Strategies and Approaches for Adapting Great Lakes Coastal Ecosystems to Climate Change
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Abstract

Natural resources practitioners working in Great Lakes coastal ecosystems face decisions about how to help coastal properties adapt to climate changes. Climate change can amplify existing stressors, interact with past coastal disturbance and management, and potentially increase the rate and magnitude of ongoing change (Shannon et al. 2019). Practitioners can strengthen their long-term plans through proactive and intentional consideration of climate changes, and by selecting adaptation options that address these changes while meeting management goals and objectives. In 2019-2021 the U.S. Fish and Wildlife and the Northern Institute of Applied Climate Science convened regional managers and scientists to develop a menu of climate adaptation strategies and approaches for Great Lakes coastal ecosystems. This menu can be used with the Adaptation Workbook to facilitate planning and implementation of climate-informed tactics. The menu is currently undergoing testing with various organizations in project-level planning across the Great Lakes watershed.

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Introduction

The Great Lakes basin contains nearly 20% of the earth’s total surface fresh water and over 9,400 miles of coastline. Climate change has and will continue to impact the physical, chemical, and biological processes of the basin, and coastal ecosystems face a unique set of challenges due to these impacts. Across the broader Great Lakes area, ecosystems are experiencing changing thermal regimes, changing storm patterns and precipitation, and shifts in species assemblages (Duvenek et al. 2014, Bartolai et al. 2015, USGCRP 2018, Wuebbles et al. 2019). In addition, coastal ecosystems face stressors that are specific to their proximity to the Great Lakes, including shrinking ice cover and duration, increasing periods of wave action, erosion, and water level highs and lows that could exceed historical records and pace of change, (Mackey 2012, IUGLS 2012, Bartolai et al. 2015, Notaro et al. 2015, USGCRP 2018).

Natural resources practitioners working in Great Lakes coastal ecosystems face decisions about how to help coastal properties adapt to these changes. At the same time, practitioners may be working to restore coastal functions disrupted by past disturbance or management. Climate change becomes an added challenge that can amplify existing stressors and potentially increase the rate and magnitude of ongoing change (Shannon et al. 2019). Practitioners can strengthen their long-term plans through proactive and intentional consideration of climate changes, and by selecting adaptation options that address these changes while meeting management goals and objectives. In Great Lakes coasts, adapting ecosystems to climate change also helps them retain valuable ecosystem services including carbon sequestration and shoreline protection, among others.

One of the major challenges of helping ecosystems adapt to climate change is translating broad concepts into specific, tangible actions. This menu is not intended to provide an overview of coastal dynamics or coastal climate vulnerabilities, which are covered well in other sources (see box 1). Likewise existing adaptation literature and reports tend to cover broad coastal adaptation concepts (e.g. US EPA 2009, WICCI 2011, Murdock & Hart 2013, Mortsch 2018), or management practices relevant to a specific system (e.g. Keillor & White 2003, NRCS 2008, Powell et al. 2018).

This menu of strategies and approaches is intended to fill a different niche. It is a flexible tool to help natural resources practitioners move from generalities to tangible, targeted adaptation tactics for their system. It can be applied to a variety of situations, accommodating diverse management goals, geographic settings, and site conditions (Swanston et al. 2016). The strategies, approaches and example tactics are derived from a wide range of contemporary reports, expert input, and peer-reviewed publications.

In Great Lakes coasts, adapting ecosystems to climate change also helps them retain valuable ecosystem services including carbon sequestration and shoreline protection, among others.

Photo National Park Service, Sable Falls.
This menu does not provide recommendations or guidance. Like other published menus, it presents options to the decision-maker, but some options will be more appropriate than others depending on the context. For example, some innovative or untested approaches may be desirable when conducting a restoration project in an already modified area but may have more risk associated with them when applied to an undisturbed coastal wetland. The text and references included for each strategy and approach will provide some context and additional considerations. Coastal professionals, reliant on their expertise and judgement, can use the adaptation strategies and approaches presented in this document to develop custom adaptation tactics based on their local conditions.

This menu draws from and compliments previously published adaptation menus including those for forested watersheds (Shannon et al. 2019), non-forested wetlands (Staffen et al. 2019), culturally relevant tribal perspectives (TAM 2019), forests (Swanston et al. 2016), and others (see forestadaptation.org/adapt/adaptation-strategies). However, given the unique climate challenges faced by coastal ecosystems throughout the Great Lakes, this menu focuses more specifically on coastal wetlands; nearshore habitats; coastal dunes; river deltas, mouths, and connecting channels; open beaches; rock cliffs and bluffs; and forests and forested wetlands (Figure 1).

Intended users include those planning and implementing on-the-ground management actions, primarily natural resources practitioners, conservation planners, land and/or aquatic resources managers, tribal leaders and natural resources departments, and decision and policy makers, among others. Additional users may include those engaging with planning in some role, such as ecologists, consultants/contractors, landowners, and other stakeholders or indigenous rights holders.

Although many of the strategies and approaches could apply to both plant and animal communities, most of the literature considered for this menu focused on vegetation, and physical and chemical processes. We recommend using the Wildlife Adaptation Menu for further ideas that explicitly consider animal communities (Handler et al. In Press).
Great Lakes Ecosystems addressed in the climate adaptation menu.

Figure 1: Great Lakes coastal ecosystems addressed in the menu of adaptation strategies and approaches.
This menu was specifically designed to be used along with the Adaptation Workbook (Swanston et al. 2016). The Adaptation Workbook provides a structured, adaptive approach for integrating climate change considerations into planning, decision-making, and implementation (Figure 2). The Adaptation Workbook and growing suite of menus have been used together in hundreds of real-world natural resources management projects, many of which are described online as adaptation demonstrations at forestadaptation.org/adapt/demonstration-projects. Other decision-making frameworks offer some similarities to the Adaptation Workbook and this menu could be used with them as well (e.g. NOAA 2016).

The menu combined with a decision-making framework can be used to consider a variety of Great Lakes coastal management projects, from planning coastal reserves, to improving coastal habitat, to coastal wetland restoration. In fact, you will not see wetland restoration listed as a specific strategy or approach, since it is an example of how this menu can be applied and will likely incorporate and overlap with several other listed strategies and approaches.

Figure 2: The Adaptation Workbook is a structured process designed to be used in conjunction with vulnerability assessments and adaptation strategies menus to generate site-specific adaptation actions (Swanston et al. 2016, online tool adaptationworkbook.org).

The remainder of this document includes a brief introduction to a framework for climate adaptation, an overview of how to use the menu, and the detailed menu.
Resources for Great Lakes coastal dynamics and climate change impacts

These resources can provide background on Great Lakes coastal dynamics and climate change vulnerabilities and may help to put the adaptation strategies and approaches in context. These and other local or regional impact and vulnerability resources can also be explicitly considered as part of the Adaptation Workbook process.


Great Lakes Water Level Dashboard: http://www.glerl.noaa.gov/data/dashboard/GLWLD.html


A review of selected ecosystem services provided by coastal wetlands of the Laurentian Great Lakes (Sierzen et al. 2012).

WICCI Climate Change Vulnerability Assessments (CCVAs): Plants and Natural Communities - https://wicci.wisc.edu/plants-and-natural-communities-working-group/climate-change-vulnerability-assessments-ccvas/
Adaptation Concepts: Resistance, Resilience, and Transition

Adaptation strategies and approaches are part of a continuum of adaptation actions ranging from broad, conceptual application to practical implementation. This continuum builds upon the adaptation framework described by Millar and colleagues (2007) (*excerpt from Swanston et al. 2016*). The concepts of resistance, resilience, and transition (Figure 3) serve as the fundamental options for managers to consider when responding to climate change. These concepts are integrated into the strategies and approaches included in this menu:

**Resistance** actions improve the defenses of an ecosystem against anticipated changes or directly defend the ecosystem against disturbance to maintain relatively unchanged conditions. Although this option may be effective in the short term (mid-century or sooner), it is likely that supporting persistence of the existing ecosystem will require greater resources and effort over the long term as the climate shifts further from historical norms. Resistance may be appropriate when there is a desire or mandate to maintain a resource with high cultural, ecological, or economic value. It may be most effective in ecosystems with low sensitivity to climate change, or in areas that are buffered from severe climate change impacts (e.g., refugia). As an ecosystem persists into an unfavorable climate, the risk of the ecosystem undergoing irreversible change increases over time.

**Resilience** actions are also fundamentally about the persistence of an existing ecosystem. This option can accommodate some degree of change but encourages a return to near-prior conditions after a disturbance, either naturally or through management. Resilience actions enhance the ability of the system to bounce back from disturbance and tolerate changing environmental conditions, albeit with sometimes fluctuating populations (Holling 1973). Such actions may be most effective in systems that can already tolerate a wide range of environmental conditions and disturbance. Like the resistance option, this option may be most effective in the short term and may be subject to increasing risk over time. Resilience is effective until the degree of change exceeds the ability of a system to cope, resulting in transition to another state.

**Transition** actions intentionally anticipate and accommodate change to help ecosystems adapt to new conditions. Transition actions intentionally facilitate the transformation of the current ecosystem into a different ecosystem with clearly different characteristics. These actions may be considered appropriate in ecosystems assessed as highly vulnerable across a range of plausible future climates, such that the risk associated with resistance and resilience actions is judged to be too great. Transition actions are typically designed for long-term effectiveness. They are often phased into broader management plans that predominantly have a shorter-term focus on resilience actions.
How to read this menu

The options of resistance, resilience, and transition serve as the broadest level in a continuum of adaptation responses to climate change (Janowiak et al. 2011, Swanston & Janowiak 2012, Swanston et al. 2016). Along this continuum, actions for adaptation become increasingly specific. Adaptation strategies are broad and help to describe how adaptation options could be employed across coastal ecosystems. The strategies within this menu are arranged from resistance-focused strategies, to transition-focused strategies. However, this is not a hard rule as it depends on how each strategy is applied (Figure 3). Strategy 6 focuses on infrastructure and includes the continuum of adaptation concepts.

The strategies, approaches and tactics are derived from peer-reviewed research and evidence-based reports on climate change adaptation, Great Lakes coastal ecosystem management, and broader coastal adaptation responses. Strategies, approaches, and tactics are not mutually exclusive; a variety of different approaches and tactics can be selected to address climate concerns for a particular project.

**Strategy** is defined as a broad adaptation response that is applicable across a variety of resources and sites, hydrologic and ecological conditions, and overarching management goals.

**Approach** is defined as a more detailed adaptation response specific to a resource issue or impact, site condition, or management objective. Adaptation approaches describe in greater detail how strategies could be employed.

**Tactic** is defined as actions designed for specific site conditions and management objectives. Tactics are the most specific adaptation response, providing direction about what, how, where and when actions can be applied on the ground. Tactics can be developed specific to a species, the ecosystem type, site conditions, management objectives, and other factors.

