NOAA Great Lakes Environmental Research Laboratory

Strategic Plan 2016-2020

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

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.

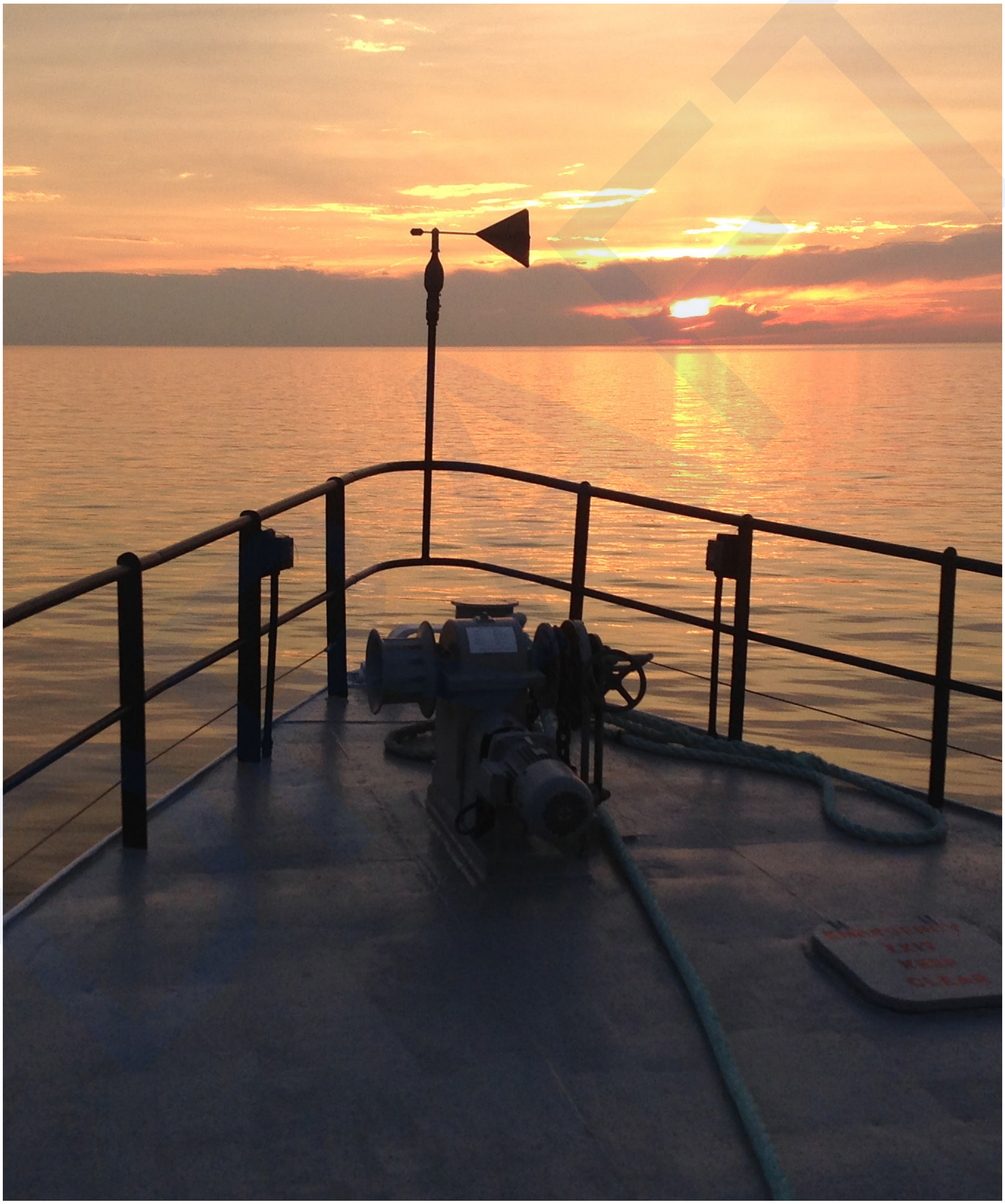
This strategic plan aims to ensure that GLERL continues to stand at the forefront in providing the scientific intelligence needed by the Great Lakes community to manage this globally unique and exceptional resource and safeguard its long-term sustainability. I look forward to an exciting five years in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

GLERL Strategic Plan 2016-2020

A Commitment to Integrated Scientific Research on the Great Lakes and Coastal Ecosystems



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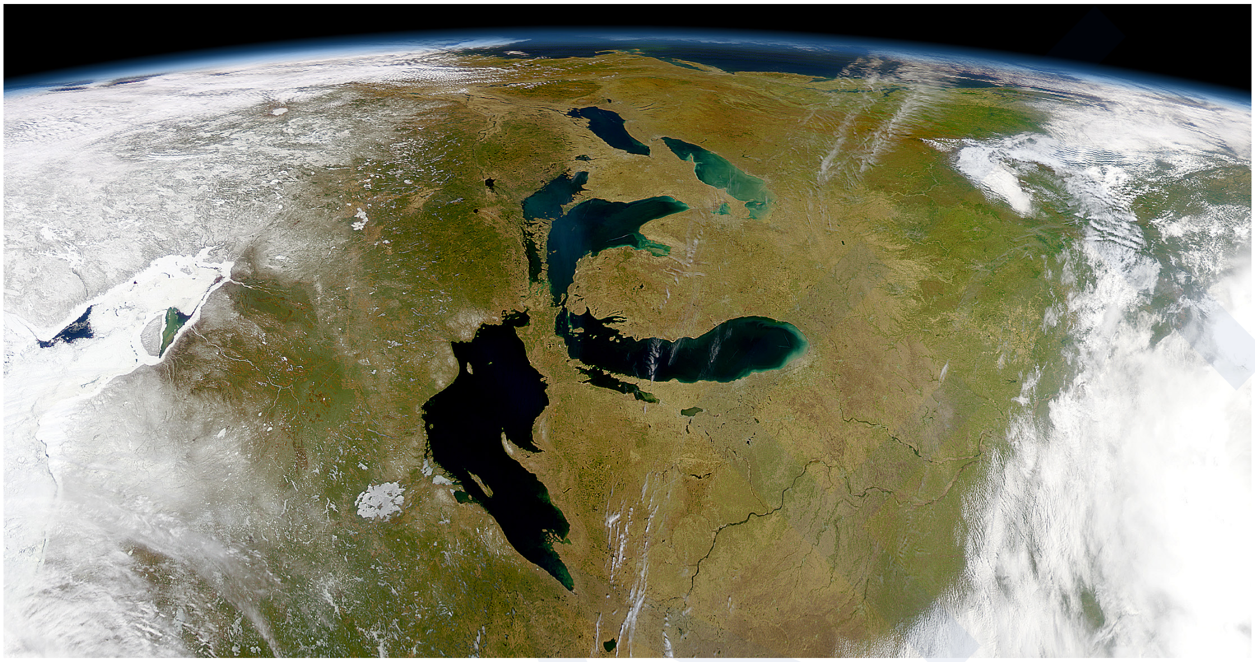

GLERL's Establishing Order

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."

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 inception in 1974.

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 supply and 20 percent of the world's surface freshwater. Shared with Canada, these "freshwater seas" provide Great Lakes communities with valuable assets, including 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 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—including 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 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 that can produce toxins, such as cyanobacteria e.g., *Microcystis*, thus posing human health risks.

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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

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.

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 level 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 15 years, beginning in 1998. This period of low water level—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 decreased 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. Conversely, in the spring of 2013 following a severe winter, this period of low water levels shifted to an extreme and rapid rise in water levels, going down in the record books as a year with the most persistent, coldest temperatures, and highest 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."

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) in 2004. Built upon a Presidential Executive Order in 2003, a unique partnership of federal, state, tribal, and local governments convened under the GLRC to develop recommendations for 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

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

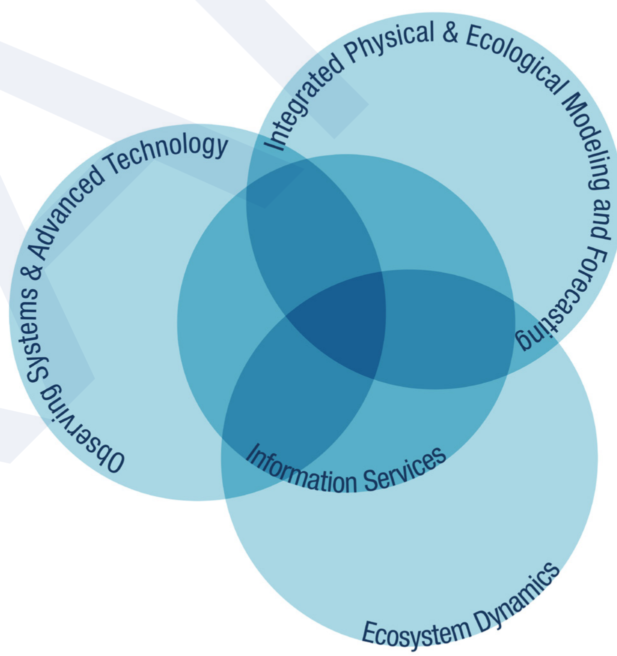
Notable Milestones have been achieved in each focus area, including the delisting of five Great Lakes Areas of Concern (AOC), a 70% increase in farm acreage enrollment in phosphorus runoff prevention programs, and the restoration, protection or enhancement of 48,000 acres of coastal, island and upland habitat. Under GLRI Action Plan II, the second phase of GLRI, federal agencies and nonfederal partners are building on the ecosystem protection and restoration work of the first five years by implementing a science-based adaptive management framework. For further information, see the GLRI Action Plan II at greatlakesrestoration.us.

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 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 Appendix A (currently in progress).

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. This approach of 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 fluctuations, 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 Appendix B (currently in progress).

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.

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 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, increase knowledge, and promote 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 environmental compliance, quality management and safety standards, and 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.

Balanced Research Portfolio | Balance GLERL's portfolio between fundamental and applied research.

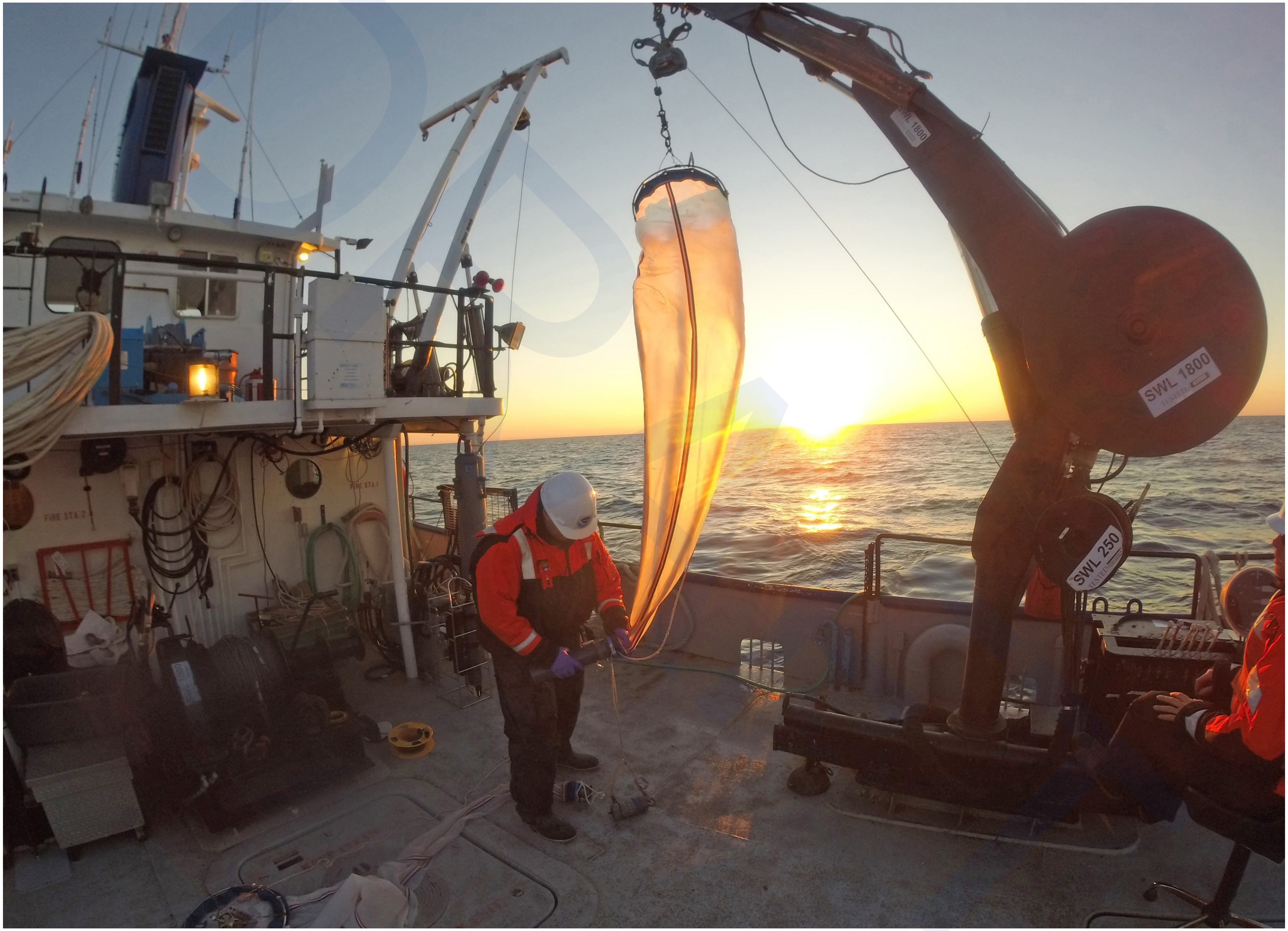
Transition to Application | Facilitate transition to operations and application (R2X) as part of the development and implementation of research programs.

