NOAA Technical Memorandum GLERL-147b

IMPACT OF CLIMATE CHANGE ON THE GREAT LAKES ECOSYSTEM A NOAA SCIENCE NEEDS ASSESSMENT WORKSHOP TO MEET EMERGING CHALLENGES - SUMMARY REPORT

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UNITED STATES
DEPARTMENT OF COMMERCE

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Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

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NOAA's Mission – To understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social and environmental needs

NOAA's Mission Goals:

- Protect, restore and manage the use of coastal and ocean resources through an ecosystem approach to management
- Understand climate variability and change to enhance society's ability to plan and respond
- Serve society's needs for weather and water information
- Support the Nation's commerce with information for safe, efficient, and environmentally sound transportation
- Provide critical support for NOAA's Mission

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July 29-31, 2008

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C.E. Sellinger, J. Wang, and C. DeMarchi

1. INTRODUCTION

From July 29 to 31, 2008, NOAA's Great Lakes Environmental Research Laboratory (GLERL) co-hosted the workshop – *Impact of Climate Change on the Great Lakes Ecosystem – A NOAA Science Needs Assessment to Meet Emerging Challenges.*

The workshop was held at the School of Natural Resources and Environment, University of Michigan Central Campus, Ann Arbor, Michigan. Workshop co-hosts were the Cooperative Institute for Limnology and Ecosystems Research (CILER), the Great Lakes Sea Grant Network, and the NOAA Great Lakes Regional Team. Event co-sponsors included: GLERL, CILER, and the Pennsylvania, Ohio, Wisconsin, Illinois/Indiana, Minnesota, and Michigan Sea Grant Programs.

The purpose of the workshop was to take the first step in developing a NOAA research strategy that addresses the impact of climate change on Great Lakes coastal ecosystems that is driven by user needs. The workshop was unique because of its focus on identifying and prioritizing research needs and future plans toward understanding the impact of climate change on the physical, chemical, and biological processes in Great Lakes coastal waters and connecting channels. Previous workshops, conferences, and reports that address climate change impacts in the Great Lake region are listed in Appendix I.

The objectives of the workshop were to:

- Examine the current state of knowledge of the physical, chemical, and biological impacts of climate change in the Great Lakes' coastal waters and connecting channels, which includes current scientific understanding, products, services, expertise, monitoring and observing systems, datasets, and forecast models.
- Start a dialogue with Great Lakes stakeholders to identify key needs related to the impact of climate change on Great Lakes resources.
- Document key challenges that climate change impacts pose in continuing effective management, restoration, and protection of the integrity of the Great Lakes Ecosystem and related resources of particular concern to stakeholders.
- Identify and apply presently available scientific expertise, products and services, that support stakeholders in confronting the impacts of climate change in protecting, managing, or restoring Great Lakes resources.

- Identify new scientific research efforts and resulting products that will enhance stakeholder capabilities to better anticipate impacts of climate change on Great Lakes resources and develop more effective, pre-emptive strategies to meet new challenges in managing, protecting, or restoring such resources.
- Compile and disseminate a report summarizing workshop proceedings and recommendations.

2. METHODS

The three day workshop consisted of two full days of scientific and stakeholder presentations followed by the break-out sessions on the third day that brought the scientists and stakeholders together to discuss the thematic areas below.

Key scientific theme focal areas were:

- Physical Environment
- Water Quantity
- Watershed Hydrology
- Water Quality and Human Health
- Fish Recruitment and Productivity
- Aquatic Invasive Species

The scientific presentations can be found online at:
http://www.glerl.noaa.gov/res/Programs/climate_change/cc_workshop_agenda.html
The full workshop Agenda is listed in Appendix II.

The workshop was a first step toward developing an expanded dialogue between the Great Lakes scientific community and Great Lakes stakeholders. Starting the dialogue can strengthen the two-way communication and continue an ongoing process that increases stakeholder awareness of existing and future scientific products, services, and expertise. Through the access to available resources stakeholders will be enabled to develop more effective, science-based strategies to meet future challenges in managing, protecting, or restoring Great Lakes resources in the face of climate change impacts. The dialogue will also increase awareness in the Great Lakes scientific community of immediate and emerging stakeholder needs and allow scientists to respond to such needs by fine-tuning existing research activities, or by planning and developing new research efforts.

The discussion questions are listed below. Some or all of these questions were posed to each of the six break-out sessions filled with a diverse group of scientists, stakeholders, and decision-makers.

What do we need and what is missing?

- What do you see as major research or information gaps in physical environment, water quantity, watershed hydrology, water quality and human health, fish recruitment and productivity, or aquatic invasive species related to climate change science?
- What do you see as immediate needs in this theme area (within the next 2-4 years) for Great Lakes climate change research?

- What do you see as longer-term needs (within the next 5-7 years) for Great Lakes climate change research?
- What type of training, if any, would help you in management efforts?
- Who are your stakeholders and how do you engage them in this issue?
- What scientific products, services, and/or expertise have you sought and from where?
- What is the best way for us to communicate to you new information, tools, and technologies related to this issue?

What is needed to get us there?

- What products/services should NOAA be aiming to develop and what type are they (tools, technology, methods, forecasts, models, or information)?
- At what scale (geographic and spatial) should NOAA work to address this need?
- What collaborations, integration, and coordination are needed to achieve useful development and application of products and services?
- Why is it of value to society?

Appendix III presents a listing of issues, needs, and suggestions identified during the First and Second Breakout Sessions within the Key Scientific Theme Areas.

3. RESULTS

An extensive review of results of the first and second breakout sessions revealed a set of overarching subject categories including:

- Forecasts, models, prediction, outlooks, scenarios, predictive / decision-making tools, uncertainty, risk and risk assessment.
- Research to increase understanding and/or to expand knowledge base.
- Data, data sets, databases, monitoring and observing systems.
- Mapping, GIS, bathymetry and related activities.
- Outreach, communications, collaboration, scientist-stakeholder engagement.
- Economic / societal value, cost-benefit, funding.

Each main thematic area is listed below with key findings from each scientific theme area break out session. Some or all of the questions were answered by break out sessions.

As a whole, the *Physical Environment* group determined that model development needed to be expanded and refined to incorporate lake level forecasts for the entire Great Lakes at multiple spatial scales and resolutions, for example, all forecasts need to be available for the whole lake down to a 100 meter resolution. Increasing the understanding of ice on ecosystem structure and improving ice modeling was also a priority. All products and tools (forecasts and maps) need to be user friendly and readily available for managers and decision makers.

The development of long-term water level forecasts and linking water quantity effects to economic vitality was a main priority for the Water Quantity breakout group. Increased and continuous monitoring and model development with varying water level scenarios would be beneficial to determining climate change impacts on near-shore / coastal communities.

Watershed Hydrology discussions focused on the need for accurate information on water quality, precipitation, and linking land use to the hydrology of the Great Lakes. The development of better models could assist in administering policies for controlling pollution run-off during adverse weather conditions, such as heavy precipitation or increased snow melt events.

The overall sense from the *Water Quality and Human Health* breakout was that the development of predictive models that provide differing scenarios correlating climate change impacts on water quality was needed. For example, bacteria concentrations and nutrient inputs to water levels and hydrodynamics is critical. Additionally, increased outreach and communication to share information, keep up-to-date on research development, and determine which groups are conducting what types of research was seen as valuable.

In regards to *Fish Recruitment and Productivity*, the main research gap is understanding physical-biological coupling and its relationship and impact on population interactions and trophic levels related to fish productivity. In addition, understanding the impact of potential changes in winter conditions and ice cover on egg survival and reproductive success was set forth as a major priority.

The *Aquatic Invasive Species* group concluded that there needs to be better coordination and organization of available resources to research the impact that invasive species will have on the Great Lakes in light of climate change. Assuming food webs will change as a result of climate change, there was discussion on whether priority should be given to sustain native species or to prepare to better manage changes in food webs as invasive species becoming integrated into ecosystems.

Appendix IV provides a table listing key issues, needs, activities, and suggestions identified within each of the overarching subject categories during breakouts of the six Key Scientific Theme Areas. This information serves as the basis of the summary that follows:

Forecasts, models, decision-making tools, uncertainty, risk, and risk assessment

The *Physical Environment* breakout put strong emphasis on forecasts and model development, in particular, a unified lake level forecast model that includes climate change impacts, three-dimensional lake-wide hydrodynamic and ecosystem models, and a Great Lakes Regional Earth System Model. In addition, they cited areas for additional work to include improved ice modeling and forecasting and increased capabilities in forecasting climate change-related increase of intensity of storms. Overall scaling for all models spanned from global to regional to local and was viewed as a critical part of model development.

For *Water Quantity*, key areas for forecasts and model development included improvement of water level forecast models to produce 5-10-year outlooks, forecast products to help improve prediction of extreme events (2-3-year outlook), and an improved, more plausible time series model (precipitation and temperature).

Prime areas for new or expanded efforts in *Watershed Hydrology* included improved flood forecasting systems, institutionalization of water quality models via interagency collaboration (at the 10 sq. km scale), development of an integrated climate watershed model for all of the lakes, and better models and practices for non-point source loadings in response to increased precipitation.

The *Water Quality and Human Health* breakout highlighted two key areas for predictive model development: (1) to assess effects of increased storm/rainfall events on combined sewer overflow (CSO) and their impact on drinking water and beaches in order to better prepare for any infrastructure needs such as moving water intakes and other long term control or construction plans, (2) to assess the impacts of climate change on overall water quality (physical, chemical, and biological). High priority was also given to near-term development of risk assessments of climate change impacts on human health and local economies. The immediate needs identified were to (1) characterize and prioritize potential health risks from toxic chemical cycling and water treatment to see which may be most harmful, (2) develop risk assessments for potential impacts-human health, economic impacts, and (3) utilize predictive tools to develop effective models.

The *Fish Recruitment and Productivity* breakout recommended the development of several models including a global/regional Great Lakes climate change model (basin-wide and by lake), an improved higher resolution three-dimensional hydrodynamic model incorporating a greater number of depth strata driven by output from the regional climate change model, a bio-physical food web model (fish recruitment) coupled with the 3-D hydrodynamic model. These models would then be used to forecast fish recruitment and productivity as a function of climate change scenarios.

The *Aquatic Invasive Species (AIS)* breakout assigned high priority to building basin-wide and lake-by-lake forecast models identifying high-risk areas most vulnerable to AIS invasions, as well as most-likely invaders and/or native species most threatened by AIS-induced extinction. Another identified key objective of model creation was use of forecast models and analysis to create scenarios of future species composition with particular focus on loss of native species with high economic or societal value. A key point was made that the identification of a target food web is important for decision-makers.

Research to increase understanding

Physical Environment: Although the breakout identified a wide array of models that warranted creation, identification of research to support such work was limited. Stakeholders identified the need to better understanding of the effects of ice on ecosystem structure and an expanded understanding of coastal processes.

