Great Lakes Observing System Enterprise Architecture Design Report Summary

Purpose of the Design Study and Report

Over the past nine months, a comprehensive, collaborative, and consensus-based enterprise architecture design process has been conducted under the direction of NOAA-Great Lakes Environmental Research Laboratory (GLERL). The project brought together multi-disciplinary experts to identify and recommend specific actions and investments for the next five years that will achieve an integrated, comprehensive, and sustainable observing system enterprise for the Great Lakes. This Great Lakes Observing System Enterprise—a highly-leveraged evolution of existing resources—will provide ready access to vital real-time and historical information to support decision-making by managers and users of this unique and invaluable resource.

This report is a summary of the collection of design report documents that have been completed under this project. The documents include a Design Report, Concept of Operations Report, Trade Study Report, and Implementation Plan. The documents also include the results of information-gathering efforts conducted in the early phases of the project that describe the current state of user needs, data management and communication systems and modeling in the Great Lakes.

What is an Observing System?

An observing system is a comprehensive enterprise that includes sensors, a network that gathers data, a data management and communications system, models and other tools that process data, and the information portals and user interfaces that make processed data

GLOSEA Partners

Sponsoring Agencies

- ***NOAA – Great Lakes Environmental Research Lab***
- ***USEPA – Great Lakes National Program Office***

Contractors

- ***LimnoTech***
- ***Applied Science Associates***
- ***Clarkson University***
- ***Michigan Tech Research Institute***
- ***University of Minnesota-Duluth***

Key Partners:

- ***GLOS - Great Lakes Observing System***
- ***USGS – United States Geological Survey***
- ***IOOS – NOAA Integrated Ocean Observing System***

External Advisory Panel Organizations

- ***International Joint Commission***
- ***University of Windsor***
- ***Great Lakes Commission***
- ***Google***
- ***IBM***
- ***NSF Division of Ocean Sciences***
- ***GLOS Board***
- ***University of Wisconsin***
- ***McMaster University***
- ***Ohio Department of Natural Resources***
- ***Environment Canada***
- ***NASA Observing System***
- ***NERACOOS - Northeast Regional Coastal Ocean Observing System***
- ***NOAA – National Weather Service***
- ***NSF - Ocean Observing Initiative***

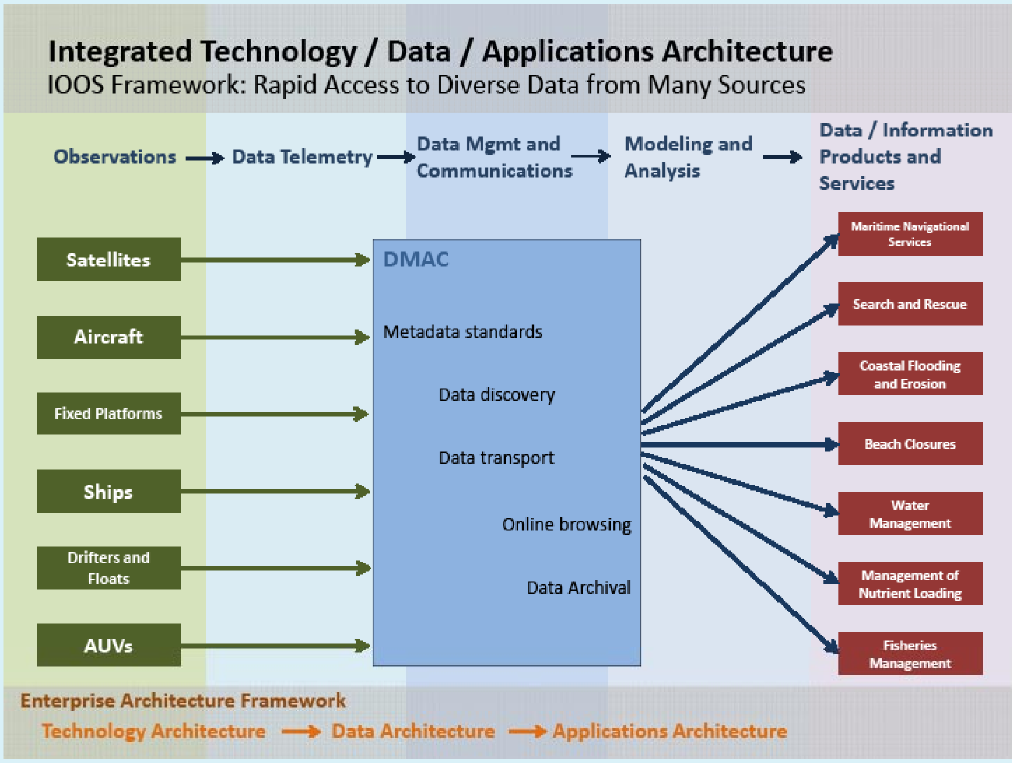


Figure 1. Elements of the Great Lakes Observing System Enterprise (adapted from IOOS)

and information available to users. Furthermore, the enterprise includes the people, organizations and institutions who use, manage, maintain and develop the system over time.

With advancements in science and technology over the past three decades (e.g., computers, sensor technology, information management systems, and the Internet), complex observing enterprise systems are being deployed by a wide range of business and science sectors. Smart businesses have invested in and built integrated information management systems that connect directly to suppliers and customers, transforming the pace and value of their business. Business enterprise managers collect, compile, analyze, communicate and store information in real-time, allowing them to improve their products, productivity, efficiency, and delivery, and expand their base of satisfied customers.

Similarly, our national weather forecasting systems provide examples of fully deployed and operational science-based observing systems. The monitoring, modeling and communication network operated by the U.S. National Weather Service and the Meteorological Service of Canada provide integrated real-time weather information, forecasts, and databases of historical weather and climate conditions for North America. The data from these systems are compiled and managed in databases, and evaluated using statistical methods and simulation models so that information regarding past, present and future weather and climate conditions can be communicated to and understood by users via the Internet and other broadcast media.

The Great Lakes Observing System Enterprise, like others around the world, is a complex and interwoven enterprise system that comprises equipment, software, data and processed information; the people who use, maintain and manage the system; and the governmental , academic, and private entities that interact with and develop the system. The collection of all of these elements into a single, multidisciplinary enterprise is depicted in Figure 1, which illustrates how sensing observations are ultimately translated into data and information products required by a broad array of users.

The Great Lakes Observing System Enterprise also provides an organizational framework for the interactions of this user community and high level research and operational users who interact to build, maintain and use the system collaboratively (Figure 2). GLOS, the nonprofit Regional Association of IOOS, plays a central role in public outreach and data coordination for the system as a whole, and the Federal agencies are also central in pursuing complementary management and scientific missions in the Great Lakes.

