Great Lakes Rivermouths

A PRIMER FOR MANAGERS

GREAT LAKES COMMISSION AND
GREAT LAKES RIVERMOUTH COLLABORATORY

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This Primer was prepared by the Great Lakes Commission and is based upon the work of the Great Lakes Rivermouth Collaboratory. Edited by Victoria Pebbles, James Larson and Paul Seelbach.

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Introduction

Between the North American Great Lakes and their tributaries are the places where the confluence of river and lake waters creates a distinct ecosystem: the rivermouth ecosystem. Human development has often centered around these rivermouths, in part, because they provide a rich array of ecosystem services. Not surprisingly, centuries of intense human activity have led to substantial pressures on, and alterations to, these ecosystems, often diminishing or degrading their ecological functions and associated ecological services. Many Great Lakes rivermouths are the focus of intense restoration efforts. For example, 36 of the active Great Lakes Areas of Concern (AOCs) are rivermouths or areas that include one or more rivermouths.

Historically, research of rivermouth ecosystems has been piecemeal, focused on the Great Lakes proper or on the upper reaches of tributaries, with little direct study of the rivermouth itself. Researchers have been divided among disciplines, agencies and institutions; and they often work independently and use disparate venues to communicate their work. Management has also been fragmented with a focus on smaller, localized, sub-habitat units and socio-political or economic elements, rather than system-level consideration.

Restoration of Great Lakes nearshore and tributary ecosystems depends on a more integrated approach that considers the central role of rivermouths.

This Primer presents the case for a more holistic approach to rivermouth science and management that can enable restoration of ecosystem services with multiple benefits to humans and the Great Lakes ecosystem. A conceptual model is presented with supporting text that describes the structures and processes common to all rivermouths, substantiating the case for treating these ecosystems as an identifiable class.[1] Ecological services provided by rivermouths and changes in how humans value those services over time are illustrated through case studies of two Great Lakes rivermouths—the St. Louis River and the Maumee River. Specific ecosystem services are identified in *italics* throughout this Primer and follow definitions described by the Millennium Ecosystem Assessment (Table1). Collectively, this primer synthesizes existing information in a new way that aims to support management of rivermouths as distinct and important ecosystems. The development and management decisions made around rivermouths today will shape the future of these ecosystems, and the human communities within them, well into the future.

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[1] The information presented in this paper was derived from discussions and draft documents of the Great Lakes Rivermouth Collaboratory. The Great Lakes Rivermouth Collaboratory was established by the U.S. Geological Survey's Great Lakes Science Center (USGS-GLSC) in collaboration with the Great Lakes Commission to engage the Great Lakes scientific community in sharing and documenting knowledge about freshwater rivermouth ecosystems. For more information, see http://www.glc.org/habitat/Rivermouth-Collaboratory.html.

Rivermouth Characteristics

Rivermouths are the mixing zones that occur at the confluence between Great Lakes tributaries (riverine ecosystems) and the Great Lakes. As such, these ecosystems are transitional, dynamic places that have some riverine and lake characteristics as well as features that are unique to the rivermouth ecosystem itself.

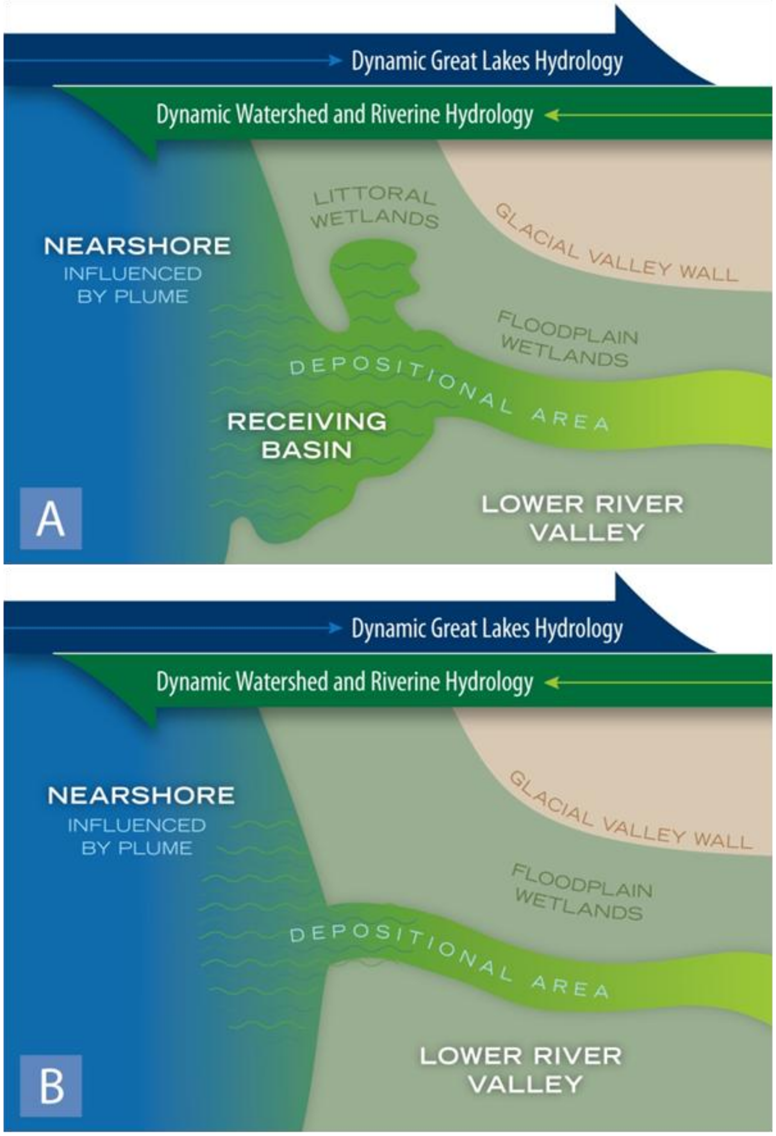

Figure 1: Some rivermouths have large, estuarine receiving basins (A) while others connect directly to the nearshore zone (B).