*We have provided examples of tactics for each approach* but do not intend that they be interpreted as recommendations or implemented without due consideration of context. The Adaptation Workbook also provides a method to explicitly consider the benefits and drawbacks of potential adaptation tactics.
Figure 3: Climate change adaptation actions work to achieve three broad adaptation options: resistance, resilience, and transition. This figure shows examples of the level of specificity for adaptation strategies, approaches and tactics included in this menu for Great Lakes ecosystems.
Using the Menu of Adaptation Strategies and Approaches

(modified from Swanston et al. 2016)

The menu of adaptation strategies and approaches can provide:

- A broad spectrum of possible adaptation actions that can help sustain healthy Great Lakes coastal ecosystems and achieve management goals in the face of climate change.
- A framework of adaptation actions from which managers select actions best suited to their specific management goals and objectives.
- Examples of tactics that could potentially be used to implement an approach, recognizing that specific tactics will be designed by those familiar with local conditions. A single tactic may also be designed that aligns with several different approaches.

The menu of adaptation strategies and approaches does not:

- Set guidelines for management decisions. It is up to the manager to decide how this information is used, potentially with the help of a decision-making framework like the Adaptation Workbook.
- Express preference for any strategies or approaches. Selection of a strategy or approach will need to be informed by location-specific factors and practitioner expertise.
- Provide an exhaustive set of tactics. We encourage managers to consider additional actionable tactics appropriate for their projects.
- Recommend tactics. Tactics included in the menu are examples of potential adaptation actions that fit within a strategy and approach. These tactics will not be appropriate in all situations. Further, some tactics have not been vetted through research and so should be employed with caution and followed-up with monitoring and adaptive management.

Photo: USGS, Black River Delta, Wisconsin.
Menu of Strategies and Approaches

**Strategy 1: Maintain and enhance fundamental hydrologic processes and sediment dynamics.**
Approach 1.1 Maintain or restore natural sediment transport processes
Approach 1.2 Maintain and restore hydrological connectivity between hydrological features
Approach 1.3 Maintain and enhance infiltration and water storage capacity of soils

**Strategy 2: Maintain and enhance water quality**
Approach 2.1 Moderate water temperature increases
Approach 2.2 Reduce sediment deposition
Approach 2.3 Reduce loading and export of nutrients and other pollutants

**Strategy 3: Maintain, restore, and manage coastal vegetation**
Approach 3.1 Retain coastal wetlands and estuaries
Approach 3.2 Minimize non-climate physical damage to coastal ecosystems
Approach 3.3 Establish living shorelines by maintaining and restoring coastal vegetation
Approach 3.4 Maintain and enhance species and structural diversity in coastal ecosystems
Approach 3.5 Prevent invasive plant and animal species establishment and minimize their impacts where they occur.
Approach 3.6 Maintain and establish refugia for plants and animals
Approach 3.7 Maintain and increase connectivity of coastal habitats

**Strategy 4: Alter coastal ecosystems to accommodate changing hydrology and shoreline erosion.**
Approach 4.1 Manage coastal systems to accommodate increased frequency and duration of low water levels
Approach 4.2 Manage coastal ecosystems to accommodate increased frequency and duration of high water levels
Approach 4.3 Promote features that reduce damage from coastal erosion
Approach 4.4 Manage sediment to respond to fluctuating water levels.
Approach 4.5 Reduce or manage surface water runoff
Approach 4.6 Maintain and create conditions for inland/waterward plant & animal movement
Approach 4.7 Manage impounded wetlands to accommodate changes in hydrologic variability

**Strategy 5: Facilitate transformation of coastal ecosystems by adjusting plant species composition**
Approach 5.1 Favor or restore native species and genotypes with wide moisture and temperature tolerances
Approach 5.2 Increase genetic diversity of seed and plant mixes
Approach 5.3 Disfavor species that are distinctly maladapted
Approach 5.4 Introduce species that are expected to be adapted to future conditions
Approach 5.5 Move at-risk species to locations that are expected to provide more suitable habitat

**Strategy 6: Design and modify infrastructure to accommodate future conditions**
Approach 6.1 Reinforce infrastructure to meet expected conditions
Approach 6.2 Design infrastructure with low impact or ecologically friendly features
Approach 6.3 Adjust placement, design, and planned lifespan of infrastructure
Approach 6.4 Remove infrastructure and readjust systems
Setting the context: community engagement, planning & policy actions

The Adaptation Strategies and Approaches have been designed primarily for those planning and implementing on-the-ground management actions. However, many adaptation actions will require or benefit greatly from community engagement, regionally coordinated planning, or changes in policy (Kraus & Klein 2009, Franks-Taylor et al. 2010, Pearsall et al. 2012a, Pearsall et al. 2012b). For example, many of the listed strategies would be bolstered by planning or policy decisions that can address issues like zoning, water quality and sediment management at a broader scale.

These actions will involve many other people and organizations beyond the coastal practitioners traditionally charged with executing treatments on the ground. In coastal ecosystems, past management decisions have often failed to consider a systems perspective, leading to unintended consequences. Engaging a variety of stakeholders and diverse perspectives can help practitioners consider the range of both positive and negative outcomes from management actions. It will be vital to engage with the community, tribes, policy makers, and different disciplines to optimize effective climate change adaptation across large scales (NOAA 2010). Though the full range of strategies involved in working with these other groups are beyond the scope of this document, we have provided some ideas from expert input and from documents that cover coastal adaptation through a planning and policy lens. Many of these ideas can be incorporated into adaptation planning processes like the Adaptation Workbook.

1. **Promote community engagement in coastal management decisions.**
   - Carefully consider how and when to collect input and/or conduct outreach on project goals, climate vulnerabilities and adaptation responses.
   - Gather input from community members with a diverse range of perspectives, for example indigenous communities, landowners, recreational users, policy makers, and others.
   - Respect and incorporate values of indigenous communities in management decisions.
   - Support facilitated visioning exercises or other processes to lay out and discuss shared group values (Mangham et al. 2018).
   - Support public-private partnerships that can help with efforts such as hazard mitigation and recovery or low-impact development and green infrastructure (Mangham et al. 2018).
   - Explicitly consider socioeconomic and community benefits when weighing pros and cons of adaptation actions.
   - Enhance knowledge, technical skills and information exchange to build capacity of local policy and land use planning authorities (Franks-Taylor et al. 2010)
   - Develop new coastal homeowner tutorials to highlight appropriate erosion solutions, methods, and materials (Mangham et al. 2018).

2. **Revise ordinances and permitting to be more responsive to coastal ecosystem changes.**
   - Revise rules and permitting processes to allow breakwater structures that can lower wave energy and allow the installation of living shorelines (Mangham et al. 2018).
   - Add fees to coastal structures that would restrict or trap sediment and use the proceeds for beach nourishment or other sediment management activities (Mangham et al. 2018).
• Develop a review and response mechanism for municipal ordinances - review policies and make changes that would allow for more sensible development either periodically or after certain criteria are met (e.g. coastal erosion reaches a certain threshold (Mangham et al. 2018).
• Develop flexible county ordinances to implement greater setbacks for developments where risks are high. Fund coastal erosion studies identify risk (e.g. erosion rates vary with substrate, elevation, and slope - see Bayfield County, WI as a model).
• Require risk assessments for coastal properties prior to sale (Mangham et al. 2018).

3. Coordinate planning across ownership and scales to respond to coastal ecosystem vulnerabilities.
• Coordinate coastal ordinances among municipalities (e.g. bluff vegetation ordinances - Mangham et al. 2018).
• Create a regional sediment management plan (Pearsall et al. 2012b).
• Develop growth management plans (Mangham et al. 2018).
• Develop and implement collaborative watershed plans that integrate green infrastructure principles (Pearsall et al. 2012b).
• Promote policies and programs that reduce nutrient losses and delivery (Pearsall et al. 2012a).
• Promote ecosystem-based watershed planning to foster closer cooperation between local towns and higher levels of government (Kraus & Klein 2009).
• Modify zoning and restrict development in sensitive areas.
• Map and prioritize refugia-retreat areas for unimpeded upland wetland migration under sustained high-water level scenarios (Morelli et al. 2016).
• Designate protected coastal sediment feeder areas and prohibit armoring of those areas to promote sediment movement (Mangham et al. 2018).
• Adjust ballast water regulations to decrease risk of invasion from aquatic invasive species (Magee et al. 2019).

4. Employ incentives to minimize coastal ecosystem vulnerabilities.
• Employ rolling easements that can help coastal ecosystems respond to fluctuating water levels (EPA 2009).
• Employ easements (or transfer of development rights) to promote undeveloped shoreline (Mangham et al. 2018).
• Purchase land that is at risk of flooding, storm damage, erosion or bluff collapse, and use it for conservation.
• Employ land exchange programs – owners can exchange property in a flood risk area for other land, allowing ecosystems to adapt to changes.
• Establish payments to farmers to implement BMPs to reduce sediment, phosphorous, and nitrogen pollution in priority watersheds (Franks-Taylor et al. 2010).
• Promote incentives like the 4R certification approach to help increase farmers’ profits while also reducing agricultural nutrient runoff (Kerr et al. 2016).

Strategy 1: Maintain and enhance fundamental hydrologic processes and sediment dynamics.

Great Lakes coastal ecosystems have and are currently being affected by disruption of soil-water connections, both nearshore and at the watershed scale (Edsall & Charlton 1997, Kraus & Klein 2009, Lin & Wu 2014). Climate changes combined with coastal uses that have fragmented, altered or obstructed water and sediment flow pathways can amplify existing ecosystem challenges. For example, shoreline hardening is common in the Great Lakes (NOAA 2019) and can contribute to down-current coastal erosion by interfering with natural sediment movement and deposition. At the same time, climate changes including more extreme water level fluctuations, increasing severity and frequency of storms, changing wave characteristics, and decreasing ice cover could exacerbate these erosion challenges (Laurence & Nelson 1994, Mackey 2012, Wuebbles et al. 2019). At the watershed scale, dams and barriers have affected the hydrology and therefore the diversity and distribution of coastal wetlands, which are further threatened by climate changes (Keilor & White 2003, Kraus & Klein 2009, Wuebbles et al. 2019). This strategy encourages the holistic consideration of a project area and beyond, the recognition of interconnected water and sediment pathways, and how these pathways may be currently disrupted (Kraus & Klein 2009, Creed et al. 2011). It encompasses many ‘building block’ ideas that may already be employed or under consideration by managers to restore more natural hydrologic processes and sediment movement and avoid further actions that impair them. Example tactics are divided into those that may be applicable at the watershed scale vs. nearshore.

Approach 1.1 Maintain or restore natural sediment transport processes.

Throughout the Great Lakes basin, coastal land uses have interrupted or altered natural sediment transport. When sediment flow is interrupted by shoreline development or other factors, regular patterns of coastal erosion and deposition that support dynamic coastline features can be disrupted, and areas that either supply or rely on regular sediment deposits can be more quickly eroded or starved (Keilor & White 2003, Lin & Wu 2014, CT DEEP 2019). Sediment deficit can lead to shoreline recession, alteration of important features like bluffs and dunes, breached barrier beaches and loss of wetland habitat among other effects (ECCC In Press). Climate changes that affect the pattern and intensity of waves and storms can amplify these losses (Mackey 2012).

At the watershed scale, streams and rivers can be important sources of sediment to river mouths and nearshore systems, and in some cases, it may be desirable to restore sediment supply from these waterways (Keilor & White 2003). However, in other situations, upland erosion and oversupply of sediment from tributaries could be a problem, and management might focus on reducing the volume of sediment transported to nearshore environments (see more on this in approach 2.2). Each of these are potential adaptation responses, but they may have different objectives as it relates to the amount of sediment ultimately reaching the Great Lakes.