A critical goal of this project's conceptual design effort has been to describe the first steps required in taking the existing observing system elements to an integrated whole, or enterprise. Much like a human central nervous system, the data management and communications system (DMAC) at the core of the observing system enterprise provides a way to take available sensed information, bring it to where it needs to be, use it to make short-term decisions, store and draw on historical information to make knowledgeable long-term decisions, and communicate information to others.

What Is the Value of a Great Lakes Observing System?

The development of a Great Lakes Observing System Enterprise presents a compelling opportunity to address the intertwined drivers of value in the Great Lakes region: environmental (particularly water) resources, and economics. As summarized in Figure 3, the Great Lakes-St. Lawrence Region contains vast environmental, social and economic resources. As the Great Lakes community has moved toward an Ecosystem Approach for stewardship of the basin, economic and environmental issues are increasingly viewed as complementary rather than conflicting concerns. The Great Lakes Observing System Enterprise provides a clear opportunity to address environmental issues while also stimulating the regional economy; in other words, it will facilitate sustainable development in the Great Lakes basin.

The Great Lakes Observing System Enterprise will transform how people connect with, enjoy, preserve and restore, and otherwise use the vast resources of the Great Lakes for generations to

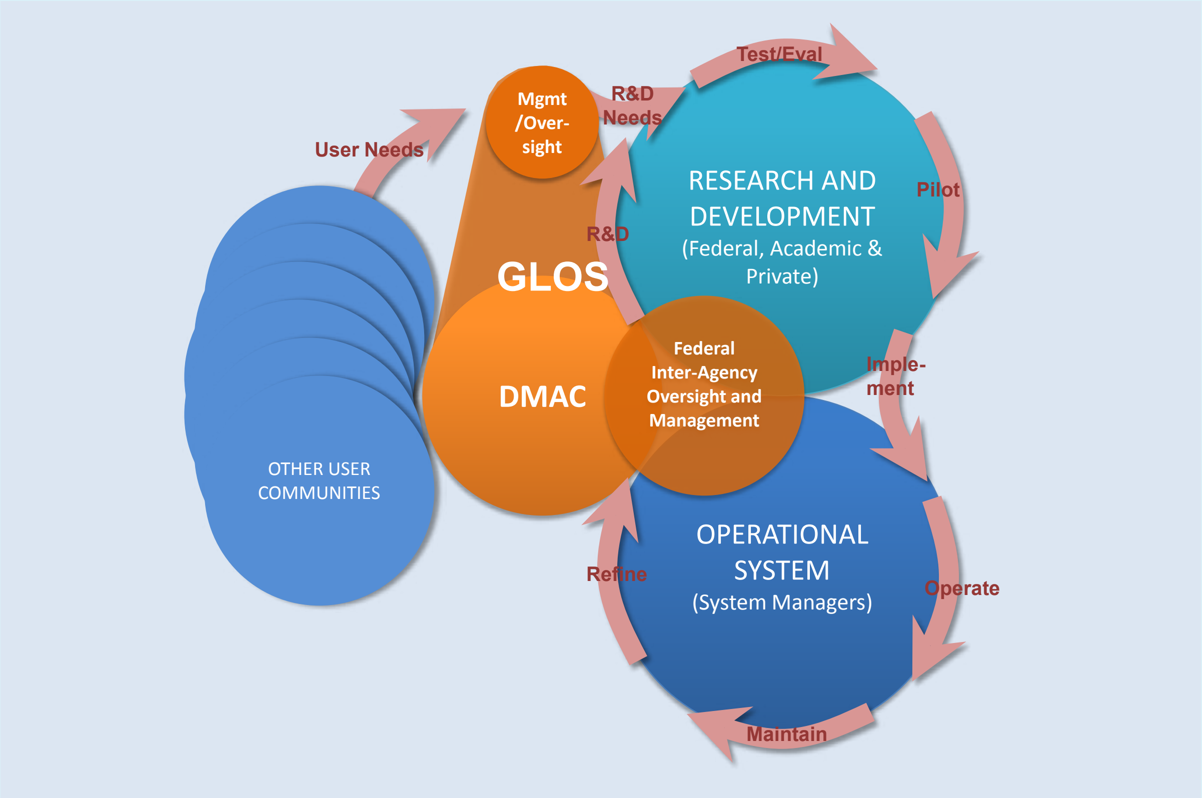


Figure 2: System Management, Development and User Framework for the GLOS Enterprise

come. The system will sense, compile, evaluate, integrate, communicate and store information on the physical, chemical, and biological conditions of coastal lands and waters of the Great Lakes so that users can make informed decisions in both the short- and long-term. The information provided by the Great Lakes Observing System Enterprise will help save lives, protect property, reduce illness, improve efficiencies, connect the community , create new businesses and jobs, and provide for better long-term monitoring, management, restoration and sustainability of the Great Lakes basin. In short, it will transform the way that we interact with and manage the irreplaceable Great Lakes ecosystem.

Who Would Use the Observing System?

Many important elements of the Great Lakes Observing System Enterprise are in place and are already routinely being used by informed users to make decisions. We therefore have a good indication of who the users currently are, and an indication of the current value of information provided. We also have information on the "market potential," future growth of the user community, and potential value that could be realized by building a fully integrated and easily accessible observing system. In addition, we expect new users to emerge and value to be created beyond those presently imagined. Like the evolution of the Internet, once the "central nervous system" (or DMAC) of the Great Lakes Observing System is fully functional, the information will be readily accessible to many. As additional users become aware of the system's capabilities, the uses and resulting value will increase exponentially. Examples of users who would benefit from the Great Lakes Observing System Enterprise are described in Exhibit 1. ***All told, economists conservatively estimate that investments in better observations in the Great Lakes could provide at least $100 million in economic returns per year.***[1]

[1] Kite-Powell, H.L. "Economic Considerations in the Design of Ocean Observing Systems." *Oceanography*, Vol. 22, No. 2. pp. 44-49)

Environmental, Social and Economic Great Lakes Resources

- **The Great Lakes – St. Lawrence (GL-SL) Region comprises 8 States and 2 Provinces**
- **The Great Lakes contain 18% of the world's supply of fresh surface water and 84% of the fresh surface water in North America**
- **The Population of the GL-SL region is 105 million**
- **The GL-SL region is the fourth largest economy behind U.S., China, and Japan, with a gross product of $4.6 trillion**
- **The Great Lakes directly support 1.5 million U.S. jobs and $62 billion in U.S. wages**
- **40 million people rely on Great Lakes for drinking water**
- **5 million recreational boats are registered in the GL-SL region**
- **Great Lakes-dependent resources provide recreation for 9.2 million anglers, 4.6 million hunters, and 23.2 million bird watchers each year**
- **Investments in Great Lakes Restoration estimated to provide $30-$50 billion in short-term economic returns**
- **Investments in the Great Lakes Observing System Enterprise will save lives and are estimated to provide at least $100 million in economic returns per year**

Figure 3: Selected Economic, Environmental, and Social Attributes of the Great Lakes-St. Lawrence Region

Exhibit 1: Users Who Will Benefit from the Great Lakes Observing System

Shipping – Great Lakes shipping is a $3.5 billion industry that provides cost-effective and virtually irreplaceable transportation of bulk cargo between Great Lakes and international ports. Information and forecasts on weather and lake conditions (ice cover, lake levels, wave heights) are critical to safe transport, and optimization of cargo loads. At a recent meeting with GLOS, one shipper indicated that each additional inch of water depth equates to an additional 670 tons of cargo that he can carry, so that with better forecasts of water depths, he can optimize his loads and better manage his business.

