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GREAT LAKES ECOLOGICAL FORECASTING NEEDS ASSESSMENT

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This paper is based on discussions and prioritization exercises at the Great Lakes Ecological Forecasting Workshop conducted August 5-6, 2003 at the Great Lakes Environmental Research Laboratory in Ann Arbor, Michigan.

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Executive Summary

To maximize the benefits of our ecosystems, to sustain these benefits into the future and to restore the benefits of impaired systems, decision-makers increasingly rely on understanding of long and short-term changes in ecosystem structure and function. Science today is challenged to play an increasing role in providing forecasts of such changes at temporal and spatial scales appropriate to these decision-making processes and sufficient to support proactive ecosystem management. Ecosystems are influenced by physical, chemical, biological and anthropogenic processes causing complex changes in system structure and function. Predicting these changes – and particularly the effect of these changes on human end-users – in a form that makes the predictions useful to decision makers is the heart of the ecological forecasting concept.

This preliminary needs assessment is largely the result of a workshop held at the Great Lakes Environmental Research Laboratory in August of 2003. Workshop participants were challenged to think broadly about the needs of the coastal constituencies whom they represent and with whom they interact on a regular basis that could be served by ecological forecasting. Workshop participants engaged in several levels of prioritization exercises leading to a preliminary recommendation as to areas in which Great Lakes research should focus in developing ecological forecasting capacity.

Overwhelmingly, the recommendations of workshop participants focus on forecasts for the nearshore zone. This is perhaps not surprising as the majority of human interactions with the Great Lakes system occur near their edges. The complex nature of the nearshore zone of the Great Lakes together with the lack of solid research-based information about fine-scale processes occurring in this zone does, however, represent a significant challenge to the Great Lakes research community. The majority of well defined forecasting needs also indicate that the most useful forecasts need to be based on refined geographic scale models which allow applicability of the forecasts to decisions made at the local level. The need to localize forecasts represents a significant challenge that must be met at both the research and outreach levels.

Significant clusters of overlapping constituent/issue combinations were readily apparent from the prioritization exercises. This report recommends that these areas be given priority in developing detailed needs assessment and in development of ecological forecasts.

- Fisheries constituents need for ecological forecasts relating to fish stock assessments,
- Water quality regulators, water dependent industry and utility, recreational users, coastal property owners, and land use planners need for ecological forecasts relating to water quantity and quality (including sediments),
- A targeted need among transportation sectors (shipping, boating and marinas) for forecasts relating to sediment management,
- A broad need by most user groups for ecological forecasts relating to weather (offshore and nearshore),
- A broadly scattered need among a variety of user groups for forecasts relating to aquatic nuisance species, particularly for forecasts of abundances,
- A broadly scattered need among a variety of user groups for forecasts relating to socio-economic factors.

Great Lakes Ecological Forecasting Needs Assessment

What is Ecological Forecasting?

Ecological forecasts predict the impacts of physical, chemical, biological, and human-induced change on ecosystems and their components.[1]

Forecasts are part of our everyday lives. Perhaps best known are the weather forecasts that the average American uses in making daily plans. But there are many other kinds of forecasts as well. Economic forecasts help both businesses and individuals to make financial decisions. Predictions of traffic patterns help commuters to decide which route to drive. Medical doctors predict the outcomes of certain behaviors or courses of treatment on patient health. All of these are forms of prediction complete with associated uncertainties.

Ecosystems are influenced by physical, chemical, and biological processes -- some of these are natural in origin while others are anthropogenic -- causing complex changes in system structure and function. Predicting these changes – and particularly the effect of these changes on human end-users – in a form that makes the predictions useful to decision makers is the heart of the ecological forecasting concept. One example of an ecological forecast is long-term prediction of extreme water levels in the Great Lakes; such a prediction could be used to set building standards to avoid flooding and other types of property damage. A shorter-term example might include prediction of the rate at which zebra mussels will foul a water intake pipe – which would allow the company to set cleaning schedules that maximize usefulness while minimizing cleaning costs. Near real-time monitoring (e.g., NOAA CoastWatch) provides 'forecasts' of surface water temperature which are used by charter captains (and others) to determine fishing locations and by the Coast Guard to determine appropriate locations for drills.

Building useful ecological forecasting capability will require integrating across disciplines, including the social and economic sciences. Frequently the forecast needed by the decision-maker (particularly in the political arena) is an economic forecast (e.g., what is the economic impact of invasive species x versus the cost of prevention or control) the accuracy of which in turn relies on biological (what would the population dynamics of x look like in the Great Lakes, what other species would it impact), chemical, or physical (what does x do – release toxins, mobilize contaminants, foul intakes, etc), and social (who are the impacted users, what are their alternatives) forecasts.

Why Ecological Forecasting?

There are three key benefits to focusing on ecological forecasts: they will lead to better decisions, they will improve communication between science and management, and they will help set science priorities.[2]

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[1] Committee on Environment and Natural Resources. 2001. Ecological Forecasting, Washington, D.C. 12. pp.

[2] A New Outlook from NOAA -- Ecological Forecasting: Expanding NOAA's Assessment and Prediction capabilities to Support Proactive Ecosystem Management. 2002. Donald Scavia, NOS Chief Scientist.

All ecosystems provide benefits to society as a whole and to particular user groups specifically. Some of these benefits are obvious and easy to quantify – for example, the value of fish harvested in the commercial fishery. Others are more diffuse – the value of a wetland in recharging groundwater or impact on a tourism economy. Still others are even more esoteric – the value of a sunset over the lakes or sighting a blue heron along the beach. To maximize the benefits of our ecosystems, to sustain these benefits into the future and to restore the benefits of impaired systems, decision-makers increasingly rely on understanding of long and short-term changes in ecosystem structure and function. Science today is challenged to play an increasing role in providing forecasts of such changes at temporal and spatial scales appropriate to these decision-making processes and sufficient to support proactive ecosystem management.

Ecological forecasting challenges environmental science to move to the next level – from description of what is occurring in these keys systems to prediction of what will occur.

Why Great Lakes Ecological Forecasting?

The Great Lakes are an ideal system in which to pilot efforts to develop ecological forecasts because the Great Lakes region has for decades been a national leader in innovative management. International cooperation toward management of a shared resource is nowhere stronger than in the Great Lakes. Two federal commissions (the International Joint Commission and Great Lakes Fishery Commission) and an interstate-provincial commission (the Great Lakes Commission) work together to ensure cooperative management is carried out by the patchwork of state and federal management authorities. The necessity for innovative management started in such international and interstate cooperation has created a framework accepting of innovative strategies towards management and a willingness among managers to move rapidly to take advantage of new data and tools. Management's willingness to embrace innovations is in part driven by demanding natural resource constituencies -- grassroots movements toward clean water (Lake Erie) and environmental cleanups (Love Canal) had their infancy in the Great Lakes region. Well-formulated environmental forecasts designed to meet management needs can be expected to be used rapidly in the Great Lakes region.

The Great Lakes are also an ideal system in which to pilot efforts to develop ecological forecasts because the resource has a large, complex and economically important user community with demonstrable ecological forecasting needs. Not only would many of the user groups in the Great Lakes benefit from the application of ecological forecasts to management, but many of the user groups are prepared to take direct advantage of a variety of ecological forecasts if such were publicly available in a format which could be applied to their unique situations.

Another factor making the Great Lakes an ideal system in which to pilot efforts to develop ecological forecasts is the diversity of contemporary, cutting edge issues facing the Great Lakes with the potential to benefit from the application of ecological forecasts. Invasive species, regional climate change, and water level fluctuations serve as examples of influences affecting long-term planning in the region. Harmful algal blooms, fish recruitment, anoxia, and storms are examples of phenomena that influence shorter-term management decisions.

Great Lakes Coastal Constituents for Ecological Forecasts

The Great Lakes are an ideal system in which to pilot efforts to develop ecological forecasts because the resource has a large, complex, and economically important user community with demonstrable ecological forecasting needs. Not only would many of the user groups in the Great Lakes benefit from the application of ecological forecasts to management, but many of the user groups are prepared to take direct advantage of a variety of ecological forecasts if such were publicly available in a format which could be applied to their unique situations.

The following examines specific coastal constituencies likely to have ecological forecasting needs. Priority user groups were defined based on the size of the constituency in terms of numbers of people and/or economic impact as well as the perceived magnitude of their need for ecological forecasts.

Three types of constituents for ecological forecasts were identified. End-users are constituents who directly need certain types of predictions. Media (writers, lobbyists, teachers, etc) need predictions in order to convey that information to end-users among their audiences. Policy-makers need predictions in order to make policies that meet the needs of end-users. End-users, media and policy-makers differ in the types of forecasts they need, even though both media and policy-makers appear to need forecasts only to serve the needs of end-users. Policy-makers need predictions that may be more (resource managers) or less (elected officials) technical and detail oriented than the end users whom they serve. Elected officials are often more interested in socio-economic forecasts than are the end-users whom they serve. Policy-makers tend to need more long-term predictions than do the end-users, though elected officials are often working in a politically-determined temporal scale. Likewise, the spatial-scales of forecasts needed by policy-makers are largely determined by their management jurisdictions. Media may request forecasts that are more or less complex than typical of their audiences and usually want forecasts where uncertainty is either minimized or expressed in easily understandable terms.

Canadian counterparts for all constituent types and categories are not explicitly considered in this document. In some cases, their forecasting needs may differ significantly from those of their counterparts in the U.S.

End Users

- **Water Safety** – Individuals with a vested interest in water safety form arguably one of the largest constituencies on the Great Lakes. Virtually anyone who spends time in, on, under, or near the Great Lakes has some safety concerns. Water safety end users include recreational (e.g., boaters, swimmers, divers, shoreline anglers), commercial (shipping, commercial fishermen), and military (Coast Guard) interests. All are interested in forecasts that could improve their personal safety – storm and weather, water temperatures, currents, ice, and pollution – though particular needs may vary considerably among subgroups. Impacts of improved ecological forecasts for this group are likely to be assessed in terms of saving human lives and health rather than in strictly economic terms. – Workshop participants flagged water safety as a priority forecasting constituency due to (a) magnitude of the constituency, (b) potential for savings in terms of human life, and (c) likelihood of significant forecast capabilities being developed in the near future given existing state of the science.

- **Seafood Consumers** – Consumers of Great Lakes seafood are a significant constituency including both recreational (and subsistence) fishermen and their families who eat fish caught in the Great Lakes as well as consumers of Great Lakes fish caught by commercial (and tribal) fishermen which are sold in supermarkets and restaurants (both within and outside the Great Lakes region). Many consumers of Great Lakes fish may not even be aware that the fish they consume originated in the Great Lakes. The top five commercial fish species (whitefish, yellow perch, walleye, smelt, and chubs) alone accounted for over 43 million pounds of fish in 2000 with a dockside value of $42 million. The primary ecological forecasting needs for this constituency relate to the concept of fish consumption advisories – accurate and understandable predictions of how safe it is to eat the fish (relative to alternative foods). Impacts of improved ecological forecasts for this constituency are to be assessed in terms of human health. – Simplified versions of the contaminant-related ecological forecasts considered for the related priority constituencies of recreational anglers, charter captains, commercial fishers, and fisheries managers (below) are expected to be useful to seafood consumers.

- **Coastal Landowners** – The Great Lakes are bordered by over 10,000 miles of shoreline. Coastal landowners – including private landowners, businesses, corporations, non-profits and government entities (e.g., state parklands) – have a significant investment in shoreline property and a significant interest in maintaining the value of that property. Impacts of improved ecological forecasts for this constituency are reflected in shoreline property values and minimization of the costs of negative impacts (e.g., storm damage). Ecological forecasts relating to coastline stability (rates of erosion and deposition) are a primary need of this constituency. Simplified versions of ecological forecasts needed by the priority constituency of land use planners (below) are also likely to be useful to this group.

- **Recreational** – Recreation in, on, under, and around the Great Lakes is more than a luxury – it is about quality of life. Additionally, Great Lakes recreation supports a variety of industries (see commercial below) with significant economic value to the region. All of the recreational subgroups examined below have significant concerns about water safety (and so are a subset of the priority water safety constituency above). Most would find uses for a variety of ecological forecasts developed primarily for other constituencies. Pros and cons of such secondary uses should be considered carefully in decisions to make specific ecologic forecasts public.

    - **Recreational Anglers** – Across the region, over 1.8 million anglers are estimated to spend 23 million days fishing in the U.S. waters of the Great Lakes. The economic value of the Great Lakes recreational fishery has been estimated to contribute between $4.3 and $7.4 billion dollars per year to the regional economy. The primary ecological forecasting question that recreational anglers want answered is 'where can I catch the fish (species) I want? Recreational anglers (and the charter fishing industry developed to meet their need – below) already make use of the Sea Grant CoastWatch system that provides near real-time satellite information on surface temperatures as a guide to where to find the fish. These CoastWatch users indicate that this information, used as a forecast of where temperature breaks will be (and thus where fish will congregate) makes the difference between a successful and unsuccessful day of fishing. Most recreational fishermen eat their catch and so are interested in ecological forecasts relating to seafood consumption (above) as well as water safety (also above). A large proportion of the Great Lakes recreational angling community is interested in the long-term sustainability of the fishery – they want fisheries managers (below) to actively manage a fishery for long-term sustainability of the resource (and often to manage for maximization of their particular favorite sportfish). Thus although few of them would express a direct need for forecasts of fish stocks or prey base they would benefit from the use that fisheries managers would make of such forecasts. Impacts of ecological forecasts for recreational anglers could be seen in measures of catch per unit effort, magnitude of the fishery (total catch), and/or economic value of recreational fishing to the regional economy. - Workshop participants flagged recreational anglers as a priority forecasting constituency due to (a) the number of recreational anglers, and (b) the economic value of recreational angling to the regional economy.

- Δ **Ice Fishers** – Ice fishers were briefly considered as a unique subset of the recreational angling and water safety constituencies. Enhanced forecasting of ice conditions and better local communication of ice conditions is a special need of this constituency.

- o **Recreational Boaters** – Recreational boaters are a significant Great Lakes constituency. One-third of all registered boaters in the U.S. reside in the Great Lakes basin. Water safety related ecological forecasts (above) are the primary ecological forecasting need of Great Lakes recreational boaters. Short and long-term water level forecasts are especially important to recreational boaters and the industries (e.g., marinas) that support them. Impacts of ecological forecasts on recreational boaters would be reflected in economic statistics relating to the supporting industries, license sales and safety statistics (e.g., number of rescues) – Workshop participants flagged recreational boating as a priority forecasting constituency due to (a) the number of recreational boaters, and (b) the likelihood of significant forecast capabilities being developed in the near future given existing state of the science.

- o **Divers** – SCUBA diving is a growing recreational interest in the Great Lakes. Ecological forecasts most needed by divers relate to water safety (above) and will be given further consideration under that category. Divers are more directly interested than most recreational groups in water clarity and would have an interest in short-term local prediction of water clarity. The Great Lakes dive community is very aware of zebra mussels – both as an agent of increasing water clarity and as an organism affecting significant changes to dive structures (e.g., shipwrecks) and Great Lakes ecosystems and would likely be interested in forecasts relating to the rate at which zebra mussel populations expand (into new geographic areas or covering specific surfaces).

- **Bird Watchers** – Specific locations along the Great Lakes shoreline are important destinations for bird watchers – as birds congregate along narrow flight corridors between the lakes and rest along the shorelines prior to migration across the lakes. Great Lakes coastal wetlands are particularly important to birds and so to the people who watch them. Great Lakes birdwatchers are interested in forecasts of location and timing of bird migrations as well as changes in species abundances. Forecasts of habitat changes, land use patterns, invasive species, and other ecological factors affecting bird populations are also of interest to birdwatchers (though perhaps less immediately).

- **Hunters** – Hunting is a significant recreational pastime in the Great Lakes region. From a purely Great Lakes perspective, waterfowl hunting is probably the most relevant variation on the theme. Waterfowl hunters are interested in maximizing use of the resource while sustaining waterfowl populations. They would be directly interested in forecasts of migratory patterns (where and when the birds can be found) and those who manage the resource on their behalf would be interested in forecasts relating to any factors controlling population dynamics including the influence of changing land use patterns.

- **Beach Using Public** – Hundreds of beaches ring the Great Lakes – some see thousands of visitors each day during the height of summer. The beach using public needs several specific types of forecasts – all aimed at helping them decide "Should I go to the beach today? and if I do, should I go in the water?" Most of these come down to water safety forecasts (above). For beachgoers these include weather, waves, and currents as well as likelihood of contamination, algae blooms, or other factors leading to beach closings or health risks.

