



## 4I. NEARSHORE PHYSICAL PROCESSES

### State of the Ecosystem

#### Introduction

Physical characteristics and natural processes structure, organize, and define aquatic ecosystems and regulate the biological and chemical elements of the system (Poff et al. 1997; Richter et al. 1998; 2000; Baron et al. 2003; Ciruna 2004). The nearshore physical processes of the Great Lakes are much more similar to marine coastal systems rather than the shallow inland lake systems which are commonly used as analogues to the Great Lakes (Goforth and Mackey, 2005). These similarities and differences are primarily due to size, scaling, and energy issues. The Great Lakes are sizeable bodies of water with the potential to rival many marine systems with respect to wave energy and ability to erode and transport geologic materials along the coast.

The physical integrity of the nearshore is based on the idea that sustainable nearshore waters and ecosystems require protection and restoration of nearshore processes, pathways, and landscapes – the three fundamental components of physical integrity (Mackey 2005). Unlike traditional approaches that historically have relied upon the ongoing measurement and monitoring of site-based system components through time, a *process-based* approach considers changes in coastal processes due to altered pathways and landscapes in the coastal margin and nearshore areas.

Even though the impact of shoreline modifications on coastal processes has been known for many decades, the impact of altered coastal processes on nearshore habitat structure, coastal ecosystems, and nearshore water quality is not generally understood. This chapter will briefly explore the concept of physical integrity within coastal margin and nearshore waters and summarize how these concepts can be applied to assess regional changes in habitat structure and impacts on coastal ecosystems.

#### Nearshore Landscapes, Processes, and Pathways

Landscapes include and are defined by the integrated components of land and water area (i.e. geology, geomorphology, and land cover) upon which natural processes act within the Great Lakes basin (Mackey 2005). The most commonly used subunit of landscapes are watersheds. Watersheds are defined by surface and/or groundwater hydrology and represent the surface area that collects and channels water into tributaries that flow into a common main stem or channel. Even though landscapes and watersheds are typically considered to represent areas with some regional extent, the terms are applicable at multiple scales. Terrestrial watersheds are linked to the Great Lakes via hydrology, i.e. the movement of surface or groundwater across and through the landscape along flow paths (pathways) into a Great Lake. The flow paths are controlled by watershed components, generally surface relief and the composition (permeability) of underlying geologic materials within the watershed.

With respect to nearshore systems, coastal margin and nearshore landscape components include river mouths and coastal wetlands; beaches, dunes, and coastal margin swash zones; coastal morphology and composition (cohesive clay bluffs, bedrock, clay banks, thin sand barriers); available sediment supply; nearshore water depths and slope; and shoreline orientation (exposure to wave energy). All of these coastal landscape components are created, maintained, and connected by the interaction of nearshore coastal processes with the landscape (Mackey 2005).

Pathways are defined as the paths along which natural coastal processes act to convey energy, water, and materials through the nearshore system (Mackey 2005). Implied in this definition are: 1) functional pathways, which include functional and physical connections between physical components of the system that includes how energy is distributed within a system, and 2) hydrologic pathways, which include flow paths, hydraulic connectivity, and how water, materials, and energy move through the system. Within nearshore systems, the primary transport mechanisms are linked to the open-lake and are driven by regional flow, wave, or storm-driven processes that transport water, materials, and energy into, through, and out of, coastal margin and nearshore areas. The pathways along which coastal waters move are defined by littoral cells, i.e. reaches of coastline where water and sediments are transported laterally along the shoreline by the energy of waves breaking on the beach. The direction of movement is influenced by prevailing winds and/or the magnitude and frequency of storms and waves impinging on the shoreline.

These littoral cells may span nearshore areas adjacent to several terrestrial watersheds and may or may not be connected to or influenced by these terrestrial watersheds. Even though there are spatial “zones of influence” where tributary outflows may affect nearshore coastal processes for limited periods of time, these zones of influence are highly dynamic and may extend laterally across multiple watershed boundaries. The dynamic nature of these nearshore pathways and variability in coastal transport processes make any meaningful linkages between watersheds and coastal margin/nearshore areas exceedingly difficult. In most cases, traditional watershed paradigms can not be applied to nearshore coastal systems.

Below are descriptions of the hydrogeomorphic processes that may directly (or indirectly) influence coastal margin and nearshore areas of the Great Lakes. Coastal margin and nearshore processes dominate, but locally other processes may also influence the coastal margin and nearshore zones. Table 1 summarizes the attributes, pathways/area, and connectivity of these hydrogeomorphic processes.