Recreational Boating and Fishing – Anyone venturing out on the Lakes needs to know if the present and forecasted conditions will be safe. As of 2010, there are 4.2 million recreational boats registered in the eight Great Lakes states, which is about 1/3 of all boats registered in the U.S. Recreational boating (motor and sail) and sports fishing represent a multi-billion industry supporting 100s of thousands of jobs, and add immeasurable value to the quality of life for residents and visitors. Information on current and forecasted weather and physical lake conditions (e.g., wave height, water temperature, water levels, and water clarity) saves lives and improves recreational experiences.

Municipal Water Suppliers - 40 million people in the U.S. and Canada get their drinking water from the normally pure fresh waters of the Great Lakes. Monitoring and protecting these supplies should be paramount. Early detection of pathogens, harmful algal blooms, turbidity, oil and chemical releases and zones of hypoxia could prevent deaths and illnesses or taste and odor issues. Elements of the observing system could provide early warning of potential impacts to water supply intakes. Further, while intakes for municipal supplies are monitored daily, the data are readily available only to each individual supplier. If uploaded and shared through GLOS, the historical intake data in its entirety could provide valuable indications of change in basin or lake-wide water quality conditions that can inform decision-makers on trends and possible future actions.

Emergency Response Teams – District 9 of the U.S. Coast Guard (Great Lakes Region) routinely dispatches 5,000-7,000 sorties annually, saving 300-600 lives per year, with 50-100 lives lost. Improved observations of weather, waves, temperature, ice cover and currents will save lives and facilitate operations of the Coast Guard and local emergency response teams.

Planners - Over the next few decades, the effects of Global Climate Change are estimated to affect water levels (coastal property erosion), the frequency and intensity of precipitation events (flooding and runoff pollution), ice cover distribution and duration, and other factors. The observing system can track changes over time and provide planners in federal, state and local agencies with trend information to better understand, prepare for, and adapt to the changes.

Fisheries Managers – The Great Lakes support a multi-billion dollar fishery. Fisheries researchers and managers are deploying independent and radio and acoustic tagging programs to better understand fish migration, survival, predator-prey, food web and reproduction relationships to habitat and other physical, chemical and biological factors. The observing system will allow for integration and communication of information critical to improved understanding and management of the fisheries.

Beach Managers and Users – Millions of residents and visitors swim, surf, and recreate at Great Lakes beaches. However, waves, rip currents, and channel currents pose hazards; in 2010 alone, 30 people drowned on Lake Michigan beaches. Further, some of the beaches are forced to close occasionally because of high bacteria levels following storms. Improved observations, forecasts, and communication of beach conditions would save lives, reduce illnesses, and improve the experience of beach-goers.

Industries - There are approximately 90 U.S. power plants located on the shores of the Great Lakes that use the vast supplies of water for cooling and steam generation. The efficiencies of the plants (and therefore energy production revenues and costs) are highly dependent upon intake water temperatures. Economists have estimated that collectively, Great Lakes power producers could save consumers 50-100 million dollars per year through power production balancing with improved observations and forecasts of water temperatures. In addition, wind power developers are preparing to deploy offshore wind turbines in the Great Lakes. Siting of generators and efficient management of power production among the various sources will be greatly enhanced by improved observations and forecasts of weather and lake conditions.

Great Lakes Ecosystem Scientists and Managers **–** All of the users identified above depend on a healthy Great Lakes ecosystem. For most of the 20th century, the Great Lakes resources facilitated technical innovation and rapid development of an unrivaled industrial powerhouse. North America and other free nations of the world continue to benefit from the manufacturing might contributed by Great Lakes industries to the successful world war efforts and subsequent economic growth. However, development of the region has taken its toll on the health of the Great Lakes ecosystem.

Fortunately, restoration efforts of the Great Lakes ecosystem have been ongoing for the past 40 years with continuing and growing local, regional and national support. Most recently, following the efforts of the Great Lakes Regional Collaboration in 2005, the Great Lakes Restoration Initiative (GLRI) was funded in 2010 and 2011 with US Federal investments of $475 Million and $350 Million, respectively. The restoration actions implemented throughout the Great Lakes basin over the past 40 years, with accelerated funding in the last two, have resulted in significant improvements in the quality of the ecosystem. But the Great Lakes remain impacted and/or are under threat from persistent legacy contaminants, nutrients and sediments in runoff, invasive species, degraded habitats, climate change, and other stressors. There is a tremendous need for sustained restoration and management efforts for at least the next several years, with continued and constant vigilance and stewardship for generations to come.

Numerous U.S. and Canadian bi-national, federal, state/provincial, regional and local agencies, industries, academic institutions and watershed groups play important roles in the restoration, protection, and stewardship of the Great Lakes ecosystem. These agencies, institutions, citizen groups and private companies collectively employ thousands of people who are contributing to ecosystem protection, preservation and restoration efforts. The coordinated efforts of these organizations and people would benefit greatly from a "one stop shop" – a fully capable and integrated Great Lakes observing system. The system would open up access to information, increase transparency and accountability of agency programs, foster inter-agency collaboration, "knock down silos", and ultimately result in greater overall productivity and efficiency and elimination of redundancies. Most importantly, the system would improve the quality and communication of information for making science-based decisions, decisions critical to detecting and responding to identified changes, and necessary for the restoration, preservation, adaptive management, and sustainable stewardship of the Great Lakes.