Water Quantity: High priority research needs included a more complete understanding of the sensitivity of the lakes to temperature, the impacts of channelization and changes in inflows and outflows on water quantity, longer-term water level trends (5-10-year increments), and the impact of water quantity removal from the basin (2007 Groundwater Conservation Advisory Commission).

Watershed Hydrology: There is a need for an assessment of projected changes in future watershed parameters and impacts of crops/agriculture, erosion, and natural vegetation.

Water Quality and Human Health: Prime needed research areas included quantification of watershed nutrient loading and groundwater nutrient concentrations and how nutrient loading/concentrations may differ based on changes in water quantity, and its impacts on drinking water quality. Determination of frequency, duration, and intensity of bacteria affecting beach closures, how climate change will impact bacteria survival, improved understanding of contaminant effects on fish populations (and implications for subsistence fishing and lower socioeconomic communities), and evaluation of climate-related health effects (waterborne and airborne) along with exposure routes and vectors.

Immediate needs are to (1) develop specific climate change scenarios to define the problem (fish harvesting, algal blooms, beach closures) including questions like, what are specific consequences (water flow, water quality), and what are human needs and how might they change? (2) Assess water intakes in the lakes and wastewater discharges including inventories of shipping channels and marinas that may be most affected by lowered water levels and what could happen? (3) Provide information on watershed discharges affecting water quantity-water intakes.

Fish Recruitment and Productivity: Key research objectives highlighted by the breakout included: (1) determine how inter-annual variability in the physical environment (e.g., water temperature, frequency of upwelling events, changes in large scale circulation patterns, etc) interact with multiple stressors (nutrient loading, invasive species) to impact aquatic food webs, (2) examine impacts of climate change on ice cover and implications for ontogeny of spring bloom, especially in Lake Erie, (3) assess impact of climate change on physical factors and subsequent effect on fish spatial distribution for various life stages, (4) identify fish species most vulnerable to climate change impacts, (5) measure changes in benthos productivity in nearshore and offshore areas, (6) forecast changes in land use, corresponding changes in wetland distribution, and their subsequent impact on fish recruitment and productivity, (7) obtain a better understanding of the influence of the lower food web on fish recruitment and productivity.

Aquatic Invasive Species: Suggested key research needs included near-term improved understanding of algae/quagga mussel interactions to support models based on temperature and productivity, and identification of vulnerable species and potential loss of native predator-prey relationships and energy flow changes.

Data, databases, monitoring, and observing systems

Physical Environment: The breakout identified an overall need for better, more complete, and unified data and datasets on a lake-region-wide scale. Feedback on data quality and making data more accessible to mangers was also given a high priority.

Water Quantity: In general, there was a consensus in support of more consistent, effective, and continuous monitoring throughout the basin with a high priority on full support of the implementation of the Integrated Ocean Observing System (IOOS) in the Great Lakes, i.e. the Great Lakes Observing System (GLOS). Near-term establishment of better observing/reporting networks and model outputs was also viewed as a high priority along with deployment of an instrument network to measure evaporation / evapo-transpiration.

Watershed Hydrology: Overall, there was common recognition of inadequate data pertaining to water quality, measured precipitation, and stream flow (gauges).

Water Quality and Human Health: The breakout suggested wider data collection on nutrient loading when/where there are gaps from all possible sources (in coastal zone and nearshore).There was also a need cited for data on frequency, concentration, and speciation of bacteria related to beach closures (watershed-by-watershed scale; weekly/daily time frame during recreational season). Development of continuous data stream sensor technology for monitoring beach bacteria levels was also rated as an important research objective. Finally the breakout recommended documentation and organization of all data on algal blooms to determine if there are climate-related trends. Immediate needs were to document and organize all the data we have about algal blooms to see if there really are trends due to climate change-an inventory.

Fish Recruitment and Productivity: The breakout emphasized the need to improve satellite monitoring of water color for chlorophyll-a (Coastwatch, AVHRR, lake-wide; 0.5–1 km resolution) with a nearshore focus, and expand and improve technology of observation platforms, and perpetuate long-term datasets and monitoring.

Aquatic Invasive Species: A high priority was assigned to expanding AIS monitoring basin-wide at the highest possible resolution while standardizing data collection and promoting greater development of expertise and increased reliance on remote sensing technology, particularly for species such as *phragmites*.

Mapping, GIS, Bathymetry

Physical Environment: Only one need was cited: production of digital bathymetric maps on a lake- and region-wide basis.

Water Quantity: Two key items identified included the development of high-resolution topography / digital elevation maps to support modeling, and creation of present and projected climate maps across a global-state-zip code scale.

Watershed Hydrology: There was full support suggested for basin-wide floodplain maps and flood forecasting systems dependent on scale of the community.

Water Quality and Human Health: The development of GIS maps with CSO locations, drinking water intakes, and other urban infrastructure overlayed with beach maps was discussed, as long as there were no threats to homeland security regarding developing these maps.

Fish Recruitment and Productivity: High priority activities recommended by the breakout included: (1) conduct comprehensive high resolution mapping of bathymetry, bottom type, and associated species throughout the Great Lakes, and (2) conduct high resolution physical and biological mapping of fish habitats (e.g. map/monitor spawning substrates; egg and fry production; egg/larvae predators; current patterns and velocities; and thermal structure).

Aquatic Invasive Species: After identification of high-risk areas, target resources with mapping, database, and GIS overlay including water quality, use, threatened and endangered species, vectors, and temperature regimes.

Outreach, communications, collaborations, and engagement

Physical Environment: Key issues in outreach and communications included recognition of a need to more effectively get lake level variation forecasts to the public, package research and model results in a form that can be readily used by managers and decision makers (at regional to local levels), and plan and conduct research that supports better management.

Water Quantity: The breakout cited critical needs to take full advantage of new communication technologies and ensure more extensive and effective use of communication networks and better organization of web information in meeting stakeholder needs with a corresponding greater identification of end-users, their needs, and feedback.

Watershed Hydrology: There was a recognized need to better translate the developing knowledge on climate change and its likely impacts into changes in the everyday practice of consultants and public servants. An important tool for this purpose would be guidelines issued by professional associations, like the American Society of Civil Engineers and the American Water Works Association, in collaboration with NOAA, about how to include the uncertain knowledge we have on climate change into infrastructure planning and operation. This would help consultants and public servants to overcome the lack of common practices on the subject. Such guidelines should be periodically updated.

An additional instrument that could help in including Climate Change knowledge into present-day infrastructure planning are the continuous education courses that professionals must take for maintaining their licenses. NOAA should work alone or with professional associations to develop courses regarding the possible climate change impact on hydrology and water quality and how to plan for minimizing their impact on the society.

Water Quality and Human Health: There was widespread agreement on the importance of communicating tangible impacts of climate change to the public to better communicate uncertainties without leading to hysteria. Other key areas included identification of infrastructure issues for future planning, through determining infrastructures such as drinking water intakes that may need to be extended or moved as a result of water level changes. Another key discussion topic is local health departments, managers, and local units of government are not aware of the state of science that is being conducted by agencies such as NOAA, so there is a need to bridge the gap between local health departments and the scientific community, encourage greater interaction between NOAA and state and regional agencies, and promote greater reliance on communication technologies through brief bulletins, an email list-serve, or a centralized database website. Furthermore, the creation of a centralized database could provide information on which agencies/organizations are doing certain research, what the progress of the research is, and how to contact each other for collaboration was discussed as a valuable tool. Outreach in the form of communicating social science, economic impacts, and risks assessments to scientists and vice versa is also needed as well as communicating to the non-scientific community.

Immediate needs include the better coordination of groups working on similar problems or issues and the centralization of information about people and projects through a website or other electronic forum. GLANSIS or GLRRIN could serve as the model.

Fish Recruitment and Productivity: There is a need to promote research on climate change impacts on fish recruitment and productivity. Some suggestions were (1) continuing education for the media, (2) climate extension service to work with state climatologists, (3) research national and international outreach, communications, collaboration, and scientist-stakeholder engagement activities regarding climate change and fisheries recruitment, (4) host a scientific symposium on impacts of climate change on the Great Lakes fishery, (5) increase use of web technologies to disseminate research findings, (6) publish research findings in peer-reviewed journals.

Aquatic Invasive Species: Key activities cited were the increased production/dissemination of peer-reviewed and informal publications, the development of greater coordination among web sites, the increased use of list serves (e.g. Enviromich), and expanding outreach to explain the algae/quagga mussel interaction and its impacts.

Economic/societal value, cost/benefit, and funding

Physical Environment: Given the above recognition of needs for new models and related research, there was a corresponding need cited to make a strong case to support funding of such work in terms of economic, societal, and ecological benefits and outcomes.

Water Quantity: There was a general recognition of a lack of information and research gaps on how water quantity affects economic vitality and an overall need for documenting economic value of climate change research (to justify additionally required research funding/staffing).

Watershed Hydrology: Incorporation of the social sciences and a need for cost/benefit ratios under climate change scenarios were identified as important areas to fully address watershed hydrology issues.

Water Quality and Human Health: Social science research is vital. Key areas included a need to fully assess the financial and economic implications of bacterial infections at the community level and the effects on human health. End users discussed the need for specific recommendations for how to deal with and adapt to water quality changes. What are the impacts of climate change on tourism and shipping channels due to water levels? What are the recommendations for urban infrastructure due to the potential for more storms or decreased drinking water access?

Outreach in the form of communicating social science, economic impacts, and risks assessments to scientists and vice versa is also needed as well as communicating to the non-scientific community. In addition, social science research is needed to determine cost and benefits, socioeconomic, and health impacts of poor water quality or water accessibility as well as the impact of climate change on economies. Immediate needs were the socioeconomic and health implications due to a lack of access to water.

Fish Recruitment and Productivity: Assess impacts of climate change on fishery harvest and economically important harvested species, evaluate economic impacts on commercial and sport fishing industries and the need for modifying regulations, create more opportunities for inter-disciplinary interactions among social scientists, limnologists, and aquatic ecologists.

Aquatic Invasive Species: Two key high priority activities suggested by the breakout were (1) meeting needs for more information on AIS economic and ecological impacts relative to the climate change outlook, and (2) recognition that uncertainty, lack of funding, and failure to make an economic case for AIS/climate change research are barriers to greater stakeholder involvement.

4. CONCLUSION AND RECOMMENDATIONS

The physical and biological communities in the Great Lakes have been affected by the variations in climate over the last decade. The physical changes in the Great Lakes are noted by higher water temperatures, less ice cover, increased evaporation, lower water levels, increased dead zone, and frequent, high-intensity storms. The biological changes are noted by the collapse of Lake Huron's fisheries, changes in the food webs, increased beach closures, viral hemorrhagic septicemia, and increased toxic algae.

