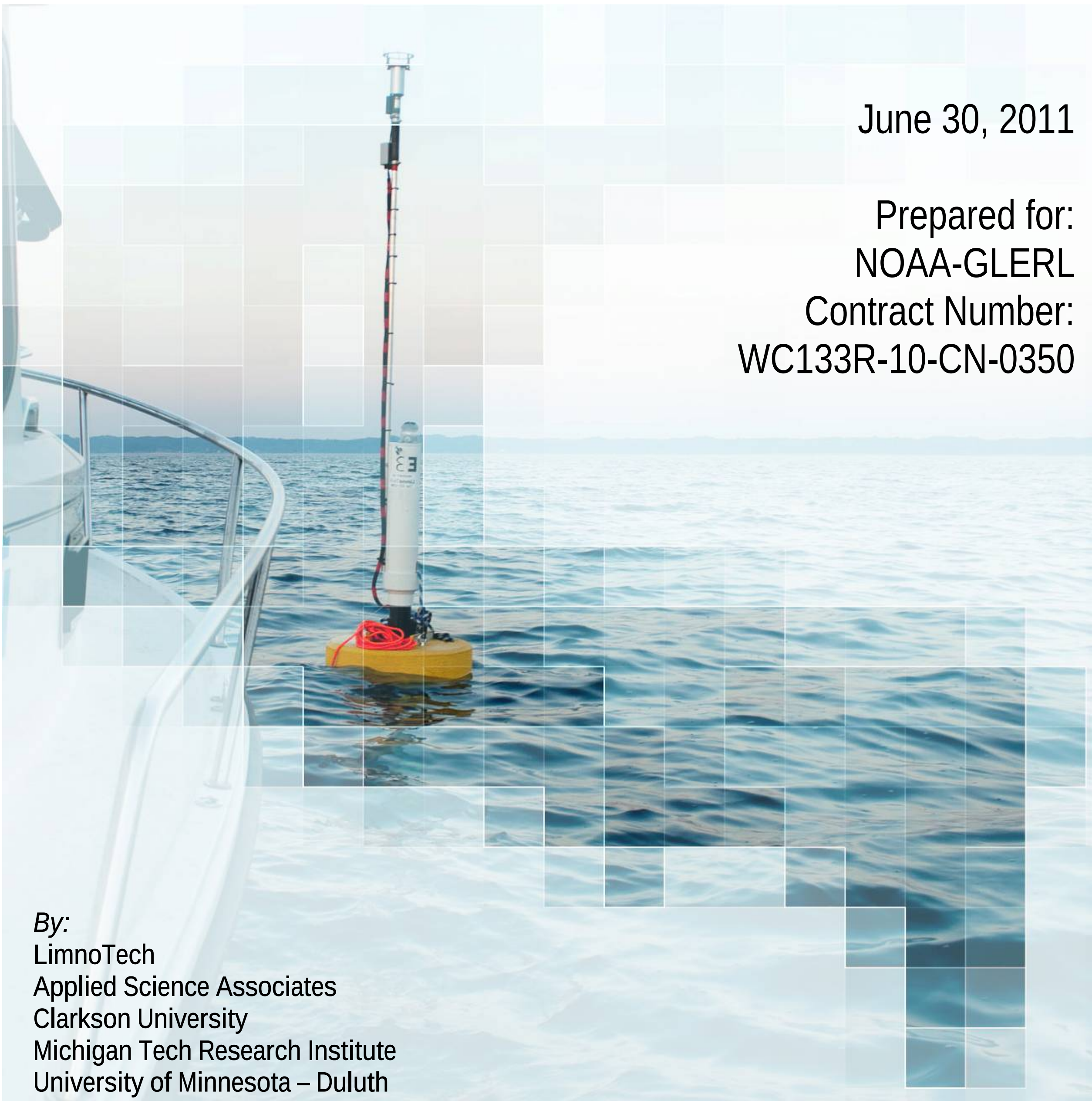
DESIGN REPORT
Near-Term Design of the Great Lakes Observing System Enterprise Architecture



June 30, 2011

Prepared for:
NOAA-GLERL
Contract Number:
WC133R-10-CN-0350

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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***

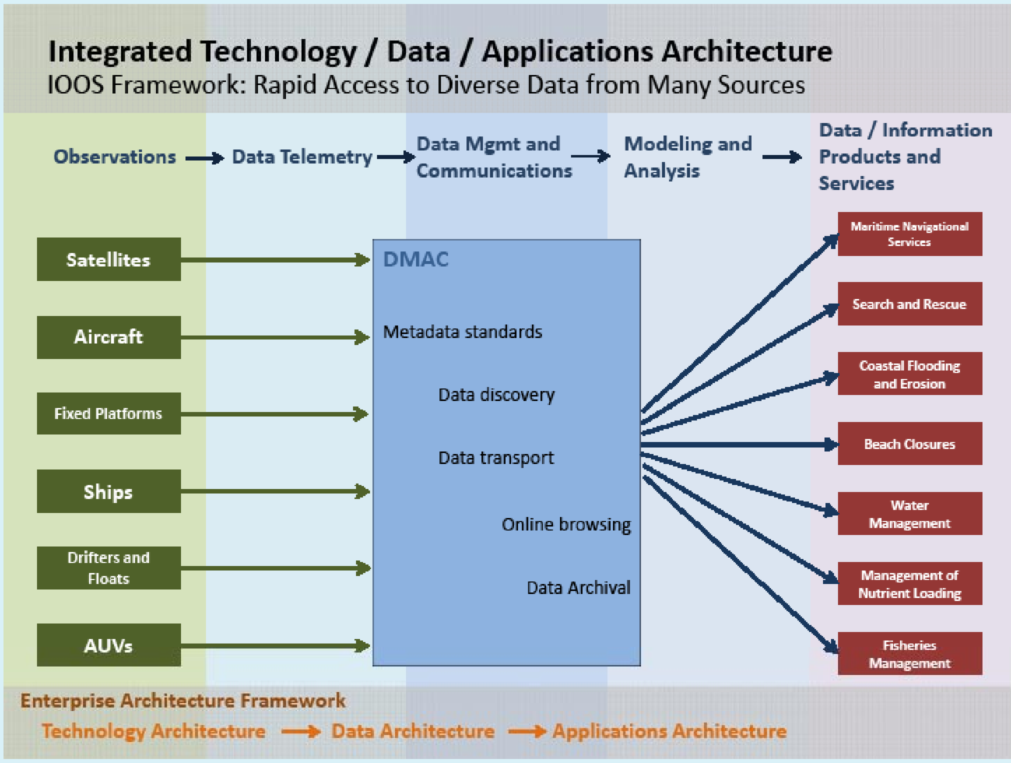


Figure 1. Elements of the Great Lakes Observing System Enterprise (adapted from IOOS)

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, 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

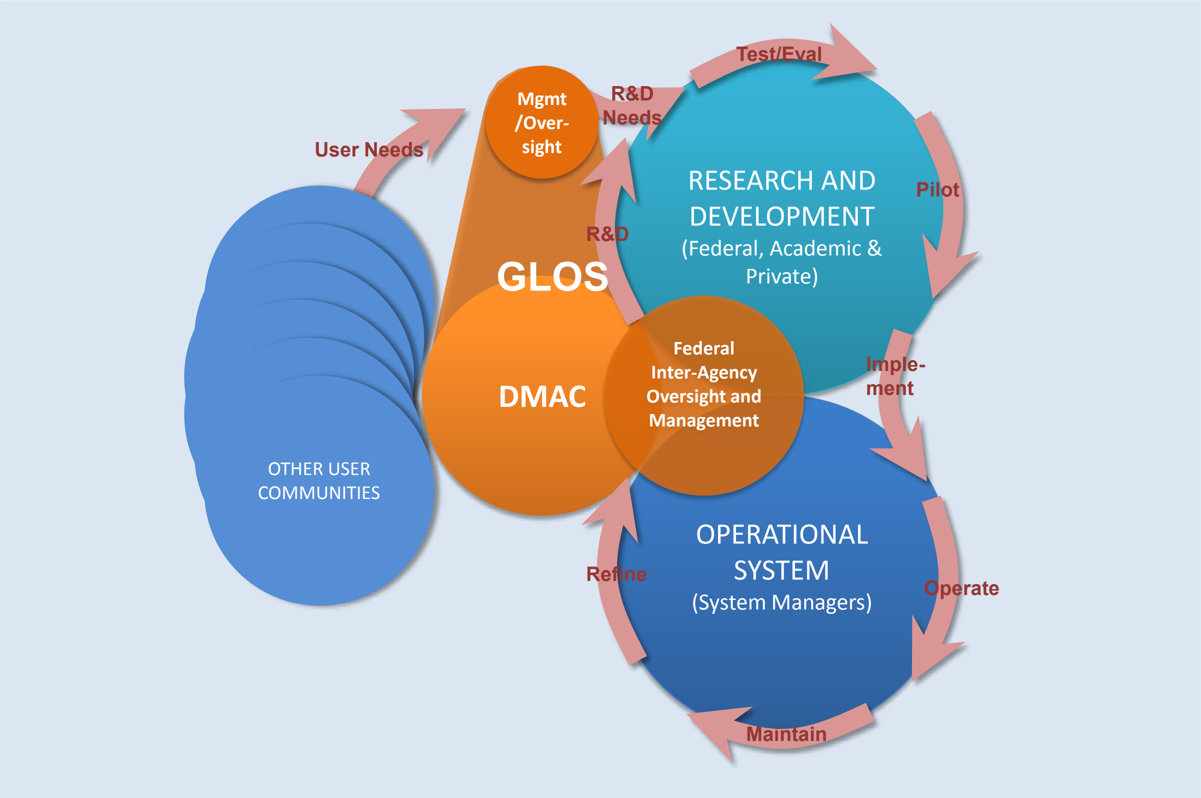


Figure 2: System Management, Development and User Framework for the GLOS Enterprise

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 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 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 India, 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 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.

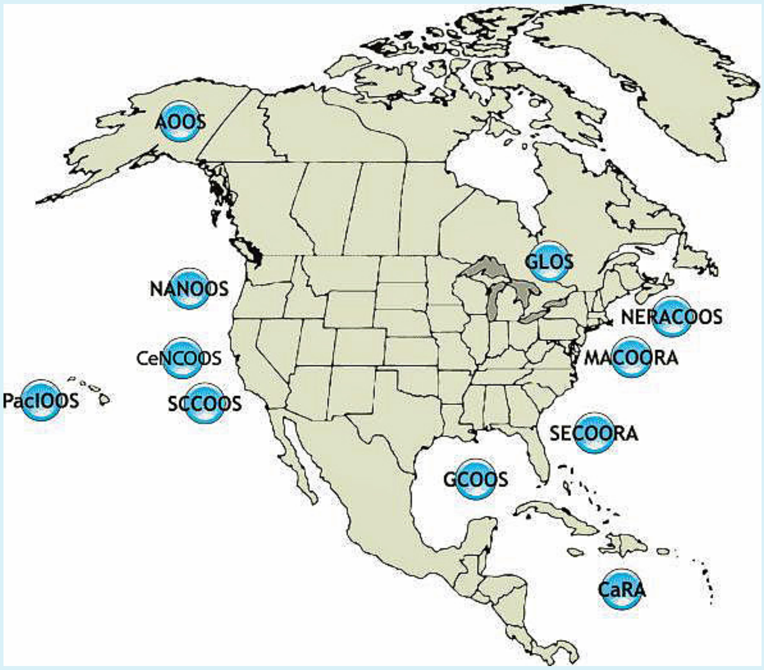
Numerous U.S. and Canadian bi-national, federal, state/provincial, regional and local agencies, industries, academic institutions and watershed groups play important roles in the restoration, protection, and stewardship of the Great Lakes ecosystem. These agencies, institutions, citizen groups and private 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 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 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. 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 Great Lakes Observing System, 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 that has been 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 GLOS. 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 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.

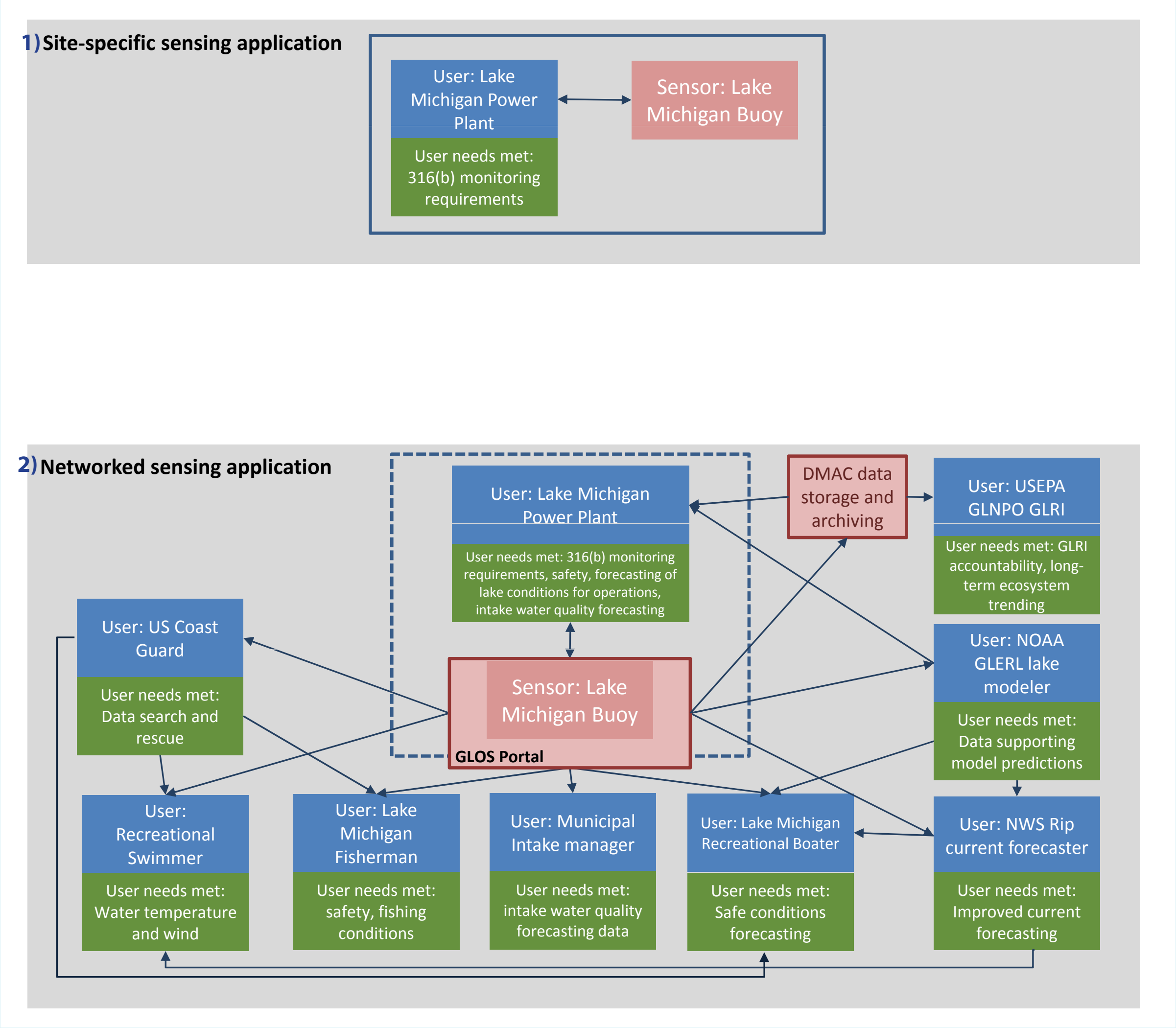


Figure 4: Demonstration of Expansion of Uses When Information Collected for a Single Purpose Is Made Available Through a Networked Observing System

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 GL observing system. 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 GLOS 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.

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. The user community is growing and is increasingly technology-savvy and interested in real-time, relevant sources of information. It is vital for GLOS 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*
	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*		
A	*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

Substantially complete within 5 years

Develop groundwork within 5 years, complete in 10-20 years

Step A2: Plan and build the DMAC. Under this task, a detailed design will be developed for the data management and communications (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.

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1. INTRODUCTION

The Great Lakes Observing System (GLOS) was established as one of 11 Regional Associations (RAs) within the U.S. Integrated Ocean Observing System (IOOS), a multidisciplinary network designed to provide data required by decision-makers to address common societal goals. The mission of GLOS is to provide all stakeholders with access to critical, real-time and historical information about the Great Lakes, St. Lawrence River and interconnecting waterways for use in managing, safeguarding and understanding these immensely valuable freshwater resources. At the same time, the National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory (NOAA-GLERL) has been a leader in the development, implementation, and maintenance of real-time monitoring systems in the Great Lakes and has endeavored to utilize those systems in the development of ecosystem forecasting models. In addition, EPA's Great Lakes National Program Office (GLNPO) has been given the responsibility of managing the considerable resources allocated to the restoration and preservation of the Great Lakes through the Great Lakes Restoration Initiative (GLRI). The USEPA also has a mandate to monitor and document the improvement in the Great Lakes basin ecosystem as a result of GLRI activities. And both Parties to the Great Lakes Water Quality Agreement (EPA and Environment Canada) have identified a number of indicators of Great Lakes status through the SOLEC (State of the Great Lakes Ecosystem Conference) process that must be regularly monitored for measuring status and trends. As the goals of these initiatives are so closely aligned, it is logical to jointly plan for the development of a Great Lakes observing system that provides broad, coordinated support to these organizations in pursuit of their different but related objectives.

The observing system will provide critical information necessary to inform and manage priority issues that affect public health and safety, ecological integrity and restoration, and the economic viability of the Great Lakes region. Information collected, evaluated and disseminated by the system has the very real opportunity to save lives and reduce illness in the Great Lakes basin. For example, information on beach conditions, storm warnings, wave conditions, and currents could potentially reduce the number of deaths from the current level of 7 deaths per year due to rip currents, 16 boating related deaths per year, and numerous swimming related illnesses caused by water-borne pathogens. Information disseminated by the system will also be important to the sustainability and improvement in the $4 billion sport and commercial fishery, the $3.4 billion commercial shipping industry, $16 billion recreational boating industry, and a vibrant tourism economy that provides 217,000 jobs in the region. The data collected and disseminated will also serve to monitor the progress of the multi-billion dollar investments in the GLRI restoration action plan and inform the adaptive management of vital ecological resources.

NOAA-GLERL received funding in 2010 under the GLRI to develop a near term design for the Great Lakes Observing System (GLOS) Enterprise Architecture. The GLOS Enterprise Architecture will be an integrated, holistic ecosystem observing system that will include the physical, chemical, and biological data collection necessary to support effective Great Lakes management. The Enterprise system will also be equipped to detect change in the Great Lakes coastal environment resulting from the basin-wide implementation of the Great Lakes Restoration Initiative (GLRI). This document presents a strategic plan for the near term GLOS enterprise design. The strategic plan is intended to leverage and build on the foundation of the existing programs and initiatives of GLOS, IOOS, NOAA-GLERL, and the GLRI.

The objective of this report is to provide recommendations for the design and implementation of prioritized elements of the observing system over the near term (next 5 years) that will build to a sustainable Great Lakes observing system over the long term. This report is the culmination of a multi-stakeholder collaborative effort with input and direction obtained directly from an expert advisory panel representing NOAA-GLERL, USEPA, USGS, USACE, and IOOS, as well as input provided to GLOS by numerous stakeholders over the past several years.

The overview, objectives, and approach of the project are presented in Section 2. The strategic plan for the GLOS Enterprise Architecture has been developed by first examining user needs as described in Section 3. The role of models as central to conversion of the raw data collected by an observing system to the information and understanding needed by users, is presented in Section 4. The observing system design principles are identified and developed in Section 4, along with key drivers, and critical data gaps and constraints. Section 6 then describes a conceptual design approach addressing these drivers at three scales that are of significance for sensing in the Great Lakes: the basin-wide scale, the whole-lake scale, and regional sensing systems that function at the more local, sub-lake scale (we call these subareas).

In Section 7, a trade studies approach for site-specific design refinement and sensing technology selection is described, with applications to example subareas of the observing system at different scales. And finally, a description of the integration of the sensing system design across scales and among the many entities that act as data providers, processors and users throughout the Great Lakes is presented in Section 8, with a focus on the data management and communications system that serves a central role in integrating, assimilating, and disseminating information provided by the sensor network, data collection efforts, data evaluation tools, and model outputs.

Section 9 summarizes the recommended implementation plan for the GLOS Enterprise Architecture, with a timeline of recommended tasks and consideration of a range of future funding scenarios. Additional details on the Trade Studies, Concept of Operations and Implementation Plan are presented in the stand-alone reports appended to this document.

2. PROJECT DESCRIPTION

2.1 PROJECT OVERVIEW

The near-term design of the Great Lakes Observing System enterprise was developed within the context of an enterprise architecture framework. The Enterprise Architecture (EA) defines the overall structure of the monitoring system, the subsystems that define the system, and relationships between the EA, its users, and the environment. In addition, the EA will provide guidelines for the ultimate design and evolution of the EA over its lifetime of service. The observing system as a whole is an enterprise that consists of people, information, and technology that work together to serve the Great Lakes community in a common effort. By clearly defining the architecture of this enterprise, this project lays the groundwork for the sustainable long-term success of the GLOS enterprise – ensuring that the system has a well-defined, common mission and that future development and evolution of the system can occur in a way that continues to support the mission.

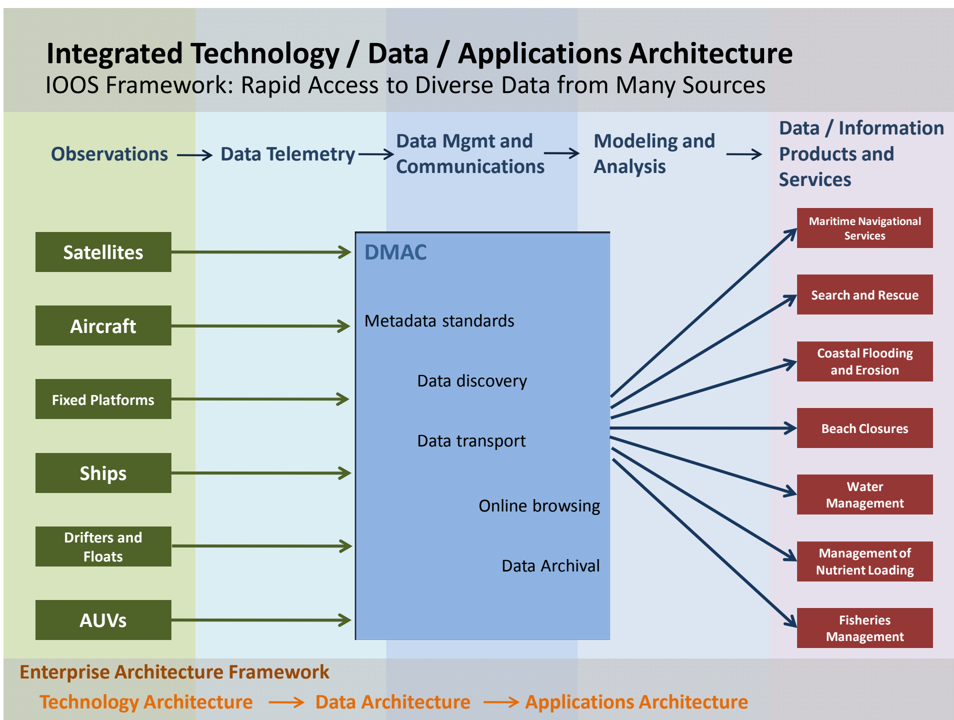

Figure 2-1. Integrated Observing System Architecture (adapted from NOAA-IOOS).

An enterprise architecture framework also defines the relationship between the systems and technology domain and the business or management framework that supports it. The conceptual model that IOOS has developed for its system of systems is depicted in Figure 2-1. The project team has developed a system design for the GLOS enterprise that is consistent with this architectural framework. The supporting network of existing scientific and management organizations and agencies that currently operate and interact successfully in the Great Lakes community will comprise the business/management framework of the enterprise.

As indicated at the bottom of the diagram in Figure 2-1, the systems and technology domain is subdivided into three sub-domains: technology architecture, data architecture, and applications architecture. In the GLOS enterprise these domains will overlap significantly, as the technologies used in a basin-wide environmental sensing system provide a data stream that requires active management, interpretation, and communication. Modeling and analysis applications provide ways to translate the data into usable technical products and information for the user community. This project describes the characteristics of these sub-domains and their interactions across all system sub-components in the Great Lakes. The system components include users, maintainers, developers, and the equipment technologies, data products, and models that they interact with.

The core project team of LimnoTech, Applied Science Associates, Clarkson University, and Michigan Tech Research Institute has collaborated with and received input and expert advice from several key partner organizations including NOAA-GLERL, GLOS, the United States Environmental Protection Agency (EPA), United States Geological Survey (USGS), and IOOS. In addition, an Expert Advisory Panel (EAP) consisting of members of other partner organizations and academic institutions having expertise on environmental observing systems has been engaged in the process and provided valued input and review.