Addressing Stakeholder Needs | Serve NOAA's customer base through communication, including needs assessment, consistent messaging and accessibility of GLERL's observations and data, scientific knowledge and information, and products and services .

Return on Investment | Provide value to the nation through effective use of taxpayers' investment.

Physical Access to the Great Lakes | Serve as a resource to NOAA and regional partners by providing physical access to the Great Lakes through GLERL's Lake Michigan Field Station and vessel fleet.

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.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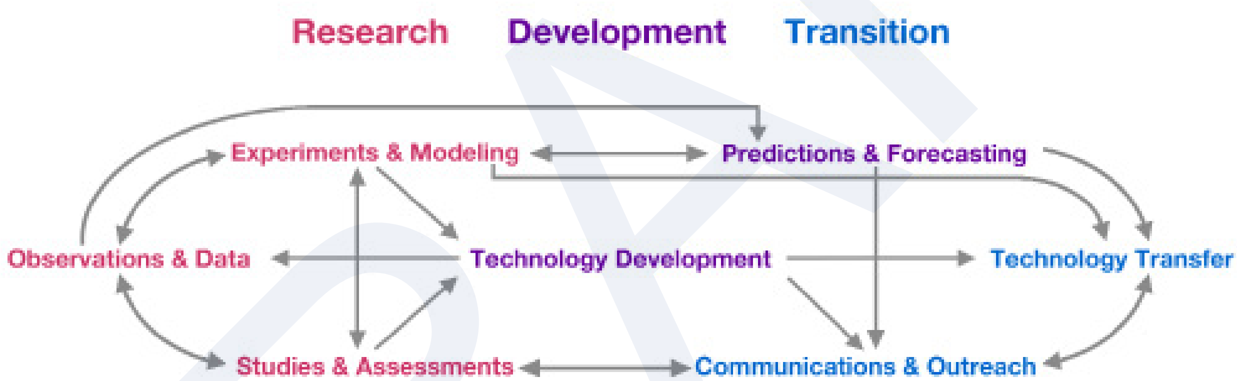
2. Activities

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

GLERL conducts interdisciplinary science across three areas: research, development, and transition (see schematic below), supported 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.

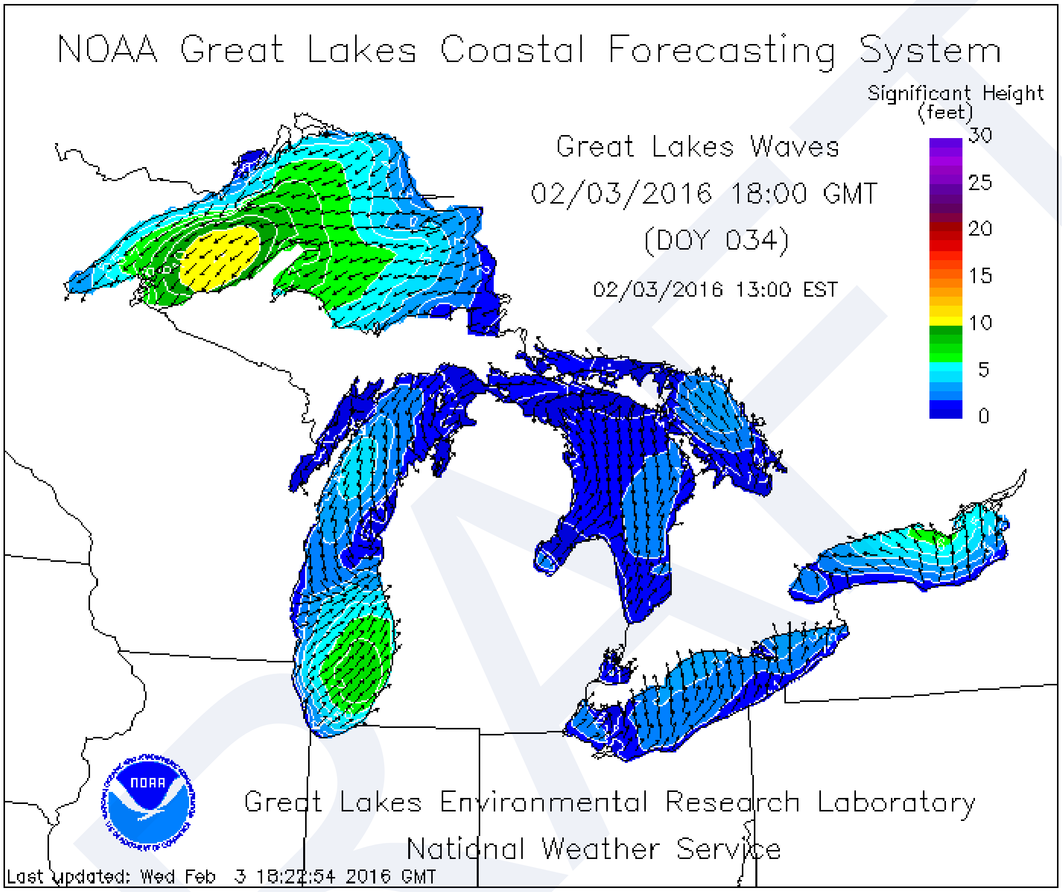
Research

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 (below).



Output from the Great Lakes Coastal Forecasting System (GLCFS)

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.

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.

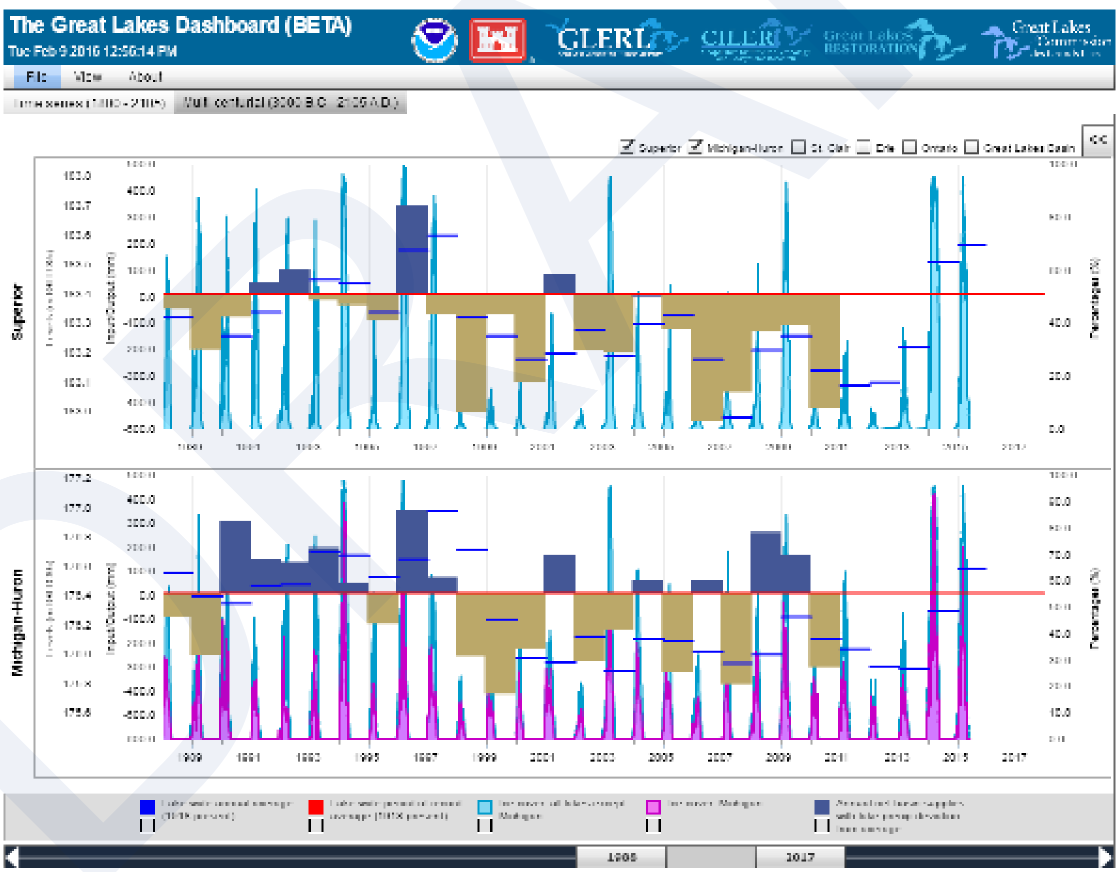
Technology Development

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 better engages stakeholders. 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, the Great Lakes Water Level Dashboard (below)

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.



The Great Lakes Dashboard (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. Built to expand as necessary, the dashboard can aid in the following of NOAA's Next Generation Strategic Plan.

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 a cohesive message on its scientific research in ways that are meaningful and actionable. In addition, communication and outreach conducted within GLERL on an internal level facilitates an overall understanding among staff for the research, development, and transition activities underway.

Examples: Media interviews and teleconferences, Great Lakes Webinar Series, Congressional briefings, stakeholder needs assessments, peer-reviewed publications, technical reports, presentations, website content, social media, factsheets, infographics, and visualizations; connecting NOAA science and scientists with the general public, with a particular focus on students e.g., Great Lakes National Science Bowl.

Students at Great Lakes National Ocean Sciences Bowl. Photo credit: GLERL

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.

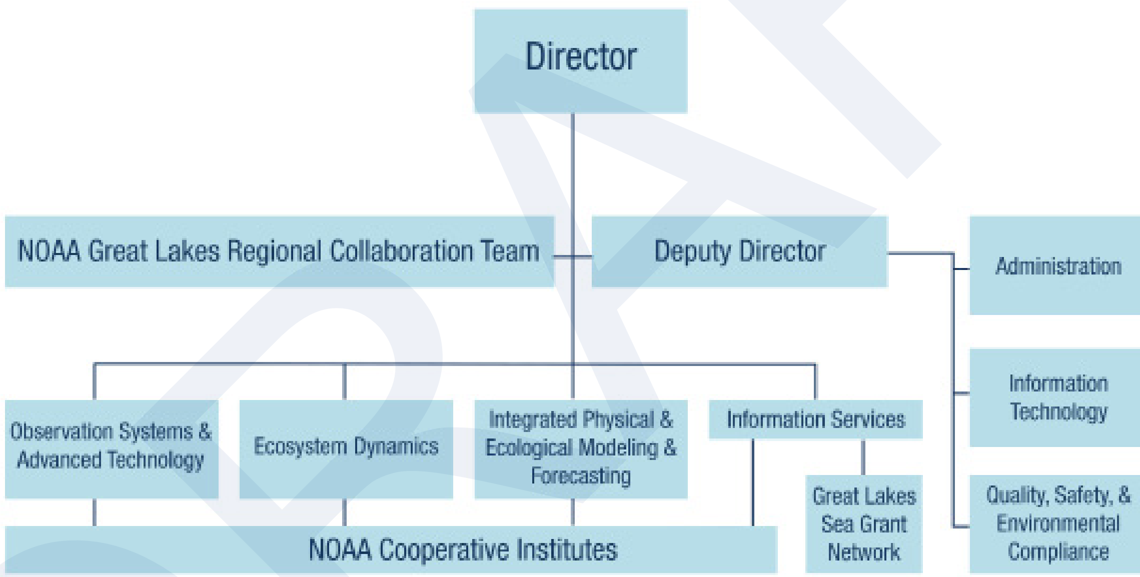
Examples: Future transfer of FVCOM operational modeling and next generation of HABs Tracker to NOS; transfer of water level forecasts to the U.S. Army Corps of Engineers; transfer of CoastWatch sea surface temperature to Sea Grant; transfer of ReCON data to the National Weather Service.