These physical and biological changes have resulted in damages to both the health and economic well-being of the Great Lakes. Understanding, forecasting, and translating the impacts of these changes to the Great Lakes community will greatly aid stakeholders (commercial power, commercial shipping, recreational boaters, beach users, municipal water supplies, fisheries, etc.) in making wise decisions regarding their use of this vast national resource.

NOAA's role is critical in mitigating damages to both the health and economic well-being of the Great Lakes. NOAA can provide the forecasts and monitoring, packaged into useful products and services needed in the Great Lakes community. Therefore, it is recommended that:

- NOAA should develop water quality forecasts to address drinking water quality, beach closures, and harmful algal blooms.
- NOAA should develop long-term (5 to 10 years) water quantity forecasts.
- NOAA should improve flood forecasting.
- NOAA should develop a better observing system equipped with water quality indicators.
- NOAA should translate their forecasts and data acquisition into user-friendly products and services.
- NOAA should work with stakeholders, state, local, and other Federal Agencies to achieve all of the needs in this report using the best science available.

To accomplish these recommendations, NOAA can take the following initial steps:

- Establish a Regional Integrated Sciences and Assessment (RISA) element in the Great Lakes that should include have social scientists, economists, and science-policy employees. These NOAA employees can provide needed risk assessments with respect to human health and invasive species as well as translate NOAA's forecasts and observation data into user-friendly products and services.
- Invest in supercomputing networks for the Great Lakes. Climate, water quality, food web, and water quantity models will require high-power computing.
- Invest in Great Lakes observing systems. Water quality buoys need to be deployed at municipal water intakes, algorithms need to be better refined for satellite observations of HABS, and acoustic instruments need to be refined for fish recruitment.

Appendices Index

Appendix I - Previous Workshops, Conferences, and Related Reports on Impacts of Climate Change in the Great Lakes Region.

Appendix II - Full Workshop Agenda.

Appendix III – Listing of Issues, Needs, and Suggestions from First and Second Breakout Sessions Within the Key Scientific Theme Areas – Physical Environment, Water Quantity, Watershed Hydrology, Water Quality and Human Health, Fish Recruitment and Productivity, and Aquatic Invasive Species.

Appendix IV - Table listing key issues, needs, activities, and suggestions identified within each of the overarching subject categories during breakouts of the six Key Scientific Theme Areas.

Appendix I - Previous Workshops, Conferences, and Related Reports on Impacts of Climate Change in the Great Lakes Region

(1) Confronting Climate Change in the Great Lakes Region – A one-day workshop that brought together Great Lakes foundations, non-government organizations, agencies, and universities, Flint, Michigan, June 27, 2008.
http://www.miseagrant.umich.edu/climate/climate-adapting-workshop.html

(2) Dempsey, D., J. Elder, and D. Scavia, 2008. Great Lakes Restoration and the Threat of Global Warming. Healing Our Waters-Great Lakes Coalition.
http://www.healthylakes.org/wordpress/wp-content/uploads/2008/05/how-global-warming-report-08.pdf

(3) Wittman, S., 2008. Climate Change in the Great Lakes Region – starting a public discussion, Summary Report, University of Wisconsin Sea Grant Institute, Publication No. WISCU-W-07-001.

Report is a summary of the "Starting a Public Discussion" series of eight seminars on likely impacts of climate change in Wisconsin and the Great Lakes Region. The seminars were held at seven Wisconsin locations in 2007.
http://aqua.wisc.edu/publications/ProductDetails.aspx?productID=552

Previous Climate Change Conferences at Michigan State University

(4) Climate Change in the Great Lakes – A Conference at Michigan State University, April 9-10, 2008.
http://www.environment.msu.edu/climatechange/presentations08.html

Climate Change in the Great Lakes Region – Decision-Making Under Uncertainty, March 15-16, 2007.
http://www.environment.msu.edu/climatechange/presentations07.html

Stakeholder Workshop, December 1, 2005

(5) U.S. Environmental Protection Agency (EPA), 2008. Effects of climate change for aquatic invasive species and implications for management and research. National Center for Environmental Assessment, Washington, DC; EPA/600/R-08/014.
http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=188305

(6) Stephenson, J.B., 2007. Climate Change – Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources. U.S. Government Accountability Office Report to Congressional Requesters, GAO-07-863.
http://www.gao.gov/new.items/d07863.pdf

(7) U.S. Environmental Protection Agency (EPA), 2008. A screening assessment of the potential impacts of climate change on combined sewer overflow (CSO) mitigation in the Great Lakes and New England regions. Global Change Research Program, National Center for Environmental Assessment, Washington, DC; EPA/600/R-07/033F.
http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=188306

(8) Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, L.R. Lindroth, S.C. Moser, and M.L. Wilson, 2003. Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems. Union of Concerned Scientists, Cambridge, MA and Ecological Society of America, Washington, DC.
http://www.ucsusa.org/greatlakes/glchallengereport.html
Note: Updated 2005 Executive Summary of 2003 UCS/ESA Report is at:
http://www.ucsusa.org/assets/documents/global_warming/GL-Exec-Summary-Update-05-doc.pdf

(9) Sousounis, P.J. and J.M Bisanz (Eds.), 2000. Preparing for a Changing Climate – The Potential Consequences of Climate Variability and Change; Great Lakes Overview – A Report of the Great Lakes Regional Assessment Group for the U.S. Global Change Research Program, University of Michigan, Atmospheric, Oceanic and Space Sciences Department, Ann Arbor, MI, ISBN 0-9705610-0-3
http://www.geo.msu.edu/glra/assessment/assessment.html
Note: Report summarizes findings from series of six workshops listed below:

Opening Workshop - "Climate Change in the Upper Great Lakes", May 4-7, 1998, University of Michigan, Ann Arbor, MI.

Follow-up Workshops -

(1) "Climate Change and Great Lakes Water Levels: What are the potential impacts? What can we do?" March 30, 2001, USEPA Great Lakes National Program Office, Chicago, IL.

(2) "Climate Change and Water Ecology: What are the potential impacts? What can we do?", June 15, 2001, University of Wisconsin-Milwaukee.

(3) "Climate Change and Agriculture in the Great Lakes Region: The Potential Impacts & What We Can Do.", March 22, 2002 ,Michigan State University, East Lansing, MI.

(4) "Climate Change & Terrestrial Ecosystems of the Great Lakes Region: The Potential Impacts and What We Can Do", June 21, 2002, Minnesota Valley Wildlife Refuge, Bloomington, MN.

(5) "Climate Change and Winter Tourism: What are the Potential Impacts & What Can We Do.", November 8, 2002, Crystal Mountain Ski Resort, Thompsonville, MI.

Appendix II - Full Workshop Agenda

Impact of Climate Change on the Great Lakes Ecosystem - A NOAA Science Needs Assessment Workshop to Meet Emerging Challenges

AGENDA – Note: Individual presentations are posted as pdf files at:
http://www.glerl.noaa.gov/res/Programs/climate_change/cc_workshop_agenda.html

TUESDAY - JULY 29, 2008
Current state of scientific knowledge of present and expected future impact of climate change on the Great Lakes ecosystem, with prime focus on effects in coastal waters and connecting channels.

8:00 AM – Check-in / Continental Breakfast SNR&E Commons

8:30 AM –Introduction / Welcome
Dr. Stephen B. Brandt, Director, NOAA/Great Lakes Environmental Research Laboratory (GLERL)

Note: All July 29th and 30th presentations and panels will be held in Rm. 1040 Dana Building, School of Natural Resources and Environment, University of Michigan Central Campus, Ann Arbor, MI

8:45 AM – **Science Panel #1 - Physical Environment** - Seasonal Warming/Cooling, Vertical Temperature Profiles and Ice Extent/ Duration
Session Chair –Dr. Jia Wang, Ice Climatologist, NOAA/Great Lakes Environmental Research Laboratory

8:45 AM – Dr. Xuezhi Bai, Research Investigator, University of Michigan School of Natural Resources and Environment/Cooperative Institute for Limnology and Ecosystems Research. *Interannual Variability of Lake Ice and Internal Climate Teleconnection Patterns* (Co-Author: J. Wang)

9:00 AM – Dr. Eric Anderson, National Research Council Post Doctoral Fellow, NOAA Great Lakes Environmental Research Laboratory. *Hydrodynamic Modeling and Forecasting in the Great Lakes* (Co-Authors: D.J. Schwab, D.J. Holtschlag, and G.A.Lang)

9:15 AM – Dr. Jia Wang, Ice Climatologist, NOAA/Great Lakes Environmental Research Laboratory. *Projections of the Great Lakes Climate in the 21st Century and Coupled Lake-Ice Modeling*

9:45 AM - Break

10:00 AM - **Science Panel #2 - Water Quantity** – Lake Levels and Flows in Connecting Channels - *Session Chair – Ms. Cynthia Sellinger, NOAA/Great Lakes* Environmental Research Laboratory

10:00 AM - Dr. Thomas E. Croley II, Senior Research Hydrologist, NOAA/Great Lakes Environmental Research Laboratory. *Great Lakes Sensitivity to Paleo Climate Change*

10:15 AM - Ms. Cynthia Sellinger, Hydrologist, NOAA/Great Lakes Environmental Research Laboratory. *The Rise and the Fall of Great Lakes Water Levels*

10:30 AM - Dr. Brent Lofgren, Physical Scientist, NOAA/Great Lakes Environmental Research Laboratory. *Modeling to Address Open Questions on the Future of Great Lakes Climate*

10:45 AM - Q&A / Discussion

11:00AM – **Science Panel #3 - Watershed Hydrology**
Session Chair – Dr. Carlo DeMarchi, Research Investigator, Cooperative Institute for Limnology and Ecosystems Research

11:00 AM – Dr. Norman Grannemann, U.S. Geological Survey, Great Lakes Program Coordinator. *Changes in Groundwater Conditions from Possible Changes in Climatic Conditions in the Great Lakes Basin*

11:15 AM – Dr. Veronica Webster Griffis, Department of Civil and Environmental Engineering, Michigan Technological University. *Potential Impacts of Climate Change on Flood Frequency and Other Surface Water Phenomena*

11:30 AM - Dr. Chansheng He, Department of Geography, Western Michigan University. *Climate Change and Non-Point Source Pollution in the Great Lakes Basin: Opportunities and Challenges* (Co-Authors: T.E. Croley, II and C. DeMarchi)

12:00 PM – Lunch – Catered buffet SNR&E Commons

1:00 PM - **Science Panel #4 - Water Quality and Human Health**
Session Chair – Ms. Sonia Joseph, Outreach Coordinator, Center of Excellence for Great Lakes and Human Health/Michigan Sea Grant

1:00 PM – Dr. Michael Murray, Staff Scientist, National Wildlife Federation, Great Lakes Natural Resources Office. *Climate Change, Water Quality and Human Health: Some Research and Policy Questions*