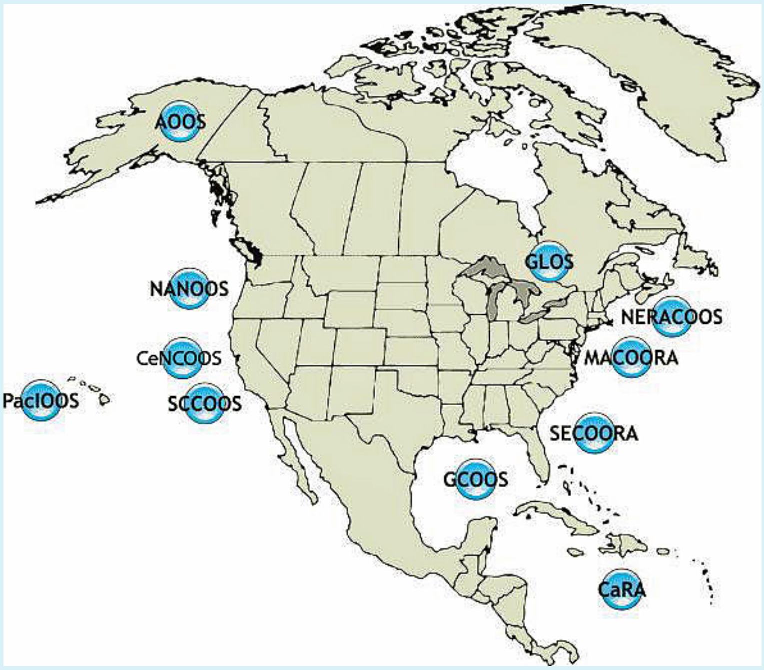
Organizations with Great Lakes Ecosystem Roles

- International Joint Commission
- USEPA
- Environment Canada
- Environmental Departments of the 8 Great Lakes States and 2 Provinces
- United States Geological Survey
- NOAA
- USACE
- U.S. Fish and Wildlife Service
- U.S. Dept. of Agriculture
- U.S. Department of Transportation
- Great Lakes Fisheries Commission
- Great Lakes Commission
- Great Lakes Protection Fund
- Great Lakes Cities
- State Of the Lakes Ecosystem Conference
- International Association of Great Lakes Researchers
- Public Health Departments
- AOCs and LaMPs
- Watershed Groups
- Council of Great Lakes Governors
- Council of Great Lakes Industries
- Universities
- Great Lakes Institutes
- Conservation Organizations
- Foundations

Where does Great Lakes Observing System Enterprise fit with other observing systems being developed in the US and World?

The GLOS Enterprise is envisioned to be part of a global observing system. Since the mid-1990s, scientists around the world have been building support for, and constructing elements of a Global Earth Observing System of Systems (GEOSS), of which GLOS is one of three GEOSS test beds. The need for constructing observing systems was punctuated by the tsunami disaster of 2004 in the Indian Ocean where observation and early warning systems could have saved thousands of lives. The US has been leading efforts to build its part of the system through NOAA-Integrated Ocean Observing System (IOOS). Until recently, U.S. IOOS development efforts have largely been accomplished through a loose confederation of willing and dedicated participants working collaboratively to enable the realization of a U.S. IOOS capability. Within U.S. IOOS, there are 17 Federal partners and 11 Regional Associations (RAs) of which GLOS is one RA. In parallel with these federal agency efforts, additional scientific support for building observing systems has been developed by The National Science Foundation (NSF), and the National Academy of Sciences (NAS). NSF has funded the Ocean Observing Initiative (OOI) to help develop the science around ocean observations, and the NAS has commissioned studies that show the need for and benefits of observing systems.

In the last couple of years, strong political support has also developed. In March of 2009, President Obama signed the Integrated Coastal Ocean Observation System (ICOOS) Act establishing statutory authority for the development of the U.S. Integrated Coastal Ocean Observing System (ICOOS). The ICOOS Act mandates the establishment of a national integrated system of ocean, coastal, and Great Lakes observing systems coordinated at the federal level. As a result, the newly formed National Ocean Council has established a National Ocean Policy, and in 2010 the Inter-agency Ocean Policy Task Force developed recommendations for observing systems. The recommendations for the near-term design of the GLOS Enterprise presented in this report are consistent with these national policies and recommendations. Representatives from IOOS and GEOSS were a part of the GLOS Enterprise design process. The GLOS Enterprise DMAC will adhere to ICOOS design standards, and will become a seamless regional element of the IOOS and GEOSS observatories.



The Great Lakes Observing System Enterprise – Why Now?

The Great Lakes-St. Lawrence region is primed to benefit from the development and implementation of an observing system. Many of the scientific and technical elements are in place, the bi-national inter-agency collaboration is in place , the user community is ready for it, and funding mechanisms and programs are available.

The Elements Are Already in Place

It is important to note that the Great Lakes Observing System Enterprise does not need to be designed and built from scratch; many of the elements and functions already exist and some are in operation. Extensive work has been conducted over the past two decades by various agencies and institutions that provide many of the components necessary for an operational Great Lakes Observing System Enterprise. However, the data from these elements are distributed among hundreds of agency departments and institutions, with only some of the data readily available through independent and largely unconnected websites. Accessing the available information currently requires that users possess intimate experience, knowledge, luck, and/or time to spend hours and days on Internet searches. The "central nervous system" of the Great Lakes Observing System Enterprise, while initiated in important fragments by different agencies, has not yet been fully built and integrated; sensors for the suite of important data have not yet been fully deployed; and feedback connections among users and providers are lacking. But given those pieces that are in place, the time is right for smart investments to build the connections and to begin filling in the missing pieces. With adequate investments now, the system could be built out over the next five years that will save lives, increase efficiencies, allow for better decision making, and generate economic returns much greater than the initial investments.

Many of the elements that are necessary for a fully capable Great Lakes Observing System Enterprise are in place, but have not yet been integrated into a fully functioning observing system. Some elements currently in operation include:

- ***Strong Existing Interagency Cooperation and Collaboration*** – Perhaps the most important element established over the past several years are the collaborative relationships that have developed between people in key federal agencies in the US and Canada for sharing information and aligning missions. Key agency departments include NOAA – IOOS, NOAA – National Data Buoy Center, NOAA – National Weather Service, NOAA – GLERL, USEPA – Great Lakes National Program Office, USEPA – Region 5, USEPA-Office of Research and Development, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, US Geological Survey, Environment Canada, International Joint Commission, Great Lakes Fishery Commission, Great Lakes Commission, Ocean Policy Council, NASA, and all of the State and Provincial Environmental and Natural Resource agencies in the basin.
- ***An Existing System of Sensors and Data Collection*** – Various agencies are already conducting much of the sensing and data collection necessary to support an observing system. For example, 22 buoys, providing real time meteorological and physical lake data are routinely deployed throughout the Great Lakes by the National Data Buoy Center in cooperation with the U.S. Coast Guard and by Environment Canada. In addition, the network of sensored buoys deployed by others (GLOS, GLERL, coastal cities, academic institutions, and industries) that upload data to the NDBC is continuing to expand. NOAA and Environment Canada maintain 96 lake level stations, and 97 fixed shore based meteorological stations. Remote sensors on NASA and NOAA satellites provide invaluable information on land and surface waters in the Great Lakes basin. Routine cruise sampling using conventional sampling methods and towed sensor arrays is conducted by the USEPA monitoring and research vessel, the Lake Guardian. The USGS maintains an extensive Water Quality Monitoring Network. Vast amounts of useful and relevant data have been and are continuing to be collected by others (e.g. municipal water suppliers, academic institutions, beach managers, local public health departments, State agencies, the Integrated Air Deposition Network., etc.).