2.2 PROJECT OBJECTIVES

The following project objectives were identified to achieve the overall project goals as described above:

1. Apply an enterprise architecture design process to develop the structure and behavior of the Great Lakes Observing System Enterprise Architecture, in terms of its technology (observing technologies and methods), data management and communication (DMAC), and applications (modeling and analysis tools) architecture. As part of this objective, the project team has also provided the rationale for the decisions made in formulating the GLOS enterprise architecture framework.
2. Develop a Concept of Operations document for the GLOS enterprise that presents the operation of the system from the perspective of operators, users, owners, developers, maintenance, and management. This analysis contributed to the overall design concept.
3. Conduct Trade Studies that assess the feasibility, performance, affordability, risk, and schedule for alternative representative designs of subareas of the enterprise. The trade studies provide a tool to support selection of a preferred design, including its architecture, operation, and applications.
4. Develop an Implementation Plan for the GLOS enterprise that describes the research, development, testing, evaluation, and support necessary to arrive at a fully operational system within the next five (5) years. The Implementation Plan will include cost estimates and a schedule of milestones for making the GLOS enterprise operational.

2.3 PROJECT APPROACH

The integrated, near-term design of the GLOS enterprise architecture builds on the conceptual plan for such a system previously developed by GLOS (GLOS, 2007a). The concepts of enterprise architecture development have been applied for designing many different large, multi-purpose systems (e.g., Mathaisel, 2005; Morganwalp, et al., 2002), and federal guidance for design of such systems describes specific process steps to be followed when developing the design of a federal enterprise system (FSAM, 2009). The design approach developed in the early phases of the project and described in the mid-term General Design Approach document follows the enterprise methodology steps adapted from FSAM, as described below.

Determine Participants and Launch the Project: The draft project plan identified initial key stakeholders, initial user needs, and a draft purpose statement for the project, as well as the specific project tasks, initial alternative scenarios, and methodologies for the trade study, and design activities. The project plan was subsequently modified based upon review and input received from the key partners obtained at the project kick-off meeting.

Define the Scope and Strategic Intent: Following the initial kick off meeting, the scope of work was refined to reflect the agreed upon strategic intent and vision for the near term GLOS enterprise. Key questions that were addressed included:

- What are the current GLOS investments, systems, and resources?
- Who are the GLOS stakeholders and what are their needs?
- Based on the high-level purpose statement, what are the strategic improvement opportunities and gaps in the existing systems?
- What is the scope of the GLOS architecture?
- What are the deficiencies or inhibitors to success within the existing data collection, management, and communication systems?
- What are the target and performance metrics for GLOS?

The above items were developed through many conversations with GLOS stakeholders, end users, and leaders in the Great Lakes scientific and technical community, as well as the broader user community. The findings were used to develop a set of critical design drivers, described in the following section.

Define Information Requirements for GLOS Enterprise: In the early phases of the project, the project design team engaged with key stakeholders to analyze the operations of existing systems and information provided by those systems to identify potential gaps, improvement opportunities, and opportunities for potential expansion to meet needs. Within this step, the team developed a comprehensive view of the user information requirements associated with the strategic improvement opportunities identified in the previous step. These information requirements are documented in [see Technical Memorandum 6 in Appendix A].

Define the Conceptual GLOS Enterprise Design Alternatives: This step occurred in preparation for the mid-term project meeting, and involved engaging with key stakeholders to evaluate the initial potential alternatives and preliminary conceptual designs. The preliminary conceptual design alternatives consider integrated views of the combined systems, services, and technology architectures that support the goals and requirements of GLOS enterprise identified in the preceding step. The preliminary conceptual design alternatives also are shaped by the need to transition from the current (as-is) data collection, management and communication system to recommended future systems.

Develop the Draft Design Documents: The team documented the previous process steps and leveraged these results to create the GLOS enterprise design documents presenting the structure and behavior of the GLOS enterprise system. The design documents will include findings and recommendations as well as supporting analyses of trade-offs among alternatives (trade studies), life cycle cost evaluations, concept of operations, implementation plans, and near-term cost and schedule estimates.

In addition to following the general guidance of FSAM, the design of the GLOS enterprise has been integrated within existing IOOS frameworks and standards. With respect to developing integrated ocean observing systems, IOOS has adopted federal concepts of enterprise architecture to provide guidance for designing the technology, data, and applications architectures of their regional association systems (de la Beaujardiere, 2007).

Defining an enterprise architecture for a system like GLOS involves balancing user needs, the state of Great Lakes science and modeling, the state of observation technology, the needs and capabilities of the DMAC for the system, operation and maintenance considerations, risk assessment and mitigation, trade studies, and business options (including capital and operational lifecycle costs and schedules for construction and implementation). Arriving at a balanced architecture has involved considering all of these components in a way that allows for an optimal and sustainable mix of observing technology, data information infrastructure, and modeling and analysis of the data that best meets user needs.

3. USER NEEDS

The Great Lakes Observing System Enterprise Architecture project is intended to leverage and build on the foundation of three similar and complimentary initiatives and programs. The project team is working and collaborating with agency partners representing the governing structure of the GLRI, the Integrated Ocean Observing System (IOOS), GLOS, and GLERL. The project is funded by the GLRI and is intended to produce an observing system design that will provide data on the physical, chemical, and biological parameters necessary for effective management of near-shore aquatic resources to support remediation, restoration, and conservation actions through the GLRI. The observing system is intended to gather data to help address the goals laid out by IOOS, GLOS, and the GLRI.

GLOS is responsible for coordinating design, implementation and operation of a regional observing system as part of IOOS. The focus of GLOS is to meet critical information needs for priority issues that affect health, ecological integrity and economic viability of the Great Lakes region. This is done through installation and operation of observational equipment and monitoring procedures; development of models that can define complex physical, chemical and biological processes, coordination of existing information, and delivery of customized products to end users.

Climate change impacts, habitat loss, decline of fisheries, invasive species, and impacts of water levels threaten the economic and ecological sustainability of the region. A combination of biological, chemical and physical factors has degraded the ecologic balance of the system. There have been fundamental shifts in the cycling of nutrients and energy in several of the Great Lakes, including dramatic declines in total phosphorus concentrations, plankton abundance and the numbers of forage fish. Under the Great Lakes Regional Collaboration (GLRC), which included input from 1,500 representatives from federal, state and local agencies, academic, and non-governmental communities, critical information needs were identified. In addition, a Brookings Institution study found that implementation of the GLRC recommendations would produce over $80 billion in short- and long-term economic benefits to the United States (Austin, et al., 2007). The Great Lakes Commission’s Great Lakes Monitoring Inventory and Gap Analysis also identified deficiencies in the existing observing and monitoring being conducted (Great Lakes Commission, 2008).

IOOS is an integrated system of observing systems (the RA’s) that routinely and continuously provides quality controlled data and information on current and future states of the oceans and Great Lakes from the global scale of ocean basins to the local scales of coastal ecosystems. It is designed to provide data in forms and at rates required by decision makers to address seven societal goals (IOOS). These goals are described below in relation to the Great Lakes (GLOS, 2007):

1. ***Improve predictions of climate change and weather and their effects on coastal communities and the nation***: Lake level variability is the largest driver of habitat diversity across the region and a major economic factor affecting the region.

Climatologists have predicted that the Great Lakes could drop by 1 to 3 meters over the next century, due to global climate change. Monitoring of water supply changes, lake level modifications, changes in outlet conditions and prevailing meteorology are a major focus for the observing system. Lower water levels on the Great Lakes increase the cost of shipping on the lakes by requiring lighter loads, cause deterioration of wooden shore structure, and reducing recreational opportunities.

2. ***Improve the safety and efficiency of maritime operations***: The Great Lakes are important to commercial navigation and the transportation of goods, being home to nearly 25% of the top 150 commercial harbors in the nation. Commercial navigation in the region is encountering unique challenges due to low water levels. Improved short-term forecasts of conveyance in the interconnecting waterways are becoming more critical, along with more frequent collection of bathymetric information in navigation channels and harbors. In addition, the Great Lakes are home to nearly 3 million recreational vessels every year. Charter fishing is a multi-million dollar industry for the region. These users rely on accurate and timely nearshore marine forecasts. Safety of marine operations also includes potential spills of oil and contaminants into the lakes.
3. ***Mitigate the effects of natural hazards more effectively***: Predominant natural hazards affecting the Great Lakes include coastal flooding, erosion, rip currents, intermittent severe meteorologic phenomena, storm surges and seiches. Coastal zone managers have increasing need to refine risk assessments that in turn can affect permits for coastal structure development and dredging operations. Nearly 160,000 land parcels make up the 5,600 miles of Great Lakes shoreline.
4. ***Improve national and homeland security:*** Includes protection of drinking water supplies for up to 40 million residents across the region. The emphasis is on improving advanced warning systems to allow municipal water system managers to shut down intakes when exposed to biological, chemical or nuclear contaminants. Improved observational capabilities would provide input to three-dimensional flow models of nearshore waves and currents for this purpose.
5. ***Reduce public health risks***: In the Great Lakes the focus is monitoring and modeling of bacterial contamination of public beaches that can cause illness and death. There are more than 600 recreational beaches on the Great Lakes that provide significant economic and intrinsic value to local communities. The lack of robust and reliable prediction capability can result in beachgoers being exposed to water that has elevated concentrations of bacteria, while beach closings cause a loss of revenue. Real-time data for nearshore currents, waves, rainfall and biologic activity used in nearshore circulation models would assist beach managers.
6. ***Protect and restore healthy coastal ecosystems more effectively***: Habitat protection and restoration is a major objective outlined in the GLRC strategy report as well as being the focus of the GLRI. Threats to ecological sustainability are increasing through the increased presence of invasive species and urbanization and detailed terrain data is needed for shoreline areas. In addition, water use is increasing across the region. Changes to the outlets of the lakes have also occurred, causing changes in lake levels and flows in the interconnecting channels.

7. ***Enable the sustained use of ocean and coastal resources (Great Lakes):*** Includes the sustainable use of the fishery and other living resources. The Great Lakes fishery has been affected by loss of habitat, competition from exotic invasive and parasitic species, and changes in water chemistry, temperatures, circulation patterns and volumes. The lakes have seen declines in native species, such as yellow perch and the amphipod *Diporeia sp*., which is a critical food source for many fish. There has also been a dramatic decline in the abundance and composition of phytoplankton and zooplankton over large areas. Increasing the observations of plankton abundance and how other physical and chemical properties interact with plankton is needed to determine why fish and plankton communities are changing.

GLOS has developed a conceptual plan for its regional coastal ocean observing system (RCOOS) that addresses how each of the IOOS societal needs will be met in the Great Lakes through its RCOOS (GLOS, 2007a). The Enterprise Architecture has been developed to meet the data and forecasting needs that GLOS has identified. The resulting GLOS goals are as follows:

1. Improve early identification of climate change impacts on the thermal structure and chemistry of the Great Lakes
2. Reduce risks of contaminated water supplies and improve predictive capabilities to protect public use of bathing beaches
3. Enhance understanding of nutrient dynamics, algal blooms, and other factors adversely affecting a viable fishery
4. Reduce loss of life and property damage to commercial navigation and recreational boating, while increasing economic efficiencies of commercial navigation operations.

The GLRI operates under the Great Lakes Multi-Year Restoration Plan (EPA, 2010). This plan identifies goals, objectives, targets and projects to address the Great Lakes most significant environmental issues within the Great Lakes ecosystem. Being funded through the GLRI, the Enterprise Architecture takes into consideration the following GLRI goals.

1. *Toxic Substances and Areas of Concern: Measuring Progress and Assessing New Toxic Threats* - Measure progress in cleaning up toxics in the Great Lakes environment through comprehensive monitoring and assessment. Identify significant sources and impacts of new toxics to the Great Lakes ecosystem through robust surveillance as well as laboratory and field studies, in order to devise and implement effective control strategies.
2. *Invasive Species: Establish early Detection and Rapid Response Capability* - Work with federal and state jurisdictions to initiate surveillance activities to detect new invaders and establish the capacity, methods, and contingency plans for a rapid response. Joint planning will allow the mobilization of shared resources to create the best opportunity for eradication.
3. *Nearshore Health and Non-Point Source pollution: Generate critical information for protecting nearshore health* - The nearshore environment of the Great Lakes is highly varied, including relatively unspoiled shorelines, highly urbanized reaches, tributary mouths, embayments, wetlands and other environmental features. These activities will promote the collection of data about nearshore conditions and stresses, the assessment of

information and management implications, or the dissemination of information to all potential users in the Great Lakes community.

4. *Habitat and Wildlife Protection: Identify, inventory, and track progress on Great Lakes Habitats, including coastal wetlands restoration* - Assess progress toward restoring Great Lakes habitats by establishing baseline conditions and tracking trends; highlight the importance of coastal wetland conservation and restoration by implementing a long-term coastal wetland monitoring program and enhancing the National Wetlands Inventory.
5. *Accountability, Monitoring, Evaluation, Communication, and Partnerships*: *Measure and Evaluate the health of the Great Lakes Ecosystem using the best available Science* - Enhance existing programs that measure and assess the physical, biological, and chemical integrity of the Great Lakes, including the Connecting Channels. Implement strategic components relevant for Great Lakes decision-making of the U.S. contribution to the Integrated Earth Observation System and the Integrated Ocean Observing System as part of the Global Earth Observing System of Systems. Promote the development and implementation of science-based indicators that will better assess and provide a better measure of accountability of actions to improve the health of the Great Lakes ecosystem.

The project team worked with GLOS and other Great Lakes resources to identify a list of users and end user requirements, drawing on the collective knowledge of the Great Lakes interests represented by the project team and the project partners. The list of Great Lakes Users encompasses a broad spectrum of stakeholders involved in science and research, recreation, commerce, power supply, public and environmental health and safety, navigation, coastal development and wildlife and habitat preservation. The User Categories representing these stakeholder interests include:

- Fisheries
- Water Quality Managers
- Climate Change Research and Planning
- Public Health (Drinking Water)
- Maritime Operations (shipping and navigation)
- Power Generation
- Beaches
- Recreational Boaters
- Emergency and Spill Response

Users also include land use planners, air quality managers and researchers, resource managers and policy makers, research scientists and engineers, educators, legislators, and public stakeholders. The data and information needs of these end users are many and wide-ranging. They include, among many others: wave and current measurements, water levels, ice conditions, thermal conditions, updated imagery of nearshore areas, improved stream gage network to assess nutrient, sediment, and contaminant loadings, more accurate beach advisories, improved tributary and nearshore sediment transport modeling, more accurate estimates of over-lake precipitation and evaporation, monitoring of the spatial and temporal extent of harmful and nuisance algal blooms (including nearshore benthic algae such as Cladophora), monitoring of changes in vegetation and extent of coastal wetlands, improved public knowledge of public health threats, fishery conditions, water use impacts, and improved data to support ecosystem forecasting models.

GLNPO's management and delisting of Areas of Concern (AOCs) would also directly benefit from the data compiled under the GLOS enterprise. Identified as areas where contaminated sediments have resulted in up to 14 beneficial use impairments (BUIs), AOCs are required under the GLRI action plan to make substantial progress in delisting their BUIs. That process requires tracking of data to demonstrate restoration of each BUI. The GLOS enterprise once implemented can assist in measuring progress on BUI delisting, as well as ensure that any developing threats in the Great Lakes are identified early so effective control strategies can be developed and implemented in a timely manner.

Table 3-1 summarizes the end users, data needs and also includes management issues identified for each user group and the associated data needs. The appropriate goals addressed by each user need are also included.

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Table 3-1. Catalogue of User Needs

User	Goals Addressed	Management Issue	Data Information Needs	Most Relevant Design Scale	GLOSEA Design Focus* Basin Wide	Whole Lake - Lake Michigan	Regional 1 - Maumee Bay	Regional 2 - Lake Ontario Nearshore
Commercial Shipping and Maritime Operations	Improve safety and efficiency of maritime operations	Maximize shipping season	Lake ice distribution	Basin wide	X			
		Manage size of cargo/load	Coastal bathymetry, water levels	Local				
		Safety	Weather/wave forecasting, other met/weather data	Basin wide	X			
		Long term planning	Great Lakes water level forecasts	Basin wide	X			
		Environmental compliance	Ballast discharge	Basin wide	X			
			Ballast treatment	Basin wide	X			
		Search and rescue	Currents (3-D), weather	Whole lake	X			
		Oil spill	Location, amount, trajectory	Whole lake	X			
Fisheries	a) Protect and restore healthy ecosystems b) Protect and restore habitat c) Improve nearshore health	Environmental Assessment	Water temperature, water quality and lower food web productivity, sedimentation	Basin wide	X		X	
		Fish Stock	Population sizes, health, distributions, viruses, fish kills	Whole lake				
		Loss of habitat	Sedimentation/solids/land cover, bottom type characterization	Local	X		X	
		Climate Change	Meterological/Physical	Basin wide	X			
		Fish Advisories	Fish contaminants	Whole lake		X		
		Safety	Weather/wave forecasting, other met/weather data	Basin wide	X			
Water Quality Managers	a) Protect and restore healthy ecosystems b) Protect and restore habitat c) Improve nearshore health d) Clean up toxics	Eutrophication	Nutrient concentrations, lower food web productivity	Whole lake	X	X		
		HABs	Phytoplankton species/abundance, microcystis, cyanobacteria, location	Local			X	X
		Nuisance benthic algae	Cladaphora, Dreissenids, lower food web productivity, location	Local		X	X	X
		Climate Change	Meterological/Physical	Basin wide	X			
		Toxics	Contaminant concentrations, bacteria, pathogens	Whole lake		X		
		Sediment load from watershed	Suspended solids	Local			X	
		Invasive species	Biological	Whole lake		X	X	X
Drinking Water	Reduce public health risks	Water levels	Bathymetry, currents, waves, water level, temperature	Whole lake				
		Climate Change	Meterological/Physical	Basin wide	X			
		Contaminants and turbidity	Contaminant concentrations	Whole lake		X	X	
Power Generation	a) Improve homeland security b) prevent invasive species	Water levels	Bathymetry, currents, waves	Whole lake				
		Climate Change	Meterological/Physical	Basin wide	X			
		Nuisance benthic algae	Phytoplankton species/abundance & location	Local			X	
		Invasive species	Biological	Whole lake				
Recreational Boaters	Improve safety and efficiency of maritime operations	Safety	Weather/wave forecasting, other met/weather data	Whole lake	X			
		Climate Change	Meterological/Physical	Basin wide	X			
		Nuisance benthic algae	Phytoplankton species/abundance & location	Local			X	
		Water levels	Bathymetry, currents, waves	Whole lake	X			
Coastal Management	a) Protect and restore habitat b) Improve nearshore health	Shoreline erosion	Bathymetry, currents, waves	Local	X	X		
		Climate Change	Meterological/Physical	Basin wide	X			
		Invasive species	Biological	Whole lake	X			
		Loss of wetlands	Land use/land cover	Local	X	X		
Beaches	Reduce public health risks	Beach closure	Pathogens	Local	X	X		X
		Safety	Weather/wave forecasting, other met/weather data	Whole lake				
		Nuisance benthic algae	Phytoplankton species/abundance & location	Local			X	X
		Water levels	Bathymetry, currents, waves	Whole lake				
Emergency Response	Reduce public health risks	Safety	Weather/wave forecasting, other met/weather data	Whole Lake	X			
		Currents	Currents	Whole lake	X			
		Water levels	Bathymetry, currents, waves	Whole lake	X			

* These management issues and data needs are being addressed as part of the Great Lakes Observing System Enterprise.Architecture Conceptual Desigr

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4. ROLE OF MODELS IN ENTERPRISE

In the previous section we have made it clear that the design of a Great Lakes observing system enterprise is driven by the needs of users for making decisions about their actions. These decisions span a range from the general public deciding on whether to go swimming at a beach or to go fishing on the lakes to water quality and fisheries managers deciding on appropriate management actions to address their resource concerns. Another design principle is that models are central to conversion of the raw data collected by an observing system to the information and understanding needed by users to make their decisions. This section discusses the role of models in the overall Great Lakes observing system enterprise and the process for making models operational within that enterprise.

4.1 ROLE OF MODELS

Models operate on the observing system data to produce information and products desired by users to support their decision making process. Our concept is that the model receives data compiled and organized by the enterprise DMAC and operates on those data in such a way that it produces the information, analysis, and visualization that best supports the decisions that end users are making and passes it on to those users in the form of synthesis and forecasting products and services through the enterprise DMAC, as depicted in Figure 4-1.

Great Lakes models used in this way can vary from relatively simple, empirical relationships to highly complex, process-oriented models. Regardless of where on the spectrum of spatial, temporal, and process complexity a model falls, its objective is to convert site-specific data collected for a particular problem domain into information and understanding that can be used to support a user decision process within that domain.

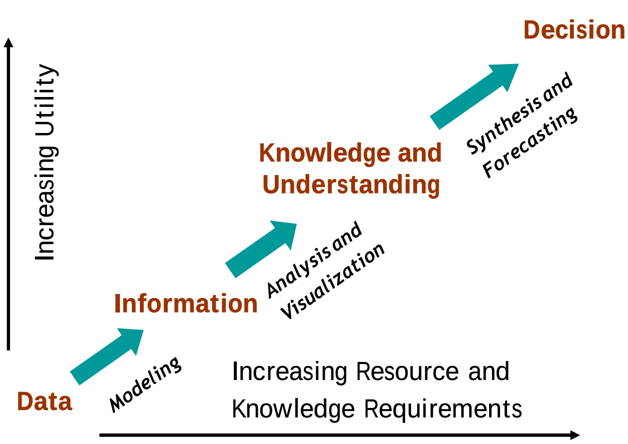

Figure 4-1. Role of modeling in converting observation data to user decision support.

An example of empirical models includes the beach swimming advisory model, SAFE (Swimming Advisory Forecast Estimate), being developed by the USGS Great Lakes Science Center (http://www.glsc.usgs.gov/ProjectSAFE.php). This model uses weather and water data at several locations in southern Lake Michigan to forecast *E. coli* levels at several beaches in the Burns Ditch area so that decisions regarding beach advisories can be made in a timely fashion relative to waiting 24 hours for water samples to be analyzed for bacteria counts.

Another example of an empirically based model is the algorithm that MTRI has developed to convert multi-spectral (MODIS, SeaWiFS) or hyper-spectral (Hyperion, AVRIS) satellite data to estimates of chlorophyll, dissolved organic carbon, and suspended minerals in coastal waters, including the Great Lakes. The algorithm has undergone a preliminary validation using both dedicated and historical/in situ/ water chemistry measurements (Shuchman, et al., 2006).

At the other end of the spectrum are fine-scale, ecosystem level, integrated process-oriented models. A recent USEPA white paper (USEPA 2008) describes the agency's concept of Integrated Modeling (IM) and presents a proposal for moving forward with integrated model development and application, especially for large aquatic ecosystems such as the Great Lakes. In this white paper, EPA defines IM as "a systems analysis-based approach to environmental assessment that includes a set of interdependent science based components (models, data, and assessment methods) that together form the basis for constructing a modeling system capable of simulating environmental systems relevant to a well specified problem statement." Integrated model frameworks typically comprise a series of multi-media, linked models that are designed to simulate the quantitative connection between multiple stressors, including human activities on the land, and ecological endpoints of concern in the aquatic system of interest. These systems also include the incorporation of observation data, tools for data and uncertainty analysis, visualization, and decision support that ultimately lead to management and policy decisions as depicted in Figure 4-2.

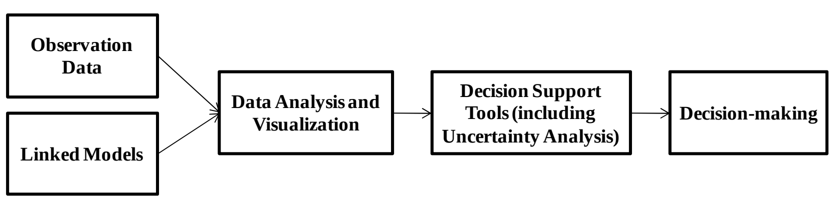

Figure 4-2. Components of an integrated modeling system.

There are several of these types of integrated models that have been develop and applied on a site-specific basis in the Great Lakes. A good example of a model that has used a process-based integrated framework to synthesize available research and monitoring data to quantitatively understand the connection between watershed loads and nearshore lake ecosystems is one recently completed by LimnoTech under funding from the US Army Corps of Engineers Great Lakes tributary sediment reduction program. In this project LimnoTech developed and applied a linked hydrodynamic – sediment transport – water quality model for the Lower Maumee River below Waterville, OH through the entire western basin of Lake Erie (LimnoTech, 2010). The model has the capability to simulate the spatial and temporal distribution of sediments, nutrients, and algal biomass that result from all external loadings of water, sediments, and nutrients to the system and from hydrometeorological conditions, including wind-driven resuspension of sediments in the western basin.

In 2009, GLOS contracted LimnoTech to produce a Great Lakes Model Inventory, which represents a knowledge base of Great Lakes models and their applications that cover the full range of model types and uses in the basin. The inventory is intended to be an online repository of modeling and assessment tools that are in use throughout the Great Lakes. The database can be accessed at www.data.glos.us/glmi. This web-based knowledge base is intended to facilitate information sharing and to promote a regional modeling community of practice that is kept up-to-date through user submissions. It is with this model knowledge base brokering and community of practice facilitation that GLOS would begin to build its portfolio of operational models that become an integral part of the overall enterprise.

4.2 DEVELOPMENT OF OPERATIONAL MODELS

Environmental models of natural systems are constructed and applied for two basic reasons: to enhance understanding and to support management. First, models improve the level of understanding of the cause-effect relationships in aquatic ecosystems by synthesizing what we do know about these systems, thus identifying knowledge and data gaps and helping to direct process and field research and monitoring. Second, models are intended to apply that increased understanding and technology to assist in management and decision-making. It is this later use for which the GLOS enterprise needs to develop operational models.

