

Climate Change Impacts on the Great Lakes

A discussion paper on the potential implications for coastal processes affecting the SE shoreline of Lake Huron within the jurisdiction of the Ausable Bayfield Conservation Authority

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1.0: Introduction

The potential effects of (human induced) Global Climate Change are likely to be significant for a whole range of activities in the Great Lakes Basin from shipping, to hydroelectric power generation, to commercial and recreational fishing, and to coastal processes controlling erosion and deposition. It is now usual for the development of management strategies for any, or all of these activities to consider the potential effects of Global Climate Change resulting from increased levels of greenhouse gases in the atmosphere and what kinds of adaptation strategies might be needed to account for this. Such considerations, for example, form part of the assessment of the management of flows and lake levels in the IJC Upper Great Lakes Study (International Joint Commission, 2012) and of management plans for major cities situated on the Great Lakes such as Toronto and Chicago (e.g., Hayhoe et al., 2010). This discussion paper reviews aspects of Global Climate Change that may be important for shoreline management in the Great Lakes and in particular for the area managed by the ABCA. No attempt is made to review the theories related to the effects of increased emission of greenhouse gases into the atmosphere on the climate of the earth or some of the issues related to this. There is now a general consensus among most scientists that Global Climate Change is real and there is considerable information being provided by scientific modelling to predict the impact of this on global and regional climates over the next 100-200 years under a range of future emission scenarios (see IPCC 2013). Therefore the approach taken here is to assume that there is a very high probability that some form of climate change will occur and that it would be negligent not to take this into consideration in planning management strategies for the next 100 years.

In considering climate change effects it is useful to begin with a general definition of some terms related to climate. The term **weather** describes processes in the atmosphere and in particular processes that affect us at, or close to the earth surface over a short period of time (hours to days), and we describe or measure aspects of it in terms of air temperature, clouds, precipitation, wind speed and direction and so on. **Climate** refers to the summation of all weather over some substantial period of time on the order of decades to centuries, and perhaps millennia. A key assumption in defining climate is that it can be described by a variety of statistical measures such as the mean and standard deviation of various parameters. It is then possible to examine trends in these statistics over time to determine if the climate is stable or changing. Global Climate Change therefore focuses primarily on defining climate over the past one to two centuries and forecasting changes over the next one to two centuries.

While the primary effect of increased greenhouse gases in the atmosphere is to raise the average temperature of the atmosphere close to the ground, the dynamic nature of the controls on earth climate means that this increase in temperature is not uniform spatially or temporally – it will be larger at higher latitudes and it will also be larger in the winter than in the summer at higher latitudes. Differential heating and cooling of water versus land and the transfer of heat through ocean currents increases the complexities of the effects and the timespan over which change takes place. Increased temperature will also affect the nature of the general circulation of

the atmosphere, likely affecting, for example, the tracks and intensity of mid-latitude cyclones and this in turn will affect the nature of precipitation events and the proportion of snow versus rain on an annual basis. Prediction of the effects of increasing greenhouse gas concentrations in the atmosphere has been explored for several decades by increasingly complex Global Climate Models or GCMs which are computer models that simulate the characteristics of the earth surface and lower atmosphere and compare the effects of different scenarios of atmospheric CO₂ on climate over the earth as a whole. There are now over 40 such models in operation and they may differ in the way they represent various processes or the degree of complexity in accounting for effects such as ocean currents with the result that there are differences between models in their outputs. The earth surface is represented in the model by grid cells that at the global scale have sides on the order of 150-300 km which means that the Great Lakes region may be represented by only a few grid cells and the complexities of the lakes and the bordering land surface are not well represented, particularly for predicting local precipitation and evapotranspiration and thus the effects on stream flow and lake levels. This problem may be addressed by various techniques for downscaling to more appropriate scales on the order of 10-30 km (e.g., Gula and Peltier, 2012; Wang et al., 2015) which give us the ability to assess what the potential effects might be on a range of climate factors affecting the Great Lakes. In addition to detailed scientific papers there are a number of recent reports that synthesise the state of knowledge on climate change in the Great Lakes Basin and adaptation strategies to these (e.g., Huff and Thomas, 2014; McDermid et al., 2015; In particular, here we address potential climate change effects on lake level, storm frequency and magnitude, littoral drift, cohesive coast erosion, and sandy beach and dune systems relevant to the management of the ABCA shoreline.

