Implications of Low Water Levels for Canadian Lake Huron Marina Operations

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.
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ABSTRACT

Recreational boating in the Great Lakes is suggested to fuel tourism and the Ontario economy. Like many other tourism sectors, boating-tourism is a highly climate-sensitive economic sector which significantly relies upon compromising climatic conditions. Climate change in the 21st century is projected to alter climatic parameters in the Great Lakes region, thereby generating low lake water conditions and inadequate water levels within some marina facilities that cater to recreational boats. This study examines the multiple implications lakeside marina facilities have previously endured during low water conditions and the possible implications they may experience during three scenarios of water level reductions as a result of climate change.

Among the five Great Lakes, Lake Huron has become one of the most prominent lakes for understanding the relationship between climate variability and water-level fluctuations. A questionnaire was administered to 58 marina operators on the Canadian Lake Huron coastline. The questionnaire results were analysed, indicating implications Lake Huron marina operators experienced at their facilities during low water conditions and methods of adaptation that they used to overcome these conditions. The results also projected future implications that may result from climate change and reduced water levels. The most imminent impacts Canadian marina facilities on the Lake Huron coastline would endure as a result of climate change and low water conditions would be the loss of docking slips and potential marina closures.

Without adaptation of marina infrastructure, future implications on some Lake Huron Canadian marina facilities may cause substantial economic loss for nearby communities and businesses. Economic losses resulting from lake level water reductions and reduced boat-based expenditures for two regions located on Lake Huron's Georgian Bay shoreline are derived in the study. It is anticipated that the results of this study will provide significant groundwork for systematic and regional evaluations on the impacts in which climate change has upon Great Lake marinas and boat-based tourism.

Keywords: Climate Change; Tourism; Marina facilities; Projected Implications

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AMIC	Annual Maximum Ice Concentration
DFO	Department of Fisheries and Oceans
ENSO	El Niño-Southern Oscillation
GBA	Georgian Bay Association
IJC	International Joint Commission
IPCC	Intergovernmental Panel on Climate Change
IUGLS	International Upper Great Lakes Study
OTMP	Ontario Tourism Marketing Partnership
PGR	Post Glacial Rebound
RMRC	Recreational Marine Research Centre
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UNWTO	United Nations World Tourism Organization
WMO	World Meteorological Organization

1.0 INTRODUCTION

1.1 Study Context

The Fourth Assessment Report (AR4) provided by the Intergovernmental Panel on Climate Change (IPCC) (2007a) indicated that, “most of the observed increase in globally averaged temperatures since the mid-20th century is “very likely” (>90%) due to the observed increase in anthropogenic greenhouse gas concentrations” and more warming is to come as a result of past emissions suspended in the global atmosphere. The AR4 strongly emphasizes the importance of anticipatory adaptation and concludes by stating there will be twice as much warming over the next two decades if no action is taken to reduce emissions (IPCC 2007a). Already, eleven of the last twelve years are ranked among the twelve hottest years on record and increasing temperatures are now linked to more intense droughts, warming ocean temperatures, modified wind patterns and decreased snowpack and snow cover (IPCC 2007a, GISS 2008). The AR4 projects that average global surface temperatures will increase between 1.8 to 4.0°C by 2100 and that a warming of 0.1°C per decade for the next several decades is unavoidable due to past emissions (IPCC 2007a). A global temperature change of this magnitude has the ability to further alter climatic trends, in turn influencing ecological systems, seasonal cycles and associated sectors which rely on the earth’s natural resources.

Global tourism is an industry that highly depends upon the earth’s natural resources and is also recognized as one of the world’s fastest-growing economic industries (Hamilton & Tol 2004). Current climatic change verifies that action needs to be taken immediately in order to avoid economic losses within the industry (Gossling 2005). The extent to which the global tourism industry is influenced by climate change depends in part upon the magnitude and nature of change, coupled with its adaptability to change (Smit *et al.* 2000). According to Smith *et al.* (1996), “Adaptation to climate change includes all adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in the climate system". The degree to which the global tourism sector can adapt to climate change is largely based upon regional/local adaptive capacities. A regions' adaptive capacity is its ability to plan, prepare for, facilitate and implement measures of adaptation, while at the same time including the influences of wealth, technology, infrastructure, institutions, social capital and equity (Klein 2002, Smit *et al.* 2006). A broad range of literature has already indicated that tourism within developing nations is less likely to adapt to the ramifications of climate change due to its limited adaptive capacities (Gossling 2003, Mitchell & Tanner 2006, IPCC 2007b, UNWTO-UNEP-WMO 2008). As a result of limited adaptive capacity (Scott 2007a), developing nations, whose economies are highly dependent upon tourism, could sink further into poverty as the global climate proceeds to change.

In view of this, a growing body of Canadian literature has implemented studies on climate change adaptation in relation to its national tourism and recreational industry, investigating the implications of future climatic trends throughout site-specific studies (Suffling & Scott 2002, Scott *et al.* 2002, Scott *et al.* 2003, Schwartz *et al.* 2004, Jones & Scott 2006, Scott & Jones 2006a,b &c, Scott *et al.* 2006, Scott *et al.* 2007c). Each site specific-locale, "…be it a ski hill, a campground, a marina or a national park, is fixed in location with sunk capital that cannot readily be liquidated and re-invested" (Wall 1998). Thus, by studying site specific-locations vis-`a-vis climate change, a greater perspective can be gained on the potential implications and most vulnerable locations in the national tourism industry.

Recreational and tourist providers within the Great Lakes are among some of the most vulnerable to the implications of climate change (Scott & Parker 1996, Wall 1998, Lindeberg 2000 Schwartz 2004, Tupman 2004). Climatic change within the Great Lakes basin is anticipated to increase water temperatures and evaporation; thereby reducing overall water levels (Mortsch *et al.* 2000 & 2006). This also has the ability to hinder the regions marina and recreational boating industry

(Bergmann-Baker *et al.* 1995, Wall 1998). There are over 200 marina operations located along the Canadian Great Lake shorelines (Great Lakes Commission 2000b, OMOA 2008). As a result of regional geography, shoreline dynamics, and infrastructure, various marina businesses are anticipated to become more at risk to reduced water levels, while some operations may benefit (Wall 1998). The overall adaptive capacity of individual marina to environmental change in the 21st century will inherently determine the sustainability of recreational boating within the Great Lakes basin.

From 1998 to 2000, the Great Lake water levels declined 50cm. During this period the Canadian federal government, through the Department of Fisheries and Oceans, announced a $15 million emergency dredging fund to assist Great Lake marina facilities in coping with low water levels (DFO 2000). The Great Lakes Water-Level Emergency Response Program started in August of 2000 and qualifying marinas received up to one-third of their dredging costs to a maximum of $100,000 (DFO 2000). However, upon completion of the program in 2002, only $4.8 million of the fund was actually spent (The Globe & Mail 2003). Many dredging initiatives went unfunded due to the fact that marina owners could not afford their share of the cost (The Globe & Mail 2003).

The circumstances of this situation emphasize the vulnerability of Canadian marina operations to climate change and reduced water levels. To date, the Canadian literature has discussed the ramifications of climate change on inland lakes (Bergmann-Baker *et al.* 1995, Wall 1998), wetlands (Mortsch *et al.* 2006) and related tourism (Scott & Parker 1996, Wall 1998); however there has not yet been a systematic assessment regarding the vulnerability of marinas and the recreational boating industry to climate change within a specific region of the Great Lakes basin. The vulnerability of all Great Lake marinas and recreational boating to reduced water levels underlines the need to identify the implications of climate change within this sector of Canadian tourism. This will assist to understand the challenges and adaptive limits when strategizing programs of management and policy within each locality. Further, it will uncover the potential economic impacts this sector may endure following changes in climatic trends.

1.2 Study Objectives

The goal of this thesis is to improve understanding of how the potential impacts, challenges and opportunities of climate change differ across site-specific marina locations on the Canadian shorelines of Lake Huron. It will also be shown how the encompassing effects of climate change on Lake Huron marina operations could influence Ontario's tourism industry. This thesis is aimed to constitute preliminary groundwork for systematic and regional evaluations of the impacts climate change has upon Great Lakes marinas.

A similar approach to Bergmann-Baker *et al's*. (1993) assessment on the impacts of fluctuating water levels on Canadian Great Lakes marinas was adopted in this research. The Bergmann-Baker *et al.* (1993) assessment was conducted in response to the concern of high Great Lake water levels during the 1980s. Both the Government of Canada and that of the United States gave the International Joint Commission (IJC) a Reference to report on "Methods of Alleviating the Adverse Consequences of Fluctuating Water Levels in the Great Lakes-St. Lawrence River Basin" (Wall 1986). The report included the possible impacts of lake level regulations on the recreational boating sector. The Bergmann-Baker *et al.* (1993) assessment systematically analyzed the implications of both high and low water levels on Canadian Great Lake marinas by investigating impacts to infrastructure and measures of adaptation within site-specific marina operations. In addition, the assessment contributed perceptions marina operators have towards water level regulation. In general this study provided a foundation for further research investigating the effects of climate change on Great Lake water levels and Canadian marina operations.

The main objectives of this thesis are:

Objective One:

To explore marina operators' perceptions of the potential causes of (1998 to 2007) low water conditions within Lake Huron and the projected low water levels associated with future climate trends.

Objective Two:

To examine Lake Huron marina operators' responses to recent low water levels throughout 1998 to 2007 and generate a list of criteria pertaining to the future implications operators anticipate to endure throughout the expected events associated with climate change.

Objective Three:

To explore the geographical distribution of Lake Huron marina operations and identify regional impacts, challenges and opportunities associated with water level reductions.

Objective Four:

To investigate the quantity of slips and marinas that will remain operational under hypothetical water level scenarios associated with climate change in the Lake Huron basin. Additionally, the repercussions of these hypothetical water level scenarios on Lake Huron's marina operations will determine the implications for boat-based tourism in Ontario.

2.0 LITERATURE REVIEW

2.1 Climate Change

Shifts in precipitation patterns, sea level rise and the decline of snow and ice are a few of the many observed changes in the global climate and related environmental systems (IPCC 2007a). Over the past century the world has become warmer and average global surface temperatures have risen 0.74°C since 1901 (IPCC 2007a). The IPCC (2007a) stated that "Warming of the climate system is unequivocal" and that some observed changes in global climate trends have been related to anthropogenic activities. The burning of fossil fuels and changes in land use are two major anthropogenic activities that have affected the dynamics of the global climate (IPCC 2007a). These activities are anticipated to maintain a continual dominance over the natural dynamics of the global climate system and persist in altering trends through and beyond the present century (IPCC 2007a,b). Consequently, global warming is expected to surpass those experienced over the past several thousand years (IPCC 2007a). The best-estimate, climate change scenarios derived by the IPCC (2007a) project an average global temperature increase from 1.8°C to 4.0°C by the end of the 21st century. Moreover, warming is anticipated to be most pronounced over land and in high northern latitudes (IPCC 2007a).

Canada's average annual surface temperatures have risen more than double the mean global surface temperature increase throughout the last half of the twentieth century (1948 to 2007) (Environment Canada 2007a). The nation's annual surface temperature increase was reported to be 1.4°C (Environment Canada 2007a). The most dramatic warming has occurred throughout the winter months, where average annual winter temperatures have increased by 2.4°C since 1948 (Environment Canada 2007a). Mean precipitation amounts across the country have also increased during the past century by 12% (Lemmen *et al.* 2008). The overall changes in Canadian average surface temperatures and amounts of precipitation during the past 100 years have led to changes in other variables, including evaporation, sea ice, permafrost and snow cover (Environment Canada 2007b). The analysis of snow trends have indicates that the Canadian snow cover season is also shortening (IPCC 2007a). Zhang *et al.* (2000) claim that, since the 1950s, there has been 0.3 days less of snow cover per year in Canada. Canada is projected to experience greater amounts of warming than most other regions of the world throughout this century. Over the last six decades each region of Canada has experienced warming and it has been projected that all, with the possible exception of the Atlantic offshore area, will continue to warm for the next 80 years (Environment Canada 2007b). On a seasonal basis, warming is expected to be greatest during the winter months (Environment Canada 2007b). Annual precipitation amounts are projected to increase from 0 to 10% in Canada's south and up to 40 to 50% in the high Arctic by 2080 (Environment Canada 2007b). As a result of the country's vast land mass and its location in high latitudes, the amount of warming and precipitation is not anticipated to be uniform throughout each region of Canada (Lemmen *et al.* 2004;2008, Environment Canada 2007b).

Regionally, Ontario has experienced increased annual temperatures between 0 and 1.4°C since 1948 (Environment Canada 2006). Given the size of the province, Ontario's climate varies widely during seasons and from one location to another. The climate of the south and central subregions within the province is influenced by the Great Lakes, resulting in higher autumn and winter precipitation constituting both rain and snow (Environment Canada 2006). Areas to the lee of Lake Superior, Lake Huron and Georgian Bay have experienced a significant increase in lake-effect snowfall since 1915 (Burnett et al. 2003) and precipitation in some locations (e.g. Maitland River valley east of Lake Huron) has become increasingly variable, with frequent episodes of high-intensity storms since the late 1950s (Mekis and Hogg 1999).

The province's annual precipitation and annual temperature are projected to continually rise for the next 20 to 50 years (Environment Canada 2006). The number of days exceeding 30°C in Ontario's south subregion is expected to more than double by 2050s and winter precipitation from south to north in the province is anticipated to rise from 10% to more than 40% (Hengeveld and Whitewood 2005). Although annual precipitation amounts are likely to rise for the majority of the region, fall and summer magnitudes for southern Ontario are expected to decrease up to 10% by 2050 (Environment Canada 2006).

2.2 Tourism

International tourist arrivals have grown from 25 million in 1950 to 438 million in 1990 to 684 million in 2000 and 922 million in 2008 (UNWTO 2009). By 2020 international arrivals are projected to reach 1.6 billion. Global tourism receipts for 2008 reached US$944 billion, rising 1.7% from 2007 (UNWTO 2009). Globally, travel and tourism currently employs nearly 240 million people and creates an estimated 10% of the world Gross Domestic Product *(GDP)* (WTTC 2008a). By 2018, global tourism is expected to contribute 10.5% to the world's GDP and employ an additional 60 million people (WTTC 2008b).

In 2007, it was reported that over 650,000 Canadians were employed by the national tourism industry (CTC 2007), and within that same year the UNWTO (2007) ranked Canada eleventh in the world's top tourist destination regions. Since 2006, Canada has reported an increase of 5.1% in tourism revenues, reaching a total of CDN$70.2 billion (CTC 2007). The Canadian tourism industry GDP value, of CDN$28.8 billion, is equal in size to the agriculture, forestry, fishing and hunting sectors combined (CTC 2007).

However, nearly 75% of Canada's tourism revenues are derived from domestic consumers (CTC 2007). International tourism revenues for Canada in 2007 was only $16.6 billion and only 0.3% higher than 2006 (CTC 2007). By contrast, domestic tourism revenues increased by 6.6% over 2006, reaching $53.6 billion in value. Ironically, during an era of increased global tourist arrivals, Canada's market share of international tourism has declined by approximately 24% (CTC 2007). The reduction in international markets can be moderately explained by border regulations, currency value and the demand for new exotic destinations (CTC 2007). Overcoming the barriers of travel, air carriers are increasing flights to formerly remote, inaccessible destinations (CTC 2007). Although, this hinders Canada's competitiveness in the international market, the national economy is benefiting from the strong demand for domestic tourism (CTC 2007).

A report by Ontario's Ministry of Tourism (OMT) (2008a) confirms there were 19.3 million tourist visits from the United States and a further 2.2 million visits from countries abroad to Ontario in 2005 (OMT 2008a). Combined, the spending by these international visitors totalled $6.4 billion (OMT 2008a). International travel in 2005 only accounted for 25% of all the tourist visits to Ontario (OMT 2008a), while domestic tourism accounted for the remaining 75% and represented more than 60% of the tourism receipts for 2005 in Ontario (OMT 2008b). Representing over 19% of the businesses in the province, Ontario's tourism sector is composed of over 160,000 tourist-related businesses and provides over 322,000 indirect and direct jobs (OMT 2008b).

A significant segment in the Canadian tourism industry is nature-based tourism. Nature-based tourism attracts the interest of participating individuals to natural settings for the enjoyment of scenery, opportunity of recreation and adventure travel (Eagles 2001). Depending greatly upon environmental quality and sustainability, nature-related activities include, camping, fishing, hunting, skiing, boating and other water activities. In 1996, Statistics Canada concluded that twenty million Canadians participated in some nature-related activities, spending a total of $11.0 billion (Environment Canada 2003). A provincial survey was conducted in 2004, concluding that Ontario accommodated 18.2 million domestic and international overnight outdoor tourists for that year (OMT 2006). In addition, the study discovered that these tourists spent an approximate $4.1 billion in Ontario and accounted for 39% of overnight tourists for that year (OMT 2006). The quantity of participating nature-based tourists and expenditures spent during their period of stay, reveal the significance of Canada's natural wealth and the importance it has upon the national economy. In 1996, nature-related activities contributed $4.5 billion to Ontario's GDP and further provided $1.4 billion in tax revenues (Federal-Provincial-Territorial Task Force on the Importance of Nature to Canadians 2000).

2.3 Climate Change & Tourism

Climate is a principal resource for the tourism industry, behaving as a major determinant in the suitability of locations for recreation and leisure-based experiences (Hamilton *et al.* 2005a,b). The tourism industry is sensitive to climate variability, therefore the degree of future implications of climate change for the industry remains uncertain (IPCC 2007b, Becken & Hay 2007, Gossling & Hall 2006b, Scott 2006, UNWTO 2003, UNWTO-UNEP-WMO 2008). The concern of the tourism community regarding the challenges and consequences of climate change has visibly increased in the last decade (Scott *et al.* 2006b). A number of international organizations, including the United Nations World Tourism Organization (UNWTO) and United Nations Environment Programme (UNEP), arranged the First International Conference on Climate Change and Tourism in Djerba, Tunisia in 2003. The Djerba Declaration established a framework for future research and policy making on adaptation and mitigation of climate change in the international tourism industry (UNWTO 2003). Individual tourism industry associations and businesses have also engaged their concerns in the issue of climate change by voluntarily implementing greenhouse gas (GHG) emission reduction targets and supporting government climate change legislation. Above all, the number of scientific publications examining the interactions of tourism and climate change has doubled between 1996-2000 and 2001-2005 (Scott *et al.* 2007). The scientific community has effectively reacted to the current and forthcoming issues of climate variability by recognizing tourism in the IPPC 4th Assessment, and establishing an Expert Team on Climate and Tourism; drawing on the expertise of both the World Meteorological Organization *(WMO)* and the UNWTO (Scott *et al*. 2008).

The challenges and consequences of climate change for the tourism community can be divided into two categories: direct and indirect effects (Browne & Hunt 2007, Scott & Jones 2006a). Both effects are likely to impact the supply of tourism and recreation opportunities by varying degrees, changing the amount, cost, and quality of each experience (Aall & Hoyer 2005). The repercussions of direct and indirect climate variability can affect tourist destinations as either a negative outcome or as a positive benefit (Scott & Jones 2006a).

2.3.1 Direct Climatic Impacts on Tourism

As a principal resource in the tourism and recreation industry, climate is critical to the supply of tourism and recreation opportunities (Mather *et al.* 2005, Lohmann & Kaim 1999, Hu & Ritchie 1993). Tourist destinations are closely tied and broadly influenced by the conditions of surrounding environmental resources. Thus, projected changes in climate trends can directly alter environmental resources, consequently affecting the quality of, quantity of, and demand for tourism. The most pronounced direct impact of climate change is anticipated to be temperature increase (UNWTO-UNEP-WMO 2008). Globally, warming temperatures are projected to change regional seasonality and increase operating costs within the tourism industry (Butler & Mao 1996, Scott & Jones 2006a, Amelung *et al*. 2007, Lee *et al.* 2008).

According to Butler (1994), tourism-related seasonality is the result of regular variations in climatic conditions directly influencing recreation and tourism. Therefore, the direct influences of climate change can alter the regular variations in natural seasonality causing unpredictable consequences (Butler 1994). In areas close to equatorial boundaries, seasonality is commonly less of an effect. However as a result of climate change, locations such as the Caribbean and Indian sub-continent have suffered extreme temperatures, monsoon rainfalls and humidity. Such direct climatic impacts have altered the seasonality in these areas, progressively reducing tourist demand during certain times of the year (Baum 1999). Studies have also suggested that the competitive position of some current popular leisure-based destination areas (i.e., Mediterranean and the Caribbean) are likely to decline; while on the other hand, areas higher in latitude (i.e., southern England and Canada) will become more appealing for tourist demands (Scott *et al.* 2004, Hamilton *et al.* 2005b, Amelung and Viner 2006, Amelung *et al.* 2007, Simpson 2008).

Projected climate change is also anticipated to have direct impacts upon tourist sectors in higher latitudes. A summary, conducted by Scott & Jones (2006b), assesses the potential impacts of climate change on the natural seasonality of Canada's outdoor recreation and tourism. The study analyzes the impacts of climate change on major winter and warm-weather recreational sectors by examining how changing climate trends may influence the length of season and demand for particular recreational activities. Reviewing both winter and warm-weather recreational activities, Scott & Jones (2006b) identify the negative and positive effects of projected climate change trends upon the national recreational sector.

Canadian warm-weather recreational sectors are anticipated to benefit from the direct impacts of projected climate change trends (Scott & Jones 2006b). The direct implications of increased Canadian temperatures are likely to extend the season length of warm-weather tourism and recreational activities in Canada (Scott & Jones 2006b & c, Wall et al. 1986). The pinnacle for Canadian outdoor recreation and related tourism generally occurs during the nation's warm season *(July, August and September)* when approximately 43% of Canada's domestic and 62% of its international tourism expenditures transpire (Wilton & Wirjanto 1998). According to Park's Canada (2004), 70 to 80% of the Canadian camping demand occurs between June and the last week of August. Therefore, the outcome of an extended warm-weather recreation season in Canada would benefit Canadian tourists expenditures and the economy by prolonging the seasonal duration of many warm-weather recreational activities, such as; camping (Scott and Jones 2006c, Wall et al. 1986), swimming, golfing (Scott and Jones 2006b), fishing and boating (Wall 1998).

Conversely, Scott & Jones (2006b) indicate that winter outdoor recreation in Canada is most at risk to climate change and rising temperatures. Canada's alpine ski industry is projected to be heavily impacted as the climate warms. Although snowmaking within the ski alpine areas is expected to significantly reduce the industry's vulnerability to climate change, the costs and number of inefficient days of snowmaking are expected to increase (Scott *et al.* 2003, 2004, 2005b & 2006a). This was previously experienced in the winter of 2004 and 2005 in British Columbia at Whistler-Blackcomb ski resort. As a result of high temperatures and a lack of snow coverage 60% of the resorts ski runs prior to mid-March were closed, decreasing the skier-visitation rate by 14% (Toronto Star 2005). Canadian snowmobiling is also anticipated to be negatively influenced by climate change. The snowmobile industry is highly sensitive to seasonal variations and depends significantly upon natural snowfall and adequate winter temperatures (Scott *et al.* 2002, Scott & Jones 2006a). During the winter of 2005 and 2006, a large portion of the Canadian snowmobile trails remained closed until late-January early-February due to record warm winter conditions and a lack of snow (Winnipeg Free Press 2006, Ontario Federation of Snowmobile Clubs 2006). Warmer temperatures and decreased snow accumulation directly affect the availability of snow and ice-based recreation further introducing new technical and economic barriers in the seasonality of Canada's winter recreations (Scott *et al.* 2002).

As Wall (1998) states, "…for many activities and destinations, the operating period is limited and profits must be made in a short period of time". Thus, variation of inter-annual climate can significantly manipulate natural seasonality and further alter the associated economic success of both winter and warm-weather tourism and recreation. The direct effects of climate change are anticipated to negatively impact winter recreation sectors in Canada. Additional expenses and reduced operating periods indicate the short-term effects of climate change in which winter recreational opportunities have encountered (Scott & Jones 2006a). Although the direct effects of climate-induced change appear to be beneficial to Canadian warm-weather recreational sectors, studies (Scott & Jones 2006c, Hunt & Haider 2004, Mortsch *et al.* 2000) have indicated that the long-term consequences may be potentially less rewarding and negatively impact both winter and warm-weather recreational sectors.

2.3.2 Indirect Climatic Impacts on Tourism

In contrast to the direct effects of climate change, the majority of indirect effects are anticipated to negatively impact the long-term supply of tourism and surrounding natural resources (Scott *et al.* 2007, Browne & Hunt 2007). Indirect effects are recognized as secondary outcomes provoking transformations of entire ecosystems, hydrological and cryological systems (Aall and Hoyer 2005, Gossling and Hall 2006b). Common impacts of indirect climate change effects include; changes in water availability, biodiversity loss, increased natural hazards, damage to infrastructure, coastal erosion and land inundation (Scott *et al.* 2007). Particularly vulnerable to these effects are the sectors of nature-based tourism, commonly located in areas of high sensitivity: mountains, islands and coastal destinations (Wall 1998).

Globally, tourist destinations will experience the results of indirect climate-induced change. Many World Heritage Sites are at risk. For instance, the Chan Chan Archaeological Zone of Peru is susceptible to flooding and erosion due to the potentially extreme events of El Nino-Southern Oscillation (ENSO) (UNESCO 2007). Likewise, Venice Italy is vulnerable to flooding due to rising sea levels (UNESCO 2007). The long-term effects of sea-level rise have the potential to eliminate small island chains (i.e., Maldives) and severely erode coastal regions (Zhang *et al*. 2004), while increasing temperatures and severe drought conditions have the ability to alter comfort levels in traditional winter destinations (i.e. Caribbean) and persuade tourists to travel domestically (Mather *et al.* 2005). Models assessing tourist behaviour and preference of choice (Richardson and Loomis 2004) have forecasted an increase in tourism to higher latitudes and more temperate climates (Hamilton *et al.* 2005a, b), where the heat stress of large urban cities can be escaped (Scott *et al.* 2004). However, although the demand for temperate climatic destinations may rise, resources within these locations will become susceptible to increasing temperatures.

Research (Hunt and Haider 2004, Englin et al. 1996) has suggested that the quality and aesthetic value of Canadian recreational experiences and nature-based tourism may diminish at the expense of indirect climate-induced change. Over time warming temperatures and erratic rainfalls are anticipated to make the Canadian boreal forest vulnerable to insect infestation and increase forest fires (Parker et al. 2002, Wotton et al. 2005). Rising temperatures are also projected to alter Canadian ecosystems and species composition. In search for cooler temperatures, recreationally desired mammals such as moose and deer are expected to retreat northward (Thompson et al. 1998). Similarly, Great Lake cold-water fish species are also projected to migrate northward, consequently altering the opportunities of hunting and angling (Government of Canada 2004). Most critical to this thesis is the long-term indirect effects of climate change on the Great Lakes and the possible repercussions for water-based tourism and recreational activities. Climate-induced change in Canada is anticipated to potentially alter the hydrological system of the Great Lakes thereby reducing average stream flows up to 30% and further decreasing average lake water levels by one meter (Mortsch et al. 2000, Lofgren et al. 2002). Such reduced water levels within the Great Lakes could significantly affect water-based recreational activities and further hinder Canadian tourism.

2.4 Great Lakes Water Levels

The Laurentian Great Lakes were formed approximately 10,000 years ago by the receding Laurentide ice sheet (USEPA 2008). The receding ice sheet carved the Great Lakes basin leaving behind vast quantities of melt water which filled and formed the connecting basin of lakes (USEPA 2008). Today, the water of the Great Lakes is influenced by a number of factors, both human and natural. Human factors that affect water levels within the Great Lakes basin include: water diversions, water control structures (i.e. dams), water use (i.e. irrigation and manufacturing) and consumption. Natural factors, which influence lake water levels, include: post-glacial rebounding[1] (Mainville & Craymer 2005) and climatic trends (Changnon 2004). The natural influences of climate will be the principal investigation of this literature review. This will assist in a better understanding of the potential implications climate change has upon the Great Lakes water levels, surrounding environments and associated sectors.

Water levels within the Great Lakes are most predominantly influenced by regional climate trends (Changnon 2004) and generally recognized as "climate indicators", incorporating seasonal and long-term variability of the climate system (Brinkman 1984, Changnon 2004, Mortsch *et al.* 2006). Commonly, Great Lake water levels depict the regional climate conditions of a given year or decade (Changnon 2004).

Since 1860, instrumented measurements have recorded mean annual Great Lake water levels to fluctuate approximately 180 centimeters (Argylian & Forman 2003, Mortsch et al. 2006). Through 1973-75, 1985-86 and 1997, Great Lake water levels were very high, reflecting the conditions of high precipitation in the region (Sellinger *et al.* 2008, Environment Canada 2008). In contrast, during 1934-35, 1964-65, 1987-88 and 2000's water levels were very low due to high temperatures and below

[1] The Earth's crust north of the Great Lakes was compressed by as much as 3km ice in the last glacial era. As the ice melted the crust began to rebound. This process is referred to as *postglacial rebound* (PGR) and is still ongoing today (Mainville & Craymer 2005).

normal precipitation (Mortsch *et al.* 2006, Environment Canada 2008). The more recent droughts in the 2000's resulted in an extremely mild winter and reduced Great Lake water levels to their lowest in 30 years (Mortsch *et al*. 2006). Water reductions in the lakes between April of 1998 and May of 1999 were equivalent to 120 cubic kilometres, which is two years of flow over the Niagara Falls (Moulton & Cuthbert 2000). As the hottest year in a 51-year record for the Great Lakes region, 1998 generated the fifth driest year within the region and increased the Great Lakes regional temperature by +2.3°C (Mortsch *et al.* 2006). The drought of 1998 lasted until 2002 significantly affecting the Great Lake water balance and further generating one of the longest water level declines in the region (Mortsch *et al*. 2006). Summer temperatures during this period ranged from 0.9 to 1.3°C above average, while below normal summer precipitation occurred in 2001 and 2002 (Mortsch *et al*. 2006). Climate-related conditions, such as regional temperature, precipitation and evaporation, have proven to significantly alter water level fluctuations in the Great Lakes (Quinn 2002, Argylian & Forman 2003). A review of literature regarding water-budget components will be used to better understand their influence upon the Great Lake water levels. Furthermore, the repercussions of these lake water-budget components when subjected to climate change will be examined.

2.5 Implications of Climate Change for the Great Lakes Basin

From 1948 to 2007, the Great Lakes and St. Lawrence lowlands region has warmed by 0.6°C on average (Environment Canada 2007). Most dramatically, the region's winter season has increased by 0.9°C, supporting amplified temperatures in the spring of 1.0°C (Environment Canada 2007). These increasing temperatures are positively correlated with changing trends in global mean air temperatures (King *et al.* 1997, 1999; McCormack & Fahnenstiel 1999; Kling *et al*. 2003). Regional warming has been strongly reflected in the timing and range of seasonal lake-level cycles (Lenters 2001, Quinn 2002) along with later freeze-up and earlier break-up ice conditions.

A study conducted by Quinn (2002) illustrates the results of the region's changed temperature by providing evidence of a shift in the timing and range of seasonal lake-level cycles. Specifically focusing upon Lakes Michigan and Huron, the study demonstrates how the lake-level minimums in the two connected water bodies have shifted by two months later (from January to March) over the past century. Quinn (2002) reports that the causes of these shifted patterns were deduced from variation in seasonal water supply resulting from regional warming. Seasonal changes were also detected from 1860 to 1990 within Lake Erie, where the annual rise and fall of lake levels advanced by approximately one month (Lenters 2001).

The Great Lakes season of ice cover has also been altered. In general, the season has been shortened by approximately one to two months throughout the last 100 to 150 years (Kling *et al*. 2003). Projected warming within the Great Lakes region has been associated with changes in the duration and extent of the ice cover. From a current average of 11 to 16 weeks, ice-in periods within the Lake Superior and Lake Erie basin are expected to further diminish by 16 to 52 days by 2050 (Lofgren *et al*. 2000). Moreover, Lake Superior, the deepest and coldest lake in the Great Lakes system, is anticipated to increase in water temperatures from 3.5 to 5°C by 2050 (Lehman 2002). The repercussions of increased regional temperatures have generated a sequence of trends by increasing the Great Lakes water temperatures, reducing ice coverage and most significantly altering the seasonal maximums of precipitation and evaporation (Quinn 2002, Argyilan & Forman 2003, de Loe & Kreutzwiser 2000).

Climate-related functions of overlake precipitation, evaporation, groundwater exchange and overland evapotranspirtation have not been historically recorded nor measured within the Great Lake basin (Mortsch *et al.* 2006). However, it has been confirmed that rising temperatures in the basin have altered these climate-related functions (Bruce and Rodgers 1962, de Loe & Kreutzwiser 2000, Brinkmann 2000, Assel et al. 2004, Sellinger 2008).

Brinkmann (2000) investigated this by demonstrating how water-budget components (i.e. precipitation, evaporation and runoff) contribute to the Great Lake water levels and more importantly change when subjected to variable climatic conditions. The study revealed that irregularity of water in the net basin supply of the upper Great Lakes is due to variability in overlake precipitation, while irregularity of water in the lower Great Lakes results from variable amounts of runoff. This conclusion was reached after constructing relative land/lake ratios, whereby the lower entity of the Great Lakes basin was determined to have a greater ratio in land, as opposed to the upper portion (Brinkmann 2000). Lake evaporation was determined to be most pronounced over the upper Great Lakes, where lake surface area is vast and most vulnerable to the dry seasons of winter and fall. In contrast, the lower portion of the Great Lake basin proved to be most receptive to land runoff due to its greater surrounding of land. The study concluded that evaporation, warmer winter temperatures and less ice coverage in the upper basin is expected to continually rise and exceed the runoff water-budget of the lower Great Lakes. Consequently, these results may generate an overall water loss for the entire Great Lakes system (Brinkmann 2000).

