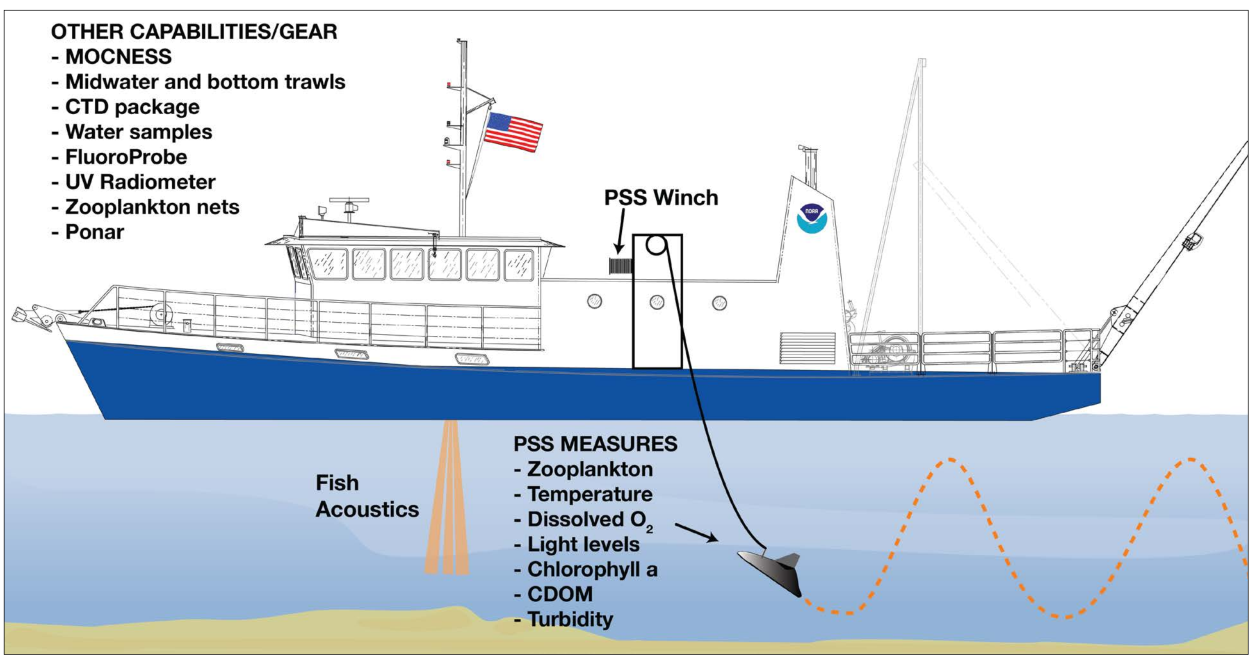
GLERL has always been at the forefront of dreissenid mussel research, largely due to the long-term benthic monitoring program that was established in Lake Michigan before mussels arrived. As a result, GLERL thoroughly documented the rapid population expansion of first zebra, and then quagga mussels from the beginning (see below). The benthic monitoring program includes whole lake surveys of all benthos every five years, plus annual surveys of dreissenid mussels in the southern basin. In addition, GLERL frequently assesses mussel condition at the Muskegon long-term research (LTR) sites and is conducting complementary field and lab experiments to help fill knowledge gaps about quagga mussel ecology. The benthic monitoring program is poised for early detection of any new invasive benthic species. Continued monitoring is needed to document the changes to come, and to provide the basis upon which to explain and predict impacts on valuable living resources.

The figure below shows the mean dreissenid mussel biomass from whole-lake surveys of Lake Michigan from 2000 to 2010. Values in between the 160 sampling stations (marked with crosses) were estimated using state-of-the-art geostatistical modeling techniques.



Research Goals and Questions

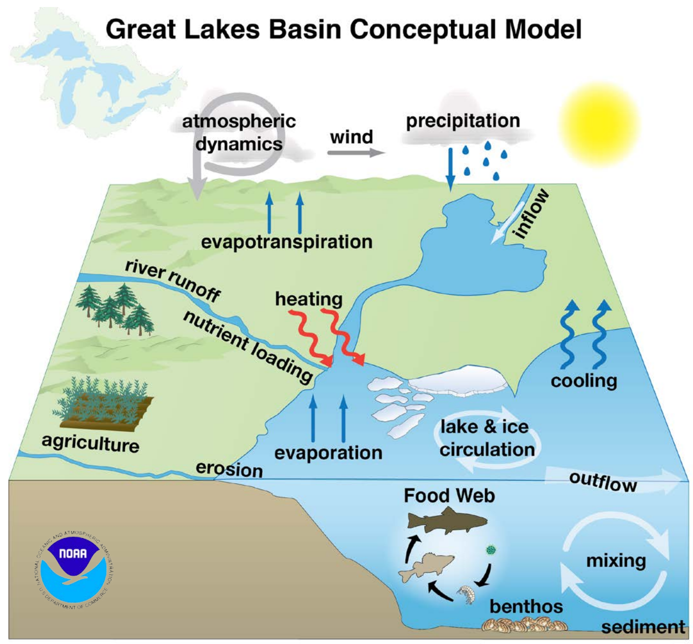
Goal	Questions
1. A holistic understanding of the role of established and potentially future invasive species on Great Lakes ecosystems	• What are the factors affecting carrying capacity and spatial distribution of invasive species in the Great Lakes e.g., dreissenid mussels, invasive cladocerans, Asian carp? • What are the quantitative effects of high-risk invasive species on Great Lakes food webs across spatial and temporal scales and trophic gradients?
2. An integrated understanding of the spatial organization of the food webs and nutrient use and transport from nearshore to offshore food webs.	• What are the spatial and temporal linkages between the lower food web and fish condition and recruitment? • How are nutrients captured by pelagic and benthic food webs as they move from tributaries to the nearshore and offshore regions?
3. The capacity to forecast effects of climate change on food webs.	• How does inter-annual variability in weather and climate affect lake thermal structure, food web spatial structure and productivity, as well as fish recruitment? • What are the synergistic interactions between climate change, nutrient loading and invasive species?
4. A quantitative understanding of the drivers of HABs to predict their concentration, extent, movement, and toxicity.	• What are the roles of phosphorus and nitrogen loading and other environmental factors in driving HAB bloom timing, abundance, toxicity, and spatial distribution? • How will Great Lakes HABs respond to a changing climate? • How do HAB events in western Lake Erie differ from blooms in other large lakes around the world, including Lake Winnipeg, Lake Taihu and Lake Victoria?



Schematic diagram of RV Laurentian and the gear used by the EcoDyn group. Note the simultaneous deployment of fish acoustics and the plankton survey system and its tow path along side of the vessel.

Integrated Physical and Ecological Modeling and Forecasting

Overview



IPEMF researchers develop integrated modeling systems that represent key environmental processes in the Great Lakes.

GLERL's Integrated Physical and Ecological Modeling and Forecasting (IPEMF) branch develops, evaluates, and applies models for use in testing scientific hypotheses and predicting the effects of natural and human-generated changes on the Great Lakes environment. The approach to IPEMF research provides information used to forecast environmental conditions at different points in time and geographic location, and to increase knowledge of the interactions between the components of the complex physical and ecological systems in the Great Lakes basin (see schematic on right). The recipients of IPEMF's research and development products, services, and information include federal, public, private, and academic organizations who apply the research outcomes to make better operational decisions supporting various societal and economic sectors.