2.0 Predicted Changes in Temperature, Precipitation, and Storm Events

In this section we examine the predicted changes in key climate variables of temperature, precipitation and the frequency and magnitude of storm events. In the following section we will examine the effects of these on key coastal processes.

2.1 Changes in temperature

Over the past 60 years temperatures in the Great Lakes region have increased on the order of 1-2°C with the temperature increase generally being greater towards the north. There is a greater reduction in minimum winter temperatures than an increase in maximum summer temperatures, all effects which are generally expected under climate change scenarios (McDermid et al., 2015). These trends are predicted to continue through the end of the century (Figure 1) with mean temperatures increasing by 2-7°C in southern Ontario (McDermid et al., 2015) and as much as 6-8°C under some scenarios (Wang et al., 2015). The number of frost-free days will increase significantly and, while the increase in summer temperatures is smaller than in the winter it will still drive a greater frequency of extreme heat alerts. Confidence in these projections is generally high (McDermid et al., 2015). Increased temperatures will influence the temperature of lake waters, stratification and the timing of turnover (Trumpicas et al., 2009; 2015) and this may have

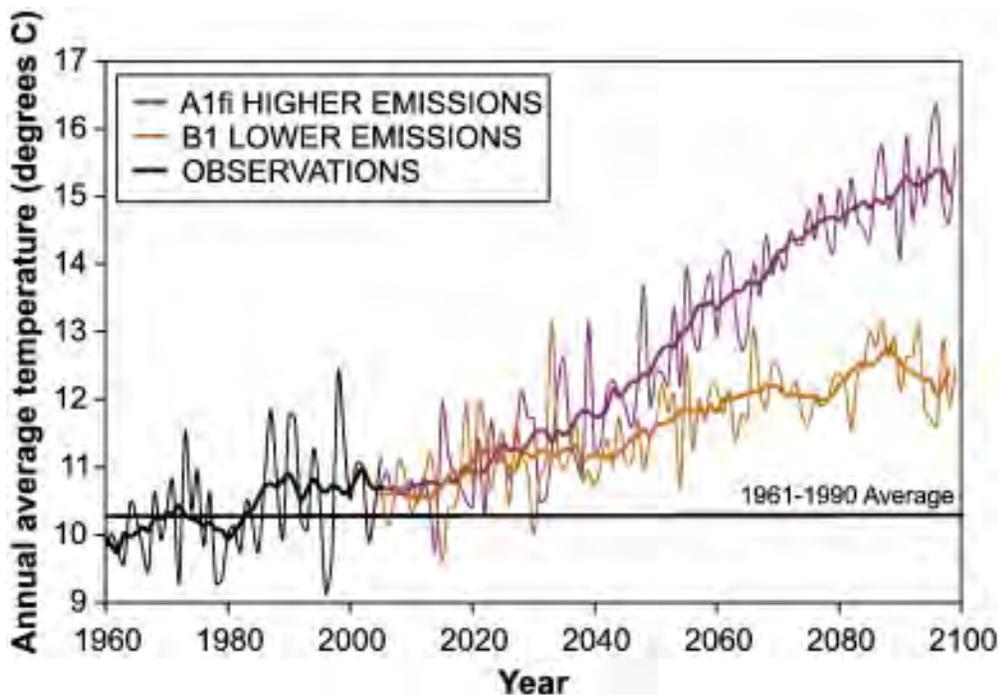


Figure 1: Observed and model-simulated historical and projected future annual average temperatures for Chicago, in degrees Celsius. Model simulations show the average of the GFDL 2.1, HadCM3, and PCM models for the SRES A1fi (higher) and B1 (lower) emission scenarios (after Hayhoe et al., 2012).

effects for example on fisheries (Lynch et al., 2010). It will lead to a very significant decrease in the extent and duration of winter ice cover on the lake and it will also have the potential to increase evaporation from the lake.