- **Long-Distance Swimmers** – As I write this segment, ultra-marathon swimmer Jim Dreyer is beginning his third attempt to swim across Lake Superior. Dreyer has 10 times set a world record while swimming across four of the five Great Lakes. In addition to his Lake Superior distance records, he was the first to swim a direct 65-mile crossing of Lake Michigan, the fastest to cross Lake Huron, and crossed Lakes Erie and Ontario as part of multi-sport events that set solo triathlon and duathlon distance records. Long-distance swimmers like Dreyer benefit from a variety of available short-term ecological forecasts – including wave, current, and water temperatures – and would likely take full advantage of additional forecasting capabilities as they were made available.

- **Surfers** – A small but dedicated constituency, Great Lakes surfers are always looking for improved forecasts of wind, weather, and nearshore waves.

- **Tourists** – The Great Lakes ecosystem supports an impressive tourism economy. In addition to those encompassed by the other recreational categories (e.g., fishing, boating, swimming, birdwatching) are others who come to watch the ships, camp, or just enjoy views. Improved weather forecasts (long term, improved accuracy) especially for the nearshore areas are probably their greatest ecological forecasting need.

- **Commercial** – The Great Lakes are an important resource for a variety of commercial enterprises. Those that work directly in and around the waters of the Great Lakes have significant water safety concerns (above). Commercial enterprises reliant on the Great Lakes also have a variety of other concerns that would benefit from ecological forecasts. Commercial enterprises generally have longer planning horizons than their recreational counterparts and are much more focused on the economics – forecasts that bear on issues of economic importance or that can be translated into economic terms are in greatest demand from the commercial sector.

    - **Fisheries -**

        - **Charter Captains** – In 2002 an estimated 1,951 charter captains plied the Great Lakes averaging 28 full day and 25 half-day trips each (carrying up to 6 passengers per trip). Charter captains thus potentially serve a community of 600,000 fishers. Charter captains report average annual revenues of $19,782; giving the industry a direct economic impact of $38 million. This figure does not include dollars spent by charter customers on hotels, restaurants, and other local tourism businesses that are a mainstay of many Great Lakes coastal communities. Great Lakes charter captains use ecological forecasts to find fish and for water safety (above). Good forecasts of fish location help charter captains to reduce transit times (looking for good locations) -- reducing fuel costs and increasing customer satisfaction. For a business that frequently hovers near the break-even point, this can be significant. At least 44% of charter captains make use of NOAA generated forecasts (CoastWatch and/or Great Lakes Forecasting System), indicating a constituency poised to take full advantage of additional forecasts as they become available. Charter captains also exhibit a surprising sophistication in their use and interpretation of the forecasting products – bringing to bear their experience of typical lake conditions in interpreting the satellite imagery and forecasts. Charter captains are currently using the available CoastWatch real-time satellite imagery to forecast the location of temperature breaks (over very short time scales) – which they find to be a good indicator of fish location. For this user group, the accuracy of the predicted water temperature (^{o}C) is less important that the accuracy of the geographic location (Lat-Lon) of the temperature breaks. – Workshop participants flagged charter captains as a priority forecasting constituency due to (a) the size of the constituency (charter captains plus the fishermen whom they serve), (b) the economic impact of the enterprise, and (c) the readiness of the constituency to take advantage of additional ecological forecasts.

        - **Commercial Fishers** – The Great Lakes support a sustainable commercial fishery. Commercial fishery operations are licensed through the states, the province of Ontario, and the tribal nations. Every lake has a Native American component of the commercial fishery except Lake Erie. The level of activity of the commercial fishery varies from state to state and the province of Ontario. The top three commercial species (whitefish, walleye, and yellow perch) alone have a dockside (wholesale) value of $39 million (at 80 cents to $2.11 per pound). Commercial fishers need ecological forecasts that help them find fish (increasing catch per unit effort and profit margins) and that help fisheries managers to maximize the allowable catch. – Workshop participants flagged commercial fishers as a priority forecasting constituency due to (a) the economic value of the enterprise.

  ◊ **Tribal Fishers** – Tribal operated fisheries comprise a large proportion of the commercial fishery. Tribal fishers are also an important component of the subsistence fisheries with many tribal members relying heavily on fisheries resources to feed their families. Due to differences in gear used, geographic locations, and other factors, the forecasting needs of tribal fishers may differ from the average non-tribal commercial fishing operation.

    - Δ **Seafood Vendors** – A broad array of vendors purchase commercially caught Great Lakes fish for resale to the public. These vendors include a variety of restaurants, seafood markets and other seafood businesses both within and beyond the Great Lakes region. The economic impact of this sector is difficult to assess, but is certainly more than double the direct wholesale value of the fish (e.g., more than $72 million). Seafood vendors are primarily interested in ecological forecasts that help to assess the relative safety of the seafood (e.g., contaminants in a fish from Lake Erie versus a Pacific caught fish) and those which help fisheries managers to work towards safer wild-caught fish (e.g., towards reducing contaminants in Great Lakes fish).

    - Δ **Bait and Tackle Industry**

  - o **Tourism Businesses and Marinas** – Workshop participants flagged tourism businesses and marinas as a priority forecasting constituency due to (a) the importance of the tourism industry to the economy of local Great Lakes coastal communities.

- **Water Users** – While the Great Lakes represent 20% of the world's fresh surface water, only about 1 percent of this water is available for use. This 1 percent represents the volume of Great Lakes water that is renewed each year, mostly through precipitation. Total water withdrawals from the Great Lakes in 1993 were estimated at 2,492 m^3/s. Power generation (nuclear and fossil combined = 70%) is the largest user (withdrawal) of Great Lakes water. Only a small fraction (<5%) of this total is consumptive use. Irrigation is the largest consumptive use of Great Lakes water (30%) followed closely by public supply (26%) and industrial use (25%). Water users have a variety of forecasting needs in common. Primary among these are a need for accurate long-term forecasts of lake water levels suitable for use in planning construction of intakes and a need for prediction of zebra mussel settling and growth for determination of intake maintenance needs.

  - o **Water Plants/Water Supply** – Over 90% of the 29 million US residents of the Great Lakes basin rely upon the Great Lakes for drinking water. Water plants supply Great Lakes water to meet this need by withdrawing the water from the lake through intakes placed at depth and some distance offshore in the lake and purifying the water to drinking standards. Long-term forecasts of extreme water level fluctuations are needed when planning for new intakes. Accurate prediction of factors impacting water quality (e.g., contaminants, water chemistry, algal blooms, temperature) at the water source (intake) could be used to maximize the efficiency of the treatment process. Prediction of other factors at short-to-intermediate time scales may also be useful in plant maintenance (e.g., predicting the timing of zebra mussel veliger settling). – Workshop participants flagged water plants as a priority forecasting constituency due to (a) the importance of the water supply in meeting needs of residents of the Great Lakes basin.

- **Agriculture** – Irrigation consumes an average of more than 740 m^3 of Great Lakes water each second. 80% of this water is estimated to be lost (to the basin) due to evaporation. Water use for agriculture in the Great Lakes region increased fairly steadily from 1960 to 1995 and is expected to continue to grow. Accurate forecasts of soil moisture content in agriculture areas of the basin could be used to target irrigation and increase the efficiency of this leading consumptive use.

- **Bottled Water** – When intrabasin trade in bottled water is subtracted from the total trade, the Great Lakes Basin currently imports about 14 times more bottled water than it exports. Most bottled water produced in the Great Lakes basin is groundwater rather than Great Lakes surface water. More accurate predictions of the impact of groundwater withdrawal on surface waters may be important to regulating this industry.

- **Sewage Treatment** – Retrofitting sewage treatment systems throughout the region to avoid or better handle the combined sewer overflow problem is a major issue facing the Great Lakes region. In wet weather, rainwater running off streets, roofs, and parking lots enters combined sewers, which collect and move both storm water and municipal sewage. These sewers were standard engineering practice until the Second World War and are still found in the older parts of many cities in the Great Lakes region. When the sewer capacity is exceeded, or high flows would threaten downstream parts of the system (such as the sewage treatment plant), excess combined sewage is allowed to escape via combined sewer overflows (CSOs) into nearby receiving waters, including the Great Lakes. In the Great Lakes region, this pollution is a major obstacle to restoring Areas of Concern such as Hamilton Harbour. Those operating sewage treatment facilities and those planning for the redesign of new systems would greatly benefit from accurate predictions of the magnitude and timing of flow events as well as from predictions of how development (e.g., increasing impervious surfaces) and climate change may interact to alter flow regimes (especially maximum flow rate). – Workshop participants flagged sewage treatment plants as a priority forecasting constituency due to (a) the potential impact on nearshore water quality.

- **Water-Dependent Power Plants** – Nuclear and fossil fuel based power generation together use nearly 70% of the water withdrawn from the Great Lakes (>40mgd). At power plants, water is used principally for condenser and reactor cooling – which is not a consumptive use. Accurate predictions of water temperature at intakes (especially in global warming scenarios) may be an important prediction for water-dependent power plants.

- **Industrial Water Users** – Industry is the second leading user (withdrawal) of Great Lakes water (behind power plants) at 12% and the second leading consumptive use of Great Lakes water (behind irrigation) at 24%. Perhaps more important is the economic significance of this sector - the Great Lakes basin is home to 20% of US manufacturing. – Workshop participants flagged industrial water users as a priority forecasting constituency due to (a) potential impact on the regional and national economy.

- **Transportation**

  - **Airports** – Localized weather patterns around the Great Lakes frequently disrupt air transport causing flight delays. Better forecasting of these local weather patterns could result in more efficient air traffic control around regional airports. – Workshop participants flagged airports as a priority forecasting constituency due to (a) numbers of constituents (indirectly) affected, (b) the likelihood of significant forecast capabilities being developed in the near future given existing state of the science, and (c) the readiness of the constituency to take advantage of additional ecological forecasts

  - **Shipping** – Great Lakes shipping handles an average of 180 million tons annually in domestic, cross-lake and overseas trade. The principle cargoes moved through the Great Lakes navigation system are bulk commodities: iron ore, coal, grain, limestone, salt, and petroleum products. Much of the movement in the Great Lakes system is connected to raw material supply for steel mills and coal-fired power plants, a backbone of the regional manufacturing base. Better prediction of water levels, storms, ice cover, and other water safety factors which influence transit times and costs would be useful to this constituency. Shipping has also been identified as a major vector for the accidental import of aquatic nuisance species – better models for prediction of vector dynamics (what species, ports of origin most risk, best management practices, etc.) which take into account the industry capabilities that could be used by this constituency to reduce the magnitude of introductions via this route. – Workshop participants flagged shipping as a priority forecasting constituency due to (a) potential impact on the regional economy.

  - **Ports and Harbors** – The Great Lakes St. Lawrence system includes more than 15 major Canadian and US ports – over half of these with a depth of more than 27 feet - and hundreds of smaller harbors. Ports and harbors are the point of access to the Lakes for shipping and boating as well as the 'front door' for many of the communities ringing the Great Lakes. Many are the economic mainstay of their local community. Port authorities and harbor managers would benefit from better prediction of water levels, storms, ice cover, and other water safety factors – especially over the long-term planning horizons (e.g., maximum water levels, frequency of storms). This constituency is also likely to be in the forefront of efforts to monitor harbors for new aquatic invaders and to implement rapid response protocols. Harbor-specific models of circulation dynamics would be useful tools in predicting the efficacy of any proposed rapid response. Predictions of the behavior of new invaders are also likely to be a valuable component of rapid response.

- **Military**

    - **Coast Guard** – The Ninth District of the US Coast Guard employs nearly 7,000 active duty, reserve, auxiliary, and civilian members. The district includes 2 air stations, 2 air facilities, 5 Group offices, 8 Marine Safety offices, 9 cutters, and 46 small boat stations. These units are responsible for over 1,000 miles along the Canadian border and 6,700 miles of U.S. shoreline spanning eight states and all five Great Lakes. Great Lakes Coast Guard missions include: search and rescue, maintenance of aids to navigation and other buoys, boating safety, military readiness, icebreaking, law enforcement, drug interdiction, environmental protection, vessel inspections, port security, and homeland security. Accurate short-term forecasts of weather, winds, waves, and currents are critical to the operations of the Coast Guard. The Coast Guard currently uses CoastWatch satellite data (surface water temperatures) in planning training missions (e.g., choosing locations exhibiting appropriate temperatures for training). Accurate real-time information (and short-term forecasts and hindcasts) on local currents could prove invaluable in search and rescue operations. Forecasts of growth rates for fouling agents (e.g., mussels) could be useful in planning for the maintenance of aids to navigation. Accurate forecasts of the extent, duration, and thickness of Great Lakes ice cover would be valuable in the operation of and planning for Great Lakes icebreaking.

    - **Army Corps of Engineers** – It is the business of the Army Corps of Engineers to plan, design, construct, operate, and maintain navigational channels and flood control measures, and to provide disaster assistance to the nation. The Corps also implements environmental restoration projects as well as regulates shoreline construction and the filling of wetland areas. All of these activities have the potential to benefit from ecological forecasts. Long-term forecasts of maximum wind, wave, storms, and water levels (e.g., in light of climate change) would be useful in the design of nearly any Corps construction project. Forecasts of the extent of invasive species, especially those with the capacity to physically alter environments (e.g., quagga mussels) would also be useful in project design (i.e., intakes might have been structured differently had we known the zebra mussel invasion was imminent). Forecasts of changing sedimentation patterns, especially under differing land use changes is critical to planning for the maintenance of navigation channels.

    - **Homeland Security** – “Maritime security is critical to ensuring our nation’s homeland and economic security,” according to Homeland Security Secretary Tom Ridge. Nowhere is this truer than the Great Lakes. The Great Lakes provide drinking water for 40 million people and 56 billion gallons per day for municipal, agricultural, and industrial use. New York Power Authority’s Niagara Project is the largest electricity generator in the state of New York – nearly all the power generated in the basin relies on Great Lakes water for condenser and reactor cooling. Great Lakes water and shipping are the backbone of regional manufacturing – 20% of the total US manufacturing base. To top that off, the Canada-US border has for years been the longest undefended international border in the world. Ecological prediction may be key to monitoring the security of this region.

- **Students** – Students, from kindergarten through graduate school, are an important Great Lakes constituency. Forecasting needs of this group likely parallel the needs of a variety of recreational users (above) and researchers (below) – but the level of detail needed may differ significantly. Students almost certainly rely heavily on secondary outlets (below), including formal educators, to filter the needed forecast information.

- **Research Entities** – Great Lakes researchers are themselves an important constituency for Great Lakes ecological forecasts. The Great Lakes Environmental Research Laboratory's (GLERL's) Meteorological Observation Network originated in the need of researchers based in Ann Arbor to make short-term forecasts of conditions in southern Lake Michigan in determining research schedules (i.e., is it worth driving to Muskegon today, or will the boat be sitting at the dock due to weather?). Specific ecological forecasts of temporal and geographic extent of phenomena of interest (e.g., sediment plume, anoxia, algal bloom) can be an important factor in determining research plans and schedules.

Decision-makers

- **Elected Officials** –In general, elected officials are elected to represent the interests of geographically defined constituencies – whether this is at the federal, state, county, or municipal level of government. Ecological forecasts with geographic boundaries that closely match the geo-political boundaries and temporal frames that match terms of the office are likely to be of greatest use to the typical elected official. This is not intended cynically – matching temporal and spatial scales of a forecast to the scale at which decisions are made is an important factor to consider in all ecological forecasting done with decision-makers as an intended primary audience. It does little good to know what the weather will be next month if you need to decide whether you are going to the beach this weekend. The interests of elected officials generally reflect the interests of the constituencies that elect them – which may run the gamut from virtually no interest in Great Lakes issues to covering the full spectrum. Elected officials usually represent constituencies with a variety of potentially or actually conflicting interests – to the extent that ecological forecasts can help constituencies understand long-term consequences of decisions, they can be useful to elected officials in resolving such conflicts. Because the primary decision-making responsibility of elected officials in most cases has to do with allocation of limited resources (e.g., $), ecological forecasts with an explicit economic dimension (e.g., potential economic impact of a new invasive species) are likely to be of greatest interest and use to elected officials.

    - **Planning Commissions** – Planning commissions are a somewhat unique subset of elected officials. Usually operating on a fairly local scale (county/municipal/township) and with variable terms, planning commissions need much longer term forecasts (20 years plus) than nearly any other Great Lakes constituency and much more detailed forecasts than typical of any other group of elected officials. (See Land Use Planning – Below).

