



Coastal Communities Working Group Report

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CLIMATE CHANGE AND WISCONSIN'S GREAT LAKES COASTAL COMMUNITIES

Coastal Communities Working Group

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CLIMATE CHANGE AND WISCONSIN'S COASTAL COMMUNITIES

EXECUTIVE SUMMARY

Nearly all of Wisconsin's communities will need to adapt to the state's changing climate over the next few decades and beyond. Most of the state's cities, villages and towns will need to adapt to changes in the frequency and intensity of rainfall events and ensuing runoff. Wisconsin's coastal communities likewise will need to adapt to increased storm runoff but also will need to prepare for changes in lake levels and wave and erosion impacts on their shorelines and harbor structures.

Although we cannot say with any certainty whether lake levels will rise or fall, the general consensus is that warmer temperatures along with reduced snowpack and shorter duration of ice cover will result in greater evaporation during the relatively dry winter months and overall lower lake levels. Low water levels will allow beaches and beach ridges to build, and the vegetation edge that anchors them will move towards the lake. In Wisconsin, the ordinary high water mark (OHWM) is determined by vegetation, not elevation; as such, the OHWM can move, based on prolonged water level changes. If construction follows the OHWM lakeward the new structures can be exposed to risk of loss or damage when severe storms strike or water levels rise.

Increased storm intensity and frequency could increase shore and bank erosion and damage existing lakefront property due to erosion from storm runoff and flooding. Changes in freeze-thaw cycles may adversely affect coastal bluff stability and accelerate slope erosion processes. Prolonged dry conditions can eventually lead to major slope failures during heavy rainfall events. Deep-rooted vegetation may help anchor coastal slopes, but changes in vegetation in response to climate changes may alter coastal vegetation forms.

Marinas and harbors are subject to climate change as well. Lower lake levels can increase the need for dredging to allow loading of freighters and avoid bottoming out of recreational vessels. Low water levels may adversely affect boat launches at marinas and public access points. Greater wave heights will be associated with higher water levels and could result in damage to harbor structures and port infrastructure and to vessels in harbors and marinas.

Climate change may significantly affect tourism on Wisconsin's Great Lakes by impacting beach health. Increased water temperatures and runoff from intense storms may create an environment that deposits and supports pathogens on beaches. More pathogens on beaches will most likely lead to more frequent beach closures. Higher lake levels may extend the reach of pathogens. Although the impact on Wisconsin has not been measured, beach closures do have economic implications.

Higher lake levels may reduce the area of beaches, limiting recreational activities on the shoreline. Lower lake levels may change the ecology of a beach and offshore habitat, which, in turn, may affect the aesthetics of the lakefront. Changing lake levels may affect boating access to piers and marinas. Changes in lake levels may impair fish spawning habitat, reducing or eliminated recruitment of young fish and affecting Great Lakes sport and charter fisheries, which could affect tourism. Aesthetic changes in receding shorelines or degraded ecosystems may make beaches and hotels less appealing to tourists.

Resources are currently in development nationally and in the Great Lakes region to assist coastal communities with planning to adapt to a changing climate. At the national level, the National Oceanic

and Atmospheric Administration's Office of Ocean and Coastal Resource Management is preparing a report titled, *Adapting to Climate Change: A Planning Guide for State Coastal Managers*. A draft includes chapters on climate change and the coast, planning process, vulnerability assessment, adaptation strategy, and plan implementation and maintenance. Adaptation measures addressed in the report include:

- Growth and development management (zoning, redevelopment restrictions, conservation easements, and compact community design)
- Property protection (acquisition, relocation, setbacks, building codes, retrofitting, infrastructure protection, and shore protection structures)
- Shoreline management (regulation and removal of shore protection structures, rolling easements, living shorelines, beach nourishment, dune management, and sediment management)
- Coastal and marine ecosystem management (ecological buffer zones; open space preservation and conservation; ecosystem protection and maintenance; ecosystem restoration, creation, and enhancement; and aquatic invasive species management)
- Water resource management and protection (stormwater management, green infrastructure, and water supply management).

Wisconsin's coastal communities will need to consider all or many of these issues as they develop action plans that accommodate climate change in their community growth. This report provides an assessment of current conditions and potential changes along the Great Lakes coasts and provides details on many of the issues community managers will need to consider in developing those plans. Finally, we outline both specific and general means of adaptation that community planners should consider as they devise means to move their communities into a future that includes climate variability and change.

The next steps in assessing climate adaptation in Wisconsin's coastal communities are (1) to acquire and review adopted comprehensive and hazard mitigation plans to assess whether and how climate change issues are addressed, (2) to determine if any coastal communities have adopted climate action plans and assess their quality, and (3) to survey planners in coastal communities to determine ongoing climate adaptation activities and assess if any technical assistance is desired.

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Climate Change and Wisconsin's Great Lakes Coastal Communities

INTRODUCTION

Nearly all of Wisconsin's communities will need to adapt to the state's changing climate over the next few decades and beyond. Most cities, villages and towns will have to adapt to changes in rainfall events and the ensuing runoff in terms of both frequency and intensity. Wisconsin's Great Lakes coastal communities, like other communities in Wisconsin, will have to adapt to increased storm runoff but will also have to adapt to changing lake levels. Because Great Lakes water levels depend on the balance between inputs such as precipitation and streamflow and losses due to outflows and evaporation, it is very difficult at this time to predict what will happen to water levels. Precipitation and snow melt may cause lake levels to rise. However, warmer winter temperatures with reduced ice cover in the dry winter months can result in significant water loss due to evaporation. Since 1860, the level of Lake Superior has varied almost 4 feet from highest to lowest during the 150 year period of record (fig. 1). During this same period, Lake Michigan has fluctuated by about 6 feet (fig. 2). Coastal communities should prepare for continuing water level changes of perhaps even greater magnitude and the resulting wave erosion impacts on their shorelines and harbor structures.

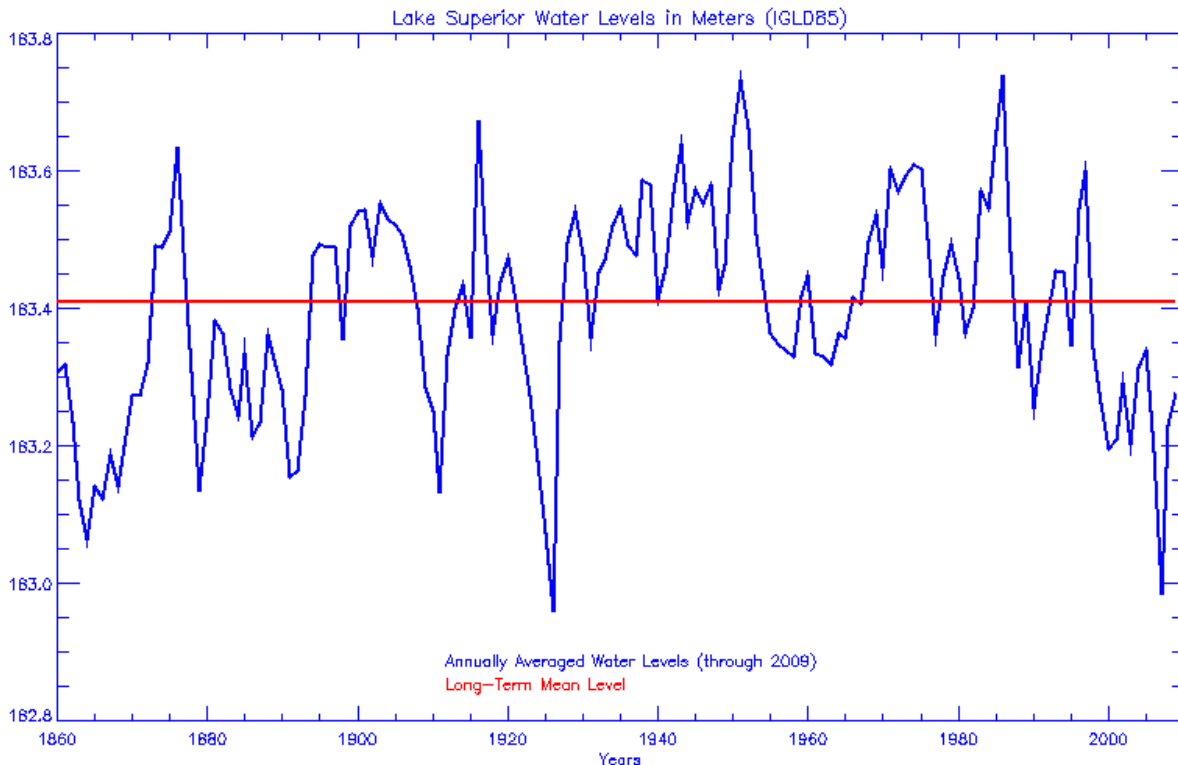


Figure 1. Fluctuation and average water level of Lake Superior since 1860 (Source: GLERL June 2010). <http://www.glerl.noaa.gov/data/now/wlevels/lowlevels/plot/Superior.gif>