The IPEMF research program advances the following NOAA objectives:

- Holistic understanding of the Great Lakes through research
- Integrated environmental modeling system
- Improved models and predictions of the climate system
- Accurate and reliable data from sustained and integrated observing systems

The IPEMF branch focuses on advancing the development of an integrated environmental modeling system for the Great Lakes. The branch also works to accelerate the transition of research to operations and applications as advised in NOAA's Annual Guidance Memorandum.

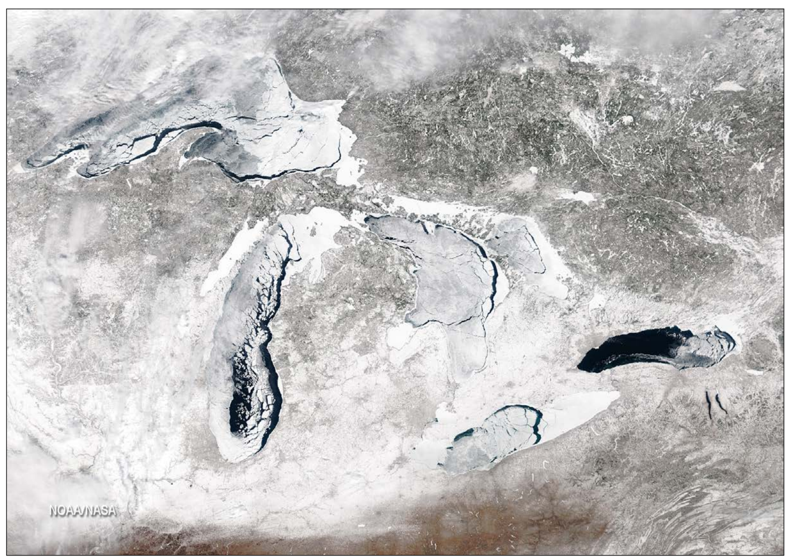
IPEMF conducts innovative research and develops numerical models to predict the physical, chemical, biological, and ecological response in the Great Lakes due to weather, climate, and human-induced changes. The forecast models and quantitative tools developed by IPEMF researchers allow scientists, coastal resource managers, policy makers, and the public to make informed decisions for optimal management of the Great Lakes and to maintain a healthy, sustainable, resilient ecosystem.

IPEMF has a long history of conducting innovative research, transitioning models from research to operations, and collaborating with academia, organizational partners, and private industry. IPEMF's primary goal is to develop and implement an integrated environmental modeling system that can provide accurate forecasts of physical, ecological, biological and chemical parameters at various time and space scales. The integrated system suite consists of climate, meteorology, lake circulation hydrodynamics, watershed hydrology, waves, ice, and ecological models. Since the ecosystem and hydrological cycles of the Great Lakes are interconnected, an important way to improve forecast capability is to understand the relationships and interactions between each component and then to develop a coupled environmental system model.

Internally, IPEMF scientists work closely with OSAT, EcoDyn, and IS branches. Environmental observations measured and collected by OSAT and EcoDyn are used to initialize, validate, verify, and improve hydrodynamic, ecological, water quality, and ice model predictions. The IS branch works with IPEMF to ensure accessibility of the modeling outcomes. IPEMF also collaborates with CILER, external agencies, organizational partners, and universities. The forms of collaboration include joint research projects, leveraging resources, application transition, and product dissemination.

The long-term focus of IPEMF is to further advance a fully coupled integrated modeling forecasting system, and to further enhance internal and external collaboration. Future work will advance capabilities in model coupling, skill assessment, performance accuracy testing, and uncertainty analysis of models. Outputs of models will be made available to constituents through a variety of means, both directly from GLERL, other NOAA partners and line offices, and in coordination with partners such as the Great Lakes Observing System.

The GLERL-developed Huron to Erie Connecting Waterways Forecasting System (HECWFS) predicts real-time water levels and currents to simulate where and how quickly potential contaminant spills could travel. The HECWFS aligns with the NOAA goals that fall under Science: Healthy Oceans and Science: Resilient Coastal Communities and Economies



The remote sensing MODIS satellite image documents maximum ice cover on Great Lakes, 92.5% on March 6, 2014. Remote sensing based on satellite imagery allows GLERL scientists to observe long-term changes in ice cover that is key in advancing the NOAA objective, Improved scientific understanding of the changing climate system and its impact. Studying, monitoring, modeling, and predicting ice coverage on the Great Lakes also plays an important role in determining climate patterns, lake water levels, water movement patterns, water temperature structure, and spring plankton blooms.

Guiding Principles

- Perform innovative research and develop an integrated modeling system to improve our forecasting capability.
- Transition our research models into operations and applications.
- Promote internal and external collaborations (among branches and other government agencies).
- Share data and model output with users in an accessible format (NOAA PARR).
- Support NOAA programs through GLERL leadership in modeling expertise.

Research Goals and Questions

Goal	Research Questions
1. Integrated modeling system to improve forecast capability of lake hydrodynamics, lake ice, hydrological response, ecological processes, water quality, and climatic variability and trends across spatial and temporal scales.	• How do we improve fine-scale predictions of nearshore processes? • Can we improve the short-term model forecast by model coupling and data assimilation? • Which models are needed to reliably predict water quality and coastal hazards (e.g., algal blooms, storm surge, waves) on short- and long-term scales? • Can we improve medium and long-range projection by uncertainty estimation and ensemble forecasting? • Can we better predict lake effect snow by two-way model coupling of atmosphere-hydrodynamics? • How can we improve our understanding and representation of over-water meteorology? • What combination of models can be used to reliably forecast large-scale water quantity parameters e.g., water levels, ice, stratification on a seasonal basis? • What are the major dynamic and thermodynamic parameters and processes in the community-based ice models needed to accurately simulate Great Lakes ice cover and Arctic sea ice?
2. Enhanced/ improved capability for medium- and long-range forecasts by quantifying uncertainty and developing skill assessment tools (long-term, decadal scale climate).	• Can we quantify or reduce uncertainty to improve the medium and long range forecasts at a climate scale? • What new skill assessment tools are required to evaluate model performance? • How do we quantify uncertainty for integrating modeling approaches? • What best practices can better address model output uncertainty and improve model skill?
3. Be a trusted scientific leader on prediction of high impact or extreme events, including prediction on water issues of regional and national significance.	• How can GLERL's expertise on hydrologic modeling in the Great Lakes basin support national initiatives on hydrologic analyses at the National Water Center? • How can GLERL expand its leadership role in advancing implementation of NOAA's Ecological Forecasting Roadmap? (Page 17) • How can the Great Lakes serve as a model for studying hypoxia? • What teleconnection patterns affect ice cover variability in the Great Lakes and the Arctic at seasonal to decadal timescales? • What are the mechanisms that drive extreme storm surge, high-frequency water level oscillations, and meteotsunamis? • What mechanisms drive water level variability at the annual timescale? • How can we incorporate emerging knowledge of mechanisms, e.g., biophysical coupling, into the modeling framework?

Information Services

Overview

GLERL's Information Services (IS) extends Great Lakes and coastal ecosystem research and promotes GLERL as both a physical and virtual hub for the Great Lakes region and the nation. The IS branch supports the integration of GLERL's scientific research program and informs leadership of emerging regional issues and research developments. IS engages with stakeholders to better understand their evolving needs and facilitates the communication of GLERL's expertise, programs, products and services to technical and non-technical audiences. In addition, the IS branch participates in the NOAA Great Lakes Regional Collaboration Team (GLRCT) Communications and Outreach Working Group (see next page).

