Practitioners' Views of Science Needs

FOR THE

Great Lakes Coastal Ecosystem

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Great Lakes Commission des Grands Lacs

Contents

Preface

The U.S. Geological Survey Great Lake Science Center (USGS-GLSC) has been a leader in fisheries and Great Lakes research for decades. The vast majority of this research has focused in the offshore, deeper waters of the Great Lakes. Persistent and recurring ecological problems in nearshore areas where people interact with the Great Lakes have drawn the USGS-GLSC, and others in the Great Lakes science community, to increase attention on the coast (i.e., nearshore and shoreline areas).

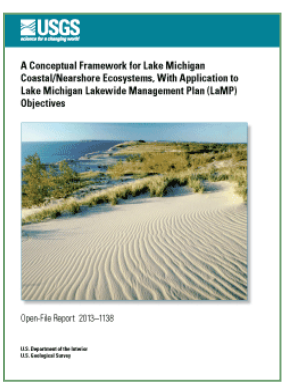
In 2014, the USGS-GLSC and the USGS-Michigan Water Science Center partnered with the Great Lakes Commission (GLC) to conduct a series of four workshops with coastal practitioners and managers across the Great Lakes basin to highlight the need for, and get input on, a Great Lakes regional coastal science strategy. To this end, this report is intended to help guide USGS coastal and nearshore science priorities, but may also help guide other science agencies. The USGS-GLSC partnership on this effort was part of a broader five-year Memorandum of Understanding between the USGS-GLSC and the GLC to enhance communications between coastal science and management communities within the Great Lakes region.

> *A USGS Coastal Science Strategy must align with decisionmaking needs at local, state and regional scales.*

Introduction

This report presents a summary and analysis of participant feedback from the four workshops held in 2014. Participant feedback included participant worksheets as well as interactive drawing sessions, individual notes and group flip chart notes from each workshop. The results are presented as a series of findings that can be used to guide USGS coastal/nearshore science priorities in support of management needs at local, state and regional scales.

The Great Lakes Coast and an Ecosystem Framework



The coast is where people meet, use, impact and appreciate Great Lakes waters. "Coast" means different things to different people. In this report, the term "coast" refers to the critical and complex transition zone where land meets lake; it includes where land most influences lake and, in turn, where lake most influences land. The coast is also influenced by tributary watersheds, lake-adjacent landscapes, and deeper offshore waters.

A 2013 USGS report, *Conceptual Framework for Lake Michigan Coastal/Nearshore Ecosystems*[1], was the foundation of this effort. The report's approach starts with identifying desired societal outcomes or

[1] Seelbach, P.W., Fogarty, L.R., Bunnell, D.B., Haack, S.K., and Rogers, M.W., 2013, A conceptual framework for Lake Michigan coastal/nearshore ecosystems, with application to Lake Michigan Lakewide Management Plan (LaMP) objectives: U.S. Geological Survey Open-File Report 2013–1138, 36 p., http://pubs.usgs.gov/of/2013/1138/.

ecological conditions, and then inventorying the component ecosystem processes (geomorphic, hydrologic, biological and societal) that necessarily support those desired outcomes. Central to this framework is the notion that insuring proper function of ecosystem processes underpins maintenance of desired outcomes. The framework further stresses that understanding the "coastal zone" requires attention to each of two neighboring zones of influence—open lake and watershed—each with distinct ecological processes.

Five Topics: Desired Societal Outcomes

The *Conceptual Framework for Lake Michigan Coastal/Nearshore Ecosystems* was used to structure a series of four workshops held across the Great Lakes basin in 2014: (September 15 in Erie, Pa.; October 10 in Toledo, Ohio; November 6 in Ashland, Wis.; and December 3 in Chicago, Ill.). Building on those described in the *Conceptual Framework for Lake Michigan*, five key desired societal outcomes for the Great Lakes coast were selected as the focus of the workshops. Each outcome falls under a general topic and provides specific ecosystem services (Table 1). The topic of "*Harbor*" reflects a historically central component of the regional economy and an increasing desire to adapt these coastal-dependent places to support a 21st century quality of life that sustains a range of desired economic activities and ecosystem services. The concept of "*Blue Coastal Planning*" derives from the growing desire to better understand the full implication of restoring processes that affect coastal property and beach values, as well as impacts on ecosystem services, notably coastal aesthetics, coastal recreation, coastal access and quality of life. The remaining three topics —*Water Supply, Healthy Habitats and Populations*, and *Swimming*—are pillars of important binational, regional and national environmental policies, such as the Great Lakes Water Quality Agreement and the U.S. Clean Water Act. Three or four of the five topics were discussed at each workshop.

Topic	Outcome	Associated Ecosystem Services	Workshop Location
Harbor	Recreational and commercial vessels can find safety and shelter	Safe navigation; storm protection	Toledo, Ashland
Blue Coastal Planning	Coastal assets and access to them are maximized to support recreation, economic prosperity and quality of life	Recreation (fishing, hunting); aesthetics; access; tourism; quality of life	Erie, Toledo, Ashland, Chicago
Water Supply	We can all drink the water	Drinking water supply aesthetics; recreation	Erie, Toledo, Chicago
Healthy Habitats and Populations	All habitats are healthy, diverse and sufficient to sustain biological communities; we can all eat the fish	Primary production; nutrient processing; habitat complexity; biological diversity; food supply; recreation (fishing, hunting)	Erie, Ashland
Swimming	We can all swim in the water	Recreation (swimming, wading)	Erie, Chicago

Table 1: Workshop Topics, Societal Outcomes, Ecosystem Services and Locations

Workshop Goal, Objectives and Design

The four workshops aimed to: 1) build a common understanding of the coastal and nearshore ecosystem processes that drive core coastal management issues; and, with these in mind 2) identify key science priorities. These objectives support the overall goal to help guide USGS coastal/nearshore science priorities in support of management needs at local, state and regional scales. This report may also help guide other science agencies.

At each workshop, coastal practitioners participated in exercises to define the important coastal processes driving particular ecosystem services, related management issues and key science gaps. The workshops were specifically designed to build in several different ways to engage participants by posing questions for them to answer through writing, drawing and discussion.

Table 1 summarizes which topics were discussed at each workshop. For each topic, participants were asked to answer the following questions:

- ***What are the driving ecological processes and where do these occur within the coastal ecosystem?***
- ***What is the key science needed to explore and understand those ecological processes?***

Following an overview of the purpose of the workshop and introductions, participants answered the questions above through silent generation of ideas on worksheets. This process, frequently used in workshop settings, enabled participants to collect and organize their individual thoughts prior to engaging in group drawing and subsequent facilitated group discussions. The combined use of facilitated group discussion, illustrative drawing and writing ideas on individual worksheets for each topic was a deliberate approach designed to maximize generation of ideas and feedback. Spreadsheets that had been previously completed by USGS scientists were provided to participants as a reference to help them think in terms of critical ecological processes and assist in generating appropriate responses to the first part of the first question. A spreadsheet was provided for each topic (e.g., desired societal outcome) that included various ecosystem processes by zones within the coast and by scientific discipline (i.e., geomorphic, hydrologic, biological and societal) (Appendices A-E). Discussing the desired outcomes and ecosystem services in terms of ecosystem *processes* was not a familiar approach for most practitioners. Accordingly, a more general framing of ecological challenges and opportunities figures prominently throughout this report along with the specific references to ecological processes.

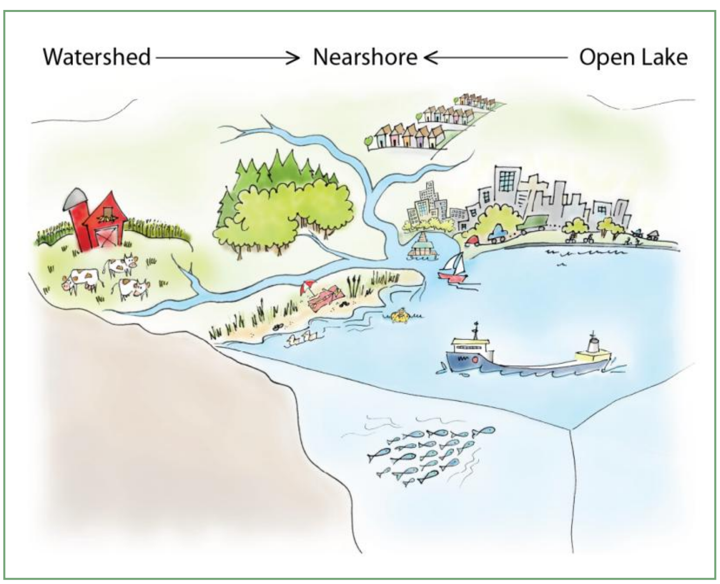


Figure 1: The Great Lakes Coastal Ecosystem

To answer the second part of question 1 — "Where do these occur within the coast?"—participants were invited to draw on a dry-erase poster while explaining their thoughts and ideas to the group. The poster featured a conceptual "coastal ecosystem" with images of various human activities, landscape features and ecological elements typically found in coastal areas (Figure 1). Three zones were shown on the poster to help participants identify spatially where key processes and associated ecosystem services occur:

- *Nearshore is* the area where the land meets the water and the immediate land (i.e., the shoreline) and water in that vicinity, and is the focus of this report.
- *Watershed* is the tributary or nearby terrestrial area that drains directly into the nearshore
- *Open Lake* is the area of open water that is adjacent to and influences the nearshore

The vast majority of workshop attendees participated actively in completing the worksheets, drawing and explaining via the poster, and in the facilitated discussion.