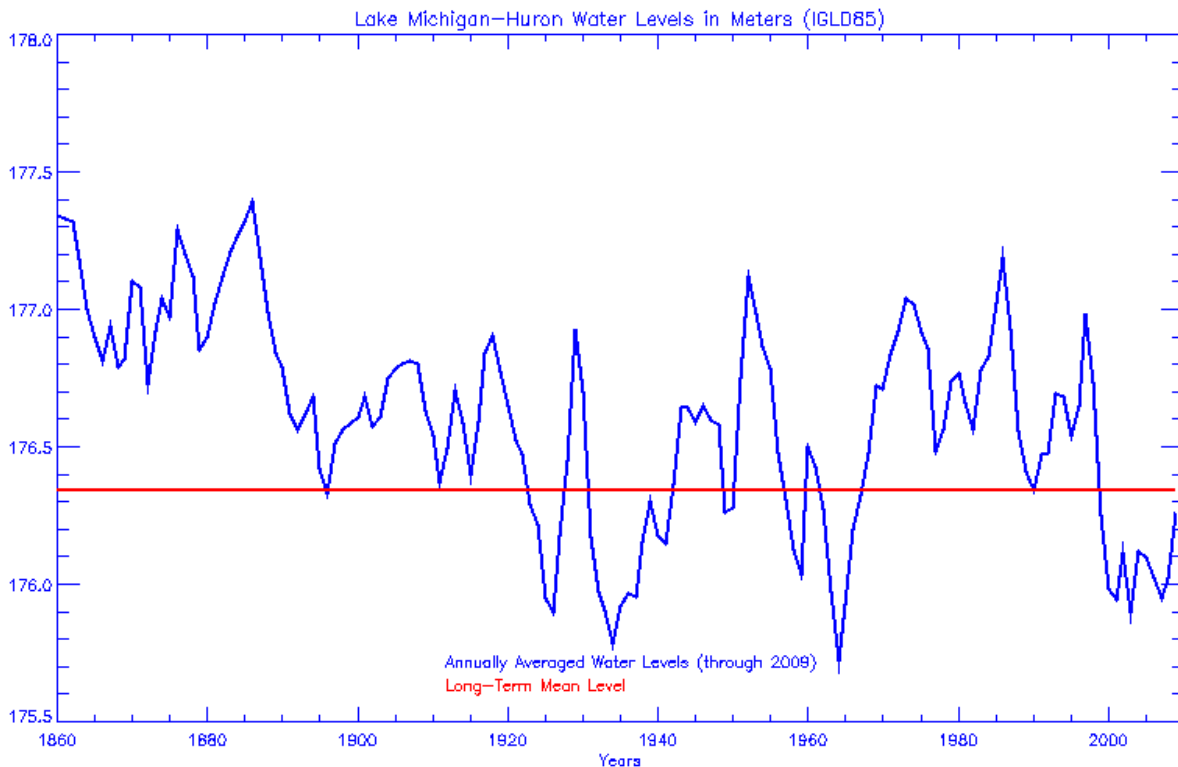


Figure 2. Fluctuation and average water level of Lakes Michigan-Huron since 1860 (GLERL June 2010). <http://www.glerl.noaa.gov/data/now/wlevels/lowlevels/plot/Michigan-Huron.gif>

Although we cannot say with any certainty whether lake levels will rise or fall, the general consensus is that warmer temperatures along with reduced snowpack and shorter duration of ice cover will result in greater evaporation during the relatively dry winter months and overall lower lake levels (T. Croley 2007). Angel and Kunkel (2009) examined the response of Great Lakes water levels with respect to future climate scenarios generated by the application of 23 Global Climate Models (GCMs) to the Advanced Hydrologic Prediction System (AHPS) developed by the Great Lakes Environmental Research Lab (GLERL). The findings indicate that Lake Superior will exhibit the smallest response among the Great Lakes and that the median declines in Lakes Michigan/Huron water levels for the period from 2080-94 are -0.8 feet (-0.25 meters) for the low emission scenario, -0.9 feet (-0.28 meters) for the mid emission scenario, and -1.35 feet (-0.41 meters) for the high emissions scenario (Angel and Kunkel 2009). There is considerable range in the results which is attributed to differences in the emission scenarios and uncertainties in the models.

More intense precipitation and storm events in conjunction with warmer and wetter winters will decrease bluff stability and, should high lake levels return, could increase coastal erosion and storm surges. Finally, as illustrated in figures 1 and 2 above, water levels are not stable and tend to fluctuate over cycles, some lasting for decades or more. All of these potential changes carry with them the need for adaptation. Our coastal communities must adapt to climate variability to maintain viable infrastructure, vibrant economic development and to continue to host national and international visitors to the Great Lakes. This report examines the Great Lakes coastal threats associated with climate change, vulnerabilities of our coastal communities and potential ways to adapt to these changes.

WISCONSIN'S STATE OF PREPAREDNESS

A recent review of 40 climate change action plans from communities across the United States shows that most of these exhibit a high level of awareness of climate issues, a moderate level of capacity for analysis of climate change, and a limited range of actions for climate mitigation (Tang et al 2010). Policy recommendations of the study include translating broader climate patterns and trends into potential local actions, identifying socio-economic vulnerabilities of climate change in local communities, conducting climate sensitivity analyses of local plans and policies, and finding a balance of adaptation and mitigation actions related to local actions.

Wisconsin's Great Lakes coastal communities have been actively developing comprehensive and hazard mitigation plans. While climate change issues have not been an explicit part of these planning processes, some coastal communities exhibit a growing awareness of climate change issues.

In October 1999, the State of Wisconsin passed a landmark local comprehensive planning law that provided local governments with the state's first definition of a local comprehensive plan and created a state grant program that has since provided over \$20 million to fund comprehensive planning efforts. The law also requires that local zoning, subdivision, and official mapping ordinances be consistent with a local government's comprehensive plan.

Wisconsin has 105 local government jurisdictions that include Great Lakes coastline (15 counties, 22 cities, 16 villages, and 52 townships). As of March 2010, 74 of Wisconsin's coastal jurisdictions (70%) have adopted plans consistent with the comprehensive planning law. An additional 22 jurisdictions (21%) are actively preparing plans, leaving only nine that are not planning.

Most Great Lakes coastal counties have hazard mitigation plans approved by Wisconsin Emergency Management. As of February 2009, these include Douglas, Bayfield, Iron, Brown, Kewaunee, Sheboygan, Milwaukee, Racine, and Kenosha Counties. Only three coastal municipalities (Superior, Sheboygan, and Milwaukee) have approved hazard mitigation plans.

Of the 1,017 mayors that have pledged to join The U.S. Conference of Mayors' Climate Protection Agreement, seven represent Great Lakes coastal communities in Wisconsin. These include all four cities on the Lake Superior coast -- Superior, Bayfield, Washburn, and Ashland and three cities on Lake Michigan -- Milwaukee, Racine, and Kenosha. All of these communities have adopted the Kyoto target for 2012 of a 7% reduction in greenhouse gas emissions from 1990 levels according to the City Climate Catalogue.

The next steps in assessing climate adaptation in Wisconsin's coastal communities are (1) to acquire and review adopted comprehensive and hazard mitigation plans to assess if and how climate change issues are addressed, (2) determine if any coastal communities have adopted climate actions plans and assess their quality, and (3) survey planners and government representatives in coastal communities to determine ongoing climate adaptation activities and assess if any technical assistance is desired.