Rivermouth Structure

Rivermouths can be characterized by their physical structure or environment in which they occur. The rivermouth ecosystem extends upstream to the furthest extent of Great Lakes influence and into the Great Lake as far as the river plume is distinct from Great Lakes waters. Rivermouths can be generally divided into three zones: 1) the lower river valley; 2) a receiving basin or hydrologic storage area; and 3) the plume-influenced nearshore. Each zone has three dimensions: vertical, longitudinal and lateral. First, rivermouths occur within lower river valleys—the final portions of the rivers where valley slope is low, wetlands and floodplains may be extensive, and floodplains are frequently inundated. Sediment erosion and deposition in the lower river valley are influenced by strong lake seiches. These influences may extend long distances upstream, far from the actual lake itself. Second, rivermouths are characterized by a receiving basin or hydrologic storage area where the river channel transitions to a more lake-like (lentic) environment and deposition rates can be very high. The receiving basin/storage area can be wide and shallow, deep and lake-like, enclosed or semi-enclosed, or absent altogether, depending on the local coastal geomorphology. Finally, all rivermouths have a nearshore area that is influenced by the plume of material flowing out of the receiving basin (or storage area). Bathymetry, rivermouth morphology and typical wind patterns all determine the timing and extent to which the plume influences the nearshore area. As a result, the plume leaving the river can be wide or narrow; can be directed out into the lake or along shore by lake currents and nearshore thermal gradients. These elements are presented conceptually in Figures 1A and 1B. Figure 1A and 1B show two contrasting rivermouths. Figure 1A shows a rivermouth with a distinct receiving basin that is wide, shallow and semi-enclosed, enabling water mixing to occur within the receiving basin, while Figure 1B shows a rivermouth where the receiving basin is virtually absent and water mixing occurs within the nearshore zone.

Rivermouth Processes and Geographic Setting

Just as rivermouths are physically located at the convergence of rivers and lakes, their underlying processes can be characterized as a mixing zone between river and lake processes: the place where waters and associated materials from river and lake interact. The relative magnitude of inputs from river and lake sources to the rivermouth is determined by landscape and coastal physiography, weather patterns, watershed morphology (tributary drainage area and flow regime) and, of course, human development patterns and engineering interventions. As a result, the location, area, shape and intensity of the mixing zone is dynamic and varies (vertically, longitudinally and laterally) both among rivermouths and through time.

Rivermouths are biologically productive, transitional ecosystems that provide diverse habitats and exhibit dynamic chemical gradients.

Flow regime has an overwhelming influence on riverine ecosystems and is likely to have similarly strong effects within rivermouths. Great Lakes tributaries vary greatly in their natural flow regimes due to geography—from very flashy to very stable—and those flow regimes can be significantly affected by the surrounding land use in the watershed. Tributary size and episodic and seasonal weather patterns are also important in determining the extent to which the rivermouth is influenced by the river and river valley. Similar to marine estuaries, rivermouth ecosystems exhibit a range of water retention times. Sediment, nutrient and contaminant delivery, deposition, and flushing rates are controlled, in part, by river flow and vary depending on baseflow characteristics, storm events and spring runoff periods.

Like their marine counterparts, freshwater estuaries feature biologically productive areas that provide critical habitats for the life-cycles of many species. Unlike marine systems, freshwater rivermouths have not been recognized as the focus of conservation and management programs.

The same watershed characteristics that affect river water also affect nearshore lake water, but those effects are moderated in the rivermouth by lake processes that occur more slowly over larger areas. Persistent seiches, currents and episodic storm surges (influenced by wind direction and fetch length), can move lake water into rivermouths resulting in dramatic differences in the extent of lake-water inputs into rivermouths. For example, larger rivermouths with a more open receiving basin take in more total volume of lake water for a given seiche. Also, depending on the rates of lake water inputs relative to tributary water inputs, the location of mixing between these two water sources can migrate through the rivermouth. For example, a system with strong tributary flows may cause the receiving basin of a rivermouth to be composed of primarily river water, with water mixing occurring in the nearshore. However, in rivermouths with lower tributary flows, or oriented such that strong wind-driven lake inputs occur, water mixing may occur in the receiving basin itself, or even further up into the river valley. Additionally, seasonal cycles in Great Lakes water levels interact with seasonal tributary cycles to produce variations in inundation depths, water sources and residence times, as well as mixing and stratification patterns.