Workshop Participants

From Ashland to Albany, nearly 70 people from across the Great Lakes basin participated in the four workshops. Because the goal of the workshops was to inform a USGS science strategy for the Great Lakes coast that is responsive to management needs, coastal practitioners were targeted as participants. "Coastal practitioners" were defined as people *whose daily work involves making decisions that influence coastal and nearshore areas of the Great Lakes*. Such practitioners were generally people who might use scientific results or otherwise rely on science-based information, but who are not principally involved in conducting scientific research. They included: representatives from local, state and U.S. federal governments; Tribal/First Nation governments; regional planning groups; academic institutions (universities and extensions), and citizen-based non-profit organizations (Figure 2). A list of participants and their affiliations is provided in Appendix F.

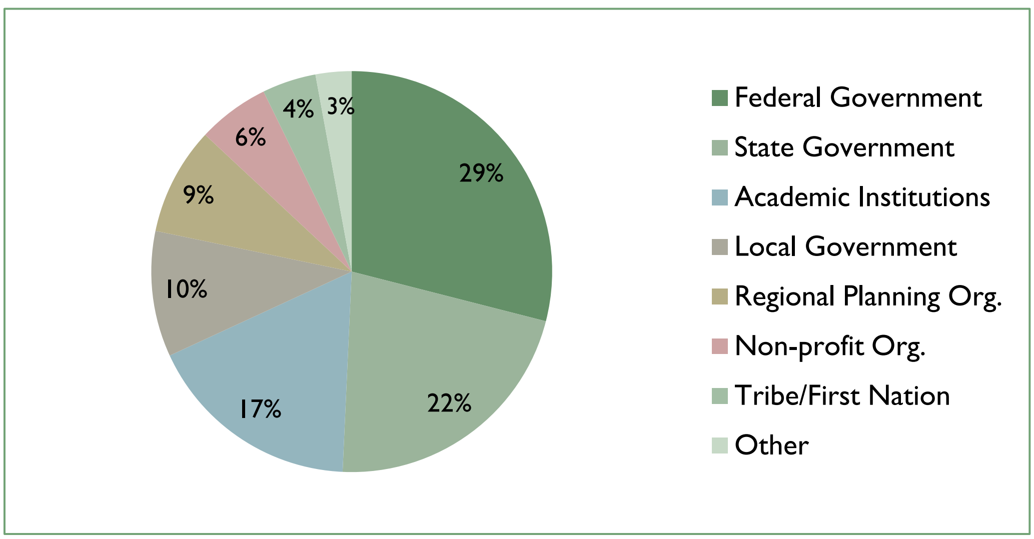


Figure 2: Workshop Participants by Sector

Workshop Findings

As noted above, the workshops were organized around five key topics and their associated ecosystem services (Table 1): *Harbor, Blue Coastal Planning, Water Supply, Healthy Habitats and Populations*, and *Swimming*. The findings presented herein integrate participant feedback with the authors' analysis of that feedback. This approach enabled the information to be summarized by topic and to weave together the diversity of feedback in a systematic way.

For each topic, the findings are organized into two major subsections: 1) ecological processes and their associated location; and 2) science needs. For each topic, these two major subsections are further broken down into thematic sub-topics. Word clouds, which graphically depict the terms or words that most frequently appeared in the workshop notes, were also created to compliment the primary analysis. Some interpretation and grouping of words/phrases was conducted to facilitate generation of these graphics. Quotations in the text boxes throughout this report are also excerpted from workshop notes.

Topic 1: Harbor

"*Harbor*" is an ecosystem service characterized by the ability of a nearshore area to provide shelter and sanctuary from storms, waves and other extreme weather. As a desired societal outcome, harbor also includes those nearshore places that have been modified to perform economic functions of ports and recreational harbors. This topic was discussed at the Toledo and Ashland workshops.

Harbors are the connection to the Great Lakes for much of the human population.

Driving Ecological Processes and Where They Occur Within the Coast

Nearshore sediment dynamics

The life-cycle of nearshore sediment dynamics is the driving process associated with *Harbor*, as most harbors/ports are in nearshore depositional areas such as rivermouths or bays, and this ongoing deposition often conflicts with navigation. Understanding the life cycle of nearshore sediment dynamics requires understanding sediment sources, transport, deposition, dredging, and resuspension as part of a system. Sediment dynamics are intensified by extreme weather events that alter underlying nearshore hydrodynamics. This is especially problematic when pollutants are attached to or embedded in sediments. Nearshore sedimentation is often caused by upstream erosion in the "watershed" zone, which is associated with intensive land use practices, impervious surfaces, deforestation and channelization; all of which can interrupt or modify natural hydrology in the watershed. Similarly, riverine sediment transport is heightened by increasing stormwater runoff and sewer overflows from storm events. Shoreline armoring and other engineered shoreline infrastructure such as levees, jetties, breakwalls and groins in the nearshore zone often alter the ability of natural rivermouths, and associated floodplains to capture, slow or store water and associated sediment.

Changing climate and nearshore hydrodynamics

Climate change has potential to significantly influence nearshore hydrodynamics and sediment mobilization, transport. Increasing tributary flows associated with more frequent or intense storm events, increasing storm surges and seiches, decreasing ice cover, and changes in lake water level as a result of climate changes will further stress the function and integrity of existing shoreline processes and built infrastructure.

Invasive species

Ports and harbors can amplify the arrival and impact of invasive species. Harbor activities can promote the spread of invasive species to the extent that recreational and commercial vessels are vectors for invasive species (e.g., ship ballast). Invasive species can negatively impact harbor function and quality, such as excessive aquatic vegetation that disrupts navigation or fouls water intake infrastructure. Invasive species are also impacted by harbor-related activities. Notably, dredging, filling or modification of the substrate can exacerbate colonization by invasive species, or fouling of infrastructure or intakes. Improved understanding of the relationship between invasive species and harbor functions under changing climate is needed. In particular, research is needed to better understand how warmer temperatures might alter the potential of vessels to be a vector for the introduction of invasive species.

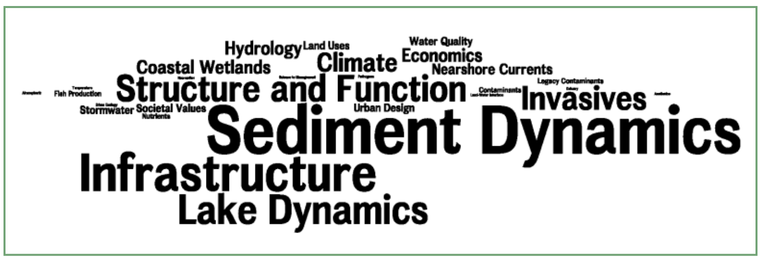


Figure 3: Harbor Ecosystem Processes

Key Science Needs to Support ***Harbor***

Sediment dynamics and shoreline infrastructure

Improved understanding of sediment dynamics is key to ensuring optimal and sustainable benefits and ecosystem services from harbors. Equally important is improved knowledge of how sediment dynamics affect and are affected by nearshore and shoreline infrastructure, particularly infrastructure that is needed to support safe and efficient navigation (e.g., dredging of shipping channels and dockage structures).

> *I'd like to have an improved understanding of the human connection to harbors and waterfronts.*

Climate change, nearshore hydrodynamics and infrastructure adaptation

Predictive systems models are needed to evaluate alternate scenarios under a range of climate possibilities and related management options. Improved design and engineering and adaptation of harbor-related nearshore and shoreline infrastructure are needed to accommodate climate change. Adaptation includes retrofitting infrastructure to prepare for extreme weather events and minimize ecosystem impacts. Related knowledge is needed on how lake level fluctuations impact harbor functions and services in a climate-changing world.

Social values and ecosystem services

More socio-economic research is needed to better understand harbor as providing ecosystem services. This includes gaining a better understanding of the uses and values of Great Lakes harbors and ports. Also needed are projections about their potential uses and how people (different users and societal sectors) value those uses, as the basis for human-harbor interactions. A collaborative vision for Great Lakes harbors is needed that can guide future development and retrofitting from both engineering and social viewpoints: i.e., covering the range of what people want and expect from harbors. This includes the economic service and value of ports and recreational harbors (e.g., navigation safety and dockage), as well as the social, recreational and cultural values that ports and harbors offer in providing safety for vessels and in connecting people to the coast. Related research is needed to understand the willingness to pay for harbor development and maintenance, as well as for sediment management alternatives. Also, the impact of invasive species introductions through harbor activities and to harbor services must be integrated into social-economic analyses.