1:15 PM – Dr. Donna Kashian, Research Investigator, Cooperative Institute for Limnology and Ecosystems Research. *Climate-induced Changes in Organic Material Influences Contaminant Exposure in Aquatic Systems*

1:30 PM - Dr. Carlo DeMarchi, Cooperative Institute for Limnology and Ecosystems Research. *Potential Impacts of Climate Change on Pathogen and Pesticide Contamination of Coastal Water* (Co-Authors: T.E. Croley, II, T.S. Hunter, and C. He)

2:00 PM – **Science Panel #5 - Fish Recruitment and Productivity**
Session Chair – Dr. Doran Mason, Research Ecologist, NOAA/Great Lakes Environmental Research Laboratory

2:00 PM – Dr. Edward S. Rutherford, Associate Research Scientist, School of Natural Resources and Environment, University of Michigan. *Impact of Climate Change on Salmon Recruitment in the Great Lakes*

2:15 PM – Dr. Henry Vanderploeg, Research Ecologist, NOAA/Great Lakes Environmental Research Laboratory. *Climate Change, Physical-Biological Coupling, and the Resource Mismatch Hypothesis for Plankton and Fish* (Co-Authors: J.F. Cavaletto, J.R. Liebig, S.A. Ludsin, and C.P. Madenjian)

2:30 PM – Dr. Doran Mason, Research Ecologist, NOAA/Great Lakes Environmental Research Laboratory. *Climate Change: Implications for Fish Growth Performance in the Great Lakes* (Co-authors: S.B. Brandt, M.J. McCormick, B.M. Lofgren, T. Hunter, and J.A. Tyler)

3:00 PM – Break

3:15 PM – **Science Panel #6 Aquatic Invasive Species**
Session Chair – Dr. Rochelle Sturtevant, Great Lakes Regional Extension Educator, Michigan Sea Grant

3:15 PM – Dr. Cindy Kolar, Assistant Program Coordinator, Invasive Species Program, U.S. Geological Survey. *USGS Research on Invasive Species and Climate Change in the Great Lakes*

3:30 PM - Dr. Henry Vanderploeg, Research Ecologist, NOAA/Great Lakes Environmental Research Laboratory. *Surprising Synergies Between Invasive Species and Climate Impacts* (Co-Authors: S.A. Pothoven, G.L. Fahnenstiel, and T.F. Nalepa)

3:45 PM – Dr. J. Michael Campbell, Department of Biology, Mercyhurst College. *Can Climate Change Make the Aquatic Invasive Species Problems in the Great Lakes Any Worse Than They Already Have Been?*

4:15 PM – Closing remarks and announcements

5:00 PM – Public Keynote Address, 1800 Chemistry Building – Dr. Henry N. Pollack, Professor of Geophysics, Department of Geology, University of Michigan. *Hockey Sticks and Politics: Science in the Arena of National Climate* Policy

6:00 – 8:00 PM - Reception – SNR&E Commons

WEDNESDAY - JULY 30, 2008
Key stakeholder issues and concerns in confronting anticipated impacts of climate change on the Great Lakes ecosystem - meeting new challenges in use, management, protection and restoration of resources.

8:00 Continental Breakfast, SNR&E Commons

8:30 AM – Morning Welcome - Dr. Stephen B. Brandt, Director NOAA Great Lakes Environmental Research Laboratory (GLERL)

8:45 AM – Dr. Rosina M. Bierbaum, Dean, School of Natural Resources and Environment, University of Michigan. *Climate Change: From Science to Solutions*

9:45 AM – Break

10:00 AM - **Stakeholder Panel #1 Recreation and Tourism**
Moderator: Ms. Melinda Huntley, Ohio Sea Grant

10:00 AM - Mr. Andrew Struck, Director of Planning and Parks, Ozaukee County Planning and Parks Department, Port Washington, WI. *Ozaukee County, A Coastal Community Case Study: Potential Impacts on Water-based Recreation and Tourism*

10:15 AM – Dr. John Coluccy, Manager of Conservation Planning, Duck Unlimited Inc. *Conserving Waterfowl and Wetlands in the Great Lakes Amid Climate Change*

10:30 AM – Ms. Rachel McNinch, Center for Water Sciences, Michigan State University. *Climate Change and Water Safety in the Great Lakes*

11:00 AM – **Stakeholder Panel #4 Land Use and Coastal Zone Managers**
Moderator: Mr. Frank Lichtkoppler

11:15 AM - Ms. Catherine Ballard, Chief, Michigan Coastal Zone Management Program. *Coastal Management Considerations in Adapting to Climate Change; Preparing for a Climate-Resilient Coast*

11:30 AM – Ms. Sandra Kosek-Sills, Coastal and Estuarine Land Conservation Program, Coordinator, Office of Coastal Management, Ohio Department of Natural Resources. *Climate Change Challenges for Coastal Management in Ohio*

11:45 AM – Dr. James Hurley, Assistant Director for Research and Outreach, Wisconsin Sea Grant. *Sea Grant Planning and the Sustainable Coastal Development Focus Area: Implications from Climate Change*

12:00 PM – Lunch – Catered buffet, SNR&E Commons

1:00PM – **Stakeholder Panel #2 Commercial and Municipal Water Users**
Moderator: Ms. Sonia Joseph, Center of Excellence for Great Lakes and Human Health

1:00 PM – Mr. Jon Bloemker, District Supervisor, Saginaw District Office, Michigan Department of Environmental Quality. *Potential Climate Change Impacts to Industry and Municipal Water Users*

1:15 PM – Mr. Abed R. Houssari, Manager of Environmental Management and Resources, DTE Energy. *Climate Change Challenges for Electrical Utilities*

2:00 PM - **Stakeholder Panel #3 Regional, State, Tribal and Local Policymakers and Managers**
Moderator: Ms. Barbara Liukkonen, Minnesota Sea Grant

2:00 PM – Mr. Tim Eder, Executive Director, Great Lakes Commission. *Climate Change Challenges and Opportunities: Perspectives of a Regional Organization*

2:15 PM – Mr. John Swanson, Executive Director, NW Indiana Regional Planning Commission. *Planning for NW Indiana Shoreline Areas*

2:30 PM – Mr. Frank Lichtkoppler, Extension Specialist, Ohio Sea Grant. *Potential Climate Impacts Affecting Fishery Stakeholders*

3:00 PM – Break

3:15 PM - Dr. Thomas R. Karl, Director, NOAA National Climatic Data Center. *Weather and Climate Extremes in a Changing Climate*

4:00 PM – Dr. Karl, Update on Present Status of NOAA National Climate Service

4:15 PM – Day 2 Closing Remarks and Announcements

4:30 PM – Adjourn

THURSDAY - July 31, 2008

8:00 AM – Continental Breakfast, SNR&E Commons

8:30 AM – Pre-Breakout Briefing/Announcements SNR&E Rm. 1040
Ms. Sonia Joseph, Center of Excellence for Great Lakes and Human Health

9:00 AM - Begin six concurrent facilitated breakout sessions

(1) Physical Environment - SNR&E Rm.1028
Facilitator - Mr. Frank Lichtkoppler
Recorder – Mr. Ari Preston

(2) Water Quantity – SNR&E Rm.1024
Facilitator – Ms. Melinda Huntley
Recorder – Mr. Sean Bratton

(3) Watershed Hydrology – SNR&E Rm. Rm.1046
Facilitator - Ms. Leslie Dorworth
Recorder – Ms. Katie Coakley

(4) Water Quality and Human Health – SNR&E Rm.1040
Facilitator – Ms. Sonia Joseph
Recorder – Ms. Katie Bush

(5) Fish Recruitment and Productivity – SNR&E Rm.1064
Facilitator - Ms. Margaret Lansing
Recorder- Ms. Ann Marshall

(6) Aquatic Invasive Species – SNR&E Rm.1006
Facilitator - Dr. Rochelle Sturtevant
Recorder – Ms. Lynne Chaimowitz

10:30 AM – Break

10:45 AM – Continue six concurrent facilitated breakout sessions

12:00 PM - Buffet Lunch, SNR&E Commons

1:00 PM – Joint Summary Session, SNR&E Rm. 1040
(Reports from six Breakouts and General Discussion) *Ms. Sonia Joseph, Moderator*

2:45 PM - Closing Remarks

3:00 PM - Adjourn

Appendix III – Listing of Issues, Needs, and Suggestions from First and Second Breakout Sessions Within the Key Scientific Theme Areas – Physical Environment, Water Quantity, Watershed Hydrology, Water Quality and Human Health, Fish Recruitment and Productivity, and Aquatic Invasive Species

Physical Environment – *First Breakout*

Information and Research Gaps / Needs

Relating ice to ecosystems, fisheries, energy balance, and water balance
Downscaling to local level
More specific inputs to run forecast models
Forecasting lake level variation (getting it to the public)
How to use large scale modeling
Boundary conditions for models
Better data (too many gaps) to help us better understand overall trends
How ice affects erosion
Regional forecasting for nearshore currents
Defining variables for research
No ice data in GLCFS (Great Lakes Coastal Forecasting System)

Priority Areas

Immediate Needs (2-4 years)
Funding
NASA/NOAA not interested in data base development and improving system
Raw data not compatible.
Research in form that is usable for managers (to save time)
Managers don't know what to request or where to go
More networking, communication
Clearing house
Help managers find the data they need
Improve ecosystem, ice, water modeling
Biological and physical models

Long-term Needs (5-7 Years)
Build up better relationships between universities and GLERL
Close water balance, incorporate entire watershed
Regional Earth-System Model (hydrology, ice, ecosystem, hydrodynamic, atmospheric modeling) for Great Lakes
1-2 km resolution for lakes, 5 km atmosphere
Global → Regional → Lake → Local
Funding for Earth-System model
Better collaboration with Canada (difficult).

