The Cooperative Institute for Great Lakes Research (CIGLR)

A Proposal to the Office of Oceanic and Atmospheric Research,
National Oceanic and Atmospheric Administration, for a new Regional Research Institute

1 July 2017 – 30 June 2022

Table of contents

I. Title page

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Year 2: $4,000,000
Year 3: $4,000,000
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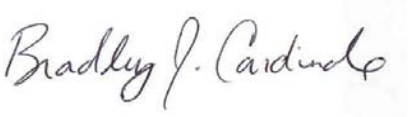
Total: $20,000,000



2/10/2017

Bradley J. Cardinale Date

The Cooperative Institute for Great Lakes Research (CIGLR)

A Proposal to the Office of Oceanic and Atmospheric Research,
National Oceanic and Atmospheric Administration, for a new Regional Research Institute

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Listed by institution in Appendix 2

Total Budget: $20,000,000
Budget Period: July 1, 2017 through June 30, 2022

II. Abstract

We propose to establish the Cooperative Institute for Great Lakes Research (CIGLR) to accelerate NOAA's mission in the Great Lakes by (1) facilitating and leading the primary research needed to meet key sustainability challenges faced in managing the Laurentian Great Lakes, (2) increasing the impacts of research by fostering engagement with resource managers and decision-makers that help turn science into action, (3) providing cutting-edge career training that prepares a diverse, and adaptable workforce of social scientists, natural scientists, engineers and design experts to be the next generation of researchers and practitioners on the Great Lakes, and (4) promoting public literacy about the Great Lakes with a coordinated outreach and communications program across the region.

CIGLR will be composed of a Research Institute and a Regional Consortium. The objective of the Research Institute will be to recruit, train, and retain highly-qualified research scientists and

scientific staff to work alongside researchers at NOAA's Great Lakes Environmental Research Lab (GLERL). The Research Institute will be complemented by a Regional Consortium that will broaden the intellectual expertise, research capacity, and geographic scope of NOAA's research programs across the Great Lakes region. CIGLR's research will focus on four themes that directly align with NOAA-GLERL research areas:

Theme 1. Observing systems and advanced technology: *monitoring environmental change to help society navigate the Anthropocene.*
Theme 2. Invasive species and food-web ecology: *tracking the dynamics and functioning of Great Lakes ecological communities.*
Theme 3. Hydrometeorological and ecosystem forecasting: *modeling physical and biological processes to help predict the Great Lakes health and future.*
Theme 4. Protection and restoration of resources: *safeguarding habitats, natural capital, and ecosystem services throughout the Great Lakes*

The foci and projects proposed for each theme address all key topics in NOAA's 20-year Grand Challenges, 5-year Research and Development Plan, and Next Generation Strategic Plan.

CILGR will transition research into practice through the Engagement, Career Training, and Outreach and Communications (ECO) Program, thus producing *Great Lakes science for society*.

Highlights of our proposal include **…**

Exceptional research capacity. Over 200 PIs at University Partners within the Regional Consortium will share their intellectual and research capacity in support of NOAA's mission in the Great Lakes, which includes 10 field stations, a fleet of 12 research vessels, more than a dozen engineering and design labs, a well-coordinated system of 38 mooring stations, mobile platforms, and remote sensing systems, and an unprecedented set of specialty labs in genomics, GIS/remote sensing, high-performance computing, and physical/ chemical analyses.

True inter-disciplinarity. We have taken seriously NOAA's Grand Challenge to *"incorporate human behavior into Earth system sciences"* and to *"integrate disciplines for a systems perspective."* Our University Partners bring together a large group of natural and social scientists, as well as experts in engineering and design who have committed to work together on projects that help NOAA-GLERL better respond to societal needs by considering human values and behaviors in the design of research, applications, model outputs, and data products.

Bi-national collaboration. Partners of this proposal include institutions on both sides of the U.S.-Canadian border who have agreed to work collaboratively with the explicit support of major international initiatives (International Joint Commission, and Council of Great Lakes Industries).

Major cost-sharing. University Partners have agreed to highly reduced indirect cost-rates that guarantee NOAA a uniformly low cost of doing research with academic institutions across the Great Lakes. In total, this proposal includes $5.33 million in cost-sharing and in-kind support over the 5-yr Cooperative Agreement.

Accelerated transition of R&D. Our proposal includes meaningful Private-sector partnerships with environmental consulting firms, technology development companies, Great Lakes industries and NGOs who will help us accelerate the transition of scientific research into applications, and augment our mission of engaging the public and policy-makers.

III. Results from Prior Research

The Cooperative Institute for Limnology and Ecosystems Research (CILER) was established in 1989 with an MOU between the University of Michigan and the Undersecretary of Oceans and Atmosphere in the U.S. Department of Commerce. Since the inception of CILER, NOAA has awarded 6 consecutive multi-year Cooperative Agreements (CAs) to the University of Michigan to help NOAA accomplish its mission in the Great Lakes region. Over the course of the last CA (2008-present), CILER had a significant impact on Great Lakes science, as demonstrated by overall grant funding, the level of NOAA and academic partnership, research outcomes, and career training activities (Fig. 1). With over $35 million in NOAA CA funding and an additional $8.4 million in external funds, CILER produced 418 journal articles representing 60% of NOAA-GLERL's peer-reviewed publications. This body of work was cited 6,575 times and mentioned 663 times in social media and public news outlets. CILER provided career training to 579 students and postdocs, and funded $13 million in university-NOAA research at partner institutions.

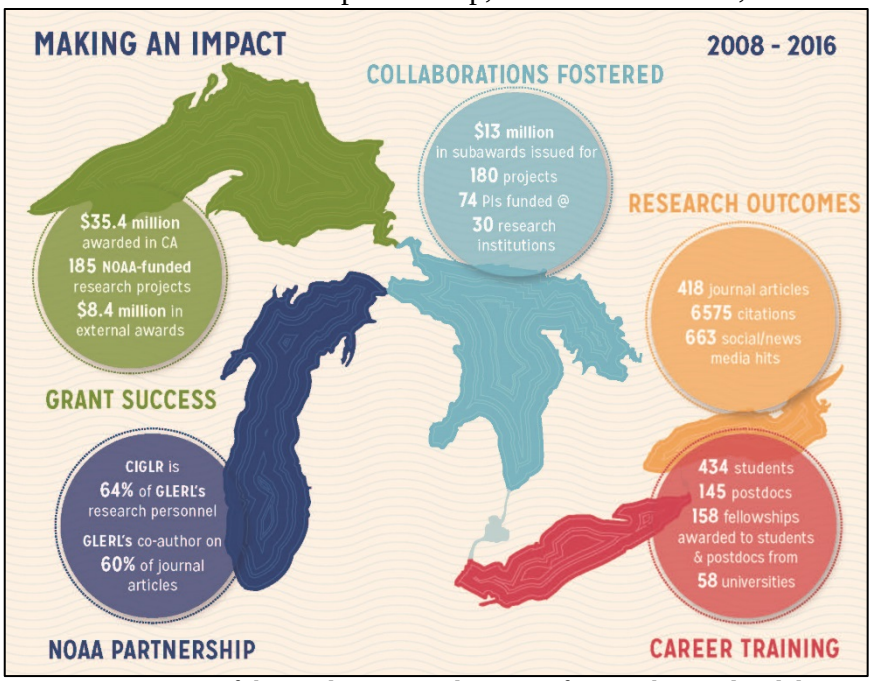


Figure 1. Summary of the productivity and impact of research completed during the last Cooperative Agreement with NOAA.

A defining strength of CILER has been our ability to directly align with NOAA-GLERL's existing research goals while maintaining the flexibility to address emerging issues. This capacity has been most notable over the past 7 years as CILER has helped implement major new efforts established under the multi-Federal agency Great Lakes Restoration Initiative (GLRI). A select subset of CILER's research accomplishments is summarized below, organized by NOAA-GLERL's three research foci. A comprehensive list of prior research is provided in Appendix 1.

Observing Systems and Advanced Technology. CILER led a multi-institution effort to implement the Great Lakes Observing System Regional Association (GLOS-RA) nearshore observing network. This project helped establish, develop, and maintain operational capabilities for an array of integrated open-lake observing systems across the Great Lakes, including buoy moorings, automated underwater vehicles (AUVs)/gliders, vessel-mounted sensors, and satellite remote sensing. Nearshore wind and wave data delivered by the buoy network provided critical missing observations used to improve wave forecasting that served public end users, such as recreational boaters. Gliders and vessel observations provided core physical-chemical observations at unprecedented temporal and spatial scales, which were used to complement multi-Federal agency efforts under the Coordinated Monitoring and Science Initiative (CMSI) for understanding how biological structure and function is organized across lake scales in

response to coastal nutrient inputs and distribution of invasive mussels. These datasets also provide unmatched scales of observations for calibration and validation of lake-scale hydrodynamic models, as well as coupled physical-biological forecasting models to assess impacts of environmental stressors or management actions. CILER also led the Synthesis, Observations, and Response (SOAR) program, a multi-institution project to develop decision support tools for regional managers based on continuous *in situ* observing system data. Within SOAR, we helped develop the first hypoxia warning system by combining observing data with meteorological and circulation models to predict entrainment of hypoxic water into public drinking water intake areas. We also produced a network of continuous monitoring buoys that provide hourly measurements of nutrients and algal distributions, which serve as a real-time warning system for harmful algal blooms (HABs). These observing systems advanced our understanding of lake-scale nutrient dynamics, which will support future assessments of how Lake Erie responds to nutrient reduction strategies developed under the Great Lakes Water Quality Agreement, and in turn, their effectiveness at addressing impacts of HABs and hypoxia.

Integrated Modeling and Forecasting. CILER significantly increased GLERL's capacity to develop and operate coupled physical-biological forecasting models that are central to the Lab's mission. We supported the Great Lakes Coastal Forecasting System (GLCFS) transition from research to operations by developing FVCOM-based hydrodynamic, ice-cover, and evaporation components of the system. GLCFS is in the process of being operationalized by NOAA National Ocean Service, beginning with the Lake Erie Operational Forecasting System (LEOFS). It provides nowcasts and forecasts of currents, temperature, and water levels to the public and resource managers to inform the use and management of the Great Lakes. CILER programmers worked closely with GLERL scientists to develop the Great Lakes Dashboard (GLD), as part of a project to model water level response to climate variability. Designed to meet the needs of scientists and natural resource managers, this publically-available online data visualization tool represents a major advancement in Great Lakes data accessibility. Within ECOFORE we helped develop a forecasting model to predict hypoxic area and DO concentration in Lake Erie, as a function of nutrient loads and physical variability. This model was used to support the development of new target phosphorus loads recently adopted by the International Joint Commission (IJC).

Ecosystem Dynamics. Invasive species research led by CILER established a foundational understanding of the ecosystem-level impacts of established and potential Great Lakes invaders. *Dreissenid* mussel research within the Lake Michigan long-term ecological monitoring program included detailed experiments on feeding, excretion, and impacts to energy cycling, which combined with geostatistical and biophysical modeling to lay the groundwork for basin-wide understanding of the impacts of this ubiquitous invader. Our biophysical modeling of Asian carp impacts to the Lake Erie food web predicted that in 20 years, Asian carp could reach their peak biomass and represent nearly 30% of total fish biomass. This work helped fisheries managers predict the ecological and economic impacts of potential Asian carp invasion. CILER's harmful algal bloom (HAB) program used biophysical modeling, experiments, and metagenomic studies to improve understanding of the environmental drivers of HAB intensity and toxicity in Lake Erie. Working with the NOAA National Centers for Coastal Ocean Science (NCCOS), this research resulted in the development of an operational HABs forecast for Lake Erie (NOAA's second operational HABs forecast) and the direct delivery of HAB-related toxicity measurements to drinking water intake managers.

IV. Project Description

Overview

The Laurentian Great Lakes are one of the most biologically diverse, economically important, and aesthetically inspiring natural resources on Earth. As the single largest body of freshwater on the planet (22,000 km^3) the Great Lakes contain 20% of the Earth's surface freshwater and 90% of surface freshwater in the United States[1]. Rich in biodiversity and abundant in habitat, the lakes provide ecosystem services like drinking water, recreational and commercial fishing, pollution control, and cultural experiences that hold incredible societal value for more than 35 million residents in the region. The basin collectively supports a gross regional product (GRP) of ~$4.1 trillion USD[2], making it one of the great "blue economies" in the world[3].

But the combination of a dense human population and intense economic activity has led to overexploitation of ecosystems and widespread degradation of habitats throughout the Great Lakes[4]. Today, fewer than half the region's original forest and wetland areas remain. Important fishery resources, such as salmon, lake trout, yellow perch, and walleye, are vulnerable to ecosystem changes and overfishing. The Great Lakes and its watersheds are increasingly under pressure by water extraction, harmful algal bloom intensity and frequency, invasive species introduction and spread, public beach closure frequency, and numerous emerging stressors[4]. The vitality of the Great Lakes, and the prosperity of people who depend on them, will ultimately be determined by our success in learning how to sustainably manage this critical resource.

We propose to establish the new Cooperative Institute for Great Lakes Research (CIGLR) to accelerate NOAA's mission to conserve and manage natural resources in the Great Lakes by (1) facilitating and leading the primary research needed to overcome the key sustainability challenges faced in managing this important freshwater resource, (2) increasing the impacts of research by fostering engagement with resource managers and decision-makers that help turn science into action, (3) providing cutting-edge career training that prepares a diverse and adaptable workforce of social scientists, natural scientists, engineers, and landscape designers to be the next generation of researchers and practitioners on the Great Lakes, and (4) promoting public literacy about the Great Lakes with a coordinated outreach and communications program.

The Cooperative Institute for Great Lakes Research (CIGLR) will supersede the existing Cooperative Institute of Limnology and Ecosystems Research (CILER). We are proposing to change the name of the institute to reflect the increasing breadth of research that we facilitate in the Great Lakes, which has evolved from its original focus on natural science (limnology and ecosystem ecology) to interdisciplinary work that includes social science, engineering, and design. While the newly proposed CIGLR will build on the foundations laid by CILER, the newly proposed institute will differ from its predecessor in several ways:

Greater investment by host

Since 1989, the Great Lakes CI has been hosted by the University of Michigan in Ann Arbor, Michigan, where it is collocated with our sponsor, the NOAA Great Lakes Environmental Research Lab (GLERL). Over the last 27 years, the CI has evolved into a highly successful research institute that has developed a well-trained, stable workforce with the technical expertise needed to support NOAA-GLERL's research foci. But the University of Michigan has increasingly realized that achieving sustainability at the scale of the Great Lakes requires more intellectual capacity and research infrastructure than any one institution can provide. Not only do we need to maintain a strong research institution, we need to increasingly engage our regional

consortium of partners who can work together, and integrate more broadly with NGO's and business partners across the Great Lakes to foster stronger engagement, communication, and outreach that promotes excellence in the region as a whole. With this recognition, the University of Michigan has pledged its largest-ever financial commitment as CI host, more than doubling its prior cost-share investment in programs that will help build strong regional partnerships and more active engagement, career training, and outreach and communications for the region.

More impactful partnerships

Meeting the grand sustainability challenge we face in the Great Lakes requires coordinated interaction across two nations, eight states, and two provinces. Institutions spanning all of the Great Lakes on both sides of the border must forge better working relationships, and do more to involve private organizations and citizen groups who are end users of information. We helped pioneer the regional consortium model for NOAA CIs during our last Cooperative Agreement. The newly proposed CIGLR will significantly expand the concept of a regional consortium by leveraging the intellectual capacity of >200 researchers, and the infrastructure of dozens of universities, NGOs, private businesses, and government agencies on both sides of the U.S.-Canadian border. These organizations have committed to work together as part of the CIGLR Regional Consortium to address the most pressing sustainability challenges and their related human dimensions in the Great Lakes.

More interdisciplinary research

Most research in the Great Lakes, including that funded by NOAA, has been led by natural scientists who have focused on understanding the physical and biological processes that underlie environmental problems. While this work has been critically important for understanding how the Great Lakes work, all sustainability problems are ultimately people problems. In planning the new CI, we have taken seriously NOAA's Grand Challenge from its 20-year Research Vision[5] to *"incorporate human behavior into Earth system sciences"* and its 5-year Research and Development Plan[6] to *"integrate disciplines for a systems perspective."* Our proposal brings together a large group of natural scientists, social scientists, and experts in engineering and design who will work together with NOAA-GLERL to better respond to societal needs by more accurately considering human values and behaviors in the design of research, applications, model outputs, and data products.

Greater focus on co-design

Lasting partnerships are forged only when all who benefit from research work together to define the original questions and prioritize the products needed to solve a problem. The newly proposed CIGLR will have a substantially expanded set of programs that are designed to foster the co-design of research between NOAA PIs, academic PIs, Great Lakes businesses and industry, NGOs, and policymakers. The new CI will also engage more in outreach and communication activities that go beyond the one-way of dissemination of information to the public; instead, we will engage stakeholders from the start to finish of research, with continual feedback among researchers and end-users of data and products.

Transitioning research to application

The value of NOAA's research ultimately depends on how well we transition research into mission-driven applications, operational services, and commercialization. With programs like the Research Transition Acceleration Program (RTAP), NOAA continues to accelerate the transition of R&D outputs into operations, applications, commercialization, and other uses for societal

benefit (referred to as R2X). CIs, with their close connections to NOAA, help address the agency mission by ensuring that breakthroughs made by CI partners are directly transitioned into the NOAA enterprise. As part of its Regional Consortium, the new CIGLR will forge private partnerships with environmental consulting firms, companies that specialize in commercial application of aquatic instrumentation, as well as numerous industries, manufacturing companies, and NGOs that will help accelerate the transition of scientific research into applications and services for the public. This ultimate goal of supporting the pathway from science to public services is reflected in the CIGLR tagline "Great Lakes Science for Society."

Mission and Goals

NOAA's mission is to *understand and predict changes in climate, weather, oceans, and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources.* To guide this mission, NOAA commissioned a suite of visioning and planning exercises (e.g., NOAA's 20-year Research Vision[5], Next Generation Strategic Plan[7], and 5-year Research and Development Plan[6]) to identify its most pressing challenges and research needs (Box 1). NOAA's Chief Scientist Dr. Richard Spinrad also led a recent evaluation of the CI program, leading to his report titled "*Prospectus for Cooperative Institutes in the 21st Century"* (CI21). A key challenge identified in CI21 was the need for stronger mission alignment between CIs and their respective NOAA labs to maximize the efficiency of NOAA's R&D programs.

Box 1. NOAA's Grand Challenges and Research Priorities

NOAA's 20-yr Research Vision & Grand Challenges (N20)

1. *Enhance atmosphere-ocean-land-biology and human observing systems*
2. *Improve predictions of the water cycle at global to local scales*
3. *Characterize how climate variation impacts oceans (Great Lakes) and coasts*
4. *Characterize uncertainties associated with scientific information*
5. *Understand how biodiversity & ecosystem processes sustain ecosystem services*
6. *Develop approaches to reduce environmental degradation*
7. *Incorporate human behavior into Earth system sciences*
8. *Communicate science effectively to policy makers, the media, and the public*

NOAA's Next Generation Strategic Plan (NGSP)

1. *Climate adaptation & mitigation: anticipating & responding to climate impacts*
2. *Weather-ready nation: preparing society to respond to weather related events*
3. *Healthy oceans and Great Lakes: sustaining fisheries, habitats, and biodiversity*
4. *Resilient communities: environmentally & economically sustainable coasts*

NOAA's 5-year Research & Development Plan (N5)

1. *Climate variation and its impacts*
2. *Managing and leveraging big data*
3. *Extreme weather and water events*
4. *Preparing for and responding to unpredictable events*
5. *Modeling and managing complex systems*
6. *Integrating disciplines for a systems perspective*

NOAA's Great Lakes Environmental Research Laboratory (GLERL) will be the primary sponsor of CIGLR and home of the Research Institute personnel. GLERL recently published its strategic research and implementation plans[8,9], which identified four foci that will organize and guide their research in the Great Lakes: (1) Observing systems and advanced technology, (2) Ecosystem dynamics, (3) Integrated physical and ecological modeling and forecasting, and (4) Information services. The mission, goals, and proposed research activities for the new Cooperative Institute for Great Lakes Research (CIGLR) overlap perfectly with NOAA-GLERL's research foci. In addition, all of our research and programmatic activities map onto NOAA's 8 grand challenges in its 20-year Research Vision, 6 research foci in the 5-year Research and Development Plan, and 4 visions in the Next Generation Strategic Plan (Box 1, Appendix 3).

CIGLR: Mission and goals

The mission of CIGLR will be to lead research, develop applications and products, and engage with stakeholders to achieve sustainable management of the Great Lakes. To achieve this mission, all CIGLR activities will revolve around 6 goals:

1. Research institute. CIGLR will operate a productive research institute that complements NOAA-GLERL's workforce with a highly-skilled, permanent group of research scientists, technicians, and staff that acts as a fully-integrated part of GLERL's scientific enterprise and serves to expand GLERL's research expertise.
2. Regional consortium. CIGLR will expand GLERL's intellectual capacity and research infrastructure by building strong partnerships with universities, NGOs, and private-sector partners throughout the Great Lakes basin who share similar research and management goals in the Great Lakes.
3. Science translation. CIGLR will help translate NOAA research in the Great Lakes into action-oriented, science-based products that meet the needs of end-user stakeholders like natural resource managers, businesses, public utilities, and citizen users of data.
4. Engagement. CIGLR will support informed decision making by advising local, state, and federal policymakers and elected officials about the importance of the Great Lakes for national security, commerce, human health, economic prosperity and sustainability.
5. Career development. CIGLR will foster the development of a diverse, skilled workforce by providing career training for undergraduates, graduate students, and postdoctoral fellows who will become the next generation of NOAA and Great Lakes scientists.
6. Outreach & communications. CIGLR will advance Great Lakes environmental literacy by communicating the value, importance, and usefulness of NOAA's research to the general public at local, state, and regional levels.

To accomplish Goal 1, the University of Michigan will recruit, train, and maintain a highly-qualified scientific staff to work alongside GLERL PIs to expand their research capabilities. To accomplish Goal 2, the University of Michigan will build and incentivize a Regional Consortium of partners that expands the geographic scope, intellectual capacity, and technical capabilities of NOAA research across the Great Lakes. Science translation (Goal 3) will be accomplished within specific research projects, each of which will be required to identify and develop products that put meaningful science in the hands of stakeholders. The new CIGLR Regional Consortium includes select Private-sector Partners that specialize in science translation and will be integral in

helping us maximize our efforts to translate NOAA science to society. Goals 4-6 are addressed in Section VI. of the proposal where we discuss our plans for the Engagement, Career Training, and Outreach & Communications (ECO) Program. Our ECO Program will be jointly implemented by the Research Institute and Regional Consortium.

In the next few sections of the proposal, we provide more details about the structure of CIGLR's Research Institute, Regional Consortium, and the research capacity they provide to NOAA.

CIGLR: Research Institute

CIGLR will be, first and foremost, a research institute. As a research institute, CIGLR will complement NOAA-GLERL's workforce with a highly-skilled, permanent group of research scientists, technicians, and staff that expands GLERL's research expertise and fully-integrate into GLERL's scientific enterprise (Goal 1). The University of Michigan is ideally suited to serve as the host institution for the Research Institute for several reasons. First, it is a highly regarded public research institution, ranked the #1 PhD granting public university by the National Science Foundation with FY16 research expenditures in excess of $1.4 billion. Second, the proximity of the University of Michigan and NOAA-GLERL in Ann Arbor, Michigan facilitates the integration of research functions, as well as communication and collaboration among researchers and staff. Lastly, the University of Michigan and NOAA-GLERL have a 27-year history of research interaction that has led to a highly-integrated university-federal workforce that is fully coordinated in its functions.

During the 2010 NOAA Science Advisory Board CI Review, the seamless integration of the CI and NOAA-GLERL's workforce, and the high level of CI research productivity and impact (Fig. 1), were highlighted as major strengths. But that same review expressed some concern that the University of Michigan was not offering sufficient financial support for the CI and its programs, including the education and outreach program. In response, the university dedicated $2 million in cost-share and in-kind support during the 5 year renewal of the current CA (2012-17) to increase research, administrative, and programmatic capacity. These funds allowed us to hire dedicated outreach and communications staff, fund postdoctoral fellows, establish and host multiple Great Lakes Summits, and strengthen connections between NOAA and other partner institutions.

As host of the next Cooperative Institute, the University of Michigan has made its strongest-ever financial commitment to NOAA, more than doubling its prior cost share commitment and pledging $2.53 million in total cost-sharing and in-kind support over the 5-year Cooperative Agreement (Attachment A. Budget narrative). The host institution will:

1. Enhance NOAA-GLERL's workforce. The University of Michigan will continue to provide NOAA-GLERL with a stable workforce that includes 5 Research Scientists who have appointments in, and salaries partly paid by, the School of Natural Resources and Environment and the College of Engineering. The university is prepared to hire a 6th Research Scientist, augmenting GLERL's workforce with a new Social Scientist PI starting in 2017 (see Attachment A. Budget narrative, Task II Personnel). This would represent one of the first hires of this kind at a CI.

2. Support new programs. The University of Michigan will financially support a suite of previously unfunded programmatic activities that are designed to foster research at NOAA-GLERL and increase interactions with partner institutions. These programs include funds for 2 postdoctoral fellowships per year, seed funding for new research initiatives and rapid

emergency responses to Great Lakes crises, funding for 3 to 5 Summits and Working Groups per year that bring multiple stakeholders together to work on Great Lakes problems and co-design research, and funds for education and outreach programs with University Partners within the Regional Consortium (see Section VI. ECO program, and Attachment A. Budget narrative "Cost Share by Host"). Through these activities, CIGLR will provide leadership in themes and directions of Great Lakes Research.

3. Expand its administration. The University of Michigan will provide physical space for CIGLR administrative offices, and expand its administrative support in human resources, grant and contracts, and financial management (see Attachment A. Budget narrative "In-Kind Support").

CIGLR: Regional Consortium

While the investment by, and long-term commitment from a host institution is vital to the success of a CI, NOAA has also emphasized the need to forge regional partnerships that include consortia of universities, federal agencies, private companies, NGOs, and other organizations that can mutually benefit from the sharing of facilities, equipment, and expertise[10]. As only the second CI to establish a Consortium, the University of Michigan was a pioneer among CIs in developing this broad partnership model to expand GLERL's ability to fulfill NOAA's mission in the Great Lakes. Scientists from CILER, Consortium universities, and GLERL have a strong history of collaborative research on the most pressing issues in the Great Lakes, including climate variability, harmful algal blooms, and protection of ecosystem services. The new CIGLR will build on this tradition by forming a larger, and more interdisciplinary consortium across the Great Lakes. Partner institutions will interact with NOAA researchers to expand their research capacity, intellectual expertise, and geographic scope. The Regional Consortium will include:

University Partners. Eight graduate-degree granting universities with the highest levels of research activity have joined the University of Michigan as partners in this proposal (Fig. 2). Together, this group of nine institutions has committed to support research at NOAA-GLERL with its research infrastructure and intellectual capacity. University Partners represent academic institutions that have been most actively involved in research at NOAA-GLERL over the last 5-years, determined from our own records of ongoing collaboration between NOAA and academic PIs, as well as from sub-award volumes. Thus, University Partners are institutions whose expertise has already proven to be most essential to the success of NOAA-GLERL research programs. University Partners have agreed to:

1. Reduced IDC. University Partners will reduce indirect cost rates to 26% for all NOAA projects sub-awarded through CIGLR, and reduce indirect costs rates to 10% for all postdoctoral and graduate fellowships funded through CIGLR's programmatic activities.