Ice coverage influences the exchange of heat and moisture between a lake and the atmosphere, making it a significant component within the Great Lakes region. Extensive ice coverage upon the lakes can reduce winter evaporation and increase water-levels for the following spring (Assel *et al.* 1995). The duration and amount of ice coverage on lakes within the northern hemisphere generally decreased throughout the 20th Century (Magnuson *et al.* 2000). Regional trends of the Laurentian Great Lakes most notably demonstrated these results with later freeze-up and earlier break-up dates (Assel *et al*. 1995, Assel & Robertson 1995, Magnuson *et al.* 2000). A study conducted by Assel *et al.* (2003) analyzes the Annual Maximum Ice Concentration (AMIC) of each Great Lake and further demonstrates the repercussions of variable climatic conditions on the formation of lake ice. The AMIC is defined as the greatest percentage of lake surface area covered by ice each winter. Basins, such as Lake Erie, that consist of a shallow lake bathymetry, accumulate a high AMIC average due to the prevalence of shallow waters. Likewise, lakes exposed to more freezing degree-days, such as the northerly Lake Superior, are also susceptible to higher AMIC's (Assel *et al.* 2003).

The winter of 1998 demonstrated the vulnerability of all five Great Lakes by setting record low AMIC values. The second lowest AMIC value was set on Lake Huron and according to Assel et al. (2003), *"Lakes Erie and Ontario were virtually ice free in winter 1998"*. Following the 1998 winter season, a four year average low (1998-2001) was established and new record low AMICs were set on Lakes Superior, Erie and Ontario (Assel et al. 2000, Assel et al. 2003). Assel et al. (2003) concluded that these trends provide noteworthy verification that mild winters generate decreased ice cover regimes (Assel et al. 2003), which in turn expose surface lake waters to extended periods of evaporation.

2.6 Climate Change Implications within the Great Lakes

Fluctuations and flow changes of lake water can highly influence nearshore infrastructure and associated lake operations. Users, such as power generators and commercial shipping industries, value the relatively high lake-level conditions in order to fully utilize equipment and infrastructure (Lake Carriers' Association 2008, Changnon 2004, Brinkmann 2000). The implication of low water conditions for these users was reported in *The Detroit News* following the 1998 decline within Lake Huron;

> "Shoals and shallow waters along lake channels have become sobering obstacles for the huge ships" and "critical to the economies of two nations". "Great Lakes freighters are forced into "light-loading", carrying 5 percent to 8 percent less in goods to guarantee precise steering and enough buoyancy to avoid running aground (Detroit News 1999)".

The article, “Shrinking Great Lakes threaten Michigan way of life”, was additionally printed by *The Detroit News* in 2002. Focusing on the many impacted stakeholders, the article discusses the adverse impacts of low water conditions upon hydropower generation.

> “The Sault Electric Co. is preparing to raise rates for the first time in six years because it can’t generate enough power from the lakes.” “Farther east, the New York Power Authority is having similar problems….near Niagara Falls and the St. Lawrence River (Detroit News 2002).”

In 2006, the *Canadian Broadcasting Corporation* (CBC) continued to report the significance of declining water levels by revealing the implications it has upon the Great Lake shorelines and ecological ecosystems;

> “Wetlands are drying up, docks are stranded and beaches in some areas are overgrown with weeds (CBC 2006).”

Some environments, such as the Great Lake coastal wetlands, prosper from lake level fluctuations for the preservation and functioning of their environment (Mortsch *et al*. 2006). However, conditions in the past have adversely impacted the Great Lake coastal wetlands because of extended periods of droughts and flooding (Scott & Parker 1996, Suffling & Scott 2002, Changnon 2004, Mortsch *et al.* 2006). In terms of the future, extended periods of drought are anticipated to persist in the Great Lakes (Croley *et al.* 1998, Lofgren *et al.* 2002, Mortsch *et al.* 2000 & 2006) and increase the vulnerability of coastal habitats and regional species.

2.6.1 Shoreline Bathymetry

The Great Lake shorelines have rich, complex ecosystems and a diverse array of landforms, ranging from vertical rock cliffs, to sandy beaches and wetland areas. Increased water temperatures and water level reductions have the potential to alter the physical integrity of the Great Lake shorelines by modifying natural lake processes and manipulating the transfer of water and nutrient exchange (Wall *et al.* 1986, Mortsch 1999).

The shoreline characteristics of inclination, landscape topography, and distribution of sediment types determine the ability and extent to which a Great Lake coastal wetland can migrate (Mortsch *et al.* 2006, Keough *et al*. 1999). If there is an appropriate off-shore slope and wave protection, during circumstances of low water levels, some wetland species may advance lakeward in search of suitable moisture and substrate conditions. Nonetheless, if the shoreline bathymetry is steep or confined by a barrier, the expansion of a wetland community is unlikely during low water conditions and may cause wetland vegetation to dry out and deplete (Bedford *et al.* 1976, Quinlan and Mulamoottil 1987). It is anticipated that the impacts of regional climate change within the Great Lake basin will vary from coastline to coastline due to differing shoreline bathymetry. As a result of climate change, projected declining water levels within the Great Lakes basin will initially impact shallow coastal environments, where the shorelines are gently sloped and wetlands are vast (Wall & Costanza 1984). In contrast, coastal environments with deeply shelved shorelines will experience less of an initial impact (Wall & Costanza 1984). The resulting effects have the potential to alter coastal wetland distributions upon the shorelines of the Great Lakes and further modify the diversity of local vegetation and fish habitat (Mortsch *et al.* 2006).

2.6.2 Coastal Wetlands, Thermal Guilds and Fish Habitat

The Great Lake coastal wetlands comprise a mixture of floating, submerged, emergent and meadow vegetation (Mortsch *et al.* 2006). Of benefit to neighbouring lakes and shorelines, coastal wetlands provide ecological habitat, water conditioning, protection against floods and erosion and a diverse range of recreational opportunity (Wall 1985). Wetland environments and plant compositions also crucially influence wildlife within the Great Lake basin (Krull 1970, Kurta 1995, Harding 1997, Angradi *et al.* 2001, Meyer 2003). Aquatic invertebrates, insects (Poole & Gill 1992, Turner & McCarty 1998), small amphibians and fish population (Aboul Hoson and Downing 1994, Minns *et al.*

1999) rely on the Great Lake wetlands for habitat breeding and foraging opportunities (Sutherland & Maher 1987, Poole & Gill 1992). A large majority of the Great Lakes fish population utilize nearshore coastal wetlands for spawning and nursery locations (Portt *et al.* 1999, Coker *et al.* 2001). The cover and density provided by the wetland vegetation influences reproduction and mortality, consequently shaping the population dynamics for the region's fish species (Aboul Hosn and Downing 1994, Randall *et al*. 1996). Under climate change, aquatic plant species, such as submerged (Kling *et al.* 2003) and floating leaved plants (Mitsch & Gosselink 2000, Wilcox & Meeker 2003) may be limited to diversify and expand, thereby potentially modifying fish populations in the region.

Depending on the age and species of lake fish, populations regularly colonize within the differing thermal guilds distributed within the Great Lakes (Meisner *et al.* 1987). Declining Great Lake water levels are anticipated to reduce water flow and lake mixing regimes, in turn modifying lake thermal guilds and generating competition between coldwater fish species (Jones *et al.* 1996, Lamouroux *et al.* 1996, Minns *et al.* 1996). In addition, increases in regional air temperatures will cause Great Lake water temperatures to increase, further reducing lake thermal habitat (Stefan *et al.* 1996) and potentially attracting invasive lake species (Mandrak 1989, Meyer *et al.* 1999). The altered magnitude and seasonality of local runoff regimes may ultimately change nutrient loads and dissolved oxygen concentrations within the Great Lakes (Magnuson *et al.* 1990) further affecting lake fish populations.

The Great Lakes are host to a diverse range of ecological habitats for the region's freshwater fish species. As described, the vast majority of wetlands that populate the region are likely to be affected by climate change in a complex and interrelated ways. Reduced water levels and increased water temperatures within the Great Lakes system have the potential to diminish water quality and modify wetland communities; systematically influencing vegetation types, and the habitat for wildlife.

As a result, the indirect implications of climate change upon the Great Lakes coastal wetlands and littoral zones may potentially hinder Ontario's highly profitable Great Lakes fishing industry.

2.7 Great Lakes Tourism

A survey completed by the Department of Fisheries and Oceans (DFO) Canada (2005) revealed that a total of 395,000 Canadian anglers participated in recreational fishing within the Great Lakes region during 2005, catching an approximate 23.6 million fish. An estimated $413 million was spent that year on durable goods used for recreational fishing within the Great Lakes region (DFO 2005). An additional study revealed that, in 2006, $930 million was spent on Ontario angling (Discover Boating Canada 2008). In general, the economic impact recreational fishing contributes to Ontario's tourism and economy is of significance. Nevertheless, the industry's co-partnership with recreational boating largely determines its overall influence upon Ontario's economy.

In Canada, recreational boating plays a major role in the country's recreational and tourism industry (Bergmann-Baker *et al.* 1995, Wall 1998). A statement by the Canadian Boaters Alliance (2008) at the 2008 Toronto International Boat Show supports this by stating that, "Boating's impact on the Canadian tourism industry is particularly relevant today with $6 billion in tourist boater activity representing nearly 10 per cent of Canada's total tourism dollars". According to an economic impact study for Canadian recreational boating in 2006, Canada's recreational boating industry is attributable to an estimated $15.6 billion of direct impact on the national economy (Discover Boating Canada 2008). Furthermore, it has generated 111, 747 jobs directly and another 42, 726 jobs indirectly (Discover Boating Canada 2008). The spending and hiring for Canada's recreational boating industry accounts for $26.8 billion and 373, 606 jobs (Discover Boating Canada 2008). As of 2006, six million Canadians owned 2.9 million pleasure boats, occupying 959 marinas and 302 yacht clubs within the country (Discover Boating Canada 2008). At this time, spending at marinas and yacht clubs was reported to total an approximate $3.7 billion worth of expenditures and $1.3 billion in sales and repairs at the 259 Canadian dry-land boat dealers (Discover Boating Canada 2008). The study also indicates that Ontario's vast coverage of the North American Great Lakes makes it the most prominent region for recreational boating in Canada (Discover Boating Canada 2008).

Data obtained from an on-line assessment conducted by Michigan State University's Recreational Marine Research Center's (RMRC) National Boater Panel estimated that on average per year American Great Lake boat owners spend approximately US$1, 400 on craft-related expenses (i.e. equipment, repairs, insurance and slip fees) and US$2,200 on boating trips (i.e. gas and oil, food and lodging) involving an average of 23 boating days (Great Lakes Commission 2000a). A detailed economic impact assessment was completed upon the Tower Marine in Saugatuck, Michigan (Great Lakes Commission 2000a). In 2004, the Tower Marine rented 395 slips. The owners of these boats spent US$2.85 million on annual craft expenses and an additional US$2.85 million on boating trips, accounting for a total of 15,000 boating days. The direct economic impact generated by these boaters was US$1.8 million in sales, US$661,000 in wages and salaries, along with US$952,000 in value added to the local economy while supporting 37 jobs (Great Lakes Commission 2000a). Like American recreational boating in the Great Lakes, Canadian boaters also have an important impact on the economy.

In 2006, the Ontario recreational boating industry was reported to have an economic impact estimated at $13 billion (Discover Boating Canada 2008). This amount accounted for nearly half of the national economic impact generated by recreational boating for that year, declaring Ontario the 'hub' of recreational boating. Of that $13 billion, $7.2 billion was put directly into the Province's economy (Discover Boating Canada 2008). Also during 2006, Ontario employed 906 employees in the boat manufacturing industry, while new boat and engine sales totalled an approximate $940 million

(Discover Boating Canada 2008). During the same year, Ontario housed 428 marinas and 92 yacht clubs. Expenditures spent at these facilities for 2006 totalled $2.5 billion (Discover Boating Canada 2008).

The Ontario Tourism Marketing Partnership (OTMP) has concluded that,

> "The tourism industry is a vital part of the economic development for the Province of Ontario", and that "…recreational boaters spend a considerable amount of money when they travel our waterways – this is an industry that fuels tourism and the Ontario economy" (Canadian Boaters Alliance 2008).

To date, there has been very little consideration of the implications of climate change for the region's recreational boating industry.

2.8 Implications of Climate Change for the Great Lake Marina Operations

The Great Lakes shorelines have long been home to many stakeholders that use the lakes' water for various applications. Each user is susceptible to water level fluctuations and therefore each has a preferred level of water which will consequently maximize their purpose. For instance, commercial shipping, navigation and electricity producers favour high water levels (Brinkmann 2000, Changnon 2004); while shoreline property owners rather prefer average levels to prevent flooding and erosion of their shoreline properties (Scott & Parker 1996). In contrast to both, the Great Lake marina operations are extremely vulnerable to water level fluctuations and rely on adequate and consistent water depths to operate (Wall 1998).

Marina facilities of the Great Lakes are generally located on the shoreline or within connected channels of a lake. Therefore, as water levels fluctuate within the Great Lakes basin, marina operations become directly impacted and exposed to various physical and economic damages. High water conditions with the combination of extreme weather have the ability to damage marina infrastructure and further jeopardize recreational watercrafts owned by the customer. However, in particular, low water levels pose the most significant threat to the Great Lakes marina facilities and are anticipated to occur with climate change (Wall 1998). Low water conditions in the lakes are capable of revealing nearshore navigational hazards and causing damage along with alterations to existing infrastructure. Moreover, reduced water levels in the Great Lakes can shorten boating seasons and prevent customer service by limiting the accessibility of launch ramps and docking areas (Wall 1998). As a result, lakeside marinas have the potential to undergo significant losses in revenue and may need to take required adaptive measures.

Water level reductions in the Great Lakes have previously demonstrated the need for adaptive measures in lakeside marina facilities. A survey undertaken in 1992 of marina operators on the

Canadian side of the Great Lakes illustrates particular adaptive measures used during conditions of low water (Bergmann-Baker *et al*. 1992-1993 & 1995). Overall, lakeside marina operators surveyed during this study had to previously dredge, make dock adjustments, restrict oversized boats, relocate boats, close slips, construct floating docks, and replace wood structures due to dry rot[2] during low water level conditions (Bergmann-Baker *et al*. 1992-1993 & 1995). Although this study provides representation of adaptive measures used by Great Lakes marina facilities during low water conditions, the precise dollar value of these adjustments and procedures was not determined.

Nonetheless, site-specific studies and reports have been completed on locations surrounding the Great Lakes and these have indicated how costly and time-consuming certain adaptations can be. In 2000, two adjoined marinas located on Lake Huron's shoreline within the community of Bayfield, Ontario, paid a $180,000 fee for adaptive dredging and later incurred an additional $100,000 dredging fee in 2001 (Richmond 2001). In 2001, the Doral Marine Resort of Midland, Ontario, underwent a $1 million dredging overhaul. This procedure removed 3,700 cubic metres of lake bed material in order to achieve an average depth of 2.7 metres in their marina perimeter (The Globe and Mail 2003). Also in 2001, Schwartz et al (2004) revealed that Huron District Contracting Ltd. was charging an hourly rate of $300 for its dredging services and an additional sum for material disposal.

Following the Great Lakes' most recent water level decline from 1998 to 2000, many marina facilities were left with no other option than to dredge. However, given the extreme costs of dredging and disposal, many facilities within the Great Lakes basin were unable to afford the cost of the procedure. Therefore, in 2000 the DFO confirmed that,

> "The low water situation…is jeopardizing the economic livelihood of marina operators"

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[2] Low lake water conditions stimulate the process of dry rot decay in wood by exposing submersed wooden structures to air. The combination of oxygen and high moisture generate ideal environments for fungi which have the potential to decompose timber and cause unstable infrastructure (Coggins 1977).

And that,

> "The federal government will fulfill its commitment and act now to promote stability in this important recreational sector for the economy (DFO 2000)."

In July of 2000, the Federal Government of Canada invested $15 million in an emergency dredging program for marinas most severely affected by low water levels in the Great Lakes (DFO 2000). The program was based under a two-year, first-come, first-serve basis and any qualifying marina could receive up to one-third of its dredging costs to a maximum of $100,000 (DFO 2000). By the end of the programs completion date in 2002 only $4.8 million was actually spent at 150 marina locations on the Great Lakes (The Globe and Mail 2003). In June of 2003, The Globe and Mail published an article, called "Docks high and dry for boat season", explaining the complications and resulting outcomes of the Federal program. The article indicated that,

> "Many dredging initiatives went unfunded because they were begun before the federal program was launched", and, "...Sites eligible for funding simply could not afford to shoulder their share of the costs and so did not dredge at all" (The Globe and Mail 2003).

Furthermore, a statement in the article by a marina operators eligible for the fund, confirmed that the complexity of the programs' application was "too intimidating" (The Globe and Mail 2003). Consequently, some operators became discouraged from spending money on dredging and legal fees for the application and were forced to remove docks and wait until adequate water levels returned (The Globe and Mail 2003).

Although several marina locations in the Great Lakes basin have been negatively impacted and are anticipated to be further negatively influenced following projected changes in climatic trends, some are also expected to prosper. Various Great Lake marina locations are geographically favoured and their operations economically stable, thus, the outcomes of climate change may not initially overcome their adaptive capacity. Also, some locations may prove to prosper from the initial effects of climate change (Wall 1998). An example similar to this was experienced in the Missouri River during the 1989-1990 drought (United States General Accounting Office, 1992). For instance, water level declines in Lake Sakakawea, a lake connected to the Missouri River in North Dakota, caused the closure of marina facilities in the lake's upper portion during the drought period. As a result, boaters were forced to relocate. During the same period, visitation rates at the Indian Hills state recreation area in the lower portion of Lake Sakakawea's reservoir increased by 111%, from 25,855 to 54,648 visitor days (United States General Accounting Office, 1992). Marina operations within the reservoirs lower portion proved to be less vulnerable to the affects of water reductions, thus benefitting from a surplus of customers (Wall 1998).

Similar effects are anticipated to be experienced throughout the Great Lakes basin. However, as a result of the basin's immense size and differing geography, each lake may be exposed to various implications of reduced water levels. In reference to the thesis topic, Lake Huron will be closely examined.

2.9 Climate Change in Lake Huron

Altered water-budget components within the Great Lakes watershed have become highly studied during recent water level reductions of 1998 to 2007. Among the five Great Lakes, Michigan and Huron have become the most prominent lakes under investigation (Sellinger *et al.* 2008, Changnon 2004, Schwartz *et al.* 2004, Argyilan & Forman 2003). Connected by the Straits of Mackinac, Lakes Michigan and Huron are hydraulically connected and are considered to behave as one (Changnon 1987). Their primary source of water inflow is supplied by Lake Superior, through the St. Mary's river, while their primary outflow is the St. Clair River, positioned between Port Huron, Michigan and Sarnia, Ontario. Of all five Great Lakes, Lakes Michigan and Huron are least affected by engineered modifications, such as hydropower generation and inflow/outflow regulations (Changnon 2004, Argyilan & Forman 2003, Changnon 1987). Thus, the two lakes are considered as principal models for understanding the relationship between climate variability and water-level fluctuations (Argyilan & Forman 2003; Sellinger *et al.* 2008). Mean monthly water level estimates for Lakes Michigan and Huron have been made available by the U.S. Army Corps of engineers since 1861 (COE 2007). These measures are accurately compared to the lakes chart datum[3]. The Great Lake waters require international coordination for the many aspects of their use and management. The most basic coordinated management is a common elevation reference or 'datum', by which water levels can be measured. The first common datum for the Great Lake waters was International Great Lakes Datum 1955 (IGLD 55). This datum was established by precisely surveying land elevation coordinates at various reference points from the Atlantic Ocean, through the St. Lawrence River and each connected lake of the Great Lakes system. At the time of the IGLD 55 it was recognized that this common datum would have to be periodically revised accounting for regional isostatic rebound. Since, the IGLD 85 was established and implemented in 1992 and is currently used. Low water datum (chart datum) on the Great Lakes-St. Lawrence River navigation charts were changed from IGLD 55 to IGLD 85. Lake Huron's chart datum changes were from 175.8m (IGLD 55) to 176.0m (IGLD 85) *(Refer to Figure 2.9.1)* (COE 2008).

Over recorded history *(Refer to Figure 2.9.1)*, it can be seen that high levels in Lake Huron were most pronounced during 1918, early 1930s and 1950s, 1970s throughout the 1980s, and in 1997. Low levels in Lake Huron were experienced in the mid 1920s, early 1930s, late 1950s, mid 1960s, and in the late 1990s leading up to 2007. In 1964, record low water levels were set in Lake Huron mainly

[3] Chart Datum of a lake is the vertical plane to which nautical charts are measured from. Commonly, chart datum measurements are known as low water datum and taken from a lakes lowest astronomical tide or mean lower low water (COE 2008).

due to a period of reduced precipitation from 1961 to 1965 (Changnon, 1993). In the early 2000s, Lake Huron water levels decreased again, nearly reaching the 1964 record lows. During this period, the Lake's low water conditions were attributed to many factors, including climate. Following a record El Nino event, Canada experienced its warmest summer on record in 1998. Lake Huron's regional temperatures increased by 1°C above normal and precipitation was reduced by 20% (Lake Huron Centre for Coastal Conservation 2003). Consequently, the continuation of high temperatures and altered climatic factors contributed to a reduction of Lake Huron water levels by approximately 1.0 meter from 1998 to 2003 (Lake Huron Centre for Coastal Conservation 2003, COE 2006a).

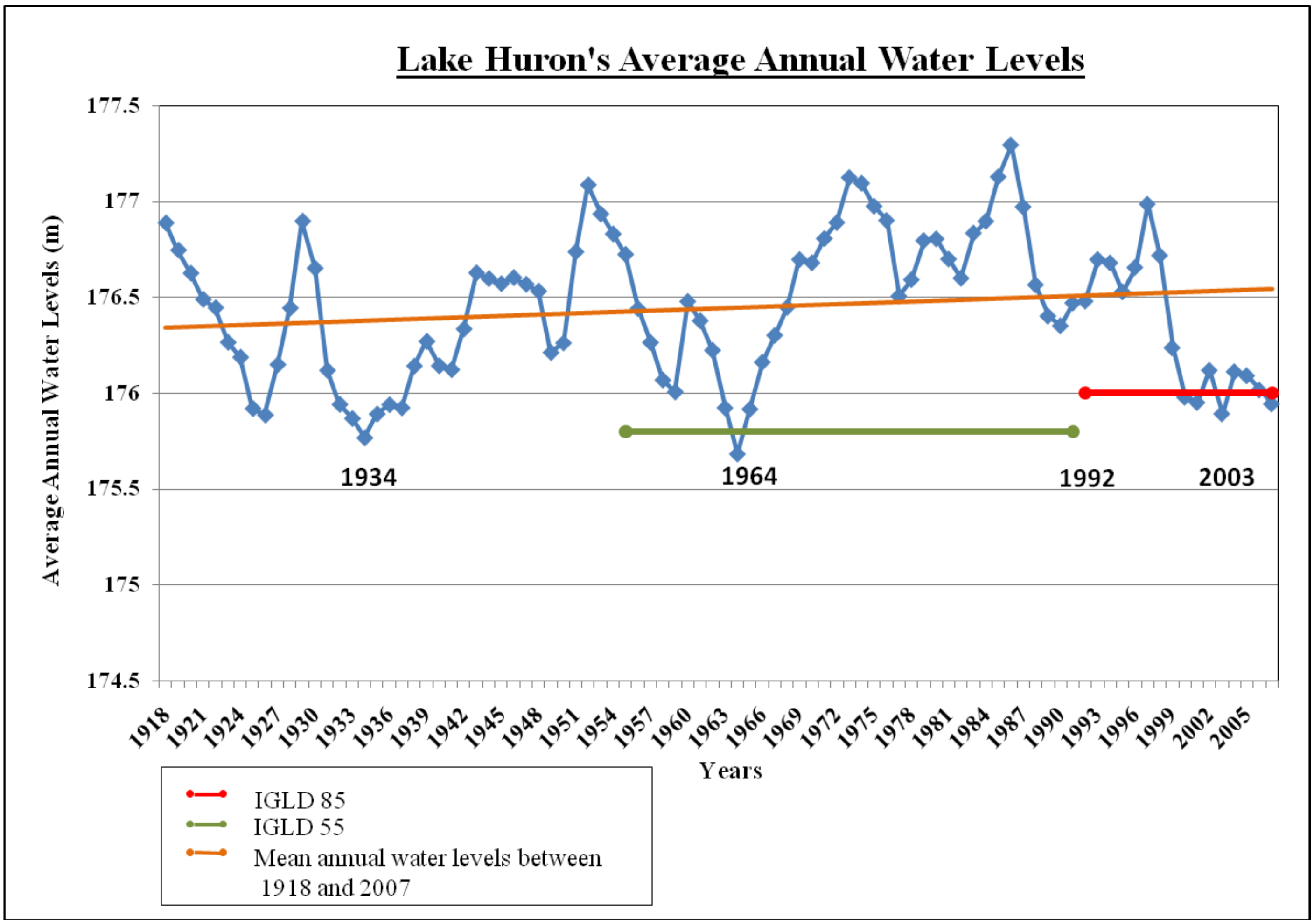


Figure 2.9.1: Lake Huron hydrograph 1918 – 2007
(Source: COE 2007)

In the future, reductions in Lake Huron's water levels are anticipated to be the most pronounced of all the Great Lakes based on explored climate change scenarios (Mortsch *et al.* 2006). With an expected lake surface temperature rise between 2.6 to 6.0 °C by 2050s (Mortsch 1999), it has also been projected that during this time extensive evaporation will cause Lakes Michigan-Huron to decline approximately 0.73 to 1.18 m from chart datum (176m) (Mortsch *et al.* 2006).

A study by Sellinger et al. (2008) investigates historic water level declines in Lakes Huron and Michigan by using water level data from 1860 to 2006. Sellinger et al. (2008) assess the relationships of the three main natural hydrologic water-budget components for Lakes Michigan and Huron and depict their historic behaviours through a Water Balance Component graph *(Refer to Figure 2.9.2)*. The purpose of the graph is to illustrate the change in water storage for Lakes Michigan and Huron by comparing water-budget component trends over the periods of 1948 to 2005. From 1948 to 1977, evaporation declined, whereas precipitation and runoff both increased; thus contributing to lake level rise (Sellinger *et al.* 2008). In contrast, following 1977, both precipitation and runoff magnitudes began to gradually decrease, while evaporation increased. This in turn contributed to decreasing lake levels. The results of this study indicate a decreasing change in storage for Lakes Michigan and Huron from 3.9mm/year to -3.12mm/year (Sellinger *et al.* 2008). Although high water levels were experienced throughout Lake Michigan and Huron in the 1980's, the study indicates that they were concurrent with high precipitation at the time and masked the progression of water-level decline. Sellinger *et al.* (2008) state that, "the underlying decline has been ongoing since ~1973", and that the Lake Huron water-level decline, "results largely from increasing evaporation".

Lakes Michigan-Huron Water Balance Components (mm/year)

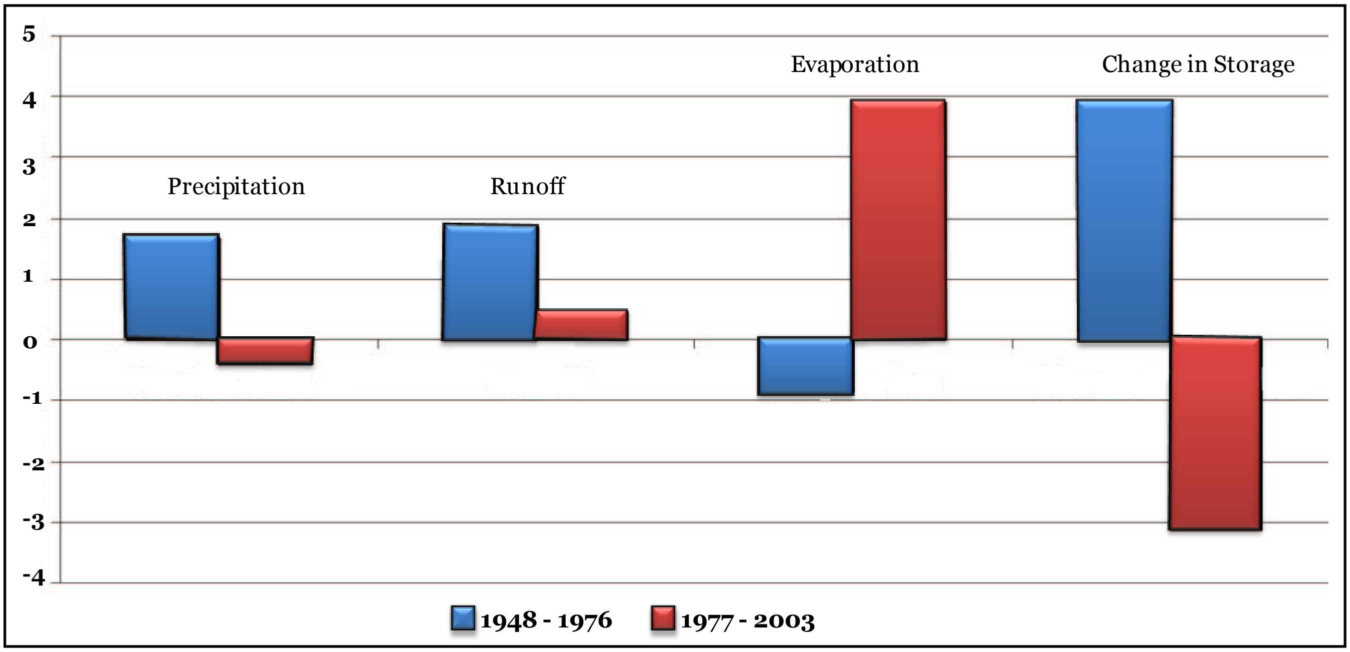


Figure 2.9.2: Lakes Michigan and Huron's water storage chart
(Source: Sellinger 2008)

2.10 Implications of Climate Change for Lake Huron

Declining water levels within Lake Huron are anticipated to first impact areas in the basin with gently sloped shorelines and shallow coastal environments (Wall & Costanza 1984). Wall and Costanza (1984) examined this by measuring the differential impacts on both the Lake Huron and Georgian Bay coastlines of the Bruce Peninsula. The west coast of the Bruce Peninsula accommodates a shallow bathymetric coast and is home to an abundance of coastal wetlands, shoreline cottages, sandy beaches and marine recreation. The study illustrates that water level reductions in Lake Huron would be most distinct in this location of the basin and significantly impact shoreline ecology and recreational opportunity. A study by Tupman (2004) also supports this assertion. Tupman (2004) studied the shoreline of Oliphant, Ontario, a small community located along the western shores of the Bruce Peninsula. With the use of climate change models and geographic information system models, climate induced water level reduction scenarios were illustrated for the Oliphant coastline *(Refer to Figure*

2.10.1). Increases in shoreline area from the 1961/1990 average to the modelled year of 2050, were estimated to be 7.4 square kilometres (Tupman 2004). Potential impacts that are projected to follow the widening of Oliphant's shoreline as a result of reduced water levels are; shoreland policy and ownership debates, increased aeolian sediment transport, fen wetland migration or dewatering, and hazardous or inaccessible marine navigation (Tupman 2004). These results, as indicated in Figure 2.10.1, illustrate the many implications of climate change for gradually shelved shorelines of Lake Huron.

a) Oliphant shoreline 2004

b) Oliphant shoreline as a result of projected Lake Huron water level declines in 2050

Figure 2.10.1: Geographical information system models of Lake Huron's Oliphant shoreline (Source: Tupman 2004)

However, Lake Huron's other coastal shelves and shoreline locations are also likely to be affected by climate change. This was illustrated in a case study by Taylor *et al.* (2006) following water level reductions from 2000 to 2004 in Lake Huron's embayment community of Sturgeon Bay.

From 2000 to 2004, Lake Huron water level reductions caused the water volume in Sturgeon Bay to diminish by 25 to 30% (Taylor *et al.* 2006). The reduction caused water exchange between the bay and the lake to decline, resulting in decreased dilution and depleted volumes of dissolved oxygen. Moreover, warmer water temperatures initiated eutrophic conditions and insufficient water quality provoking public health warnings and a depletion of coldwater fish populations (Taylor *et al.* 2006). Similarly, during the same period, other shoreline embayment communities on the Lake Huron coastline reported comparable issues of decreased coldwater fish populations and reduced water quality (Taylor *et al*. 2006, Schiefer 2003).

The scientific literature exploring the causes of Lake Huron's recent water level decline, starting in 1998, caused much uncertainty in the perceptions of surrounding stakeholders. Huron basin lobby groups have organized to advocate for the preservation of the Lake's coastal wetlands and surrounding shorelines. In doing so, they have attempted to influence government to pursue a remedial plan of action and limit Lake Huron's water outflow at the mouth of the St. Clair River.

2.10.1 Lake Huron Water Level Controversy

The St. Clair River extends 63km between Lake Huron and Lake St. Clair. This river channel compensates for the elevation difference of 1.5m between both lakes (COE 2006). The narrowest point of the River is located between Sarnia, Ontario and Port Huron, Michigan, directly beneath the International Blue Water Bridge (COE 2006). At this narrow point, the breadth of the river is 240m with depths ranging from 9 to 21m. Maximum velocities of the St. Clair River occur within this location, generating high magnitude surface and deep water currents (COE 2006). Beginning in 1908, sand and gravel were removed from the bed of the river for commercial use. This procedure was later prohibited in 1925 within both U.S. and Canadian waters. It was estimated that between 1908 and 1925, 2.5 million m^3 of sand and gravel were removed for commercial purposes (Quinn 1999, COE 2006). Shortly after, in 1933, dredging began within the St. Clair River to accommodate a 7.5m navigation project (Quinn 1999). Upon completion in 1936, all spoil material from the project was reported as discarded in deeper locations of the river. An additional navigational project of 8.0m was later introduced in 1960, requiring much more excavation in conjunction with a new cut-off channel (Quinn, 1999). Upon completion of the 1960s project, spoil material was discarded in locations other than the St. Clair riverbed leaving the river 'uncompensated' and vulnerable to changes in water flow. As a result of this uncompensated project, the river channel became more efficient and required less of a decline for the flow of water from Lake Huron to Lake St. Clair (Quinn 1999, COE 2006b).