ENVIRONMENTAL THREATS

Extreme Wave Conditions

Increased storm events, increased wind velocity over the lakes and reduced ice cover will result in greater offshore wave development. Higher nearshore waves along the coast can then be expected which can create a number of threats to a coastal shoreline and bluff. Larger waves can cause greater shoreline and bluff toe erosion, greater destructive forces on shoreline structures (increasing the potential for greater damage) and greater nearshore lakebed downcutting (the process of a permanent lowering of the nearshore lakebed which in turn often causes greater shoreline erosion).

Should high water levels return, increased storm frequency could increase shore and bank erosion by waves as well as damaging existing lakefront property due to erosion from storm runoff and flooding. Changes in freeze-thaw cycles may adversely affect coastal bluff stability and accelerate slope erosion processes (fig. 3). Prolonged dry conditions can eventually lead to major slope failures during heavy rainfall events. Deep-rooted vegetation may help anchor coastal slopes, but changes in vegetation in response to shifting shorelines due to lake level changes may alter coastal vegetation.



Figure 3. Aerial photo of the Lake Michigan shoreline in southern Ozaukee County showing a high, eroding bluff. Virmond County Park is in the northern part of the photo (Source: D. Mickelson).

Coastal Flooding

In response to precipitation patterns, regional climate changes and outflows from the basin, water levels in the Great Lakes fluctuate over decades. The differences between the record high and low monthly mean lake levels are: Superior 3.8 feet (1.2 meters); Michigan and Huron 6.2 feet (1.9 meters); Erie 6.0 feet (1.8 meters); and Ontario 6.5 feet (2.0 meters).

National Oceanic and Atmospheric Administration (NOAA) has nine water level gages on Lake Michigan and Superior that have been recording still water levels since 1860. High lake level periods cause widespread shoreline erosion and flooding. Coastal flooding affects all of Wisconsin's coastal counties. Wind set-up, wave run-up and lake levels affect the degree of coastal flooding. Flood hazards depicted on the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs) include

flood inundation, wind set-up, and in some cases waves and wave run-up. Along Lake Michigan, coastal flooding is a serious issue in southern Kenosha County and along the southern end and western shore of Green Bay. Wind set-up, or storm surge, occurs when sustained high winds from one direction push the water level up at one end of a lake, which makes the level drop by a corresponding amount at the opposite end. Sustained winds out of the north can cause a significant storm surge at the southern end of Green Bay. On Lake Superior, northerly winds blowing into Chequamegon Bay can cause flooding in the City of Ashland while winds out of the northeast blowing down the length of the lake can cause flooding in the City of Superior.

Coastal Erosion

Although current climate models cannot predict with any certainty whether lake levels will rise or fall, the general consensus is that warmer temperatures along with reduced snowpack and shorter duration of ice cover will result in greater evaporation during the relatively dry winter months and overall lower lake levels (T. Croley 2007). Whether lake levels go up or down, increasing storm magnitude and frequency will have an impact on rates of shore erosion on the Lake Michigan and Lake Superior shorelines (fig. 4). Not only is there the potential for increased wave erosion because of the storms, but bluffs along the shore will become less stable if they are more consistently saturated. An increase in the length of time the lakes are ice free, and therefore the length of time wave erosion can take place, will likely increase erosion rates.



Figure 4. High water and large waves combine to contribute severe erosion at the base of bluffs. This bluff is on the Lake Superior shoreline. (Source: D. Mickelson)

Storm surge and storm waves can dramatically increase the amount of property damage and shoreline erosion during periods of high water. Shoreline erosion is less during periods of low water levels except in the nearshore zone. This relationship was documented in *An Assessment of Lake-Level Fluctuations on Beach and Shoreline Changes* (LaValle, 2000). The results demonstrated that over the 18-year period of the study, fluctuating lake levels are associated with shifts in shoreline position and the development of various aggradational and degradational states at the beach. A sustained rapid rise in lake levels will initiate an erosional sequence which will persist even with declining water levels. With a persistent decline in water levels the beach and shoreline will adjust from unstable, erosional states to an aggradational state. (LaValle, 2000).

Several types of Wisconsin's coasts are vulnerable to regional climate changes that affect lake level. The low, sandy terraces deposited at ancient high lake level stages are vulnerable. In 1985, as water levels were rising on Lake Michigan, a few storms removed 30 to 50 feet of front yard terraces at some coastal homes in just a few days. The beach ridges and swales deposited and vegetated since the high water levels of 1986 are also vulnerable. High water levels and storms in the 1970s and 1980s removed hundreds of feet and several rows of vegetated beach ridges and swales at some locations along Wisconsin's Lake Michigan coast. Low water levels will allow beaches and beach ridges to build and the vegetation edge that anchors it will move towards the lake.

Along nearly the entire coast, prolonged low lake levels will lead to irreversible down-cutting (erosion) of the near shore lakebed. This erosion allows more storm waves to reach farther inland when water level later rises and will lead to more severe damage when high water levels return.

The stability of a cohesive coastal bluff is sensitive to variations in soil properties and groundwater conditions (Vallejo and Edil 1979, Edil and Vallejo 1980, Sterrett and Edil 1982, Chase et al 2005). Climate changes that increase precipitation, increase ground water retention, increase the number of freeze/thaw cycles or cause high lake levels, will accelerate slope erosion processes (see Table 1 below). A key factor in the stability of the soils that make up the bluff is the amount of water in the soil column. The friction between the soil particles holds them in place. Water in the soil column lubricates the contact between soil particles making them more "fluid" and therefore less stable. This is why most bluff slumps occur after large rainfall events (fig. 5).



Figure 5. A large slump on the Lake Michigan shoreline in southern Milwaukee County. Oak Creek power plant is in the distance. This slump took place in spring after rapid snow melt and heavy rainfall. (Source: D. Mickelson)

An on-going study of bluff erosion along the Michigan shore of Lake Michigan (involving 11 years of monitoring) showed that "slumping in some form is, by far, the most effective method of long-term erosion" (Chase 2007). Early snow melt, especially if accompanied by large rainfall events, triggers bluff slumping as slope soils become saturated with melt water. If there are more warm intervals in winter when slope soils thaw, there will likely be proportionately more slump failures and more shallow slides and flows of material down coastal slopes.

Prolonged dry weather conditions also affect coastal slopes. Initially, as slope soils dry out, weathering tends to produce desiccation cracks a few inches deep that weaken the surface soils (fig. 6). Increased shallow slope failures and surface erosion result. As prolonged dry weather turns into a severe drought lasting years to a decade or more, the groundwater table in coastal bluffs will lower and in the short term, that is likely to improve bluff stability. However, deep fractures will develop in the drying cohesive bluff soils allowing rapid access of surface water deep into the bluff soils. Occasional (or rare) heavy rainfall events may cause rapid loading of these dry, cracked bluff soils with water from the surface and cause major slope failures (fig. 5). The net effect of these stabilizing and de-stabilizing factors is uncertain (Mickelson and others, 2004). Most of the observed fractures in the top 20 to 30 feet of clay till bluff soils may have formed in ancient warm periods when the ground water table was much lower. Deep-rooted vegetation (not shallow-rooted grasses) helps anchor coastal slopes. As the climate changes, there may be changes in native vegetation as growing zones shift northward.

Table 1. Selected climate changes and their anticipated effects on erosion of cohesive slopes (from Luloff and Keillor, in review).

Climate change	Potential deep rotational slumps	Typical shallow translational slides	Solifluction (mud flows)	Sheetwash and rill erosion	Soil creep (mostly Lake Superior slopes)
Warmer, wetter winters, more freeze/thaw events	More failures only if shallow frost penetration thaws	More slides	More mud flows	More erosion	Even more erosion, weaker soils
Much warmer, wetter winters, no freeze/thaw	More failures	More slides	More mud flows	More rain impact, more erosion	Even more erosion, weaker soils
More intense precip. events in winter with frozen soil (1)	No effect	No effect	No effect	No effect	No effect
More intense precip. events in winter without frozen soil	More failures	More slides	More mud flows	More erosion	Even more erosion, weaker soils
More intense precip. events with dryer summer, fall, soils	No effect	More slides	No effect	More erosion	Even more erosion, weaker soils
No ice cover on lakes (2)	More failures	More slides	No effect	No effect	No effect
Short-term drought (3)	No effect	More thin slides	More erosion	More erosion	Uncertain
Severe drought: years or longer (3)	Initial fewer failures, long term uncertain	More slides	More erosion	More erosion	Uncertain

1. Presumes face of slopes remain frozen during intense precipitation events.
2. Presumes more wave attack with storm waves reaching bases of slopes.
3. Presumes occasional or rare intense precipitation events. Uncertainty about the net effect of drought on slope stability.