2.2 Changes in precipitation

There is much greater uncertainty in predicting changes in precipitation due to climate change than is the case for temperature. While there was a small increase in precipitation over the Great Lakes Basin in the last half of the 20th century this is likely within the range of variation and the first decade appears to have seen a decline. Future projections suggest an increase in the order of 20% by the end of the century with greater amounts towards the north compared to the southern half of the basin (Notaro et al., 2014; Wang et al., 2015; McDermid et al., 2015; Bartolai et al., 2015) but there is a great deal of uncertainty in this projection. There is, however general agreement that the proportion of precipitation falling as snow will decrease and there will be an accompanying decrease in the duration and depth of snow cover. Lake effect snowfall will probably decrease in southern Lake Huron in December and January but may increase slightly in mid to late winter (Notaro et al., 2015). Heavy downpours have been increasing in the basin and this is expected to continue through the 21st century (McDermid et al., 2015).

The small projected increase in precipitation may offset all or some of the projected increase in evaporation as a result of higher temperatures. This makes assessment of the effect on mean lake level more uncertain. Heavier rainstorms and a switch to rain rather than snow in late fall and early winter may increase erosion of cohesive bluffs.

2.3 Changes in storms, storm tracks and winds

There is some suggestion in the literature that average wind speeds will increase slightly and that wind speeds during storm events may be stronger (e.g., Peck et al., 2012; Wang et al., 2014). However, there does not seem to be enough certainty on this to project the impact on coastal processes. In any event, changes to wave generation and storm surge are limited by the existing shoreline configuration and water depth so that small changes in wind speed are not likely to have a significant effect. A significant change in wind direction, e.g., fewer storms with strong NW winds, might alter the littoral drift pattern and rate of bluff erosion but again the effect is likely to be small because of the position of the ABCA shoreline at the south end of the lake.

3.0 Climate Change Effects on Coastal Processes Within the ABCA Shoreline.

Changes in temperature and precipitation predicted under various Climate Change scenarios will have varying influences on coastal processes at the south end of Lake Huron. In this section we consider potential effects on lake level, wave climate, littoral sediment transport, erosion of cohesive bluff shorelines and aeolian sand transport.

3.1 Mean and range of fluctuation in the level of Lake Huron

Mean lake level and the range of fluctuations of the Lake Huron/Michigan Lake respond primarily to precipitation and evaporation /evapotranspiration over the lake and its basin. In addition because of the inflow from Lake Superior precipitation and evapotranspiration over that basin also have an effect. Ice jams at the entrance to the St. Clair/Detroit River during the winter may also affect flows and thus affect lake level for periods of months. The increased temperatures and reduced ice cover predicted by Climate Change models all suggest that there should be an increase in losses through evaporation from the lake and to supplies from rivers and groundwater through evapotranspiration. However, because recent modelling suggests an increase in precipitation, particularly in northern areas of the basin and over Lake Superior there is uncertainty as to the extent to which the losses through evaporation and evapotranspiration will be offset by increased supply (Angel and Kunkel, 2009; IJC Upper Great Lakes Study 2012; MacKay and Seglenicks, 2013; Bartolai et al., 2015). The prolonged period of low lake level between 2002 and 2012 was attributed by some as evidence of the impact of Climate Change but the recent increase in levels in Lake Superior and Lake Huron/Michigan have suggested that this was simply part of the long-term lake level fluctuation. Given the absence of any strong evidence for significant change under the climate change scenarios it is perhaps best to assume that mean

lake level will remain within historic limits, or perhaps decrease slightly, and that there will continue to be decadal-scale fluctuations.

Changes in precipitation and winter ice cover may lead to a change in the seasonal lake level cycle with somewhat lower levels at the end of the summer and higher levels in the winter (MacKay and Seglenicks, 2013 see Figure 2).