It should be noted that Great Lakes models can be placed on a gradient of model use that extends from models developed strictly for the first reason (we might call these “research models”) to those that are intended strictly for management and decision-making use (these might be called “operational models”). Depending on the specific model, it might fall anywhere in the spectrum between these two extremes. Models that are closer to the research end of the spectrum will have more flexibility in their use and more tolerance in their degree of QA/QC procedures and acceptance criteria. On the other hand, as models move toward the fully operational end of the spectrum, their development and skill assessment requirements are much more prescriptive and their application use is much more defined. Also, as models move from research to operation, their development and application cost move from R&D type expenditures to operating expenditures. Another important characteristic that must change as a model moves along the research to operation path is that the requirements for operator skill must decrease. These are important considerations as the GLOS enterprise looks to move existing Great Lakes models more toward operational use.

Another important consideration for the development of operational models within the GLOS enterprise is that we may define two types of operational models, forecast-based and scenario-based models, as follows:

- Forecast applications are conducted either by forecasting the impacts of changes over time in forcing functions that drive the model or, in the case of those applications where the forcing functions are meteorological in nature, downloading these forcing data from real-time observational systems and using these external inputs to produce a forecast (either deterministic or a bounded range based on uncertain model parameterization) of the system response to those forcing functions. An example of an ecological forecast might be the prediction of the time and location of shoreline contact of a harmful algal bloom once the bloom is initially detected by remote sensing.

- Scenario applications provide projections of how a system will respond to management or natural (i.e., climate) changes in the forcing functions for that system. For example, scenario models are used to evaluate a system's responses to alternative management actions; a model used in this way is instrumental in applying an adaptive management process. An example of a scenario-based model would be assessments of long-term changes in phytoplankton biomass and/or bottom water dissolved oxygen in response to changes in nutrient loading.

Both of these types of operational models require a thorough and scientifically-valid model development process before the model can become operational. Although the specifics of the development process and the acceptance criteria for each may differ, the general steps that should be followed and the interactions with system data are depicted in Figure 4-3. EPA has published a guidance document that provides advice on conducting all of these steps in the environmental management modeling process, including ongoing interaction with the public policy process and peer review process and the communication of management application and uncertainty analysis results to policy makers and managers (i.e., model users) (USEPA 2009). Before committing any Great Lakes model to operational status within the GLOS enterprise, it should undergo this development and review process.

Once a model has undergone extensive review, calibration/confirmation, skill assessment, and uncertainty analysis as depicted in Figure 4-3, it may be deemed ready to be used in an operational mode provided it meets a defined set of model-specific criteria. Then there are several decisions and associated steps that must be taken to actually "operationalize" the model. The first set of decisions comprises developing a model operation plan. This model-specific operation plan requires addressing the following questions:

- What are the model input data needs for its operation and how will those data be obtained?
- How often will the model be run and will it be run in a scenario or a forecasting mode?
- How will the model output be analyzed and visualized prior to delivery to the user/decisions-maker?
- How will the model results be delivered to the user/decision-maker?
- What is the plan for ongoing refinement/updating of the model, including the ongoing data collection and research required to inform that refinement?
- What is the plan for data and model input/output storage and archiving?

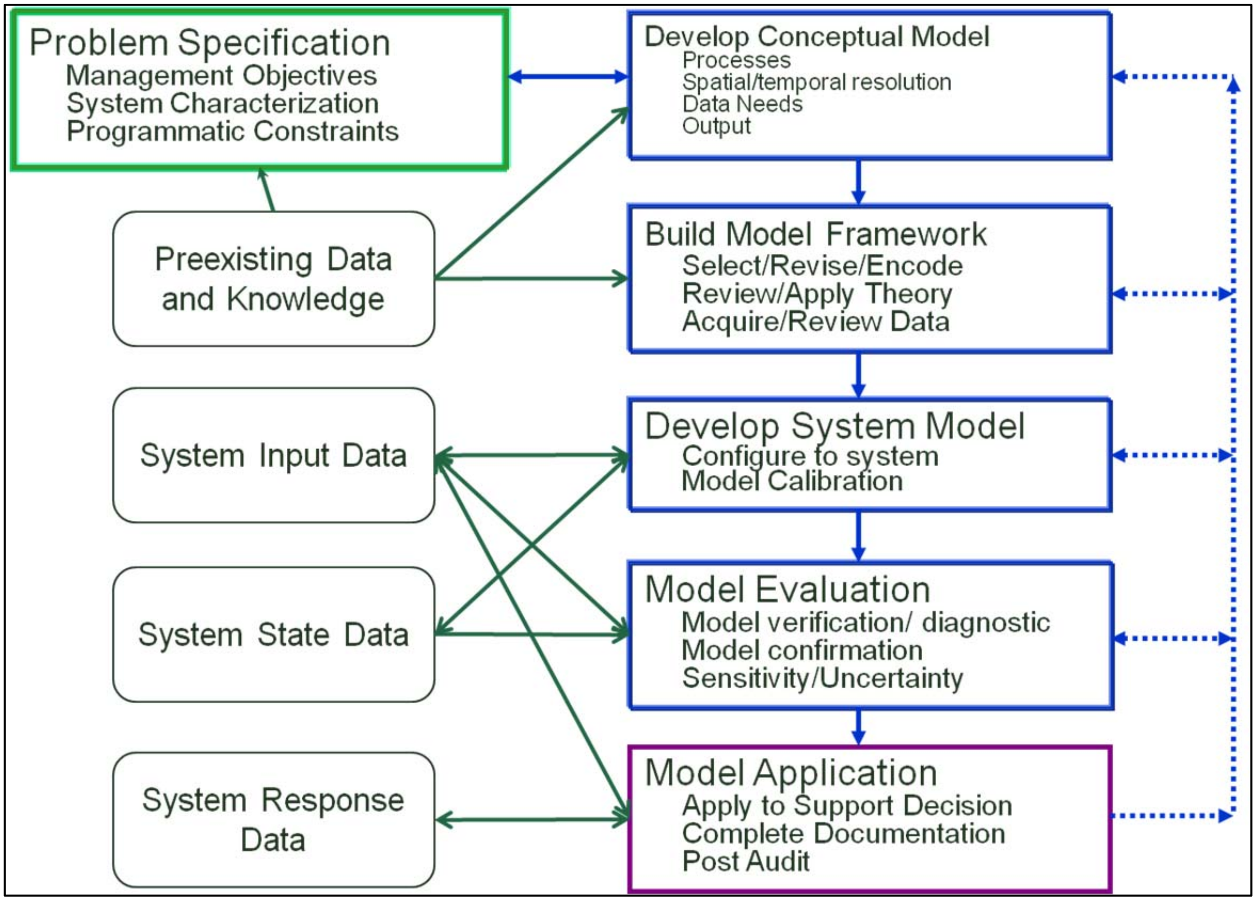

Figure 4-3. Process for development and application of an environmental model, including interaction with data throughout the process.

In addition to development of a model operational plan, a decision must be made as to the institutional/operational home for the model and a funding plan for implementing the model operation plan. In particular, it is important to decide whether the responsibility of preparing and updating model inputs, executing the model, refining the model as necessary, and presenting model results to users/decision-makers rests with a new entity or is contracted to the model developer.

The enterprise architecture conceptual design and the implementation plan presented later in this report provide recommendations for initial operational models in the Great Lakes. Each of these models should follow the above process as they are made operational within the GLOS enterprise. We recommend the establishment of a "Great Lakes Operational Model Steering Committee" to:

- Oversee the process of selection of Great Lakes models to be made operational;
- Develop the criteria for acceptance of models for operational use;
- Define the process for converting research and management models in the Great Lakes to operational models within the GLOS enterprise; and

- Specify how these models would operate in forecasting and scenario operational modes within the GLOS enterprise DMAC and entire enterprise.

This committee might be patterned after the recently formed Lake Michigan Modeling and Forecasting Workgroup that is supporting the Lake Michigan water quality and fisheries management community and the LaMP to develop an operational management model for that system. It would be a logical role for GLOS to serve as organizer and facilitator for this committee.

5. CRITICAL DESIGN DRIVERS AND CONSTRAINTS

5.1 DESIGN DRIVERS

As described above, a critical early step for the project was to develop a clear set of factors or design drivers that would define the course of the design of the enterprise system. These drivers were developed through many conversations with technical experts, stakeholders and users across all domains of the enterprise system: spanning both the management and technology domains, and integrating the technical subdomains of sensing technologies, telemetry, data management and communication, models, and end user products. While many drivers were identified, a critical subset of drivers that were frequently highlighted and broadly supported is described below:

User Needs Focus/Management Decision Making Support. The Great Lakes Observing System exists to support a broad range of users across the basin, and the needs of these users govern the present use and future expansion and development of the observing system. User needs provide a way to identify new uses of the observing system, prioritize funding, and to measure the value of the observing system's contribution to the Great Lakes community.

Model-Centrality. The Great Lakes science community is advanced in the use of models as tools to organize and synthesize data, testing scientific hypotheses about the physical, chemical, biological and ecological function of the Lakes, nowcasting and forecasting of Lake conditions, and support management actions aimed at lake protection and restoration. Models should be central to the GLOS enterprise and integrated broadly across the different technical domains of the observing system.

Build-out Flexibility. The build-out of the observing system is likely to be irregular, as funding availability changes and as priorities shift across the basin. The architecture of the enterprise should be flexible enough to tolerate this irregularity and allow for organic growth of the system, while maintaining the integrity of the system as a whole.

Funding Flexibility. Similarly, the timing and scale of funding sources will likely vary significantly over time, pointing to a need for a system that is adaptable to a broad array of funding sources and timetables.

Sensing Technology Flexibility. The Great Lakes currently employs a very broad array of different sensing technologies and telemetry methods. The pace of development of sensing technologies is rapid and increasing, necessitating a system that is robust in incorporating and adapting to changing sensing technology.

Support to the Great Lakes research community. The Great Lakes have the significant benefit of a strong scientific community and a long history of collaborative research across the basin. The GLOS enterprise must serve this community and continue to foster its strong research and collaboration environment.

Support to the operational user community. Many governmental, industrial, commercial and non-governmental organizations across the basin employ sensing technologies or use the data produced by Great Lakes sensing. This community has already operationalized parts of the current sensing system and should be served by a developing observing system going forward.

Need for interoperability of systems across scales. The Great Lakes are a very large system with physical, biological and ecological processes and complexity that operate at multiple scales. The GLOS enterprise needs to provide functional benefit at the scale of the entire basin, at the scale of an individual lake, and at a regional scale that may characterize a rivermouth or nearshore zone of critical interest. Systems that operate at the nearfield scale as well as the whole basin scale need to inform each other and allow for information to pass across scales.

Binational Focus. The Great Lakes span a national boundary and the multiplicity of user requirements are broadly binational. The design needs to be supported by both sides of the border, and needs to meet needs on both sides.

Recognition and preservation of extensive in-place sensing systems. Extensive work has already been done to develop, test and operationalize sensing systems across the Great Lakes. The design must recognize and build on the value of these existing systems.

Need for interoperability of systems across Great Lakes regions. At the regional scale, systems should be developed with consideration of interoperability and data portability across regions. These considerations will lead to improved efficiency in monitoring and broadened scientific value of local sensing systems.

Need for standardization of data sharing and storage protocols, and metadata standards. The data management and communications system that will be developed as part of this design effort will need to strike a balance between flexibility in implementation and the stability that comes with standardization. The design must consider the full range of available DMAC models and consider hybridization to meet the complex needs of the GLOS enterprise.

The design drivers described above were expanded to create a set of specific, testable criteria that could be used to evaluate the performance of different sensing technologies or design implementations. These are described in greater detail in the Trade Studies Report included in Appendix B.

5.2 SCALE AS AN OVERARCHING DESIGN CONSIDERATION

A critical, crosscutting factor affecting the majority of the design drivers listed above is the issue of scale, and the need for the enterprise system to function across the broad range of scales relevant to sensing in the Great Lakes Basin. Scale affects the technical performance of the sensing system, the management requirements of the system, the funding mechanisms that support the system, and the political environment in which the system exists. Consequently, a decision was made early in the project definition phase to segment the design effort into three different scales of consideration that are convenient for focusing the design and addressing the user needs that the system serves.

Figure 5-1 provides a simple description of how the designed observing system relates to the user needs that drive the design at different scales. At the basin scale, user needs are varied and numerous, as tabulated in Table 3-1. Because these needs are so varied and complex, the observing system that operates at the basin scale is relatively generic and provides a basic, common level of services that the entire user community can benefit from. Conversely, observing system development at the regional scale is typically driven by a single need or a focused set of prioritized user needs, and consequently the system is site-specific and may have a greater level of complexity (i.e., higher spatial and temporal resolution and a more extensive parameter list) required to address that need in a more comprehensive way. At the intermediate, or Lake scale, a longer prioritized list of user needs may be addressed by a system of intermediate complexity and site-specificity.

A useful analogy is a road network that includes interstate highways, primary and secondary roads, and driveways at the smallest scale. At the largest scale, interstate highways provide a generic service, highly efficient transportation along a very restricted path, to a large number of users. At the smallest scale, an individual user who wants to have a very specific service, access from a secondary road to his front door, contracts individually to create a site-specific roadway: his driveway. There are significant differences in how the highway and driveway are funded, regulated, built, maintained, and used; necessitating very different approaches for design and planning. Similarly, the observing system functions very differently across scales. Consequently, the design effort described here employs scale considerations as a recurring structuring concept that runs through most of the remaining sections of the design report.

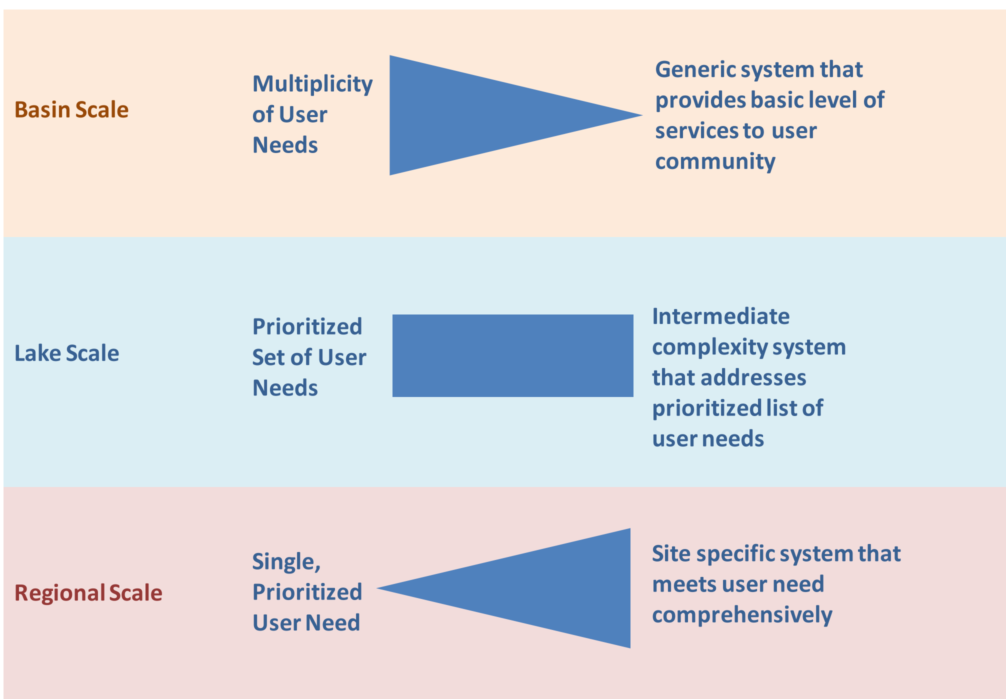

Figure 5-1. Design drivers in the GLOS enterprise subareas differ with scale

5.3 DEFINITION OF OBSERVING SYSTEM SUBAREAS

The spatial domain of the Great Lakes Observing System enterprise is defined at its largest scale by the areal extent of the Great Lakes Basin. At smaller scales, the observing system can be separated into subareas with distinct drivers and design requirements. At the intermediate (Lake) scale, the five Great Lakes provide a useful subdivision into observing system subareas, again with distinct characteristics for planning and design.

At finer (regional, sub-lake) scales, the design drivers become more site specific and the geometries of the observing system subareas are flexibly defined to meet the specific requirements of the relevant local design drivers. Possible rationales for defining the areal extents of observing system subareas could include:

- Existing Areas of Concern (AOCs) as defined under the Great Lakes Water Quality Agreement;
- Proximity to population centers, or areas of extensive human use of the shoreline;
- Proximity to areas of ecological value, such as coastal wetlands or nearshore habitats;
- Portions of the Great Lakes, including rivermouths, embayments, Lake St. Clair, and connecting channels, that are subject to specific environmental impacts that require focused monitoring;
- Portions of the Great Lakes, including rivermouths, embayments, Lake St. Clair, and connecting channels, that are critical for their resource value; and
- Portions of the Great Lakes, including rivermouths, embayments, Lake St. Clair, and connecting channels, that are critical for shipping, commercial or industrial uses.

For the purposes of this document, the definition of observing system subareas at the regional scale is left open and flexible, to allow for the full range of user needs that may drive the ultimate use of the GLOS enterprise. The concept of observing system subareas is defined in greater detail in the following section.

6. DESIGN AT THE REGIONAL, LAKE AND BASIN SCALE

6.1 INTRODUCTION

A comprehensive observing enterprise begins with an array of data collecting systems, including satellites, aircraft, fixed platforms and buoys, drifters and floats, automated underwater vehicles, towed sensor arrays, and ships. The data collected from these observing systems must then be transmitted to a DMAC system, which stores and organizes the data for use by the various tools that make up the modeling and analysis system. The modeling and analysis system synthesizes, visualizes, and interprets the data to provide information and understanding in the form of various products and services delivered to end users by the DMAC to support their decision-making. Our approach for the design of the GLOS enterprise architecture is to begin with the user needs within the Great Lakes (discussed in Section 3) and work our way backward through the above progression to ultimately propose an observations and sensing system that will best support those user needs.

As indicated in the previous section, scale is a very important design criterion. All aspects of an observing system design depend on the scale at which the system is being deployed, especially the mix of various observation technologies and the resolution at which those technologies are deployed. In turn, the user needs and associated management issue/s being addressed, along with the aquatic system scale of concern for the user needs, will dictate the scale of the observing system that is required. To illustrate how these factors come into play, we present in this section a design approach for three characteristic scales of Great Lakes observing systems: basinwide, whole lake, and a regional scale that focuses on part of a whole lake. For regional scale, we have identified three regional subareas to present example designs for an actual user/management endpoint in an actual Great Lakes environment. These example subareas are intended merely to be representative of the many potential observing system subareas that might receive dedicated observing systems as part of the GLOS enterprise. It should be recognized that the designs for these representative subareas can easily be adapted to other areas of the Great Lakes that correspond to the same scale and have similar management issues.

For each design scale, we have identified the current observation system that is in-place at that scale to form a baseline observing system (Level 0) (Technical Memorandum 3 in Appendix A). We have then described a Level A observing system, the planned next steps or "near term" design level. Moving to a Level A observing system includes the following actions:

1. Completion of ongoing projects or readily accomplished projects that have existing planning and funding mechanisms in place (across the basin);
2. Instituting a DMAC plan to support all scales of observation in terms of hardware, protocols and standards (across the basin);
3. Implementing a minimum level of sensing required (unique to each GLOS enterprise subarea); and
4. Developing a plan for operational models required for each subarea (unique to each GLOS enterprise subarea).

Items 1 and 2 above are activities that are to be conducted across the basin, thus they can be dealt with at the basin-wide scale, although many of the ongoing observing system projects will also contribute to lake and regional subarea needs. Items 3 and 4 will be subarea-specific, and examples of the design process and outcome for representative subareas will be presented below. Finally, we will present a series of design alternatives for a specific system that have been informed by our trade studies applied to the particular scale and management application being developed (Level B alternatives). Below is presented the design approach to achieve Level A for each design scale and the development of design alternatives for expansion of that scale of system beyond Level A.

6.2 BASIN-WIDE SCALE OBSERVATION SYSTEM

6.2.1 Objectives and Conceptual Design

The basin-wide scale observation network forms the backbone of the GLOS enterprise. It is directed at user needs and associated issues that operate or are relevant at the basin-wide scale. As discussed earlier, the basin-wide network serves data needs of virtually all users but in many cases does not provide all of the data needs of a given user (see Figure 5-1). This is because the basin-wide scale network is distributed at relatively low spatial resolution across the entire basin and does not routinely observe many of the chemical and biological parameters that would serve many user needs. That being the case, the present-day basin-wide network (Level 0) is focused primarily on physical issues such as water levels, wave heights, ice cover, and basin-wide hydrology.

6.2.1.a Current Sensing System (Level 0)

The basin-wide conceptual design will build on the existing basin-wide observation networks (including GLOS, NOAA, USGS, USEPA, and other programs) to form a base Great Lakes sensor network over the next five years. The existing network includes a range of shore and lake based environmental monitoring systems that either operate in real time or event (cruise) based modes. The locations of these observing systems are shown in Figure 6-1 and are briefly summarized below.

The real-time observation network consists primarily of the Coastal-Marine Automated Network (C-MAN) maintained by NOAA and other agencies on the US side of the Great Lakes and by the Atmospheric Environment Service (AES) on the Canadian side of the Great Lakes. In both countries the stations are fixed platforms along the shoreline (lighthouses, piers, etc.) or rugged offshore buoys that house standard meteorological instruments in addition to wave and water temperature sensors for buoys. Other meteorological stations, primarily situated at airports close to the Great Lakes, are integrated into the Automated Surface Observing System (ASOS) maintained by NOAA. A network of real-time water level gages is maintained by NOAA National Ocean Service (NOS) and the Canadian Water Survey.

The routine cruise-based water quality sampling typically conducted aboard research vessels is conducted by federal and state agencies. Basin wide coverage is provided by the Environmental Protection Agency's Great Lakes National Program Office (EPA GLNPO) through the Open Lake Surveillance Program and by Environment Canada. State agencies such as the Michigan Department of Environmental Quality (MDEQ) also routinely monitor regional bodies of water.

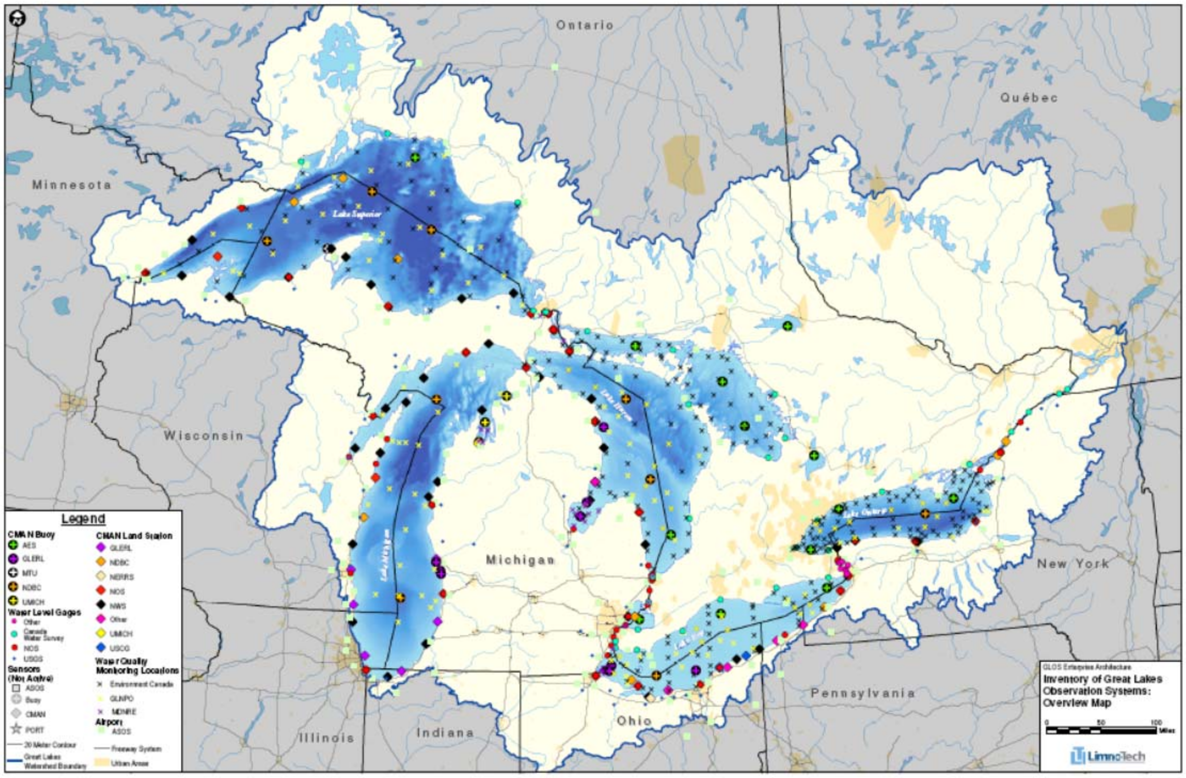

Figure 6-1. Overview map of existing Great Lakes observation network.

The USGS also maintains an observation network of real time and water quality stations around the Great Lakes region. Only the most downstream stations on major Great Lakes tributaries are highlighted in Figure 6-1.

