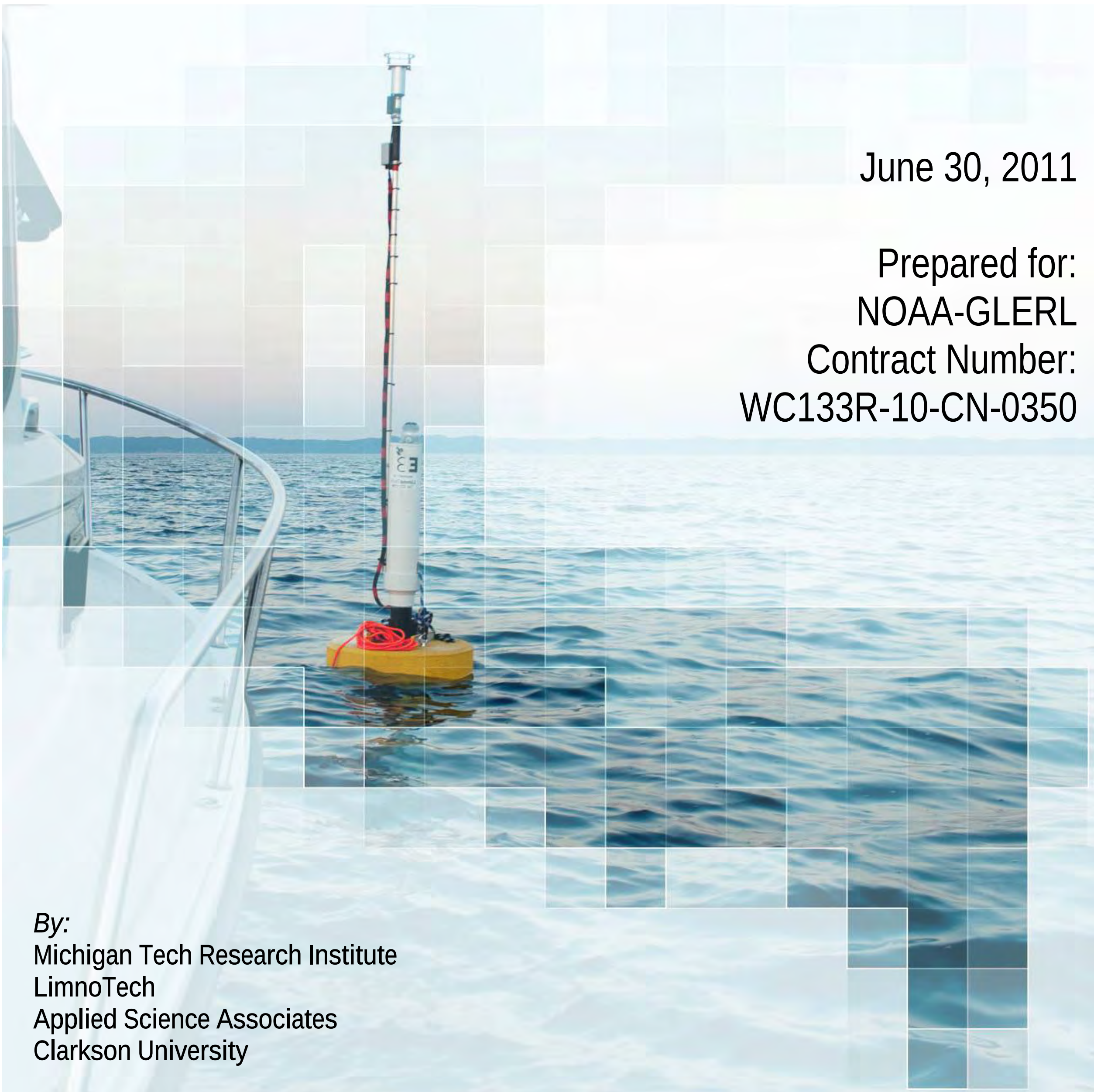
IMPLEMENTATION PLAN

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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1. KEY ELEMENTS AND OVERVIEW

This implementation plan for the Great Lakes Observing System (GLOS) Enterprise Architecture (EA) presents a roadmap or methodology that describes the research, development, testing, evaluation, and operational support steps that should be taken over the near term (over the next five years) that are necessary to ultimately arrive at a fully operational system that is consistent with the recommendations presented in the master design document. These studies considered multiple scenarios utilizing a combination of models, in-situ measurements, and the use of remote sensing to satisfy a specific set of user requirements and produced a set of recommendations based on the best technology available and the most affordable solutions that also meet the majority of the user requirements.

This implementation plan specifically discusses the roadmap to transition from Level 0 (the current level of capability), to Level A, the planned next steps or "near term" design level, which 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 (unique to each GLOS subarea),
4) Developing a plan for operational models required for each subarea (unique to each GLOS subarea).

Items 1 and 2 above are activities that are to be conducted across the basin, resulting in a basin-wide move to enact ongoing projects, bring them into communication with the GLOS, and standardize and regularize the data management and communications protocols by instituting a DMAC that supports all scales of observation. Transitioning to Level A also requires site-specific action within each of the GLOS 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. 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 Implementation Plan also includes cost estimates, Life Cycle Analyses (LCA) cost comments, and the identification of models and data inputs from remote sensing, geographic information systems (GIS), and in-situ instrumentation necessary to provide relevant user-driven information in the near term.

Key elements of an operational observing system that must be considered in developing the implementation plan are shown in Figure 1. User needs determine a set of model-based, blended products that satisfy specific requirements of the GLOS stakeholder community, a group that includes resource managers, regulators, researchers, industry, tribal communities, government agencies, and the general public. The needs of the stakeholder community will drive the specific models and outputs that are needed to address their problems and data needs. The models and products will then have specific data requirements that will allow them to meet user information needs; therefore, the requirements of the models and other derived products will drive the data parameters that need to be collected. In turn, trade studies, costs, and available technology will impact the actual technology mix used for a given observing system. Finally, the DMAC, which stores and organizes the data for use in various models and analysis, has the function of managing and integrating the data that are collected and then delivering the value-added products that satisfy user needs.

Each of the key elements (sensing technologies, models and other derived products, and DMAC) of the implementation plan will be presented in a separate section. For each element, each of the three scales will be discussed with particular attention to their differing implementation procedures. At each scale, we have identified the current observation system that is in place to form a baseline observing system (Level 0) and then described the next steps or "near term" design level activities (Level A) that can be found in Tables 1 through 3. The plan concludes with a summary of suggested investments over the next five years.

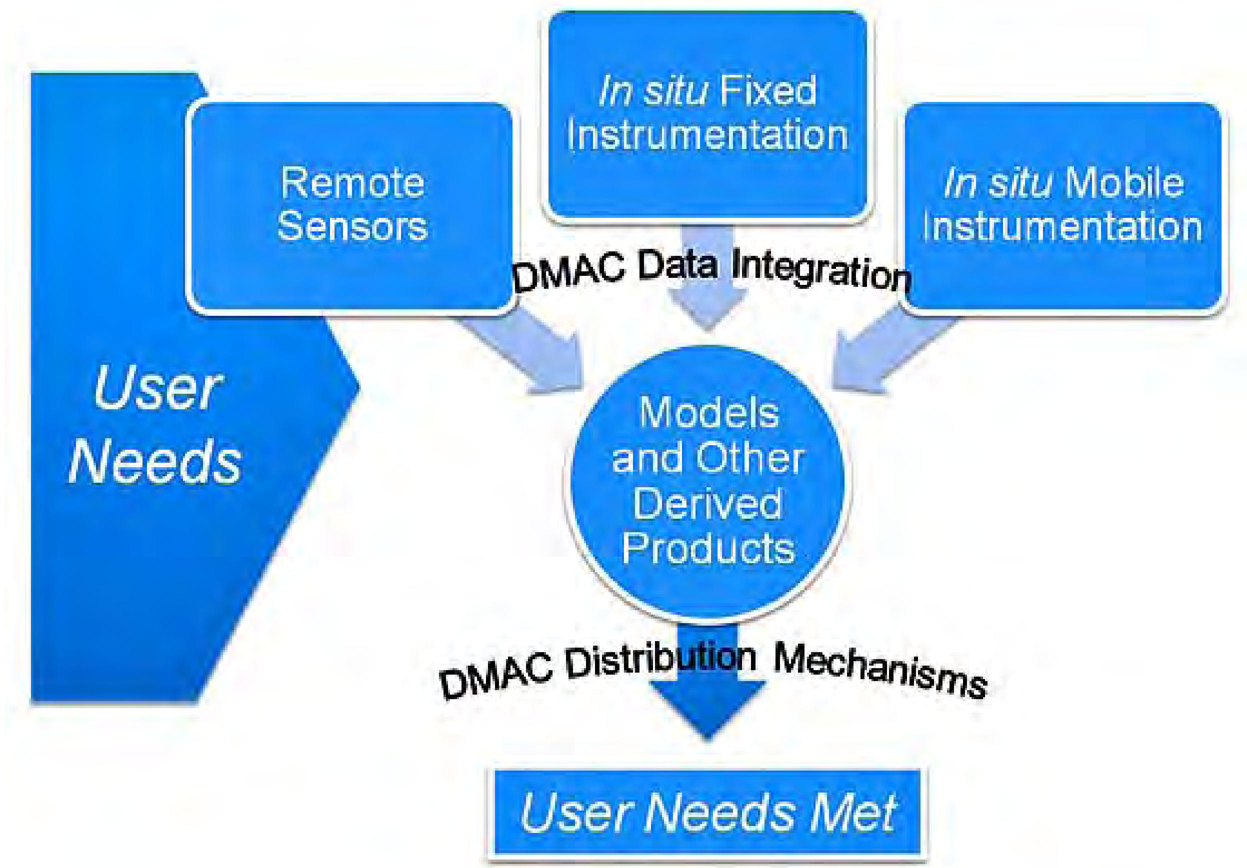

Figure 1. Diagram of the various components of an operational observing system that must be considered in developing an implementation plan.

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2. MODELS

Models are of central importance to synthesizing diverse data sets and focusing stakeholder/user needs, which determine the models that are generated and the sequence in which they are generated. Furthermore, the models must be both site- and problem-specific to address Great Lakes issues. Models within the enterprise framework range in complexity from the simple (e.g. aggregation of point measurements into a geospatial map) to the complex, such as a 3D circulation model for a given region of one of the Great Lakes. Table is a summary of current modeling capabilities (Level 0) and desired capabilities for Levels A and B at each scale (regional, lake and basin wide). As indicated in the table, the basin-wide Level 0 models include:

1) NOAA Great Lakes (GL) Operational Forecast System,
2) Great Lakes Environmental Research Labs (GLERL) Large Basin Runoff Model,
3) GLERL GL Ice Model,
4) GLERL and U.S. Army Corps of Engineers (USACE) water level models, and
5) GLERL Coastal Forecasting System (which is the research version of item 1).

The present set of models at the basin scale make up a backbone upon which a more comprehensive operational modeling framework could be built. Level 0 models at the Lake Michigan-scale include the five presented above as well as the Lake Michigan Toxics Mass Balance and Lake Michigan Eutrophication models. At the regional scale, where the models are required to be both problem-specific as well as site-centric other examples include: 1) the LMR-MB (lower Maumee Bay model which is a coupled wind wave/sediment transport water quality decision support system) and 2) National Oceanic and Atmospheric Administration (NOAA) Harmful Algal Blooms (HABs) Forecasts.

Suggested models at Level A that should be developed at all scales over the next five years are also presented in Table . At the basin-wide scale, a suggested suite of new models is as follows:

1) Operational, basin-wide models that have regular forecast updates and ongoing data assimilation;
2) GLERL next-generation Advance Hydrologic Prediction System (AHPS) ;
3) GLMOD basin-wide, multi-media screening model for chemicals of emerging concern.

Within the next five years, the goal for lake-scale models is to:

1) Refine and operationalize the Lake Michigan Ecosystem Model. The refinement needs for this model are presented in section 6 of the Design Document; and
2) GLERL high-resolution coastal forecast system for each lake.

At the regional scale, examples of possible Level A models include:

1) the Lower Maumee rivermouth – western basin linked hydrodynamic – sediment transport – eutrophication model (LMR-MB);

2) the Center for Sponsored Coastal Ocean Research (CSCOR) Ecological Forecasting Program (ECOFORE) hypoxia forecasting system for the central basin of Lake Erie; and
3) Application of the USGS Swimming Advisory Forecasting Estimate (SAFE) model to selected beaches around the basin.

The recommendations for models identified at all three scales for both Level 0 and A in Table should be considered the minimum required to realize the goals of the modeling component of the GLOS EA. These recommendations are to be developed and agreed upon by a multiagency, multidisciplinary group of stakeholders as an initial step in the implementation plan schedule detailed later in this document.

Expansion opportunities (Level B) for models include future development of regional models to address new questions or problems that should arise. To address the specific remediation and management issues in regional subareas such as Areas of Concern (AOCs), focused models have been or will be developed. These models will be selected for incorporation into the GLOS Enterprise from among those submitted to the GLOS GLMAC models inventory database.

Key research activities that are needed to fund support of Levels 0 and A modeling include model refinement, evaluation and skill assessment, and transition to operational models whose results are regularly shared with stakeholders using GLOS DMAC. Models developed for and configured to specific subareas may be transferred to other subareas dealing with the same problem. Also, the pre- and post-processing, visualization, and data delivery mechanisms might also be replicated among models in order to be more cost-effective.

Costs of the models identified in the table are specific to each but, in general, 1.5 full-time equivalent (FTEs) per model would be required. It is envisioned that the models will be developed through a partnership between government, academia, and the commercial environmental consulting sector. It is anticipated that models will typically reside in places other than the DMAC, but that results can be shared through the DMAC. For example, GLERL will host and deliver model outputs from their own research models; the same can be said for academic and commercial environmental consulting models. With respect to LCA, the operational model plan for each model should include all of the activities indicated in section 4.2 of the Design Report, including a plan for ongoing model refinement as new data become available and ongoing archiving of model input and output data files. The NOAA-GLERL Large River Basin Model (LRBM) 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 rivermouth 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 Great Lakes Forecasting System (GLFS), is fundamental to all users who are concerned with physical conditions in the Great Lakes Basin. Model outputs can be significantly improved, however, to provide better closure of G-reat Lakes water budgets, hydrology forecasts, prediction of the onset and extent of climate change impacts, and system hydrology. To address these needed improvements and make the model operational in the Level A timeframe it is suggested that the model be re-calibrated and confirmed and that additional flow gauging stations are installed on key tributaries not currently gauged.