Alternative scenarios for ports and harbors

Spatial and temporal models are needed to help visualize how rivermouth ecosystems might respond to alternate, future harbor/port management scenarios. These should illuminate how vessel or infrastructure design or management might influence aquatic habitats and biota, recreational services and spread of invasive species; especially given anticipated warming temperatures.

Figure 4: Harbor Science Needs

Topic 2: Blue Coastal Planning

Blue Coastal Planning (BCP) is a concept that integrates urban design, coastal planning and coastal ecosystem management disciplines to optimize the potential values of coastal economies, quality of life and ecosystem services (e.g., aesthetics or recreation). By contrast, traditional urban planning that incorporates some coastal features but does not fully consider coastal ecological functions and impacts on processes is not BCP. BCP is "blue" because it goes beyond physical revitalization of waterfronts by considering coastal processes and incorporating them into restoration and revitalization opportunities in ways that maximize human access to, and appreciation and awareness of, coastal ecosystems and the services they provide. BCP was discussed at all four workshops: Erie, Toledo, Ashland and Chicago.

Driving Ecological Processes and Where They Occur Within the Coast

Decisionmaking/governance at multiple scales

Integrated coastal/urban/ecosystem planning must occur at and across a range of local, county, state, and regional scales. There are strengths and weaknesses at each scale, and tying these together allows for leveraging of complementary strengths.

> *Blue Coastal planning incorporates restoration of ecosystem services into coastal development, redevelopment and revitalization.*

Shoreline infrastructure influences nearshore hydrodynamics

Shoreline hardening and other structures interrupt the natural flow of water, sediments and nutrient cycling, altering nearshore hydrodynamics, sediment dynamics, biological migrations, and other ecological processes. Better understanding of these processes and their relationships can guide improved designs so that revitalization and retrofitting efforts can optimize a broader range of ecosystem services.

Green infrastructure BMPs can mitigate increasing stormwater challenges

Natural hydrologic regimes are critical to supporting multiple ecosystem services, particularly in the watershed and nearshore areas. By mimicking natural hydrologic regimes, some green infrastructure can offset the effects of urban coastal impervious surfaces and other development impacts that obstruct or degrade hydrologic regimes and related ecological processes. Proper planning, design construction and maintenance of green infrastructure can optimize ecosystem services to manage and treat water and otherwise mitigate against extreme storm and peak flow events. This includes detaining greater volumes of storm flows as well as treating or reducing the amount of pollutants that move through a system during these extreme events. For example, the “first flush” storm runoff after a relatively dry period can carry high concentrations of pollutants from the landscape to tributaries.

Connecting people to the coast

Access to a variety of recreational opportunities along the shoreline is vital for maintaining a human connection to the coast. Shoreline access fosters appreciation for the coast and development of a "sense of place". Without shoreline access, the opportunity to interact with the coast is limited; coastal ecosystem services are not valued and therefore not reflected into planning, design, and investment objectives. In other words access creates connection and connection creates human value. Recreation, including ecotourism, is important to heighten human interactions and thereby human values and to consider associated planning and investments that reflect those values.

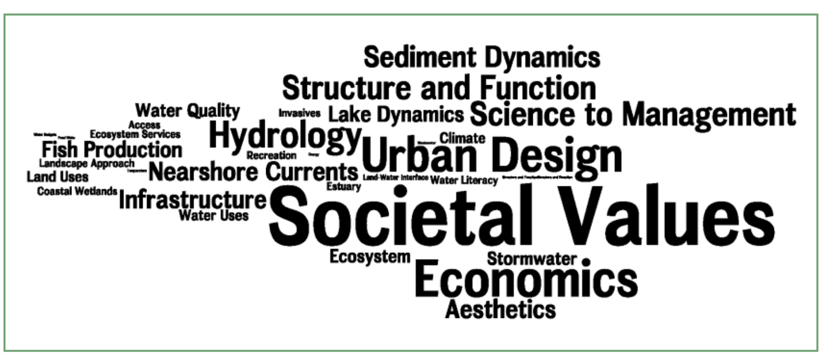


Figure 5: Blue Coastal Planning Ecosystem Processes

Key Science Needs to support ***Blue Coastal Planning***

Full cost accounting for green infrastructure

Blue Coastal Planning prompts the question: "Which ecosystem services can be restored or supported?"

Improved understanding of the costs and performance of green or soft infrastructure is needed. This should go beyond the costs associated with design and construction to include costs and benefits to the full range of interests and stakeholders, to account for improved or restored ecological processes and their ancillary benefits. Research is needed to better understand how natural systems respond to green infrastructure and whether there are multiplier effects. Such analyses should show costs of inaction ("do nothing" or "business as usual," including cost of deferred remedial/restorative action). Also of interest is understanding which demographic segments value the coast and why. For example, local communities of different sizes versus tourists and different societal sectors.

Better understanding of changes in hydrology from land use and development (especially stormwater runoff), particularly under changing climate conditions, is another science need. This requires looking at how flows are affected in the upstream watershed by surrounding land uses as well as in rivermouths and nearshore areas where current dynamics come into play.

Economic valuation of blue coastal planning and related ecosystem services

Economic valuation of ecosystem services impaired or improved by different management decisions is a critical need. This approach can be particularly helpful in assessing the value of green infrastructure as compared to traditional hard or grey infrastructure. Exploring economic impacts of degraded coastal ecosystem processes as a result of poor shoreline management, aquatic invasive species, urbanization and tourism is needed. Conversely, the economic valuation of habitat restoration, fish production, stormwater control, shoreline access, and the general value of well-designed and natural spaces to the public is an important area of needed research.

Work is needed to articulate and validate the value of Blue Coastal Planning that can help build it as a field of practice where knowledge about nearshore ecology is integrated into urban planning and design, and that planning is implemented in ways that more fully reflect societal values of ecosystem services provided by coastal areas. Efforts are needed to prioritize access to the nearshore for various recreational activities. This reinforces the earlier point that the public needs to be connected to the resource to provide proper support for coastal planning and protection. Related research is needed to identify what is expected from certain spaces, and to define what the "new natural" is.

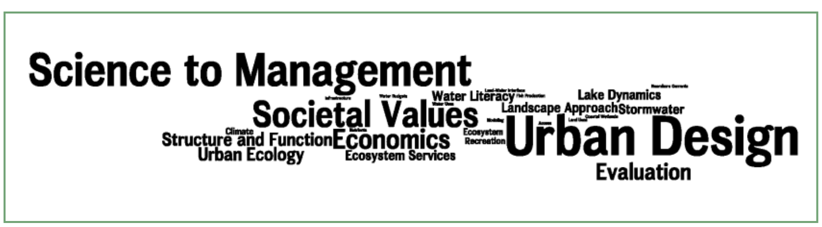


Figure 6: Blue Coastal Planning Science Needs

Topic 3: Water Supply

Water Supply is easily understood as both a desirable societal outcome and a service provided by the ecosystem. The U.S. Geological Survey generally identifies two categories: 1) those who obtain their own water; and 2) those who obtain water through publicly-distributed sources. The latter category is known as "public water supply." Public water supply is characterized by water that is distributed to the public through a physically connected system of treatment, storage and distribution facilities serving a group of largely residential customers, and that may also serve industrial, commercial and other institutional users. Those that supply their own water (self-suppliers) include: residential, industrial, commercial, agricultural and power (thermoelectric and hydroelectric). The discussion of water supply at the Erie, Toledo, and Chicago workshops was not pre-defined to include or exclude any water use category. Still, the area of greatest interest was the sustainable provision of clean, fresh water to municipalities, individual homes, and industries and power plants through the public water supply.

Driving Ecological Processes and Where They Occur Within the Coast

Sources and transport of contaminants in the watershed

The watershed or upstream zone is understood to be critical to ecological processes that support healthy water supply, even when that water supply source is in the nearshore or open lake. Sources of contaminants are often in the watershed zone and transported to the nearshore. Upstream land use is a primary driver of pollutant and sediment deliveries. Sediment dynamics are recognized as having an important role in the mixing and dispersion of pollutants and contaminants as they are delivered and deposited in the nearshore and open lake zones. Legacy contaminants in the watershed can leach into runoff, enter streams and storm sewers and, ultimately end up in the nearshore zone posing risks to the water supply. Similarly, excess nutrients from agriculture and urban sources are delivered through tributaries to the nearshore, which can lead to algal blooms that can produce toxins or undesirable taste and odor compounds. Understanding how best management practices in the upstream watershed area influence nutrient delivery to the nearshore is critical to reducing risks to safe and reliable drinking water supply.