Example Nearshore tactics:

- Strategically remove shoreline hardening in identified sediment source areas to allow for natural sediment erosion and transport processes (Livchak & Mackey 2007, Zuzek 2020, ECCC In Press).
- Seek natural shoreline stabilization techniques where feasible and avoid shoreline hardening (Mangham et al. 2018).
- Identify and acquire undeveloped shoreline properties that may provide a source of material for beaches and bar systems (Livchak & Mackey 2007).
• Bypass sand to the downdrift side of large shoreline structures that trap and prevent sediment drift (Livchak & Mackey 2007).

*Example Watershed-level tactics:*

• Where they exist, modify river discharge controls to increase sediment supply where sediment shortages exist, for example at the mouth of a river during high lake level conditions (Scavia et al. 2002, Wigand et al. 2017).
• Remove dams and barriers that prevent the natural transport of sand and sediment to river mouths and the nearshore ecosystem, where increased sediment supply is desirable (ECCC In Press).
• In areas where reducing sediment supply to nearshore areas is desirable, see approaches 2.2 and 4.3.

**Approach 1.2 Maintain and restore hydrological connectivity between hydrological features.**

Water level fluctuation is a natural feature in Great Lakes coastal ecosystems and contributes to habitat diversity and other critical ecological functions (IUGLS 2012, Mortsch 2018). Likewise, hydrologic connections between the lakes, coastal wetlands and fens, and tributaries help coastal ecosystems respond to short and long-term hydrologic change, and provide key habitat connectivity for different life stages of native species. Many of these hydrologic connections have been interrupted by dams and barriers, water level regulation, aquifer withdrawals, and various forms of shoreline development, which can lead to range compression and loss of coastal ecosystem biodiversity and function, particularly affecting coastal wetlands (Keilor & White 2003, Kraus & Klein 2009, IUGLS 2012). Climate change is adding hydrological challenges to these ecosystems, including changes in precipitation timing and intensity, and fluctuating water levels that may cause both loss of hydrologic connectivity and periodic inundation (Mackey 2012, Wuebbles et al. 2019). Restoring hydrologic connectivity may be a first step in helping to restore coastal habitat diversity and the ability of ecosystems to cope with these changes.

*Example Nearshore tactics:*

• Remove or avoid diking shoreline wetlands, or consider reconnecting diked wetlands to maintain natural hydrologic regimes (NOAA 2010).
• Avoid dredging rivers or channels that can cause changes in Great Lakes water levels and disrupted hydrologic connections (Quinn 1985).
• Protect mineral-rich groundwater sources of fens from drainage or other alterations in hydrology.
• Avoid road construction through fens to prevent hydrologic alterations, impeded surface flows and significant changes in species composition and structure as a result of sustained flooding on one side of a road while the other side becomes drier and subject to increased shrub and tree encroachment (ECCC In Press).

*Example Watershed-level tactics:*

• Modify dams and weirs to manage water flow to mimic a more natural flow regime (i.e., frequency, magnitude, duration and timing of flood pulses) at both high flows and low flows (Kraus & Klein 2009, Yochum 2017).
• Reconnect floodplains adjacent to incised river channels using stream restoration techniques to restore channel morphology and connectivity (Yochum & Reynolds, 2020).
• Rebuild or re-establish wider riparian zones and buffers along rivers and streams to handle greater flow variability (e.g., increase bank storage and riparian relief in high flows, increase baseflow conditions, re-adjust baseflow cross-section in low flows - Dove-Thompson et al. 2011, Herb et al. 2016).
• Reroute streamflow from ditches to historical or reengineered channels (Perry et al. 2015)
• Protect base flows against significant extraction at times when low flows are of concern (Herb et al. 2016)
Replace causeways that limit flow with bridges, or modify bridges and culverts to maximize water conveyance and hydrologic connectivity (Clarkin et al. 2006, Yochum 2017, Olson et al. 2017, Molina-Moctezuma et al. 2021).

**Approach 1.3 Maintain and enhance infiltration and water storage capacity of soils.**

Porous soils capture, absorb, and slowly release water to groundwater and downstream sources, providing critical regulation of water quality, regulating flooding, and reducing coastal erosion (Keilor & White 2003, Smith et al. 2016, Abdallah et al. 2018). Climate change is expected to cause more frequent and intense rain events in the Great Lakes region, increasing rates of erosion, runoff and soil losses (Wuebbles et al. 2019). This further increases the need to protect and restore soil properties that enhance infiltration. Many existing guidelines and best management practices describe actions that can be used to enhance soil-water infiltration, and many of these actions are also likely to be beneficial in the context of climate adaptation, either in their current form or with modifications to address climate change impacts. For tactics on reducing surface water runoff, please see Approach 4.5.

**Example tactics:**

- Maintain vegetated buffers or plant buffer strips in agricultural fields adjacent to streams and wetlands and incorporate grassed drainageways to slow runoff and bank erosion (Lucke et al. 2014, Faber-Langendoen et al. 2016)
- Minimize operation of heavy machinery (e.g. restrict to seasonal or conditional use), confine the use of heavy machinery (e.g. controlled traffic farming), use lower impact tracked or autonomous vehicles, and remediate lands after use of heavy machinery to minimize soil compaction and impacts to vegetation (Raper 2005, Mariotti et al. 2020).
- Wait for suitable moisture conditions to use heavy machinery (University of Minnesota Extension 2018).
- Restore or enhance headwater and mid-watershed wetlands using a range of techniques including: ditch plugs, ditch filling, removing drain tile, and shallow scrapes (NRCS 2008, NRCS 2011).
- Establish no-cut buffers around coastal fens and avoid road construction and complete canopy removal in stands immediately adjacent to fens to prevent increased surface flow.
- Maintain natural shorelines and pervious surfaces adjacent to the Great Lakes.
- See also Approach 4.5 – Reduce and manage surface water runoff.

**Strategy 2: Maintain and enhance water quality.**

Natural resources managers may already implement actions to sustain or enhance coastal water quality, but climate changes such as warming temperatures and changing precipitation regimes may amplify water quality impairments (Sinha et al. 2017, Wang et al. 2018, Wuebbles et al. 2019). For example, increases in the frequency and intensity of rain events can increase sediment and nutrient runoff into the Great Lakes. When combined with warmer temperatures, nutrient runoff can lead to harmful coastal impacts such as algal blooms and hypoxic conditions (Mackey 2012, Wuebbles et al. 2019). The emphasis of this strategy is on anticipating and preventing increased stresses before water quality impairment occurs. It may encompass ‘business as usual’ actions that are currently well-known in coastal management.
Approach 2.1 Moderate water temperature increases.

Warmer surface water temperatures can affect the thermal structure and chemistry of the Great Lakes, with several implications for coastal ecosystems (Mackey 2012). Warmer waters can cause changes in species assemblages, increases in primary productivity, more rapid decomposition and respiration, and lower dissolved oxygen levels (Dove-Thompson et al. 2011, Mackey 2012, Wuebbles et al. 2019). These changes can increase the potential for hypoxic conditions, particularly in shallow coastal areas and tributaries. Warmer water temperatures may also encourage the growth of harmful algal blooms, which could further increase the risk of hypoxic conditions and public health risks (Dove-Thompson et al. 2011). As Great Lakes water temperatures continue to increase, finding ways to limit further thermal impairment may help reduce (or slow) the extent and degree of warming.

Example tactics:

- Incorporate natural infrastructure and forested buffers to limit warm storm water runoff, particularly near high-quality or sensitive areas (Kaushal et al. 2010, Sutton-Grier et al. 2018).
- Identify major locations of thermal pollution in and adjacent to coastal wetlands and modify or remove small dams and other barriers to improve thermal condition (Dove-Thompson et al. 2011).
- Maintain and restore groundwater-fed headwater wetlands to promote cooler, late summer flows to coastal waters (Erwin 2008).
- Maintain and restore groundwater fed coastal fens that act as stable temperature refugia (Krause & White 2009).

Approach 2.2 Reduce sediment deposition.

This approach emphasizes physical remediations that can reduce sedimentation in Great Lakes tributaries and nearshore coastal ecosystems. Sediment is a natural part of element cycling in aquatic ecosystems. However excessive suspended sediments and their deposition can negatively influence watershed hydrology and flow pathways, decrease water clarity and photosynthesis, skew aquatic plant composition towards turbidity-tolerant species, and negatively affect aquatic organisms (Sierszen et al. 2012, Kjelland et al. 2015). Sedimentation can also increase nutrient availability in coastal ecosystems with deleterious effects on ecosystem function and quality (see also approach 2.3). Climate change is intensifying hydrologic regimes in the Great Lakes and may increase sedimentation through changing patterns of precipitation, hard freeze, snowmelt, and increasing wave energy, all of which will interact with human activities and land use changes that cause sedimentation.

Example tactics:

- Increase instream sediment retention by re-establishing vegetation, woody debris, boulders, or beaver dams to aggrade the channel and raise the water table (Perry et al. 2015).
- Create upland buffers to reduce stormwater runoff and sediment transport to coastal areas (FFWCC 2016).
- Slow road surface drainage and reduce sedimentation by directing water into forested or densely vegetated areas with lead off ditches, broad based dips, bioswales and water bars (Keller & Ketcheson 2015, Strauch et al. 2015).
- Encourage adoption of agricultural best management practices to help mitigate erosion (Pearsall et al. 2012b).
- Restore stream morphology and meandering, and reconnect streams with their floodplain to help balance flow/sediment loads and provide long-term sediment capture. This type of restoration may have to be done at a large scale to provide a benefit (Thompson et al. 2018).
- Stabilize eroding streambanks by establishing vegetation particularly at sites with sparse canopy, sparse litter cover, or steep slopes.
Approach 2.3 Reduce loading and export of nutrients and other pollutants.

This approach emphasizes actions at multiple scales (local to watershed) to reduce delivery of nutrients and pollutants in coastal ecosystems. Climate change coupled with land uses are expected to influence the export and loading of nutrients and pollutants in Great Lakes waters. Nutrient exports from agricultural fertilizers, urban wastewater, and soil erosion heavily influence Great Lakes ecosystems; they are a primary cause of negative ecological impacts such as harmful algal blooms, low oxygen levels, and altered water chemistry and species composition (Kraus & Klein 2009, Wuebbles et al. 2019). Climate changes including warmer waters and increased heavy precipitation events are expected to exacerbate these ecological impacts (Mackey 2012, Wuebbles et al. 2019). Other chemical pollutants such as salt can also negatively influence coastal ecology. Actions that enhance the ability of the ecosystem to retain nutrients or intercept the export of pollutants to Great Lakes waters may become increasingly important to sustain a quality of water at or below critical thresholds.