Training Needs

Workshops like this one to get up to speed
Bring managers into workshops earlier so there is better communication

Bring in people from Natural Resource Agencies. Need resource managers to help define what is needed in decision making (DNR,CZM,Utilities)
GLOS has useful information (trying to increase database)
Deliver climate forecast information to local government

Stakeholder Engagement -Who Are They and How Do You Engage Them in the Issue?
What do they use it for?
Communication gap
Science wants feedback (lacking)
Coastal management in Silver Springs, MD
Other agencies, local government in Gulf Coast
EMS → first response, hazard mitigation plan, climate change impacts
Getting data from Canadians
GLERL – Army Corps of Engineers, USGS
Wisconsin - state DNR
Local → Agency/Government/Public

Scientific Products, Services and Expertise
Results on internet
Field site (local concerns)
Customized for locals (sea grant/extension)
Direct contact
Training → local office staff
FEMA hard to get in touch with
Scientists need intermediate contact

Communication of New Information, Tools, and Technologies
Email update of research status (distribution lists) – avoid overload
Websites (provided in emails)
Get feedback on data
Phone for direct contact
Monthly newsletter (GLERL)
Possible quarterly newsletter?
Fitting climate change into larger framework of ecosystem management
Add climate change information to existing media outlets (magazines, newspapers)
More outreach to avoid time gap

Conclusion
Better coastal processes information
Research to support better management
2-way communication system
Great Lakes coastal erosion gap (like AK)
Loss of wetlands – WI, NY 60% hard surface (need data)
Make case for funding and downscaling
Great Lakes hydrological model (1 watershed)
Feedback loop

2-D → 3-D GLCFS – lake by lake (waves, surface temperature, profiles of temperature, currents, water levels)
Digital bathymetric map
Suggestions that storms will be more intense – forecast modeling?
Empirical, fast statistical modeling

Physical Environment – *Second Breakout*

Products / Services	**Scale (temporal, spatial, geographical)**	**Collaborations, Integration, and Coordination**	**Value to Society**
Lake level unified forecasting model (climate change)	100 m coastline, entire watershed (up to year)	universities, USGS, coastal management	help decision makers (management)
Unified data base	lake-region wide US, Canada (back as far as possible)	US, Canada, GLERL, universities	improve research efficiency
Unified Great Lakes 3-D ice-hydrodynamic model	lake wide (up to 1 week) point source, light source	GLERL	useful for water balance, entire watershed dynamic
Feedback loop	Great Lakes region	GLERL, Sea Grant, coastal managers, universities	improves products
3-D ecosystem model (physical + ice + biological)	hindcast, lake by lake → local (downscale)	universities, GLERL, Sea Grant, USGS, EPA	improving product (making it useful)
Network outreach (needs assessment)	lake by lake → local	universities, GLERL, Sea Grant, USGS, EPA	making products more useful
Downscaling climate to regional impact	lake by lake	universities, GLERL, Sea Grant, USGS, EPA	making product useful
Direct contact (training)	local level	universities, GLERL, Sea Grant, coastal training program	better understanding → better decision making
Morphological models (erosion)	local level – lake level (decades)	universities, GLERL, Sea Grant, USGS	better planning, design for coastal structures improvement of product
Ice modeling and forecasting	hindcast, lake by lake → entire watershed	GLERL, universities, NIC (ice center), USACE	primary productivity for fisheries, useful for navigation, coastal erosion, effect on storms, lake effect snowfall

Water Quantity – *First Breakout*

Information and Research Gaps / Needs

Water quantity effects on economic vitality (ie. Shipping channels and ports)
Gaps in efficient ways of cost effective disposing of dredge materials (ie.PCB's)
Water balance future of great lakes is highly uncertain
Help user groups face uncertainty
Long term precipitation trends
Monitoring methods such as radar coverage
No evaporation pans, or equipment to measure evaporation / evapotranspiration
Speak to people making decisions on quantity of water (waterways)
Water level forecasts (long term), need more efficient models
Better understanding on impacts of extreme atmospheric events
Understanding tolerance level of uncertainty within user groups
More plausible time series models (precipitation, temperature)
How sensitive are the lakes to temperature increases
Which impacts have a larger influence - temperature increases or precipitation decrease/increases?
High res. topography/digital elevation maps for modeling purposes
Ground water (aquifer) /flood plan mapping
Practical applications of research
Short term/long range forecasting
Defining/forecasting effects of extreme events in terms of low-flow, base-flow, extreme flood events.
Better understanding of impacts of channelization and changes in inflows and outflows
Thermal structure of the lakes
Better access in use of community grass roots monitoring programs (ie. Friends of….)

Priority Areas

Immediate Needs (2-4 Years)
Research identifying economic value of climate change research needs (justify investment in research needs) (1)
Better understanding of prediction of extreme events and quantifying impact of land use alternatives. (2)
Establishing better observing/reporting networks and model outputs (3)
Additional research teams/funding and comprehensive plan
Research on better understanding decision making process of users
Are the water levels going to go up or down (5 to 10 year increments) and what is the uncertainty

Long-term Needs (5-7 Years)
More consistent, effective, and continuous monitoring
Direct measurement technology
Alignment of polices with current capabilities
Climate model capabilities for 5-10 year scale
Research needs into the impacts of water quantity removal from the basin (2007 Ground Water Conservation Advisory Committee)
Demand forecasting
Demand management research

Training Needs
Coastal Services Center workshops/on the ground training
User/science combined workshops (translate uncertainty)
Congressional staff training
Communicate importance of Great Lakes to entities
Finding synergy between local communities training needs and data needs
More extension and outreach

Stakeholder Engagement – Who Are They and How Do You Engage Them in the Issue?
Better understanding of available data and stakeholder networks.
Fisheries
Ports
Marinas
Resource managers
Public health
Property owners
Public utilities
Tourism
Emergency managers
Planning/zoning
Local/state/federal government officials
Consultants
Recreational boaters

Scientific Products, Services and Expertise - What and where have you sought scientific products, services, expertise?
Need for a gateway to effectively deliver services
Need to continually reach out to direct stakeholders
Lake level/forecast information
Coastal States Organizations
Seamless networks between NOAA agencies

Communication of New Information, Tools, and Technologies
Need to more/better use communication networks
Better organized material on web
FAQ sites
Better product development
Focus on information content vs. agency identification
Be more aware of user needs and capabilities
Importance of peer review and reliability
Taking advantages of new technology and participatory
Increase human touch
Need to communicate non-computer literate stakeholders
More input from users

Conclusions

Water Quantity - *Second Breakout*

Products/services	Scale (temporal, spatial, geographical)	Collaborations, integration, and coordination	Value to society
Producing water level 2-3 year outlooks	Lake wide national outreach focus (individual lakes)	- USGS - Environment Canada - Regional models driven by global projections - Sea Grant - State Coastal Zone Management - Stronger connection to core networks - NERR - Bi-national inter-agency product	- Influence on policy - Increase awareness of issue - Allocation of budget - Minimizing economic loss - Identifying nation/international focus of the Great Lakes
Product to help users/planners adapt to extreme events and plan mitigation	- Local - 2 to 3 year reaction times	- County engineers - Local watershed groups - Emergency management teams - FEMA - EPA - State geological - Meteorology community - Utilities - State environmental agencies	- Minimize loss of life and property - Watershed management programs
Fully support implementation of IOOS observing systems on the Great Lakes	- Basin wide - Lake wide	- USGS - Fish and wildlife service - EPA - Environment Canada - Public utilities	- Saves property and lives - Improves forecasts - Reduces uncertainty - Help planning for future

Watershed Hydrology – *First Breakout*

Information and Research Gaps / Needs
Public and construction sector need access to education/information
Inadequate information pertaining to water quality, measuring precipitation, stream flow gauges
Social sciences are missing

Priority Areas
Immediate Needs (2-4 Years)
Studies on cost/benefit ratio under climate change scenarios
Design infrastructure based on long term scale
Model Integration - Climate watershed model for all Great Lakes
Improve extreme weather event forecasting - drought, floods, air quality
Project changes in watershed parameters
Crops/agriculture, erosion, natural vegetation
Urban growth model - land usage, infrastructure, parking lots
How to mitigate flood peaks without building dams -
Decreasing abrupt flooding
Reestablishing wetlands and rain gardens
Wetland restoration and flood attenuation in important areas
Which part of wetlands should be restored?
Management of pollution sources and water quantity
Better models/practices for NP loadings in response to increased precipitation
Collaboration -
USGS
USDA
USACE
EPA
State and Local Agencies
Universities
NGO's
Coast Guard
FEMA
Park Services

Training Needs

Stakeholder Engagement

Scientific Products, Services, and Expertise

Communication of New Information, Tools, and Technologies

Conclusion

Watershed Hydrology - *Second Breakout*

Products/Services	Scale (temporal, spatial, geographical)	Collaborations, integration, and coordination	Value to Society
Improve floodplain maps/ flood forecasting systems	Dependent on scale of community	USGS, stream gauges and cooperators, FEMA, insurance industry	Personal safety, economic security, minimizing damage to infrastructure
Institutionalize water quality models	Great Lakes, 10's of square kilometers	Inter-agency collaboration, state environmental agencies, EPA, Coast Guard, USGS, NWS	Beach closures, quality of drinking water
Present and projected climate maps	Global to state to zip code	Universities, USDA, Park Service	Public education, agriculture and forestry industries, research

Water Quality and Human Health – *First Breakout*

Information and Research Gaps / Needs

Quantify nutrient loading to watersheds and quantity of water
Groundwater nutrient concentrations: sub-marine groundwater discharge
Climate change may affect amount of exchange
Frequency, duration and intensity of bacteria affecting beach closures
Survival of bacteria
Financial implications and economic implications of bacterial infections at community level and effects on human health
Incorporate more physical information for predictive models for watersheds, algal blooms, etc
Hydrologic information
Integrate data along standards to make more comparable: include similar parameters across models
What are the recommendations for urban infrastructure?
Fish populations affected by contaminants and implications for subsistence fishing and lower socioeconomic communities
Specific recommendations for dealing with water quality changes: how to adapt
Communicate tangible impacts of climate change to the public
Concern over lake levels-affecting tourism, shipping channels
New water treatment techniques: treating contaminants like *microcystis*
New demands on water treatment infrastructure due to climate change and potential for more storms
Integrate tributary and watershed data into problems in bays and lakes
Influence of climate on toxic chemical cycling and impact on human exposure
Quantify changes in potential health effects: water and airborne
Exposure routes and vectors affecting human health
Develop link with local policy makers about scientific information-best ways to communicate clearly without losing the complexity of the problem

Decision making tools policy makers use and what are the implications for human health
Assessing cost/benefit
How policy makers prioritize

Priority Areas
Immediate Needs (2-4 Years)
Better coordinating of groups working on similar problems or issues
Centralize information about people and projects (website)- invasive species, using GLANSIS or GLRRIN as a model
Document and organize all the data we have about algal blooms to see if there really are trends due to climate change-an inventory
Characterize and prioritize potential health risks from toxic chemical cycling, water treatment etc to see which may be most harmful
Utilizing predictive tools to develop effective models
Experimental research-what are the environmental conditions leading to algal blooms
Develop risk assessment for potential impacts-human health, economic impacts
Develop specific climate change scenarios to define the problem (fish harvesting, algal blooms, beach closures)
What are specific consequences (water flow, water quality)
What are human needs and how might they change?
Prioritize those needs
Address issues of infrastructure for future planning (utility, municipal planning)
What are the needs of local governments?
User-based needs assessments
Assessing water intakes in the lakes and wastewater discharges
Inventories of shipping channels, marinas-which may be most affected by lowered water levels
What could happen?
Socioeconomic and health implications of lack of access to water
Information on watershed discharges affecting water quantity-water intakes