Groundwater processes and source water quality

Groundwater as a source and the role of groundwater in the overall water system were highlighted at the Chicago and Toledo workshops. Groundwater is an important source in the upstream watershed zone and also plays into water budgets for the nearshore zone. Although groundwater and surface waters are one linked system that is sensitive to land use modifications, actual groundwater supplies do not necessarily match surface watershed maps and there are very few resources for understanding, modeling and mapping groundwater resources. Processes that drive the surface water/groundwater connection have great significance for water supply.

Nearshore processes and source water quality

As the source of drinking water for more than 30 million people, protecting the Great Lakes as a water supply for humans is paramount. Participants at the workshops expressed appreciation of the importance of processes within the nearshore zone where a majority of water supply intakes are located for Great Lakes coastal communities. Emphasized here is the significance of nearshore hydrodynamics, and associated sediment transport and deposition as drivers of delivery and dispersion of nutrients, contaminants and pathogens, which impact source water quality. The nexus between human activity impacts on ecological processes and human activity impacts on human health is important and deserves more attention. For example: how do human activities impact environmental health/ecological conditions and how does that, in turn, affect public water supply? Drinking water supply issues are most often a result of poor source-water quality due to excessive nutrient loads, pathogens and chemical contaminants. Treatment options are often limited and protection of source waters and intake infrastructure is costly. Nonetheless, protection of source water is critical to ensuring a safe public drinking water supply. The economics of water supply was also cited as critical, especially how water pricing relates to the provision of safe and sustainable public water supply.

Agricultural land use, excessive nutrients and algal blooms

Major concerns were raised about agricultural practices increasing nutrient loads beyond acceptable thresholds and driving nearshore algal blooms that can threaten water supplies. The link between excessive nutrients (especially phosphorus), algae blooms and risks to water supply was discussed at length during the Toledo workshop. In contrast, other workshop discussions linked excessive nutrient (i.e., phosphorus) pollution from agriculture with risks to swimming and blue coastal planning as well as water supply. The heightened focus on water supply at the Toledo workshop is likely driven by the drinking water crisis in the Toledo area in August 2014 after a harmful algae bloom (HAB) had formed in western Lake Erie near the city of Toledo's drinking water intake threatening the water supplied by the city. After laboratory results detected unsafe levels of microcystin, a toxin produced by HABs, more than 400,000 people in southeast Michigan and northwest Ohio were advised to avoid drinking and cooking with city-supplied water for several days.

Inadequate infrastructure to treat emerging contaminants

The discharge of emerging pollutants, such as chemicals of concern, pharmaceuticals and personal care products into human wastewater is increasingly problematic. Publicly-managed wastewater systems often treat and discharge wastewater into the same water bodies from which drinking water supply is drawn. If those wastewater treatment systems are not designed to remove harmful pharmaceutical or personal care product substances, then those substances end up in the ecosystem with detrimental consequences. Moreover, there are risks to public health where the public water supply systems draw water from those same water bodies and the treatment also does not remove those harmful substances.

Figure 7: Water Supply Ecosystem Processes

Key Science Needs to Support ***Water Supply***

Connecting watershed and nearshore processes to support management decisions

Improved understanding of pollutant transport and delivery into source waters (e.g., the nearshore zone) is important, as is more concrete information about existing wastewater infrastructure capacity and treatment capability, and potential impacts on source water supplies and treatment needs. Another need is better understanding of how nearshore processes (such as intensive filtering by invasive mussels) connect to open lake processes further offshore.

Changing climate impacts on nearshore water quality

The impacts of changing climate on both quantity and quality of water supplies are a key concern and more research is desired to understand those relationships. Climate change is expected to alter lake levels and lake level variability, as well as storm dynamics. Inherently-complex questions such as "how do we manage the coast in a dynamic environment?" and "what is the desired trophic level in a changing climate?" become even more so in the face of climate change. Better understanding of potential climate change impacts will help reduce risk and enhance an adaptive approach for citing water supply intakes. Not surprisingly, more effective nutrient monitoring associated with public water supply is also a critical need. Workshop participants generally believed that climate change will also exacerbate pollutant delivery to the coastal area.

Contaminant effects and thresholds

Establishing targets for specific contaminants is an important research priority and believed to be primarily a federal responsibility. Similarly, there is a desire to establish critical and achievable load reduction targets for other environmental parameters such as nutrients. Since returning to a zero/no impact scenario is impossible in many situations, it would be helpful to determine a reasonable and achievable reduction goal for many environmental stressors. For some of these stressors, responsibility falls to the state and local level. However it is a federal responsibility to set baseline targets for new environmental contaminants, such as pharmaceuticals and personal care products and the (algal-produced) toxin microcystin.

Costs of public water supply and willingness to pay

> *What is the most economically feasible way to ensure a clean and reliable water supply?*

There is a need for improved social science regarding costs associated with maintaining a clean and healthy water supply, and the associated willingness to pay for those costs. Water supply costs are often elusive in part because the cost of clean, safe water is relatively inexpensive in the Great Lakes region. This creates a disconnection from reality: people have the expectation of clean and safe water, but they have little or no grasp of how much that costs. This has implications for people's willingness to pay to maintain and improve the water infrastructure that delivers the public water supply. At the Toledo workshop, discussion heightened the need for better real-time information that can assist decisionmakers in ensuring safe water distribution in times of emergency.

Comprehensive water budgets, with inclusion of groundwater resources

A holistic understanding of water budgets that support major water supplies and their sustainability is needed. Detailed information on water sources, evapotranspiration losses, withdrawals and uses, and infrastructure leakage are rarely available. Currently many decisions are based on surface water information because knowledge, mapping and modeling are limited for groundwater resources. Better information on where and how much groundwater exists, and where and how it connects to surface water supplies is needed for a full accounting of water sources.

Agriculture BMPs and source water quality

More information on the effectiveness of agricultural conservation and best management practices and their potential to ameliorate impacts on quantity and quality of water supply is desired. Aspirations were conveyed about scientific research results informing cultural shifts and associated policy changes related to agricultural land management practices. An urgent priority involves further examination and improved understanding of nutrient sources and loadings, how nearshore processes respond to or are impacted by those loadings, and their contribution to harmful and nuisance algal blooms.

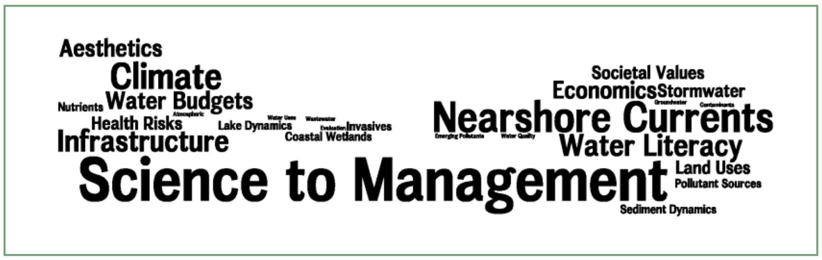


Figure 8: Water Supply Science Needs

Topic 4: Healthy Habitats and Populations

Healthy Habitats and Populations is a desired outcome associated with a variety of ecosystem services, including food supply, fishing/hunting, recreation and aesthetics. A surrogate for the ecosystem service *habitat complexity*, Healthy Habitats and Populations also serves as a barometer of the health of supporting ecosystem services, including *nutrient processing* and *primary production,* which are the building blocks for many other ecosystem services.[2] In sum, these ecological areas can sustain vibrant populations of species that are desired by humans for consumption or recreation, and also support underlying ecological processes fundamental to many ecosystem services. The topic of Healthy Habitats and Populations was discussed at the workshops in Erie and Ashland.

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[2] Larson, James H. et al, 2013. *Great Lakes Rivermouth Ecosystems: Scientific Synthesis and Management Implications*. Journal of Great Lakes Research 39 (2013) 513–524.

Driving Ecological Processes and Where They Occur Within the Coast

Land uses impact hydrology and nearshore pollutant loadings

Intuition says coastal nearshore areas are affected 75 percent by watershed/upland processes and 25 percent by open lake processes.

Nearshore eutrophication is directly tied to land use in the watershed, tributary hydrology, and how these two interact to mobilize, transport and deliver pollutants to the nearshore zone. Residential, commercial and industrial development, as well as agricultural practices in the watershed, are concerning as they each impact tributary hydrology, sediment transport and, ultimately, nearshore habitat structure and condition. Land use and development impacts are not limited to the watershed, however. Urban development likewise disrupts or accelerates sediment transport and sedimentation in immediate coastal landscapes. Impervious surfaces, in particular, interrupt and exacerbate water flows and attendant pollution loadings. Resulting nearshore eutrophication has a major impact on habitat quality. Excessive phosphorus loadings from agricultural as well as urban land use practices across the coastal zone become a crisis when nuisance and harmful algal blooms result in the nearshore, displacing and degrading healthy coastal habitats and associated species populations. In sum, the problems of greatest concern for coastal habitats are understood to originate both in the watershed and/or in the nearshore itself.