Example tactics:

- Collaborate with agricultural landowners in the watershed to encourage BMP’s that reduce nutrient loads, such as on-farm reductions in fertilizer application, removal of drain tile systems, use of cover crops, and use of riparian buffers (Pearsall et al. 2012a).
- Modify stormwater outfalls that affect nearshore habitats (FFWCC 2016).
- Identify and restore wetlands upstream in agricultural watersheds to help reduce the flow of nutrients and pollutants to nearshore waters, particularly in areas with high P surplus (Cheng et al. 2020).
- Design wetland creations and enhancements to increase the area and duration of soil saturation to improve reduction of nutrients; for example, "in-line" wetlands along ditches and small streams that intercept and remove nutrients from flows before entering high-quality coastal waters (Staffen et al. 2019 following Hansen et al. 2018).
- Apply a nutrient management plan that includes limiting manure spreading and fertilizer application on frozen surfaces, steep slopes, and near Great Lakes tributaries or coasts.
- Encourage the use of voluntary certification programs that reduce nutrient runoff from agricultural lands, for example 4R certification (Kerr et al. 2016).
- See also ‘slow the flow’ tactics under Approach 4.5.

Photo: NOAA Coastal Program, Sleeping Bear Dunes National Lakeshore.
Strategy 3: Maintain, restore, and manage coastal vegetation

This strategy addresses coastal vegetation structure and composition as a key ecological building block in allowing coastal ecosystems to cope with a changing climate. Coastal plant communities have evolved in response to a range of natural disturbance regimes, however they are currently subject to direct and indirect climate stressors including increased annual and seasonal temperatures, changing hydrology, changing habitat suitability for species, reduced ice cover and increased wind and wave disturbances (Wuebbles et al. 2019). These stressors may lead to changes in plant community structure and composition, chemical processing, and habitat quality. At the same time, coastal vegetation can help buffer human and natural communities against climate-caused disturbances, such as wind and wave energy, and flooding. Retaining existing healthy coastal vegetation and avoiding extensive manipulation and disruption to ecosystems such as coastal wetlands are components of this strategy. In addition, active management to increase structural and species diversity, control invasive species, and maintain connectivity and unique habitats may enhance coastal ecosystem resilience to climate pressures.

Approach 3.1 Retain coastal wetlands and estuaries.

Coastal wetlands in the Great Lakes are particularly vulnerable to climate change, affected by changing water level regimes, increased storm frequency and intensity, and increased surface water temperatures (Wuebbles et al. 2019). At the same time, healthy wetlands and estuaries are integral to helping Great Lakes coastal systems cope with climate changes; they stabilize shorelines, provide shelter, filter runoff to capture nutrients and sediments, and can buffer against flooding and wave damage (Sierszen et al. 2012, Cheng et al. 2020). Many coastal wetlands in the Great Lakes are degraded in some way or have been converted altogether to other uses. However, there are also high-quality wetlands that can be prioritized for conservation efforts (Cvetokovic & Chow-Fraser 2011). This approach recognizes the importance of coastal wetlands in overall climate change response and emphasizes conserving areas that are unmanipulated before more extensive restoration is necessary. Restoring coastal wetlands may also be an important action and encompasses many of the approaches and tactics included throughout this menu.

Example tactics:
- Avoid converting existing coastal wetlands to other habitat types, for example draining wetlands for agriculture or converting wetlands to open beach.
- Reduce fragmentation and infilling of coastal wetlands and other coastal habitats.
- Avoid constraining the upslope side of a coastal wetland with built infrastructure (road embankments, commercial docks, channels, etc.), allowing vegetation to move dynamically.
- Prioritize healthy coastal wetlands and estuaries (high biotic integrity, hydrologic connectivity, high water quality) for conservation and protection, particularly in lakes where wetlands tend to be more degraded (Kraus & Klein 2009, Cvetokovic & Chow-Fraser 2011).

Approach 3.2 Minimize non-climate physical damage to coastal ecosystems.

Climate changes are expected to cause physical stress to coastal ecosystems, for example through increased wind and wave energy and shorter periods of protective ice cover (Mackey 2012). This approach focuses on limiting or eliminating stressors from recreation, visitation, and other human uses that may physically degrade coastal vegetation or animal habitat (McLachlan et al. 2013, Klein & Dodds 2017). Reducing this direct physical damage could help improve the health of coastal vegetation and its ability to cope with added climate pressures. Built infrastructure development represents a particular category of physical disturbance and is addressed more specifically in Strategy 6.
**Example tactics:**
- Implement no-wake zones to reduce physical damage to sensitive nearshore habitats due to recreational or commercial use.
- Put in paths and boardwalks to minimize impacts of informal social trails and trampling on vegetation (NOAA 2010, WSP).
- Restrict location or timing of beach access in sensitive habitat areas to accommodate species life cycles and ecosystem recovery (McLachlan et al. 2013). For example, Piping Plover habitat on Montrose Beach, Chicago.
- Redirect recreation or physical access away from areas where coastal vegetation and features might be negatively impacted (e.g. fens, swales, coastal mineral marshes, dunes/banks – McLachlan et al. 2013).
- Limit foot-traffic and climbing on sensitive coastal cliffs and rock ledges, or marginally stable coastal bluffs and banks to protect vegetation and reduce erosion.
- Prevent off-road vehicles access to sensitive coastal fens to prevent deep ruts in the loose soils, altered surface flows and species composition, and invasive plants.

**Approach 3.3 Establish living shorelines by maintaining and restoring coastal vegetation.**

Living or vegetated shorelines (sometimes called nature-based shorelines) have many advantages from an adaptation standpoint. Coastal vegetation can reduce wave energy, coastal erosion, and flood hazards, while providing co-benefits such as runoff filtration, aesthetic value, and habitat value for species that may be vulnerable to climate pressures (Keilor & White 2003, NOAA 2015, Sutton-Grier et al. 2015, Sutton-Grier et al. 2018, SAGE 2019, Shea 2020). Living shorelines may also be less costly to establish and maintain than built infrastructure alternatives, and more able to respond dynamically to fluctuating water levels. Built infrastructure and shoreline hardening can help prevent erosion, however, may cause problems elsewhere by interrupting sediment movement; in addition, these features lack the ecological co-benefits and adaptability of living shorelines (Keilor & White 2003, NOAA 2015). Living shorelines may include other elements in addition to vegetation, such as coir logs, rock, netting and erosion control blankets (NOAA 2015, Shea 2020). Increasingly, hybrid strategies that combine natural coastal infrastructure with some built elements are being recognized as important coastal adaptation options (Sutton-Grier et al. 2018). In this approach, timing of planning and establishing a living shoreline is key; it is generally much more difficult to implement this approach effectively when high water or erosion are already causing problems.

**Example tactics:**
- Restore vegetated shorelines or add fronting vegetation to dampen wave action (Hanley et al. 2020).
- Plant native vegetation on disturbed dunes to anchor sand (SAGE 2019).
- Manage herbivory to promote the regeneration of desired vegetation in coastal systems.
- Where shorelines have been artificially steepened (e.g. with previous hardening measures), grade the bank and densely plant with vegetation (Erdle et al. 2006).
- Use removable seawalls to protect planted vegetation in its early stages of growth (Sutton-Grier et al. 2015), or biodegradable toe protection like coir logs for slopes (Shea 2020).
- Where possible, utilize lower wave energy environments provided by shoreline infrastructure like breakwaters or harbors to establish vegetation and other habitat elements along the open coast of the Great Lakes.
- Reverse wetland losses by restoring converted wetlands, such as areas that have been drained and used for agricultural use (Crooks et al. 2011, WI DNR 2015b, WICCI 2017b, Magyera et al. 2018).
• Directly stock, seed, or transplant desired wetland vegetation in areas where coastal wetlands are being restored. This may need to follow other restoration actions, for example ensuring that hydrologic conditions can support wetland vegetation (Wilcox & Whillans 1999, Crooks et al. 2011).
• See also tactics under Approach 3.2.

**Approach 3.4 Maintain and enhance species and structural diversity in coastal ecosystems.**

Climate change may create conditions that are less suitable for some plant species and that provide challenges to seed germination and growth, for example through temperature changes, early spring warming, changing precipitation patterns, and prolonged inundation (Walck et al. 2011, Duveneck et al. 2014). Diverse ecological communities may be less vulnerable to climate change impacts because risk is distributed among multiple species (Engelhardt & Kadlec 2001, Duveneck et al. 2014). Similarly, maintaining a diversity of size and age classes may reduce risk, as species vulnerability to climate change may vary with life stage. In some coastal ecosystems, another measure of diversity may be ‘functional redundancy’, where important plant traits and roles are represented by multiple species (Brotherton & Joyce 2015). Active management may be applied to enhance these various aspects of species, structural and functional diversity. Caution is warranted to avoid introducing species that may damage native plant communities. In fact, controlling the spread of non-native Typha spp. and Phragmites spp. are among the most effective ways to maintain and enhance species diversity in coastal wetlands, especially coastal peatlands – see Approach 3.5 for more related tactics.

**Example tactics:**

• Incorporate diverse species mixes when doing planting or seeding for restoration projects, using native species where possible and non-invasive species in all cases
• Promote landform heterogeneity in coastal areas to help achieve species and structural diversity.
• Use silvicultural practices (e.g. canopy gap creation, and understory thinning, underplanting) to promote a diversity of tree species in coastal forests (Fahey 2014, WI DNR 2015a).
• Develop ex-situ seed banks and living repositories for native plants that are vulnerable to climate change to ensure that plant species are not lost in the wild. Work with tribes to identify and store culturally important species in a culturally appropriate way.
• Retain forest cover following loss of ash from emerald ash borer in hardwood swamps and floodplain forests, for example through interplanting, reforestation, and control of invasive plants (WICCI 2017b; D’Amato et al. 2018).
• See Staffen et al. 2019 for more tactics specific to coastal wetlands
• See also tactics under Approach 3.5.

**Approach 3.5 Prevent invasive plant and animal species establishment and minimize their impacts where they occur.**

Climate change may alter the distribution, abundance, and impact of invasive species (Hellmann et al. 2008). In some coastal ecosystems, climate change might produce conditions that favor invasives; for example, reed canary grass (Phalaris arundinacea) may benefit from warmer temperatures, longer growing seasons, and higher nutrients (Zedler 2007). Similarly, warmer water temperatures, reduced ice cover, and greater nutrient runoff may benefit some aquatic invasive species, with potential consequences for native biodiversity (Rahel & Olden 2008). In coastal ecosystems, invasive species may severely reduce plant diversity and other ecological functions that might help those ecosystems adapt to new climate conditions (Lishawa et al. 2015). Climate change may require new ways to prevent invasions or prioritize control efforts. It
may also offer opportunities for controlling invasions, for example through seasonal drying or poorer conditions for coldwater invasives (Hellmann 2008, Rahel & Olden 2008).

**Example tactics:**
- Prevent invasions by following BMPs, such as wood and plant material quarantines, equipment cleaning, inspection (boats, construction, shoes), and site user education (Poff et al. 2002, WICCI 2017b).
- Incentivize the harvest and use of invasive species for food, medicine, or other personal uses at the edge of invasion (Magee et al. 2019).
- Remove invasive cattails in younger stands to encourage greater native plant recovery (Lishawa et al. 2015).
- Continue with chemical and biological control efforts for species, for example hemlock wooly adelgid, especially in the adelgid’s northern range (McAvoy et al. 2017).
- Establish early detection and rapid response protocols and support networks, to identify and control new species infestations in a coordinated manner (Hellmann et al. 2008).
- Prioritize high-quality sites and upstream sites (e.g. seed sources) for eradicating invasive plants through physical or chemical treatments (Boos et al. 2010, Hazelton et al. 2014).
- Actively monitor for and address new invasions, for example Phragmites and Reed Canary Grass establishment following extreme storm events or wave disturbance (WICCI 2017a).
- Engage with existing networks on best practices for monitoring and managing invasive species, for example the Great Lakes Phragmites Collaborative (Great Lakes Phragmites Collaborative).
- If invasive plant species are providing stabilization benefits for coastal slopes, plan for quick revegetation after invasive species removal to ensure the slope is not vulnerable to erosion for long.