Unique Geographic Setting

Rivermouth zones are dynamic and can move vertically, laterally and longitudinally in response to a rivermouth's local geography. The local geographic setting interacts with the river and lake hydrologic regime to determine rivermouth hydrology and habitat structure (e.g., bathymetry, water residence times, sediment composition and shoreline exposure). Glacial and Lake level histories largely determine the degree to which Great Lakes rivermouths have been carved into deep (sometimes drowned) channels versus filled with sand or mud-flats, how steeply banks slope, and the extent to which rivermouths develop floodplains and seasonally connected backwater areas. Local topography and shoreline orientation determine the degree of exposure to or shelter from wind and waves, and the orientation of the opening from the rivermouth to the lake. While the size of the mouth opening depends on river size, the geographic setting dictates the slope of the lower rivermouth zone, with implications for lake water inflow and access to lacustrine fish and invertebrates. Thus, the physiographic setting plays a substantial role in structuring a major habitat element of rivermouth ecosystems. [2]

Provisioning Services *Products obtained from ecosystems*	**Regulating Services** *Benefits obtained from maintaining ecosystem processes*	**Cultural Services** *Nonmaterial benefits*
Fish production (commercial and sport fisheries)	Harbor (storm protection)	Aesthetics (viewscapes)
Wildlife production	Erosion and sedimentation regulation	Recreation (boating, fishing, beach use)
Water supply (municipal and industrial)	Water quality regulation	Tourism
Floral production (e.g., wild rice)	Waste Assimilation	
Supporting Services *Services necessary for the production of all other ecosystem services*		
Nutrient Processing	Primary Production	Habitat Complexity

Table 1: Great Lakes Rivermouth ecosystem services as developed by the Great Lakes Rivermouth Collaboratory

This table was inspired by and builds on the Millennium Ecosystem Assessment (MEA) categorization scheme. The designation of some of these services is subtly different than designations used in other schemes to emphasize the particular human uses believed to be important. For example, the particular properties of rivermouths that make them useful for navigation are collected in the term Harbor, which includes storm protection (by reducing wave-energy through the maintenance of sand bars and embayments). This list may not be comprehensive and follows the MEA definitions that may not be appropriate for strict economic analysis but is an initial framework for discussing the human services provided by rivermouth ecosystems.

The particular structure and function of each rivermouth is controlled by the unique combination of river, lake and local conditions, and the type and extent of human influence on those conditions. It is

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[2] Much more detail on the physical, chemical and biological aspects of Great Lakes rivermouths, along with complete references, is provided in *Great Lakes Rivermouth Ecosystems: Scientific Synthesis and Management Implications.* Journal of Great Lakes Research (publication forthcoming) 2013.

precisely their highly dynamic and variable character that makes these ecosystems important and unique. Nonetheless, as illustrated above, there are processes and physical characteristics common to all rivermouth systems, suggesting the propriety of considering these systems as a collective whole. Further, intense research efforts on a handful of individual rivermouths (e.g., the Maumee [OH], the Muskegon [MI], and the St. Louis [MN, WI]) and coastal wetlands can be used to develop a more holistic understanding of rivermouths as a class.

Rivermouth Ecosystem Services

The dynamic properties of rivermouths enable these ecosystems to provide a diversity of services. Ecosystem services are the benefits people obtain from nature. These include the physical products extracted from those ecosystems [e.g., *fish and flora production* (e.g., food), *water supply]*, the functions that ecological processes perform (e.g., *waste assimilation, flood control*), the cultural values associated with particular ecosystems (e.g., *recreation, aesthetics*), and the structures and processes that allow ecosystems to support these other services (e.g., *primary production*). Although other frameworks for defining and assessing ecosystem services exist, we have used the Millennium Ecosystem Assessment framework to create this initial list of services (Table 1).

Great Lakes rivermouth ecosystems have long supported the social and economic networks that surround the Great Lakes. These systems were vital to Native American cultures, served as focal points for European settlement of the Great Lakes region, and continue to be centers of urbanization, industrial development and recreation. Individual rivermouths provide services to local communities, while rivermouths, as a class, contribute to the services provided by the broader Great Lakes ecosystem. As a result of their ecological variability, there is considerable variability in the type and the location of the most important ecosystem services in rivermouths.

Quantifying the link between rivermouth ecological processes and the ecological services derived from them remains an area of active research. This is because the underlying ecological processes are still being investigated and, in part, because the analytic tools are not well-developed and have not been widely used to quantify related benefits from ecosystem services. Some ecosystem services are not readily valued with traditional, market-based approaches (e.g., *aesthetics* and *waste assimilation*); as a result, their importance is underappreciated by society and weighing the cost of their loss is difficult.

Other ecosystem services associated with rivermouths (e.g., *harbor*, *fish production*) are widely appreciated and more easily valued through traditional markets. Management of the rivermouth as a system should consider all ecosystem services, not just those that pass through traditional markets (i.e., those that are relatively easy to value). Managing for habitat conservation can enhance multiple ecosystem services. For example, restoring wetlands can enhance nutrient removal (*water quality regulation*) and *waste assimilation*, *fish production*, *aesthetics* and *habitat complexity*.

The provisioning of ecosystem services by rivermouth ecosystems in the Great Lakes has been deeply altered by human activities at regional and local scales, both intentionally and inadvertently. In many cases, services that can be easily assessed with traditional markets have been enhanced at the expense of other services. For example, infrastructure development such as pier construction, dredging, and shoreline armoring to enhance shipping and nearshore industries (i.e., enhancing services such as *harbor* and *erosion, and sedimentation regulation*) lead to reduced water residence times, microhabitat diversity, and the loss of shallow, metabolically active habitats. In turn, these changes often reduce fish production and recreational opportunities. Physical modifications within the rivermouth itself have tended to act synergistically to degrade many ecosystem services by promoting riverine and minimizing lake habitat.