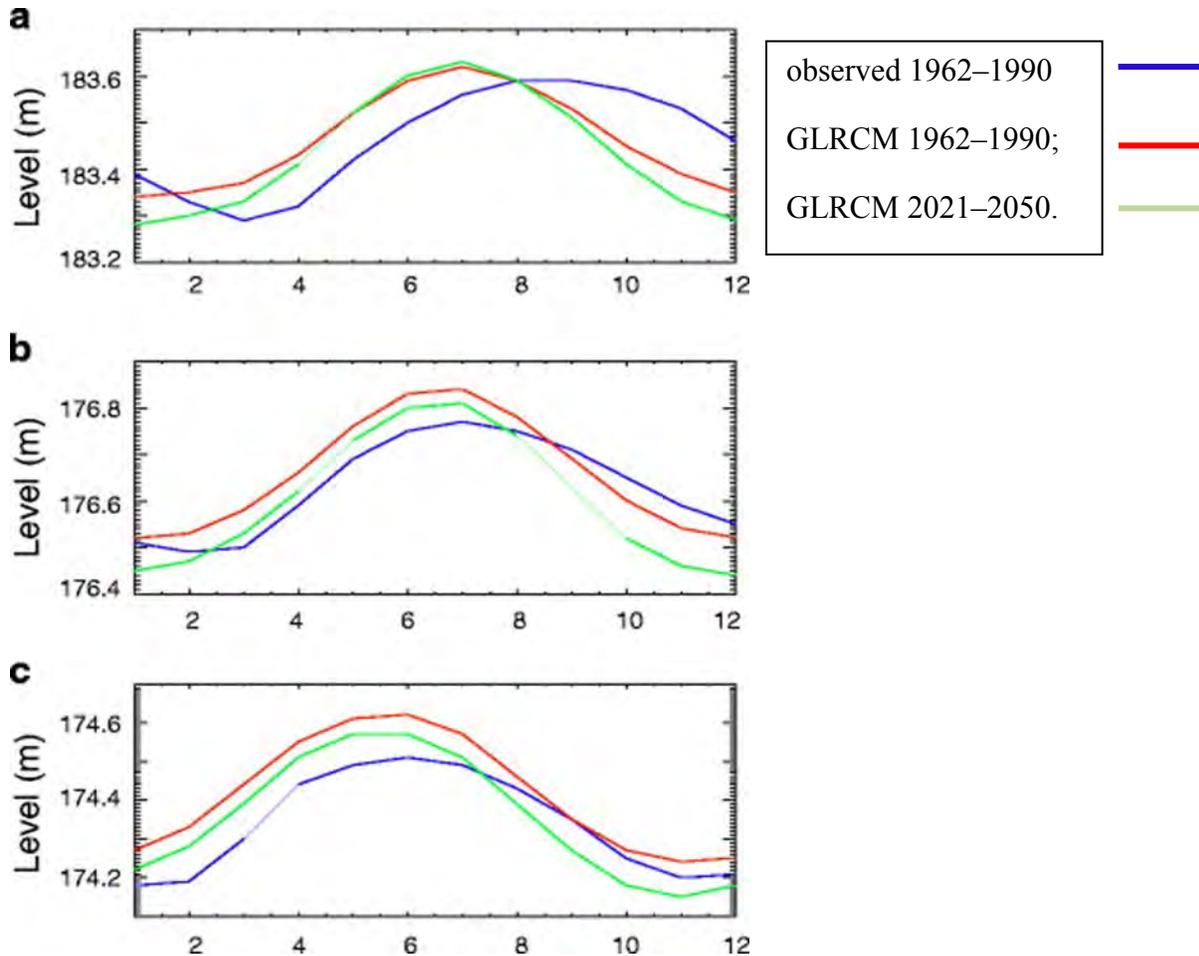


Figure 2: Lake level mean seasonal cycle for: a Lake Superior; b Lake Michigan – Huron; c Lake Erie. Units are m referenced to the International Great Lakes Datum 1985 (after MacKay and Seglenick, 2013, Figure 4).

3.2 Storm frequency, magnitude and wave climate

As noted above, there is little information on potential changes in storms and wind regime over the Lake Huron basin (Cheng et al., 2012) and no real indication that this will have a significant impact on the wave climate. However, the marked increase in temperature, particularly winter

temperatures, is already producing a decrease in extent of ice cover during winter as measured by a decrease in the length of the ice season and in the thickness and extent of ice cover (Howk, 2009; Wang et al., 2012; see also Brown and Duguay (2010) for a review of the factors controlling ice formation and the duration of the ice season). Wang et al. (2012) found a significant decrease in annual lake ice coverage for all the Great Lakes for the period 1973-2010 averaging about 2% per year for Lake Huron over that period (Figure 3). The analysis of Wang et al. also shows that the large inter-annual variation in lake ice occurs at periods of about 8 and 4 years. These periodicities are likely linked to major global pressure indices (Bai et al., 2010). The 8 year oscillation is linked to AO/NAO (Arctic Oscillation/ North Atlantic Oscillation) and associated with cold conditions and very large ice cover; the 4 year periodicity is linked to ENSO (El Nino Southern Oscillation) and is associated with mild winters and small ice cover.