Climate-induced habitat loss and change

Strong concerns were expressed about how a changing climate is influencing and will continue to influence tributary stormflows, as well as currents and seiches in the nearshore and open lake zones. Climate change is also expected to alter nearshore water temperatures, another fundamental habitat character, with cascading impacts on nearshore habitat structure and function. Wetlands are a keystone habitat type for coastal areas. The filling and destruction of wetlands, which would otherwise attenuate excessive flows and waves, process seasonal nutrient deliveries and provide healthy habitats is an historical and ongoing challenge. Climate change presents many risks to wetlands and other coastal and riparian habitat types. Changing nearshore currents, watershed streamflows and water temperatures in all zones are examples of direct climate change impacts that are likely to affect wetland structure and function—primarily in the nearshore zone. Similarly, more intense and/or frequent storm events will influence tributary flows, with consequences for nearshore habitat and supporting ecological processes.

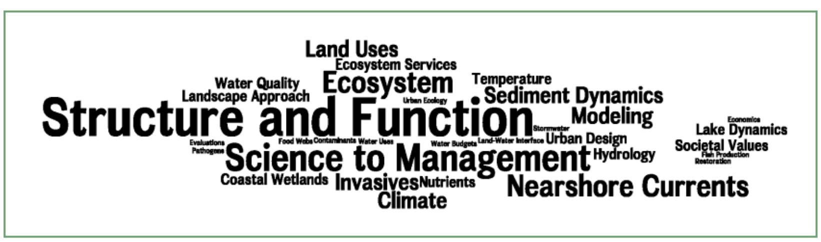

Figure 9: Healthy Habitats and Populations Ecosystem Processes

Key Science Needs to Support ***Healthy Habitats and Populations***

Influence of nearshore hydro- and sediment-dynamics on habitat

> *We need better forecasting of ecological responses.*

Key among the sciences needed to support healthy habitats is improved understanding of nearshore currents and sediment dynamics, and how these are influenced by watershed- and open-lake processes. Nearshore and coastal habitats are governed by nearshore and upstream hydrologic and geomorphic processes. In many coastal areas around the Great Lakes, these processes have been altered by human development. For example, many miles of coastal wetlands have been extensively modified by nearshore infrastructure (e.g., levees) that prevents direct lake connection. Also, many streams and rivers have been heavily modified by dams and other urban development. Improved understanding is desired on how these modifications influence coastal habitats as well as a better awareness of how to alter development to minimize impacts on coastal habitats.

Coastal wetland responses to flow and sediment dynamics; and climate change

Lower river floodplains and coastal wetlands process and often store nutrients. Climate change can alter these wetland functions by affecting hydrology (especially tributary flow), nearshore water levels, temperature and currents. Restoring lost wetlands can provide vital resilience in the face of expected increasing storm severity. Understanding how these impacts would affect whether and how invasive species colonize, disperse or move to other areas is of interest. Research is needed to improve understanding of the relationship between currents, tributary flow and mixing (e.g., of nutrients and sediments); and how these relationships impact coastal wetlands and the species that depend on them. Better monitoring and mapping of bottom substrate would help. These themes suggest a more fundamental need for greater understanding of physical coastal processes and related habitats within the nearshore zone, as influenced by neighboring zones.

Science-based restoration

Science-based restoration requires knowledge of a reference condition, current status, and potential management treatments and outcomes. The science of habitat restoration should include more explicit science regarding restoration targets and metrics for evaluating and assessing effectiveness of habitat restoration efforts, particularly in nearshore areas. For example, with the majority of wetlands lost, what are estimated current and potential roles of wetlands in restoring habitat quality? Thoughtful development of such tools would enhance efforts to restore coastal habitats.

Societal understanding and valuation of habitat/population services

More information is needed regarding the benefits and values of ecosystem services derived from habitats and wildlife. Improved economic valuation of ecosystem services provided by healthy habitats will help integrate impacts on those services into every-day decisions. For example, greater appreciation of the financial impacts of excessive fertilizer application on habitat (fish), water supply (drinking water) and recreation (swimming) could go far in changing if, how and when fertilizer is applied. Similarly, understanding which ecosystem services are most vulnerable to certain development or other decisions could prevent or minimize their loss. This could enable more informed decisions about where certain human activities are acceptable and where they are not.

Linking science to decisionmaking

Decisionmakers and the public need to understand trade-offs among alternative scenarios, based on knowledge of specific habitats and the ecosystem service benefits (and costs) in specific locations. Likewise, increased appreciation of natural systems and their variability (e.g., changing lake levels and climate) will enhance science-based decisionmaking.

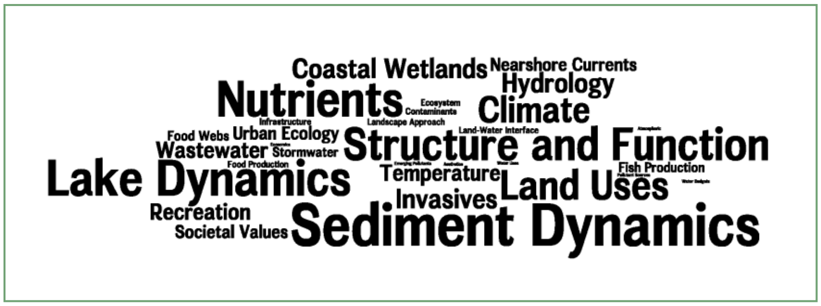

Figure 10: Healthy Habitats and Populations Science Needs

Topic 5: Swimming

The desire for safe and aesthetic swimming is embedded in the Great Lake Water Quality Agreement and the U.S. Clean Water Act, both of which call for waters that are "swimmable."[3] In the context of the workshops and this report, "swimming" as a desired ecological outcome is, therefore, strongly linked with people who go to the beach, whether or not they actually swim, simply sunbathe, watch children play in the sand, or wade in the water. Swimming was discussed at the workshops in Erie and Chicago: two places where swimming is a major draw for tourists and a core recreation activity for locals. Access to safe and aesthetically pleasing swimming is an important economic driver for many Great Lakes coastal communities. Swimming is a primary recreational activity connecting people to the Great Lakes. It has significant cultural and quality of life value to those who dwell along the coast, as well as visitors and tourists.

Driving Ecological Processes and Where They Occur Within the Coast

Nearshore combined sewer overflows and stormwater outfalls

Planning, design and development that does not account for runoff and attendant pollutants often results in impeding natural ecological processes that would otherwise sustain desirable swimming conditions. Coastal practitioners understand that during heavy rain events, combined waste and storm water systems result in untreated sewage being discharged into receiving waters—often where people would enjoy swimming or other contact with the water. Such Combined Sewer Overflows (CSOs) help transport sediments and deliver chemical and biological contaminants, including bacteria and other pathogens. This was highlighted as the most pressing issue that can

[3] The U.S. Clean Water Act requires that states designate uses for each water body; those uses must include recreation and aquatic life, otherwise known as the "fishable/swimmable" goals. Similarly, the Great Lakes Water Quality Agreement calls for waters of the Great Lakes that "allow for swimming and other recreational use, unrestricted by environmental quality concerns."

impact whether waters are safe for swimming. Increased storm events associated with climate change can be expected to result in more CSO events.

Nearshore hydro-and sediment-dynamics

Nearshore hydro- and sediment-dynamics and associated transport, deposition and concentration of pathogens and harmful/nuisance algae are key coastal processes that affect the ability to swim in the Great Lakes and their tributary rivers and streams. Detrimental effects on hydrodynamic processes from improper or poor infrastructure design and construction, and other coastal development are generally known to exist and are of concern, but are not well understood.

Nutrient loadings influencing harmful algal blooms

In addition to pathogen pollution from CSOs, there is also concern over increased nutrient loadings influencing harmful algal blooms that affect beach use. Where harmful and nuisance algal blooms occur in the nearshore, these blooms prevent swimming and other beneficial human uses of coastal waters. The system dynamics that create harmful or nuisance algal blooms are not well understood. However, their negative impact on swimming and beach recreation is unambiguous: large decaying algal mats are unattractive and concentrate potential pathogens.

Value of beaches and access to swimmable waters

Because "swimming" as an ecological service is predicated on the opportunity to recreate safely in nearshore waters of the Great Lakes, the concept aligned well with valuing all of the things that are often associated with "a day at the beach": the ability to go to a place that is pleasant, safe and accessible. Of paramount importance are access to the beach, generally, and the ability to swim, wade or have safe contact with the water. In addition to Erie and Chicago where this topic was discussed, whether the water is "safe for swimming" can have a significant impact on the local economy of beach communities across the Great Lakes region. Shutting down the beach for one day can cost a community many thousands of dollars and have a ripple effect lasting weeks or longer until public perceptions shift.