2. Research Infrastructure. University Partners will grant full access by NOAA scientists, CI scientists, and University Partner scientists to their Great Lakes research vessels and laboratory facilities at their discounted in-house cost.

These two conditions guarantee NOAA a uniformly-low cost of doing research with University Partners across all 5 Great Lakes, and ensure access to the most productive and strategically located research vessels and research labs in the basin. **University Partners are collectively committing to $2.8 million in in-kind support for NOAA research and programs. When**

added to the cost-share pledge by the host institution, the value of this proposal for NOAA totals $5.33 million over the 5-yr Cooperative Agreement.

In exchange for their intellectual expertise, access to research infrastructure, and in-kind support of research and programs, the University of Michigan will provide University Partners with a suite of programs designed to foster interactions between academic PIs, CIGLR scientists, and NOAA-GLERL researchers. These programs include 2 postdoctoral and 2 graduate fellowships per year, funding for 3 to 5 working groups and summits per year, small grants of < $10K that can be approved within 48-hrs to initiate emergency responses to crises in the Great Lakes (Rapid funding), and supplemental funding to coordinate education and outreach activities (Section VI. ECO program). All University Partners have signed Memoranda of Understanding with the University of Michigan (Appendix 4) in which they have agreed to the above terms.

Figure 2. The new Cooperative Institute for Great Lakes Research (CIGLR) will be composed of a Research Institute hosted at the University of Michigan, complemented by a Regional Consortium of an additional 8 University Partners, 25 University Affiliates, 5 Private-sector Partners, and numerous supporting initiatives and NOAA-related programs that span all 5 Great Lakes.

University Affiliates. In addition to the 9 University Partners, 25 universities that span the Great Lakes have agreed to join CIGLR as University Affiliates. Although University Affiliates have historically had fewer research interactions with NOAA-GLERL and lower CI research volumes than University Partners, they have served as essential collaborators for select PIs at NOAA-

GLERL. University Affiliates have agreed to continue their relationships with the newly proposed CIGLR, which will continue to issue sub-awards to University Affiliate PIs that have expertise or resources essential to NOAA-GLERL research. Note, however, that University Affiliates have not agreed to in-kind support of NOAA research with reduced indirect cost rates or access to infrastructure (as University Partners have). All University Affiliates have provided letters of support for this proposal (Appendix 5).

Private-sector Partners. NOAA has repeatedly emphasized that partnerships with the private-sector are important for maximizing the impact of its R&D programs[10]. Not only are private organizations key to developing applications for NOAA-funded research, industries, NGO's, and citizen groups are also key to engaging policy-makers and resource managers in ways that bridge science with public interests. CIGLR's Regional Consortium of 9 University Partners and 25 University Affiliates will be augmented by 5 Private-sector Partners with significant expertise to help fulfill CIGLR's science translation goal:

- The Nature Conservancy (TNC) is one of the world's largest and most respected charitable organizations. TNC's mission is to *"conserve the lands and waters on which all life depends."* One of their most significant conservation initiatives is the TNC Laurentian Great Lakes Project, which works in 8 states and Canada to develop practical, outcome-based solutions to protect water quality and ensure the health of the region's watersheds and coasts. TNC has provided a letter of support for this proposal (Appendix 5) in which they have expressed their desire to partner with CIGLR in research activities that involve conservation and protection of the Great Lakes. In addition, TNC has also expressed a desire to partner in our ECO program (Section VI) to expand CIGLR's engagement, communication, and outreach efforts to reach the broader audience associated with TNC around the Great Lakes.

- The National Wildlife Federation (NWF) is the United States' largest private, nonprofit conservation education and advocacy organization, with over 6 million members and supporters, and 51 state and territorial affiliated organizations. Since 1982, NWF's Great Lakes Regional Center has been a leader in protecting the Great Lakes for wildlife and humans that depend on this invaluable resource. One of NWF's strengths lies in advocating for conservation of habitat and wildlife throughout the Great Lakes region. They have an unparalleled number of agreements and interactions with other NGOs and business leaders throughout the Great Lakes who share mutual interests in conservation. In addition, NWF runs the National Advocacy Center that is one of the best at engaging policy-makers from state to federal levels. NWF has provided a letter of support (Appendix 5) in which they have agreed to partner with CIGLR to help us expand our efforts in policy engagement.

- LimnoTech is a leading water sciences and environmental engineering consulting firm. Founded in 1975, the company is headquartered in Ann Arbor, Michigan, with regional offices in Washington, DC, the Minneapolis-St. Paul region, and the Los Angeles region, with other personnel in Austin, TX, and Greensboro, NC. LimnoTech plays a key role in Great Lakes observing and monitoring systems, having led the Great Lakes Observing System Enterprise Architecture Design[11], which was a comprehensive, interdisciplinary process conducted with NOAA-GLERL to recommend specific actions and investments for the next 5 years to achieve an integrated observing system for the Great Lakes. LimnoTech also manages a set of observing systems (16 water quality monitoring stations in western Lake Erie) that are an integral part of the Great Lakes Observing Systems (GLOS), and

which help characterize source water for intakes. Lastly, LimnoTech serves as the Data Management and Communications (DMAC) center for GLOS. LimnoTech has provided a letter of support for this proposal (Appendix 5) in which they have agreed to partner with CIGLR to coordinate and expand observing systems – particularly to assist operators of public utilities such as water treatment plant operators in the Great Lakes. LimnoTech will continue its current role as lead of the Data Management and Communications branch for the Great Lakes Observing System (DMAC for GLOS), and expand its role by helping CIGLR develop more public applications for NOAA related data.

- Fondriest Environmental, Inc. is a leading distributor and integrator of equipment for natural resource professionals, and a certified repair center for a variety of leading sensor, platform, and telemetry equipment. Located in the lower Great Lakes and Ohio River Valley, they provide integrated solutions for sensor, platform, and equipment needs and work closely with NexSens Technology, a company that specializes in the design and manufacture of real-time environmental measurement and monitoring systems. Fondriest Environmental has provided a letter of support for this proposal (Appendix 5) and agreed to partner with CIGLR by making available engineers, computer programmers, and other staff to support CIGLR's monitoring efforts in the Great Lakes; build and deliver instrumented monitoring stations that help NOAA and CIGLR accomplish research goals; and offer ongoing support and repair services for NOAA-GLERL and CIGLR's existing fleet of monitoring instrumentation and systems deployed throughout the Great Lakes.
- Great Lakes Environmental Center, Inc. GLEC is an environmental consulting firm that has performed laboratory and field investigations concerned with the protection and restoration of the Great Lakes under contracts to U.S. EPA, Michigan Department of Environmental Quality (MDEQ), and the U.S. Army Corps of Engineers. GLEC headquarters in Traverse City, MI has labs for aquatic toxicology, environmental chemistry, and taxonomy. Additional toxicology labs operate at GLEC's Columbus, OH facility, with satellite offices in Farmington Hills, MI and Eau Claire and River Falls, WI. GLEC toxicologists, ecologists, and biologists have played a key role in establishing ecologically-based national, state, and site-specific water quality standards and criteria. GLEC has provided a letter of support for this proposal (Appendix 5), agreeing to partner with CIGLR by making available staff to support CIGLR's monitoring efforts in the Great Lakes, and to assist with toxicology studies, when needed, to fill the current gap in NOAA-GLERL's expertise.

Supporting Initiatives and NOAA Programs. A wealth of NOAA programs, government centers, and national and international commissions already serve various functions in research, policy engagement, or public outreach and communications in the Great Lakes. Some of the most important and influential initiatives and programs in the Great Lakes have agreed to support CIGLR and work with us to leverage expertise, funding, and programs to the mutual benefit of all programs that serve the Great Lakes. These include:

- Great Lakes Observing System (GLOS). GLOS 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 work to provide data for tools and forecasts to improve safety, enhance the economy, and protect our environment. We have deliberately selected University Partners, University Affiliates, and Private-sector Partners who are also

partners with GLOS to ensure that the research programs of CIGLR and GLOS are well integrated and mutually beneficial. In fact, numerous projects proposed in Section V Research Themes were developed in consultation with GLOS partners and the Executive Director of GLOS, Kelli Paige. Because of the explicit integration of GLOS into CIGLR's research and programs, Ms. Paige has provided a strong letter of support and endorsement for our proposal (Appendix 5), and has committed to work together with the new CI to accomplish our joint goals. Our coordination with GLOS will be facilitated by the recent collocation of GLOS administrative offices with CIGLR at NOAA-GLERL, where Ms. Paige and CILER's current Director (Brad Cardinale) meet regularly.

- NOAA National Estuarine Research Reserves (NERRS). NERRS is a network of 28 coastal sites designated to protect and study estuarine systems. Two of these reserves are in the Great Lakes (Old Woman Creek, and the Lake Superior Reserve), and both have agreed to work with CIGLR on research and education projects of mutual interest. The managers of both reserves (Frank Lopez and Erika Washburn) have collaborated in the development of research projects proposed in Section V. Research Themes, and both have provided strong letters of support promising to work closely with CIGLR if funded (Appendix 5). In addition, the NERRS Science Collaborative, which coordinates funding opportunities and supports user-driven collaborative research and transfer activities that address coastal management needs, is hosted at the University of Michigan. Director Dr. Jennifer Read, who is co-PI on this proposal, will help coordinate NERRS activities with related CIGLR activities to leverage research, education, and outreach in ways that maximize NOAA's impact in the Great Lakes estuarine reserve system.

- NOAA National Marine Sanctuaries. The superintendents of both of NOAA's National Marine Sanctuaries in the Great Lakes – Thunder Bay (Jeff Gray) and the newly proposed WI-Lake Michigan designated Sanctuary (Ellen Brody) – have provided a letter of support agreeing to partner with CIGLR and GLERL on research activities (Appendix 5), working together to characterize and monitor sanctuary resources, and promoting education programs that are mutually beneficial. Several activities have been proposed (Section V. Research Themes) to complement the goals and ongoing programs in these sanctuaries.

- USGS Great Lakes Science Center. The USGS-GLSC exists to meet the Nation's need for scientific information for restoring, enhancing, managing, and protecting living resources and their habitats in the Great Lakes basin ecosystem. The Center is headquartered in Ann Arbor, MI, but supports 25 Principal Investigators at 7 locations that span the entire Great Lakes Basin. In addition, USGS-GLSC owns and operates 5 state-of-the-art research vessels and 3 major aquatic laboratories. In his attached letter of support for our proposal (Appendix 5), the Director of USGS-GLSC Russ Strach – writes *"We often work with the NOAA's lab via scientist-to-scientist connections but we are lacking in the broader, program scale coordination (esp. involving synergies with the regions universities) that is offered via collaboration with the proposed CI for Great Lakes Research."* Therefore, the USGS is anxious to collaborate and coordinate research efforts with CIGLR.

- Great Lakes Commission (GLC). The GLC is an interstate compact agency that promotes the integrated development, use and conservation of the water and related natural resources of the Great Lakes basin. Its members include the 8 Great Lakes states with associate member status for the Canadian provinces of Ontario and Québec. Each jurisdiction appoints a

delegation of 3 to 5 members representing senior agency officials, legislators and/or appointees of the governor or premier. GLC's specialty is policy and advocacy, including their annual Great Lakes day on Capitol Hill in Washington D.C. GLC has provided a letter of support (Appendix 5) in which they have agreed to leverage their connections and expertise to help CIGLR be successful in its engagement with policy-makers.

- International Joint Commission (IJC). The IJC is an independent binational organization established by the United States and Canada under the Boundary Waters Treaty of 1909. It assists in the protection of the transboundary environment, including the implementation of the Great Lakes Water Quality Agreement and the improvement of air quality, and it alerts the governments to emerging issues along the boundary that may give rise to bilateral disputes. The IJC is particularly enthusiastic about our proposal for the next CI because our University Partners include both U.S. and Canadian institutions who have agreed to work together. IJC has provided a letter of support (Appendix 5) and agreed to co-sponsor conferences, meetings and round table discussions that invite stake-holders to participate in public consultations and give perspective on research priorities, outcomes, and decisions of joint interest in the Great Lakes.

- Council of Great Lakes Industries (CGLI). CGLI is a tax-exempt organization that represents the common interests of U.S. and Canadian industrial organizations from the manufacturing, utilities, transportation, communications, financial services and trade sectors in the Great Lakes. CGLI's goal is to promote the economic growth and vitality of the region in harmony with its human and natural resources (sustainable development). CGLI works to encourage active industry participation in developing and implementing sustainable development policies and practices in the Great Lakes region. Kathryn Buckner, President of CGLI, has provided a letter of support (Appendix 5) agreeing to work with CIGLR by helping organize representation by key Great Lakes businesses and industry in CIGLR's proposed Summits and Working Groups (Section VI. ECO Programs). This interaction will foster the co-design of Great Lakes science, bringing researchers from universities and government agencies to the table alongside representatives from industry to work together to define the most important research topics and most useful data products.

CIGLR: Research Capacity

As host institution, the University of Michigan has selected Dr. Bradley Cardinale to be lead PI on this proposal, and Director of the new CI. Dr. Cardinale was hired in May 2016 as Director of the current CI. He is an elected fellow of AAAS, a renowned aquatic researcher, and one of the world's most widely cited ecologists. Dr. Cardinale was chosen because he has considerable experience leading interdisciplinary research initiatives. He served on the 20-year visioning committee for the U.S. National Science Foundation's Long-term Ecological Research Program (LTER), which formulated a plan for integration of social sciences into ecological research programs. He served on the Science and Education Committee of the U.S. National Ecological Observatory Network (NEON), which designed a continental-scale observation network for monitoring ecological change through time. Most recently, Dr. Cardinale served on the Science Board of *Future Earth*, which merged the four United Nations Environmental Change Programs (UNEP) into a new 10-year Global Sustainability Initiative composed of natural scientists, social scientists, engineers, and landscape designers. Since his hire, Dr. Cardinale has laid the groundwork for the next generation of NOAA cooperative research by forging new partnerships,

negotiating >$2 million in annual cost-sharing and in-kind support for NOAA research, and bridging disciplines to create an interdisciplinary research plan.

The interdisciplinary focus of the next CI is also represented by the list of co-PIs from University of Michigan, which includes 3 aquatic ecologists (Cardinale, Diana, Johengen), a civil engineer (Kerkez), an expert in coastal planning and management (Norton), and 4 social scientists from human geography (Brown), environmental history (Read), human psychology (Arvai), and political science (Lemos). These 9 individuals are all internationally recognized leaders in their respective disciplines, and all have led or participated in major national and international initiatives focused on environmental sustainability. Collectively, these individuals represent the Dean of the School of Natural Resources and Environment (Brown) who will host and fund the institute, the Director of the Erb Institute for Global Sustainable Enterprise (Arvai) that pushes for environmentally sustainable business practices, the Chair of the Urban and Regional Planning Program in the Taubman College of Architecture & Urban Planning (Norton), and the directors of all NOAA-related programs on the University of Michigan campus (CILER – Cardinale, Johengen, Sea Grant – Diana, GLISA – Lemos, and NERRS – Read). These individuals have committed to coordinate and leverage activities and research programs at the University of Michigan to further advance NOAA's overall research mission in the Great Lakes.

The host institution also supports 5 Research Scientists who have partial research faculty appointments in the School of Natural Resources and Environment and College of Engineering. These 5 PIs have more than a century of experience working at NOAA-GLERL in support of research on the Great Lakes, with expertise in hydrodynamic modeling (Beletsky), climate and weather modeling (Fujisaki-Manome), bio-physical modeling (Rowe, Zhang), physical limnology (Johengen), invasive species (Zhang), and harmful algal blooms and hypoxia (Johengen, Rowe). If funded, the host institution has agreed to complement this group with the hire of a 6th PI-level social scientist who focuses on environmental economics or human behavior and decision-making.

In addition to the host institution, this proposal includes 9 co-PIs representing each University Partner within our Regional Consortium. These nine co-PIs have hundreds of years of collective experience in research and management of the Great Lakes, and represent some of the most prominent and influential scientists in the region. They also represent universities who have worked with scientists at NOAA-GLERL most frequently, and are all acting directors of prolific water centers and research institutes on the Great Lakes. Collectively, the University Partners offer NOAA-GLERL a wealth of research infrastructure (Table 1), including:

- Field stations and laboratories. University Partners collectively manage 10 field stations that are located on all 5 Great Lakes. These stations have wetlab space, analytical facilities, housing for researchers and students, classrooms for teaching and hosting of seminars, and world-class mesocosm facilities for experiments.

- Fleet of research vessels. University Partners own and operate a fleet of 12 research vessels in all 5 Great Lakes, including several of the largest and most well-equipped vessels available (e.g., *Blue Heron*, *Laurentian*, *W.G. Jackson*).

- Monitoring instrumentation. University Partners own and manage 38 buoys, AUVs, ROVs, and gliders that already form a large portion of the Great Lakes Observing System (GLOS). The University of Windsor, which has joined the Regional Consortium as a Canadian

Partner, has a $16 million grant pending from the Canadian Foundation for Innovation to form a new Real-time Aquatic Ecosystem Observation Network (RAEON) composed of sensory arrays, 5 Slocum Gliders, and *in situ* instrument pools (e.g., ADCPs, water quality instruments, acoustic telemetry, etc.). This new infrastructure will be made available for the Great Lakes community through the CIGLR partnership.

- Specialized engineering and research facilities. All University Partners have engineering and design labs that specialize in materials design (plastics, metals, glass), development of instrumentation, marine hydrodynamics, and perpetual robotics for autonomous navigation and mapping systems. University Partners also operate a suite of highly specialized laboratory facilities that further expand NOAA's capabilities in the Great Lakes, including numerous labs for remote sensing and GIS, genomics and sequencing, bioinformatics, high-performance computing, marine hydrodynamics, elemental and isotopic analyses, advanced microscopy, geomicrobiology, sedimentology, and fisheries and aquaculture.

In addition to the research infrastructure being offered by University Partners, we offer NOAA-GLERL a breadth of topical and disciplinary expertise that includes:

- An interdisciplinary group of 148 natural scientists, 42 social scientists, and 36 experts in engineering and design who have a history of working on issues related to sustainability in the Great Lakes.
- Substantial depth and expertise in every NOAA theme. University Partner PIs represent some of the most influential researchers in every theme that NOAA emphasized in the FFO for this new CI (Table 1, Appendix 2).
- A suite of Engagement, Career Training/Education, and Outreach and Communications (ECO) Programs. University Partners all have programs with staff whose primary job involves policy engagement or public outreach and education in the Great Lakes.
- The 9 University Partner institutions collectively offer 72 M.S. and Ph.D. programs that are relevant to NOAA's goals and the training of the next generation of Great Lakes scientists. These include degrees in the biological sciences (e.g., ecology, genomics), physical sciences (e.g. limnology and oceanography, atmospheric science, geology), social sciences (e.g., water policy, human behavior), interdisciplinary degrees that train students in sustainability (e.g., sustainable systems, policy and planning), and natural resource management (e.g., fisheries & wildlife, conservation biology).
- A strong commitment to diversity, inclusion, and equity. All University Partners administer programs that are specifically designed to foster and maintain diversity in the workplace, including (1) increased opportunities for training and preparation of ethnic and socio-economic minority groups in the STEM topics (science, technology, engineering and math), (2) increased representation and retention of individuals from traditionally under-represented groups such as ethnic minorities, women, the LBGT community, and veterans, and (3) enhanced opportunities for those who are disabled or have special needs.

We plan to leverage this intellectual capacity, diverse workforce, and coordinated set of engagement, career training, and outreach and communications programs to benefit NOAA's mission across all of the Great Lakes. A summary of the research infrastructure and intellectual capacity of University Partner institutions is given in Table 1, with further details in Appendix 2.

Table 1. A summary of the research capacity of 9 University Partners who have joined together in this proposal for the next Cooperative Institute for Great Lakes Research (CIGLR). A full list of the research capacity at these institutions is provided in Appendix 2.

		CMU			S			UMD		UWM
Research Vessels		38' *Chippewa* 7 small vessels	29' Trawler 5 small vessels	66' *W.G. Jackson* 45' *D.J. Angus* 4-6 small vessels	---	47' *Gibraltar III* 37' *M/V BioLaB* 34' *Carmen* 27' *Echo* 3 small vessels	80' *Laurentian*	86' *Blue Heron* 25' *Kingfisher*	---	71' *Neeskay* 4 small vessels
Observing Systems		Ship-based system (L Michigan)	1 buoy (Oneida L)	1 buoy (Muskegon L), 5 ROVs	1 glider (regional)	1 buoy (L Erie) 2 ROVs (L Erie)	7 buoys (L Erie, L Michigan, Little Traverse Bay); 2 AUVs (regional); 3 gliders (regional)	2 buoys (L Superior) 2 gliders (L Superior)	5 gliders (regional)	2 buoys (L Michigan); 1 buoy (Green Bay); 2 ROVs, Ship-based system (L Michigan)
Field Research Stations	**Facility**	CMUBS: 130 ac, boat house, 4 labs, library, cafeteria	CBFS: 500 ac, 20 buildings, labs	AWRI: 14,000 ft^2 with 8 labs, vessel docks, meeting & office space, library	KBS: 17 km^2 bio-station, 3600 ft^2 greenhouse, 12 labs, library	StoneLab: 16ac biostation, vessel docks, 3,000 ft^2 lab space, office & meeting space, cafeteria, library	UMBS: 10,000 ac biostation, 24,000 ft^2 lab space, dining hall, library	LLO: 224 ac campus on L Superior, analytical labs	PERC: 22 ac research center, Point Pelee FERC: 3300 ft^2 center, Detroit R	GLWI: 160,000 ft^2 facility, 30 labs, deep water dock, ship staging area
	Experimental Facilities	350 gal (12) climate cont aquaria	800 gal (16) climate cont aquaria	350 gal (12) climate cont aquaria	30 m dia ponds (18)	450 gal tanks (4), 75 gal climate cont streams (2), 2500 L pools (54), 30 m hatcheries (2)	10 L (180) climate cont algal chemostats 1000 L (160) tanks	---	3000 L (18) climate cont aquaria 40 x 60 x 2 m deep ponds (4)	Aquaculture center Aquarium facilities
	Housing	12 cabins, 1 dorm, sleeps 146	Cabins & dorms, sleeps 40	---	3 cabins, 12 dorms, 30 apts, sleeps 100+	2 cottages, 12 dorm suites, 12 houses, sleeps 90	100 cabins, 14 dorms, sleeps 300+	---	---	---
	Classrooms	3	2	2	6	6	17	1	---	6
Specialized Laboratories and Facilities		Biomolecular; Engineering/ design; Gas (volatile, & semi-volatile) spectroscopy: HP computing	Bioacoustics: Biomolecular: Engineering/ design; Satellite imagery; GIS; Remote sensing	Biomolecular; Engineering/ design; Satellite imagery; GIS; Remote sensing; Sedimentology	Biomolecular; Engineering/ design; HP computing; Stable Isotopes; Satellite imagery; GIS; Remote sensing	Biomolecular; Engineering/ design; Radioisotope; HP computing; Satellite imagery; GIS; Remote sensing	Aquaculture; Biomolecular; Engineering/ design; HP computing; Satellite imagery; GIS; Remote sensing	IRMS; LC-MS; XRF; Bio-molecular; Coring & core processing; Engineering/design	Biomolecular; Engineering/ design; HP computing; Satellite imaging; GIS; Remote sensing	Aquaculture; Biomolecular; Data visualization; Engineering/ design; HP computing; Radioisotope
Number of NOAA related PhD and MS programs (examples)		5 (Earth Science, Ecosystem Science, Mathematics, Conservation Biology)	9 (Ecology, Aquatic Science, Wildlife Science, Policy)	3 (Biology, Aquatic Sciences)	10 (Fisheries, Ecology, Environ Science & Policy, Communication, Tourism, Protected Area Management)	12 (Ecology, Environ Social Science, Fisheries & Wildlife, Watershed Systems, Atmospheric Sci)	12 (Conservation, Human behavior, Sustainable Systems, Policy & Planning, Atmospheric & Oceanic Sci)	8 (Chemistry, Physics, Limnology & Oceanography, Geology, Conservation)	6 (Aquatic Ecotoxicology, Ecology, Invasion Biology, Biogeochemistry)	7 (Ecology, Ecotoxicology, Fish & Aquaculture, Environ Health, Water Law & Policy, Atmospheric Sci)
# of PIs in:	**ED/NS/SS**	0/25/0	2/19/10	0/13/2	4/15/9	11/10/4	12/18/7	0/12/0	2/13/2	5/23/8
	Theme 1-4	8/8/18/7	6/16/22/11	3/7/13/13	9/18/8/12	18/12/13/10	19/16/11/15	9/6/12/0	5/9/11/5	9/20/8/24

V. Research Themes

Administrative Task IA Activities

The primary role of administration is to support research carried out in CIGLR's Research Institute and Regional Consortium, and to support the Engagement, Career training, and Outreach and Communications (ECO) Programs. Two of the most important administrative tasks will be facilitating financial elements of the regional consortium and developing, implementing, and coordinating multi-university research programs. The other administrative activities that are important to the CI include interacting with PIs, communicating with NOAA research and administrative staff, and providing administrative support for CIGLR postdoctoral fellows, student fellows, visiting scientists, and research staff. The administrative and organizational structure of the CI are further detailed in the Business Plan (Section VII).

Non-administrative Task IB Activities

Task IB activities will include career training and outreach activities that align with the missions of CIGLR and NOAA-GLERL. These include:

- Graduate Research Fellowships. CIGLR will administer 2 graduate fellowships per year ($25K ea.) to students affiliated with University Partners. Graduate fellows must be performing research in the Great Lakes on topics related to NOAA-GLERL's mission and be working in collaboration with both a University Partner PI and a NOAA-GLERL or CIGLR scientist. Funds may be used for tuition, stipends, research materials/supplies, or travel. University Partners have agreed to a reduced IDC rate of 10% on graduate fellowships.

- Great Lakes Summer Fellows Program. CIGLR will administer NOAA funding for 8-12 summer internships per year to upper level undergraduate and graduate students to work with CIGLR and NOAA-GLERL research scientists on ongoing Great Lakes research projects.

- Visiting Scientist Program. CIGLR will coordinate opportunities for distinguished Great Lakes academic scientists to spend all, or part of their sabbatical leaves in residence at NOAA-GLERL to advance research activities with NOAA PIs. We will complement the sabbatical fellows program with shorter-term, residency programs that allow academic scientists to have office space at CIGLR and/or NOAA-GLERL, and local accommodations for a period of 1-2 weeks to enhance work on select projects with NOAA PIs.