- ***A Scientifically Based Set of Operational and Near-Operational Models*** – There has been significant model development conducted in the Great Lakes over the past 30 years. Some models developed by NOAA are already operational and provide now casts and forecasts and are accessible on various web-sites (e.g. NOS and NWS meteorological and Great Lakes forecasting models, NOAA and USGS water level forecasting models), and other models are near operational, providing provisional real time forecasts such as the NOAA-GLERL Great Lakes Coastal Forecasting models and the Huron-Erie corridor hydrodynamic model. In addition there are a host of Great Lakes models that have been developed for research and management purposes and could become operational without starting from scratch (e.g. Lake Michigan Mass Balance Model, Saginaw Bay and Maumee Bay linked hydrodynamic ecosystem models, etc.).
- ***Existing Programs***: The agency programs, departments and partnerships necessary to support the Great Lakes observing system are already established and functioning, including, GLOS, NDBC, NOAA-GLERL sensing and forecasting, Great Lakes Beaches Program, USGS WQ Network, NOAA and NASA satellite imagery programs, , regular Great Lakes environmental monitoring by EPA and Environment Canada, the State of the Lakes Ecosystem Conference (SOLEC), the binational Cooperative Science and Monitoring Initiative (CSMI), the International Joint Commission, and all of the accountability aspects of the Great Lakes Restoration Initiative (GLRI).

The User Community is Prepared to Grow with the Observing System. In addition to meeting needs of present-day users, there will be other unanticipated users who will benefit from the GLOS Enterprise. One recent example clearly demonstrates the potential unanticipated demand by many users for information provided by an integrated and networked observing system in the Great Lakes (Figure 4). A power plant on Lake Michigan is currently evaluating alternatives for meeting the standards of newly proposed cooling water regulations. As part of their studies, they deployed a real-time data buoy off the southwest coast of Lake Michigan in early June, 2011. Rather than following a site-specific sensing approach (i.e., collecting, compiling and storing the data for their own internal use), they connected the buoy to the NOAA-National Data Buoy Center network. Within days, plant managers received comments from a wide variety of users at the individual, state and federal levels expressing thanks for installing the buoy. The lesson is clear: when a single user made the information collected for one site-specific purpose available on the network, unanticipated users began accessing the information, and the usefulness of the information was multiplied many times in a matter of days. The Great Lakes Observing System Enterprise design is flexible and expandable, so that as new uses and data sources are identified, and as new technologies are developed, the user community grows and this increased user base in turn stimulates new technological advances.

Funding Mechanisms and Programs Are Available. The congressional authority and agency programs that could serve as the federal funding mechanisms for the Great Lakes observing system have been enacted and established. The build-out of the Great Lakes observing system is consistent with the missions of the GLRI and the NOAA-IOOS programs, and initial investments using these existing and funded programs would expedite the critical next steps. Shared funding or in kind contributions from other federal, state, and local programs and organizations could be developed over the next few years.

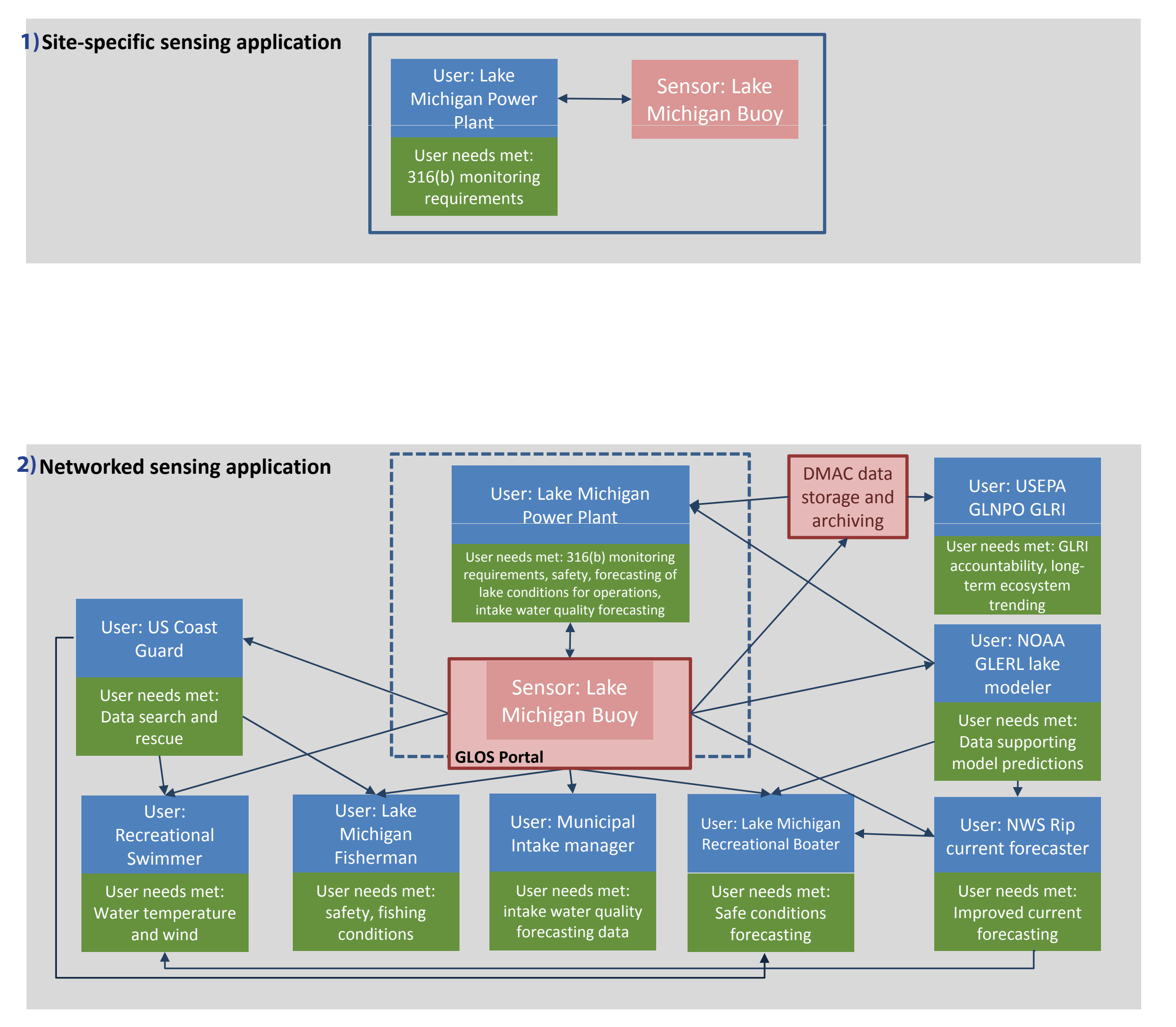


Figure 4: Demonstration of Expansion of Uses When Information Collected for a Single Purpose Is Made Available Through a Networked Observing System

Project Approach

The near-term design of the GLOS enterprise architecture presented herein is the product of a multidisciplinary, integrative approach. This approach married the science and technology domain with the business and management domain through careful planning and extensive communication between a number of different components, including the enterprise architecture framework, the concept of operations, risk assessment and mitigation, and implementation plans.

