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Coastal Zone Management under a Changing Climate in the Great Lakes

Ontario
Ministry of Natural Resources

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Terrace Bay
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Oshawa
Goderich
Toronto
Lake Ontario
U. S. A.
Lake
Michigan
Pinery
Hamilton
Welland Canal
Sarnia
Niagara Falls
Lake
St. Clair
Walpole Island
Port Colborne
Long Point
Lake Erie
Windsor
Point Pelee
0
250
500
kilometres

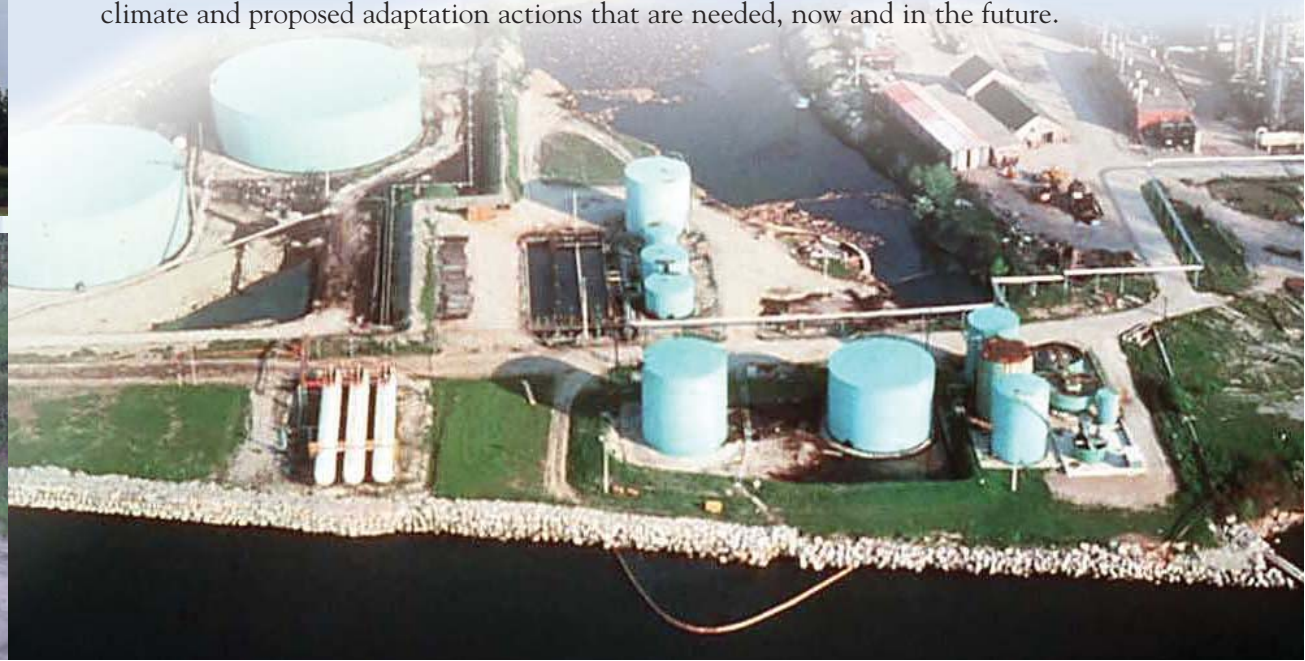
Adapting to Climate Change in Canadian Great Lakes Communities

THE GREAT LAKES BASIN in Ontario is presently home to over 12 million Canadians (approximately 30% of the country's population) who rely on these large lakes for fresh water, marine transport, food, recreation and tourism. Manufacturing and commerce are important to the economy of major urban centres located near or on the shores of the Great Lakes, including Toronto, Hamilton, Windsor, Sarnia, Sault Ste. Marie and Thunder Bay. Agriculture is a significant industry in southern Ontario while forestry provides an economic base for many communities in the north. Commercial and recreational fisheries are important on all of the lakes although the species composition of the catch has changed dramatically in the last 50 years as a result of invasive species.

Climate plays an important role in helping to shape the social, cultural, economic and spiritual development of the Great Lakes Basin, and in sustaining its natural ecosystems. Although climate has been changing since the Earth was first formed, there is mounting scientific evidence that, in the past century or so, changes in our global, regional and local climates have been occurring at an unusually rapid rate. The international scientific community has attributed much of the observed global warming and subsequent changes in climate since the mid-20th century to human activities. Fossil fuel consumption and land use change have resulted in a sharp increase in atmospheric greenhouse gases (GHGs) and a disruption to their natural balance. These gases occur naturally within the atmosphere and are critical to sustaining the temperature of the Earth necessary to maintain life. However, any increase in their normal concentration leads to increasing warming of the atmosphere and subsequently other changes in the climate system. Within the Great Lakes Basin, temperatures have warmed, precipitation patterns have changed, Great Lakes ice coverage has decreased, Great Lakes water levels have reached new record lows in recent years and changes in weather extremes have been recorded since the start of the 20th century. Scientists have concluded that warming of our climate system is unequivocal and that further warming and significant changes to our climate system will occur during the 21st century.