Sources: Chase (2007), Edil and Mickelson (2007).



Figure 6. Severely fractured clayey till along the Lake Superior shoreline in western Bayfield County. These fractures fill with water in rainstorms, lubricating slide surfaces and creating instability on most slopes. (Source: D. Mickelson)

Wisconsin's relatively undeveloped Lake Superior coastal slopes are more prone to severe slope failures (including deep rotational slumps) than are the state's Lake Michigan and Green Bay shore slopes. This is partly because of the common problem of soil creep in the red clay soils along the Superior shore (fig.7). In some coastal slopes, there is a slow down-slope movement of soil known as plastic creep movement or plastic creep deformation (Forrester, 2000).



Figure 7. Slope along the Lake Superior shoreline failing by creep and shallow slides. (Source: D. Mickelson)



Figure 9. Larger new houses often replace more modest original dwellings (Source: D. Mickelson 2007).

Coastal hazards in these developed areas include flooding, storm waves, shoreline erosion, bluff recession, storm surge and rare, large-edge waves (seiches) usually associated with low-pressure systems or cold fronts. Storm surges and damaging wave action and run-up are a function of wind speed, direction, duration and fetch.

Shore Recession

Much of the Wisconsin coastline consists of relatively high (50 to 150 feet) bluffs composed of glacial till and glacial lake deposits that are prone to slumping (figs. 10, 11). These landslides are precipitated by heavy rainfall, stormwater runoff and groundwater outflow.

The terms *erosion* and *recession* are often used interchangeably. However, recession is the landward movement of a feature, such as a bluff or dune crest, while erosion is the wearing away of land or lake bottom. Recession is expressed as a distance or a change in distance, while erosion is sometimes expressed as a volume or a change in volume. Recession can be thought of as a consequence of erosion. Bluff recession is the most visible aspect of coastal erosion and receives the most attention. However, using only bluff recession as an indicator of erosion rates or erosion trends can be misleading because of the length of time, or lag that usually occurs between erosion and bluff recession. Coastal erosion occurs over the area roughly from the top of the bluff out into the nearshore region to about the 30-ft. water depth. As a result, erosion processes (particularly those that occur on the nearshore lake bottom) often do not become apparent as bluff recession until days, weeks, months, or even years have passed. In addition, erosion, particularly bluff erosion and recession, does not occur at a constant rate. It is very common for a reach of coastline to have no bluff recession for months or years and then experience severe bluff slumping over a period of days or weeks. This bluff recession might occur during a period of little or no storm activity.

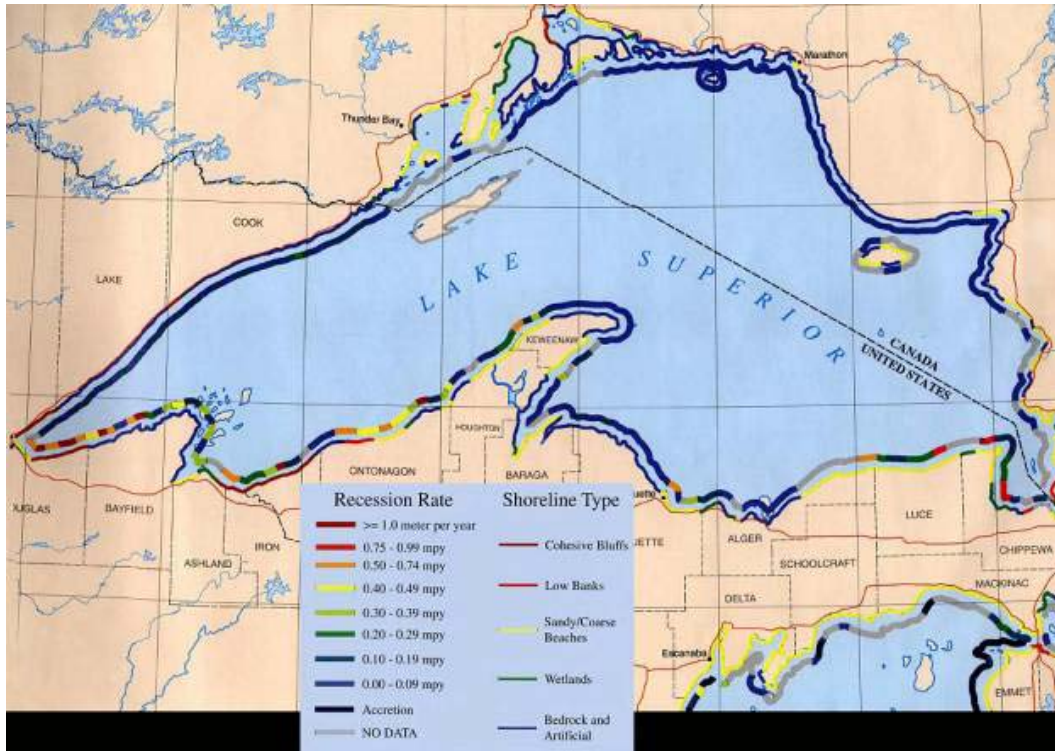


Figure 10. Map of Lake Superior showing shoreline classification and average recession rates. (Source L. Pope et al., 1999).

Coastal erosion in the Great Lakes is affected by many factors, including cyclically changing lake levels, disruption of long shore transport of beach building material, and storms. Rates of bluff and dune erosion along the shores of the Great Lakes vary from near zero to tens of feet per year because of annual variability in wave climate and lake levels (National Research Council, 1990). The Great Lakes experienced a series of high lake levels in the 1970s and 1980s, with the highest peak occurring in 1987 (U.S. Army Corps of Engineers Detroit District, 1997). High lake levels cause increased bluff recession by eroding the base of the bluff. In many areas of the Great Lakes, bluff erosion produces beach-building sediments.

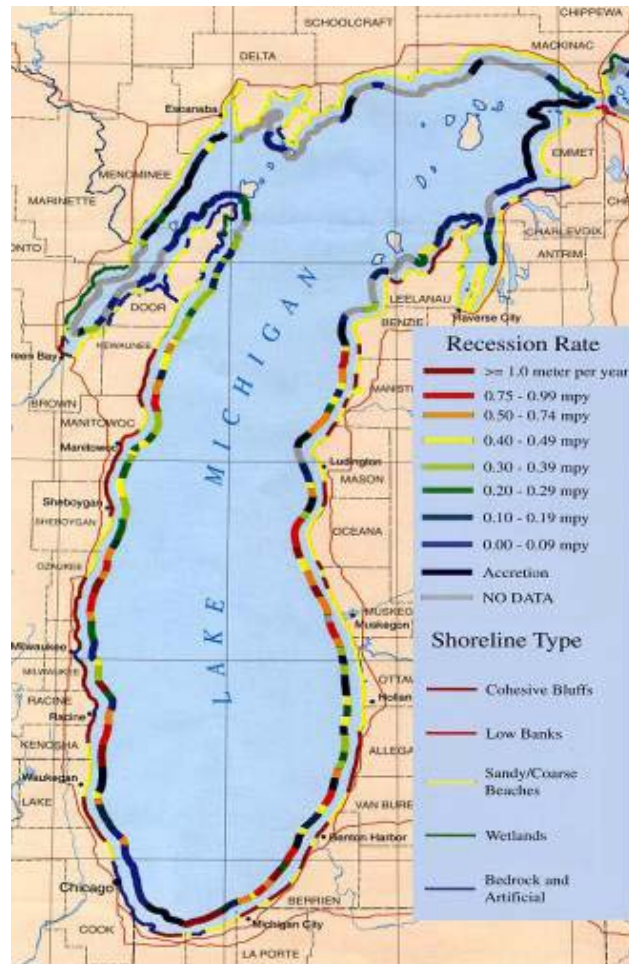


Figure 11. Map of Lake Michigan showing shoreline classification and average recession rates. (Source: Pope et al., 1999).