- **Resource Managers**

  - **Fisheries Managers –** Fisheries managers serve a variety of end users including recreational, commercial, tribal, and subsistence fishers as well as seafood consumers. The economic value of the Great Lakes fishery certainly exceeds $5 billion and by some estimates may exceed $8 billion. Jurisdiction for management of various aspects of the Great Lakes fishery are shared by two nations, eight states, the province of Ontario, and tribal authorities. The Great Lakes Fishery Commission facilitates and coordinates fisheries management by these entities in addition to holding direct responsibility for management (control) of sea lamprey. State (Departments of Natural Resources and NY Department of Environmental Conservation) and provincial (Ontario Ministry of Natural Resources) natural resource agencies have the lead in Great Lakes fisheries management – all are signatory to the Joint Strategic Plan for the Management of Great Lakes Fisheries and participate in consensus-based decision-making through the Great Lakes Fishery Commission's Lake Committees. This allows most fisheries management decisions to be made at the lake scale, though implementation strategies (e.g., stocking, quotas, bag limits, fines, and enforcement) vary across geopolitical boundaries. Despite increasing recognition of fish migrations between lakes, decisions are generally not yet made at the basin scale. The most useful ecological forecasts for this group of decision-makers will thus be made at the lake scale (though forcing functions such as stocking or recruitment may take place at finer scales). Great Lakes fisheries management is based on the theories of optimum sustainable yield and ecosystem management. Optimum sustainable yield allows for the inclusion of social and economic factors (fish value) in management decisions, thus forecasts of the economic impacts of ecological changes may be an important facet of ecological forecasting. Ecosystem management emphasizes the importance of co-managing a variety of species, thus forecasts of the changes occurring in different parts of the food web (e.g., fish-eating birds, trout, perch, and forage fish) are critical to Great Lakes fisheries management. Stocking and other management decisions usually take place on an annual basis, though forecasts at scales relating to fish life spans are appropriate for many types of decisions. – Workshop participants flagged fisheries managers as a priority forecasting constituency due to (a) the magnitude and variety of end users served including sport and commercial fishers and charter captains, (b) the economic value of the resource, and (c) the capacity of the managers to understand and rapidly incorporate appropriate forecasts into decision-making processes.

  - **Park Managers** – The US portion of the Great Lakes basin includes an array of protected lands managed at the national, state, and local levels: Parks, Forests, Dunes, Lakeshore, Wildlife Areas, Recreational Areas, Marine Sanctuaries, Underwater Preserves, Research Reserves, etc. Each has unique management needs that might benefit from specific ecological forecasts.

  - **Beach Managers** – Beach managers serve the thousands of visitors that come to each of the hundreds of Great Lakes beaches every day during the summer – including swimmers, birdwatchers, and tourists. Beach managers are generally responsible for water safety – testing waters for pollution (e.g. coliform indicators, harmful algae) and posting the results of such tests. Delay between drawing a sample and posting of the results is a major concern – standard delays exceeding 24 hours may endanger public health or result in economic losses associated with closures of safe beaches. Insufficient funding for frequent testing is also a concern. Ecological forecasting holds great promise as a potential tool to address these types of concerns. Wind and current information could potentially be used to forecast conditions under which testing is likely to result in beach closings – standard monitoring could be intensified during the period just prior to, during, and immediately following the 'risk' period – resulting in faster response and more efficient use of monitoring resources. Such forecasts would be needed over relatively short time scales (a week or less) and would need to be geographically localized (i.e., to the specific beach) to be most effective. Priority sites should be determined based on socio-economic factors (e.g., number of visitors).

- **Regulators**

    - **State Water Quality Regulators –** Great Lakes water quality directly affects every citizen of the basin as well as the millions of visitors to the region through drinking water, industry, recreation, and the economy. Although Great Lakes water quality regulation is binational in scope (Boundary Waters Treaty of 1909 and Great Lakes Water Quality Agreements 1972, 1978, 1987 – the International Joint Commission (IJC) has authority to resolve disputes and to advise federal governments) and nationally coordinated (Clean Water Act – Environmental Protection Agency/Great Lakes National Program Office has responsibility) most of the day-to-day work of water quality monitoring and regulation falls to state offices (e.g., state Environmental Protection Agencies, Departments of Environmental Conservation, or Departments of Environmental Quality). Monitoring is complex and perennially under funded. Forecasts that can help to replace or better target monitoring programs are a high priority for water quality regulators. Forecasts relating to natural (e.g., currents) and unnatural phenomena (e.g., exotic species peaks) impacting water quality could be important to regulators. Long-term predictions of changing flow regimes (including storm water runoff) could be particularly important in planning for upcoming changes to regulations and infrastructure (e.g., to address combined sewer overflows). – Workshop participants flagged state water quality regulators as a priority forecasting constituency due to (a) the magnitude and variety of end users served including nearly all water users, (b) priority binational importance placed on water quality (Great Lakes Water Quality Agreement), and (c) the capacity of the regulators to understand and rapidly incorporate appropriate forecasts into decision-making processes.

    - **Land Use Planners –** Land use is undoubtedly among the most significant issues facing the Great Lakes region – affecting all residents of the basin directly or indirectly. Land-use planners generally operate at a fairly local scale (county/municipal/township); though the need for larger scale efforts is recognized, little progress has been made in this direction. Land-use planners operate at several temporal scales – local planning commissions typically have a 3-5 year election, formal planning frameworks are typically decadal, 30 year bonds are not unusual, and impacts are generally considered in 50 year increments (typical construction 'built to last' 50 years) – all of which are among the longest forecasting horizons of any Great Lakes user group. The contrast of small geographic scales and large temporal scales are a challenge that must be met in any ecological forecasts designed to serve this constituency. – Workshop participants flagged land use planners as a priority forecasting constituency due to (a) the magnitude and variety of end users served - including all citizens residing in the Great Lakes basin, (b) the potential impact of decisions residing in the authority of this group on water and ecosystem quality in the Great Lakes and their tributaries, and (c) the suitability of the planning horizons employed by this sector situate them to take advantage of long-term forecasting.

  - **Public Health Officials** – Public health is clearly a priority research area, making public health officials a logically important decision-making constituency. Within the Great Lakes focus, the forecasting needs of public health officials are likely to overlap with the water supply, sewage treatment, or beach related constituencies and issues (above).

- **Restoration** – Restoration and cleanup of toxics in the Great Lakes region, in particular focusing on the internationally designated Areas of Concern, has been a hot button issue in the region for more than 30 years. Recent legislative initiatives (Great Lakes Environmental Restoration Act - S. 1398) may lead to a renewed surge of interest in and need for ecological forecasts in this area. Decision-makers working in these areas (exemplified by Remedial Action Planning and Lakewide Management Planning committees) need highly localized forecasts of contaminant transport (including source and fate) to target cleanup and monitoring efforts.

- **Other NOAA agencies** – Workshop participants were aware of recent NOAA efforts to increase communications across NOAA offices and to matrix manage key issues. Forecasting needs of other NOAA agencies operating in the Great Lakes region were highlighted as priority areas within this context without going into significant detail.

- **Other Natural Resources Decision-makers** – Workshop participants briefly considered a variety of other decision-making groups with ties to management of Great Lakes natural resources. While not designated priority constituencies in themselves, these groups likely have significant overlap with the above priority constituencies and their needs should be considered in conjunction with (or supplemental to) the above constituencies in determining relative priority of specific ecological forecasting needs. These decision-makers include:

  - County Engineers
  - Tourism Agencies
  - Naturalists
  - State Climatologists
  - Meteorologists
  - Watershed Councils
  - Economists
  - Homeland Security

Media and Secondary Outlets

Public sector constituencies can be expected to directly use scientifically based ecological forecasts only in very rare cases. Rather, some intermediary – traditional media, education or other secondary outlets – will be translating these forecasts and delivering them to the end users. Up-front consideration of the limitations and needs of these media as we formulate the ecological forecasts, which we intend them to deliver, can greatly influence the usefulness of the forecasts to the target constituencies. Workshop participants developed a brief list of potential secondary outlets that could serve as partners to deliver ecological forecasts to Great Lakes coastal constituencies.

- Outdoor/Environment/Science/Business Writers
- Editorial (Media)
- Citizen Organizations/Non-governmental Organizations
- Environmental Foundations
- Lobbyists
- Museums
- Educators
- Sea Grant Extension
- University Faculty/Administration
- Youth Leaders
- Celebrities

Workshop participants did not go into detail as to the target audiences best served by each of the following outlets and peculiarities of each that might influence the development of ecological forecasts that they could deliver. Researchers working on development of ecological forecasts are strongly encouraged to consult with appropriate outlets early in the development of an ecological forecasting concept.

Great Lakes Ecological Forecasting Issue Areas

Nearly every issue of significance to the Great Lakes region has some identifiable need for forecasting. Nearly every research area of significance to the Great Lakes region likewise holds the potential for enhancement of forecasting capabilities. The following segment was developed by workshop participants to categorize and prioritize issue areas that hold the greatest need and/or the greatest promise for the development of ecological forecasts.

The following examines specific Great Lakes issues likely to generate ecological forecasting needs. Priorities were determined based on estimation of both need for the forecast as well as on the promise of ecological forecasting to meet that need. Assessment of need for forecasts in a given issue area is based on discussion of ties to current or imminent action (legislation, regulation, cleanups, management, etc.), the need for forecasts to drive action, the variety of audiences engaged in the issue (and the priority placed on those audiences above), and speculation as to the likely growth of the issue area in the near future. Assessment of the promise of ecological forecasting to meet needs in a given issue area was based on discussion of the current state of science in a given issue area, and the potential for direct utilization of forecasts to specific problems.

Cross-Cutting Forecasting Factors

Workshop participants raised a variety of issues which cut across traditional disciplines and which should be given consideration in developing ecological forecasts for any specific topical issue. These relate to factors that (a) are likely to impact forecasting of ‘unrelated’ issues, (b) deal with technologies applicable to a broad range of forecasting types, or (c) touch on forecasting ‘philosophies.’

- **Global Models** - Global-scale predictive models for climate, atmospheric deposition, and other physical phenomena are well under development. However, predictions at geographic resolutions larger than the regional scale are generally not useful to either end-users or the majority of management authorities. Efforts to repackage and reinterpret global-scale models at regional (or even more refined) geographic scales will greatly increase the usefulness of such forecasts.

- **Long-term Forecasts** - Three crosscutting issue areas deserve special consideration in the context of long-term ecological forecasting (>20 years). Workshop participants agreed that in order to be useful, long-term predictions must take into account changes in climate, invasive species, and land use. Any long-term forecasts that fail to take into account the potential complication posed by shifts in climate, invasions, or land use changes will be limited in usefulness. The current state of knowledge in each of these areas is considered to be seriously inadequate to support most long-term ecological forecasting needs.

- **Seasonality** – The vast majority of ecological phenomena in the Great Lakes region exhibit marked seasonal patterns. Forecasts extending beyond a 1-year timeframe need to explicitly account for seasonal patterns – especially in interpretation for public consumption.

- **Satellite Imagery** – Satellite imagery is increasingly used as a tool for very short-term forecasts and nowcasts of ecological phenomena. Creation of products that provide easily understood visual interpretation of satellite data, in real-time or forecasting contexts, holds great promise for rapidly expanding such forecasting capability.

- **Model Discrepancies** – Most forecasting products are based on models of the natural system rather than on direct observations. Being simplifications of the natural phenomena that they represent, models based on different underlying assumptions (or even the same assumptions put together differently) frequently give different results. Such discrepancies among model predictions are probably the single most frustrating factor for end-users attempting to base real decisions on forecasts. Most critical are model discrepancies that differ in kind – for example, Model A predicts water levels will go up and Model B predicts they will go down. In the absence of further information about and interpretation of the models, the average user (including managers with a fair degree of technical knowledge in the subject area) are unable to determine which model to apply to their situation; usually resulting in neither prediction being used. When a model forecast differs from a previously (or simultaneously) developed forecast, additional effort must be made to interpret these discrepancies (why do the models differ, which one applies best in which situations, what additional information might resolve the discrepancy) for the users.

- **Decision Analysis for Precautionary Management** – Forecasts that support decisions, particularly management decisions, should take priority over forecasts that merely inform. Increasingly, natural resources management philosophy is driven to shift toward employment of a precautionary approach to management. Management strategies supporting precautionary management often focus on avoiding events in the tail of a distribution (e.g., less than a 0.1% chance that this management strategy will cause an extinction). Forecasts which report not only the most likely (average) case but also the range of possible responses (e.g., probabilistic forecasts) are likely to be especially useful in this context.

- Vulnerability to homeland attacks and other threats – In the current political climate, homeland security is a high profile issue area. Any ecological forecasts that can play a role in reducing threats to national security or human health should be considered a high priority.

Physical Forecasting Issues

- **Water Quantity** – In April of 1998, the province of Ontario approved a permit for a venture capital corporation, the NOVA Group, to export Lake Superior water. While the permit was later relinquished and the markets have never fully materialized, coinciding as it did with the onset of a period of low Great Lakes water levels, this process spurred a tremendous concern in the Great Lakes region about water quantity issues. Implications of international law, binational treaties, and national enabling legislation were all reexamined in this context. The International Joint Commission was asked to report on current and potential diversions and consumptive uses of Great Lakes water, the effects of such and the policies effecting sustainability of the resources from a water quantity viewpoint. In June of 2001 the governors of the Great Lakes states signed Annex 2001, a non-binding agreement setting forth a framework and commitment to working toward development of a new set of decision-making standards for water quantity (focused particularly on consumptive use and diversion). Workshop participants flagged water quantity as a priority forecasting issue category due to (a) the high public and political profile the issue area currently enjoys, (b) the number of specific physical issues which fall into the water quantity category, and (c) the likelihood that any available forecasting information will be quickly incorporated into management decisions.

    - **Water Levels** – During the past 30 years, the Great Lakes have seen water levels higher than the long-term average. Starting in the fall of 1998, lake levels began to drop precipitously, quickly reaching lows that had not been observed since the mid-1960's. This rapid drop (and continuing low relative to recent highs) spurred great public interest and concern about the water levels of the Great Lakes. Great Lakes water levels impact a variety of environmental and societal concerns in the Great Lakes: coastal process (such as erosion, beach building, and flooding), sedimentation, water quality (especially at nearshore intakes), movement and exposure of toxic sediments, dredge spoil disposal, fish habitat, wetlands, commercial navigation, recreational boating, marinas, and tourism. Two water level regulation points are overseen by the International Joint Commission – the outflow of Lake Superior at the Soo Locks and outflow of Lake Ontario through the St. Lawrence River. The Lake Ontario - St. Lawrence River Study Board is in the midst of a comprehensive 5-year study for the International Joint Commission (IJC) to assess and evaluate the current criteria used for regulating water levels on Lake Ontario and in the St. Lawrence River. The Study is intended to consider, develop, evaluate, and recommend updates and changes to the 1956 criteria for Lake Ontario-St. Lawrence River water levels and flow regulation, taking into account how water level fluctuations affect all interests and changing conditions in the system including climate change. Similar studies have been proposed for Lake Superior control and overall Great Lakes water quantity management. Important water level forecasts thus include not only short- (annual) and long- (20 year +) term forecasts of Great Lakes water levels, but also forecasts of the impacts of water level fluctuation patterns on the Great Lakes environment, communities, and economy. Workshop participants flagged Great Lakes water levels as a priority forecasting issue due to (a) the variety of coastal issues impacted directly or indirectly by water level, (b) the magnitude of economic impacts of water level fluctuations, and (c) the potential for water level forecasting related information to be incorporated into IJC regulation and local planning.

Δ Within the water level forecasting issue area, workshop participants noted long-term forecasting of Great Lakes water levels (30 year cycles?) as the highest priority forecasting need. In order to be useful, such forecasts need to incorporate the impact of climate change and may need to incorporate an understanding of changing land use patterns (as such influence evaporation and runoff patterns). Forecasts should focus on factors such as the mean water level, high water level, low water level, cycle length, etc. – factors which should be taken into account in the long-term planning strategies of land use planners and shoreline developers as well as in the construction (or remodeling) of any water intake.

o **Runoff** – Workshop participants flagged runoff as a priority forecasting issue due to (a) the need for runoff predictions as a key step in the development of priority water level forecasts (above), (b) the variety of contemporary issues that would benefit from runoff prediction, and (c) the future potential changes of runoff patterns with changes in land use. Accurate prediction of runoff is an important component of water level prediction (above). Prediction of tributary water levels is even more tied to runoff patterns – and prediction of these water levels is growing in importance as development (and water intakes) move inland along these waterways. Increasing 'flashiness' of streams and tributaries with changing land use patterns is of growing concern. Runoff also impacts directly on a variety of other issues. Contemporary efforts to address nonpoint source pollution and combined sewer overflows would benefit from more accurate predictions of runoff. These forecasts need to be local in scale and are needed for both short-term (how much runoff are we going to get next week?) and long-term (what is our maximum daily runoff going to be 20 years from now?) planning. This type of prediction is especially important now as communities grapple with the CSO issue and the redesign of sewage systems.

Δ Within the runoff forecasting issue area, workshop participants noted prediction of changes in runoff quality and quantity under different land use and climate change scenarios as an immediate priority forecasting need. NEMO and Citizen Planner programs provide an immediate conduit by which specific forecasts or models allowing local prediction of the long-term effects of land use patterns on runoff could reach land use planners and land use planning commissions who could use such in making decisions.