Broader-scale impacts to rivermouths include intentional and inadvertent manipulations to the climate, landscapes and lake water levels. For example, increased flashiness and nutrient loads are associated with urban and agricultural development. Increased nutrient and sediment loading and hydrologic manipulation can facilitate dominance by vascular plants with poor habitat value and by toxin-producing strains of cyanobacteria. Agricultural development generally results in greater sediment loading, which can, in turn, require more dredging. Agricultural development may further result in drastically altered littoral vegetation and changes in the composition of primary producers and consumers. Often, the tolerant fauna that come to dominate degraded rivermouth locations are considered undesirable for fish production. In general, increasing intense human land uses in the watershed results in corresponding shifts of the biotic community of rivermouth food webs to “undesirable” or invasive species. These species are generally considered to be less valuable than native species in that they tend to reduce *habitat complexity* and other supporting ecosystem services (Table 1). Other broad-scale impacts such as climate change and fluctuating lake water levels are also likely to have significant, but poorly understood, impacts on rivermouths.

Rivermouth Conservation and Management

Management decisions affecting Great Lakes rivermouths are made by public and private entities representing different interests at many different scales. These decisions are often driven by a narrow focus such as industrial or residential development, navigation or remediation of legacy contaminants. For example, channelization, dredging and fill of depositional areas may enhance some ecosystem services but likely reduce the suite of services we associate with rivermouth ecosystems, because they make these areas less like a rivermouth and more like ‘just’ a river. Although not necessarily perceived as “management of rivermouths,” these activities influence the ecological processes that generate ecosystem services in the rivermouth and should thus be recognized as rivermouth management decisions.

Management and conservation activities intended to promote a particular ecosystem service often influence the provisioning of other services. A holistic approach would explicitly recognize all ecosystem services and carefully evaluate and account for ecosystem service gains and losses associated with any management decision.

A plethora of federal, state and local laws bracket the range of decisions available to decisionmakers at rivermouths, but most decisions are ultimately made at the local level. U.S. programs operated by state or federal agencies (e.g., U.S. Army Corps of Engineers, U.S. Environmental Protection Agency) often strive for coordination and promote a holistic approach in principle, but are limited by time and resource constraints that can complicate integrative management approaches. Conservation authorities on the Canadian side operate at the watershed scale and have a bit more holistic approach.

In contrast to marine estuaries, which have received distinct recognition in federal and state environmental policy, rivermouths have not received attention as a distinct ecosystem type. Consequently, management and conservation activities in rivermouths have been generally focused on preventing or mitigating a specific impact (e.g., habitat loss or erosion) or enabling a specific service (e.g., *harbor*, *sedimentation regulation* for navigation).

At different points in time, society has valued some ecosystem services over others. For example, at times when *harbor* services are particularly valuable, management decisions (e.g., dredging) might promote that service with little or no regard to how that decision impacts other services (e.g., *habitat complexity*) (Figure 2). Some services may not be consciously acknowledged or well understood if they have always been available without cost or interruption. In these instances, ecosystem services are often not recognized until they are no longer available or they have been seriously degraded.

"Ideally, management and policy decisions, and economic transactions would include evaluation of perceived (qualitative) or actual (quantitative) value of all rivermouth ecosystem services. A first step is to identify and document all of the inherent ecosystem services and to map the location of those services within the rivermouth. Next, is to identify the actual or potential beneficiaries (human and non-human) of each of those services and engage those beneficiaries in a dialogue or exercise to articulate and/or quantify the benefits they receive from various ecosystem services. These steps offer a starting point to assess the extent to which decisions might impact a particular set of ecosystem services and the effect of that impact relative to all the other ecosystem services. More fundamentally, this approach will expose and raise awareness of the full array of ecosystem services and those who stand to gain or lose from a given management decision.