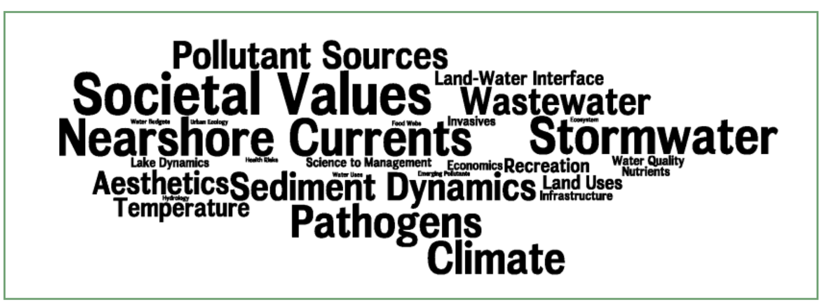

Figure 11: Swimming Ecosystem Processes

Key Science Needs to Support ***Swimming***

Shoreline infrastructure and beach nourishment

Coastal practitioners expressed widespread concern about infrastructure that interrupts natural sand nourishment at beaches; such as levees, jetties, breakwalls and groins. The fundamental ways that these structures interfere with sediment movement is generally understood. Less understood are alternatives that preserve sediment processes while providing desired societal services (e.g., protection from storms, wind or wave action; or maintaining shipping/boating channels). More research is needed to develop infrastructure that does both and more effort is needed to bring this research to managers and other decisionmakers that can use it to modify or replace disruptive infrastructure with more ecologically sustainable options.

Timely and accurate monitoring of beach quality

Improved and more robust indicators of fecal pollution and bacteria at beaches were noted as a key science need. This has been an issue for some time at beaches around the region. Disseminating real-time warnings about polluted beaches to the public in a timely manner is a real struggle for many coastal communities. Previous beach monitoring methods had a delay between when the water was tested and when results were made available to the public. Newer methods can provide more timely information so decisions are made based on the same day that the waters are tested. Participants in Erie distinguished between protocols for monitoring and testing of individual beaches that should come from state-level policies, versus the federal role in setting more beach-relevant national beach pollution standards.

> *We need better beach monitoring because what is more dangerous than saying that the water is safe when it isn't?*

Economic valuation of beaches

Some research has been conducted but more is needed to demonstrate the economic valuation of a day at the beach. Social science research is needed to evaluate the willingness to pay for ongoing monitoring and maintenance that ensures safe and clean beaches.

Also worth understanding is the value of sand that forms the beach. A better understanding is needed of geomorphic erosion, littoral drift and how these relate to beach nourishment. Where managed nourishment is required, costs should be understood and factored into the value equation. Associated research is needed to better understand the economic losses due to polluted beaches and beach closures, specifically those associated with waterborne illness (i.e., caused by pathogens). Social science can help answer these questions. Science is also needed to improve the understanding of the relationship between sediment dynamics and pathogens, particularly the sources and transport of sediment-related pollutants that end up in sewage overflows.

Beach management protocols related to algal blooms

Figure 12: Swimming Science Needs

Finally, the desire for access to safe coastal swimming also raised the critical need to develop or critically evaluate and improve management protocols to prevent or mitigate against harmful and nuisance algal blooms.

Conclusion

Attendance and the depth of discussion and engagement at the workshops indicate the need for substantially enhanced science to support more effective and ecologically sustainable decisions in Great Lakes coastal areas. Participants voiced high value for the ecological and societal services provided by these ecosystems, as well as serious concerns about future challenges to restoring or sustaining them.

The *Conceptual Framework for Lake Michigan Coastal/Nearshore Ecosystems* was effective in framing and guiding workshop discussions in terms of outcomes, ecological zones, science disciplines and system processes. The findings for each of the five major desired outcomes are distinct and yet share some common threads, which is evident in the narrative, the word clouds and in the words and other marks made on workshop posters. Figure 13 summarizes the primary ecological processes that were identified at each workshop and the zone where each is understood to occur within the larger coastal ecosystem. It will be important to integrate key messages across the five topics discussed.

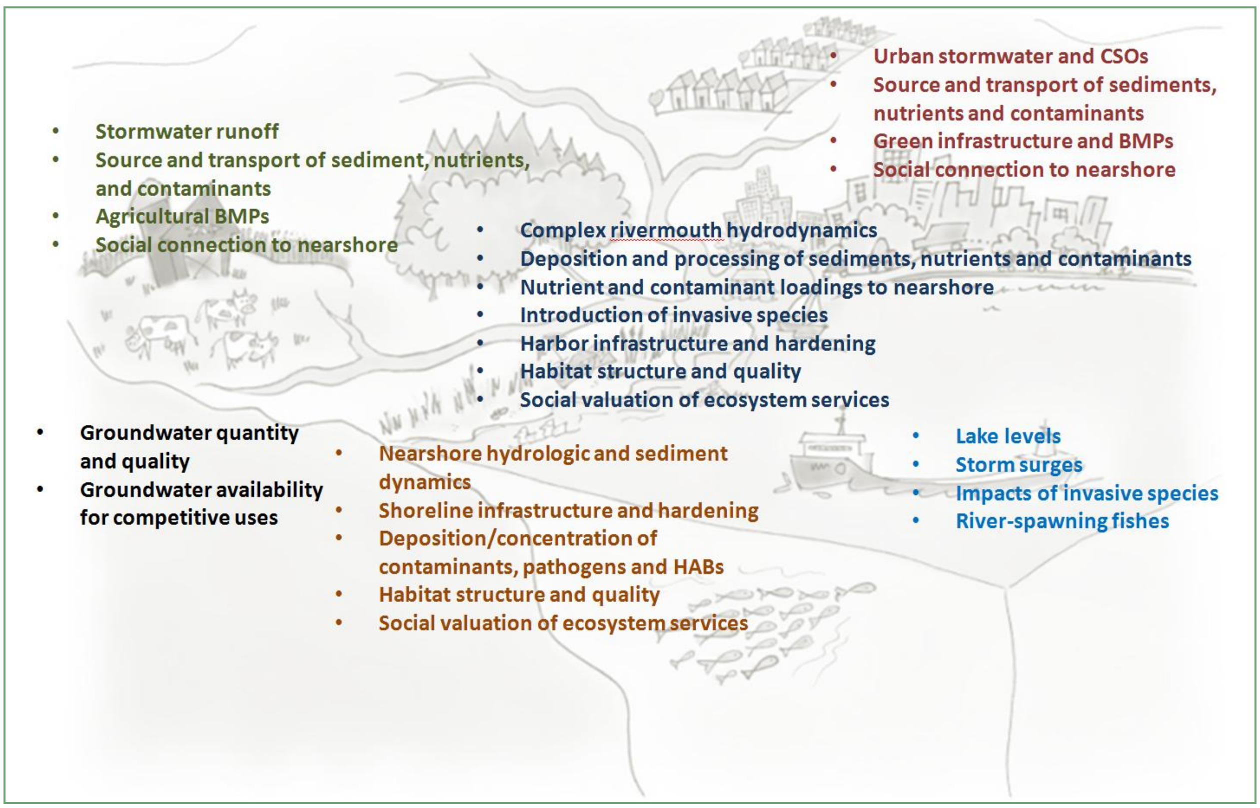

Figure 13: Ecological processes and their importance across different coastal ecosystem zones.

Findings also show that participants easily connected issues among watershed, coastal and nearshore zones. Connections between offshore and nearshore zones were not discussed as much, likely indicating a gap in familiarity and understanding of this linkage. While both ecological and social science needs are identified, the workshop discussions and, therefore, the findings in this report often emphasize the social sciences. Our design likely influenced this result: the five topics discussed and their associated desired societal outcomes were presented as—and therefore heavily weighted to—desired societal outcomes. The relatively large number of social science needs may also reflect the fact that most science conducted in support of natural resources management is focused on improving understanding of ecological processes. Less “natural resources science” focuses on how ecological information is used in decisionmaking. This echoes the recurring theme of the need to improve “science to management,” as illustrated in the word clouds for each topic. It also reaffirms the gap between and the need to better link natural science and social science in ways that can impact daily coastal management decisions, such as investments in infrastructure or conservation. The coastal practitioners that attended the workshops were attuned to this gap in science linkages and translation. An improved “science to management” approach will require a more deliberate investment in iterative relationships between scientists and their research, and coastal practitioners whose everyday decisions affect the Great Lakes coast.

While all major natural resource science disciplines were well represented at the workshops, and to some degree integrated in discussions and findings, this report does not represent a formal gap analysis. Nonetheless, the findings indicate that there is agreement that gaps exist in areas including nearshore physical processes (e.g., sediment dynamics, nearshore currents, lake dynamics) and social sciences (e.g., societal values, economics, linking science to decisions). Likewise, there is a need to do a better job of bringing that information to practitioners in ways that can result in more ecologically sustainable decisionmaking.