IS coordinates and supports information flow internally among staff, throughout NOAA, and externally with stakeholders and the general public to advance science, service, and stewardship of the Great Lakes and coastal ecosystems.

IS operates on multiple organizational levels:

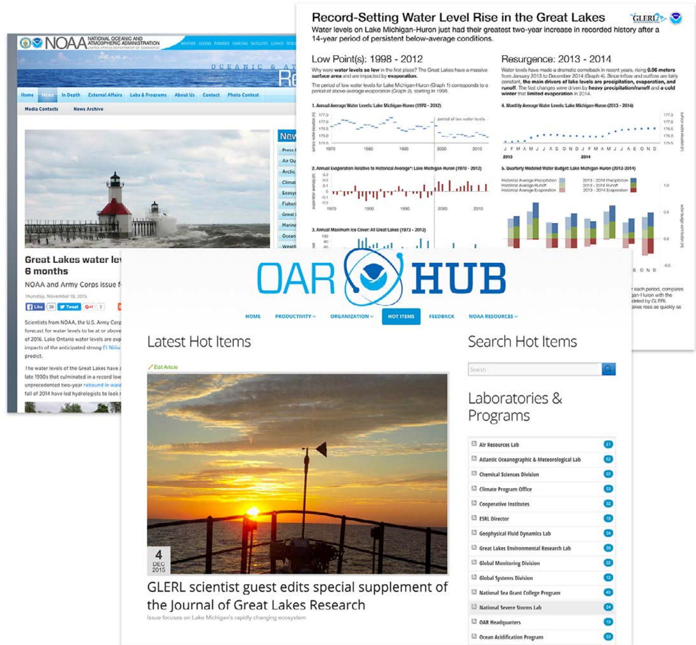
Inward | IS facilitates information exchange to promote a collaborative environment among staff from GLERL, NOAA's Cooperative Institute for Limnology and Ecosystems Research (CILER), the Great Lakes Sea Grant Network, and NOAA Great Lakes partners co-located in GLERL facilities. This "inreach" fosters connectivity between staff and elevates awareness of NOAA-wide research, programs, and goals.

Upward | IS elevates awareness and understanding of GLERL expertise, programs, products, and services to NOAA Oceanic and Atmospheric Research, NOAA leadership, and Congress.

Outward | IS anticipates, solicits, and responds to the information needs of constituent groups and the general public to elevate awareness and understanding of the Great Lakes ecosystem, GLERL and NOAA expertise, programs, products, and services.

Organizational Responsibilities

IS provides prioritized coordination and execution of information support services to GLERL staff. These services include: editorial and graphics support for GLERL scientific publications, synthesis of program documents, summaries of research outcomes, and the development of communication products tailored to specific audiences. IS oversees the GLERL library, website, media and congressional affairs, and social media. The branch plays a coordinative role in internal GLERL operations through representation on the Management, Science and Infrastructure Councils and through facilitation of cross-branch information flow. Additionally, IS supports the Communications and Outreach Working Group of the NOAA Great Lakes Regional Collaboration Team (GLRCT) to foster connectivity among NOAA communicators within the Great Lakes region.



The Information Services branch develops a variety of science translation products to promote GLERL's research. Examples include: fact sheets, infographics, media events, social media campaigns, and website content.

Guiding Principles

- Facilitate communications and information flow to foster integration across GLERL's science branches and NOAA programs.
- Elevate awareness of NOAA's mission and priorities in the Great Lakes region.
- Enhance connectivity between NOAA staff at GLERL facilities in Ann Arbor and Muskegon, Michigan.
- Work collaboratively to develop consistent messages and success stories.
- Promote synergy and connectivity among local, regional, national, and international partners in the development and implementation of NOAA products and services.
- Maintain and enhance NOAA's relevance in the everyday lives of stakeholders.
- Engage with stakeholders to advance understanding of Great Lakes and coastal environmental challenges and issues.
- Ensure accessibility of information through a suite of communications products that convey environmental science concepts and research results.

NOAA Great Lakes Regional Collaboration Team Communications and Outreach Working Group

The NOAA Great Lakes Regional Collaboration Team (GLRCT)—one of eight NOAA regional collaboration teams across the country—is currently led by the Director of GLERL with support from OAR's Great Lakes Regional Team coordinator. In 2015, the NOAA GLRCT formally recognized the Great Lakes NOAA Communications and Outreach Working Group, operating out of the GLERL Ann Arbor facility. The group includes representatives from all NOAA line offices, the NOAA Cooperative Institute for Limnology and Ecosystems Research, the Great Lakes Sea Grant network, and the Great Lakes Observing System. A current focal point for the group is to build a NOAA in the Great Lakes communication and outreach toolkit that highlights NOAA expertise, products, and services in the region.

Goals and Drivers

Goal	Drivers
1. A collaborative organizational environment that fosters information flow, transparency, trust, and a team-building approach, thus enhancing the functionality of GLERL programs and staff.	• Promote an informed and engaged staff with an awareness and support for NOAA's mission, GLERL's strategic plan, and the annual planning cycle. • Facilitate information exchanges across GLERL's organizational structure to include: Management Council, Infrastructure Council, Science Council, science branches, the Lake Michigan Field Station staff, Ann Arbor staff, CILER, and other NOAA in-house partners. • Enhance the integration of GLERL's research program and support scientists' information needs using a variety of communication channels. • Facilitate staff awareness and understanding of GLERL's scientific research projects and programs by coordinating a communications strategy from the beginning of the project planning stage, through its implementation. • Raise awareness and facilitate dialogue among staff on emerging issues regarding research, stakeholder needs and public perceptions.
2. Increased awareness and understanding of GLERL expertise, programs, products, and services among other NOAA programs, NOAA leadership and Congress.	• Demonstrate the relevance of GLERL programs to national NOAA initiatives. • Communicate with a coordinated "One NOAA" regional voice to elevate the effectiveness of GLERL's messaging. • Develop uniform and consistent messages on NOAA in the Great Lakes, GLERL's expertise, research products and services to Congress.
3. Information needs of constituent groups (e.g. other governmental agencies, resource managers, decision-makers, researchers, media, private industry, educational institutions, NGO's, general public) in the Great Lakes region are met.	• Leverage existing resources and partners to communicate GLERL's research. • Analyze the scope of NOAA communication in the Great Lakes region, identify target audience groups and, based on findings, fill unmet stakeholder needs. • Translate scientific information to a variety of audience groups with different technical capacities. • Foster meaningful interaction between GLERL scientists and constituents. • Increase opportunities for scientists to collaborate among their research communities. • Prioritize the investment of communications staff and resources with regard to stakeholder groups' requests (i.e., customer demand). • Inventory existing communication tools and identify new tools that can be used.
4. Recognition of NOAA GLERL as a resource for research products and services utilized by constituent groups and partners in the Great Lakes and beyond.	• Strengthen IS branch understanding of GLERL's reach and branding. • Devise mechanisms for overall improvement of the IS programs. • Ensure that GLERL's products and services are appropriately acknowledged. • Evaluate, document, and report impacts of GLERL research.