NOAA Technical Readiness Level Definitions

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 Appendix C (currently in progress).]

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 an emphasis at GLERL to work on a cohesive level, across the science and information services branches and in coordination with 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.

In facilitating GLERL's research and development, the director collaborates with external stakeholders to ensure that the laboratory's research addresses identified 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.

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, and information technology. In addition, the deputy director serves as a non-technical 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 the Annual Operating Plan.

Science & 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 IS 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.

NOAA Cooperative Institutes

The NOAA Cooperative Institutes are academic and non-profit 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. 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 demands of stakeholders.

CILER
Cooperative Institute for Limnology and Ecosystems Research

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: Great Lakes observing and forecasting systems, invasive species, ecological risk assessment, protection and restoration of ecosystem services, and education and outreach.

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.

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.

Infrastructure

Administration

The administrative staff in Ann Arbor, and Muskegon, Michigan provides operational support to GLERL staff and internal partners in the areas of personnel, budgeting, training, time and attendance, travel, office support, property, facilities, security, procurement and contracts. GLERL's administrative staff serves as a team of professionals committed to the delivery of innovative, effective and efficient customer services while maintaining fiscal integrity.

The priorities of the administrative team are to:

- Provide effective services by ensuring that administrative staff is appropriately trained in budget, procurement, time and attendance, and travel procedures.
- Enhance staff expertise and maintain certifications.
- Provide GLERL management with staffing summaries for evaluation of the laboratory's staffing plan.
- Collate and track funding decisions for scientific projects and operational accounts.
- Improve efficiencies in administrative processes and operations.
- Provide a safe, healthy, and secure work environment through facility oversight and building improvements.

Information Technology

The Information Technology (IT) team provides researchers and support staff with advanced data processing and storage capacity as well as basic computer and telecommunications capabilities. IT services include integrating computer systems, coordinating and providing training, negotiating and managing information technology related contracts, and technology assistance and support.

The priorities of the information technology team are to:

- Educate staff on the need for security to be everyone's business.
- Provide reliable and secure IT infrastructure hardware and software.
- Promote continuous learning and provide formal training for IT staff career development.
- Leverage emerging technology and software for innovative new solutions in addressing common IT challenges.
- Maintain a technological environment that enables GLERL staff to expeditiously access vital information using the most efficient and cost effective system hardware and software.

Lake Michigan Field Station

Located on Lake Michigan's Muskegon Lake Channel, GLERL's field station occupies three buildings and houses research staff, vessel crew, a marine superintendent, and administrative personnel.

The LMFS 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.

The priorities of the LMFS team are to:

- Ensure safety and security of the LMFS work environment.
- Enhance LMFS laboratory and workspace facilities to support experimental and process-based research, including the new construction of LMFS building 3.
- Take advantage of the LMFS's proximity to Lake Michigan LTR sites, providing the capacity to process time-critical samples immediately after collection in the LMFS EcoDyn lab and the ability to sample during episodic events e.g., upwelling, spring flooding, or during short weather windows during inclement periods.
- Increase capacity for "wet testing" of instrumentation and scientific mooring preparation and deployment, thus enhancing Marine Instrumentation Laboratory (MIL) capabilities.

- Focus on place-based opportunities for community engagement, outreach and education.
- Enhance public relations with partners from local and the regional west Michigan area government and organizations.

Vessel Operations

Vessel operations, based at the LMFS, support GLERL science branches by providing a safe and secure work environment in the conduct of scientific research. Additionally, vessel operations provide expertise to NOAA in small research vessel (SRV) operations. The mobility of GLERL vessels offers unique place-based opportunities for communications and education at Great Lakes Ports of Call.

The priorities of vessel operations are to:

- Acquire, manage, and maintain GLERL's vessel fleet to meet current and new initiatives and long-term critical capabilities e.g., vessel fleet recapitalization.
- Provide licensed captains and well-trained crews that implement best practices in promoting safe and efficient field research.
- Manage efficient coordination of ship scheduling for GLERL and regional partners, including use of sampling gear and applied technologies.
- Maintain leadership for Great Lakes regional research vessel coordination such as the Great Lakes

Association of Science Ships.

- Provide technical assistance, engineering, maintenance, overhauls, and modifications to support vessel best management practices.
- Maintain recognition as experts and leaders in marine innovation, through the following:
  - Continued leadership in design, enhancement of technical expertise, and certification for the advancement of Green Initiatives, including 'Green Ships.'
  - Building on extensive experience in repurposing and redesigning vessels and providing expert consulting services on an agency-wide scale.
  - Ongoing exploration of innovative approaches for the development and use of marine technology.
- Engage stakeholder groups through the use of vessels as a place-based platform for community outreach.

For further information on the strategic vision for vessel operations, see Appendix D (currently in progress).

The Ann Arbor Facility

GLERL leases a customized 45,000 square foot facility in Ann Arbor, Michigan which houses:

- 101 offices
- 5 conference spaces (including a 150-seat lecture hall)
- 17 laboratories (11 wet labs, 6 dry labs)
- 2 computer labs
- 14 storage areas
- 10,000 square foot outdoor wareyard

Shared office space serves as a base for staff from NOAA's Great Lakes Cooperative Institute as well as partner agencies including NOAA National Ocean Service (NOS) Marine Sanctuary Program, NOAA National Marine Fisheries Service (NMFS) Habitat Restoration Program, NOAA Great Lakes Regional Collaboration Team, Great Lakes Sea Grant, and the International Association for Great Lakes Research. The facility also serves as a physical hub for regional collaboration within its conference spaces

The laboratories—managed and coordinated by the GLERL lab team—house instrumentation and equipment for use by GLERL and NOAA Cooperative Institute and visiting scientists. The facilities design allows for both dedicated and flexible lab spaces.

The dedicated laboratory spaces include:

- The Biological Preservation Laboratory and Microscope Room, used to sort, identify and count preserved microbial organisms, phytoplankton, zooplankton, larval fish, and benthos for food web studies.
- The Molecular Biology Laboratory, used to implement molecular techniques for measuring HAB toxins

and genetics.

- The Limnology Laboratory, used to analyze water chemistry, including chlorophyll concentration.
- The Experimental Biology Laboratory, used to conduct small scale experiments and includes cinematography capabilities for observation and experiments with plankton and benthos.

The priorities of the lab team are to:

- Ensure laboratory space is available for use by researchers needing it
- Maintain state-of-the- art laboratory instrumentation and equipment.
- Ensure laboratory staff is properly trained on various instruments.

Marine Instrumentation Lab

Within the Ann Arbor lab facility, the Marine Instrumentation Laboratory (MIL) provides the resources necessary 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. The field experience of the MIL staff is also vital to assure success in the harsh, challenging marine environment. As such, the MIL functions in the collection of measurements of scientific parameters from the real world into the data used by GLERL and its partners for scientific research.

The priorities of the MIL team are to:

- Develop and prototype new and cutting-edge in-situ data collection techniques.
- Develop techniques to collect data year-round in the Great Lakes, including under-ice observations.
- Improve the efficiency of in-situ data collection.
- Improve the collection of real-time data for use by GLERL and its partners.

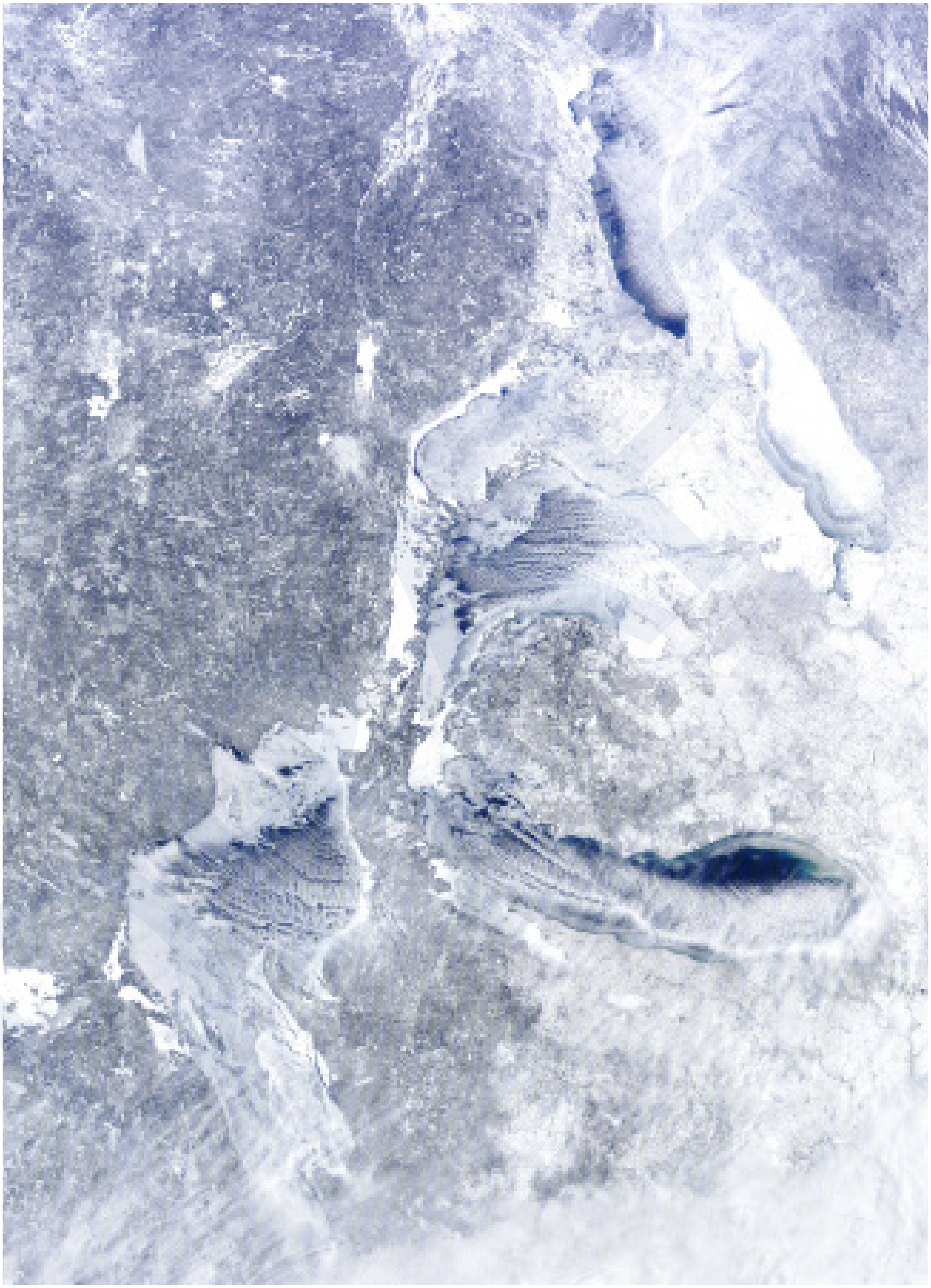
Quality, Safety, and Environmental Compliance

The quality, safety, and environmental compliance (QSEC) officer fosters a work environment where operations are conducted in a safe environmentally compliant manner, while producing quality products and achieving outcomes that meet the needs of GLERL customers. A full plan will be developed to guide GLERL staff on quality, safety, and compliance issues; a summary of this plan is outlined in Appendix E (currently in progress).

The priorities of the QSEC officer are to:

- Continue to improve GLERL's safety and environmental compliance programs with participation from the safety committee, chaired by the QSEC officer.
- Ensure adequate safety and environmental compliance staffing at GLERL facilities.

- Improve the project review process to include: the voice of the customer needs; planning documentation, including a NEPA review; an evaluation of progress/performance component that includes “lessons learned” for continuing projects; and evidence-based decision making.
- Strengthen project planning and performance management activities of approved projects.
- Advance data management and quality assurance/quality control activities through routine development and use of data management plans.
- Advance Information Quality Act through routine use of NOAA Guidelines.
- Promote organizational excellence through the advancement of a comprehensive quality management plan.