- o **Precipitation –** Over the past 150 years, the Great Lakes Basin has seen cycles of high and low precipitation that run over a decadal scale. Workshop participants flagged precipitation as a priority forecasting issue due to (a) the need for precipitation predictions as a key step in the development of priority water level and runoff forecasts (above), (b) the need for precipitation forecasts as a key element of priority coastal weather forecasting enhancement (below), (c) the need for precipitation prediction as a key step in a variety of other ecological forecasts (drought/flood), and (d) the variety of economically important constituent sectors directly impacted by precipitation patterns (agriculture, tourism) and long term changes in the means and extremes (development, construction). Ecological forecasting needs run the gamut from the very local and short-term (e.g., better prediction of nearshore squalls for boater safety) to the regional and long-term (e.g., is precipitation in the Great Lakes region becoming more concentrated into larger events with global warming - for use in constructing flood control structures).

- o **Hydrologic Transport and Discharge** - Workshop participants flagged hydrologic transport (the movement of water through the system) as a priority forecasting issue due to (a) the need for such predictions as a key step in the development of priority water level forecasts (above), and (b) the need for such predictions to feed into mass balance modeling of contaminants and the prediction of contaminant movement. Discharge forecasting was specifically identified as a priority within this area because of the linkage to the contemporary problem of addressing combined sewer overflows (see above, runoff).

- **Surface Dynamics, Thermal Structure, and Circulation**

  - o **Waves and Surface Dynamics** – Workshop participants flagged hydrologic transport (the movement of water through the system) as a priority forecasting issue due to (a) its importance as a water safety issue for a broad sector of the Great Lake community, and (b) due to a perception that the current state-of-the-science is such that a useable forecasts of waves and surface currents of the type needed could be developed fairly quickly. Most of the priority ecological forecasts discussed for this issue area are short-term (<1 week) and local in scale. Wave nowcasts and short-term forecasts (<24 hours) such as those currently under development as part of the Great Lakes Coastal Forecasting System were explicitly mentioned as a product nearing the stage where the general public would benefit from the forecasts. Over the July 4 weekend just prior to the workshop, several drownings occurred in the Great Lakes that were attributed to rip currents. This was discussed as an example of a priority case for ecological forecasting of transient currents – had such currents been predicted, lives might have been saved. Search and rescue operations were mentioned as benefiting from more accurate forecasting (nowcasting or even slight hindcasting) of local currents. Need for several types of longer-term, regional-scale wave and current forecasts were also discussed, though accorded lower priority. In particular, long-term prediction of changes in mean and average wave height/strength with climate change was noted as important for coastal construction.

- o **Thermal Structure** – Lake thermal structure is a driving factor in many biological lake processes, including fish distribution. Forecasts of (and nowcasts or real-time information about) lake thermal structure are one of many specific types of ecological forecasts of interest to fishers and fish managers.

  - Δ Workshop participants expressed an interest in the potential of Real-Time Vertical Temperature Profiling (one of the experimental products under development as part of the Great Lakes Coastal Forecasting System) as an option for supplementing the existing CoastWatch sea surface temperature profiles. Forecasting options available to compensate for cloud cover problems in CoastWatch satellite imagery were also mentioned as an important facet for improving existing nowcasts.

- o **Recharge** – Consumptive uses of ground and surface waters are of increasing importance in the Great Lakes basin. More accurate predictions of recharge of heavily utilized systems were noted as an important facet of water quantity prediction.

- o **Flooding** – Flooding is one of the most obvious of several water quantity related coastal processes for which more accurate forecasts would be useful. This topic was discussed as an area for research in the contexts of climate change and land use planning.

- **Sediments** –The importance of forecasting sediment movement was discussed both from a direct aspect (management of coastal processes including erosion, beach nourishment, and dredging) as well as from a contaminants perspective (movement and burial of contaminants is generally believed to be associated with sediment processes). Prediction of all stages of sediment transport – erosion, loading, littoral-to-offshore movement, deposition, and resuspension – were considered by the participants in the workshop to be high priority forecasting needs. The US Army Corps of Engineers has the most direct responsibilities for management of Great Lakes sediments (dredging, construction) while the US Environmental Protection Agency (EPA) has the most direct responsibilities (on a federal level) for management (remediation) of contaminants in the Great Lakes. The US Department of Agriculture (USDA) also has some responsibilities relating to upstream (erosion prevention in tributary streams) management of sediments in the Great Lakes basin. Each of these agencies should be consulted in the formulation of more specific objectives for sediment forecasting. A variety of local interests (watershed councils, Remedial Action Planning committees, etc) may also have local management responsibilities that would benefit from better forecasting of sediment transport. Each of the management agencies are managing the system to the benefit of a large, diverse, and economically important group of Great Lakes stakeholders which includes: shipping, marina operators and users, boaters, beach goers, and coastal property owners, as well as constituencies which benefit from contaminated sediment cleanup (seafood consumers, wildlife enthusiasts, tourism, and other Great Lakes recreational interests).

- **Coastal Erosion** – Shoreline erosion along the Great Lakes is a matter of increasing concern. In some regions, the shoreline is moving landward at rates in excess of 30 feet per year. Retrospective studies of these erosion rates have been made (and erosion/deposition zones mapped), but little has been done in way of formal forecasting of these rates into the future. Rates of coastal erosion are linked to a variety of coastal processes (water levels, storms); better prediction of these processes are likely to be a necessary precursor to sufficiently accurate predictions of coastal erosion at local scales. Long term prediction of changes in Great Lakes shorelines (even if only under if-then scenarios relating to land use, development and climate change patterns) is needed for the better management of both private and public coastal property and for the long term protection of coastal structures both manmade (docks, harbors, buildings) and natural (beaches, wetlands). Shorter-term local-scale predictions are also needed by individual landowners (including public lands) to make decisions about how to best manage the property that they own (i.e., where/how to build a dock, shed, public shelter, etc).

- **Loading** – Agricultural and suburban runoff carries nutrient and pesticide loads as well as large volumes of sediment into the Great Lakes and its tributaries. High sediment loads choke navigation channels, making it necessary to dredge in order to maintain navigation. High sediment loads can also destroy habitat and impair the littoral and benthic environments. On the upstream end, loss of topsoil contributes to the decline of farm production and increasing reliance on chemical fertilizers. Associated nutrients enter the water column, potentially contributing to eutrophication of the system, to harmful or nuisance algal blooms, and to the development of ‘dead’ zones. Load-associated toxins (including, but not limited to pesticides) complicate efforts to cleanup areas of concern and other restoration efforts. Better prediction sediment loads (where, when, how much) on even an annual scale (5-10 years better for ACE planning horizons) can help to direct management efforts and to target prevention programs. The more refined the spatial scales for such models can become (which segments of stream contribute most to the load) the greater the ability to target innovative management and prevention programs will be. Existing prioritization of tributaries (by sediment loading) done by the Great Lakes Basin Program should be used to drive prioritization of fine-scale forecasting efforts for sediment management. Other tributaries may be more important from the contaminant (e.g., upstream of Areas of Concern) and nutrient management (e.g., upstream of dead zones) perspectives.

- **Transport** – Physical, chemical, and biological processes are all responsible for the movements of both sediments and their associated contaminants around the Great Lakes.

As the Episodic Events Great Lakes Experiment has demonstrated, these movements can at times be quite significant. Better prediction of these sediment transport patterns are needed to support efforts to manage dredging programs (including locating appropriate sites for disposal of dredge spoil), beaches and other coastal lands (erosion/deposition patterns), coastal development (sites for structures, intakes, etc.), habitat restoration (including wetland reconstruction), and cleanup of contaminated sediments. Priority forecasting needs are in the nearshore zone – movement of sediments (and contaminants) within and entering/exiting the littoral zone.

- **Deposition and Fate** – Forecasts of the patterns of deposition and fate of sediments, particularly in nearshore zones, were accorded a high priority by workshop participants for reasons similar to those cited for transport (above). Dredging programs, beach nourishment programs, and contaminated sediment remediation programs will all particularly benefit from forecasts of sediment fate.

- **Resuspension** – Sediments (and associated contaminants) slowly settle out of the water column and are buried by the succeeding sediment load. Unfortunately, sediments are often resuspended by the actions of wind, currents, ships, dredging, and wildlife. Contaminants associated with resuspended sediments re-enter the water column, and frequently re-enter both the food chain and airshed as well. A 1992 study by the EPA found that greater than 90% of the PCB contamination in Green Bay sport fish came from contaminated sediments rather than new sources. Better prediction of resuspension, particularly at local scales for sites of known contaminated sediments, is essential to further progress toward Great Lakes cleanup.

- **Associated Contaminants** – Prediction of sediment associated contaminants – loading, transport, fate, and resuspension, was separately designated as a high priority forecasting category by workshop participants. In addition to the priorities and considerations discussed above in the context of sediment forecasting in general, workshop participants noted the need for better understanding of the direct and indirect influences of zebra mussels and episodic events on the movement of contaminants in the nearshore zone as a necessary precursor to forecasts of contaminant movement in the Great Lakes.

- **Climate and Weather**

  - **Lake Weather** – Accurate short and long-term forecasting of weather patterns in the Great Lakes, particularly over the lakes themselves and in the nearshore coastal zones was designated as a priority by workshop participants. Short term, local predictions – on the scale of hours to days – were considered extremely important for water safety. Long-term predictions at the regional scale (e.g., changes to storm patterns with climate change over a 20-50 year horizon) were considered a priority for planning of coastal construction (development, intakes, etc).

- ∆ **Nearshore Storm Prediction**

    - ◊ **Short-term forecasting** - Sea Grant extension staff living in and working with coastal communities on a daily basis noted a pervasive dissatisfaction with the current (National Weather Service) capability for forecasting nearshore weather – particularly storms. Nearshore weather systems are known to be extremely volatile – current advance warning is considered by many to be insufficient for small boaters who may be unable to reach harbors of refuge within the current warning period, especially for smaller storms (which are still dangerous to these smaller vessels). These forecasts are needed on a scale of hours to days and were considered a high priority for water safety by workshop participants.

    - ◊ **Storm event damage to coastal areas** – Enhanced mid-term forecasting (days to weeks) for storms likely to cause damage (e.g., due to winds, waves, or flooding) to coastal areas is needed for coastal residents and property owners to better prepare their property to withstand such potential damages.

    - ◊ **Frequency and severity of episodic events** (storms, wind) – Long-term forecasts of changes in episodic events such as storms under regional climate change prediction scenarios are need for long-term planning of coastal development and construction as well as for long-term prediction of many other ecosystem features (e.g., sediment transport).

- ∆ **Fog** – One reality of life near the water is the prevalence of fog. Workshop participants living in or working with constituencies living in coastal communities noted the insufficiency of current fog forecasting capability (NSW). Fog was highlighted as an important safety issue for both boaters (particularly small craft) and aircraft. For the many small and large airports surrounding the Great Lakes, better fog prediction can also be an issue for efficiency and economics of operation.

- ∆ **Open Lake** – Though discussions lacked the urgency of those relating to nearshore forecasts, workshop participants also highlighted a need for improvements to open lake weather forecasts as important to the safety of the Great Lakes shipping community.

- ∆ **Waves** – Improved wave forecasts were highlighted as an important facet of the need for improved weather forecasts in both nearshore and open waters of the Great Lakes. Waves are among the most important facets of weather forecasts in determining water safety, particularly for shipping and boating, but also for other recreation and protection of coastal property. More accurate forecasts are needed, as are extensions of forecasts to approach 24 hours.

- ∆ **Snow/Ice Cover Predictions** - Workshop participants noted both short and long (seasonal) term needs for improved predictions of ice cover and lake effect snow. Shipping was the primary constituency noted as needing improved predictions of ice cover. The most important aspect of ice cover forecasting needed by this constituency is an accurate prediction of when the shipping season will close and reopen (with and without icebreaking capacity). Better prediction of ice cover (spatial variations in thickness, seasonal patterns for the coming year, etc) will help the Coast Guard in planning for carrying out its annual icebreaking responsibilities. Ice fishermen (and other folks going out on the ice for winter recreational activities) were noted as a secondary constituency for ice forecasts. Forecasts supporting the needs of this group will be much more concentrated in the nearshore zone, as well as much more local and short-term in scale. Lake effect snow is a significant factor for the safety of residents of, and visitors to, coastal areas of the Great Lakes basin. Local and state funds spent annually on snow removal in the basin are not insignificant. Better short-term (days-to-weeks) prediction of lake effect snow can reduce traffic accidents as well as promote more efficient utilization of snow removal equipment. Improved seasonal forecasts (e.g., will this be a mild winter?) can promote more efficient use of limited funding. Longer-term predictions (e.g., influence of changing climate on snow patterns) can be used in longer term planning for snow removal (e.g., equipment purchases).

o **Climate Change** – Climate change and particularly the influence of global changes in climate on regional climate in weather patterns have been noted as an overarching theme complicating nearly all efforts at long-term ecological forecasting. Workshop participants noted that at the current time there is a real need (at least in terms of outreach) for a simple summary of the regional-scale predictions of each of the various climate change models (agreement/disagreement) – as well as an analysis of the gaps in knowledge which need to be filled in order to resolve these discrepancies.

Chemical Forecasting Issues

- **Water Quality** – The US and Canada have formally cooperated to address water quality problems in the Great Lakes since the signing of the Boundary Waters Treaty in 1909. The Great Lakes Water Quality Agreement (GLWQA 1972, amended 1978, 1987) establishes common water quality objectives for phosphorus, oil, solid waste, and persistent toxic chemicals and sets forth a process for establishing Lakewide Management Plans (LaMPs) for critical pollutants. The GLWQA also designates 43 binational Areas of Concern (AOCs) and the framework for Remedial Action Planning Committees (RAPs) responsible for developing the cleanup strategies for each. Ecological forecasting priorities for water quality should be based on these critical designations and meet the needs of these binationally recognized groups. While much progress towards cleanup has been made in the past 3 decades, diligent attention to water quality and a need for innovative solutions to cleanup remain an important regional priority. Dealing with the legacy of toxic contamination in the Great Lakes, particularly the remediation of contaminated sediments, is the focus of recent political movements to 'restore the greatness'. While the region has made great strides in controlling point sources of new pollutants, nonpoint source pollution has grown in its relative contribution to the region's toxic pollution problem. Nonpoint sources of priority concern include agriculture runoff, urban and suburban runoff, combined sewer overflows (CSOs), and atmospheric deposition as well as the impact of land use planning and other management decisions on these sources. Great Lakes water quality directly or indirectly impacts nearly every resident of the Great Lakes basin – starting with the 40 million U.S. and Canadian citizens who rely on the Great Lakes for drinking water. Workshop participants discussed a variety of specific ecological forecasting needs relating to water quality. These are presented below in rough order of decreasing priority.

- **Bio-Assessment Use Classifications** (Beneficial Use Designations) – The GLWQA defines 14 impairments of beneficial uses which are used in determining priority for cleanup of contaminants as follows: *(i) restrictions on fish and wildlife consumption; (ii) tainting of fish and wildlife flavour; (iii) degradation of fish wildlife populations; (iv) fish tumors or other deformities; (v) bird or animal deformities or reproduction problems; (vi) degradation of benthos; (vii) restrictions on dredging activities; (viii) eutrophication or undesirable algae; (ix) restrictions on drinking water consumption, or taste and odour problems (x) beach closings; (xi) degradation of aesthetics; (xii) added costs to agriculture or industry; (xiii) degradation of phytoplankton and zooplankton populations; and (xiv) loss of fish and wildlife habitat.* Forecasting the impacts of management strategy options on the pace and degree of restoration of these beneficial uses, particularly for the designated Areas of Concern (AOCs) as well as in the context of the Lakewide Management Plans (LaMPs), should be considered the highest priority ecological forecasting need relating to Great Lakes water quality. A variety of intermediate steps (other forecasts) may be needed to reach this long-term goal. Assigning relative priorities to these intermediate forecasts should take into consideration both the degree to which they move toward this long-term forecasting goal as well as the more direct benefits of the particular forecast.

- **Trophic Status under Varying Loading Conditions** – Eutrophication was considered by many to be the most important problem driving the signing of the GLWQA. In the 1960's, eutrophication caused by nutrient pollution (primarily phosphorus) led to severe degradation of the lower Great Lakes and embayments of the upper lakes. Decomposition of algae resulted in anoxia, bad odors, and taste problems in drinking water. Forage fish died in large numbers, and many areas were nearly devoid of higher forms of aquatic life. Reductions of annual phosphorus loadings set in the GLWQA have been met for all five lakes, and phosphorus controls have been largely successful in controlling nuisance algal blooms and anoxia. However, the central basin of Lake Erie continues to have seasonal problems with anoxia, as do some of the bays. Exotic species (zebra mussels) may be altering the trophic structure of the system. Regional changes in climate may be altering the physical capacity of the system to absorb nutrient inputs. Changes in land use patterns, especially those affecting runoff and nonpoint sources of nutrient pollution may also be impacting the capacity of the system to resist eutrophication. Thus the science on which the original targets were based may be becoming dated. Ecological forecasts of trophic status under varying loading conditions in light of the factors will likely be necessary to maintain and continue the progress that has been made towards this important water quality goal.