Overall, the channel modifications completed on the St. Clair River, from 1908 and 1962, have been estimated to reduce the Lake Michigan-Huron levels by approximately 27cm (Quinn 1999, Changnon 2004). In addition, recent declines in the Lake Huron water levels are still being attributed to dredging. As described by Quinn (1999), the St. Clair River has had a permanent impact on the upstream Lake Huron water levels due to a backwater effect; where there is less obstruction in the St. Clair River channel to delay and prevent high magnitude flows from Lake Huron. It is believed, that after the completion of the 8.0m navigational project, a thick layer of riverbed sediment, containing large pebbles and cobbles, was excavated exposing a new layer of fine sand and silt sediment. Overtime, the high magnitude water current exiting Lake Huron and entering the mouth of the St. Clair River eroded the fine layer of riverbed and enlarged the river's opening (Quinn 1999, GBA 2008). This in turn has convinced many that the flow within the St. Clair River has amplified, and water levels within Lake Huron are continuously and more effectively declining (GBA 2008).

In June of 2005, a lobbyist group, the Georgian Bay Association (GBA), funded W.F. Baird and Associates Coastal Engineers LTD. to prepare a report investigating the water level decline in Lake Huron. The GBA is an organization that protects Georgian Bay cottage establishments and lobbies senior levels of government for impact control on Georgian Bay water quality and levels (GBA 2008). The conclusion of the Baird and Associates investigation was that dredging in the St. Clair River lead to reduced water levels in Lake Huron. The Baird report estimated that the channel modifications completed on the St. Clair River reduced Lake Michigan-Huron levels by 80cm and that the ongoing erosion under the International Blue Water Bridge has resulted in a daily outflow of 3.2 million m^3 of water (W.F. Baird 2005, GBA 2008).

In August of 2007, CTV news covered the story, "Great Lakes leaking from 'drain hole': group" (CTV News 2007). The story recaptured statements that were earlier voiced in 2007 by environmental and lobbyist groups, including the GBA. Some of the statements included;

> "There's a "drain hole" in the Great Lakes basin that's haemorrhaging almost 9.5 billion litres of water a day and must be patched up by the Canadian and American governments"
>
> "Navigation dredging, riverbed mining and shoreline alterations on the St. Clair River near Port Huron, Mich., and Sarnia, Ont., have affected the flow of the Great Lakes and is draining water into the Atlantic Ocean at a rate that's three times greater than original estimates"
>
> "…water levels in lakes Michigan and Huron and the Georgian Bay have fallen 60 centimetres since 1970."
>
> "The loss of water is senseless and will negatively affect water quality in the Great Lakes, as well as boating, fishing and commercial shipping…"
>
> "We think it's really important that the government do some serious study to figure out the cause and to figure out what we can do" (CTV News 2007).

In April of 2007, the IJC appointed the International Upper Great Lakes Study (IUGLS) board to determine if the conveyance capacity of the St. Clair River had changed and to assess if there was ongoing erosion in the river bed (IJC 2007a). The IUGLS was able to retrieve various sources of riverbed material, obtain video footage of the riverbed and compile several cross-sectional surveys. In May of 2009, a draft report released by the IUGLS determined that erosion in the St. Clair River was not ongoing and recommended that "remedial measures not be undertaken at this time" (IUGLS 2009). The report also identified three key factors contributing to lake water level decline:

1. A change in the conveyance of the St. Clair River (deepening of the river bed), possibly resulting from a major ice jam within the last decade.

2. Post-glacial rebounding varies through the Lake Huron basin, however is most pronounced on the eastern Georgian Bay coastline.

3. Changes in climatic patterns have reduced water supplies to Lake Michigan-Huron and Lake Superior. This factor has become most significant, accounting for an estimated 75% of the decline in Lake Huron between 1996 and 2005 (IUGLS 2009).

These results have generated controversy between Huron basin stakeholders and national governments in both the U.S. and Canada (Toronto Star 2007). Although the IJC concluded that the riverbed of the St. Clair River was non-erosive, groups such as the GBA argue that the results are premature and that the riverbed was fully eroded prior to the IJC's six month preliminary study. In addition, Huron basin stakeholders, such as the GBA, believe that the national government have not committed enough resources to address their concerns (GBA 2008).

Water level changes have implications for both the social and ecological parameters of Lake Huron. Consequently, as water level reductions within the Great Lakes system continue, further implications are projected to unfold, essentially affecting the region's associated tourism industry. The Ontario tourism sector greatly relies upon the Great Lake's water availability for vacation destinations and recreational opportunities, such as cottaging, angling and boating. Therefore, a decline in lake water levels may hinder tourism within the Province, in turn affecting the economic value of Ontario's tourism industry.

The next portion of this thesis will investigate the significance that Lake Huron Canadian Marina operations have on Ontario's tourism sector. This will be examined through the use of a marina operator's questionnaire which will be discussed in Chapter three.

3.0 METHODOLOGY

3.1 Introduction

The aim of this research was to build on the work of Bergmann-Baker *et al's*. (1993) Great Lake water-level impact study on the recreational boating sector by examining the impacts of recent low water levels and investigating the perceptions of marina operators towards the current and potential implications of future climate variability.

This chapter is divided into four sections. First, it will introduce the area of study and background information on the area, along with how and where the questionnaire for marina operators was implemented. Second, the questionnaire and its format will be described with additional information pertaining to the nature of questions and the relevance of hypothetical climate change scenarios. Third, the chapter will discuss the equipment and sampling method used to obtain physical measurements. Finally, the chapter will outline the limitations of the research approach.

3.2 Study Area

The study area for this research is the Canadian coastline of Lake Huron. The Lake is minimally influenced by water level regulations set on Lake Superior and remains unregulated by structures used for hydropower generation or commercial navigation (Changnon 2004). Thus, water levels within the Lake Huron system respond primarily to climatic forces and additionally provide evidence as to how regional climatic drivers are changing (Sellinger 2008). Water level measurements of Lake Huron have been made available by the U.S. Army Corps of engineers since 1861 (COE 2006a) and are accurately compared to the lakes chart datum, which is 176m above sea level.

Lake Huron's basin area is 193,700km^2, and the lake houses 3,540km^3 of water (NOAA 2000). The lake has an average depth of 59m and a maximum depth within the Bruce Basin of 229m (NOAA

2000). These dimensions make Lake Huron the world's third largest freshwater lake and provide a total shoreline length of 6,157km (NOAA 2000). As part of the Great Lakes connected system, Lake Huron's primary source of inflow water is Lake Superior through the St. Mary's river *(Refer to Figure 3.2.1)*. This channelled river is located near Sault Ste. Marie, Ontario, and has been regulated since 1921 *(Refer to Figure 3.2.2)* (Changnon 2004). Outflow regulations were established in 1977, seeking to bring both Lakes Superior and Michigan-Huron to historic levels, and more specifically aiming to keep Lake Superior levels at chart datum, 183.2m above sea level (COE 1997, Changnon 2004). Lake Huron's primary outflow source is the St. Clair River. Positioned between Port Huron, Michigan and Sarnia, Ontario the breadth of the river's mouth is 240m with depths ranging from 2m to 9m *(Refer to Figures 3.2.1 & 3.2.3)* (NOAA 2000).

Figure 3.2.1: Lake Huron's primary inflow & outflow sources (Source: NASA 2007, modified by Jordan Stewart)

Figure 3.2.2: Outflow controls of Lake Superior
Photograph taken by Jordan Stewart

Figure 3.2.3: Mouth of the St. Clair River
(Source: Bluewater Bridge 2008, modified by Jordan Stewart)

Background

The waterways within the Great Lakes region have been attractions for leisure activities since the early industrial age. Recreation within the region became a significant economic and social activity in conjunction with road and rail travel during the 19th century (Ellis 1974). During this time, newly constructed canals for commercial shipping complemented a thriving pleasure-boat industry (American Museum of Natural History 1980). Industrial growth in the 20th century and associated increases in personal disposable incomes generated more leisure time to be spent outside of the city limits and near the coastal margins of the Great Lakes (American Museum of Natural History 1980). Also in the 20th century, governments of both the Unites States and Canada acquired lands surrounding the Great Lakes in order to protect valuable resources and provide populations with recreational areas (Allen 1970). This promoted the development of extensive park and conservation areas along with lakeside resorts, restaurants and marinas. In some areas of the Great Lakes basin, recreation and tourism have become a significant component of the local economy (Allen 1970, Ellis 1974, American Museum of Natural History 1980).

The waters of Lake Huron are renowned for recreational boating (*Refer to Figure 3.2.4 for background information)*. Lake Huron's North Channel has been noted as one of the "best freshwater cruising grounds in the world" (Canadian Yacht Charters 2008). The North Channel offers plenty of recreational boating opportunity with a vast number of uninhabited islands and magnificent views of the Canadian Shield (The North Channel 2008). South of the North Channel is Lake Huron's Georgian Bay. Approximately 320km long by 80km wide, the bay covers 15,000km^2 (Historical Atlas of Canada 1987). The eastern edge of the bay incorporates the southern portion of the Canadian Shield, accommodating a large quantity of islands. Collectively, these islands are known as the "Thirty Thousand Islands", and they constitute a popular boating destination (Georgian Bay 2008). The south western part of the Georgian Bay offers recreational waterfronts and sandy beaches which attract many cottagers from the Greater Toronto Area and other nearby urban centers (Georgian Bay 2008). The shorelines within this area provide an excellent view of the Niagara escarpment. Connected to the western portion of the Georgian Bay is the East edge of the Bruce Peninsula which is a desirable location for sailors within Lake Huron (Bruce County Tourism 2008). The core area of the UNESCO Niagara Escarpment World Biosphere Reserve is located on the northern tip of the Bruce Peninsula and attracts many domestic and international boaters (Bruce County Tourism 2008). The northern tip of the Bruce Peninsula also provides excellent sites for boaters with towering limestone cliffs from the Niagara Escarpment and unique geological Flowerpot Island formations (Bruce County Tourism 2008). The west coast of the Bruce Peninsula along with Lake Huron's south eastern ridge holds some of Ontario's and Canada's best beaches (i.e., Sauble Beach, Wasaga Beach and Grand Bend). This area accommodates many water recreational enthusiasts and has a high volume of boat traffic during the summer months.

As of 2007, the OMOA reported 72 registered marinas on the Lake Huron Canadian coastline. The OMOA is Canada's largest recreational marine trade association and consists of both private and municipal marinas (OMOA 2008). The 72 marinas accommodated an approximate 12,000 slips for recreational boats on the Lake Huron Canadian coastline. The economic impact and expenditures of Lake Huron recreational boating is unknown, but is considerable.

Figure 3.2.4: Lake Huron's Canadian Shoreline
(Source: NASA 2007, modified by Jordan Stewart)

3.3 Questionnaire Design

The marina operator's questionnaire instrument was organized in three parts. Part one collected information on the background, physical structure and characteristics of the marina. Part two was designed to document current and past water levels, and methods of adaptation that were used during low water periods. Part three of the questionnaire dealt with the potential impacts of reduced water levels and how the marina operators would react to various future low water scenarios projected under climate change. The complete questionnaire can be found in Appendix One.

Background and Physical Structures of the Marina

The first portion of the marina operator's questionnaire instrument was used to collect information on the location, type and size of marina operation along with additional information on acceptable boat sizes and water depths. For comparability, several questions from the Bergmann-Baker *et al.* (1993) questionnaire of 1991 were adopted for this study.

In addition to Part I of the 1991 marina survey, this questionnaire asked marina operators to indicate where most of their clientele resides based on a list of six areas (Local, GTA, Tri-city's, London Middlesex, U.S.A or International). This question is used to further understand the demographics and source markets of Lake Huron recreational boaters and illustrate the significance of particular destination locations along the Lake Huron coastline.

Water Levels and Adaptation Strategies

The second section of the questionnaire is focused on minimum, maximum and optimal ranges of water levels that prevent or complement operations at each marina location. It is further aimed as understanding the methods of adaptation used to avoid the associated effects of low water. The marina operator's questionnaire was similar to Bergmann-Baker *et al*. (1993) 1991, providing a check list of experienced impacts and measures of adaptation. Additional questions on government funding were asked. Marina operators were asked if government funding was received during periods of low water, the approximate amount, and if it was effective assistance.

Climatic Scenarios

The third section of the marina operator's questionnaire was asked about the potential effects of climate change and the associated implications of low water levels. This portion of the instrument was intended to obtain marina operators perceptions towards climatic variability within Lake Huron. Secondly, the questionnaire presented three hypothetical scenarios of reduced water levels expected under climate change. The reduced water level scenarios measured: (1) -25cm; (2) -50cm; and (3) -75cm. Each scenario was developed from a study completed by Mortsch *et al.* (2003). For better understanding, the three scenarios were presented in comparison to Lake Huron's chart datum levels.

In addition to Part III of the questionnaire, marina operators were given the opportunity to provide their insights on other plausible water depleting mechanisms (i.e., diversions, dams and controlled navigational routes) within Lake Huron. The purpose of this question was to present a non-partisan outlook at the potential of lake water reductions and allow the respondents to speak openly about the issue. Furthermore, this question allowed the study to access the concerns of climatic variability throughout the region.

3.4 Bathymetry and Water Depth Analysis Equipment

The principle of the surveys was to acquire data from marina operators on the background of past experiences, preferences and motives for adaptation. The survey allowed participants to state their views of various matters related to lake water level reductions. However, to better understand the vulnerability of operations to low water levels, depth measurements for a sample of marina locations were recorded using a sonar device.

Connected to the exterior of a personal kayak, a depth finder *(Eagle FishElite 642c IGPS)* was used to obtain dimensions. The depth finder's digital monitor and affiliated sonar device was fastened to the exterior of the kayak with a mounted metal brace *(Refer to Figure 3.4.1)*. The sonar was deployed below the water-line during measurements and calibrated for each test *(Refer to Figure 3.4.2)*. The interior of the kayak housed the 12 volt battery for the device *(Refer to Figure 3.4.3)*. The size of the sonar device and personal kayak made loading, transporting and sampling manageable for one individual and proved to be efficient for the majority of the marinas located on the Huron coastline.

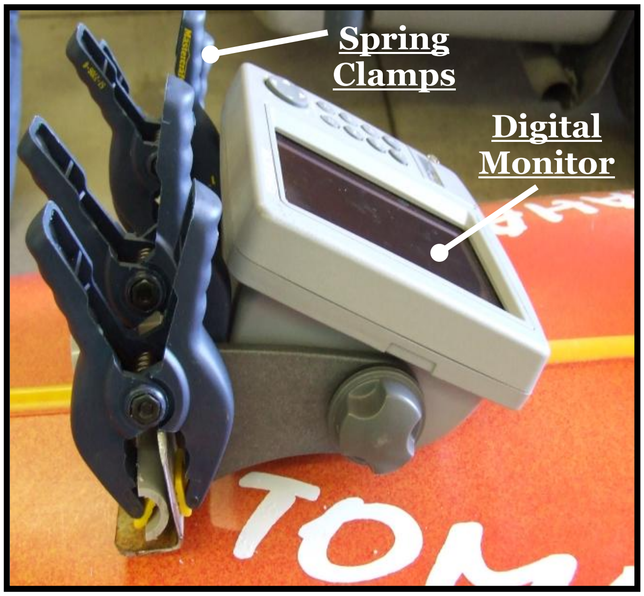


Figure 3.4.1: Digital Monitor mounted to exterior of kayak
Photograph by Jordan Stewart

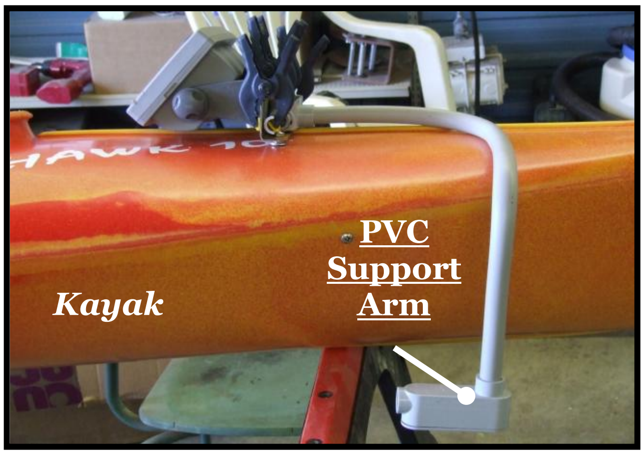


Figure 3.4.2: Support arm and sonar support
Photograph by Jordan Stewart

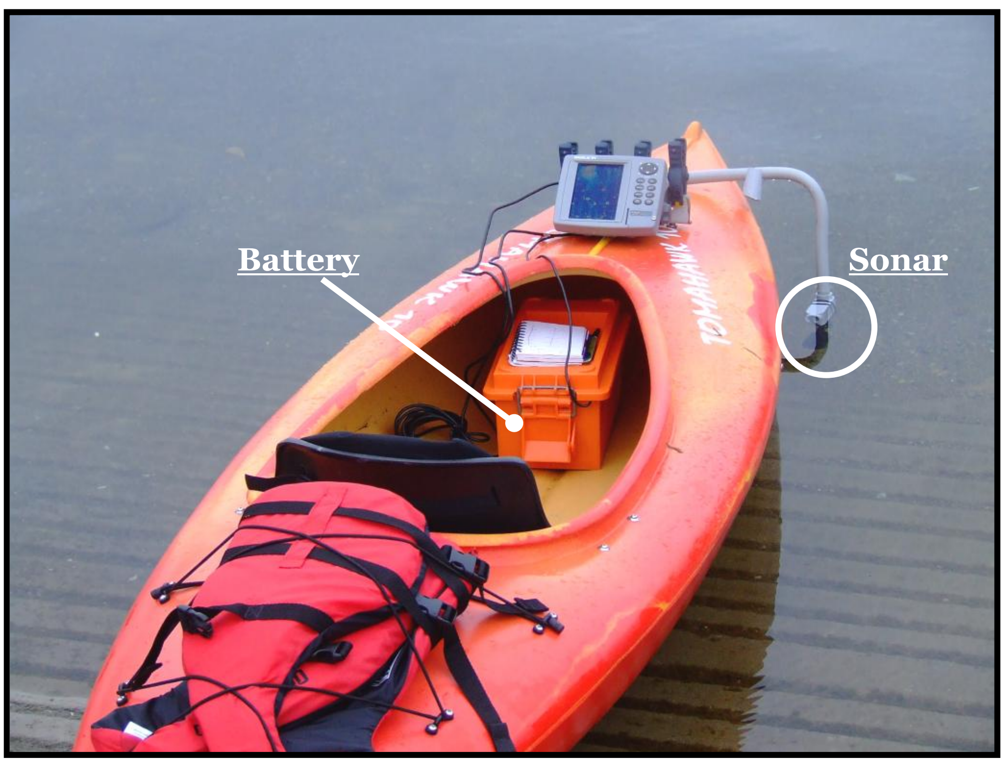


Figure 3.4.3: Battery Housing
Photograph by Jordan Stewart

3.5 Implementation of the Marina Operators Questionnaire

The marina operator's questionnaire was administered in person to both public and private marina's located on the Canadian coastline of Lake Huron. The respondents were owners or experienced managers of the marina business. The time spent in the field was from September 9th, 2007 to October 12th, 2007. If the participating marina official was unavailable for the questionnaire in person, they were later contacted by phone. Phone conducted surveys were administered from November 5th, 2007 to December 12th, 2007. Marina officials who were unavailable to be surveyed in person or by telephone were considered incomplete.

An information letter presented at the time of the survey introduced the researcher and informed participants of the purpose and content of the material within the questionnaire as required by the University of Waterloo Ethics Review *(Refer to Appendix Four)*. On the consent form, the participating marina officials were asked to acknowledge the questionnaire by checking and signing three separate columns: (1) I agree, of my own free will, to participate in this study; (2) I agree to have my survey conversation audio recorded; and (3) I agree to the use of anonymous quotations in any thesis or publication that comes of this research. This form ensured the participant that the survey was voluntary and that the information in which they provided would remain confidential.

During the survey process, the Canadian Lake Huron coastline was divided into six regions according to shoreline dynamics and geology. Each region consisted of 7 or more marinas that were registered under the OMOA during 2007. The regions were as follows: (1) North Channel; (2) Eastern Georgian Bay; (3) Parry Sound Inlet; (4) Severn Sound Inlet; (5) Eastern Bruce Peninsula; and (6) South-eastern Lake Huron Ridge *(Refer to Figure 3.5.1)*.

Overall, from the six regions and 72 Canadian Lake Huron marinas registered under the OMOA during the 2007 season, 58 marina operator's responded to the questionnaire, generating a 81%

response rate. In total 43 on-site surveys were conducted while an additional 15 were conducted via phone.

Additionally, 11 of the 72 registered Lake Huron OMOA marinas were accessible for depth measurements using sonar. The purpose of conducting sonar measurements was to verify the accuracy of suggested average depth measurements recorded by the marina operators questionnaire. Due to the restrictions of time and privacy of some marinas, access for depth measurements was limited.

Figure 3.5.1: Lake Huron Regional Shoreline Map
(Source: NASA 2007, modified by Jordan Stewart)

3.6 Limitations

There were three known limitations to the questionnaire during implementation. First, was the duration of time spent in the field. Financial constraints limited the amount of time available in the field and therefore reduced opportunities for questionnaires to be deployed. Marina officials who were talked with on site were more able to fully describe and display answers. Second, participating marina officials who were recently hired were unaware of past conditions, limiting historical insight. The third limitation was questionnaire distribution. Again, due to financial constraints and time, marina surveys could only be conducted on the Canadian side of Lake Huron.

3.7 Chapter Summary

This chapter outlines the area of study and incorporates relevant background information. It additionally gives justification to the questionnaires theories and questions. Response rates and limitations of the applied research are documented within the chapter. Quantitative results for the questionnaire are compiled in chapter four.

4.0 MARINA OPERATOR’S QUESTIONNAIRE ASSESSMENT RESULTS

4.1 Introduction

This chapter presents the results of the marina operator’s questionnaire for Canadian Lake Huron facilities. Each study region is discussed separately throughout each section of the chapter and answers to the questionnaire are segregated into three parts for each section. They are categorized as: Background information; Water level, impacts and adaptations; and lastly, Climate change and potential scenarios.

4.2 Region of South-eastern Lake Huron Ridge

The South-eastern Ridge *(Refer to Figure 4.2.1)* extends from Sarnia, Ontario to the northern tip of the Bruce Peninsula. Urban centers within this region include Sarnia, Grand Bend, Bayfield, Goderich, Kincardine, Port Elgin and Sauble. For most of the region, the land rises gradually from Lake Huron providing a shallow shoreline and excellent beaches. The subsidence of post-glacial Lakes Algonquin, Nipissing and Algoma deposited large expanses of sand and gravel within the region (Chapman and Putnam 1973). Over time, the post-glacial sand deposits have been influenced by prevailing northwesterly winds and the gently shelved coastline, which has essentially formed a high concentration of coastal sand dunes along the regions shorelines (LHCCC 1999). The shoreline substrate is composed heavily of sand, silt and clay loam with frequent to abundant mixtures of stones, gravels and small boulders in various areas. Muck is also very frequent within barrier beaches across the mouths of creeks and small watercourses. Lake Huron’s south-eastern ridge comprises five primary watersheds that drain into the lake along its shoreline. These outlets include the Sauble River at Sauble Beach, the Saugeen River at Southampton, the Maitland River emptying at Goderich, the

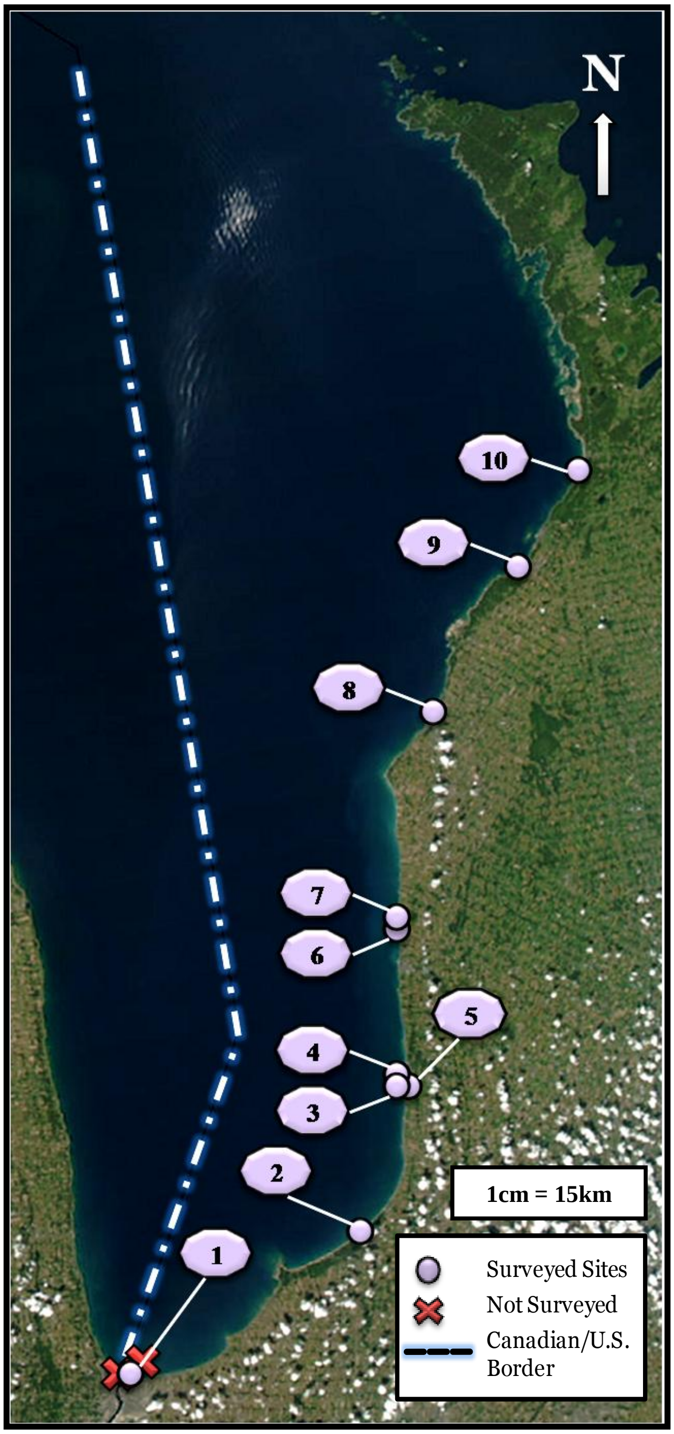


Figure 4.2.1: South-eastern Lake Huron Ridge (Source: NASA 2007, modified by Jordan Stewart)

Bayfield River flowing out at Bayfield and the Ausable River at Port Franks (LHCCC 1999). Under the OMOA 2007 registry, 12 marinas were located within this region (*Refer to FIG. 4.2.1*). In total seven marinas were surveyed in person, while an additional three were surveyed by phone.

<u>Background information for the South-eastern Lake Huron Ridge Marinas</u>

The 12 marinas identified by the OMOA in 2007 within the South-eastern Lake Huron Ridge accommodated a total of 2440 slips for recreational boats. The 10 marinas surveyed within this region contained 1465 recreational slips, accounting for 60% of the total slips in the region. Marina officials were asked to identify the percentages of their slips used for seasonal occupancy and the percentage rented during the 2007 season. Overall, 73% (1069) of the slips at the surveyed marinas were used for seasonal occupancy and 71% (1040) were rented for the 2007 season. Marina officials were further asked to identify the percentages of floating (unfixed) slips at their marina. Responses indicate that 35% (513) of the surveyed slips within the South-eastern Lake Huron Ridge were floating.

Marina officials were asked to summarize their customer demographics and identify the length of boating season at their location. Of the 10 marinas surveyed, eight indicated that they receive customers from the United States; four stated that they receive customers from the GTA, London Middlesex and Tri-city area, and six reported receiving customers from the local area. Four respondents noted that their docking season lasted from May to October, five said their season lasted from May to November and one marina stated that the season length was from May to September.

The questionnaire also asked marina operators the maximum possible draft measurement of recreational boats permitted within their marinas. As indicated in *Table 4.2.1*, all surveyed marinas on the South-eastern Lake Huron Ridge could accept drafts greater than 1.0 meter. The majority of operators (six) stated that their marinas were capable of accepting drafts from 2.0 to 3.0 m, while three operators indicated that they could only accept drafts between 1.0 to 1.9 m. Only one of the surveyed marinas on the South-eastern Lake Huron Ridge could withstand drafts larger than 3.0 m.

Table 4.2.1 Maximum Draft Acceptability

Maximum Possible Draft Measurements (depth of boat in water) (m)	Total Number of Marinas n=10
<1	0
1.0 to 1.9	3
2.0 to 3.0	6
>3	1

Operators were also asked to categorize the sediment substrate present at the bottom of their marina's perimeter. Of the surveyed operators, eight indicated sand and six indicated the presence of gravel. A smaller portion of marinas were identified as having silt as their bottom material and one location noted rock.

<u>Historical Water Levels, Impacts and Adaptations</u>

Each operator was asked to verify years in which their marina was impacted by low water conditions. One marina was impacted prior 1996 and from 2001 to 2002; two marinas were impacted during 2000 and from 2003 to 2006; and three of the marinas reported negative impacts throughout the 2007 boating season only.

Marina operators were then asked to identify the impacts they experienced during low water levels at their location. As indicated in *Table 4.2.2,* five marinas located on the South-eastern Lake Huron Ridge reported problems with boat ramp access and increased aquatic weed growth. In addition, four marinas in the region verified problems with dock and berth access, two marinas confirmed a reduction in number of useable slips and dry rot of wooden structures and one marina reported a shorter boating season and ceasing of operation. Overall, the majority of surveyed marinas (eight) on South-eastern Lake Huron Ridge declared inadequate channel depths during low water levels.

Table 4.2.2 Experienced Impacts during Low Water Levels

Experienced Impacts of Low Water Levels	Total Number of Marinas Impacted n=10
Inadequate channel depths	8
Problems with docks and berth access	4
Problems with boat ramp access	5
Reduction of usable slips or berths	2
Ceasing of operation	1
Shorter boating season	1
Reduced demand for winter storage	0
Dry rot of wooden structures	2
Increased aquatic weed growth	5

Operators were then asked to identify measures of adaptation they have used to reduce impact or retain normal operations *(Refer to Table 4.2.3)*.

Table 4.2.3 Measures of Adaptation

Measures Adaptation Used During Low Water Levels	Total Number of Participating Marinas n=10
Dredging	9
Closing of Slips	2
Closing of Channels	0
Restriction to smaller and shallower draft boats	2
Adjust docks to new water levels	7
Have had to shift boats within marina	2
Construction of adjustable floating docks	2
Replacement of structures due to dry rot	1
Closure of marina	0

Within the region, seven of the 10 surveyed marinas were obligated to adjust docks to new water levels; at least two marinas were forced to close slips, restrict boats and construct new adjustable floating docks; and one marina was required to replace structures due to dry rot. A large number of nine marinas on the South-eastern Lake Huron Ridge were required to dredge as an adaptive measure during low water conditions.

Officials were then asked if low water conditions within their location had ever negatively impacted business. Four of the surveyed operators responded ‘yes’ and six responded ‘no’. Further, businesses that were negatively impacted were asked if they received government assistance during low water conditions. In total, three out of the four negatively impacted South-eastern Lake Huron Ridge marinas received government assistance and two of the marinas found the assistance ‘very effective’, while one of the marinas found the assistance ‘moderately effective’. The government assistance that subsidized the three marinas within the South-eastern Lake Huron ridge assisted them in continuing with normal operations.

Surveyed marina operators were also asked to identify critical minimum depths of water that would prevent operations at their location. As depicted in *Table 4.2.4*, on the shoreline of the South-eastern Lake Huron Ridge, one of the respondents stated that the current levels within their marina’s location were preventing operation. Half (five) of the surveyed operators stated that operations would be prevented if they lost 0.15 to 0.3m of water depth, while one marina reported operation disruption from 0.31 to 0.6m of water level decline. The remaining three surveyed marinas within the South-eastern Lake Huron Ridge claimed that water levels would have to decline over 0.6m in order to prevent operations at their locations.

Table 4.2.4 Critical Minimum Depths

Critical Minimum Depths that Would Prevent Operations (m)	Total Number of Marinas n=10
Current Levels	1
Loss of 0.15 to 0.30	5
Loss of 0.31 to 0.6	1
Loss > 0.6	3

Climate Change and Potential Water Level Scenarios

Within the third portion of the questionnaire, operators were asked to reply ‘yes’, ‘no’ or ‘uncertain’ when questioned “if recent warm winters and prolonged ice free conditions have impacted water levels within their location?”. Of the 10 surveyed operators within the South-eastern Lake Huron Ridge, seven responded ‘yes’, one respondent replied ‘no’ and two operators were ‘uncertain’.

Part three of the survey instrument also asked marina operators to reply ‘yes’, ‘no’ or ‘uncertain’ when asked, “Are you concerned that conditions could get worse because of climate change?”. Overall, four of the 10 surveyed operators within the South-eastern Lake Huron ridge replied ‘yes’, three of the respondents answered ‘no’, and the remaining three surveyed operators were ‘uncertain’.

Marina operators were then asked to identify the adaptive measures they would have to pursue under three potential scenarios of low water levels generated by climate change *(Refer to Table 2.2.5)*.

Scenario One: The first scenario was a potential water level reduction of 0.3 m. Of the ten marina operators surveyed in the South-eastern Lake Huron Ridge, one reported no impacts and two indicated closure. Of the seven remaining operators who stated they would not endure impacts or closure, four indicated they would start dredging; three operators noted that they would implement boat restrictions; and one declared slip loss.

Scenario Two: The second scenario was a potential water level reduction of 0.45 m within. Of the ten operators, only one marina indicated no impacts while three indicated closure. From the remaining six operators, two reported slip loss and three indicated they would start to dredge and implement boat restrictions.

Scenario Three: The third scenario was a potential water level reduction of 0.6 m. Of the ten operators surveyed in the region, four reported they would close following a scenario three water level reduction. Of the six remaining operators, two operators indicated slip loss; three stated they would implement boat restrictions; and six reported they would start to dredge.