4. Approaches

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

Introduction

The Approaches section is the core of GLERL's strategic plan which focuses on how GLERL pursues scientific environmental research, development, and transition to operations and applications. This section charts a road map 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.

GLERL research is committed to the needs of the Great Lakes community, 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 in Appendix F (currently in progress), 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.

The Approaches 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 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.

In conjunction with an integrated approach, adaptive management affects how scientific research is conducted at GLERL. The iterative, long-term, systematic process of using an adaptive integrated

Uncertainty in Scientific Research & Communication

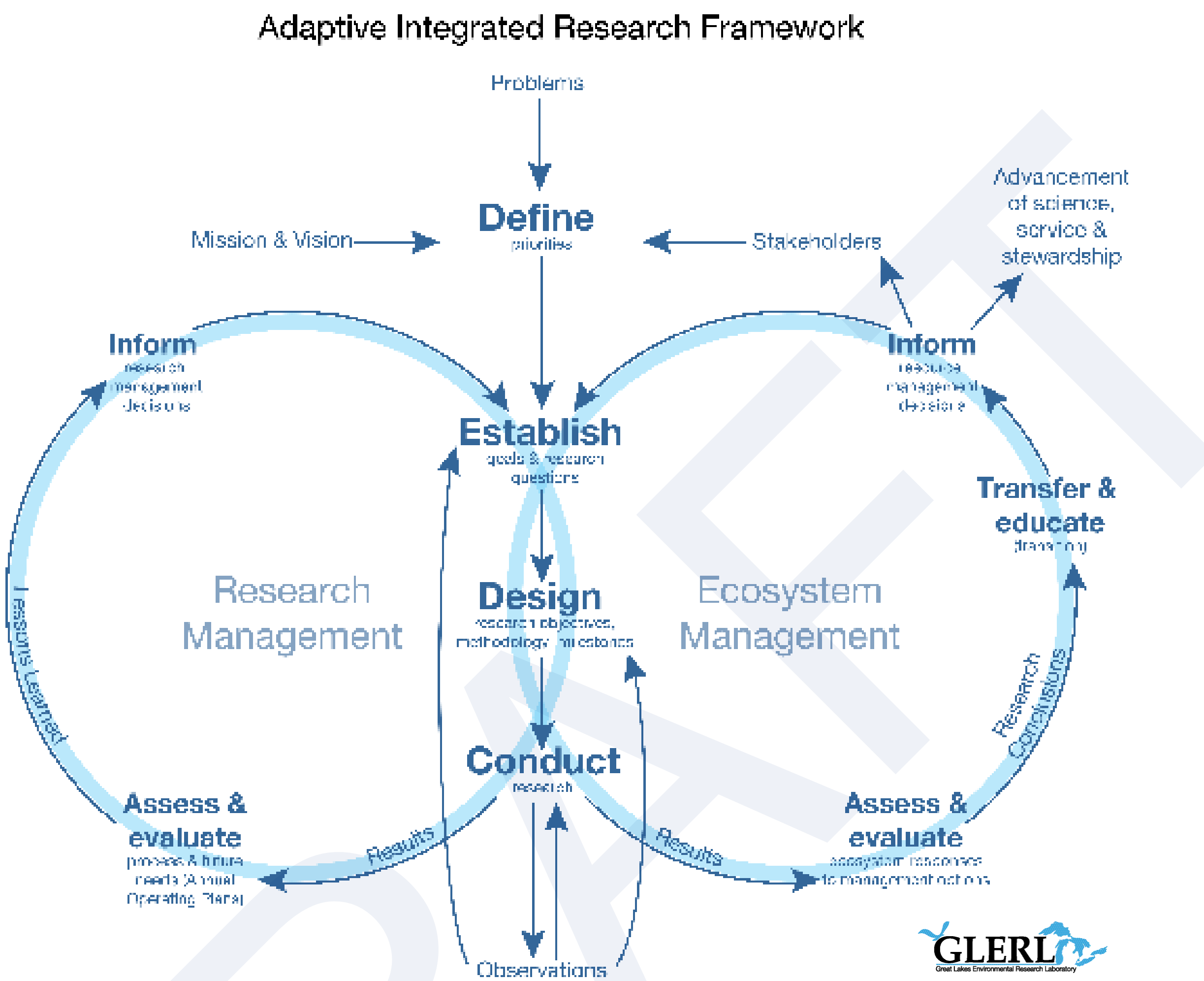
"In science, there's often not absolute certainty. But, research reduces uncertainty. In many cases, theories have been tested and analyzed and examined so thoroughly that their chance of being wrong is infinitesimal. Other times, uncertainties linger despite lengthy research. In those cases, scientists 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 (http://www.ucsusa.org/global_warming/science_and_impacts/science/certainty-vs-uncertainty.html#.VqucRLIrKUk)

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*
- *Objective uncertainty (lack of clarity of goals and objectives)*
- *Management uncertainty*

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



research framework (above) 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. These feedback loops help facilitate the progressive development of more effective ecosystem management options and more deliberate research management by taking advantage of the discovery of new knowledge from scientific investigation.

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 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.

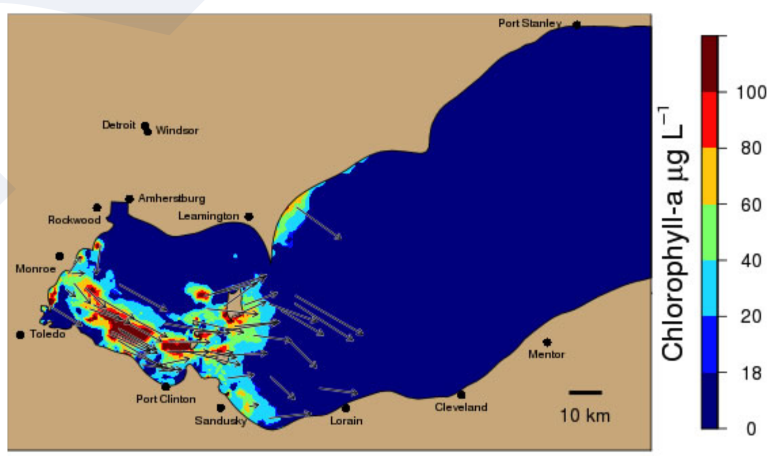
Harmful Algal Bloom Research: A Case Study for Adaptive Integrated Research

The application of an adaptive integrated research approach is well demonstrated by GLERL's research program on harmful algal blooms (HABs) in the western basin of Lake Erie and Saginaw Bay. The HABs research program at GLERL is conducted with participation from all of GLERL's four branches and in collaboration with the Cooperative Institute of Limnology and Ecosystems Research (CILER) and NOAA's National Centers for Coastal Ocean Science (NCCOS). The primary ecological problem is the extent, duration and toxicity of HABs in response to human-induced stressors, thus impacting the water quality of Lake Erie's western basin and other regions of the Great Lakes.

GLERL's interdisciplinary approach to research integrates physical, chemical and biological sciences as well as advanced technologies. The study of the physical component begins with the primary source of the problem— excess nutrient loading. A large portion of nutrients are transported by precipitation and tributary flow from the watershed, followed by the circulation of the nutrients in the lake and horizontal and vertical movement of algal blooms driven by currents, winds, and buoyancy. The chemical component of HABs research includes both nutrient chemistry driving bloom growth and the form of the toxins produced. Related physiochemical aspects of this research are the thermal structure and hypoxic (oxygen depleted) conditions that evolve seasonally. The biological component focuses on the seasonal genetics of algal populations, responses by HAB-forming genera to specific environmental changes, and drivers of bloom toxicity. The HABs team is developing techniques to measure toxin concentrations, strain identity and toxicity by applying various genetic and molecular (–omics) approaches as well as use of autonomous sampling devices, such as the Environmental Sample Processor (see sidebar on next page).

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), monitoring, and modeling, the experimental HAB Tracker produces daily 5-day forecasts of surface chlorophyll concentrations and vertical mixing of the water column, with the capacity to estimate the current size 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.



To further illustrate the integrated approach, the HABs program has a diverse range of expertise including engineers, hydrologists, limnologists, geneticists, ecologists, mathematical modelers, as well as human dimensions, outreach and communication specialists. The program uses advanced observing systems, including satellite imaging, remote sensing buoys, and in situ monitoring programs 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 the development of predictive models, led by the IPEMF branch. These models currently drive forecasts of bloom extent and intensity, and, in the future, will incorporate toxicity (see HAB Tracker on previous page). These critical products inform stakeholder groups (drinking water managers, recreational user groups, and land-use managers) through outreach from GLERL's IS branch and CILER, as well as through GLERL's publicly available website, to reduce risks to human and ecosystem health.

Ongoing efforts of this long-term program have strengthened GLERL's understanding of the environmental factors driving HAB growth and toxicity, leading to better 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.

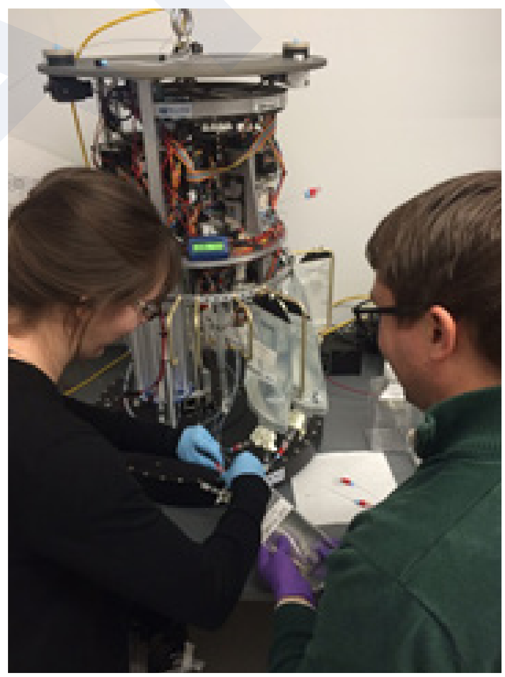
The following discussion of HAB research conducted at GLERL is illustrative of the ecosystem management cycle of the adaptive integrated research approach (refer to right feedback loop of the figure on page 27.)

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

- The problems caused by HAB impacts on water quality and the ecosystem health in the Great Lakes has 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."

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 cyanobacterial 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.

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 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 aquatic ecosystems?

Design Research Objectives, Methodology, and Paths

Investigate environmental drivers and impacts and their relationship to HABs. For example, designing deliberate, structured experimentation to test the effect of phosphorus (P) reduction on algal growth as well as that of nitrogen (N) on algal growth and toxicity. Develop and improve NOAA forecast products to predict harmful algal blooms through in situ monitoring of water quality and toxicity, traditional water quality observations, hyperspectral flyovers, and hydrodynamic modeling.

- 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 structure; and the role of dreissenids in promoting HAB-forming genera.
- Models are developed to forecast bloom size and distribution. GLERL's focus is on the operation of the experimental HAB Tracker built upon the best available science, observations, and data to generate predictions and forecasts of HABs.
- Observations provide information for model development and validation. Variables for HABs research include measurements of temperature, chlorophyll concentration, precipitation, current circulation, 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, HAB Tracker, HABs Bulletins, 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 in order 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:

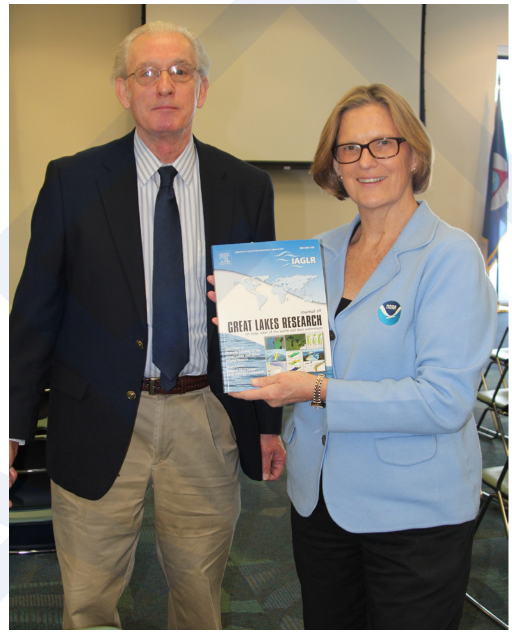
- Stakeholder feedback provides input to assist scientists and managers, as well as state and federal legislators on the priority setting process.
- Given that prior research (results and conclusions) suggests that the effects of nitrogen, dreissenid mussels, and climate change could play a role in HAB 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 spatial and temporal scale of 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 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.