Not discussed here are the myriad of university and other organization's research programs that collect data from around the Great Lakes. Many of these programs could be considered part of regional based observing systems, but the lack of a centralized data management and communications plan prevents many of these programs from being considered operational components of the present Great Lakes observing system.

6.2.1.b 5-year (Level A) Priorities

Given the existing Level 0 system, we are proposing a series of implementation activities that would be intended to bring the basin-wide system up to a base condition (Level A system) that addresses a broad set of objectives described in the GLOS RCOOS conceptual plan (GLOS, 2007). This base level of sensing is defined as a level of observation, data management and analysis that addresses a broad range of user needs or significantly improves support for existing programs. The base level of sensing also supports operationalized or prioritized models designed to support existing critical user needs. The Level A system should also support to the extent possible the seven IOOS societal needs, the four priority GLOS societal needs, the GLRI support needs, and the AOC priorities.

In conducting the evaluation of the existing basin-wide network, the project team has considered the following information:

- A summary of the existing inventory of Great Lakes sensors and monitoring efforts (Appendix A - Technical Memorandum No. 5),
- The total capital value of these assets,
- Costs of ownership, operation, maintenance, and life cycle replacement (GLOS/other public/private),
- Existing and possible external funding sources,
- Summary of existing Great Lakes DMAC infrastructure, and
- Summary of existing Great Lakes basin-wide models and their potential to be made operational.

SOLEC provides an additional set of indicators that will benefit significantly from development of the (Level A) basin-wide observation network. The SOLEC indicators are also important for GLRI accountability and include many of the IOOS key parameters. Recommendations for indicators to be monitored by the Level A basin-wide system include:

- Atmospheric deposition of toxics and general air quality – the basin-wide system should incorporate the International Atmospheric Deposition Network (IADN) Great Lakes network, and could potentially add stations that focus on open-water deposition and air quality and deposition and air quality in population centers;
- Nearshore and offshore nutrient concentrations - add PO_4 and NO_3 sensors to existing platforms to inform spatial and long-term temporal trends;
- Phytoplankton and benthic algae – remote sensing and probes on platforms could potentially inform nearshore and offshore biomass levels and long-term trends;
- Suspended sediment available for coastal beach nourishment;
- Water level fluctuations that are important for a number of basin-wide user interests, including navigation, recreational boating, hydropower, coastal erosion, coastal flooding, water supply intakes, and coastal ecosystem health and integrity;
- Climate change indicators – intensity/frequency of storms, wind velocities, air and water temperatures, water levels, ice cover extent and duration; and
- Several indictors that can be inventoried and tracked for long-term changes by remote sensing technologies and data conversion algorithms, including:
    - Area and quality of special coastal communities (cobble beaches, alvars, sand dunes, islands);
    - Extent of hardened shorelines;
    - Areal extent and flora diversity of coastal wetlands; and
    - Changes in coastal land use and land cover (urban, agricultural, forested, etc.).

We have also considered the need to sustain baseline operations of the existing basin-wide system for an additional 20 years. These operational funds must support the following:

- Sensor network operations and maintenance,
- Sensor replacement costs to be applied over the sensor duty cycle,
- Additional DMAC needs required to integrate and support the basin-wide network,

- Operational modeling at the basin-wide scale, and
- A research and development component.

6.2.1.c Level A Gap Analysis

This understanding of the existing basin-wide system and the requirements of the system driven by the seven IOOS societal needs, the four priority GLOS societal needs, the GLRI support needs, the AOC priorities, and the SOLEC criteria supported a characterization of gaps in the existing sensing network. This gap analysis was conducted during the first phase of the project by collecting stakeholder input on sensing needs and priorities as part of the process of information gathering for the major components of the sensing system: the existing sensors and telemetry systems, remote sensing systems, existing DMAC, and models.

During the course of this analysis the following gaps were identified:

- DMAC development. There is a significant identified need for a DMAC to serve as a community base for gathering and disseminating sensing data, and making data available for use by both the modeling and end-user communities.
- Remote Sensing. Significant advances have been made and are being made in the area of 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.
- Models. Models are central to the operation of the current observing system, and there are significant opportunities to be gained from the widespread dissemination and use of these models. Some basin-wide models are close to operational, serving specific user needs, but not widely accessible or formalized in terms of long-term maintenance and operations.
- Sensing. Sensing requirements flow from the gaps identified above and will require significant further input from Great Lakes stakeholders and the scientific community to be developed and refined. 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. There is a general need to address the current needs of the operational system.
    - 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.

This gap analysis, along with knowledge of additional programs that are in the process of being designed, built, and/or implemented, has led to development of a conceptual design of the base level of sensing. When complete, the combination of sensing, data management and analytical tools will constitute the Level A basin-wide observing system.

A description of the Great Lakes basin-wide DMAC conceptual design is presented in the Concept of Operations Report located in Appendix C.

6.2.1.d Conceptual Design

Having considered the user needs and conducted the gap analysis described above, the conceptual design for the Level A observing system is described here. This design description focuses primarily on the data and development necessary for operationalizing three models/analytical tools that are important at a basin-wide scale for serving a majority of identified user needs. They are:

- The Great Lakes Operational Forecasting System (GLOFS), which is already operational by NOAA for forecasting hydrodynamic/physical conditions (wave heights, currents, water temperature);
- The Large Basin Runoff Model (LBRM), which has been developed by NOAA-GLERL to predict basin-wide hydrology (tributary flows, evapotranspiration, lake water levels, connecting channel and St. Lawrence River flows) by including 121 watersheds and the movement of net basin supplies of water through the Great Lakes-St. Lawrence River system (the LBRM is now a component of GLERL's Advance Hydrologic Prediction System (AHPS)); and
- The algorithms that can be used to convert remote sensing satellite imagery to useful measures of key parameters in surface waters.

The Great Lakes Operational Forecasting System provides valuable information to commercial navigation, recreational boating, sport fishing, and portions of the needs of other users. It is operated by using real-time meteorological forcing data and weather forecasts to make nowcasts and short-term forecasts for lake hydrodynamic conditions. It updates its forecasts daily by assimilating observed system data and revising the nowcasts and forcing data that is used for forecasts. The outputs of this modeling system can benefit from higher resolution of meteorological forcing data and lake wave height and circulation data.

The LBRM is a full Great Lakes Basin hydrology model that serves the needs of virtually all users in one way or another by providing flows at the rivermouths of 121 major tributaries, all connecting channels, and the St. Lawrence River; and water levels in all five lakes and Lake St. Clair. This hydrology, along with the hydrodynamics and temperature outputs of the GLFS, is fundamental to all users who are concerned with the physical conditions in the basin; but it also provides the foundation for assessing all chemical and biological conditions in the basin.

A particularly important use of the LBRM is in the development of water level and flow regulation plans and adaptive management of Great Lakes water levels and flows. It was an important component of both the Lake Ontario-St. Lawrence River Study (LOSL) and the ongoing International Upper Great Lakes Study (IUGLS), both binational studies conducted under the auspices of the International Joint Commission. The Great Lakes basin-wide observing system and an operational LBRM can greatly support the adaptive management plan (IUGLS, 2009) being developed as part of the IUGLS and thereby reduce water level related costs by tens of millions of dollars. The needs of the IUGLS include: better closure of Great Lakes water budgets, better hydrology forecasts, and regular regulation plan performance evaluations and updates. In particular, better prediction of the onset and extent of climate change impacts on water levels, flows, and temperatures relies on better measurement of system hydrology components (precipitation, runoff, evaporation, connecting channel hydraulics) and better prediction of system hydrology with the LBRM.

The LBRM is not currently being used in a routine operational mode, but rather being applied on a project-specific basis. Also, it has not been re-calibrated and confirmed for approximately 25 years. Therefore, considerable model refinement should be performed by its developers before it can be confidently used in an operational mode. One aspect of the LBRM that leads to considerable uncertainty is the fact that about 40% of the Great Lakes basin contributing watershed is ungaged and hence its prediction of flows from those ungaged areas cannot be confirmed. A suggestion for the Level A basin-wide observing system would be to obtain approximately six portable flow gaging systems that could be deployed at key ungaged tributaries in a given lake on a five year rotating basis to provide measurements that can test the ability of LBRM to simulate flows from ungaged areas. Another monitoring need to help reduce hydrological prediction uncertainty is a system of measuring evaporation throughout the basin to help close the basin supply calculations. This information will allow the operational model to be refined on a regular basis and to do a better job of predicting the impacts of climate change on Great Lakes hydrology.

There is considerable work being conducted in the Great Lakes on the use of remote sensing imagery to provide a mapping of surface water chlorophyll *a*, total suspended solids, and the areal extent and density of Cladophora in the Great Lakes. These and other remotely sensed parameters mentioned above can have great value in informing the Great Lakes SOLEC indicators and GLRI accountability assessment. Although the capability to convert remote sensing imagery through calibrated algorithms to these indicators is still being developed and not yet operational, the progress to date offers the likelihood for making this GLOS enterprise service operational within the next five years. One of the most important needs for moving these models to an operational mode would be to obtain ground-truth data on the state variables of these algorithms to allow better calibration and model refinement. The Level A basin-wide observing system can provide this ground-truth data.

6.2.2 Level B Design Alternatives Development

The design for expansion of the GLOS enterprise will be guided by a number of design directions. These design directions represent major paths that the design could take, given decisions regarding issues such as the ownership of the sensing system, the fundamental technology types relied upon by the system, and expectations about build-out, funding and long-term management of the system. A partial list of these design directions is as follows:

- Sensing technology: predominantly in-situ monitoring (including fixed platforms, mobile platforms, and field campaigns) vs. predominantly remote sensing
- Ownership: predominantly private vs. public entity ownership
- Funding levels: small vs. large
- Funding reliability: steady vs. opportunistic
- Ultimate management responsibility
- Phasing strategy: focus on early vs. later phases of infrastructure development

The selected alternative for any of these design directions would impact all future design choices. For example, selecting private ownership and funding of an observing system would likely affect the choice of sensing technology. For this study, the selection of an appropriate observing platform mix to best address the management issues was chosen as the first design consideration. A trade study tool was developed to evaluate the appropriate observing platform mix at a variety of scales. The trade study tool uses 40 criteria to evaluate the performance of various sensing network configurations. The tool was applied to example design areas at the basin-wide, lake-wide, and regional scales. The trade studies are summarized in Section 7 of this report and detailed in Appendix B.

Developing the basin-wide observing system beyond its Level A status, which is the near-term five-year goal, will require expansion decisions that will depend on the desire to support the long-term design objectives of the GLOS Enterprise Architecture. The prime question here is how should the basin-wide observing system be expanded over the next 5 to 10 years after achieving the Level A condition defined for the near-term (2015). A primary consideration in laying out these alternatives is the recognition that the basin-wide system must support the full range of Great Lakes user needs at some level, but it is unlikely that all of those needs can be fully supported at the basin-wide scale. It is difficult at this time to project what the best expansion decisions over the post-near-term period will be (5-20 years from now), because we do not know what new technologies and models will be developed during that time. However, we can use trade studies to provide guidance regarding the relative investment emphasis on fixed platforms, mobile platforms, field campaigns, or remote sensing.

6.3 LAKE SCALE OBSERVATION SYSTEMS

6.3.1 Objectives and Conceptual Design

In order to address issues that operate and require data at a whole-lake scale, we will develop a conceptual design for an example design area that covers an entire lake. Issues that have been identified by the Lakewide Management Plans (LaMPs) for each Great Lake and have been the subject of lakewide research and modeling efforts will be the focus of the enterprise design at the whole-lake scale.

Any one of the five Great Lakes could be used as the representative for this scale, but we have selected Lake Michigan as our example lakewide design area for several reasons. First, the Lake Michigan LaMP has been quite progressive in identifying several whole-lake issues and has developed and begun implementing management plans to address these issues. Second, there have already been a number of large research and modeling studies on Lake Michigan that have made considerable headway in addressing some of the whole-lake management issues. These projects are listed below:

- Lake Michigan Mass Balance Study to develop a comprehensive model of nutrient and toxics sources, transport, and fate in Lake Michigan;
- NOAA-NSF funded EEGLE project (Episodic Events – Great Lakes Experiment) to study the physical, chemical, and biological impacts of large resuspension events in the southern basin of Lake Michigan;
- GLERL’s considerable research efforts on the impacts of Dreissenids on the lake’s ecosystem and on the fish community ecology;

- University of Wisconsin – Milwaukee research on the development and impacts of the large Cladophora blooms on the western shore of the lake and its potential impacts on nutrient cycling and offshore productivity in the lake;
- Cooperative Science and Monitoring Initiative (CSMI) in Lake Michigan that occurs every five years; and
- USGS Lake Michigan pilot study for development of a National Monitoring Network for U.S. Coastal Waters and their Tributaries.

The above ongoing projects provide an overview of management issues of importance in Lake Michigan, and form a basis for establishing the objectives of the Level A, basic level of sensing for Lake Michigan. Many or most of the identified sensing objectives for Lake Michigan parallel those previously described for the basin scale design, as driven by the basin-scale SOLEC criteria, and consequently the majority of the design requirements for a Level A sensing design for the lake are met with the basin scale planning Level A planning effort. Additional sensing requirements will be driven in particular by the priorities of the CSMI efforts described above.

As for the basin-wide system, the conceptual design process for the intermediate scale system has been initiated by compiling all the information available on the existing observation activities in Lake Michigan. A summary of existing observation technology for Lake Michigan is presented in Technical Memorandum 3 (Appendix A), and a similar summary of existing Lake Michigan whole lake models is presented in Technical Memorandum 5 (Appendix A).

As the project moves into implementation, detailed design of the Lake Michigan Level A sensing strategy will necessarily involve direct interactions with the stakeholders managing and funding the projects identified above. While the sensing objectives described above are strongly supported technically, finalization of the Level A sensing strategy will require development of consensus among federal agencies prior to initiation of detailed design.

6.3.2 Level B Design Alternatives Development

Following establishment of a baseline level of sensing, modeling and DMAC at the lake scale, the system will be prepared for implementation of expansion alternatives that address specific user needs and management issues. The mix of observing platforms for a Lake Michigan sensing network will depend on the management issues that are to be addressed. As part of the trade studies (Section 7 and Appendix B), two Lake Michigan trades were performed: one specifically to address the issue of nearshore-offshore trophic gradients and one to address four management issues identified in the Lake Michigan LaMP and presented in Section 6.3.1.

While the Lake Michigan LaMP has identified many issues to address at the whole- lake scale, we have selected four significant issues on which to focus this intermediate enterprise architecture design:

1. Nearshore/offshore water quality and productivity gradients as impacted by Dreissenids and nearshore benthic algae;
2. Exposure and effects of persistent, bioaccumulative, toxic substances (e.g., mercury, PCBs, atrazine) on biota and humans;
3. Loss of important shoreline wetland areas; and

4. Coastal erosion of beaches and riparian shorelines.

These issues are not unique to Lake Michigan; they are representative of important whole-lake issues in most of the other Great Lakes as well. Additionally, the data needs for these issues span most types of observational data collected in the Great Lakes. The enterprise architecture developed for Lake Michigan will therefore be transferable to the other lakes for the development of observation systems at the same scale. Also, as indicated earlier, the Lake Michigan nearshore-offshore trophic gradient observing system has been selected as one of our two end-to-end design illustration case studies. The observing system, including operational modeling and DMAC, for this site-specific, problem-specific system is being developed in more detail to illustrate the process that would be undertaken relative to any lake scale management issue being addressed in the Great Lakes.

In order to demonstrate this process, we will develop the conceptual design for the end-to-end trophic gradient case study for this system; this conceptual design would represent a near-term (next 5 years) observing system that addresses the nearshore-offshore trophic gradient management needs.

6.3.3 Lake Michigan Nearshore-Offshore Trophic Gradient System

6.3.3.a Background on Management Issue

Over the past 20 to 25 years, the Great Lakes ecosystem has changed considerably relative to the state it was in when the water quality community was addressing the eutrophication problems by establishing target phosphorus loads intended to achieve whole lake chlorophyll a goals on a lake-specific basis. It seems that these changes have been brought about by a combination of multiple stressors, including nonpoint sources of nutrients and invasive species. The increase of watershed nonpoint source loads of bioavailable phosphorus, in combination with Dreissenid mussel ecosystem re-engineering, appear to be the primary contributors to nearshore eutrophication. This seems to be occurring through Dreissenid filter feeding that increases water clarity in the nearshore and traps the nonpoint source phosphorus loading in the nearshore, thus contributing to benthic algal bloom problems that have not been experienced in the Great Lakes since the 1970s (Hecky, et al., 2004; Auer, et al., 2010). At the same time this nearshore shunt phenomenon is threatening the Great Lakes deepwater fishery by preventing its access to lower food web carbon that is produced from primary production (Evans, et al., 2011; Barbiero, et al., 2011). Lake Michigan is a prime example of this nearshore-offshore trophic gradient phenomenon and the water quality and fisheries management community have expressed a need to quantitatively understand this problem in order to develop management strategies (e.g., agricultural runoff, urban stormwater, and other watershed best management practices) that will not simply “fix” the nearshore eutrophication problem at the expense of offshore fish carrying capacity.

6.3.3.b Conceptual Design

The lake scale observing system presented here is intended to provide the data needs for development of an operational, fine-scale ecosystem model that can inform an adaptive management process for this issue in Lake Michigan. A similar observing system can be designed and implemented in any of the other lakes to address this issue in those systems.

The water quality model framework proposed here to understand and predict the interaction between the nearshore and offshore regions of Lake Michigan was developed as part of the Lake

Michigan Mass Balance Project (LMMBP). The model, LM3-Eutro is a high resolution (5 km), carbon-based lake eutrophication model. A description of the original model development and calibration is discussed by Pauer, et al. (2006, 2008) and Melendez, et al. (2009). Originally developed to be part of the integrated model framework for simulating the fate and transport of toxic chemicals, the LM3-Eutro is capable of predicting nutrient and phytoplankton dynamics in Lake Michigan. The kinetic equations used in the model are similar to the Water Quality Analysis Simulation Program (WASP) and CE-Qual-ICM. In total the model has 17 state variables including fractions of key nutrients (phosphorus, nitrogen, carbon, and silica) and a simplified lower food web (diatoms, non-diatoms, and zooplankton). It also has a coupled sediment diagenesis and flux sub-model. A simplified conceptual diagram of the model is shown in Figure 6-2.

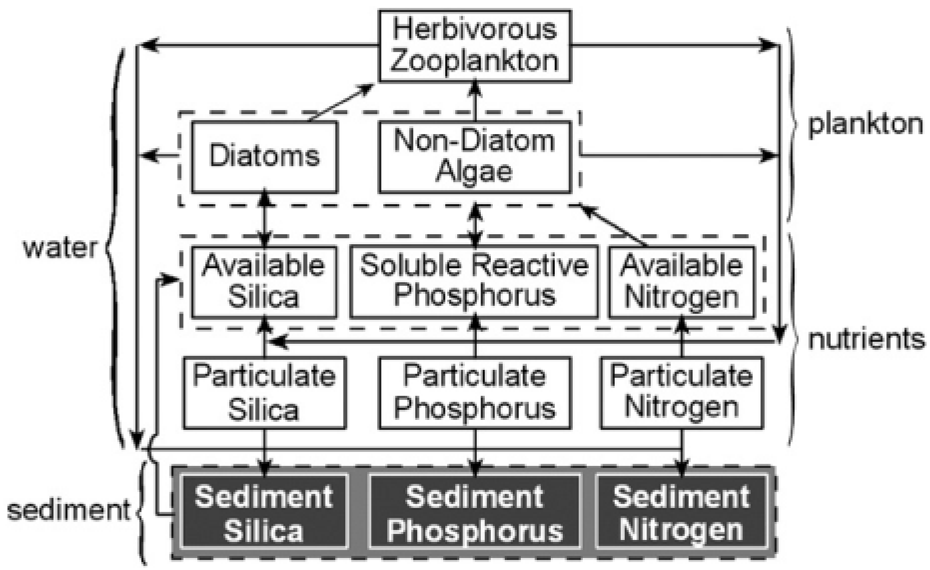

Figure 6-2. Simplified conceptual diagram of LM3-Eutro showing major state variables and transformations links

The water quality model is linked to a modified version of the Princeton Ocean Model (POM), which is a hydrodynamic model maintained by the NOAA Great Lakes Environmental Research Laboratory (Beletsky and Schwab, 2001; Schwab and Beletsky, 1998). The hydrodynamic linkage includes flows, diffusion coefficients, volumes, and water temperature data for all cells in the model grid. Both POM and LM3-Eutro utilize the same model grid. The linked hydrodynamic-eutrophication model will also require water, suspended solids, and nutrient loading from the watershed. This will be provided by a combination of a selected watershed loading model (e.g., SPARROW, SWAT, HSPF) and water quality and flow data collected at USGS gages around the basin. The integrated watershed-lake model will then represent the basic framework required to simulate the loading, transport, and fate of nutrients and biological interactions between tributaries, the nearshore zone, and the offshore zones of Lake Michigan.

Since the development of the original model in the 1990's the ecosystem of Lake Michigan has undergone dramatic changes as summarized above. Therefore, in order to address the management questions and be capable of use in an operational mode to support adaptive management of the trophic gradient issue, the model will require enhanced process formulations and spatial resolution. Among the model development needs based on the existing model framework are: an integrated sub-model for Dreissenid bioenergetics and their effects on nutrient cycling, water clarity, and lower food web dynamics; an integrated sub-model for benthic algal growth (in particular Cladophora – the existing Great Lakes Cladophora Model of Auer, et al., (2010) can be used); incorporation of the invasive carnivorous zooplankton Bythotrephes into the food web; and the development of a finer nearshore resolution to permit simulation of the fine-scale gradients that exist in the nearshore zone up to 20 meters deep. All of this model development work must be included in the near-term design for this system.

The lake scale data collection necessary to support the revised LM3-Eutro model will consist of *in situ* and remote observations via fixed, mobile, and satellite platforms. The observation system will collect data necessary to develop the ecosystem model, provide coherent data sets for both calibration and confirmation of the model, and continue to collect data necessary for ongoing operation of the model.

The hydrodynamic model will require atmospheric and hydrologic time series data. The atmospheric data requirements include at least hourly measurements of barometric pressure, air temperature, relative humidity, cloud cover, solar radiation, wind speed, and wind direction. The hydrologic dataset includes at least daily estimates of evaporation and rainfall rates, river flow inputs and outputs for tributaries and connecting channels. The atmospheric data will primarily be measured by fixed platforms, but can be supplemented with satellite observations (cloud cover and wind speed). The hydrologic dataset is also measured primarily by fixed platforms, but can be supplemented with environmental models of ungaged watersheds and remote sensing of rainfall (via radar). The hydrodynamic model can also utilize ice cover data to accurately predict the heat flux, wave heights, and atmospheric exchange rates. Other baseline data for the hydrodynamic model include bathymetric data.

In situ data used for model to data comparisons include water temperature, water velocity, and measurements of wave height. These measurements can be made via fixed, mobile, or satellite platforms. The most useful measurements would come from fixed buoys using thermistor chains and velocity profilers to obtain a continuous three dimensional view of temperature and water velocity.

The water quality model requires a much broader set of time series and other baseline data than the hydrodynamic model. The water quality model inputs can be broken down into a few major groups including inorganic solids, nutrients, other water quality parameters, and biological parameters.

Inorganic solids are typically measured in tributaries by grab samples or continuously by turbidity meters calibrated to solids data. For major tributaries targeted wet weather sampling is crucial to monitoring the sediment (and nutrient) inputs during large rainfall and snowmelt induced runoff events. In situ measurements are typically done by grab samples, although accurate concentrations at the surface can be obtained from satellite platforms.

The nutrient group encompasses fractions of phosphorus, nitrogen, silica, and carbon. Each nutrient includes dissolved and particulate fractions as well as further breakdowns by bioavailability (e.g. labile and refractory). Nutrients are typically measured on a routine basis in tributaries and lakes by grab samples analyzed in the lab. However some recent advances in technology replicate the lab method in situ, allowing for near real time measurements of nutrient levels. The model would require higher spatial and temporal resolution for key nutrients (e.g.

phosphorus), but daily to monthly loads for major tributaries and in situ concentrations at master stations are typical.

Other water quality parameters include chloride, dissolved oxygen (DO), and light penetration characteristics. These parameters are critical components in modeling sensitive ecosystems and are typically measured by grab samples (chloride), fixed and mobile platforms (light penetration and DO). Conductivity can be measured with fixed or mobile platforms and used in place of chloride. In Lake Michigan, chloride and light penetration should be measured along with nutrients in grab sample cruises, however fixed and mobile platforms should include these parameters near major tributaries or areas heavily affected by mussels and benthic algae.

The major biological parameters include phytoplankton, zooplankton, and benthic algae and invertebrates. Phytoplankton biomass is typically approximated by chlorophyll concentration measured by grab samples, however it has been reliably measured on fixed and mobile platforms with fluoroprobes and from satellites. All three platforms would be required to cover the wide spatial and temporal variability observed in Lake Michigan. Phytoplankton speciation is typically measured through visual identification from grab samples, however recent advances in technology can distinguish between major algal groups on fixed and mobile platforms. Zooplankton biomass and speciation are almost always measured by grab samples. Both phytoplankton and zooplankton should be measured at least monthly at master stations in the lake. Phytoplankton should be measured at the mouths of major tributaries on a routine basis as nearshore concentrations of phytoplankton will be heavily influenced by the concentration in the river. Benthic algae and invertebrates are typically conducted by grab sampling methods one or two times per year at master stations. Benthic algae stations would be clustered more towards the shore, while invertebrate surveys (including for dreissenids) would cover nearshore and offshore areas. Remote sensing should be used to estimate benthic algae coverage along long stretches of shoreline.