- GLERL-CIGLR Seminar Series. As part of its outreach and communications plan, CIGLR will co-sponsor and coordinate a joint GLERL-CIGLR Seminar Series. This series will bring in internationally recognized researchers to talk about topics that are pertinent to both GLERL and members of our Regional Consortium. These events will facilitate collaborations between researchers, provide an educational opportunity for NOAA and university scientists, and serve as an outreach forum for stakeholders and the general public to attend.

In addition to the above activities, CIGLR will provide administrative support for our internally funded programs, which include: (1) annual postdoctoral fellowships, (2) Summits and Working Groups that convene experts from Federal and state agencies, academia, NGOs, and private businesses to co-design Great Lakes research programs, (3) Rapid grants that provide seed funds for responses to emergencies in the Great Lakes region, and (4) education and outreach funds to promote the societal benefits of NOAA research in the Great Lakes. These programs will not be

paid from Task I funding, but rather, will be paid by cost-share funding from the University of Michigan. These programs are outlined in Section VI. ECO Program of the proposal.

Research Programs. Tasks II and III Activities

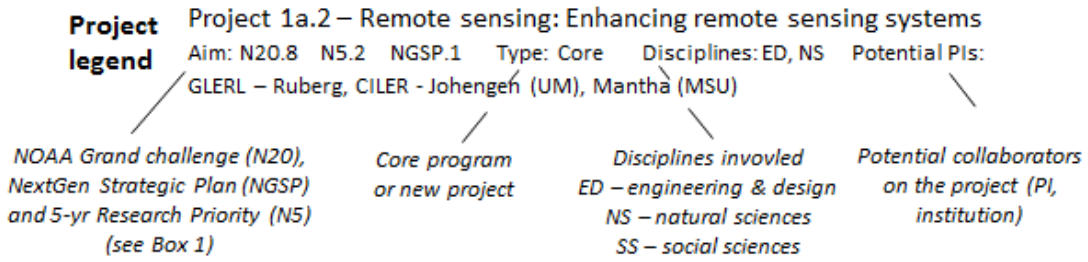
Here we propose a collection of research projects designed to help NOAA-GLERL execute its strategic research plan[8,9] and CIGLR accomplish its mission to lead research, develop applications and products, and engage with stakeholders in the Great Lakes. Of the proposed projects, 20 represent "core" projects that are fundamental to ongoing research efforts at NOAA-GLERL. An additional 24 are "new" projects that we propose to expand NOAA-GLERL's ongoing efforts in key areas. We recognize that the volume of proposed projects is greater than what NOAA would fund at any one time. However, this collection is presented to show the broad research capacity and potential that our Regional Consortium brings to the disposal of NOAA. We will work with PIs at NOAA-GLERL to prioritize annual projects, and will apply for external funding to support the additional ideas proposed here.

The suite of proposed projects is organized by the 4 research themes that were identified in the NOAA FFO that called for a new Great Lakes CI: (1) Observing Systems & Advanced Technology, (2) Invasive Species and Food-web Ecology, (3) Hydrometeorological & Ecosystem Forecasting, (4) Protection and Restoration of Resources. Note we have altered the name of Theme 3 from that in the FFO (which focused solely on invasive species) because NOAA-GLERL has a strong history of research in food-web dynamics and other aspects of ecological forecasting that extend beyond invasive species. We have also re-ordered the sequence of themes to emphasize that data collected from observational systems (Theme 1) and ecological observations (Theme 2) are then used for forecasting (Theme 3), which facilitates the protection of natural resources for the good of society (Theme 4).

Within each of the 4 research themes, subdivisions show 'foci' that represent substantive areas of research that are either essential to GLERL's core research programs, or that represent new areas that would substantially expand NOAA's impact on our understanding and management of the Great Lakes. Each focal area is populated by a suite of projects, all of which are tractable on the time scale of a 5-yr Cooperative Agreement, and which represent a robust mix of natural science, social science, and engineering and design. An example of the organization of this section is:

Theme 1. Observing Systems & Advanced Technology
Focus 1a. Development and operation of observing systems
Project 1a.1 – Observing Systems: Implementing a regionally distributed network of nearshore and open water real time observing systems

Following the title of each project, we provide a legend that maps the proposed work onto NOAA Grand Challenges from the 20-yr Research Vision[5], Research Foci from the Next Generation Strategic Plan[7], and Research Priorities from the 5-yr Research and Development Plan[6]. The legend suggests PIs that could collaborate on the project, which disciplines are involved, and whether the project is core or new research program. An example of a legend is:



In addition to the legends for each individual project, Appendix 3 shows how the full collection of projects maps onto NOAA's 20-year Research Vision[5], Next Generation Strategic Plan[7], and 5-year Research and Development Plan[6]. Appendix 3 also shows how the projects map onto specific research gaps identified in NOAA's FFO for the next CI, and highlights the inter-disciplinary nature of our work showing projects that involve natural scientists, social scientists, and experts from engineering and design. We have not explicitly mapped projects onto Research Themes outlined in GLERL's Strategic Plan[8] because they overlap in entirety (our Theme 1 = GLERL (1) Observing systems and advanced technology + (4) Information systems, our Theme 2 = GLERL (2) Ecosystem dynamics, Our Theme 3 = GLERL (3) Integrated physical and ecological modeling and forecasting). Note, however, the Theme 4 of our proposal (Protection and Restoration of Resources) is complementary to NOAA's goals, and expands their capabilities with more integrated natural and social science.

Theme 1. Observing Systems and Advanced Technology
Monitoring environmental change to help society navigate the Anthropocene

The Great Lakes are used by a diverse group of stakeholders whose health, economic well-being, and quality of life are fundamentally dependent on the use, protection, and management of the region's water related natural resources. Making scientifically sound decisions on how to use these natural resources requires well-integrated observing systems that monitor key aspects of the Great Lake environment at high spatial and temporal resolution. Comprehensive, well-integrated Earth observing systems are also needed to quantify natural levels of variation, identify natural and human-induced disturbances, provide the data needed to develop climate, weather, and ecosystem forecasts, and to prepare the baselines needed to assess the success of management decisions. To support NOAA's short and long-term research objectives in the Great Lakes, the newly proposed CIGLR will focus on 4 focal areas of research for Theme 1:

Focus 1a. Development and operation of observing systems
Focus 1b. Advancing technology for observing systems
Focus 1c. Data products for the scientific community and the public
Focus 1d. High risk, potentially transformative projects

In the following section, we detail specific projects proposed under each research focus:

Focus 1a. Development and operation of observing systems

- Project 1a.1 – Observing Systems: Implementing a regionally distributed network of nearshore and open water real time observing systems

  Aim: N20.1,3,4 NGSP.1,2 N5.1,3,4,5,6 Type: Core Disciplines: NS, ED Potential PIs: GLERL - Ruberg, CIGLR - Johengen (UM), Steinman (GVSU), Klump (UWM), Bootsma (UWM), Austin (UMD), Read (UM), Verhamme (LimnoTech), Paige (GLOS)

During its last Cooperative Agreement, CILER worked with the IOOS Great Lakes Observing System (GLOS) to develop, implement, and coordinate the Great Lakes Nearshore Observing Network that serves multiple federal and academic partners, and which provide GLOS with coordinated data management, product development, and data dissemination[12]. We propose to maintain the current expansive network of observation systems that are presently managed by our Regional Consortium members, and strategically expand these observing systems to address emerging needs throughout the Great Lakes.

We will continue operation of the established GLOS observing assets (buoys, gliders, vessel of opportunity) over the 2016-20 Cooperative Agreement and continue to align our activities with priorities identified in the 2014 GLOS Blueprint: A Strategy for Data for Decision Making[13]. Specifically, the network will support observations that address four main focus areas for GLOS: Climate Adaptation, Ecosystem Health, Maritime Operations, and Public Health and Water Security. Data needs for these priority areas will be addressed by the integrated array of nearshore observing buoys that consist of standard configuration with cellular communications, wind speed and direction, air temperature and relative humidity, solar radiation, barometric pressure, precipitation, thermistor string, YSI sondes, a current profiler, and wave sensor. The observing network also supports mobile platforms, including gliders and AUVs that provide detailed three-dimensional observations of thermal structure, as well as surveys focused on harmful algal blooms, invasive species, and coastal nutrient inputs. These broader lake-wide surveys are being done in collaboration with other federal partners including the EPA's Great Lakes National Program Office (GLNPO), and the USGS as part of the Coordinated Science and Monitoring Initiative. To complement the mobile platforms, our University Partners have instrumented numerous cross-lake ferries to collect repetitive observations of surface water chemistry that help assess ecosystem health, carbonate chemistry, and coastal stormwater inputs. Data from observing systems are made available through the GLOS Data Portal to help GLOS meet its mission for the Great Lakes region as a whole. At the same time the network is sufficiently flexible, and locally controlled such that the individual activities can be tailored to local user needs.

We also propose to enhance the current observing network. Members of our Regional Consortium have led numerous prioritization and planning efforts for network expansion (e.g., GLOS Blueprint[13], the Enterprise Architecture report[11], and the joint NOAA/IOOS National Strategy for a Sustained Network of Coastal Moorings Plan[14]). Together, we have strategically identified two future priorities for the Great Lakes: (1) expansion and operational development of a Great Lakes Evaporation Network to fill in critical knowledge gaps for quantifying over water eddy covariance flux rates and improving water budget models that are key for operational Great Lakes water level forecasts; and (2) development of year-round observing stations piloted within select lake systems. The absence of winter-time observations during four months of the year limits the development real-time nowcast/forecast model development, including hydrodynamic, biological, and water quality models. Year-round observatories will greatly expand our knowledge of key periods of storm intensity and spring warm-up of the lakes and greatly improve investigations of long-term or climatic trends. Similarly, they will greatly improving validation, reliability and usability of operational models such as the NOAA-GLERL Great Lakes Operational Forecast System, and WaveWatch 3 and provide critical data the physical model research and development for the Great Lake Evaporation Network. To guide even further expansion, CIGLR and GLOS

to jointly coordinate annual planning workshops to prioritize new projects, evaluate existing projects, and coordinate membership and engagement in the observing network.

- Project 1a.2 – Remote sensing: Enhancing remote sensing systems to support integrated observation networks

  Aim: N20.1,3,4 NGSP.1,2 N5.1,3,4,5,6 Type: Core Disciplines: NS, ED Potential PIs: GLERL - Leshkevich, Chu, CIGLR - Brown (UM), Austin (UMD), Johengen (UM), Green (Cornell), Shum (OSU), Heumann (CMU), Zheng (CMU), Qi (MSU), Shum (OSU), Grgicak-Mannion (Windsor)

  Conventional observation systems like those in Project 1a.1 are limited in spatial coverage and temporal frequency. Remote sensing can provide a complementary source of data at local to global scales and higher temporal frequencies. Environmental monitoring of the Great Lakes from space began in the 1970's with initial remote sensed products coming from the Nimbus-7 and CZCS satellites. Presently, regional remote sensing applications are derived from a suite of airborne and satellite systems that include both radar and ocean color sensors. Ocean color satellites such as SeaWiFS, MODIS, MERIS, VIIRS and the most recent Ocean Land Colour Instrument (OLCI) on Sentinel 2, generate images of the Great Lakes on a daily basis and provide opportunities to generate derived remote sensing products like estimates of chlorophyll), dissolved organic carbon, and suspended mineral concentrations, cdom absorption; light attenuation, photosynthetically active radiation and photic zone depth; sediment plume extent, and the location and severity of HABs. The goal of this project is to expand efforts to tailor remote sensing systems to support an integrated network of observing systems.

  In the last Cooperative Agreement, CIGLR and its University Partners generated weekly "snap-shots" of water quality properties for all five Laurentian Great Lakes, and efforts are underway to transition some of these estimations into the operational arm of NOAA CoastWatch. Additional research products being generated include estimations of HABs extent and severity for the Western Basin of Lake Erie using MODIS 1km data. Future research under CIGLR will focus on development of new chlorophyll *a* satellite algorithms throughout the Great Lakes using the MODIS Aqua satellite sensor and the newly launched Sentinel II OLCI satellite sensor. One approach is to examine a semi-analytical algorithm that uses the inherent optical properties acquired from in situ measurements that have been collected throughout the Great Lakes over the past five years. Secondly, research will be directed at improving the current OC3 (Ocean Color version 3) satellite algorithm after calculating new coefficients for the linear regression using a larger historical dataset than previously documented from ongoing field observations led by CIGLR and GLERL over the past five years. Accurate backscatter and absorption coefficients are necessary inputs into Great Lakes satellite-based algorithms that provide chlorophyll, dissolved organic carbon (DOC), CDOM, TSM, HABs, water clarity, and photic zone estimates. Previous *in situ* optical property measurements collected under CIGLR projects using AC-S, BB9, Satlantic Profiler, Surface Reflectance (Hypergun or ASD), and the BBE Fluoroprobe are archived and accessible within the Great Lakes Optical Properties Geospatial Database (GLOPGD) (http://glopgd.org/). CIGLR will continue to direct research focused on measurement of these inherent optical properties throughout each of the Great Lakes to further refine CPA-A hydro-optical (HO) model performance. Measurements will be conducted to examine seasonal and spatial changes in IOPs due to shifts in phytoplankton composition and help quantify nearshore and offshore gradients in IOP. Research will also help differentiate

dominant sediment contributions from phytoplankton retrievals to improve HAB-specific hydro-optical models and HAB satellite retrieval estimations of intensity and spatial extent.

Working with our University Partners, who represent much of Great Lakes remote sensing community, CIGLR will lead efforts to compare a variety of published algorithms for chlorophyll and harmful algal blooms retrievals by comparing matched date and time remote estimations against *in situ* measurements generated from our weekly HABs monitoring program to see which algorithms are behaving the best for the western basin of Lake Erie. Algorithms can be tested during specific times of the year and varying conditions (i.e. bloom versus no bloom and case 1 versus case 2 waters) for both historical (2008 to 2016) and current time periods. This remote sensing "cook-off" will aid in the decision-support goals of our complimentary SOAR program, by evaluating what algorithm behaves the best during specific conditions and within a water mass type, following the objective to move towards a predictive capability for chlorophyll and cyanobacteria in real-time.

Lastly CIGLR's efforts in remote sensing are directly aligned with, the Cyano-bacteria Assessment Network (CyAN) which is a multi-agency project operated by NASA, NOAA, USGS, and EPA to develop an early warning indicator system using historical and current satellite data to detect algal blooms in U.S. freshwater systems. The objectives of the CyAN program that CIGLR research will contribute to include: (1) development of a uniform and systematic approach for identifying cyanobacteria blooms using ocean color satellites; (2) creating a strategy for evaluation and refinement of algorithms across satellite platforms; (3) characterizing exposure and human health effects in drinking water sources and recreational waters; and (4) characterizing behavior responses and economic value of the early warning system based on remote sensed observations.

- Project 1a.3 – Local monitoring systems: Expanding observation networks to meet the local needs of key end-users of observational data

  Aim: N20.1,8 NGSP.2,3,4 N5.3,4, 5 Type: New Disciplines: ND, SS, ED Potential PIs: GLERL – Ruberg, Davis, CIGLR - Verhamme (LimnoTech), Winslow (OSU), new social science PI (UM)

  Since the 2014 Toledo water crisis many water utilities along Lake Erie have installed real-time water quality sensors at their water intake or pump station. These sensors monitor spatial and temporal shifts in water properties at unprecedented resolution, which has prompted subsequent research on newly discovered phenomena involving nearshore hypoxia, abrupt changes in surface and bottom chlorophyll and cyanobacteria pigments, pH changes related to blooms, and winter blooms under the ice. Sensors are presently installed at the following utilities: Monroe, Toledo, Oregon, Ottawa County, Marblehead, Sandusky, Elyria, Avon Lake, Cleveland, Ashtabula, and Mentor. This is ad-hoc network of sensors has been driven by the needs of local utilities, and it presently operates with limited plans for oversight of data quality or interpretation. This is true despite the widespread use of data from these local network sensors by other utilities and members of the research community for year-round monitoring. This project has three goals: (1) coordinate the operation, calibration, and data reporting for the existing network of local utilities sensors, (2) expand this network to other Great Lakes utilities, and (3) initiate a training program for utilities operators to manage their local sensor network and get data uploaded to GLOS.

  The Great Lakes Observing System (GLOS) has developed a data viewing utility to make real-time data from the local sensor network publicly available, but GLOS cannot support

inter-calibration or other needed sensor network coordination functions. The specific tasks included as part of this project include: (1) Support a minimum of four inter-calibration events per year for the above-mentioned water utilities in cooperation with other CIGLR researchers at University of Michigan, University of Toledo, and Ohio State University, 2) Participate in annual outreach activities at regional water utility workshops, (3) Perform ongoing QA/QC support to identify poor quality data and work with participating utilities to address this in a timely manner, (4) Provide an annual data report to GLOS and other utilities about past year performance of sensors and a QA/QC summary, (5) Participate in utility sponsored user groups and encourage other utilities to participate in installation and sharing of data from new or existing sensor. The user sponsored groups include ones organized by the American Water Works Association, Electric Power Research Institute, and Council of Great Lakes Industries. This project would likely include cost share from utility and regulatory agency partners, and potentially other researchers.

Focus 1b. Advancing technology for observing systems

- Project 1b.1 – Fixed moorings: Advancing technologies for toxin and contaminant measurement in the Great Lakes

  Aim: N20.1-4 NGSP.1-3 N5.1,3,4,6 Type: Core Disciplines: NS, ED Potential PIs: GLERL – Ruberg, Davis, Vander Woude (Federal Contractor), CIGLR - Johengen (UM), Tan (MSU)

  The application of new technologies in sensor systems and observing platforms can increase our ability to collect environmental observations at meaningful spatial and temporal scales, in turn, improving predictive uses of observing data. Although there can be substantial upfront infrastructure costs for developing new technologies, efforts should be evaluated relative to the quantity, quality, and unique spatial and temporal scales that the observed data can be delivered for a particular cost. The goal of this project is to utilize the intellectual and infrastructure resources offered by our Regional Consortium for development and application of state of the art technologies on fixed mooring platforms that provide information to managers and the public on a near-real-time basis.

  One of our key areas of research will be the continued development and deployment of the first ever freshwater Environmental Sample Processor (ESP) for detecting harmful algal bloom species and associated toxins in real-time. Pilot deployments of the ESP were conducted in 2016, and our goal is to implement fully functional deployments throughout the entire bloom period to improve range and accuracy of toxin detection. Future efforts will be directed toward the development of a multiplex microcystin/saxitoxin assay for the ESP to address other known toxins that are being produced by local HABs. CIGLR will support both the laboratory and fieldwork associated with the preparation and deployment of the ESP, and work with Dr. Tim Davis (NOAA-GLERL) and Dr. Greg Doucette (NOAA-CCEHBR), to develop the specific protocols for the microcystin/saxitoxin multiplex ELISA assay. CIGLR Partners are also looking to develop new technologies for cyanotoxin detection using a GaN-based immunoFET platform that operates on molecule specific absorption and detection. This technology would be ideally suited for finished drinking water testing to confirm that no toxin break-through has occurred during the treatment process.

  A second focus will be on advancement of in situ nutrient observations performed at hourly intervals. We have developed a network of four water quality monitoring buoys in western

Lake Erie that include a SeaBird Coastal SUNA spectrophotometric nitrate sensor and HydroCycle P wet chemistry phosphate sensor. These technologies have provided unprecedented temporal scales of in-lake nutrient monitoring that improve our understanding of inter-annual and seasonal patterns in HABs development. They also provide a true capability of tracking how the ecosystem will respond to the pending nutrient loading guidelines developed under the Great Lakes Water Quality Agreement Annex 4. Several years of effort have gone into improving the reliability and quality of these high frequency nutrient observations and we plan to work with Partners to expand the application of novel technologies into additional regional monitoring programs and potentially expand their application into watersheds for more accurate tributary loading estimations. All monitoring data will be transmitted in real-time via GLERL's Real Time Coastal Observation Network (ReCON) and disseminated publicly through GLERL and GLOS web portals.

Lastly, through the IOOS Alliance for Coastal Technologies program we are involved with the multi-agency Nutrient Sensor Challenge and are actively participating with our six international companies or research labs on the development and testing of the next generation of nutrient sensors. We are assisting in the Performance Evaluation testing of these sensors and are offering piloting opportunities within our observing system networks.

- Project 1b.2 – Mobile platforms: Advancing technologies for monitoring of physical, chemical, and biological parameters

  Aim: N20.1-4 NGSP.1-3 N5.1,3,4,6 Type: Core Disciplines: NS, ED Potential PIs: GLERL - Ruberg, Mason, CIGLR - Klump (UWM), Austin (UMD), Rudstam (Cornell), Green (Cornell), Johengen (UM), Hashsham (MSU)

  Mobile observing platforms have potential to monitor key parameters of ecosystem health (e.g., cyanotoxins, phosphorus, invasive species, microbial pathogens) in real-time at a reasonable price. But measurement techniques for most of these parameters are cumbersome, slow, and expensive, which leads to limited spatial and temporal coverage. Similarly, acoustic surveys of the distribution and abundance of pelagic fishes for fisheries management are performed on large research vessels, which again, are expensive to operate. The development and application of new acoustic sensor technology on autonomous surface platforms (Wave Gliders) could drastically increase the temporal frequency and spatial coverage of fisheries acoustic sampling, and significantly reduce data collection costs and constraints. The goals of this project are to: (1) broadly integrate mobile platform sensor technologies into the core monitoring programs of NOAA-GLERL and other federal agencies in the Great Lakes, (2) develop an integrated platform for automated analysis of selected toxins, chemicals, and molecular markers in field conditions using novel molecular analytics, and (3) advance the development of mobile platforms to provide a flexible and cost-effective pilot implementation of new technologies throughout the Great Lakes.

  CIGLR's University Partners presently operate a set of 2 Slocum Gliders and 2 IVER AUVs as part of their mobile platform operations. NOAA-GLERL recently acquired two new Wave Gliders, which CIGLR will engineer and upgrade with new sensor arrays, program, deploy, and integrate into the existing array of mobile platforms. Consortium Partners have also been developing new molecular approaches that can be adopted for use on field-deployable platforms that could provide routine measurements for (1) eDNA of dozens of invasive

species, (2) genes related to harmful algal blooms, waterborne pathogens, and antimicrobial resistance, and (3) chemical species of concern such as cyanotoxins and phosphorus.

Additional work for the next five years includes: (1) development work to make mobile platforms more compact, lightweight, lower in power consumption, and with flexible incorporation of in-situ environmental sensors (cyanobacteria, dissolved oxygen, temperature, chlorophyll, and photosynthetically active radiation). (2) Application of buoyancy and wave gliders to extend spatial and temporal scales of ongoing GLERL and EPA regionally directed ecological monitoring programs. CIGLR will support the operations the Slocum 2 buoyancy gliders in coordination with the GLOS-RA of the Integrated Ocean Observation System. Gliders will be used to support science missions in each of the Great Lakes associated with the EPA Coordinated Science and Monitoring Initiative, expand the temporal and spatial coverage of the monthly GLERL ecological monitoring program in Lake Michigan, and continue science operations in Lake Superior focused on climate impacts to Lake thermodynamics. (3) Integration of a two-frequency, split-beam, fisheries acoustics system into a SV2 Wave Glider to conduct long-term and high temporal frequency autonomous fish surveys that can be integrated into a real-time coastal observing network (ReCON) on Lake Michigan. Initial efforts will resolve design, operational, and engineering challenges of this application with the longer goal of developing standardized operational guidelines and performance specifications to ensure consistent and comparable data quality for Wave Glider based fisheries assessments performed across the Great Lakes. (4) For the advanced integrated platform, we will design, validate, and deploy analytical devices with microfluidic cards capable of automatically analyzing at least 75 selected markers including cyanotoxins and associated functional genes, phosphorus, eDNA for dozens of invasive species, sentinel markers of antimicrobial resistance genes (e.g., integron-integrase IntI1), and indicators of waterborne pathogens. Initially such platforms will be portable or hand-held and allow automated analysis of collected waters. In the long-term, they will be integrated with automated surface water sampling systems for continuous monitoring, interconnected for data sharing and control. (5) Advancements in mobile platform technology will involve developing the capability of autonomously collecting physical samples, adding a propeller propulsion mode for control in violent waves or rapid currents, integrating cellular and satellite communications modules to enable communication with other observing platforms throughout the Great Lakes, and developing planning and control algorithms to coordinate adaptive sampling of individual and groups of these robots. The target end product will be a cost-effective (< $10K) autonomous mobile sensing platform with a highly modular architecture for sensing/sampling payloads, locomotion modes, and communication capabilities, smart algorithms for operating as individuals or a collaborative swarm, and data interfaces to work with other observing platforms in the Great Lakes.

- Project 1b.3 – Airborne platforms: Advancing technologies for improved lake-scale assessments of harmful algal blooms

  Aim: N20.1-4 NGSP.1-3 N5.1,3,4,6 Type: Core Disciplines: NS, ED Potential PIs: GLERL - Ruberg, Davis, CIGLR - Johengen (UM)

  Currently, satellites only provide 60-70 cloud free images per year for the Great Lakes, and these are limited to scales of 0.5-1 km. For the HABs growing season (July – October) this frequency may be as low as 20 useable images for guiding the operational HABs bulletin and experimental HABs Tracker forecasts. To partly overcome this limitation, the GLERL-

CILER HABs team initiated routine flyovers of water intake systems with a hyperspectral camera that flies under the clouds, allowing more frequent and high resolution (1m spatial resolution and 246 spectral bands) updates of HABs distribution and intensity to support NOAA's operational bloom forecast models. Airborne platforms can generate significantly improved observations and data products over satellite estimates alone. The application of aerial drones could reduce costs even further and increase the frequency at which observing missions can be conducted. In addition, the high bandwidth and resolution provided by these new hyperspectral sensor technologies gives an opportunity to better resolve phytoplankton classification to improve accuracy of HAB forecasts.

The goal of this project is to develop state of the art airborne platforms, including autonomous drones and integrated sensor technologies, to provide improved spatial resolution of remote sensed observations near critical nearshore zones where public water utilities operate and tributary pollutant inputs occur. Weekly hyperspectral overflights initiated in 2015 will be continued, with the additional focus of resolving specific phytoplankton functional types (PFTs) from the remote sensing reflectance values (Rrs). A spectral library of Rrs signatures will be built from a variety of mono-clonal cultures of varying species using the WET Labs ac-s and BB9, as well as accounting for the absorption of CDOM and non-algal particles *in situ*. The algorithm for PFTs will be an inversion method that will account for uncertainty under different bloom forming conditions and concentrations of biomass. Improved classifications will lead to improved forecasts in Lake Erie to inform water intake managers of the location of HABs (i.e., cyanobacteria). With the frequency of overflights, the succession of genera within the lake can also be described on an unprecedented temporal and spatial frequency. The cyanobacterial genera (*Microcystis, Planktothrix, Anabaena, and Aphanizomenon*) that are the dominant bloom formers within Lake Erie will be differentiated from green algae, diatoms/dinoflagellates, and cryptophytes in the hyperspectral imagery. The historical *in situ* absorption, scattering, and attenuation spectra will also be used to differentiate functional groups from past *in situ* monitoring of inherent and apparent optical properties and the dominant bloom forming groups that were found during the previous 2014-16 field seasons. Verification of the final algal classifications estimations from hyperspectral sensors can be conducted from comparison of surface mapping with a multi-excitation fluorometry as well as from pure laboratory cultures. We will work with NOAA-GLERL and NCCOS to automate and calibrate data processing of the hyperspectral observations for inclusion in the current HAB tracker forecasting model. Inclusion of these data can provide improved information on community dynamics throughout the bloom period by pulling out different functional groups of phytoplankton.