- **Predict when Fish Consumption Advisories will be Lifted –** Five of the fourteen priority beneficial use impairments are related directly to the fisheries of the Great Lakes. Perhaps the most important of these to those people within and outside of the Great Lakes basin are the fish consumption advisories. The ability to predict when fish consumption advisories will be lifted is a complex and overarching goal involving prediction of social factors (management strategies and their impacts), biological factors (such as invasive species alterations to food web and bioaccumulation pathways/cycling), medical considerations (what levels are acceptable), chemical factors (such as partitioning of various toxics within the system and breakdown models), and physical factors (such as transport and fate). Individually, these intermediary forecasts can be quite valuable in influencing management decisions relating to cleanup of the Great. Most of the intermediary forecasts useful to this overarching goal will also serve as endpoint or intermediaries for other water quality related forecasting goals.

- **Predict Runoff** (including precipitation and evaporation) quality under different land use and climate change scenarios – Runoff is currently the primary vector for nonpoint source pollutants entering the Great Lakes. Patterns of runoff are believed to be rapidly changing in the Great Lakes basin with changes in land use, and this pace is likely to accelerate in the immediate future due to the interaction of both accelerating development and climate change. The impact these changes will have on water quality is not currently well understood. Prediction of such changes in runoff quality can be directly used by local land use planners (in making development permitting decisions) as well as influencing a variety of other water quality related forecasts. Other forecasts relating to prediction of water quality of runoff entering the Great Lakes and its tributaries may also be important to development of other priority forecasts.

- **Watershed-to-Stream-to-Lake Linkages** – Governments and citizens in the Great Lakes basin are increasingly aware that upstream water quality (and the decisions which influence it) are often magnified downstream. Capability for ecological predictions of stream and lake water quality based on watershed factors can play an important role in helping local planners grasp the big picture – the totality of the impact of local decisions (as opposed to merely local consequences). If-then model predictions of the consequences of local watershed water quality changes on downstream quality (e.g., if water quality along tributary x decreases 10%, the result for downstream water y will be some quantifiable decrease in water quality) may also aid in political apportionment of responsibility for water quality decisions.

- **Hypoxia/Anoxia** – Predictions of hypoxia and anoxia, particularly for the central basin of Lake Erie, was separately considered to be a priority ecological forecasting need by workshop participants. Discussion of this priority is in part included above with the discussion of changes in trophic status with nutrient loading. Specific predictions of hypoxia/anoxia (particularly research into the non-nutrient loading factors which influence this phenomenon) will be critical in evaluating management capacity to maintain/achieve target reductions in anoxia through current phosphorus management strategies.

- **Air Deposition** - From a basin-wide perspective, atmospheric deposition remains the single most important pathway by which certain critical contaminants enter the Great Lakes. While the significance of air pollution sources within the Great Lakes should not be underestimated, contaminants reaching the Great Lakes may also originate from outside the basin and even outside North America. More accurate prediction of the influence of these global influence on Great Lakes contaminants levels will help to drive political processes moving toward reductions and in setting realistic management goals for the region.

- **Beach Contamination** – Beach closures are currently a high profile issue in the Great Lakes region, and water quality is the primary factor influencing beach closures. While workshop participants placed higher priority on the geographic international priorities established by the GLWQA (AOCs) over beach locations in discussion of water quality issues, beaches should clearly be given due consideration as an important geographic area for local-scale water quality forecasting.

- **Water Quality at Water Intakes** – The Great Lakes provide about 56 billion gallons of water daily for municipal, agricultural, and industrial use including drinking water for over 40 million U.S. and Canadian citizens. Water quality at the intakes for these users is of particular concern that should be given consideration as a geographic priority for ecological forecasting.

- **Watershed use Reclassification and TMDLs** – Under the Clean Water Act, water quality standards are set by States, Territories, and Tribes. They identify the uses for each water body, for example, drinking water supply, contact recreation (swimming), and aquatic life support (fishing), and the scientific criteria to support that use. A TMDL or Total Maximum Daily Load is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. The calculation must include a margin of safety to ensure that the water body can be used for the purposes the State has designated. The calculation must also account for seasonal variation in water quality. TMDLs are used to allocate allowable pollutant sources (permits). Ecological forecasts supporting decisions relating to the water quality standards, use classifications, and TMDL classifications were considered a priority by a number of workshop participants who work closely with these decision-making groups.

- **Estrogenic Compounds and Wetting Agents** – Recent research shows several new classes of compounds to be an increasing threat to fish, wildlife, human health, and water quality in general. While some of these compounds fall under existing priorities (e.g., GLWQA critical contaminants), others, such as pharmaceuticals (which generally enter the lakes with treated sewage waters), may not be covered yet. Ecological forecasts in line with the above priorities (but related to these contaminants in particular) have the potential to help determine what priority should be placed on regulation of these compounds as well as helping to get ahead of the curve in advising management strategies which may be most effective.

Biological Forecasting Issues

- **Fisheries** – Across the Great Lakes over 1.8 million anglers spend over 23 million days each year angling in U.S. waters of the Great Lakes (USFWS 2001). In U.S. waters, the Great Lakes produce over 18.7 million pounds of fish (USGS 2002). According to a report by the American Sportfishing Association, U.S. Anglers that went fishing in just Michigan during 1996 spent over $1.5 billion for goods and services in many businesses throughout the state. The economic impact of these expenditures – for just one state - totaled nearly $2.9 billion (MDNR 2003). Commercial fishing is also an important industry to the region. The top eight commercial fish species have a combined dockside value (Canadian + US) of over $43 million. Commercial and recreation fisheries are the mainstay of local economies for many smaller communities along the shores of the Great Lakes. On the basis of economic value, workshop participants ranked fisheries-related ecological forecasting among the highest priority forecasting needs and noted that economically important (commercial and recreational) species should be the priority within any of the following subcategories – followed by the forage fish bases that support these species. Each of these economically important Great Lakes species is actively managed in a cooperative fashion (as are a variety of prey fishes, nuisance species, endangered species, and threatened natives). Consensus Great Lakes fisheries management priorities as determined through the Great Lakes Fishery Commission (GLFC) processes (Lake Committees, Fish Community Objectives, etc) should be used as a guideline in determining which species (or assemblages) should be the priority focus for ecological forecasting efforts on each lake. The management infrastructure (GLFC Technical Committees) needed to rapidly make use of appropriate Great Lakes fisheries related forecasts is in place. The following sub-categories were suggested by workshop participants immersed in Great Lakes fisheries management issues as among the highest priorities for ecological forecasting based on a combination of the availability of current science needed as a basis to develop forecasts and the ability of fisheries managers to take immediate advantage of such.

    - **Fish Stock Assessment** – A fish stock is the unit of management for fisheries, a group of genetically similar fish found together in a geographic region. Fish stock assessments have two distinct components – assessment of the biology of the fish and assessment of the human fishing activities for the stock. Both biological and social predictions, therefore, may be important to accurate prediction of fish stocks. Biological predictions are given further consideration here and social factors in the segment on ‘Social Forecasting Issues’ (below). Accurate information about and predictions of fish stocks are critical to development of successful management strategies.

        - **Sustainable Harvest** (Harvestable Surplus) – Unfished stocks are relatively stable at or near the carrying capacity of the system with moderate rates of fish production. Fished stocks, on the other hand, are dynamic populations of somewhat younger fish (on average) held somewhat below carrying capacity of the system with significantly higher rates of fish production. Some of the new production of fish in any given year must be allowed to grow and reproduce to maintain the population. Reproduction of additional fish results only in increased competition and slower growth. Harvest of these ‘excess’ fish is the basis of the concept of a harvestable surplus or sustainable harvest. The amount of harvestable surplus may vary year-to-year – some years, conditions may be such that only a few spawning fish would be capable of maintaining the population while in poorer years, more spawners might be needed. Estimates of harvestable surplus are the critical management control point for all fish stocks – predictions of sustainable harvest a year in advance or even accurate nowcasts would greatly improve management capacity.

- Δ **Recruitment** - Recruitment is a measure of the number of fish entering a certain class during a period of time. Critical recruitment measures include (1) recruitment of larval and young of year fishes to the age-1 size class (with significantly less natural mortality), (2) recruitment of fish to a ‘fishable’ size class, and (3) recruitment of fish to the spawning population. Recruitment estimates are used in making management decisions for all managed fish stocks. Better prediction of year class strength (for each year class, but particularly for recruitment at the above 3 life stages) will greatly aid in management decisions. Current estimates are largely based on labor-intensive sampling. Prediction of year class strengths based on climate or other physical variables would reduce the need for sampling thus reducing strain on assessment budgets as well as supporting critical management needs.

- Δ **Prey Base (Food Web) –** Assessment of the prey base – including forage fishes, zooplankton, benthic invertebrates, and phytoplankton – currently drive predictions of fish growth and recruitment. Enhanced capability to predict the prey base (in total and/or for specific components) will support these management needs and reduce reliance on labor-intensive (expensive) sampling. Assessment of the prey base is particularly critical in making management decisions relating to fish stocking – one of the major management tools used on the Great Lakes. Stocking is a waste of limited management if the prey base will not be there to support the stocked fish. Thus predictions of the prey base most closely allied with this management need (for items in the diets of stocked species, at geographic locations where fish are stocked) should be considered priorities for prey base forecasting. Fingerlings are typically stocked after a year or more of growth in fish hatcheries. Thus stocking decisions must be made at least 2 years in advance of the actual stocking. Prediction of prey base should therefore provide at least a 2-year advance prediction if they are to be useful in supporting these critical management decisions.

- Δ **Fish Location –** Prediction of fish locations (habitat, movement, migration) can help to determine complex management strategies (where to stock, where habitat restoration is needed, etc). To meet management objectives, ecological forecasts of fish locations are needed on a seasonal scale (migration patterns) for each managed stock. Prediction of fish locations also reduces cost of doing business for commercial and charter fishing industries – maximizing economic value of the fishery. The forecasting needs of these groups are much finer in spatial and temporal scale (nowcasts to week forecasts, sub-basin geographic scale). Both management and user groups have shown an aptitude for making use of available nowcast/forecast information as indices for prediction of fish location. Most commercial and charter fishers on the Great Lakes access CoastWatch satellite imagery and/or Great Lakes Forecasting System models routinely before going out as a piece of information in determining where they believe fish are likely to be.

- ∆ **Remotely Detect Tagged Fish** – Tagging studies are a mainstay of fisheries stock assessment. If satellite or other remote sensing technologies could be developed to detect tags at a distance, that could greatly enhance the state of fisheries stock assessments providing valuable additions to the management capability. While not ecological forecasting in and of itself, technology development along these lines would support broader fisheries management objectives and support development of several of the forecasting priorities above.

- o **Consumption Advisories –** Fish consumption advisories are a priority Great Lakes public health issue for Great Lakes seafood consumers including consumers of commercial, recreational, subsistence catches. Significant adverse health effects have been documented for at risk groups (women of childbearing age, children, subsistence fishers). Fish consumption advisories are also a public perception issue. While fish consumption by most consumers is well within the acceptable risk for most Great Lakes species (less than one meal per week) consumption advisories have the effect of driving consumers away from Great Lakes fish towards other seafood or non-seafood options. Better prediction of the risks associated with particular contaminant levels as well as the local patterns of contamination (tied to fish movements) could lead to enhanced utilization of the resource. This issue and the associated ecological forecasting needs are discussed more fully within the segment on Water Quality located under 'Chemical Forecasting Issues' (above).

- **Aquatic Invasive Species (AIS)** – More than 130 non-indigenous species have become established in the Great Lakes since the 1800's, while the introduction rate increased dramatically with time. Invasive species are considered a major threat to the region's rate and endangered species and pose a significant threat to the regional economy. Efforts to prevent the introduction and spread of invasive species as well as to manage such species and the invaded system when control is no longer feasible, require a great deal of scientific research and forecasting support.

- o **AIS Prevention and Control** – Capacity to predict new invasions is the lynchpin of AIS prevention. Effective AIS prevention strategies are predicated on the capability to predict (a) what invasive species are likely to be coming, (b) the likely sources of the species, (c) the vector(s) by which species will arrive, (d) characteristics of the species, and (e) window of opportunity for the invasion (seasonality, associated with certain shipping patterns, invasion pressure, etc). Better prediction of any of these factors can help to assess what management strategies will and will not be effective in preventing an invasion. The single most important factor in determining the effectiveness of a control strategy (preventing spread as opposed to preventing introduction) is early intervention – which relies on our ability to detect the invasion before it is beyond control. Effective early intervention relies on early detection – monitoring targeted based on better prediction of the location of an invasion (e.g., which harbors are most likely to be invaded first by species x) greatly increases the probability that an invasion will be caught early enough for effective control.

- **AIS Impacts on Food Webs** (broader ecosystem) – While many of the species that have invaded the Great Lakes over the last century have had no serious ecological impact, the introduction of a single species is capable of bringing about a sudden and dramatic shift in the entire ecosystem structure. New species can dramatically change the interactions between existing species (and between those species and their non-living environment) creating ecosystems that are unstable and unpredictable. Thus the success of all long-term ecological prediction is predicated on an accurate forecast of the influence of non-native species that may enter the system and become established during the forecast period. Predicting the longer-term ecological consequences of species that have recently become established in the Great Lakes (e.g., zebra mussels, round goby) is a high priority ecological forecasting need. Prediction of the likely consequences of invasions which have not yet occurred (but are considered likely within the next decade – e.g., *Caspian kilka*) are much more difficult but are also essential if ecological forecasts approaching the decadal scale (or longer) are to have any practical meaning. Prediction of changes in species composition and interactions among species (trophic change) with invasions is clearly difficult but an important facet of AIS prediction.

- **Prediction of Abundances** – Prediction of AIS abundances at fine temporal and geographic scales is an important factor in learning to live with species that have become established in the Great Lakes. Prediction of changes in abundances of native species that may be altered by the presence of invasives (e.g., nuisance/harmful algal blooms, botulism, and other outbreaks, fouling, etc) is also an important facet of meeting this need. Forecasts of this type are generally needed at seasonal to annual time-scales. One example (cited by workshop participants as particularly high priority) is a seasonal forecast of veliger abundance and timing of their settling. Water intake managers could use this information in timing control programs to maximize efficiency and reduce the cost of control strategies.

- **Food Webs**

  - **Predict Food Web Structure and Dynamics with Ecosystem Changes** – Changes in the food web structure of the Great Lakes ecosystem has the potential to affect many other ecological (particularly biological) forecasts. This topic was considered by workshop participants to be a priority for ecological forecasting work because of the far-reaching implications of such changes and because of the great impact that such changes potentially have on most other ecological forecasts. This issue area is related to the areas of fisheries, AIS control, and water quality (eutrophication/anoxia) and may impact sediment transport and other water quality parameters. Climate, AIS, and contaminant impacts are particularly priorities as a basis for other long-term ecological forecasts.

- **Species Composition** – Workshop participants, noted prediction of species composition, in general, as a potential area for ecological forecasting. Value of species composition predictions can be expected to correlate with the positive or negative economic or societal value placed on the assemblage (e.g., prediction of sport fish species composition would be high, species composition of a rare benthic assemblage lower).

    - **Zooplankton** – Workshop participants noted zooplankton population dynamics as a potential area for ecological forecasting. The most important ecological forecasts relating to zooplankton dynamics are in the context of their role as a prey base supporting fish production (particularly for forage fishes and juvenile fish) and are discussed in that context in the segment on "fish stock assessments – prey base" above.

    - **Waterfowl** - The Great Lakes region is a major stopover for migratory waterfowl. Migratory waterfowl are also an important natural resource to the region (hunting) in cultural terms. Better prediction of migratory patterns and population fluctuations could aid in the management of these species.

    - **Benthic Macroinvertebrate** – Recent catastrophic declines in the *Diporeia* populations of the Great Lakes has raised awareness of the importance of these benthic organisms in supporting fish populations. Prediction of changes in *Diporeia* abundances and the abundances of other benthic macroinvertebrates (which may play a role in their decline, provide alternative food sources to fish, or other important ecological roles) is a potentially important area for ecological forecasting.

- **Habitat** – Habitat loss is one of the two major factors contributing to the decline of threatened and endangered species in the Great Lakes region today (the other is AIS). Habitat restoration is increasingly a component of the management toolbox in the Great Lakes region. Recent legislative and political movements in the region have also included habitat restoration as a central goal. Thus ecological predictions relating to changes in habitat are likely to become an increasingly important issue for Great Lakes ecological forecasting in the near future.

    - **Wetland Extent** –Over two-thirds of the Great Lakes wetlands have already been lost and many of those remaining are threatened. These wetlands serve important ecological roles – habitat for birds, wildlife, and fishes; stabilization of the shoreline; and filtering nonpoint source pollution. Monitoring and prediction of continuing changes in the extent of Great Lakes wetlands are both needed to assess progress towards restoration goals. Predicting the impact of water level fluctuation on wetland extent and species is an important component of this type of forecast.