Presently, the only truly operational model for the Great Lakes is the hydrodynamic forecast model developed by GLERL[1]. Other models have been developed throughout the Great Lakes basin by a great many entities. In general, these models are site-specific and problem-specific and have been developed either for a research objective or a management objective. For example, GLERL researchers have developed several such models, including the Great Lakes Coastal Forecasting System and the Advanced Hydrologic Prediction System (AHPS). The AHPS, the next-generation of GLERL's Large Basin Runoff Model, is already available but will continue to be refined in the near future. Other models have been developed at lake or regional scale and have focused on such topics as eutrophication, toxic chemical exposure and effects, fisheries, sediment transport and coastal processes, and ecological systems. Should any of these models be targeted for operationization within the GLOS enterprise there are a series of steps that must be followed to impolement them within the enterprise in an operational mode. That process has been described in section 4.2 of the Design Report. Specific steps to implement the modeling element of the implementation plan include:

1) Identify management/user issues and associated modeling needs for the design subareas of most pressing concern.
2) Select model or develop conceptual model that best addresses the modeling needs for the various design subareas of most pressing concern.
3) Implement the procedure (including model calibration, confirmation, skill assessment and uncertainty analysis, and pre- and post-processor developmet) to transform research and site-specific management models generated by academia, governments, and commercial consultants into the GLOS operationalized modeling framework.
4) Develop operational model plans for transformed models, including organization that will operate each model and how the operation will be funded.
5) Develop the model linkage with the GLOS DMAC, including DMAC integration and delivery of observation data to the model and DMAC receipt of model output and delivery to users.

[1] http://www.glerl.noaa.gov/res/glcfs/

Table 1. Actions recommended to transition from Level 0 to Level A in modeling capabilities at all scales

Design Levels 0 and A for Models at All Scales

	Basin-Wide	Lake-Wide	Regional
Level 0	- GLERL Large Basin Runoff - GLERL Great Lakes Ice Model - NOAA Great Lakes (GL) Operational Forecast System-GLERL Coastal Forecasting System	- Mass balance models (e.g. Lake Michigan Toxics) - Lake eutrophication models (e.g. LM3-Eutro)	- Linked hydrodynamic-sediment transport-water quality models (eg LMR-MB model) - Hydrodynamic modeling of sediment transport - Harmful Algal Blooms (HABs) modeling
Level A	- Operational basin-wide models - Regular forecast updates utilizing data assimilation - GLERL Advanced Hydrologic Prediction System (AHPS) - GLERL Experimental (higher-resolution) Coastal Forecast - GLMOD: basin-wide, multi-media PBT exposure/effects - Recalibration and confirmation of AHPS	- Update of lake ecosystem models; operational status - Ecosystem models account for Cladophora, Dresseinids… - Enhancement of lake eutrophication models including increased spatial resolution and sub-models	- Making NOAA HABs forecast models operational - Making Great Lakes Coastal Forecast System operational - Linked, 3D water quality models (e.g. ECOFORE hypoxia)
Level B	– Select basinwide models to operationalize from among those submitted to GLMAC models inventory database	– Select lakewide models to operationalize from among those submitted to GLMAC models inventory database	– Select site-specific models to operationalize from among those submitted to GLMAC models inventory database

3. IN-SITU INSTRUMENTATION

In-situ instrumentation includes sensors and other elements of monitoring networks that are located in the location of and in contact with the phenomena they are measuring. The existing Level 0 capabilities (see **Error! Reference source not found.**) that support investigations at basin- and lake-wide scales include:

1) Water- and weather-monitoring buoys (NOAA National Data Buoy Center [NDBC] and GLOS, including University-run GLOS buoys),
2) National Weather Service (NWS) meteorological stations,
3) U.S. Geological Service (USGS) stream gauges and nutrient-monitoring sites,
4) Canadian weather office stations,
5) NOAA water level stations,
6) Canadian Water Act long-term sites,
7) Canadian aquatic biomonitoring network,
8) Canadian Clean Air Regulatory Act monitoring stations,
9) the Integrated Atmospheric Deposition Network (IADN), and
10) Environmental Protection Agency (EPA) and Environment Canada (EC) research vessel monitoring.
11) Many other in-situ sensors maintained at the regional scale.

Level 0 regional in-situ instrumentation includes use of the above as well as GLERL Real-time Environmental Coastal Observation Network (RECON) buoys, GLERL HABs sensors and data collection, state and local monitoring, and university observations.

As for the modeling implementation plan, the basin- and lake-wide in-situ instrumentation plan over the next five years (Level A timeframe) will require an initial step in which the recommendations made in this document are further developed and agreed upon by a representative group of stakeholders with interested in Great Lakes monitoring. The assessment of gaps to be remedied by the level A build-out indicated that the primary driver of sensing requirements during this phase would be the existing models that are moving toward operationalization, which are directly addressing user needs and require support and integration of real-time data. Recommended elements of the implementation plan for in-situ sensing at these scales include:

1) New GLOS-funded buoys with expanded instrumentation (e.g. thermistor chains, Acoustic Doppler Current Profiler measurements, water quality, photosynthetically-active radiation),
2) Cabled, bottom-mounted sensors to obtain observations throughout the year,
3) water intake data assimilation,
4) increased deployment of autonomous underwater vehicles (gliders),

5) beach measurements,
6) expansion of USGS predictive beach forecast (includes in-situ sampling),
7) Great Lakes coastal wetlands consortium monitoring,
8) expansion of USGS river gauging and nutrient monitoring,
9) basin-wide inventories of fish populations and invasive species, and
10) incorporation of the International Atmospheric Deposition Network (IADN) sites.

In particular, the incorporation of the Great Lakes IADN sites will provide focus on deposition and air quality over open water and in heavily-populated areas. Nearshore and offshore nutrient concentrations at the basin scale can also be improved by adding PO4 and NO3 sensors to existing in-situ platforms for the derivation of spatial and long-term temporal trends. The State of the Great Lakes Ecosystem Conference (SOLEC) has identified these and other basin-scale monitoring needs including water-level fluctuations and climate change indicators.

The Level A instrumentation for the regional scale again incorporates the level A build-out activities conducted at the basin- and lake scales, along with detailed measurements of areas-of-concern (AOC) tributaries, and site-specific regional monitoring.

Level B expansion opportunities for in-situ instrumentation most notably include increased ship surveys, increased use of ferry-boxes and utilization of vessels of opportunity. In addition, data collected from campaigns supported by funding outside of GLOS should be incorporated into the DMAC wherever and whenever possible.

An important process and part of integrating in-situ instrumentation into the GLOS EA is the efficient transmittal of data using the appropriate method of telemetry. Where collection is automated, these datasets are typically transmitted wirelessly (less frequently through wired backhaul) or are downloaded during routine visits to the site. For real-time access and as coverage expands where backhaul is not an option, all sites need to support wireless data transmission using either cellular telephone infrastructure or satellite uplink services (such as the Iridium or ARGOS networks) where cellular service is not available; Wi-Fi may be practical in some areas. Direct (wired) internet connections are possible for shore-based observations. Database updates in real-time are critical for the DMAC to remain the leading source for Great Lakes data and they allow for a standards-compliant, application-based web architecture to be easily maintained.

The overarching challenge with in-situ instrumentation is limited coverage in time and space. Typically, ice cover prevents in-situ sensors from collecting data between late fall and early spring in much of the Great Lakes. As part of near-term implementation, increased use of bottom-cabled/shore-cabled sensors to extend the annual observation period to include the winter months is recommended. The multiple data collection initiatives and monitoring networks share a common need for site expansion in the immediate future to capture data in areas not currently monitored. Information needs should be prioritized to identify areas where these gaps are most critical. To that end, attention should be paid to the utilization of vessels of opportunity and the expansion of autonomous “ferry boxes” on vessels that have repeatable transects wherever possible. Cost for a typical ferry box including annual operation is approximately $50k/unit. In the short term, expansions in the number of measured parameters to include new variables and capabilities will also be important, such as expanding the USGS monitoring sites on rivers to include nitrogen and phosphorous estimation.

With the emergence of social networking on the web there arise new opportunities for data mining in order to reduce data gaps. One area where so-called "crowd-sourcing" of data (soliciting public data generation on the web) could be useful is in collecting ship reports. Investigating the capabilities of social networking to produce useful data is recommended as part of near-term implementation steps.

From the perspective of data sharing, another problem that can be addressed within the near-term DMAC design is increased agreement as to what parameters should be measured for each phenomenon and the units to use, as well as the data formats to record, transmit, and store data for the long term. While most in-situ monitoring activities would clearly benefit from collaboration, there is currently a diversity of different entities collecting these data concurrently. Coordination of these activities in the future, and providing a home to at least the outputs of these varied efforts through the GLOS DMAC, should help reduce redundancies and avoid duplication without stifling innovation or reducing the pool of entities participating.

It is likely and realistic that the diversity of monitoring efforts, often led by university researchers, will continue to be a major data source into the foreseeable future, even with the periodic challenges in continuing funding for data collection, buoy maintenance, and modeling efforts. This implementation plan recognizes that challenge and encourages the continued use (and support where possible) of efforts led by academia. As noted, this will help maintain interest and cooperation in the academic community in sharing their efforts with GLOS and helping it become the major regional data exchange for Great Lakes data and models.

Specific steps to take with respect to the in-situ instrumentation element of the implementation plan include:

1) Identify gaps in coverage and prioritize areas where new instrumentation should be placed.
2) Standardize measurements, quality control, data formats and reporting.
3) Increase the use of ship of opportunity observations and “ferry box” sensors.
4) Increase the use of autonomous underwater vehicles (gliders) at the lake and regional scales.
5) Create a program to develop and deploy shore-cabled, bottom-mounted sensors that can collect data throughout the year.
6) Develop a methodology to incorporate instrumentation provided by non-U.S. government entities in the GLOS EA (i.e. academia and industry).
7) Develop a funding strategy to help fund and encourage continued collaboration from these academic and industry instrumentation development efforts after the technology is deployed and validated.

Table 2. Actions recommended to transition from Level 0 to Level A in in-situ instrumentation capabilities at all scales

Design Levels 0 and A for In-Situ Instrumentation at All Scales

	Basin-Wide	Lake-Wide	Regional
Level 0	- Canadian Weather Office stations - Canadian Aquatic Biomonitoring Network - Canadian Clean Air Regulatory Act monitoring stations - 2009 Canadian Water Act Long-Term sites - EPA and EC research vessel monitoring - NOAA water level stations - IADN Great Lakes	- Basin-wide capabilities (e.g. NDBC, NWS, USGS) - Federal ship monitoring programs - GLERL RECON, UGLOS buoys - University monitoring (e.g. OSU Sandusky in Erie Central) - Rivermouth monitoring and stream gauges - Autonomous vehicle deployments	- Some infrequent ship surveys - Vessels of opportunity - Some infrequent glider and autonomous vehicle deployments - Fixed, in-situ monitoring buoys
Level A	- Bottom-mounted sensors (e.g. Wisconsin DNR) - Assimilation of water intake data - Beach data - Expansion of USGS predictive "nowcast" models (GLRI) - Great Lakes Coastal Wetlands Consortium modeling - River data (e.g. USGS nutrient monitoring sites) - Additional tributary gauges - Basin-wide inventories of fish populations, invasive species - Additional IADN Great Lakes stations focusing on open-water deposition and air quality - PO4 and NO3 sensors - Higher temporal resolution of lake level fluctuation	- Additional GLERL buoys with thermistors, DO sensors - Increased deployment of autonomous underwater vehicles (gliders)	- Increased tributary monitoring (e.g. by USGS/GLOS/NOAA) - Increased ship surveys - Increased use of gliders and other autonomous vehicles - New fixed, in-situ monitoring buoys
Level B	- Utilization of data collected from campaigns not supported by GLOS-related funds - Ship reports and vessels of opportunity (e.g. ferry boxes)	- Utilization of data collected from campaigns not supported by GLOS-related funds	- Utilization of data collected from campaigns not supported by GLOS-related funds - Increased utilization of vessels of opportunity

4. REMOTE SENSING AND GIS DATA

Remote sensing is defined as non-contact, indirect measurement. Remote sensors provide unprecedented synoptic (i.e. lake and basin-wide) coverage. Algorithms have been developed to extrapolate information at depth from these shallow measurements. For example, knowledge of the relationship of chlorophyll concentration and depth allow for primary productivity estimates to be generated. In addition, water clarity in the Great Lakes has increased drastically since the 1970s, which allows for the mapping of bottom types and benthic algae like Cladophora. The use of Geographic Information Systems (GIS) also support the GLOS-EA. Historical as well as newly-collected information displayed in a geospatial format is an important tool for resource managers.

Satellite remote sensing data are generally available free of charge in their basic, raw, moderate-resolution, and synoptic form. The basic data require transformation through a set of algorithms (and models with algorithms at their core) to generate the derived products that are presented in the requirement tables for the regional, lake-wide and basin-wide scenarios. Prior to implementation, the products derived from remote sensing, identified in **Error! Reference source not found.** for the various scales, need to be prioritized. This prioritization should include consideration of algorithm complexity, cost of development as well as importance of observation. Various governments, academic and commercial entities are actively developing the algorithms identified in the table and this public-private partnership is working to advance the state of useful Great Lakes remote sensing science.

The Level 0 remote sensing products for all three scales are basically the same and include:

1) Satellite imagery,
2) Surface lake temperature maps,
3) Partial, high-resolution bathymetry,
4) Canadian Great Lakes shoreline photos, and
5) the National Ice Center (NIC) forecasts.

An exception to this is HABs detection in the Maumee portion of Lake Erie.

Level A remote sensing products recommended for implementation over a 5-year time frame are also independent of scale and are generally presently under development. These include:

1) Chlorophyll, dissolved organic carbon (DOC), and suspended minerals (SM),
2) HABs (extent and concentrations where possible),
3) Primary productivity,
4) Sediment plume mapping,
5) Lake bottom-type near-shore maps (e.g. Cladophora extent) and microwave radar-derived maps of surface wind speed.