Long-term Needs (5-7 Years)
Responding to current findings
Continue sustainability of current quality of life-recreation, commerce
Cultural and behavioral changes to mitigate effects of impacts
Energy conservation, water usage etc
Help the public understand effects of climate change
Consequences of use of biofuels as an example
Develop greater public transportation infrastructure
Cost and planning for developing new infrastructure in response to climate change
Develop information on water elevation levels
Effectiveness of best-use practices in minimizing human health risks

Training Needs

Stakeholder Engagement

Research Community

Community and local health departments-bridge gap between local policy makers and scientific research
Assess water users and their needs-beach users, anglers, recreational users etc.
Engage local, state officials, elected officials
Economic development agencies
Non-profits, watershed groups, outreach to faith community, economically disadvantaged
Opening communication between conflicting groups, eliminate distrust
Building collaboration between development and environment groups
Engage members of groups (Sierra Club, other NGOs etc) who are ready and willing to take action

Scientific Products, Services, and Expertise

Infrastructure needs come from EPA reports, regional councils, regional authorities
Techniques and effectiveness of infrastructure needs from consultants and private sector
Executive summaries
Web-based searches
Media reports raise public interest
Scientific information from technical reports, professional journals
Regional partnerships and information sharing
Water and wastewater utilities, marinas, port authorities
Personal contact with researchers-understand what may not have worked in the past
Observations and anecdotal reports for additional information
Federal and State agencies

NOAA Communication of New Information, Tools, and Technologies

Have NOAA people interact with state and regional agencies
Personal contact to share NOAA's information
Explain what is new on the outreach side to the researchers and what's new with researchers on the outreach end
Give people information directly-brief bulletins
Outreach to non-scientific community
Email similar to GLNPO-announce upcoming events

Conclusion

Water Quality and Human Health - *Second Breakout*

Products/services	Scale (temporal, spatial, geographical)	Collaborations, integration, and coordination	Value to society
Data collection on nutrient loading where there are gaps from all possible sources	Coastal zones, nearshore	Federal agencies and universities, state agencies	Nutrient loading affects water quality, fish populations, algal blooms
Data Needs: Frequency, concentration, speciation of bacteria relating to beach closures Sources: Non-point, sewers, watershed sources, human and non-human Utilize models, raw data	Beach by beach specific Watershed by watershed Weekly/Daily during recreational season	State and local health departments and units of government, state EPA, USGS, beach managers	Economic impacts, human health protection
Sources (point and non-point) and pathways of chemical pollutants and environmental factors	Lake, river, tributary, coastal area wide Monthly, storm event related	International collaborations, state, federal, industry, IJC, watershed groups	Human health, economic risks, affect on algal blooms (phosphorous)
Develop sensor technology for monitoring beach bacteria levels	Continuous data stream	Universities, USGS, local authorities, state	Human health risks
Predictive model assessing the effect of increased storm/rainfall events on CSO plans and long term control plans	Individual wastewater utility Yearly (individual storm trends) or seasonally as it relates to storm events	EPA, city planners and public works, regional planning authorities, state	Protect drinking water, beach closings, efficient resource use
Predictive model for assessing impacts of climate change on overall water quality including biological and chemical, physical parameters	Lake regions, multi-counties (e.g. Lake Erie Eastern, Central, Western basins)	State and federal EPA, IJC, health departments, agriculture extension	How we may need to adapt to climate change

Fish Recruitment and Productivity – *First Breakout*

Information and Research Gaps / Needs

Understanding the coupling of climate change on Regional and basin scale to fisheries recruitment and production:

Continue long term Ecological Long Term Monitoring studies/data sets, and integrate new long term studies, (e.g. seasonal (weekly to bi weekly) inter-disciplinary studies on other trophic levels, physics, and chemistry).

Improve collaborations with other Great Lakes research institutions.

Link physical and biological sciences together towards understanding and predicting fish recruitment and productivity.

Quantify seasonal variation in density and distribution of fish life stages and food web interactions to address recruitment hypotheses.

Identify and quantify linkages (in transport of nutrients, sediments and biota) between inshore and offshore zones.

Document extremes in inter-annual variability across the food web and physical environment.

Develop a predictive understanding of habitat shifts and range expansions due to landuse and climate changes.

Understand the effects of climate change on fish diseases (frequency, magnitude, and potentially new diseases) and existing and potentially new invasive species.

Develop short term hypothesis-driven studies and models (statistical models, simulation models, food web models, bio-physical coupling models).

Produce comprehensive hi-resolution mapping efforts, e.g. bathymetry, bottom type, and species associations.

Pay increased attention to watershed-Great Lakes linkages.

Priority Areas

Immediate Needs (1-2 Years).

Identify indicator fish species most vulnerable to climate change impacts.

Synthesize current knowledge re: fish recruitment and productivity via a special journal issue that considers impacts of climate change on the Great Lakes.

Quantify economic impacts of climate change on commercial industry, sports fishery and the need to modify outdated regulations.

Immediate Needs (2-5 Years)

High resolution mapping of critical habitat, e.g. spawning success, thermal structure.

Understand how interannual variability in the physical environment may impact current food web dynamics?

Determine the impacts of ice cover on fish recruitment and production (especially Lake Erie).

Determine the importance of nearshore zones for fish recruitment and how this affects offshore aquatic communities.

Changes on fishery harvest and its impact on economically important species.

Importance of ultraviolet radiation and deep light penetration on growth and survival of plankton and fish early life stages.

Understand factors influencing the spatial distributions of fishes at various life stages.

Quantify interannual variability in the carrying capacity of the lakes to support fish production

Role of nearshore and offshore benthic productivity pathways and implications.

Long-term Needs (5-10 Years)
Meeting long-term needs will be facilitated by perpetuation of long term data sets, design for minimalist research program, commitment for funding and personnel, proactive approach, a long-term scientific vision beyond tenure of leadership, and infrastructure improvements to make better use of existing field stations. Examples of long-term surveys to address information needs include USGS-GLSC trawl survey, and Oneida Lake.

Priority areas:

Couple regional climate models with 3-D physical lake models and stream habitat for fish recruitment dynamics.

Determine how wetlands may change due to anticipated large scale changes in land use, and how this will influence fish recruitment and productivity.

Evaluate current fishery programs, e.g. lamprey controls, stocking programs, species restoration, invasives in the context of climate change senenarios.

Make forecasts from bio-physical models driven by various climate change scenarios, and use these forecasts to develop probabilistic management strategy.

Develop adaptive management scenarios for climate change, e.g., fish stocking at different locations, preserving critical fish habitats.

Determine the synergistic effects of climate change and other environmental stressors (e.g. nutrient loading, invasive species, fishing, contaminants, etc) on aquatic food webs and fisheries.

Determine impacts of climate change on the lower food web.

Role of nearshore benthic productivity pathways and implications.

Training Needs

Improve opportunities for interactions amongst disciplines, e.g. bring in sociologists, economists, climatologists.

Communications skills in short term training sessions, e.g. continuing education workshops for media, press, and mapping.

Add courses in fisheries climatology to existing university programs in climate change and aquatic ecology and fisheries; create cross-disciplinary internships for study of climate change impacts on fisheries.

NOAA headquarters management development programs: sponsored training: cross line office, cross discipline, do something in climate context.

Climate extension service, interact with state climatologists.

Learn from other national and international programs on climate change and fisheries.

Stakeholder Engagement

Stakeholders include management agencies, fisheries industry, anglers, charter fisheries, duck hunters, bird watchers, educators at all levels, industry, farmers, developers, property owners, coastal communities, decision makers, politicians.

Engage stakeholders through media, existing outlets e.g. NGO’s, Sea Grant.

Assessments should be geared towards stakeholders, e.g. documents on-line.

Scientists should brief high level groups annually (state level government, Science Advisory Board, Natural Resource Commission).

Provide Ecosystem Forecasts for different interest groups. Identify needs and interests of various groups and what information they would like to know (e.g. forecast where fish are for anglers).

Communicate long-term data trends to stakeholders - this will help stimulate public support for funding; example: Michigan DNR provides red flag reports on an annual basis to characterize health of salmon fisheries and food webs. Provide climate report cards.
Engage stakeholders thru media, existing outlets (e.g. NGO's, Sea Grant).
Provide assessments geared towards stakeholders (e.g. documents on-line).
Scientists should provide annual briefings to high level management groups (state government, Science Advisory Boards, Natural Resource Commission).

Scientific Products, Services and Expertise
Deliver information to decision makers to facilitate good decision making about quotas, make fisheries sustainable.
Use existing organizations and mechanisms that are charged with communicating (ex. NGOs, Sea Grant)
Use existing venues, but bring inter-disciplinary groups together on a regular basis (climatologists, social scientists, aquatic ecologists, limnologists).
Scientific symposium on implications of climate change on Great Lakes fishery.

NOAA Communication of New Information, Tools, and Technologies
Designate as new theme area at various agencies, mention in call for proposals (Sea Grant, Great Lakes Fisheries Commission, Great Lakes Fishery Trust).
Improve/Increase use of web technologies to deliver results of research.
Use or develop a shared information portal among different agencies (could be Great Lakes Information Network site) which attracts funding.
Write peer reviewed journal articles.
Create an endowed chair in climate change studies at academic institutions in Great Lakes basin.