    - **Sensitive Habitats** (Preservation) – A variety of unique Great Lakes habitat types are sensitive to human disruption and should be made priorities for preservation. Ecological predictions helping to identify these sensitive habitats, to predict the changes that their loss would mean to the system as a whole, and to predict the impacts of specific management strategies are needed to further efforts to preserve these important resources.

- **Rehabilitation/Restoration** – On scales both small and large, groups throughout the Great Lakes region ranging from state and federal agencies to local non-profits and individual landowners are increasingly engaged in the process of restoring habitat. Predictive models constructed on a project-specific scale will be extremely useful in selecting effective restoration strategies and in directing efforts to monitor the pace of restoration.

- **Benthic Habitat Mapping** – Great Lakes benthic habitats are probably among the most unexplored on the face of the planet. Mapping these habitats (including the modifications being made to them by zebra mussels) is an important first step in our ability to predict changes to the system likely to occur as a result of the 'benthification' of the Great Lakes system hypothesized to be occurring due to recent invasions (Dreissenids, gobies, etc).

- **Genetics** – In the last decade, genetic analysis has come into its own as a discipline useful to environmental science. Predictive models that take advantage of the strides made in this arena – from examination of fish stocks from a genetic perspective to examination of the genetic diversity of endangered (or invasive!) species – hold great potential for use in addressing a variety of issues.

Social Forecasting Issues

- **Resource Socioeconomics** - The failure to address social and economic issues in the management of environmental resources is widely considered to be one of the key reasons for the ineffectiveness of many natural resource management initiatives. Prediction of the social and economic implications of ecological changes and management initiatives should therefore be considered a key facet of the development of useful ecological forecasts. Socio-economic aspects of ecological forecasting are especially important to decision-makers – especially those operating in a political context.

  - **Predict Human and Economic Responses to Changing Ecosystem Attributes** – Workshop participants rated prediction of human and economic responses to changing ecosystem attributes as the highest priority socio-economic issue area for forecasting. Human uses of the Great Lakes can reasonably be expected to change in response to any change in the ecosystem. In the realm of fisheries, for example, this might include changes in angler perception of the value of particular fish species. As a species declines it might be considered more valuable or anglers could switch to another species. Prediction of human responses has an important role to play in determining long-term management goals. Continuing with the above example, if the anglers switch to another species, management goals will need to be expanded to include the alternative species. Because the Great Lakes are an important natural resource from an economic perspective, the economy also responds to changes in the ecosystem. One example of an economic response would be the price of commercially harvested fish. Another example of an economic impact would be the additional costs incurred for keeping water intakes free of zebra mussels. Prediction of the economic impact of ecosystem change is valuable both to the affected industries and to decision-makers (especially in the political arena) who support them. Prediction of economic impacts is especially useful in making decisions as to actions that should be taken to prevent or mitigate environmental changes.

  - o **Valuation of Ecological Services** – Valuation of ecological services is closely related to the prediction of economic impacts of ecosystem change and in many cases will be a necessary precursor to development of such economic forecasts. In effect, it is a forecast of the economic value of the resource in the absence of ecosystem change.

  - o **Anthropogenic Impacts** – Human impacts on ecological systems have been profound. For the Great Lakes system in particular, anthropogenic impacts have far outweighed natural shifts in the system (with the possible exception of water level fluctuations). Prediction of future anthropogenic impacts – both the trends for impacts already being felt and those only just beginning – is thus an important component of nearly any long-term forecast. Important changes to the human dimension likely to impact the ecosystem include changes in human population of the basin and changes in land use patterns. Predicting secondary and cumulative impacts of land use changes will be particularly important for land use management.

- **Naval Architecture** – Naval architecture is an interesting field in which ecological forecasting could play an important role. Predicting the impact of waves on ship designs (different sizes and types of boats) is very important for water safety. This type of prediction is important both for new ship designs and for changes in wave regimes (e.g., with climate change).

Priority Ecological Forecasts

Participants in the Great Lakes Ecological Forecasting Workshop were divided into two groups. One group was asked to determine the highest priority ecological forecasts (up to 10) based on prioritization of user groups. The second group was asked to determine the highest priority ecological forecasts (up to 10) based on prioritization of issues. This represents a significant cut to the broader prioritizations generated in discussion of potential user groups and potential issues. It was anticipated that there would be a significant overlap in the two priority lists, as in fact proved the case. The following matrix (see Matrix.xls) represents graphically the two priority lists and their overlap.

Significant clusters of overlapping constituent/issue combinations are readily apparent from the matrix. These included:

- o Fisheries constituents need for ecological forecasts relating to fish stock assessments,
- o Water quality regulators, water dependent industry and utility, recreational users, coastal property owners, and land use planners need for ecological forecasts relating to water quantity and quality (including sediments),
- o A targeted need among transportation sectors (shipping, boating and marinas) for forecasts relating to sediment management,

	Fish Stock Assessment					Water Quantity				Water Quality			Sediments						ANS				Lake Weather					Socio-Economic				Habitat
	Recruitment	Prey Base (Food Web)	Sustainable Harvest	Fish Location	Consumption Advisories	Water Levels	Runoff	Precipitation	Transport	BioAssessment Use Classifications	Watershed-to-stream-to-Lake	Trophic Status with loading	Transport	Deposition and Fate	Resuspension	Loading	Erosion	Associated Contaminants	Prevention and Control	Prediction of New Invasions	Prediction of Food Web Impacts	Prediction of Abundances	Nearshore Storms	Fog	Open Lake	Waves	Ice	Human Response to ES Change	Economic Response to ES Change	Economic Impact of ES Change	Value of Ecological Service	...
Fisheries Managers	x	x	x	x	x	x				x	x	x			x			x	x			x	x				x	x	x	x	x	x
Sport Anglers	x	x	x	x	x	x												x			x	x	x	x	x	x	x				x	x
Commercial and Charter Fishers	x	x	x	x	x	x												x			x	x	x	x	x	x	x	x	x	x	x	x
Recreational Boating						x																	x	x	x	x	x					
Marinas						x							x	x			x													x		
Transportation						x								x	x	x			x				x	x	x	x	x		x	x	x	
Water Safety						x				x													x	x	x	x	x					
Water and Sewer Utilities							x	x	x	x		x	x	x	x	x	x	x			x	x								x	x	
Water Dependent Industries						x	x	x	x	x	x	x	x		x			x				x					x	x		x	x	
State Water Quality Regulators							x	x	x	x	x	x	x		x	x	x	x			x	x						x	x	x	x	
Land Use Planners						x	x	x	x	x				x			x						x				x	x	x	x	x	x
Recreational Users						x		x		x		x			x		x	x		x		x	x	x	x	x	x				x	
Coastal Property Owners						x				x		x		x			x	x				x	x	x	x	x	x			x	x	

*Policy-makers are a cross-cutting user group. Defined broadly, policy-makers are interested in all topic areas and make policies that affect all user groups. Policy-makers tend to be most directly interested in socio-economic forecasts.

**Order within the matrix does not indicate a prioritization.

- A broad need by most user groups for ecological forecasts relating to weather (offshore and nearshore),
- A broadly scattered need among a variety of user groups for forecasts relating to aquatic nuisance species, particularly for forecasts of abundances,
- A broadly scattered need among a variety of user groups for forecasts relating to socio-economic factors.

Within each cluster, it is anticipated that the specific forecasting needs of users might vary significantly in terms of spatio-temporal scales or other particulars. Additionally, specific forecasts developed to meet needs identified within a priority cluster might serve additional needs of non-priority (or lower priority) groups. It is recommended that in developing ecological forecasts, researchers first look carefully at the needs of the core priority groups, and then consider these broader interests.

Within some of the clusters, discussion among workshop participants indicated that meeting the needs of management level users and decision makers should be given priority consideration in developing forecasts. Thus, for example, designing specific ecological forecasts to meet the stock assessment needs of fisheries managers should be given higher priority than meeting forecasting needs of other fisheries constituencies (recreational, commercial and charter interests).

Detailed ecological forecasting needs could not be determined for every coastal constituency and every issue area in the context of this paper. Detailed ecological forecasting needs for a small set of priority constituencies were determined for particular issue areas. These were determined by the workshop participants based on the matrix clusters and previous discussion in the broader context of rationale for prioritization (magnitude of the constituency, economics, political will for action, potential use of the forecasts, state of the science/data to support forecasting, and readiness of users/managers to make use of forecasts). In selecting this small set for detailed consideration, some consideration was also given to including a diversity of issues and users as well as encompassing a variety of likely spatio-temporal forecasting scales. These should serve both as examples of the real and diverse ecological forecasting needs of the Great Lakes region and as a starting point for research priorities to meet ecological forecasting needs.

Audience: Fisheries Managers
Issue: Fish Stock Assessment

In the broadest sense, ecological forecasting needs of fisheries managers would ultimately be met by a model that predicts which management actions will result in meeting the Fish Community Objectives set forth in the Strategic Plan for Great Lakes Fisheries Management (SGLFMP) and the individual Lake Management Plans of the Great Lakes Fishery Commission's Lake Committees. These Objectives are complex, simultaneously involving the stocks of many species.

In the nearer term, ecological forecasts relating to a variety of fish stock assessments for any of the managed species (and/or their forage base) would be useful to fisheries managers. Such ‘intermediary’ forecasts will be useful in their own right as well as feeding into development of models for the higher forecasting goal. Examination of the goals and critical management points for fisheries helps to shed light on what some of these intermediary forecasting needs are.

Management Goal: Sustainable Harvest

Critical Control Points for Management:

1. How many fish should we put in? When? - Stocking
2. How many fish can we take out? When? – Regulation
3. How can we modify the environment to support more/different fishes - Habitat

Habitat management for fisheries was noted to be an emerging control point; most management strategies in the Great Lakes region focus on Stocking and Regulation.

Current management decisions relating to stocking and regulation are based on assessment of the fish stock. Fish stock assessment consists of several parts – assessment of the fish populations (number of fish and size/year classes for each species), assessment of the prey base (amount of food available for fish growth), and fishing pressure (fish mortality). Questions relating to fish stock assessment include:

- What is the annual sustainable harvest by species?
- What will the forecasted prey base (and abiotic factors) support?
- What is the natural reproductive rate?
- What is the recruitment rate?

Each of these questions translates directly to an ecological forecasting objective.

Fish managers need information at various time scales, reflecting the time frames at which decisions are made. It is expected that in the near future, the Great Lakes region will take a serious look at the precautionary strategies going in place for the marine systems. These management strategies go two directions - adaptive to take advantage of real-time information (i.e., if real-time data shows stocks higher than anticipated, seasons could be liberalized), as well as longer-term looking at a generation of fish rather than a year-class. Ideally, long-term predictions would cover the lifespan of a fish (a generation) for each species. This could range from two years (for many of the smaller species) to as many as 50 years (for lake sturgeon). Angling regulations currently alter annually (or 2-3 years in some states). Thus a predictive scale of 2 years would be appropriate for most ecological forecasts designed to meet the needs of Great Lakes fisheries managers. Specific ecological forecasts needed take the following form, for fish stock x:

- What will the sustainable harvest (# fish per geographic management unit) be 2 years from now?
- How many young of the year fish will the prey base support two years from now?

Priority U.S. Commercial Fish Species (2000 Dockside Value $)

Species	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario	Total
Lake Whitefish	$1,365,776	$5,152,409	$3,706,606	$31,331	NR	$10,256,122
Yellow Perch	NR	$153,113	$246,309	$2,530,721	$104,275	$3,034,896
Chubs	$55,476	$1,532,739	$691	NR	NR	$1,588,906
Smelt	$28,495	$721,539	NR	$0	NR	$751,793
Lake Trout - lean	$98,127	$336,212	$75,424	NR	NR	$531,462
Lake Trout - siscowet	$21,699	NR	NR	NR	NR	
Channel Catfish	NR	NR	$133,825	$165,425	NR	$299,270
Carp	NR	NR	$19,825	$120,990	NR	$140,837
Walleye	NR	NR	$12,636	$479	NR	$38,851
Lake Herring	$247,900	NR	NR	NR	NR	NR
Round Whitefish	NR	$11,102	NR	NR	NR	NR
Pacific salmon	NR	NR	$240,107	NR	NR	NR
White Bass	NR	NR	NR	$257,335	NR	NR
White Perch	NR	NR	NR	$103,496	NR	NR
Sheepshead	NR	NR	NR	$51,605	NR	NR
Bullhead	NR	NR	NR	NR	$4343	NR

Priority U.S. Recreational Species (2001)

Species	Angler-Days
Yellow Perch	6,597,000
Bass	6,355,000
Walleye	5,521,000
Salmon	3,985,000
Lake Trout	3,605,000
Steelhead	3,698,000

- How many larval fish will hatch 2 years from now? (stocking should not exceed the difference between what the base will support and natural reproduction)
- How many fish (# per geographic management unit) will be recruited (enter the 'fishable' size class) two years from now?

The question of recruitment, especially recruitment of young of the year fishes (but also recruitment of adults), was considered by workshop participants to be among the highest priority areas for ecological forecasting in support of fisheries management. In general, strong hatches survive to produce strong 'fishable' year classes – but most Great Lakes fish exhibit significant variability in year class strength, with the result that a given population is often made of primarily of fish of only a few year classes separated by irregular gaps. Abiotic factors are believed (on limited evidence) to be a primary driver determining the success of a hatch and recruitment of a particular year class. Even a simple index (+/-) predicting the influence of particular aboitic factors on year class strength would be useful in taking predictive capacity beyond the 'real-time' assessment (hindcasting rather than forecasting) toward the 2-year management framework and in targeting current real-time larval population assessments.

These predictions need to be made for each major fish stock beginning with the economically valuable (commercial and/or recreational) fish species first followed by the fish that support them (major forage species). Consideration should also be given to management needs relating to endangered, threatened, or invasive species as well as these economic-based priority species. Interactions among the fish species should not be neglected, but considering factors for the species independently can teach much of value.

Aquatic invasive species (AIS) need to be given special consideration in developing long-term fisheries forecasts (i.e., those approaching the life-spans of longer-lived fishes). AIS have a tremendous potential to significantly alter food webs in the Great Lakes. Climate change also has an unrealized potential to significantly alter the results of long-term fisheries forecasts. In light of changing ecosystem structure (due to climate change, AIS) it may not be possible to predict what the ecosystem will look like in 10 years.

Audience/Issue: Water Safety

Individuals with a vested interest in water safety form one of the largest constituencies on the Great Lakes. Virtually anyone who spends time in, on, under, or near the Great Lakes has some safety concerns. Water safety end users include recreational (e.g., boaters, swimmers, divers, shoreline anglers), commercial (shipping, commercial fishermen), and military (Coast Guard) interests. Decision-makers managing the system on behalf of these end user groups would include public land managers such as beach managers and state park managers, but this is an issue area in which end users can be expected to want direct (or via traditional media) access to the forecasts. All water safety issues have a significant extension component need to develop methods of outreach as well as the forecasts. Water safety was broadly defined to include a variety of human health issues (e.g., pollution-related) as well as more obvious physical factors (e.g., waves) that affect safety. Each group is interested in forecasts that could improve their personal safety – storm and weather, water temperatures, currents, ice, and pollution – though particular needs may vary considerably among subgroups. Specific examples of water safety related forecasting needs include:

- **Lakes Level Forecasts** (particularly seiches) – One important aspect of boater safety is getting warnings of storms sufficiently in advance that the boat can reach a harbor of refuge or other location at which the storm can be rode out in relative safety. Storm surges and seiches are a little recognized but crucial facet of such prediction as a sudden drop in water level of even a few inches can effectively close harbors and smaller marinas. More accurate advance prediction of such short-term water level fluctuations can also be critical to Great

Lakes shipping (particularly in transit through shallower channels and ports) as well as to others living, working, or recreating along the Great Lakes shorelines. These forecasts are needed on a scale of hours to days.

- **Weather Forecasts** (particularly storms, lake effect snow, fog, and volatile shoreline conditions) - Nearshore weather systems are known to be extremely volatile – current advance warning is considered by many to be insufficient for small boaters who may be unable to reach harbors of refuge within the current warning period, especially for smaller storms (which are still dangerous to these smaller vessels). These forecasts are needed farther in advance than currently provided and need better accuracy, perhaps indicative of a need for more nearshore observations and nearshore groundtruthing of model-derived forecasts. Farther advance warning (weeks) of larger storms may allow coastal residents (and non-resident property owners) take appropriate precautions to minimize property damage. Another reality of life near the water is the prevalence of fog. Fog was highlighted as an important safety issue for both boaters (particularly small craft) and aircraft. For the many small and large airports surrounding the Great Lakes, better fog prediction can also be an issue for efficiency and economics of operation. Fog forecasts should operate on temporal scales similar to current weather forecasts (days). Lake effect snow is a significant factor for the safety of residents of and visitors to coastal areas of the Great Lakes basin. Local and state funds spent annually on snow removal in the basin are not insignificant. Better short-term (days-to-weeks) prediction of lake effect snow can reduce traffic accidents as well as promote more efficient utilization of snow removal equipment. Improved seasonal forecasts can promote more efficient use of limited funding and longer-term predictions can be used in longer term planning for snow removal.