Table 4.2.5 Hypothetical Scenarios and Potential Implications

South-eastern Lake Huron Ridge marinas that may experience following implications under scenarios of water level reduction		Water Level Scenarios		
		One (-0.3m)	**Two (-0.45m)**	**Three (-0.6m)**
		n=10		
Potential Implications	**No Impact**	1	1	0
	Closure	2	3	4
	n = 10 - (No Impact + Closure)	**n= 7**	**n= 6**	**n= 6**
	Slip Loss	1	2	2
	Boat Restrictions	3	3	3
	Dredge	4	3	6

When concluding the questionnaire, marina operators were asked to identify if they would like measures that regulate lake levels. Within the South-eastern Lake Huron Ridge, three of the 10 surveyed operators answered ‘yes’, two operators replied ‘no’ and the remaining five were ‘uncertain’. Of the three surveyed operators that responded ‘yes’, one operator suggested that U.S. diversions and consumption should be regulated, while two operators suggested that Lake Huron’s outflow be “controlled” at the mouth of the St. Clair River.

4.3 Eastern Bruce Peninsula Region

The Eastern Bruce Peninsula region *(Refer to Figure 4.3.1)* stretches from the northern tip of the Bruce Peninsula to the southern Georgian Bay community of Collingwood. The municipalities found within this region are Tobermory, Lions Head, Wiarton, Owen Sound, Meaford, Thornbury, and Collingwood. Wrapped by the Niagara Escarpment, this region is mostly composed of steep cliffs and dolostone ledges (*Refer to Figure 4.3.2*) which gradually merge with wave rounded cobbles.

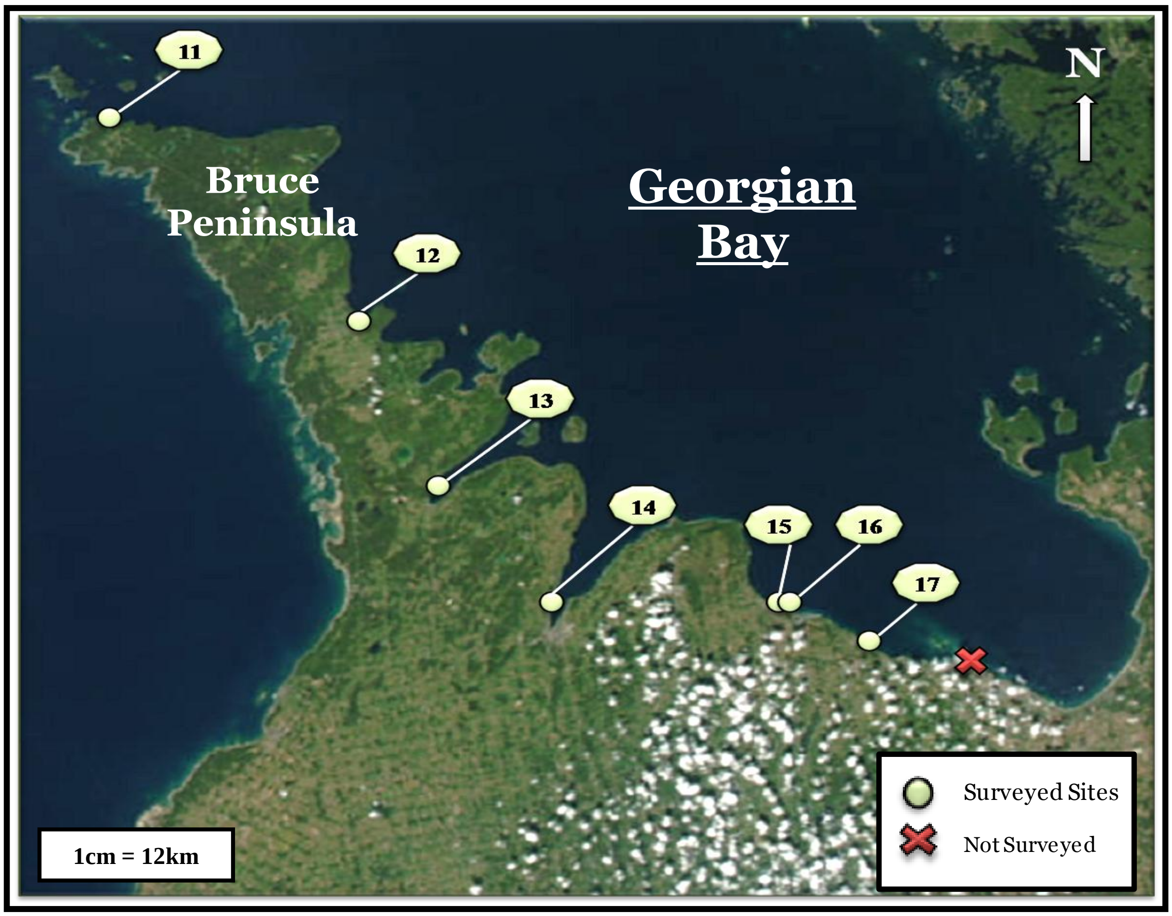


Figure 4.3.1: Eastern Bruce Peninsula
(Source: NASA 2007, modified by Jordan Stewart)

The deepest sections of Lake Huron-Georgian Bay basin are located within this region running parallel with the eastern Bruce Peninsula coastline (NOAA 2000). According to the 2007 OMOA registry, eight marinas were located within this region. In total, seven marinas were personally surveyed during the study.

Figure 4.3.2: Lions Head Dolostone Ledges
Photograph by Jordan Stewart

Marina background information for the Eastern Bruce Peninsula Region

The eight marinas registered under the OMOA in 2007 for the Eastern Bruce Peninsula housed 1575 recreational boating slips for the region. The seven marina operators surveyed in this region contained 1460 recreational slips, accounting for 93% of the registered OMOA slips in the region. The total percentage of slips used for seasonal occupancy in the Eastern Bruce Peninsula region was 95% (1387). During the 2007 season, 83% (1212) of the slips at the surveyed sites were rented. In total, 89% (1299) of the slips at the surveyed sites were classified as floating.

Of the seven marinas surveyed in this region, six indicated that they receive customers from the local area and three reported serving customers from the GTA, London Middlesex and Tri-city area. Marinas in the region also received customers from the United States (four) and other international countries (one). For five of the surveyed marinas here, the boating season lasted from May to November. The remaining two marinas stated that their boating season was from May to October.

As a result of the depths found within the Eastern Bruce Peninsula, all seven surveyed marinas stated their maximum draft to be greater than 2.0 m *(Refer to Table 4.3.1)*. Overall, four of the marina operators stated that they could accommodate boat drafts from 2.0 to 3.0 m. While the remaining three were capable of accepting boat drafts larger than 3.0 m in depth.

Table 4.3.1 Maximum Draft Acceptability

Maximum Possible Draft Measurements (depth of boat in water) (m)	Total Number of Marinas n=7
<1	0
1.0 to 1.9	0
2.0 to 3.0	4
>3	3

The majority of surveyed marinas within the Eastern Bruce Peninsula region (five) reported sand at the bottom and three locations stated that silt was also present. One of the surveyed marinas identified clay as their bottom material and no marinas listed rock or gravel compositions.

Historical Water Levels, Impacts and Adaptations

Of the seven surveyed operators with the Eastern Bruce Peninsula region, two were negatively impacted by low water levels in 1999 and 2007, and another in 2005.

As indicated in *Table 4.3.2*, three impacted marinas indicated inadequate channel depths during historical low water level conditions, and two reported problems with their docks and berth access. In addition, two impacted marinas also had a reduction of useable slips and berths, while four experienced increased aquatic weed growth. Only, one marina indicated dry rot of wooden structures.

Table 4.3.2 Experienced Impacts during Low Water Levels

Experienced Impacts of Low Water Levels	Total Number of Marinas Impacted n=7
Inadequate channel depths	3
Problems with docks and berth access	2
Problems with boat ramp access	0
Reduction of usable slips or berths	2
Ceasing of operation	0
Shorter boating season	0
Reduced demand for winter storage	0
Dry rot of wooden structures	1
Increased aquatic weed growth	4

As *Table 4.3.3* suggests, four marinas had to dredge and shift boats around, while one was forced to close slips. Two marinas in the region were obligated to restrict large draft boats and adjust docks to new water levels.

Overall, four of the surveyed operators within the Eastern Bruce Peninsula region responded ‘yes’ and three responded ‘no’ when asked if they have ever experienced low water levels that had negatively impacted business. Of the four marinas that were negatively impacted by low water conditions, two received government assistance while two did not. The two marinas that received government funding found the subsidy ‘very effective’ and both were able to return to their normal marina operations.

Table 4.3.3 Measures of Adaptation

Measures of Adaptation Used During Low Water Levels	Total Number of Marinas n=7
Dredging	4
Closing of Slips	1
Closing of Channels	0
Restriction to smaller and shallower draft boats	2
Adjust docks to new water levels	2
Have had to shift boats within marina	3
Construction of adjustable floating docks	0
Replacement of structures due to dry rot	0
Closure of marina	0

Of the seven marinas surveyed within the Eastern Bruce Peninsula region, three indicated that the current water levels were preventing operations *(Refer to Table 4.3.4)* and one stated that operations would be disrupted if water depths within the marina were to decline from 0.15 to 0.3 m. Three surveyed marinas also stated that operations would be limited if there was a loss greater than 0.6 m within their marina water levels.

Table 4.3.4 Critical Minimum Depths

Critical Minimum Depths that Would Prevent Operation (m)	Total Number of Marinas n=7
Current Levels	3
Loss of 0.15 to 0.30	1
Loss of 0.31 to 0.6	0
Loss > 0.6	3

<u>Climate Change and Potential Water Level Scenarios</u>

Within the Eastern Bruce Peninsula region, five of the seven surveyed operators responded ‘yes’ when asked, “if recent warm winters and prolonged ice free conditions have impacted water levels within your location?”. Of the remaining two surveyed operators within this region one stated, ‘no’ and the other ‘uncertain’.

A total of four surveyed operators responded ‘yes’, two operators responded ‘no’ and one operator was ‘uncertain’ when asked, “Are you concerned that conditions could get worse because of climate change?”.

Indicated in *Table 4.3.5* are the responses for the potential scenarios of water level decline generated by climate change.

Scenario 1: The first scenario was a potential water level reduction of 0.3 m. From the seven marinas surveyed on the Eastern Bruce Peninsula shoreline, three indicated that they would not be impacted and one marina reported they would close. Of the four remaining surveyed operators who stated they would not experience impacts or closure, two declared slip loss and three indicated that they would implement boat restrictions.

Scenario 2: The second scenario was a potential water level reduction of 0.45 m. Of the seven surveyed operators, two reported no impacts and one indicated closure. Of the four remaining operators, two stated they would implement boat restrictions and declared slip loss, while three operators said they would start to dredge.

Scenario 3: The third scenario was a potential water level reduction of 0.6 m. From the seven surveyed operators, one indicated no impacts and one reported closure. Of the five remaining operators, two said they would lose slips and implement boat restrictions, while four stated they would start to dredge.

Table 4.3.5 Hypothetical Scenarios and Potential Implications

Eastern Bruce Peninsula marinas that may experience following implications under scenarios of water level reduction		Water Level Scenarios		
		One (-0.3m)	**Two (-0.45m)**	**Three (-0.6m)**
		n=8		
Potential Implications	**No Impact**	3	2	1
	Closure	1	1	1
	n = 10 - (No Impact + Closure)	**n= 4**	**n= 5**	**n= 6**
	Slip Loss	2	2	2
	Boat Restrictions	3	2	2
	Dredge	0	3	4

From the seven surveyed marina operators on the Eastern Bruce Peninsula shoreline, six operators answered ‘yes’ for measures that regulate Lake Huron water levels, while one operator was ‘uncertain’. Of the six operators that answered ‘yes’ for measures that regulate Lake Huron water levels, three operators recommended that U.S. diversions and consumption rates be regulated and two suggested subsidized dredging along with adaptive measures to regulate Lake Huron outflows at the mouth of the St. Clair River.

4.4 Region of Eastern Georgian Bay

The Eastern Georgian Bay region *(Refer to Figure 4.4.1)* is the entire eastern shoreline of the Georgian Bay, excluding both the Parry Sound and Severn Inlet. Municipalities within this region include Britt, Pointe au Baril, MacTier, Penetanguishene, and Wasaga Beach. The eastern shoreline of the Georgian Bay is shallow with two bedrock types. As mentioned previously, the Severn Inlet marks the contact zone between the Canadian Shield and the St. Lawrence Platform. Therefore shorelines within the St. Lawrence Platform generally consist of sedimentary bedrock that provide flat lying terrain with soft marsh and sandy substrates. North of the Severn Inlet, the Eastern Georgian Bay region is surrounded by the Canadian Shield where the shorelines are composed of low-lying, glacier sculpted granite bedrock with thinly scattered outwash of sands and gravels. The eastern shorelines are also home to the Thirty Thousand Islands and house many embayment wetlands. During the 2007 season under the OMOA registry, eight marinas were registered within the Eastern Georgian Bay Region. Overall, five marinas were surveyed in person, while an additional two were surveyed via telephone.

Marina background information for the Eastern Georgian Bay Region

The eight marinas identified by the OMOA 2007 registry for the Eastern Georgian Bay region accommodated 846 slips for recreational boats. Seven marinas were surveyed in the region containing 766 recreational boating slips. Of the seven surveyed marinas, 95% (728) of the slips were used for seasonal occupancy and 94% (720) were rented during the 2007 boating season. Overall, 97% (743) of the slips housed by the surveyed marinas in the Eastern Georgian Bay region were floating.

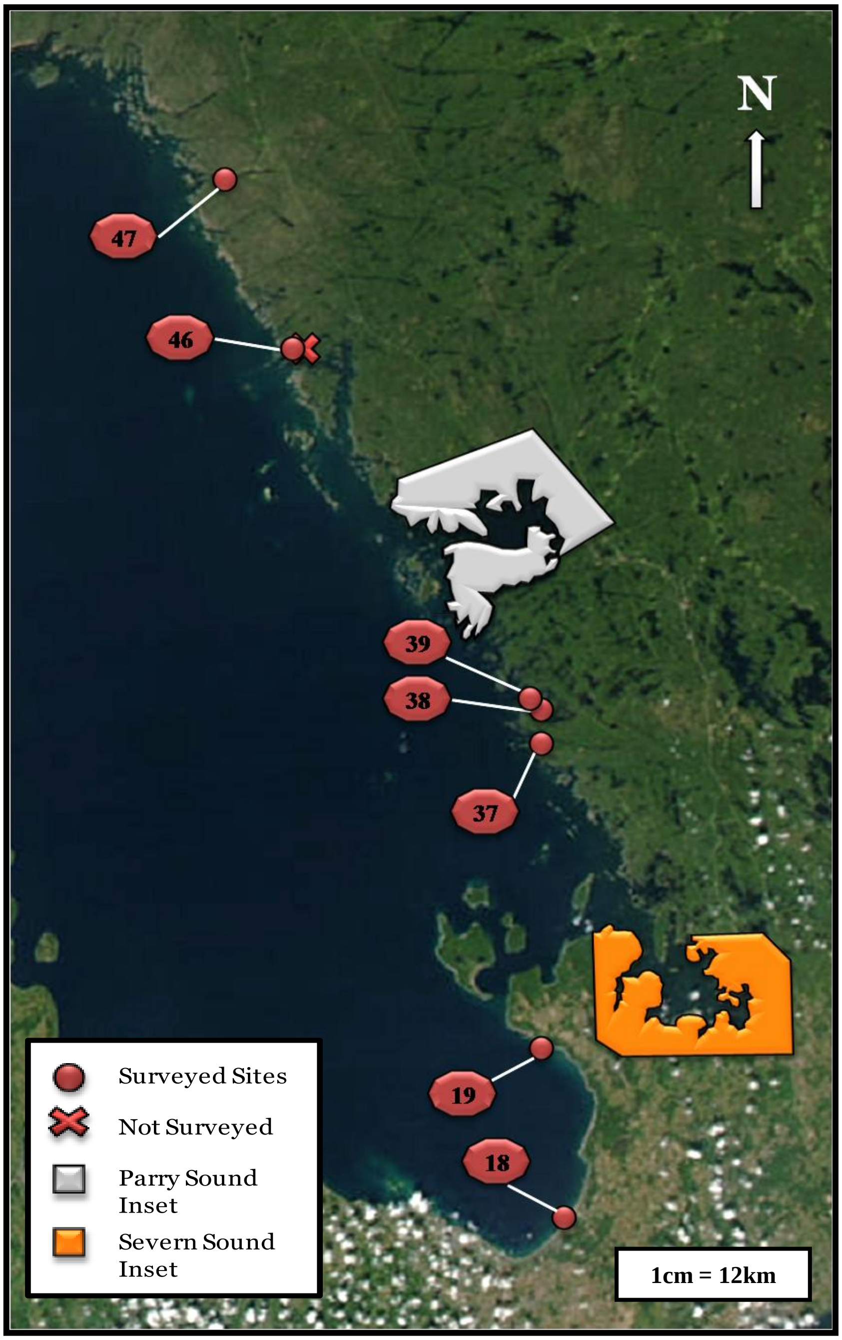


Figure 4.4.1: Eastern Georgian Bay
(Source: NASA 2007, modified by Jordan Stewart)

In the Eastern Georgian Bay region, six of the surveyed marinas stated that they accommodate customers from the GTA, London Middlesex, and Tri-city area. Additionally three of the respondents identified receiving customers from the local area and one marina in the region serviced boating customers from the United States. In terms of seasonal length, one of the seven marinas stated that their season was from May to September, while three marinas reported a season length of May to October and three a seasonal duration from May to November.

As suggested in *Table 4.4.1*, all of the surveyed marinas within the Eastern Georgian Bay region could accommodate boats with drafts larger than 1.0 m. The majority of surveyed marinas (five) on the Eastern Georgian Bay shoreline stated that they could withstand maximum boat drafts between 1.0 to 1.9 m in depth. The remaining two surveyed marinas confirmed that their locations could accommodate boats with drafts greater than 3.0 m.

Table 4.4.1 Maximum Draft Acceptability

Maximum Possible Draft Measurements (depth of boat in water) (m)	Total Number of Marinas n=7
<1	0
1.0 to 1.9	5
2.0 to 3.0	0
>3	2

In general, five of the surveyed sites within the Eastern Georgian Bay region confirmed that sand was present as a bottom material within their marina's perimeter and three reported the presence of clay. Two marinas reported both silt and gravel and four marinas identified rock as their bottom material.

Historical Water Levels, Impacts and Adaptations

From the Eastern Georgian Bay shoreline, two marinas were affected by low water conditions during the 2000 boating season. One marina was impacted prior to 1996 and during 1999, 2003 and 2007.

Common impacts experienced at five marinas of the Eastern Georgian Bay were problems with docks and berth access, reduction of useable slips, and increased aquatic weed growth within their location *(Refer to Table 4.4.2)*. In addition, four of the marinas reported problems with boat ramp access, three marinas confirmed inadequate channel depths and one marina reported a shorter boating season, reduced demand for winter storage and dry rot of wooden structures during low water conditions.

Table 4.4.2 Experienced Impacts during Low Water Levels

Experienced Impacts of Low Water Levels	Total Number of Marinas Impacted n=7
Inadequate channel depths	3
Problems with docks and berth access	5
Problems with boat ramp access	4
Reduction of usable slips or berths	5
Ceasing of operation	0
Shorter boating season	1
Reduced demand for winter storage	1
Dry rot of wooden structures	1
Increased aquatic weed growth	5

As *Table 4.4.3* indicates that four of the seven marinas surveyed on the Eastern Georgian Bay shoreline had to adjust docks to new water levels and shift boats within their marina's perimeter. Three marinas were obligated to construct new adjustable floating docks as well as dredge within their location. In addition, two marinas within the region were forced to close slips and one marina replaced structures due to dry rot and safety precautions.

Of the seven marina operators surveyed within the Eastern Georgian Bay region, five marinas responded 'yes' after being asked if historical low water conditions had negatively impacted their businesses. The remaining two responded 'no'. From the five marinas that experienced impacts during low water conditions on the Eastern Georgian Bay shoreline, one marina was assisted by government funding. The funding allowed the marina to continue with normal operations and was reported as 'moderately effective'.

Table 4.4.3 Measures of Adaptation

Measures of Adaptation Used During Low Water Levels	Total Number of Participating Marinas n=7
Dredging	3
Closing of Slips	2
Closing of Channels	1
Restriction to smaller and shallower draft boats	3
Adjust docks to new water levels	4
Have had to shift boats within marina	4
Construction of adjustable floating docks	3
Replacement of structures due to dry rot	1
Closure of marina	0

As *Table 4.4.4* shows that three of the seven surveyed sites within the Eastern Georgian Bay region stated that water levels would have to decline from 0.15 to 0.3 m within their marinas before interfering with normal operations. One marina reported water levels would have to decline from 0.31 to 0.6 m and three of the surveyed marinas verified that water levels would have to reduce 0.6 m or greater before normal operations were prevented.

Table 4.4.4 Critical Minimum Depths

Critical Minimum Depths that Would Prevent Operation (m)	Total Number of Marinas n=7
Current Levels	0
Loss of 0.15 to 0.30	3
Loss of 0.31 to 0.6	1
Loss > 0.6	3

Climate Change and Potential Water Level Scenarios

When asked, "Have water levels in your location been impacted by recent warm winters and prolonged ice free conditions", four of the seven marina operators surveyed on the Eastern Georgian Bay shoreline responded 'yes' two replied 'no', and the remaining one marina was 'uncertain'.

When asked, "Are you concerned that conditions could get worse because of climate change?", six of the seven operators surveyed on the Eastern Georgian Bay shoreline responded 'yes', while one operator answered 'no'.

Indicated in *Table 4.4.5* are the responses for potential water level reduction scenarios generated by climate change.

Scenario 1: The first scenario was a potential water level reduction of 0.3m. From the seven surveyed operators on the Eastern Georgian Bay coastline, two declared no impacts and one indicated closure. Of the four remaining operators who did not indicate closure or no impacts, four reported they would implement boat restrictions and lose slips, while two said they would start to dredge.

Scenario 2: The second scenario introduced was a potential water level reduction of 0.45 m. Of the seven operators surveyed, two indicated no impacts and another two reported closure. From the remaining three operators, three stated they would implement boat restrictions and lose slips, while one indicated they would start to dredge.

Scenario 3: The third scenario introduced was a potential water level reduction of 0.6 m. Of the seven surveyed operators, one stated no impacts and a notable five indicated closure. The one remaining operator reported they would implement boat restrictions, start to dredge and lose slips following a scenario three water level decline.

Table 4.4.5 Hypothetical Scenarios and Potential Implications

Eastern Georgian Bay marinas that may experience following implications under scenarios of water level reduction		**Water Level Scenarios**		
		One (-0.3m)	**Two (-0.45m)**	**Three (-0.6m)**
		n=7		
Potential Implications	**No Impact**	2	2	1
	Closure	1	2	5
	n = 10 - (No Impact + Closure)	**n= 4**	**n= 3**	**n= 1**
	Slip Loss	4	3	1
	Boat Restrictions	4	3	1
	Dredge	2	1	1

From the seven surveyed marina operators within the Eastern Georgian Bay region, two operators responded 'yes' for measures that regulate Lake Huron water levels. The remaining five marinas were 'uncertain'. Of the two respondents who answered 'yes', both recommended Lake Huron's outflow be regulated at the mouth of the St. Clair River.

4.5 Region of Severn Sound Inlet

The region of the Severn Sound Inlet *(Refer to Figure 4.5.1)* is an enclosed embayment located on the south-eastern coast of the Georgian Bay. The total watershed covers an area of 1,098 square kilometres and houses a group of bay municipalities that include Penetanguishene, Midland, and Honey Harbour. The primary water input for the inlet is from the Severn River, which connects Lake Huron to Lake Ontario via Trent-Severn waterway. The Severn Sound Inlet marks the contact zone between the Precambrian rocks of the Canadian Shield in the north and the St. Lawrence Platform in the south. The north shores of the Severn Sound Inlet comprise largely of folded, irregular, metamorphic rocks and an abundance of islands populating the coastline.

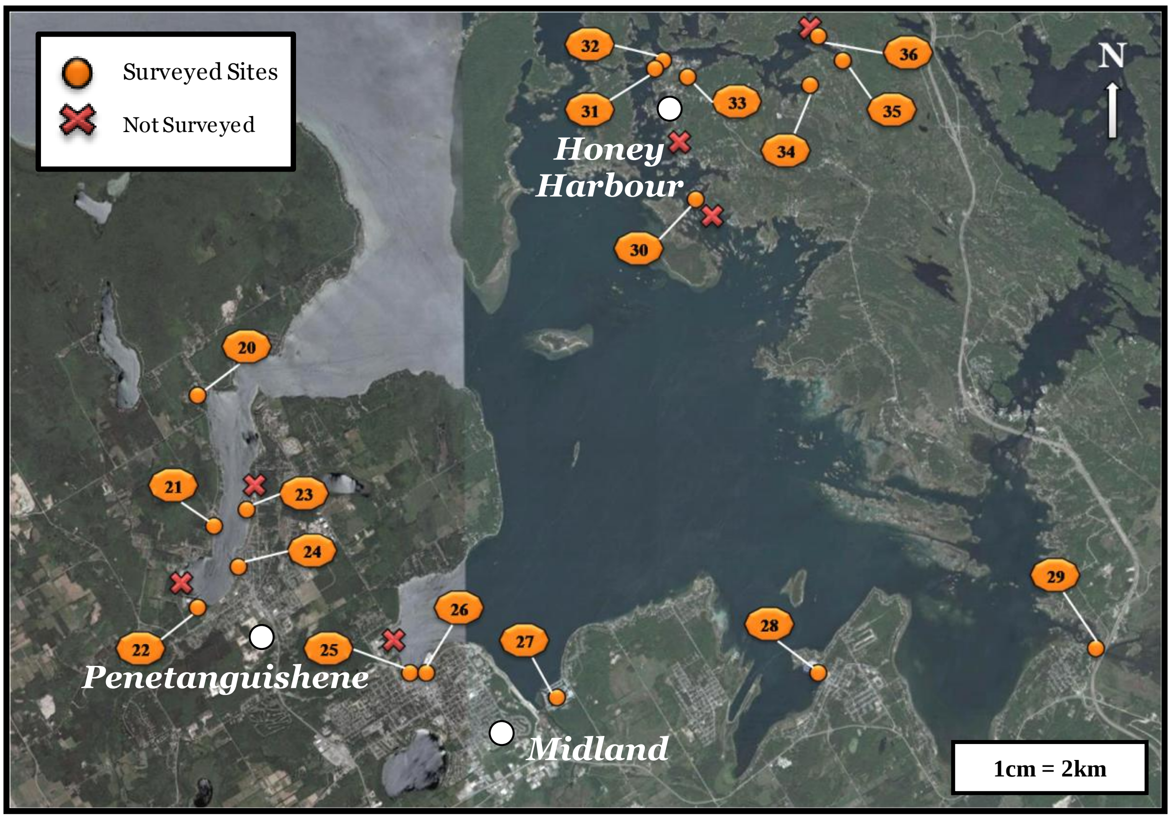


Figure 4.5.1: Severn Sound Inlet
(Source: Google Earth Imagery 2008a, modified by Jordan Stewart)

The south and west shoreline of the Inlet is comprised of sedimentary rocks. The Ordivican age sedimentary bedrock provides a relatively flat lying terrain with numerous wetlands composed of soft marsh substrates. Depending on the prevailing wind direction and season, wind seiches can manipulate water levels in this embayment. Under the OMOA 2007 registry, 23 marinas were located in this region. In total, 11 marinas were surveyed in person, while an additional six were surveyed by phone.

Marina background information for the Severn Sound Inlet Region

The 23 marinas located in the Severn Sound Inlet region contain 4,930 recreational boating slips. The overall 17 surveyed marinas provided 3,328 recreational slips, which accounted for 68% of the total slips within the region. Overall, 92% (3062) of the slips at the surveyed marinas were used for seasonal occupancy. Responses indicated that 87% (2895) of the surveyed slips were rented for the 2007 boating season and 2,496 slips (75%) were recognized as floating.

Of the 17 marinas surveyed, 15 indicated that they receive customers from the GTA, London Middlesex, and Tri-city area, and five marinas reported customers from the local area. Four marinas surveyed stated that they accommodate customers from the United States and only one marina indicated customers from other international countries. The docking duration for 12 of the marinas in the region was from May to October. The remaining five surveyed marinas stated that their season was from May to November.

Over half (ten) of the surveyed marina operations within the Severn Sound Inlet region could accommodate maximum boat drafts of 1.0 to 1.9 m in depth *(Refer to Table 4.5.1)*, and five marinas indicated a maximum draft of 2.0 to 3.0 m. Two could accommodate maximum drafts greater than 3.0m.

Table 4.5.1 Maximum Draft Acceptability

Maximum Possible Draft Measurements (depth of boat in water) (m)	Total Number of Marinas n=17
<1	0
1.0 to 1.9	10
2.0 to 3.0	5
>3	2

A large portion of the surveyed marinas (13) in the Severn Sound Inlet indicated silt intermixed within their bottom material and seven indicated the presence of clay. A small total of the surveyed marinas within the region identified rock (three) and sand (two) within their bottom material.

Historical Water Levels, Impacts and Adaptations

Of the 17 surveyed marinas in the Severn Sound Inlet only one marina reported negative impacts due to low water conditions during the 2003 and 2004 boating season. Two marinas were negatively impacted in 1997, 2002 and from 2005 to 2007, while three marinas were impacted in 1998 and four during the 1999 and 2001 season. The most pronounced was for the 2000 boating season, when eight marinas indicated negative impacts from reduced water levels.

Four of the 17 surveyed marinas stated inadequate channel depths during periods of low water in the region, while nine marinas indicated to have had problems with dock access and increased aquatic weed growth *(Refer to Table 4.5.2)*. Eight marinas found problems with boat ramp access and 11 marinas said they had a reduction of usable slips. Three marinas reported dry rot of wooden structures. Only one marina claimed a shorter boating season and two marinas, of the 13 negatively impacted in the region, stated operations were ceased during low water conditions.

Table 4.5.2 Experienced Impacts during Low Water Levels

Experienced Impacts of Low Water Levels	Total Number of Marinas Impacted n=17
Inadequate channel depths	4
Problems with docks and berth access	9
Problems with boat ramp access	8
Reduction of usable slips or berths	11
Ceasing of operation	2
Shorter boating season	1
Reduced demand for winter storage	0
Dry rot of wooden structures	3
Increased aquatic weed growth	9

As *Table 4.5.3* suggests, from the 17 surveyed marinas in the region that experienced low water levels, 13 had to dredge, adjust docks and shift boats in their marinas perimeter. Eight respondents limited the size of boats entering f their marinas, six marinas constructed new adjustable floating docks, and five had to close slips. Two of the regions surveyed marinas replaced structures due to dry rot.

A number of 13 of respondents in the region replied ‘yes’ when asked if they had experienced low water levels that negatively impacted business. The remaining four marinas responded ‘no’. Six negatively impacted marinas in the Severn Sound Inlet received government funding during low water conditions. Of the six funded marinas, four found the assistance ‘very effective’, and two identified the funding as ‘moderately effective’. The government assistance allowed five marinas to continue normal operations, and one marina was unable to continue normal procedures with assistance.

Table 4.5.3 Measures of Adaptation

Measures of Adaptation Used During Low Water Levels	Total Number of Participating Marinas n=17
Dredging	13
Closing of Slips	5
Closing of Channels	0
Restriction to smaller and shallower draft boats	8
Adjust docks to new water levels	9
Have had to shift boats within marina	9
Construction of adjustable floating docks	6
Replacement of structures due to dry rot	2
Closure of marina	0

Indicated in *Table 4.5.4*, three surveyed marinas stated that current water levels were interfering with normal operations. Four marinas reported that business would be disrupted if water levels were to decline 0.15 to 0.3 m. Five surveyed operators indicated that critical minimum depths would be reached if water levels were to drop from 0.31 to 0.6 m, and an additional five claimed water levels would have to decline over 0.6 m before normal operations were obstructed.

Table 4.5.4 Critical Minimum Depths

Critical Minimum Depths that Would Prevent Operation (m)	Total Number of Marinas n=17
Current Levels	3
Loss of 0.15 to 0.30	4
Loss of 0.31 to 0.6	5
Loss > 0.6	5

Climate Change and Potential Water Level Scenarios

When asked, “Have water levels in your location been impacted by recent warm winters and prolonged ice free conditions”, 15 surveyed operators responded ‘yes’. Two operators said they were ‘uncertain’ and ‘no’. A number of 14 operators responded ‘yes’ and one said ‘no’ when asked, “Are you concerned that conditions could get worse because of climate change?”. The remaining two were ‘uncertain’.

As *Table 4.5.5* describes the responses for potential water level reduction scenarios generated by climate change:

Scenario 1: The first scenario introduced to the surveyed marina operators of the Severn Sound Inlet was a potential water level reduction of 0.3 m. Of the 17 marinas surveyed, one marina reported no impacts would occur and one indicated closure. From the remaining 15 operators who did not indicate closure or no impacts, five stated slip loss; seven said they would start to dredge; and four reported they would implement boat restrictions.

Scenario 2: The second scenario introduced was a potential water level reduction of 0.45 m within their location. Of the 17 surveyed operators, a notable six indicated closure. From the 11 remaining operators, eight declared slip loss; nine said they would start to dredge; and four would implement boat restrictions.

Scenario 3: The third scenario introduced was a potential water level reduction of 0.6 m. Of the 17 surveyed operators, six indicated closure. The 11 remaining surveyed operators reported identical impacts as listed in scenario two.

Table 4.5.5 Hypothetical Scenarios and Potential Implications

Severn Sound Inlet marinas that may experience following implications under scenarios of water level reduction		Water Level Scenarios		
		One (-0.3m)	**Two (-0.45m)**	**Three (-0.6m)**
		n=17		
Potential Implications	**No Impact**	1	0	0
	Closure	1	6	6
	n = 10 - (No Impact + Closure)	**n= 15**	**n= 11**	**n= 11**
	Slip Loss	5	8	8
	Boat Restrictions	4	4	4
	Dredge	7	9	9

From the 17 surveyed marina operators in the Severn Inlet region, 12 operators answered 'yes' for measures to regulate Lake Huron water levels, one operator replied 'no' and four of the regions operators were 'uncertain'. Twelve operators also answered 'yes' for measures that would regulate Lake Huron water levels and 11 operators recommended that Lake Huron's outflow at the mouth of the St. Clair River be controlled. Only one operator suggested to regulate U.S. diversion and consumption rates.