Additional average annual warming of 2-5°C and precipitation increases of up to 15% are projected for the Great Lakes area by the middle of this century, with even greater increases expected during some seasons, particularly winter. Even with projected increases in precipitation, warmer temperatures and a longer ice free period will result in increased evaporation and an expected lowering of the Great Lakes water levels (up to 1 metre). Perhaps more important than changes to the "average" climate will be the expected increase in extreme weather events. Human health, safety, prosperity and the natural environment have the potential to be significantly impacted as a result of climate change. It will therefore be important to understand the impacts and develop adaptation strategies that will help coastal zone communities prepare for and respond to the range of projected changes in climatic conditions. As the changes in climate and their associated impacts will differ for each of the Great Lakes, the adaptation strategies will need to reflect unique regional and local characteristics. These "no-regret" adaptation strategies will help to increase our adaptive capacity and reduce the vulnerability of Great Lakes communities to these changes, while taking advantage of potential opportunities and benefits.

Adaptation activities can be classified into the following categories: scientific, technological, institutional, behavioural, political, financial, regulatory and/or individual adaptation actions. This report is based on a series of community-based workshops that were held throughout the Canadian Great Lakes Basin to help identify the impacts of a changing climate and proposed adaptation actions that are needed, now and in the future.



Climate Change in the Great Lakes Basin during the 21st Century

AIR TEMPERATURE:

- Increase in annual and seasonal air temperature
- Increase in number of hot days and heat waves
- Decrease in number of extreme cold days and extreme minimum temperatures

PRECIPITATION:

- Increase in annual precipitation and on average, increases to seasonal precipitation
- Increase in intensity and frequency of heavy rainfall events
- Increase in frequency and severity of drought
- More precipitation falling as rain and freezing rain rather than snow
- Potential increase in ice storms

WIND:

- Possible increase in wind speeds with changing wind patterns, shifting storm tracks, and increase in extreme weather events (changes in wind patterns and speeds at the local mesoscale level are particularly difficult to project)
- Increase in winter storm winds associated with projected increases in the number of intense winter storms

WATER TEMPERATURE:

- Increase in water temperature

WATER LEVELS:

- Declines in Great Lakes water levels

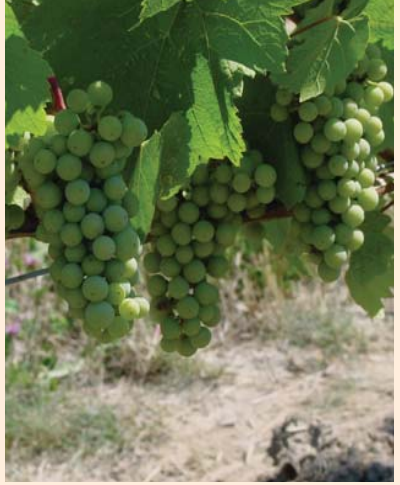




The Lake Ontario Coastal Zone

THE GOLDEN HORSESHOE OF THE LAKE ONTARIO COASTAL ZONE is a densely populated and heavily urbanized area at the west end of Lake Ontario. The area stretches from Niagara Falls at the eastern end of the Niagara Peninsula to Oshawa on the north shore. Overall this coastal area is relatively low-lying, with the most prominent topographic feature being the Niagara Escarpment at the western end of the lake. The Scarborough Bluffs in Toronto and cliffs in Prince Edward County rise over 60 metres above Lake Ontario. The Niagara Peninsula on the south shore of the lake is a major fruit-growing and wine-producing region while the area's metropolitan centres are home to over 25% of Canada's population with Toronto being the largest of these cities. The built environment is a prominent feature along the urbanized shoreline and includes buildings such as Toronto's CN tower, industries, harbours, marinas, power plants, water treatment plants and other infrastructure.

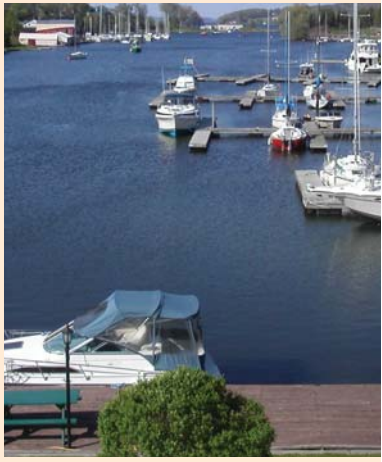
Deforestation, agriculture, urbanization, industrial development, damming of the majority of rivers, and the exploitation of the fisheries has resulted in substantial alteration to the region's natural environment over the past 200 years. Many of the natural bays, wetlands and river mouths along the shores of Lake Ontario have been modified significantly through infilling, dredging and armouring. Nevertheless, there are still some natural areas along the shores of Lake Ontario that have been protected as provincial and municipal parks and conservation areas, providing refuges for fish and wildlife as well as areas for recreation. In particular, the few remaining coastal wetlands are very important for preserving habitat for a diverse variety of fish and wildlife species. Despite these preservation efforts, fish and wildlife habitat is fragmented in many areas.