All of the observations required for model development, calibration, and ongoing operation will be integrated into the DMAC so that data can flow seamlessly from multiple sources into a central node that modelers can easily access. The DMAC will also ensure that data used by the model has gone through quality control checks.

6.4 REGIONAL SCALE OBSERVATION SYSTEMS

6.4.1 Objectives and Conceptual Design

In addition to the basin-wide and whole-lake scale designs described above, regional sensing network designs should be developed to explore more detailed sensing requirements of specific user needs in regional subareas smaller than a whole lake. As indicated in Section 5.3 and Figure 5-1, regional subarea designs are more focused on Level B system expansion alternatives that build on the base level of sensing developed at the basin and lake scales. The system expansions are intended to address a specific prioritized user need in a defined region of a lake and to address that need comprehensively. The regional subarea designs will typically require greater complexity than is required in either the basin-wide or lake-wide systems. They will involve higher spatial and temporal resolution for sensor deployments, greater diversity of physical, chemical, and biological sensor types, or observations relating to higher ecosystem complexity. For example, eutrophication-related issues (e.g., harmful algal blooms or nuisance benthic algae) in Great Lakes embayments or rivermouth areas will require a relatively dense observation network that covers a broad range of parameters of concern. Similarly, specific problems in Great Lakes AOCs for which efforts are being made to delist the AOC may require subarea observation systems to monitor progress. Also, detecting and documenting change associated with local GLRI projects can also be served by this scale of system.

Just about any Great Lakes shoreline zone, rivermouth area, embayment, or lake sub-basin can be defined as a subarea for design and implementation of a regional scale observing system. To illustrate the possibilities, we have created a map that illustrates a candidate set of subareas around the basin (Figure 6-3). It includes all of the Great Lakes AOCs plus other named potential subareas that may be logical candidates for an observing system.

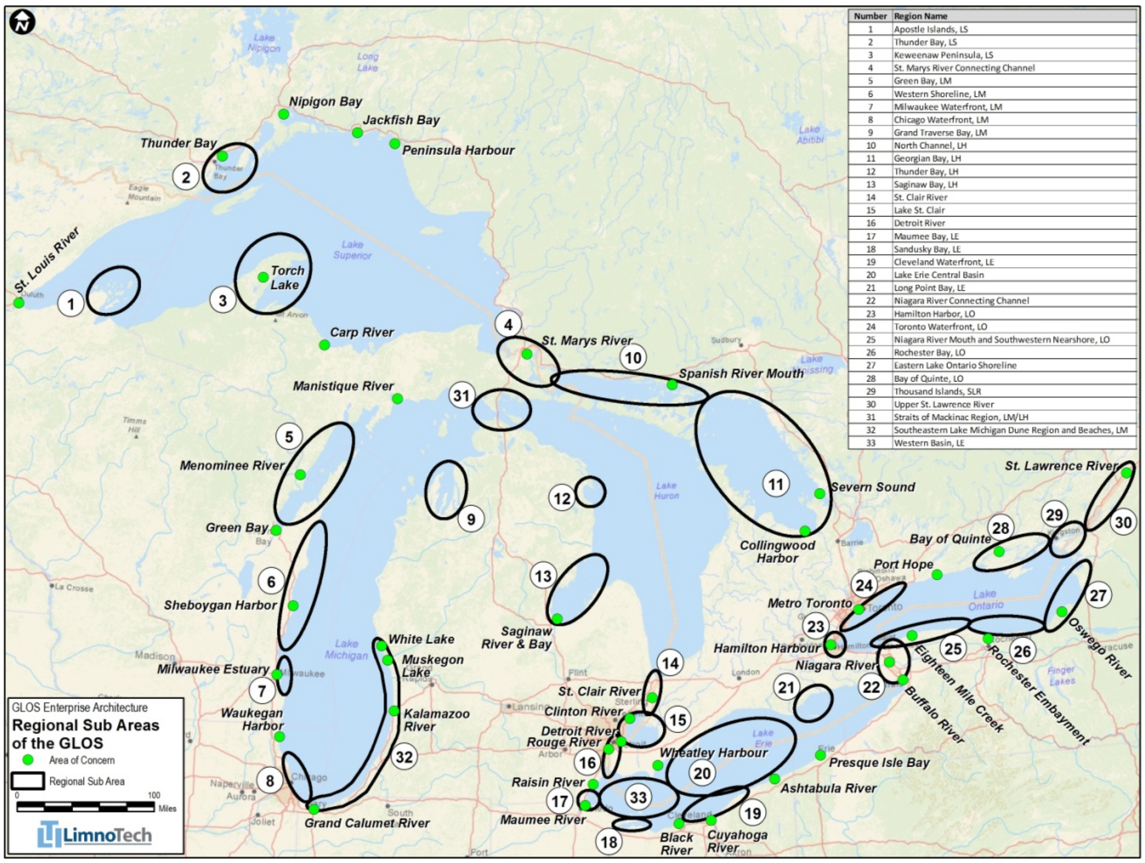

Figure 6-3. Example subareas that may be identified for development of a regional observing system as part of the overall GLOS Enterprise

In order for a regional subarea such as those illustrated in Figure 6-3 to move into the design and implementation process, it should have formulated the following design information:

- A defined geographic domain for which the regional observing system is intended;
- Specification of a single primary user need and associated management issue, plus any other related secondary issues, that is being addressed by the regional observing system;
- Specification of modeling framework or data integration product that addresses the management need identified for the subarea;

- Specification of the required monitoring of physical, chemical, and biological parameters that support the model/user products provided by the observing system;
- Specification of a plan for integrating the regional subarea observing system into the GLOS enterprise DMAC; and
- An estimate of the capital and life cycle operation and maintenance costs for the system and identification of potential ownership and funding sources for the system.

As for the other scales, regional observing systems should support the seven IOOS societal needs, the four priority GLOS societal needs, the GLRI focus area priorities, AOC beneficial use impairment delisting priorities and additional needs.

GLOS has already developed a pilot regional observing system for hydrodynamic nowcast/forecast in the Huron-Erie Corridor (http://glos.us/hecwfs/). GLOS is also initiating a program of deploying observation equipment (buoys, AUVs, and other platforms) in five tributary/rivermouth systems within AOCs: 1) St. Louis River; 2) Lower Fox River and Green Bay; 3) Saginaw River and Bay; 4) Maumee River/Bay; and 5) Genesee River and Rochester Embayment AOC (http://glos.us/trib_monitoring/). This work represents the initiation of development of full regional observing systems for these designated subareas.

To conceptualize the design process for a regional subarea in the Great Lakes, we will present the design approach for two representative regional subareas: 1) the lower Maumee River and western basin of Lake Erie; and 2) the Niagara River and the southern Lake Ontario nearshore region in the Niagara plume. Finally, we will present a more extensive design development for our regional subarea end-to-end case study of the Lake Erie central basin hypoxia impact on Cleveland drinking water intakes.

It should be noted that the establishment of regional subarea observing systems at any location in the basin can benefit greatly from the lake scale and basin-wide scale observing system networks because they will provide, through an integrated DMAC, necessary boundary condition data for the subarea models. Conversely, the networks being developed for the regional subareas will be contributing platforms and sensors that can supplement the lake and basin-wide systems.

6.4.1.a Lower Maumee River and western basin of Lake Erie Regional Subarea

The Lower Maumee River is the tributary that drains the Maumee Watershed into the western basin of Lake Erie. It represents the largest single tributary source of sediment to the Great Lakes and also contributes significant amounts of nutrients and seed algae to large harmful algal blooms (blooms of *Microcystis sp.*) that have formed major late-summer plumes from the lower river through Maumee Bay and into Lake Erie. Managing nutrients and harmful algal blooms and sedimentation in the Navigation Channel of the Lower Maumee River and western basin of Lake Erie defines two related, important user needs and associated management issues.

There is a considerable research, monitoring, and modeling effort already taking place for this system. Heidelberg University and the University of Toledo both have ongoing research and monitoring programs for this system (Heidelberg University measures water quality loads at the USGS gage location at Waterville and the University of Toledo monitors water quality and algal bloom conditions in the bay and out into the western basin on a regular basis). Also, the University of Toledo is installing new fixed sensor platforms with funding from an NSF equipment grant that will provide data to this subarea. NOAA-GLERL has fixed sensor systems that are deployed in the subarea and is initiating additional observation sensors in collaboration with GLOS for the above-mentioned tributary monitoring program.

There are two modeling programs that can support the management problems for this subarea with the input from the monitoring programs mentioned above. LimnoTech has developed a linked hydrodynamic–sediment transport–advanced eutrophication model to inform restoration and management decisions in this system. Application of the modeling framework will specifically include evaluation of how localized sediment accretion/erosion behavior changes in the River and Bay relative to alternatives for dredged material placement, island building, etc. This model will also be used to quantify the relationship between nutrient loads, zebra mussel density, and physical (hydrodynamics, temperature, light) factors as stressors and algal blooms in this system, including hazardous algal blooms of *Microcystis* and benthic attached algal blooms that lead to shoreline fouling and diversion of energy from the fish community. The model will also support decisions on clean sediment management and watershed nonpoint source control actions by predicting the benefits of these actions for enhancing fish and wildlife habitat and associated commercial and recreational uses. NOAA-GLERL has developed a Harmful Algal Blooms (HABs) transport forecasting model that uses satellite images of blooms and a hydrodynamic model to forecast the expansion and transport of blooms in this system.

If this system were identified as a GLOS enterprise priority regional subarea observing system, development of a formal design for this system over the next year or two could proceed by building on these ongoing efforts. The design process for this observing system would proceed as follows:

- Summarize the inventory of existing sensors and monitoring efforts, capital value of these assets, costs of ownership, operation, maintenance, and life cycle replacement of the existing system;
- Specification of the data needs (all physical, chemical, and biological parameters) to support the confirmation of the two management models for running the two models in an operational mode at their respective time scales;
- Specification of the observing network that would supply those data needs at the required spatial and temporal resolution (supported by our Trade Study Tool);
- Specification of the DMAC needs for management of the data and delivery of data products and model results to users; and
- Development of a detailed implementation plan and concept of operations for this subarea.

6.4.2 Lake Erie Central Basin Hypoxia Regional Subarea

6.4.2.a Definition of Management Issue

The central basin of Lake Erie contains a region of hypoxia in the late summer and fall that has the potential to impact drinking water treatment plants that rely on Lake Erie as a primary water source. The City of Cleveland, OH is particularly vulnerable and has experienced severe taste and odor issues when the hypoxic waters are pumped into the plant. In recent years the City of Cleveland has been trying to improve treatment processes to minimize taste and odor issues when low DO water is drawn into the plant. However, in order for the new processes to be effective, the plant must have sufficient time to switch over to the alternative treatment process.

The alternative method is more costly compared with traditional treatment methods, so predicting the start and end of the hypoxic period is critical.

To date, plant operators have relied on real time DO measurements in the intake water and from in situ measurements from moored buoys operated by NOAA-GLERL. Measurements in the intake water provide zero warning time to switch treatment process and in situ measurements are not maintained as operational.

6.4.2.b Conceptual Design

To meet the needs of the Cleveland Water District and other drinking water intakes along the southern coast of the central basin, a combination of real time monitoring and forecasting is proposed. The monitoring and forecasting system will be able to estimate the area and depth of the hypoxic zone and predict the potential for low DO water to impact drinking water intakes. The real time monitoring will consist of moored buoys positioned around the affected area in addition to enhanced monitoring at water intakes. The forecasting model will use real time data, in addition to historical data, to develop a warning system that will let plant operators know when the probability that low DO water is near their intakes is high.

The observation network will consist of a series of moored buoys located in the central basin of Lake Erie that can detect the progression (area and thickness) of the hypoxic zone throughout the summer and into the fall (see Figure 6-4). The buoys will be positioned to capture the initial onset of hypoxia in the deepest part of the central basin and in highly productive areas near Sandusky Bay. A buoy will also be placed between these two buoys and between the shore and center of the lake to measure the horizontal DO gradients. Sensors on the buoys will measure DO, conductivity, pH, and water temperature at several depths. One or more buoys will also measure atmospheric data (air temp, relative humidity, pressure, wind speed and direction) and water velocity data (Acoustic Doppler Current Profiler (ADCP)).

The network will also include daily sampling and analysis of drinking water intakes for DO, temperature, conductivity, pH, color, and turbidity. Every two weeks from mid-June to mid-August, field cruises will be conducted to obtain water quality profiles every mile along a northeast transect from the City of Cleveland drinking water intakes to the existing NOAA buoy (labeled CLVBC in the attached map). At each water quality profile location, a probe will be lowered through the water column to record DO, temperature and pH measurements. At select locations, grab samples will be collected to measure total phosphorus, total nitrogen, silica and chlorophyll. GPS coordinates will be recorded for each profile location along the transect.

These data will support the development and operational application of a forecasting model that addresses this issue. The forecasting model will consist of an empirically based model that can use real-time data to predict/project the growth of the hypoxic zone (both area and thickness) over long time scales (weekly to monthly). The product of this model will be an estimate of the DO at the water intakes throughout the summer and into the fall. As data are collected the “trajectory” of the plot will be adjusted to reflect the new prediction and model results will be replaced with data. Error bars will illustrate the model uncertainty in predicting DO concentrations further from the present.

As a supplement to the long term predictions, a shorter term mechanistic based modeling approach will simulate dynamic events that could temporarily shift the hypoxic zone towards the intakes. This modeling approach would use the long term projections in association with hourly and daily hydrodynamic model forecasts (using the Lake Erie GLFS model) to forecast on an hourly to daily time scale the likelihood that hypoxic waters would reach the intakes.

The products that would be produced for users would include time series plots of data collected at buoys, daily maps of the hypoxia zone in the central basin, short and long term model forecast of the hypoxia zone, with alerts of probability of hypoxia at water intake locations.

6.4.3 Level B Design Alternative Development

The appropriate mix of observing platforms for each of the example regional design sub-areas was evaluated using the trade study tool (Section 7 and Appendix B). For the end-to-end case study in the central basin of Lake Erie, a second iteration trade study was performed, which used the results from the more general first iteration to develop a series of more specific design alternatives. The evaluation of these alternatives was used to inform the conceptual design of the sensing network to address hypoxic intrusion in the Cleveland drinking water intake.

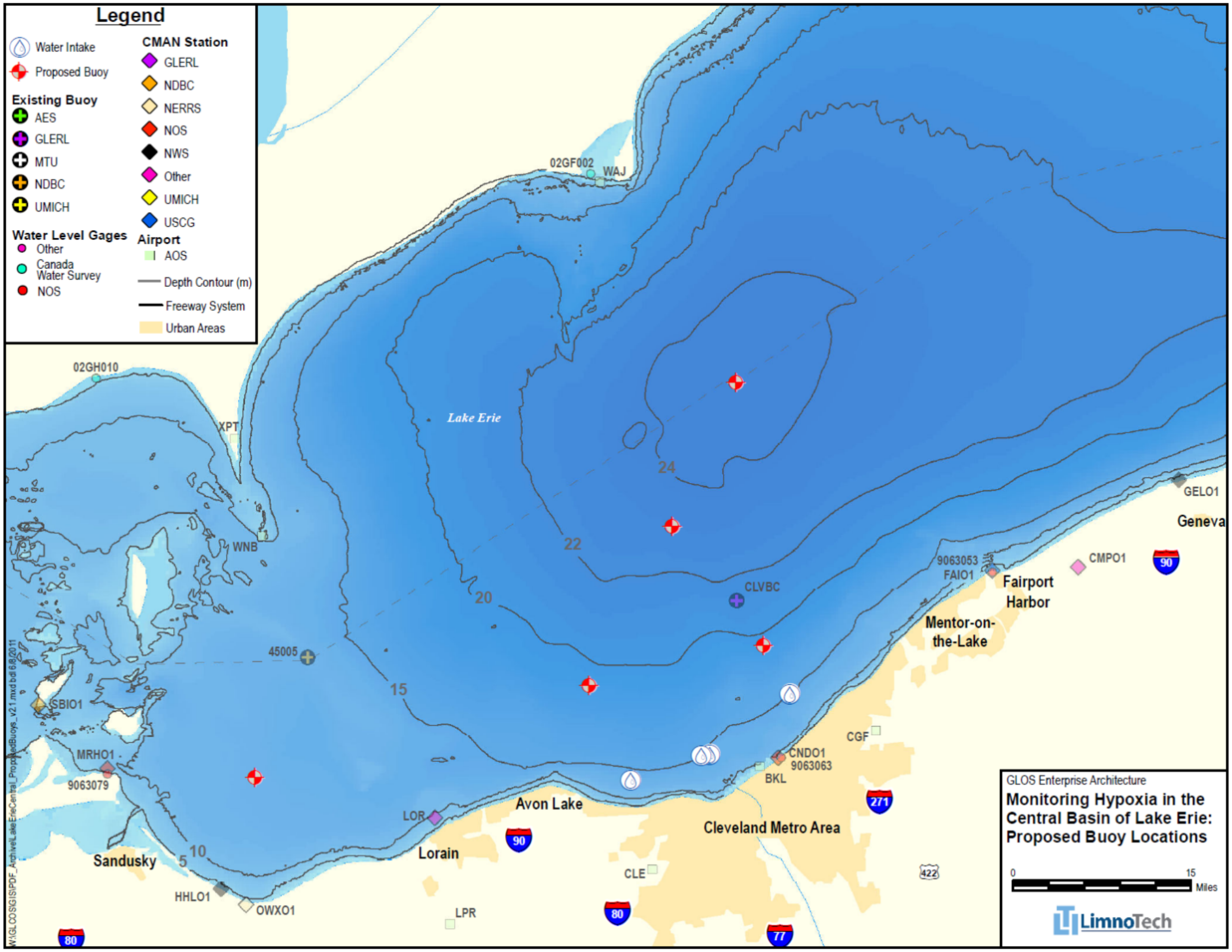

Figure 6-4. Central Basin Lake Erie buoy locations

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7. TRADE STUDIES

7.1 INTRODUCTION

Trade studies are systematic and transparent decision-making tools that allow for the comparison of competing design alternatives. For the development of the GLOS enterprise architecture, trade studies were used to evaluate the mix of observing platforms that would be most appropriate for the expansion of the GLOS sensing network. The project team used trade studies to make specific recommendations as part of this investigation and to demonstrate a process that will facilitate the design of future regional sensing networks. The trade studies were applied as follows:

- A single trade iteration was performed for each example design area described in Section 5 to illustrate how the preferred observing platform mix could vary based on scale and design management issues.
- Two iterations of the trade studies were applied to each of the end-to-end case studies (see Section 5) to demonstrate how the trade study process can move from general guidance to a comparison of specific observing network alternatives.
- The trade study process was used to generate specific design recommendations for advancing the basin-wide observing network from its current state (Level 0) to a desired near-term configuration (Level A).

This section provides an overview of the trade study process and summarizes the results of the completed trades. A more detailed description of the trade studies is presented in Appendix B.

7.1.1 Observing Platform Alternatives

Three forms of in-situ measurements (fixed platforms, mobile platforms, and field campaigns) plus remote sensing were evaluated as part of each trade study. The observing platform alternatives are described below.

7.1.1.a Fixed Platforms

Fixed platform use sensors placed in the same location for the duration of sampling or deployment. The types of observation technologies evaluated in the category of fixed platforms include:

- Long-term moorings (surface, sub-surface)
- Buoy systems
- Cabled systems
- Vertical profiling systems

Surface long-term moorings lend themselves to flexibility, ease of maintenance and deployment within the observing system. Sub-surface moorings require more stringent design considerations and specialized maintenance support, however, they allow for year round monitoring. Buoy systems are the workhorse of observing systems and are relatively easier to support. For longer term observations, cabled systems might be desirable and can support larger payloads and more specialized equipment. Vertical profilers are either surface or sub-surface units that provide the capability to profile the entire water column for a variety of parameters.

7.1.1.b Mobile Platforms

Mobile platforms utilize similar sensors, and therefore can measure similar parameters, as fixed platforms. However, mobile platforms provide greater spatial resolution, but less temporal resolution at individual locations. Typical components of this category include:

- Towed sensor bodies
- Autonomous underwater vehicles (AUVs)
- Gliders
- Drifters
- Vessels of opportunity

Tow-bodies are capable of undulating through the water column generating a vertical profile while the vessel is underway, providing a moderate resolution dataset at relatively high sampling frequency. AUVs behave similarly to tow-bodies except they are independent of a parent vessel for support and can be deployed as a fleet to provide higher spatial resolution. They typically support short duration sampling experiments. Gliders and glider fleets will have the similar characteristics to AUVs, but can support longer term deployments. Drifters are comparable to buoys but are free to drift with the currents and do not possess active controls. Vessels of opportunity are not dedicated observing system platforms, but are regular water craft that have volunteered to carry instrument payloads while underway. The Ranger III, a ferry to Isle Royale in Lake Superior, is an example of a vessel of opportunity in the Great Lakes.

7.1.1.c Field Campaigns

Field campaigns are traditional sampling techniques which rely heavily on grab sampling. For many parameters, particularly biological measurements, field campaigns are still the only possible monitoring method. Research vessels and any sample procurement that uses laboratory analysis are included in this category.

7.1.1.d Remote Sensing

Remote sensing relies on non-contact sensing methods. Typical remote sensing platforms are:

- Satellite based systems
- Aerial platforms (aircraft, balloons, sondes)
- Land-based (radar, infrared)

Remote platforms provide extensive coverage but may be limited in terms of spatial resolution and sampling frequency. A variety of free satellite imagery is available; however, the imagery requires processing to provide useful products. Land-based radar units such as high frequency (HF) radar provide surface current mapping but may not have enough coverage in fresh water systems while infrared sensors can provide sea surface temperature mapping. For higher sampling frequency, aerial platforms can provide sufficient coverage relative to satellite overpasses but cost of deployment may become a limiting factor.

7.1.2 Objective Criteria

The project team identified 12 criteria categories and 40 individual criteria by which to evaluate the observing platform alternatives. Many of these criteria are related to the design drivers presented in Section 5. However, a number of those design drivers are outside the scope of these trades, such as those related to data standardization. The criteria used for the trades performed as part of this investigation were developed to evaluate the ability of observing technologies to address defined management issues.

Following the preliminary evaluations with the trade study tool, it was determined that the criteria fell into two broad categories: those that measured a characteristic intrinsic to the technology for a particular scale (e.g., system reliability and data quality) and those that measured a characteristic that varied depending on the management issue being addressed (e.g., provides adequate spatial resolution). The technologies that measured a characteristic that depended on the management issue were generally given higher criteria weights, which are discussed later in this section. Table 7-1 shows the criteria categories and the individual criteria used in the trade studies.

Table 7-1. Criteria categories and individual criteria used to evaluate observing platform technologies

Criteria Category	Criteria
Platform Intrinsic Criteria (for Scale of Application)	
Functional requirements	Does not need further analyses / post-processing
	Supports year round sampling
Operational requirements	Ease of deployment
	Flexibility
	Scalability
Technical risk	Reliability
	Maintainability
	Availability
	System Safety
	Data Quality
	Human Factors
	Environmental Impact
	Hazardous Materials
System maturity	System maturity
	Developmental support
Support	Logistics support
	Engineering support
	Testing support
	Ease of data integration
Management Issue Dependent Criteria	
Functional requirements	Ability to measure relevant parameters
	Ability to provide appropriate sensor placement
Performance requirements	Provides adequate spatial coverage
	Provides adequate spatial resolution
	Provides adequate temporal resolution (sampling frequency)
Programmatic requirements	Ability to address design issue
	Ability to address other user needs (IOOS, GLRI, etc.)
Cost	Development cost
	Lifecycle cost
Financial opportunity	Amenable to steady funding (federal, state, etc.)
	Amenable to opportunistic funding
Schedule risk	Long-term schedule risk
	Medium-term schedule risk
	Short-term schedule risk
Operations	Amenable to internal operations
	Amenable to external operations
	Amenable to opportunistic sampling
Ownership	Suitability for academic ownership
	Suitability for federal ownership
	Suitability for state/local ownership
	Suitability for private-party ownership

Weights were assigned to the each of the criteria to represent their relative importance to the successful design of a sensing network. Initial criteria weights were determined through a survey of the study team. These initial weights were generally applied in each trade; however, some of the criteria weights were adjusted based on the management issue that was being addressed. For example, providing adequate spatial coverage was given greater weight for the basin-wide system than for the central basin of Lake Erie.

7.1.3 Scoring the Alternatives

Each alternative was given a score from 0-10 to reflect its performance with regard to each of the criteria. The scoring of the criteria was oriented so that a higher score always indicated better performance. For example, a higher score in the cost criteria indicated a lower cost. For this study, the scores were based on expertise of the members of the GLOS Enterprise Architecture team. A survey was conducted to gather initial scores from each organization with experience deploying and operating the various observing platforms: LimnoTech, Clarkson, and MTRI. In the cases in which the initial scores from the different groups were fairly close, the average value rounded to the nearest integer was used as the score for that alternative. The criteria that had more disparate initial score responses were discussed further to develop consensus-based scores.

The individual scores were multiplied by the criteria weights to calculate a Total Score for each alternative. The Total Score is calculated for each alternative based on the following equation:

$$TS_j = \sum_{i=j=1}^{n} w_i r_j$$

where w_i is the weight for each criterion and r_j is the score for each alternative. The matrices of scores and weights used to develop a Total Score for each trade are presented in Appendix B.