**Approach 3.6 Maintain and establish refugia for plants and animals.**

Within a broader coastal landscape, there may be variation that creates unique sites with the right characteristics to act as refugia. Climate refugia are areas that remain relatively buffered from contemporary climate change over time and enable desired species to persist (Morelli et al. 2016). In coastal ecosystems, refugia may be tied to specific hydrologic settings (Galatowitsch et al. 2009, Sherwood & Greening 2013). For example, certain areas may be sheltered from more extreme water level fluctuations, or less exposed to nutrient runoff. Managers may need to commit additional resources to identifying refugia, maintaining their unique site conditions, and protecting them from additional stressors. Managing for potential refugia along an inland/waterward gradient may also help species adjust to changing water levels – see Approach 4.6.

**Example tactics:**
- Preserve areas where unique combinations of microtopography and coastal processes create diversity or provide a buffer from climate stressors.
- Preserve and/or enhance topographic and bathymetric heterogeneity within coastal wetland habitats to provide high- and low-water refugia (Beller et al. 2019).
- Increase microhabitat sizes for refugia (Powell et al. 2018).
- Modify canopy thinning operations to maintain shade that sustains vernal pools as refugia areas for amphibians (Powell et al. 2018).
- During periods with unfavorable conditions, support and create habitat for key species. For example, during prolonged periods with low ice scour, remove herbaceous and woody vegetation and redistribute cobble/gravel on beaches to create open beach conditions for the piping plover. (Note that vegetation removal has potential negative consequences that would need to be considered).
• Promote sites that support species and habitats culturally important to tribes (e.g., wild rice in coastal wetlands, paper birch in maritime forests, blueberries in coastal pine and barrens habitats)
• Limit foot-traffic and climbing on sensitive coastal cliffs and rock ledges that support at-risk species.
• Where possible, retain or create connectivity among refugia to allow species movement and mixing (see also Approach 3.7).

**Approach 3.7 Maintain and increase connectivity of coastal habitats.**

This approach is focused on increasing connectivity between coastal habitats to enable species to respond more easily to disturbances or changing conditions. Managing coastal landscapes and waterways for connectivity may enhance the flow of genetic material, allow for easier species movement, and reduce lags in migration. Connectivity at multiple scales (local to regional) will be important in responding to climate pressures (Hilty et al. 2020, Albright et al. 2021). For example, in coastal ecosystems, it may be important to maintain connections between habitat types that support species at different life stages such as vernal pools and larger coastal wetland complexes. The ideas here are focused on general habitat connectivity; related tactics in Approach 4.6 explicitly consider providing opportunities for inland/waterward migration in response to changing water levels.

**Example tactics:**

- Select restoration sites that maximize connectivity between riparian habitats, facilitating species range shifts (Perry et al. 2015, following Seavy et al. 2009)
- Provide for both terrestrial and aquatic habitat connectivity across roadways or other barriers (such as fences, dams, or energy infrastructure) that divide important habitats (Albright et al. 2021).
- Acquire property for preserves or create easements on private landholdings adjacent or close to existing natural areas (Swanston et al. 2016).
- Restore and enhance migration routes that protect species access to important habitats, for example spawning and nursery areas (Dove-Thompson et al. 2011).
- Develop wide corridors (> 1 km) as they are more functional than narrow corridors because they tend to offer more diverse microclimates and provide live-in habitat for slow dispersers (Albright et al. 2021).
- Manage natural areas or riparian corridors that act as migration corridors to promote their maximum habitat value and prioritize management in those locations (Swanston et al. 2016, Albright et al. 2021).
- Identify, map, and manage the connectivity of aquatic habitats in the vicinity of coastal wetlands, such as vernal pools, their drainage connections, and pool networks that serve as travel corridors to larger coastal wetland complexes (Wenning 2015).

*Photo: NOAA coastal program, Apostle Islands National Lakeshore.*
Strategy 4: Alter coastal ecosystems to accommodate changing hydrology and shoreline erosion.

Climate change may contribute both to periods of low and high-water levels, and the challenge for many coastal managers will be considering and preparing for both (IUGLS 2012, Notaro et al. 2015, Wuebbles et al. 2019). It is uncertain whether these fluctuations will be outside of the historic range of variability or not. Climate factors that contribute to periods of low water levels include periods of drought, decreased inputs from tributaries, and increased evaporation caused by higher temperatures and decreased ice cover (IUGLS 2012, Wuebbles et al. 2019). Higher average precipitation in the Great Lakes region, increased heavy precipitation events, increased stream inputs, and periods of low evaporation may contribute to high lake level periods (Cherkauer & Sinha 2010, IUGLS 2012, Gotkowitz et al. 2014, Wuebbles et al. 2019, Gronewold et al. 2021). Climate change is also expected to increase waves and storm surges due to increased wind speeds and storm frequency and intensity (Mackey 2012, WICCI Coastal Resilience Issues In preparation). When combined with high water levels, increasing waves and storm surge have the potential to cause substantial coastal impacts, including coastal erosion, bluff failure, and inundation (Wuebbles et al. 2019, WICCI Coastal Resilience Issues In preparation).

Proactive consideration of hydrologic change in the Great Lakes can help managers reduce future risks and take advantage of opportunities to sustain ecosystem functions (Erwin 2009).

Approach 4.1 Manage coastal systems to accommodate increased frequency and duration of low water levels.

Climate change is expected to lead to periods of low water levels in the Great Lakes through decreased ice cover and increased periods of evaporation and late season drought. Water level fluctuations are a natural feature of hydrology in the Great Lakes, however longer periods of low water levels could cause significant concerns for coastal systems, particularly as human communities seek to maintain access and proximity to the water. Low lake levels could reduce hydrologic connectivity between tributaries and the lakes (Wuebbles et al. 2019) and expose or eliminate productive nearshore zones and coastal wetlands that serve important ecological functions (Poff et al. 2002, Taylor et al. 2006). Coastal wetlands could become isolated, reducing habitat for species that require them for spawning and nursery habitat (Poff 2002). As the Ordinary High Water Mark, a common regulatory boundary, moves lakeward under low water levels, development may encroach lakeward as well. It is important to note that any tactics undertaken during low water levels should consider and prepare for eventual increases in water levels.

Example tactics:

- Help plants become established further Lakeward by protecting new plantings (Poff et al. 2002), and disallowing mowing of wetland plants in favor of open beaches.
- In sites with open wetlands that are drying, inter-seed with native wet meadow species tolerant of lower water levels (e.g. with wetland ratings of FACW and FAC) suitable for the region (Staffen et al. 2019 following Galatowitsch et al. 2009). Consider in advance how these species may respond when water levels come back up.
- Where diverse, open wetland communities are desired, manage woody species encroachment.
- Promptly control colonizations by non-native wetland species (e.g., Typha spp.) known to invade coastal wetlands at greater rates during low water periods (Lishawa et al. 2015).
- In coastal wetlands, fill in ditches, block them at their outlets, and re-direct flow away from them to prevent low water tables at higher elevations during low water years (Wilcox & Whillans, 1999).
Prioritize shoreline restoration efforts during periods of low water (with the exception of coastal wetlands), particularly those that restore habitat types that can help reduce risk during high water levels (Keilor & White 2003).

Remove infrastructure and hard measures that restrict water flow to and through coastal wetlands (Shannon et al. 2019).

**Approach 4.2 Manage coastal ecosystems to accommodate increased frequency and duration of high water levels.**

Recent years, particularly 2017 into 2021, provide an example of what periods of high Great Lakes water levels might look like and the effect on coastal areas. Climate change may contribute to increased periods of high water in the Great Lakes through greater annual precipitation and intense rainfall events in the Great Lakes basin (Cherkauer & Sinha 2010, Wuebbles et al. 2019, Gallagher et al. 2020). This approach focuses on managing and helping coastal ecosystems cope with flooding and inundation as a result of high water levels. However, approaches 4.3-4.6 also contain ideas that may help meet management goals under high water periods by providing coastal protection, reducing water inputs, and providing opportunities for ecosystems to move inland in response to increased lake levels. Similarly, Strategy 6 includes tactics related specifically to coastal built infrastructure. It is important to note that any tactics undertaken during high water levels should consider and prepare for potential return to low water levels.

**Example tactics:**

- Move built infrastructure back from the shoreline and allow native vegetation to grow in front (Sutton-Grier et al. 2015, Mangham et al. 2017).
- Assess wave energy environment and identify extent to which living shorelines are feasible in high water conditions (Gallagher et al. 2020)
- **Protect and restore** protective barrier beaches (‘beach ridges’) and sand spits that historically protected coastal wetlands (Wilcox & Whillans 1999); some communities are having success with reusing dredge spoils to create these types of barriers.
- For coastal restoration projects that include planting and seeding, select native species that can tolerate periods of inundation.

**Approach 4.3 Promote features that reduce damage from coastal erosion.**

Shoreline erosion is expected to worsen with increased wind and wave energy and more frequent storms in the Great Lakes, particularly when these coincide with periods of high water or low winter ice cover (Mangham et al. 2017, Wuebbles et al. 2019). Climate change may also be shifting the direction of storms and wave energy, causing erosion concerns in new areas (Mackey 2012). Traditional methods of managing coastal erosion and flooding have focused on shoreline hardening; however it is now apparent that these techniques can have consequences ranging from erosion and damage of adjacent sites, to the elimination of important shallow water habitat, to disrupting hydrologic connections that better enable coastal ecosystems to respond to change (Erdle et al. 2006, Lin & Wu 2014, Sutton-Grier et al. 2015, 2018). Tactics to reduce damage from coastal erosion will need to account for local conditions and risk tolerances, as well as the type of shoreline (e.g. cohesive bluff vs. sandy shoreline). Taking action before erosion becomes problematic may greatly increase chances of success - see also Approach 3.3.
Example tactics:

- Install offshore reef and breakwater structures to protect coastline habitats (SAGE 2019), while considering nearshore processes that should be maintained. Great Lakes examples of restoration designs featuring offshore structures include Kenosha Dunes (sills) and Marquette’s Lakeshore Boulevard managed retreat project (Superior Watershed Partnership and Land Conservancy 2018, SEWI Coastal Resilience).
- Install underwater barriers for diffraction and additional friction against wave energy (Tulaikova 2018).
- Retain or plant vegetation on the top and face of shoreline bluffs to slow erosion and improve stability (Mangham et al. 2017).
- Frame lake views through areas of low-growing and selectively pruned vegetation rather than removing vegetation.
- Plant a vegetated buffer of deep-rooted native plants at the bluff-top edge and maintain a no-mow buffer of at least 10 feet from the bluff-top edge.
- Physically alter the shape of a bluff to make the slope more gentle, or include terraces to increase bluff stability (Keilor & White 2003, Mangham et al. 2017).
- Use drainage systems to reduce excess groundwater level in a coastal bluff to improve its stability. Do not drain all groundwater from the bluff or deep-rooted vegetation may not be able to survive. (Mangham et al. 2017).
- Install sand fences to capture shifting and blowing sands and stabilize dunes (NOAA 2010).
- Install hard infrastructure to prevent localized flooding and erosion, where necessary, and with full understanding of potential downsides (EPA 2009, Mangham et al. 2017, Gallagher et al. 2020).