"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.

Presented as the first branch plan in the Approaches section, OSAT holds a pivotal 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 plan for managing the data that is collected by OSAT, in coordination with the other branches, is presented in Appendix G (currently in progress).

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 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 GLERL's customers.

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 provided a stronger foundation for research in the Great Lakes and coastal communities.

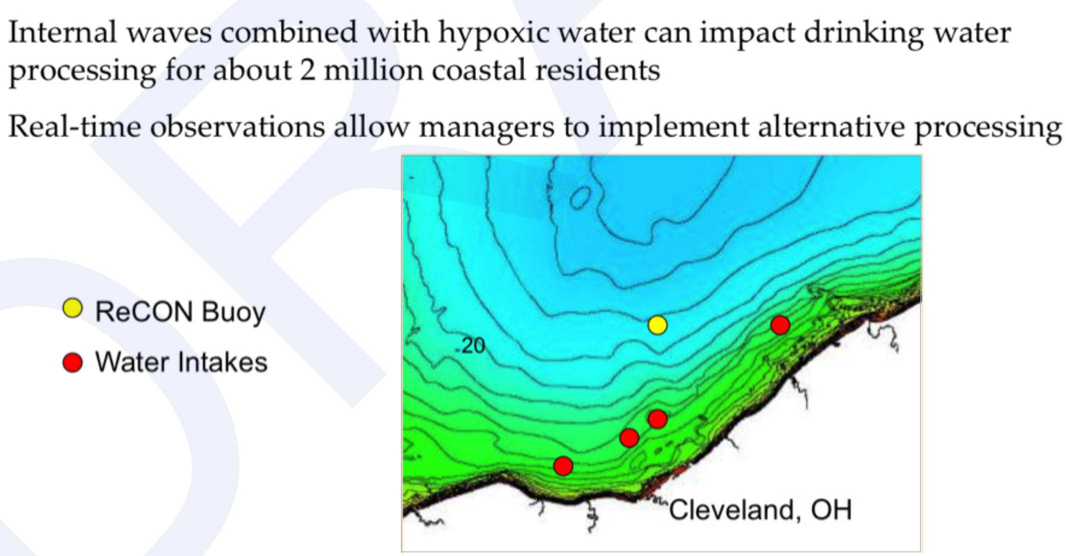
Remote Sensing Observations

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 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



OSAT supplies ReCON buoy technology for real-time dissolved oxygen observations, providing advanced warning to drinking water 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, was successfully transitioned to the Great Lakes Observing System for operations. In the future, OSAT will expand Hypoxia Warning System efforts to other impacted areas in the Great Lakes.

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 services and products 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.

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, actual hardware)

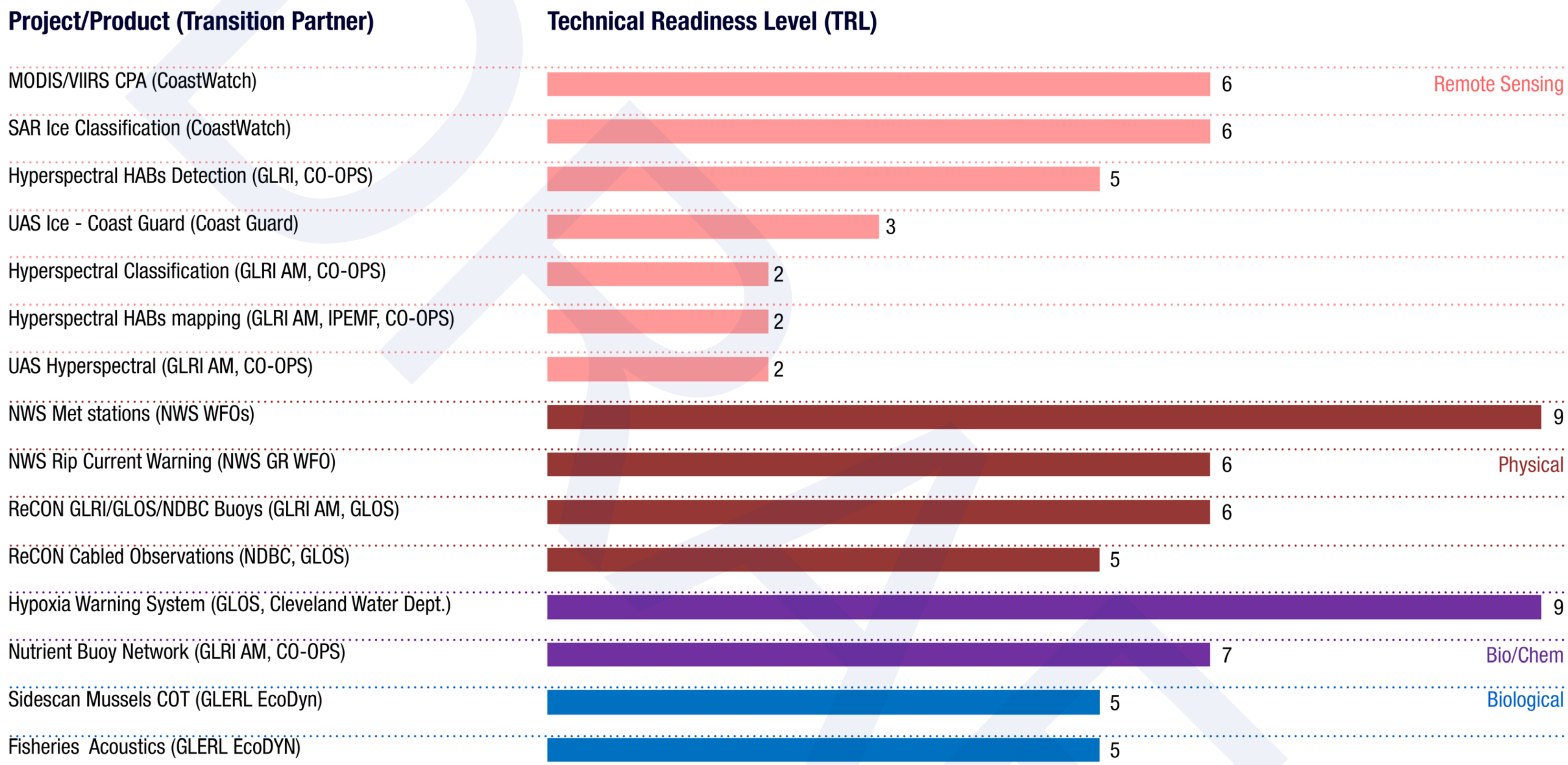
Research Goals and Drivers

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.

Paths and Related Milestones (2016-2020)

Path	Milestones
1. Establish a routine hyperspectral monitoring capability on western Lake Erie and Saginaw Bay, including the use of persistent UAS.	• 2016: Deploy hyperspectral imaging system from aircraft and begin UAS hyperspectral testing. • 2017: Test hyperspectral algorithms capable of detecting and classifying cyanobacterial and algal species and integrate hyperspectral map product into the GLERL HAB Tracker. • 2018: Develop and test UAS docking station on Lake Erie offshore structure. • 2019: Transition hyperspectral imaging capability into operational use for HAB Tracker.
2. Continue development, transfer, testing and optimization of SAR ice type algorithm and CPA (color producing agent) algorithm with NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) to support operational product development.	• 2016: Enhance optical properties database to improve hydro-optical models in collaboration with Michigan Tech Research Institute-MTRI. • 2016: Improve and validate CPA algorithm in optically complex waters in collaboration with MTRI. • 2016: Complete Great Lakes CoastWatch move to new server for improved image and data distribution and accessibility. • 2016: Test Visible Infrared Imaging Radiometer Suite (VIIRS) ocean color data for use in Great Lakes CPA algorithm and HAB algorithm. • 2017: Test and optimize SAR ice type algorithm and CPA algorithm with NESDIS toward operational implementation.
3. Develop real-time HAB, nutrients, and episodic hypoxia monitoring network on Lake Erie and Saginaw Bay.	• 2016: Deploy HAB, nutrients, and hypoxia monitoring buoys on western Lake Erie. • 2016: Deploy HAB and episodic hypoxia buoy on Saginaw Bay • 2017: Extend Saginaw Bay observations to include nutrient monitoring
4. Develop a hypoxia warning capability on Lake Erie.	• 2016: Deploy hypoxia and coastal current monitoring buoys in central Lake Erie. • 2016: Transition the central basin hypoxia-warning buoy into operations by GLOS. • 2017: Deploy a hypoxia-monitoring buoy in the Sandusky Basin. • 2018: Support development of a coupled FVCOM hydrodynamic and hypoxia model to forecast onset and position of the hypoxic water mass in central Lake Erie.
5. Continue to develop and deploy year-round, under-ice systems for ecological and physical observations.	• 2016: Deploy and test bottom-mounted profiler on Lake Erie. • 2016: Deploy ecological observing node on Lake Michigan with active and passive acoustics. • 2016: Deploy sensors for evaporation estimation on ReCON buoys and offshore structures. • 2017: Deploy a year-round, under-ice ReCON station in western Lake Erie reporting waves, currents, temperature, ice characteristics, and HAB data profiles. • 2018: Deploy year-round, under-ice ReCON stations in lakes Superior, Michigan and Huron reporting waves, currents, temperature, and ice characteristics. • 2019: Deploy UAV docking station in Lake Superior. • 2019: Add passive and active acoustics systems to Lake Huron and Lake Superior ReCON stations.

6. Test and evaluate real-time ship-based ice reconnaissance, ice transmittance, mapping algorithm, and ice thickness measurement capability.	• 2017: Measure Photosynthetic Active Radiation (PAR) transmittance of additional major ice types and evaluate for use with SAR ice classification maps to produce PAR attenuation maps of the Great Lakes. • 2018: Evaluate airborne and satellite ice thickness measurement technologies e.g., IceSAT, SAR constellations, and Ground Penetrating Radar.
7. Develop real-time vessel observations capability.	• 2017: Install communications and flow-through systems on LMFS vessels.



Technical Readiness Level (TRL) Definitions

1: Basic principles have been observed and reported.

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

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

4: Component/subsystem validation in laboratory environment.

5: System/subsystem validation in relevant environment.

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

7: System prototyping demonstration in an operational environment.

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

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

Technical readiness level of OSAT products.

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 Great Lakes 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.

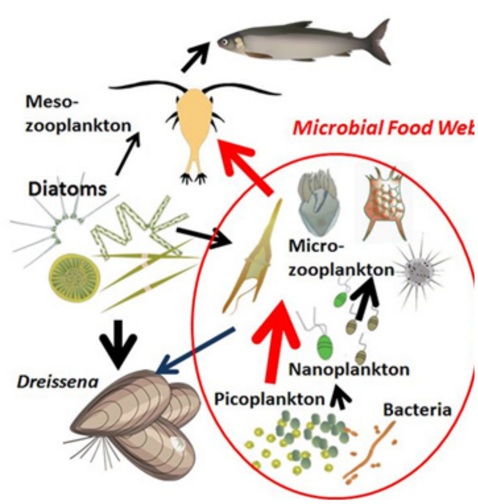
The EcoDyn branch strives to anticipate, monitor, analyze, understand, and forecast changes in the Great Lakes and coastal ecosystems to strengthen capacity for managing water quality, fisheries, and ecosystem and human health.

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

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. We suspect much of the energy now flows indirectly to zooplankton through the microbial food web potentially leading to less zooplankton and fish.

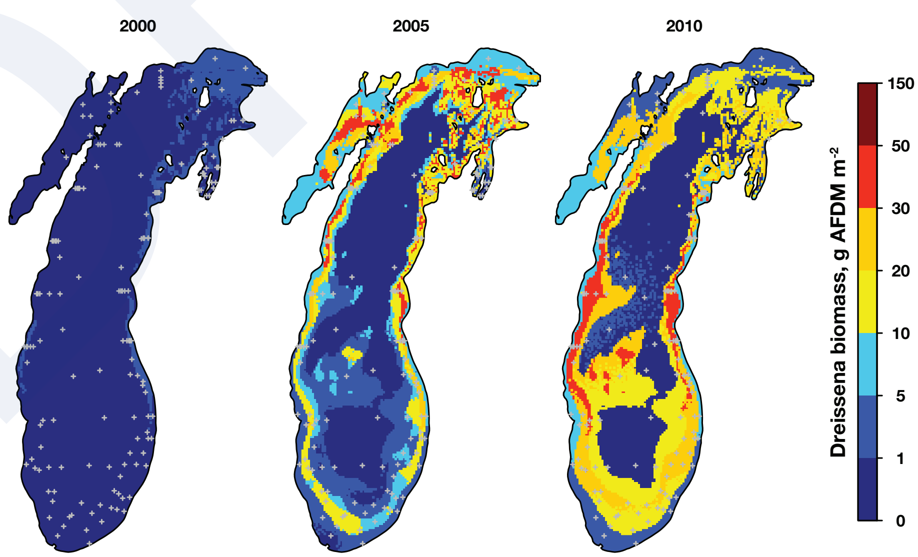
experiments. Key to EcoDyn's operation is acquisition and maintenance of critical equipment. For more details on GLERL's critical equipment, see Appendix H (currently in progress).