4.6 Region of Parry Sound Inlet

Enclosed within Georgian Bay's eastern shorelines is the Parry Sound Inlet *(Refer to Figure 4.6.1)*. This region is an embayment, including the communities of Parry Sound, Nobel, and Killbear and has an abundance of granite islands. Although the Parry Sound port is recognized as the world's deepest freshwater port, the narrows between island chains can become shallow. The inlet is surrounded by glacier-sculpted and scarred granite rock of the Precambrian Canadian Shield (Chapman & Putman 1984). The surrounding terrain contains embayment wetlands and low-lying rocklands. The shoreline substrate varies considerably over short distances. Outwash sands and gravels to fine grained silts and clay are thinly scattered in some locations, while granite bedrock is exposed in others. The region's water tends to be clear and low in nutrients due to the low alkalinity provided by the granite bedrock (Chapman & Putman 1984). Seven marina's were registered in this region under the OMOA registry for the 2007 boating season. Four marinas were surveyed in person, while an additional two were surveyed by phone.

Marina background information for the Parry Sound Inlet Region

The seven registered OMOA marinas in the Parry Sound Inlet house 1,083 recreational boat slips. The six marinas that were surveyed accommodate 993 recreational slips, accounting for 92% of the registered OMOA slips within the region. In total, 78% (775) of the surveyed slips were used for seasonal occupants and during the 2007 boating season all slips were rented. Overall, 87% (864) of the slips at the surveyed marinas were categorized as 'floating systems'.

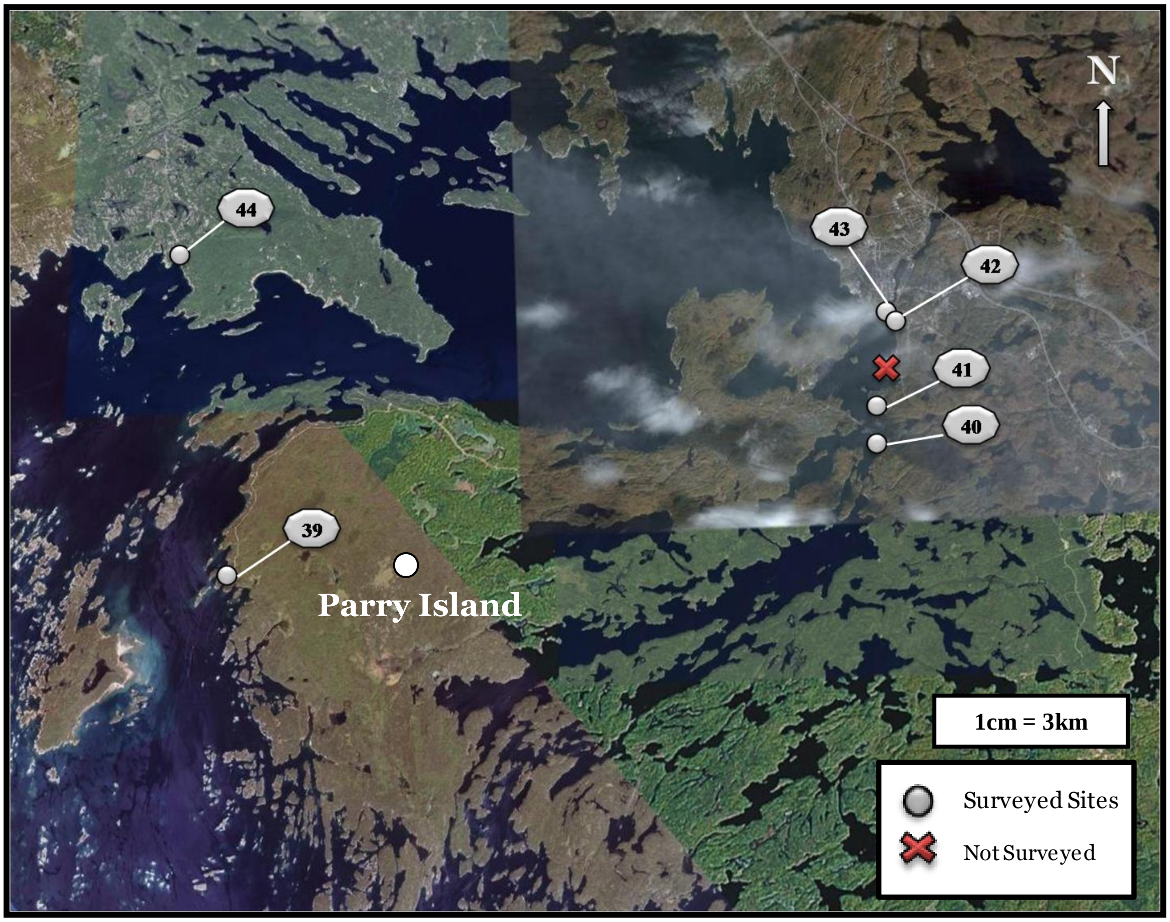


Figure 4.6.1: Parry Sound Inlet
(Source: Google Earth Imagery 2008b, modified by Jordan Stewart)

Only one marina stated to receive customers from the surrounding local area, the United States and other international countries. Half of the surveyed marinas (three) reported customers from the GTA, London Middlesex and Tri-city area. In terms of season length, two marinas stated that their season was from May to September, while two marinas reported a season length of May to October and two a seasonal duration from May to November.

Half of the marinas surveyed (three) stated that they could accommodate maximum boat drafts over 3.0 m in depth *(Refer to Table 4.6.1)*, while two marinas reported they could accept boat drafts from 2.0 to 3.0 m, and one could accept boats with drafts of 1.0 to 1.9 m in length.

Table 4.6.1 Maximum Draft Acceptability

Maximum Possible Draft Measurements (depth of boat in water) (m)	Total Number of Marinas n=6
<1	0
1.0 to 1.9	1
2.0 to 3.0	2
>3	3

Four of the surveyed marinas indicated silt as their bottom material, while three identified sand, and one reported clay. Two surveyed marinas indicated rock as a bottom material.

Historical Water Levels, Impacts and Adaptations

Of the six surveyed marinas, one reported experiencing impacts from low water from 1996 to 2007. Two marinas reported impacts during the 2006 and 2007 seasons.

As *Table 4.6.2* indicates, one marina reported to have inadequate channel depths, problems with docks and berth access, ceasing of operation and a shorter boating season. Two marinas reported a reduction of usable slips, reduced demand for winter storage and dry rot of wooden. Three marinas in the Parry Sound Inlet stated problems with boat ramp access and increased aquatic weed growth.

Table 4.6.2 Experienced Impacts during Low Water Levels

Experienced Impacts of Low Water Levels	Total Number of Marinas Impacted n=6
Inadequate channel depths	1
Problems with docks and berth access	1
Problems with boat ramp access	3
Reduction of usable slips or berths	2
Ceasing of operation	1
Shorter boating season	1
Reduced demand for winter storage	2
Dry rot of wooden structures	2
Increased aquatic weed growth	3

Two of the six surveyed marinas in the Parry Sound Inlet had to restrict large boat drafts, adjust docks to new water levels, construct adjustable floating docks and replace structures due to dry rot. Only one of the marinas dredged, closed useable slips and shifted boats in the marina's perimeter *(Refer to Table 4.6.3)*.

Table 4.6.3 Measures of Adaptation

Measures of Adaptation Used During Low Water Levels	**Total Number of Participating Marinas n=6**
Dredging	1
Closing of Slips	1
Closing of Channels	0
Restriction to smaller and shallower draft boats	2
Adjust docks to new water levels	2
Have had to shift boats within marina	1
Construction of adjustable floating docks	2
Replacement of structures due to dry rot	2
Closure of marina	0

Of the six surveyed marinas, three responded 'yes' and three responded 'no' when asked if low water levels have negatively impacted business. Of the three negatively impacted marinas in the Parry Sound Inlet, only one marina received government funding and found it moderately effective allowing the marina to continue with operations.

Indicated in *Table 4.6.4*, two surveyed marinas stated that a water level decline of 0.15 to 0.3 m would interfere with normal operations. Additionally, one marina reported water levels would have to decline from 0.31 to 0.6 m and three marinas verified that water levels would have to reduce 0.6 m or greater before critical minimum depths were reached.

Table 4.6.4 Critical Minimum Depths

Critical Minimum Depths that Would Prevent Operation (m)	Total Number of Marinas n=6
Current Levels	0
Loss of 0.15 to 0.30	2
Loss of 0.31 to 0.6	1
Loss > 0.6	3

Climate Change and Potential Water Level Scenarios

Four of the six surveyed marinas answered 'yes' and one answered 'no' when asked "Have water levels in your location been impacted by recent warm winters and prolonged ice free conditions?".

When asked, "Are you concerned that conditions could get worse because of climate change?", four of the five operators responded 'yes', while one operator was 'uncertain'.

Responses for potential water level reduction scenarios generated by climate change are depicted in *Table 4.6.5.*

Scenario 1: The first scenario introduced to the surveyed marina operators of the Parry Sound Inlet was a potential water level reduction of 0.3 m. Of the six surveyed operators, one stated no impacts and one indicated closure. From the remaining four operators who did not report closure or no impacts, two reported they would start to dredge and implement boat restrictions, while one indicated slip loss.

Scenario 2: The second scenario was a potential water level reduction of 0.45 m. Of the six surveyed operators, one claimed no impacts and one indicated closure. From the four remaining operators, two reported they would implement boat restrictions, start to dredge and lose slips.

Scenario 3: The third scenario was a potential water level reduction of 0.6 m. The operator responses for scenario three water level reductions were identical to scenario two.

Table 4.6.5 Hypothetical Scenarios and Potential Implications

Parry Sound Inlet marinas that may experience following implications under scenarios of water level reduction		Water Level Scenarios		
		One (-0.3m)	**Two (-0.45m)**	**Three (-0.6m)**
		n=6		
Potential Implications	**No Impact**	1	1	1
	Closure	1	1	1
	n = 10 - (No Impact + Closure)	**n= 4**	**n= 4**	**n= 4**
	Slip Loss	1	2	2
	Boat Restrictions	2	2	2
	Dredge	2	2	2

From the six surveyed marina operators within the Parry Sound Inlet region, three responded 'yes' for measures that regulate Lake Huron water levels. The remaining two were 'uncertain'. Of the three respondents who answered 'yes' for measures that will regulate Lake Huron water levels, one suggested subsidized dredging, while two stated regulations be made in Lake Huron's outflow.

4.7 Region of the North Channel

The North Channel Region *(Refer to Figure 4.7.1)* is located on Lake Huron's north shoreline and is bordered by the Georgian Bay, the St. Marys River and the islands of Manitoulin, Cockburn, Drummond and St. Joseph. The Channel extends 160 nautical miles from Ontario's Sault Ste. Marie to the municipality of Killarney. Other municipalities located within the region include Manitowaning, Little Current, Gore Bay, Spanish, Blind River, Thessalon, Hilton Beach, Richards Landing, and Desbarats. The North Channel is surrounded by granite bedrock of the Precambrian Canadian Shield and quartzite hills and cliffs from the LaCloche Mountain range. Smoothly carved islands populate the North Channel creating ranges of water depths. Outwash sediments, such as sand, gravel and muck, sporadically cover the granite shorelines. In 2007, 14 marinas were registered in the North Channel region under the OMOA marina registry. Five marinas were surveyed in person, while an additional six were surveyed by phone.

Marina background information for the North Channel Region

The 14 marinas located in the North Channel registered under the 2007 OMOA registry had a total of 1086 recreational boating slips. The 11 marinas surveyed within the region housed 962 slips, which accounted for 89% of the slips in the region registered under the OMOA. A total of 58% (558) of the surveyed slips were used for seasonal occupancy and 58% of the slips were rented during the 2007 season. Overall, 96% (923) of the total surveyed slips within the North Channel were categorized as floating.

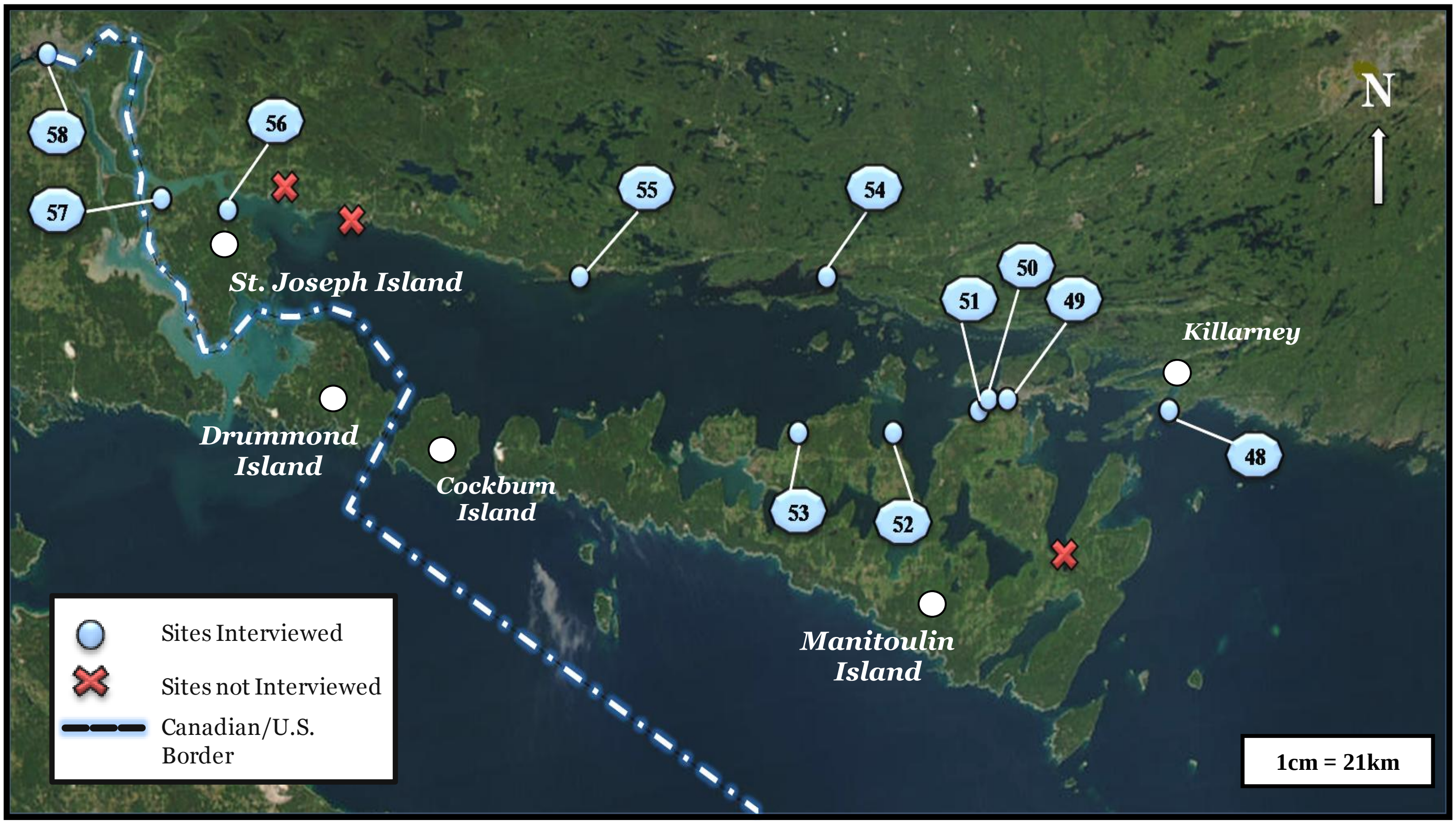


Figure 4.7.1: North Channel
(Source: NASA 2007, modified by Jordan Stewart)

From the 11 marinas surveyed, six indicated to receive customers from the surrounding local area and five reported customers from the GTA, London Middlesex and Tri-city area. Ten surveyed marinas reported to receive customers from the United States. The boating season for five surveyed marina was from May to September. The remaining four surveyed marinas reported their season was from May to October and two had a season length from May to November.

Four surveyed marinas were limited to boat drafts between 1.0 and 1.9 m, while an additional four indicated they could accommodate maximum boat drafts from 2.0 to 3.0 m *(Refer to Table 4.7.1)*. The remaining three surveyed marinas reported they could accept boat drafts larger than 3.0 m.

Table 4.7.1 Maximum Draft Acceptability

Maximum Possible Draft Measurements (depth of boat in water) (m)	Total Number of Marinas n=11
<1	0
1.0 to 1.9	4
2.0 to 3.0	4
>3	3

Six of the 11 surveyed marinas in the North Channel indicated rock as a bottom material within their location and four of the marinas also identified the presence of clay. Two marinas identified the presence of silt and three locations stated sand as their bottom material.

Historical Water Levels, Impacts and Adaptations

From the 11 surveyed marinas in the North Channel region, five stated they were impacted during 2005 and 2007 and four reported being affected by low water conditions during 2000, 2001 and 2004. Three marinas identified being impacted through 2002, 2003 and 2006 seasons, while two marinas through the 1999 season. Only one marina reported impacts during 1996, 1997 and 1998.

As indicated in *Table 4.7.2*, a common impact of low water conditions endured by six surveyed marinas in the North Channel region was a reduction of useable slips. Five marinas reported problems with docks and boat ramp access; four marinas indicated inadequate channel depths; and three marinas reported an increase in aquatic weeds. The ceasing of operation, a shortened boating season and dry rot of wooden structures was experienced by one marina.

Table 4.7.2 Experienced Impacts during Low Water Levels

Experienced Impacts of Low Water Levels	Total Number of Marinas Impacted n=11
Inadequate channel depths	4
Problems with docks and berth access	5
Problems with boat ramp access	5
Reduction of usable slips or berths	6
Ceasing of operation	1
Shorter boating season	1
Reduced demand for winter storage	0
Dry rot of wooden structures	1
Increased aquatic weed growth	3

In response to the low water conditions *(Refer to Table 4.7.3)*, six surveyed marinas had to dredge, restrict large draft boats and adjust docks to new levels; five closed slips, shifted boats and constructed new adjustable floating docks. One impacted marina was forced to replace structures due to dry rot and close the marina entirely.

Of the 11 marinas surveyed, eight responded ‘yes’ and three responded ‘no’ when being asked if they have experienced low water conditions that have negatively impacted their business. Six of the impacted marinas indicated they received government assistance during low water conditions and two marinas stated they did not. Of the six subsidized marinas, five reported the funding as ‘very effective’ and one identified it as ‘moderately effective’. All six marinas that were compensated returned to normal operations.

Table 4.7.3 Measures of Adaptation

Measures of Adaptation Used During Low Water Levels	Total Number of Participating Marinas n=11
Dredging	6
Closing of Slips	5
Closing of Channels	0
Restriction to smaller and shallower draft boats	6
Adjust docks to new water levels	6
Have had to shift boats within marina	5
Construction of adjustable floating docks	5
Replacement of structures due to dry rot	1
Closure of marina	1

As *Table 4.7.4* suggests, two of the 11 marinas surveyed in the North Channel indicated that current water levels were interfering with normal operations. Six surveyed marinas stated that if water levels in their location declined from 0.15 to 0.30 m, operations would be disrupted. If water levels declined 0.31 to 0.60 m, two of the surveyed marinas indicated their critical minimum depth would be reached. One marina reported that depths within their location would have to decline over 0.6 m before normal operations were impacted.

Table 4.7.4 Critical Minimum Depths

Critical Minimum Depths that Would Prevent Operation (m)	Total Number of Marinas n=11
Current Levels	2
Loss of 0.15 to 0.30	6
Loss of 0.31 to 0.6	2
Loss > 0.6	1

Climate Change and Potential Water Level Scenarios

Ten of the 11 surveyed operators responded ‘yes’ and one operator replied ‘no’ when asked “Have water levels in your location been impacted by recent warm winters and prolonged ice free conditions?”. When asked “Are you concerned that conditions could get worse because of climate change?”, seven operators said ‘yes’, one answered ‘no’ and the remaining three operators were ‘uncertain’.

The responses for potential water level reduction scenarios generated by climate change are recorded in *Table 4.7.5*.

Scenario 1: The first scenario introduced to the surveyed marina operators of the North Channel was a potential water level reduction of 0.3 m. From the 11 surveyed operators, two reported no impacts and two indicated closure. Of the seven remaining operators who did not indicated closure or no impacts, six stated they would implement boat restrictions and lose slips, while two said they would start to dredge.

Scenario 2: The second scenario was a potential water level reduction of 0.45 m. From the 11 surveyed operators, one indicated no impacts and a notable four reported closure. Of the six remaining operators, six stated they would implement boat restrictions; four would lose slips; and one said they would start to dredge.

Scenario 3: The third scenario was a potential water level reduction of 0.6 m. From the 11 surveyed operators, notably seven indicated closure. Of the four remaining operators, four said they would implement boat restrictions and lose slips.

Table 4.7.5 Hypothetical Scenarios and Potential Implications

North Channel marinas that may experience following implications under scenarios of water level reduction		**Water Level Scenarios**		
		One (-0.3m)	**Two (-0.45m)**	**Three (-0.6m)**
		n=11		
Potential Implications	**No Impact**	2	1	0
	Closure	2	4	7
	n = 10 - (No Impact + Closure)	**n= 7**	**n= 6**	**n= 4**
	Slip Loss	6	4	4
	Boat Restrictions	6	6	4
	Dredge	2	1	0

Of the 11 surveyed operators, six operators answered ‘yes’ for measures that will regulate Lake Huron water levels and one answered ‘no’. The remaining four surveyed operators were ‘uncertain’. Of the six operators who answered ‘yes’, three operators suggested that the U.S. diversions and consumption rates be regulated, while an additional three recommended to Lake Huron’s outflow be regulated.

4.8 Summary of Lake Huron Canadian Marina Survey Results

Background information for marinas of Lake Huron

The 58 OMOA registered Lake Huron marinas for which an operator was surveyed during the 2007 season accommodated 8974 slips. A total of 7199 (80.2%) slips were rented during the 2007 season at the surveyed locations and 5521 (61.5%) of the slips were categorized as floating docks.

Of the 58 operators surveyed on the Lake Huron Canadian coastline, 39 (67%) reported receiving customers from the GTA, London Middlesex and Tri-city Area. A total of 28 (48%) of the surveyed locations confirmed servicing customers from the U.S.A. and 24 (41%) confirmed servicing customers from the local area. Only three (5%) marinas reported servicing international customers.

A total of 27 (46%) marina operators on the Canadian Lake Huron coastline indicated their docking season extended from May to October, while 22 (38%) marinas stated their season was from May to November. Only nine (16%) marinas reported a shorter season from May to September.

Of the 58 marinas, 23 (40%) reported that they could accommodate a maximum boat draft of 1.0 to 1.9 m. A total of 21 (36%) marinas stated that they could accommodate a maximum draft of 2.0 to 2.9 m and the remaining 14 (24%) indicated a maximum draft acceptability greater than 3.0 m in depth.

A total of 26 (45%) marinas indicated the presence of sand and silt in their marina's bottom material; additionally, eight (14%) reported gravel, while 17 (29%) stated clay. Overall, of the 58 surveyed Lake Huron marinas, 13 (22%) locations were established on rock.

The average number of years in which most surveyed marinas had been established on the Lake Huron coastline was 35 and the average number of years in which surveyed operators had worked at the facilities was 13 *(Refer to Table 4.8.1).*

Table 4.8.1 Average Years of Operation and Employment

Average Number of Years Surveyed Marina Operations have been Opened	Average Number of Working Years for Surveyed Operators
35	13
Pertaining to year of Survey (2007)	
1972	1994

Historical Water Levels, Impacts and Adaptations

Of the 58 surveyed marinas, three (5%) were negatively impacted due to low water prior to 1996; two (3%) were impacted throughout 1996; four (7%) were impacted during 1997; and five (9%) were negatively impacted through the 1998 season. Following 1998, impact incidence began to rise: during the 1999 season, nine (16%) were negatively influenced; 17 (29%) marinas were impacted in 2000; ten (17%) marinas were negatively influenced in 2001; and seven (12%) marinas experienced the repercussions of low water levels in 2002. Throughout the 2003 and 2004 seasons, eight (14%) sites reported being negatively impacted. An increase of 11 (19%) marinas were negatively influenced throughout 2005 and eight (14%) were again impacted in 2006. At the time of the surveys, 14 (24%) of the 58 marina operators confirmed being negatively impacted by low water conditions for that season *(Refer to Table 4.8.2)*.

During periods of low water conditions in Lake Huron, 28 of the 58 (48%) surveyed marinas experienced a reduction of usable slips and 25 (43%) had problems with dock and berth access along with increased aquatic weed growth within their marina's perimeter. In addition, 25 (43%) reported problems with their boat ramp access and 23 (40%) declared inadequate channel depths as a result of low water conditions. Also, ten (17%) of the surveyed marinas experienced dry rot of wooden structures and three (5%) marinas claimed they experienced a reduced demand for winter storage. Of the entire Canadian Lake Huron coastline, five (9%) of the surveyed marinas experienced a shorter boating season and were required to cease operations during low water conditions *(Refer to Table 4.8.3)*.

In order to adapt to low water conditions on the Lake Huron Canadian coastline, *Table 4.8.4* indicates that 36 (62%) marinas were obligated to dredge between 1996 and 2007 in order to adapt to low water levels. Additionally, 25 (43%) of the surveyed locations were forced to adjust docks to new water levels, while 23 had to shift boats around their marina's perimeter. A total of 22 (38%) surveyed marinas were forced to set boat restrictions during low water conditions, 16 (28%) had to close slips, 17 (29%) had to construct new adjustable floating docks and seven (12%) were required to replace structures due to dry rot. Overall, one (2%) marina reported closure of the channel and marina as their best adaptable measure during low water conditions between 1996 and 2007.

Of the 58 surveyed marinas on the Lake Huron Canadian shoreline, 36 (62%) reported that their business was financially impacted during low water conditions from 1996 to 2007. In addition, 22 received government assistance during low water conditions between 1996 and 2007. Overall, 15 of the marinas that received the funding reported it as 'very effective', while the remaining seven operators stated that it was 'moderately effective'.

Nine surveyed operators on the Lake Huron Canadian coastline confirmed that the current levels during the 2007 season generated critical minimum depths preventing normal marina operations. The remaining: 21 surveyed marinas affirmed that a water reduction of 0.15 to 0.3 m within their location would prevent normal operations; ten declared a loss of 0.31 to 0.6 m would prevent operations; and 18 marinas stated that a loss greater than 0.6 m within their location would impact normal operations.

Table 4.8.2 Years Lake Huron Marina Operators Reported Impacts Due to Low Water Levels

Lake Huron's Canadian Coastal Regions	Total Number of Marinas												
	<1996	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
South-eastern Lake Huron Ridge	1	0	0	0	0	2	1	1	2	2	2	2	2
Eastern Bruce Peninsula	0	0	0	0	1	0	0	0	0	0	1	0	2
Eastern Georgian Bay	1	0	0	0	1	2	0	0	1	0	0	0	1
Severn Sound Inlet	0	0	2	3	4	8	4	2	1	1	2	2	2
Parry Sound Inlet	1	1	1	1	1	1	1	1	1	1	1	1	2
North Channel	0	1	1	1	2	4	4	3	3	4	5	3	5
Total	**3**	**2**	**4**	**5**	**9**	**17**	**10**	**7**	**8**	**8**	**11**	**8**	**14**
% of surveyed marinas impacted	5%	3%	7%	9%	16%	29%	17%	12%	14%	14%	19%	14%	24%

Table 4.8.3 Implications Lake Huron Marina Operators Experienced During Periods of Low Water Levels (1998 to 2007)

Lake Huron's Canadian Coastal Regions	Total Number of Marinas								
	Inadequate channel depths	Problems with docks and berth access	Problems with boat ramp access	Reduction of usable slips or berths	Ceasing of operation	Shorter boating season	Reduced demand for winter storage	Dry rot of wooden structures	Increased aquatic weed growth
South-eastern Lake Huron Ridge	8	4	5	2	1	1	0	2	5
Eastern Bruce Peninsula	3	2	0	2	0	0	0	1	4
Eastern Georgian Bay	3	5	4	5	0	1	1	1	5
Severn Sound Inlet	4	9	8	11	2	1	0	3	9
Parry Sound Inlet	1	1	3	2	1	1	2	2	3
North Channel	4	5	5	6	1	1	0	1	3
Total	**23**	**26**	**25**	**28**	**5**	**5**	**3**	**10**	**29**
% of surveyed marinas which experienced listed impacts due to low water conditions	40%	45%	43%	48%	9%	9%	5%	17%	50%

Table 4.8.4 Measures of Adaptation Lake Huron Marina Operators Used During Periods of Low Water Levels (1998 to 2007)

Lake Huron's Canadian Coastal Regions	Total Number of Marinas								
	Dredging	Closure of slips	Closure of channel	Boat restrictions	Adjust docks to new water levels	Have had to shift boats within marina	Construction of new adjustable floating docks	Replacement of structures due to dry rot	Closure of marina
South-eastern Lake Huron Ridge	9	2	0	2	2	1	1	1	0
Eastern Bruce Peninsula	4	1	0	2	2	3	0	0	0
Eastern Georgian Bay	3	2	1	3	4	4	3	1	0
Severn Sound Inlet	13	5	0	8	9	9	6	2	0
Parry Sound Inlet	1	1	0	1	2	1	2	2	0
North Channel	6	5	0	6	6	5	5	1	1
Total	**36**	**16**	**1**	**22**	**25**	**23**	**17**	**7**	**1**
% of surveyed marinas which have been obligated to use listed adaptive measures	62%	28%	2%	38%	43%	40%	29%	12%	2%

Climate Change and Potential Water Level Scenarios

As indicated in *Table 4.8.5*, a total of 45 surveyed operators on the Lake Huron Canadian coastline responded 'yes' and seven replied 'no' when asked, "if recent warm winters and prolonged ice free conditions have impacted water levels within their location". The remaining five were 'uncertain'. *Table 4.8.6* indicates that 39 of the 58 surveyed operators responded 'yes' and eight answered 'no' when asked, "Are you concerned conditions could get worse because of climate change?". The remaining ten surveyed marinas replied 'uncertain' when asked this question.

Table 4.8.5 Operators Response Rate to Question 16

Lake Huron's Canadian Coastal Regions	Yes	No	Uncertain
South-eastern Lake Huron Ridge	7	1	2
Eastern Bruce Peninsula	5	1	1
Eastern Georgian Bay	4	2	1
Severn Sound Inlet	15	1	1
Parry Sound Inlet	4	1	0
North Channel	10	1	0
Total	**45**	**7**	**5**
% of surveyed operators answered	78%	12%	9%

Table 4.8.6 Operators Response Rate to Question 17

Lake Huron's Canadian Coastal Regions	Yes	No	Uncertain
South-eastern Lake Huron Ridge	4	3	3
Eastern Bruce Peninsula	4	2	1
Eastern Georgian Bay	6	1	0
Severn Sound Inlet	14	1	2
Parry Sound Inlet	4	0	1
North Channel	7	1	3
Total	**39**	**8**	**10**
% of surveyed operators answered	67%	14%	17%

Responses for potential water level reduction scenarios generated by climate change are as follows:

Scenario 1: The first scenario (*Refer to Table 4.8.1)* introduced to the surveyed marina operators was a potential water level reduction of 0.3 m. Of the 58 surveyed marinas, ten (17%) reported no impacts following a scenario one water level reduction and eight (14%) proposed closure. From the remaining 40 marinas that would not experience impacts or closure, 17 (29%) reported they would start dredging, and 19 (33%) marinas indicated slip loss and post boat restrictions.

Scenario 2: The second scenario (*Refer to Table 4.8.2)* introduced to the surveyed marina operators was a potential water level reduction of 0.45 m. Of the 58 surveyed marinas seven (12%) claimed no impacts would occur and 17 (29%) declared closure. From the remaining 34 marinas, 22 reported they would start to dredge; 20 (34%) indicated that they would need to implement boat restrictions and 21 (36%) reported slip loss.

Scenario 3: The third scenario (*Refer to Table 4.8.3 for results)* introduced to the surveyed marina operators was a potential water level reduction of 0.6 m. Of the 58 surveyed marinas, three (5%) indicated no impacts, while 24 (41%) notably reported closure. From the remaining 31 marinas, 22 (38%) stated they would start to dredge, 20 (34%) affirmed slip loss and 17 (29%) locations indicated they would implement boat restrictions.

Table 4.8.7 Lake Huron's Hypothetical Scenario 1 and Potential Implications

Surveyed marinas that may experience listed impacts following **Scenario One** water level reductions	**Potential Impacts**				
	No Impact	**Closure**	**Slip Loss**	**Boat Restrictions**	Dredging
	n=58		[n = 58 – (10+8)] **n=40**		
Total	10 (17%)	8 (14%)	19	19	17

Table 4.8.8 Lake Huron's Hypothetical Scenario 2 and Potential Implications

Surveyed marinas that may experience listed impacts following **Scenario Two** water level reductions	**Potential Impacts**				
	No Impact	**Closure**	**Slip Loss**	**Boat Restrictions**	**Dredging**
	n=58		[n = 58 – (7+17)] **n=34**		
Total	7 (12%)	17 (29%)	21	20	22

Table 4.8.9 Lake Huron's Hypothetical Scenario 3 and Potential Implications

Surveyed marinas that may experience listed impacts following **Scenario Three** water level reductions	**Potential Impacts**				
	No Impact	**Closure**	**Slip Loss**	**Boat Restrictions**	**Dredging**
	n=58		[n = 58 – (3+24)] **n=31**		
Total	3 (5%)	24 (41%)	20	17	22

4.9 Summary of Bathymetry and Water Depth Analysis

Of the 58 surveyed marina locations, 11 marinas were measured for depth analysis using the Eagle FishElite sonar device (*Refer to Figures 3.4.1 – 3.4.3)*. The 11 sampled marinas are listed in *Table 4.9.1* including their average boat bay perimeter depths taken by the sonar device. Detailed maps, including sonar readings of each marina included in the water depth analysis are illustrated in Appendix Two, Figures A to L. *Table 4.9.1* also includes a comparison of the average water depths recorded in the questionnaire with the average depths derived by the sonar measurements.