- Fluvial processes – Processes associated with channelized flow. These processes and flows are highly dynamic; may be spatially and temporally episodic; are generally unidirectional (down slope); and act within or along linear stream corridors and/or drainage networks within watersheds. Fluvial processes are highly dependent upon lateral hydraulic connectivity with adjacent floodplain and watershed surfaces, and longitudinal down-slope hydraulic continuity and connectivity within stream channels.
- Groundwater processes – Processes associated with infiltration and groundwater flow – hydraulic continuity. These processes and flows may be dynamic; spatially and temporally episodic; unidirectional and/or bidirectional; and may act across broad landscape surfaces and/or within stream channels or lakes. Groundwater processes are highly dependent on potentiometric surface (water table elevation), surficial geology and soils (aquifers), hydraulic continuity (groundwater-surface water connections), and recharge area.
- Coastal margin and nearshore processes – Processes associated with wave and storm-generated currents and flows, except where influenced by fluvial processes and flows near river mouths. These processes and flows are highly dynamic, spatially and temporally variable and episodic, may be oscillatory (bidirectional) or unidirectional, are water-depth dependent; and generally act parallel to shore with a seasonal onshore-offshore component. Coastal margin and nearshore processes are highly dependent on shore-parallel hydraulic connectivity (littoral processes) and shore-normal hydraulic connectivity (deltaic, estuarine, wetland, barrier-dune hydraulic connectivity).
- Open-lake processes – Processes associated with wave and storm-generated currents and flows, superimposed over broad-scale hydraulic (riverine) or thermally driven (seasonal) flows. These processes and flows are dynamic, spatially and temporally variable and episodic, may be oscillatory (bidirectional) or broad-scale unidirectional flows, and act within and between lake sub-basins, major connecting and tributary channel inflow and outflow points. Broad-scale regional unidirectional flows act within and between lake sub-basins and major connecting and tributary channel inflow and outflow points. Open-lake processes are highly dependent on lateral hydraulic connectivity between adjacent water masses and major connecting and tributary channel inflows and outflows.

Insert Table 1. Physical Processes that affect Nearshore and Coastal Margin Zones.

Ecological benefits of water are related to the spatial and temporal pathways within the landscape and the type and severity of impairments. The path that water takes across, or through, the landscape allows biological communities to utilize energy and materials as water moves through the system. There is a time-distance relationship between water and the benefits that water provides to the ecosystem. In general, as flow path complexity increases so do the ecological benefits. Constrained by existing impairments, the ecological value of a gallon of water varies as a function of its location and residence time on, or within, the landscape. Factors that control the time that water stays within the system are: flow velocity, path length (direction and distance traveled), and connections between landscape components. The importance of these factors is clearly demonstrated in riverine systems by the work by Poff et al. (1997) and subsequent work by Richter et al. (1998; 2000), Baron et al. (2002), and others.

Similarly, in nearshore systems, the coastal processes that move water and nutrients along shore provide ecological benefits and create habitat structure. Additional complexity is introduced due to water exchanges between watersheds (river mouths), coastal margin environments (wetlands and embayments), and the open lake. The nearshore zone is the conduit through which those exchanges occur. Changes in Great Lakes water levels can

directly affect where and how these water exchanges occur. Moreover, anthropogenic disruptions to nearshore coastal processes may directly impact these pathways and affect Great Lakes coastal and nearshore ecosystems.

### Pressures

Landscape stressors create hydrologic impairments by altering flow characteristics and/or the functional connections and pathways between fundamental components within the system. Within the Great Lakes, all of the natural processes listed in Table 1 act along pathways or within hydrogeomorphic areas that have been impaired by anthropogenic activity. These impairments affect not only the ability of natural processes to convey energy, water, materials, and biota, but alter the benefits that water provides to the ecosystem as well. Physical modifications of the shoreline, altered water levels and flow regimes, and loss of littoral sediment supplies and hydraulic connectivity have changed the hydrologic interactions between watersheds, coastal margin and nearshore zones, and waters of the open lake.

**The single most important anthropogenic factor disrupting nearshore coastal processes and pathways is increasing shoreline development and the physical alteration of the land-water interface.** These changes fundamentally change the coastal processes and pathways along which those coastal processes operate. These changes impact not only local areas, but have cumulative regional impacts as well.