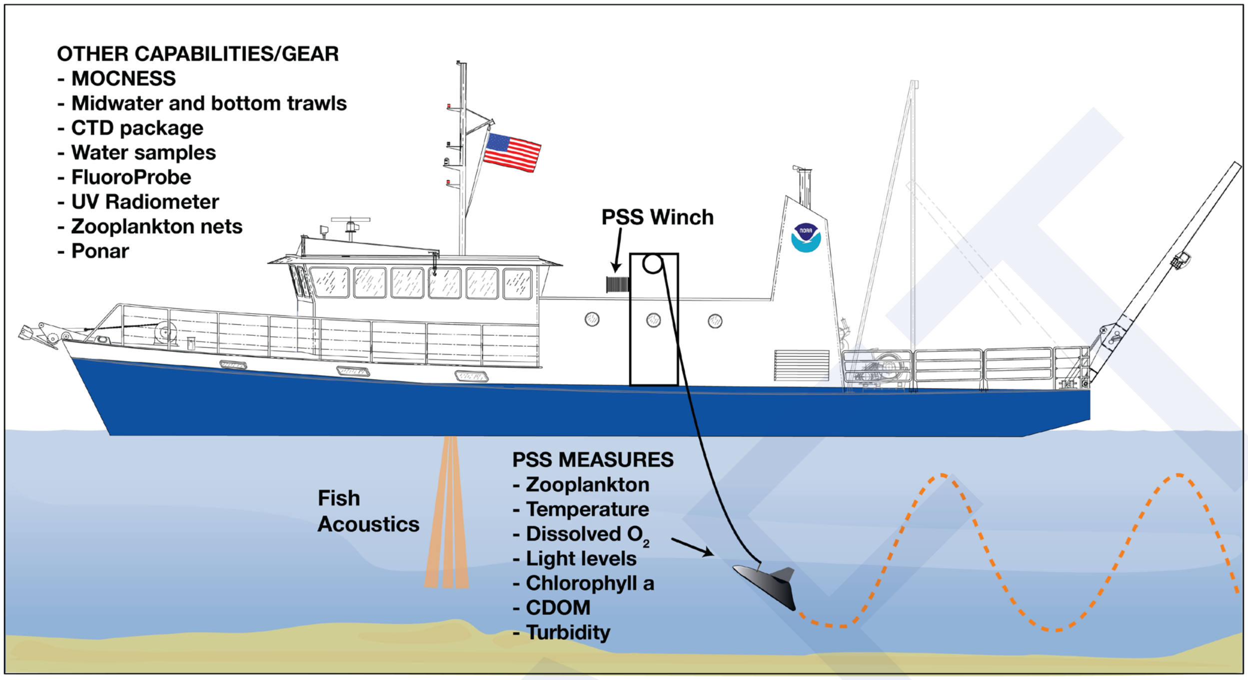
EcoDyn's Long-Term Research (LTR) program on Lake Michigan integrates a core set of long-term observations on biological, chemical, and physical variables, accompanied by process studies and field experiments, for understanding and forecasting ecosystem change. The LTR program makes seasonal observations 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 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.

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 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.





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.

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. 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, conducted jointly by GLERL and CILER scientists, is presented in the case study, *Harmful Algal Bloom Research: A Model Program for Adaptive Integrated Research* (page 29).

Models & Applications

EcoDyn modeling consists of nowcasts and scenario-based forecasts to predict the effects of invasive species, climate, nutrient loadings, and meteorology on Great Lakes 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.

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 Great Lakes 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 including Lake Winnipeg, Lake Taihu and Lake Victoria?

Paths and Related Milestones (2016-2020)

Path	Milestones
1. Continue LTR program on critical food web variables in nearshore and offshore Lake Michigan to meet management and forecasting needs.	• 2017: Compile long-term data sets from the Muskegon transect studies conducted during 1983-2015. • 2017: Analyze relationships between primary productivity, zooplankton, dreissenid mussels, and climate to determine impacts of multiple stressors on Lake Michigan zooplankton. • 2020: Evaluate whether changes in the lower food web have affected growth, density, and potential recruitment of larval alewife, bloater, and lake whitefish.
2. Continue to define and understand spatial interactions of nutrients and food-web components from microbes to fishes in lakes Michigan and Huron, and their consequences to food web production using state of the art technologies e.g., fisheries acoustics, laser optical plankton counter, and environmental sensors.	• 2016: Improve methodologies used on spatial cruises—integrate MOCNESS into sampling protocol. • 2018: Working with partners, characterize the importance of the microbial food web to planktonic and larval fish production in Lake Michigan. • 2017: Participate in Lake Huron Coordinated Science Monitoring Initiative (CSMI) • 2017 using the lessons learned from Lake Michigan CSMI 2015. • 2020: Understand spatial interactions among nutrients and food web components in lakes Michigan and Huron. • 2021: Develop a suite of ecosystem indicators from spatial data that can quantify the state of the system and the likelihood that it would transition to an alternate state.
3. Continue to monitor the status of benthic macroinvertebrate and dreissenid mussel populations in Lake Michigan and conduct experiments to evaluate factors that affect mussel abundance, feeding, growth, and condition in the Great Lakes as well as mussel impacts on Great Lakes food webs.	• 2016 and 2021: Update dreissenid density and biomass maps for the southern basin and the whole lake (2016, 2021). • 2018: Conduct in situ growth experiments to elucidate observed mussel biomass patterns. • 2019: Complete mussel feeding and growth experiments (at LMFS and Ann Arbor laboratories) to understand field growth observations and calibrate mussel bioenergetics models. • 2021: Define role of dreissenid mussel nutrient capture, excretion, and cycling in the Great Lakes.
4. Develop understanding of drivers of HAB dynamics in Lake Erie for development of tools to predict spatial distribution, extent, seasonal dynamics and toxicity.	• 2017: Include realistic estimates of Microcystis growth rates, mortality rates, and buoyancy in the HAB Tracker Model. • 2017: Detect microcystins using the ESP in western Lake Erie. • 2018: Understand the role of nitrogen in driving toxin production within and between different populations of HABs in western Lake Erie. • 2019: Develop a Great Lakes HAB genetic database to be used for the interpretation of laboratory and field based molecular and genetic ('omics') experiments. • 2020: Understand the interactions of plankton and benthic grazing, light and nutrients on HAB formation and toxicity.

5. Develop ecosystem models to provide scenario-based, nowcast, and forecast applications addressing Great Lakes ecosystem research and management questions.

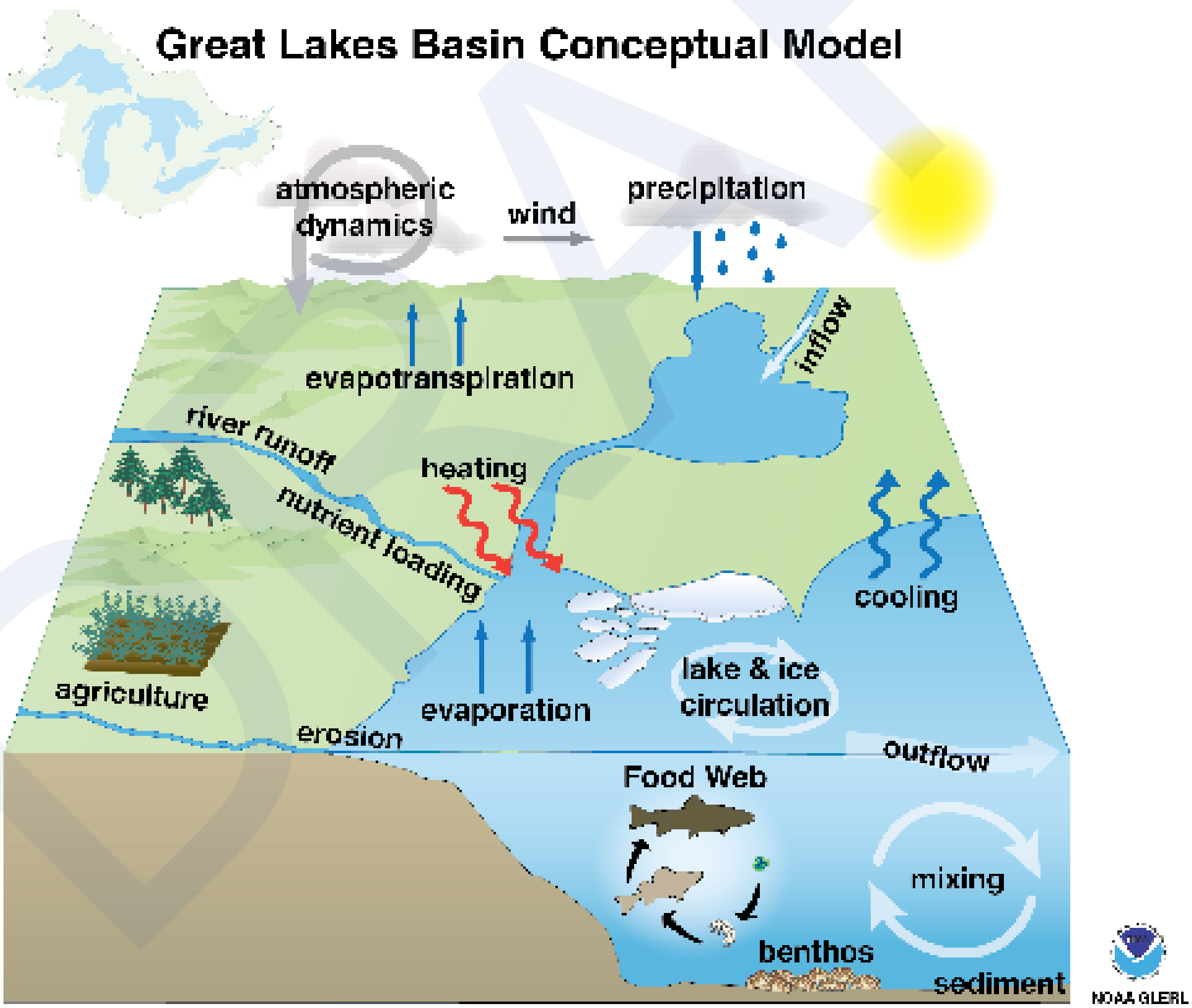
- 2017: Develop a water quality and lower food web model for 5-day and seasonal forecasts of Lake Erie HAB extent, distribution, and toxicity.
- 2017: Develop a Lake Michigan water quality and lower food web model that can be applied for development of nearshore and lake-wide nutrient criteria, and forecasts of prey fish recruitment potential and game fish distribution and migration.
- 2017: Develop and calibrate the Atlantis Ecosystem model to evaluate invasive species, climate, and nutrient impacts on food webs and fisheries in lakes Michigan, Erie and Huron.
- 2021: Make scenario-based and nowcast/forecast applications for water quality and lower food web models of Lake Erie central basin hypoxia.
- 2017: Analyze GLANSIS (Great Lakes Aquatic Nonindigenous Species Information System) data on spatial distribution of established nonindigenous species to improve prediction of species spread and guide monitoring.
- 2019: Update GLANSIS Watchlist to include additional species at risk of invading and becoming established in the Great Lakes based on the peer-reviewed scientific literature.

GLERL's EcoDyn team is initiating test runs on use of the MOCNESS with strobe to evaluate its ability to improve fine-scale sampling of Bythotrephes, Mysis, and larval fishes. Photo Credit: Courtesy: LTER Network Office

Integrated Physical and Ecological Modeling and Forecasting

Overview

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 below). 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.