Approach 4.4 Manage sediment to respond to fluctuating water levels.

Climate change is expected to cause prolonged periods of both low and high water levels in the Great Lakes (IUGLS 2012, Notaro et al. 2015, Wuebbles et al. 2019). Supporting and restoring natural sediment transport processes (see Approach 1.1) can help coastal ecosystems respond to these fluctuations. However, in some cases more active and deliberate sediment management may be warranted. For example, managers can plan for low and high water by using sediment dredged during low water periods to proactively nourish or protect areas that might be affected by high water. Some of these tactics should be approached with caution as they may have effects on disturbance-dependent coastal species, downstream consequences, or may have to consider sediment contamination issues (Brown et al. 2016).

Example tactics:

- Add or stabilize sediment along shorelines (beach nourishment - Carmo 2018, SAGE 2019).
- Replace goin fields with riverfront restoration and artificial sand nourishment in river delta and beach areas (Sherwood & Greening 2013, Carmo 2018).
- Use a combination of beach nourishment, sand traps and planting to establish sand dunes to provide storm protection to landward hard defenses (Keilor & White 2003, Hanley et al. 2020)
- Strategically use and recycle dredged sediment to create islands/shoals for wildlife, prevent erosion, and recreate wetland protective features. Take advantage of accelerated dredging during low lake level periods for the Great Lakes (ECCC In Press).
- Conduct large-scale beach nourishment by constructing a ‘sand engine’ or other supply that distributes sediment via natural currents over longer (decadal) time periods (de Schipper et al. 2016, Brown et al. 2016, Carmo 2018).
**Approach 4.5 Reduce or manage surface water runoff.**

The Great Lakes region is projected to receive increased annual precipitation, with increases likely concentrated in winter and spring and with more precipitation falling in heavy rain events (Cherkauer & Sinha 2010, Wuebbles et al. 2019). Even modest changes in precipitation can amplify the magnitude and volume of surface runoff and cause higher peak flows and flashiness in Great Lakes tributaries, increased flooding, and increased duration and frequency of soil saturation and inundation (Magyera et al. 2018). In addition, increased runoff from agricultural and urban areas may compromise Great Lakes water quality (Wuebbles et al. 2019). In bluff systems, runoff can erode the top and face of the bluff, significantly decreasing bluff stability (Mangham et al. 2017). Actions for reducing surface runoff and overland flow may include actions to increase surface roughness, maintain soil porosity (see also Approach 1.3), and otherwise disperse concentrated or fast-moving flows of water. These actions may be particularly important in areas prone to erosion or bluff collapse, adjacent to built infrastructure, and subject to early and rapid snowmelt over frozen soils (Shannon et al. 2019).

**Example tactics:**
- Strategically place downed wood to deflect, slow and pool overland flow water as snow melts over saturated soils and frozen soils.
- Add retention or detention structures to slow runoff to streams (Perry et al. 2015, WI DNR 2015a)
- On bluffs, direct runoff from impervious surfaces away from the bluff-top edge, potentially toward a storm sewer or private drainage system that routes water away from the bluff edge. (WICCI 2011, Mangham et al. 2017).
- Where concentrated flow enters a wetland, such as at a culvert or a storm sewer outfall, install energy dissipation features to limit negative impacts of extreme runoff events on wetlands (Minnesota Stormwater Manual 2019).
- Reduce impervious surface area (Perry et al 2015).
- Utilize green infrastructure practices that retain water on the landscape and/or release it slowly, such as permeable pavement, green and blue roofs, and bioretention features. For bluff systems, limit use of rain gardens or other infiltration features near the bluff-top edge to avoid contributing to groundwater issues.
- Minimize septic system inputs to groundwater near the bluff-top edge.
- Limit irrigation of lawns and gardens near the bluff-top edge.
- If shoreline access is desired, use pervious, switchback pathways down the bluff to avoid creating pathways for runoff to concentrate.
- Restore or construct wetlands to store water on the landscape.
- See also Approach 1.3 – Maintain and enhance infiltration & water storage capacity of soils

**Approach 4.6 Maintain and create conditions for inland/waterward plant & animal movement.**

Coastal development and land use can often restrict or complicate the ability of coastal ecosystems to shift dynamically in response to changing water levels. Since both high water and low water conditions are expected in the Great Lakes under future climates, maintaining and improving the ability of species to move inland and waterward according to their hydrologic requirements will be crucial (Kraus & Klein 2009). For coastal wetlands for example this might include providing inundatable lands inland from existing wetlands and protecting nearshore processes and conditions for waterward migration (ECCC In Press). Given enough time, this could allow wetlands to migrate in response to change. Similarly, providing inland migration opportunities could allow coastal forests, beaches, and other ecosystems to persist where coastal erosion or other nearshore processes are affecting current habitat. This approach focuses on removing barriers, addressing geomorphic constraints, and actively preparing areas for species inland/waterward movement.
Example tactics:

- Remove man-made structures or alter geomorphic conditions to allow wetlands to adapt/migrate in response to new water level conditions (Mortsch 1998).
- Maintain open space for ecosystem migration with changing water levels, for example using conservation easements (Murdock & Hart 2013).
- Manage invasive species on inland properties that can act as critical migration corridors and retreat areas to improve the ability of native ecosystems to establish inland (Morelli et al. 2016, ECCC In Press – see also Approach 3.5).
- Preserve and restore habitat corridors along river systems, including both wetland and uplands, to provide for both linear movement of species along the river corridor and lateral movement to and from upland and wetland to river (Perry et al. 2015, WI DNR 2015a).
- Regrade to remove elevation barriers to allow ecosystem migration.
- Use a GIS-based approach to identify, map, and prioritize refugia-retreat areas for unimpeded upland wetland migration under sustained high-water level scenarios (Morelli et al. 2016, Zuzek 2020).

Approach 4.7 Manage impounded wetlands to accommodate changes in hydrologic variability.

In many Great Lakes coastal areas, wetland communities are maintained through impoundments where water level and flow are controlled by dikes or other structures. Impoundments have been used to sustain wetlands for a variety of reasons (Doka et al. 2006). For example, development and land use constraints on the upslope edge of a wetland, or flat topography coupled with high water periods can make it difficult or impossible for wetlands to persist without water control structures. In some cases, a diked wetland with managed water levels may provide an opportunity to preserve specific wetland functions where they might otherwise be lost (Doka et al. 2006, Audubon Great Lakes 2019). However, impounded wetlands have several downsides that can inhibit some of the ecological functions that may be important under future climates. For example, diked wetlands may be less able to tolerate changing water levels or help absorb sediment and nutrient runoff (Doka et al. 2006) and may be more conducive to invasive species (Herrick & Wolf 2005). In some cases, impounded wetlands may no longer be viable or desirable, and actions like strategic breaching or installation of structures that can restore connectivity to adjacent waters may need to occur along with appropriate risk assessments.

Example tactics:

- Rehabilitate impoundment structures where feasible to be more resilient to changing water levels.
- Install selective fish passage structures to prevent undesirable fish (e.g. common carp) from entering impounded wetlands (Wilcox & Whillans 1999).
- Where diked wetlands should be preserved, maintain high plant and structural diversity by creating well interspersed vegetation communities (Doka et al. 2006), and remove and reduce invasive and nonnative plants (Herrick & Wolf 2005).
- Mechanically manage water levels to meet restoration goals; for example, mimic more natural lake level fluctuations to support desired species (Kahl et al. 2014, Audubon Great Lakes 2019).
- Create and maintain deep water areas and channels to create refuge for fish and wildlife during winter drawdowns and extended periods of ice cover and low oxygen in winter (ECCC In Press).
- Where temporary isolation of wetlands from lakes is required, consider the use of temporary dikes using aquadams (Wilcox & Whillans 1999).
• Reestablish hydrologic connections and natural water level fluctuations through portable cofferdams, dewatering to allow wetland plants to grow from the seed bank (Kowalski et al. 2009).
• Discourage the construction of new permanent dikes unless mimicking the protective function of a lost barrier beach, and include water control structures to allow hydrological connection similar to the original wetland (Wilcox & Whillans, 1999).
• Where dikes are degraded and costly to repair, strategically breach to recouple coastal wetland processes with the open waters.

Strategy 5: Facilitate transformation of coastal ecosystems by adjusting plant species composition.

Climate change may drive alterations in coastal community composition. Climate parameters are changing at a rapid and unprecedented pace, setting up conditions where local plants may no longer be ideally suited to local conditions (Breed et al. 2013, Prasad et al. 2014, Staffen et al. 2019). Climate change has already altered the range distributions of species, leading to introduction of novel species into ecosystems (Wuebbles et al. 2019). As species move in response to climate change, new communities will form, new invasive species will emerge, and ecosystem functions will be altered (Mortsch 2018). For example, changes in phenology may decouple interdependent events, leading to changes in community composition and ecosystem functioning (Mortsch 2018). Managers may determine that maintaining current conditions or restoring ecosystems to a previous condition is not feasible at some sites, and that managing for a range of acceptable trajectories is more practical. This strategy seeks to maintain overall ecosystem function, health, and habitat value by enabling and assisting transitions of species and communities in suitable locations (Shannon et al. 2019). Many of these actions may be most suitable for and pose less risk to ecosystems that are already disturbed, as opposed to intact systems. Though this strategy is focused on plants, please see the wildlife adaptation menu for more on facilitating the transition of animal communities (Handler et al. In Press).

Approach 5.1 Favor or restore native species and genotypes with wide moisture and temperature tolerances.

Some native and locally occurring species may be more adapted to novel site conditions or stressors associated with climate change, such as greater periods of inundation and drought. Promoting the establishment of these species could help to transform more vulnerable coastal communities into sustainable and functional systems. In coastal forests, using management to favor native species with wide ecological amplitude and persistence under a wide variety of climate and site conditions may help facilitate a gradual shift in forest composition (Shannon et al. 2019). This approach does carry some risk; it may favor common species and may run counter to goals that are focused on conservation of culturally important, rare or threatened species.

Example tactics:
• Favor genotypes or species that are better adapted to frequent or severe fluvial disturbance and higher water availability and locate plantings on both appropriate surfaces for current conditions and higher surfaces protected from increased disturbance (Perry et al. 2015).
Favor plant species in wetlands that are resistant to desiccation, such as perennial species that spread by runners, and those with deep tap roots (Shannon et al. 2019). Facultative (FAC) and Facultative-Wetland (FACW) species are less vulnerable to periods of drought than obligate wetland (OBL) species.

Establish plant species that can survive in high-energy coastal habitats and tolerate increased wave action, for example common threesquare (Schoenoplectus pungens - Albert et al. 2013).

Plant native flood-tolerant species in coastal areas that are vulnerable to flooding and inundation, but that currently do not support such species. Look to nature for candidates, such as native species associated with emergent and submergent marsh communities (Epstein 2017).

In coastal forests, underplant a variety of native species on a site to increase overall species richness and provide more options for future management.