The overall project was organized to develop a conceptual design for all of these components in parallel. A leadership role for each component was assigned to specific team members armed with appropriate expertise, who were then able to draw on relevant staff within the entire team. Weekly team phone calls supplemented by individual conversations throughout the project supported ready assessment of progress and coordination between the components. Additional opportunities for input and review by NOAA, our Key Partner agencies, and the invited Expert Advisory Panel (representing many stakeholder agencies and academia) were provided through presentation and delivery of midterm and draft final products. Feedback was incorporated into the continuing development and the final product.

Our enterprise architecture design approach builds on the existing GLOS conceptual plan, and is modeled to reflect IOOS guidance on component architectures and to include key steps laid out in the Federal Segment Architecture Methodology:

- Determine Participants and Launch the Project
- Define the Scope and Strategic Intent
- Define Information Requirements
- Define Conceptual GLOS Design Alternatives
- Develop the Draft Design Documents

The design balances user needs, the states of Great Lakes science, modeling, and observation technology, DMAC needs and capabilities, operation and maintenance, Risk Assessment and mitigation, and business options, including capital and operational life-cycle costs and schedules for construction and implementation Risk Assessment. The balance is informed by the detailed trade study considerations of these factors and delivers a range of optimized and sustainable mixes of sensors, infrastructure, and analysis that best meet the user needs cataloged in this study.

Project Findings and Recommendations

As the design proceeded and stakeholder input was received, several themes of consensus emerged that are important for guiding the build out of the Great Lakes Observing System Enterprise. These observed themes were viewed as design drivers and/or viewed to present opportunities to leverage the existing status of the system, and led to primary recommendations for the near-term. The design drivers and opportunities, and the primary recommendations are summarized below.

Design Drivers and Opportunities

User Needs and Observing System Enterprise Elements Necessary to Address Those Needs Vary by Scale – Some user needs are common across the entire Great Lakes basin, other needs are specific to each individual lake or connecting channel, and others are more local and should be addressed through regional scale observing system elements. The design and implementation of the GLOS Enterprise will be best accomplished considering these different scales, and providing flexibility in the DMAC to handle the variety of data at all scales. Funding approaches, timing, and phasing of the build out will also likely be different for these different scales.

> ***Basin-wide User Needs*** – Ecosystem resource managers, global climate change scientists, and the national weather service depend on data collected from stations across the basin. Conditions such as water levels, ice cover distribution and duration, water temperature, basin water balance, total area and distribution of wetlands, air deposition of contaminants, etc., will require basin-wide sensing.
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> ***Lake-wide User Needs*** – Fisheries and lake scientists and ecosystem resource managers need information on issues that are specific to each lake. Existing and potential stressors and issues in Lake Superior are different than those in other lakes. The design of the sensing and forecasting systems to address lake-wide issues may be different for each lake, and may be different from, but draw on the basin wide and regional scale sensing networks.
>
> ***Regional Scale User Needs*** – The potential for deadly rip currents, bacteria contamination of water supplies or beaches, harmful and nuisance algal blooms, zones of hypoxia, chemical spills, coastal erosion, or other issues will vary by locality. Sensing and sampling designs for monitoring issues important to specific regions will need to be developed on a region by region basis. Similarly, the build out of regional observing elements will likely be best driven by the local communities.

User Needs and Observing Elements Necessary to Address Those Needs Vary by Time. Some users will need instant access to real-time information such as weather, wave, and hydrodynamic now casts and forecasts. Other users will be interested in data collected and reported on a daily, monthly or annual basis. Other users such as resource scientists and managers will be interested in data to determine long-term trends. The observing system will need to be flexible to accommodate the collection, compilation, analysis, storage and communication across these different time scales.

Date Management and Communication Element Is Critical. There is a significant identified need for a Great Lakes basin-wide DMAC to serve as a community base for gathering and disseminating of sensing data, and making data available for use by the both the modeling and end-user communities. The DMAC needs to be interoperable with IOOS and GEOSS, so coordination efforts such as the GEOSS test bed project and IOOS participation should continue.

Existing Remote Sensing Capabilities Present Significant Opportunities. Significant advances have been made and are being made in the area of satellite based remote sensing, and the observing system should be positioned to respond effectively to these opportunities. There is a gap in the current ability of researchers and users across the system to access and benefit from remote sensing data, and also a gap in the availability of tools and algorithms to process the data. Filling these gaps should be a priority. The investments that have been made by NOAA and NASA in satellite infrastructure and operations should be fully leveraged to maximize the value of the sensing data to address monitoring needs for the Great Lakes.

Existing Models Present Significant Opportunities. Models are central to the operation of the Great Lakes observing system enterprise, and there are significant opportunities to be gained from the widespread dissemination and use of these models. There is a great wealth of model development and application throughout the Great Lakes Basin and for a wide range of environmental issues and user needs. Some of those models are largely research focused while others are more management focused. A concerted effort is needed to move models that serve user needs at all scales to an operational status within the enterprise. This report makes recommendations for proceeding along this path.

The Existing Sensing Array Is Extensive and Can Be Leveraged to Create Greater Value. Addressing remaining gaps in the sensing system will require further input from Great Lakes stakeholders and the scientific community. Major gaps in the sensing area are as follows:

- There is a need to provide data support to the models that are currently close to operational status, are supported financially and politically, and are addressing specific user needs. These data needs will need to be identified and focused through interactions with the current caretakers of these models
- Many components of the currently operating system are operational but do not have long-term maintenance and upgrade plans in place.
- The current sensing system is primarily based on in-situ, fixed sensing. The value of these systems will need to be augmented and balanced against the opportunities presented by emerging technologies such as remote sensing and AUVs.
- Coordinate the Lake scale sensing system with the Cooperative Science and Monitoring Initiative (CSMI). The CSMI focuses monitoring on one lake per year, rotating through each lake, on a 5-year schedule. The build-out of the lake scale sensing system should be coordinated with the CSMI. For example, a group of real-time buoys that provide refined information at the lake scale could be rotated among the lakes on the same schedule as the CSMI.