Focus 1c. Data products for the scientific community and the public

- Project 1c.1 – Data management: Support for the GLOS Data Assembly Center (DAC)

  Aim: N20.1-4 NGSP.1-3 N5.1-6 Type: Core Disciplines: NS, ED Potential PIs: GLOS - Paige, CIGLR - Slawecki (LimnoTech), Johengen (UM)

  The Great Lakes Observing System (GLOS) works to make real-time and historical data publicly available to the larger Great Lakes community, benefiting data users and decision makers in the Great Lakes. GLOS also provides data services to support the region's need for data, modeling, and other data tools or products. Data is accessible through a web based Data Portal and tailored for end-users applications through specialized decision support tools. The

Data Portal provides browsing access to near – real time data for: Point Observations (winds, waves, water temperature, water levels, air temperature, dissolved oxygen, streamflow and turbidity), Satellite Observations (base reflectivity including weather hazards, chlorophyll concentration, colored dissolved organic matter, dissolved organic carbon, natural color, suspended minerals and water surface temperature), and Model Forecasts (currents, ice thickness, water level, waves, winds).

A primary goal of GLOS is to serve as a Data Assembly Center (DAC) for the Great Lakes by providing data assembly, quality control, and discovery and access services across multiple observing systems, platforms, and data types to address stakeholder needs and increase product development and operational efficiency. CIGLR's private-sector partner, LimnoTech, presently leads the GLOS DMAC, and we will continue to work with LimnoTech to ensure that all of our observing system and monitoring data, and corresponding modeling efforts are made available in support of this regional service. Specifically CIGLR will seek to: (1) integrate prioritized data sets into the GLOS DMAC system in ways that support stakeholder needs for information using required IOOS or community-adopted requirements and standards and the GLOS quality management system, (2) provide support services to advance the development and implementation of bi-national, national, and regional standards and protocols for delivery of observed data, and (3) provide support to GLOS to enable open data sharing and to advance GLOS as a leader in the region for data management by implementing a complete lifecycle management approach that supports discoverability, access, usability, curation and preservation for GLOS-served datasets. The outcome of these activities will be to support stakeholder-driven projects that address information needs related to managing ecosystem health, maritime safety, climate adaptation, and public health and safety issues.

- Project 1c.2 – Real-time information systems: Support for Great Lakes CoastWatch

  Aim: N20.1,8 NGSP.1,2 N5.1-4,6 Type: Core Disciplines: NS, SS Potential PIs: GLERL – Leskevich, Davis, Ruberg, CIGLR - Klump (UWM), Austin (UMD), Johengen (UM), Lemos (UM)

  CoastWatch is a NOAA-wide program that provides a rapid supply of up-to-date, coordinated, environmental information (remotely sensed, chemical, biological, and physical) to support federal and state decision makers and researchers who are responsible for managing the nation's coastal ecosystems. NOAA CoastWatch focuses on specific regional priorities, such as unusual environmental events (e.g., harmful algal blooms), mapping wetland change (e.g., change detection), and mapping ice cover/ice thickness (e.g., hazard mitigation). The goal of this project is to support the Great Lakes CoastWatch program's ability to develop and deliver real-time and retrospective satellite observations and derived products for the Great Lakes.

  CIGLR will help develop Great Lakes regional products from remotely sensed data to facilitate dissemination of CoastWatch data, products, and information for research, operational, and educational purposes. Planned tasks include development of mapping products based on remote sensing data, management of data dissemination, and research on algorithm development of remotely sensed data. Planned products include upwelling, color producing agents (chlorophyll, CDOM, suspended mineral), and ice type mapping. These regional products and applications for the Great Lakes will contribute to the operational responsibilities of sister agencies, such as the U.S. Coast Guard and NOAA National

Weather Service, and will foster additional research applications by regional data users, such as detection and tracking of thermal fronts, analysis of circulation patterns and upwelling (e.g., fish recruitment studies), and modeling and forecasting Great Lakes parameters (e.g., Great Lakes Forecasting System (GLCFS)). All Great Lakes CoastWatch products are publically available on the Great Lakes CoastWatch website.

- Project 1c.3 – Advanced warning systems: Public applications of observing systems

  Aim: N20.1,8 NGSP.1-4 N5.1,3,4,6 Type: Core Disciplines: NS, SS Potential PIs: GLERL - Leshkevich, Ruberg, CIGLR - Johengen (UM), Arvai (UM), Cardinale (UM)

  Over the past 5 years, the CI has supported development of the Great Lakes Synthesis, Observations and Response System (SOAR) at NOAA-GLERL to coordinate regional coastal observations that support regional priorities, including Great Lakes restoration. The observing systems data that are collated and distributed by SOAR provides real-time information to help public utility managers maintain high quality drinking water, and informs the public on current water quality conditions. Furthermore, observations are being used to develop decision support tools that provide warnings to regional managers and support adaptive management decisions on water quality, harmful algal blooms (HABs), and hypoxia in locations like Maumee Bay, Saginaw Bay, Muskegon Lake Area of Concern (AOC), Lake Michigan and Lake Erie. The goal of this project is to expand the Advanced Warning Systems offered by SOAR, and the number of end-users of data.

  CIGLR will (1) provide real-time, quality assured, nutrient and optical data for the web-based decision support system disseminated through GLERL and Great Lakes Observing System (GLOS) web portals, (2) provide data for calibration and validation of satellite remote sensing estimates used in operational HAB forecast products, (3) develop necessary lake ecosystem data to assess the effectiveness of Great Lakes Water Quality Agreement proposed watershed remedial actions, and (4) develop predictive models to improve the accuracy of decisions for water intake and beach managers to better protect public health. To accomplish these goals, continuous measurements of nutrients, physio-chemical water properties, and estimates of total and cyanobacterial algal biomass from CIGLR's observation systems will be transmitted via GLERL's Real Time Coastal Observation Network (ReCON) data management system and disseminated publically through GLERL and GLOS web portals. We will continue to support field collection of ground-truth samples to validate and refine remotely sensed determinations of sediment plumes and nuisance algal blooms, and conduct profiles to measure inherent optical properties using the Satlantic hyperspectral profiler, the Satlantic hand-held hyperspectral imager, and WETLabs ac-s and BB9 absorption and backscatter instruments to aid in algorithm development and validation of remote sensing estimations of color producing agents.

- Project 1c.4 – Beach forecast systems: Health and water-quality monitoring to protect coastal recreation

  Aim: N20.1,6,7,8 NGSP.3,5 N5.6 Type: New Disciplines: NS,SS Potential PIs: GLERL - Davis, CIGLR - Dreelin (MSU), Rose (MSU), Freedman (MSU), Lee (OSU), Alm (CMU), McLellan (UWM)

  Millions of people in the Great Lakes region live within a short drive of a Great Lakes beach. Beach recreation is not only an integral part of Great Lakes culture, it is also one of the most lucrative forms of tourism. Healthy beaches and clean water are crucial to residents and local

economies, and a robust forecasting system for beach health and water quality is needed to protect beach recreation. Water and sand that become polluted with sewage, stormwater, and agricultural runoff may contain harmful feces-associated bacterium like *Escherichia coli* (*E. coli*) or other disease-causing microorganisms (pathogens). Beach sands can become reservoirs for the long-term persistence of *E. coli*, which can complicate beach monitoring efforts and make it difficult to predict how these pathogens will affect swimmers, kayakers, or surfers when they ingest the contaminated water or sand. The goal of this project is to develop improved beach health monitoring and warning systems, and have them more widely distributed to managers throughout the Great Lakes.

First, we will investigate what promotes the prolonged survival of *E. coli* in beach sand and use the genes in pathways associated with survival as markers to monitor these potentially harmful *E. coli* populations. Specific tasks are to (1) identify mechanisms of prolonged survival through comparative genomics and laboratory and field experiments that will link specific genetic traits to the phenotypic characteristics resulting in prolonged survival, and (2) develop quantitative PCR assays for genetic markers of traits linked to survival and use these assays to survey beaches to determine the proportion of the sand reservoir made up of naturalized *E. coli*. The end product will be a quantitative determination of naturalized *E. coli* in the sand environment and an enhanced understanding of the relationship between *E. coli* reservoirs and healthy beach ecosystems.

Second, we plan to foster the widespread use of new molecular techniques for monitoring *E. coli*. Current methods used to evaluate recreational beaches do not provide for same-day reporting or for determining the source of contamination. Molecular techniques, such as qPCR, are available but many health department labs do not have the capacity to run the tests. Members of our Regional Consortium have worked with the Michigan Department of Environmental (MDEQ) to develop the capacity allowing 20 labs in Michigan to successfully run qPCR and monitor beaches in near-real time. We propose to take the next step towards implementation of this method across Great Lakes beaches. Specific tasks include hosting a series of workshops or working group meetings with key stakeholders such as the U.S. EPA, divisions of environmental quality in all 8 Great Lakes states, as well as local. We will also collect and analyze all available qPCR beach data to provide an evaluation to the working group. For our second goal, we will expand our training program to add training and technical assistance for source tracking. The source tracking training will include hands-on training sessions at MSU and host labs as well as technical assistance for participating labs.

Final products of this project will include development of new qPCR water quality standards or methods for beaches to calculate their own standards, manuals for technical guidance documents for source tracking, and training sessions. In addition, we will integrate our efforts with the GLRI-funded Great Lakes BeachCast, which provides online reporting for Beach Health and Water Quality throughout the Great Lakes, including a cell phone application that beach-goers can use in real-time.

Focus 1d. High-risk, potentially transformative projects

- Project 1d.1 – Social observing systems: Developing and deploying a Great Lakes Observing System for Human Dimensions (GLOS-HD)

Aim: N20.1,3,7,8 NGSP.1,2,4 N5.1,,3,4,6 Type: New Disciplines: SS Potential PIs:, CIGLR - Washburn (NERR), Lupi (MSU), Dietz (MSU), McCright (MSU), Franks (MSU), Brown (UM), new social science PI (UM), Cardinale (UM)

To navigate the Anthropocene, more data is needed to understand the socioeconomic and sociocultural elements of human communities[15]. Great Lakes basin-wide data and observation systems are entirely lacking in this regard, especially at actionable scales where social science can deliver information to decision-makers and inform policy. To complement the strong biophysical monitoring systems that presently exist, we propose to develop the architecture, structure and approach for a Great Lakes HD monitoring program. Projects in this area will make use of NOAA's place-based programs- the NERRs and the Sanctuaries- to develop, deploy, test and refine an observing system that collects and analyzes key sociocultural and socioeconomic data for coastal communities.

To initiate a tractable human dimensions observing system, initial efforts will focus on collecting data that relates to human health, water quality, and shoreline recreation through an examination of related social, cultural and economic services that are attached to these. Services that can be quantified economically include (a) recreational uses of shoreline beaches and parks for use in valuation studies that rely on travel cost methodologies, (b) shoreline property sales and values for use in hedonic pricing studies, and (c) Great Lakes-dependent coastal businesses sales and profits for use in market valuation studies. Non-economic metrics of social or cultural values can be quantified from repeated surveys of users 'sense of place', 'identity' and the value of 'local heritage'. HD observations will be collected from three primary sources: (1) a broad-based collection of existing and remotely collected data (e.g., data mining, social media, web cams), and (2) systematically designed, randomized surveys to quantify coastal residents' activities and social values related to them (e.g., shoreline visitation, fishing, cultural practices), and (3) focused in-depth interviews and qualitative analysis of smaller subsamples in concert with place-based programs to measure attitudes, satisfaction, place attachment and broader values. The GLOS-HD will fill a key gap in the currently sporadic efforts to measure economic, social or cultural values of Great Lake ecosystem services, and form the basis needed by managers to understand how constituencies interact with the Great Lakes.

Theme 2. Invasive Species and Food-web Ecology
Tracking the dynamics and functioning of Great Lakes ecological communities

The genes, populations, species, and communities of microbes, plants and animals that inhabit the Great Lakes form a vast biological inventory that is responsible for much of the prosperity that is enjoyed in this region of the world. Understanding how this biological inventory changes through time, detailing the consequences of biological change for natural and human systems, and ensuring that ecological communities are resilient in the face of future pressures is essential to achieving biological and economic sustainability. To help facilitate sustainability in the Great Lakes, CIGLR will focus on 4 focal areas of research for Theme 1:

Focus 2a. Invasive species
Focus 2b. Food-web dynamics
Focus 2c. Development of ecological 'omics'
Focus 2d. High risk, potentially transformative projects

In the following section, we detail specific projects proposed under each research focus:

Focus 2a. Invasive species

- Project 2a.1 – Prevention: A coupled human-natural systems approach to predicting and preventing species invasions

  Aim: N20.6,7 NGSP.3 N5.4-6 Type: New Disciplines: NS, SS Potential PIs: GLERL – Vanderploeg, Rutherford, CIGLR - Zhang (UM), Fisk (Windsor), Lodge (Cornell), Stedman (Cornell), Knuth (Cornell), Lauber (Cornell), Lepak (Cornell), Wagner (MSU), Cardinale (UM)

  Because populations of invasive species are difficult to control or eradicate once established, preventing the initial introduction of these species is critical to protecting the Great Lakes region from invasive species effects. These preventive efforts necessarily include identifying the most important vectors for invasive species, as well as the human actions and behaviors that contribute to introductions. To improve prevention efforts, CIGLR will engage in three types of research projects:

  First, we will seek to identify the most important conduits for invasive species into the Great Lakes region with studies that: (1) identify the highest risk species that might be introduced into the Great Lakes and use this information to effect policy approaches that limit introductions (e.g., by limiting live trade of organisms); (2) assess the risk of river and stream systems as conduits for invasive species introduction and spread; (3) investigate the efficacy of barriers for preventing the spread of invasive species through critical canals and rivers in the Great Lakes. Second, we will continue our ongoing efforts to prevent the release of nonindigenous species through ballast water by working with national ballast water treatment system testing labs and the USCG to evaluate effective tools for monitoring shipboard compliance with newly effected ballast water discharge regulations. The USCG currently has limited ability to ensure that onboard treatment systems are being operated with the same efficacy as established during their approval testing and that ballast water discharges are in compliance with the standards. We are actively involved in experimental testing of fluorometers and ATP sensors for assessing live cell densities and will work with USCG on piloted ship-based testing. Lastly, we will engage social scientists to identify human behaviors that are most likely to contribute to the introduction and spread of invasive species, and identify which behaviors are most likely to be managed effectively to reduce introductions, spread, and impacts. We will assemble an expert panel comprising Great Lakes scientists and resource managers to participate in a Delphi exercise[16,17]. This team will identify the human behaviors that have the highest likelihood to contribute to (or limit) the introduction and spread of the most critical types of invasive species. We will complement this exercise with a combination of survey and focus group techniques to assess the extent to which different management strategies designed to influence these human behaviors are likely to be adopted and result in the desired change to behaviors that limit the introduction, spread, and eventual impacts of aquatic invasive species in the Great Lakes.

- Project 2a.2 – Monitoring and early detection: Using eDNA to scan for potential invaders

  Aim: N20.6,7 NGSP.3 N5.4-6 Type: New Disciplines: NS, SS Potential PIs: GLERL – Elgin, Davis, Rutherford, CIGLR - Lodge (Cornell), Gomez (Cornell), Bland (Cornell), Hare (Cornell), Getchell (Cornell), Therkildsen (Cornell), McComas (Cornell), MacIsaac (Windsor), Sepulveda-Villet (UWM), Cuhel (UWM)

"Omics" technologies have become powerful tools to apply to surveillance and monitoring of organisms in natural environments. Many of the members of this project pioneered the development and application of environmental DNA (eDNA) tools to the surveillance of invasive species, including pathogens, in the Great Lakes watershed, refined the eDNA approach to detect many species from the same analysis (metagenetics using ultrasequencing vs. single species qPCR), and adapted eDNA approaches to be suitable for citizen science (to expand the scope of sample collection while simultaneously educating the public). Team members also pioneered the use of ancient DNA (aDNA) and other genomics tools to reconstruct evolution in exploited fish populations to inform improved fisheries management. Such aDNA approaches could be applied also to invasive species. Two new laboratories at Cornell built specifically for eDNA and aDNA have state-of-the-art architecture, equipment, and procedures to prevent contamination and assure high quality environmental genomics data. A persistent challenge to the adoption of genetic-based detection for surveillance, monitoring and regulation results from the additional uncertainty that exists because genetic detection is indirect (no specimen in hand); this additional uncertainty complicates the risk communication and corresponding actions by managers.

CIGLR will work to further develop eDNA and other metagenetic (metabarcoding) methods for application in surveillance and/or monitoring programs for invasive species of interest to GLERL. Specifically, we will (1) expand the metagenetic tools for use on a wider variety of taxonomic groups, including plants, pathogens, and parasites; (2) optimize sampling strategies for different taxonomic groups and habitats (benthic vs. pelagic); (3) optimize the laboratory procedures and bioinformatics pipelines to extract population level inferences from single-species and/or metagenetic analyses; (4) test and improve existing research-grade and commercial technology platforms or create new ones to increase the speed, portability, and field deployment of genetic-based detection; and (5) test communication strategies for decision making under uncertainty with agency decision-makers and the public.

- Project 2a.3 – Rapid response: Support to guide eradiation or containment of new invaders.

  Aim: N20.6,7 NGSP.3 N5.4-6 Type: Core Disciplines: NS, SS Potential PIs: GLERL – Elgin, Rutherford, Mason, Vanderploeg, CIGLR - Zhang (UM), Rowe (UM), Lodge (Cornell), Rudstam (Cornell), Carrick (CMU), Fisk (Windsor), Berges (UWM), Kelly (UMD)

  As a research lab, NOAA-GLERL rarely leads a rapid response program to eradicate or contain a newly detected invasive species. However, NOAA-GLERL's research is used to support the planning and execution of rapid response efforts for invasive species as well as other environmental emergencies, and CIGLR's work plays a prominent role in these efforts.

  First, our extensive network of nearshore observing systems is used to provide local wind wave and meteorological conditions to support vessels and diving operations that are required for a rapid response. For example, we established a local on-site observing buoy to support a U.S. Coast Guard rapid response effort to survey and drain a discovered leaking oil barge in Lake Erie. Second, CIGLR's hydrometeorolgical modeling is used to help predict, and potentially contain the spread of passively dispersed invasive species like *Dreissena*. CIGLR Research Scientists (Beletsky) previously developed a larval transport model to predict the spread of *Dreissena* throughout Lake Michigan. This model was based on a lake circulation and temperature model that was partly developed by CIGLR researchers, and further modified to incorporate larval transport of passive dispersers. While the model was

developed for larval transport of Dreissena, it is applicable for modeling the rate of dispersion of potential invasive species control substances (e.g. Zequanox) in Great Lakes waters to predict the needed concentration and exposure time for effectiveness. It can also link to food web models such as the Ecopath with Ecosim type of modeling done by Zhang and Rutherford that consider how food web manipulations impact invasive species (stocking or harvest of the invasive species themselves or their predators). Lastly, as part of its programmatic activities, CIGLR will provide Rapid funds to University Partner PIs to facilitate rapid responses to issues facing the Great Lakes. Rapid funds are small seed grants of $10K or less that can be awarded quickly (48-hrs or less) to help initiate an emergency response to invasive species, or other environmental problems in the Great Lakes.

- Project 2a.4 – Impacts: Community and ecosystem impacts of key invasive species

  Aim: N20.6,7 NGSP.3 N5.4-6 Type: Core Disciplines: NS, SS Potential PIs: GLERL – Elgin, Rutherford, Mason, Vanderploeg, CIGLR - Zhang (UM), Ozersky (UMD), Lodge (Cornell), Rudstam (Cornell), Ivan (MSU), Lupi (MSU), Carrick (CMU), Denef (UM), MacIsaac (Windsor), Cardinale (UM)

  The CI has considerable experience working with NOAA-GLERL PIs (Vanderploeg, Rutherford, Mason, and Elgin) to quantify the ecological effects of invasive species on algae[18], nutrient dynamics[19-21], and lake productivity[22]. We will continue to broadly support NOAA-GLERL's research on invasive species with studies that detail their ecological and economic impacts in order to predict the potential impacts of spread.

  Some of the most profound and disruptive effects of invasive species relate to food web alterations and impacts[23]. These effects can dramatically alter the composition and function of whole ecosystems. CIGLR will engage in research that characterizes the nature and magnitude of food web disruptions in the Great Lake such as (1) surveys, experiments, and biophysical models that predict the impacts new invaders, such Asian Carp on Great Lakes food-webs and fisheries[24]; (2) experimental, observational, and modeling approaches to understand the food-web consequences of exotic zooplankton species; (3) empirical approaches to assessing the impacts of invasive species on trophic communities in riverine and stream ecosystems; (4) quantifying the impact of important invasive species, like quagga mussels (*Dreissena bugensis*) and round gobies (*Neogobius melanostomus*) on trophic structure, nutrient dynamics and energy flow in nearshore regions within the Great Lakes.

  Invasive species also pose serious economic threats to invaded ecosystems[25]. For example, the introductions of sea lamprey, dreissenids, and gobies, have been linked to the failure of recreational fisheries in Lake Michigan and Lake Huron. CIGLR's Regional Consortium will continue its progress on the development of economic models of recreational and commercial fishing demand and value and then use this information to build empirical models that help quantify the potential economic losses associated with invasive species and other impairments to recreational fisheries[26].

- Project 2a.5 – Control and management: Support for education and outreach efforts

  Aim: N20.6-8 NGSP.3 N5.4-6 Type: Core Disciplines: NS, SS, Potential PIs: GLERL – Elgin, Rutherford, Mason, Vanderploeg, CIGLR – Diana (UM), Taylor (MSU), Wilson (OSU).

  While eradication of invasive species may not be feasible, targeted control and management efforts can help slow the rate of range expansion and lessen the impacts of invasive populations. Since invasive species often span geographic and jurisdictional boundaries,

effective application of control and management strategies requires communication and regionally coordinated action. CIGLR will work with existing, and highly successful programs already established throughout the Great Lakes to enhance their efforts for invasive species control and management.

First, we will coordinate and leverage our education and communications programs with each of NOAA's Sea Grant programs throughout Great Lakes states. Our Regional Consortium includes the Directors or Associate Directors of six Sea Grant programs, including Michigan Sea Grant (Diana – UM, Taylor – MSU), Ohio Sea Grant (Wilson – OSU), Indiana-Illinois Sea Grant (Höök – Purdue), Wisconsin Sea Grant (Hurley – UW-Madison), New York Sea Grant (Wise – SUNY), and Minnesota Sea Grant (Downing – UMinn). Sea Grant has a large, well-established network of extension teams who work directly with the public to provide education on the risks of spreading aquatic invasive species, as well as education on the application of best management practices to reduce the spread associated with recreational uses of invested waterbodies. CIGLR will foster these programs with our own programs (see Section VI. ECO Program) that include: (1) distribution of funds to University Partners for public education and outreach events; (2) financial support for working groups and summits that bring together scientists, NGOs, businesses, and the public to co-design strategies to deal with invasive species; and (3) funding for graduate and postdoctoral projects to assist local communities in development of invasive species management plans.

In addition to our work with Sea Grant, CIGLR will work with the Great Lakes Commission (GLC), which organizes the Great Lakes Aquatic Nuisance Special Panel to advance efforts to prevent or control the introduction and spread of aquatic nuisance species. The primary means by which GLC accomplishes this goal is by providing a forum for discussion, consensus-building, coordination and action among relevant public, private sector and user group interests in the United States and Canada. GLC has provided a letter of support for our bid, partly they are excited about the coordination our CI would bring to institutions throughout the Great Lakes, which they see as a benefit for advancing goals of the Great Lakes Aquatic Nuisance Special Panel.

- Project 2a.6 – Coordination & leadership: The Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)

  Aim: N20.6-8 NGSP.3 N5.4-6 Type: Core Disciplines: NS, SS Potential PIs: GLERL - Vanderploeg, Elgin, Mason, CIGLR – Zhang (UM), Diana (UM), Read (UM), Lodge (Cornell), Fisk (Windsor)

  Aquatic nonindigenous species are perhaps the greatest stressor currently facing Great Lakes aquatic ecosystems, altering energy pathways, lowering food web and fisheries productivity, and costing millions of dollars annually in control and mitigation. NOAA's Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) is a searchable database with fact sheets, threat assessments, and maps designed to improve stakeholder education and inform prevention, management, and control of aquatic nonindigenous species. The goal of this project is to improve and enhance GLANSIS to better inform managers of current and future threats from nonindigenous species.

  Specific tasks include maintenance and updates to the GLANSIS database, addition of new species to the watch list of likely invaders, and improvement of information extraction capability, enhancement of information to support ANS control, and addition of ANS habitat

suitability maps. Because GLANSIS serves a clearinghouse role by compiling information on ANS in the Great Lakes, the project will engage academic researchers from across the basin to collect the most relevant, up-to-date data on these species. In the course of providing the most current information on ANS, GLANSIS staff will perform data synthesis research that leads to a better understanding of current and potential impacts of ANS to the Great Lakes ecosystems. The information served through GLANSIS will help managers make informed decisions when devising and implementing strategies to prevent, control, and mitigate the introduction and impacts of ANS and thus protect the natural resources and economic well-being of the Great Lakes. As a database and information clearinghouse, GLANSIS's main function is to disseminate scientific information to both the science and public sectors, and in the process highlight the scientific role that NOAA can play at the regional level. Finally, GLANSIS provides both paid and volunteer internship opportunities to high school, undergraduate, and graduate students with interest in invasive species and the use of bioinformatics. All data and information produced by, and included in, the GLANSIS database available to the public.

Focus 2b. Food-web dynamics

- Project 2b.1 – Pelagic ecosystems: Supporting core ecological monitoring with advanced sensors to document status and trends of Great Lakes fish and invertebrate communities

  Aim: N20.5 NGSP.3 N5.1,2,5 Type: Core Disciplines: NS Potential PIs: GLERL – Vanderploeg, Rutherford, Mason; CIGLR - Rudstam (Cornell), Smith (UWM), Sullivan (Cornell), Watkins (Cornell), Greene (Cornell), Fisk (Windsor), Johengen (UM), Cardinale (UM)

  CIGLR will continue to work with the Ecosystem Dynamics branch at NOAA-GLERL on their collection of long-term ecological data that is intended to improve our understanding of ecosystem structure and function for managing water quality, fisheries, and other ecosystem services in the Great Lakes. Future research activities will be developed to support both recurrent vessel-based surveys, process based lab experiments, and implementation of emerging sampling technologies (defined below). The geographical scope of these research activities will be centered in Lake Michigan; however, we will also support NOAA, USGS, and EPA research efforts within the other Great Lakes as part of the EPA Coordinated Science and Monitoring Initiative (CSMI).