Matrix: GLERL Goals by Branch[1,2] X NOAA Science and Education Goals and Objectives

GLERL Branch Goals / NOAA Goals and Objectives

NOAA Goals and Objectives	OSAT				ECODYN				IPEMF			IS			
	1	2	3	4	1	2	3	4	1	2	3	1	2	3	4
Science: Climate Adaptation & Mitigation															
Improved scientific understanding of the changing climate system and its impacts	X	X	X	X			X	X	X	X	X				
Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions							X	X	X	X	X		X	X	
Mitigation and adaptation efforts supported by sustained, reliable, and timely climate services									X	X	X		X	X	
A climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions							X	X	X	X	X		X	X	X
Science: Weather-Ready Nation															
Reduced loss of life, property, and disruption from high-impact events	X	X	X	X					X	X	X		X	X	X
Improve freshwater resource management	X	X	X	X				X	X	X	X	X	X	X	X
Improve transportation efficiency and safety	X	X	X	X					X	X	X		X	X	
Healthy people and communities due to improved air and water quality services	X	X	X	X				X	X	X	X		X	X	X
A more productive and efficient economy through information relevant to key sectors of the U.S. economy	X	X	X	X					X	X	X			X	
Science: Healthy Oceans															
Improved understanding of ecosystems to inform resource management decisions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Recovered and healthy marine and coastal species															
Healthy habitats that sustain resilient and thriving marine resources and communities					X				X	X	X		X	X	
Sustainable fisheries and safe seafood for healthy populations and vibrant communities					X	X	X							X	
Science: Resilient Coastal Communities and Economies															
Resilient coastal communities that can adapt to the impacts of hazards and climate change	X	X	X	X					X	X	X			X	
Comprehensive ocean and coastal planning and management					X	X	X	X	X	X	X		X	X	
Safe, efficient and environmentally sound marine transportation	X	X	X	X					X	X	X		X	X	X
Improved coastal water quality supporting human health and coastal ecosystem services	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Safe, environmentally sound Arctic access and resource management									X	X	X				
Education: Science-Informed Society															
Youth and adults from all backgrounds improve their understanding of NOAA-related sciences by participating in education and outreach opportunities	X	X	X	X						X	X		X	X	X
Formal and informal educators integrate NOAA-related sciences into their curricula, practices, and programs	X	X		X							X		X	X	
Formal and informal education organizations integrate NOAA-related science content and collaborate with NOAA scientists on the development of exhibits, media, materials, and programs that support NOAA's mission	X	X		X							X		X	X	
Education: Safety and Preparedness															
Youth and adults from all backgrounds are aware of, prepare for, and appropriately respond to environmental hazards that impact health, safety, and the economy in their communities	X	X		X							X		X	X	X
Formal and informal educators use and produce education materials and programs that integrate and promote consistent science-based messaging on hazards, impacts, and societal challenges related to water, weather, and climate	X	X		X							X				
Formal and informal education institutions integrate water, weather, and climate hazard awareness, preparedness, and response information into curricula, exhibits, and programs that create learning opportunities for youth and adults	X	X		X											
Education: Future Workforce															
Students, particularly from underrepresented groups, consider education and career pathways in disciplines that support NOAA's mission														X	
Postsecondary students, particularly from underrepresented groups, pursue and complete degrees in disciplines critical to NOAA's mission											X		X	X	
Graduates completing NOAA-supported student opportunities continue education, enter the workforce, and advance in careers that support NOAA's mission											X		X		
Education: Organizational Excellence															
Leaders internal and external to NOAA recognize and support education investments as a way to achieve agency mandates, mission, and goals												X	X		
NOAA educators and partners collaborate at local, regional, and national levels to coordinate efforts, build capacity, and better serve educational audiences													X	X	
NOAA develops and supports a coordinated portfolio of products, programs, and partnerships that improves education opportunities in NOAA-related content areas for underserved audiences														X	

[1] GLERL Science Branches:
OSAT- Observing Systems and Advanced Technology
EcoDyn - Ecosystem Dynamics
IPEMF - Integrated Physical and Ecological Modeling and Forecasting
IS - Information Services

[2] GLERL goals are indexed by science branch, and can be found on the next page.

Matrix Crosswalk: GLERL Goals by Branch

Branch	Goal
OSAT	1. Expanded use and application of technology to enhance remote sensing capacity to assess ecosystem impacts and for use in modeling and operations. 2. Improved *in situ* observational capacity to increase number of sites and number of instruments and sensors at those sites. 3. Observational infrastructure (e.g., instrumentation and equipment, mobile and fixed platforms, and data management) provides reliability and flexibility needed for innovation on a long-term basis. 4. Operational capacity that supports research and the transition of products to operations.
EcoDyn	1. A holistic understanding of the role of established and potentially future invasive species on Great Lakes ecosystems. 2. An integrated understanding of the spatial organization of the food webs and nutrient use and transport from nearshore to offshore food webs. 3. The capacity to forecast effects of climate change on food webs. 4. A quantitative understanding of the drivers of HABs to predict their concentration, extent, movement, and toxicity.
IPEMF	1. Integrated modeling system to improve forecast capability of lake hydrodynamics, lake ice, hydrological response, ecological processes, water quality, and climatic variability and trends across spatial and temporal scales. 2. Enhanced/improved capability for medium- and long-range forecasts by quantifying uncertainty and developing skill assessment tools (long-term, decadal scale climate) 3. Be a trusted scientific leader on prediction of high impact or extreme events, including prediction on water issues of regional and national significance.
IS	1. A collaborative organizational environment that fosters information flow, transparency, trust, and a team-building approach, thus enhancing the functionality of GLERL programs and staff. 2. Increased awareness and understanding of GLERL expertise, programs, products, and services among other NOAA programs, NOAA leadership and Congress. 3. Information needs of constituent groups (e.g. other governmental agencies, resource managers, decision makers, researchers, media, private industry, educational institutions, NGO’s, general public) in the Great Lakes region are met. 4. Recognition of NOAA GLERL as a resource for research products and services utilized by constituent groups and partners in the Great Lakes and beyond.

Evaluation

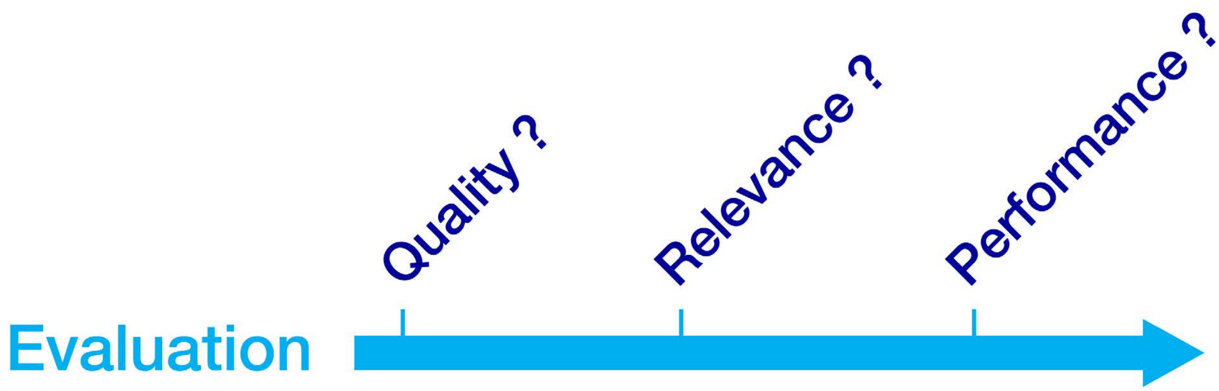
How do we judge success? What evidence informs programmatic decisions? How well are we doing in terms of quality, relevance, and performance?