Threats to Structures on the Coast

As the regional climate changes, it is possible that future levels of lakes Michigan, Huron and Superior will move beyond the historic ranges of levels recorded since 1860. Most scenarios predict continued lower water levels on the Great Lakes due primarily due to reduced ice cover resulting in increased evaporation (Croley 2007; Angel and Kunkel in press). However, some of the plausible scenarios include higher water levels – water levels beyond the range of levels for which Wisconsin cities, coastal infrastructure, harbor structures, navigation channels and coastal buildings were designed and built. Under either the low or high water level scenarios coastal areas are at risk of serious damages and serious disruptions as lake levels change in response to climate changes.

In Wisconsin, the Ordinary High Water Mark (OHWM) is determined by signs of wave erosion and destruction of terrestrial vegetation and other biological and physical indicators, not elevation; as such the OHWM can move lakeward if there are prolonged periods of lower lake levels and vice-versa. If construction follows the OHWM lakeward the new structures can be exposed to risk of loss or damage when severe storms strike or water levels rise (fig. 12).

The definition of Wisconsin's Ordinary High Water Mark (OHWM) is tied to the point on the bank or shore up to which the presence and action of water is so continuous as to leave a distinct mark either by

erosion, destruction of terrestrial vegetation or other easily recognized characteristic. The OHWM sets the boundary between the public lake bed and private property. The OHWM is the point from which Wisconsin's shoreland zoning setback is measured. During prolonged periods with low lake levels, there is increased pressure to re-delineate wetlands (especially fringe wetlands along the coast) because the plant community has shifted from a hydrophytic to non-hydrophytic plant community. Removing the wetland classification opens up these areas for future development. The indicators associated with the OHWM have shifted lakeward in recent low water conditions and will continue to shift if climate changes bring about greater variations of prolonged high and low lake levels (fig. 13). If the lakeward boundaries of coastal construction setbacks are allowed to shift with the changing erosion/vegetation boundary, the present prolonged period of low lake levels might allow building construction on beach ridges and dunes that are rapidly destroyed when high water levels return.



Figure 12. Aerial photo (2007) of part of the Door County shoreline showing structures below the ordinary high water mark of Lake Michigan (Source: D. Mickelson).



Figure 13. Aerial photo of the shoreline along the west side of Green Bay showing low water conditions in 2008. (Source: D. Mickelson)

Ports, Harbors And Marinas

Wisconsin's ports, harbors and marinas are also vulnerable to the impacts of climate change (fig. 14). Lower lake levels can increase the need for dredging to allow loading of freighters and avoid bottoming out of recreational vessels. Low water levels may adversely affect boat launches at marinas and public access points. It is likely that as the temperature gradient between the water and air diminishes, wind speeds over the lake will increase (Desai et al. 2010). Greater wave heights associated with higher water levels could result in damage to harbor structures and port infrastructure and to vessels within the harbor or marina. Increased storm intensities can increase the amount of stream and river sediment entering the lake, resulting in greater port, harbor and marina sedimentation volumes. The high channel velocities may also re-suspend existing material that may be contaminated.

The degrees of susceptibility to climate change impacts vary whether we are talking about ports and harbors (normally large scale commercial maritime operations with fixed height structures) or marinas (smaller recreational facilities with smaller docks, either fixed or floating). Unfortunately, the typical lifespan of the associated infrastructure is on the order of 40-50 years for marinas and slightly longer for ports and harbor infrastructure. Because of the long-term projections and that observations for the potential climate change impacts may not be seen for several years, the majority of Wisconsin ports, harbors and marinas rarely plan now for future events. Often, infrastructure, management and operational changes are made only when the facilities are actually being threatened or damaged (USEPA 2008).



Figure 14. Aerial photo (2007) of the harbor at Kewaunee. This is an example of a harbor that would be affected by substantial changes in lake level (Source: D. Mickelson).

The three major climate change impacts that are most relevant to ports, harbors and marinas are water level, storm and precipitation, and temperature changes. Water level changes (either higher or lower) which are different than the normal ranges typically observed on the Great Lakes affect facilities in several different ways. Lower water levels create situations in ports and harbors where ships cannot be fully loaded, may need to carry less cargo per trip, damage vessels by hitting the channel or slip bottom,

require the need for additional dredging (which can create further problems with where to dispose of the additional material, may be difficult if the existing channel bottom is rock and can undermine the existing structure), could require modifying the dock to accommodate the change in elevation between the vessel and cargo area, may require rock scour protection at the base of the dock wall or necessitate the relocation of the entire facility (Jensen 2008). For marinas, the potential issues with lower water levels include the need for increased dredging (fig. 15), the potential for boat bottoms to be damaged by the shallow depths (fig. 16) and potential safety concerns if the dockage is at a fixed height and the vertical distance from the water level to the dock is too great (fig. 17).



Figure 15. Dredging may be required to deepen channels in marinas during periods of low water. (Gene Clark, Wisconsin Sea Grant)



Figure 16. Low water can make marina facilities inaccessible. (Source: Gene Clark, Wisconsin Sea Grant)

Higher water levels can impact port, harbor and marina infrastructure stability and overall strength. In addition to the structure issues, higher water levels can create a greater potential for flooding of

critical land areas and operational structures. A climatic change resulting in the increase in storms (both severity and frequency) and increased precipitation can also have detrimental effects on ports, harbors and marinas. The increased storms can create larger waves, higher seiches and greater storm surges which can damage port and harbor infrastructure to the point of requiring rehabilitation or replacement (fig. 18). In addition, the storms can affect the vessel maneuverability, vessel speeds and mooring problems. In marinas, storms can damage dockage and boats while moored to those docks. In addition to the infrastructure issues, increased storms can increase channel sedimentation or the re-suspension of existing material that may be contaminated, which would invoke additional dredging problems analogous to the lower water level scenarios. Storm winds may also impact vessel and boat mooring requirements and could affect some facility operations.



Figure 17. Low water can create safety issues when the distance from a fixed dock to the water increases. (Gene Clark, Wisconsin Sea Grant)



Figure 18. Wind-generated waves overtopping the harbor structure in Canal Park in Duluth, Minnesota. (Gene Clark, Wisconsin Sea Grant)

The predicted increase in Great Lakes water temperature has both potential negative and positive impacts for Wisconsin ports, harbors and marinas. Higher temperatures in the Lake Superior region could mean less ice cover in the winter. Howk (2009) reviewed 150 years of data for the closing and opening of navigation in the Bayfield, Wisconsin harbor and found that the duration of ice cover is now 45 days shorter when compared to the beginning of the record. Less ice cover could lead to longer shipping seasons. However, less ice would also increase lake evaporation during the winter months which would contribute to lower lake levels. A longer shipping season would also lead to operational changes due to less lay-up time for vessel and facility repair work. If the Northwest Passage ice were to melt, it could lead to total shipping traffic changes that could completely change the Great Lakes ports and harbor usage. In addition, higher global temperatures could lead to changes in port and harbor “heating” product shipping requirements and needs (such as coal, oil and gas).

Dredging And Re-Suspension Of Contaminated Sediments

Lower water levels in Great Lakes recreational marinas and harbors may require additional dredging to accommodate navigation. Marinas and harbors may contain contaminated sediments once considered “safe” because they were too deep to be disturbed from navigation traffic. If no previous sampling has been conducted to characterize the extent and nature of the pollutants, this would need to be completed before dredging occurs. Additionally, lowered or increased fluctuation of Great Lakes water levels will lead to increased potential for erosion in streams where the lower reaches are influenced by estuarial-type hydrodynamics. This will lead to increased deposition sediments in Great Lakes bays and harbors. Streams with contaminated sediments are another potential risk. Wetter conditions and more intense rainfall could result in higher rates of streambank erosion placing downstream locations at risk of new exposure to pollutants.

Site characterization and dredging are both costly endeavors and the process often takes years to complete. Sites not located within a Great Lakes Area of Concern have few options for federal funding to assist with clean up costs, which places the financial burden on the State and/or local communities. Few coastal communities have the necessary resources to pay for these activities yet they depend heavily on their recreational marinas and harbors for their economic viability.