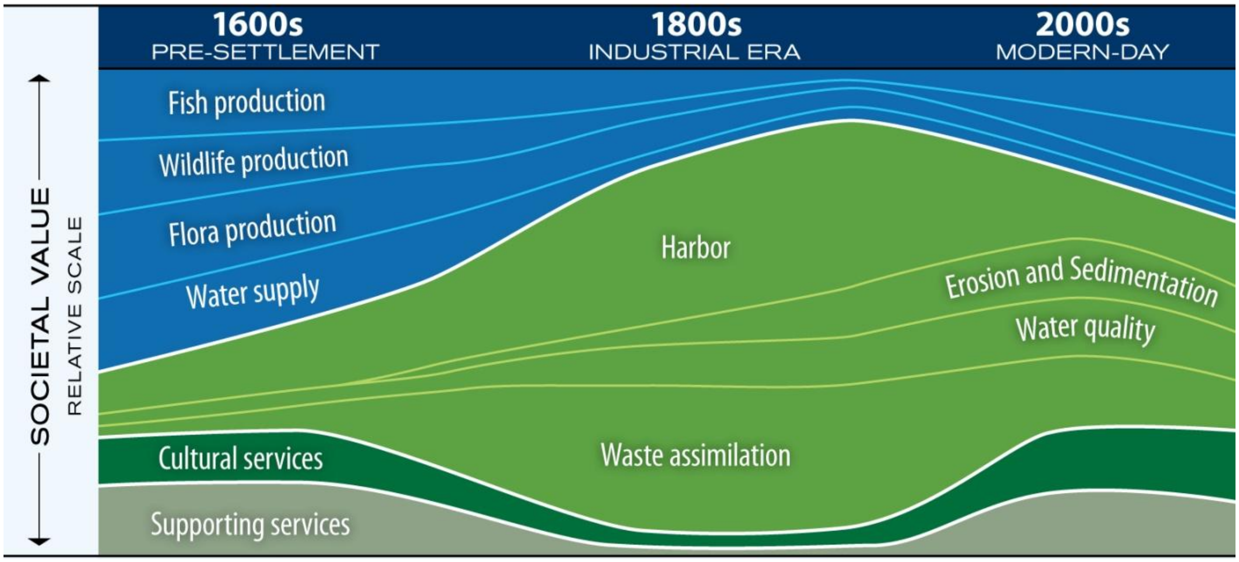

Figure 2. Over the last several hundred years, the values of communities around the Great Lakes have changed considerably and so has the importance of particular rivermouth ecosystem services (hypothetical example shown).

At the end of this primer is a checklist that, absent more robust decision support tools, can help decisionmakers consider the cascading effect of one decision on the entire suite of rivermouth ecosystem services. Those who use the checklist in concert with the steps outlined above will be better equipped to ascertain whether an activity to protect or enhance one ecosystem service might impair or enhance other rivermouth ecosystem services.

Case Studies

The following two case studies illustrate how changing values, and resulting conservation and management decisions, affect the ability of the rivermouths to deliver ecosystem services. These two Great Lakes rivermouths are geographically and ecologically distinct, with different structure, function and, accordingly, some inherent differences in ecological services. Both have experienced intensive use, modification and degradation; and both are the focus of ongoing conservation and restoration efforts. It is hoped that these case studies are the beginning of a much longer set of stories that illustrate the lessons learned from, and opportunities to improve on, conservation and management of Great Lakes rivermouths.

The St. Louis Rivermouth

Introduction

The St. Louis River runs 179 miles through Minnesota and Wisconsin and drains 3,634 square miles into the western edge of Lake Superior at the towns of Duluth, Minn., and Superior, Wis., to form a 12,000 acre rivermouth system (Figure 3). The rivermouth is protected from the harsh forces of wind and waves of Lake Superior by a baymouth sandbar.[3] Historically, there was a single opening to Lake Superior present on the far eastern side of the bay. With protection from scouring waves along with the co-mingling waters of Lake Superior, the St. Louis River and the Nemadji River created a dynamic, productive rivermouth system. Historic accounts of the region tell of the broad expanse of shallow, emergent marshes and braided channels within the St. Louis rivermouth system that provided an array of ecosystem services.

Figure 3: Aerial View of the St. Louis Rivermouth (courtesy of Google Earth).

Early Uses of the St. Louis Rivermouth

Prior to European settlement, the bountiful crops of wild rice and large populations of lake whitefish and lake sturgeon found in the estuary supported the Fond du Lac band of Lake Superior Chippewa (*fish*

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[3] Baymouth sandbars are long, narrow bands of sand deposited across bays by wind and wave action, and are unusual, in Lake Superior, the Great Lakes and globally.

production, wild rice production). At the time of European arrival (late 1600s), Native Americans used the rivermouth as a source of food (f*ish production, wildlife production*), drinking water (*water supply*), waste removal (*waste assimilation*) and transportation (*harbor*). European settlement of the area was motivated by the safe *harbor* provided by the rivermouth and the easy access the St. Louis River provided to the interior of North America via the short portage to the Mississippi River watershed. Early outposts would have involved only small-scale shoreline modifications.

Industrial Era

The 1855 construction of locks at Sault Ste. Marie, Mich., made possible an unobstructed water shipping route between Lake Superior and the lower Great Lakes and facilitated exploitation and transport of natural resources (e.g., iron ore, coal, lumber) from the surrounding area.r. In 1872 a ship canal was cut through the sandbar to provide a second egress from the rivermouth and in 1873 dredging of the lower rivermouth began in earnest. These events mark the advent of large-scale manipulation of the rivermouth to enhance a subset of ecosystem services (*harbor, water supply*). By 1902 the rivermouth receiving basin supported a harbor that included 17 miles of shipping channels excavated to a depth of 20 feet, and numerous docks. Shoreline armoring and an extensive waterfront road and railroad network were constructed to support the rivermouth port, which became the western hub of a Great Lakes industrial system. Ready access to fresh water and transportation fueled the growth of other waterfront industries, including breweries, oil refineries, steel mills, tanneries, sawmills, and pulp and paper factories. Many of these industries discharged solid and liquid waste directly to the rivermouth (*waste assimilation*).

Over the same period, the St. Louis River ceased to be a significant provider of other lesser-valued ecosystem services. Shipping-related dredging, infilling and shoreline hardening eliminated large areas of wetland and littoral habitat, reducing the ability of the system to provide *nutrient processing*, *primary production*, *habitat complexity* and the associated services that depend on these fundamental ecosystem services: *fish production, flora production,* and *aesthetics.* Widespread anoxia and chemical contamination, resulting from waste discharges, decimated benthic invertebrate and fish communities including valued species such as walleye and lake sturgeon. Water quality became problematic for human use, as evidenced by bathing advisories (excessive bacterial counts), an unpleasant taste and odor in fish, and aesthetic issues such as oil slicks and fish kills.