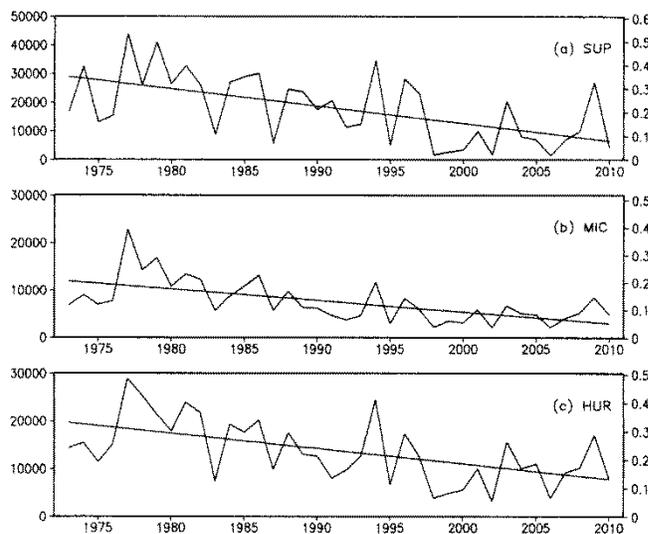


Figure 3: Annual mean lake ice area (km^2) for Lakes Superior, Michigan and Huron for the period 1973-201 and least squares trend line (from Wang et al., 2012, Figure 5).

The predicted increase in air and lake temperatures in the 21st century will lead to further decreases in the extent and duration of ice cover on Lake Huron. Modelling by Notaro et al. (2015) shows a decrease in maximum ice cover in February from the present level of about 50% to about 40 % by mid-century and 25% near the end of the century (Figure 4). The decrease in the duration and extent of ice cover will have a significant effect on the wave climate of southern Lake Huron because it will permit wave generation by an increasing number of storms in December and January, and again in March and April when ice cover in the lake under conditions at the turn of the century would usually have prevented this. The result will be an increase in the total annual wave energy. The effect may be magnified because these periods are often associated with more intense storms than in the middle of the year. The increase in the

number of storms that generate significant waves during the year will likely have a significant impact on sand transport by wave action, the net littoral drift, and erosion of the nearshore profile and the bluff toe on cohesive shores.