The algorithms to produce the Level A products that are presently under development are being funded by GLOS, including funding an upgrade of the Great Lakes CoastWatch data server. The funding provided by GLOS should be sufficient to generate and validate the necessary algorithms. The present budget does not support time series analysis of historical satellite data nor does it support upgrading the CoastWatch system so that products are delivered to the stakeholders in a more informative and user-friendly fashion. To realize these additional upgrades, a significant level of effort (order of 3 FTEs) is needed. The assessment of lifecycle for the remote sensing hardware portion is straightforward; over the next five years no upgrades will be necessary beyond the GLOS-funded upgrades already planned.

As the algorithms from the various stakeholders are validated, a more formal mechanism needs to be developed so they are easily transferred to existing, long-term data-sharing programs such as NOAA-GLERL for inclusion into the NOAA Great Lakes CoastWatch node (Level B). The CoastWatch program is an integral part of NOAA, has been and will be around for the foreseeable future and is already established to share Great Lakes remote sensing-derived products. Using CoastWatch as the information delivery mechanism is consistent with the hybrid approach suggested in the DMAC discussion, and takes advantage of an existing, in-place delivery mechanism for the derived remote sensing products. The other desirable feature about this existing framework—with the suggested modification of formalizing the algorithm transfer process—is that one can leverage off short-term, funded research activities within the academic or private sector and capture useful algorithms before they get lost (as the entities move on to other funded activities). More complicated models such as lake-wide food webs that, for example, might use MODIS-derived primary productivity as an input would not be a part of the CoastWatch products; rather, such model outputs would be delivered through the DMAC. Additionally, the GLOS web portal has infrastructure in place, at the current Level 0, to share observations data. In addition, as new sensors and algorithms become available they should be incorporated into the GLOS enterprise system.

As discussed in the trade studies, Canadian SAR satellite imagery (namely that of Radarsat II)—very useful in generating lake ice cover maps, high resolution 1-km wind maps and information on the dominant gravity wave field—is quite expensive (between $3,600 and $8,400 per scene, depending on the exact product, with swath widths ranging from 10-500 km). Additionally, the high-resolution (~0.5 to 2 m) commercial electro-optical (EO) satellite data useful for detailed analysis of the design subareas, AOCs, and areas in recovery have costs similar to Radarsat II. There are, however, U.S. government programs that fund acquisition of Radarsat data as well as commercial EO satellite imagery. For example, the National Geospatial-Intelligence Agency (NGA) makes large purchases of EO high-resolution satellite imagery data to satisfy Department of Interior (DOI) data requirements, and the NIC through NOAA purchases a significant number of Radarsat scenes. The U.S. Fish and Wildlife Service's (FWS) National Wetlands Inventory (NWI) has been instrumental in making the commercial satellite imagery more widely available in the Great Lakes region, recently sharing Digital Globe satellite imagery with its Great Lakes Restoration Initiative (GLRI) project partners. Partnerships should be identified to reduce or eliminate the costs of remote sensing data acquisition.

GLERL, USGS, other DOI agencies, EPA and GLOS will need to organize requests for coverage over the Great Lakes and coordinate requests for data collections as a group to gain more leverage and prevent redundant requests. Whenever and wherever existing data have been approved for wider distribution, these data should be assimilated into the remote sensing workflow of the DMAC. This might include cases where data have been recently declassified or data from existing sensors, purchased by non-GLOS funds, are approved for other uses.

Remote sensing data are applicable at all scales (regional, lake and basin). As one moves from the basin to regional scale, the spatial resolution required for finer, spatial scale-derived information increases. Satellites with resolution on the order of 100 m are needed to address the regional issues and, in particular, to address the AOCs; Landsat (at 30 m resolution) is a workhorse sensor near that resolution for regional scale issues and has an upcoming Continuity Mission planned to keep the data available through 2015 and beyond. In the absence of satellites with such spatial resolution, the use of UAVs (unmanned autonomous/aerial vehicles or systems) and AUVs (autonomous underwater vehicles) should be considered as well as airborne remote sensing platforms (e.g. Army Corps' CHARTS multispectral and LiDAR data collection system). Thus, part of implementing remote sensing is a need to formulate how airborne platforms and autonomous vehicles will augment the data provided by the satellite sensors based on user and model data needs.

Geographic information systems (GIS) commonly use remote sensing data and products derived from them as well as traditional vector data. These GIS "layers" (datasets) are vital products for the DMAC to offer and have been used for a long time in a number of applications of interest to Great Lakes stakeholders. These datasets are typically updated periodically so that end users are looking forward to new releases. The USGS National Hydrography Dataset (NHD) with higher-resolution versions, the National Land Cover Database (NLCD), and the NOAA Coastal Change Analysis Program (C-CAP) land cover are three such examples. The near-term implementation of the GLOS EA must account for new releases of these datasets, making them available in standard, well-documented, geospatial formats; other updated geospatial inventories at a wide range of scales must also be delivered. Other data-sharing partnerships such as the Great Lakes Information Network (GLIN), an initiative with goals similar to GLOS, will feature their own next-generation designs, such as the current "GLIN 2.0" effort underway at the Great Lakes Commission (GLC).

Recent inventories of Great Lakes GIS data include state GIS databases; the Great Lakes GIS effort of the Institute for Fisheries Research[2] should be made available or linked to through the DMAC and an updated GLOS website. These are "low-hanging fruit" that would be straightforward to implement within the next five years and move the GIS part of the enterprise from Level 0 to Level A with relatively little cost beyond a partial (0.5 or less) FTE to gather the data and ensure standard documentation. It is not anticipated that GLOS would become the updating group for GIS data, but instead be the program that helps people access existing data and new data as they become available, through a combination of linking to existing geospatial data sites and sharing them through the GLOS observations portal or similar GLOS site using distributed web services or similar sharing methods.

GIS and geospatial analysis have been shaped by advances in personal and distributed computing as well as innovations in data storage and networking, such as data sharing through Web Mapping Services (WMS). As data formats and standards evolve with new technology, GLOS must maintain the flexibility to serve these datasets with support for multiple formats and standardized metadata while improving access and reliability. Recent efforts to simplify the metadata process, as represented by the North American Profile (NAP) of the International

[2] http://ifrgis.snre.umich.edu/projects/GLGIS/

Standards Organization (ISO) 19115 ("Geographic Information - Metadata"), are recommended as the main standard for metadata in the new Enterprise Architecture. More information on this Federal Geographic Data Committee is available online[3], and these issues are addressed in great detail in the project Concept of Operations.

The State of the Great Lakes Ecosystem Conference (SOLEC) provides an additional set of GIS data indicators for management issues that will benefit significantly from developing the basin-wide observation network, including area and quality of special coastal communities (e.g. cobble beaches, alvars, sand dunes, islands), the extent of hardened shorelines, the areal extent and floral diversity of coastal wetlands, and land-use and land-cover change.

In summary, the following steps are necessary to implement the remote sensing portion of the plan:

1) Prioritize information needs.
2) Leverage the diverse set of standards into derived products that are cost effective and achievable within the framework.
3) Formalize the procedures (i.e. mechanism) to transfer algorithms developed in the academic and private sector into the GLERL Coast Watch System.
4) Secure a “fair share” of U.S. government purchased commercial satellite imagery of the Great lakes.
5) Develop a plan to utilize airborne and AUV assets to support the GLOS EA.
6) Identify the key set of models needed to satisfy the stakeholders and define inputs that can be provided by in-situ instrumentation and remote sensing.

For the GIS portion of the implementation plan the following key steps are needed:

1) Identify and capture relevant GIS base layers (e.g. most recent census data, CCAP data, transportation infrastructure, topography and elevation).
2) Improve access to existing Great Lakes geospatial data efforts through a linking and data sharing effort through a GLOS site such as the GLOS observation page.
3) Ensure the DMAC is capable of sharing updated geospatial data sets as they become available.
4) Help share documented GIS data that has metadata using up-to-date, simplified, especially the North American Profile of the ISO 19115 metadata standard.
5) Use current data sharing methods such as WMS to make data more easily available to GLOS stakeholders.

And again, as for the previous sections on models and n-situ sensors, the above steps are presented as recommendations to be further developed and agreed upon during the first stages of the implementation schedule described in Section 6.

[3] http://www.fgdc.gov/metadata/geospatial-metadata-standards#nap

Table 3. Actions recommended to transition from Level 0 to Level A in remote sensing and GIS capabilities at all scales.

Design Levels 0 and A for Remote Sensing and GIS at All Scales

	Basin-Wide	Lake-Wide	Regional
Level 0	- Satellite imagery (e.g. MODIS, MERIS, Landsat, AVHRR) - Satellite imagery products (e.g. NOAA CoastWatch) - Partial high-res bathymetry (USACE/NOAA) - Canadian Great Lakes Shoreline Photos - National Ice Center (NIC) forecasts - Existing GIS (e.g. Great Lakes GIS-IFR, GLIN-GLC) - Hydrography (e.g. NHD) and watersheds - High-res shoreline (1:70k) - Land-use / Land-cover data (e.g. C-CAP, NLCD) - Canada Great Lakes Sediment Database*	- Basin-wide capabilities	- Basin-wide capabilities - NOAA Harmful Algal Blooms (HABs) forecasts
Level A	- Satellites (microwave) - Primary productivity: Lake Michigan - Sediment plume mapping - Lake bottom-type near-shore maps (e.g. benthic algae) - Increasing user-friendly interface capabilities for end users - Operational chlorophyll, DOC, suspended minerals output - Harmful Algal Blooms (HABs) mapping - Update GIS base layers and context for all ISO 19115 categories- Next-generation GLIN - Improved GIS access through GLOS, etc... - Streaming GIS data to end users (e.g. WMS) - Area/quality of coastal communities - Extent of hardened shorelines - Areal extent of coastal wetlands - Vegetation diversity	- Updated GIS base layers and context for all ISO 19115 categories	- Improvement of NOAA HABs forecasts - Improved remote sensing algorithms (e.g. from MTRI)
Level B	- Utilize any opportunity to incorporate remote sensing data acquired outside GLOS into the DMAC, be it new or recently released - Process critical archived and new data with the most up-to-date remote sensing algorithms - Validated remote sensing algorithms generated outside of GLOS should be incorporated into the GLOS EA	- Utilize any opportunity to incorporate remote sensing data acquired outside GLOS into the DMAC, be it new or recently released - Validated remote sensing algorithms generated outside of GLOS should be incorporated into the GLOS EA	- Update local GIS base layers as often possible for all ISO 19115 categories

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5. DMAC

Outlined in this section are the essential attributes and requirements of the DMAC implementation. As the implementation of the DMAC is a critical step in the overall development of the GLOS enterprise system, its design has been advanced and is described in greater detail than other elements of the system. This description is primarily contained in the accompanying Concept of Operations report, with a summary description of current conditions in project Technical Memorandum 4. As the technical details to realize the DMAC are outside the scope of the Implementation Plan, the specific steps to implement the DMAC system are described in the Concept of Operations report.

The other elements of the GLOS enterprise mentioned thus far will be incorporated into the DMAC through standards-based data assimilation. The DMAC is the centerpiece of data archiving and distribution. The products available through the DMAC will be blended datasets derived from in-situ monitoring networks, remote sensing, GIS data and model results. For most observing system subareas, some degree of modeling will be involved in the processing and delivery of all data products available. Here, models serve as transforms for input datasets and may consist merely of data formatting or include robust, predictive and/or statistical models such as forward models and regression. In this sense, models are truly the workhorse of data integration and information extraction. The products that are available to the end-user are then the most useful and accessible outputs of a variety of data collection campaigns. A model-based DMAC also lends itself toward improved standardization of input datasets that can feed models.

Current data-sharing portals including the current generation of the Great Lakes Observing System (GLOS) and its partners have limitations that are cited in Technical Memo 4. Overall, these portals lack the essential qualities of a community DMAC like as recommended by this project, instead relying on and redirecting users to a distributed network of portals, usually managed by the data owners themselves. However, the data owners and providers cannot be discounted and it is more likely that a "hybrid" system, comprised of a centralized DMAC that leverages data and services provided through a distributed network of websites maintained by data owners, would be a successful centerpiece for design. The capabilities that currently need enhancement in the GLOS architecture include data quality-checking (QC), capacity for additional sensors, and redundancy/failover.

In 2010, the Integrated Ocean Observing System (IOOS®) declared that its partners must "demonstrate how the DMAC subsystem component will be implemented and sustained" based on key guiding principles[4]. Only the principles most relevant to a discussion about implementation of the DMAC are discussed here.

Among these principles is the philosophy that the DMAC should employ a service-oriented architecture (SOA), which is a set of principles in itself that guide the development of loosely-

[4] Full text: Guidance for Implementation of the Integrated Ocean Observing System (IOOS®) Data Management and Communications (DMAC) Subsystem NOA IOOS® Program Office White Paper (v1.0), March 12, 2010

coupled, interoperable services accessible through the web. These services are accessed through different protocols based on their functionality and the interface typically uses Extensible Markup Language (XML). The interoperability afforded by these services, provided they have well-defined, well-understood interfaces, reduces the cost and time required to develop new web services built on top of existing services. To access these services, developers use standards-based protocols (which ensure compatibility with any platform); the services respond to requests by ingesting or emitting messages in a data interchange format (such as XML).

The IOOS® further recommends some basic data access services they currently use themselves and which have seen widespread adoption elsewhere. Many of these services are defined in standards maintained by the Open Geospatial Consortium (OGC)[5]. The recommended distribution of gridded data and model outputs is through a Web Coverage Service (WCS), georeferenced imagery by a Web Mapping Service (WMS), and in-situ observations (points, profiles, and trajectories) by a Sensor Observation Service (SOS). In addition, they recommend some common data formats for data storage specifically the Network Common Data Format (NetCDF) for binary and gridded data and comma-separated value (CSV) text formatting for in-situ data, both following Climate and Forecast conventions. Additional requirements for the DMAC include permanent archiving of observations, outputs, and metadata. For reasons already obvious in addition to these considerations, a relational database—preferably hosted on separate physical or virtual server(s)—will be an essential component of the DMAC. The WMS and WCS web services will provide access to a data storage and retrieval system optimized for gridded and raster images which (to improve performance) should not be stored in a relational database. Rather, these datasets should be served by an Open-source Project for a Network Data Access Protocol (OPeNDAP) server (e.g. TDS) or a lightweight, scalable tile server (e.g. ncWMS, GeoServer[6]). In-situ observations, point measurements, profiles, and trajectories, on the other hand, are well-suited for database storage provided that the database is geospatially-enabled. Many enterprise-scale database management systems (DBMS) offer geospatial support including the open-source PostgreSQL[7] server with the PostGIS[8] extension. The applications requiring a geospatial database and the associated capabilities (e.g. spatial queries, spatial joins...) are too numerous to mention but, suffice to say, nearly all of the products offered by the DMAC are intrinsically geospatial. Consequently, a geospatially-aware relational database is essential for the DMAC.