  We also plan to extend NOAA-GLERL's core monitoring program with new sampling technologies that overcome key problems. Ongoing research by CIGLR-GLERL in Lakes Michigan and Huron have shown strong diel vertical migration of zooplankton, micro-nekton, and fishes that lead to concentrated densities in relatively thin layers of the water column that are associated with thermal structure and high phytoplankton concentration. Despite extensive sampling of the food web by traditional methods, critical questions remain about the vertical position and movement of zooplankton, larval fish, and fish predators. Precise quantification of spatial structure and density of these organisms are essential to understanding the structure and function of the lake food web, but these areas of biological concentration can only be effectively sampled with the application of new technology.

  Fisheries acoustics is used extensively for stock assessment in both marine and freshwater systems. However, the application of acoustics technology to investigate abundance and distribution of invertebrates is more limited. In the past we have developed methods for analyzing the abundance of mysid shrimp using single frequencies and explored acoustic

returns from this species over a range of frequencies. With data from more sound frequencies, we can estimates distribution and abundance of other smaller zooplankton species. As development continues on hardware (simultaneous emission of multiple frequencies), theory (target strength models), statistical analysis (spatial statistics and Bayesian hierarchical methods) and deployment platforms (wave gliders, AUV), acoustic estimates of more biological components of the pelagic ecosystem are going to be possible. We will develop and apply new methods to track zooplankton distribution over large spatial scales using multifrequency hydroacoustics data. These data should be collected in conjunction with new Multiple Opening Closing Nets Environmental System Sampler (MOCNESS) at NOAA-GLERL, which allows for detailed investigations of the identity of various scattering layers in the Great Lakes and will help calibrate acoustic estimates.

In parallel development, we will expand our use of acoustics to follow the movement of individual fish, both through various pop-up tags and internal acoustic tags that are picked up by an array of acoustic receiver deployed as part of the Great Lakes Acoustic Telemetry Observation System (GLATOS) network. These data not only give information on the large scale movement patterns of predatory fish, but can give information on the use of the water column by these predators. With a better understanding of the distribution of zooplankton, prey, and predatory fish, we will be in position to better quantify the food web interactions that determine how energy at the bottom of the food web is translated to fish production.

- Project 2b.2 – Benthic ecosystems: Long-term monitoring to assess impacts of invasive species on food-webs

  Aim: N20.5 NGSP.3 N5.1,2,5 Type: Core Disciplines: NS Potential PIs: GLERL – Elgin, Mason, Vanderploeg, Rutherford, CIGLR - Johengen (UM), Rowe (UM), Nalepa (UM), Carrick (CMU), Denef (UM)

  CIGLR will collaborate with the Ecosystem Dynamics branch at NOAA-GLERL to continue their collection of long-term ecological data that are critical for understanding ecosystem structure and function for managing water quality, fisheries, and other ecosystem services in the Great Lakes. The current Long-Term Research (LTR) program of GLERL integrates a core set of long-term observations on biological, chemical, and physical variables, with short-term process-based studies for understanding ecosystem change. Such information is essential for the development of new models and forecasting tools to explore impacts of various stressors on the ecosystem. The single most important stressor in the system remains dreissenid mussels, and we recognize that monitoring within the pelagic realm alone is no longer an option. Dreissenid mussels, because of their high filtration rates and high abundance in all depth zones of the lake, have decimated the spring phytoplankton bloom and decreased the abundance of phytoplankton in the hypolimnion and deep chlorophyll layer during the stratified season. They have also reengineered the ecology of the entire food web by increasing water clarity and altering nutrient cycling. It is believed they have had a negative effect on the carrying capacity of our upper food web, which is putting the valuable sport fishery at risk, and is exacerbating nuisance growths of algae (HABs) in the nearshore.

  Future research activities will support recurrent vessel-based spatial surveys, process based studies, and implementation of emerging sampling technologies to provide data for the development of models and forecasting capabilities. The geographical scope of these research activities will be centered in Lake Michigan; however, we will also support NOAA, USGS, and EPA research efforts within the other Great Lakes as part of the EPA

Coordinated Science and Monitoring Initiative (CSMI). CSMI studies are aimed at examining structure and function of the open water food web and relating patterns across lakes to major drivers such as tributary inputs and spatial distribution of invasive dreissenid mussels. CIGLR will continue to support long-term observations of dreissenid abundance and condition in the Southern Lake Michigan basin A benthic survey at 40 sites in the southern basin will be made in late summer, and monthly collections of mussels at our shallow, mid-depth, and deep sites along our Muskegon transect will be examined quarterly for condition (based on weight). These data will be combined with experimental research on feeding and nutrient excretion rates to develop models of mussel population growth and bioenergetics and to develop models of mussel impacts to the food web. CIGLR will continue to conduct laboratory experiments to determine selective feeding on the whole spectrum of seston (from bacteria to microplankton), quantify nutrient recycling, and examine factors limiting growth of mussels in Lake Michigan. We will support in-lake experiments to assess quagga mussel growth under different levels of food quantity and quality, and in different temperatures using in situ mussel cages, and extend this work with complementary biophysical modeling.

- Project 2b.3 – Littoral ecosystems: A basin-wide long-term ecological assessment of Great Lakes coastal wetlands to inform restoration and conservation efforts.

  Aim: N20.5 NGSP.3,4 N5.1,2,5 Type: New Disciplines: NS Potential PIs: GLERL – Vanderploeg, CIGLR - Uzarski (CMU), Brady (UMD), Ruetz (GVSU), Ciborowski (Windsor)

  Since European settlement, more than 50% of coastal wetlands have been lost in the Great Lakes basin, leading to growing concern and increased monitoring by government agencies. To facilitate collaboration and information sharing between public, private, and government agencies throughout the Great Lakes basin, we developed standard methods and indicators used for assessing wetland condition by multiple universities and government agencies across the Great Lakes basin, US and Canada. Sampling began in 2011 and will continue at least through the summer of 2020 as part of a 10 year $20 million grant from the USEPA. Physico-chemical and biotic data are collected from all components of each wetland. After quality assurance/quality control these data are entered in mathematical models and stored in a publicly accessible database greatlakeswetlands.org. The goals of this current study are to (1) incorporate functional assessment protocols; and (2) link these functions to nearshore and offshore waters to develop energy flow models to inform managers and lawmakers.

  Since our current monitoring protocols do not currently include measures of fish recruitment or energy flow, specific tasks for this project include additional sampling in wetlands and adjacent nearshore/offshore waters. This can be done in part by collaborations with projects 2b.1 and 2b.2. We will sample physico-chemical, invertebrate, and fish during spring and fall in conjunction with our current summer sampling regime. Additional samples will be collected for isotope and trace element analysis. Concurrent samples will be collected in the nearshore/offshore areas adjacent to each site to explore carbon out welling and nearshore shunt. Sound management stems from data-driven decisions of ecosystem functions and values. These data are not currently available and linkages, for the most part, are unknown.

Focus 2c. Development of ecological “omics”

- Project 2c.1 – Prokaryotes: Opening the Great Lakes microbial black box using genomics

Aim: N20.5 NGSP.3 N5.2,4,5 Type: New Disciplines: NS Potential PIs: GLERL - Davis, CIGLR - Dick (UM), Denef (UM) Sheik (UMD), Alm (CMU), Mouser (OSU), Rich (OSU), Newton (UWM)

Prokaryotic organisms like bacteria are known to regulate some of the most important ecosystem-level processes, including carbon flows and respiration of entire lakes, as well as the cycling of all biologically essential nutrients. At the same time, certain prokaryotes are the underlying cause of some of the greatest environmental problems faced in the Great Lakes, such as harmful blooms of cyanobacteria. Until recently, microbiologists lacked the tools needed to perform routine surveys and monitoring of microbes, which precluded us from predicting their diversity, spread, and whether their function are beneficial or detrimental. But recent advances in DNA and RNA sequencing technology have given microbial biologists the unprecedented ability to survey microbes in near real-time, and advances in computational algorithms and databases have provided the means for analysis and dissemination of large genomic datasets. We are, for the first time, in a position to open the black box of the Great Lakes microbial community and begin tracking and predicting the composition of prokaryotes that perform both beneficial and detrimental functions.

The goals of this project are to (1) characterize the diversity and function of microbes across the Great Lakes, and (2) develop methods to track the genes that microbes use to produce toxic compounds, such as cyanobacterial toxins associated with blooms of cyanobacteria. To accomplish goal 1, we will initiate a multi-year sampling of all 5 Great Lakes to collect microorganisms, and apply high-throughput DNA sequencing and advanced post sequencing algorithms to assemble genomes from microbial species. We will then generate a searchable, open access database of microbial genomes recovered for dissemination to other researchers. To accomplish goal 2, we will focus on cyanobacterial blooms, which are a model system for identifying and tracking genes involved in toxin production. The dominant bloom-forming organism in the Great Lakes, *Microcystis*, is a major concern due to the production of microcystin, a toxin harmful to humans and other organisms. While the gene pathway responsible for the biosynthesis of microcystins by *Microcystis* is well described, the broader repertoire of natural products, including toxins, in cultured isolates and naturally occurring blooms of *Microcystis* are poorly understood. We will identify specific genetic pathways and regulatory controls for the biosynthesis of natural toxins in cyanobacterial blooms using western Lake Erie as a pilot study. Using a comparative genomics analysis pipeline that consists of comparative gene clustering, we will use a native graph database to identify genes (or gene clusters) that show up- or down-regulation in various bloom or growth stages of *Microcystis*. Gene clusters can be linked to neighboring genes to identify potential operons which show multiple functions within a single pathway needed for protein synthesis and transport. These pathways can then be analyzed by predictive software to identify the structure and function of the protein produced. The ultimate product will be to produce a gene or protein based microarray that can be used by water managers and/or citizen science groups for rapid analysis and tracking of the expressed genes that produced toxins.

- Project 2c.2 – Eukaryotes: Using eDNA to monitor the populations of rare and threatened vertebrate species

Aim: N20.5 NGSP.3 N5.2,4,5,6 Type: new Disciplines: NS, ED Potential PIs: GLERL – Rutherford, Mason, Davis, CIGLR - Lodge (Cornell), Getchell (Cornell), Therkildsen (Cornell), McComas (Cornell), Hare (Cornell)

"Omics" technologies such as use of environmental DNA (eDNA) have become powerful tools for surveillance and monitoring of organisms in natural environments. Members of our Regional Consortium pioneered the development and application of environmental DNA (eDNA) tools to the surveillance of rare species. Multiple studies now show that eDNA sampling can be more sensitive at detecting low-density target species than traditional sampling methods, and is less costly and labor intensive. The goal of this project is to develop eDNA and other metagenetic (metabarcoding) methods for applications in surveillance and monitoring for rare and threatened species.

CIGLR will further develop eDNA and other metagenetic (metabarcoding) methods for application in surveillance and/or monitoring programs for rare and threatened species. To begin we will (1) assess the ability of environmental DNA to detect the presence/relative densities and distribution of relatively rare species of fish like muskellunge, northern pike, american eel, and round goby in the Upper St. Lawrence River (SLR) and its tributaries; and (2) test the same water samples collected from areas known to harbor Muskellunge using a highly sensitive, quantitative RT-PCR assay. We will then compare this eDNA data with the results from prey fish species captured during TIBS trap net collections and tested with the same assay. Following this pilot, we will expand the metagenetic tools for use on a wider variety of taxonomic groups of interest to GLERL.

Focus 2d. High risk, potentially transformative projects

- Project 2d.1 – Cyberinfrastructure for environmental omics of the Great Lakes

  Aim: N20.5 NGSP.3 N5.2,4,5 Type: New Disciplines: NS Potential PIs: GLERL – Davis, CIGLR - Dick (UM), Lodge (Cornell), Fisk (Windsor)

  Rapidly emerging environmental "omics" approaches offer exciting new windows into the diversity and functioning of biological communities as they occur in aquatic ecosystems. Environmental genomics, transcriptomics, and proteomics of uncultured microorganisms and environmental DNA (eDNA) have all demonstrated unique insights into biogeochemistry, environmental drivers of harmful algal bloom toxicity and severity, and surveillance of pathogens, invaders, imperiled species, and other species of interest. However, fully harnessing these new technologies has been thwarted by challenges in making sense of the vast and complex data produced. There is no dedicated database or analysis pipeline for such data, and current databases and analytical tools require inaccessible software and associated expertise. The lack of a dedicated database increases the time and computational resources required for even simple queries, such as the determining the abundance of toxin-producing cyanobacteria at different stations across a field season. The goal of this project is to develop a "next-generation" database capable of synthesizing complex environmental and omics data, and which is accessible to a wide range of scientists and water quality professionals. Such a database will not only ensure the effective storage and dissemination of omics data, it will enable unprecedented studies of the microbial communities that compose harmful cyanobacterial blooms and their interaction with the environment.

  We will develop a "graph" database that defines networks of relationships between aquatic organisms, genes and metabolic pathways and their expression, and environmental processes and conditions. To streamline this process we will use Neo4j's scalable native graph database software. This structure is optimal for the multi-dimensional nature of

environmental omics data (i.e., genes, transcripts, proteins, genomes, taxonomy, biochemistry, environmental data), and it would allow for investigations of how genes and their activity (and associated organisms and metabolic pathways) vary over time and space as a function of environmental variables (e.g., temperature, concentration of nutrients, chemicals, toxins). This database will be applicable to any environmental omics or eDNA datasets on the Great Lakes. The main product of this project will be a publically available yet secure website that will serve as an interface for querying, analyzing, and visualizing the data. This database will be updated with additional information and data as they are made available (or generated) to keep the content "state of the art". Ultimately, this capability will enable meta-analyses and leverage growing temporally and spatially rich datasets for the development of predictive models. These downstream products will be of direct use by stakeholders such as drinking water intake managers and policymakers.

Theme 3. Great Lakes Hydrometeorological and Ecosystem Forecasting
Modeling physical and biological processes to help predict the Great Lakes future

Hydrometeorological and ecosystem forecasts rely heavily on both monitoring to describe changing environments, and modeling to translate those changes into quantifiable terms that can be predicted into the future. Theme 3 supports NOAA's priority of providing information and services to make communities more resilient by advancing earth system and ecosystem models, data assimilation, and ecological forecasting as well as increasing operational services that promote coastal resilience. To improve ecosystem forecasting for the Great Lakes, the newly proposed CIGLR will focus on 4 areas of research for Theme 3:

Focus 3a. Hydrological/hydrodynamic models and forecasts
Focus 3b. Climate and weather forecasts
Focus 3c. Ecosystem state forecasts
Focus 3d. High risk, potentially transformative projects

In the following section, we detail specific projects being proposed under each research focus:

Focus 3a. Hydrological/hydrodynamic models and forecasts

- Project 3a.1 – Hydrological forecasts: Integrating the Great Lakes into the new National Water Model

  Aim: N20.2,3,4 NGSP.1,2 N5.1,3,4 Type: Core Disciplines: NS Potential PIs: GLERL – Gronewold, Anderson, Lofgren, CIGLR - Riseng (UM), Beletsky (UM), Rowe (UM), Kelly (UMD)

  CILER and GLERL are currently partnering with the National Center for Atmospheric Research (NCAR), NOAA National Water Center (NWC), and National Centers for Environmental Prediction (NCEP) to integrate Great Lakes hydrological data into the new NOAA National Water Model (NWM). The NWM is an operational hydrologic model that simulates observed and forecast streamflow over the entire continental United States. Despite the unprecedented spatial and temporal coverage of the NWM, a number of known deficiencies exist in the representation of lakes and reservoirs, including no representation of the Great Lakes system. The CI has been working with GLERL to develop the Weather Research and Forecasting hydrological modeling extension package (WRF-Hydro) to be incorporated into the new NWM for the Great Lakes region. This project will develop an initial, simplified, baseline representation of the Great Lakes in the NWM upon which future

development work can build. The new formulations implemented will be guided by, and evaluated using, ongoing NOAA Hydrometeorology Testbed (HMT) data collection and modeling activities.

CIGLR will continue to integrate Great Lakes bathymetric data into the WRF-Hydro National Water Model (NWM), modify WRF-Hydro input/output functions to improve reservoir water management accounting, and conduct reservoir level data assimilation experiments. In addition, CIGLR will develop standardized and harmonized input data files available from the Great Lakes Aquatic Habitat Framework (GLAHF) database to be used in WRF-Hydro simulations in the Great Lakes region. These high-resolution habitat data will serve as a foundation for GLERL's GIS data warehouse, in addition to providing the required input to configure and test WRF-Hydro. This project will also create critical datasets and data layers in uniform format that can be used for future development of the Great Lakes Forecasting System (GLCFS). Completion of the work will result in new modeling capabilities ready for deployment into the existing operational NWM. The primary outcome will be integration of the Great Lakes into the new NOAA National Water Model's visualization tools, which will be used by the National Weather Service (NWS) to improve their flood prediction capabilities. Data outputs will also provide valuable boundary condition inputs for other lake-scale ecological forecasting models.

- Project 3a.2 – Water level forecasts: Improving water level models for shipping and commerce

  Aim: N20.2,3,4 NGSP.1,2 N5.1,3,4,6 Type: New Disciplines: NS, ED Potential PIs: Gronewold, Anderson, Lofgren, CIGLR - Beletsky (UM), Rowe (UM), Kerkez (UM), Roebber (UWM)

  In support of the International Joint Commission's (IJC) need for understanding water levels and future water supplies in the Great Lakes, CIGLR will develop new models to improve Great Lakes water budget estimates and water level simulations. We will create a new historical record of monthly runoff, over-lake evaporation, over-lake precipitation, and connecting channel flows for each of the Great Lakes using a novel statistical model that (through an explicit acknowledgment of bias and uncertainty) reconciles discrepancies between model- and measurement-based estimates of each component while closing the Great Lakes water balance. We will also develop a new, authoritative, coordinated numerical model that efficiently and accurately simulates water levels and connecting channel flows in the Great Lakes system given user-specified net basin supply (NBS) scenarios. The goals of this project are to provide a robust historical dataset for each Great Lake that explain changes in observed water levels based on the relative importance of each component of the water balance, and to provide a relatively simplified water level modeling framework designed to meet current and future needs of regulatory authorities. This project is expected to result in the first comprehensive water budget estimate for the Great Lakes system that systematically closes the entire water balance, while addressing both measurement bias and uncertainty.

  Specific steps include: (1) recoding the existing Great Lakes water balance model to improve computational efficiency, (2) soliciting and incorporating input from regional stakeholders and project partners on a priori beliefs regarding bias and uncertainty associated with existing measurement-based and process model-based estimates, (3) running the model over a period dating back several decades across all of the Great Lakes, and (4) effectively communicating the new results to the Great Lakes water resources management community and other

interested stakeholders. This project will result in: (a) software code and documentation (programmer's guide and user's manual) for the water level model, (b) a new set of estimates for each component of the Great Lakes water budget dating back several decades (~1950 to present), (c) a summary report, and (d) a statistical water budget model that could be encoded in future phases of this project (not addressed here) within a graphical-user interface suitable for use by agencies and individuals water budget estimates. These modeling products are primarily intended for members of the IJC's Great Lakes-St. Lawrence River Adaptive Management (GLAM) Committee, water resources management staff from NOAA, USACE, and Environment Canada, and members of the Coordinating Committee on Great Lakes Basic Hydrologic & Hydraulic Data. Results will be included in NOAA's Great Lakes Water Level Dashboard.

- Project 3a.3 – Coastal currents forecasts: The NextGen Great Lakes coastal forecast system

  Aim: N20.2,3 NGSP.1,2 N5.1,3,4,6 Type: Core Disciplines: NS, ED Potential PIs: GLERL – Anderson, Wang, Gronewold, CIGLR - Beletsky (UM), Manome-Fujisaki (UM), Bravo (UWM), Rowe (UM)

  CIGLR will continue to support NOAA-GLERL in the transition from research to operations (R2O) of the next generation (generation 3) NOAA Great Lakes Coastal Forecasting System (GLCFS[27,28]). The operational GLCFS is run by the National Ocean Service as part of the Great Lakes Operational Forecasting System. The 3rd generation of GLCFS is currently under development using the Finite Volume Coastal Ocean Model (FVCOM[29]) and began its transfer to operations in 2015, starting with the Lake Erie Operational Forecasting System (LEOFS[27,30]). CIGLR will continue to conduct model analyses and evaluations to facilitate R2O for the other four Great Lakes, particularly for the thermodynamics, hydrodynamics, and evaporation components. Specific goals of this project are (1) to improve the flux algorithm for heat and evaporation in the operational Great Lakes forecasts by evaluating model-predicted heat flux and evaporation, (2) to further investigate lake hydrodynamics and the accuracy of hydrodynamic modeling as they relate to harmful algal blooms (HABs) and hypoxia, (3) to gain a greater understanding of the factors and processes involved in the storage of heat in the Great Lakes, the role played by ice cover and its phenology, and by the thermocline and its process of formation and decay, and (4) to explore the quality of alternative meteorological forcing functions to improve the accuracy of hydrodynamic model predictions in GLCFS.

  Products will include an improved bulk flux algorithm (COARE) in the Great Lakes ice-hydrodynamic forecast model, which will be used in the next generation GLCFS, as well as in the forecast model at the Center for Operational Oceanographic Products and Services (CO-OPS). Results of hydrodynamic modeling will serve as a basis for model skill assessment and ultimately improve the development of operational HAB and hypoxia forecasts for Lake Erie, to be incorporated into the GLCFS. Data products will be integrated into the Great Lakes Hydro-Climate Dashboard and shared through the GLCFS framework. The improved GLCFS, and operational GLOFS, provide nowcasts and forecasts of currents, temperature, ice cover, and water levels to the public and resource managers at the GLCFS website to inform the use and management of the Great Lakes.

Focus 3b Climate and weather forecasts

- Project 3b.1 – Climate forecasts: Regional climate modeling to aid decision-making

Aim: N20.3 NGSP.1,2 N5.1,3,6 Type: Core Disciplines: NS, ED Potential PIs: GLERL – Lofgren, Chu, CIGLR - Manome-Fujisaki (UM), Rowe (UM), Mantha (MSU)

Previous research by CILER and GLERL scientists took initial steps toward the development of a Great Lakes Earth System Model (GLESM). The GLESM greatly expands the range of climate variability and impact scenarios from those currently available. Development of individual modeling components, including the Great Lakes Ice-Circulation Model (GLIM), the unstructured grid Finite Volume Community Ocean Model (FVCOM), a Great Lakes regional implementation of the Weather Research and Forecasting (WRF), and the Process-based Adaptive Watershed Simulator (PAWS), have laid the groundwork for a fully coupled model with two-way interactions among the atmosphere (WRF), hydrology (PAWS), lake dynamics and ice (FVCOM-based GLIM), and the lower trophic level ecosystem (nutrient-phytoplankton-zooplankton-detritus model, NPZD). The goal of this project is to produce an integrated model of the Great Lakes physical environment, including the atmosphere, hydrologic system, 3-dimensional lake dynamics, and lake ice dynamics, to couple these with models of lake primary productivity.

CIGLR will continue development and analysis of individual models (WRF, PAWS, GLIM), using additional general circulation models (GCMs) as lateral boundary forcing. The PAWS model will continue to be applied in new watersheds, including those in Lake Erie. Analysis of historical drivers of Great Lakes physical conditions will continue by investigating the impacts of teleconnection patterns, including El Niño-Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), and Atlantic Multi-decadal Oscillation (AMO). The project will produce a set of dynamically downscaled climate projection models that simulate conditions on a local scale and can be used to guide natural resource decision-making by government agencies (federal and state) and non-profit conservation organizations. Model results will be disseminated using the Great Lakes Water Level Dashboard. In previous years, the downscaled models were used by USGS, Michigan Department of Environmental Quality, and Michigan Department of Natural Resources to predict future changes in lake and stream temperatures and potential spread of aquatic invasive species; by Ducks Unlimited, MDNR, and others to explore future changes in weather severity and implications to food availability and migratory behavior of dabbling ducks; by USDA Forest Service to assess forest ecosystem vulnerability across northern WI and upper MI; and by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) to aid in adaptation planning for species that tribes harvest and GLIFWC regulates.

- Project 3b.2 – Weather forecasts: Lake-effect snow and cloud forecasting for the Great Lakes

  Aim: N20.2,3,7,8 NGSP.1,2,4 N5.4,6 Type: New Disciplines: NS, SS Potential PIs: GLERL – Chu, Anderson, Lofgren, CIGLR - Manome-Fujisaki (UM), Chen (MSU)

  Lake-effect snowfall is one of the most hazardous events in the Great Lakes region, yet it is extremely challenging to forecast such events accurately. In order to predict the timing and amount of the snow and ice, it requires 1) high spatial and temporal resolution meteorological forcing, 2) accurate operational coupled hydrodynamic lake circulation-ice model, 3) fully validated surface heat flux formulation and 4) accurate or data assimilative quantitative precipitation forecasts. This project aims to provide Great Lakes weather forecasters with improved lake effect snow and ice predictions by addressing the above requirements and leveraging existing model development and transition to operations efforts at CILER and GLERL. We have developed a coupled lake hydrodynamic-ice system

(FVCOM-Ice) to provide improved short-term forecasts of winter conditions (e.g. ice extent, icing, surface temperature, evaporation) that enables improved forecast capability for lake-effect snowfall. FVCOM-Ice is currently being validated and transitioned to operations at National Ocean Service/ Center for Operational Oceanographic Products and Services (CO-OPS) as part of the Great Lakes Operational Forecast System (GLOFS).

We will work with partners at NOAA-GLERL, the National Weather Service Weather Forecast Office, and NOAA's Earth System Research Laboratory to provide improved forecasts of (1) lake-ice conditions, (2) latent and sensible heat fluxes from the lake surface, and (3) lake-effect snowfall and visibility/cloud forecasts. Currently, no forecasted ice information is available for the Great Lakes, and parameters critical to lake-effect snowfall prediction such as lake heat flux components and lake evaporation have not been rigorously validated and tested in a quasi-operational environment. Therefore, this project will fill critical gaps in coastal hydrodynamic forecasting and provide operational forecasters improved lake-effect snowfall, precipitation, and ice forecasts guidance and ultimately protect safety of the citizens in the Great Lakes region.

- Project 3b.3 – Ice cover forecasts: Improved ice modeling for the Great Lakes

  Aim: N20.2,3 NGSP.1,2,4 N5.1,3 Type: Core Disciplines: NS Potential PIs: GLERL – Wang, Chu, Lofgren, CIGLR - Manome-Fujisaki (UM), Notaro (UW-Madison)

  This project advances modeling techniques in predicting sea ice, lake ice, and ecosystem dynamics. In the Arctic Ocean, CIGLR will continue ongoing efforts to improve understanding of ocean/sea ice circulation and ice-ocean-ecosystem dynamics using modelling techniques (i.e., Coupled Ice-Ocean Model (CIOM), Princeton Regional Ocean Forecast (and Hindcast) System's (PROFS), and Physical-Ecosystem Model (PhEcoM). Data from the Russian-American Long-term Census of the Arctic (RUSALCA) nutrient and plankton moorings near the Bering Strait will be used for conducting independent data analysis for model validation. Climate variability scenarios in the Pacific Arctic Region (PAR) will be processed and the key climate patterns that impact the physical and ecological oceanography in the region, such as the Arctic Dipole Anomaly, will be identified. This study will have a broad impact on 1) understanding the ice-ocean-ecosystem dynamics that explain the high primary productivity region in the Arctic Ocean, seasonal phytoplankton blooms, and interannual variability, and 2) ice edge changes due to climate variability and the subsequent impacts on primary and secondary productivity. The modelling results will be shared with research scientists conducting RUSALCA field observation projects and an optimal sampling strategy will be designed to improve coverage. The modeling framework for the Bering-Chukchi Seas marine observatory is available on the NOAA Climate Program Office Arctic Research Program website: http://www.arctic.noaa.gov/.