Threats To Infrastructure

Millions of people living around the Great Lakes depend on vulnerable lakeside and harbor facilities for drinking water, electrical power, sewage treatment, and energy and manufacturing supplies, among many other services vital to lakeshore and inland residents alike. In areas with high bluffs, roads along a coastline can become at risk as the bluff recedes. A good example of this is County LS in northern Sheboygan County. In 2003, sections of the road were within ten feet of the 70 foot high bluff. During a site visit of federal, State, local officials and property owners, the group conversation stopped and everyone’s eyes were fixed on a school bus as it drove by the area of concern. The next day Phil Keillor, the Wisconsin Sea Grant Coastal Engineer sent a certified letter warning the county of the potential consequences. While the road was never closed, school buses were rerouted. The county worked with the U.S. Army Corps of Engineers and was able to get the Corps to design and partially fund an Emergency Shoreline Protection Project to protect this segment of the road. Unfortunately, there is an additional mile of road to the north also within the unstable erosion hazard area along the bluff which has not been stabilized.

Water Intakes

Drinking water may be affected by climate change. For example, increasing water temperatures and decreasing oxygen concentrations may favor certain green or blue-green algal species resulting in blooms. Changes in lake currents may alter areas where pollutants concentrate and increased storm intensity is likely to affect non-point source pollution and sewer overflows. Significantly lower water levels may place water intakes at a depth subject to greater algal abundance, mussel growth or suspended sediments.

Marina and harbor dredging may affect water quality and lower lake levels could allow ice to interfere with water intakes. Water treatment facilities that serve large metropolitan areas with large runoff volumes may also be adversely affected. Intakes near harbors or near existing or newly-exposed contaminated sediments may likewise be unduly affected by low water levels.

Tourism And Beaches

Climate change may significantly affect tourism on Wisconsin's Great Lakes. Beach health may be impacted by climate change in a number of ways. Increased water temperatures may create an environment that supports pathogens (NRDC 2009). Increased and more intense storms may create more runoff, depositing sediments and pathogens on beaches (IPCC 2008). According to the U.S. Centers for Disease Control and Prevention, "The combined effects of increased temperature and precipitation are likely to worsen the burden of water- and food-borne disease in the US, though the magnitude of this effect is difficult to project with certainty." (CDC 2010). The increase in pathogens on beaches will most likely lead to more beach closures. Higher lake levels may extend the reach of pathogens. Although the impact to Wisconsin has not been measured, it is apparent that beach closures do pose economic implications (Wiley 2006).

Climate change and related changes in the lake levels may affect access to Wisconsin's Great Lakes beaches. Higher lake levels may reduce the area of beaches, limiting recreational activities on the shoreline. Lower lake levels may change the ecology of the beach and off-shore habitat, which in turn, may affect the aesthetics of the lakefront. Changes in lake levels may impair fish spawning habitat reducing or eliminate recruitment of young fish and affecting Great Lakes sport and charter fisheries which could affect tourism. The average economic impact of registered boats in Wisconsin is estimated at \$2.493 billion (GLC 2010). Changes to access or fisheries could have a dramatic affect on boating. Hotels may suffer from changes to access to beaches and the water. The aesthetic changes to receding shorelines or degraded ecosystems may make the beaches and hotels less appealing to tourists, as well.

Increased temperature and lower dissolved oxygen concentrations in conjunction with low water levels may result in algal blooms including toxic blue-green algae. Rising water temperatures may cause zebra and/or quagga mussel populations to flourish which in turn, can promote growth of algae or bacteria. Lower water levels could expose new beach hazards and will expose new shoreline that can attract gulls, be colonized by Phragmites or other undesirable forms or vegetation that can limit beach access and adversely affect lake views. Storm events or changes in lake circulation may increase non-point source pollution, sewer overflows or other nutrient inputs resulting in beach closures. Extremely warm weather may increase public demand on beaches. As such, coastal communities with persistent beach health problems could suffer more negative economic impacts.

Beach areas particularly vulnerable to low water levels will be those in shallow water and which are already prone to nuisance algal blooms. Beaches near large metropolitan areas or areas of nutrient inputs such as agricultural lands may also be predisposed to climate change impacts.

ADAPTATION STRATEGIES

This section describes the types of adaptation strategies that could be implemented in the near and long term to adapt to climate change in Wisconsin.

Comprehensive Community Planning and Implementation

Resources are currently in development nationally and in the Great Lakes region to assist coastal communities with planning to adapt to a changing climate. At the national level, the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management is preparing a report titled “Adapting to Climate Change: A Planning Guide for State Coastal Managers.” The draft includes chapters on Climate Change and the Coast, Planning Process, Vulnerability Assessment, Adaptation Strategy, and Plan Implementation and Maintenance. Adaptation measures documented in the report include:

- Growth and Development Management (Zoning, Redevelopment Restrictions, Conservation Easements, and Compact Community Design);
- Property Protection (Acquisition, Relocation, Setbacks, Building Codes, Retrofitting, Infrastructure Protection, and Shore Protection Structures);
- Shoreline Management (Regulation and Removal of Shore Protection Structures, Rolling Easements, Living Shorelines, Beach Nourishment, Dune Management, and Sediment Management);
- Coastal and Marine Ecosystem Management (Ecological Buffer Zones, Open Space Preservation and Conservation, Ecosystem Protection and Maintenance, Ecosystem Restoration, Creation, and Enhancement, and Aquatic Invasive Species Management); and,
- Water Resource Management and Protection (Stormwater Management, Green Infrastructure, and Water Supply Management).

The NOAA Great Lakes Regional Collaboration Team and the Great Lakes Sea Grant Network recently received funding to assist Great Lakes coastal communities with climate change adaptation. The project will develop three training modules:

- What are coastal communities adapting to?
- What is an adaptation plan?
- What tools and information are available to help coastal communities?

Supporting the module on development of an adaptation plan, Marty Jaffe, Environmental Planning Specialist with Illinois-Indiana Sea Grant, suggests a local climate adaptation plan should address ecosystem resiliency, shoreline infrastructure, stormwater management, urban heat islands, drought management, and flood management. The planning process should include vulnerability assessments and benchmarking to monitor the effectiveness of adaptation measures (Jaffee and Miller 2010).

Coastal Bluff Recession

During the high lake level period of the 1970s, an extensive study of bluff erosion along Wisconsin’s Great Lakes shorelines was undertaken. Bluff recession rates were calculated in the types of bluff failure taking place where documented. Since that time there have been more localized studies of bluff erosion that also contribute to our knowledge of the physical processes that take place on the bluffs.

Based on the 1970s bluff studies a Wisconsin Coastal Setback Model Ordinance was developed for adoption by counties and municipalities (Yanggen 1981). This recommended setback of buildings is based on bluff recession rates and other factors. It was adopted by several counties, but many other counties adopted modified versions or no setback ordinance at all. In some counties the only setback is the minimum 75 foot setback required on inland lakes by the state of Wisconsin; these inland lake setbacks do not take into consideration Great Lakes coastal dynamics. Development of previously undeveloped shoreline has increased in recent years and much of the Lake Michigan shoreline is completely developed. There remains considerable undeveloped shoreline on Lake Superior, but a booming economy in the 1990s and early 2000s increased development pressure there as well.

Ohm (2008) updated and expanded the advice available to coastal communities concerning regulations to reduce coastal hazards in a report titled "Protecting Coastal Investments: Examples of Regulations for Wisconsin's Coastal Communities." The report provides background on programs and provisions that address coastal development and provides example ordinance language for coastal setbacks, site planning, and hazard disclosure.

If, because of climate change, we are entering a period when there will be increased shore erosion as discussed above, then bluff top recession will certainly increase as well, but perhaps with a time lag of a few years to a few tens of years. Properties that are already developed will be increasingly threatened by bluff recession. Many of the houses that were built along the bluff in the last two decades are large and represent huge investments by individual families. There are some infrastructure considerations like threats to roads and utilities as well.

There are two possible solutions for a building threatened by bluff retreat. One solution is to move the building back from the bluff edge. In many cases, this is the most reasonable response. But costs are substantial and in many cases, lots are not deep enough to allow moving the building. In these situations, it may be possible to use public funds to purchase threatened properties as they were in the town of Oliver in northwestern Wisconsin in the late 1990s (Vargas 2004).