Overall, the average depths reported by the marina operators were largely confirmed by the sonar depth measurements. The majority of depths differ from 0.1m to 0.2m. These differences can be a result of, inconsistent sonar measurements, differing dates of the questionnaire and sonar depth analysis, and lastly wind direction and wave action.

Table 4.9.1: Comparison of sonar depth measurements and marina operators questionnaire

Appendix 3 Figure Listing	Lake Huron Marinas Surveyed for Water Depth Analysis	Average Depths of Sonar Measurements (m)	Average Depths Reported in Questionnaire (m)	Difference between Sonar and Questionnaire Measurements (m)
A)	Tobermory Marina	3.5	3.7	-0.2
B)	Bruce Mines	1.8	1.9 - 2.0	-0.1
C)	Grand Bend Harbour	1.6	1.8	-0.2
D)	Bayfield Marina	2.8	2.3	0.5
E)	South Shore Marina	1.2	1.8	-0.6
F)	Owen Sound Marina	2.3	0.9-2.1	0.2
G)	Meaford Harbour	3.5	3.2	0.3
H)	Cliff Richardson's	1.6	1.5	0.1
I)	Gore Bay Marina	4	3.8	0.2
J)	Kincardine Municipal Marina	2.3	2.1	0.2
K)	Port Elgin Harbour	2.7	2.5	0.2

5.0 IMPLICATIONS OF CLIMATE CHANGE FOR LAKE HURON CANADIAN MARINA OPERATIONS

Based on the results of the marina operators' questionnaire (*Refer to Section 4*), the resulting effects of recent Lake Huron water declines have negatively influenced the majority of Canadian lakeside marina facilities. The results also indicate that projected lake water levels, as a result of climate change, have the ability to negatively impact and potentially close some marina facilities along this shoreline. This could lead to a decreasing supply of marina services and infrastructure that may offset Lake Huron's demand for recreational boating. This in turn, may reduce the industry's economic contribution to the Ontario tourism sector. The following section will outline the pivotal role climate change could have on Canadian Lake Huron marina operations and further discuss climate change-related issues that are common across all regions. Additionally, future climatic scenarios of Lake Huron water level reductions will be investigated and the reactions of surveyed operators towards potential future water level declines will be discussed.

5.1 Perceptions towards climate change in Lake Huron

The results of the marina operator's questionnaire indicated that a minority of the surveyed population was sceptical of the processes of climate change and its potential implications for Lake Huron water levels and marina operations. When asked if, "recent warm winters and prolonged ice free conditions have impacted water levels within their location", 45 of the 58 (78%) respondents replied 'yes'. Additionally, when asked if, "they were concerned that conditions of warm winters, prolonged ice free conditions and reduced water levels could intensify as a result of 'climate change' ", a majority of 39 (67%) respondents, replied 'yes' while five were 'uncertain' and one answered 'no'.

Although the majority of the surveyed population were aware of the implications climate change may have for their lakeside businesses, 88% still confirmed that, "they would like measures that would regulate Lake Huron water levels". A total of 38% stated that infrastructure is needed at the mouth of the St. Clair River to better regulate Lake Huron's outflow and 14% claimed that better management practices are needed in the Chicago Illinois River diversion which drains from Lake Michigan. The remaining 36% of the surveyed operators who responded 'yes' to the introduction of measures that would regulate Lake Huron water levels or remained uncertain as to where and how measures would succeed.

5.2 Implications of low water conditions from 1998 to 2007 for Lake Huron's Canadian coastal marina operations

As illustrated in *Figure 5.2.1*, following a rapid increase in annual average surface water temperatures during 1998, Lake Huron's water levels responded by, declining 0.75m by 2000. As a result, 17 of the 58 (29%) surveyed Canadian Lake Huron coastal marinas reported that they had been impacted by the low water conditions during the 2000 boating season (*Refer to Figure 5.2.2*). Implications upon Canadian Lake Huron marina operation were continually demonstrated until 2007 as lake surface temperatures remained above average and annual average water levels fluctuated 10cm above and below chart datum. From 1998 to 2007, 36 marinas experienced financial impacts as a result of low water levels and costly measures of adaptation.

Some of the marinas experienced reoccurring effects from low water between 1998 and 2007 due to their geographical location upon the Lake's shoreline *(Refer to Figure 5.2.3)*. Lake Huron's variety of shoreline gradients and differing lake-bed material affect the Lake's coastal environments differently during low water conditions.

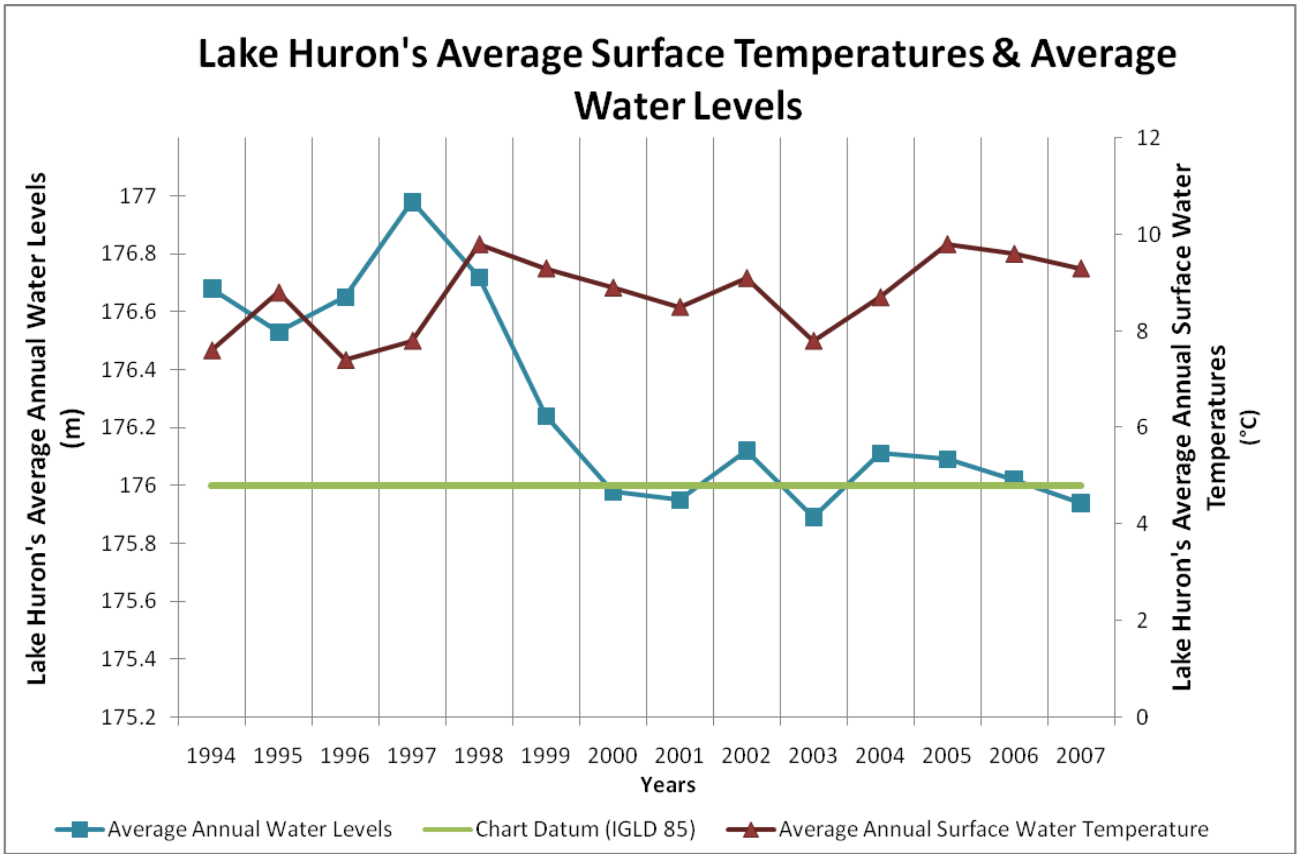


Figure 5.2.1: Depicts Lake Huron's average surface temperature and water levels from 1994 to 2007 (Source: COE 2007)

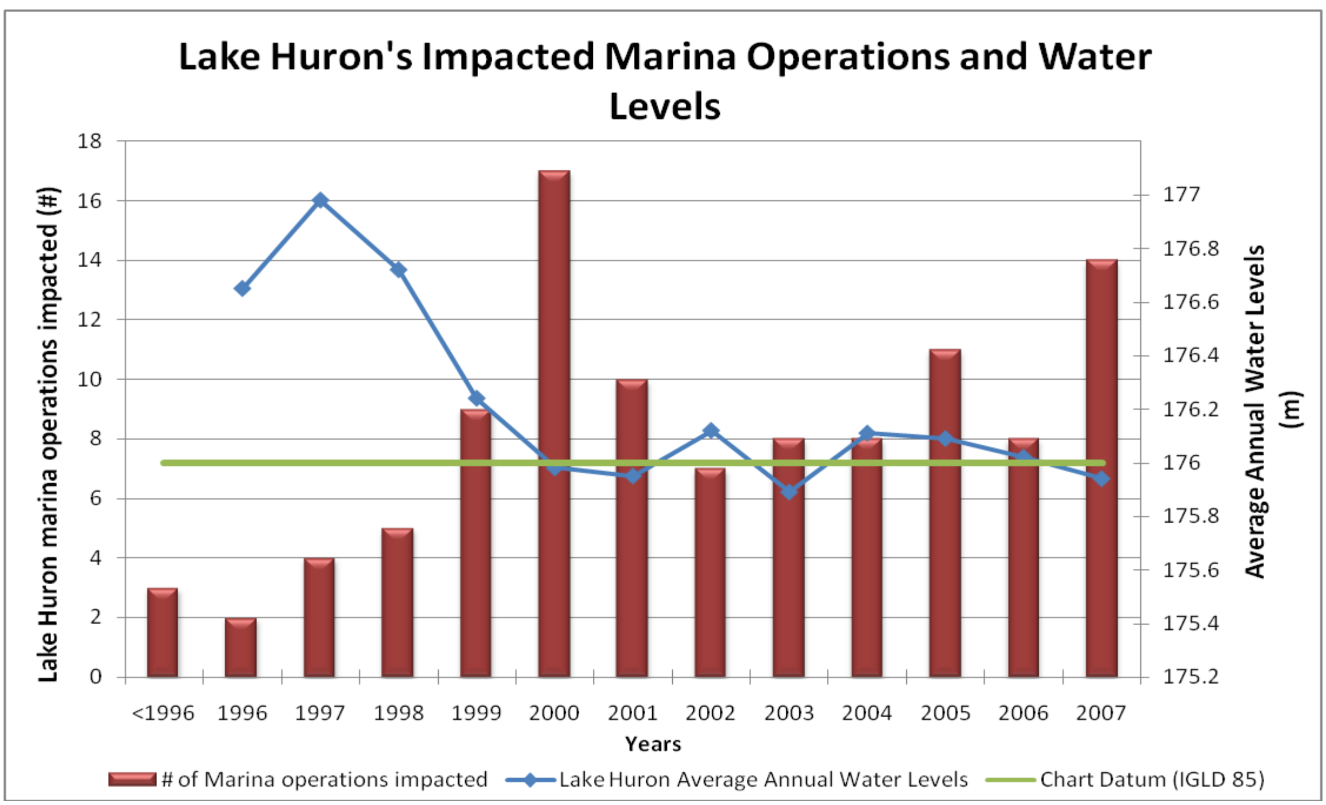


Figure 5.2.2: Illustrates Canadian Lake Huron marina operators impacted by low water from 1996 to 2007

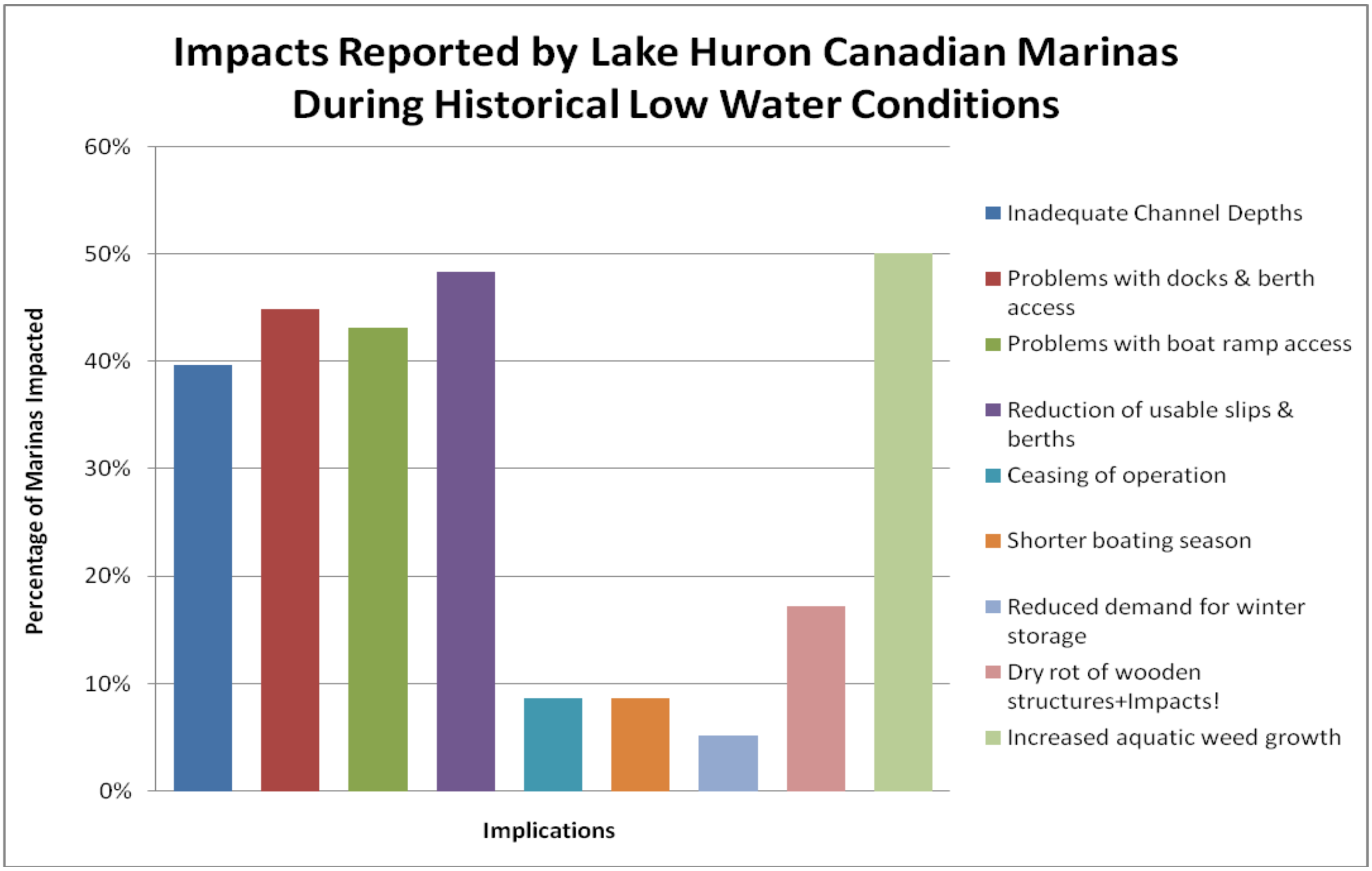


Figure 5.2.3: Implications endured by Canadian Lake Huron marina operations from 1996 to 2007

<u>Reduction of useable slips and problems with boat ramp, dock and berth access</u>

During Lake Huron's average water level decline from 1998 to 2007 common implications that were experienced by the surveyed marinas were a reduction of useable of slips (48%); problems with boat ramp access (43%); and problems with dock and berth access (45%). Although these implications were a common impact for 25 of surveyed facilities, each was experienced differently.

Lake Huron's entire North Channel is located upon the Canadian Shield and over half (six marinas) of the operators surveyed in the region reported the presence of bedrock within their marina's perimeter. Similarly, four marinas in the Eastern Georgian Bay region and three in the Severn Sound Inlet are also had Shield bedrock. Dredging within these areas is commonly completed to remove layers of fine silts and sands to reduce slip loss and boat restrictions. However, extensive water level declines in Lake Huron have proven to additionally involve bedrock 'blasting' with heavy explosives.

In conjunction with initial dredging costs, blasting and removal of bedrock material is an additional expense which deters marina operators from pursuing this as an adaptive measure to overcome reduction of slips and problems with dock and boat ramp access.

The Severn Sound Inlet primarily reported reduced slip usability and problems with boat ramp and dock access due to water level declines resulting from shallow bathymetric conditions and seiche-induced currents. Comparable to much of the eastern Georgian Bay coastline, the basin of the Severn Sound Inlet has a shallow bathymetry and is extremely susceptible to overall lake water declines. Average water level declines in Lake Huron can remove a great magnitude of water from the Inlets shallow basin. Moreover, seiche-induced currents also have the tendency to withdraw large quantities of water from the region.

A strong west wind can temporarily raise water levels along the eastern Georgian Bay coast, thrusting water currents into the Severn Inlet. Conversely, a strong east wind can withdraw water from the Inlet and cause levels in the region to decline. Thus, reductions of water in the inlet due to average Lake Huron water level declines and the additional seiche effects can cause dramatic temporary reductions. During previous low water conditions and high easterly winds, boat launch ramps and travel lifts have become inaccessible within the region, preventing boat removal services and regular operations within local marinas.

Inadequate Channel Depths

Lake Huron's South-eastern ridge marina operations' greatest effect was inadequate channel depths. This impact was experienced in this region as a result of coastal sedimentation. A large majority (90%) of the surveyed marinas in this region are located within watershed outlets that connect to Lake Huron (*Refer to Section 3*). The region's predominant wave direction is from the northwest (Reinders 1989, Lawrence & Davidson-Arnott 1997) and its primary sediment source is sand, deposited by post-glacial lakes thousands of years ago (R*efer to section 3*). On a net basis, the longshore current moves the sand and other nearshore sediments from the north to south. However, during the summer months, winds and waves tend to change direction and come from the southwest, altering longshore currents in northward direction. This has consequently led to estuary sedimentation (Reinders 1989, Lawrence & Davidson-Arnott 1997, LHCCC 1999). This process occurs when a watershed outlet, generally part of an extensive coastal system, traps traveling longshore sediment (commonly sand) in its opening between the estuary and lake or nearby sandbanks close to the entrance (Carter 1988). If wave action or ebb currents[4] are not strong enough to re-suspend and retract the concentrated sediment, additional sediment will continue to accumulate and block the estuaries entrance. The ramifications of estuary sedimentation further escalate as sediment from the adjoined watershed cumulates with concentrations at the entrance (Carter 1988).

As noted by a marina official in Grand Bend, Ontario, estuary sedimentation has long been occurring on the South-eastern Lake Huron ridge. For the past 30 years, to avoid dredging applications and cost, the Grand Bend marina, situated on the mouth of the Ausable River, has been 'blowing sediment' within its channel (*Refer to Appendix Three, Figure C*). This process requires a boat with an underwater plough controlled by a hydraulic shaft, which grades the lakebed sediment in the channel to adequate depths. Taking into consideration that the lakebed material is only being pushed or 'blown' to either side of the channel, dredging permits and applications are not required. This procedure has also been carried out at other neighbouring community marinas, such as in Bayfield, Ontario. Estuary sedimentation on the South-eastern Lake Huron ridge was amplified throughout low water conditions from 1998 to 2007. As water levels declined, large concentrations of sand were quickly deposited at the entrance of many estuaries on the South-eastern ridge. The low water levels could not provide

[4] Ebb current is a tidal current associated with tide that is flowing out from shore or causing a lower water level (Carter 1988).

sufficient tidal currents to reduce the sand concentrations, by generating navigational hazards within local marina channels. Towards the end of the boating season of 2007, it was reported that a $250,000 yacht grounded at the Bayfield marina entrance. Damages to the yacht were substantial and lawsuits were filed against the marina for improper depth analysis.

Ceasing of Operation, Shorter Boating Seasons and Reduced Demand of Winter Storage

The three implications of reduced demand for winter storage (3%), shorter boating season (9%) and ceasing of operation (9%) were experienced infrequently by the surveyed marinas on the Canadian Lake Huron coastline from 1998 to 2007. Although these implications were least experienced they can accumulate to be the most costly throughout low lake water conditions.

Surveyed marina operators who were forced to cease operations did so as result of insufficient water depths or the need for urgent remedial actions (i.e., dredging and dock adjustments). Ceasing of marina operations protects customers and potentially avoids lawsuits, but it prevents service and revenue.

A shortened boating season was experienced by some of the surveyed Lake Huron operators due to annual low water conditions consistent with seasonal water level fluctuations. Throughout the fall season, Lake Huron’s water levels commonly decline prior to ice coverage. However, in combination with low water conditions, some marina operators were forced to extract boats at an early date to prevent damage. A shortened boating season was experienced by 9% of the surveyed marinas from 1998 to 2007. Considering that 84% of the surveyed operators remove their boats between the months of October and November, reduced boating seasons can cause significant economic ramifications on the Canadian boating industry.

Although a reduced demand for winter storage was only experienced by a total of three surveyed marinas, it is still viewed as a serious impact. Many of the marinas included in the study provided the service of boat extraction and winter storage at their location. Therefore, a decline in water levels may persuade clients to pursue other marina locations for service, in turn, reducing the demand for winter storage services and clientele for the next boating season.

Dry Rot of Wooden Structures

Although wooden dry rot was not experienced at many of the surveyed marinas (17%), it did occur at all study regions located on the Canadian Lake Huron coastline. This impact was most problematic in the now old marina facilities on the Canadian Lake Huron coast which contained aged wood that has been previously preserved by adequate water levels. A total of seven surveyed marinas confirmed that they would have to replace structures due to dry rot and low water levels. The remedial aftermath to repair these structures can be expensive and time consuming. An example of this was observed at Tobermory's municipal marina. Although depths were sufficient for boat docking and loading within the bay area of the municipal marina, low water conditions demonstrated the impacts of dry rot decay on the marinas boardwalk. The decomposed structure caused concern and was assessed in 2007 (*Refer to Figure 5.2.4*)

Increased Aquatic Weed Growth

The implication experienced by half of the surveyed Canadian Lake Huron marina operators, was an aggressive increase of aquatic vegetation within their boat bay areas. As a result of low water levels in conjunction with increased water temperatures, Lake Huron's Canadian coastal margins provide suitable conditions for increased aquatic vegetation growth. Regions on the Canadian coastline with shallow and gently sloped shores, such as Lake Huron's Canadian South-eastern ridge, Severn Sound Inlet and sections of the Eastern Georgian Bay, were most prone to enhanced growth from 1998 to 2007. Operators of marinas within deep bathymetry, such as Eastern Bruce Peninsula and the Parry

Sound Inlet, stated that aquatic vegetation growth had started to become most recognized during this timeframe; however, it had not become a viable threat to normal operations.

Excessive aquatic weed growth within marina perim proves to have an impact on operations by obstructing boat propellers, preventing the use of boating slips and channels, while further covering navigational hazards. In addition, aquatic vegetation diminishes the aesthetic value of marina operations by reducing water visibility and increasing odours. As indicated by the Canadian Environmental Assessment Agency (2007), the municipal marinas of Port Elgin and Meaford proposed for the removal of aquatic vegetation in their facilities to return operations to normal. Aquatic weed extraction is completed by methods of harvesting and submersible herbicides.

Figure 5.2.4: Illustrations of dry rot
Photograph by Jordan Stewart

5.2.1 Summary of Regional Impacts

Following the completion of the 2007 marina operator's questionnaire, it was evident that impacts resulting from past low water conditions were most predominantly experienced within regions of the Lake with shallow and gently sloping shorelines (South-eastern Lake Huron Ridge, Eastern Georgian Bay, Severn Sound Inlet and sections of the North Channel). Marinas in areas with sufficient water depths (Eastern Bruce Peninsula, Parry Sound Inlet and sections of the North Channel) experienced impacts, but to a lesser degree. Nevertheless, marina operators within all regions of the Canadian Lake Huron coastline claimed the underwent measures of adaptation in order to preserve services and their economic livelihood.

Measures of Adaptation

Beyond the adaptation measures of sediment blowing and cultivation of aquatic weeds, various marinas on the Canadian Lake Huron coastline were required to take measures between 1998 and 2007 to prevent further business loss or closure. Measures taken by the surveyed population during the 1998 to 2007 period involved the adjustment of docks to new water levels (43%) and the reconstruction of new adjustable floating docks (29%). The rebuilding and adjustments of docking systems proved to be costly and time consuming for some locales and consequently forced 28% of the surveyed marinas to close slips. Other measures used during low water conditions were boat restrictions (38%) and shifting boats within their marinas perimeter (40%). The most commonly used adaptation by the surveyed populace was dredging. A total of 36 operators (62% of the surveyed) confirmed that they had dredged between 1998 and 2007 in order to pursue regular operations at their facility.

Although temporarily effective, current adaptation measures used for low water conditions are anticipated to be insufficient for future water level declines associated with climate change. Projected water level reductions in Lake Huron resulting from climate change are expected to far exceed low levels attained between 1998 and 2007. The majority of the surveyed population were able to forecast amplified implications at their locations that would occur resulting from anticipated water level declines.

5.3 Future implications of projected climate change trends for Lake Huron's Canadian coastal marina operations

5.3.1 Services

A total of 30 surveyed operators (52%) confirmed that a reduction exceeding Lake Huron's chart datum water level of 0.15 to 0.3m would prevent their normal marina services by restricting the use of some equipment and damaging surrounding infrastructure. Much of Lake Huron's marina infrastructure and equipment was designed for lake levels above chart datum. Surveyed operators of all study regions confirmed that equipment regularly used within their facilities would be challenged by lake level reductions below chart datum. For instance, low water conditions have the potential to restrict boats from approaching gas dock areas. During low water conditions from 1998 to 2007, some marinas were required to extend gas lines, lengthen gas docks and dredge to prevent the closure of their gas bar. Marina operators anticipate that various gas bar services located on the Canadian Lake Huron coastline may become inoperable with projected low water trends as a result of climate change. Other marina services that require adequate water depths are loading ramps and travel lifts. Both are essential components, allowing marina facilities to launch and extract seasonal and non-seasonal boats. With future climatic trends and projected low lake water levels, various operators on the Canadian Lake Huron coastline anticipate losing this service. Already, this effect occurred at various surveyed sites during low water conditions between 1998 and 2007. Large draft boats (i.e., sail boats) could not approach boat launch ramp and travel lift areas as a result of insufficient water depths in the marina's perimeter. Customers were therefore required to relocate to other marina facilities.

5.3.2 Infrastructure

An example of Lake Huron marina infrastructure that is expected to undergo adverse implications following water level reductions as a result of climate change is sheet piling walls. Sheet piling walls are used to support and protect coastal land surrounding marina facilities. However, as exemplified through the 1998 to 2007 low water conditions, some walls were not designed for extended periods of water level reductions and consequently allowed shoreline soil to subside *(Refer to Figure 5.3.1)*. The results caused the protective walls to deform and become unstable. Further reductions could prevent the use of entire docking systems attached to sheet pile walls within boating bay areas.

The loss of useable slips due to low water conditions is projected to be the most significant implication as a result of climate change on Canadian Lake Huron marina infrastructure. With low water conditions, marina operators confirmed that boating slips would have to undergo reconstruction to appropriate water levels, relocation to deeper water or simply closure to prevent boat damage. Moreover, marinas that contain fixed docking systems will suffer the consequences of projected lake level trends as a result of climate change. Of the 8974 boating slips accounted for at the 58 surveyed sites, a total of 3453 slips (38%) were considered fixed docks and not adaptable to fluctuating water levels *(Refer to Figure 5.3.2)*. Although adaptable measures of extended ladders and adjoined floating docks can be used to accommodate low water conditions, dock accessibility will eventually become a problem as a result to climate change.

As global climate change unfolds, impacts on marina infrastructure and equipment will continue in all regions of the Lake Huron Canadian coastline. Some areas on the coastline may provide adequate water depths throughout low water conditions, but their

Figure 5.3.1: Subsiding sheet piling wall
Photograph by Jordan Stewart

a

b

Figure 5.3.2: Depicts fixed docks and low water conditions (a&b)
Photograph by Jordan Stewart

services may not be proportionate. As a result, boaters may be forced or choose to relocate in search of marinas with adequate services.

5.3.3 Boater Relocation & Reduced Expenditures

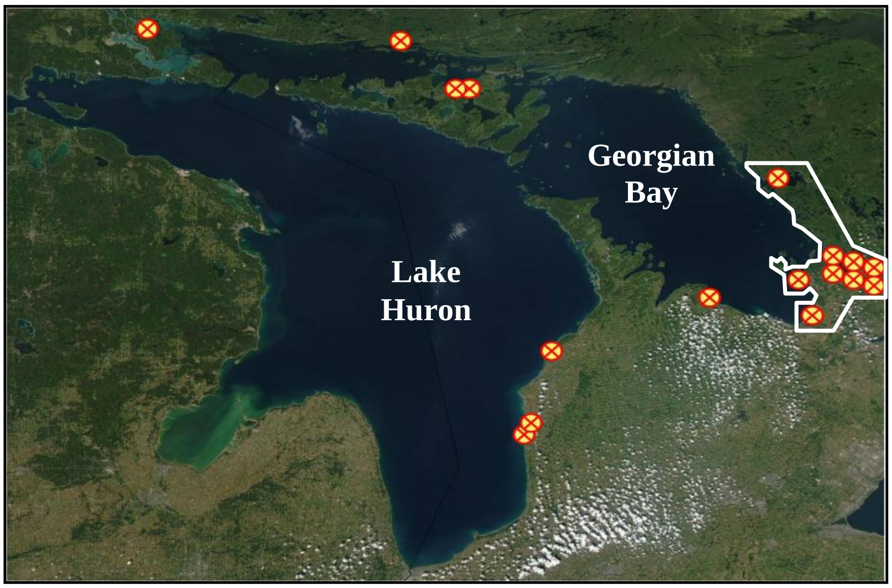
During periods of low water conditions in Lake Huron, boater relocation will negatively influence some lakeside marinas while benefiting facilities that maintain operational equipment and accessible infrastructure. Examples of this scenario are illustrated in *Appendix Three* using water depth analysis achieved by sonar sounding measurements. *Figures G and H of Appendix Three* depict the depths of two adjacent marinas located on Lake Huron's Eastern Bruce Peninsula shore in the municipality of Meaford, Ontario. The southerly marina is a privately owned operation, and at the time of the sounding survey, contained a total of 25 fixed boating slips and a shallow travel lift area of 1.3 to 1.5m in depth. The marina located north of the privately owned operation is Meaford's municipal harbour. At the time of the sounding survey, the municipal harbour contained 190 floating docks, an average boat launch ramp depth of 2.2m, and an adequate overall bay perimeter ranging from 2.0 to 4.0m in water depth. Under the circumstances of climate change, Meaford's municipal harbour may benefit from the initial low water conditions due to their adaptive docking system and lack of competitive business within the area. Sufficient water depths and adequate services during low water conditions are capable of swaying customer preferences. Various marina facilities located on the Canadian Lake Huron coastline may suffer the loss or prosper the gain of clientele as water levels decline as a result of climate change in Lake Huron (*Refer to Appendix Three, Figures D & E*).

The future implications of boater relocation were further illustrated when operators were asked to verify important implications that would transpire at their marina's location following three scenarios of lake water level reductions.

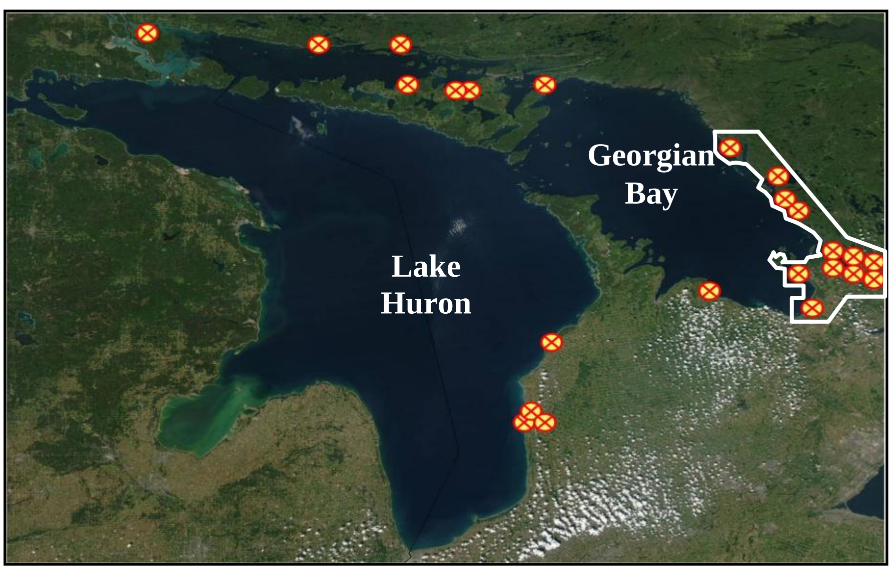
A lake water level decline of 0.3m exceeding average chart datum levels in all of the 58 surveyed Canadian Lake Huron marina operations could potentially cause 38% of the operations to undergo boat restrictions and 33% to lose slips. Overall, eight of the respondents on the Canadian Lake Huron coastline confirmed closure of their marina following a 0.3m water level reduction. A potential 0.45m water level decline, may force 34% of the respondents to post boat restrictions and 36% to experience slip loss. An additional nine operators declared closure following a 0.45m water level decline. A water leve decline of 0.6m may cause 29% of operations to restrict boats and 34% to lose slips. An additional 17 surveyed operators indicated closure following a decline of this magnitude. *Figure 5.3.3 (a, b & c)* depicts the number of Lake Huron surveyed marinas that confirmed closure for each suggested water level reduction scenario.