  Because Arctic ice-ocean-ecosystem models bear features similar to temperate ice-covered waters, the Bering Sea ice-ocean-ecosystem models developed for this project can be applied to the Great Lakes Earth System Model (GLESM). The modified Finite-Volume Community Ocean Model (FVCOM) for Great Lakes ice circulation (FVCOM-ice), an individual modeling component of GLESM, will be used to investigate the lake-ice system response to climate variability in the Great Lakes. The Great Lakes Ice Atlas, publically available at https://www.glerl.noaa.gov//data/ice/atlas/index.html), will be updated each year and seasonal ice projections will be developed. Seasonal ice projections will continue to be

provided to end users in search and rescue operations, navigation (i.e., commercial shipping), and recreational/subsistence ice fishing. These forecasts also provide decision makers with tools to aid in protecting the Great Lakes ecosystem and the public.

Focus 3c. Ecosystem state forecasts

- Project 3c.1 – Harmful algal bloom forecasts: Predictive models to prepare water users

  Aim: N20.5,7-8 NGSP.3 N5.4-6 Type: Core Disciplines: NS, SS Potential PIs: GLERL – Davis, Anderson, CIGLR - Johengen (UM), Ostrom (MSU), Knuth (Cornell), Miller (UWM), Newton (UWM)

  The CI has played a key role in developing NOAA's Lake Erie and Saginaw Bay harmful algal bloom (HAB) forecasts, and supported the direct monitoring and reporting of microcystin toxin concentrations and water quality. University Partners (UWM) have expanded research and monitoring into Green Bay, WI. The goal of this project is to continue core monitoring programs that provide critical observations for developing predictive models that forecast the formation, spread, and toxicity of harmful algal blooms. Future model development will focus on: (1) improving the Lake Erie HAB Bulletin using the new Lake Erie Operational Forecasting System hydrodynamic models and simulated three-dimensional transport of HABs, and (2) coupled biophysical models that produce forecasts of HABS extent and toxicity as a function of management actions to reduce nutrient loading.

  Weekly core monitoring programs will continue in Lake Erie, Saginaw Bay, and Green Bay to characterize HAB intensity, toxicity, and water quality (nutrients, turbidity, optical properties) throughout the water column. Sampling intensity and spatial extent will depend on the timing and extent of HABs indicated by satellite imagery, but with a goal of weekly sampling through the bloom season (Jul-Oct), with initial sampling in May to evaluate antecedent conditions. Data will be used to (1) determine whether significant amounts of the HAB toxin, microcystin, are entering drinking water supplies, (2) elucidate the drivers of bloom development and subsequent movements through ecosystems, (3) share field sampling results with NOS for use in the Lake Erie HAB Bulletin, (4) share weekly field sampling results with public water system managers to help monitor toxicity levels in source water and aid in the treatment planning process, and (5) support further model development.

  We also plan to improve the HAB Tracker by refining model parameterizations, incorporating additional observational data into hindcast skill assessments, and developing a means to express model output on a probabilistic scale. We will improve the parameterization of *Microcystis* buoyancy using data on colony size distribution and buoyancy velocity as a function physiological condition, nutrients and light. We will express model output as a probability of exceeding toxin concentration thresholds that correspond to public advisory levels from Ohio EPA. We will use a database of ~4000 microcystin measurements that have been compiled from our monitoring programs, and use these to hindcast simulations for 2008-16 so we can compare model output to observed microcystin concentrations. A second modeling approach is underway to develop a biophysical deterministic model to examine relationships between key environmental factors on *Microcystis* blooms. We are updating a previous mass-balance Nutrient Phytoplankton Zooplankton Detritus model to include dreissenid mussels and couple it to the FVCOM hydrodynamics model. We will develop model projections of the extent and intensity of HABs and in-lake phosphorus distributions, and compare projections under various phosphorus loading scenarios. We are also developing a continuous Bayesian network model

to link Lake Erie spring nutrient loadings to monthly microcystin concentrations. We will develop predicted monthly microcystin concentrations that can be used for risk assessment of high toxin events and generate a modeling framework for annual risk forecasting.

To facilitate co-design of modeling and data-products that are useful to end-users such as public water systems, CIGLR's Communications and Outreach program coordinator will work with GLERL PIs to identify and assess user needs related to HAB data and information for decision making, and develop effective mechanisms to disseminate CIGLR and GLERL HAB research tools and forecasts. To do this, we will build on previous work in which we have conducted focus-group workshops with the Lake Erie fisheries community to introduce NOAA's HAB forecasting tools and follow up with additional studies to receive feedback on how the tools are being used for decision-making by various stake-holder groups. We will also use these workshops to educate stakeholders on HABs and to identify new areas of research that are driven by their needs. With increased sampling effort in Saginaw Bay, we will establish new relationships with drinking water intake managers, county health departments, and water quality/environmental managers in the area through educational meetings and presentations. Through the same process of co-design, we will identify HAB informational gaps and research needs, and introduce NOAA's HABs forecasting products.

- Project 3c.2 – Hypoxia forecasts: Modeling dissolved oxygen for public water systems

  Aim: N20.5,8 NGSP.3 N5.4-6 Type: Core Disciplines: NS, SS Personnel: GLERL – Anderson, Davis, CIGLR - Rowe (UM), Johengen (UM), Beletsky (UM), Zhang (UM), new social science PI (UM)

  Lake Erie provides drinking water to 11 million people through > 30 public water systems. Strong water quality differences exist between surface and bottom water during summer stratification in the central basin of Lake Erie. Weather-driven dynamics during stratification can cause water intakes to be alternately exposed to surface or bottom water, requiring public water systems to adapt treatment processes to changing raw water quality. Surface water has higher pH, and may have high concentrations of phytoplankton, dissolved organic matter, and algal toxins. In contrast, the bottom water is usually hypoxic, with a low pH and elevated iron and manganese concentrations. The goal of this project is to give public water systems advance warning of lake circulation events that are likely to cause changes in raw water quality at their intakes through the development of an operational dissolved oxygen forecast model for Lake Erie. This system will allow drinking water managers to prepare for episodic events that cause hypoxic water movement into the vicinity of water intakes.

  This project builds on and significantly expands NOAA GLERL's Hypoxia Warning System. The proposed models will be an extension of the existing, next-generation Lake Erie Operational Forecasting System that became operational at NOAA's National Ocean Service Center for Operational Oceanographic Products and Services in 2016. The first new model will be physically-based, requiring the addition of a dissolved oxygen (DO) component to the existing hydrodynamic model. It is expected that this model will provide an experimental real-time, forecast product in the second year of the project, and be skill-assessed to begin transition to operational status near the end of the five-year project. The second new model will require addition of the chemical and biological drivers of hypoxia (nutrients, phytoplankton) to the physical DO model. Additionally, the development of the biophysical model in tandem with the physical model will offer an opportunity to address a current, pressing management question and a broader philosophical question regarding model

complexity. First, under the 2012 Great Lakes Water Quality Agreement (GLWQA) the United States and Canada are committed to "minimize the extent of hypoxic zones … associated with excessive phosphorus loading, with particular emphasis on Lake Erie". However, the available models were limited and the proposed target phosphorus load was based on the projected average hypolimnetic DO concentration, rather than the areal hypoxic extent. These new models will help differentiate the relative importance of the physical and biological drivers of hypoxia, and guide future decision-making in the Adaptive Management phase of target load implementation under the GLWQA. Second, the rigorous comparison of predictions from these two models will offer a basis to evaluate whether the added complexity of the biophysical model provides better predictive accuracy, a question that remains unresolved in the modeling community. Third, the field observations along with the biophysical model will improve our understanding of the relative importance of winter-spring algal production versus summer-time cyanobacterial production in terms of organic supply to the central basin and their influence on oxygen consumption rates within the hypolimnion. Model development will be supported by field sampling to gather data for a model skill assessment, and to better characterize the central basin oxygen demand rates. Sensor deployments will be used to monitor DO conditions, which can change rapidly in nearshore areas, where the drinking water intakes are located.

- Project 3c.3 – Land use: Forecasting tipping points in Great Lakes water quality

  Aim: N20.6-8 NGSP.3,4 N5.4-6 Type: Core Disciplines: NS, SS Personnel: GLERL – Rutherford, Mason, Stow, CIGLR - Zhang (UM), Basso (MSU), Hyndman (MSU), Lupi (MSU), Garnache (MSU), Ostrom (MSU), Stevenson (MSU), Carrick (CMU), Graziano (CMU), Cardinale (UM)

  Since 2011, the Tipping Points team has identified tipping points in watershed land use that affect the health of Great Lakes tributaries and nearshore areas. Based on extensive research, the team developed and published a Tipping Points and Indicators Planner support system – an online program for use by extension specialists, coastal managers, and consultants who work with land use commissions and watershed planning committees. This tool helps watershed leaders identify land-based activities that lead to increased nutrient loading, runoff, and nonpoint source pollution that threatens the sustainability of ecosystems in their watershed, as well as policy and management interventions to keep ecosystems from crossing a tipping point and moving to an unstable condition. The goals of this project are to improve and expand the Tipping Points and Indicators program by (1) incorporating decision making and restoration efforts that occur more locally, at sub-watershed levels where most management take place, and (2) coupling the present biophysical models with extensions to economic models that predict the economic consequences of environmental shocks.

  To accomplish goal 1, we will enhance the Tipping Point Planner (TPP) with high-resolution data for nutrient sources in select Areas of Concern (e.g., the Fox River, Saginaw River, and Maumee River AOCs) and with models that relate nutrient sources to multiple endpoints. Specific tasks include identifying the relationships between nutrient loads and ecosystem variables (e.g., water quality, fish productions) and implementing these relationships into the DSS, engaging local stakeholders (e.g., extension land use professionals, consultants, and/or agency watershed officials) in improving the predictions, and training facilitators to employ the DDS for community visioning and planning. The end product of this project is an improved TPP DSS, again made publically available (http://tippingpointplanner.org) for use by local stakeholders engaging in watershed planning activities.

To accomplish goal 2, we will link the outputs of biophysical models to inputs for regional economic and planning models. We will focus on two complementary socio-economic models: (1) Economic Impact Analysis for Planning, (IMPLAN), which characterizes primary sectors (e.g. water utilities), but it is not a dynamic model, and (2) Regional Economic Modeling (REMI), which is a dynamic model that includes both a demographic and a fiscal component, but lacks a precise break down of primary sectors. For both models, parameters of water quality (e.g., P-loads, density of harmful algae) will be developed as quantitative functions that lead to reductions in specific sectors, including an influence on 'amenity values'. These impacts on amenity values can then be used to approximate the marginal cost of changes to the bio-physical variables to the sector of the economy identified. Rather than providing exact cost estimates of environmental stress, our objective will be to develop a new framework that links the ecological drivers of tipping points to the human and socio-economic components that drive policymaking in a relative sense.

- Project 3c.4 – Fisheries: Improving biophysical models to predict changes in Great Lakes recreational and commercial fish populations

  Aim: N20.5,6 NGSP.3 N5.5 Type: New Disciplines: NS Potential PIs: GLERL - Vanderploeg, Anderson, CIGLR - Rowe (UM), Bence (MSU), Brenden (MSU), Robinson (MSU), Zhang (UM), Galarowicz (CMU), Ruetz (GVSU), Bootsma (UWM), Liao (UWM)

  Climatic variation has potential to induce state changes in fish population size, abundance, and geographic distribution. Yet, we lack the biophysical models needed to link key aspects of climate variation to lake trophic models, or fisheries assessments that forecast shifts in fish species of commercial or recreational importance. The goals of this project are to (1) integrate key environmental conditions (e.g., warming temperatures, reduced ice-cover) as explanatory variables in population assessment models to improve linkages between population status and environmental conditions, and (2) explore effects of environmental conditions on fish population recruitment, mortality, and fishery fleet dynamics.

  To accomplish these goals, we will link the Great Lakes Earth System Model (GLESM, Project 3b.1) and the widely used CSIRO Atlantis ecosystem model, which is a modular modeling framework capable of producing realistic simulations of ecosystem dynamics. We will then (1) conduct model assessment of each model's performance and prediction skills for the period 1993-2015, and (2) conduct probabilistic seasonal projections of regional atmosphere, lake hydrodynamics, food web biomass and fish distributions for 2018-19. In particular, we will focus on ecological effects of extreme warm and cold climate scenarios that are associated with global teleconnection patterns. The end products will be the linked WFA modeling system for Lake Michigan, seasonal prediction of regional climate, lake hydrodynamics and thermodynamics, food web dynamics, and fish distributions and movements. These seasonal prediction outputs in both graphic and digital formats will be displayed on the GLERL website and archived in our GLERL computer for users to download. The final WFA modeling system will be run and maintained at GLERL with the seasonal prediction directly linked to NOS' website and will be transferred to NOS and run for seasonal prediction with further funding. Output from FVCOM then serves as input to models of higher trophic levels, which will focus on several species of commercial and recreational fisheries (Chinook salmon, lake trout, lake whitefish, walleye, and yellow perch) that represent a multi-billion dollar industry[31].

Focus 3d. High risk, potentially transformative projects

- Project 3d.1 – Predicting adoption of best management practices

  Aim: N20.6-8 NGSP.3 N5.6 Type: New Discipline: NS, SS Potential PIs: GLERL – Stow, Mason, CIGLR - Wilson (OSU), Brown (UM), new social science PI (UM), Gasteyer (MSU), Irwin (OSU), Martin (OSU), Kalcic (OSU), Labarge (OSU)

  We now know that the increasing severity and frequency of harmful algal blooms in Lake Erie are the result of both meteorological trends and the agricultural management practices of farmers across the western Lake Erie basin (WLEB)[32]. However, the focus of most forecasting models is on the physical as opposed to social or behavioral drivers in the coupled human and natural system. These models could be substantially improved if they more accurately captured human behavior as a driver of ecosystem outcomes. If we want to go a step further and inform decisions designed to offset the negative impacts of climate variation on Lake Erie, we will need to better understand the roles of human behavior, and the ways in which behavior can be altered to create a more sustainable and resilient system. The goal of this project is to integrate human behavioral complexity into biophysical forecasting models to better explain current fluctuations in phosphorus loading so that we can better predict future fluctuations that result from changes in behavior across the landscape.

  We will limit our modeling to three best management practices that have shown to be effective at reducing phosphorus loading into Lake Erie[33]: Cover crops, subsurface placement of fertilizer and filter strips. These practices cover the range of potential tools from those focused on avoiding nutrient loss (subsurface placement), to those that control nutrient loss (cover crops), to those that trap nutrient being lost from the field (filter strips). We have preliminary data on farmer baseline and future likely adoption of these practices building on extensive survey research by the project leads. We will leverage this existing data to develop a spatially explicit model of the probability of adoption of each practice for a given spatial unit across the WLEB. A spatial unit (e.g., field, county, etc.) can be assigned a particular probability given certain characteristic of the unit (such as soil type, slope of the field, etc.). These probabilities can then be used to inform scenarios in hydrological models (e.g., SWAT) that predict the movement of phosphorus across the landscape given changes in agricultural land use and management, which in turn can be linked to lake dynamic models based on phosphorus loading inputs.

Theme 4. Protection and Restoration of Resources
Safeguarding habitats, natural capital, and ecosystem services throughout the Great Lakes

This theme recognizes the important connection between Great Lakes habitat, considered broadly, and human physical, economic, and social well-being. The Great Lakes region sustains an economy for some 30 million people and provides the ancestral homeland of 35 federally-recognized Indian Tribal Nations. Habitat throughout the region provides people with a multitude of ecosystem services, including goods such as food and water, services such as flood protection and water purification, and cultural benefits such as recreation and tourism. Many of these services have measurable economic value that has yet to be quantified and accounted for in existing markets. Other services cannot be bought and sold in existing markets; for example, the value of the Great Lakes for climate regulation or the amount you would pay to protect the Great Lakes so that your children could enjoy them in the future. Still other services are not easily quantified in dollars; for example, the value of the Great Lakes for mental and physical health.

Unfortunately, the goods, services, and cultural benefits provided by the Great Lakes have been degraded and compromised by a long history of over-exploitation, invasive species introductions, and pollution. We use the lakes and their tributaries to dispose of large volumes of wastewater, dredged sediments, and runoff from urban and agricultural areas. We have eliminated more than half of the original forests and wetlands around the lakes; the region would be unrecognizable to the people who settled here less than 200 years ago. We have altered food-webs with a long-list of invasive species. Clearly, careful management and protection of the remaining habitats, coupled with restoration of those that are already disturbed, is of vital importance to the long-term sustainability of ecosystem services.

In the Great Lakes region, place-based programs such as marine sanctuaries and NERRS sites offer opportunities to address the key threats and issues that will generate tools, techniques and technologies to help managers restore habitats and improve system resilience. While the proposed work will develop distinct tools and technologies, the project teams will coordinate and share insights related to their methodologies and seek to share data wherever possible. To facilitate the protection and restoration of Great Lakes habitat, their natural and social resources, and the services they provide, CIGLR will focus on 3 research areas for Theme 4:

Focus 4a. Valuation of ecosystem services
Focus 4b. Habitat protection and restoration
Focus 4c. Social adaptation and resilience of coastal communities

In the following section, we detail specific projects being proposed under each research focus:

Focus 4a. Valuation of ecosystem services

- Project 4a.1 – Economic valuation: Quantifying use and non-use values of Great Lakes water quality

  Aim: N20.6-8 NGSP.3,4 N5.6 Type: New Disciplines: NS, SS Potential PIs: CIGLR - Lupi (MSU), Sohngen (OSU), Steinman (GVSU), Garnache (MSU), Herriges (MSU), Stevenson (MSU), Graziano (CMU), Gopalakrishnan (OSU), Cardinale (UM)

  As one of the world's iconic geologic features, the Great Lakes provide a vast array of ecosystem goods and services to this residents of the region. Yet, few studies have attempted to estimate the economic value of the many goods and services the Great Lakes provide. Of studies that do exist, most focus on use-values of the Great Lakes, such as the value of commercial and recreational fishing, or the value of water for municipal and industrial uses. But a large fraction of the value of the Great Lakes lies in non-use values, such as options, existence, and bequest values that are not easily captured in existing markets. The International Joint Commission (IJC), which has supported our bid for the CI, recently conducted a review of available economic information about harmful algal blooms and concluded that studies on non-use values will help improve societal commitment to Great Lake water quality. The goal of this project is estimate both use and non-use values stemming from changes in nutrient loadings to the Great Lakes.

  We will expand existing water quality production models that link nutrient sources and best management practices to nutrient loads, and then nutrient loads to several ecosystem services that can be measured over a range of spatial scales. Both statistical and process-based models will be advanced with existing and new data. A multi-modeling approach will be used to evaluate the causal basis and predictive capability of the water quality production modeling.

This will, in turn, enable us to examine how use and non-use values change with the specific metric used to characterize ecosystem services (e.g., water quality ladder, water clarity, beach fouling, harmful algal blooms, the biomass of individual sport and non-sport fish populations, or a continuous water quality index) and the spatial scale at which they are specified. Surveys will then be fielded to gather information on peoples revealed and stated preferences for these ecosystem services. Focus groups, pre-tests and the survey instruments will be used to assess public understanding and compare measures of use and non-use value based on physical measures of nutrients, levels of the water-quality ladder, and other quantified ecological conditions. Total willingness to pay (TWTP) will be deconstructed into use and non-use components. We will then produce a model that predicts changes in use and non-use values with the metrics used to characterize the ecosystem services and the spatial scales at which services are provided, which can then be related to nutrient loads, tradeoffs among management strategies and goals, as well as costs to reduce nutrient loads.

- Project 4a.2 – Non-economic valuation: Complementing monetary techniques with non-monetary values of Great Lakes ecosystem services

  Aim: N20.6-8 NGSP.3,4 N5.6 Type: New Disciplines: SS Potential PIs: CIGLR - Read (UM), Washburn (NERR), Webster (UM), Balzano (UM), Vaccaro (UM)

  In 2014, a binational, multi-sector group delivered to the Great Lakes governors and premiers a proposed approach for understanding and assessing a range of ecosystem services provided in the Great Lakes region, e.g., those related to social values and quality of life, sustainable human uses, and healthy aquatic ecosystems. The approach was designed to help managers better set priorities and allocate resources to restore and sustain a healthy Great Lakes ecosystem and economy. The Blue Accounting Report[34] identified nine common regional goals, based on an evaluation of the key binational and regional environmental agreements. Some of these goals are economic or function-based ecosystem services, such as safe and sustainable water supplies, functional nearshore and coastal processes, or healthy, diverse and connected habitats, while others are indicators of less tangible spiritual and social services provided by ecosystems, such as public awareness of water value, stewardship of water resources, and sustainable human uses. The ability to identify, measure, and track changes over time in the less tangible ecosystem services would not only provide insight into the status and impact of non-economic ecosystem services, but is key to appreciating public awareness of, support for, and willingness to continue investing resources in restoring and sustaining regional ecosystems. The goal of this project is to identify and operationalize a suite of non-economic indicators of ecosystem services (e.g., social, spiritual) that can be incorporated into the Blue Accounting program that is under development by the Great Lakes Commission and The Nature Conservancy.

  The project team will recruit a multi-sector advisory group from organizations already engaged in the Blue Accounting program, which will be facilitated by the proposed project PIs, some of whom are members of the Blue Accounting Advisory Committee with close connection with the program and its participants. A systematic review of the extant peer-reviewed literature related to the effects of ecosystem investments on community social and spiritual well-being will be conducted. The material will be summarized and presented in the form of a conceptual model that will include potential indicators. The project team will convene a workshop comprised of the advisory group and an invited, multi-disciplinary group of researchers to consider the proposed conceptual model and indicators. The

workshop will consider appropriate analytical approaches, sources of data (both those readily accessible as well as those more challenging), and identify three to five useful indicators to consider for a pilot study. Working with the Blue Accounting program team and with the input of the advisory group, who will help identify up to three test cases, the project team will assemble data to compare the pilot indicators across test cases to evaluate their value in supporting regional decision making. The primary outputs of this effort will be a suite of pilot indicators to be considered by regional decision makers – local through federal – for refinement and incorporation into the Blue Accounting program.

- Project 4a.3 –Business and enterprise: Towards adoption of ecosystem services by Great Lakes industries

  Aim: N20.6-8 NGSP.3,4 N5.6 Type: New Disciplines: NS, SS Potential PIs: CIGLR - Árvai (UM), Lupi (MSU), Lodge (Cornell), Buncker (CGLI), Dietz (MSU), Wilson (OSU), McGrath (TNC)

  Increasingly, the private sector is recognizing the importance of making strategic decisions that account for the triple-bottom-line, which entails balancing environmental, social, and economic objectives. To make defensible triple-bottom-line decisions, business leaders must have access to both high quality data that characterizes impacts as they relate to these objectives, and processes that help decision-makers overcome systematic biases that emerge when they work in complex systems. All sophisticated business enterprises maintain data that characterizes the economic costs and benefits of their operations. However, it is not uncommon for even the most sophisticated enterprises to have inadequate models and limited working knowledge of social and environmental risks, costs, and benefits. Moreover, attempts to value different ecological systems and services by businesses have suffered from a number of limitations that can be traced to a disproportionate emphasis on those elements of systems that are easiest to value because of available data, rather than on the appropriate range of system characteristics that a broad array of stakeholders care about. Likewise, few enterprises have developed decision-support systems that take these values and use them in frameworks that account for the inevitable tradeoffs across environmental, social, and economic objectives. As a result, efforts to protect and restore natural resources suffer.

  Working with the Center for Great Lakes Industries, which is a supporter of our proposal, CIGLR will work with large-scale enterprises in the Great Lakes region (e.g., energy companies that provide electricity and natural gas to people in the region) to develop a robust framework for eliciting, characterizing, and modeling ecosystem services as they relate specifically to interests of the business. In doing so, we will rely on theoretical insights and tools from the ecological and decision sciences (e.g., tools for developing and reality-testing natural, proxy, and constructed impact measures). Then, we will work with partner enterprises to develop and deploy a multi-stakeholder decision-aiding framework for informing multi-attribute choices (e.g., associated with energy development in the Great Lakes region). Such a framework must provide necessary background information, and analytic models and tools (e.g., for portfolio development and tradeoff analysis) that will facilitate internally consistent choices (i.e., choices that are in line with users' prioritized objectives). The product of this effort will be set of science-based best practices and freely-available decision-support tools for use by business enterprises looking to improve their triple-bottom-line decision-making capabilities.

Focus 4b. Habitat protection and restoration

- Project 4b.1 –Sanctuaries and reserves: Mapping ecological and socioeconomic resources for NOAA protected areas

  Aim: N20.6-8 NGSP.3,4 N5.6 Type: New Disciplines: NS, SS Potential PIs: GLERL – Rutherford, Leshkevich, Chu, CIGLR – Brody (NMS), Gray (NMS), Riseng (UM), Klump (UWM), Fitzgerald (Windsor)

  In 2016, an 875-square-mile area of western Lake Michigan was designated as a national marine sanctuary. The Wisconsin-Lake Michigan National Marine Sanctuary is only the second sanctuary to be proposed within the Great Lakes (the other is Thunder Bay on Lake Huron) and is notable because it was nominated through a new community-based Sanctuary nomination process. The nominated area contains an extraordinary collection of 37 known shipwrecks, 18 of which are listed on the National Register of Historic Places, and a reported 80 which are yet to be discovered. It also encompasses a key portion of an early transportation corridor that was critical to the expansion of the United States and the development of the agricultural and the industrial core of the Nation. Over the next three years, National Centers for Coastal Ocean Science (NCCOS) is coordinating with NOAA's Office of National Marine Sanctuaries and local partners, including municipalities, the Wisconsin Historical Society and other state agencies, Wisconsin Sea Grant, the University of Wisconsin, and the NOAA Great Lakes Environmental Research Laboratory, to conduct ecological and socio-economic assessments and habitat mapping. The goal of this project is to characterize existing nearshore resources and provide information needed to develop conservation priorities and identify recreation and tourism opportunities.

  Working in partnership with NOAA-GLERL and NCCOS, CIGLR will lead the compilation of existing habitat, water quality, lake bed mapping, unique ecological features, shipwrecks and other socioeconomic data. We will use an existing geospatial framework, the Great Lakes Aquatic Habitat Framework (GLAHF) that has all existing habitat and water quality data available for Lake Michigan including the WI Sanctuary area, attributed to a common geospatial framework. GLAHF has also developed an ecological classification system that can be used to identify unique ecological areas and compare those to similar areas within Lake Michigan. This data is currently available in an online viewer (glaf.org) to which additional spatial data and imagery can be added.