The authors appreciate the thoughts and guidance provided by these participants and anticipate the findings being influential to USGS science strategy going forward. We encourage similar use by sister federal, tribal, state and provincial science agencies and hope this initial report can begin an interactive, integrated process toward an effective, common science agenda for the Great Lakes coastal ecosystem.

Appendices

Appendix A: Spreadsheet Matrix on Ecological Processes for Harbor

Appendix B: Spreadsheet Matrix on Ecological Processes for Blue Coastal Planning

Appendix C: Spreadsheet Matrix on Ecological Processes for Water Supply

Appendix D: Spreadsheet Matrix on Ecological Processes for Healthy Habitats and Populations

Appendix E: Spreadsheet Matrix on Ecological Processes for Swimming

Appendix F: List of Workshop Participants

This report is available online at:

http://glc.org/projects/habitat/coastal-ecosystem

Appendix A Spreadsheet Matrix on Ecological Processes for Harbor

	Open lake	Coastal/nearshore	Watershed (tributaries)
Geomorphic	Glacial processes that shaped lake depth, and form and texture of lake-bottom terrain (ridges, troughs, plains).	Coastal sediment dynamics influencing erosion, transport, and deposition of sediments within harbor areas	Glacial processes that shaped watershed size, topography, sediments, and valley structure.
	Sediment erosion, transport, and deposition dynamics influencing texture of lake-bottom sediments.	Tributary dynamics influencing erosion, transport, and deposition of sediments within coastal/nearshore habitats.	Watershed and valley specific sediment dynamics driving erosion, transport, and deposition of sediments within channel and flood plain.
	Climate change altering seasonal lake storms and wave patterns		
Hydrologic	Seasonal lake mixing and large-scale currents influencing wave patterns	Lake storm surges, seiches, upwellings influencing erosion and impacting harbor structures	Watershed-driven, tributary flow regimes driving erosion and altering harbor flow patterns
	Winter ice-cover regimes.	Tributary inflow regimes influencing clarity, nutrient, and temperature regimes.	
Biological	Altering of harbor structures by dreissenid mussels	Distribution and dynamics of sunken wood debris recruited from coasts and tributaries.	Stream channel interactions with riparian flood-plain ecosystems and river-channel habitats
		Altering of harbor structures by dreissenid mussels	Modifications to riparian vegetation that effect flow patterns and sedimentation
Societal	Nuisance effects from accidental species introductions.	Elimination or disconnection of wetland habitats.	Altered watershed and valley sediment dynamics
	Climate change altering seasonal lake temperatures and ice regimes.	Effects of Piers and breakwalls modifying shoreline currents	Diking and hardening of channel shorelines

Appendix B Spreadsheet Matrix on Ecological Processes for Blue Coastal Planning

	Open lake	Coastal/nearshore	Watershed (tributaries)
Geomorphic	Glacial processes that shaped lake depth, and form and texture of lake-bottom terrain (ridges, troughs, plains).	Glacial processes that shaped topography and texture of lowest river-valley segment, delta, embayment, and coastline.	Watershed- and valley-specific sediment dynamics driving erosion, transport, and deposition of sediments within channel and flood plain.
	Sediment erosion, transport, and deposition dynamics influencing texture of lake-bottom sediments.	Coastal sediment dynamics influencing erosion, transport, and deposition of sediments within coastal habitats.	Glacial processes that shaped watershed size, topography, sediments, and valley structure.
Hydrologic	Distribution and dynamics of floating and sunken wood debris recruited from coasts and tributaries.	Lake storm surges, seiches, upwellings influencing clarity, nutrient, and temperature regimes.	Watershed-driven, tributary flow regimes driving instream clarity, nutrient, and temperature regimes.
	Winter ice-cover regimes.	Tributary inflow regimes influencing clarity, nutrient, and temperature regimes.	Hydrologic sources to riparian ecosystems
	Restructuring bottom and altering nutrient pathways by nuisance dreissenid mussels.	Dynamic hydrologic connectivity with coastal wetlands.	Modifications to riparian vegetation that effect flood-plain and channel habitats.
Biologic	Seasonal lake mixing (both vertical and with nearshore), and large-scale currents influencing clarity, nutrient, and temperature regimes.	Distribution and dynamics of sunken wood debris recruited from coasts and tributaries.	Stream channel interactions with riparian flood-plain ecosystems and river-channel habitats; effects on shading, bank structure, recruitment of woody structure.
	Distribution and dynamics of juvenile fishes produced in coastal/nearshore and tributary habitats.	Distribution and dynamics of juvenile fishes produced in open-lake, coastal/nearshore, and tributary habitats.	Instream dynamics of nutrient pulses in the form of fish eggs and fry (nutrients) imported from open-lake habitat.
		Eutrophication-driven high algal concentrations shading bottom.	Instream distribution of sources of primary production.
Societal	Air- and precipitation-borne contaminants and chemicals (acids).	Piers and breakwalls modifying shoreline processes, and lake influence and exchange with rivermouths and embayments.	Altered watershed and valley sediment dynamics (loads, erosion, transport, deposition).
	Climate change altering seasonal lake temperatures and ice regimes.	Municipal and industrial wastewater discharges.	Diking and hardening of channel shorelines that reduces habitat complexity in channel and flood plain.
	Increased predation by hatchery-reared salmonids.	Nonpoint runoff from local or tributary watershed urban or agricultural landscapes.	Modified watershed landscape hydrology changing instream clarity, nutrient, and temperature regimes.
	Nuisance effects from accidental species introductions.	Reduced hydrologic connectivity with coastal wetlands.	Point- and nonpoint-source inputs of contaminants.
	removal of dead trees; commercial log harvest	Increased predation by hatchery-reared salmonids.	Development within flood-plain valleys that eliminates wetland services.

Appendix C Spreadsheet Matrix on Ecological Processes for Water Supply

	Open lake	Coastal/nearshore	Watershed
Geomorphic	Sediment composition and interstitial spacing that drives bioavailability via contaminant burial or resuspension	Topography/hydraulics of lowest river-valley segment, embayment, and coastline influencing contaminant retention/ exchange with open lake.	Substrate adherence and leaching from substrate.
		Substrate adherence and leaching from substrate.	Watershed substrate, area and slope
		Coastal sediment dynamics driving erosion, transport, and deposition of contaminants within coastal/nearshore habitats.	Groundwater hydrogeology.
Hydrologic	Seiche	Currents that drive contaminant dispersion and deposition.	Tributary flow regime driving instream dispersal.
	Large-scale currents that drive contaminant dispersion and deposition.	Persistence within the system due to physical and chemical properties determining contaminant half-lives.	Groundwater flow paths.
	Seasonal lake mixing that drives contaminant resuspension from sediments.	Seasonal lake mixing that drives contaminant resuspension from sediments.	Overland flow, infiltration, and associated contaminant transport to surface-water and groundwater systems.
Biological	Differential transport and persistence of different microbes.	Development cycle of cyanobacteria.	Natural sources, such as birds and wildlife.
		Survival and naturalization of fecal indicator bacteria and pathogens.	Differential transport and persistence of different microbes.
		Oxidation and reduction of chemicals and compounds.	Chemical pollutant degradation.
Societal	Atmospheric contamination.	Storm drains and urban runoff that deliver contaminants.	Chemical use (fertilizers, road salt, pesticides, etc)
	Air- and precipitation-borne contaminants and chemicals.	Substrate adherence and leaching from substrate.	Altered sediment dynamics.
	Boat and ship waste dumping.	Point-source runoff from industrial land use; infrequent accidental loadings.	Failing or leaking municipal sanitary waste systems, combined-sewer overflows, and sanitary-sewer overflows.
		Nonpoint runoff from local urban and agricultural landscapes.	Modified hydrology (drains, wetland removal, impervious surfaces).
		Placement of water intakes.	Water-well placement.
		Storm drains that deliver biological contaminants.	Point-source runoff from industrial land use;
		Shoreline septic systems that deliver biological contaminants.	Nonpoint runoff from local urban and agricultural landscapes.
			Wastewater-treatment-plant effluent discharges.