Conclusion

Fish Recruitment and Productivity - *Second Breakout*

Products/services	Scale (temporal, spatial, geographical)	Collaborations, integration, and coordination	Value to society
Satellite measures of water color for chlorophyll-a	Lake wide, 0.5 - 1 km resolution	Ground truthing calibration on transects and fixed stations. Span state and federal agencies, universities, Great Lakes Observing System (GLOS)	Primary production data will facilitate more accurate forecasts of fish recruitment and production for managers
Coastwatch web site http://coastwatch.glerl.noaa.gov Advance Very High Resolution radiometer AVHRR, etc.	Need higher resolution depiction, especially nearshore	Span state and federal agencies, universities, Great Lakes Observing System (GLOS). Shipping industry to supply data	- Recreational boaters and anglers - Charter Fishing Industry - Scientists - Law enforcement agencies - Educators
Global Regional Climate Change Model	By lake and basin wide	NOAA Climate Groups, Environment Canada	All of above, plus shipping and boating industry, weather forecasters
Sub-models of above: Statistical models: look at El Nino, La Nina	By lake and basin wide	OMNR, NOAA Climate Group Span state and federal, provincial, tribal agencies, universities	Weather forecasters, Scientists
3-D hydrodynamic modeling	- Increase number of strata. - Adaptive gridding for nearshore versus offshore - Improve vertical water movement - Turbulence coefficient - Bottom boundary exchange - Improved 3D Temp.	Ground truthing calibration on transects and fixed stations Span state and federal, provincial, tribal agencies, universities, GLOS	Resource managers, property owners, water users, law enforcement, EPA, anglers, academic community

Fish Recruitment and Productivity - *Second Breakout (continued)*

Products/services	Scale (temporal, spatial, geographical)	Collaborations, integration, and coordination	Value to society
Bio-physical food web model (fish recruitment, using 3-D hydrodynamic model	See above	- Ground-truthing, calibration on transects and fixed stations - Short term hypothesis driven research (mechanisms and processes - Span state and federal, provincial, tribal agencies, universities, GLOS,	Scientists, Resource managers, EPA, Anglers, academic community
State of the art sampling technology (nets, sensors, acoustics, optics, towed vehicles, Autonomous Underwater Vehicles (AUVs), buoys, ROVs	- Milli-seconds – years (all) - cm to km - affordable technology	Span state and federal, provincial, tribal agencies, universities, GLOS, industry, technology developers	All of the above
High resolution habitat mapping (physical and biological)	1 meter	Scientists and managers	Developers, managers, scientists
Improved Technology: observation platforms (towed vehicles, AUVs, buoys, acoustics: improving real-time, near real-time information delivery, add more sensors	Fixed station Spatial res: cm to 10s of meters Temporal: seconds to hours	Span state and federal, provincial, tribal agencies, universities, GLOS	Developers, managers, scientists, and commercial harvesters
Service: Rapid delivery of information using traditional sampling techniques via most appropriate medium	Meters to km	Span state and federal, provincial, tribal agencies, universities, GLOS,	Provides information needed for science, management, and safe and efficient commerce
Forecast fish recruitment and productivity, as a function of climate change scenarios	Annual	Scientists, managers, harvesters, coastal communities, planners	Managers, anglers, commercial fishers, scientists

Aquatic Invasive Species – *First Breakout*

Information and Research Gaps / Needs

AIS experts
Species shift information is limited
Experimentation methods are missing
Literature is speculative
Aquatic Nuisance Species Management Plans
Forecasting potential impact
There is no identification of high risk areas or highly vulnerable areas in the Great Lakes and analysis of different scenarios of what could possibly happen
Looking at specific areas that are identified for future planning
Long-term monitoring and data information
Are there other diseases or pathogens in other parts of the world that could come due to climate change?
Identified likely invaders
Develop a list of species not considering future warming of the water temperature and nearshore areas
Future scenario of lower lake levels and potential problems
Predictive models, make the prevention case
Economic and ecologic effect, (i.e. looking at marshes, invertebrates, fish recruitment)
Are there ways to intercept the pathways?
Biological control research?
Support mitigation, look at southern states control, methods / technologies
Will climate change cause mass northward shifts in whole communities or large segments of communities? If so, should 'new' species introduced via range expansion be considered native or non-native? Should we be facilitating northward migrations of species adapting to human-induced climate change or trying to preserve historic communities that are no longer well adapted to the local climate? If there are native species which are lost from the Great Lakes due to such range shifts -- particularly if those species are of social or economic value – should we be facilitating the introduction of other species to fill the vacant niches?
Survival rates of new aquatic invasive species
Algae and the relationship with the quagga mussels
Demand for biofuels…and the invasive species are usually targeted, what is the likelihood of biofuel plants becoming invasive
Wind turbines, what is the impact of invasive species on this?
Genetic changes/ adaptations
Disease rates and parasites
Increased human dimension, more pressure on shorelines, land use and impact on the nearshore area

Priority Areas

Immediate Needs (2-4 Years)
Data to look at trends- monitoring
Scenarios
Key geographic areas to target resources
Predictive models for vulnerable species, loss of natives, predator-prey relationships, energy flow changes
Algae/quagga mussel relationship
Examining phosphorus trapping/ biofuels harvesting

Other immediate needs:
Identify likely invaders
Look at disease pathogens and parasites
Biocontrols (prevention- make sure they won't be invasive)
Make sure energy solutions are not creating other problems
Climate-> erosion -> dredging -> contaminants -> Dreissenids (resuspension)

Long-term Needs (5-7 Years)
Change in lake level and what that is going to do to coastal wetlands
Look to southern states for control methods/technology
Offshore development technology impact on invasive species
Wind power
Vector shifts
Flooding as a vector

Training Needs
Fisheries best practices for managers
More scientists in invasive species and climate
Monitoring, training for NR field staff (and the public), how to identify and how to identify unusual species. Heightened awareness. What to do when you see an invasive species?
Especially high propugule overwintering
Satellite /aerial tools, Remotely-Operated Vehicles (ROVs) for monitoring and people trained how to use those for guiding control

Stakeholder Engagement
State and federal agencies
Recreational users
Watershed councils
The Nature Conservancy
Local/regional planners
Municipalities
Commercial interests
Research institutions
Policy Makers
General public
Marinas/coastal communities/land owners
Vector related industries

Barriers
Uncertainty
Active opposition
Vested interest in status quo
Defining invasive species
Competing priorities
Funding
Making the economic case

Terminology
Changing the social paradigm

Scientific Products, Services and Expertise
Staff scientists
Work with Sea Grant research
Federal agencies
Other states

Communication of New Information, Tools, and Technologies
Publications (peer reviewed and informal)
More coordination of the websites
Keeping in connection with projects as they are going on, stakeholder engagement
Enviromich
GL Aquatic Nuisance panel
State Partners
Information overload is possible - need to keep the public information simple and consistent in light of the huge uncertainties associated with both invasive species and climate changes and particularly at the interface of the two
Michigan State Invasive Species Initiatives
IJC research inventory (don't use)
NOAA or Sea Grant site
Google Earth and other new tool that could be applied to monitoring/tracking/mapping/communications about the distributions of invasive species
Office of the Great Lakes
Booklets
List serves and clipping services

Conclusion

Aquatic Invasive Species - *Second Breakout*

	Products/services	Scale (temporal, spatial, geographical)	Collaborations, integration, and coordination	Value to society
What is our target food web?	Forecast, supported by a model. * need science on likely invaders (extinctions to support).	Basin wide and each lake.	Research, social science, policy makers, GL Fishery Commission. Needs input from and engagement of a diverse array of stakeholders to make it successful.	It is in interest in those groups. It is a value laden decision.
Identifying likely invaders and their impacts	Modeling, forecasting, high risk vs. low risk rating lists, preventative education tools, legislator briefing – avoid species that are banned, informing legislation, identifying the most likely vectors.	Time is relative to the temperature change, basin and lake levels (and sub-ecosystems), goes back to key geographic areas.	University and researchers who have the data of where the invaders would come from, (donor areas) Communicate with most likely vectors to communicate risks (industries associated with vectors).	Being a step ahead of the potential socioeconomic damages that would occur.
Algae/ quagga mussel	Improved understanding, increase knowledge base, forecast, modeling based on temperatures and productivity, tool /process developed to interrupt, public education/outreach, economic impact, looking at the uses for the waste product.	Nearshore coastline areas, identify potential areas, targeted regional area, as soon as possible, forecast from next summer to several years.	Research community, DNR parks and recreation, local county parks, local government recreation departments, Sea Grant.	Huge issue right now, aesthetic and economic.
Monitoring	Training on satellite aerial tools, making the imaging available, radars, phragmites location, training to get more people involved, standardized data collection process, determine if overwintering, identify the responsible party (owner of doing this), public education and information management and connecting to response teams, mapping and database, GIS for overlay (water quality, use, endangered spp, vectors, temperature regime) to target high risk. Understanding the barriers, facilitate integration, data management, data rescue and preservation.	Basin wide, and as fine as possible, BARRIERS: getting the information to the people who need it.	Michigan Recreational Boater Information System, states.	

Appendix IV - Table listing key issues, needs, activities, and suggestions identified within each of the overarching subject categories during breakouts of the six Key Scientific Theme Areas

	Forecasts, Models, Prediction, Outlooks, Scenarios, Predictive / Decision-Making Tools, Uncertainty, Risk and Risk Assessment
Physical Environment	▪ Lake level unified forecast model that incorporates climate change impacts for entire Great Lakes watershed (100 m resolution - coastline). ▪ Unified Great Lakes three-dimensional ice-hydrodynamic model (lake-wide; up to one week; point source; light source). ▪ Three-dimensional Great Lakes ecosystem model (physical, ice, biological; lake-by-lake downscaled to local). ▪ Long-term need for Great Lakes Regional Earth-System Model (hydrology, ice, ecosystem, hydrodynamic, atmospheric modeling); 1-2 km for lakes, 5 km for atmosphere. ▪ Convert two-dimensional Great Lakes Coastal Forecasting System (GLCFS) to three-dimensional model. ▪ Improved ice modeling and forecasting. ▪ Improve forecast model capabilities to address anticipated climate change-related increase in intensity of storms . ▪ Regional nearshore current forecasts.
	Research to increase understanding and/or to expand knowledge base
Physical Environment	▪ Increase understanding of the role of ice on ecosystem structure and function related to fisheries, energy balance and water balance. ▪ Expand understanding of coastal processes.
	Data, Data Sets, Databases, Monitoring and Observing Systems
Physical Environment	▪ Overall need for better data to better understand overall trends (too many gaps) and unified lake-region-wide database. ▪ Raw data is not compatible. ▪ Managers need help in getting the data they need and direction on where to go for such information; create clearinghouse (2-4 years). ▪ Get data from Canadians as means of promoting stakeholder engagement. ▪ Get feedback on data.
	Mapping, GIS, bathymetry and related activities
Physical Environment	▪ Digital bathymetric maps lake- and region wide.
	Outreach, Communications, Collaboration, Scientist-Stakeholder Engagement
Physical Environment	▪ Need to get lake level variation forecasts to public. ▪ Present research results in form that can be readily used by managers and decision makers (regional – local). ▪ Plan and conduct research that supports better management. ▪ Encourage closer relationship between GLERL and universities. ▪ Foster greater collaboration with Canada. ▪ Science needs feedback from stakeholders to improve products. ▪ Use email, web, newsletters, media outlets to get word out on research activities/findings and science products, services, and expertise.
	Economic / Societal Value, Cost-Benefit, Funding
Physical Environment	▪ Make case for funding (of research and modeling) and downscaling.