As described in Technical Memo 1, the following data classes will be managed by the DMAC:

- Regular grid
- Unstructured grids
- Curvilinear grids
- Point time series
- Profile time series
- Collections of points or profiles

[5] http://www.opengeospatial.org
[6] http://www.geoserver.org/
[7] http://www.postgresql.org/
[8] http://postgis.refractions.net/

- 2D and 3D trajectories
- Collections of trajectories
- Swaths
- Polygons

Careful design of the DMAC will take into consideration each of these classes both in server-side and client-side development. The client-side requirements to effectively deliver and present these data classes include: a) scalable coordinate planes (i.e. maps), b) plots and graphs, and c) tables that can be sorted and filtered.

The key to the DMAC system is that these data and data products are made available via standard web services so many client applications can access them using the agreed upon protocols of the web service. Client software can then be built or customized to meet the needs and technology requirements of different user groups. As an an example, client applications or extensions could be built for Matlab, ArcGIS, as well as numerous web and mobile-based applications. Building dynamic web and mobile applications and selecting the appropriate technology is a challenge. There are numerous criteria for selection of the client/server development suite.

Many data applications on the web have been built with Adobe Flash/Flex such as WeatherSpark[9] (a robust application for weather pattern reporting and forecasting) and the Alaska Ocean Observing System (AOOS) Data Portal[10] (a Flex application connected to DMAC-type services leveraging Adobe data exchange for high performance).

The challenge with selecting rich internet applications (RIAs) such as Flex, Silverlight or Java is that they require client-side libraries to be installed and updated which can be a challenge for users, particularly government users, who are not allowed to install or update software on their network computer. There are also many challenges related to deployment of these applications on mobile devices.

Many pure or "thin" web applications utilize Javascript (no relation to Java), the programming language of the web browser, to provide interactive, asynchronous user-interfaces that feel like desktop applications. Such applications, using Javascript to extend dynamic HTML (DHTML) pages, require no client software other than the web browser. Many different Javascript libraries already exist that could be leveraged to build a number of disparate web portals providing the same data products (delivered by the DMAC in a "hybrid" system like the one described here); interacting with the DMAC through a standardized application programming interface (API). These Javascript libraries offer interactive charts, time series plots, and tables that are populated directly by databases.

The open-source Javascript library OpenLayers[11] allows for the development of interactive maps similar to Google Maps or Microsoft Bing Maps. Such maps can use the Google Maps and Bing Maps services as base maps (for context) and also overlay additional datasets provided by WMS/WCS. A relevant example comes from the Southeast Coastal Ocean Observing Regional

[9] http://www.weatherspark.com

[10] http://data.aoos.org/maps/arctic_assets.php

[11] http://www.openlayers.org/

Association (SECOORA), an IOOS® component; their Interactive Regional Map[12] utilizes the ExtJS library to provide a rich user-interface on top of an OpenLayers map which allows access to real-time buoy data in a geospatial context, overlays of parameters such as SST, and the Google Maps API as a base layer. Yet another Javascript library, Highcharts[13], is utilized to display interactive time series charts for buoy parameters.

The challenge of DHTML-with-Javascript approaches is the wide variety of browsers in use, each with a different interpretation of the HTML standard and a different Javascript engine. The effect is that these applications may run differently, or not at all, on different browsers. Fortunately, many robust Javascript frameworks (libraries) are available that automatically avoid cross-browser compatibility issues by providing a layer of abstraction above pure Javascript—essentially, the framework determines how the application ought to be written in real time after determining the browser and platform of the client. Also, best practices for DHTML and Javascript programming have been defined to help developers avoid common problems that arise from discrepancies between browsers. If designed correctly, these applications also run well in a mobile environment.

The evolution of mobile devices and applications is leading IOOS® regional associations to experiment with mobile applications. Again, this provides a technology selection challenge; select a development environment for a specific device (e.g. iPhone) that is built specifically to take advantage of that device's capabilities, or build a generic mobile application that can be ported to multiple mobile platforms, but may not take advantage of the specific device's capabilities. Some software vendors have developed frameworks that allow the development of applications for multiple platforms using a single programming language (e.g. Sencha Touch, a Javascript framework for creating mobile applications) but these may provide constraints on an application's functionality in closed ecosystems.

These web and mobile applications will connect to data and analysis services hosted on the DMAC server(s). Technical Memo 1 also described the DMAC subsystem as a collection of data services of two classes: data access services and data subscription and alert services. The first class of services is best accommodated by a client-server architecture based on representative state transfer (REST) principles. Asynchronous, RESTful communication between the DMAC subsystem and the web application in the browser allows for fast, reliable interfaces to be developed and enables power users, with the right permissions, to have unfettered access to the database with an experience similar to using a desktop DBMS client. The second class of services, data subscription and alert services, will require server mailing and the collection and storage of user input, which can create security concerns. To best minimize the potential for security issues, user data should be mostly anonymous where possible and two levels of input validation should be performed. A requirement of client-side interface development should be to perform initial validation of user input (e.g. making sure e-mail addresses are valid). Additional validation should be performed by the server to scrub input data of invalid values or potentially malicious instructions (e.g. SQL injection).

A basic model of subscription-based alerts should allow for one-stage subscription (i.e. anonymous visitor submits his/her e-mail address to the database) and unsubscription (e-mail

[12] http://secoora.org/maps/

[13] http://www.highcharts.com/

alerts always contain a link with a unique hash which calls upon a resource that removes from the database the e-mail address associated with that hash code).

In addition to these services, which likely constitute the bulk of the DMAC subsystem's functionality, additional utility services necessary for support have been identified:

- Service registry (SOA convention)
- Data catalog service
- Mapping and visualization service
- Format conversion service
- Coordinate transformation services
- Product generation services
- Data integration services
- Workflows

The service registry is an SOA convention where all of the web services are delineated and where information such as a description of the interface, service levels, and parties responsible for maintaining that service are detailed. Datasets available are listed in the data catalog service for data discovery. The mapping and visualization service draws from multiple packages, chiefly comprised of the server-side geospatial and plotting resources, transmitted from server to client, that enable the display of associated datasets. Format conversion of text data should be done in the client but file formats, especially raster imagery formats, will need to be converted by the server. Offering format conversion as a central service is important as many data services will undoubtedly rely on the capability. A coordinate transformation service is provided for the same reasons.

In summary, the DMAC will serve as a consolidated data archive, service registry and library. It is to be the entry point for scientists and analysts to discover what Great Lakes data are available (be they basin-wide, lake-wide or regional in scope), how to access the data and how to include the data in their own web mapping visualizations or algorithms. In addition, it catalogs the data formatting and processing services that are available and exposes them on the web. Links to data providers and their own web services are also provided in a registry and this is one of the DMAC features that should be of use to policy makers and the general public as well as they will find outreach efforts, white papers and increased local or "grassroots" focus at websites in the DMAC's distributed network. The DMAC itself is a system of services (SOA) where models are exposed as web services and standards-based web communication protocols are used for receiving sensor data in real time. Vertical integration across observation scales is provided through the intrinsic geographic nature of the datasets. Tying services and data into a geospatial context allows for rapid inquiries to retrieve the most relevant, accurate and real-time Great Lakes data available.

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6. RECOMMENDED IMPLEMENTATION PROCEDURE

6.1 IMPLEMENTATION FRAMEWORK

This document presents a roadmap for research, development, testing, evaluation, and operational support steps that should be taken over the near term (over the 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 the GLOS to begin to undertake targeted expansion alternatives in response to identified user needs (design Level B).

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,
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, 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 at within each of the GLOS 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, opportunistic and may or may not arise within the project timeline. 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 in a particular direction, resulting in a site-specific design at a defined scale within a particular GLOS 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.

6.2 IMPLEMENTATION STEPS

The implementation of the GLOS Enterprise has already been initiated with this project (in the present year), and a series of steps that structure the implementation are described below and presented in **Error! Reference source not found.**. A timeline for completion of these activities is also presented as . In both tables, 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. These tables will be discussed in detail in Section 7, where an estimation of the cost requirements is presented. 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.

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 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 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 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 6 of this report and in the Concept of Operations report and supporting DMAC Technical Memorandum. 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 the 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 scale 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 5, 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 Distributed Large Basin Runoff Model (DLBRM), 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 exisiting 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 5 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 2-3 OS 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

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.

Table 4. Overall summary of 5-year Implementation Plan

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

Table 5. Expansion of 5-Year Summary Plan with details by FY Quarters

Design Scale	Design Level	Implementation Step	Present Study Concluding 6/11			Federal Fiscal Year: Year 1				Year 2				Year 3				Year 4				Year 5			
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Basin	0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC .*				Long-term geospatial database maintenance																			
	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							
		Step A3: Design and to the extent possible, implement a Level A sensing strategy		Concep. Design		Design phase			Build Phase																
		Step A4: Develop and where possible, operationalize models required for each subarea (unique to each GLOS subarea)		Concep. Design		Design phase			Build Phase																
	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)								
Lake	0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC .*				Long-term geospatial database maintenance																			
	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							
		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							
		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																
	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)								
Regional	0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC .*					Long-term geospatial database maintenance																		
	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							
		Step A3: Design and to the extent possible, implement a Level A sensing strategy		Concep. Design		Design phase		Build Phase (opportunistic funding sources, third party build out)																	
		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)																	
	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																

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7. SUGGESTED INVESTMENT SCHEDULE

The conclusions from the trade studies and end- to- end case studies indicated that the scale (regional, lake or basin-wide) strongly influences the relative importance of using fixed, mobile or remote platforms. For example, the Lake Erie regional case study of hypoxia indicated priority should be given to using fixed platforms, with mobile and ship platforms providing secondary observations. In contrast, remote sensing along with fixed platforms, mobile platforms and ship survey all play key roles at the synoptic lake and basin-wide scales. At the regional scale, applications tend to be very specific and the focus is on solving the specific regional management issues. This section provides a suggested investment schedule that allocates investment dollars across the basin, lake and regional scales, with more direct investment at the basin and lake scales, and more indirect investment and incentivizing of local efforts at the regional scale. This process is illustrated using a $25 million dollar investment over a five year period as a way to focus the recommendations.

Historically, due to funding opportunities and institutional personnel organization along disciplines, Great Lakes funding was divided into the categories depicted in Figure 1, namely remote sensing and GIS, in-situ fixed and mobile instrumentation, modeling, and data delivery. Specific recommendations for each of these categories have been presented in a generalized way at the three scales to aid management by science discipline on how to transition from Level 0 to Level A products as presented in Tables 1-3. That said, it is not the recommendation of the GLOS-EA group to implement activities along the categories (pillars) but rather implement the various components in an interdisciplinary fashion at the appropriate scale of interest. For example, to implement the Lake Michigan-wide ecosystem model the use of both fixed and mobile in-situ measurements are needed along with the use of remote sensing and ship surveys. These data need to be integrated into the ecosystem model while both the basic observations and the derived information should be captured within the DMAC, accessible through a user-friendly web interface.

Regional-scale management issues are problem-specific but still can be addressed in an interdisciplinary fashion. For a regional problem like the Lake Erie Central Basin hypoxia case study, the problem first needs to be defined in detail. Realistic budget and time constraints need to be identified as well as specific program goals, measurements needs, models, decision support system(s), data storage and data delivery. Specific program goals will be used to define what needs to be measured in order to address the management issue and the modeling requirements; to provide the decision support system framework for the resource managers and at the same time determine how the basic data and derived information will be archived and disseminated from the DMAC. Thus, some decision inputs and capabilities utilized at the regional scale can inform activities at the lake and basin scales.

7.1 INVESTMENT SCHEDULE

Error! Reference source not found. presents the overall summary of the five-year implementation plan. Each of the key implementation steps for design levels 0, A and B are identified for each scale. The color coding indicates expected completion dates for each level as a function of scale where green denotes complete within this study, blue substantially complete within five years, and the orange develop groundwork in the next five years , with completion within ten. In summary, **Error! Reference source not found.** proposes that at the end of five years: 1) The catalogue of existing systems and the geospatial data base aspect of the DMAC is complete, 2) The design and construction of a basin wide DMAC is complete, and 3) All Level A activities for the basin are essentially complete as well as near completion at the lake scale. Regional scale Level A steps have a ten year horizon.

is an expansion of **Error! Reference source not found.**, presenting specific details on each step as a function of scale by FY quarters over the next five years. The color-coding is consistent with the previous table and breaks each activity down by phase (conceptual, design, build, and maintain). Note the finer resolution in indicates that for both the basin and lake scale a design for Level B will be completed in the five year horizon.

These tasks are further described in Table 6a 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 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 Table 6b and c also present similar investment schedules at a higher level of funding ($50M) and a lower level of funding ($10M). 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.

7.2 COST DETAILS

This section provides additional detail on the cost estimates for critical implementation plan tasks

7.2.1 Design and Implementation of Level A Sensing Strategy (A3)

Table 7 details the budget breakdown in the $25 M funding scenario for Step A3 only. The $25 M scenario has allotted $8.4 million for Step A3 to design and implement, where possible, a lake-wide Level A sensing strategy. There are four domains to the sensing strategy presented herein: fixed sensors (including moored buoys, shore-cabled platforms and bottom-mounted sensors), mobile sensors (primarily gliders and unmanned aerial vehicles but also vessels of opportunity and ferry boxes), ship surveys (dedicated missions) and remote sensing and geographic information systems (GIS) data.

At $8.4 million over 5 years, the following deliverables are enabled: 5 new buoys and 5 cabled platforms (one of each per lake), 2 gliders and 2 unmanned aerial vehicles per lake, 1 dedicated research cruise per lake, streaming of GIS data through web services, updated GIS layers, and operational remote sensing algorithms including lake surface temperature (LST), color-producing agents (CPAs), primary productivity, sediment plumes, bottom type maps, and harmful algal blooms (HABs). In the $50 M GLOS EA scenario, an associated two-fold increase of Step A3 funding would double the number of buoys and cabled stations that could be deployed to 2 of each per lake, double dedicated cruises allowing for 2 per lake and double the number of gliders and UAVs to 4 of each per lake. The $50 M GLOS EA scenario would also allow for winds, waves, ice cover, currents, and lake level remote sensing models, in addition to those listed above, to become operational. At the minimum investment of $10 M for the GLOS EA, only 2 buoys, 2 cabled stations and 1 dedicated cruise could be deployed for the entire basin, each lake could see the deployment of just 1 UAV and glider, and the LST, CPA, and primary productivity remote sensing models alone could become operational.