As depicted in *Figure 5.3.3*, the impacts of marina closures in all three suggested water level reduction scenarios in Lake Huron, is most commonly experienced in shore reaches with gradually sloping shorelines. These reductions appeared to be most pronounced on Lake Huron's Georgian Bay south-easterly coastline *(Outlined in Figure 5.3.3 a, b & c)*, which is comprised of the Severn Sound Inlet and Eastern Georgian Bay study regions. As a result of the two regions being close in proximity to the GTA, they accommodate high populations of cottagers and tourists from these areas which further support much of the surrounding marinas' clientele base *(Refer to Appendix Two, Table B)*. In 2007, the Severn Sound Inlet and Eastern Georgian Bay regions accounted for almost half (48%) of the registered OMOA docking slips on the Canadian Lake Huron coastline. Of the 24 surveyed marinas in the two regions, approximately 90% of their 4,094 boating slips were rented during the 2007 boating season. Consequently, the implications of slip loss and possible marina closures as a result of climate change on the south-eastern Georgian Bay coastline may generate important implications for the local economy.

a) Scenario One
0.3m water level decline



b) Scenario Two
0.45m water level decline



c) Scenario Three
0.6m water level decline

Figure 5.3.3: Illustrates marina closures following each water level reduction scenario (outlined areas indicate regions of concern) (Source: NASA 2007, modified by Jordan Stewart)

Adaptation measures the south-eastern Georgian Bay may use to prevent implications of climate change include expanding current infrastructure to greater depths of water, and constructing marinas in new locations. Physical restrictions, environmental regulations, and insufficient investments, as well as other factors, may prevent the implementation of adaptation measures. If so, the south-eastern Georgian Bay could suffer substantial revenue losses as boaters relocate to marinas in other areas of the lake. To further illustrate the economic loss these two regions could experience as result of climate change, quantities of slip loss and reduced boater expenditures are estimated below.

Average Slip Occupant Expenditures

According to the Great Lakes Commission (2007), common boat sizes on the Lakes range from 4.0 m to 7.0 m (16ft to 24ft). Using this average boat size, costs of a seasonal docking package were derived by averaging the annual rates of 15 surveyed marinas on the Canadian Lake Huron coastline. Seasonal docking packages include the services of summer dockage, dockside hydro, water, pumpouts, launch and haul, winter storage and parking. On average, the seasonal docking package for a 7m boat at a marina located on the Canadian Lake Huron coastline was valued at approximately $1,600. In addition, as discussed in Chapter 3, an on-line assessment completed by Michigan State University's RMRC National Boater Panel in 2000 estimated that American Great Lake boat owners spend approximately US$ 2,200 (CDN$ 2,600) on average per year in boating trips alone. Expenditures of a boat trip include gas, oil, food and lodgings. By integrating these two expenditures, it is estimated that an average of CDN$4,200 per year in boat and marina expenditures is spent per slip.

Scenario One – 0.3m water level reduction in Lake Huron

A potential 0.3m water level decline has the potential to close three marinas in the Severn Sound Inlet and Eastern Georgian Bay regions, accounting for the loss of 376 recreational boating slips. The estimated average annual expenditure of $4,200 per slip occupant has the potential to reduce boat related expenditures in the two regions by $1.6 million per year.

Scenario Two – 0.45m water level reduction in Lake Huron

A water level reduction of 0.45m, has the potential to close an additional six marinas in the two eastern Georgian Bay regions, accounting for the loss of 1,141 recreational boating slips. This could potentially account for an annual loss of $4.8 million per year.

Scenario Three – 0.6m water level reduction in Lake Huron

A water level decline of 0.6m, has the potential to close an additional three marinas, accounting for loss of 1,498 recreational slips in the two regions. This reduction could conceivably deprive the eastern Georgian Bay by as much as $6.3 million per year.

These values represent estimated losses for the surveyed marina locations and nearby communities which claimed closure following the three suggested water level decline scenarios. Projected figures of revenue loss for these two regions of Georgian Bay have the potential to surpass these estimated values throughout the three implied scenarios of water level decline. Marina operators on the south-easterly coastline of the Georgian Bay that indicated their facilities would not close following the three scenarios of water level decline reported they may experience slip loss. These operators were unable to precisely quantify the number of slips that would become inoperable under the three suggested scenarios. The marina operators questionnaire found, that ten of the 24 (42%) surveyed in the Severn Sound Inlet and Eastern Georgian Bay lakeside area confirmed slip loss for each scenario of water level decline. Such additional slip closures would further contribute to boating revenues lost under lower water level conditions.

Many factors must be taken into consideration when considering the potential outcome of lower water levels at the community level. Marinas with adequate services, sufficient depths and accessible slips may be may be available at other locations on the Lake Huron coastline. However, what remains uncertain is whether boaters from the eastern Georgian Bay and Severn Sound Inlet will travel to further marina destinations to utilize their boats and lose the convenience of marina access nearby to their cottage.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Overview

Since the 19th century, recreational boating in Lake Huron has been a significant economic and social activity in the region. Marina operations on the Lake Huron shoreline have long relied upon adequate water levels within the lake in order to facilitate and service the demands of recreational boating. However, as a result of global climate change in the 21st century, Lake Huron water levels are anticipated to decline (Mortsch *et al.* 2006). This in turn has some marina business owners questioning the sustainability of their operations under reduced water level scenarios.

Lake Huron's previous water level decline from 1998 to 2007 caused many marinas on the Lake's Canadian coastline to endure impacts. Various options of adaptation were used to respond to the reduction. Nonetheless, these measures are short-term methods that would ultimately be overcome by global climate change in the 21st century.

The purpose of this thesis is to understand how the potential impacts, challenges and opportunities of climate change in Lake Huron may significantly alter marina operations and thereby affect regional boat-based tourism and the provincial tourism sector. Four main research objectives were studied: (1) To explore marina operator's perceptions of the potential causes in recent (1998 to 2007) low water conditions within Lake Huron and the projected low water levels associated with future climate trends; (2) To examine Lake Huron marina operator's response to recent low water levels throughout 1998 to 2007 and generate a synopsis of future implications operators anticipate to endure throughout the expected events associated with climate change; (3) To explore the geographical distribution of Lake Huron marina operations and identify regional impacts, challenges and opportunities associated with water level reductions; and lastly (4) To investigate the quantity of slips and marinas that will not remain operational under hypothetical water level scenarios associated with climate change in the Lake Huron basin. Additionally, the repercussions of these hypothetical water level scenarios on Lake Huron's marina operations will determine the implications for boat-based tourism in Ontario.

6.1 Main Findings & Conclusion

6.1.1 Main Findings

A questionnaire was used to obtain information from marina operators located on the Canadian Lake Huron shoreline. A total of 58 operators responded. Answers were tallied and used to explore relationships between reduced lake water levels and the potential impacts on the Canadian Lake Huron shoreline marinas. Answers were reported as percentages.

In response to the first research objective, it was evident that most of the surveyed marina operators perceived the recent water level decline from 1998 to 2007 as a result of improper lake water governing. Although 78% of the surveyed operators confirmed that water levels from 1998 to 2007 were impacted by warm winters and prolonged ice free conditions, 88% speculated that low water conditions were a result of improper lake governing and many indicated that new measures are required to regulate the Lake's water levels. Thirty-four operators wanted either U.S. diversions to be more regulated or controlling structures to be introduced at the mouth of the St. Clair River to prevent further water level reductions.

In response to the second research objective, Lake Huron's average annual lake temperature rise of 2°C from 1997 to 1998 was simultaneously followed by an annual water level decline of 1.0m from 1997 to 2000. In turn, these events impacted a total of 17 surveyed marinas in 2000 and initiated the DFO's $15 million emergency dredging fund. The most common impacts endured by 45% to 50% of the surveyed marina populations throughout low water levels from 1998 to 2007 were problems with dock and berth access, a reduction of useable slips and an increase of aquatic weed growth within boat bay areas. The most common adaptive measure for these implications was dredging. A total of 62% of the surveyed marina operations pursued this practice.

A summary of future implications Lake Huron operators anticipate to endure through climate change and water level reductions involve marina services, impacted boat launching and extracting sites; marina infrastructure, extended loss of useable slips; and lastly, customer supply is anticipated to become more irregular at some facilities.

In response to the third research objective, negative impacts for each study region were indicated during low water conditions. Marina operations in Lake Huron's North Channel, parts of Eastern Georgian Bay and the Severn Sound Inlet regions are heavily exposed to granite bedrock. Low water conditions cause marinas in these locations to be challenged by their inability to dredge. This results in associated impacts of reduced slip usability and problems with berth, boat ramp and dock access. A large majority of facilities in the Severn Sound Inlet region are primarily challenged by low water conditions due to the inlets shallow bathymetric conditions and extreme susceptibility to seiche-induced currents. During periods of low lake water levels and high winds, associated impacts which occur in this region are reduced slip usability and problems with berth, boat ramp and dock access. Marina operations located on Lake Huron's South-eastern ridge are predominantly challenged during low water conditions by high volumes of sand deposits in conjunction with coastal and estuary sedimentation. Associated impacts in this region that are generated as a result of low water conditions are inadequate channel depths leading to boat bay areas of the regions marinas. Facilities located in the Eastern Bruce Peninsula and Parry Sound regions of Lake Huron's coastline remain least affected by low water conditions due to the substantial lake depths in the area. At times of low water, marinas in these regions benefit from the surrounding lake depths and experience minimum implications.

In response to the fourth research objective the study specifies closure and slip loss for each hypothetical scenario of lake water level reductions.

- Scenario One – 0.3m water level reduction in Lake Huron

  Eight surveyed operators on the Canadian Lake Huron coastline indicated closure following a 0.3m water level decline. Of the eight, three marinas were located on the eastern Georgian Bay coastline in the two study regions of the Severn Sound Inlet and Eastern Georgian Bay. The three marina closures would account for the loss of 376 recreational boating slips and potentially reduce the coastlines boating expenditures by as much as $1.6 million per year.

- Scenario Two – 0.45m water level reduction in Lake Huron

  An additional nine surveyed operators on the Canadian Lake Huron coastline indicated closure following a 0.45m water level reduction. Six of these marina closures were identified on the eastern Georgian Bay coastline, accounting for the potential loss of 1,141 recreational boating slips and $4.8 million in annual expenditures.

- Scenario Three – 0.6m water level reduction in Lake Huron

  Following a water level reduction of 0.6m, an additional 17 Canadian Lake Huron marina operators declared closure. Three of these closures were on the eastern Georgian Bay coastline, accounting for the potential loss of 1,498 recreational boating slips and $6.3 million in annual expenditures.

6.1.2 Conclusion

The results of this research indicate that marina operators located on the Canadian coastline of Lake Huron are generally aware of the implications their facilities face when subjected to reduced water levels. Recent water level reductions from 1998 to 2007 have strongly demonstrated the associated impacts and required measures of adaptation in which Canadian Lake Huron marina operations experience and endure throughout low water conditions. However, as global climate change in the 21st century unfolds, reduced water levels and associated impacts on Canadian Lake Huron marina facilities are anticipated to become more severe.

This research has attempted to indicate the future implications of global climate change for Lake Huron water levels and the lake's Canadian marina industry. It has further projected estimated economic reductions by which surrounding lake communities in the Georgian Bay area may suffer as a result to declining lake levels and inadequate marina services. In doing so, only the surveyed marinas that confirmed closure following suggested water level reductions in the two Georgian Bay study regions were considered for this projection of possible economic loss. At the same time, only an average Great Lake boat size of 24-feet and its average seasonal docking fee at 15 Lake Huron marinas were used. Although this produced a hypothetical economic loss for each suggested scenario of water level decline, there are still factors to be considered in this projection.

Factors that the three scenarios of water reduction fail to regard are:

- Additional slips lost by surveyed marinas that will remain operational under each scenario
- Boat restrictions for those surveyed marinas that will remain operational under each scenario
- Non-average boat sizes exceeding 24-feet in length and larger drafts
- Non-average seasonal docking fees and boater expenditures
- Non-surveyed operators located on the Canadian Lake Huron coastline along with facilities not affiliated with OMOA marina registry
- Other boating expenditures, such as services and insurance fees

Consideration of these factors could lead to a greater boat-based economic loss for the south-eastern Georgian Bay coastline, concluding this studies projection of economic loss for this area as a conservative estimate. Boater's choice and behaviour must also be considered in the next phase of research for future implications of climate change on the Canadian Lake Huron recreational boating industry. Without adaptation of marina infrastructure, projected water level declines in Lake Huron may:

- increase boating costs as marinas increase docking and service fees as the supply of slips diminishes under lower water level conditions
- increase the travel expenses for some boaters as they relocate to new and further marina destinations in search for adequate services
- decrease boat-based revenues on Lake Huron as boaters relocate to other lakes
- deter boating and decrease the quantity of recreational boaters in some areas of the lake

Climate change in the Great Lakes region is expected to provide better conditions, of increased air and water temperatures, for recreational boating and possibly generate a higher demand for marina services. However, as low water conditions continue to burden marina operations, supply for these demands will slowly diminish. As a result, demands for the recreational boating in the Great Lakes may be potentially overcome, in turn greatly affecting a multi-billion dollar provincial industry.

6.3 Recommendations for Policy and Future Research

By recognizing the key implications marina operators of the Canadian Lake Huron coastline have experienced during past water level reductions and the potential negative effects climate change may inflict upon their facilities, a list of recommendations for further research has materialized. The following section presents recommendations for further research and policy decisions in regards to the future effects of climate change on the Great Lakes recreational boating sector.

6.3.1 Recommendations for Policy

Implement and subsidize additional strategies of adaptation

As discussed in section 1.1, following the completion of the DFO's $15 million emergency dredging fund, the Globe and Mail announced that only $4.8 million dollars of the fund was issued to 150 marinas located on the Great Lakes shoreline. It is recommended that the remainder of this fund be used to assist marina operations in further adaptive strategies, rather than primarily focusing on dredging methods. A total of 38.5% of the recreational boating slips at the surveyed marinas on the Canadian Lake Huron coastline are considered 'fixed' and unable to adjust to fluctuating water levels. Subsidizing the construction of new floating docks may prolong marina operations following projected water level declines resulting from climate change.

Increased governing for climate change adaptation strategies

Prior to dredging within a boat bay area, Ontario marina operations are first required to seek authorization by the Province's MNR. This process involves receiving a permit of approval for the project which can be extensive and prolonged in time (MNR 2008). In some circumstances, during low Lake Huron water levels from 1998 to 2007, immediate measures of adaptation (dredging) were required for various marina operations in order to avoid drastic revenue reductions. As a result of the extensive period for authorization, operators were commencing dredging procedures without permits. They rationalized that a fine administered by the MNR was less costly than the potential lost revenues their facility would face without immediate action. As climate trends continue to influence lake water levels it is recommended that additional government assistance by the MNR attempt to reduce processing times. This would ultimately serve the needs of many lakeside stakeholders and assist in the protection of lake conservation and biodiversity.

6.3.2 Recommendations for Research

Extending assessment of marina operations for the entire Great Lake system

Due to time constraints, this study primarily focused on assessing the potential impacts of climate change particularly on Canada's Lake Huron marina operations. However, the repercussions of climate change are projected to impact all Great Lake water levels (Mortsch et al. 2000, Lofgren et al. 2002) thereby provoking implications on all Great Lake marina facilities. It is recommended that further analysis and assessments of climate change effects on all of the Great Lake marinas is considered. In doing so, a greater outlook can be achieved on the potential economic implications in which climate change may generate within the boat-based tourism industry.

Conduct assessments of reduced water levels for each geographical region

As discussed in *Section 3.5*, the study areas of the Lake Huron coastline were divided into six geographical regions as a result of variations in shoreline dynamics and underlying sediments. This procedure must be considered in future research for climate change implications upon any Great Lake marina operation. Shoreline dynamics and underlying sediments contribute greatly to the implications and methods of adaptations in which marinas will undergo during low water conditions.

Conduct in-depth assessment for individual lakeside facilities

Moreover, future studies must also consider in-depth climate change analyses for independent operations. A strategic analysis of each marina and their susceptibility to reduced water levels will assist to identify locations of highest vulnerability.

Appendix One: Marina Operator’s Questionnaire

Marina Operator's Questionnaire

Marina Name: ____
Marina Owner Name:____
Part A
Background Information

1	What percentage of your slips are on floating docks?
2	How many of the total slips are used for seasonal occupancy?
3	What percentage of these seasonal slips were rented this season (2007)?
4	What is the occupancy rate of the transient slips at this marina?
5	When does your docking season usually begin, and until when does it usually last?
6	What is the maximum possible draft (depth of boat in water) at your marina?
7	In your years of experience as this marina operator, what is the minimum average depth of water ever experienced at your marina?
8	What is the critical minimum depth of water that prevents operations?
9	What is the best average depth of water for optimum marina operation conditions?
10	What does the bottom material at your marina consist of?
11	Where are most of your costumers from (Local, GTA, Tri-city's, London Middlesex, U.S.A or other)?

Part B
Water Levels, Impacts & Adaptations

12		Have you experienced water levels that have negatively impacted business operations?
	a)	(If Yes) Can you recall which year(s)?
	b)	Was your marina better/worse off than competing businesses?
13		What type of effects did you experience?
		[ ] Inadequate channel depths
		[ ] Problems with docks and berth access
		[ ] Problems with boat ramp access
		[ ] Reduction of usable slips/berths
		[ ] Ceasing of operation
		[ ] Shorter boating season
		[ ] Reduced demand of winter storage
		[ ] Dry rot of wooden structures
		[ ] Increased aquatic weed growth
		[ ] Others

Part B
Water Levels, Impacts & Adaptations

14		What measures did you take to deal with low water levels?
		[ ] Dredging
		[ ] Closing of slips
		[ ] Closing of channels
		[ ] Restriction to smaller and shallower draft boats
		[ ] Adjust docks to new water levels
		[ ] Had to shift boats within boat bay area
		[ ] Construction of adjustable/floating docks
		[ ] Replacement of structures due to dry rot
		[ ] Closure of the marina
		[ ] Others
15		Did your marina receive any type of government assistance through periods of low water?
	a)	(If Yes) What was the approximate value?
	b)	(If Yes) How effective was the assistance? [ ] Very [ ] Moderately [ ] Not
	c)	(If Yes) Did this allow your marina to return to normal operations? [ ] Yes or [ ] No

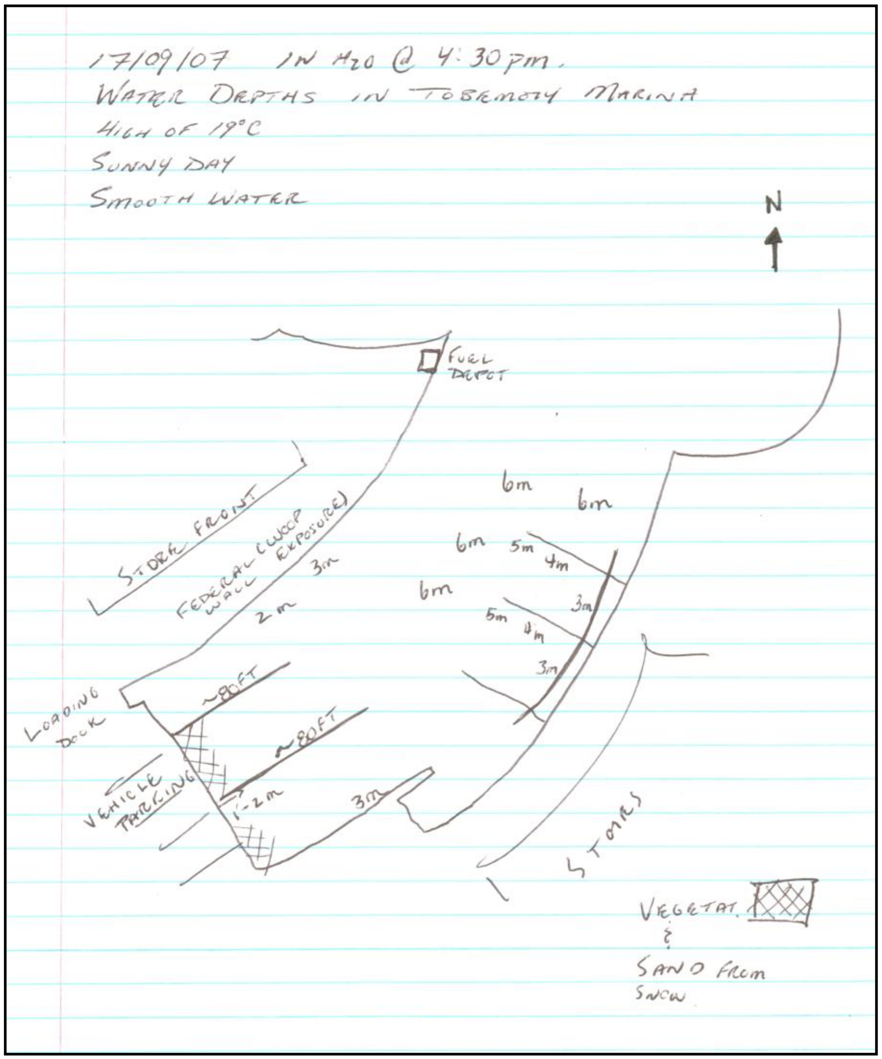
Part C
Climate Change and Potential Water Level Scenarios

16		Do you think water levels within your location have been impacted by the recent warm winters and prolonged ice free conditions?	
17		Are you concerned that conditions of low water could progress because of climate change?	
18		If water levels continue to drop in Lake Huron, what actions will you take as a marina operator to prevent business disruption?	
	a)	Are you able to complete these actions on your own or will government assistance be required?	
19		What would happen to the marina's business if current water levels (September 2007) were to drop by:	
	a)	**Climate Change Scenarios**	*30cm water level reduction within boat bay area*
	b)		*45cm water level reduction within boat bay area*
	c)		*60cm water level reduction within boat bay area*
20		Would you like to see measures that regulate Lake Huron water levels introduced? [ ] Yes [ ] No or [ ] Uncertain If yes, what measures would you suggest?	

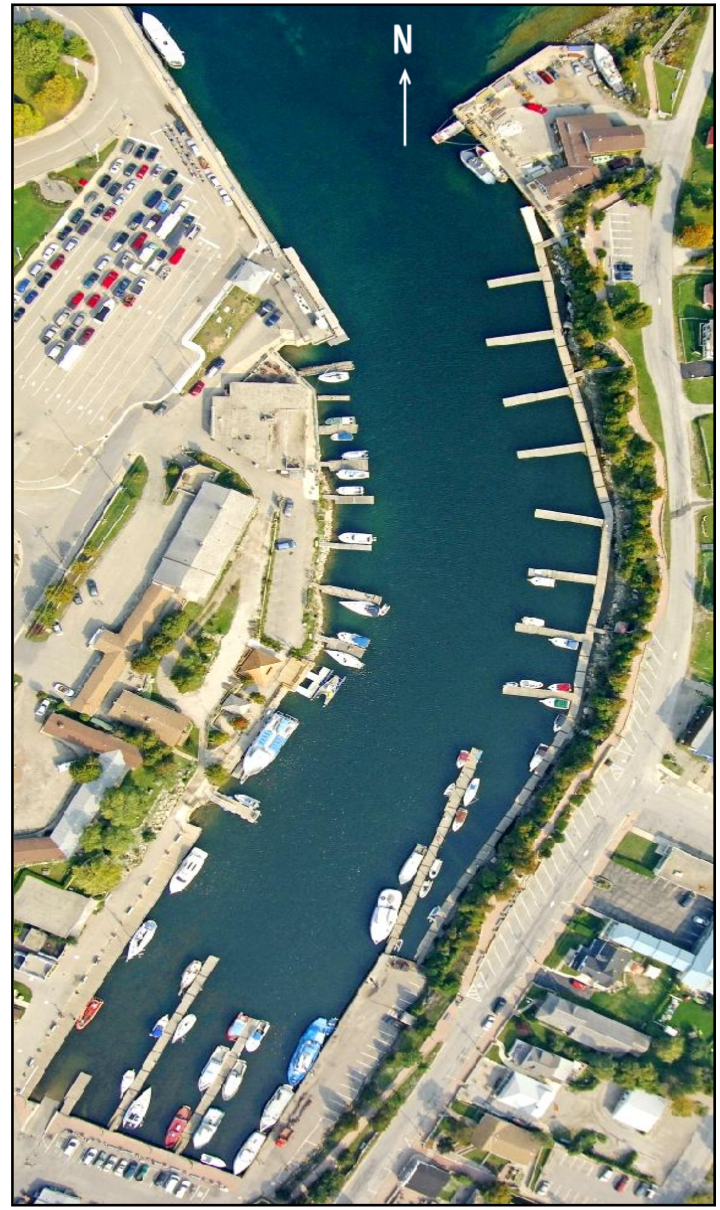
Appendix Two: Bathymetric Measurements and Schematics

*Note: all sonar depths are measured in meters

A) Tobermory Marina

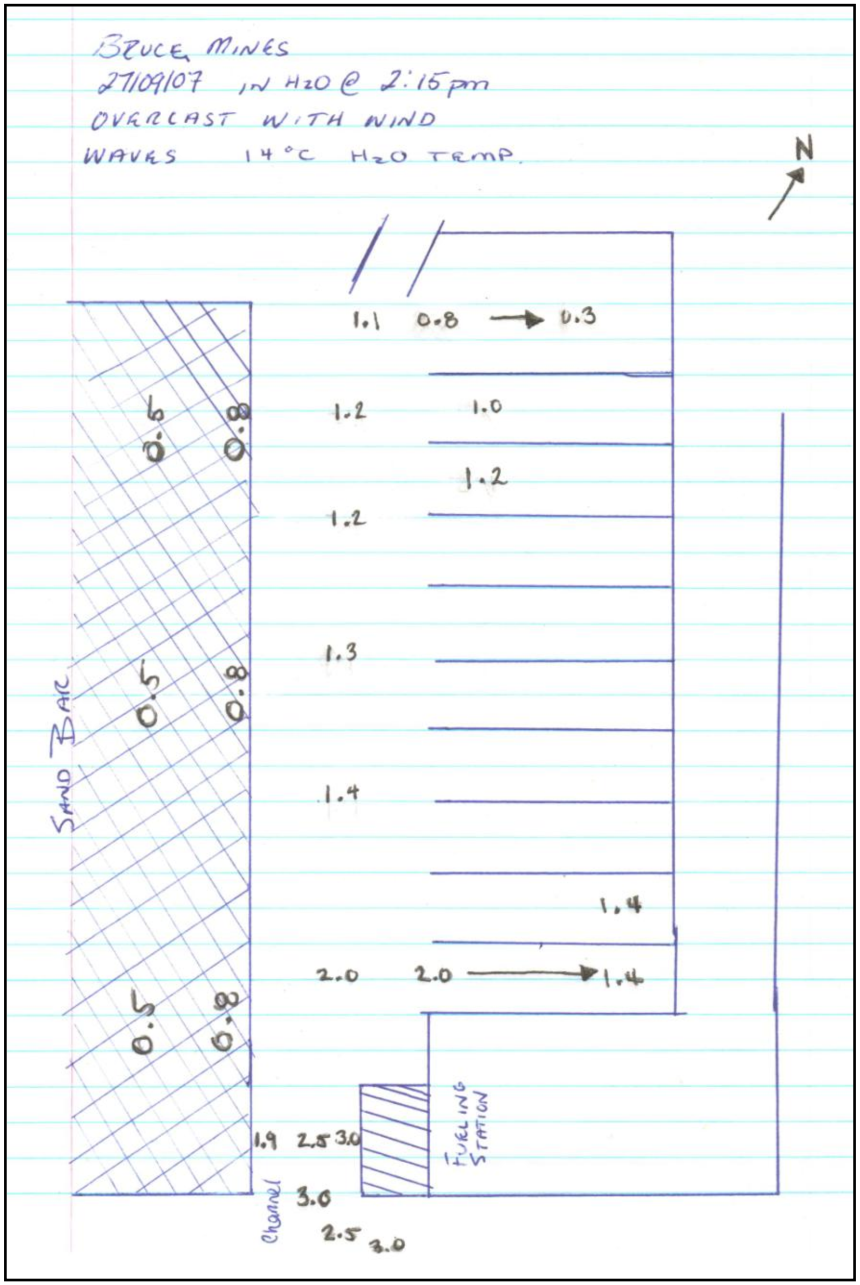


(Sounding Survey by Jordan Stewart 2007)

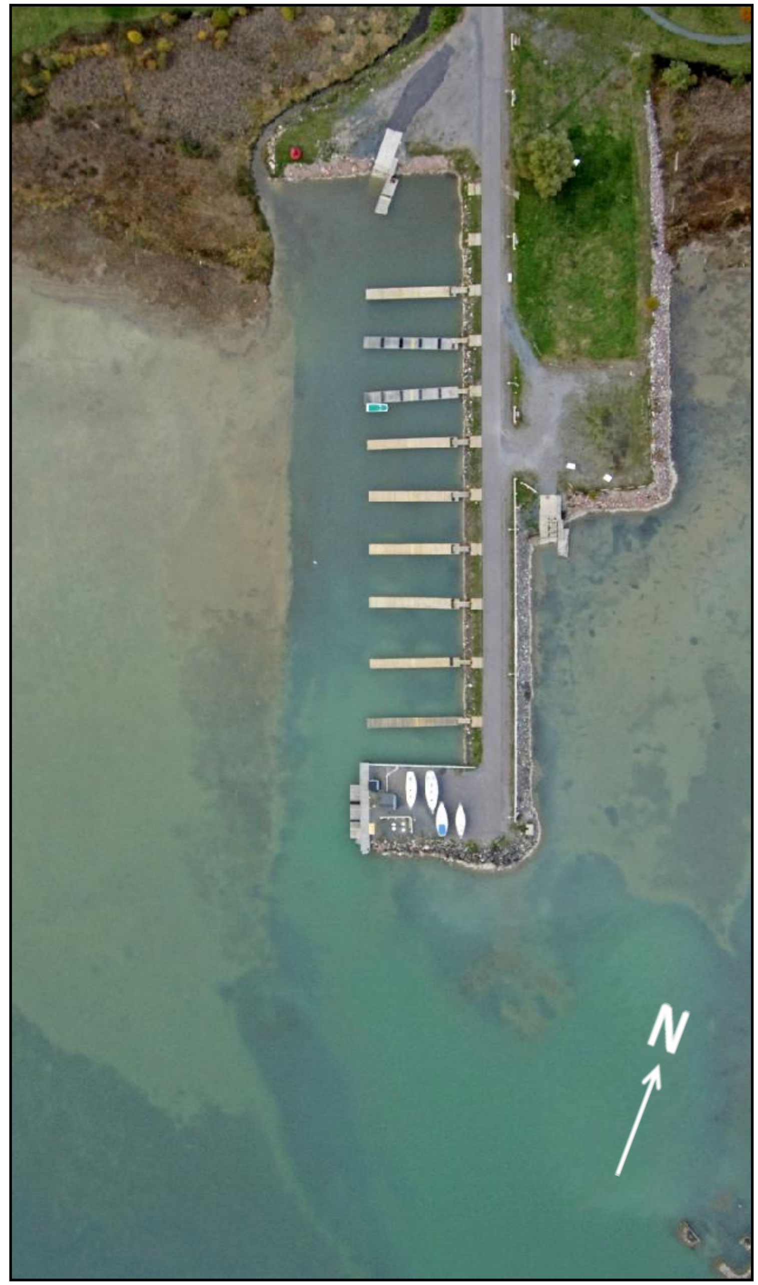


(Source: Marinas.com 2008)

B) Bruce Mines

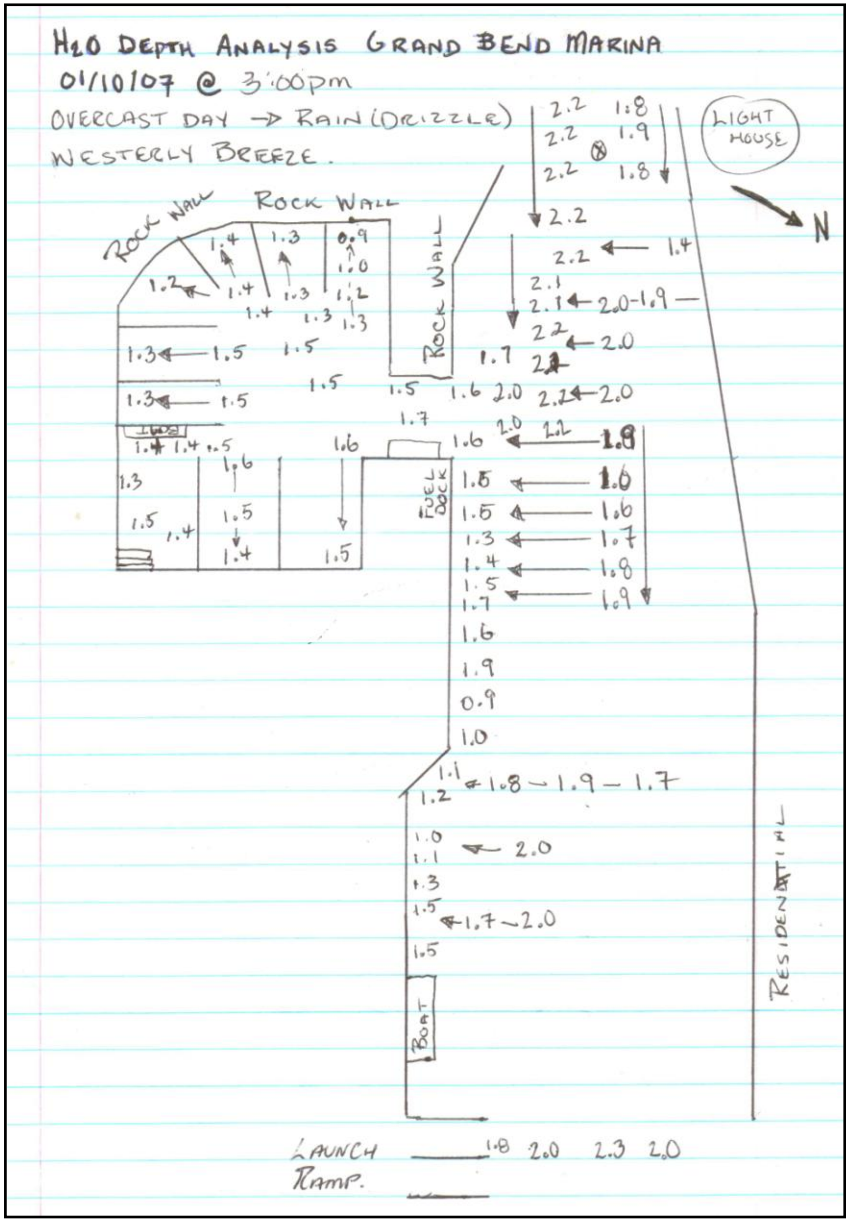


(Sounding Survey by Jordan Stewart 2007)