Evaluation is essential to advance organizational excellence. The process of reviewing performance compared to performance measures and desired outcomes informs the next iteration of program planning. The evaluation process identifies opportunities for improvement and actions needed to continually enhance research program efforts.

GLERL's evaluation process considers three overarching categories: quality, relevance, and performance. Quality refers to the merit of research and development within the scientific community. Relevance is the value of research, development and application to users beyond the scientific community. Performance measures the effectiveness and efficiency with which activities are organized, directed, and executed.

In GLERL's strategic planning process, the organizational goals (presented in the Aims section of this document) serve as the framework for program development, implementation and evaluation. For each organizational goal, specific criteria (posed as questions) and metrics are identified for evaluating GLERL on a program-wide level. Specific performance measures are established from the variety of metrics options identified below and captured in GLERL's Annual Operating Plan.

This final section of the strategic plan focuses on evaluation of the laboratory as a whole, in response to the five-year OAR Laboratory Science Review cycle. Additional evaluation is ongoing at GLERL and occurs on multiple levels (e.g., projects and personnel performance). The outcomes from such evaluations inform GLERL's adaptive integrated research program in the advancement of organizational excellence.



The evaluation process at GLERL is driven by its adherence to quality, relevance, and performance—factors that are based upon organizational goals and related criteria and metrics.

Quality

Quality refers to the merit of research and development within the scientific community. Assessing the quality of scientific and technical work involves peer review. Bibliometric data on peer-reviewed publications and citations, as well as awards and other professional recognitions are used to understand the performance of individuals and organizations. Such quality-based evaluations are also used to provide benchmark comparisons to other organizations of similar size and scope.

Goal	Criteria	Metric
Preeminent Research Conduct preeminent research, aligned with NOAA goals, to advance the state of science and knowledge that promotes sound decision making and ecosystem management.	Does GLERL have a well-cited and high publication record in fundamental and applied science research journals?	H-factor table; number of publications including peer-reviewed and technical reports; quantitative comparison to other OAR laboratories.
	Does GLERL research use firmly established scientific principles in new ways? Do results lead to innovative products?	Percentage of projects/products that are high risk/high reward, innovative, or cutting-edge e.g., 1 per branch or 10%.
	Does the quality of GLERL research based on peer-reviewed manuscripts achieve preeminence?	Number of submissions and acceptances of manuscripts to high impact journals.
	Is GLERL respected in the regional and international scientific research community? Do research societies recognize GLERL's work?	Awards (including nominations), invitations to present papers, participation on panels; special sessions organized or convened, invitations to review manuscripts and proposals; associate editorships, and information requests on publications.
Integrity & Quality Execute research with integrity and quality, abiding by quality management, safety standards, and environmental compliance, as well as acknowledging uncertainty.	Are scientists trained in ethically-based research and are they implementing best practices?	Ethics and integrity training required on a regular basis, implementation of best ethics practices incorporated as part of annual performance reviews.
	Does the laboratory acknowledge uncertainty in research and outreach publications as well as in verbal communication?	Review of publications and presentations for inclusion of uncertainty.
	Are quality management standards established and are these standards met?	Established quality assurance plans for projects, documented standard operating procedures, data management plans are established and implemented.
	Do GLERL operations and facilities comply with safety and environmental standards?	Trainings and certifications, risk assessments, documentation of safety and environmental compliance inspections, and implementation of standard operating procedures.

Relevance

Relevance refers to value of research and development to users beyond the scientific community. Documented impacts and societal benefits are indicators of the relevance of scientific research. The impact of research and development is realized through the application of scientific knowledge to address stakeholder needs, policy decisions, and ecosystem management.

Goal	Criteria	Metric
Addressing Stakeholder Needs Serve NOAA's customers by integrating their priority needs in the development and implementation of research, inclusive of the transition of research to operations and application (R2X), and accessibility of GLERL's observations and data, scientific knowledge and information, and products and services.	Is GLERL working on relevant issues that are important in the Great Lakes and coastal ecosystems?	GLERL's research portfolio is consistent with regional priority documents and stakeholder needs assessment.
	Does GLERL research provide information for societal benefit, such as decision making, policy development, and resource management?	Number of requests from resource managers; citations in resource management publications; number of topical scenarios (e.g., HABs, lake level fluctuation) supported by scientific research that address resource management issues; requests to participate as subject matter experts on advisory panels or committees.
	Is GLERL's scientific expertise "in demand" in terms of external requests? Is GLERL respected as a source of reliable scientific information among the general public and media?	Number of information inquiries, speaking requests, media requests, congressional inquiries, press mentions.
	Is GLERL providing public access to environmental data generated within the laboratory?	Development of a plan to comply with the NOAA Plan for Public Access to Research Results (PARR), percentage of recent and historic data made publically available, number of data-based products, web statistics on data products.
	Is GLERL providing public access to research results/outcomes?	Number of research publications, public outreach events and teleconferences, website and social media statistics, number of factsheets.
	Is there effective communication of GLERL products and services through a variety of information channels tailored to specific audience groups?	Measurement of customer satisfaction and accuracy of communication, number of requests, response time to requests, survey of under-served audience groups, gap analysis of research topics that are under-communicated.
	Does an appropriate portion of GLERL's research make the transition to operations/applications (R2X)?	Number of products transitioned to other NOAA line offices and other agencies or partners, number of technical reports or other data archives transitioned to an operational level.
	Does GLERL effectively communicate about research products in the R2X pipeline that will be transitioned?	Number of transition plans in place.
	Are GLERL products producing economic and social benefits, directly or indirectly?	Regional downward trends in HAB exposure incidents, excess nutrients, and drowning deaths attributed to marine events such as rip currents or meteotsunamis.

Performance

Performance refers to the effectiveness and efficiency with which research and development activities are organized, directed, and executed. Assessing performance involves ensuring the work that GLERL performs supports the goals of both NOAA and GLERL, and that GLERL has the workforce, infrastructure, and leadership necessary to achieve these goals. This involves understanding the quality of management, interaction with stakeholders, strategic direction, and the balance of research and development.

Goal	Criteria	Metric
Organizational Excellence Achieve excellence by building the capacity of NOAA personnel, infrastructure, and business practices that advance and support NOAA's mission of science, service, and stewardship.	Is there a balance of expertise at GLERL and is GLERL investing in professional development for its staff?	Implementation of staffing plan, gap analysis for support staff needs, professional development plans.
	Does GLERL sufficiently invest in infrastructure and business practices to support science, quality, safety and environmental compliance, security, data management, and operational efficiency?	Ongoing documentation of safety/environmental/security compliance and inspection records, data management plan in place and executed, infrastructure and business practices are not limiting GLERL's capacity to achieve quality metrics.
	Does GLERL's strategic plan provide achievable goals that meet customer needs and can be used by staff to evaluate progress as well as areas for improvement, thus providing direction for organizational excellence?	Branch/project-specific metrics are tracked and analyzed yearly to measure progress towards strategic plan goals.
	Is there prioritized use of GLERL assets, including scientific research facilities in Ann Arbor and Muskegon? Is GLERL making critical investments in scientific equipment and investing in the future of NOAA's facilities and vessel fleet?	Number of milestones met for critical equipment, infrastructure, and property inventory.
	Is GLERL effectively reaching milestones within a reasonable timeframe?	Milestone checklist from strategic plan and Annual Operating Plans (AOPs).
	Is GLERL using funds efficiently?	Percentage of funds obligated by the end of the fiscal year (99%).
	Do GLERL's infrastructure investments provide sufficient physical access to the Great Lakes to support research and development, marine innovation, and community engagement?	Number of internal and external projects supported, number of community engagements, number of awards and recognitions for marine innovation, number of support agreements with other NOAA line offices and cooperative academic institutions.
	Are vessels being used to an optimal efficiency?	Ship days used per vessel.