Primary Recommendations

Support and maintain the existing sensing system. Where appropriate, continue critical data collection efforts that are underway and institutionalized. But, be prepared for change – see 3b.

Leverage the Data. Integrate, manage, and communicate the data that are being collected by designing, constructing and populating a flexible, adaptable, and expandable DMAC that includes real time data as well as historical data bases.

Turn the Data into Useful Products for Decision-making. Accelerate the development of tools that turn data into information, information into knowledge and useful products that improve decision making. These tools provide broad benefits to both the general user and management community:

> ***General User Community***. Data products provide benefit to the commercial, industrial, municipal, recreational, and scientific communities. The GLOS enterprise provides a network in which developers can verify, operationalize, and improve models and other analytical tools that turn data into information, increase understanding, and allow for forecasting that supports decisions critical to the Great Lakes, and the regional economy that depends on the Lakes. This includes short term and long-term forecasts of lake levels for shipping, currents for beach conditions forecasting for recreational users, remote sensing for monitoring the extent of Cladophora blooms, sensing to support power generation and municipal water, and many other applications critical to the Great Lakes economy.

> ***Management Community***. Data products provide federal agencies with a way to clearly discern how observations are being used, where they are providing benefit, and where redundant or unclear missions exist. A primary goal of the sensing system is transparency: of the data being collected and its applicability to specific user requirements. The enterprise allows managers and funding agencies to evaluate, prioritize, eliminate redundancies, and implement improvements to data collection to improve the quality of information and knowledge in the Great Lakes

Reach out to the Public Users of the GLOS Enterprise. The user community is growing and is increasingly technology-savvy and interested in real-time, relevant sources of information. It is vital for the GLOS Enterprise to grow, expand the user and contributor network as well as identifying and securing funding mechanisms.

Expand Sensing Where Needed to Address Pressing User Needs. This effort is focused on setting baseline sensing requirements to address user needs at the basin scale and at the scale of individual Lakes:

> ***Basin-wide Scale***: Implement the targeted addition of critical data collection sensors to achieve a functional observing system at the basin-wide scale.

> ***Lake Scale***: Implement a pilot OS at the Lake Scale that would serve to provide an operational Lake scale observing system as well as a model for adaptive management of the lake ecosystem, and to inform the development of Lake-Scale observing systems in the other Lakes

Leverage Third-party Sensing. Provide a framework to incorporate data and information developed by others on a regional scale under a planned and opportunistic basis.

Diversify Funding Over Time. Ultimately, the enterprise system architecture presented in this report is intended to serve as an open environment that supports sensing activity by academics, municipalities, commercial and industrial entities, and state and federal agencies. The funding of these sensing activities should be similarly diverse, and differing with scale—with greater federal support and control at the basin scale, more third-party funding and flexibility at the regional scales.

Planning for Implementation

The implementation of the GLOS Enterprise has already been initiated with this project, and a series of steps that structure the implementation are described below and presented in the table below. The table summarizes tasks that follow different timelines for completion, including tasks that will be substantially complete with the close of this project, shown in green. Tasks that are planned for completion within the 5-year timeframe of the near-term design are shown in blue, and tasks that are initiated during the 5-year timeframe but have a longer schedule for completion are shown in orange. The major tasks are summarized as follows:

Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC. Under this task, a complete inventory of existing sensing systems and descriptions of monitored parameters, frequency and spatial locations is gathered for all systems in the Great Lakes.

Step A1: Catalogue and monitor completion of Level A activities. Under this task, the team lead will identify and monitor the completion of ongoing projects or readily accomplished projects that have existing planning and funding mechanisms in place, across the basin and at all regional, lake, and basin scales.

Recommended 5-Year Implementation Planning Steps

Design Level	Implementation Level	Basin Scale	Lake Scale	Regional Scale
0	*Step 0: Catalog existing systems and build the geospatial database of observing systems for the DMAC*	*Catalog is complete with this project, geospatial database initiated*	*Catalog is complete with this project, geospatial database initiated*	*Catalog is complete for RDAs, with this project geospatial database initiated*
A	*Step A1:Catalog ongoing or funding-in-place activities*	*Catalog is complete with this project; monitor through 2013*	*Catalog is complete with this project; monitor through 2013*	*Expand catalog to include all regional-scale activities; monitor through 2012*
	Step A2: Plan and construct basin-wide DMAC	*Within 5 years: Plan and build out DMAC to serve all scales of observation*		
	Step 3A: Design and to the extent possible, implement a Level A sensing strategy	*Design and implement minimum level of sensing at the basin scale*	*Design and implement minimum level of sensing in Lake Michigan, coordinated with CSMI activities*	*Develop a 5-year plan for minimum sensing in regional observing system subareas*
	Step 4A: Develop and where possible, operationalize models required for each subarea (unique to each GLOS subarea)	*Plan and operationalize basin-scale models, incorporating remotely sensed data*	*Operationalize Lake Michigan models, develop plan in 5 years to operationalize key models at the lake scale*	*Use lake-scale plan to inform plan for opportunistically operationalizing regional models*
B	*Step B1: Develop a set of targeted expansion alternatives, and plans for implementation*	*Within 5 years: Gather and prioritize user need -based drivers that will govern observing system expansion alternatives at the basin, lake, and regional scales*		

- Substantially complete within this project (green)
- Substantially complete within 5 years (blue)
- Develop groundwork within 5 years, complete in 10-20 years (orange)

Step A2: Plan and build the DMAC. Under this task, a detailed design will be developed for the DMAC system to support all scales of observation across the basin, followed by a period of construction and then maintenance of the DMAC. The DMAC design will be basin scale in extent but will explicitly include functional capability to accommodate sensing system input and user interactions at the lake and regional scales.

Step A3: Design a Level A Sensing Strategy and implement at the Basin Scale, in Lake Michigan, and regionally on an opportunistic basis. Under this task, the Level A sensing strategy will be designed in detail and implemented across the Great Lakes, bringing the system to a baseline level of capability across the basin.

Step A4: Develop a plan for operationalizing models, and implement at the basin scale, in Lake Michigan, and regionally on an opportunistic basis. Under this task, a plan for operationalizing models will be developed in detail and implemented to different degrees at the basin, lake and regional scale.

Step B1: Develop a set of targeted expansion alternatives, and plans for implementation. The Level A design activities described above set the stage for expansion alternatives that target specific user needs and management issues with diverse objectives and funding strategies. We recommend that the implementation effort start with an intentional process of opportunity identification and prioritization, and then target 2-3 OS subarea projects for implementation over the 5-year near-term design period.