	Forecasts, Models, Prediction, Outlooks, Scenarios, Predictive / Decision-Making Tools, Uncertainty, Risk and Risk Assessment
Water Quantity	▪ Improve Great Lakes water level forecast models to produce 2-3 year outlooks (lake-wide; outreach to make Great Lakes a national focus; individual lakes). ▪ Product to help users/planners adapt to extreme events and plan mitigation (local; 2-3 year reaction time). ▪ Fully support International Ocean Observing System (IOOS) on the Great Lakes (basin-wide; lake-wide). ▪ More plausible time series models (precipitation, temperature). ▪ Better understanding and prediction of extreme events (2-3 years into future) and quantifying impact of land use alternatives.
	Research to increase understanding and/or to expand knowledge base
Water Quantity	▪ Assess and document the sensitivity of lakes to temperature increases including thermal structures. ▪ Develop a better understanding of impacts of channelization and changes in inflows and outflows on water quantity. ▪ Determine trends and in future water levels in 5-10-year increments (2-4 years). ▪ Meet needs for research on water quantity removal from basin (2007 Groundwater Conservation Advisory Committee).
	Data, Data Sets, Databases, Monitoring and Observing Systems
Water Quantity	▪ Fully support implementation of the Great Lakes Observing System (GLOS) basin-wide and lake-wide. ▪ Establish better observing/reporting networks and model outputs (2-4 years). ▪ Meet need for an instrumentation network to measure evaporation / evapotranspiration. ▪ Promote more consistent, effective and continuous monitoring. ▪ Find synergy between local community training needs and data needs.
	Mapping, GIS, bathymetry and related activities
Water Quantity	▪ Develop high resolution topography / digital elevation maps in support of modeling. ▪ Create present and projected climate maps (global-state-zip code scales).
	Outreach, Communications, Collaboration, Scientist-Stakeholder Engagement
Water Quantity	▪ Ensure more/better use of communication networks and better organization of material on web. ▪ Take advantage of new communication technologies. ▪ Develop greater awareness of user needs and get their input.
	Economic / Societal Value, Cost-Benefit, Funding
Water Quantity	▪ Lack of information and research gaps on water quantity effects on economic vitality. ▪ Research identifying economic value of climate change research needs (justify value of research needs) (2-4 years). ▪ Additional research teams/funding and comprehensive plan (2-4 years).

	Forecasts, Models, Prediction, Outlooks, Scenarios, Predictive / Decision-Making Tools, Uncertainty, Risk and Risk Assessment
Watershed Hydrology	▪ Improve flood forecasting systems dependent on scale of community ▪ Institutionalize Great Lakes water quality models via interagency collaboration (scale of 10"s of square kilometers) ▪ Develop integrated climate watershed model for all of the Great Lakes ▪ Develop better models/practices for non-point loadings in response to increased precipitation in the management of pollution sources and water quantity
	Research to increase understanding and/or to expand knowledge base
Watershed Hydrology	▪ Assess projected changes in future watershed parameters and impacts of crops/ agriculture, erosion, natural vegetation
	Data, Data Sets, Databases, Monitoring and Observing Systems
Watershed Hydrology	▪ Inadequate data pertaining to water quality, measured precipitation and stream flow (gauges)
	Mapping, GIS, bathymetry and related activities
Watershed Hydrology	▪ Support improvement of floodplain maps and flood forecasting systems dependent on scale of the community
	Outreach, Communications, Collaboration, Scientist-Stakeholder Engagement
Watershed Hydrology	There was a recognized need to better translate the developing knowledge on climate change and its likely impacts into changes in the everyday practice of consultants and public servants. An important tool for this purpose would be guidelines issued by professional associations, like the American Society of Civil Engineers and the American Water Works Association, in collaboration with NOAA about how to include the uncertain knowledge we have on climate change into infrastructure planning and operation. This would help consultants and public servants to overcome the lack of common practices on the subject. Such guidelines should be periodically updated. An additional instrument that could help in including Climate Change knowledge into present-day infrastructure planning are the continuous education courses that professionals must take for maintaining their licenses. NOAA should work alone or with professional associations to develop courses regarding the possible climate change impact on hydrology and water quality and how to plan for minimizing their impact on the society.
	Economic / Societal Value, Cost-Benefit, Funding
Watershed Hydrology	▪ Social sciences are missing ▪ Need studies on cost/benefit ratios under climate change scenarios

	Forecasts, Models, Prediction, Outlooks, Scenarios, Predictive / Decision-Making Tools, Uncertainty, Risk and Risk Assessment
Water Quality and Human Health	▪ Predictive model assessing effects of increased storm/rainfall events on CSO plans and long term control plans ▪ Predictive model for assessing impacts of climate change on overall water quality (physical, chemical, biological) ▪ Develop risk assessment for potential impacts of climate change on human health (2-4 years)
	Research to increase understanding and/or to expand knowledge base
Water Quality and Human Health	▪ Quantify nutrient loading to watersheds, quantity of water and groundwater nutrient concentrations ▪ Determine frequency, duration and intensity of bacteria affecting beach closures ▪ Expand understanding of how fish populations are affected by contaminants and implications for subsistence fishing and lower socioeconomic communities ▪ Quantify climate-related changes in potential health effects (water and airborne) and exposure routes and vectors affecting human health ▪ Identify conditions leading to algal blooms
	Data, Data Sets, Databases, Monitoring and Observing Systems
Water Quality and Human Health	▪ Inadequate data pertaining to water quality, measured precipitation and stream flow (gauges)
	Mapping, GIS, bathymetry and related activities
Water Quality and Human Health	*No references*
	Outreach, Communications, Collaboration, Scientist-Stakeholder Engagement
Water Quality and Human Health	▪ Communicate tangible impacts of climate change to the public ▪ Identify infrastructure issues for future planning (utility, municipal planning); user-based and local government needs ▪ Bridge gap between local health departments and scientific researchers ▪ Encourage greater interaction between NOAA staff and state and regional agencies ▪ Develop greater reliance on web, email, list serves, bulletins
	Economic / Societal Value, Cost-Benefit, Funding
Water Quality and Human Health	▪ Need to assess financial and economic implications of bacterial infections at community level and effects on human health; assess cost-benefits ▪ Evaluate socioeconomic and health implications of lack of access to water (2-4 years)

	Forecasts, Models, Prediction, Outlooks, Scenarios, Predictive / Decision-Making Tools, Uncertainty, Risk and Risk Assessment
Fish Recruitment and Productivity	▪ Global regional Great Lakes climate change model (basin-wide and by lake) including statistical sub-models (El Nino, La Nina impacts). ▪ Improved three-dimensional hydrodynamic model (increased number of strata; adaptive nearshore vs. offshore gridding; improved vertical movement/turbulence; bottom boundary and temperature. ▪ Bio-physical food web model (fish recruitment) coupled with 3-D hydrodynamic model. ▪ Forecast fish recruitment and productivity as a function of climate change scenarios.
	Research to increase understanding and/or to expand knowledge base
Fish Recruitment and Productivity	▪ Determine how inter-annual variability, temperature and thermal structure interact with an unstable food web right now (2-4 years). ▪ Examine spring season, impacts of ice cover (especially on Lake Erie) (2-4 years). ▪ Assess impact of climate change on physical factors and subsequent effect on fish spatial distribution for various life stages (2-4 years). ▪ Identify fish species most vulnerable to climate change impacts (2-4 years). ▪ Study the role of nearshore/offshore benthic productivity pathways (2-4 years). ▪ Document anticipated change in land use and corresponding change in wetland distribution and extent and subsequent effect on fish recruitment and productivity. ▪ Obtain a better understanding of influence of lower food web on fish recruitment and productivity.
	Data, Data Sets, Databases, Monitoring and Observing Systems
Fish Recruitment and Productivity	▪ Promote greater satellite monitoring of water color for chlorophyll-a (Coastwatch, AVHRR, lake-wide; 0.5 – 1 km resolution) with nearshore focus; groundtruthed calibration along transects and fixed stations. ▪ Expand and improve technology of observation platforms (nets, sensors, acoustics, optics, remote- and autonomous underwater vehicle, buoys); cm – km ; milliseconds – years; real-time – near real-time. ▪ Perpetuation of long term data sets and monitoring, design minimalist program with commitment, proactive approach and based on long term scientific vision beyond tenure of leadership.
	Mapping, GIS, bathymetry and related activities
Fish Recruitment and Productivity	▪ Conduct comprehensive high resolution mapping, e.g. bathymetry, bottom type and associated species. ▪ Carry out high resolution mapping (physical and biological) of critical habitat, e.g. spawning success, thermal structure.
	Outreach, Communications, Collaboration, Scientist-Stakeholder Engagement
Fish Recruitment and Productivity	▪ Offer continuing-education for media to improve communication. ▪ Develop a climate extension service that would interact with state climatologists. ▪ Look at what's being done in Europe ▪ Expand reliance on existing organization.s (NGO's, Sea Grant) to improve communications ▪ Host scientific symposium on impacts of climate change on the Great Lakes fishery. ▪ Improve/increase use of web technologies; peer-reviewed journal articles; endowed university chair.

	Economic / Societal Value, Cost-Benefit, Funding
Fish Recruitment and Productivity	▪ Assess consumptive fish use changes and the impact on economically-important species ▪ Evaluate economic impacts on commercial fishery industry and sport fishery and need to modify regulations ▪ Create more opportunities for different disciplines to interact (economists, social scientists, climatologists).

	Forecasts, Models, Prediction, Outlooks, Scenarios, Predictive / Decision-Making Tools, Uncertainty, Risk and Risk Assessment
Aquatic Invasive Species	▪ Basin-wide and lake-by-lake forecast models that identify high risk areas most vulnerable to AIS invasions, most likely invaders and/or native species most threatened with AIS-induced extinction. ▪ Use forecast models and analysis to create likely scenarios of future species composition. What native species would be lost that are of societal and economic value? What is target food web? ▪ Uncertainty about effects of climate change on AIS threats and outcomes is a barrier in promoting greater stakeholder engagement.
	Research to increase understanding and/or to expand knowledge base
Aquatic Invasive Species	▪ Need improved understanding of algae/quagga mussel interactions to support models based on temperatures and productivity (2-4 years). ▪ Identify vulnerable species and potential loss of native, predator-prey relationships and energy flow changes.
	Data, Data Sets, Databases, Monitoring and Observing Systems
Aquatic Invasive Species	▪ Overall need for better data to better understand overall trends (too many gaps) and unified lake-region-wide database. ▪ Raw data is not compatible. ▪ Managers need help in getting the data they need and direction on where to go for such information; create clearinghouse (2-4 years). ▪ Get data from Canadians as means of promoting stakeholder engagement. ▪ Get feedback on data.
	Mapping, GIS, bathymetry and related activities
Aquatic Invasive Species	▪ Identify key high-risk geographic area to target resources (2-4 years) with mapping, database and GIS for overlay (water quality, use, threatened and endangered species, vector, and temperature regimes).
	Outreach, Communications, Collaboration, Scientist-Stakeholder Engagement
Aquatic Invasive Species	▪ Increase production/dissemination of peer-reviewed and informal publications. ▪ Develop greater coordination among web sites. ▪ Increase use of list serves (e.g. Enviromich) and clipping services. ▪ Expand outreach in explaining the Algae/quagga mussel interaction and it impacts.
	Economic / Societal Value, Cost-Benefit, Funding
Aquatic Invasive Species	▪ Need for more information on AIS economic and ecological impacts relative to climate change outlook. ▪ Lack of funding and failure to make the economic case are barriers to greater stakeholder engagement.