7.2 TRADE STUDY CONCLUSIONS

A single iteration of a trade study was completed for each design area. The Total Scores for each broad observing platform category are presented in Table 7-2.

Table 7-2. First iteration Total Scores from trade studies for each example design area

Example Design Area	Fixed Platforms	Field Campaigns	Mobile Platforms	Remote Sensing
Regional sub-areas				
Central basin of Lake Erie	569	495	517	425
Maumee Bay	562	534	536	548
Whole-lake design area				
Lake Michigan (multiple user needs)	521	560	534	568
Lake Michigan (trophic gradient)	469	494	459	466
Basin-wide design area				
Great Lakes Basin	481	534	536	548

Note: A trade study was conducted for a Lake Michigan sensing network that addresses multiple user needs as defined in the RDA presented in Section 5. Additionally, a trade study was conducted to develop a design for the Lake Michigan end-to-end case study which only addresses the issue of the nearshore-offshore trophic gradient.

The single iteration trade studies show that the appropriate observing platform mix is highly dependent on both the scale and the management issues that the observing system is intended to address. The fixed platforms tend to be the preferred technology at the regional scale, while remote sensing tends to be more valuable at larger scales. The mobile platforms and field campaigns tend to score in the range that indicates they should serve as complimentary observing system components. However, some management issues, such as the nearshore/offshore primary productivity gradient, are still best monitored with parameters that can only be measured with field campaigns.

A single iteration trade study will provide only very general guidance regarding the appropriate sensing network design. Further iterations are needed to develop and evaluate more specific alternatives. To illustrate this process, second iteration trade studies were performed for each of the end-to-end case studies.

For the central basin of Lake Erie, the first iteration trade study showed that fixed platforms were the preferred observing technology. Therefore, fixed platforms were the primary technology in each of the alternatives developed for a second iteration. Conversely, remote sensing scored low for the central basin example design area, primarily because it does not measure dissolved oxygen and it cannot provide depth profiling. Remote sensing was not considered as a component in the second iteration alternatives. Field campaigns and mobile platforms both scored well enough to be considered as complimentary observing technologies. Importantly, field campaigns and mobile platforms both scored well in providing spatial resolution and spatial coverage, two areas of relative weakness for fixed platforms.

Three design alternatives of approximately equal cost were developed based on the outcome of the first iteration trade study:

- Fixed platforms only: six buoys and sensors at drinking water intakes
- Fixed platforms supplemented with field campaigns: five buoys, sensors at drinking water intakes, and semi-monthly field campaigns during summer months
- Fixed platforms supplemented with mobile platforms: four buoys, sensors at drinking water intakes, and semi-monthly AUV deployment during summer months

Table 7-3. Second iteration Total Scores from trade studies for central basin of Lake Erie end-to-end case study

Design Issue and Area	Fixed platforms only	Fixed platforms supplemented with field campaigns	Fixed platforms supplemented with mobile platforms
Hypoxic intrusion in drinking water intakes in the central basin of Lake Erie	569	581	567

The results from the second iteration trade study indicated that of the alternatives evaluated, the alternative using five buoys, sensors at the drinking water intakes, and semi-monthly field campaigns was preferred. These results were used to inform the central basin of Lake Erie design described in Section 6.4.2.b.

The first iteration trade study for the Lake Michigan trophic gradient end-to-end case study indicated that a balance of sensing technologies was needed, but that field campaigns should be a substantial component. Three alternative configurations were developed. All of the alternatives included additional fixed platforms to inform the hydrodynamic model, field campaigns to measure parameters that cannot currently be measured with sensors, and the development of new remote sensing algorithms to measure cladophora, chlorophyll, total suspended solids (TSS), and dissolved organic matter (DOM). From that base level of sensing, the alternatives were expanded in three directions: increased emphasis on field sampling, increased emphasis on fixed platforms, and increased emphasis on remote sensing. Table 7-4 provides the details about the three alternatives considered in the second iteration trade study.

Table 7-4. Second iteration alternatives from trade studies for Lake Michigan end-to-end case study

	Fixed platforms	Field campaigns	Mobile platforms	Remote sensing
Emphasis on Field Campaigns	• 8 buoys to measure meteorological data, currents, and water temperature. 4 with multi-parameter sonde*. • 1 cabled year-round platform to measure water temperature, waves, current, and ice cover	• 10 research vessel cruises along 6 transects to buoys with measurements for nutrients, phytoplankton and zooplankton biomass and speciation, and benthic algae and organism abundance	• Towed arrays as part of field campaigns to measure , Chl-a, turbidity, PAR, conductivity, DOM, temperature, DO, side-scan sonar and lake-bottom video • 2 multi-day glider deployment with same sensor payload as towed arrays	• Analysis for cladophora, chlorophyll, TSS, and DOM using existing free satellite imagery
Emphasis on Fixed Platforms	• 15 buoys to measure meteorological data, currents, and water temperature. 9 with multi-parameter sonde*. • 2 cabled year-round platforms to measure water temperature, waves, current, ice cover	• 6 research vessel cruises along 6 transects to buoys with measurements for nutrients, phytoplankton and zooplankton biomass, and benthic algae and organism abundance	• Towed arrays as part of field campaigns to measure , Chl-a, turbidity, PAR, conductivity, DOM, temperature, DO, side-scan sonar and lake-bottom video • 2 multi-day glider deployments with same sensor payload as towed arrays	• Analysis for cladophora, chlorophyll, TSS, and DOM using existing free satellite imagery
Emphasis on Remote Sensing	• 8 buoys to measure meteorological data, currents, and water temperature. 4 with multi-parameter sonde*. • 1 cabled year-round platform to measure water temperature, waves, current, and ice cover	• 6 research vessel cruises along 6 transects to buoys with measurements for nutrients, phytoplankton and zooplankton biomass, and benthic algae and organism abundance	• Towed arrays as part of field campaigns to measure , Chl-a, turbidity, PAR, conductivity, DOM, temperature, DO, side-scan sonar and lake-bottom video • 2 multi-day glider deployment with same sensor payload as towed arrays	• Analysis for cladophora, chlorophyll, TSS, and DOM using high resolution satellite or airborne imagery

The second iteration alternatives were evaluated with the trade study tool. The Total Scores are presented in Table 7-5.

Table 7-5. Second iteration Total Scores from trade studies for Lake Michigan end-to-end case study

Design Issue and Area	Emphasis on Field Campaigns	Emphasis on Fixed Platforms	Emphasis on Remote Sensing
Nearshore/offshore trophic gradients	522	498	497

The results from the second iteration trade study are consistent with the first iteration in that they indicate that field campaigns should be an area of emphasis for addressing the trophic gradients in Lake Michigan. However, the process of developing specific alternatives revealed that additional fixed platforms were needed to inform the hydrodynamic model. The investment in the base level of fixed platforms would be greater than the field campaigns, even in the alternative that emphasizes field campaigns.

Trade studies are useful as a systematic approach to decision-making; however, they should only be regarded as one tool that may guide the design of an observing system. The need to meet specific design considerations, such as measuring particular model inputs, may supersede the results of a group-based decision-making process.

An additional tool that may inform the appropriate sensing network design to better inform system modeling is an Observing System Simulation Experiment (OSSE). OSSEs can help identify the specific information needs that are most likely to reduce uncertainty in the predictions of operational models. The application of OSSEs is well-established within NOAA and NASA (Masutani, 2006). For the GLOS, the use of OSSEs would be most appropriate for improving the performance physical models such as the Great Lakes Forecasting System.

8. DESIGN INTEGRATION ACROSS ALL SCALES

The development of a conceptual design of the Great Lakes Observing System at three scales of interest – the Basin, Lake, and regional scales – has been described in previous sections of this document. However, the requirement that the entire system perform as an integrated whole is as critical as the need to address each scale of interest. This integration occurs across the scales of interest, but also across other aspects of the project:

- between the technology, data, and applications architecture subdomains (Figure 2-1);
- between the management and technical domains that maintain and grow the enterprise, and;
- between the different user communities that access the enterprise, and give it its purpose.

These interacting elements are brought together under the GLOS enterprise system management, development, and user framework depicted in Figure 8-1.

In this framework, the DMAC layer plays a central role in interfacing with the user community, and providing access and centralized data management for the research and development community and operational system managers. The overall system is developed and maintained by a distributed network of Federal, academic and private research and development entities and system managers. Research and development and operations are managed separately, but their activities are closely related as new sensing technologies, networks, and models are developed and spun off into the operational realm, and as operational system refinements point to new research needs. Management and oversight of the DMAC and interactions with the user community is provided by GLOS, and overall management and oversight of the entire enterprise is provided by an inter-agency federal consortium.

For this design effort, the inclusion of a well-designed DMAC infrastructure at the central location in this framework is critical to the overall success of the enterprise. This section summarizes the concept of operations for the DMAC and then describes the proposed configuration of the DMAC framework. Some notes on implementation and staffing are also provided.

The design effort for the DMAC has progressed to a somewhat more advanced level of detail and specificity than the other, more conceptual components of the enterprise design. This emphasis here and in the concept of operations document is appropriate given the importance of the DMAC in ensuring a strong start and long-term viability and robustness of the enterprise as a whole.

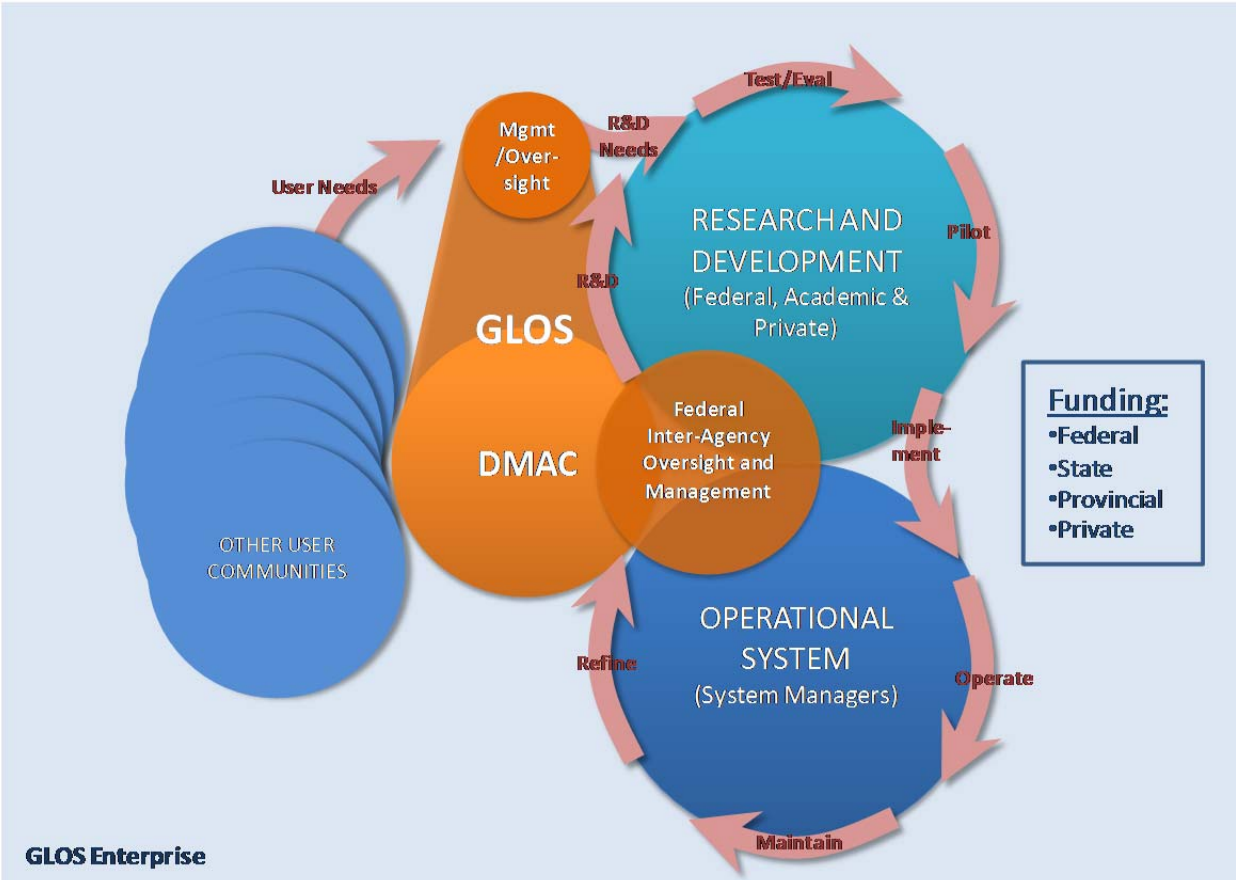

Figure 8-1. GLOS enterprise system management, development and user framework

8.1 CONCEPT OF OPERATIONS

This section summarizes important aspects from the GLOS Enterprise Architechture DMAC Concept of Operations report that inform the design of the DMAC through review of the current state of DMAC, and consideration of user classes, user needs, and a demonstration application. As the fundamental interface between data providers and data consumers, the operation of the DMAC in many ways defines the operation of the entire observing system.

8.1.1 DMAC Current State

DMAC for the existing observing system in the Great Lakes can be characterized as a Community Distributed System (Figure 8-2) as described in the project Technical Memorandum "Alternatives Development: Data Management and Communications (DMAC)." In the existing DMAC, some centralized data management is provided by GLOS in the form of guidance and support, but overall, observational data passes from data provider to end user through independent and inconsistent pathways. This does not imply inaccuracy of results; for example, data from a particular buoy may be accessible directly from the provider, through GLOS, and from NOAA's National Data Buoy Center – with all three streams providing accurate and reliable observations.

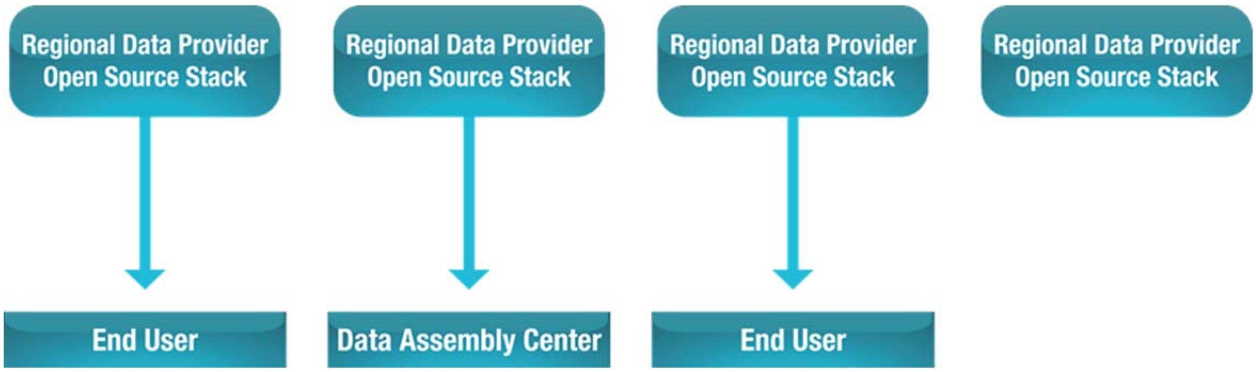

Figure 8-2. Conceptual design of a Community Distributed System.

The existing DMAC encompasses access to a wide range of data sources provided by federal and state agencies, academic organizations, and others. Figure 8-3 summarizes data resources that are currently available for the Great Lakes. More specifics about available data sources are supplied in Table 3 and Appendix A of the DMAC Concept of Operations document (Appendix C).

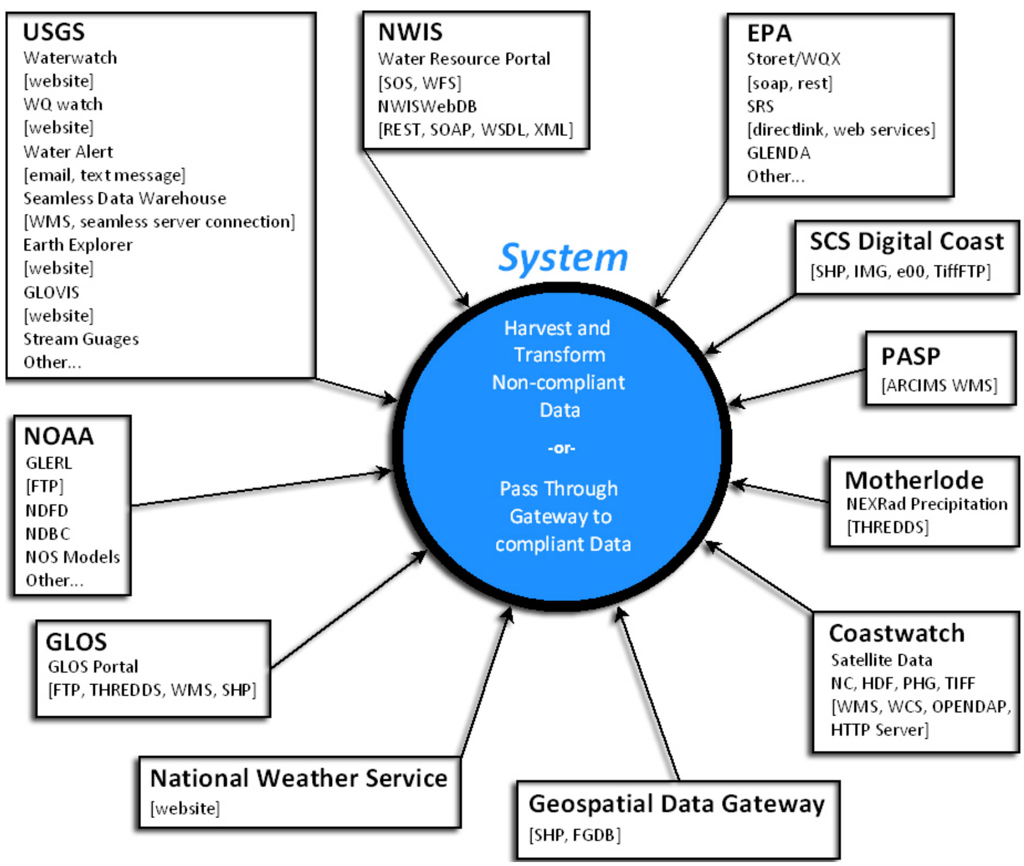

Figure 8-3. Great Lakes observation data resources for integration through DMAC

8.1.2 User Classes

There are three important classes of users who interact with the DMAC on a regular basis.

Data providers interact with the DMAC manually and automatically. Manual interactions consist of communication with DMAC staff to negotiate data transfer protocols and implementation of the protocols. Automated interactions transfer observed data or model results to the DMAC infrastructure.

Data managers are responsible for the administration and operation of the DMAC infrastructure. In addition to day-to-day activities maintaining the DMAC infrastructure and improving reliability and performance, the data managers interact with data providers and data consumers to negotiate data transfer protocols and to continually improve access and presentation of data.

Data consumers use the DMAC to access data for a number of purposes:

- Researchers access data for use in detailed analyses, including modeling of environmental processes
- Managers use forecast data to make operational decisions about activities on the lake that may be impacted by extreme conditions, such as high winds or waves
- Members of the public use data to guide recreational decisions and plan lakeside/on-lake activities.

All three classes of users should be considered in the design of the DMAC.

8.1.3 User Needs

As discussed in Technical Memorandum 6 and in Section 3 of this report, the observing system must serve a wide range of data consumer needs. The organizational goals presented in Section 3 are recapitulated here in brief:

- Improve predictions of climate change and weather and their effects on coastal communities and the nation (IOOS 1)
- Improve the safety and efficiency of maritime operations (IOOS 2)
- Mitigate the effects of natural hazards more effectively (IOOS 3)
- Improve national and homeland security (IOOS 4)
- Reduce public health risks (IOOS 5)
- Protect and restore healthy coastal ecosystems more effectively (IOOS 6)
- Enable the sustained use of ocean and coastal resources (Great Lakes) (IOOS 7)
- Improve early identification of climate change impacts on the thermal structure and chemistry of the Great Lakes (GLOS 1)
- Reduce risks of contaminated water supplies and improve predictive capabilities to protect public use of bathing beaches (GLOS 2)
- Enhance understanding of nutrient dynamics, algal blooms, and other factors adversely affecting a viable fishery (GLOS 3)

- Reduce loss of life and property damage to commercial navigation and recreational boating, while increasing economic efficiencies of commercial navigation operations (GLOS 4)
- Toxic Substances and Areas of Concern: Measuring Progress and Assessing New Toxic Threats (GLRI 1)
- Invasive Species: Establish early Detection and Rapid Response Capability (GLRI 2)
- Nearshore Health and Non-Point Source pollution: Generate critical information for protecting nearshore health (GLRI 3)
- Habitat and Wildlife Protection: Identify, inventory, and track progress on Great Lakes Habitats, including coastal wetlands restoration (GLRI 4)
- Accountability, Monitoring, Evaluation, Communication, and Partnerships: Measure and evaluate the health of the Great Lakes Ecosystem using the best available science (GLRI 5)

Indicators established by the joint US EPA/Environment Canada State of the Lakes Ecosystem Conference (SOLEC) are also of interest to resource managers and therefore represent important user needs:

- Atmospheric Deposition of Toxics and General Air Quality;
- Nearshore and Offshore Nutrient Concentrations;
- Phytoplankton and Benthic Algae;
- Suspended Sediment available for coastal beach nourishment;
- Water Level Fluctuations;
- Climate Change Indicators; and
- Long-term Change Analysis.

More information of the SOLEC indicators is provided in Section 6.2.1 of this report.

Addressing these goals requires the DMAC to provide multi-scale access to available observation data and to results from operational models. Specific user needs related to these goals as identified in this project are catalogued in Table 3-1. The necessary data access may be needed at a basin-wide, whole-lake, or local scale.

Many of the necessary data access pathways to address these needs and goals already exist within the current DMAC, but centralized provision of data and metadata could improve efficiency of data access for users. Some of the data required to address user needs and progress towards organizational goals are not yet available, either because the observation platforms are not installed, or the necessary operational model is not developed or connected. Any evolution of DMAC should consider how to support the addition of new data sources that are similar to existing sources as well as sources that expand data delivery capabilities.

The DMAC design should implicitly work to address the needs of data managers, who will have the responsibility within the DMAC framework of developing processes and protocols to facilitate delivery of data by data providers.

8.1.4 Demonstration Application

In order to evaluate the ability to access disparate data and services, project team member ASA developed a prototype web portal to demonstrate end-to-end data connections. Built in Flex and incorporating ArcGIS, WMS, and SOS services, the portal integrates in-situ observations, GIS, remote sensing, and models into a Great Lakes portal. The portal provides access to:

- GIS data, including location of observation platforms;
- Model output for USGS SPARROW, NOAA LBRM, and NOAA nowcast models;
- Observed data at NDBC buoys;
- US Coast Guard Environmental Data Server nowcasts, forecasts and remote sensing of hydrodynamic and atmospheric conditions; and
- Historical EPA data from the GLENDA and STORET databases.

An example screen shot is shown in Figure 8-4. Additional screen shots and detail about the end-to-end prototype portal are presented in the DMAC Concept of Operations document (Appendix C).

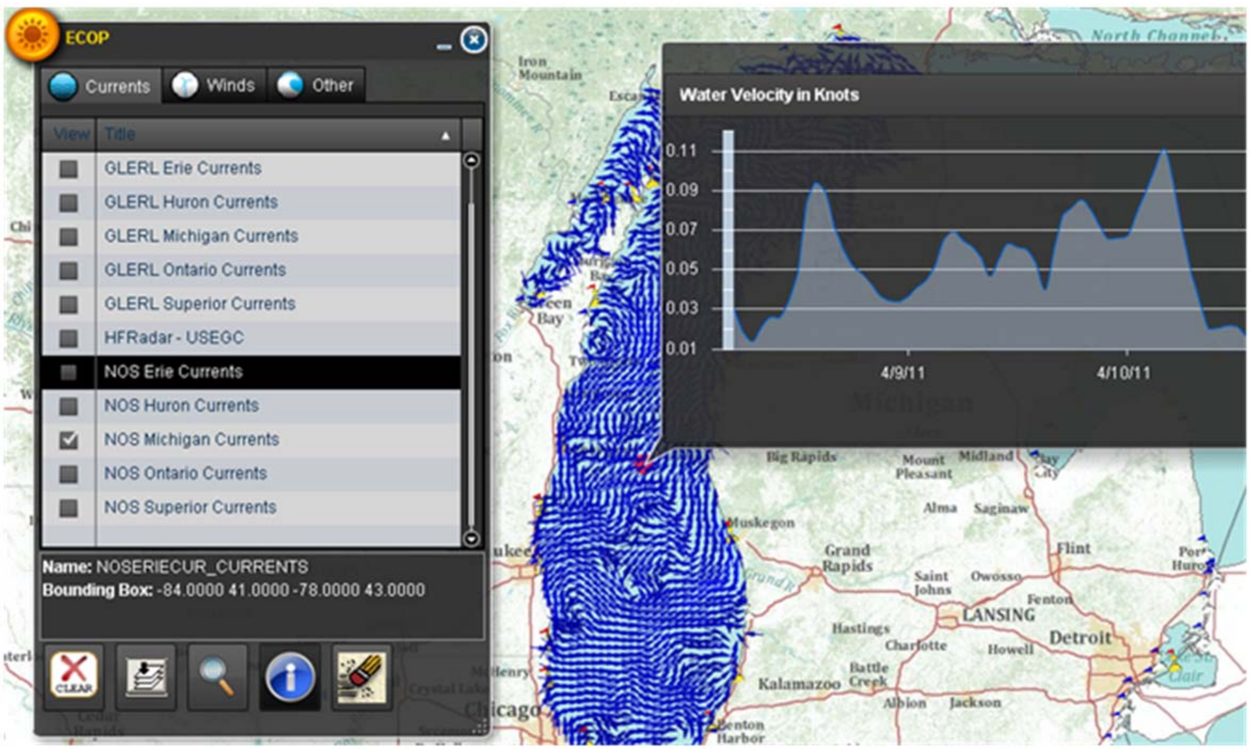

Figure 8-4. Screen snapshot of prototype web portal showing forecast lake currents.