Funding for the Implementation Plan.
A funding schedule was developed in the implementation plan assuming a $25M total investment over 5 years. The funding schedule places significant emphasis on the initial design and construction of the DMAC, which is critical to the success of the overall system. A significant level of funding is also allocated to sensing systems that build the enterprise to a base level of sensing capability required to address based user needs comprehensively after five years. The emphasis of this build-out is directly building this base capability at the basin scale, while creating the capacity for third-party investment in the sensing system at the regional scale; consequently investment is greatest at the basin scale and more targeted toward incentivizing third-party funding at the regional scale.

It is anticipated that the level of investment in the GLOS enterprise will be uncertain and will likely vary from year to year. Consequently, the project implementation plan also presents similar investment schedules at a lower level of funding ($10M over 5 years or $2M per year) and a higher level of funding ($50M over 5 years or $10M per year). The funding distribution under these alternative funding scenarios changes to reflect the critical priorities of the enterprise system build-out. More details on each of these funding scenarios are provided in the implementation plan, but the outcomes at all three levels can be summarized as follows:

- ***$50M Funding level ($10M per year).*** At this level of funding, significant advances can be made in all domains of the observing system, including the physical observing system, the data management and communications system, and the models and other analytical tools used to meet user needs. Significant advances are made in the capability of the system to monitor long-term ecological trends and progress toward ecological restoration, address the safety of recreational users, and optimize the use of the lakes for commercial shipping, power plant cooling, and production of municipal water. This level of funding also provides a strong basis for leveraging of public-private partnerships, encouraging third-party investment in sensing and data distribution. This level of funding is about 5-10% of the economic returns estimated to be generated by the investment, and less than 3% of current levels of GLRI investments.

- ***$25M Funding level ($5M per year).*** This level of funding moves the observing system forward in each enterprise domain, but with decreased opportunity for addressing limitations of the current physical sensor network. The primary emphasis is placed on design and build-out of the data management and communications infrastructure, with some funding available for addressing sensing gaps, operationalizing models, and incentivizing third-party contributions to the network. This level of funding creates the DMAC and basic sensing improvements to improve the ability of system to monitor long-term ecological trends and progress toward ecological restoration, address the safety of recreational users, and optimize the use of the lakes for commercial shipping, power plant cooling, and production of municipal water. At this spending level, minimal funds are available for leveraging of public-private partnerships. This level of funding is about 2-5% of the economic returns estimated to be generated by the investment, and less than 2% of current levels of GLRI investments.

- ***$10M Funding level ($2M per year).*** At this restricted level of funding, activities are focused almost exclusively on the central task of DMAC design and construction. Minimal funding is available for addressing gaps in the current sensing system, operationalizing models, or making progress on sensing of parameters of importance for monitoring long-term ecological trends and restoration progress. The construction of the DMAC lays the critical groundwork for the harmonized function of the greater observing system, and consequently primary allocation of funds to this task makes the most significant advances possible under the minimal funding of this scenario. The development of a DMAC infrastructure provides some improvement in the ability of the enterprise to address the safety of recreational users, monitor parameters relevant to the ecological function of the system, optimize the use of the lakes for commercial shipping, and support commercial uses of the water body. However, real progress in these areas is deferred until a later date. At this funding level, minimal funds are available for leveraging of public-private partnerships. This level of funding is less than 1% of the economic returns estimated to be generated by the investment, and less than 1% of current levels of GLRI investments.

Conclusions and Outcomes

The Great Lakes are critical to the region, forming our identity, defining our sense of place, and providing the natural resources and rich ecological diversity that are closely tied to our economic success. In recent years, the vitality of the Great Lakes has increasingly come under threat due to the effects of climate change, invasive species, and other effects of human activity such as nutrient loading, persistent environmental contaminants, and water withdrawals and diversions. At the same time, the connection between the economic vitality of the region and the continued health of the Great Lakes has never been more clear.

It is in this context that we bring forward this design and plan for implementation of the Great Lakes Observing System Enterprise. By laying out an architecture for the observing system that addresses the totality of the enterprise, from sensors to a core data management and communications system to the models and analytical tools that turn sensing into real benefit to users, we are proposing a system that provides many linkages: between users and the information they need, between scientists and entrepreneurs who will accelerate the economy of the region, between elected officials and the multiplicity of organizations and federal agencies who serve critical roles as caretakers of the lakes. We strongly believe that creating these connections will provide the transparency and openness that will serve the two critical needs of our region: the stewardship of the Great Lakes and the acceleration of the regional economy.

Implementation of the GLOS enterprise architecture will further standardize all aspects of data-related activities—collection, transmittal, storage and usage—in the Great Lakes Basin. This will build on existing investments in sensors, storage and dissemination technology while laying a strong foundation for future evolution of the GLOS Enterprise Architecture. Expansion of the depth and breadth of monitoring will be simple, as the GLOS Enterprise Architecture will enable a fully modular approach to growth.

As the GLOS enterprise architecture is implemented, data collected throughout the Great Lakes Basin will become more readily available to scientific researchers, resource management decision-makers, and to the general public. These data will support characterization of the state of the Great Lakes and the contributing watershed, allowing assessment of progress towards restoration goals.

Implementation of the GLOS enterprise architecture will also provide economic opportunities within the Great Lakes Basin, as the standardization of the system components will gradually move their operation out of highly specialized research lab settings into the private sector.

Once the integrated Great Lakes central nervous system (DMAC) is constructed and the sensing is more fully populated, and as the broader Great Lakes community becomes aware, the utility of the information will likely spawn new products, revenue, and jobs. From useful mobile applications for beach-goers, sailors and fishermen, to energy optimization products for power companies, to new sensor technologies, the GLOS Enterprise will seed innovation and entrepreneurship.

Economic studies have indicated that improvements in observations in the Great Lakes will save lives each year and create value on the order of tens to hundreds of millions of dollars per year. However, investments will be necessary to achieve these gains.

Given the value that the data provide to certain users, such as power companies, coastal communities, recreational boaters, significant investment is already underway by entities other than the Federal government. The system has already and likely will continue to encourage co-investments from municipalities, Areas of Concern, user groups, private industry, and the States and Provinces that make up the Great Lakes community.

The lakes are a powerful economic engine for the region, and the caretaking of this resource has the potential to create businesses and jobs throughout the observing system enterprise. Similar to the way the National Weather Service provides the products that allow multi-billion dollar businesses like Accuweather and The Weather Channel to exist, the observing system in the Great Lakes has the potential to provide a framework for investment and economic activity that aligns economic and environmental goals for the region – not just jobs, but the right kind of jobs for a new economy of the Great Lakes.