In the $25 M GLOS EA funding scenario, capital costs are roughly 24% of all costs at Step A3 across all four domains (fixed, mobile, ship surveys, and remote sensing/GIS). Capital costs are largest in the fixed platform domain. Remote sensing and GIS capital costs are comprised mostly of commercial data purchases. The capital costs for mobile platforms are low because adequate gliders and UAVs are already available among Great Lakes researchers. As with ship surveys, the capital costs of mobile platforms generally include only sensor instrumentation. Capital costs are expected to be $450k in FY1, $400k per year in FY2-FY4, and $350k per year in FY5.

Research costs are roughly 11% of all costs at Step A3 across all four domains (in the $25 M scenario). These costs are fairly consistent each year. The research costs of fixed and mobile platforms primarily stem from the need to design custom platforms, sensor mounts and, sometimes, custom sensor instrumentation to deal with unique challenges or to improve sensor interoperability. There are no additional research costs associated with the proposed ship surveys as these are expected to be routine data collects. Research and development costs are highest in remote sensing and GIS where gap funding is needed to bring research-grade models to operational status. These costs diminish over time as the models near operational status, the responsibilities of maintaining them transfer costs to operations and maintenance (O&M). Research and development costs are expected to be $200k each year in FY1-FY4 and $150k in FY5.

Operations and maintenance (O&M) costs are the bulk of all costs (in the $25 M scenario) at Step A3: roughly 65%. This is due to several factors including capital equipment already owned (gliders and UAVs), the high level of technical expertise required to process data as well as the necessarily enduring nature of any enterprise architecture. These costs are highest for the mobile sensors domain which require sophisticated field support for deployment, recovery, hardware maintenance and data acquisition/offloading. Such costs are similar for fixed instrumentation but are lower in the early years of the project since some equipment isn't purchased until later years. Remote sensing O&M costs are a direct result of algorithm development and the require updates to maintain their relevance. O&M costs are expected to be $1M in FY1, $1.05M in FY2, $1.15M in both FY3 and FY4 and $1.1M in FY5.

7.2.2 Targeted Expansion Alternatives (B1)

Targeted expansion alternative activities conducted under task B1 will be highly site-specific and supported almost entirely by non-federal funding. The design of these observing subsystems will vary significantly in depth and breadth of sampling activity, complexity, and resolution, and consequently will also vary significantly in cost. This section provides two examples of targeted expansion alternatives and related costs.

The first expansion alternative is a relatively simple, single-buoy sensing system used to support operations and planning at a power plant located on Lake Michigan. The buoy used for cost estimating purposes is an S2 Yachts TIDAS 900 marine research buoy with capabilities for sensing temperature, velocity, turbidity, wave period and height, and meteorological parameters. Capital and operating expenses for operation of the buoy over a 5-year period are summarized in Table 8, with a total of $125K in capital costs and $351K in operating costs for the period, or a total of approximately $0.5M.

This type of installation provides significant benefit to the local sponsor in terms of operations and compliance with permitting requirements, and also provides significant additional benefit to the local community, as well as the broader scientific community.

The second expansion alternative example is the Central Lake Erie Basin hypoxia monitoring and alert system. The configuration of this system is described in the main body of the design report and also in Attachment 1 to this Implementation Plan. The system is comprised of 5 fixed platforms to measure DO, conductivity, pH, and water temperature at select locations within Central Basin Lake Erie. Four fixed sensor installations will be located at water intakes within the region augmented by field cruises conducted every two weeks from mid-June to mid-August to obtain water quality profiles. During these cruises, a probe will be lowered every mile to measure temperature, DO, conductivity, and pH. At select locations, grab samples will be collected to measure TP, TN, silica and chlorophyll. One buoy will be dedicated to meteorological and water current measurements, a total of 6 buoys.

Costs for this expansion alternative are developed in Attachment 1 and are summarized in Table 8, with a total of $2.2M in capital and $4.2M in operating costs, for a total five year cost of implementation of $6.4M.

This installation is representative of a regional-scale observing system subarea design, in which benefit is provided to a localized region of the Great Lakes. This installation provides benefit to municipal water intake managers on the south shore of Lake Erie, with particular benefit provided to the City of Cleveland. Significant benefit is also provided to the Great Lakes ecological science community, which is focused on the management of hypoxia and its impacts on the ecology of Lake Erie.

7.2.3 Lake-Scale Ecological Sensing Implementation: Lake Michigan (A3)

A description of the Lake Michigan Offshore Gradients Monitoring System is provided in Attachment 2 to the Implementation Plan and is also discussed in the Design Report. This system is designed to provide sensing of nearshore-to-offshore gradients in parameters critical to the viability of the Lake Michigan ecosystem.

The system is comprised of three main observing system components; fixed platforms, mobile platforms and field campaigns. Of the first component, there will be 9 total fixed platforms; 8 are buoy based surface units configured to measure meteorological data, currents, and water temperature at select locations within Lake Michigan. Four of these surface units are equipped with multi-parameter sondes to provide complementary parameters including dissolved oxygen (DO), conductivity, pH, turbidity, CDOM and chlorophyll. One fixed platform will be a sub-surface cabled unit providing year round sampling capability to measure water temperature, waves, current, and ice cover. The second component will involve field campaigns conducted within the region surrounding the fixed platforms. Datasets provided from 10 field cruises conducted each year along six transects will provide profiles of nutrients, phytoplankton, zooplankton biomass and speciation, as wells as benthic algae and organism abundance. During these cruises, an undulating tow body will be used in providing 3-dimensional profiles of Chl-a, turbidity, PAR, conductivity, CDOM, temperature, DO. Additional payload on the tow body will include a side scan sonar and submersible video equipment for lake bathymetry and lake-bottom video. The third component will comprise mobile platform primarily a glider based system equipped with the same payload as on the undulating tow body and will be used each year to conduct two extensive surveys spanning several days in length.

Costs for this expansion alternative are developed in Attachment 2 and are summarized in Table 8, with a total of $4.1M in capital and $7.1M in operating costs, for a total five year cost of implementation of $11.2M.

This installation is representative of a lake-scale observing system subarea design, in which benefit is provided to an entire Great Lake. This installation provides benefit to managers of the Great Lakes ecosystem, as well as the broader Great Lakes research community and recreational, commercial, and industrial users of the lake as a resource.

7.3 LEVERAGING INVESTMENTS IN GLOS

The observing system subarea cost examples described in the previous section 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 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 federal 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 the project 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 design build effort, other federal dollars, and leveraged non-federal dollars enabled by the 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 Lakes, as listed at the bottom of Table 9. 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 6a. Estimated funding requirements ($k) to support the proposed Implementation Plan (25m)

Design Scale	Design Level	Implementation Step	Present Study Concluding 6/11 (Q1, Q2, Q3)	Federal Fiscal Year: Year 1 (Q4, Q1, Q2, Q3)	Year 2 (Q4, Q1, Q2, Q3)	Year 3 (Q4, Q1, Q2, Q3)	Year 4 (Q4, Q1, Q2, Q3)	Year 5 (Q4, Q1, Q2, Q3)	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 (Q2)			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 (Q3)					
				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 (Q3)					
				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) (Q3)			
						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 (Q2)			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 (Q3)			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 (Q3)					
				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) (Q3)			
						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 (Q2)			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) (Q2)					
				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) (Q2)					
				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 (Q3)					
				200	160	100	100	100	660
		Totals: (K$)		4860	4620	5790	4980	4820	25070

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Table 6b. Estimated funding requirements ($k) to support the proposed Implementation Plan (50m)

Design Scale	Design Level	Implementation Step	Present Study Concluding 6/11			Federal Fiscal Year: Year 1				Year 2				Year 3				Year 4				Year 5				Totals (K$)
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	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																				
						280				210				140				70				0				700
	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								
						1010				1260				1390				1390				1260				6310
		Step A3: Design and to the extent possible, implement a Level A sensing strategy		Concep. Design		Design phase			Build Phase																	
						4370				3640				3640				3280				3280				18210
		Step A4: Develop and where possible, operationalize models required for each subarea (unique to each GLOS subarea)		Concep. Design		Design phase			Build Phase																	
						1260				1260				1260				1260				1260				6300
	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)									
														1750				880				880				3510
Lake	0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC.*				Long-term geospatial database maintenance																				
						150				110				80				40				0				380
	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								
						100				130				140				140				130				640
		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								
						1600				1600				1600				1600				1600				8000
		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																	
						450				450				450				450				450				2250
	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)									
														630				310				310				1250
Regional	0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC.*					Long-term geospatial database maintenance																			
						20				30				30				30				30				140
	A	*Step A1: Catalogue ongoing or funding-in-place activities.*				50																				
		Step A2: Plan and Construct Basin-wide DMAC		Concep. Design				Build Phase										Maintain Phase								
						50				50				50				50				50				250
		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)																		
						50				50				50				50				50				250
		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)																		
						110				110				110				110				110				550
	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																	
						390				330				200				200				200				1320
		Totals: (K$)				9840				9230				11520				9860				9610				50060

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Table 6c. Estimated funding requirements ($k) to support the proposed Implementation Plan (10m)

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Design Scale	Design Level	Implementation Step	Present Study Concluding 6/11 (Q1 Q2 Q3)	Federal Fiscal Year: Year 1 (Q4 Q1 Q2 Q3)	Year 2 (Q4 Q1 Q2 Q3)	Year 3 (Q4 Q1 Q2 Q3)	Year 4 (Q4 Q1 Q2 Q3)	Year 5 (Q4 Q1 Q2 Q3)	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 60	40	30	10	0	140
Basin	A	*Step A1: Catalogue ongoing or funding-in-place activities.*							
Basin	A	*Step A2: Plan and Construct Basin-wide DMAC*	Concep. Design	Design phase; Build Phase 410	520	570	Maintain Phase 570	520	2590
Basin	A	*Step A3: Design and to the extent possible, implement a Level A sensing strategy*	Concep. Design	Design phase; Build Phase 620	520	520	470	470	2600
Basin	A	*Step A4: Develop and where possible, operationalize models required for each subarea (unique to each GLOS subarea)*	Concep. Design	Design phase; Build Phase 200	200	200	200	200	1000
Basin	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) 350	180	180	710
Lake	0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC.*		Long-term geospatial database maintenance 30	20	20	10	0	80
Lake	A	*Step A1: Catalogue ongoing or funding-in-place activities.*							
Lake	A	*Step A2: Plan and Construct Basin-wide DMAC*	Concep. Design	Design phase; Build Phase 20	30	30	Maintain Phase 30	30	140
Lake	A	*Step A3: Design and to the extent possible, implement a Level A sensing strategy*	Concep. Design	Design phase; Build Phase: Lake Michigan Only 210	210	210	Build Phase: other lakes as funding allows 210	210	1050
Lake	A	*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 210	210	210	210	210	1050
Lake	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) 130	60	60	250
Regional	0	*Step 0: Catalogue existing systems and build the geospatial database of observing systems for the DMAC.*		Long-term geospatial database maintenance 0	10	10	10	10	40
Regional	A	*Step A1: Catalogue ongoing or funding-in-place activities.*		10					
Regional	A	*Step A2: Plan and Construct Basin-wide DMAC*	Concep. Design	Build Phase 10	10	10	Maintain Phase 10	10	50
Regional	A	*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) 10	10	10	10	10	50
Regional	A	*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) 20	20	20	20	20	100
Regional	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 80	70	40	40	40	270
			Totals: (K$)	1880	1870	2360	2040	1970	10120

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Table 7. Implementation Step A3: Design and to the extent possible, implement a Level A sensing strategy (at $8.4M)

GLOS Program Element	FY 2012			FY 2013			FY 2014			FY 2015			FY 2016			Subtotals ($M)	
	Capital Develop. ($k)	Resrch. ($k)	O + M ($k)	Capital Develop. ($k)	Resrch. ($k)	O + M ($k)	Capital Develop. ($k)	Resrch. ($k)	O + M ($k)	Capital Develop. ($k)	Resrch. ($k)	O + M ($k)	Capital Develop. ($k)	Resrch. ($k)	O + M ($k)		
Fixed Sensors 5 new buoys (1/lake) 5 cabled platforms	200	50	150	200	50	200	200	50	300	200	50	300	200	50	300	2.50	
Mobile Sensors 2 gliders/lake 2 UAVs/lake	50	50	400	50	50	400	50	50	400	50	50	400	50	50	400	2.50	
Ship Surveys 1 dedicated cruise/lake	50	N/A	200	50	N/A	200	50	N/A	200	50	N/A	200	50	N/A	200	1.25	
Remote Sensing& GIS Operational models for LST, CPAs, primary productivity, plumes, bottom maps, HABs	150	100	250	100	100	250	100	100	250	100	100	250	50	50	200	2.15	
Totals ($M)	0.45	0.20	1.00	0.40	0.20	1.05	0.40	0.20	1.15	0.40	0.20	1.15	0.35	0.15	1.10		8.4
																8.4	$M

Table 8. 5-Year Observing System Subarea Cost Estimates

Lake Michigan Power Plant - Single TIDAS Buoy, Physical Parameters

	yr1	yr2	yr3	yr4	yr5	Total
Capital Expense	85	10	10	10	10	125
Design & Development	15	5	5	5	5	35
Equipment	65					65
Facilities	5	5	5	5	5	25
Operating Expense	64	67	70	74	77	351
Engineering	3	3	3	3	3	14
Operations	15	16	17	17	18	83
Calibration, Test & Integrat	5	5	6	6	6	28
Deployment	8	8	9	9	10	44
Materials & Supplies	6	6	7	7	7	33
Analytical	10	11	11	12	12	55
Maintenance support	15	16	17	17	18	83
Insurance	2	2	2	2	2	11
GRAND TOTAL	149	77	80	84	87	476

Lake Erie Central Basin - 5 Buoy System + Field Surveys

	yr1	yr2	yr3	yr4	yr5	Total
Capital Expense	1,655	124	126	129	131	2,166
Design & Development	265	44	46	49	51	456
Equipment	1310	0	0	0	0	1310
Facilities	80	80	80	80	80	400
Operating Expense	730	836	866	899	930	4,260
Engineering	35	64	67	71	74	310
Operations/Surveys	302	318	334	351	367	1672
Calibration, Test & Integrat	78	81	85	90	94	428
Deployment	60	60	60	60	60	300
Materials & Supplies	86	86	86	86	86	430
Analytical	19	19	19	19	19	95
Maintenance support	84	142	149	156	164	695
Insurance	66	66	66	66	66	330
GRAND TOTAL	2,385	960	992	1,028	1,061	6,426

Lake Michigan Onshore - Offshore Gradient / Ecosystem Model Support

	yr1	yr2	yr3	yr4	yr5	Total
Capital Expense	2,661	700	263	229	235	4,090
Design & Development	353	249	163	129	135	1031
Equipment	2208	351				2559
Facilities	100	100	100	100	100	500
Operating Expense	1,183	1,399	1,449	1,504	1,565	7,110
Engineering	142	242	252	266	280	1184
Operations	418	441	464	484	509	2317
Calibration, Test & Integrat	156	163	170	180	189	859
Deployment	65	65	65	65	65	325
Materials & Supplies	135	135	135	135	135	677
Analytical	18	18	18	18	18	90
Maintenance support	139	225	235	246	259	1106
Insurance	110	110	110	110	110	552
GRAND TOTAL	3,844	2,099	1,712	1,733	1,800	11,200

Table 9. Leveraged 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

ATTACHMENT 1

5 YEAR COST ESTIMATE FOR THE CENTRAL BASIN LAKE ERIE HYPOXIA MONITORING AND ALERT SYSTEM

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Attachment 1:
5-Year Cost Estimate for the Central Basin Lake Erie Hypoxia Monitoring and Alert System

The system comprises of 5 fixed platforms to measure DO, conductivity, pH, and water temperature at select locations within Central Basin Lake Erie. Four fixed sensor installations will be located at water intakes within the region augmented by field cruises conducted every two weeks from mid-June to mid-August to obtain water quality profiles. During these cruises, a probe will be lowered every mile to measure temperature, DO, conductivity, and pH. At select locations, grab samples will be collected to measure TP, TN, silica and chlorophyll. One buoy will be dedicated to meteorological and water current measurements, a total of 6 buoys.