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

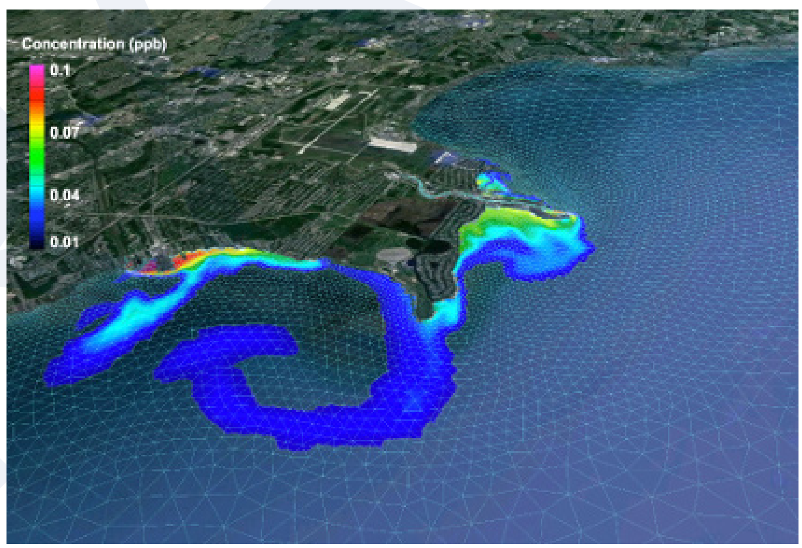
The IPEMF research program advances the following NOAA objectives:

- 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.



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.

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 our 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 (GLOS).

Guiding Principles

- Perform innovative research and develop an integrated modeling system to improve our forecasting capability
- Transition our research models into operations and applications (R2X)
- 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

Definitions of R2X

R2X

"Application of the best available science and technology is essential to meeting the NOAA mission. This demands an operations enterprise that is able to quickly recognize and apply significant new research products and methods; a research and development enterprise focused on the ultimate application of emerging science and technology to user needs; and a formalized management structure that ensures that both the research and development enterprise encourage and support the transfer of research to operational status or information services to meet mission responsibilities." (NAO 216-105: Policy on Transition of Research to Application)

Research to Operations (R2O)

R2O is the pathway by which fundamental research is developed into a useful tool or product that is run regularly and automatically. These tools and products provide routine real time and forecast guidance for application and use by the public.

Research to Application (R2A)

R2A is the pathway by which information from fundamental research is transferred to decision-makers or other end users in a non-operational framework.

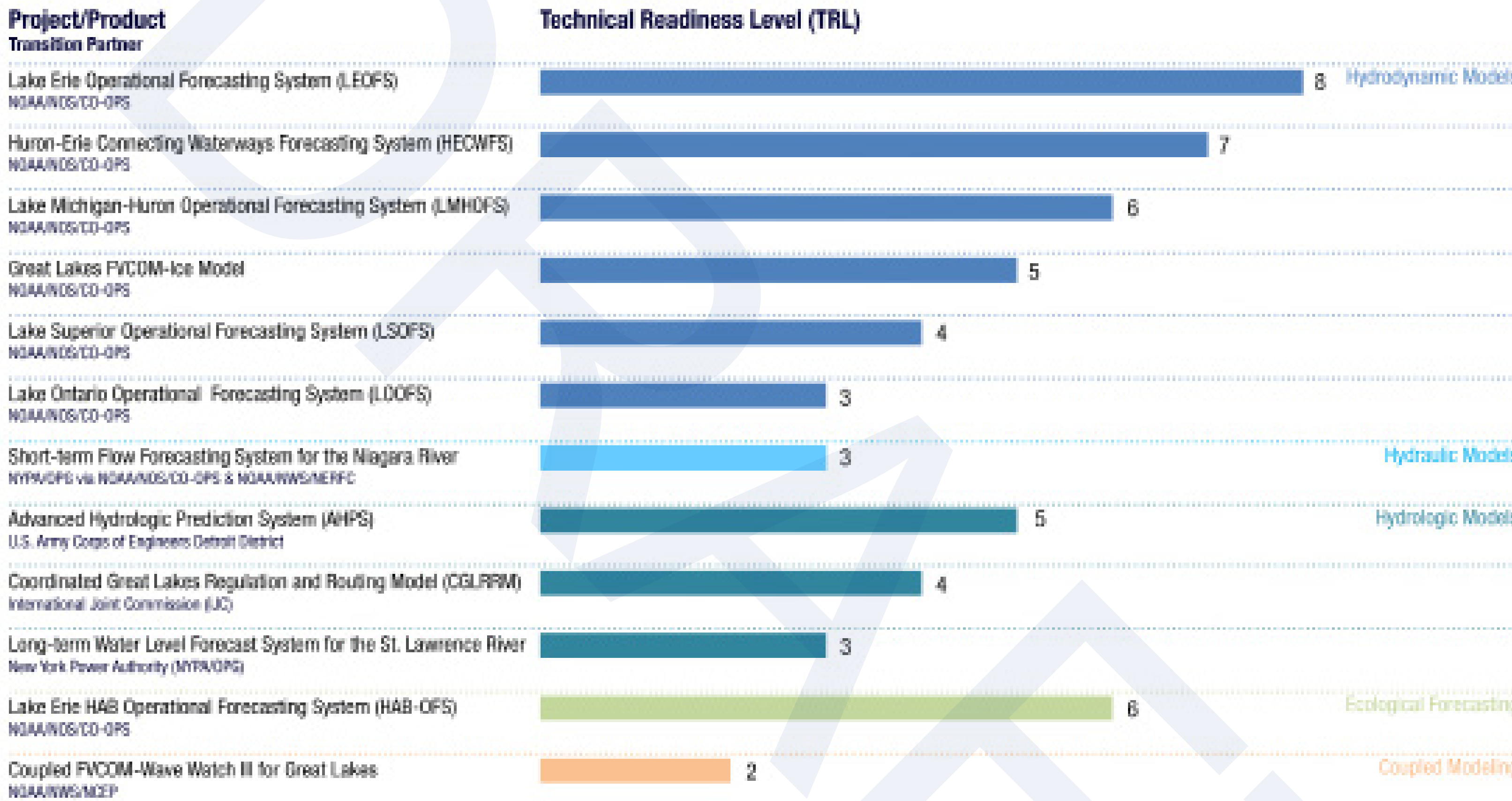
Goals and Research Questions

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? (Fig. X) • 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?

Paths and Milestones

Path	Milestones
1. Model integration and model improvement.	• Develop and implement a coupled atmosphere-lake-ice-wave forecasting system. • Develop and verify an ecological forecasting system (EFS) for HABs, hypoxia, and habitat. • Develop an atmospheric-hydrologic prediction system (i.e., Weather Research and Forecast Model for Hydrology (WRF-Hydro)) for the Great Lakes to improve prediction of large-scale water quantity and quality parameters. • Develop a coupled physical/biological model as a first step toward a fully integrated ecological modeling system. • Expand regional modeling efforts to predict the impacts of climate on physical and ecological conditions on a multi-decadal scale. • Provide reliable extended forecasts via ensemble techniques and reduced uncertainty. • Improve model accuracy and extend forecast period by assimilating satellite data and field measurements • Improve FVCOM-Ice model and apply the improved version to all five Great Lakes and the Arctic Ocean
2. Research to Operations (R2O): Research-based models are transitioned to operations through collaboration with NOAA partners.	• See R2O technical readiness chart below.
3. Research to Applications (R2A): Research-based models are transitioned to applications through collaboration with important stakeholders or other government agencies.	• See R2A technical readiness chart below.

4. Continue and expand role in leading internal and external collaboration and, scientific expertise and knowledge transfer on a regional and national level.	Internal • Collaborate with EcoDyn branch scientists and CILER to monitor HABs and hypoxia for use in the development of ecological and water quality models • Collaborate with OSAT branch engineers to assimilate data (field observations or satellite remote sensed data) to improve computer model accuracy. External • Conduct workshops, symposiums, IJC Annex Committees, public presentations, publications in response to policy needs and regional governance • Biannual Inter-agency Water Levels update media tele-conference (spring/ fall for the next 5 years). • 2016-2018: Execution of IAHR Ice Symposium and publication of conference proceedings • Enhance collaboration with Sea-Ice Modeling Working Group • Play a leadership role in Pacific Arctic Group Planning • Great Lakes Water Quality Agreement (Annexes 2 , 4, 9, 10: Nearshore Framework, Nutrient, Climate, Science) • 2016-2020: Continue to provide leadership and expertise on Coordinating Committee on Great Lakes Basin Hydraulic and Hydrologic Data and in this role advance over-lake precipitation products with a goal of publicly disseminating the product • Continue to conduct research and provide scientific leadership in support of GLRI • 2016-2020: Maintain leadership roles on the NOAA Ecosystem Forecasting Roadmap Technical Teams – HABs/Hypoxia, Infrastructure and Planning, Habitat and Species Distribution • 2016-2017: Ecological Forecasting Roadmap deliverables support transition of the HAB Bulletin • 2016 -2020: Support National Water Center team in the development of deliverables for calibrating and evaluating the WRF-Hydro model for the Great Lakes • 2016: Host NOAA-Environment Canada Bi-Lateral Agreement Marine Forecasting Workshop • 2016: Host Bi-National Geo Fabric Workshop • 2016: Continue to provide leadership and expertise for the IJC Adaptive Management Committee to complete work plan for developing lake regulation performance • 2017: Complete model comparison with Environment Canada for Great Lakes hydrodynamic forecast systems
5. Establishing methodology for uncertainty estimation and probabilistic forecasting.	• 2018: Develop a nutrient loading model and the skill assessment tools in a Bayesian network framework • 2017: Advance seasonal ice forecast incorporating uncertainty estimation • 2018-2020: Develop appropriate matrix and tools to evaluate model skills • 2019: Develop skill assessment and uncertainty estimation for HABs forecasting • 2017: Develop seasonal forecast regression models for lake ice cover in all five individual lakes



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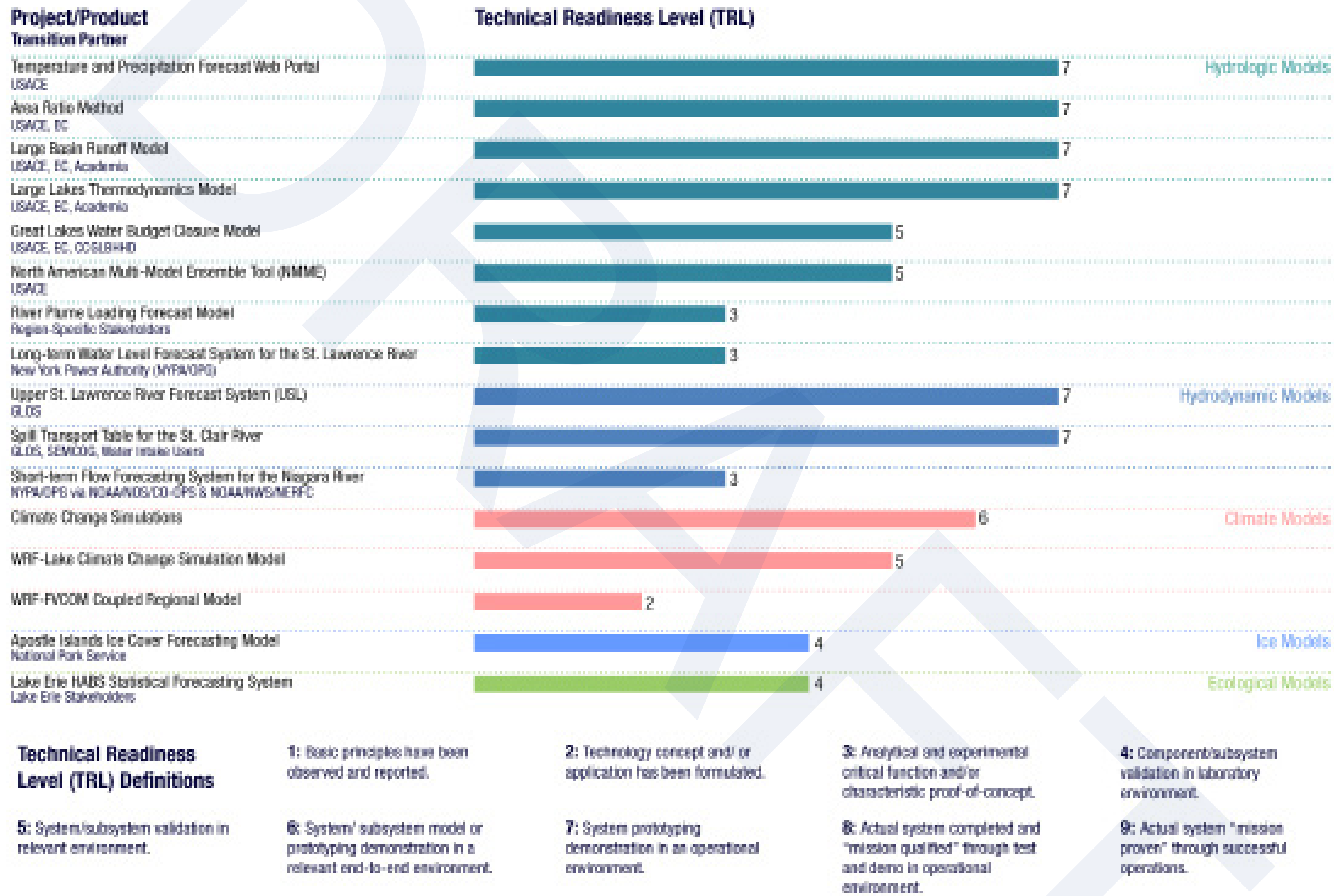
7: System prototyping demonstration in an operational environment.