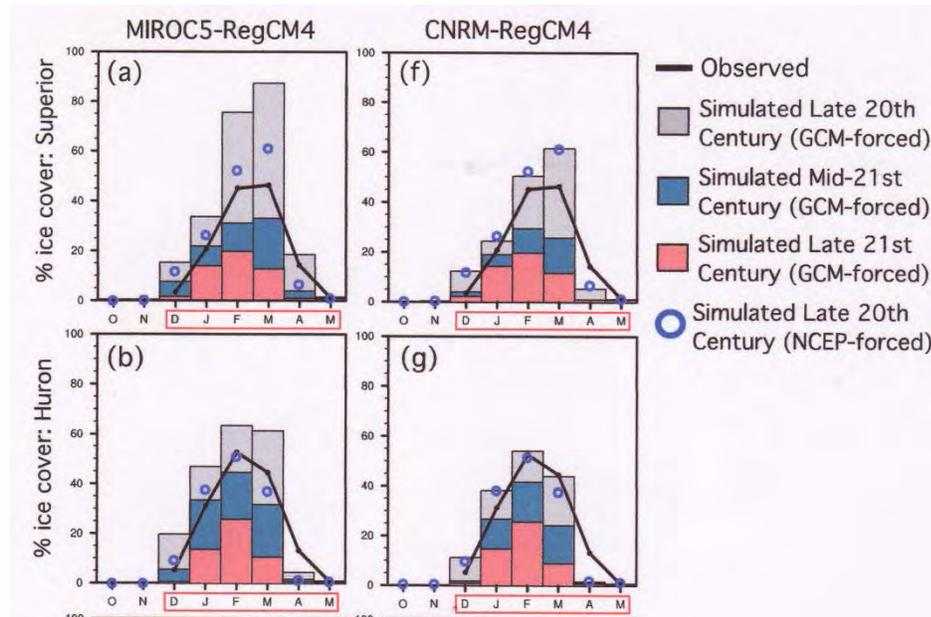


Figure 4: Mean seasonal cycle (October–May) of percent lake ice cover across Lakes (a),(f) Superior and (b),(g) Huron, from NOAA’s Great Lakes Ice Atlas (black line) and from (left) MIROC5-RegCM4, (right) CNRM-RegCM4, and NCEP-RegCM4. Simulated results for the late twentieth century (1980–99) are shown with gray bars for MIROC5-RegCM4 and CNRM-RegCM4 and blue circles for NCEP-RegCM4. Simulated results for the late (mid) twenty-first century (2080–99) from MIROC5-RegCM4 and CNRMRegCM4 are shown with pink (aqua) bars. Red rectangles in the x axis indicate time periods with significant ($p, 0.1$) reductions in mean ice cover by both mid- and late twenty-first century (from Notaro et al., 2015, Figure 8).

3.3 Littoral drift magnitude and patterns

The southerly transport of sediment within the ABCA shoreline is driven by its position at the south end of the lake and the dominance of waves from the NW blowing over the longest fetch. That general pattern is therefore not likely to change, but the magnitude of net longshore transport is likely to increase and, depending on the relative magnitude and duration of winds from the north quadrant during the period which is now normally ice covered, these may be significant changes – possibly on the order of 20-30%. An example of the differences between high and low ice cover winters is shown in the work of BaMasooud and Byrne (2012). At Point

Pelee on Lake Erie they measured much higher rates of erosion during the winter of 2005-06, which was characterised by very low ice cover, compared to very little erosion during the winter of 2003-04 which was characterised by very extensive ice cover that persisted for much of the winter. Mattheus (2014) also noted a similar role for ice cover in explaining changes in sedimentation at beaches on the south shore of Lake Erie.

Advances in modelling wave transformation and nearshore sediment transport have greatly improved our ability to model transport by waves (Figure 3). Recent work by Manson et al. (2016a, b) and the addition of a version of Delft 3D modified to include a new algorithm for simulating the effects of wave attenuation by ice provides a means of testing the effect of reduced ice cover on all coasts where ice is present in winter. Preliminary results for the north shore of Prince Edward Island show that reduced ice cover in the Gulf of St. Lawrence could lead to an increase in mean sediment transport by 50% or more (Manson, G., personal communication March, 2016) and it is likely that the effect along the ABCA shoreline would be of the same order of magnitude. The effect of this could be to reduce the volume of sand and gravel retained on beaches in the erosional sectors and thus a reduction in the beach width.

3.4 Cohesive coast nearshore and sub-aerial bluff erosion

Similar to the effect of reduced ice cover on nearshore sediment transport there will also be an enhancement of the rate of erosion of cohesive till in the nearshore because of the increase in the number of storm events on an annual basis. Most underwater erosion results from abrasion by sand and gravel rolling over the till surface under storm waves so that an increase in the number of storm events generating large waves will increase this process (Davidson-Arnott and Ollerhead, 1995; Davidson-Arnott and Langham, 2000). In turn, because the process of till erosion is irreversible, this will lead to an increase in wave energy reaching the bluff toe and ultimately to an increase in the rate of bluff recession. The magnitude of this increase is likely to scale with the increase in wave energy and so an estimate can be generated from the predicted pattern of decrease in ice cover and the average wind regime for those periods of the year during which wave generation in Lake Huron is presently inhibited by the presence of ice. The magnitude of this increase is likely to be on the order of 10-30% in the next few decades.