Modern Day Issues and Management Approaches

Although impacts of pollution on water quality and fisheries had been known for decades, the creation of the Western Lake Superior Sanitary District (WLSSD) in 1971 marked the first tangible response within the St. Louis rivermouth to an increasing environmental awareness and concern by the American public. The formation of the WLSSD, combined with initiatives prompted by the 1972 Clean Water Act, lead to the creation of combined residential and industrial wastewater treatment plants in Duluth, Minn., and Superior, Wis., in the late 1970s. Installation of modern treatment facilities lead to a rapid improvement in dissolved oxygen levels, especially in the upper portions of the system where high biological oxygen demand associated with pulp and paper discharges had regularly produced anoxia. This, along with fish stocking throughout the 1980s, led to a gradual improvement in fish quantity and quality. Recovery of aquatic communities was also aided by a variety of site-specific sediment cleanup and habitat restoration efforts, fueled by designation of specific hazardous waste sites under the Superfund program and by designation of the entire St. Louis rivermouth as an Area of Concern (AOC) under the Great Lakes Water Quality Agreement. Today the rivermouth provides a greater diversity of ecosystem services to the surrounding community (*harbor, recreation, aesthetics, tourism, fish production).* Shipping and heavy industry remain important to the economies of Duluth and Superior, but tourism and recreation fueled by good fishing, clean water and beaches, and attractive waterfront locations have also become prominent. Improvements notwithstanding, the rivermouth is still an Area of Concern and there are many impediments to full recovery—where the rivermouth provides the diversity and robustness of ecosystem services inherent to the system. Key challenges that remain include excessive nutrient and sediment loading (restoring *nutrient processing*; Figure 4), fish consumption advisories (restoring f*ish production*) and combined sewer overflows (restoring *waste assimilation*). State and tribal resource management agencies have established AOC coordinators to help facilitate efforts that restore multiple beneficial uses, which should also support restoration of associated ecosystem services in the St. Louis Rivermouth and other rivermouth AOCs.

Figure 4: The waters of the St. Louis River turned orange as suspended clay particles were washed downstream by the record breaking rains of June 2012. Image courtesy of Minnesota Public Radio. Though not typical, extreme storm events like this may become more frequent with climate change.

The Maumee Rivermouth

Introduction

The Maumee River has the largest drainage area of the Great Lakes tributaries, running 137 miles and draining all or part of 25 counties located within three states (Ohio, Michigan and Indiana) for a total drainage area of 8,316 square miles. The Maumee River flows into Maumee Bay, a large, shallow (21 sq. miles, average depth of 5 feet) and relatively open receiving basin on the western shore of Lake Erie, near Toledo, Ohio. Due to the large drainage area, the Maumee River is the largest contributor of sediment and associated nutrients to Lake Erie. While problematic in excess, these nutrient subsidies fuel nearshore fish and wildlife production, and contribute to the high levels of productivity (e.g., primary production) in the western basin of Lake Erie. Figure 5 depicts the spatial location of some ecosystem services within the Maumee rivermouth.

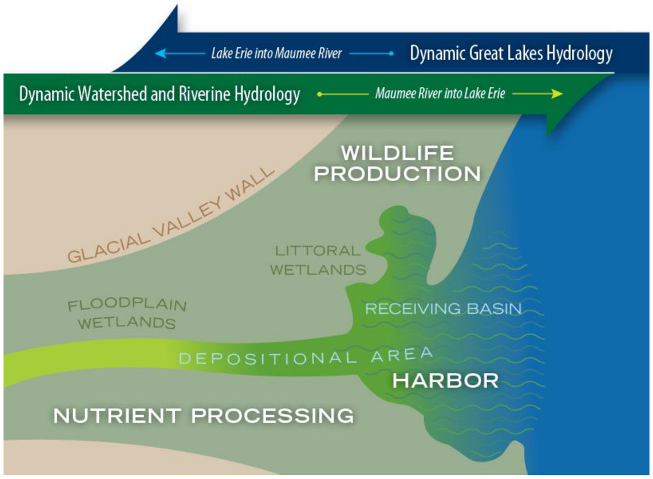

Figure 5: Schematic of Ecosystem Service Locations within the Maumee Rivermouth.

Early Uses of the Maumee Rivermouth

The Maumee basin was one of the last areas around Lake Erie to be settled by Europeans due to the presence of an expansive (<1,500 square mile) forested wetland, known as the Great Black Swamp. Maumee Bay was thought to provide the most prolific fish spawning habitat in Lake Erie and Native Americans and early settlers used the area mainly for *fish and wildlife production.* Drainage of the Great Black Swamp, for agriculture and timber, was initiated in the 1840s and involved the installation of an extensive system of ditches and tile drains that quickly moved water from forested wetlands and fields into streams and rivers. Drainage made productive farming possible, but destroyed habitat for *fish and wildlife production* and provided a direct route for nutrients and sediment runoff to Lake Erie, which impaired services such as *municipal and industrial water supply* and *erosion and sedimentation regulation*.

Industrial Era

Between the late 1800s and mid 1900s, the Maumee River was used heavily to ship oil, natural gas, coal and other minerals, and the *harbor* services provided by the rivermouth were of great value. Toledo experienced large population growth and was one of the top 30 most populated cities in the United States, increasing the use of Lake Erie as a dependable source of *municipal water supply*. Industrial growth was also rapid during this period. Economic activity in the Maumee rivermouth depended on a reliable *industrial water supply* to support manufacturing for the auto and glass industries as well as oil refineries. However, Maumee River floodplains, wetlands and waterways were used extensively for *waste assimilation* as untreated industrial wastes were discharged directly into wetlands and waterways. As a result of the unregulated, overuse of these certain ecosystem services, other services were degraded or destroyed, notably *aesthetics, beach use, recreation and water quality*.