CLIMATE CHANGE IMPACTS AND ADAPTATION STRATEGIES

Variable	Impacts	Adaptation and Management
Air Temperature	■ Seasonal shifts in energy demand: • increased demand for summer air conditioning • reduction in winter heating	■ Use of lake water for cooling buildings ■ Increase generating capacity using Great Lakes water ■ Improved insulation for buildings– energy efficiency
	■ Increased demand for coastal recreation areas, natural parks and conservation areas	■ Increase parks and recreational facilities along coast ■ Increased revenue for water sport activities and marinas ■ Review of/changes to park management policies and operations
	■ Adverse heat-related health impacts	■ Expansion and implementation of heat-health alert systems (and response systems in partnership with municipalities, Environment Canada and Health Canada)
	■ Change in growing season length and harvest times	■ Agricultural extension services providing new crop data/information for farmers ■ New early-warning predictions provided for water availability and water conservation actions
	■ Adverse impacts on ice wine production	■ Improvement in seasonal climate predictions ■ Northward expansion of ice wine industry, where viable

Variable	Impacts	Adaptation and Management
Precipitation	■ Flooding of low lying areas, basements etc.	■ Restrict development in floodplains ■ Use berms and dykes to protect against flooding
	■ Failure of storm sewers, culverts etc. in extreme precipitation events ■ Potential increase in disruption to/failure of electrical distribution/transmission systems, communication towers (with potential increase in ice storms)	■ Review/update design specifications for stormwater conveyance structures, buildings, transmission and communication towers and lines and other infrastructure, and develop new specifications to consider climate change
	■ Water availability and low water level concerns during more frequent and severe periods of drought	■ Review/update provincial and municipal water level response programs and associated actions (including water conservation programs)
Wind	■ Increased seiche effects and wave run-up, which will affect shipping in shallow channels of the St. Lawrence River and some Great Lakes harbours	■ Enhanced wind and water level advisories/warnings for shipping, boating
	■ Damage to trees from wind storms	■ Planting of wind-firm trees ■ Increased diversity of trees
	■ Damage to built infrastructure (including power lines) from wind storms	■ Review of engineering practices, infrastructure design standards ■ Emergency preparedness planning for coastal areas
	■ More intense wind storms could result in damage to marinas, coastal facilities	■ Construction of berms to protect marinas and coastal facilities from wind/storm damage



Variable	Impacts	Adaptation and Management
Water Temperature, Changes in Great Lakes Ice Cover	■ Cold water fisheries decline; cool and warm water fisheries increase	■ Change in fisheries, open fishing seasons and productivity
	■ Increase in blue-green algae	■ Water filtration plants improved
	■ Increased coastal erosion with reduced ice cover/ exposure to winter storms	■ Modify harbour installations as necessary ■ Improved land-use planning in coastal zones (i.e. Municipal Official Plans)
	■ Longer ice free navigation season	■ Increase in length of shipping season
	■ Increase in over-wintering waterfowl	■ Change in waterfowl hunting regulations
Water Levels	■ Redistribution, reduction in and/or loss of wetlands	■ Dyking of natural wetlands and/or creation of artificial wetlands
	■ Reduction in depth of shipping channels resulting in reduction of commercial shipping loads	■ Dredging harbours, marinas and shipping channels
	■ Shoreline retreat (especially in shallow water areas) affecting property boundaries and ownership	■ New regulations and surveying for riparian properties ■ Boundaries for some parks extended with beach area increased – property ownership policies developed

The Lake Erie and Lake St. Clair Coastal Zone

LAKE ERIE is the shallowest of the five Great Lakes and the smallest in volume. The very shallow and smaller LAKE ST. CLAIR is also part of the Great Lakes system. With the exception of the major urban city of Windsor, agriculture is the predominant land use along the north shore of Lake Erie and around Lake St. Clair with many high value crops grown in this warmest area of Ontario. The national and provincial parks, conservation areas, marinas and small towns along the shoreline provide major recreational opportunities for many Canadians and visitors from the United States. The lakes also provide significant commercial and recreational fishing opportunities.