(Source: Marinas.com 2008)

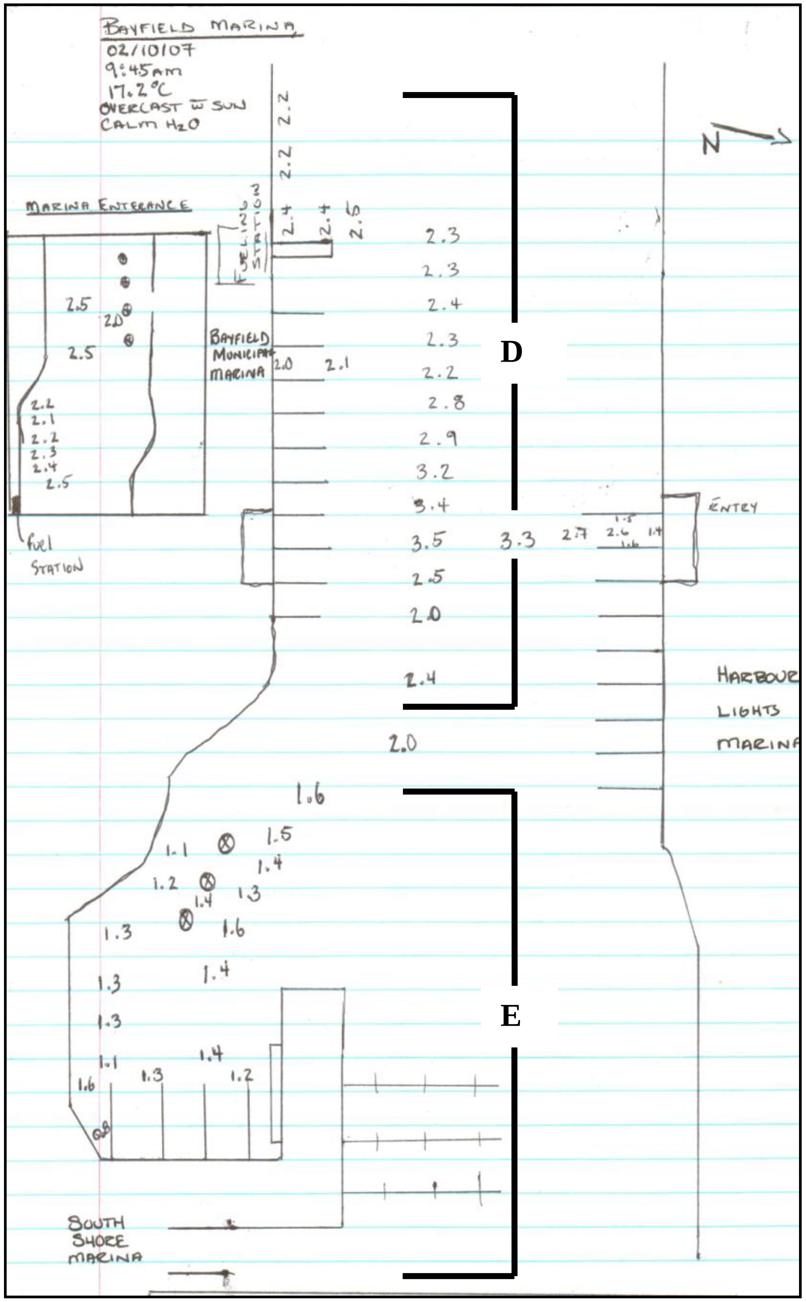
C) Grand Bend



(Sounding Survey by Jordan Stewart 2007)

(Source: Marinas.com 2008)

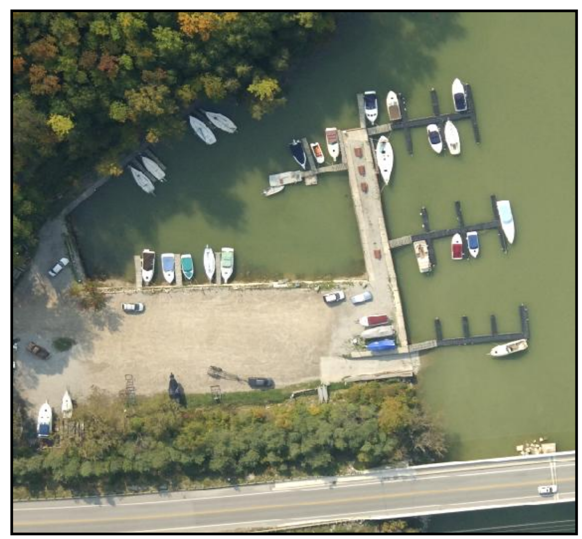
D) Bayfield Marina   E) South Shore Marina



(Sounding Survey by Jordan Stewart 2007)

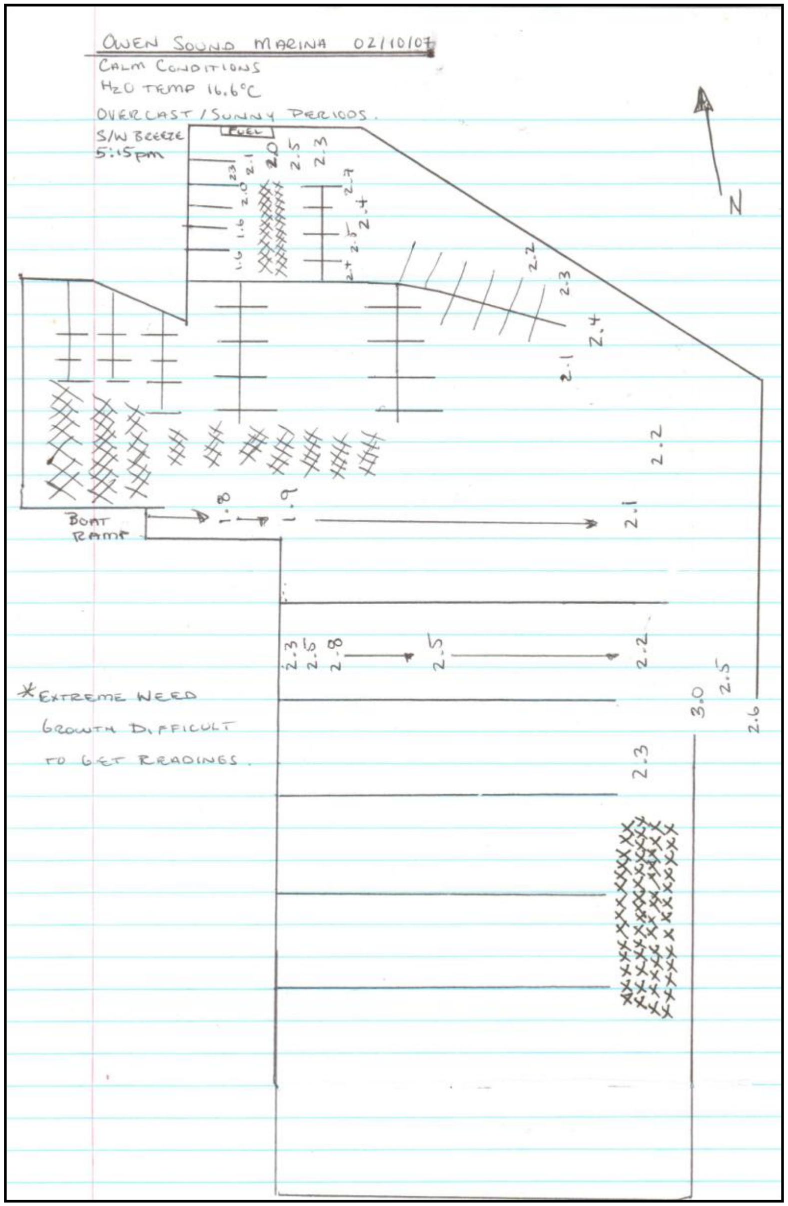
D)

E)

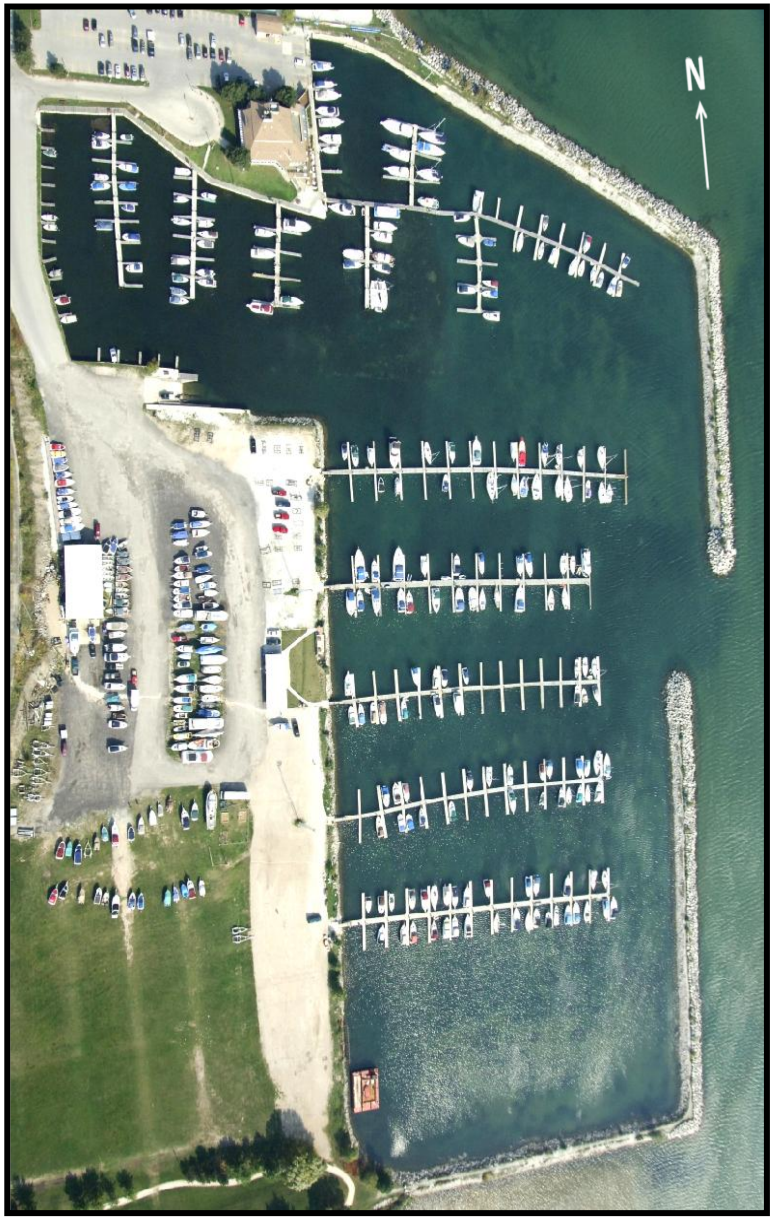


(Source: Marinas.com 2008)

F) Owen Sound Marina

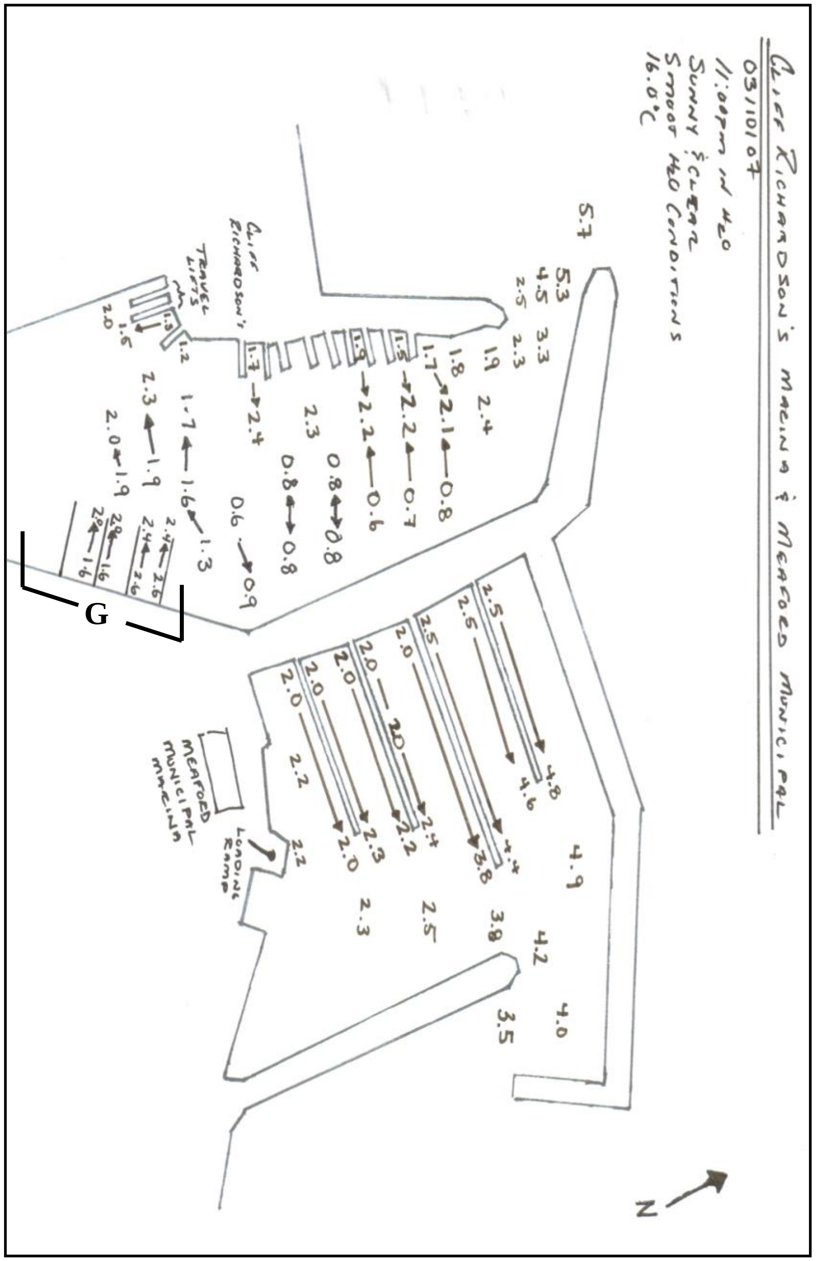


(Sounding Survey by Jordan Stewart 2007)



(Source: Marinas.com 2008)

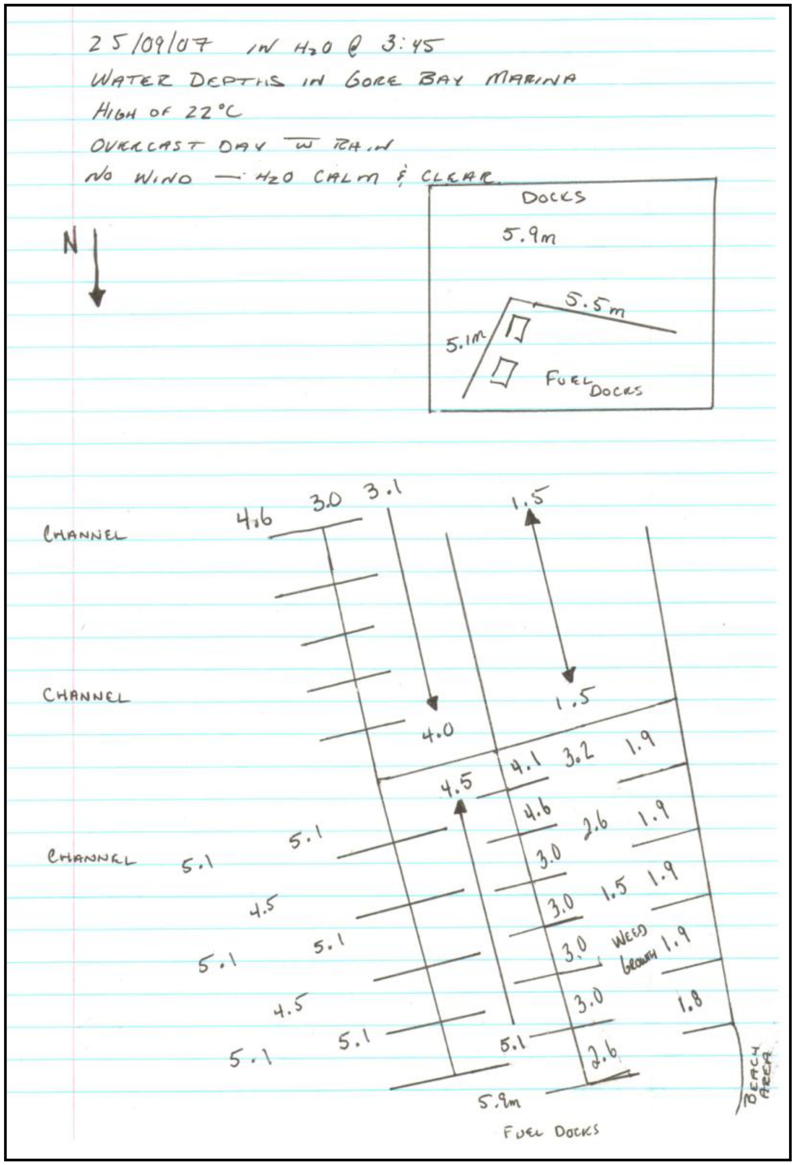
G) Meaford Harbour   H) Cliff Richardson's



(Sounding Survey by Jordan Stewart 2007)

(Source: Marinas.com 2008)

I) Gore Bay Marina

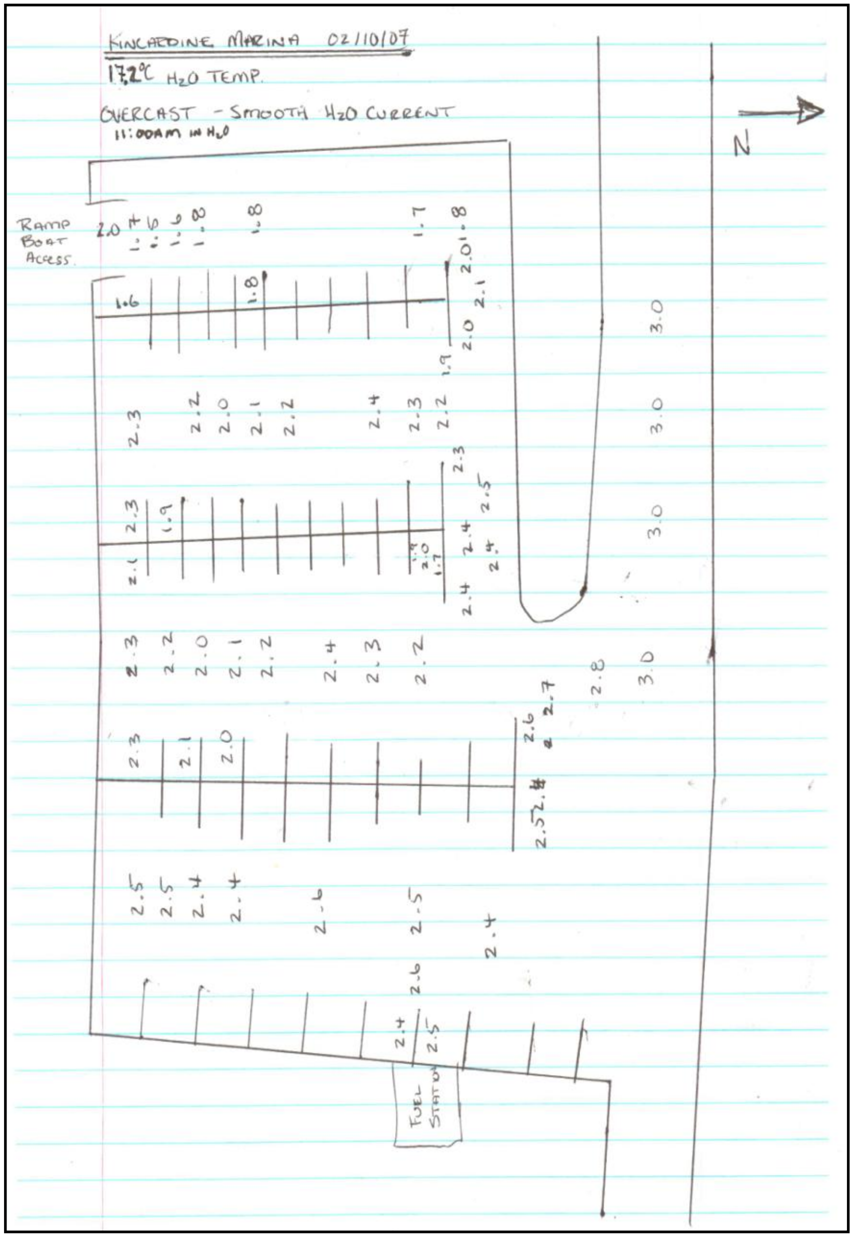


(Sounding Survey by Jordan Stewart 2007)

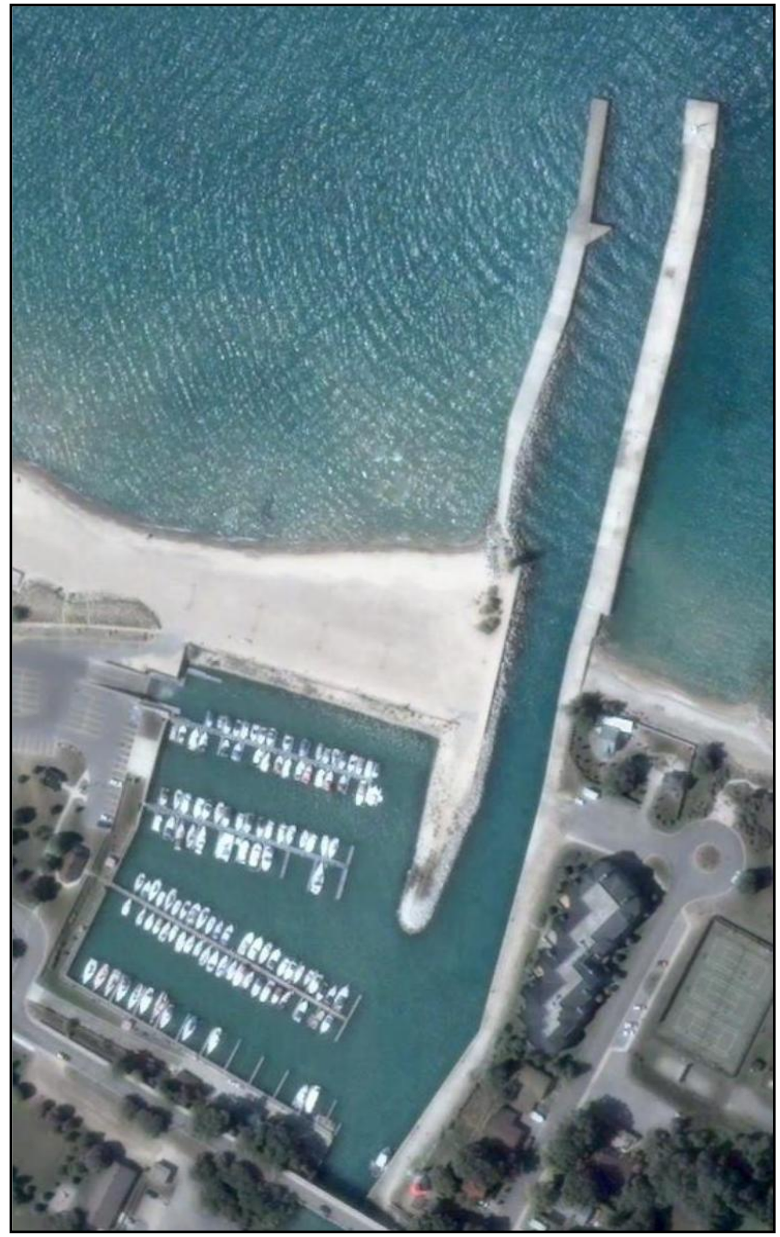
a) Prior Setup (Source: Marinas.com 2008)

b) New Setup – used to maximize depth in marina's bay perimeter (Source: Marinas.com 2008)

J) Kincardine Municipal Marina

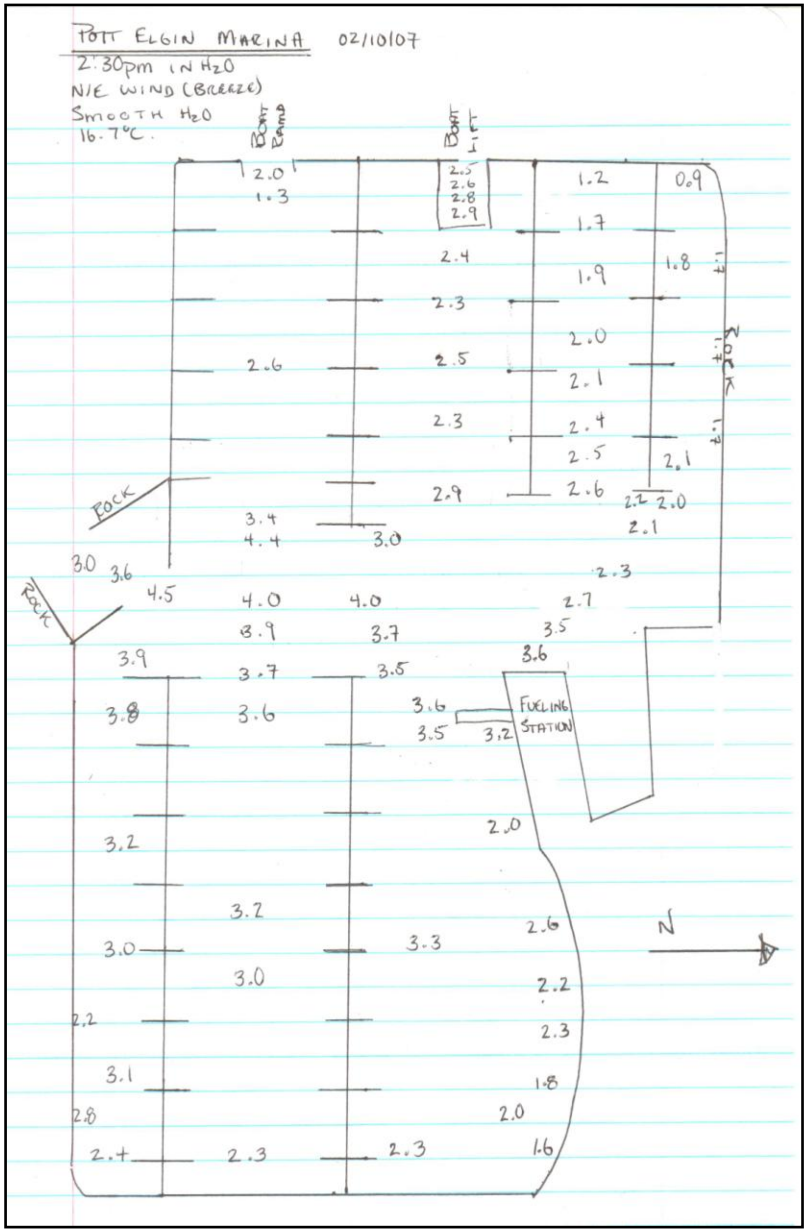


(Sounding Survey by Jordan Stewart 2007)

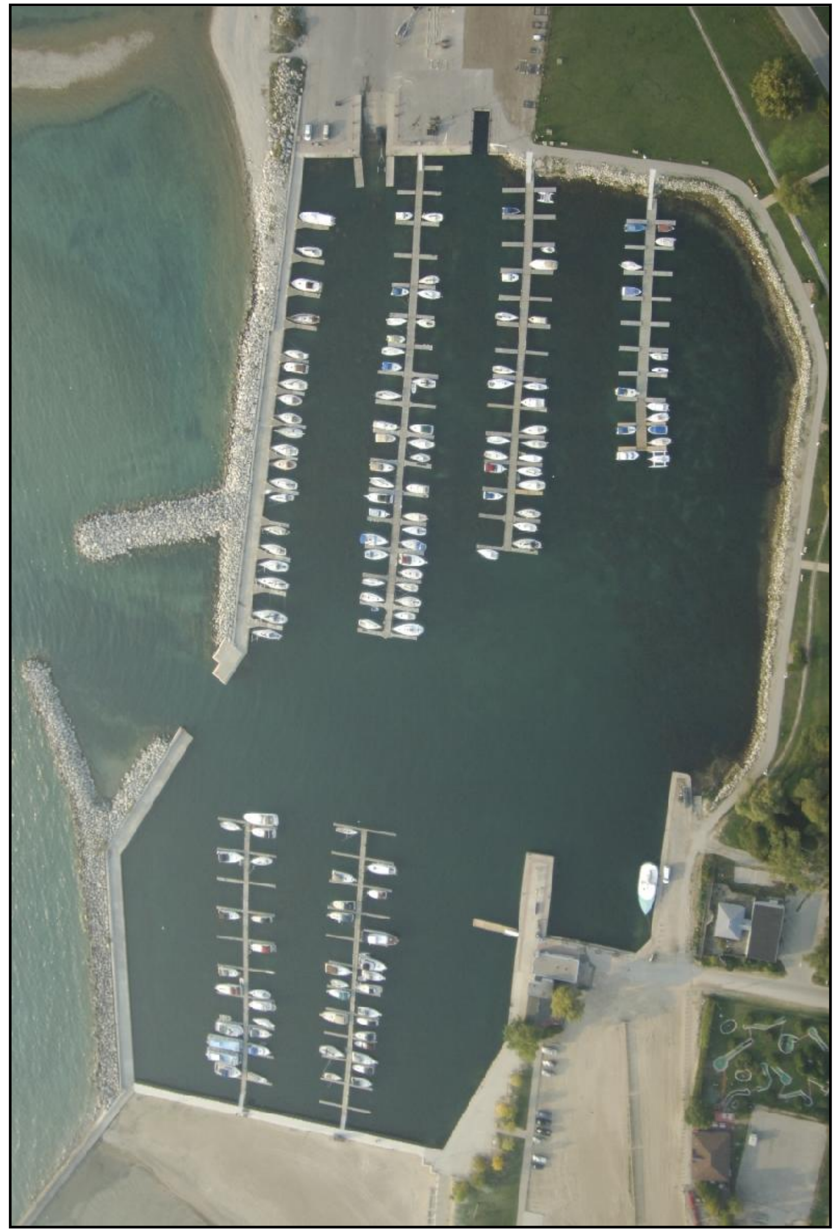


(Source: Marinas.com 2008)

K) Port Elgin Harbour



(Sounding Survey by Jordan Stewart 2007)



(Source: Marinas.com 2008)

Appendix Three: Ethics Consent Form

University of Waterloo

Date: ______________________________

Dear: ______________________________

This letter is an invitation to consider participating in a study I am conducting as part of my Master's degree in the Department of Geography at the University of Waterloo under the supervision of Professor Dr. Daniel Scott. I would like to provide you with more information about this project and what your involvement would entail if you decide to take part.

The study I am conducting is on *THE IMPACTS OF REDUCED WATER-LEVELS ON CANADIAN LAKE HURON MARINA OPERATIONS*. I am looking for people to survey about their experiences as marina operators on the Lake Huron coastline. The purpose of this research is to investigate marina operations on the Canadian Lake Huron coastline and their vulnerability to reduced lake levels of the past few years and in the future.

This study will focus on the values of Lake Huron Marina's and further illustrate the possible impacts in which marina operations will undergo with reduced lake levels. Therefore, I would like to include your marina as one of several marinas to be involved in my study. I believe that because you are actively involved in the management and operation of your marina, you are best suited to speak with regarding the various issues;

1) *the physical structure of marina operations upon the Lake Huron coastline;*
2) *the impacts of low water levels upon marina operations;*
3) *adaptation techniques in which marinas are using to prevent the affects of low water levels;*
4) *the continuing future trends of climate change in the Lake Huron basin and how marinas may later be impacted*

Participation in this study is voluntary. It will involve an survey of approximately 0.5 hours in length to take place in a mutually agreed location or if more convenient a telephone survey can be arranged. You may decline to answer any of the survey questions if you wish. Furthermore, you may decide to withdraw from this study at any time by advising the researcher. With your permission, the survey conversation will be tape-recorded to facilitate collection of information, and later transcribed for analysis. All information you provide is considered completely confidential. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used. Data collected during this study will be retained for one year in a locked office in my supervisor’s lab and then confidentially destroyed. Only researchers associated with this project will have access. There are no known or anticipated risks to you as a participant in this study. If you have any questions regarding this study, or would like additional information to assist you in reaching a decision about participation, please contact me at jj2stewa@fes.uwaterloo.ca. You can also contact my supervisor, Professor Dr. Daniel Scott at 519-888-4567 ext. 35497 or email dj2scott@fes.uwaterloo.ca.

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics at the University of Waterloo. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes of this office at 519-888-4567 ext. 36005.
I very much look forward to speaking with you and thank you in advance for your assistance in this project.

Yours Sincerely,

____

Jordan Stewart
Student Investigator

University of Waterloo

CONSENT FORM

I have read the information presented in the information letter about a study being conducted by Dr. Daniel Scott and Jordan Stewart of the Department of Geography at the University of Waterloo. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted.

I am aware that I have the option of allowing my survey conversation to be tape recorded to ensure an accurate recording of my responses.

I am also aware that excerpts from the survey may be included in the thesis and/or publications to come from this research, with the understanding that the quotations will be anonymous.

I was informed that I may withdraw my consent at any time without penalty by advising the researcher.

This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director, Office of Research Ethics, at 519-888-4567 ext. 36005.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

☐ Yes ☐ No

I agree to have my survey conversation audio recorded.

☐ Yes ☐ No

I agree to the use of anonymous quotations in any thesis or publication that comes of this research.

☐ Yes ☐ No

Participant Name:____________________________ (Please print)
Participant Signature:_________________________
Witness Name:______________________________ (Please print)
Witness Signature:___________________________
Date: ____________________________________

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