The prototype portal demonstrates the feasibility of a centralized data access system that allows users to interactively view and query metadata to identify observational resources that record data that addresses their needs and to then view the data directly, albeit in a restricted number of formats. In brief, the technology certainly exists to implement an observing system DMAC that integrates a wide range of data and services into a cohesive and useful system responsive to user needs.

8.2 DMAC DESIGN

This section describes the recommended conceptual design for the DMAC layer in the GLOS Enterprise Architecture. The conceptual design is intended to lead to a practical balance between regional needs and resources, and the implementation of the complete array of DMAC recommendations, such as those found in the IOOS DMAC Concept of Operations document (January 2009). More details about the DMAC design can be found in this projects Concept of Operations document (Appendix C).

The core aspects of the conceptual design are simple:

- The system must deliver data to end-users in a useful form;
- This useful form will vary based on the user, so multiple data formats/services must be made available to meet different user's needs;
- Users must be able to easily find and access available data and data products;
- Centralization of data management roles to facilitate successful data management and data product generation;
- The use of a common data model (CDM) to store data and provide different access methods from the data store;
- Scalability – able to increase capacity to address increased data volumes – and expandability – able to increase capabilities to handle new types of data and support new data products;
- Ability to work at regional, whole-lake, and basin-wide scales;
- Focus on performance and robustness;
- Coordination with federal/international programs;
- A design that recognizes and preserves existing data management systems maintained by leading technical and research organizations in the basin; and
- A design that provides ways to management and access data across different time scales, from real-time, immediate data to long-term sensing of annual and decadal trends.

Review of the current observing system has demonstrated that the existing GLOS core infrastructure, which has shown considerable achievement to date in managing disparate data, developing data products and meeting IOOS standards requirements, is an appropriate foundation for near-term expansion.

We therefore recommend that the observing system should formally adopt the Community Managed System alternative presented in the project Technical Memorandum "Alternatives Development: Data Management and Communications (DMAC)." (Appendix A), and that GLOS should take the lead role within the Community Managed System in organizing and maintaining centralized servers and in providing a data management team. Also, the final design and implementation plan should consider offsite provisioning of necessary server resources in order to improve reliability and minimize potential bandwidth limits, and development of appropriate system redundancy to support high availability of proposed operational models and critical data feeds.

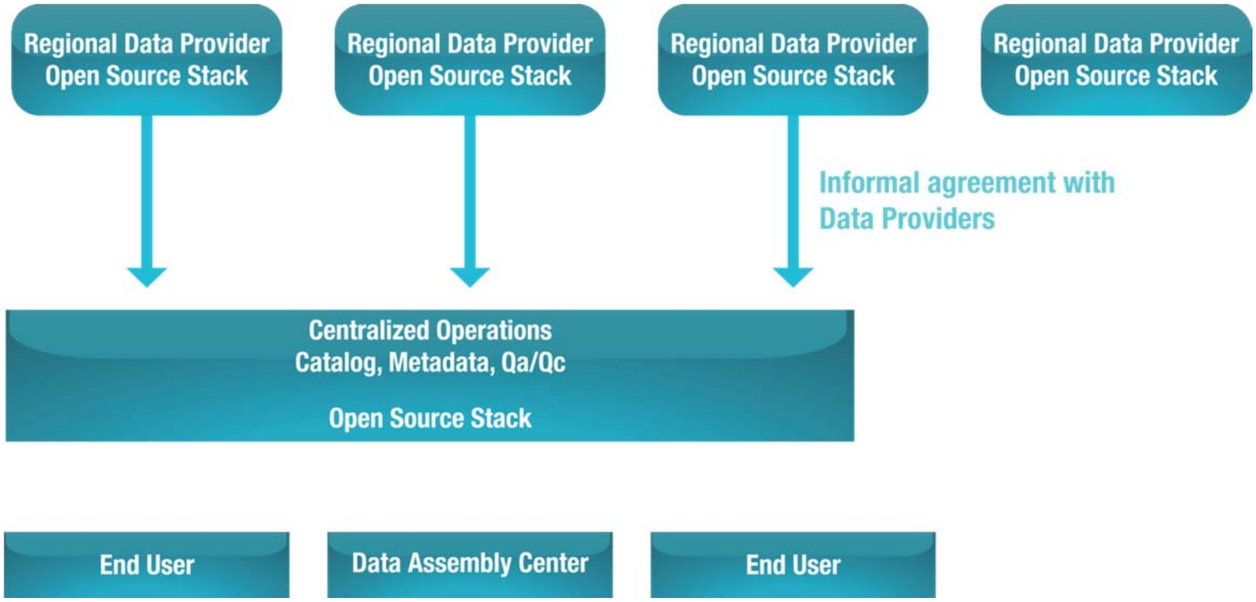

Figure 8-5. Conceptual design of a Community Managed System.

As shown in Figure 8-5, in a Community Managed System, a central group organizes and maintains all of the data from all providers, and central servers containing open source technology(s) stack will be managed by a central data management team. The central servers will continually harvest data from data providers, who have the responsibility to make their data available to the central server using defined protocols. However, depending on user needs, data from certain systems (e.g. NDBC), may instead be made available to users directly from those systems and not replicated in the Community Managed System central servers. Data harvesting will focus on sources that are not readily accessible and/or not generally compliant with data access standards. The result is a hybrid gateway both to centralized harvested data and to distributed data providers.

External data access will be performed through a central gateway. The agreement between the central data center and the data providers is informal with no formal SLA (Service Level Agreement) in place.

The following specific recommendations are presented for the various DMAC components:

- **Storage and Data Formats –** the observing system DMAC should incorporate a GIS store as a building block for other observing system data products, continue use of NetCDF and relational databases, and address archiving at the federal and regional levels.
- **Catalogs, Data Discovery, Metadata, and Vocabularies** – the DMAC should include an effective GeoNetwork or ESRI GeoPortal server as a catalog, metadata should be registered and available for harvesting, and GLOS enterprise vocabularies should be aligned with others in the field.
- **Quality Control** - The observing system DMAC should include formal QA/QC processes for all data types.
- **Data Sharing/Delivery**- the observing system DMAC should use common data models in relational databases or gridded formats such as NetCDF, allowing layering of existing

tools and services on top and potentially adding Sensor Observation Service (SOS), WaterML, new Web Map Service (WMS) technologies, Open-source Project for a Network Data Access Protocol (OPeNDAP), Web Coverage Service (WCS), Web Feature Service (WFS), or ESRI Services.

- **Data Products –** A dedicated team of staff within GLOS and across the complete observing system is necessary to address the wide range of users, user needs, and data products.

These recommendations are presented in more detail below along with comments about staffing levels. Additional detail is presented in the Concept of Operations (Appendix C) and Implementation Plan (Appendix D) documents.

8.2.1 Storage and Data Formats

These design recommendations are related to the Storage and Data components of the DMAC system.

- Incorporate a central GIS store that stores relevant spatial data (including coastline, bathymetry, and hydrology) and provides a portal connected to a map server. This will serve as a building block for other OS data products.
- Continue support of Unidata tools like NetCDF for time-varying gridded data such as model results and satellite data, allowing integration with OOI-CI as it comes online.
- Continue use of a relational database to handle time-varying observation data from stationary observatories and extend to handle non-stationary observatories; explore use of existing frameworks such as GLENDA or SCRIBE.
- Enter into an agreement with the National Oceanographic Data Center (NODC) as a federal archiving facility, and develop appropriate regional archiving capabilities.
- Examine whether hosting DMAC components, including storage, in the "cloud" is a cost-effective alternative.

8.2.2 Catalogs, Data Discovery, Metadata, and Vocabularies

- The DMAC must include an effective catalog; GLOS's current GeoNetwork server is more than adequate, but evaluation of ESRI's Geoportal Server as an alternative is suggested.
- All data in the observing system should be registered with the IOOS Obs Registry, and metadata catalog information should be made available in Web Accessible Folders (WAF) for easiest access to harvesters.
- The current GLOS GeoNetwork server provides excellent metadata capabilities that can be extended through implementation of ncISO with TDS to harvest metadata in ISO formats from the THREDDS catalog and data sets.
- All metadata should be available using the ISO convention, though perhaps stored in a single form and then presented in different representations, including ISO and FGDC.
- GLOS should become a partner in the Marine Metadata Interoperability (MMI) project to ensure consistency in usage of technical terms and ease of communication within the marine research and observation community through sharing of vocabularies.

8.2.3 Quality Control

The observing system DMAC should include formal QA/QC processes for all data types. The ongoing implementation by GLOS of EPA quality control standards could be augmented with the QARTOD (Quality Assurance of Real-Time Ocean Data) processes as they mature.

8.2.4 Data Sharing/Delivery

Overall, the observing system DMAC should harvest and store data using common data models in relational databases or gridded formats such as NetCDF, allowing the DMAC team to layer existing tools and services on top and support additional data sharing methods, including.

- Sensor Observation Service (SOS) server to supplement existing efficient GLOS JSON implementation.
- WaterML (later implementation) to support data harvesting from CUAHSI/hydrology community and data delivery.
- New Web Map Service (WMS) technologies beyond current GLOS WMS capabilities, including multi-core implementation for performance, compliance with latest OGC standard, and support for the time specification and widely used projections.
- Continued support for GLOS's THREDDS Data Server

Web Coverage Service (WCS), Web Feature Service (WFS), and (depending on technology stack for data products) ESRI Services are also services that may be considered for inclusion in the DMAC.

8.2.5 Data Products

Wide ranges of users, user needs, and relevant data products have been identified previously for the Great Lakes (this project, 2007 GLOS Conceptual Plan). Because of the breadth of needs, we recommend that staffing for the observing system include a dedicated data product team that can respond efficiently to develop products that address high-priority needs. Initial discussions between users and this team will help refine the implementation details for the DMAC design, including:

- Back end technology stack (open source, commercial, or both)
- Relational database (open source, commercial, or both)
- Web client tool options:
- Mobile App platforms
- Desktop/Tool Product Support

8.3 DMAC IMPLEMENTATION AND STAFFING NOTES

This section presents some initial considerations for implementation and staffing of the DMAC.

8.3.1 DMAC Implementation Notes

Implementation of the expanded observing system is described in detail in the Implementation Plan document (Appendix D) and summarized in Section 8 of this report. In brief, the implementation plan builds the observing system from Design Level 0 (the current level of capability) to Design Level A, a basic level of functionality over a five-year period, positioning the system to undertake additional targeted expansion alternatives in response to identified user needs (Design Level B). Overall, this build-up will result in full implementation over five years of a basin-wide observing network supplemented by opportunistic implementations at lake and regional scales.

For the DMAC, however, Level A implementation will put in place necessary infrastructure to address observing system needs at all three spatial scales (basin-wide, lake and regional) within the first three years. This reflects the expectation that deployment of new observing platforms and connection of observing data streams to the DMAC will be independent of the spatial scale of observing system applications, provided that the DMAC design is readily scalable to accept additional data sources. Early implementation of a complete DMAC infrastructure ready to integrate new data feeds from any effort – local, lakewide, or across the Great Lakes Basin – will encourage deployment of new observing platforms and development of new models and data products by providing a ready-to-use framework for data collection, archiving and dissemination.

8.3.2 DMAC Staffing Notes

Implementation in short order of a complete DMAC infrastructure for the observing system will require careful attention to necessary resources. During the development of the DMAC conceptual design, the project team considered the importance of appropriate roles in staffing and necessary levels of effort. In Table 8-1, we present recommended roles and ranges of effort for the staffing of an observing system DMAC that address an aggressive implementation schedule and a continuing high level of support for scaling and expansion of the DMAC post-implementation. Additional information about each role is presented in Section 3.7 of the DMAC Concept of Operations report (Appendix C).

Table 8-1. DMAC Management and Implementation Team Roles

Role	Budget
Front Office	0.5 FTE
DMAC Operations Manager	1.0 FTE
Metadata/Catalogs/Registry, QA/QC/Federal Facility Liaison	1.0 FTE
Model Data Manager/Liaison	1.0 - 2.0 FTEs
Observation Data Manager/Liaison	1.0 FTE
Systems Administrator	0.5 - 1.0 FTE
Web Site Designer UI/UX	0.5 – 1.0 FTE
Data Products	1.0 – 5.0 FTEs

The overall staffing is anticipated to require at least 6.5 FTEs/year for the full five-year duration of the observing system implementation. Staffing may include outside consultants during the design and early implementation stages, but the expectation is that expertise and knowledge will transition in-house within three years. The roles shown in this table could be fulfilled solely within GLOS, but it is likely that efforts for certain roles, such as Model Data Manager/Liaison, Observation Data Manager/Liaison, and Data Products will be shared with organizations that provide data and data products.

8.4 END-TO-END DMAC DEMONSTRATION

A final exercise was undertaken during the development of the DMAC Concept of Operations to validate the feasibility and flexibility of the proposed design. In this exercise, ASA led the project team's review of the data needs and interconnections needed to implement an end-to-end modeling application for assessment and management of Lake Michigan trophic gradients, and examined how these factors related to the proposed DMAC design approach. Section 5 of the DMAC Concept of Operations document describes the data sources, how they map to the data categories previously identified for the DMAC, and anticipated processing steps. The resulting DMAC schematic for the demonstration application is shown in Figure 8-6.

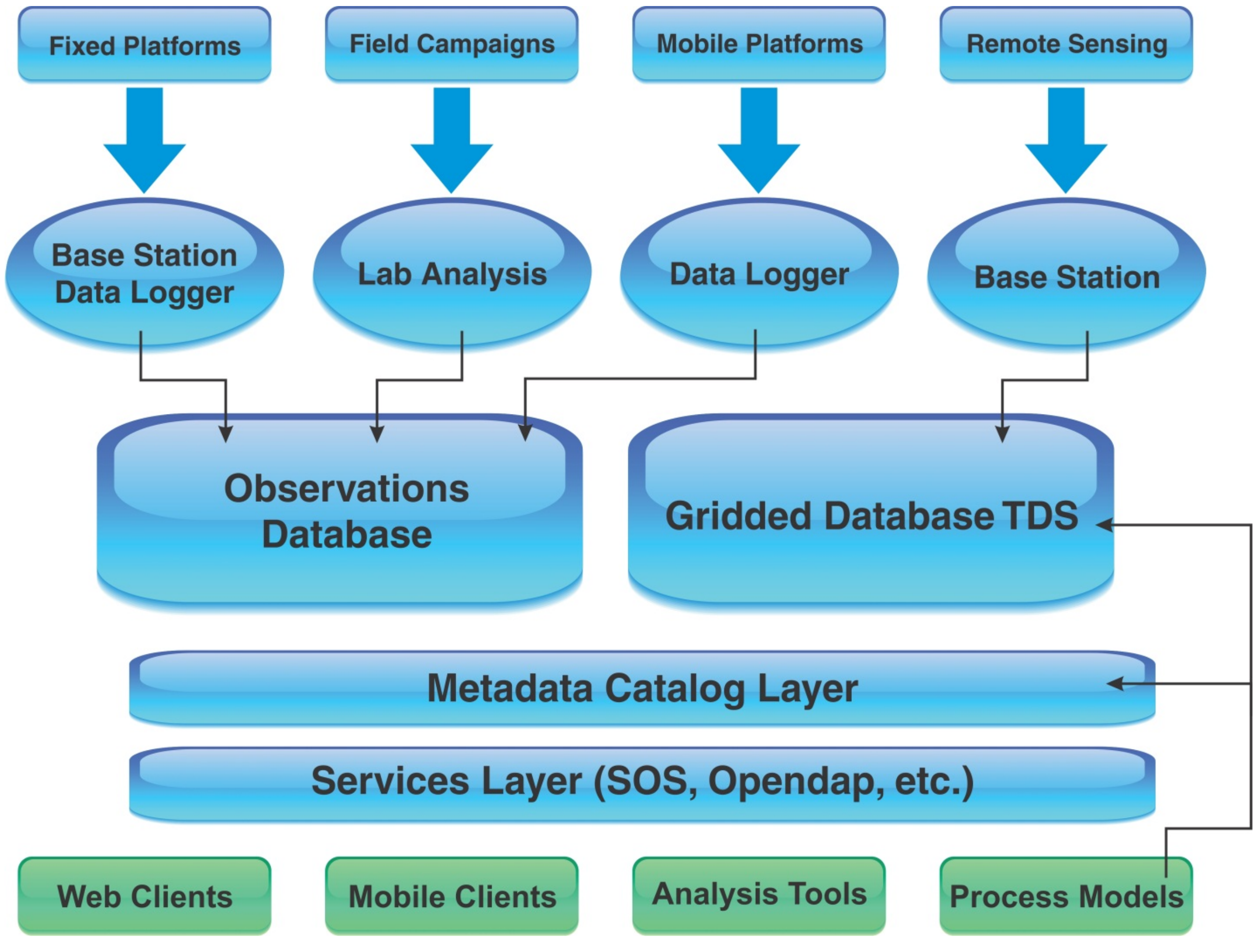

Figure 8-6. DMAC schematic for end-to-end model demonstration.

9. IMPLEMENTATION PLAN

9.1 IMPLEMENTATION FRAMEWORK

The plan for implementation of the GLOS Enterprise Architecture is described in the accompanying Implementation Plan report (Appendix D). This document presents a roadmap for research, development, testing, evaluation, and operational support steps that should be taken over the near term (next five years) that are necessary to ultimately arrive at a fully operational system. Specifically, the implementation plan discusses the steps required to transition from a Design Level 0 (the current level of capability), to Design Level A, a basic level of functionality, and then positions GLOS to begin to undertake targeted expansion alternatives in response to identified user needs (Design Level B).

These levels of design are described in Section 6.1 and are recapitulated here. Level A describes a state of design build-out that completes ongoing and planned activities and brings the system up to a basic level of functionality. Specifically, design Level A includes the following elements:

1. Completion of ongoing projects or readily accomplished projects that have existing planning and funding mechanisms in place (across the basin);
2. Instituting a data management and communications (DMAC) plan to support all scales of observation in terms of hardware, protocols and standards (across the basin);
3. Implementing a minimum level of sensing required; and
4. Developing and to the extent possible, implementing a plan for operational models required for the basin and each subarea.

Items 1 and 2 above are activities that are to be conducted across the basin, resulting in a basin-wide effort to enact ongoing projects, bring them into communication with the GLOS enterprise, and standardize and regularize the data management and communications protocols by instituting a DMAC that supports all scales of observation. Items 3 and 4 describe how transitioning to Level A also requires basin-scale activity and site-specific action within each of the GLOS enterprise subareas: bringing each subarea up to a basic level of sensing, and developing a plan for operational models in each subarea.

Completion of the Level A stage of development then sets the stage for further expansion of the system in response to identified user needs, system maturity, and available funding. These expansion alternatives begin to advance the system to a new stage of the design build-out (Level B) and are conducted to bring the system to a new level of responsiveness to user needs at the scale (regional, lake, basin) most appropriate to respond to those needs.

Level B expansion alternatives are necessarily site-specific, and a description of the range and variety of possible expansion alternatives is well beyond the scope of this conceptual planning effort. Instead, the implementation plan describes a process by which an identified user need can be used to drive expansion of the GLOS enterprise in a particular direction, resulting in a site-specific design at a defined scale within a particular GLOS enterprise sub area. To describe this process by example, the implementation plan presents an approach for implementation phasing of two end-to-end demonstration observation systems, or case studies: observing the nearshore-offshore productivity gradient in Lake Michigan and constructing a Lake Erie drinking water hypoxia warning system in Lake Erie. The expansion alternatives and phasing selected for these two examples are based on site- and problem-specific trade studies described in the Trade Studies report.

The GLOS enterprise data integration and distribution framework is shown in Figure 9-1 below, in which a central data management and communications core receives data from a variety of sensing sources and integrates with models and other producers of derived products to address user needs. The specific steps that will be taken to build the GLOS enterprise through the different design levels will involve developing and building elements of this data integration and distribution framework. Specific recommended steps are described in the following section.

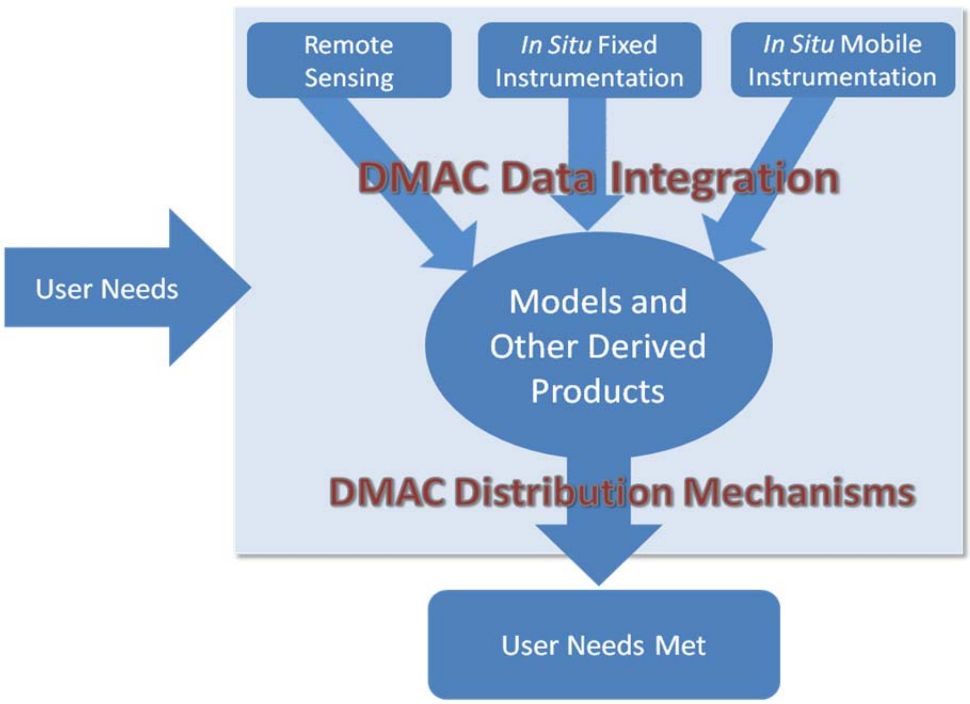

Figure 9-1. GLOS data integration and management framework.

9.2 IMPLEMENTATION STEPS

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 Table 9-1. A timeline for completion of these activities is also presented as Figure 9-2. In both figures, tasks are shown 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. Table 9-2 shows how the implementation of the GLOS Enterprise addresses the user needs discussed in Section 3.

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. With the conclusion of this project, this task is largely complete at the basin and lake scales, building on information developed previously by GLOS, collected during the information gathering phase of this project, and reported in Technical Memorandum 3. A significant amount of information on local and regional sensing has also been gathered and reported in the Technical Memorandum, but will require additional effort and continuing effort to cover all local and regional monitoring activities over time. The final product will be a comprehensive description of all currently operated sensing systems, to be maintained as a live geospatial database that serves as an index to the DMAC to be maintained by GLOS in perpetuity.

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. The catalogue of existing systems will be expanded to reflect the completion of these activities, and the sensing systems will be brought into the GLOS enterprise geospatial database as they come on line, expanding the index to be accessed by the DMAC. Ongoing Level A activities have been identified at the basin and lake scales under this project, and this task will be substantially complete at these scales at the close of the project. Additional activities at the regional scale that are underway will require further tracking and addition to the geospatial database.

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 initial detail design activity will be conducted over a period of half a year, followed by a two-year build phase. Following the build phase, the DMAC will go into a long-term maintenance phase, during which sensing system additions and phase-outs will be identified and incorporated into the DMAC.

The DMAC design and build-out will include hardware, protocols and standards development across the basin as described previously in Section 8 of this report and in the Concept of Operations report (Appendix C) and supporting DMAC Technical Memorandum (Appendix A). 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. Activities to be conducted under this implementation step will differ at the basin, lake and regional scales.

At the basin scale, a GLOS basin-scale baseline sensing plan will be developed in the first three quarters of the implementation period. This activity will build on the cataloging of user needs and sensing priorities that have been developed previously by GLOS and many other organizations in the Great Lakes, and described in this report and supporting technical documents. A next step will be to refine the prioritization of user needs that would be broadly served by a baseline sensing network that has been developed with this design effort, and develop consensus across the major sensing organizations and federal agencies, academic groups and NGOs that support sensing in the Great Lakes. Following prioritization a detailed design effort will be conducted to develop specific sensing technologies and locations for deployment, refining the initial trade studies evaluations conducted under this work effort.