- Project 4b.2 –Sanctuaries and reserves: Quantifying sociocultural services in National Estuarine Research Reserves (NERR) and NOAA Marine Sanctuaries

  Aim: N20.5-8 NGSP.2,4 N5.6 Type: New Disciplines: NS, SS Potential PIs: GLERL – Rutherford, Mason, CIGLR - Washburn (NERR), Lopez (NERR), Brody (NMS), Gray (NMS), Read (UM), Cardinale (UM), Liesch (CMU), Vail (GVSU)

  Some of the most difficult ecosystem services to assess and analyze are those that are not easily measured or quantified, many of which fall under social or cultural services at the individual or community scale, such as sense of place, identity and the value of local heritage. Yet these sociocultural services are some of the most important and valuable to people[35], influencing individual behaviors and collective decisions. When characterized and studied at the community scale, these sociocultural services can ground truth more broadly collected data and provide insight into values, behavior and decision-making not otherwise discernible. The goal of this project is to develop and refine a community level, place-based assessment and analysis protocol to quantify sociocultural services of National Estuarine

Research Reserve (NERR) sites and to analyze and display the richness and variety of these services and social values.

We will use Rapid Assessment Protocol methodologies, employing semi-structured interviews and targeted surveys, to collect and analyze qualitative data within coastal watersheds, focusing on people's connection to nature, leisure time, cultural fulfillment and social cohesion at Sanctuary and NERR sites. Qualitative analytical software and a grounded theory analytical framework will be deployed to examine these data, characterize the social and cultural services and measure related social values. Together with more easily quantified ecosystem services, this information will support a more comprehensive characterization of human and community well-being while revealing the rich fabric of human values related to prospective decisions for restoration or protection. Information from this project will be developed into outreach and education material in partnership with NERR and Sanctuary staff to best address their community and partner needs. These results will not only support the missions of these place-based programs, but, by providing this baseline, the NERRS would then be positioned to adopt local and sustained sociocultural monitoring through their System Wide Monitoring Program. Piloting an approach to address sociocultural ecosystem services in this manner would ultimately be of benefit to the entire NERR System, National Marine Sanctuaries, National Estuary Programs, and other place-based efforts.

- Project 4b.3 – Unique habitats: Exploring novel habitats within NOAA Marine Sanctuaries

  Aim: N20.1 NGSP.3,4 N5.6 Type: New Disciplines: NS, ED Potential PIs: GLERL – Davis, Ruberg, CIGLR - Dick (UM), Biddanda (GVSU), Sheik (UMD)

  Time, water, and geologic forces have converged to create underwater sinkholes in the deep, dark waters of Lake Huron that support chemosynthetic ecosystems resembling those found at deep-sea hydrothermal vents ("black smokers"), which transformed our understanding of biology on this planet. Although the habitat of the Great Lakes is much different (shallower, freshwater), the energy source for this chemosynthesis is the same as in the deep sea: sulfur. Rather than coming from a hydrothermal source, the Lake Huron mats are sustained by sulfur-rich groundwater seeping out of ancient marine evaporites in the region's karst aquifers. Nevertheless, we have found that the bacterial species inhabiting the Lake Huron sinkholes are related to those found at deep-sea vents and seeps. The presence of such a unique ecosystem in the Great Lakes, and within the Thunder Bay National Marine Sanctuary, provides excellent opportunities for scientific research. However, the distribution of these deep sinkholes and their associated chemosynthetic ecosystems is unknown. While there is geologic and bathymetric evidence for their widespread occurrence, only two have been confirmed. The goal of this project is to survey known and suspected locations of deep sinkholes within this designated protected area and explore their biological diversity.

  Working in partnership with NOAA's Thunder Bay National Marine Sanctuary and NOAA-GLERL, we will mount a systematic interdisciplinary exploration of deep sinkholes in Lake Huron. This will be done by characterizing the geophysical environments of the deep water sinkhole via shipboard multibeam imaging, ROV-based laser scanning, and underwater video. We will also characterize hydrographic conditions with multi-parameter water quality sondes, and microbial composition and diversity by bright-field/epifluorescence microscopy and DNA sequencing. These studies will identify the locations of these unique chemosynthetic ecosystems, and could have implications for conservation, including

potential expansion of the sanctuary. Proposed products include publication of peer-reviewed publications describing the scientific results, an accessible report that will disseminate project results to a wider audience including conservation groups and other stakeholders, an amendment to the NOAA Marine Sanctuaries website for Thunder Bay that will provide access to data, and educational exhibits at the Thunder Bay National Marine Sanctuary Great Lakes Maritime Heritage Center and the University of Michigan Museum of Natural History.

- Project 4b.4 – Areas of Concern: Evaluating the benefits of restoring AOCs

  Aim: N20.5,7,8 NGSP.3,4 N5.3,4,6 Type: New Disciplines: NS,SS Potential PIs: GLERL – Anderson, Elgin, Rutherford, CIGLR - Steinman (GVSU), Biddanda (GVSU), Rowe (UM), Read (UM), Washburn (NERR), Moore (UM), Snyder (GVSU), Klaper (UWM), Cardinale (UM)

  Considerable effort and investment is being placed into the restoration and delisting of AOCs through the Great Lakes Restoration Initiative. As these beneficial use impairments are addressed, and restoration targets are met, desired ecological conditions are returning, and community pride is being restored. Meaningful assessments of the effectiveness of AOC restoration efforts will require both natural science studies that examine ecological outcomes of restoration activities, and social science research to examine the economic and other societal benefits achieved from the restoration. Unfortunately, few studies to date have quantified the return on investment in AOCs.

  CIGLR's Regional Consortium will lead some of first ever assessments of the ecological and societal benefits of AOC restoration. To address the natural science aspect of AOC restoration, we will work with NOAA to implement projects that address specific objectives defined in the Muskegon Lake Habitat Blueprint. The Habitat Blueprint is a process that directs NOAA's expertise, scientific resources, and on-the-ground conservation efforts in targeted areas to maximize investments and benefits to coastal communities. Proposed research activities will be aligned with stakeholders working with the NOAA Great Lakes Regional Collaboration Team including: Michigan Department of Environmental Quality; Michigan Department of Natural Resources; Great Lakes Commission; West Michigan Shoreline Regional Development Commission; USGS; Grand Valley State University Annis Water Resources Institute; Muskegon Lake Watershed Partnership; Muskegon County; and the NOAA Coastal and Estuarine Land Conservation Program.

  Muskegon Lake is a 4,232 ac drowned river mouth of the Muskegon River located on the west shoreline of Michigan's Lower Peninsula. The lake provides nursery habitat for Chinook salmon, largemouth and smallmouth bass, walleye, yellow perch, and threatened native species such as the lake sturgeon. However, degradation of water quality and habitat have resulted from extensive shoreline filling, loss of wetland habitat, deposition of mill debris, untreated sewage, and sediment contamination from heavy metals, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). Consequently the U.S. EPA designated Muskegon Lake as an AOC, and NOAA selected it as a Habitat Blueprint Focus Area. CIGLR presently operates a time-series buoy that monitors meteorological and water quality parameters (http://www.gvsu.edu/wri/buoy/) along with core ecological measures. We are developing a 3-D FVCOM hydrodynamic model for Muskegon Lake that will ultimately be coupled to full lake-scale biophysical model to discern how material loading, water circulation and hydraulic residence time shape the lake's ecology, and how these coupled physical and biological processes are impacted by restoration activities. With

this integrated model, we can quantify ecosystem response and recovery of beneficial use impairments due to improvements in watershed management. Lessons learned from this system can be applied to other similar coastal and estuarine systems

To address the social science data gaps of AOC restoration, we will conduct economic valuation studies in 3 AOCs around the Great Lakes. We propose to conduct these analyses in one AOC that has been de-listed (White Lake, MI) and two that are in the process of de-listing (Milwaukee Estuary, WI and St. Louis River, MN). A comparison across these sites will allow us to establish baseline valuation data from which future studies can assess the effect of de-listing on use and non-use values. We will use consistent methodology in conducting valuation analyses, following the protocols developed for restoration activities in Muskegon Lake[36]. Briefly, the valuation consists of three main elements: (1) a travel cost survey based on surveys to recreational users accessing the AOC water body for fishing, boating or jet-skiing, bird/wildlife watching, walking, or biking at multiple access sites; (2) a contingent valuation survey, designed as a dichotomous choice survey instrument[37] to elicit stakeholder willingness-to-pay for additional habitat restoration of the AOC. The survey provides background information about the AOC and its historical environmental problems, then describes the restoration projects, and finally asked for the respondent's willingness to make a one-time payment of $X, which is randomized from six different amounts ($25, $50, $75, $100, $150, $200) to establish of a hypothetical fund to pay for future restoration work; and (3) a hedonic housing valuation, to explore the relationship between the price of a house and the proximity to natural or hardened shoreline. Data about the characteristics of the houses will be obtained as independent variables in a hedonic model to predict housing prices from the appropriate county. Spatial data to align the proximity of a house to AOC characteristics will be analyzed using a GIS platform; details are provided in Isely et al.[36].

Focus 4c. Social adaption and resilience of coastal communities

- Project 4c.1 – Climate adaptation: Enhancing risk communication to prepare for climate variation

  Aim: N20.7,8 NGSP.1,2,4 N5.1,3,5 Type: New Disciplines: SS Potential PIs: CIGLR - McComas (Cornell), Arvai (UM), Lemos (UM), Norton (UM)

  Successful engagement of coastal community members in efforts to build resilience in the face of climate variation entails not only acceptance and support of proposed actions but also sustained participation over time. Even the best efforts to build resilience will fail if residents do not adopt the proposed actions or participate in the process due to a lack of trust in risk managers. The goal of this project is to investigate factors encouraging or discouraging coastal community decision makers from adopting proposed actions and participating in the decision-making processes related to preparing for climate variation. The work will focus on how key outcomes are influence by trust in the risk managers, perceived fairness of the public engagement process, beliefs about variation in climate and weather, and self- and collective-efficacy in the face of proposed actions.

  CIGLR will lead multi-method case study approaches over two phases of data collection. Phase I employs qualitative techniques to characterize stakeholder interaction in one or more communities, chosen with input from CIGLR partners and NOAA collaborators. During these site visits, researchers will conduct semi-structured interviews with local officials and

leaders. These site visits and interviews will help to uncover possible unidentified factors deemed important for enhanced adoption and sustained participation in planning and implementation. In addition, site visits will facilitate the collection of documents and other archival evidence, which will help characterize the community and any preceding interactions between risk managers and community residents. Phase II entails a community survey to better understand and predict factors that influence community members' trust in risk managers, satisfaction with the participation process, intentions to adopt or support risk mitigation behaviors, and willingness to continue to participate. Experimental techniques will help to test the influence of different methods of framing risk information on dependent variables. Statistical analysis will examine the consistency and variance of responses by community. Resulting products will provide detailed insight into what encourages and discourages adoption of proposed actions and sustained community participation in the preparation process for climate variation impacts in the Great Lakes.

- Project 4c.2 – Coastal resilience: Scenarios to support resilience to changing water levels

  Aim: N20.3,8 NGSP.2,4 N5.1,4,6 Type: New Disciplines: NS,ED Potential PIs: GLERL – Gronewold, Anderson, CIGLR – Steinschneider (Cornell), Fujisaki-Manome (UM), Beletsky (UM), Norton (UM)

  Recently, the International Joint Commission approved a new lake level management plan for Lake Ontario, dubbed "Plan 2014," aimed at restoring more natural lake level variability to promote ecosystem health. Communities along the southern shore of Lake Ontario in New York State are concerned that increased variability in lake levels will increase flood damages to shoreline property during wet periods and inhibit lake access during dry periods, and that these impacts may worsen with climate variation. These impacts could require additional investments in breakwaters and other lakeside flood protection and may negatively impact tourism, an important source of income for these communities. These challenges would further burden the already strained finances of lakeside New York communities, which have suffered losses to their tax base with regional economic decline. Plan 2014 also includes an innovative adaptive management plan that is being implemented with the support of the Great Lakes-St Lawrence Adaptive Management (GLAM). The goal of this project is to work with GLAM and south shore communities, such as the Wayne County (New York) Soil and Water Conservation District, in order to provide realistic lake level scenarios under a wide range of climate futures that can be used to both plan for local adaptations, and support adaptations in Plan 2014.

  We will develop a lake-level management model that replicates Plan 2014 operations and explore lake-level variability under a range of net basin supply scenarios. These scenarios will be driven by a publically available, large (234 member) ensemble of downscaled climate projections from the Coupled Model Intercomparison Project Phase 5 in order to explore the effects of future climate uncertainty on the possible range of lake levels. This effort will supplement past assessments of Plan 2014, which only tested the plan under four scenarios of future climate. We will develop and use a basin-scale rainfall-runoff model and net evaporation model to develop net basin supply scenarios for Lake Ontario from the ensemble of climate projections. We will use Bayesian methods to propagate uncertainty from these hydrologic models into scenarios of net basin supply. Finally, using available lake-level data from buoys along the southern shore of Lake Ontario, will develop probabilistic models of actual lake levels based on modeled lake levels. In this way, uncertainties from future climate, hydrologic modeling, and spatial lake level heterogeneity will be propagated into the

scenarios of lake levels. Working with GLAM and south shore community users we will use the resulting large, probabilistic ensemble of potential future lake levels to develop scenarios that report on relevant metrics for the community, such as the frequency and duration of extreme high and low lake-level events, or anticipated number and magnitude of shorter-term episodic events (e.g., storms and seiches).

- Project 4c.3 – Coastal management: Local planning for resilient communities

  Aim: N20.7,8 NGSP.1,2,4 N5.1,3,4,6 Type: New Disciplines: NS, SS, ED Potential PIs: GLERL – Gronewald, CIGLR – Norton (UM), Read (UM), new social sciences PI (UM), Cardinale (UM), Shriberg (NWF), McGrath (TNC)

  Substantial portions of Great Lakes shorelines are held in private ownership. Given institutional arrangements in the U.S. and, to a lesser extent, Canada, local governments enjoy substantial authority to plan for the development and use of those privately owned lands within their coastal zones through local master plans or functional plans (e.g., shoreland area management plans), and then to implement those plans through zoning codes, other regulations, and a variety of infrastructure policies. With prior support from NOAA and the Michigan Coastal Zone Management Program, a team of urban planners, natural resource scientists, and coastal engineers at UM, Michigan Technological University, and the non-profit planning firm LIAA (Land Information Access Association) has been working collaboratively with select Great Lakes coastal communities in Michigan to develop planning techniques using "off-the-shelf" data and analytical methods. These techniques have been designed so that coastal localities can adapt them to provide more robust coastal area management analyses in their master plans and then to implement those plans through various land management tools. Results from this work to date have been published on-line in the form of technical guidance materials.

  The goal of this project is to extend our work to other shoreline communities in the Great Lakes states, and possibly the Province of Ontario, to explore how local attitudes and willingness to manage shoreland development vary across state lines and shoreline dynamics. Work conducted to date has advanced our understanding of how coastal localities in Michigan along the shores of Lake Michigan view their responsibilities and authorities to more intentionally manage near-shore Great Lakes. However, it is not clear how well this knowledge translates to other states with different institutional arrangements and other lakes with different physical dynamics. Because this approach requires the collaboration of community partners, the final numbers and locations of study localities, and the types of land management efforts engaged (e.g., plan updates, zoning code amendments), will depend on the availability of partner communities, which will be determined in collaboration with NOAA-GLERL and other CIGLR team members who can help expand the sources of data used and further test of the robustness of the analytical planning methods developed.

VI. ECO Program - Engagement, Career Training, and Outreach & Communications

CIGLR's Engagement, Career Training, and Outreach & Communications (ECO) Program will facilitate the transfer of Great Lakes research and knowledge into actionable science. With financial support from the University of Michigan, our network of 9 University Partners, and NOAA-GLERL, CIGLR strives to achieve 3 goals through the ECO Program:

Engagement – *Support informed decision making* by advising local, state, and federal policymakers and elected officials about the importance of the Great Lakes' ecosystem services for national security and prosperity.

Career Training – *Promote a skilled and diverse workforce* by providing career training for undergraduates, graduate students, and postdoctoral fellows who will become the next generation of Great Lakes and NOAA scientists.

Outreach & Communications – *Advance environmental literacy* by communicating the value, importance, and usefulness of NOAA's Great Lakes research to the general public at local, state, and regional levels.

The University of Michigan has committed $1.2 million in cost-share funding over the next five years to support CIGLR's ECO Program (Attachment A. Budget narrative). ECO Program funding will also come from NOAA-GLERL, which has historically provided ~$100K annually in Task IB funds to support student fellowships and the Great Lakes seminar series. In addition, individual CA research projects (Task II/III) are all required to have a science translation component and encouraged to include postdoctoral and student support in their budgets.

The ECO Program will be implemented by CIGLR's Program Manager, with support from the CIGLR Outreach and Communications Specialist and guidance from the CIGLR Director. The sections that follow detail activities to achieve each of the ECO Program goals.

Engagement – *Supporting Informed Policy and Decision Making*

CIGLR will advise local, state, and federal policymakers and elected officials about the economic, environmental, and societal value of the Laurentian Great Lakes. CIGLR aims to take a leadership role in guiding the wise management and protection of the Great Lakes by translating research findings, providing NOAA's tools and data products, and identifying critical research needs to key Great Lakes decision makers. At the Federal level, we will focus on success stories of projects from the Great Lakes Restoration Initiative (GLRI) to advocate for continued legislative support for this program. Our engagement activities will target Federal and State decision makers from the following offices: Great Lakes and St. Lawrence Cities Initiative, Michigan Office of the Great Lakes, Conference of Great Lakes and St. Lawrence Governors and Premiers, Great Lakes Congressional Task Forces, U.S. EPA Great Lakes National Program Office (GLNPO), and the International Joint Commission (IJC).

To accomplish our engagement goals, CIGLR will collaborate with Private-sector partners (the Nature Conservancy, and the National Wildlife Federation Great Lakes Regional Center), and supporting initiatives (Great Lakes Commission, International Joint Commission) who represent the strongest advocates for science-based decision making in the Great Lakes. In addition, we will work with other CI Directors to share the importance of our work with NOAA on Capitol Hill, at the Department of Commerce, and in the Office of Management and Budget.

The CIGLR Director and Program Manager will be responsible for implementation of the engagement activities within the ECO Program, which include:

- Summits and Working Groups (3-5 per year). CIGLR will convene top experts from Great Lakes universities, NGOs, government agencies, and businesses to participate in Summits and Working Groups (SWGs) that focus on the most pressing research and management needs to achieve sustainability in the Great Lakes. SWGs are centered on CIGLR's research themes, and are designed to advance Great Lakes science and contribute to NOAA-GLERL's research capacity across the Great Lakes through the co-design of research priorities. Summits comprise groups of 20-30 experts meeting for 2-3 days to summarize the state of knowledge and recommend future directions on Great Lakes problems that span decadal time scales. Working groups bring together smaller groups (8-12) for up to one week to make detailed progress on more narrow Great Lakes issues with solutions on the time scale of months to years. University Partners within the Regional Consortium will be invited to submit proposals to an annual call for funding of SWG's. CIGLR will facilitate the review and selection process, giving priority to proposals involving NOAA scientists, and will then host SWGs at the University of Michigan-Ann Arbor. The ultimate goal for SWGs is to produce an agenda for the future of Great Lakes research that is co-designed by researchers and end-users of NOAA data. Written products will include peer-reviewed publications, and an annual Great Lakes Vision white paper that includes results and recommendations from all SWGs held that year. The resulting written products will be used as a platform to make the case for increased funding for Great Lakes research, and used to drive research that provides key information for decision makers.

- Great Lakes Day (1x per year). The CIGLR Director and Program Manager will participate in the annual Great Lakes Day in Washington, D.C. This event is hosted by the Great Lakes Commission and the Northeast-Midwest Institute to convey a unified message to Congress expressing the Great Lakes region's priorities for legislation and appropriations to protect our environment and support our economy. It includes a Congressional breakfast reception and visits to Capitol Hill. CIGLR's message to Great Lakes policy makers will center on our annual Great Lakes Vision white paper, produced as part of our SWGs.

- Great Lakes Vision Reception (1x per year). With our University Partners, CIGLR will host an annual reception for Great Lakes elected officials at the local, state, and Federal level. We will showcase NOAA's impact in the Great Lakes and highlight the CIGLR Regional Consortium's contributions to Great Lakes science. The focus will be outlining a vision for Great Lakes research, through identifying critical next steps and funding needs.

- Great Lakes policy advocacy. CIGLR and our Regional Consortium members will communicate with local, state, and Federal policy makers with written letters and phone calls when pending legislation has potential to impact the health and safety of the Great Lakes and the communities that rely on them. We will urge them to consider science in their decision

making and highlight the economic benefit of protecting and restoring Great Lakes ecosystem services. In addition to letters and phone calls, CIGLR will actively provide input to the International Joint Commission (IJC) as members of Participate IJC, an online democracy forum for contributing to the assessment of progress by U.S. and Canadian governments under the 2012 Great Lakes Water Quality Agreement.

Career Training – *Promoting a skilled and diverse workforce*

CILGR will continue the highly successful career training program that has a proven track record for producing Great Lakes and NOAA scientists and professionals. Along with NOAA-GLERL, our Regional Consortium members, and the University of Michigan, we provide NOAA-mission related research experience and career training to undergraduates, graduate students, and postdoctoral research fellows. Since 2008, we have provided research training to more than 579 students and postdocs, 158 of whom were awarded CILER-GLERL graduate or postdoctoral fellowships. CILER students, postdocs, and staff progressed to GLERL positions (i.e., federal hire or government contractor) 7 times over the same period, fulfilling the program's ultimate goal of producing the next generation of NOAA scientists in the Great Lakes. Two of the federal hires, Drs. Ashley Elgin and Eric Anderson, advanced from CILER postdoctoral fellows to be GLERL principal investigators.

We strive to shape a workforce that is not only skilled in NOAA mission-related research priorities, but also one that is diverse. CIGLR is committed to supporting diversity in an inclusive environment, in alignment with the 2016 Diversity, Equity, and Inclusion Strategic Plans issued by the University of Michigan and SNRE. We will continue our ongoing efforts to actively encourage students from groups traditionally underrepresented in the aquatic sciences workforce to participate in our fellowship programs. We accomplish this by directly communicating our fellowship opportunities to program officers, professors, and group leaders that have contact with students from traditionally underrepresented backgrounds. Examples include the University of Michigan Office of Multi-Ethnic Student Affairs, Hampton University (historically black university), American Indian Science and Engineering Society (AISES), and Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS). We receive guidance in this effort from the SNRE Diversity, Equity, and Inclusion Office and the NOAA Equal Employment Opportunity (EEO)/Diversity Program Office. Asking optional questions on race/ethnicity and gender on the fellowship applications allows us to track our success in reaching students from underrepresented groups. In 2016, 22% of applicants identified themselves as non-white or Caucasian and 44% identified themselves as female. These ratios are slightly higher than the 21% and 42%, respectively, among the University of Michigan campus community (https://diversity.umich.edu/our-commitment/). We will continue to build relationships with diversity leaders and expand our list of contacts for distributing fellowship announcements to students from underrepresented backgrounds. We will also work with fellowship mentors to develop student projects that could benefit from traditional knowledge or cultural perspectives. In addition to our fellowship recruitment efforts, CIGLR research scientists will continue to mentor students in the University of Michigan's Doris Duke Conservation Scholars Program, which aims to diversify the conservation workforce.

The CIGLR Associate Director and Program Manager are responsible for implementing the career training activities described below. Specific activities include:

- Great Lakes Summer Fellowships (8-12 per year): CIGLR will continue to administer the annual Great Lakes Summer Fellows Program, which is a partnership with NOAA-GLERL and helps place promising young undergraduate and graduate students with both university and Federal research mentors. Through this program, students get the opportunity to work on substantive research issues in the Great Lakes that, in turn, support CIGLR's and NOAA's research mission in the region. CIGLR will continue to support 8-12 upper level undergraduate and graduate students per summer.
- Great Lakes Graduate Research Fellowships (2 per year): CIGLR will administer a year-long fellowship program that funds graduate students (Master and Ph.D.) to work with CIGLR University Partner PIs on important topics for the Great Lakes region, in collaboration with GLERL or CIGLR scientists. The goals are to: 1) increase training and educational opportunities for students in Great Lakes research; 2) enhance academic and NOAA collaborations to improve research effectiveness; and 3) increase student retention within the freshwater aquatic sciences. CIGLR will support 2 Graduate Research Fellowships per year.
- CIGLR Postdoctoral Fellowships (1-2 per year): CIGLR will provide salary and research support for postdoctoral fellows who will work closely with a CIGLR University Partner PI and a CIGLR or GLERL scientist on a project of mutual interest. In the past, these fellowships have been offered opportunistically, as research funds allowed. However, with additional support from the University of Michigan, we are now able to competitively fund 1-2 postdoctoral fellows per year under a cost matching agreement. CIGLR will provide 1 year of funds and University Partners will provide a matching 2nd year of funds, and agree to a reduced 10% IDC.
- Graduate Student Projects: As research grant funding allows, CIGLR research scientists will continue to serve as mentors for University of Michigan graduate students completing Master of Science (M.S.) research projects.
- Doris Duke Conservation Scholars Program (2 per year): CIGLR research scientists will mentor at least 2 undergraduate students per year participating in University of Michigan's Doris Duke Conservation Scholars Program. The goal of the program is to introduce greater diversity into the environmental conservation workforce and teach an approach to conservation in which diversity and inclusion are integral. As part of the program, students complete an 8-week internship at an environmental organization. Students mentored by CIGLR scientists will complete this requirement at NOAA-GLERL.
- Project-specific Student and Postdoc Experience (25-40 per year): CIGLR and Regional Consortium members routinely hire undergraduates, graduate students, and postdocs to fulfill CIGLR research project needs. These students and postdocs are mentored by leading research scientists at CIGLR, GLERL, or collaborating institutions/organizations, gaining valuable experience and career training. CIGLR will continue to include student and postdoc support in our annual research proposal budgets.

Outreach & Communications – *Advancing environmental literacy*

CIGLR's outreach and communications activities are designed to translate and promote NOAA research in the Great Lakes at local, state, regional, and national levels. We work with our University Partners to expand our outreach efforts across the basin. Our key messages relating to CIGLR and our research are formulated using input gathered from CIGLR leadership

and principal investigators, and modified as needed for specific target audiences. CIGLR's target audiences include internal and external groups. Internal audiences are SNRE, the CIGLR Regional Consortium, NOAA-GLERL, NOAA CI Program Office, NOAA GLRCT, and NOAA senior leadership. External audiences include the general public, media, and stakeholders (e.g., resource managers; industry; local, state, and federal government officials; NGOs).