- **Water Temperature Forecasts** (particularly hypothermia risk and upwelling) – Insofar as water temperature effects numerous other coastal ecosystem processes (e.g., fish locations) for which there are also defined ecological forecasting needs, enhanced resolution of water temperature forecasts is an important first step in building Great Lakes ecological forecasting capacity. Water temperature forecasts are directly useful to a variety of coastal constituencies ranging from the occasional beachgoer to power plant operators using Great Lakes water or cooling. Each of these user groups has differing uses for the forecasts and so differ in the priorities placed on particular locations and temporal scales needed in a forecast. The majority of need appears to be in the nearshore zone (swimmers, surfers, small craft, most search-and rescue, water intakes, etc.) and there appears to be a particular need for predicting the location of temperature breaks (upwelling, currents, mixing, fish populations, water quality). The Coast Guard currently uses CoastWatch temperature maps as a short-term forecast for planning training missions (i.e., they want to work in a low temperature area to train for search and rescue under hypothermia-inducing conditions). Improved forecasting of regions of hypothermic conditions could serve as a warning to coastal constituents of situations (locations or times) in which additional precautions should be taken.

- **Wave Forecasts** (wave height, impact) - Improved wave forecasts were highlighted as an important facet of the need for improved weather forecasts in both nearshore and open waters of the Great Lakes. Waves are among the most important forecasts in determining water safety, particularly for shipping and boating, but also for other recreational users and protection of coastal property. More accurate forecasts are needed, as are extensions of accurate forecasts to approach 24 hours. Longer-term forecasts of mean and average wave height and energy would be extremely valuable to planning for coastal construction and long-term land-use planning for coastal zones.

- **Current Forecasts** (particularly rip currents and littoral currents) – Like water temperature, currents affect a variety of other coastal ecological processes (resuspension, sedimentation, erosion, contaminant movement, etc) that makes them an important first step in building Great Lakes ecological forecasting capacity. In the water safety context, prediction of strong short-term, local-scale, transient currents -- such as rip currents -- was noted as a high priority. Rip currents were discussed as an example of a priority case – each year several drownings occur on the lakes that could be prevented by better understanding and prediction of these currents. Forecasts of such dangerous nearshore phenomena are needed real-time to ½ day advance. Forecasts formulated as 'Watch' conditions (as in a severe storm watch) that identify conditions likely to set up a particular stretch of shoreline for dangerous nearshore currents would be useful to coastal constituencies. Priority locales for such local scale forecasts would be public beaches if longer stretches of shoreline proved unfeasible. On a regional scale, maps identifying 'at risk' areas would be useful in targeting educational efforts as would more information on what conditions (e.g., high water levels) make dangerous currents more likely. Search and rescue operations could also benefit from more accurate forecasting (nowcasting or even slight hindcasting) of local currents.

- **Ice Forecasts** (particularly ice cover relative to safety in crossing and icebreaking for commercial shipping) - Shipping was the primary constituency noted as needing improved predictions of ice cover. The most important aspect of ice cover forecasting needed by this constituency is an accurate prediction of when the shipping season will close and reopen (with and without icebreaking capacity). Accurate forecasts of the extent, duration, and thickness of Great Lakes ice cover as well as spatial variations in thickness and seasonal patterns for the coming year, would be valuable in the operation of and planning for Great Lakes icebreaking. Winter recreationalists (including ice fishers) were noted as a secondary constituency for ice forecasts. Forecasts supporting the needs of this group will be much more concentrated in the nearshore zone, as well as much more local and short-term in scale.

- **Water quality forecasts** (particularly *E. coli* and other influences on beach closings) - Great Lakes water quality directly affects every citizen of the basin as well as the millions of visitors to the region through drinking water, industry, recreation, and the economy. Constituencies for water quality forecasts are thus diverse, with priority overlapping decision-makers including public health officials, federal and state regulatory agencies, water supply, sewage treatment, and beach managers. Workshop participants recommended a focus on Beneficial Use Impairments (as defined in the GLWQA) form the cornerstone for prioritizing water quality forecasting needs. Workshop participants also identified three specific types of locations as priorities for development of geographically focused forecasts: beaches, water intakes (particularly drinking water), and the internationally designated Areas of Concern. Together, these locale types reflect the priority that needs to be placed on the nearshore zone in the context of water quality forecasting.

- **Beaches** - Beach closings are listed among the 14 beneficial use impairments designated in the GLWQA. Beach closures are currently a high profile issue in the Great Lakes region and water quality is the primary factor influencing beach closures. Currently, beach closures are determined based on local monitoring of water quality (usually for the indicator species *E. coli*). Recent research shows that the usefulness of *E. coli* as an indicator species may be compromised by the diversity of *E. coli* types and sources (e.g., *E. coli* from seagulls is not an indicator of a sewage spill and may not accurately reflect the health risk). Because the closure occurs at some point after the samples are taken and test results returned (usually > 24 hours later), closures are perennially a 'day late' in protecting human health. Monitoring is expensive and as a result may be sporadic (many beaches take water samples only weekly) and inconsistent. Forecasts are needed which (a) help to target monitoring, (b) provide better advance warning – at least to real-time, preferably several days, and (c) more accurately reflect the risk to human health. Forecasts based on physical factors such as currents and water temperatures may have the potential to fill this need.

- **Water Intakes** - The Great Lakes provide about 56 billion gallons of water daily for municipal, agricultural, and industrial use including drinking water for over 40 million U.S. and Canadian. Restrictions on drinking water consumption and added costs to agriculture or industry are two of the 14 beneficial use impairments designated in the GLWQA. Forecasts are needed at several temporal scales. Short-term forecasts providing accurate prediction of factors impacting water quality (e.g., contaminants, water chemistry, algal blooms, temperature) at the water source (intake) could be used to maximize the efficiency of water treatment processes. Prediction of other factors at short-to-intermediate time scales may also be useful in plant maintenance (e.g., predicting the timing of zebra mussel veliger settling). Longer-term forecasts of water quality (e.g., in light of invasive species, climate change, or water level shifts) are needed for appropriate design (and siting) of new intakes.

- **Areas of Concern** – The GLWQA also designates 43 binational Areas of Concern (AOCs) and the framework for Remedial Action Planning Committees (RAPs) responsible for developing the cleanup strategies for each. Ecological forecasting priorities for water quality should be based on these critical designations and meet the needs of these binationally recognized groups. While much progress towards cleanup has been made in the past 3 decades, diligent attention to water quality and a need for innovative solutions to cleanup remain an important regional priority. Baseline forecasts of natural attenuation and 'if-then' model allowing decision-makers to forecast the effect of alternative cleanup strategies are urgently needed for most of the AOCs as well as forecasts which incorporate continuing sources of contaminants. These needed forecasts are long-term (decadal scale) with a tight geographic focus.

Audience: Land-Use Planners

Land use is undoubtedly among the most significant issues facing the Great Lakes region – affecting all residents of the basin directly or indirectly. Governments and citizens in the Great

Lakes basin are increasingly aware that upstream water quality problems are often magnified downstream. Capability for ecological predictions of stream and lake water quality based on watershed factors can play an important role in helping local planners grasp the big picture – the totality of the impact of local decisions (as opposed to merely local consequences).

Watershed use reclassification (and TMDLs) may provide an important regulatory framework for considering ecological forecasting priorities for land use planning. Under the Clean Water Act, water quality standards are set by States, Territories, and Tribes, which identify the uses for each water body and the scientific criteria to support that use. A Total Maximum Daily Load (TMDL) is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. TMDLs are used to allocate permits. Ecological forecasts supporting decisions relating to the water quality standards, use classifications, and TMDL classifications were considered a priority by a number of workshop participants who work closely with these decision-making groups.

Land-use planners generally operate at a fairly local scale (county/municipal/township); though the need for larger scale (regional) efforts is recognized, little progress has been made in this direction. Land-use planners operate at several temporal scales – local planning commissions typically have a 3-5 year election, formal planning frameworks are typically decadal, 30 year bonds are not unusual, and impacts are generally considered in 50 year increments (typical construction 'built to last' 50 years) – all of which are among the longest forecasting horizons of any Great Lakes user group. The contrast of small geographic scales and large temporal scales are a challenge that must be met in any ecological forecasts designed to serve this constituency. Working at the longer temporal scales also implies that meaningful forecasts must take into account parallel changes brought about by climate change or invasive species. Prediction of ecosystem changes which affect the value of 'natural capital' (e.g., the economic value of an ecosystem product such as fish or service such as a wetland filtering water) are also of importance to land use planners who must weigh the benefits of development against the costs of its impact. Perhaps even more importantly, land-use planning forecasts must take into consideration the potential anthropogenic impacts – both the trends for impacts already being felt and those only just beginning. Important changes to the human dimension likely to impact the ecosystem include changes in human population of the basin and changes in land use patterns themselves as well as the secondary and cumulative impacts of land use decisions themselves. If-then model predictions (forecasts) thus are likely to be of particular value to land-use planners. Prediction of breakpoints and limits will be key features of the most useful forecasts for land use planners. Integration of models is also important to land-use planners; forecasts suggesting a solution to one problem without accounting for potential problems in other areas will not be as valuable a decision-making tool as the integrated alternative.

Outreach programs for land-use planning audiences are currently in their infancy, but are coming online at a rate suggesting that they will be readily available to convey forecasts to the appropriate audiences as forecasts become available. Nonpoint Source Education for Municipal Officials (NEMO) and Citizen Planner programs are two such programs that could provide an immediate conduit by which specific forecasts or models allowing local prediction of the long-term effects of land use patterns could reach the land use planners and land use planning commissions who could use such in making decisions. Land-use planners would be particularly receptive to further refinement of NEMO-style decision models.

Participants discussed several specific examples of ecological forecasts for land use planners. These were considered to be high priorities, but by no means an exhaustive list.

- **Water Levels** - Workshop participants noted long-term forecasting of Great Lakes water levels (e.g., 30-year cycles) as a high priority forecasting need. In order to be useful, such forecasts need to incorporate the impact of climate change and may need to incorporate an understanding of changing land use patterns (as such influence evaporation and runoff patterns). Forecasts should focus on factors such as the mean water level, high water level, low water level, cycle length, etc. – factors which should be taken into account in the long-term planning strategies of land use planners and shoreline developers as well as in the construction (or remodeling) of water intakes.

- **Runoff and Flooding** – Increasing 'flashiness' of streams and tributaries with changing land use patterns (particularly the increase in impervious surface with development) is of growing concern to land use planners. Workshop participants noted prediction of changes in runoff quality and quantity under different land use and climate change scenarios as a priority forecasting need. Such forecasts are needed both in the short-term (e.g., what will the runoff volume entering the combined sewer be during next week's storm?) and long-term (e.g., what peak capacity runoff do I need to design a system to handle over the next 50 years?). Contemporary efforts to address nonpoint source pollution and redesign sewage treatment systems to combat combined sewer overflows would benefit from more accurate predictions of runoff. Flooding is another obvious impact of increased flashiness of concern to land use planners – models predicting long-term changes to the floodplain in light of climate change over the next 50 years would be useful in addressing these concerns. Prediction of tributary water levels is growing in importance as development (and water intakes) move inland along these waterways. Impacts of changing runoff patterns to water quality and other facets of the environment are also of growing concern. Land use planners need to be able to answer the question of how much development can occur (and in what configurations) before impacts to water quality occur.

- **Coastal Erosion** – Shoreline erosion along the Great Lakes is a matter of increasing concern to land use planners with jurisdictions overlapping the coastal zone. In some regions, the shoreline is moving landward at rates in excess of 30 feet per year. Rates of coastal erosion are linked to a variety of coastal processes (water levels, storms); better prediction of these processes are likely to be a necessary precursor to sufficiently accurate predictions of coastal erosion at local scales. Long-term prediction of changes in Great Lakes shorelines (even if only under if-then scenarios relating to land use, development and climate change patterns) is needed for the long-term protection of coastal structures both manmade (docks, harbors, buildings) and natural (beaches, wetlands).

- **Sediment, Nutrient and Non-Point Source Pollution Management** – Agricultural and suburban runoff carries nutrient and pesticide loads as well as large volumes of sediment into the Great Lakes and its tributaries. On the upstream end, loss of topsoil contributes to the decline of farm production and increasing reliance on chemical fertilizers. High sediment loads choke navigation channels, making it necessary to dredge in order to maintain navigation and destroy habitat. Associated nutrients enter the water column, potentially contributing to eutrophication of the system, to harmful or nuisance algal blooms, and to the development of 'dead' zones. Load-associated toxins (including, but not limited to pesticides) complicate efforts to cleanup areas of concern and other restoration efforts. Physical, chemical, and biological processes are all responsible for the movements of both sediments and their associated contaminants around the Great Lakes. Changes in land use patterns, especially those affecting runoff and nonpoint sources of nutrient pollution may also be impacting the system. Better prediction of these sediment loading and transport patterns are needed to support efforts to manage dredging programs (including locating appropriate sites for disposal of dredge spoil), beaches and other coastal lands (erosion/deposition patterns), coastal development (sites for structures, intakes, etc.), habitat restoration (including wetland reconstruction), and cleanup of contaminated sediments. Priority forecasting needs are in the nearshore zone – movement of sediments (and contaminants) within, entering and exiting the littoral zone – and in the main shipping channels. Better prediction of sediment loads (where, when, how much) on even an annual scale (5-10 years would be better for Army Corps of Engineers planning horizons) can help to direct management efforts and to target prevention programs. The more refined the spatial scales for such models can become (which segments of stream contribute most to the load) the greater the ability to target innovative management and prevention programs will be. Existing prioritization of tributaries (by sediment loading) done by the Great Lakes Basin Program should be used to drive prioritization of fine-scale forecasting efforts for sediment management. Other tributaries may be more important from the contaminant (e.g., upstream of AOC locations) and nutrient management (e.g., upstream of dead zones) perspectives.

Appendix 1. Climate Change Summary

Preliminary Needs Assessment for Great Lakes Climate Change Forecasting Executive Summary August 2004

> This paper is based on discussions and prioritization exercises at the Great Lakes Ecological Forecasting Workshop conducted August 5-6, 2003 at the Great Lakes Environmental Research Laboratory in Ann Arbor, Michigan. Excerpt from "Preliminary Great Lakes Ecological Forecasting Needs Assessment"

Climate change has a vast potential influence over ecological processes and complicates most attempts to predict ecological processes beyond a 20-30 year timeframe. Such long temporal scales are most frequently needed for forecasts used in long-term planning or construction – siting of water intakes and wells, design of sewage treatment systems, coastal development, land use planning, water use planning, and shipbuilding. Fifty years from now we will likely still be living with the consequences of long-term planning and construction decisions being made today – lending an urgency to the need for accurate prediction of the climatic changes that we will be facing. Such infrastructure development projects carry a high price tag – poor decisions based on inadequate forecasts of climate change impacts have the potential to exact a terrible economic and environmental cost.

Invasive species and land use change issues are particularly intertwined with climate change forecasting. Needs in all three of these issue areas have a particular focus on long-term (20 year+) impacts. All three have complicated anthropogenic drivers with roots deeps in the global economy – pointing to a need for socio-economic forecasts capable of delineating the 'cost of doing nothing'.Climate change may exacerbate (e.g., flashiness of streams, eutrophication) particular consequences of changing land use patterns. Climate change will likely increase the rate of invasion of new species (e.g., current species assemblages displaced northward) as well as changing the potential suite of invaders. Each of these three is likely to significantly impact food webs – how they will interact in this arena is uncertain.

Global-scale predictive models for climate are well under development. However, predictions at geographic resolutions larger than the regional scale are generally not useful to either end-users or the majority of management authorities. Efforts to repackage and reinterpret global-scale models at regional (or even more refined) geographic scales will greatly increase the usefulness of such forecasts.

Discrepancies among climate model predictions are probably the single most frustrating factor for end-users attempting to base real decisions on forecasts. Most critical are model discrepancies that differ in kind – for example, Model A predicts water levels will go up, and Model B predicts they will go down. In the absence of further information about and interpretation of the models, the average users (including managers with a fair degree of technical knowledge in the subject area) are unable to determine which model to apply to their situation; usually resulting in neither prediction being used. When a model forecast differs from a previously (or simultaneously) developed forecast, additional effort must be made to interpret these discrepancies (why do the models differ, which one applies best in which situations, what additional information might resolve the discrepancy) for the users.