Consult planting guides to understand what types of vegetation might be suited to current and future conditions – for example this planting guide for bluff systems in Southeastern Wisconsin: https://sewicoastalresilience.org/wp-content/uploads/2021/02/selecting_bluff_vegetation.pdf

**Approach 5.2 Increase genetic diversity of seed and plant mixes.**

In many coastal areas, natural gene flow has been limited or interrupted due to habitat fragmentation and loss. In addition, local seed sources commonly used in restoration projects may be poorly adapted to future climate conditions (Broadhurst et al. 2008, Prober et al. 2015, Berrang 2019). Increasing genetic diversity of plant and seed mixes in restoration projects could mimic more natural gene flow, potentially increasing population fitness and adaptive capacity. Introducing genotypes from new areas has associated risks, including the potential for outbreeding depression, maladaptation, and inadvertent introduction of aggressive genotypes (Broadhurst et al. 2008). These risks may be lessened by carefully delineating seed transfer zones and avoiding longer-distance introductions. Failing to broaden seed and plant sources in restoration programs on the possibility that a minority of populations will be negatively impacted may also be undesirable (Broadhurst et al. 2008).

**Example tactics:**

- Employ “regional admixture provenancing” by collecting seed from several wild sources (e.g., five or more) within a defined seed transfer zone (Bucharova et al. 2019).
- Collect seed from large populations rather than small fragmented ones to help limit the introduction of undesirable traits associated with inbreeding depression (Breed et al. 2013).
- Plant seeds or seedlings originating from seed zones that resemble the expected future conditions of the planting site (Huff & Thomas 2014, Berrang 2019).
- Use small amounts of seed collected from updated seed sources to establish seed production areas for restoration projects. Since it can take 30 or more years for some tree species to start producing useful amounts of seed, these seed production areas should be established well before they are needed (Berrang 2019).
- Employ “climate-adjusted provenancing” by supplementing locally collected seed with seed collected along a linear climate gradient that aligns with climate change projections (Prober et al. 2015).
Approach 5.3 Disfavor species that are distinctly maladapted.

Climate change may alter coastal environments beyond a species’ ability to adapt. For example, a species at the southern edge of its range may face more pressures as conditions change (Duveneck et al. 2014). Models that incorporate climate change and species’ life history characteristics can help to identify species that are likely to decline (Prasad et al. 2014). Species declines may require management responses to maintain vegetation and ecosystem function during periods of transition. This may include shifting management focus and effort away from declining species or restoration efforts with low success to redirect resources elsewhere. It could also mean actively promoting new species assemblages in ecosystems where the dominant species are declining or likely to disappear (Shannon et al. 2019). This approach should be used with caution; for example if a species is of cultural importance to tribes, it may be worth extra time and effort to retain that species on the landscape as long as possible, and to seek out refugia where supporting that species might be more successful. In addition, many endemic species in the Great Lakes are located in coastal areas, so efforts to retain these species may be warranted.

Example tactics:

- Remove unhealthy individuals of a declining species in order to promote other species expected to fare better. This does not imply that all individuals should be removed, and healthy individuals of declining species can be retained as legacies (Shannon et al. 2019).
- Anticipate and manage rapid decline of species with negative prognoses in both the short and long term (e.g., hemlock, ash) by having adequate seed stock of a desired replacement species expected to do well under future climate conditions (Shannon et al. 2019).
- Retain species of cultural concern as long as possible and make an effort to locate and protect refugia for these species (e.g. hemlock, ash).
- Avoid establishing plant species or stocking fish species where local conditions are no longer favorable for their survival.

Approach 5.4 Introduce species that are expected to be adapted to future conditions.

Maintaining ecosystem function may involve the active introduction of species or genotypes to areas that they have not historically occupied, an action known as assisted migration, or assisted colonization (Hoegh-Guldberg et al. 2008, Handler et al. 2017). Different forms of assisted migration carry different levels of risk that need to be carefully considered in each management context. Assisted migration may be more appropriate in severely fragmented ecosystems, or when rehabilitating disturbed areas where there are minimal risks to existing species (Hoegh-Guldberg et al. 2008, Handler et al. 2017). Confining the movement of species within their current or historic range, or slightly beyond is considered a more conservative approach (Havens et al. 2015). For example, including common or widespread species in a restoration project from nearby southerly or drier locales (Galatowisch et al. 2009). It may also be appropriate to focus efforts on species where there is ample information on their life histories, and less chance of them posing an invasion risk (Hoegh-Guldberg et al. 2008, Havens et al. 2015).

Example tactics:

- Shift tree species mixes to include species less vulnerable to climate change, particularly in ecosystems already impacted by ash mortality that require reforestation (WICCI 2017c).
- Plant flood-tolerant species, such as swamp white oak and silver maple, on sites that are expected to become more prone to flooding and that are currently not occupied by flood-tolerant species (Shannon et al. 2019).
• Plant drought-tolerant species in sites that are expected to experience more frequent dry conditions throughout the growing season (e.g. due to soil or hydrological characteristics - Staffen et al. 2019).
• Consult planting guides to understand what types of vegetation might be suited to current and future conditions – for example this planting guide for bluff systems in Southeastern Wisconsin: https://sewicoastalresilience.org/wp-content/uploads/2021/02/selecting_bluff_vegetation.pdf

Approach 5.5 Move at-risk species to locations that are expected to provide more suitable habitat.

A subset of assisted migration, sometimes called species-rescue assisted migration, focuses on avoiding extinction of species threatened by climate change (Pedlar et al. 2012, Handler et al. 2017). This may be an approach to consider for species that are culturally significant, rare, threatened, or restricted in movement by highly fragmented landscapes. Considerable uncertainty surrounds the likelihood for success in longer-distance relocations, and a high failure rate for establishment is common (Godefroid et al. 2011). Risks include potentially invasive behavior of a translocated species, alteration of ecological processes (e.g., nutrient cycling), transport of diseases and parasites, and hybridization with closely related species (Maschinski & Albrecht 2017, Staffen et al. 2019). In the case of species that are culturally significant to tribes, care may need to be taken to provide access for tribal members to continue to harvest or otherwise interact with these species once they are moved.

Example tactics:
• Plant or seed a rare or threatened plant species that is at risk for extinction to a newly suitable habitat outside its current range, targeting multiple locations to build redundancy (Powell et al. 2018, Shannon et al. 2019).
• Store seeds of vulnerable plant species for establishment at a suitable location in the future (Powell et al. 2018).
• Assist the migration of aquatic or terrestrial wildlife around barriers by trapping and releasing in newly suitable locations.
• Employ resources such as the NatureServe Climate Vulnerability Index or U.S. Fish and Wildlife Service’s RAMP program to identify species that are vulnerable to climate change as well as areas where habitat is projected to be suitable for them (Staffen et al. 2019)

Strategy 6: Design and modify infrastructure to accommodate future conditions.

Climate changes like fluctuating water levels, increased wind and wave action, warmer winters and less ice cover, extreme rainfall, and altered coastal visitor use will all affect coastal infrastructure including docks, piers, shoreline protection structures, bridges, roads, trails, water treatment facilities, coastal residences and more (Keilor & White 2003, Wuebbles et al. 2019, Gallagher et al. 2020). In some cases, coastal infrastructure may be maladaptive; for example, it may alter sediment transport dynamics that supply sand to dynamic beaches, bars and spits that protect ecosystems like barrier wetlands (Livchak & Mackey 2007). In other cases, infrastructure may pose safety hazards, for example if it is unable to withstand flooding events (Sutton-Grier et al. 2018). The effects of coastal infrastructure on local landforms, hydrology, and shoreline vegetation also need to be considered (Shannon et al. 2019). If appropriately designed, coastal infrastructure can be used to help enhance habitat and human safety as the climate changes, for example by offering some wave protection for vegetation or human communities (Sutton-Grier et al. 2018, SAGE 2019). Changing conditions will require consideration of how infrastructure design and placement can harm or support ecosystems and/or coastal safety.
Approach 6.1 Reinforce infrastructure to meet expected conditions.

In some cases, it may be necessary to improve and update built-infrastructure to respond to climate pressures, particularly when that infrastructure serves a high-value or critical purpose. For example, high-energy or working waterfronts may necessitate upgraded shoreline structures to account for increased wave energy or changing direction (SAGE 2019). Built infrastructure can also play a role in supporting natural resources goals. For example, updating water treatment infrastructure to eliminate combined sewer overflows may help improve the water quality of the Great Lakes while accommodating increasing heavy rainfall (Wuebbles et al. 2019). This approach should be employed with caution and with a full understanding of potential drawbacks or maladaptive characteristics of reinforced infrastructure, for example the disruption of sediment flow (Livchak & Mackey 2007).

**Example tactics:**
- Enhance existing breakwaters to attenuate wave impact on wildlife habitat (EPA 2009, SAGE 2019)
- Upgrade shore protection structures to accommodate increasing wave energy (Mangham et al. 2017).
- Update and maintain urban water treatment infrastructure to account for increasing runoff and sedimentation (Wuebbles et al. 2019).
- Improve dikes or other impoundment structures to be more resilient to changing water levels.
- Enhance bottom scour protection at the base of coastal protection structures and infrastructure to protect against undermining at low water levels.
- Establish routine shore protection inspection protocols to identify damage early so repair or replacement can be made before damage worsens and severely threatens facility assets and operations.
- Conduct vulnerability assessments to identify priority assets to protect and/or repair.

Approach 6.2 Design infrastructure with low impact or ecologically friendly features.

In areas where coastal infrastructure is needed, there may be ways to design and build that are more supportive of coastal ecosystem health and processes. For example, combining natural and built infrastructure may meet coastal protection needs while supporting coastal ecosystem habitat goals (Sutton-Grier et al. 2015, 2018). At the watershed scale, design approaches that use natural materials (e.g., soils and plants) and that enable the landscape to distribute water rather than concentrate it may minimize impacts on vulnerable downstream and coastal sites (Ahiablame et al. 2012).

**Example tactics:**
- Construct lower seawalls when they are deemed necessary by enhancing and maintaining natural vegetated foreshores that reduce wave impact on seawalls (Hanley et al. 2020).
- Minimize new artificial shoreline structures like permanent piers, breakwalls, seawalls, rip-rap, jetties, etc. (WICCI 2017a).
- Design or retrofit bulkheads to provide aquatic habitat value (Green Bulkheads for Cuyahoga River Navigation Channel).
- Use textured surfaces on concrete structures such as those in harbors to improve habitat for aquatic species (Shea 2020).
- Divert and disperse storm water from impervious surfaces (such as walkways, roofs, roads, trails) to forests, densely vegetated areas, swales and filter strips to increase water retention on site and enhance filtering of water (Ahiablame et al. 2012).
- Use pervious pavement for new coastal walkways, roads or trails.
Where concentrated flow enters a wetland, such as at a culvert or a storm sewer outfall, install energy dissipation features to limit negative impacts of extreme runoff events on wetlands (Minnesota Stormwater Manual 2019).