The buoys will use 3-m discuss buoys as base deployment platform equipped with a suite of sensors to measure the set of water quality parameters. Water quality sensors mounted at the intakes will rely on existing infrastructure for support. The following water quality and meteorological parameters will be measured:

- DO
- Conductivity
- pH
- Water temperature
- Air temperature
- Wind speed
- Barometric pressure
- Humidity
- Turbidity
- CDOM
- TP
- TN
- Si
- Chlorophyll

Measurement of these parameters will require the following probes:

- Dissolved Oxygen (DO) probe
- Conductivity, temperature Depth (CTD) probe
- pH probe
- Meterological station (wind speed, air temperature, humidity) and water current (ADCP)
- Fluorescence (CDOM, chl-a) probe
- Turbidity sensor

These probes are constituted into three sensor suites (S1, S2, and S3) in order to meet the programmatic requirements for this system. Pricing schedule for these sensor suites are presented below:

Table 1. Sensor Configuration and Pricing

	Unit Cost	Sensor suite S1	Sensor suite S 2	Sensor suite S3
DO sensor	$5,000	x		x
CTD	$3,000	x		x
pH probe	$3,000	x		x
Met. Station/ADCP	$30,000		x	
Fluorescence (CDOM, chl-a)	$5,000			x
Turbidity	$5,000			x
Total cost		**$11,000**	**$30,000**	**$21,000**

Equipment

Cost of sensors and base platforms are detailed under capital expenses. Sensor suite S1 is configured for deployment on five buoys; sensor suite S2 is configured for deployment on one buoy dedicated for atmospheric and water current measurements; sensor suite S3 is configured for deployment from mobile platforms (e.g. an undulating tow body, AUV) and from water intake structures. For this particular system, a research vessel outfitted with an undulating tow body will be used in deploying sensor suite S3 during field campaigns while a fixed installation will be used at the four intakes using existing infrastructure for support. For this system, the total (capital) cost of sensors are incurred during year one; five (5) of S1, one (1) of S2 and five (5) of S3 totaling an investment of $190,000. Six (6) buoys are required at a base cost of $145,000 totaling an investment of $870,000. In addition, a research vessel outfitted with an undulating tow body is procured at $250,000 bringing the total capital investment in platforms (fixed and mobile) to $1,120,000. Combined investments in equipment total $1,310,000 incurred in yr1. Other capital expenditure include design and development totaling $456,700 and facilities ($80,000 per year) totaling $400,000 over 5 years.

Personnel

Staffing costs are detailed under operating expenses. Personnel requirements for this type of system will include a crew dedicated to perform engineering, technical and maritime functions according to the following schedule. Internal staffing structure is assumed with a base hourly rate calculated on the basis of salaries and fringe. The detailed cost schedule (Table 1) allows for a 5% yearly cost of living increase.

Table 2. Staffing Costs by Function

Staffing Function	Base Hourly Rate	Description of duties
Engineering	$85	Design and development, engineering support
Field Technician I	$60	Platform operations, deployment, test and integration
Field Technician II	$55	
Instrument Tech	$65	Sensor calibration, test and integration
Maintenance Tech II	$55	Sensor and platform maintenance
Maintenance Tech II	$45	
Maritime Specialist	$70	Daily operations, scheduling and work plans

Engineering – A total of $1,034,800 is required over 5 years in engineering costs (86% fixed platforms, 14% field campaigns) including research and development, system troubleshooting and diagnostics, equipment and technical specifications. Platform placement and maintenance planning duties, spares inventory requirements and tracking.

Operations – A total of $1,674,800 is required over 5 years for daily operational support. Two field technician levels (Tech I and Tech II) and a maritime specialist are required to perform specific duties as determined by engineering.

Field Tech I & II, maritime specialist: 39% supports fixed platform operations

Field Tech I & II, maritime specialist: 61% supports field campaigns

Calibration Test and Integration – A total of $429,600 is required over 5 years for calibration, test and integration of platforms and sensors within the network; 87% in support of fixed platform operations and 13% in support of field campaigns.

Maintenance Support – A total of $697,360 is required over 5 years to cover the costs of maintaining the platforms. Two maintenance technician levels (Tech I and Tech II) are required to perform specific duties as determined by engineering.

Maintenance Tech I & II: 75% supports fixed platform operations

Maintenance Tech I & II: 25% supports field campaigns

Other

Deployment – A total of $300,000 ($60,000 per year; $50,000 fixed platforms, $10,000 field campaigns) is required over 5 years in support of deployment activities to cover daily work barge rates ($2500 per day), travel and other associated costs.

Materials & Supplies – A total of $427,500 is required over 5 years; $327,500 in spares (79% fixed platforms, 21% field campaign) and $100,000 (50% split between fixed platforms and field campaigns) in consumables.

Analytics – A total of $96,000 ($19,200 per year) is required in laboratory analysis.

Insurance – A total of $327,500 is required over 5 years ($65,500 per year) to cover potential loss of equipment.

Table 3. Cost Schedule for Regional Scale Sensor Network (x1000 dollars)

	5 yr Summary					
	yr1	yr2	yr3	yr4	yr5	Total
Capital Expense	**1,655**	**124**	**126**	**129**	**131**	**2,167**
Design & Development	265	44	46	49	51	456
Equipment	1,310	0	0	0	0	1,310
Base platform	1,120	0	0	0	0	1,120
Sensor suite	190	0	0	0	0	190
Facilities	80	80	80	80	80	400
Operating Expense	**807**	**984**	**1,020**	**1,060**	**1,102**	**4,975**
Engineering	115	213	223	235	247	1,034
Operations	302	318	334	351	367	1,674
Calibration, Test & Integration	78	81	85	90	94	429
Deployment	60	60	60	60	60	300
Materials & Supplies	86	86	86	86	86	428
Consumables	20	20	20	20	20	100
Spares	66	66	66	66	66	328
Analytics	19	19	19	19	19	96
Maintenance support	84	142	149	156	164	697
Insurance	66	66	66	66	66	328
GRAND TOTAL	**2,465**	**1,111**	**1,150**	**1,192**	**1,236**	**7,154**

Summary

The 5-yr total cost of ownership (TCO) is estimated at **$7.154 MM** with 67% allocated to fixed sensor platforms and 33% allocated to field campaign efforts. Each of these (fixed platforms and field campaign) have associated capital and operating costs as detailed in the table and summarized below. **$1.655 MM** is required in yr-1 for equipment procurement and observing system design and development.

1. Capital

A total of **$2.167 MM** is required over a 5-yr period which will cover the cost of 6 buoys equipped with sensor suite, 4 fixed sensor packages installated for measuring water quality and meteorological parameters as wells as one vessel equipped with undulating tow body for field campaigns. One buoy is configured for basic meteorological measurements while a research vessel/work boat (**$0.636 MM**) is required for field campaigns and maintenance support. Total cost of the sensor suite is estimated at **$0.190 MM** while total cost of the base platforms are estimated at **$1.12 MM**. Over the 5-yr period, **$0.457MM** is required for design and development costs while facilities cost is estimated at **$0.400 MM** over the same period.

Of the total capital, 71% is allocated to fixed platforms and 29% to field campaign efforts. Facilities costs are split evenly between both observing system components.

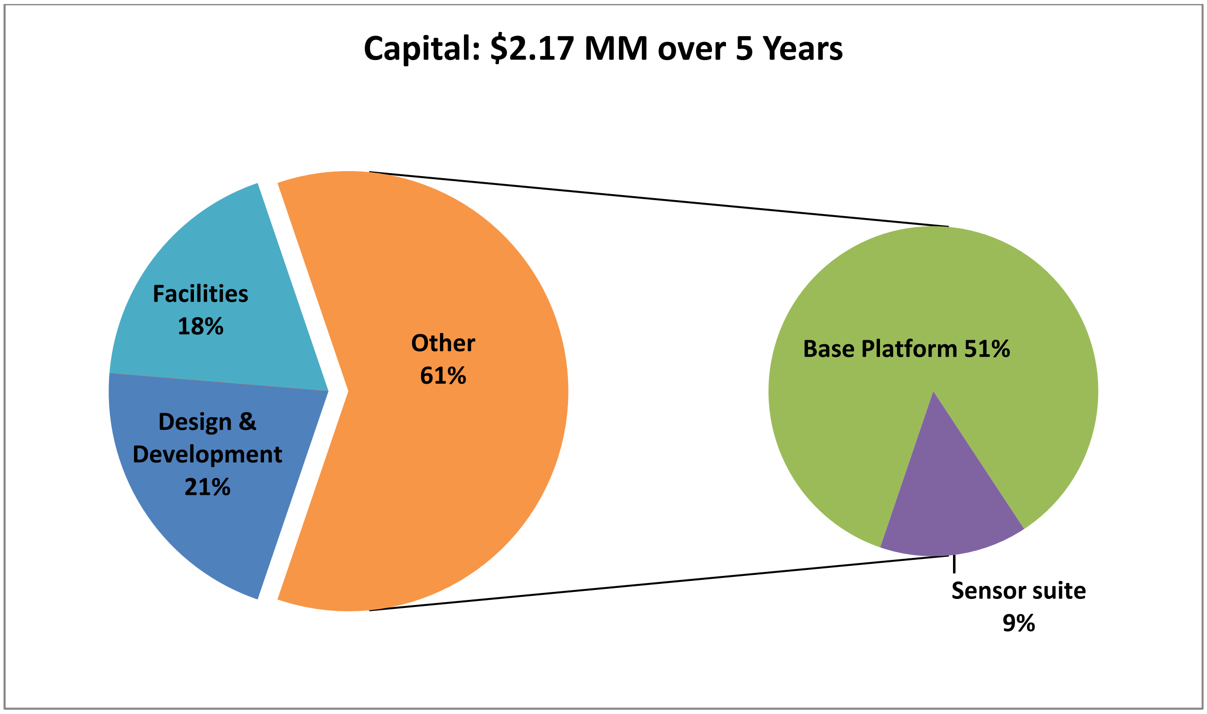

Figure 1: Capital cost over 5-yr period

2. Operating

A total of **$4.99 MM** is required over a 5-yr period which will cover engineering support (**$1.035 MM**), daily operations (**$1.675 MM**), test & integration (**$0.429 MM**), deployment (**$0.3 MM**), materials & supplies (including spares; **$0.427 MM**), laboratory (i.e. analytical; **$0.096 MM**), maintenance support (**$0.697 MM**) and insurance (**$0.0.328 MM**). A 5% cost-of-living adjustment is used in the 5-yr plan with 65% of the operating expense associated with fixed platforms and 35% associated with field campaign efforts.

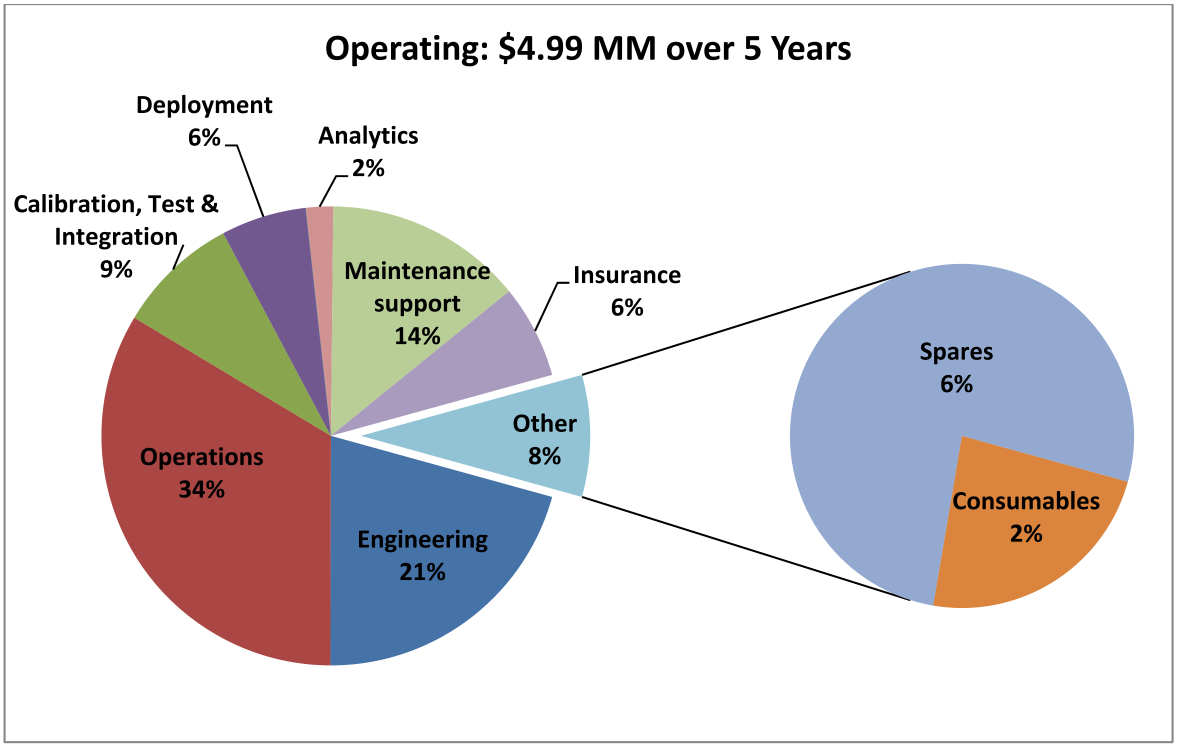

Figure 2. Operating cost over 5-yr period

LimnoTech
Water | Environment | Scientists | Engineers

MEMORANDUM

FROM: Ed Verhamme

TO: GLOSEA Team

DATE: 4/28/11
PROJECT: GLOSEA

CC:

SUBJECT: Example "Scope of Work" for Central Lake Erie Hypoxia Monitoring and Forecasting

The purpose of this memo is to lay out an example scope of work for monitoring and forecasting hypoxia in the central basin of Lake Erie.