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

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

Technical readiness level of IPEMF research to operation (R2O) products.



Technical readiness level of IPEMF research to applicatoin (R2A) products.

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.

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 co-located NOAA Great Lakes partners in Ann Arbor and Muskegon. This "inreach" fosters connectivity between staff and elevates awareness of NOAA-wide 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.

NOAA Great Lakes 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 membership includes representatives from all the 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's projects is building NOAA in the Great Lakes communication and outreach tool kit that highlights NOAA expertise, products and services in the region.

Guiding Principles for Information Services

- 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 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 booth with hands-on educational activities for elementary kids attending the Muskegon Area School District Water Festival, October 2, 2014 (S. Pothoven). Credit: NOAA

Goals and Drivers

Goal	Drivers
1. A collaborative organizational environment that fosters information flow, transparency, trust, and a team-building approach, and enhances 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 Great Lakes 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 the ISB's understanding of GLERL's reach and branding • Devise mechanisms for overall improvement of the ISB's programs • Ensure that GLERL's products and services are appropriately acknowledged • Evaluate, document, and report impacts of GLERL research

Paths and Related Milestones (2016-2020)

Path	Milestones
1. Facilitate an internal information flow that promotes a collaborative, interdisciplinary organizational environment.	• Continue to facilitate/support GLERL strategic planning, science leadership, operational leadership · Full participation on Director's team (ongoing), Science Council (ongoing), Infrastructure Council (ongoing), Strategic Planning team (2016) , and GLERL Science Program Review Team (2016) · Support All-Hands Meetings (monthly) · Coordinate the development and writing/editing of GLERL's 2016-20 Strategic Plan (2016) • Maintain and enhance the integration of GLERL programs through a variety of internal communication mechanisms (ongoing) · White boards/bulletin boards (refresh monthly) · Council minutes (disseminate bi-weekly) · Email announcements (as needed by request) · GLERL Newsletter (4 issues per year) · Great Lakes Seminar Series (4/year) and GLERL Brown Bag Series, ensuring cross branch engagement (6/year) · Intranet: Revaluate content (2016) and update content (2017) · Monthly in-person ISB working sessions at LMFS • Maintain and administer ISB operations to ensure continued functionality of GLERL communications · Assess and fill staffing needs (ongoing) · Assess, prioritize and address maintenance, supplies, equipment and infrastructure needs (ongoing) · Conduct budgeting, planning, reporting, supervising (ongoing) · ISB staff training (ongoing)
2. Provide information support to GLERL staff to enhance their functionality.	• Expedite the editing, review, submission, and tracking of scientific manuscripts, posters and technical memorandum (ongoing) • Continue to support the GLERL science branches by overseeing all aspects of GLERL library services, to include: executing journal subscription process, fulfilling library service requests, and recruiting supplementary volunteer assistance (ongoing) • Training (e.g., media training, program design, etc.) (1 per year) • Workshop support (materials, give tours, provide information booklets, promotional materials, social media (ongoing) • Support VIP site visits (ongoing) • Provide talking points, slide support, graphics, photography, videos (ongoing)

3. Raise awareness and promote understanding of GLERL expertise, programs, products and services among other NOAA programs, NOAA leadership, and Congress.

- Execute coordination of GLERL's 5 year science review and strategic plan (2016)
    - Interface with OAR Program Planning and Evaluation Team (PPE) and NOAA leadership (2016)
    - Follow laboratory review timetable as described in "Laboratory Review Implementation Plan and Guide to Laboratories" and meet deadlines accordingly, including, providing logistical support for Provide support to GLERL staff in the development and writing of the strategic plan, including facilitation of sessions to build consensus in developing the plan (2016)
    - Generate a prioritized list of infographics for strategic plan and program review (2016) and create at least one infographic per GLERL branch (2016)
    - Incorporate comments/feedback from the program review into the strategic plan (2016)
- Serve on and inform OAR's Evaluations Community of Practice (2016-2017)
- Provide information support for NOAA and Congressional data calls / information requests (ongoing)
- Promote GLERL expertise and produce a variety of program and reporting documents to document/track impacts (ongoing)
    - Organize tracking of GLERL publication, reprints, presentations, accomplishments, media inquiries, press mentions, information requests (ongoing)
    - OAR Hot Item submissions (weekly)
    - OAR Media Weekly submissions (as appropriate)
    - GLERL Newsletter (quarterly)
    - Publication reports (monthly/quarterly/annual)
    - Information requests reports (quarterly)
    - Media inquiry/press-mention reports (quarterly)
    - Provide support to NOAA Legislative Affairs, NOAA International Affairs, OAR Formulation and Congressional Analysis office to plan and execute Congressional Hill visits (annual)

4. Advance Great Lakes regional collaboration

- ISB Chief works in conjunction with Great Lakes Sea Grant Network specialist to establish an MOU to formalize Great Lakes Regional Outreach Extension position (2016)
    - Coordinate with GLERL, Michigan Sea Grant, and National Sea Grant Program Office (ongoing)
- Coordinate with GLRCT working group to advance their action plan
    - ISB graphic designer to work in conjunction with GLRCT to update Great Lakes Regional Collaboration Team website (2016)
    - Create target list and coordinate on tabling /NOAA booths at regional events (2016)
    - Develop strategies to better coordinate on Congressional interactions with an emphasis on Congressional district office visits (2017)
    - Begin to identify best practices for (local) coordination of events, conferences, proposals and hosting (2018)
    - Create an inventory of NOAA communications, education and outreach expertise, products and services in the Great Lakes (2018)

5. Identify and meet information needs of constituent groups, while promoting GLER's expertise, products and services.

- Produce a variety of science translation products to promote GLERL scientific research (ongoing)
  - Factsheets (ongoing)
    - Evaluate portfolio and determine which to update, archive and identify gaps for the development of new factsheets (2016 overhaul and annually thereafter)
    - Develop new (4/year) and update existing factsheets (ongoing)
  - Infographics
    - Create an inventory of existing infographics and priority list of needed community outreach infographics (2016)
    - Create infographics identified as priorities (4/year)
  - Social media campaign (ongoing)
    - Evaluate GLERL social media program and assign staff (2016)
    - Explore social media options to enhance stakeholder science exchange (e.g. blog on a science issues) (2017)
    - Maintain social media program (ongoing)
  - Web Site
    - Execute rollout of new web site template (2016)
    - Update content on top level navigation pages (2016)
    - Update and maintain information posted on GLERL's internal and external website in accordance with established design, style, and organization of content and federal accessibility requirements (ongoing)
    - Maintain and refresh web site content (ongoing)
    - Evaluate GLERL website traffic, pre and post template launch (2017) and annually thereafter
  - Webinars, seminars, and media teleconferences covering recent research developments (ongoing)
    - Evaluate and prioritize updates for AV equipment in conferences rooms in conjunction with IT staff (2016)
    - Advance webinar Standard Operating Plan in conjunction with IT staff (2016)
    - Coordinate with CILER and GLERL committee to identify and recruit speakers for the Great Lakes seminar series
    - Promote GLERL science via media teleconferences in conjunction with OAR Media Affairs and other research partner media affiliates (as appropriate)
  - Photo, video, and data visualization products
    - Inventory and evaluate products (2017)
    - Identify and fill gaps (ongoing)

- Tours
    - Evaluate and update GLERL facility tour document (2017)
    - Create a tour document for Lake Michigan Field Station (2018)
    - Strategize how to prioritize tour requests (2017)
    - Organize, coordinate and give tours (ongoing)
- Other miscellaneous outreach and events
    - Attend a variety of events to promote GLERL research, job opportunities, and promote environmental stewardship within the general public
    - Disseminate GLERL promotional products (ongoing)
- Respond to information requests (ongoing)
- Respond to media requests (ongoing)
- Conduct workshops on priority issues (ongoing)
- In accordance with NOAA guidance, goals and vision, develop an internal branding and communications guidelines document, that ensures appropriate credit, logo use, taglines etc. and disseminate to the ISB team and GLRCT communications and outreach working group (2016)

NOAA GLERL booth at Ann Arbor Green Fair, June 14, 2013. Credit: NOAA.

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 inform 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 these different types of evaluation inform GLERL's scientific research program.

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 and 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.	Do we 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 our 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 environmental compliance, quality standards, safety standards, and 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 environmental and safety standards?	Trainings and certifications; risk assessments; and 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 customer base through a commitment to communication, including needs assessment, consistent messaging and accessibility of GLERL's scientific knowledge and information, observations, data, 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 our 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.
	Are we providing public access to our 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 our 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.
Transitioning Research Products Facilitate transition to operations (R2O) and application (R2A) as part of the development and implementation of research programs.	Does an appropriate portion of GLERL's research make the transition to operations/applications (R2X)?	Number of products transitioned to other NOAA line offices, number of products transitioned to 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 R2O pipeline that will be transitioned?	Number of transition plans in place.

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 organizational excellence by building 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, safety, security, quality, data management, and operational efficiency?	Ongoing documentation of safety/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?	Percentage of metrics achieved from year to year to track progress.
Interdisciplinary & Partnership Approach Integrate an interdisciplinary approach and use partnerships, such as those with NOAA Cooperative Institutes, to strengthen capacity to advance GLERL's mission and vision.	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.
Balanced Research Portfolio Balance in GLERL's portfolio between fundamental and applied research.	Is there a balance between fundamental and applied research in GLERL's research portfolio?	Percentage of research in each category that meets targeted balance. (30% fundamental and 70% applied)

Return on Investment Provide value to the nation through effective use of taxpayers' investment.	Are we effectively reaching milestones within a reasonable timeframe?	Milestone checklist from strategic plan and Annual Operating Plans (AOPs).
	Are we using funds efficiently?	Percentage of funds obligated by the end of the fiscal year (99%).
	Are we prioritizing use of GLERL assets, including scientific research facilities in Ann Arbor and Muskegon? Are we 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.
	Are our products producing economic and social benefits, directly or indirectly?	Reduced HAB exposure incidents, reduction in excess nutrients, reduced drowning deaths due to marine events such as rip currents or meteotsunamis
Physical Access to the Great Lakes Serve as a resource to NOAA and regional partners by providing physical access to the Great Lakes through the GLERL Lake Michigan Field Station and vessel fleet.	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.
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 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, GLERL management requests for staff input, incorporation of bottom up strategic planning, Baldridge Survey Outcomes.
	Do we work towards reaching diverse audience groups?	Number of communication and outreach events targeting underserved audience groups.

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 in the face of uncertainty, 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 of Limnology and Ecosystems, affiliated with NOAA Cooperative Institutes— a consortium of academic research institutes in the Great Lakes region— supporting 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 (sponsored by the U.S. Environmental Protection Agency and NOAA) 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.

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.

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 control 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 that 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 activities 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.

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 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.

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.

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 refers to the pathway by which information is transferred from the research phase to decision-makers or other end-users in a non-operational framework.

R2O | Research to operations refers to the pathway by which fundamental research is developed into a useful product or service that is provided automatically and with regularity. These products and services provide routine, real-time and forecast information for use by the public.

R2X | Research to operations or other applications refers to the pathway described by the following | "Application of the best available science and technology is essential to meeting the NOAA mission. This demands an operations enterprise that is able to quickly recognize and apply significant new research products and methods; a research and development enterprise focused on the ultimate application of emerging science and technology to user needs; and a formalized management structure that ensures that both the research and development enterprise encourage and support the transfer of research to operational status or information services to meet mission responsibilities" (NAO 216-105 | 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 to absorb 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.