Our continued participation in NOAA communications and outreach groups at multiple levels allows us to coordinate communications and outreach efforts with NOAA programs across the basin, resulting in broader impact, cohesive messaging, and increased visibility for NOAA in the Great Lakes. We are active members of the GLERL Information Services (IS) Communications Group. During weekly IS meetings, we coordinate and strategize CI and GLERL communications and outreach activities, share successes and ideas for improvement, and receive guidance on working with the larger NOAA communications network. We also participate in monthly meetings of the NOAA Great Lakes Regional Collaboration Team (GLRCT) Communications and Outreach Working Group, composed of representatives from the CI, NOAA Line Offices, Great Lakes Sea Grant Network, and the Great Lakes Observing System (GLOS). We are also connected with the OAR Communications and Outreach Working Group, and participate in their monthly nationwide conference calls.

At the university level, CIGLR has ongoing relationships with key communications offices at the University of Michigan that increase our exposure from department level up to global scale. We have a well-developed relationship with the science writer and videographer for Michigan News (the university's news and media office), as well as the SNRE Communications Office. Michigan News produces feature stories and videos that are picked up by the press worldwide.

The CIGLR Program Manager and Outreach and Communications Specialist are responsible for implementing the activities described below:

- Great Lakes Seminar Series (8-12x per year): CIGLR will co-sponsor and coordinate the joint CIGLR-GLERL Great Lakes Seminar Series, which brings in regional, national, and international researchers to talk about pertinent new and emerging scientific issues in the Great Lakes. These events facilitate collaborations between researchers, provide an educational opportunity for NOAA and university scientists, and serve as an outreach forum for stakeholders and the general public to attend. Seminars are held at NOAA-GLERL or the University of Michigan and are broadcast via webinar for remote participation. Webinar recordings are available to the public on the CIGLR website and YouTube channel.

- Website (weekly): CIGLR remains committed to a strong web presence that facilitates effective science translation, provides visibility to CIGLR and NOAA research, and informs stakeholders, students, and the public about events and opportunities. We use Google analytics to track website usage and popular products. The website continually updated and under active management. The website address is ciler.snre.umich.edu.

- Social Media (daily): CIGLR will continue to connect with the public, stakeholders, scientists, and NOAA on social media through our on Facebook (@CILER.UMich), Twitter (@CILER_UM), Instagram (CILER_UM), and YouTube (CILER_UM) accounts. Collectively, CIGLR has 2,737 followers in these social media outlets. The CIGLR Outreach and Communications Specialist holds primary responsibility for maintaining a strong and active presence on social media. CIGLR posts 3+ times per day on Twitter, 3+ times per

week on Instagram, and 1-2 times per week on Facebook. We are committed to increasing our social media reach and engagement with our followers.

- News Media (4x per year): CIGLR will continue to produce press releases on research results and contact Michigan News with media-worthy stories. News articles will be available on the CIGLR website and promoted on social media.
- NOAA OAR Hot Items (4x per year): CIGLR will contribute Hot Item articles to NOAA OAR promoting CIGLR research results. OAR Hot Items articles are accessible only to the internal NOAA community. GLERL IS will assist CIGLR in this effort.
- NOAA GLRCT Regional Highlights (3x per year): CIGLR will contribute articles to the GLRCT for publishing on the Regional Highlights portion of their website. These articles will use CIGLR research results to address one of the GLRCT goals for the region: address regional challenges by connecting people and resources, exchange both national and regional insights that inform action, and improve understanding of and respect for NOAA's broad mission and regional capabilities.
- Quarterly E-newsletters (4x per year): CIGLR will continue publishing quarterly e-newsletters highlighting CIGLR research, partner interactions, opportunities, and events. Quarterly e-newsletters are directly emailed to a wide audience, including CIGLR Regional Consortium members, NOAA (OAR Communications Office, CI Program Office, GLERL), University of Michigan (UM Water Community [listserv], SNRE faculty/staff/students), NOAA UM Programs (GLISA, NERRS, Michigan Sea Grant), Great Lakes Information Network (GLIN; listserv), and the CIGLR Executive Board. They are also posted on social media and the CIGLR website. We use analytics included with our newsletter delivery service to track e-newsletter reach and interest.
- Annual News Magazine (1x per year): CIGLR will publish an annual news magazine featuring our accomplishments over the year, promoting student opportunities, and highlighting research collaborations. The news magazine will be distributed via direct mail to those who request hard copy, and electronically to the same recipients as our quarterly e-newsletters. Hard copies will also be used to promote CIGLR and NOAA at outreach events.
- Fact Sheets (6-8): CIGLR will update and co-produce with GLERL a series of fact sheets on Great Lakes topics that highlight CIGLR and GLERL research. The updated fact sheets will be posted on the CIGLR website and used for informational tables at outreach events.
- Outreach Events (8-12x per year): CIGLR will continue to have informational tables at community and university outreach events, and at scientific conferences. Community/ university events include Ann Arbor Mayor's Green Fair, Huron River Day, UM Student Visit Day, UM Green Career Fair, and the State of Michigan Earth Day Event. Scientific conferences include the International Association for Great Lakes Research (IAGLR) Conference and the Healing Our Waters-Great Lakes Coalition (HOW) Annual Great Lakes Restoration Conference. We will also continue to coordinate participation in outreach events with other NOAA programs, such as Great Lakes Sea Grant, GLOS, NOAA GLRCT, and NOAA GLERL. To broaden CIGLR's outreach across the Great Lakes, we will provide University Partners with funds to support undergraduate or graduate research students who incorporate a public outreach or education component into their work. The student's education and outreach efforts must highlight NOAA, CIGLR, and University Partner

contributions to research and management of the Great Lakes. Examples include K-12 education activities, community outreach events, public education talks, social media communication, factsheets, newsletters, and magazines.

- Research Project-Related Outreach: All CIGLR research projects will be required to define an outreach component and report on progress in annual project reports. Our ongoing harmful algal bloom (HAB) and hypoxia research in Lake Erie is a prime example of effective project-supported outreach to end users of the data (i.e., drinking water intake managers), which has helped inform and tailor our research products.

VII. Business plan

Organization and operation

The organization and operation of CIGLR will be formatted in accordance with NOAA's CI Handbook[38], which outlines procedures for establishing and maintaining CIs. The University of Michigan will serve as the host and administrative lead for the CI, and bear responsibility for CIGLR operations and management. The CI will be located in the School of Natural Resources and Environment (SNRE) and consist of a Research Institute and a Regional Consortium.

CIGLR administrative leadership will consist of a Director, Associate Director, and a Program Manager who will oversee and manage both the Research Institute and Regional Consortium (Fig. 3). CIGLR administration will be located at both NOAA-GLERL and SNRE, with administrative time divided between the two locations as follows: the CIGLR Director and Program Manager will hold an 80:20% time split and the CIGLR Associate Director will hold a 20:80% time split between SNRE and NOAA-GLERL, respectively. Research Institute staff will include Research Scientists (5 now on staff + a new social sciences PI), postdoctoral fellows, and research technicians. CIGLR's staff in the ECO Program and grants and contracts will support both the Research Institute and Regional Consortium (Fig. 3). The Cooperative Institute will form and manage a Regional Consortium consisting of 9 University Partners, 25 University Affiliates, 5 Private-sector Partners, and 7 Supporting Initiatives and NOAA Programs (Fig. 2, and described in Section IV). Principal investigators from the 9 University Partners are included in the proposed CIGLR organizational structure, whereas the University Affiliates, Private Sector Partners, and Initiatives/Programs serve a less formal, supporting function. The roles and responsibilities of each of these CIGLR entities are summarized below.

Director (Dr. Bradley Cardinale). The Director will serve as the chief executive officer of the CI, reporting to the Dean of the School of Natural Resources and Environment (SNRE). The Director's responsibilities will be to (a) oversee the administration and budget of CIGLR, (b) serve as CIGLR's chief science advisor, (c) develop and maintain CIGLR's programmatic activities, (d) build research and development partnerships between Regional Consortium members and CIGLR and GLERL scientists, (e) mentor CIGLR's Research Scientists and Research Fellows, and (f) serve as CIGLR's primary spokesperson to university leadership, NOAA leadership, media outlets, and the public. Dr. Cardinale is a full Professor in SNRE, is a renowned aquatic researcher, is one of the world's most widely cited ecologists, and has considerable experience organizing and leading interdisciplinary research initiatives.

Associate Director (Dr. Thomas Johengen). The Associate Director will co-manage CIGLR's research activities and report to the Director. The Associate Director's primary responsibilities will be to (a) provide quarterly progress updates on all research activities within the Institute,

(b) provide quarterly updates and projections of the CIGLR research budget to the Director, (c) foster partnerships between Regional Consortium members and CIGLR and GLERL scientists, (d) lead CIGLR's career training activities, and (e) on behalf of the Director, serve as a spokesperson for CIGLR to university leadership, NOAA leadership, media outlets, and the public. Dr. Johengen has a 27-year research and administration history with CIGLR, including a previous appointment as Director, and conducts leading-edge Great Lakes ecological research.

Program Manager (Mary Ogdahl). The Program Manager will manage CIGLR's programmatic activities, proposal development, research and administrative budgets, and personnel. The Program Manager's primary responsibilities are to (a) lead implementation of the Engagement, Career Training, and Outreach & Communications (ECO) Program, (b) create and maintain research and administration budget projections, (c) conduct CIGLR hiring and manage personnel research project assignments, (d) oversee research proposal development, and (e) lead the preparation of CIGLR's annual Performance Progress Report. The Program Manager reports to the Director.

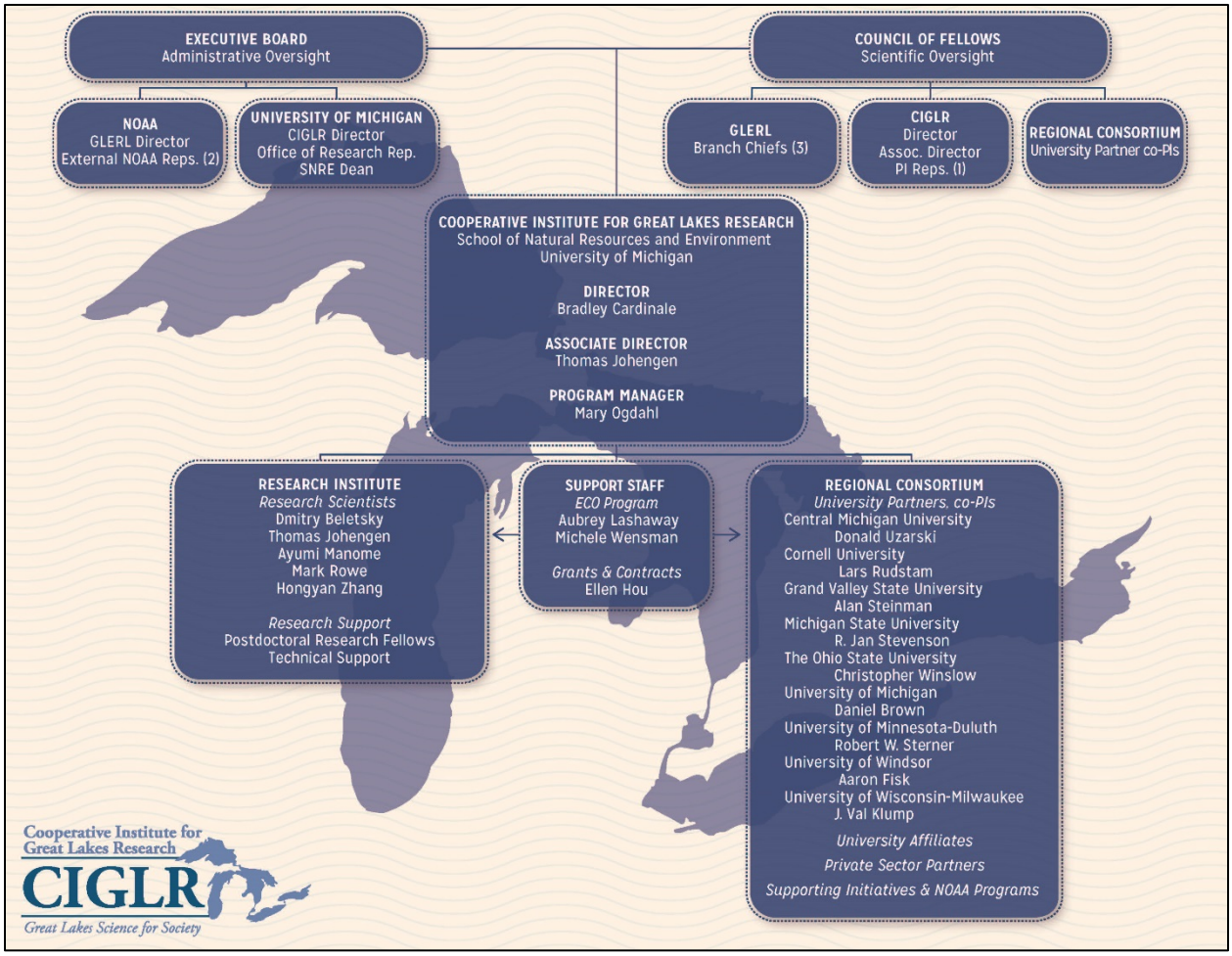


Figure 3. The organizational structure of CIGLR will consist of a Research Institute and a Regional Consortium, which are overseen by an administrative leadership team and governed by an Executive Board and Council of Fellows.

ECO Program Support (Aubrey Lashaway & Michele Wensman). ECO Program support staff will implement CIGLR's Outreach and Communications activities within the ECO Program. Responsibilities are to (a) manage and maintain the CIGLR website, (b) lead the preparation of quarterly and annual newsletters, (c) interact with CIGLR and Regional Consortium researchers to generate project updates for ECO Program activities and performance tracking, (d) lead CIGLR community outreach activities, (e) manage CIGLR social media accounts, and (f) maintain a database of CIGLR's products and performance tracking metrics. The Outreach and Communications Specialist reports to the Program Manager.

Grants and Contracts Specialist (Ellen Hou). The Grants and Contracts Specialist is responsible for the processing grants, contracts, and Cooperative Agreements. The Grants and Contracts Specialist's primary responsibilities are to (a) process all Cooperative Agreement and external grant proposal submissions, (b) perform post-award grant management, (c) establish and monitor sub-awards, and process invoices (d) prepare quarterly budget reports, and (e) ensure compliance with University of Michigan financial policies and procedures. The Grants and Contracts Specialist will report to the SNRE Business Manager.

Research Institute Staff. The responsibilities of CIGLR Research Scientists are to (a) serve as principal investigators on Cooperative Agreement and external proposals, (b) engage in collaborative research with NOAA scientists and Regional Consortium partners, (c) provide research updates to ECO Program staff to facilitate outreach and communications, and (d) mentor undergraduates, graduate students, and postdoctoral fellows. Postdoctoral fellows work with CIGLR and GLERL research scientists to receive early career training in a NOAA mission-related research topic in the Great Lakes. Research support staff will work with CIGLR and GLERL principal investigators on technical aspects of their research projects. All research institute staff are expected to produce high-quality research outcomes, such as peer-reviewed publications, technical reports, and presentations at scientific seminars and conferences.

Regional Consortium. The 9 University Partners will each designate a co-PI to serve as the primary point of contact for CIGLR administration, research, and ECO Program activities. These co-PIs will be responsible for (a) developing relationships between their university and CIGLR and GLERL scientists, (b) facilitating infrastructure access by NOAA, CIGLR, and University Partner researchers, (c) communicating with their institution's administration on CIGLR's behalf, (d) providing CIGLR-related research updates to ECO Program staff, (e) ensuring compliance with terms of the CIGLR Memorandum of Understanding (MOU), and (f) serving on the CIGLR Council of Fellows (see below). PIs and directors of University Affiliates, Private Sector Partners, and Supporting Initiatives and NOAA Programs will work with the CIGLR Director to develop and strengthen relationships with CIGLR and GLERL scientists, participate in NOAA research opportunities, and help identify their organization's areas of research, development, applications, and engagement that could enhance NOAA programs.

Fiscal and human resources management

The CI will be administered through the School of Natural Resources and Environment (SNRE) at the University of Michigan. Oversight of CIGLR human resources and fiscal management will be the responsibility of SNRE's Director of Budget and Administration (Jeff Keeler). CIGLR will receive financial management and human resources support from the SNRE Administrative Office, including recruiting, hiring, conflict mediation, promotions, effort management and certification, budget analysis and planning, and financial reporting.

All personnel hired by CIGLR will be employees of the University of Michigan with affiliations in SNRE. All University of Michigan human resource rules and benefits will apply. Consistent with the guidelines for CIs, staff of the new CIGLR will be supervised by an appropriate University of Michigan employee. In cases where CIGLR staff receive technical leadership from NOAA scientists, the University of Michigan supervisor will regularly communicate with the Federal mentor and the employee to maintain productive working relations. The performance of CIGLR staff will be evaluated annually as part of SNRE's merit review process. For technical staff, performance plans will involve setting 6-month achievement criteria that are used to assess work progress. For research scientists, performance is based on scientific productivity and accomplishments for each annual reporting period.

Strategic planning, accountability, and progress reviews

The CIGLR Strategic Plan will be developed by the Council of Fellows and approved by the Executive Board (see Governance below). The CIGLR Director will hold ultimate responsibility for accountability of the CI and be responsible administratively to the Executive Board and programmatically to the Council of Fellows. The CIGLR Director will report to the Dean of the SNRE at the University of Michigan. CIGLR and GLERL will also form a Management Team that will meet quarterly to discuss the CI's programmatic and operational progress. The Management Team will consist of the GLERL Director, Deputy Director, and Administrator, and the CIGLR Director, Associate Director, and Program Manager. CIGLR will prepare an annual report of performance measures that tracks progress toward strategic plan goals. The annual progress report will be reviewed by the Executive Board, who will provide recommendations for improvement. The annual progress reports and Executive Board reviews will be used to prepare for the 5-year CI Science Advisory Board review. Performance measures to be included in the report are in Section VIII.

Governance

The CI will be governed by two advisory boards, consistent with NOAA's CI Handbook[38]. CIGLR will receive administrative oversight from the Executive Board and scientific oversight from the Council of Fellows (Fig. 3).

Executive Board. The Executive Board will provide administrative oversight and consist of (a) 2 NOAA representatives from Line Offices outside of the Office of Ocean and Atmospheric Research (OAR) (b) the Director of the Great Lakes Environmental Research Lab (GLERL); (c) the University of Michigan Vice President for Research (or designee), (d) the CI Director (ex officio), and (e) the Dean of SNRE. The Executive Board will meet once per year, and be responsible for:

- Reviewing, providing recommendations on, and approving CIGLR's Strategic Plan.
- Making recommendations to CIGLR's Director concerning the administrative budget.
- Approving appointments for the Council of Fellows.
- Reviewing the annual budget and progress report of the CI.
- Reviewing agreements or addenda to CIGLR's Cooperative Agreement, as may be entered into in the future, and making recommendations about such agreements to the Director.
- Reviewing general policies of CIGLR and initiating appropriate recommendations.
- Assuring that CIGLR maintains a basin-wide approach in the Great Lakes and fully engages the Regional Consortium in research, outreach, education, and communications.

Council of Fellows. The Council of Fellows will provide scientific oversight and consist of (a)

the Branch Chiefs of GLERL's 3 research programs, (b) the CIGLR Director, (c) the CIGLR Associate Director, (d) 1 appointed CIGLR Research Scientist, and (e) co-PIs from each of the 9 University Partners. The Council of Fellows will meet two times per year, and be responsible for:

- Providing leadership in maintaining high standards of research for the CI.
- Analyzing the CI's programs and science direction, identifying critical research needs, and recommending new research foci.
- Advising CIGLR's Director on selection of new Council of Fellows members and reappointment of current Fellows.
- Making recommendations to the CIGLR Director on the selection of Visiting Fellows.
- Reviewing grants and applications from Task IB non-administrative programs, including the Postdoctoral Fellowships, Visiting Fellows, and Graduate Research Fellowships, and making recommendations to the CIGLR Director about priority applicants.

Project identification and selection

On an annual basis, the CIGLR Council of Fellows will meet to identify critical research needs in the Great Lakes Basin, and potential research teams to address if funding becomes available. CIGLR funding opportunities include (a) direct solicitation from our NOAA host lab (NOAA-GLERL), other Line Offices, or NOAA programs in response to an immediate research need (Task II research), (b) Federal funding opportunities (FFOs) associated with open NOAA award competition (Tasks II and III), and (c) external award competitions related to NOAA's mission, typically in collaboration with NOAA scientists. The Council of Fellows will develop criteria to guide CIGLR responses to funding opportunities, including identifying the most appropriate research team and selecting the best project to propose. When funding opportunities arise, the CIGLR Director and Associate Director will communicate with the Council of Fellows to begin the team identification, project selection, and proposal development process.

Communication and collaboration with NOAA

CIGLR's long history of collocation and integration with NOAA-GLERL has formed a foundation of strong communication and collaboration with NOAA. At the administrative level, CIGLR and NOAA-GLERL will continue to interact and collaborate through the joint Management Team (described above). In cases when CIGLR staff are working with a NOAA scientist, CIGLR supervisors will hold quarterly meetings with the staff person and NOAA mentor, to assure that high standards of performance are being met. CIGLR Research Scientists and research support staff will continue to attend monthly NOAA-GLERL research branch team meetings, where they share research updates, plan for upcoming project needs, and discuss research outcomes. CIGLR will continue to participate in NOAA communications and outreach efforts at multiple levels, including weekly Information Services (IS) Communications Group meetings, where we coordinate and strategize CI and NOAA-GLERL activities, share successes and ideas for improvement, and receive guidance on working with the larger NOAA communications network. We participate in monthly meetings of the NOAA Great Lakes Regional Collaboration Team (GLRCT) Communications and Outreach Working Group, composed of representatives from CIGLR, NOAA Line Offices, Great Lakes Sea Grant Network, and the Great Lakes Observing System (GLOS). We are connected with the NOAA OAR Communications and Outreach Working Group, and participate in their monthly nationwide conference calls. CIGLR also maintains communication with the NOAA CI Program Office (CIPO) and participates in CI Director and Administrator group meetings.

VIII. Performance measures

To assess progress annually and for our 5 year review, CIGLR will track performance measures within 7 categories that capture our productivity and impacts. Annual summaries of all performance measures will be produced for review and comment by the CIGLR Executive Board, and for the annual Performance Progress Report to the CI Program Office. Select performance measures will be continually updated on the CIGLR website and included in quarterly newsletters. CIGLR's performance and impacts will be assessed by the following measures:

Grant Success

- Total NOAA grant funding and number of amendments awarded to CIGLR through CA. Target: \$4 million yr^{-1}, 20 amendments.
- External (non-NOAA) funds awarded to CIGLR PIs. Target: \$500K yr^{-1}.
- Number of CIGLR Research Institute personnel supported through CA and external funding. Target: 25.

NOAA-University Partnership

- CIGLR Research Institute contribution to GLERL scientific workforce, as percentage of research personnel. Target: 60%.
- CIGLR contribution to GLERL's scientific productivity, as percentage of publications and technical reports co-authored by Research Institute or Regional Consortium members. Target: 60%.
- University of Michigan cost share and in-kind support. Target: ≥\$511K yr^{-1}.
- Regional Consortium cost share funding and in-kind support. Target: ≥\$555K yr^{-1}.
- Number of NOAA, CIGLR, and Regional Consortium scientists performing visiting research at a NOAA-GLERL or Regional Consortium facility. Target: 2 yr^{-1}.
- Number of times University Partner facilities are accessed by NOAA, CIGLR, or other University Partner researchers. Target: 10 yr^{-1}.

Regional Collaboration

- Number and amount of sub-award funding issued to Regional Consortium members, broken down by member categories (i.e., University Partner, University Affiliate, etc.). Target: \$1.4 million yr^{-1} and 15 sub-awards yr^{-1}, with 80% to University Partners.
- Percentage of total CIGLR research (Tasks II and III) and programmatic funding sub-awarded to Regional Consortium members. Target: ≥38%.
- Number of Regional Consortium PIs receiving sub-awards. Target: ≥50 unique PIs over the 5-year CA.
- Number of institutions, organizations, and businesses receiving sub-awards. Target: ≥20 unique recipients over the 5-year CA.
- Number of Regional Consortium-affiliated students receiving support. Target: 40 yr^{-1}.
- Number of Summits and Working Groups funded; number and type of products from Summits and Working Groups. Target: 3 summits or working groups yr^{-1}; 1 peer-reviewed publication or summary white paper (Great Lakes Vision) from each.

Research Outcomes

- Number of peer-reviewed publications resulting from CIGLR funding; number of peer-reviewed publications with CIGLR-funded first authors. Target: 40 publications yr^{-1}; 20 first-authored publications yr^{-1}.
- Number of citations for all CIGLR-produced peer-reviewed publications. Target: 200

citations per year; 10,000 citations during the 5-year CA.

- Altmetric scores for CIGLR publications. Target: 5 articles yr^{-1} with scores > 50.
- Number of social & news media hits related to CIGLR research. Target: 100 yr^{-1}.

Engagement

- Number of public decisions (laws, policies) affected by CIGLR science and advocacy. Target: 5 during the 5-year CA.
- Number of legislative actions and policy documents referencing CIGLR research. Target: 5 during the 5-year CA.
- Number of inquiries about CIGLR research by elected officials. Target: 5 during the 5-year CA.
- Number white papers that address Great Lakes research/funding priorities. Target: 1 yr^{-1}.

Career Training

- Number of undergraduates, graduate students, and postdocs receiving support through CIGLR. Target: 40 yr^{-1}.
- Amount of funding to support student and postdoctoral fellowships, student employees, and postdoctoral employees. Target: $1 million yr^{-1}.
- Number of students and postdocs located at GLERL. Target: 20 yr^{-1}.
- Number of student and postdoctoral fellowships awarded. Target: 7 yr^{-1}.
- Number of university affiliations of supported students. Target: 20 yr^{-1}.
- Number of CI students, postdocs, and staff obtaining NOAA employment. Target: 1 yr^{-1}.
- Number of CIGLR and GLERL peer-reviewed publications and technical reports co-authored by students. Target: 8 yr^{-1}.
- Percentage of self-identified non-white/Caucasian and female fellowship applicants. Target: >25% non-white/Caucasian and >45% female.

Outreach and Communications

- Number of in-person and virtual (webinar) Seminar Series attendees; number of seminar recording views on YouTube. Target: 50 total attendees per seminar, 50 online views.
- Website metrics, including number of hits and popular pages. Target: 20,000 visits $month^{-1}$, 5,000 visitors $month^{-1}$ (site-wide).
- Number of social media followers; social media engagement/reach metrics. Target: >1,000 followers on Facebook and Instagram, >2,000 followers on Twitter.
- Number of press releases picked up by media; number of interview requests; number of stories and videos produced by Michigan News. Target: 4 press releases yr^{-1}, 8 interview requests yr^{-1}, 4 Michigan News stories yr^{-1}.
- Number NOAA OAR Hot Item articles submitted; number of Hot Items that advance to OAR Secretary's weekly briefing; number of Hot Items that advance to White House. Target: 4 Hot Items yr^{-1} submitted, 1 Hot Item yr^{-1} advancing to OAR Secretary and White House.
- Number of e-newsletter subscribers; percentage of e-newsletter opens/views. Target: >500 subscribers, >50% open rate.
- Number of annual news magazine subscribers; percentage of electronic opens/views. Target: >500 subscribers, >50% open rate.