See also tactics in Approaches 3.3 (living shorelines) and 4.7 (impounded wetlands) 

**Approach 6.3 Adjust placement, design, and planned lifespan of infrastructure.**

While climate change projections and impacts were likely not considered in infrastructure design processes until recently, such considerations are vital now, particularly for infrastructure located in coastal areas prone to flooding or with highly erodible soils, and for high-traffic areas such as roads, bridges and trails (Strauch et al. 2015, Staffen et al. 2019). Since Great Lakes water levels are expected to include both periods of high and low water, infrastructure may need to be designed creatively to accommodate both conditions, or may need to be adjusted for a shorter period of use. Using infrastructure with a shorter planned lifespan (e.g. temporary boardwalks, bridges) can minimize long-term risks associated with permanent structures while still meeting near-term goals. While initially costly, the relocation or rerouting of vulnerable infrastructure to less vulnerable areas may reduce long-term maintenance costs and limit structural losses (Keller & Ketcheson 2015, Strauch et al. 2015, Staffen et al. 2019).

**Example tactics:**

- Construct docks to accommodate greater water level fluctuations (Krumenaker, 2014).
- Reroute road and trail infrastructure out of areas with flood risk (Strauch et al. 2015).
- Adopt setback regulations for new development based on anticipated erosion over the useful life of a building to reduce need/temptation to armor shorelines to (Luloff & Keillor 2016).
- Move built infrastructure (e.g. boardwalks, buildings, visitor facilities) back from the shoreline or to areas with low flooding risk (Strauch et al. 2015).
- Relocate existing buildings away from the shoreline, particularly in bluff areas where shoreline stability is complex and erosion control is difficult (Keilor & White 2003).
- Design trails, boardwalks or other visitor accommodations with a planned lifespan, and re-evaluate their placement and necessity at the end of a planned period of use.
- Promote relocation of homes and other assets as an alternative to shoreline hardening to protect properties.
- Adopt long-lot formats for new coastal subdivisions that can make future home relocation easier.
Approach 6.4 Remove infrastructure and readjust systems.

Roads, trails, levees, seawalls, and other forms of infrastructure may become increasingly difficult to maintain as the climate changes. Impacts such as more severe storms, fluctuating lake levels, and higher flow events exert greater and more frequent stress on coastal infrastructure and may even jeopardize human safety. In some situations, removing or decommissioning infrastructure may represent the most practical and cost-effective approach. Such actions may also be leveraged to improve quality and functionality of coastal ecosystems. For example, reducing impervious surfaces may result in decreased overland flow and stormwater velocity, thus reducing runoff and erosion, and improving water quality. Infrastructure removal may present opportunities to restore natural hydrologic fluctuations to coastal wetlands or other ecosystems (NOAA 2010). Finally, removing hard shoreline infrastructure and allowing it to be replaced by natural infrastructure and vegetation can promote habitat value, water filtration and carbon storage among other ecosystem services (Sutton-Grier et al. 2015).

Example tactics:
- Remove shoreline hardening structures such as bulkheads, dikes, and other engineered structures to allow for shoreline migration (EPA 2009).
- Decommission and revegetate unnecessary roads or trails (Shannon et al. 2019).
- Strategically remove shoreline hardening in identified sediment source areas to allow for natural sediment erosion and transport processes.
- Strategically breach dikes to recouple coastal wetland processes with the open waters, where dikes are degraded and costly to repair.
- Remove hard measures that restrict flow such as undersized culverts, dams, concrete armoring, weirs and undersized structures (Shannon et al. 2019; Yochum & Reynolds 2020).

Photo: Danielle Shannon. Black Creek Nature Sanctuary, Calumet MI.
Menu of Adaptation Strategies and Approaches

Developed for Great Lakes Coastal Ecosystems

**Strategy 1: Maintain and enhance fundamental hydrologic processes and sediment dynamics.**
Approach 1.1 Maintain or restore natural sediment transport processes
Approach 1.2 Maintain and restore hydrological connectivity between hydrological features
Approach 1.3 Maintain and enhance infiltration and water storage capacity of soils

**Strategy 2: Maintain and enhance water quality**
Approach 2.1 Moderate water temperature increases
Approach 2.2 Reduce sediment deposition
Approach 2.3 Reduce loading and export of nutrients and other pollutants

**Strategy 3: Maintain, restore, and manage coastal vegetation**
Approach 3.1 Retain coastal wetlands and estuaries
Approach 3.2 Minimize non-climate physical damage to coastal ecosystems
Approach 3.3 Establish living shorelines by maintaining and restoring coastal vegetation
Approach 3.4 Maintain and enhance species and structural diversity in coastal ecosystems
Approach 3.5 Prevent invasive plant and animal species establishment and minimize their impacts where they occur.
Approach 3.6 Maintain and establish refugia for plants and animals
Approach 3.7 Maintain and increase connectivity of coastal habitats

**Strategy 4: Alter coastal ecosystems to accommodate changing hydrology and shoreline erosion.**
Approach 4.1 Manage coastal systems to accommodate increased frequency and duration of low water levels
Approach 4.2 Manage coastal ecosystems to accommodate increased frequency and duration of high-water levels
Approach 4.3 Promote features that reduce damage from coastal erosion
Approach 4.4 Manage sediment to respond to fluctuating water levels.
Approach 4.5 Reduce or manage surface water runoff
Approach 4.6 Maintain and create conditions for inland/waterward plant & animal movement
Approach 4.7 Manage impounded wetlands to accommodate changes in hydrologic variability

**Strategy 5: Facilitate transformation of coastal ecosystems by adjusting plant species composition**
Approach 5.1 Favor or restore native species and genotypes with wide moisture and temperature tolerances
Approach 5.2 Increase genetic diversity of seed and plant mixes
Approach 5.3 Disfavor species that are distinctly maladapted
Approach 5.4 Introduce species that are expected to be adapted to future conditions
Approach 5.5 Move at-risk species to locations that are expected to provide more suitable habitat

**Strategy 6: Design and modify infrastructure to accommodate future conditions**
Approach 6.1 Reinforce infrastructure to meet expected conditions
Approach 6.2 Design infrastructure with low impact or ecologically friendly features
Approach 6.3 Adjust placement, design, and planned lifespan of infrastructure
Approach 6.4 Remove infrastructure and readjust systems


This is a supplemental topic to be used in the Adaptation Workbook decision-support framework – Swanston et al, 2016. Forest Adaptation Resources: climate change tools and approaches for land managers, 2nd edition. http://www.treesearch.fs.fed.us/pubs/52760  **More information can be found at** www.forestadaptation.org/strategies
Setting the context: community engagement, planning & policy actions

The Adaptation Strategies and Approaches have been designed primarily for those planning and implementing on-the-ground management actions. However, many adaptation actions will require or benefit greatly from community engagement, regionally coordinated planning, or changes in policy (Kraus & Klein 2009, Franks-Taylor et al. 2010, Pearsall et al. 2012a, Pearsall et al. 2012b). For example, many of the listed strategies would be bolstered by planning or policy decisions that can address issues like zoning, water quality and sediment management at a broader scale.

These actions will involve many other people and organizations beyond the coastal practitioners traditionally charged with executing treatments on the ground. In coastal ecosystems, past management decisions have often failed to consider a systems perspective, leading to unintended consequences. Engaging a variety of stakeholders and diverse perspectives can help practitioners consider the range of both positive and negative outcomes from management actions. It will be vital to engage with the community, tribes, policy makers, and different disciplines to optimize effective climate change adaptation across large scales (NOAA 2010). Though the full range of strategies involved in working with these other groups are beyond the scope of this document, we have provided some ideas from expert input and from documents that cover coastal adaptation through a planning and policy lens. Many of these ideas can be incorporated into the adaptation planning processes like the Adaptation Workbook.

5. Promote community engagement in coastal management decisions.
   - Carefully consider how and when to collect input and/or conduct outreach on project goals, climate vulnerabilities and adaptation responses.
   - Gather input from community members with a diverse range of perspectives, for example indigenous communities, landowners, recreational users, policy makers, and others.
   - Respect and incorporate values of indigenous communities in management decisions.
   - Support facilitated visioning exercises or other processes to lay out and discuss shared group values (Mangham et al. 2018).
   - Support public-private partnerships that can help with efforts such as hazard mitigation and recovery or low-impact development and green infrastructure (Mangham et al. 2018).
   - Explicitly consider socioeconomic and community benefits when weighing pros and cons of adaptation actions.
   - Enhance knowledge, technical skills and information exchange to build capacity of local policy and land use planning authorities (Franks-Taylor et al. 2010)
   - Develop new coastal homeowner tutorials to highlight appropriate erosion solutions, methods, and materials (Mangham et al. 2018).

6. Revise ordinances and permitting to be more responsive to coastal ecosystem changes.
   - Revise rules and permitting processes to allow breakwater structures that can lower wave energy and allow the installation of living shorelines (Mangham et al. 2018).
   - Add fees to coastal structures that would restrict or trap sediment and use the proceeds for beach nourishment or other sediment management activities (Mangham et al. 2018).
• Develop a review and response mechanism for municipal ordinances - review policies and make changes that would allow for more sensible development either periodically or after certain criteria are met (e.g. coastal erosion reaches a certain threshold (Mangham et al. 2018).
• Develop flexible county ordinances to implement greater setbacks for developments where risks are high. Fund coastal erosion studies identify risk (e.g. erosion rates vary with substrate, elevation, and slope - see Bayfield County, WI as a model).
• Require risk assessments for coastal properties prior to sale (Mangham et al. 2018).

7. Coordinate planning across ownership and scales to respond to coastal ecosystem vulnerabilities.
• Coordinate coastal ordinances among municipalities (e.g. bluff vegetation ordinances - Mangham et al. 2018).
• Create a regional sediment management plan (Pearsall et al. 2012b).
• Develop growth management plans (Mangham et al. 2018).
• Develop and implement collaborative watershed plans that integrate green infrastructure principles (Pearsall et al. 2012b).
• Promote policies and programs that reduce nutrient losses and delivery (Pearsall et al. 2012a).
• Promote ecosystem-based watershed planning to foster closer cooperation between local towns and higher levels of government (Kraus & Klein 2009).
• Modify zoning and restrict development in sensitive areas.
• Map and prioritize refugia-retreat areas for unimpeded upland wetland migration under sustained high-water level scenarios (Morelli et al. 2016).
• Designate protected coastal sediment feeder areas and prohibit armoring of those areas to promote sediment movement (Mangham et al. 2018).
• Adjust ballast water regulations to decrease risk of invasion from aquatic invasive species (Magee et al. 2019).

8. Employ incentives to minimize coastal ecosystem vulnerabilities.
• Employ rolling easements that can help coastal ecosystems respond to fluctuating water levels (EPA 2009).
• Employ easements (or transfer of development rights) to promote undeveloped shoreline (Mangham et al. 2018).
• Purchase land that is at risk of flooding, storm damage, erosion or bluff collapse, and use it for conservation.
• Employ land exchange programs – owners can exchange property in a flood risk area for other land, allowing ecosystems to adapt to changes.
• Establish payments to farmers to implement BMPs to reduce sediment, phosphorous, and nitrogen pollution in priority watersheds (Franks-Taylor et al. 2010).
• Promote incentives like the 4R certification approach to help increase farmers’ profits while also reducing agricultural nutrient runoff (Kerr et al. 2016).

References

Adaptation Workbook. Online decision-support tool. https://adaptationworkbook.org/


Great Lakes Phragmites Collaborative. Retrieved from https://www.greatlakesphragmites.net/pamf/training/


Strategies and Approaches for Adapting Great Lakes Coastal Ecosystems to Climate Change