In shallow-water nearshore areas, nearshore sand and beach deposits are in fact part of the same littoral system and historically, thick sand deposits extended hundreds of meters offshore. As we have continued to develop and armor our shorelines, the amount of sediment available to keep our beaches supplied with sediment has been decreasing as shoreline armoring increases. Most of the sand-sized sediment that make up Great Lakes beaches are derived from direct erosion of coastal bluffs, which comprises approximately 90% of the total volume of littoral sediments along many Great Lakes coastlines (e.g. Bolsenga and Herdendorf, 1993; Mackey, 1995).

Coastal margin and nearshore zones are dynamic high-energy environments and sand is continually transported in a downdrift direction by waves and littoral currents. Without a continual supply of sand, beaches (and associated nearshore sand deposits) become progressively thinner and narrower through time. The loss of these sediments increases nearshore water depths thereby increasing available wave energy. Eventually the sand deposit becomes thin enough that the entire deposit is mobilized during periods of significant wave activity, which accelerates the irreversible lakebed downcutting process.

Similar effects can be observed adjacent to large harbor structures. In these cases, large harbor structures extend well out into the nearshore zone disrupting natural littoral transport processes. As sand accumulates on the updrift side of the structures, beaches become wider and water depths become shallower. Downdrift of the structure, beaches become narrower and disappear, and water depths become deeper due to a loss of beaches and lakebed downcutting. The loss of sand due to shoreline armoring and/or large harbor structures results in coarse-grained lag deposits and increased substrate heterogeneity in the nearshore zone. These changes have created excellent habitat for lithophilic invasive species (Dreissenids and round gobies).

Impacts to local littoral sediment sources may also influence nearshore sand distributions. For example, the construction of dams on many Great Lakes tributaries has trapped significant quantities of coarse-grained sediment in the pools behind those dams. The entrapment of coarse-grained sediment by dams has reduced the available sediment supply river mouths. Moreover, most large river mouths are heavily altered by shore protection and/or bulkheads to facilitate shipping. These areas are also dredged on a regular basis to maintain navigable waterways.

**Channel alterations due to dredging may alter tributary (river mouth), coastal margin, nearshore, and open-lake flow patterns and connectivity.** Associated with armoring of river mouths, recent reductions in Great Lakes water levels has led to an increase in dredging activity in shallow-water nearshore areas. Not only do these dredged materials need to be disposed of, but the widening and/or deepening of navigation channels (particularly in river mouths) may significantly alter the flow regimes and pathways that transport water and materials into the Great Lakes. Channel modifications and bank hardening may have a significant detrimental effect on coastal margin, nearshore, and open-lake circulation, flow patterns, and hydraulic connectivity.

**Loss of protective nearshore sediment supplies has resulted in erosion and resuspension of fine-grained cohesive sediments increasing turbidity and reducing nearshore water quality.** This is particularly

evident during major storm or wind events when large waves mobilize thin sand and gravel deposits that scour and erode the underlying cohesive clays. It is not uncommon to see turbid waters in the nearshore zone during major wind events, even though tributary loadings are minimal. The processes and mechanisms of nearshore lakebed downcutting are clearly described in Part III Chapter 5 of the Coastal Engineering Manual (Nairn and Willis 2002).

In riverine (fluvial) systems, altered flow regimes may cause an increase bank and channel erosion, especially during major precipitation events, thereby increasing tributary sediment loads. Locally, these suspended sediments could have short-term detrimental impacts on coastal margin and nearshore areas by increasing turbidity, reducing water clarity, and potentially introducing harmful contaminants into the water column.

Currently, the cumulative impacts of altered flow regimes on the Great Lakes ecosystem are unknown, primarily because we have only started to consider the question. Existing data sets are inadequate to perform the assessment in a meaningful way (GLC 2003). Over the long term, altered flow regimes, diversions, and consumptive losses may lower water levels changing open-lake circulation patterns and connectivity; nearshore coastal processes; and connectivity between coastal margin and wetland/barrier systems within the Great Lakes.

## Management Implications

Within the context of physical integrity, sustainable natural processes are created when energy, water, and materials are conveyed through a system in ways that correspond to undisturbed natural conditions, maintain system integrity, and promote system resiliency and regeneration - irrespective of natural and anthropogenic perturbations. The importance of physical integrity to protection and restoration efforts cannot be overemphasized.