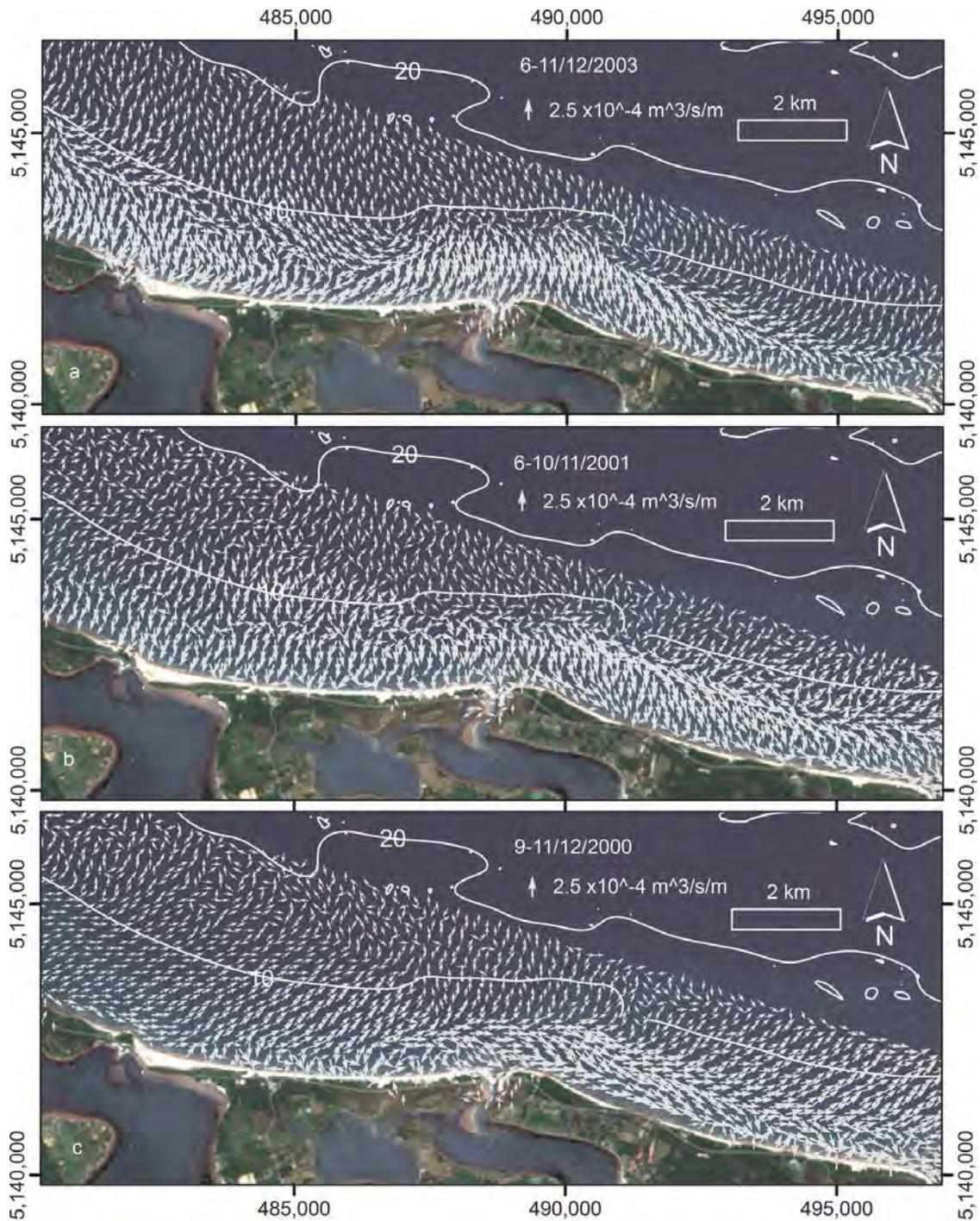


Figure 5: Example of the use of Delft3D hydrodynamic model to simulate sediment transport off the north coast of Prince Edward Island during open water conditions (Manson et al., 2016a). Shown are: a) mean bedload; b) suspended load; and c) total load transport with weighted mean transport directions during three fall storms. The arrows indicate the direction of transport and the length of the arrow is proportional to the mass of sediment transported.

3.5 Aeolian sand transport and coastal dune formation and stability

Reduced snow cover and increased wave activity during the winter may lead to an increase in the potential sand transport into the foredune zone in the dynamic beach area which stretches from Oakwood to Port Franks. This will be offset somewhat by wetter conditions and rainfall and by the enhanced potential for wave erosion during major storm events. The direct impacts of effects of climate change on coastal foredune plant communities are likely to be relatively small and difficult to predict locally because of the dominance of controlling factors, such as burial by sand and heat stress, and the relative resiliency of the plants in that zone (Reed et al., 2010). It is likely that marram (*Amophila breviligulata*) will continue to be the dominant species colonising the embryo dune and foredune zones since it is well adapted to somewhat warmer temperatures and is tolerant of sand burial and the hotter conditions that may prevail in the summer months.