The other possible solution when buildings are threatened by bluff recession along an already developed shoreline is bluff stabilization. Therefore, there will be increasing demand for engineering solutions to bluff recession. For high bluffs, these are expensive and require substantial bluff face modification. In the past, these bluff modifications were almost always combined with shore protection to reduce wave erosion at the base of the bluff. This shore protection inevitably has an adverse impact on adjacent properties and may not be necessary if lake levels decline as predicted by most climate change scenarios.

Property owners should be encouraged to be proactive if there is even a remote threat that bluff top recession will affect buildings and should implement water management practices on the property that would not contribute to bluff instability. It takes time to do a site investigation develop a plan and put that plan into practice. Communities should consider organizing groups of property owners who can work together to minimize cost and result in bluff stabilization work that does not have negative effects on nearby properties. Generally costs of bluff stabilization are borne by individual property owners, not the community.

For undeveloped properties there are more solutions available to minimize future property damage or loss of life due to bluff erosion. Counties and municipalities should re-examine their setback ordinances

to be sure that they make sense given a likely increase in bluff recession due to bluff slumping. Advice on implementing coastal hazards setbacks in Wisconsin is available in two recent reports sponsored by the Wisconsin Coastal Management Program and the National Sea Grant Law Center (Lulloff and Keillor, in review; Ohm 2008). A setback ordinance should be based in part on past bluff recession, but should recognize that future recession could be substantially faster, at least over periods of tens to hundreds of years. Any setback ordinance should also take into account the present slope angle and the likely retreat of the bluff top even if there is no further wave erosion at the base. Development of LIDAR coverage along the shore may allow this to be done remotely. Bayfield County is in the process of developing a scientifically defensible setback ordinance for new development there (<http://www.bayfieldcounty.org/coastal/>).

For lots without sufficient depth to allow the necessary setback, there may be other solutions. One of these is to construct a building that can be moved when it becomes necessary, or to allow a variance for non-permanent dwellings such as mobile homes that otherwise might be discouraged by local zoning.

Ports, Harbors and Marinas

Ports and harbors can adapt to extreme water level changes by anticipating and planning for greater dredging and the potential need for addition bottom scour protection at the base of their dock walls for lower water levels. They can also anticipate potential dock top elevation modifications and/or modified loading/unloading procedures. For higher water levels, ports and harbors can increase the working dock heights, modify loading/unloading operational methods or relocate important facility features to higher land to provide for flooding protection.

Ports and harbors can adapt to greater waves, seiches and storm surges by rehabilitating, modifying or replacing weaker portions of their infrastructure to withstand the greater wave forces (fig. 19). Marinas can adapt to changing water level extremes by the conversion of fixed dockage to floating dockage. They can also modify slip layout schemes to position shallower draft boats in the shallow areas and restrict the larger craft to the deeper portions of the marina. However, marinas still may have to dredge periodically if sedimentation increases. Marinas can adapt to higher waves, higher seiches and greater storm surges by utilizing stronger dock designs, especially where docks join one to another (connection points are often the weakest link of a marina dock system).



Figure 19. Reinforcing a break wall to better withstand storm surges. (Gene Clark)

Ports, harbors and marinas can anticipate and adapt to many of the potential climate change issues by using cost effective facility components which allow for both greater flexibility and structural strength. In addition; port, harbor and marina high risk areas can be identified and wherever possible, avoided to minimize the future effects of extreme water level changes, greater storm impacts, greater channel and slip sedimentation rates and flooding potential (fig. 20).



Figure 20. Floating docks can help marinas adapt to changing water levels. (Gene Clark)

Shore Protection Structures

When owners of existing coastal developments experience increased shoreline/bluff erosion that threatens property or buildings, the long-standing common practice is to install shore hardening structures such as riprap or other solid erosion control structures (i.e. sea walls, revetments, jetties, groins, etc.) (figs. 21, 22). Existing Wisconsin and local government shoreland and coastal zone policies on shore protection structures do not take into account that such structural “solutions” can adversely affect coastal property owners and the condition of the public lakebed and near shore waters of the Great Lakes. These factors include:

- Lakebed erosion (the erosion of the near shore lakebed which then allows for greater wave attack) in some locations that eventually undermines most types of shore protection structures, requiring more frequent repair or shortening their useful lives.
- Long-term negative impacts of some shore protection structures on the stability of coastal slopes and the loss of beach material where the structures are located and on neighboring properties for some distance along the coast. This includes the negative impacts of designing and building shore protection structures adequate to meet a broadening range of likely future lake levels and extreme storm conditions.
- Reduced sand supply to replenish beaches.
- The blocking of littoral drift that can increase shoreline erosion on down drift properties.
- Negative impacts of shore protection structures on public recreation use and nearshore habitat for aquatic organisms.



Figure 21. The Lake Michigan shoreline in Racine County in 1976 (upper) and 2007 (lower). Large black arrows point to the same barn in each photo. In 1976 water level was high and severe erosion was taking place. By 2007 all the shoreline here had been armored with rip rap or concrete. (Source: D. Mickelson).



Figure 22. View along the shoreline in southern Milwaukee County showing an old groin field that has been effective at stabilizing the slope behind it (wooded slope). But, partly as a consequence, there has been increased erosion in the area south of the groin field (foreground). (Source D. Mickelson.)

Hardened shoreline structural measures should only be used to protect existing developments as a last resort and with caution to fully consider and avoid potential unintended consequences to other properties and public interest values. Shore perpendicular structures should be designed to maintain the supply of sediment to down drift properties (e.g. pre-filling groins and/or bypassing sand blocked by jetties).

Once shoreline structures have been constructed, adaptation to climate change depends in part to the types of climate change variables and their relative rapidity of occurrence. Adaptation strategies for existing structures should be easier if climate change variables change relatively slowly and result in lower lake levels, less precipitation and fewer storm events. Strategies become much more challenging if the opposite is true.

Adaptation strategies for conditions that lake levels may continue to drop, falling well below historic low lake level records may make shore protection structures in coastal reaches unnecessary for the purpose of protecting coastal slopes from wave attack. Non-structural alternatives recommended in the *Living on the Coast* booklet (USACE/Wisconsin Sea Grant. 2003) should be considered in Wisconsin. Methods include the restoration of beaches and dunes in front of the structures (a return to natural shoreline protection methods). Another strategy would be to replace part or all of the hardened structure with a non-structural solution, especially incorporating native plant species. Wood structures should be inspected frequently for signs of increased deterioration, especially in regions where the wood was underwater the majority of the previous time. Due to lower lake levels the wood will experience a greater number of wet/dry cycles which greatly increases the damage to the wood due to rot. Lower lake levels can also allow rock to deteriorate faster due to greater freeze/thaw exposure. Greater freeze/thaw cycles may cause the rock to crack and become less protective (smaller stone sizes).

It is possible that lake levels will not continue to decline indefinitely and that the state's coasts may experience more frequent and more intense storm precipitation and storm wave events. It's also possible that lake levels will rise again, even to previous record high elevations. Adaptation strategies for existing shoreline structures under these conditions are harder to implement (or at least are more costly). Structure heights will need to be increased to protect the land or slope behind the structure from wave overtopping and scour. In addition, the structure integrity itself may be at risk as it may have not been originally designed for the greater wave energy and may fail. Greater wave energy at the structure will also produce scour at the base of the structure and if not protected could cause a complete collapse of the structure. To mitigate against this potential failure mode, additional scour protection would need to be placed at the base of the structure. This issue is especially important to vertical structures such as those built with vertical faces.

In summary, adaptation strategies for existing shoreline hardening structures to potential climate change must be considered and implemented if applicable. Otherwise, structure failures are only a matter of time. Structures must be designed with potential climate change impacts in mind. A detailed risk assessment can be completed to compare the economic, social and natural resource risks of such structures with the potential impacts and timing of the climate change variables.

Future near shore reconnaissance projects, including the probing of near shore lakebeds in select suspect areas for the presence of soft, easily-erodible clay tills, should be considered to identify potential areas where shore protection measures will not be effective due to the high likelihood of lakebed erosion.