Commercial shipping traverses the lakes from Port Colborne at the head of the Welland Canal in the east to the dredged channel through Lake St Clair in the west. Shipping operations are particularly vulnerable to low water levels in the lakes due to their normally shallow depths. Water levels in Lake Erie are also affected by wind-caused changes in lake levels (seiches). Strong winds exacerbate low water levels by causing oscillations in lake levels that can lead to differences in water levels of up to 5 metres between the east and west ends of the lake. Ships subsequently become grounded in the shallow waters. In areas where water levels are high during storms, the lake shorelines are highly erodible and dynamic as there are no significant cliffs and bluffs along the lakes. Many of the once extensive swamps and wetlands along the shores have been dyked and drained, and Carolinian woodlots have all but disappeared. Large wetlands associated with Long Point, Point Pelee and Walpole Island remain as very significant staging and breeding areas for fish and wildlife.

CLIMATE CHANGE IMPACTS AND ADAPTATION STRATEGIES

Variable	Impacts	Adaptation and Management
Air Temperature	■ Longer growing season	■ Changes to agricultural practices/crops grown; more high-value crops grown ■ Greenhouse operations in coastal region become more cost effective
	■ Longer summer recreational season	■ Increased revenue for water sport activities and marinas
	■ Increased recreational demand for coastal parks and facilities	■ Review of/changes to park management policies and operations
Precipitation	■ Erosion of drainage canals with sediment and contaminant (i.e. fertilizer, chemicals) transport to the Lakes, resulting in eutrophication of coastal waters and major algal blooms	■ Develop better riparian buffers ■ Improve agricultural tillage techniques and best management practices
	■ Impacts to crops with more frequent/severe drought ■ Possible reduction in water availability for irrigation during drought	■ Introduction of new crop varieties ■ Changes in irrigation and drainage techniques ■ Improved water availability prediction and management

Variable	Impacts	Adaptation and Management
Wind	■ Seiche effects create increased navigation problems for shipping	■ Enhanced water level monitoring and wind/water level forecasts for shipping
Water Temperature, Changes in Great Lakes Ice Cover	■ Longer ice-free navigation season	■ Extend length of shipping season
	■ Expansion of non-native species	
	■ Increased productivity favourable to warm water fish species	■ Could require changes to recreational fishing regulations
	■ Longer swimming season at coastal parks (provided water quality is acceptable)	■ Could require changes to park management policies/ practices, including an extended park operating season with provision for camping facilities and waste management
	■ Permits more over-wintering of waterfowl	■ Ensure that protected area management strategies meet changing requirements for the care of fish and wildlife species and their habitats

Variable	Impacts	Adaptation and Management
Water Levels	■ Negative impacts on shipping through Lakes Erie and St. Clair with low water levels	■ Management options will need to be explored. Further dredging of the St. Clair River and the channel through Lake St. Clair may NOT be an option, as this will lead to lower water levels in Lakes Huron and Michigan, and cause significant impacts to their coastal zones.
	■ An increase in riparian property boundaries as lake water levels drop (i.e. in some parts of Lake St. Clair, a one metre drop in water levels under climate change could result in a lakeward movement of the shoreline by as much as six kilometres due to the shallowness of the lake)	■ New regulations and surveying for riparian properties ■ Boundaries for some parks and beach areas expanded ■ Develop legal and management programs to address emerging property and ownership issues
	■ May force closure of some marinas (for example, in shallow water areas where dredging is not advised or possible)	■ Assessment of vulnerable marinas and properties, and development of cost-effective management strategies
	■ Drying of wetlands/ marshes and migration of boundaries lakeward	■ Beneficial management practices developed ■ Agricultural lands in some coastal areas such as Lake St. Clair will be expanded

The Lake Huron Coastal Zone

THE COASTAL REGION OF LAKE HURON may be the most naturally diverse of all the Great Lakes. In the south, its shoreline is characterized by low-lying bluffs and some very extensive beach and sand dune systems. Further north are the rocky shores of the Georgian Bay coast with a complex series of bays, inlets, sounds, islands and shoals. Of tens of thousand of islands in the Bay, Manitoulin Island is the world's largest lake island, separating the North Channel and Georgian Bay from Lake Huron's main body of water. Georgian Bay supports a high level of terrestrial and marine biodiversity, with numerous wetlands and small bogs. In contrast, most of the natural vegetation on the southeastern shores of Lake Huron was cleared in the late 1800's and land use is primarily agriculture with no extensive wetlands. The world's deepest freshwater port is located at Parry Sound on the eastern shore of Georgian Bay, while the community of Goderich is an important port on the south shore of Lake Huron.

The southern and eastern coastlines of Georgian Bay are popular sites for summer homes although many of these cottages are only accessible by water. The inland areas to the lee of Georgian Bay and Lake Huron also support outdoor winter recreational activities such as skiing and snowmobiling. Three national parks (including one marine), numerous provincial parks and conservation areas in the region preserve the unique terrestrial and marine environment, as well as provide recreational opportunities.