Greater exposure to intense storms may also lead to more frequent dune erosion and rebuilding cycles, leading to shorter times for foredune recovery and the potential for more sand to be transported onto the crest and lee slopes of the foredune. However, the impact of this disturbance should be contained within the primary foredune zone and have little impact on the area landward.

3.6 Adaptation to predicted impacts of Climate Change

The predicted effects of Climate Change will have an impact on coastal processes along the southern Lake Huron shoreline, with the most important impacts likely being an increase in the rate of longshore sediment transport north of Grand Bend and an increase in the rate of downcutting in the nearshore and bluff toe erosion along the cohesive coast sections. At this time the predicted impacts on coastal processes are significant, but represent relatively modest changes to the magnitude of the operating processes within the existing system **not** a catastrophic change to the system itself. Nevertheless, it is important to consider them in assessing the existing policies and framework of the Shoreline Management Plan for the ABCA and what changes might be needed to strengthen these in the development of a revised and updated plan.

The timing and magnitude of these effects due to Climate Change is uncertain but there is also considerable uncertainty in our understanding of the processes themselves and our ability to predict the exact nature of coastal evolution over the next century and the scale of hazards due to erosion and to flooding associated with periods of above average lake level and storm surge. The general framework for shoreline management within the Provincial Policy is designed to be sufficiently flexible to accommodate these uncertainties by providing a sufficiently large buffer for setbacks of new development so that there is adequate time to accommodate short-term variability in the controlling processes as well as longer-term changes to the mean values. In particular, the use of a 100 year time horizon for recession rates and a 100 year flood elevation for lake level and storm surge should provide sufficient protection against the existing hazards as well as accommodating changes due to the predicted effects of Climate Change. In particular, if

there is an increase in the recession rate along the cohesive bluff shoreline this can be detected in decadal shoreline change mapping and accommodated through revisions to the average annual recession rate so that the setback for new development is adjusted to the new rate. Similarly, the setbacks already in existence on dynamic beaches in the ABCA should be able to accommodate any changes that do occur along those sections of the shoreline. In summary, while the effects of Climate Change are significant, they can be accommodated within the existing management framework and it is important not to focus on this to the exclusion of the other factors, particularly human factors, that together control the nature of coastal hazards and ecological integrity within the shoreline managed by the ABCA.

4.0 Conclusions

- 1) Average annual temperatures in the region will likely increase on the order of 2-7°C by the end of the century with much of this resulting from a large increase in winter temperatures and a somewhat smaller increase in summer temperatures. In turn this will have an impact on lake temperatures, lake effect snowfall, winter ice cover and fish habitats. It will likely also have an impact on the length of the recreational season.
- 2) Precipitation is predicted to remain approximately the same or to increase by up to 20%, mostly in the northern half of the basin. Because of the warmer temperatures more precipitation will fall as rain rather than snow, and there may be more frequent heavy downpours. Confidence is much lower in these predictions than for temperature. The number of intensive storm may rise.
- 3) Because of the large uncertainty with respect to predictions for precipitation and evapotranspiration it is difficult to predict what will happen to mean lake levels. Recent modelling suggests that they will likely remain similar to historical levels.
- 4) The duration and extent of ice cover in southern Lake Huron had already decreased and is predicted to decrease further by the end of the century. The most important impact of this longer ice-free season on coastal processes will be an increase in the number of storms associated with large waves and large storm surges. This effect is enhanced by the fact that storms during the winter months are generally more frequent and more intensive than spring and summer. In turn, the greater frequency of storms and increased number of intense storms will drive larger volumes of longshore sediment transport and an increase in the rate of downcutting of the nearshore and erosion of the bluff toe along cohesive shorelines. There may be some changes in the vegetation along sandy beaches and the potential for some increase in sand transport from the beach to the foredune and the frequency of events leading to erosion of the foredune.
- 5) The potential for enhanced rates of longshore sediment transport and bluff erosion as well as impacts on the dynamics of sandy beach and dune systems can be addressed within the general framework of the shoreline management plan and the Provincial Policy. However, it will require increased vigilance to ensure that the average annual recession rates are updated regularly as new aerial photography, and possibly LiDAR, become available.

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