Current coastal margin and nearshore management paradigms focus on individual system components and do not consider impairments to the processes or pathways that connect and functionally link those components together. This is the main reason why local, State, Provincial, and federal agencies have been singularly unsuccessful in managing coastal margin and nearshore habitats in any meaningful way. Moreover, most coastal regulatory programs are applied on a site-by-site basis (one property at-a-time) without due consideration of the long-term cumulative impacts on coastal margin or nearshore areas. Projected increases in population and associated growth and development in coastal areas will increase.

More effective management means taking into account nearshore coastal processes and the pathways along which those processes act in coastal margin and nearshore zones. Restoration or rehabilitation of nearshore physical processes can be accomplished by managing the shoreline at a coarser scale, say littoral cell by littoral cell; and implementing solutions designed to mimic the functionality of these coastal processes.

## Comments from the author(s)

### DEFINITIONS

#### Coastal Margin and Nearshore Areas

- Coastal Margin area - shallow water depths < 3 m
- Nearshore area – water depths > 3 m and < 15 m

#### Attributes of Landscapes

- Geology – surface and subsurface distribution of geologic materials; soils; hydrophysical characteristics (permeability, porosity, aquifers, aquatards...).
- Geomorphology – shape, pattern, distribution, and physical features of the land surface; landforms and drainage pattern (topography, slope, hydrography, channel morphology and bathymetry, connectivity and pattern).
- Land Cover – shape, pattern, and distribution of biological and anthropogenic features on the land surface; Land Use.

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## **List of Tables**

Table 1. Physical Processes that affect Nearshore and Coastal Margin Zones.

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<b><i>Natural Process</i></b>	<b><i>Attributes</i></b>	<b><i>Pathways/Area</i></b>	<b><i>Connectivity</i></b>
<b><i>Fluvial Processes</i></b>	<ul style="list-style-type: none"> <li>• Channelized flow</li> <li>• Highly dynamic</li> <li>• Spatially and temporally variable and episodic</li> </ul>	<ul style="list-style-type: none"> <li>• Generally unidirectional (down slope) flow</li> <li>• Acts within or along linear stream corridors and/or drainage networks within watersheds</li> </ul>	<ul style="list-style-type: none"> <li>• Lateral hydraulic connectivity with adjacent floodplain and watershed surfaces</li> <li>• Longitudinal hydraulic down-slope continuity and connectivity within stream channels</li> </ul>
<b><i>Groundwater</i></b>	<ul style="list-style-type: none"> <li>• Infiltration and groundwater flow</li> <li>• Highly dynamic</li> <li>• Spatially and temporally variable and episodic</li> </ul>	<ul style="list-style-type: none"> <li>• Unidirectional and/or bidirectional flows</li> <li>• Act across broad landscape surfaces and/or within stream channels or lakes</li> </ul>	<ul style="list-style-type: none"> <li>• Hydraulic continuity (groundwater-surface water connections) and recharge area</li> <li>• Potentiometric surface (water table elevation) – surficial geology and soils (aquifers)</li> </ul>
<b><i>Coastal Margin and Nearshore</i></b>	<ul style="list-style-type: none"> <li>• Wave and storm-generated currents and flows</li> <li>• Intermittent fluvial influence near river mouths</li> <li>• Highly dynamic</li> <li>• Spatially and temporally variable and episodic</li> </ul>	<ul style="list-style-type: none"> <li>• Oscillatory bidirectional and/or unidirectional flows</li> <li>• Act within or along both shore-parallel and shore-normal linear corridors with seasonal onshore-offshore components</li> <li>• Water-depth dependent</li> </ul>	<ul style="list-style-type: none"> <li>• Shore-parallel hydraulic connectivity (littoral processes)</li> <li>• Shore-normal hydraulic connectivity (deltaic, estuarine, wetland, barrier connectivity)</li> </ul>
<b><i>Open Lake</i></b>	<ul style="list-style-type: none"> <li>• Wave and storm-generated currents and flows</li> <li>• Superimposed over broad-scale hydraulic (riverine) or thermally driven (seasonal) flows</li> <li>• Spatially and temporally variable and episodic</li> </ul>	<ul style="list-style-type: none"> <li>• Oscillatory bidirectional and/or unidirectional flows</li> <li>• Broad-scale regional unidirectional flows</li> <li>• Act within and between lake sub-basins, major connecting and tributary channel inflows and outflows</li> </ul>	<ul style="list-style-type: none"> <li>• Lateral hydraulic connectivity with adjacent water masses</li> <li>• Hydraulic connectivity with major connecting and tributary channel inflows and outflows</li> </ul>

(Mackey 2005)