Interdisciplinary & Partnership Approach Integrate an interdisciplinary approach and use partnerships, such as those with the NOAA Cooperative Institutes, to strengthen capacity in reaching institutional goals.	Does GLERL's staff have the expertise to conduct research integrating the range of disciplines necessary for quality Great Lakes environmental research?	Number of cross-branch projects, number of disciplines represented on a project, program, and laboratory level.
	Does GLERL build partnerships (both internal and external to NOAA) to enhance the capacity to produce results?	Number of partners, co-PIs from other institutions, multidisciplinary publications, workshops, conferences, seminars, and research initiatives with GLERL participation.
Diversity Secure a diverse workforce that is supported by an organizational culture of inclusiveness.	Is GLERL making an effort to promote a diverse workforce (all demographics)?	Number of career fairs and educational events attended to target under-represented groups; number of NOAA equal opportunity fellows e.g., Educational Partnership Programs (EPP) and Minority Serving Institutions (MSI) recruited; examples of efforts made to recruit under-represented speakers.
	Does the staff feel included in how GLERL is being managed? Does GLERL create an atmosphere of inclusiveness?	Number of in-house trainings, Equal Employment Opportunity (EEO) seminars, All Hands meetings, Partnership Council meetings, and GLERL management requests for staff input, as well as application of 'bottom-up' strategic planning, and Baldridge Survey outcomes.
	Does GLERL work towards reaching diverse audience groups?	Number of communication and outreach events targeting underserved audience groups.

The Lake Michigan Field Station's proximity to Lake Michigan LTR sites provides the capacity to process time-critical samples immediately after collection in the LMFS EcoDyn laboratory and to sample during natural events (e.g., upwelling, spring flooding) or short weather windows during inclement periods. The LTR program is unique among federal agencies and academic institutions in its long-term commitment to seasonal observations of pelagic and benthic food webs in nearshore, transitional, and offshore waters. By providing direct access to Lake Michigan, as well as the other Great Lakes, the LMFS not only contributes to the success of observation-based programs, but also supports the conduct of in-depth process studies with potential for increasing complexity. Photo: View of Lake Michigan from just outside of the Lake Michigan Field Station in Muskegon, Michigan.

Glossary / Acronyms

Adaptive management | A systematic approach for improving resource management by learning from management outcomes. The process of adaptive management involves a structured, iterative process of robust decision making, with an aim for improved results and outcomes by reducing uncertainty over time through system monitoring.

AOP | The Annual Operating Plan is the framework used by GLERL for project planning and budgeting.

AUV | Autonomous Underwater Vehicles autonomously-operated, electro-mechanical machines that perform survey missions to gather physical, chemical, and biological information about the underwater environment. When a mission is complete, the AUV will return to a pre-programmed location and the collected data can be downloaded and processed the same way as data collected by shipboard systems.

Bibliometric | A statistical analysis of written publications.

Bioenergetics | The study of the transformation of energy in living organisms, involving the making and breaking of molecular chemical bonds.

CILER | Cooperative Institute for Limnology and Ecosystems is a consortium of academic research institutes in the Great Lakes region affiliated with NOAA Cooperative Institutes that advance NOAA's mission and goals.

CoastWatch | A NOAA program that obtains, produces, and delivers environmental data and products for near real-time observation. GLERL is a regional node for the NOAA CoastWatch program, providing access to near real-time and retrospective satellite observations and *in situ* Great Lakes data.

CSMI | Coordinated Science and Monitoring Initiative | A multi-agency program associated with the binational Great Lakes Water Quality Agreement that coordinates science and monitoring on each Great Lake over a five-year cycle. Outcomes from CSMI research help advance an integrated understanding of the ecosystem dynamics of the Great Lakes system. The CSMI program is sponsored by the U.S. Environmental Protection Agency and NOAA.

Cyanobacteria | Commonly referred to as 'blue-green algae,' cyanobacteria are a genetically diverse group of photosynthetic bacteria found in marine, freshwater and terrestrial systems. In lakes, rivers and coastal regions, large blooms of cyanobacteria may foul coastlines with scums capable of producing toxins and can impact aquatic ecosystems e.g., alter food web dynamics, reduce benthic vegetation and cause hypoxia (oxygen depletion), fish kills, and threaten animal and human health.

Diel | The vertical migration pattern of some organisms, such cladoceran zooplankton, over large distances between the bottom zone and surface water that occur over a 24 hour period or less.

DOC | Department of Commerce

Dreissenid mussels | A family of freshwater mussels that is native to Eastern Europe. Two species, zebra and quagga mussels were first introduced to the Great Lakes in the late 1980s and early 1990s, most likely via ballast water discharged from ships. The dreissenid mussels quickly spread and became established and, as efficient filter feeders, are linked to the collapse of the lower food web, which threatens valued fisheries such as trout and salmon.

EcoDyn | Ecosystem Dynamics, one of GLERL's integrated research branches.

Ecological Forecasting Roadmap | A NOAA-wide program to develop and apply ecological forecasting capability, providing access to dependable, high quality forecast products on a broader temporal and spatial scale with consistent delivery.

Ecosystem | An interacting community of living organisms (i.e., producers, consumers, and decomposers) and abiotic (non-living) components and the processes (e.g., nutrient cycles and energy flow) that drive ecological dynamics.

EEO | Equal Employment Opportunity

Enterprise | A purposeful undertaking that generally requires the coordination of different organizations, types of expertise, and capital.

EPP | Educational Partnership Program

ESP | Environmental Sample Processor is state-of–the-art instrumentation that provides an *in situ* platform for identifying and quantifying marine/freshwater organisms and their gene products. This electromechanical/fluidic instrument is designed to collect discrete water samples, concentrate microorganisms, and autonomously analyze samples using molecular probe assays that help expand the scientific understanding of cyanobacterial community composition and toxicity during harmful algal blooms (HABs) in western Lake Erie.

Environment | The physical and biological factors along with their chemical interactions that affect an organism or a group of organisms.

FTE | The number of hours worked by an employee that is equal to full-time employment.

FVCOM | Finite Volume Community Ocean Model is a modeling tool that enables high resolution (30 meters – 2 km) unstructured grid (i.e., triangular shapes of adaptable size) representation of the coastal system. FVCOM provides a better approximation of the integral form of the equations of motion; tracking of seasonal lake level fluctuations; inflows and outflows at major connecting channels; expanded coverage to connecting waterways (Straits of Mackinac, St. Clair River, Lake St. Clair, Detroit River, and the upper St. Lawrence River).

GLANSIS | Great Lakes Aquatic Nonindigenous Species Information System functions as a Great Lakes node of the U.S. Geological Service Nonindigenous Species (USGS NAS) national database. The GLANSIS database provides a core list of nonindigenous species to the Great Lakes basin (not native to any part of the basin). Also included in the database is a list of range expansion species (native only to a portion of the basin) and a Watchlist (not currently found in the Great Lakes but assessed as likely to invade via current pathways in the peer-reviewed scientific literature as of 2010).