CLIMATE CHANGE IMPACTS AND ADAPTATION STRATEGIES

Variable	Impacts	Adaptation and Management
Air Temperature	■ Longer summer and cottage recreational season ■ Extend recreational demand for coastal parks, conservation areas and their facilities ■ Northward expansion of warm weather crops and Carolinian forest zone	■ Longer economically active season for local businesses ■ Increased revenue for water sport activities, marinas ■ Review of/changes to park and conservation area management policies and operations ■ Changes to farm and forestry management practices
Precipitation	■ More rain than snow in a shorter winter season with less Great Lakes ice cover (although lake-effect snow could increase in the near future) will impact winter recreation (ice-fishing, snowmobiling, skiing)	■ Diversify or increase business enterprises to warm season recreation ■ Ski resorts, where feasible, will need to place greater reliance on artificial snow making ■ Changes to municipal winter maintenance operations
Wind	■ Changes to wind patterns/speeds could impact either negatively or positively on the wind energy industry ■ More intense wind storms could result in a more dynamic shoreline zone and sand movement ■ More intense wind storms could result in damage to marinas and other coastal facilities	■ Potential for increase in wind energy/wind farms if increase in winds within favourable turbine operating thresholds ■ Protection for dune systems (i.e. plant stabilizing vegetation) ■ Improved wind/storm protection for marinas and coastal facilities ■ Improved land-use planning in Municipal Official Plans

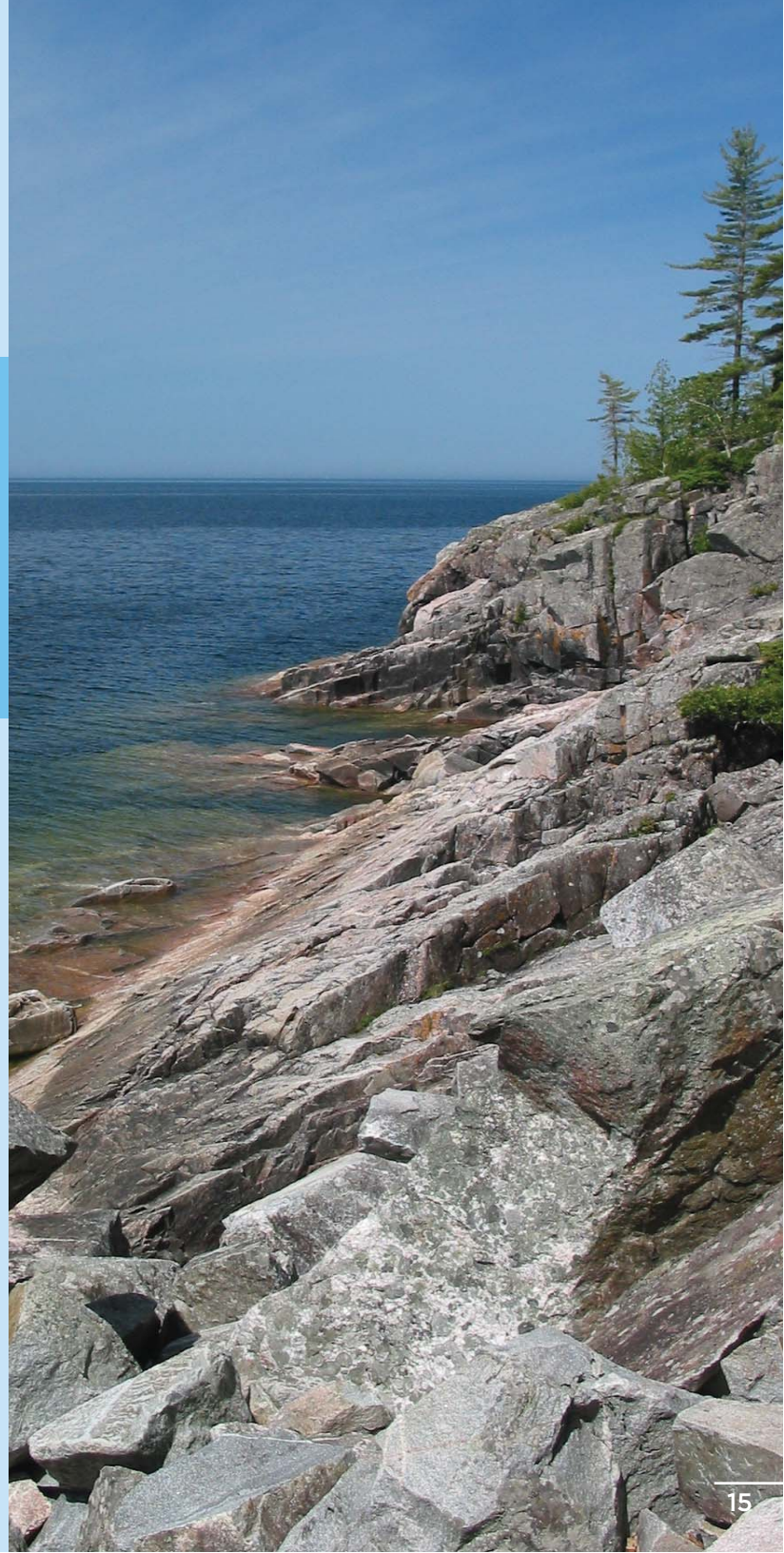
Variable	Impacts	Adaptation and Management
Water Temperature, Changes in Great Lakes Ice Cover	■ Increased blue-green algae growth, algal blooms	■ Improved water filtration techniques
	■ Changes in fish species distributions	■ Increase in warm water fisheries ■ Trout aquaculture can adapt by lowering cages to deeper, cooler water – operations could become more productive
	■ Extended swimming season in parks and conservation areas (provided water quality is acceptable)	■ Increased demand and changes to management policies and practices
Water Levels	■ Reduction in water access to properties on islands, inlets	■ Dredging harbours, marinas and shipping channels, where possible and sustainable
	■ Reduction in access to docks at marinas, private shoreline properties	■ Property owners may acquire extendable dock systems
	■ Reduction in depth of shipping channels	■ Develop short and long term strategies for vulnerable shipping lanes (i.e. reduce commercial shipping loads)
	■ Drying out of wetlands	■ Dyking of natural and/or creation of artificial wetlands
	■ Impacts on municipal water intake pipes	■ Extend water intake pipes further into lake
	■ Shoreline retreat (especially in shallow water areas) affecting property boundaries	■ New regulations and surveying for riparian properties ■ Boundaries for some Parks extended with beach area increased in the south (i.e. Pinery and Wasaga Beach Provincial Park beaches)
	■ Reduction in water erosion damage to coastal bluffs in lower Lake Huron	■ Water erosion reduced but wind erosion may become more prevalent requiring new management practices