Predicting the impacts of climate change increases in difficulty as one moves from predictions relating to physical phenomena (temperature, precipitation, water levels) to chemical (water quality, contaminant resuspension), to biological (fish recruitment, forage base), to socioeconomic (ship design, value of the commercial fishery). Fortunately, most of the immediate need for climate change forecasts is based firmly on the physical level – with particular need for prediction of changes in weather and hydrologic parameters (precipitation patterns, runoff, flow, waves, water levels) as well as sediment-related parameters (erosion, resuspension, transport, deposition).

Climate change holds the potential to limit the effective life of even short-term predictive models (for other ecological phenomena) that fail to take such changes into account. A fish recruitment model which works well when constructed (to predict each succeeding year's recruitment) may suddenly fail 10 years from now when ice cover (or any other climate-driven change in the system) changes beyond the implicit limits of the model (i.e., the model assumed ice cover had no impact so long as it fell within the historic range).

Appendix 2. Fisheries Summary

Preliminary Ecological Forecasting Needs Relating to the Great Lakes Fisheries Executive Summary August 9, 2004

> This paper is based on discussions and prioritization exercises at the Great Lakes Ecological Forecasting Workshop conducted August 5-6, 2003 at the Great Lakes Environmental Research Laboratory in Ann Arbor, Michigan and is an extract from "Preliminary Great Lakes Ecological Forecasting Needs Assessment" (2004)

The Great Lakes fisheries are an ideal system in which to pilot efforts to develop ecological forecasts because the resource has a large, complex, and economically important user community with demonstrable ecological forecasting needs. Not only would many of the fisheries constituencies in the Great Lakes benefit from the application of ecological forecasts to management, but many of the these groups are prepared to take direct advantage of a variety of ecological forecasts if such were publicly available in a format which could be applied to their needs. Fisheries managers are likewise poised to take immediate advantage of ecological forecasts in making decisions relating to the management of the resource. Many of the ecological forecasts developed for direct use by fisheries constituencies and fisheries managers would benefit a much greater diversity of user groups (e.g., shipping, boating, beaches, drinking water, etc).

Fisheries-related ecological forecasting needs are defined broadly in this report to include direct fisheries forecasting needs (e.g., prediction of fish locations or fish populations), indirect fisheries forecasting needs (e.g., prediction of water quality, climate, and other factors affecting fisheries, economic forecasting needs (e.g., prediction of market values for commercial fish species) and other ecological forecasting needs of fisheries constituencies (e.g., prediction of water safety factors such as storms).

Constituencies for fisheries forecasts include fisheries managers, commercial and recreational fishers, charter businesses, seafood consumers and vendors, and supporting industries (e.g., boating, marinas, bait and tackle, tourism, Coast Guard, etc.). Needs of these groups often overlap significantly with the forecasting needs of other Great Lakes coastal stakeholders. Water safety and water quality forecasts have the greatest overlap with ecological forecasting needs of other Great Lakes coastal constituent groups and in many cases are critical preliminary steps toward development of the more focused fisheries forecasts.

The most important aspect of boater safety is getting warnings of storms sufficiently in advance that the boat can reach a harbor of refuge or other location at which the storm can be rode out in relative safety. Nearshore weather systems are known to be extremely volatile – current advance warning is considered by many to be insufficient for small boaters who may be unable to reach harbors of refuge within the current warning period, especially for smaller storms (which are still dangerous to these smaller vessels). Wave activity and surface currents are among the crucial factors needing more explicit forecasts. Storm surges and seiches are another a little recognized but crucial facet of such prediction as a sudden drop in water level of even a few inches can effectively close harbors and smaller marinas. These forecasts are needed on a scale of hours to days and are needed farther in advance than currently provided as well as needing better accuracy, perhaps indicative of a need for more nearshore observations and explicitly nearshore modeling. Longer–term forecasts (ranging to the life-span of the fish species of interest) of similar factors (e.g., weather-related factors such as storms, runoff, and ice which influence fish recruitment) are needed to support the more direct fisheries forecasts.

Fish are often used as an integrated indicator of water quality – one of the reasons that 5 of the 14 officially designated Beneficial Use Impairments under the Great Lakes Water Quality Agreement are directly related to fish. Impairments to water quality have the potential to negatively impact fish populations, fish behavior, fish health, and seafood safety. Ability to predict when fish consumption advisories will be lifted and intermediate forecasts supporting development of such forecasting capability were designated as priorities for water quality forecasts in support of fisheries. Priorities for intermediate forecasts match the temporal scale of direct fisheries forecasts (seasonal to the lifespan of the fish).

Workshop participants recommend focusing on the forecasting needs of fisheries managers as the priority for direct fisheries forecasts. In the broadest sense, ecological forecasting needs of fisheries managers would ultimately be met by a model that predicts which management actions will result in meeting the Fish Community Objectives set forth in the Strategic Plan for Great Lakes Fisheries Management (SGLFMP) and the individual Lake Management Plans of the Great Lakes Fishery Commission's Lake Committees. These Objectives are complex, simultaneously involving the stocks of many species. A variety of 'intermediary' forecasts will be useful in their own right as well as feeding into development of models for this higher forecasting goal – these were designated as the immediate priority and include: ecological forecasts of fish stock assessments for managed species (and/or their forage base), forecast of the sustainable harvest for each commercial and recreationally harvested species, forecast of the natural reproductive (and recruitment) rates. A 2-year forecasting time-scale was noted as coinciding with the current management framework – forecasts at shorter temporal scales (seasonal to annual) would allow better adaptive management and forecasts ranging to the average lifespan of the fish would allow better longer-term management planning. Forecasting the impacts of invasive species occurring within these temporal scales is one of the greatest challenges to development of reliable fisheries forecasts. True long-term forecasts (exceeding 20 years) were not identified as an immediate priority need. While potential impacts of climate change are not critical to models at the priority time scales, it is recognized that impacts of climate change may need to be incorporated into forecasts in the future.

The immediate need for all fisheries-related forecasts (including water safety and water quality) is concentrated in the nearshore zone of the lake – both because this is the location where the majority of recreational and commercial fishing occurs and because of the importance of this zone as fish habitat. Specific priority locations may differ significantly from the needs of other users of these forecasts; fisheries constituencies would likely prefer a geographic focus on harbors and fish nursery habitat while other constituencies favor beaches, water intakes, and contaminated sites.

Appendix 3. Human Health Summary

Preliminary Ecological Forecasting Needs Relating to the Great Lakes Human Health Executive Summary August 2004

> This paper is based on discussions at the Great Lakes Ecological Forecasting Workshop conducted August 5-6, 2003 at the Great Lakes Environmental Research Laboratory in Ann Arbor, Michigan and is an extract from "Preliminary Great Lakes Ecological Forecasting Needs Assessment" (2004)

Human health in the Great Lakes forms an ideal issue area in which to pilot efforts to develop ecological forecasts. Over 90% of the 29 million U.S. residents of the Great Lakes basin rely upon the Great Lakes for drinking water. Millions flock to the Great Lakes shores each year for commercial and recreational opportunities. Not only would many of the constituencies in the Great Lakes benefit from the application of ecological forecasts to management, but many of the these groups are prepared to take direct advantage of a variety of ecological forecasts (e.g., beach closures and fish consumption advisories). Public health officials and resource managers are likewise poised to take immediate advantage of ecological.

Human health-related ecological forecasting needs are defined broadly in this report to include both water safety (e.g., storm and current forecasting) and water quality (forecasting exposure to pathogens or toxins though a variety of vectors). The greatest forecasting needs are concentrated in the nearshore zone where the majority of the public comes in direct contact with the lakes. This is an issue area in which end users can be expected to want direct (or via traditional media) access to the forecasts. Thus all human health issues will have a significant extension component need to develop methods of outreach as well as the forecasts.

Individuals with a vested interest in water safety form one of the largest constituencies on the Great Lakes. Virtually anyone who spends time in, on, under, or near the Great Lakes has some safety concerns. Water safety end users include recreational (e.g., boaters, swimmers, divers, shoreline anglers), commercial (shipping, commercial fishermen) and military (Coast Guard) interests. Nearshore weather systems are known to be extremely volatile – current advance warning is considered insufficient. Storm surges and seiches are one crucial facet of such prediction as a sudden drop in water level of even a few inches can effectively close harbors and smaller marinas (harbors of refuge). Fog, lake effect snow, and ice are other elements of coastal weather that can be critical to the safety of small boaters, shippers, and travelers in the coastal zone that need better forecasting to ensure public safety. Wave, current, and water temperature (hypothermia risk) forecasts are especially important to safeguarding the safety of swimmers and others working in and on the lakes as well as to Coast Guard search and rescue operations. Most of the forecasting needs relating to weather are short-term (hours to days) and local in scale.

Great Lakes water quality directly affects every citizen of the basin as well as the millions of visitors to the region through drinking water, industry, recreation, and the economy. Constituencies for water quality forecasts are thus diverse, with priority overlapping decision-makers including public health officials, federal and state regulatory agencies, water supply, sewage treatment, and beach managers. Workshop participants recommended a focus on Beneficial Use Impairments (as defined in the GLWQA) form the cornerstone for prioritizing water quality forecasting needs. Most Beneficial Use Impairments are directly related to or indirect indicators of human health concerns. Workshop participants also identified three specific types of locations as priorities for development of geographically focused forecasts: beaches, water intakes (particularly drinking water), and the internationally designated Areas of Concern.

Beach closures are currently a high profile issue in the Great Lakes region, and water quality is the primary factor influencing beach closures. Currently, beach closures are determined based on local monitoring of water quality (usually for the indicator species *E. coli*). Recent research shows that the usefulness of *E. coli* as an indicator species may be compromised by the diversity of *E. coli* types and sources. Because the closure occurs at some point after the samples are taken and test results returned, closures are perennially a 'day late' in protecting human health. Monitoring is expensive and as a result may be sporadic or inconsistent. Forecasts are needed which (a) help to target monitoring, (b) provide better advance warning – at least to real-time, preferably several days advance, and (c) more accurately reflect the risk to human health.

The Great Lakes provide about 56 billion gallons of water daily for municipal, agricultural, and industrial use including drinking water for over 40 million U.S. and Canadian citizens. Short-term forecasts providing accurate prediction of factors impacting water quality (e.g., contaminants, water chemistry, algal blooms, temperature) at the water source (intake) could be used to maximize the efficiency of water treatment processes. Prediction of other factors at intermediate time scales may also be useful in plant maintenance (e.g., predicting the timing of zebra mussel veliger settling). Long-term forecasts of water quality are needed for appropriate design (and siting) of new intakes.

The GLWQA designates 43 binational Areas of Concern (AOCs) and the framework for Remedial Action Planning Committees (RAPs) responsible for developing the cleanup strategies for each. Ecological forecasting priorities for water quality should be based on these critical designations and meet the needs of these binationally recognized groups. While much progress towards cleanup has been made in the past 3 decades, diligent attention to water quality and a need for innovative solutions to cleanup remain an important regional priority. Baseline forecasts of natural attenuation and 'if-then' model allowing decision-makers to forecast the effect of alternative cleanup strategies are urgently needed for most of the AOCs as well as forecasts which incorporate continuing sources of contamination. These needed forecasts are long-term (decadal scale) with a tight geographic focus.

The capacity to accurately forecast particle movements through the Great Lakes and its watershed at short time scales (hours to weeks) and with a refined geographic scale (~100 meters) may be a critical first step in meeting the water quality forecasting needs of the region. Capacity to predict watershed hydrology may help predict the long-term sewage treatment needs for the region ultimately reducing water pollution sources which currently lead to human health risks. Capacity to predict movement of sediments, nutrients, and chemical contaminants may similarly help us to address non-point source pollution problems. Prediction of the development and movement of harmful algal blooms and their associated toxins may help drinking water plants to adapt management strategies to provide safer drinking water. Likewise, prediction of the movements of pathogens (e.g., in sewage) may better help us predict when beaches should be closed to protect human health. Over longer scales, prediction of the transport of contaminants through the system (and through the food web) may help us better manage the system to reduce risks of consuming Great Lakes fish.

Appendix 4. Aquatic Invasive Species Summary

Preliminary Great Lakes Ecological Forecasting Needs Relating to Invasive Species Executive Summary -- August 2004

> This paper is based on discussions and prioritization exercises at the Great Lakes Ecological Forecasting Workshop conducted August 5-6, 2003 at the Great Lakes Environmental Research Laboratory in Ann Arbor, Michigan and is an extract from "Preliminary Great Lakes Ecological Forecasting Needs Assessment"

More than 130 non-indigenous species have become established in the Great Lakes since the 1800's and the introduction rate increased dramatically with time. Invasive species are considered a major threat to the region's threatened and endangered species and pose a significant threat to the regional economy. Efforts to prevent the introduction and spread of invasive species as well as to manage such species and the invaded system when control is no longer feasible, require a great deal of scientific research and forecasting support.

Ecological forecasting needs relating to the invasive species issue fall into three major categories: (1) resource managers and regulators need ecological forecasts for a variety of factors which influence capacity to develop and implement management strategies which minimize the introduction and spread of these species, (2) forecasts of the ecological and economic impacts of invasive species are needed to determine management priorities and to mitigate the impacts, and (3) invasive species impact scientific capacity to develop other priority ecological forecasts, especially over the long-term.

Our capacity to predict new invasions is the lynchpin of aquatic invasive species prevention. Effective AIS prevention strategies are predicated on the capability to predict (a) what invasive species are likely to be coming, (b) the likely sources of the species, (c) the vector(s) by which species will arrive, (d) characteristics of the species, and (e) window of opportunity for the invasion (seasonality, associated with certain shipping patterns, invasion pressure, etc). Better prediction of any of these factors can help to assess what management strategies will and will not be effective in preventing an invasion. The single most important factor in determining the effectiveness of a control strategy is early intervention – which relies on our ability to detect the invasion before it is beyond control. Effective early intervention relies on early detection – monitoring targeted based on prediction of the location of an invasion (e.g., which harbors are most likely to be invaded first) greatly increases the probability that an invasion will be caught early enough for effective control. Prediction of the behavior of potential invaders and local physical features (e.g., local circulation patterns in a harbor) can also be important to rapid response planning. Implementation of appropriate best management practices to avoid transferring invasive species are also aided by local prediction – for example, ships can avoid ballasting in sediment plumes or algal blooms if the location of such features can be accurately predicted.

Predicting both short- and long-term ecological consequences of species that have recently become established in the Great Lakes (e.g., zebra mussels, round goby) is a high priority ecological forecasting need. Prediction of the likely consequences of invasions which have not yet occurred (but are considered likely within the next decade – e.g., *Caspian kilka*) are much more difficult but are also essential. Prediction of the expansion pattern of new invaders can help industries and coastal constituencies better plan for how to address impacts. A variety of impact forecasts are needed for the planning, operation, and maintenance of essential infrastructure such as water intakes. Better prediction of settling and growth rates for invasive fouling organisms such as the zebra mussels could be used to improve maintenance of water intakes, buoys, and ships. Prediction of food web changes resulting from invasive species, particularly displacement of native and commercially important species and alterations to contaminant bioaccumulation were considered high priorities. Prediction of the capacity of invasive species to affect physical alterations to the ecosystem by altering substrate (e.g., zebra mussel shells), shoreline stability (e.g., emergent plants can stabilize shorelines, other species can increase erosion rates), bottom stability (e.g., burrows, resuspension), light penetration, and water clarity was also identified as a priority forecasting need. Predictions relating to the capacity of invasive species to directly impact water safety (such as Eurasian watermilfoil that can grow so densely as to pose a hazard to swimmers and boaters) and human health (carrying human pathogens or promoting toxic algal blooms) were also accorded a high priority.

New species can dramatically change the interactions between existing species (and between those species and their non-living environment) creating ecosystems that are unstable and unpredictable. Thus the success of all long-term ecological prediction is predicated on an accurate forecast of the influence of non-native species that may enter the system and become established during the forecast period. Our capacity to predict invasive species limits our ability to develop useful long-term forecasts needed for fisheries management such as fish stocks, fish recruitment, fish behavior, and fish consumption advisories. Our capacity to predict the influence of invasive species also limits our capacity to predict such diverse ecosystem features as algal blooms, hypoxia, nearshore water quality, sediment resuspension and transport, shoreline erosion, and integrity of coastal structures (e.g., seawalls and docks).

Climate change and land use issues are particularly intertwined with invasive species forecasting needs. Needs in all three of these issue areas have a particular focus on long-term (20+ years) impacts. All three have complicated anthropogenic drivers with deep roots in the global economy – pointing to a need for socio-economic forecasts capable of delineating the true ‘cost of doing nothing’. Climate change will likely exacerbate the rate of invasion of new species (e.g., current assemblages displaced northward) as well as changing the suite of potential invaders. System disturbances resulting from changes in land use will also likely make systems more vulnerable to invasion. All of these influences are likely to significantly impact food webs – how this interaction will play out is uncertain.