Introduction

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.

Approach

To meet the needs of the City of Cleveland and other municipalities in the region 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.

Methods

1. In-situ Monitoring

    a. Buoys (see attached map)

A network of moored buoys located in the central basin of Lake Erie will measure the progression (area and thickness) of the hypoxic zone throughout the summer and into the fall. The buoys will be positioned to capture the initial onset of hypoxic 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 dissolved oxygen, conductivity, and pH at one or more depths and water temperature at several depths. One or more buoys will also measure atmospheric data (air temp, RH, pressure, wind speed and direction) and water velocity data (ADCP).

b. Intake water monitoring

    i. Locations: every intake drawing surface water

    ii. Key Parameters: DO, Temperature, Conductivity, pH

    iii. Other Parameters: turbidity

2. Field campaigns

Every two weeks from mid-June to mid-August, water quality profiles will be recorded 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 TP, TN, silica and chlorophyll. GPS coordinates will be recorded for each profile location along the transect.

3. Forecasting Model (area and thickness of dead zone)

The forecasting model will consist of an empirical 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 is 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. The output from this simulation would be meshed with the long term forecast to increase the likelihood that hypoxic waters would reach the intakes on an hourly to daily time scale.

a. Long term forecasting (monthly empirical model that needs developing)

    i. Analyze historical data to identify a relationship between data and other factors (day of year, water temp, phosphorus, wind, water level, etc..)

    ii. Validate the relationship against historical data and adjust as needed

b. Short term forecasting (hourly to daily GLCFS combined with long term forecasted area and depth)

    i. Investigate ways to tie in the existing forecasting model to predict short term events

c. Develop a prediction "calendar" showing likelihood of intakes drawing in anoxic water. Show reasonable uncertainty bounds with the prediction

Data Products

1. Real time data
    a. Time series plots
    b. Comparisons to model results
2. Model Predictions
    a. Calendar
    b. Time Series
    c. Spatial profiles (kriged maps)

ATTACHMENT 2

5 YEAR COST ESTIMATE FOR THE LAKE MICHIGAN OFFSHORE GRADIENTS MONITORING SYSTEM

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Attachment 2:
5-Year Cost Estimate for the Lake Michigan Offshore Gradients Monitoring System

The system comprises of three main observing system components; fixed platforms, mobile platforms and field campaigns. Of the first component, there will be 9 total fixed platforms; 8 are buoy based surface units configured to measure meteorological data, currents, and water temperature at select locations within Lake Michigan. Four of these surface units are equipped with multi-parameter sondes to provide complementary parameters including dissolved oxygen (DO), conductivity, pH, turbidity, CDOM and chlorophyll. One fixed platform will be a sub-surface cabled unit providing year round sampling capability to measure water temperature, waves, current, and ice cover. The second component will involve field campaigns conducted within the region surrounding the fixed platforms. Datasets provided from 10 field cruises conducted each year along six transects will provide profiles of nutrients, phytoplankton, zooplankton biomass and speciation, as wells as benthic algae and organism abundance. During these cruises, an undulating tow body will be used in providing 3-dimensional profiles of Chl-a, turbidity, PAR, conductivity, CDOM, temperature, DO. Additional payload on the tow body will include a side scan sonar and submersible video equipment for lake bathymetry and lake-bottom video. The third component will comprise mobile platform primarily a glider based system equipped with the same payload as on the undulating tow body and will be used each year to conduct two extensive surveys spanning several days in length.

The eight surface units will use 3-m discuss buoys as base deployment platform equipped with a suite of sensors to measure the required set of parameters. The sub-surface unit will comprise a cabled underwater vertical profiling system. A 35 ft vessel equipped with an undulating tow body will provide the base system for field campaigns while the mobile platform will be a glider based system. The following water quality and meteorological parameters will be measured:

- DO
- Conductivity
- pH
- Water temperature
- Air temperature
- Wind speed
- Barometric pressure
- Humidity
- Turbidity
- CDOM
- TP
- TN
- Chlorophyll
- Phytoplankton
- Zooplankton (biomass)
- Zooplankton (speciation)
- Benthic algae
- Lake bathymetry
- Lake-bottom video
- Ice cover

Measurement of these parameters will require the following probes:

- Dissolved Oxygen (DO) probe
- Conductivity, temperature Depth (CTD) probe
- pH probe
- Meterological station (wind speed, air temperature, humidity) and water current (ADCP)
- Fluorescence (CDOM, chl-a) probe
- Turbidity sensor
- Side scan sonar
- Submersible video equipment

These probes are constituted into three sensor suites (LM1, LM2, and LM3) in order to meet the programmatic requirements for the Lake Michigan monitoring system. Pricing schedule for these sensor suites is presented below:

Table 1. Sensor Configuration and Pricing

	Unit Cost	Sensor suite LM1	Sensor suite LM2	Sensor suite LM3
DO sensor	$5,000		X	x
CTD	$3,000	x	X	x
pH probe	$3,000		X	x
Met. Station/ADCP	$30,000	x	X	X
Fluorescence (CDOM, chl-a)	$5,000		X	X
Turbidity	$5,000		x	X
Side scan sonar	$30,000			X
Submersible video	$10,000			x
Total cost		**$33,000**	**$51,000**	**$91,000**

Equipment

Cost of sensors and base platforms are detailed under capital expenses. Sensor suite LM1 is configured for deployment on four surface buoys; sensor suite LM2 is configured for deployment on four surface buoys and cabled sub-surface unit; sensor suite LM3 is configured for deployment from the mobile system and glider. A 35 ft research vessel outfitted with an undulating tow body will be used in deploying sensor suite LM3 during field campaigns while a glider will carry the same LM3 payload. For this system, the total (capital) cost of sensors are incurred in years 1 & 2; four (4) of LM1, five (5) of LM2 and two (2) of LM3 totaling an investment of $569,000. Eight (8) buoys are required at a base cost of $145,000 totaling an investment of $1,160,000. In addition, a research vessel outfitted with an undulating tow body at $250,000 and a glider at a base cost of $280,000 are procured bringing the total capital investment in platforms (fixed and mobile) to $1,990,000. Combined investments in equipment total $2,559,000 incurred in years 1 & 2. Other capital expenditure include design and development totaling $1,031,800 and facilities ($100,000 per year) totaling $500,000 over 5 years.

Personnel

Staffing costs are detailed under operating expenses. Personnel requirements for this type of system will include a crew dedicated to perform engineering, technical and maritime functions according to the following schedule. Internal staffing structure is assumed with a base hourly rate calculated on the basis of salaries and fringe. The detailed cost schedule (Table 2) allows for a 5% yearly cost of living increase.

Table 2. Staffing Costs by Function

Staffing Function	Base Hourly Rate	Description of duties
Engineering	$85	Design and development, engineering support
Field Technician I	$60	Platform operations, deployment, test and integration
Field Technician II	$55	
Instrument Tech	$65	Sensor calibration, test and integration
Maintenance Tech II	$55	Sensor and platform maintenance
Maintenance Tech II	$45	
Maritime Specialist	$70	Daily operations, scheduling and work plans

Engineering – A total of $1,184,560 is required over 5 years in engineering costs (75% fixed platforms, 13% field campaigns, 12% mobile platforms) including research and development, system troubleshooting and diagnostics, equipment and technical specifications. Platform placement and maintenance planning duties, spares inventory requirements and tracking.

Operations – A total of $2,317,440 is required over 5 years for daily operational support. Three field technician levels (1 x Tech I and 2 x Tech II) and a maritime specialist are required to perform specific duties as determined by engineering.

Field Tech I & II, maritime specialist: 42% supports fixed platform operations

Field Tech I & II, maritime specialist: 44% supports field campaigns

Field Tech I & II, maritime specialist: 14% supports mobile platform operations

Calibration Test and Integration – A total of $859,200 is required over 5 years for calibration, test and integration of platforms and sensors within the network; 87% in support of fixed platform operations and 7% in support of field campaigns and 7% in support of mobile platforms.

Maintenance Support – A total of $1,106,120 is required over 5 years to cover the costs of maintaining the platforms. Three maintenance technician levels (1 x Tech I and 2 x Tech II) are required to perform specific duties as determined by engineering.

Maintenance Tech I & II: 68% supports fixed platform operations

Maintenance Tech I & II: 16% supports field campaigns

Maintenance Tech I & II: 16% supports mobile platforms

Other

Deployment – A total of $325,000 ($65,000 per year; $45,000 fixed platforms, $10,000 field campaigns, $10,000 mobile platforms) is required over 5 years in support of deployment activities to cover daily work barge rates, travel and other associated costs.

Materials & Supplies – A total of $677,000 is required over 5 years; $552,000 in spares (68% fixed platforms, 15% field campaign, 17% mobile platform) and $125,000 (40% split between fixed platforms and field campaigns and 20% mobile platforms) in consumables.

Analytics – A total of $90,000 ($18,000 per year) is required in laboratory analysis.

Insurance – A total of $552,000 is required over 5 years ($110,400 per year) to cover potential loss of equipment.

Table 3. Cost Schedule for Intermediate Scale Sensor Network (x1000 dollars)

	yr1	yr2	yr3	yr4	yr5	Total
Capital Expense	**2,661**	**700**	**263**	**229**	**235**	**4,090**
Design & Development	353	249	163	129	135	1,031
Equipment	2,208	351				2,559
Base platform	1,690	300				1,990
Sensor suite	518	51				569
Facilities	100	100	100	100	100	500
Operating Expense	**1,185**	**1,400**	**1,451**	**1,505**	**1,567**	**7,111**
Engineering	142	242	252	266	280	1,184
Operations	418	441	464	484	509	2,317
Calibration, Test & Integration	156	163	170	180	189	859
Deployment	65	65	65	65	65	325
Materials & Supplies	135	135	135	135	135	677
Consumables	25	25	25	25	25	125
Spares	110	110	110	110	110	552
Analytics	18	18	18	18	18	90
Maintenance support	139	225	235	246	259	1,106
Insurance	110	110	110	110	110	552
GRAND TOTAL	**3,847**	**2,100**	**1,715**	**1,735**	**1,803**	**11,202**

Summary

The 5-yr total cost of ownership (TCO) is estimated at **$11.202 MM** with 63% allocated to fixed sensor platforms, 22% allocated to field campaign efforts and 15% to mobile sensor platforms. Each of these (fixed platforms, mobile platforms and field campaign) have associated capital and operating costs as detailed in the table and summarized below. **$2.652 MM** is required in yr-1 and **$0.700** in yr-2 for equipment procurement and observing system design and development.

1. Capital

A total of **$4.091 MM** is required over a 5-yr period which will cover the cost of 8 surface buoys and1 sub-surface unit equipped with sensor suite for measuring water quality and meteorological parameters. One 35 ft vessel equipped with undulating tow body is required for field campaigns as well as one glider; both systems having sensor payload which costs are included in this estimate for capital expenditure. The research vessel will double as a work boat (**$0.706 MM**) for maintenance support tasks. Total cost of the sensor suites are estimated at **$0.569 MM** while total cost of the base platforms are estimated at **$1.990 MM**. Over the 5-yr period, **$1.031 MM** is required for design and development costs while facilities cost is estimated at **$0.500 MM** over the same period.

Of the total capital, 64% is allocated to fixed platforms, 19% to mobile platforms and 17% to field campaign efforts. Facilities costs are split 40%, 20% and 40% respectively between observing system components.