The Lake Superior Coastal Zone

LAKE SUPERIOR is the largest, deepest and coldest of the five Great Lakes, and the largest freshwater lake in the world (by surface area). Its coastal zone is a mixture of rocky cliffs and shores with a number of rivers draining the hinterland but no extensive wetlands. The majority of the Lake Superior coastal region is forested, with many areas of the rugged coastline having never been logged. The Heritage Coast along the shores of Lake Superior and Lake Huron is managed to protect scenic beauty, natural ecosystems, and to promote recreation, tourism and other economic benefits through a network of parks and protected areas.

The north and east shores of Lake Superior are sparsely populated with only two major urban centres at Thunder Bay on the west shore and Sault Ste Marie in the southeast. The Sault Locks at Sault Ste. Marie allow ships to transport goods between Lake Superior and the lower Great Lakes.

The impacts of climate change to the coastal region of Lake Superior are expected to be less than those associated with the other Great Lakes. This is primarily as a result of the low level of human settlement and that it will require many decades before the climatic conditions change sufficiently to allow expansion of southern ecosystems northward. The great size and depth of Lake Superior may also tend to moderate the warming along the shoreline expected under climate change.



Variable	Impacts	Adaptation and Management
Air Temperature	■ Northward expansion of southern species	■ Changes to afforestation and reforestration programs
	■ Potential elimination of existing Arctic flora habitats	■ Assessment of in-situ habitats and other vulnerable species
	■ Extend recreational demand for coastal parks and facilities in summer	■ Review of/changes to park management policies and operations ■ Possible increase in revenue for marinas
	■ May change predictability of recreational activities such as skiing and snowmobiling	■ Tourism operators develop/apply adaptation strategies, as required (i.e. diversify operations; increase snow-making)
Precipitation	■ Increased fire hazard, especially during longer and more frequent periods of drought	■ Changes to forest management policies and operations, especially forest fire management
	■ Increases in insect infestations and diseases	■ Changes in detection and management of invasive insects and diseases
	■ Extreme flooding impacts on rail/road transportation (i.e. washouts)	■ Emergency disaster planning, and updating and development of new codes/standards for drainage infrastructure

Variable	Impacts	Adaptation and Management
Wind	■ Changes to wind patterns/speeds could impact either negatively or positively on the wind energy industry ■ More intense wind storms could increase hazards to shipping	■ Potential for increase in wind energy/wind farms on eastern shore of Lake Superior if increase in winds within favourable turbine operating thresholds ■ Enhanced marine wind advisory/warning programs
Water Temperature	■ May affect a few shallow coastal areas, generally negligible impacts	
Water Levels	■ Reduction in depth of shipping channels and reduced access to some harbours ■ Negative impacts on hydro-electric generation (i.e. at Sault Ste. Marie) ■ No significant impacts of water level changes in areas of steep rocky shores and low human settlement	■ Reduction in draft of ships ■ Potential to increase dredging in harbours (i.e. Sault Ste. Marie) – but with associated environmental risks and costs ■ Review of Lake Superior water regulation ■ Review of types of vessels navigating the Great Lakes ■ Changes in power generation procedures

"Climate Change isn't coming. It's here and it's in your own backyard. We need to find ways to adapt to it; We need to find ways to win."