GLCFS | Great Lakes Coastal Forecasting System is a set of hydrodynamic computer models that predict lake circulation and other physical processes (e.g., thermal structure, waves, ice dynamics) of the lakes and connecting channels in both a real-time nowcast and a forecast model).

GLERL | Great Lakes Environmental Research Laboratory is one of seven of NOAA Ocean and Atmospheric Research (OAR) laboratories located across the country. OAR conducts an integrated program of research, technology development, and provides services to improve an understanding of the Earth's atmosphere, oceans, and inland waters, and describe and predict changes occurring to them.

GLOS | Great Lakes Observing System is one of 11 Regional Associations of the Integrated Ocean Observing System (IOOS®), working to enhance the ability to collect, deliver, and use ocean and Great Lakes information. IOOS is a partnership among federal, regional, academic and private sector parties that works to provide new tools and forecasts to improve safety, enhance the economy, and protect our environment (GLOS website).

GLRI | Great Lakes Restoration Initiative is a multiagency initiative aimed at restoring and protecting the health of the Great Lakes. Since 2010, GLRI resources have been used to create measurable benefits for Great Lakes communities and habitats in the following five focus areas:

- Toxic Substances and Areas of Concern
- Invasive Species

- Nonpoint Source Pollution Impacts on Nearshore Health;
- Habitats and Species
- Accountability, Education, Monitoring, Evaluation, Communication, and Partnership.

GLWQA | The Great Lakes Water Quality Agreement is a commitment between the United States and Canada to restore and protect the waters of the Great Lakes. The Agreement provides a framework for identifying binational priorities and implementing actions that improve water quality. Under the Agreement, the U.S. Environmental Protection Agency coordinates water quality improvement initiatives within the United States and Environment Canada coordinates those within Canada.

Ground-Penetrating Radar | A geophysical method that uses radar pulses to image the subsurface of the earth.

GLRC | The Great Lakes Regional Collaboration is a unique partnership built upon a Presidential Order of 2004, recognizing the Great Lakes as a "national treasure" that are important to restore and protect. The GLRC is designed to create a better coordinated program to maximize the efficiency of investments as well as to better measure progress resulting from project investments. See: www.gpo.gov/fdsys/pkg/FR-2004-05-20/pdf/04-11592.pdf.

GLRCT | NOAA's Regional Collaboration effort is a network of NOAA employees and partners that represent the agency's diverse capabilities based on eight geographic regions across the country. The Great Lakes Regional Collaboration Team (GLRCT), established in 2004, reflects the diversity of NOAA's presence in the region. The GLRCT is strengthened by membership not only from NOAA's line offices, but also by membership of multiple core partners.

Goals | Specific components of GLERL's strategic vision of the future, delineating high-level priority results sought to be achieved on both an organizational and branch level.

Great Lakes Dashboard | A data portal that serves multiple agencies providing a data visualization for long-term, basin scale, time series data on hydrologic conditions (e.g., water levels), climate, and other environmental variables for the Great Lakes.

Green Ships | A fossil fuel emission reduction initiative to convert all NOAA research vessels from petroleum-based fuels and lubricants to renewable and environmentally-friendly products, as part of its larger stewardship mission.

H-index | A metric that gives an estimate of the importance, significance, and impact of a scientist's cumulative research contributions. The index, calculated on the number of publications as well as citations, serves as useful criteria to evaluate scientific achievement.

HAB | Harmful algal bloom is the proliferation of cyanobacteria or algae resulting from rapid growth in response to high nutrient and/or light levels. These events can have severe impacts on the ecology of systems where they occur as well as on the economics of surrounding regions and the health of humans, wildlife, pets and livestock.

HAB Tracker | A prediction tool, operated on an experimental basis that combines remote sensing, monitoring, and modeling to produce daily 5-day forecasts of bloom transport and concentration.

HABs Bulletin | A weekly bulletin during harmful algal bloom season that provides information about bloom extent and toxicity in Lake Erie.

Hypoxia | A condition of low dissolved oxygen concentration that can be detrimental to aerobic organisms, a problem that has been prevalent in Lake Erie. Hypoxic conditions can also cause taste and odor problems in drinking water supplies, and, therefore, result in increased treatment costs.

IAHR | International Association for Hydraulic Research

IceSAT | Ice, Clouds, and Land Elevation Satellite is the benchmark Earth Observing System mission for measuring ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristics.

IJC | The International Joint Commission is an independent binational organization established by the United States and Canada under the Boundary Waters Treaty of 1909. The two main responsibilities of the IJC are regulation of shared water uses, and investigation of transboundary issues and recommending solutions. The IJC's recommendations and decisions take into account a wide range of water uses, including drinking water, commercial shipping, hydroelectric power generation, agriculture, industry, fishing, recreational boating, and shoreline property.

***In situ* |** A term used in the aquatic science that refers to the examination of a phenomenon in place where it occurs, in the water (i.e., without moving it to a special medium).

IOP | Inherent optical property describes the absorption and scattering properties of a medium such as sea water. IOPs are properties of the medium and do not depend on the ambient light field. That is, a volume of water has well defined absorption and scattering properties whether or not there is any light there to be absorbed or scattered. This means that IOPs can be measured in the laboratory on a water sample, as well as in situ in the ocean.

IPEMF | Integrated Physical Ecological Modeling and Forecasting, one of GLERL's integrated research branches.

IS | Information Services, one of GLERL's integrated branches.

IT | Information Technology | GLERL's IT team provides researchers and support staff with advanced data processing and storage capacity as well as basic computing and telecommunications capabilities.

LMFS | Lake Michigan Field Station, strategically located on Lake Michigan's Muskegon Lake Channel, supports GLERL's long-term observations, field work, and process studies that are essential for understanding the Great Lakes ecosystem and developing future ecological services.

LTR | The Long Term Research program is led by GLERL's EcoDyn's team, which integrates a core set of long-term observations on biological, chemical, and physical variables on Lake Michigan, accompanied by process studies and field experiments, to understand and forecast change on the Great Lakes ecosystem. The term is used in the context of the Lake Michigan LTR program, on southern Lake Michigan. Currently, GLERL has research programs on other lakes, however, none are consistent or extensive enough through all seasons to characterize them as LTR sites.

Meteotsunamis | Meteorological tsunamis or "meteotsunamis" are similar to seismic tsunami waves, with periods of two minutes to two hours. Meteotsunamis, however, are generated from meteorologic disturbances of strong gradients in wind speed and barometric pressure associated with a convection storm front. Often meteotsunami waves become dangerous when they enter a harbor or bay, in which amplification yields destructive wave heights. In the Great Lakes or enclosed basins, wave reflection and focusing can yield dangerous conditions along the open coast line.

MFW | A microbial food web representing combined trophic interactions among microbes in aquatic ecosystems, including viruses, bacteria, algae, heterotrophic protists (i.e., ciliates and flagellates) but often includes microzooplankton in the 15-200 um range that may not be protists (e.g., rotifer).

Microcystis | A toxin-producing genus of freshwater cyanobacteria, which include the harmful algal bloom species, Microcystis aeruginosa.

Microcystin | A class of toxins produced by certain freshwater cyanobacteria, primarily Microcystis aeruginosa, but also other taxa (or genera). Microcystins can be produced in quantities during algal blooms that pose a major threat to drinking and irrigation water supplies.