By 1930, Maumee Bay was the most polluted area in the western basin of Lake Erie. Industrial waste and agricultural runoff fouled waters, led to dead zones (*i.e.,* areas with low dissolved oxygen) and increased turbidity. Simultaneously, remaining wetlands were drained and converted to agricultural production throughout the watershed. These hydrologic alterations further impaired the ability of the system to provide those ecosystem services, which were seemingly valued insofar as they were heavily relied upon for human activities such as *waste assimilation, primary production, nutrient processing, or fish* and *wildlife production.* The lack of explicit valuation of these services through economic or social transactions likely led to the exploitation of the rivermouth until it was so impaired that it was no longer able to provide the services that people relied on directly or indirectly.

Modern Day Issues and Management Approaches

Despite knowledge of serious environmental degradation and loss of services, remedial actions in the Maumee rivermouth did not commence in earnest until the late 1960s and early 1970s during a period of rising environmental awareness, which led to the passage of the U.S. Clean Water Act and the binational Great Lakes Water Quality Agreement in 1972. In 1987 under the Great Lakes Water Quality Agreement, the Maumee River was designated as a Great Lakes Area of Concern along with many other Great Lakes rivermouths, including the St. Louis River. Focused efforts on the Maumee led to improvements in aesthetics and water quality.

Concurrently, growing recognition that waterfowl populations were in decline led to an increased emphasis on *wildlife production* and *recreation* services and the restoration and protection of wetland areas. Wetlands were "restored" by developing an extensive system of dikes, or earthen berms, constructed to sustain wetland conditions and facilitate management. However, these dikes also reduced the connectivity between the rivermouth and its supporting wetlands, preventing organisms such as fish from accessing wetlands for spawning, and hampering the rivermouth's ability to provide *water,* and *erosion* and *sediment regulation*.

Figure 6: Aerial View of the Maumee Rivermouth and Bay (courtesy of Google Earth, 2011).

Restoration of the Maumee rivermouth has been slow and complicated by the sheer size of the watershed (more than 8,000 square miles) and the broad scope of issues and stakeholders. Restoration of ecosystem services such as *nutrient retention* and *sediment regulation* has been particularly slow or neglected in favor of other services such as use of the *harbor* and agricultural uses (*flora production);* outside the rivermouth proper but in the surrounding watershed). Phosphorus and sediment loads remain high within the Maumee rivermouth (Figure 6). Extensive annual dredging of Maumee Bay (nearshore zone of the rivermouth) is necessary to maintain the *harbor*. Legacy issues from the industrial era, and an increase in harmful and nuisance algae, such as the record breaking toxic algal bloom in late summer and early fall of 2011, further degrade the capacity of the system to provide ecosystem services once inherent to the Maumee rivermouth.

The recent emphasis on delisting AOCs coupled with increases in the occurrence of harmful algal blooms has renewed focus on the Maumee rivermouth with particular attention to water quality (*water supply*), fishery (*fish production*), habitat (*habitat complexity*) and resource use issues (e.g., *recreation*). However, if ecosystem services are evaluated independently, rather than in an integrated fashion, this may lead to project outcomes with competing purposes.

There is evidence of mounting support for a more holistic approach. The Maumee was recently designated a priority watershed by the U.S. EPA, which has led to increased funding by organizations that require collaborative partnerships. Examples of such partnerships include: 1) the Lake Erie Synthesis Team; 2) a partnership between Ohio State University and Case Western Reserve University to investigate how public perception, climate change and land use in the Maumee watershed may be impacting ecosystem services in Lake Erie; and 3) a partnership between Ohio EPA, Ohio DNR, Division of Wildlife, University of Toledo and Heidelberg University to monitor water quality and fish in the nearshore zone including the Maumee, Portage and Sandusky rivermouths. While the focus on collaborative research, modeling and monitoring is expanding our knowledge of the Maumee Rivermouth system, the impact of restoration efforts on rivermouth ecosystem services is harder to evaluate. Further research and related management efforts are needed to assess progress beyond removing "beneficial use impairments" to restoring ecosystem services.

Conclusion

Great Lakes rivermouths are unique ecosystems that provide a shared, yet diverse, suite of ecosystem services. Research on Great Lakes rivermouths to date has been piecemeal; the bulk of relevant research has focused on certain river or lake processes or areas, but not directly on the rivermouth itself. Management and restoration of these systems have similarly been fragmented across multiple jurisdictions and decisionmaking authorities. This primer is based on a seminal effort of the Great Lakes Rivermouth Collaboratory in 2011 and 2012 to integrate relevant existing research to describe the distinct ecological attributes of rivermouth ecosytems as a class.

The rivermouth ecosystem services described herein are based on relevant work on ecosystem services. These services have been valued differently at different times throughout human history with some services being “enhanced” at the expense of others. At times, focus on a particular set of values, a lack of environmental regulations, and/or an inability to explicitly value these services through economic or social transactions may have led to a “tragedy of the commons,” in which some rivermouth ecosystem services were severely degraded. The St. Louis rivermouth and the Maumee rivermouth are two examples of such extreme degradation and loss of ecosystem services. These also demonstrate some success, and ongoing challenges and opportunities for rivermouth restoration.