(Don MacIver, Director, Environment Canada's Adaptation and Impacts Research Division, 2007)

THE SCIENTIFIC EVIDENCE is clear. Our climate is changing, from the global to the local scale, and Great Lakes communities are already feeling its impacts. For the coming decades, scientists project an accelerated rate and amount of warming, additional changes to our precipitation patterns and increases in the severity and frequency of our extreme weather. The inhabitants, economy, infrastructure and natural environment of the Great Lakes Basin will face significant impacts from a changing climate: an environment and society already challenged with stressors such as increasing population, land use change and pollution. Helping us to prepare for and reduce our vulnerability to a changing climate and its extremes will require the development and implementation of effective adaptation strategies and options. The adaptation process will need to involve all levels of government, industry, stakeholders and community decision-makers.

Adaptation will involve enhancing the resiliency and adaptive capacity of our systems to deal with the impacts of climate change. The economic resources, skills and technology within Ontario suggest that the province should have a strong capacity to adapt. However, this capacity is not uniform across all regions and sectors, and the types of adaptation options that will need to be implemented will vary between regions, sectors and communities. Climate change will need to be integrated or "mainstreamed" into decision making and planning processes, including regulation

and policies. Many of the types of adaptation actions will be “no regrets” measures, including water and energy conservation, community emergency preparedness and land-use planning, restricted development in floodplains, and improvements in our weather and flood forecasts and warnings. These “smart” planning actions are needed now to help us reduce our vulnerability to the current climate variability and change, and extremes, as well as help us become better prepared for the future.

Climate change will create new and complex challenges for municipalities in Ontario. To meet these new challenges, municipal staff will need to understand how the forecasted changes will impact on their infrastructure, programs and natural environment and then develop adaptation solutions for the future. This will require the development of both short and long-term management plans, incorporation of climate change into existing risk management frameworks, and coordination of regional and land use planning. Development, implementation and enforcement of regulations, standards, and codes will be an important part of this process at municipal, provincial and federal levels of government.

Community emergency management response planning, as required under Ontario’s Emergency Management and Civil Protection Act (Bill 148), helps municipalities prepare for, respond to, and recover from high impact weather events. This will become increasingly important in a changing climate where extreme weather events are projected to increase. Our built infrastructure is particularly vulnerable to such extremes, especially in highly urbanized areas. Adaptation options for our infrastructure will need to be prioritized and include, at a minimum, a review and update of climatic design information for building codes, engineering design standards and practices. Restrictions to waterfront growth and development in floodplains will also be needed. The costs associated with the adaptation process could prove to be significant, particularly if upgrades to existing infrastructure and changes to infrastructure design and buildings are required. However, the costs of inaction could be even higher.

Shoreline property boundaries are often defined in Ontario by the high water level. In recent years when Great Lakes water levels have been well below the long-term average, conflicts have arisen over riparian rights and water access. These conflicts can be expected to escalate as further declines in Great Lakes water levels occur under climate change, leading to major changes in property boundaries under current laws. All levels of government that have jurisdiction on riparian areas will need to address issues of water access, ownership of riparian lands and emerging "new" beachfronts. Policies and regulations will be required to protect the public interest, as well as acknowledge past practices and laws pertaining to riparian lands and shoreline ownership. Harbours, ports, marinas, waterfront parks and beaches will be impacted by declining Great Lakes water levels. Dredging of marinas and harbours may be required. However, dredging may not always be a viable option depending on the shoreline composition and underlying bedrock, as well as the associated environmental risk factors. This could ultimately force the closure or relocation of some of these marinas and harbours. Beachfront will be increased, but access to water for lakeshore homeowners, as well as marina operators, may also be lost unless docks are extended. Extendable docks have been used under past conditions of low water levels but there is an eventual limitation to how far these docks can be extended. Some municipalities may need to extend their water intake pipes further into the lake, particularly in those communities that already have relatively shallow coastal waters. The shipping industry and regulatory agencies will need to reassess load capacity, the management of shipping channels, and regulations that impact on or are affected by lower water levels.

Agricultural production is of key importance in the Great Lakes region and in Ontario is valued at $10 billion annually. The agricultural industry has always been sensitive to climate and its variability and extremes, and has developed crop production and water management practices to adapt to the climate. Adaptation measures that will be required for the future may be even more difficult, but they will need to be developed and implemented. For example, meeting the increased water demands of urban areas as well as increased irrigation requirements for livestock and crops could lead to additional challenges that will need to be resolved, especially if sources continue to be groundwater.

Noticeable changes in ecosystem composition, structure, and function are already being observed in the Great Lakes Basin and are expected to continue with climate change. In some areas, novel species assemblages will emerge, altering the existing lake and river, forest, and wetland ecosystems in the Great Lakes Basin. Biodiversity will change in response to the combined influences of climate, human activity, the movement of indigenous and non-indigenous species, and natural disturbances such as fire (which is also modified by climate). Some species will acclimate and/or adapt to changing conditions; others will not. Species with high reproductive rates that are able to move long distances, rapidly colonize new habitats, tolerate humans, and survive in a broad range of bio-physical conditions will be most successful.