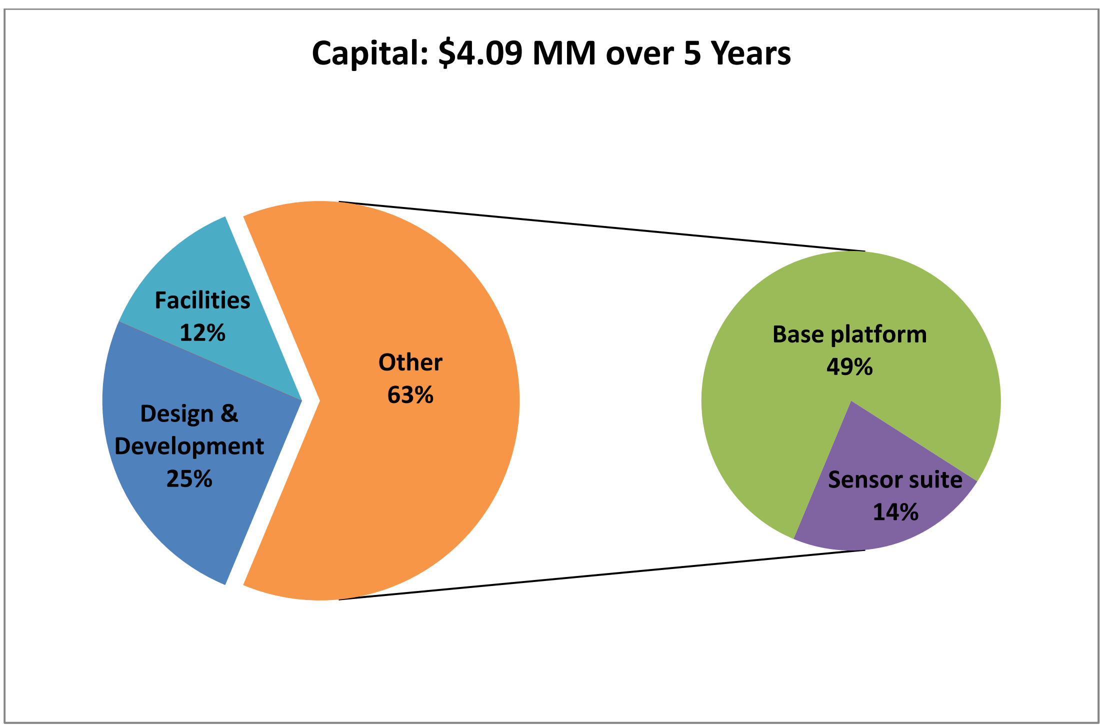

Figure 1. Capital cost over 5-yr period

2. Operating

A total of **$7.111 MM** is required over a 5-yr period which will cover engineering support (**$1.185 MM**), daily operations (**$2.317 MM**), test & integration (**$0.859 MM**), deployment (**$0.325 MM**), materials & supplies (including spares; **$0.677 MM**), laboratory (i.e. analytical; **$0.090 MM**), maintenance support (**$0.1.106 MM**) and insurance (**$0.552 MM**). A 5% cost-of-living adjustment is used in the 5-yr plan with 62% of the operating expense associated with fixed platforms, 14% mobile platforms and 25% field campaign efforts.

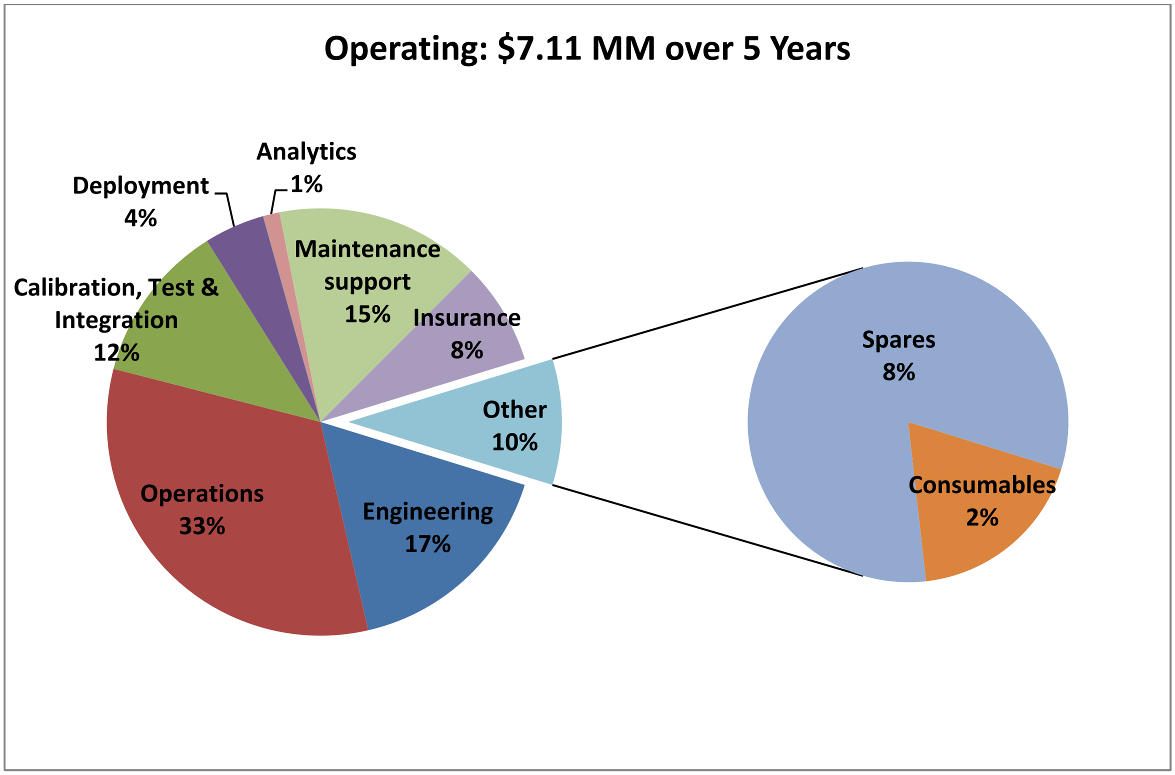

Figure 2. Operating cost over 5-yr period

LimnoTech
Water | Environment | Scientists | Engineers

MEMORANDUM

FROM: Ed Verhamme

DATE: 6/30/11

PROJECT: GLOSEA

TO: GLOSEA Team

CC:

SUBJECT: Lake Michigan Ecosystem Model Observing System Components

Introduction and Background

Over the past 20-25 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.

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

Approach

In order to understand and predict the impact of multiple stressors on the nearshore region of Lake Michigan a combination of environmental monitoring and modeling is proposed. The environmental monitoring 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, verify calibration, and continue to collect data for ongoing model operation. The model will utilize the framework of the Lake Michigan Ecosystem Model developed by USEPA. However, the model framework will require modification to include finer nearshore resolution and new biological process models for Dreissenids and Cladophora.

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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.

Model

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, LM-3 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 predict the fate and transport of toxic chemicals, the model 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). In addition it includes state variables for nutrients in the sediment bed. A schematic of the state variables is shown in Figure 1below.

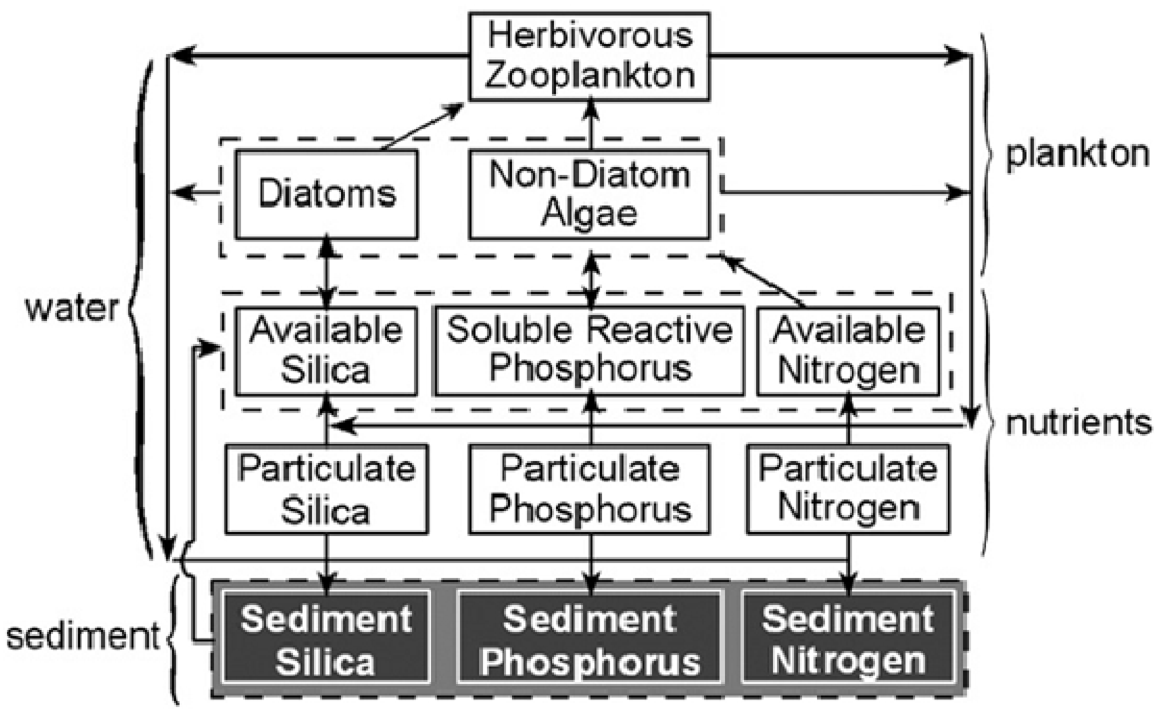

Figure 1. Diagram of LM3-Eutro showing major state variables and transformations links.

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 been 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.

Model Requirements (Variables/Parameters)

1. Operational Model Requirements
    a. Hydrodynamic Model (hourly to daily)

        i. Heat flux/atmospheric inputs (pressure, air temp, solar radiation, relative humidity, evaporation, rainfall, cloud cover)
        ii. Wind speed and direction
        iii. Inflows and outflows from tributaries
    b. Water Quality Model
        i. Continuous inputs (hourly t o weekly)
            1. Inorganic solids loads/concentrations from tributaries
            2. Nutrient loadings/concentration from tributaries
                a. Carbon (DOC, POC)
                b. Phosphorus (TP, SRP, DTP)
                c. Nitrogen (NO23, KN, NH4)
                d. Silica
            3. Other parameter loads (chloride, DO, CHL,)
        ii. Non continuous inputs (irregular to monthly)
            1. Dreissenids (species, density, and size)
            2. Benthic algae substrate

2. Ongoing Model Calibration/Evaluation Data

a. Hydrodynamic (hourly)
    i. Water temperature
    ii. Wave height and period
    iii. Water level
    iv. Water speed and direction

b. Water Quality
    i. Continuous (bi weekly to monthly)
        1. Solids (TSS, VSS, turbidity)
        2. Nutrients
            a. Carbon
            b. Phosphorus
            c. Nitrogen
            d. Silica
        3. Other
            a. Chloride
            b. DO
            c. Ke (PAR or secchi)
        4. Phytoplankton (abundance and species)
            a. Chlorophyll
            b. % Biomass breakdown by major algal groups
        5. Zooplankton (abundance and species)
        6. Benthic algae (density, coverage, and species)
    ii. Non continuous

Data Sources

1. Hydrodynamic model inputs
    a. Atmospheric Inputs (pressure, air temp, wind speed and direction, etc..)
        i. Airports & other land based stations
            1. NOAA sponsored stations
            2. Other collaborators not in CMAN
        ii. Shoreline Stations
            1. CMAN (NWS, GLERL, NOS, etc..)
            2. Other collaborators not in CMAN

    iii. Buoys
        1. NDBC (NDBC, UMICH, MTU, etc..)
        2. Other collaborators not in NDBC
    iv. Remote Sensing
        1. Satellite (temperature, wind speed and direction)
        2. Land based radar (rainfall)
    v. Weather Models
  b. Water Balance Inputs and Outputs
    i. Tributary Inflows
        1. Gaged Tributaries
            a. USGS (may require additional inputs or scaling downstream of gage)
            b. Canadian Water Survey
        2. Ungaged Tributaries
            a. Drainage Area Ratio (related to nearby gaged river)
        3. Watershed Hydrology Model (based on rainfall, e.g. LBRM)
    ii. Connecting Channels Flow
        1. Level/Flow regressions
        2. Model Results (HECWFS, Niagara River)
    iii. Point Sources (probably only power plants)
        1. NPDES data (constant values)
        2. Real-time from source

2. Hydrodynamic model calibration
  a. Shoreline stations
    i. NOAA – NOS
        1. Level, surface temperature, Velocity (river mouths)
    ii. Canadian Water Survey
        1. Level, surface temperature
    iii. Water Intakes (public and private)
  b. Buoys
    i. NOAA – NDBC
        1. surface temperature, wave height and period
    ii. NOAA – GLERL
        1. Temperature profiles, wave height and period, water speed and direction (ADCP)
    iii. Other Buoys (MTU, U of M, etc..)
        1. Temperature profiles, wave height and period, water speed and direction (ADCP)
        2.
  c. Ships/Mobile Platforms
    i. Ships of Opportunity
        1. Parameters…
    ii. Research specific Cruises
        1.
        2. Parameters…
    d. Remote Sensing
        i. satellite
            1. Surface temperature

3. Water Quality Inputs
    a. Tributaries
        i. Real time data
            1. USGS (Conductivity, DO, turbididty, etc..)
            2. Canadian (?)
            3. Others (?)

- ii. Grab Sample data
  1. USGS
  2. Canadian
  3. States
  4. Others
- iii. Model data
  1. DLBRM (?)
  2. Others (?)
- iv. Load calculation
  1. Gaged tributaries with wq data at gage: Calculate load directly and add in sources (point or non-point) downstream of gage
  2. Gaged tributaries with no wq data at gage: Use historical or nearby wq data to generate loading curves and add in sources downstream of gage
  3. Ungaged tributaries: Estimate concentration and apply to DAR or modeled flows (from a runoff model)
  4. Water Quality/Hydrologic model: Use a watershed model to estimate concentration/load
- v.

b. Atmospheric Loads
- i. Estimate from literature
- ii. Estimate from monitoring
- iii. Estimate from models

c. Open Boundary Concentration (if any)
- i. Estimate from monitoring data

4. Water Quality Calibration Data

a. Shoreline
- i. Water Intakes (public and private)
  1. Turbidity, conductivity
  2. Other parameters (?)

b. Buoys
- i. Coastal Buoys (1 to 2 vertical depth sampling)
  1. Turbidity
  2. Conductivity
  3. Phytoplankton (chlorophyll, pigments)
  4. Nutrient (phosphate)
  5. Other Parameters (DO, etc..)
- ii. Open Water Buoys (many vertical depths)
  1. Turbidity
  2. Conductivity
  3. Phytoplankton
  4. Other parameters (DO, etc..)

c. Ships
- i. Ships of Opportunity
- ii. Research Cruises/Towed Sensors

d. Remote Sensing
- i. Satellites
  1. Chlorophyll
  2. HABS
  3. TSS
- ii. Airborne

e. Grab Samples

i. Regular Monitoring Programs
   1. EPA/GLNPO – Open Lake Surveillance
   2. CMSI (US and Canadian)
   3. State agencies (MDNRE, etc..)
   4. Local agencies (GBMSD, Cleveland, etc..)
   5. Universities
   6. Others (?)

ii. Special Research Programs (IFYLE, KITES, EEGLE, etc..)
   1. Government sponsored (GLRI, etc..)
   2. University research (GLPF, NSF, GLRI, NOAA, etc..)
   3. Other Public funded research (county, municipal, etc..)
   4. Privately funded (AEP, etc..)