Ecosystem services are sometimes discussed prior to planning and management decisions, but a holistic approach calls for a more concerted effort to engage those stakeholders in identifying, documenting, and mapping those services and their value.

Of the 36 active Great Lakes Areas of Concern (24 U.S., seven Canadian, and five binational connecting channels), all but three (92%) are rivermouths or areas that encompass several rivermouths (i.e., harbors and connecting channels). These areas have been the focus of intense political and management efforts to restore “beneficial uses” (remove Beneficial Use Impairments) identified under the Great Lakes Water Quality Agreement. The establishment of AOC coordinators is an institutional change that reflects a more recent shift in management approach. These AOC coordinators could be empowered to take on a more holistic approach in conserving rivermouths. This approach more explicitly recognizes the interconnectedness of resource management decisions and should result in a more comprehensive approach to restoring ecosystem services in rivermouths that are AOCs. However, many Great Lakes rivermouths are not AOCs and, along with the AOCs that have been restored (i.e., delisted), these rivermouths must contend with a confusing array of programs with many agencies having jurisdiction or responsibility for the river’s resources. Thinking about restoring ecosystem services rather than eliminating a problem or impairment requires a change in how we think about rivermouth ecosystems. This change in thinking is analogous to the difference between treating a symptom and improving overall health. Actions addressing specific issues may improve that issue but managing rivermouths as a system is more likely to optimize the delivery of many ecosystem services. A similar, systems-based approach is advocated by the Great Lakes Environmental Assessment and Mapping Project (http://www.greatlakesmapping.org).

Ideally, management and policy decisions would reflect the perceived or actual value of all rivermouth ecosystem services. However, present tools and methods are ill-suited to incorporate those values into economic transactions: they do not provide or enable an assessment of tradeoffs among management and policy decisions or consider how a decision or set of decisions affects a particular set of ecosystem services relative to all the other services provided. When applied along with the steps to identify and map rivermouth services as described above, the checklist provided below can facilitate a more holistic approach for evaluating the impact of individual decisions on, and the potential tradeoffs among, rivermouth ecosystem services.

Rivermouth Conservation and Management Checklist

Use this checklist to consider the impacts of different management decisions on rivermouth ecosystem services and the associated tradeoffs among ecosystem services.

☐ **Fish production (commercial and sport fisheries) (*Provisioning Service)***

- How and Where: Many species pass through rivermouths to upstream river spawning sites. Other species reproduce in rivermouths themselves (low-flow depositional areas). Species spawning both upstream and locally return through the rivermouths to the Great Lakes, often stopping to feed and grow there. Some species use rivermouth depositional areas as nursery habitat.

- Threats: Loss of habitat complexity (through dredging, armoring, vegetation destruction, etc.), reduced water quality, and barriers to upstream and downstream movement may all reduce fish production.

☐ **Water supply (Municipal and industrial) *(Provisioning Service)***

- How and Where: Water supply for municipalities and industry may be derived from within and adjacent to rivermouths. Historically this was a very important service, although nowadays many Great Lakes cities have gone to offshore intake pipes.

- Threats: Churned water (water extracted then re-released into the river or rivermouth) and consumptive uses may change water quality and the seasonal balance of lake and river water in the rivermouth. Shoreline and watershed development as well as legacy contamination can reduce the quality of water for residential or commercial uses.

☐ **Erosion and sedimentation regulation (*Regulating Service)***

- How and Where: Riparian zones and floodplains bordered by low-flow areas (outside of primary channels) allow for both erosional and depositional processes.

- Threats: Wetland fill and development causes a loss of depositional areas, alteration of storm-related flow peaks by impervious surface expansion in riparian areas may lead to increased water power (and thus increased erosion) in areas that were once depositional.

☐ **Harbor (storm protection) (*Regulating Service)***

- How and Where: Protection from Great Lakes storm activity and wave energy depends on the morphology of the rivermouth system.

- Threats: High sedimentation fills channels used by recreational or commercial boats.

☐ **Aesthetics, Recreation (Boating, fishing, beach use) *(Cultural Services)***

- How and Where: The value of the rivermouth to boaters, tourists and other non-consumptive users depends on a variety of factors both easy and difficult to quantify (e.g., perceived natural status, ease of access, etc.).

- Threats: Algal and cyanobacterial blooms, poor water quality, loss of habitat complexity, impacts to the "viewscape" and the loss of productive wildlife and fisheries resources may lead to reduced value.

☐ **Habitat complexity *(Supporting Service)***

- How and Where: Rivermouth ecosystems typically feature a mosaic of habitat types that support high production and diversity of plants and animals.

- Threats: Existing habitat complexity can be reduced by the destruction of depositional areas and the hardening of shoreline (i.e., replacing vegetated shorelines with seawalls or other structures). Dredging and channelization can divert flows away from erosional zones and homogenize flow regimes. Invasive species may homogenize the biophysical structure of an area.

☐ **Nutrient processing *(Supporting Service)***

- How and Where: Nutrient retention occurs primarily in areas with low flow and heavy sediment deposition. Primary production is greater in areas with high levels of nutrients and light.

- Threats: Nutrient retention and processing occurs primarily in areas with longer water residence times (i.e., depositional areas) so activities that channelize the rivermouth or fill depositional areas will dramatically affect nutrient dynamics in the rivermouth.

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