Short- to long-term adaptation strategies to address climate change ecosystem concerns will need to be developed, implemented and integrated into a suite of natural resource management plans (i.e. fire protection, parks, sustainable forest management, fisheries management plans, wetland management plans, and invasive species management strategies) that are used by municipal, provincial, and federal agencies. The adaptive measures may benefit from any existing or new strategies to conserve biodiversity, such as reducing fragmentation and degradation of habitats, increasing connectivity between habitat areas, maintaining migration corridors and reducing other human-induced environmental stresses.

Protection and preservation of coastal wetlands will require effective management plans, policies and programs to account for declining water levels, warmer water temperatures, changes to water quality, hydroelectric power generation requirements, and demand for recreation. Dyking and the creation of artificial wetlands may be required as part of these programs, while effective land use planning will also be an important component. Regulatory control of water levels in the Great Lakes will face the challenge of considering the needs and preservation of wetlands and the coastal environment, while also trying to satisfy the water requirements of municipalities, industry, hydroelectric power generation, recreational boating and shipping.

As fish species and distributions shift in the warmer lake temperatures of a changing climate, commercial and recreational fishing and aquaculture will see subsequent changes. Regulation of fisheries and shifting to warm water fishing could help the fisheries sector successfully adapt to climate change. The natural forestry system will have some capacity to adapt but the forestry industry will still need to develop and implement adaptation strategies, including biodiversity conservation, forest protection, regeneration, park and wilderness area management and silvicultural management.

Invasive species are significantly impacting Great Lakes ecosystems and will continue to do so in the future. In a warmer climate, range expansion of invasive species that currently survive in the Great Lakes and the arrival of new species will significantly alter aquatic ecosystem composition, structure, and function. Stringent management policies and legislative controls will need to be implemented to help control or eliminate harmful invasive species and their threat to fisheries and wildlife. Attempts to limit rapid population growth and expansion of invasive species in our current climate have in some cases proven to be ineffective (i.e. control of Zebra Mussels and the Double-crested Cormorant). Thus our ability to control the ecology of the lakes once new species have appeared or been introduced may be limited.

The Great Lakes Basin coastal zone faces significant impacts in a changing climate. Proactive planning and taking effective adaptive actions now will help us increase new opportunities and benefits while reducing our current and future vulnerability to a changing climate.

PHOTO CREDITS

China Meteorological Administration: 13 *(bottom right)*

Don McNicol, Canadian Wildlife Services, Environment Canada: 13 *(top left)*, 17 *(top centre)*, back cover

Environment Canada: 1 *(upper middle)*, 3 *(centre, centre left)*, 5 *(top right, top centre left, bottom right)*, 6 *(top right)*, 9 *(top left, top right, bottom right)*, 10 *(top left, bottom left)*, 11 *(top right)*, 13 *(top right)*, 14 *(top centre)*, 16 *(top left, top right, bottom left)*, 17 *(top left, top right, bottom right)*, 18, 19 *(bottom, centre)*, 20 *(bottom)*, 21 *(bottom)*, 22 *(centre)*

Gary Klaassen: 13 *(top centre left)*, 15, 20 *(top)*

John Hall, Hamilton Remedial Action Plan, Environment Canada: front cover, 4, 5 *(top centre right)*

Karl Schiefer, EcoMatrix: 1 *(lower middle)*, 3 *(left)*, 7 *(top left)*, 11 *(top left)*, 13 *(top centre right)*, 14 *(top right)*, 20 *(centre)*, 22 *(left)*

Mark Taylor: front cover, 1*(top)*, 2 *(bottom left)*, 3 *(centre right, right)*, 5 *(top left)*, 7 *(top right, right centre, bottom right)*, 9 *(top centre left, top centre right)*, 11 *(bottom right)*, 12, 13 *(right centre)*, 22 *(bottom right)*

U.S. Army Corps of Engineers *(public domain)*, **http://www.lre.usace.army.mil/_kd/go.cfm?destination=page&pge_id=1324:** 16 *(top centre)*

Spacing Photos *(public domain)*, **http://spacing.ca/photoblog/?page_id=42:** 6 *(top centre)*

Rukavina, N.A. 2004. NWRI Sediment Archive. Products and Services, www.nwri.ca: 1 *(bottom)*, 2 *(bottom right)*, 8, 10 *(top centre, top right)*, 11 *(top centre, right centre)*, 14 *(top left, left centre, bottom left)*, 21 *(top, centre)*, 23

Weatherpix Stock Images, http://www.weatherpix.com: 2 *(top left)*, 6 *(top left, bottom left)*

Weatherstock/Warren Faidley: 19 *(top)*