MIL | The Marine Instrumentation Laboratory supports GLERL research by providing the resources to collect *in situ* data from the Great Lakes and other areas of interest. The MIL uses a multidisciplinary approach in data acquisition, instrumentation and mooring design, fabrication, calibration, deployment and retrieval, real-time communications, data analysis, and quality assurance.

Milestone | A term used in GLERL's strategic plan that provides a timeframe for when paths will be achieved.

Mission | A term used in GLERL's strategic plan that provides a summary of the agency's fundamental mandates and responsibilities driving organizational operation and functions on a long-term basis.

MSI | Minority Serving Institutions comprise a category of educational establishments (federally recognized Title IV colleges and universities) based on enrollment criteria (typically the percentage of enrolled minorities at a particular school). Those meeting the MSI criteria are eligible for federal funding.

MOCNESS | Multiple Opening Closing Net and Environmental Sensing System is an apparatus used for fine-scale sampling of Bythotrephes, Mysis, and larval fishes.

N | Nitrogen is a nutrient found in fertilizers and other substances that can stimulate algal growth when transported to the aquatic ecosystems in run-off.

NCCOS | NOAA National Centers for Coastal Ocean Science

NEPA | The National Environmental Policy Act is one of the first laws in the United States establishing a broad national framework for protecting the environment. NEPA's basic policy is to assure that all branches of government give proper consideration to potential risks to the environmental prior to undertaking any major federal action.

NESDIS | NOAA National Environmental Satellite and Data Information Service

NMFS | NOAA National Marine Fisheries Service

NOAA | National Oceanic and Atmospheric Administration

NOAA Cooperative Institutes | The NOAA Cooperative Institutes are academic and nonprofit research institutions that demonstrate the highest level of performance and conduct research that supports NOAA's mission, goals, and strategic plan. The geographic locations of Cooperative Institutes extend from Hawaii to Maine and from Alaska to Florida. Currently, GLERL's Cooperative Institute is the Cooperative Institute for Limnology and Ecosystems Research, led by the University of Michigan.

NOAA's Ecological Forecasting Roadmap | An operational framework for a NOAA-wide ecological forecasting capability to effectively and efficiently provide dependable, higher quality forecast products on a broader spatial and temporal scale with consistent delivery.

NOAA GLRCT | NOAA Great Lakes Regional Collaboration Team—one of eight NOAA regional collaboration teams across the country— comprises a network that promotes coordination of NOAA's diverse assets within regions and collaboration with external partners to respond to stakeholders' shared regional concerns. The GLRCT is currently led by GLERL's director with support from OAR's Great Lakes Regional Team coordinator.

NOAA PARR | The Plan for Public Access to Research Results describes activities that will be undertaken by NOAA in order to meet the goals and requirements of the White House Office of Science and Technology Policy Memorandum, Increasing Access to the Results of Federally Funded Scientific Research, issued February 22, 2013. The goal of PARR is to increase public accessibility of publications and digital data produced by federal agency researchers or by recipients of federal funds.

NOS | NOAA National Ocean Service

NWS | NOAA National Weather Service

OAR | NOAA Office of Oceanic and Atmospheric Research is GLERL's parent line office.

Oligotrophic | A water body with low nutrient content, resulting in low primary productivity. Typically, these water bodies have low algal production, very clear waters, and well-oxygenated bottom waters.

Operational | Reference to sustained, systematic, reliable, and robust mission activities with an institutional commitment to deliver appropriate, cost-effective products and services.

OSAT | Observing Systems and Advanced Technology, one of GLERL's integrated research branches.

P | Phosphorus is a nutrient found in fertilizers and other substances that can stimulate algal growth when transported to the aquatic ecosystems in run-off.

PAR | Photosynthetically active radiation is electromagnetic radiation in a specific spectral range which photosynthetic organisms use to produce energy.

Path | A term used in GLERL's strategic plan to describe how goals and research questions/drivers are being achieved.

Pelagic | The open water zone of a natural water body (e.g., lake, river, stream) that is not directly affected by the shore and bottom.

Physiochemical | relating to physics and chemistry or physical chemistry.

PI | Principal investigator, typically serving as lead scientist for GLERL's research investigations.

QSEC | Quality, safety, and environmental compliance serve as the primary components of GLERL's quality management plan.

R2A | Research to Applications. Applications are defined as the use of NOAA R&D (Research and Development) output as a system, process, product, service or tool. Applications in NOAA include information products, assessments, and tools used in decision making and resource management (NAO 216-105A | Policy on Transition of Research to Application).

R2O | Research to Operations. Operations are defined as sustained, systematic, reliable, and robust mission activities with an institutional commitment to deliver specified products and services (NAO 216-105A | Policy on Transition of Research to Application).

R2X | The transition of R&D to any operation, application, commercialization or other use to include products like 24 hours/7days weather forecasts (typically referred to as research to operations), information products used in resource management (research to application), commercially available *in situ* sensors (research to commercialization), or government policies, regulations, synthesis of research, public education and outreach (research to other uses) (NAO 216-105A | Policy on Transition of Research to Application).

ReCON | Real-time Coastal Observation Network is a project that is developing a network of coastal platforms (buoys and off-shore structures) processing nodes capable of seabed to sea-surface observations. ReCON is built upon a wireless Internet observation system, with each platform collecting meteorological data and providing sub-surface measurements of chemical, biological, and physical parameters.

Resilience | The ability of a system or community to "bounce back" after hazardous events, such as flooding, coastal storms, extreme water level fluctuations, or water quality impacts, without significant change in condition or function.

Strategy Planning | An organizational activity used to develop a mission statement and related vision statement with a corresponding set of long-term, strategic organizational goals that—in GLERL's case—convey the entity's fundamental direction and value to society. The strategic plan is the resulting document used to communicate to employees and stakeholders the identified priority elements and the actions needed to achieve goals and all of the other critical elements developed during the planning exercise.

SRV | Small Research Vessels are boats that are greater than 65 feet in length overall, but less than 300 gross tons.

Transition | The transfer of knowledge or technology from a research or development setting to an application, including operational settings. Transitions occur in two phases | demonstration (e.g., the use of test-beds to confirm operational usability or demonstration using rapid prototyping), which is part of R&D, and deployment (e.g., the integration of new people, equipment, or techniques into an operational environment), which is part of applications, including NOAA operations. Transitions may occur from NOAA-conducted R&D to NOAA operations, from NOAA-conducted R&D to an external partner, or from external partner-conducted R&D to NOAA operations (NOAA Office of Program Planning and Integration).

UAS | Unmanned Aircraft Systems is a term referring to an aircraft without a human pilot aboard, controlled with various kinds of autonomy either by a given degree of remote control from an operator, located on the ground or in another vehicle, or fully autonomously, by onboard computers.

Vessel Recapitalization | Organization of GLERL's vessel capital structure to allow funds for sustainable vessel operations and future vessel procurement.

VIIRS | The Visible Infrared Imaging Radiometer Suite is a scanning radiometer that collects visible and infrared imagery and radiometric measurements of the land, atmosphere, cryosphere, and oceans (NASA website).

Vision | A term used in GLERL's strategic plan that describes a future state of society and the environment that could not be achieved without GLERL's integrated scientific research, projecting long-term success in terms of value-added to society.

WRF-Hydro | Weather Research and Forecast Model for Hydrology is a framework that allows for coupling of atmospheric models and terrestrial hydrological models.