Appendix D Spreadsheet Matrix on Ecological Processes for Healthy Habitats and Populations

	Open lake	Coastal/nearshore	Watershed
Geomorphic	Substrate adherence and leaching from substrate.	Substrate adherence and leaching from substrate.	Substrate adherence and leaching from substrate.
	Sediment composition and interstitial spacing that drives bioavailability via contaminant burial or resuspension.	Topography/hydraulics of river-valley segment, embayment, and coastline, altering contaminant retention/exchange	Interaction among hydrologic regime, geomorphic), and wood-recruitment processes that create patterns in mesohabitats (eg. Pools)
	Glacial processes that shaped lake depth, and form and texture of lake-bottom terrain (ridges, troughs, etc)	Glacial processes that shaped topography and texture of lowest river-valley segment, delta, embayment, and coastline.	Glacial processes that shaped watershed size, topography, sediments, and valley structure.
	Sediment erosion, transport, and deposition dynamics influencing texture of lake-bottom sediments.	Coastal/tributary sediment dynamics driving erosion, transport, and deposition of contaminants within coastal habitats.	Watershed-/valley-specific sediment dynamics driving erosion, transport, and deposition of sediments within channel and flood plain.
Hydrologic	Seasonal lake mixing that drives contaminant resuspension from sediments.	Large-scale currents, upwellings, and storm-induced surges that drive contaminant and pathogen dispersion and deposition.	Tributary flow regime driving instream dispersal and transport of chemicals and pathogens.
	Large-scale currents that drive contaminant and pathogen dispersion and deposition.	Groundwater flow and delivery of contaminants and pathogens.	Groundwater flows that contribute dissolved contaminants to tributaries.
	Persistence within the system due to physical/chemical properties determining contaminant half-lives.	Topography/hydraulics of river-valley segment, embayment, and coastline influencing water retention and exchange with open lake.	Watershed-driven, tributary flow regimes driving instream clarity, nutrient, and temperature regimes.
	Changing water levels that effects water and sediment temperatures	Tributary inflow regimes influencing clarity, nutrient, and temperature regimes.	Surface runoff that may deliver or disturb sediments.
Biological	Fish life history, foraging ecology, and metabolism.	Methylation of mercury by bacteria.	Presence, survival, and reproducibility of pathogens.
	Methylation of mercury by bacteria.	Impact of terrestrial and aquatic invasive species	Toxicity from water- and sediment-related contaminants.
	Distribution and dynamics of floating and sunken wood debris recruited from coasts and tributaries.	Distribution and dynamics of juvenile fishes produced in open-lake, coastal/nearshore, and tributary habitats.	Dynamics of aquatic and wetland macrophytes, and terrestrial plants.
Societal	Restructuring bottom and altering nutrient pathways by nuisance dreissenid mussels.	Piers and breakwalls modifying shoreline processes	Channelization that modifies contaminant deposition vs dispersal to coastal and offshore zones.
	Climate change altering seasonal lake temperatures and ice regimes.	Eutrophication-driven high algal concentrations shading bottom.	Point-source and nonpoint source runoff from industrial and agricultural land use
	Siting of offshore spoil areas for contaminated dredging materials.	Reduced hydrologic connectivity with coastal wetlands.	Diking/hardening of channel that reduces habitat complexity in channel & flood plain.
	Nuisance effects from accidental species introductions.	Fishery practices determining targeted species and locations.	Development within flood-plain valleys that eliminates wetland services.

	Open lake	Coastal/nearshore	Watershed
Geomorphic		Topography and hydraulics of embayment, and coastline influencing contaminant retention and exchange with open lake.	Sediment dynamics.
		Substrate adherence and leaching from substrate.	Watershed area and slope.
		Coastal sediment dynamics driving erosion, transport, and deposition of contaminants within coastal/nearshore habitats.	Groundwater hydrogeology.
Hydrologic	Large-scale currents that drive contaminant dispersion and deposition.	Currents that drive contaminant dispersion and deposition.	Tributary flow regime driving instream dispersal.
	Effects of seiches	Persistence within the system due to physical and chemical properties determining contaminant half-lives.	Groundwater flow paths.
		Dispersion and physical processing.	Differential transport and persistence of different microbes.
		Lake-groundwater interaction.	Overland flow, infiltration, and associated contaminant transport to surface and groundwater systems.
Biological		Natural sources, such as birds and wildlife.	Natural sources, such as birds and wildlife.
		Cladophora growth and decay.	Survival, refugia, and naturalization of fecal indicator bacteria and pathogens.
Societal	Boat and ship waste dumping.	Storm drains that deliver biological contaminants.	Manure application and runoff into nearby waters.
		Shoreline septic systems that deliver biological contaminants.	Failing or leaking municipal sanitary waste systems, combined-sewer overflows, and sanitary-sewer overflows.
		Substrate adherence and leaching from substrate.	Wastewater-treatment-plant effluent discharges.
		Impervious surfaces in beach catchment.	Altered sediment dynamics.
		Contaminated nearshore groundwater.	Channelization and artificial reservoirs that modify contaminant deposition versus dispersal to coastal/nearshore and offshore zones.

Appendix F List of Workshop Participants

First	Last	Organization
Randy	Lehr	Northland College
Terry	Brown	University of Minnesota - Duluth
Amy	Eliot	University of Wisconsin - Lake Superior Research Institute
Lucinda	Johnson	University of Minnesota - Duluth
Thomas	Cermak	Pennsylvania Sea Grant
Anthony	Foyle	Pennsylvania State Erie - The Behrend College
Frank	Lichtkoppler	Lake County, OH
Tom	Bridgeman	University of Toledo
Gene	Clark	Wisconsin Sea Grant
Titus	Seilheimer	Wisconsin Sea Grant
Anna	McCartney	Pennsylvania Sea Grant
David	Skellie	Pennsylvania Sea Grant
Philip	Willink	Shedd Aquarium
Becky	Sapper	Lake Superior National Estuarine Research Reserve and University of Wisconsin - Extension
David	Bolgrien	U.S. Environmental Protection Agency
Bradley	Frazier	Bureau of Indian Affairs
Ulf	Gafvert	National Park Service - Apostle Island National Lakeshore
Jay	Glase	National Park Service - Apostle Island National Lakeshore
Ted	Koehler	U.S. Fish and Wildlife Service - Coastal Program
Ted	Angradi	U.S. Environmental Protection Agency
Brenda	Moraska Lafrancois	National Park Service
Paul	Seelbach	U.S. Geological Survey - Great Lakes Science Center
Julie	Van Stappen	National Park Service - Apostle Islands National Lakeshore
David	VanderMeulen	National Park Service -Apostle Islands National Lakeshore
Mark	Vinson	U.S. Geological Survey - Great Lakes Science Center, Ashland Station
Jon	Hortness	U.S. Geological Survey
Lisa	Fogarty	U.S. Geological Survey
Amie	Brady	U.S. Geological Survey - Ohio
Mark	Rogers	U.S. Geological Survey
Richard	Bartz	U.S. Geological Survey
Kristi	Arend	Old Woman Creek National Estuarine Research Reserve
Brad	Potter	Upper Midwest and Great Lakes Landscape Conservation Cooperative
Rachael Franks	Taylor	National Oceanic and Atmospheric Administration - Coastal Zone Management
Thomas	Bergman	Comprehensive Planning/Land & Zoning - Iron County, WI
Larry	MacDonald	Mayor, City of Bayfield
Diane	Nelson	Environmental Works Division - City of Superior

Steve	Roberts	City of Superior, WI
Timothy	Huemmrich	Bureau of Sewers - City of Erie, PA
Karen	Tobin	Department of Health - Erie County, PA
Jake	Welsh	Department of Planning - Erie County, PA
Joe	Cappel	Toledo-Lucas County Port Authority
Steve	Lavalley	Wisconsin Department of Natural Resources - Water Division
Ben	Brockschmidt	Illinois Chamber of Commerce
John	Matousek	Michigan Department of Environmental Quality
Adam	Mednick	Wisconsin Department of Natural Resources
Daniel	Injerd	Illinois Department of Natural Resources
Steve	Greb	Wisconsin Department of Natural Resources
Vic	Santucci	Illinois Department of Natural Resources
Diane	Tecic	Illinois Department of Natural Resources
Matt	Preisser	Michigan Department of Environmental Quality
Timothy	Bruno	Pennsylvania Department of Environmental Protection
MD	Hoque	New York Department of Environmental Conservation
Jim	Lehnen	New York Department of Environmental Conservation
Harry	Leslie	Pennsylvania Department of Conservation and Natural Resources
Jacob	Moore	Pennsylvania Department of Environmental Protection
Barry	Pendergrass	New York Department of State - Office of Planning and Development
Judy	Beck	Lake Michigan League of Women Voters
Mary	Khoury	The Nature Conservancy
Douglas	Pearsall	The Nature Conservancy
Kristy	LaManche	Finger Lakes-Lake Ontario Watershed Protection Alliance
Sandra	Kosek-Sills	Ohio Lake Erie Commission
Jason	Laumann	Northwest Wisconsin Regional Planning Commission
Victoria	Pebbles	Great Lakes Commission
Matt	Doss	Great Lakes Commission
Jennifer	Wasik	Metropolitan Water Reclamation District of Greater Chicago
Tom	Slawski	Southeastern Wisconsin Regional Planning Commission
Lacey	Hill-Kastern	Bad River Band of Lake Superior Chippewa- Natural Resources Department
Jessica	Strand	Bad River Band of Lake Superior Chippewa- Natural Resources Department
Brian	Napont	Grand Traverse Band of Ottawa and Chippewa Indians