Dredging and Resuspension of Contaminated Sediments

Use bathymetric data to identify at-risk and high-risk port, harbor and marina facilities. Work with the owners to develop strategies to adapt to changing lake levels and identify alternatives to dredging. For example, is relocation an option? Proactively address contaminated sediment sites as identified in the risk analysis and develop improved funding options for remediation of sites not within Great Lakes basin Areas of Concern.

Water Intakes

Consider the potential impacts of climate and lake level change, particularly extreme low water levels when locating new or upgrading existing water intakes. Communities should plan and budget for relocation of water intakes and increased water treatment needs where necessary. Communities should also plan for increased storm intensity and runoff volume to avoid sewer overflows and to decrease potential erosion and non-point source pollution. Finally, implement water conservation measures to offset any increased need for Great Lakes water with decreasing groundwater supplies.

Tourism and Beaches

Adaptation strategies for tourism must include planning efforts by local governments, especially in regions that rely on Great Lakes tourism. Careful siting of hotels and recreational facilities may help to address potential access and erosion issues. Visualization and GIS tools may help communities in their coastal planning efforts.

Stormwater management that includes reducing runoff and prevention of non-point source pollution in urban and agricultural settings along with beach grooming may help to reduce pathogens and consequent beach closures. Reducing impervious surfaces and increasing buffers near beaches will help control stormwater runoff. Monitoring water quality at beaches and communication of results may lead to beach closures but will likely prevent illness. Communities should be encouraged to address non-point source pollutants to beaches especially in areas that directly impact beach water quality. Some examples include: agricultural best management practices that specifically address nutrient loads, urban Low Impact Development (LID), bioretention, pervious pavement in parking lots, and rain gardens at storm sewer outfalls. Consideration should be given to *where* the BMPs are applied as certain ones are **not** appropriate on bluffs (see section on *Site Design for Stormwater Runoff* below).

Site Design for Stormwater Runoff

Building on the Great Lakes shorelines, particularly on bluff shorelines, presents a serious danger from bluff and gully erosion. The stability of coastal bluffs is threatened by excessive surface water runoff and high groundwater levels on coastal properties. Surface water flows over the face of a slope or through adjacent ravines and gullies, accelerating erosion. Groundwater flowing within soil layers towards the slope reduces the soil strength. This contributes to deep or shallow slumps and slides on the coastal slope or on the slopes of gullies or ravines that lead to the lake.

Proper planning to avoid property damage and possible injury will be increasingly important if large-scale rainfall events occur more often in the future. The effects of climate change on bluff recession and recommendations for changes in required setbacks are discussed in another section of this report. This section outlines another important planning consideration, the management of surface and groundwater during and after construction.

Run off from rainstorms and snowmelt must go somewhere. It is important to realize that on bluff shorelines, where this water is channeled can have a huge impact on bluff erosion and on the growth of gullies from the bluff onto adjacent property. An important consideration in site development is to have minimal impact on natural vegetation already on the site. This is especially important near the edge of the bluff where even limited removal of vegetation and exposure of soil can initiate the growth of large gullies. Cutting trees near the edge of the bluff or near gullies may improve the view, but will likely cause problems in the future. Hard surfaces such as paved driveways and roofs of buildings concentrate water. In general, a development plan should aim to minimize surface water flow to the top of the bluff or into gullies already present on or adjacent to your property. Water should be routed away from the bluff if that is possible.

Low Impact Development (LID) is a relatively new approach to stormwater management that promotes stormwater infiltration within individual lots in a subdivision. Some LID concepts can potentially be modified for unstable bluff tops (e.g. multi-barrel slow release rain barrel systems). However, others (e.g. rain gardens and porous pavement) that increase groundwater flow toward the bluff face can make bluffs less stable and should be avoided. Other sources of water such as sump pump effluent, and downspouts should be prevented from infiltrating the ground and routed away from the bluff.

In many places along our great lakes shorelines, water percolates through sandy sediment down to a clay layer and then moves as groundwater laterally to the bluff face where it emerges as a spring. On-site waste disposal systems, including mound systems, are in some locations constructed too close to bluff slopes. The added weight of these systems increases the loads and stresses on nearby slopes. The liquids that infiltrate into underlying soil migrate to adjacent slopes and seep from the bluff face onto the beach and into the lake. This partially treated sewage may contain fecal materials that are a health hazard, reduces the strength of slopes, adds pollutants to the lake and contributes to slope failure.

In summary, if there will be increasing frequency of large magnitude rainfall events it is more critical than ever to control surface water runoff along the shoreline and on bluffs. Before building:

1. Develop an erosion control and storm water management plan.
2. Minimize disturbance of vegetation, especially within 50 feet of the bluff top or gully edges.
3. Limit compaction of soil on routes to the construction area by keeping equipment on driveway or parking area.
4. Divert surface water away from disturbed areas and away from the bluff.
5. Use sediment fences where necessary to contain sediment.
6. Except in rare cases do nothing to retard the flow of surface water off site as long as it is not over the bluff edge.
7. Do not construct stormwater infiltration systems (e.g. rain gardens) unless they are specifically adapted to avoid destabilizing the bluff.
8. Locate septic system drain field away from bluff and gully.
9. Do not construct a pond on the site.
10. Do not locate a swimming pool near bluff or gully edges.

In addition to things mentioned above, the following issues are very important during the construction phase of any new buildings:

1. Preserve existing grass and trees and re-vegetate disturbed areas as soon as possible.
2. Place soil piles and construction materials away from bluff and gully edges.

3. Confine heavy equipment to driveway or gravel pad.
4. Use silt fences to minimize spread of sediment and to avoid sediment washing into gullies or over the bluff edge.

ADDITIONAL RESEARCH AND INFORMATION NEEDED

The next steps in assessing climate adaptation in Wisconsin's coastal communities are (1) to acquire and review adopted comprehensive and hazard mitigation plans to assess if and how climate change issues are addressed, (2) determine if any coastal communities have adopted climate action plans and assess their quality, and (3) survey planners in coastal communities to determine ongoing climate adaptation activities and assess if any technical assistance is desired.

The data listed below will help to further define the projected impacts to our coasts and refine the proposed adaptation strategies.

- Updated long-term projections of potential lake levels based on downscaling of general circulation models for the Great Lakes region.
- Detailed nearshore bathymetry for multiple time periods to study lakebed downcutting.
- Current, high resolution LiDAR data to construct integrated topographic/bathymetric models to visualize the impacts of variable water levels.
- Current and historical orthophotography to calculate rates of bluff and shore erosion.
- Parcels, tax assessment data, and planimetric mapping to assess buildings and infrastructure at risk to coastal hazards.
- Higher density and frequency of coastal observations (buoys and other sensors measuring wind, waves, water levels, etc.).
- Up to date coastal demographics.
- Extent of beaches and coastal wetlands.

Topic-Specific Data Needs

Port, Harbor and Marina Facilities

- Bathymetric and nearshore data of sufficient resolution to understand which harbors or marinas may be at risk due to shallow depths
- Geodatabase of ports, harbors and recreational marinas including infrastructure characterization with respect to type, condition, channel depths and potential for adaptation to changes in water levels (Task Group 3, International Navigation Association Environmental Commission, 2008).
- Identification and characterization of sensitive habitats in nearshore areas
- Preliminary site evaluation for high risk ports, harbors and marinas to determine if contaminated sediments deposits exist.

Tourism

- More study on economic impacts of reduced tourism, such as the cost of beach closures, lost recreational fishing opportunities
- Economic losses associated with hotel rooms, fishing gear, sunblock, etc.
- Determine how changing lake levels may affect existing recreational facilities, hotels, and beaches.

Beaches

- Shallow water substrate (bathymetry data mentioned above)
- Current land use.
- Cladophora and zebra/quagga mussel range
- Anticipated change in water temp and chemistry and expected affects on lake community (algae, invertebrates, exotics...).
- Identification and characterization of sensitive habitats in nearshore areas
- Location of storm water outfalls, parking lots and other direct sources of pollutants to beaches
- Projected changes in rainfall-runoff in coastal watersheds
- Locations of known non-gamefish spawning areas near current shoreline

Water Intakes

- All data required to make vulnerability determinations listed above including location and depth of intakes and surrounding substrate.
- Bathymetric data of sufficient resolution to make these determinations.

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