At the lake scale, a subarea baseline sensing plan will be developed for Lake Michigan that is coordinated with the basin scale plan described above, and with the existing CSMI program. Similar to the work to be conducted at the basin scale, this activity will build on the cataloging of user needs and sensing priorities for Lake Michigan that have been developed previously as described in this report and supporting technical documents. A next step will be to refine the prioritization of user needs that would be broadly served by a baseline sensing network that has been developed with this design effort, and develop consensus across the major sensing organizations and federal agencies, academic groups and NGOs that support sensing in Lake Michigan. Following prioritization, a detailed design effort will be conducted to develop specific sensing technologies and locations for deployment in in-situ, mobile, and remote sensors, refining the initial trade study evaluations conducted under this work effort.

At the regional scale, a baseline sensing plan will be developed that is focused on providing local uplinks to the lake and basin-scale sensing plans. A detailed plan for sensing strategies to be employed at this scale will be developed in the early stages of the 5-year implementation period. Actual implementation of baseline sensing will be conducted on an opportunistic basis, in tandem with Level B expansion alternatives activity – as projects are identified, funded and implemented at the regional scale, the plan will ensure that baseline monitoring requirements are met and that sensing systems built at these scales will include uplinks to the lake and basin scale baseline sensing system. These regional activities will be initiated within the 5-year implementation period, but will continue through a longer, 10-20 year time frame.

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. The scale-specific design and implementation strategies are described below.

At the basin scale, a detailed plan for fully operationalizing three identified models and analytical systems will be developed and implemented in the 5-year implementation period. As described in Section 4, these models were identified during the early phases of the project as models that serve a broad range of user needs and are at an advanced stage of development that could be brought to fully operational status at the basin scale. Models to be made operational under this effort are:

- The Great Lakes Forecasting System (GLFS),
- The Advance Hydrologic Prediction System (AHPS)), and
- A unified framework for processing and serving remotely sensed data.

At the lake scale, efforts to operationalize models will be focused on Lake Michigan, in tandem with the efforts to be conducted under Task A3. This effort will focus on two existing modeling efforts that are at an advanced stage of development, target a prioritized set of user needs, and are appropriate for operationalizing within the project timeline. These are:

- The LM3 Eutro Modeling Framework
- The USGS SAFE model for forecasting of beach closings

These models are described in greater detail in Section 4 of this report. In the other Great Lakes, a plan will be developed in five years to identify, prioritize and operationalize models, building on the Lake Michigan build-out effort.

At the regional scale, operationalizing of models will lag the efforts to be conducted at the basin and lake scales, and activities will be conducted opportunistically as community support and funding develops. To support the development of operational models at this scale, design activity at the outset of the implementation period will focus on completing the catalogue of models, gauging their operational status, and identifying opportunities for operationalization. Following this design effort, operationalized regional models will be developed primarily through third party funding, possibly with incentivization by federal agencies.

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 to 3 observing system subarea projects for implementation over the 5-year near-term design period.

At the regional scale, this step will initiate with an opportunities identification process to identify sensing activities that would present:

- Significant opportunities for benefit to human health (e.g., reduced boating hazard, reduced human exposure to pathogens, etc).
- Significant opportunities to realize industrial, commercial, economic benefit (e.g., power plant intakes and 316(b), municipal water intakes, industrial processes, shipping).
- Significant opportunities for benefit of GLOS to regulatory compliance.
- Significant opportunities for benefit of GLOS to completion of GLRI priorities.

Regional expansion alternatives will rely primarily on third party funding sources, but could be incentivized by federal cost-share. The opportunities identification described above should be paired with incentivization to generate opportunities for development. Incentives include:

- Cost share / seed money
- Technical assistance
- Logistical assistance (e.g. research vessel support)
- Opportunity for sensing organizations to have a long-term connection into the GLOS enterprise

Expansion alternatives are also possible at the lake and basin scales. At the largest scales, basin-scale expansion alternatives will rely primarily on federal funding, while activities conducted at the lake scale may rely upon a mix of federal funding and support from regional entities or public/private consortia.

While the design process for any given expansion alternative will be highly site specific, we have provided examples of how expansion alternative design can be conducted in Sections 5 and 6 of this report. Section 6 provides a summary of how the design process for expansion alternatives occurs, using the case studies as examples, and the Trade Studies (Section 7) describes a structured process by which the technology mix for a given sensing strategy can be tested against a comprehensive list of design criteria developed under this project effort. Similarly, it is strongly recommended that the design of any new expansion alternative include a process of identification of user needs and major design drivers, technology evaluation and selection using the trade studies process, and adoption of the project guidelines for integration into the DMAC.

9.3 PROPOSED INVESTMENT SCHEDULE

The completion timeline shown in Figure 9-2 graphically describes the tasks from the previous section and how they can be accomplished over the 5-year implementation timeframe of this design effort. These tasks are further described in Figure 9-3 in terms of estimated level of funding by fiscal year under the assumption of a $25M 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 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) and a higher level of funding ($50M). The funding distribution under these alternative funding scenarios changes to reflect the critical priorities of the enterprise system build-out: design and construction of the DMAC remains central to the plan under all funding scenarios, and the level to which physical sensing can be developed to address user needs and models that provide user products scales with the available funding. Details of each of these funding scenarios are provided in the implementation plan, but the outcomes can be summarized as follows:

- $10M Funding level:
    - Characterize existing system and develop database of all existing sensing systems and associated metadata
    - Plan and construct basin-wide DMAC
    - Design and minimal implementation of Level A sensing strategy, minimally address Table 3-1 user needs
    - Minimally operationalize models for creating end user products
    - Minimal coordination and incentivizing of third-party expansion alternatives buildout
- $25M Funding level:
    - Characterize existing system and develop database of all existing sensing systems and associated metadata
    - Plan and construct basin-wide DMAC
    - Design and implementation of Level A sensing strategy – primarily physical parameters, address subset of Take 3-1 user needs.
    - Operationalize models for creating end user products as described in implementation plan (Basin-wide, Lake Michigan)
    - Coordination and incentivizing of third-party expansion alternatives buildout

- $50M Funding level:
  - Characterize existing system and develop database of all existing sensing systems and associated metadata
  - Plan and construct basin-wide DMAC
  - Design and implementation of Level A sensing strategy – physical and biological parameters, address broader list of Table 3-1 user needs.
  - Operationalize models for creating end user products as described in implementation plan (Basin-wide, lake-scale at multiple lakes)
  - Coordination and incentivizing of third-party expansion alternatives buildout.

9.4 LEVERAGING INVESTMENTS IN GLOS

The implementation plan describes several observing system subarea examples and breaks out the costs for each. These are examples only and as such are imperfectly representative of the true costs for implementation expected at any given lake, regional, or local observing system subarea. Nevertheless, these costs of implementation can be used to extrapolate the scope of the larger observing system implementation that is enabled by this project and the federal and non-federal costs associated with the implementation effort.

Table 9-3 presents a summary of this larger scope and illustrates how the mid-range $25M investment in the Great Lakes Observing System fits in with other federally funded activities and leveraged non-federal funds. The table summarizes the costs associated with construction and maintenance of very localized observing systems (municipal water intake buoys, power plant intake buoys, and buoys sponsored by local tourism regions, recreational boating organizations, etc), with regional observing system subareas as depicted in Figure 6-3 of this design report, with Lake-scale observing system subareas, and with the basinwide buildout of the Level A sensing system.

Each of these components will be initiated or completed in the 5-year timeframe of this near-term design effort, as indicated in the first column of the table. The total costs in the right column are apportioned between federal dollars allocated to this GLOS enterprise design build effort, other federal dollars, and leveraged non-federal dollars enabled by GLOS. The funding allocations differ by scale: local components of the system are financed locally, intermediate scale components are funded via a mix of sources, and the largest scale basin-wide activities are funded federally through this effort, enabling much of the activity that happens at smaller scales.

This effort is closely related to and highly consistent with the missions of the various state, provincial, and federal organizations that contribute to present-day monitoring of the Great Lakes, as listed at the bottom of Table 9-3. The addition of the GLOS enterprise framework provides a mechanism for improved interactions between the many federal entities doing work in the Great Lakes, and also for more clearly and transparently defining their respective missions. The proposed investment in the GLOS enterprise provides a way to better administrate the significant federal funds already invested in the Great Lakes, while also enabling significant additional non-federal investment in the region.

Table 9-1. Recommended 5-year implementation planning steps and anticipated completion

Design Level	Implementation Step	Basin Scale	Lake Scale	Regional Scale
0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC .*	Catalogue is complete with this project, geospatial database initiated	Catalogue is complete with this project, geospatial database initiated	Catalogue is complete for RDAs with this project, geospatial database initiated
A	*Step A1: Catalogue ongoing or funding-in-place activities .*	Catalogue is complete with this project; monitor through 2013	Catalogue is complete with this project; monitor through 2013	Expand catalogue 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 A3: 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 A4: 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 with this project
- substantially complete within 5 years
- develop groundwork in 5 years, complete in 10-20 years

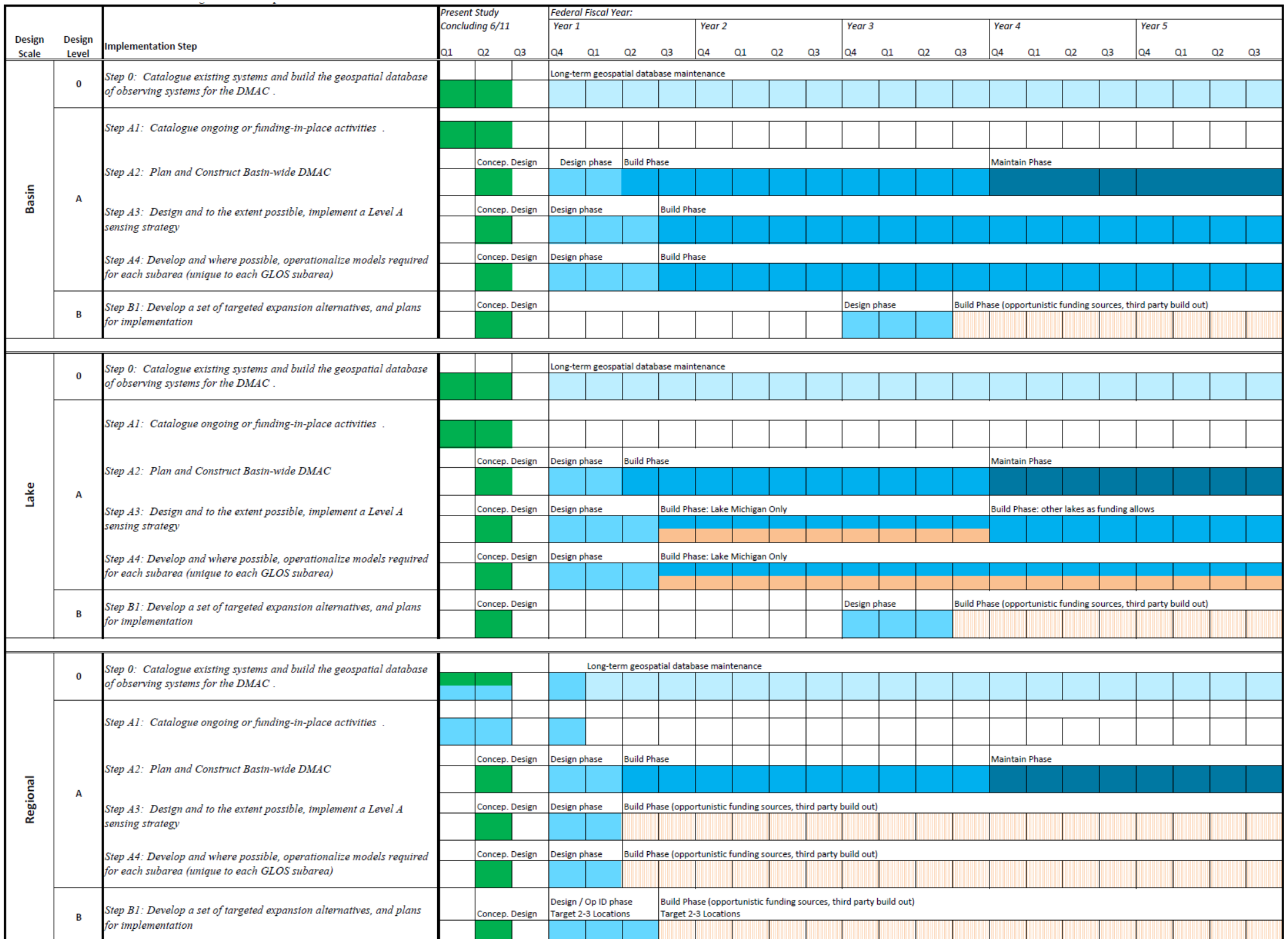

Figure 9-2. Completion timeline

Table 9-2. User needs addressed

◑ = Sensing systems
● = DMAC

User	Goals Addressed	Management Issue	Data Information Needs	Most Relevant Design Scale	Step 0	Step A1	Step A2	Step A3	Step A4	Step B1
Commercial Shipping and Maritime Operations	Improve safety and efficiency of maritime operations	Maximize shipping season	Lake ice distribution	Basin wide	◔		●	◑	RS	
		Manage size of cargo/load	Coastal bathymetry, water levels	Regional	◑		●	◕	GLFS	
		Safety	Weather/wave forecasting, other met/weather data	Basin wide	◑		●	◕	GLFS	
		Long term planning	Great Lakes water level forecasts	Basin wide	◑		●	◕	GLFS, LBRM	
		Environmental compliance	Ballast discharge	Basin wide			●			
			Ballast treatment	Basin wide			●			
		Search and rescue	Currents (3-D), weather	Whole lake	◔		●	◕	GLFS	
		Oil spill	Location, amount, trajectory	Whole lake	◔		●	◕	GLFS	
Fisheries	a) Protect and restore healthy ecosystems b) Protect and restore habitat c) Improve nearshore health	Environmental Assessment	Water temperature, water quality and lower food web productivity, sedimentation	Basin wide	◔		●	◑	LMEM	
		Fish Stock	Population sizes, health, distributions, viruses, fish kills, fish movement	Whole lake	◔	◑	●	◕	LMEM	
		Loss of habitat	Sedimentation/solids/land cover, bottom type characterization	Regional			●	◑	LMEM	
		Climate Change	Meterological/Physical	Basin wide	◑		●	◕	GLFS, LBRM	
		Fish Advisories	Fish contaminants	Whole lake	◔		●	◑	GLMOD	
		Safety	Weather/wave forecasting, other met/weather data	Basin wide	◑		●	◕	GLFS, LBRM	
Water Quality Managers	a) Protect and restore healthy ecosystems b) Protect and restore habitat c) Improve nearshore health d) Clean up toxics	Eutrophication	Nutrient concentrations, lower food web productivity	Whole lake	◔	◑	●	◕	LMEM	
		HABs	Phytoplankton species/abundance, microcystis, cyanobacteria, location	Regional	◔	◑	●	◕	LMEM, RS	
		Nuisance benthic algae	Cladaphora, Dreissenids, lower food web productivity, location	Regional	◔	◑	●	◕	RS	
		Climate Change	Meterological/Physical	Basin wide	◑		●	◕	GLFS, LBRM	
		Toxics	Contaminant concentrations, bacteria, pathogens	Whole lake	◔		●		GLMOD	
		Sediment load from watershed	Suspended solids	Regional	◔	◑	●	◕		
		Invasive species	Biological	Whole lake			●			
Drinking Water	Reduce public health risks	Water levels	Bathymetry, currents, waves, water level, temperature	Whole lake	◑		●	◕	GLFS, LBRM	
		Climate Change	Meterological/Physical	Basin wide	◑		●	◕	GLFS, LBRM	
		Contaminants and turbidity	Contaminant concentrations	Whole lake			●			
Power Generation	a) Improve homeland security b) prevent invasive species	Water levels	Bathymetry, currents, waves	Whole lake	◑	◕	●		GLFS, LBRM	
		Climate Change	Meterological/Physical	Basin wide	◑		●	◕	GLFS, LBRM	
		Nuisance benthic algae	Phytoplankton species/abundance & location	Regional			●		RS	
		Invasive species	Biological	Whole lake			●			
Recreational Boaters	Improve safety and efficiency of maritime operations	Safety	Weather/wave forecasting, other met/weather data	Whole lake	◑		●	◕	GLFS, LBRM	
		Climate Change	Meterological/Physical	Basin wide	◑		●	◕	GLFS, LBRM	
		Nuisance benthic algae	Phytoplankton species/abundance & location	Regional	◔		●	◑	RS	
		Water levels	Bathymetry, currents, waves	Whole lake	◑		●	◕	GLFS, LBRM	
Coastal Management	a) Protect and restore habitat b) Improve nearshore health	Shoreline erosion	Bathymetry, currents, waves	Regional	◑		●	◕	GLFS, LBRM	
		Climate Change	Meterological/Physical	Basin wide	◑		●	◕	GLFS, LBRM	
		Invasive species	Biological	Whole lake			●			
		Loss of wetlands	Land use/land cover	Regional	◔		●	◑	RS	
Beaches	Reduce public health risks	Beach closure	Pathogens	Regional	◔	◑	●	◕	BAM	
		Safety	Weather/wave forecasting, other met/weather data	Whole lake	◑		●	◕	GLFS, LBRM	
		Nuisance benthic algae	Phytoplankton species/abundance & location	Regional	◔		●	◑	RS	
		Water levels	Bathymetry, currents, waves	Whole lake	◑		●	◕	GLFS, LBRM	
Emergency Response	Reduce public health risks	Safety	Weather/wave forecasting, other met/weather data	Whole Lake	◑		●	◕	GLFS, LBRM	
		Currents	Currents	Whole lake	◑		●	◕	GLFS, LBRM	
		Water levels	Bathymetry, currents, waves	Whole lake	◑		●	◕	GLFS, LBRM	

Step 0: Catalogue existing systems and build geospatial database for DMAC
Step A1: Catalogue and monitor completion of Level A activities
Step A2: Plan and build DMAC
Step A3: Design a Level A Sensing Strategy and implement at the Basin Scale, in Lake Michigan and regionally on an opportunistic basis
Step A4: Develop plan for operationalizing models, and implement at the basin scale, in Lake Michigan, and regionally on an opportunistic basi:
Step B1: Develop set of targeted expansion alternatives, plans for implementation

GLFM	Great Lakes Forecasting Model
LBRM	Large Basin Runoff Model - next generation is Advanced Hydrologic Prediction System
RS	Remote sensing algorithms
BA	Beach Advisory Models
GLMOD	
LMEM	Lake Michigan Ecosystem Model

Design Scale	Design Level	Implementation Step	Present Study Concluding 6/11 (Q1–Q3)	Phases (Federal Fiscal Year)	Year 1	Year 2	Year 3	Year 4	Year 5	Totals (K$) Y1 - Y5
Basin	0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC.*		Long-term geospatial database maintenance	140	110	70	40	0	360
	A	*Step A1: Catalogue ongoing or funding-in-place activities.*								
		Step A2: Plan and Construct Basin-wide DMAC	Concep. Design	Design phase; Build Phase; Maintain Phase	730	910	1000	1000	910	4550
		Step A3: Design and to the extent possible, implement a Level A sensing strategy	Concep. Design	Design phase; Build Phase	2020	1680	1680	1510	1510	8400
		Step A4: Develop and where possible, operationalize models required for each subarea (unique to each GLOS subarea)	Concep. Design	Design phase; Build Phase	490	490	490	490	490	2450
	B	*Step B1: Develop a set of targeted expansion alternatives, and plans for implementation*	Concep. Design	Design phase; Build Phase (opportunistic funding sources, third party build out)			880	440	440	1760
Lake	0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC.*		Long-term geospatial database maintenance	80	60	40	20	0	200
	A	*Step A1: Catalogue ongoing or funding-in-place activities.*								
		Step A2: Plan and Construct Basin-wide DMAC	Concep. Design	Design phase; Build Phase; Maintain Phase	50	60	70	70	60	310
		Step A3: Design and to the extent possible, implement a Level A sensing strategy	Concep. Design	Design phase; Build Phase: Lake Michigan Only; Build Phase: other lakes as funding allows	800	800	800	800	800	4000
		Step A4: Develop and where possible, operationalize models required for each subarea (unique to each GLOS subarea)	Concep. Design	Design phase; Build Phase: Lake Michigan Only	230	230	230	230	230	1150
	B	*Step B1: Develop a set of targeted expansion alternatives, and plans for implementation*	Concep. Design	Design phase; Build Phase (opportunistic funding sources, third party build out)			310	160	160	630
Regional	0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC.*		Long-term geospatial database maintenance	10	10	10	10	10	50
	A	*Step A1: Catalogue ongoing or funding-in-place activities.*			30					
		Step A2: Plan and Construct Basin-wide DMAC	Concep. Design	Build Phase; Maintain Phase	30	30	30	30	30	150
		Step A3: Design and to the extent possible, implement a Level A sensing strategy	Concep. Design	Build Phase (opportunistic funding sources, third party build out)	30	30	30	30	30	150
		Step A4: Develop and where possible, operationalize models required for each subarea (unique to each GLOS subarea)	Concep. Design	Design phase; Build Phase (opportunistic funding sources, third party build out)	50	50	50	50	50	250
	B	*Step B1: Develop a set of targeted expansion alternatives, and plans for implementation*	Concep. Design	Design / Op ID phase Target 2-3 Locations; Build Phase (opportunistic funding sources, third party build out) Target 2-3 Locations	200	160	100	100	100	660
		Totals: (K$)			4860	4620	5790	4980	4820	25070

Figure 9-3. Proposed five-year investment schedule

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Table 9-3. Leverage Federal Investment in the GLOS

System Component	Total Units	5 year OS System Cost/unit	5 Years: Federal (GLOS Investments)	Federal Other	Non-Federal	5 Year Total
Great Lakes Municipal Water Intakes (20% buildout)	100	0.5	0.0	0.0	10.0	10.0
Great Lakes Power Intakes (20% buildout)	90	0.5	0.0	0.0	9.0	9.0
Other Locally-Sponsored Buoys (tourism regions, sportsmen's organizations, recreational boating, etc., 50% buildout)	20	0.5	0.0	0.0	5.0	5.0
Regional Observing System Subareas (25% buildout)	25	5	1.3	15.0	15.0	31.3
Lake Scale Observing System Subareas	1	10	6.3	2.4	1.3	10.0
Mobile CSMI Lake monitoring	1	5	0	5.0	0.0	5.0
Basin-wide Level A Build-out, DMAC, Model Operationalization	1	17.5	17.5	0.0	0.0	17.5
Other Federal Programs supporting Great Lakes Observing:						
NOAA Coastwatch						
Great Lakes Operational Forecasting System						
NOAA RECON						
Great Lakes Fishery Commission						
State and Provincial Nearshore Monitoring Programs						
USEPA GLNPO Great Lakes Monitoring, GLRI						
Environment Canada Great Lakes Surveillance Program						
USGS Great Lakes Science Center Fisheries Monitoring						
		Totals:	25.1	22.4	40.3	87.8

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10. RECOMMENDED NEXT STEPS

The previous section describes the detail of the proposed implementation of the near-term plan for the GLOS enterprise system. In the numerous interactions our design team has had with our project lead, project partners, members of the external advisory panel, and other stakeholders in the Great Lakes region, we have received strong encouragement for the proposed plan and recommendations regarding critical next steps, both for laying the groundwork for implementation, and also for building knowledge and support for the development of the enterprise system. These steps are summarized below:

- Solicit stakeholder input on the proposed implementation plan, focusing on the present and future users of the observing system, and expanding the characterization of user needs provided in this document.
- Seek expressions of support for the ideas outlined in this design report from the relevant federal agencies, demonstrating a strong commitment to joint efforts in developing a unified, collaborative observing system that will strengthen and focus Great Lakes scientific research and the missions of the respective agencies.
- Develop a detailed summary of GLOS enterprise funding alternatives and economic drivers in support of the Great Lakes / St Lawrence Area regional economy, in consultation with committed agencies such as The Brookings Institution, the Mowat Foundation, and the Michigan Economic Development Corporation.
- Compile a summary of regional sensing system implementation “success stories” similar to the D.C. Cook Nuclear Power Plant GLOS buoy (deployed June 2011) that, in addition to fulfilling its mission of improving Cook Power Plant operations and 316(b) planning, is currently providing valuable data to area fishermen, recreational boaters, the National Weather Service, NOAA, and the U.S. Coast Guard.
- Develop a process for converting research and management models in the Great Lakes to operational models within the GLOS enterprise. Begin with the work done by the recently formed Lake Michigan Modeling and Forecasting Workgroup as a start on this effort. Consider the roll of GLOS as a facilitator/broker of these activities. Examine how models would operate in forecasting and scenario operational modes with the GLOS Enterprise Architecture DMAC and entire enterprise.
- Hold interview/working sessions with the developers of candidate enterprise operational models to get input from them on the status of their models relative to calibration/confirmation, skill assessment, and uncertainty relative to use of the model in an operational mode and identify what additional data collection by the GLOS enterprise would provide the most value in reducing uncertainty and increasing model value within the enterprise.

- Identify one or two regional subareas that present promise and a state of readiness for serving as pilot programs for observing system subarea design and buildout. Criteria used to evaluate these candidates would include availability of development resources, ecological concern, availability of initiated observations and supporting models in place, and significance to the GLRI objectives. Target and seek funding for these subareas as pilot programs to initiate.
- Identify and provide funding for a team to begin to develop and implement a basinwide DMAC in accordance with the GLOS Enterprise Architecture implementation plan, with GLOS as the organizer for this effort. Consider beginning this process by building a web-based portal that would provide universal access to GLRI project data.

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